F I N A L R E P O R T

FOCUSED FEASIBILITY STUDY FOR THE UPPER AQUIFER

LIBBY GROUNDWATER SITE
LIBBY, MONTANA

REVISION 2

Prepared for

International Paper Company
Memphis, Tennessee

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AECOM

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Project No. 60550003

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List of Acronyms

°C	degrees Celsius
°F	degrees Fahrenheit
>	greater than
µg/L	micrograms per liter
acfm	actual cubic feet per minute
AEI	Arrowhead Engineering, Inc.
Agencies	EPA and MDEQ
amsl	above mean sea level
ARARs	applicable or relevant and appropriate requirements
ARM	Administrative Rules of Montana
bgs	below ground surface
BTEX	benzene, toluene, ethylbenzene, and xylene
BTU/hr	British thermal units per hour
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
cfs	cubic feet per second
CGA	controlled groundwater area
COC	contaminant of concern
cp	centipoise
CWA	Clean Water Act
DNAPL	dense non-aqueous phase liquid
DO	dissolved oxygen
EM	electromagnetic
EO	Executive Order
EPA	United States Environmental Protection Agency
ERH	electrical resistance heating
ESD	Explanation of Significant Differences
FFS	focused feasibility study
FR	Federal Register
FS	feasibility study
ft/d	feet per day
ft^2/day	square feet per day

List of Acronyms

ft^3	cubic feet
$(ft^3/d)/ft$	cubic feet per day per foot
g/cm^3	grams per cubic centimeter
GAC	granular activated carbon
gpd	gallons per day
gpm	gallons per minute
HAPs	hazardous air pollutants
HDPE	high density polyethylene
HP	horsepower
HW/SEE	hot water/steam enhanced extraction
IC	institutional control
IET	Innovative Environmental Technologies, Inc.
IP	International Paper Company
ISB	in situ biosparging
ISCO	in situ chemical oxidation
ISGS	in situ geochemical stabilization
ISSS	in situ soil stabilization
ITRC	Interstate Technical and Regulatory Council
K_d	soil-water distribution coefficient
L/kg	liters per kilogram
Lb	pound
lbs/hr/well	pounds per hour per well
LNAPL	light non-aqueous phase liquid
LOSL	Libby on-site laboratory
MAH	monocyclic aromatic hydrocarbons
MCA	Montana Code Annotated
MCL	maximum contaminant level
MCLG	maximum contaminant level goal
MDEQ	Montana Department of Environmental Quality
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
mg/L/hr	milligrams per liter per hour

List of Acronyms

mL	milliliter
MNA	monitored natural attenuation
MnO_2	manganese dioxide
MPE	multi-phase extraction
MRDLG	maximum residual disinfectant level goal
NAAQS	National Ambient Air Quality Standards
NAPL	non-aqueous phase liquid
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NFA	no further action
NHPA	National Historic Preservation Act
NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List
NPV	net present value
NSDWR	National Secondary Drinking Water Regulations
NSZD	natural source zone depletion
O&M	operation and maintenance
OWS	oil-water separator
PAH	polynuclear aromatic hydrocarbon
PCP	pentachlorophenol
PLC	programmable logic controller
PVC	polyvinyl chlorinated
POTW	publically owned treatment works
ppb	parts per billion
PPE	personal protective equipment
psig	pounds per square inch gauge
PV	pore volume
R	retardation factor
RAO	remedial action objectives
RD/RA	remedial design/remedial action
RI	remedial investigation
ROD	Record of Decision
ROI	radius of influence

List of Acronyms

SAETS	source area extraction and treatment system
SCADA	supervisory control and data acquisition system
SCFM	standard cubic feet per minute
SDWA	The Safe Drinking Water Act
SEE	steam enhanced extraction
S-ISCO	surfactant enhanced in situ chemical oxidation
Site	Libby Groundwater Site
SMCL	secondary maximum contaminant level
SOW	Statement of Work
SVE	soil vapor extraction
SVOC	semi-volatile organic compound
TBC	to be considered
TCH	thermal conduction heating
TEA	terminal electron acceptor
TI	technical impracticability
TSDF	treatment, storage, and disposal facility
UIC	underground injection control
UST	underground storage tank
UV	ultraviolet
VOC	volatile organic compound
WCC	Woodward-Clyde Consultants

Executive Summary

ES1.0 INTRODUCTION

AECOM prepared this Draft Final Report: Focused Feasibility Study (FFS) for the Upper Aquifer on behalf of International Paper Company (IP) to present the development and evaluation of remedial alternatives for the Upper Aquifer at the Libby Groundwater Site (Site), located in the City of Libby, Montana (Libby or City) (Figure ES-1). The Site consists of the excavated area shown on Figure ES-1, all surface areas which are contaminated with contaminants of concern (COCs) in and around the excavated area including sub-strata material, all former or future treatment areas and the full extent of the contaminated groundwater plume emanating from the surface contamination. Historical wood treating operations occurred at the Site from 1946 to 1969, resulting in impacts to soil and the underlying groundwater. The Site was listed on the National Priorities List (NPL) in 1983 to address soil and groundwater contamination. A remedial investigation and feasibility study were completed in 1988, under the direction of the United States Environmental Protection Agency (EPA) and the Montana Department of Environmental Quality (MDEQ). Remediation of soil and Upper Aquifer groundwater has been ongoing at the Site since 1988 under an EPA consent decree. IP acquired the Site remediation responsibilities upon its merger with Champion International Corporation on December 31, 2000.

The primary COCs in groundwater are pentachlorophenol (PCP) and polynuclear aromatic hydrocarbons (PAHs). To date, groundwater cleanup goals have not been met in the Upper Aquifer, particularly in areas that still contain non-aqueous phase liquids (NAPL). This FFS Report is focused on the Upper Aquifer and newer remedial technologies that have been developed or further refined since the original feasibility study was completed in 1988.

The Upper Aquifer extends from the groundwater table, at an average depth of 15 feet below ground surface (bgs), to a total depth of approximately 70 to 75 feet bgs. Three Upper Aquifer subunits with differing hydrogeologic properties and/or COC impacts have been characterized, including the shallow, middle, and deep subunits. Historical domestic wells in Libby were typically screened in the shallow subunit of the Upper Aquifer.

A baseline human health endangerment assessment was prepared in 1986 as part of the original feasibility study. It included an assessment of the current and future human health risks from contaminated water in the Upper Aquifer, and early actions were taken to prevent risks to human health until groundwater cleanup could be achieved. EPA's 1986 Record of Decision (ROD) required a City ordinance that prohibits well drilling for human consumption or irrigation. Also a "buy water" plan was initiated to provide residents with monetary compensation for using City water in lieu of their existing wells. The City ordinance is still in place today and IP still subsidizes a portion of the City water cost for residents. There is no known use of impacted groundwater for human consumption and irrigation outside of the City limits. Thus, EPA concluded in their 2015 Five Year Review that the current Site remedy is protective of human health and the environment because no known completed exposure pathway exists.

The former mill property is sparsely developed and is currently used for light industrial or commercial purposes. This property is subject to institutional controls (ICs) requiring access for remediation and the exercise of due care to avoid exacerbation of hazardous substance releases (i.e., excavation or groundwater pumping without EPA authorization). A portion of the former mill land, owned by Lincoln County Port Authority, is currently being developed for industrial and commercial use. City water can be made available for future industrial and commercial users of the former mill property. A public fishing pond was recently constructed adjacent to the Libby Creek diversion canal in the southeast portion of the property for recreational purposes (Figure ES-1).

EPA, in cooperation with MDEQ and other State agencies and the City-County Board of Health for Lincoln County, is currently considering establishing a Controlled Groundwater Area (CGA) to consolidate existing institutional controls and provide a comprehensive and consistent way to address future, potential groundwater consumption and plume stability until full cleanup occurs.

ES2.0 IDENTIFICATION AND SCREENING OF ALTERNATIVES

Remedial action objectives (RAOs) were updated for the Upper Aquifer based on more recent Site characterization information and recommendations in EPA's 2010 Five Year Review for the Site. The following RAOs were developed for the Upper Aquifer to address the Site-specific media and COCs:

- Prevent ingestion of Upper Aquifer groundwater with Site-related COCs that exceed preliminary revised groundwater cleanup levels.
- Protect human health and the environment by reducing Site-related COCs in Upper Aquifer groundwater to preliminary revised groundwater cleanup levels.

The preliminary revised groundwater cleanup levels are federal maximum contaminant levels (MCLs) for the COCs that have MCLs, and Montana's Circular DEQ-7 numeric groundwater quality standards for those COCs that do not have MCLs.

Preliminary applicable or relevant and appropriate requirements (ARARs) were identified in this FFS to reflect current Site conditions, COCs, and the remedial alternatives developed. Three categories of ARARs were identified including chemical-specific, location-specific, and action-specific.

General response actions are broad classes of actions that may be implemented alone or in combination to satisfy the RAOs. The response actions identified in this FFS were no action, access restriction, physical containment, removal, and in situ treatment.

Applicable technologies and process options for each response action were identified, focusing on those applicable to wood-treating sites with an emphasis on treatment technologies that address NAPL and are typically used for remediation of PCP and PAHs. The technologies and process options retained in this FFS are provided below in Table ES-1.

Table ES-1. Technologies/Process Options Retained

General Response Action	Potential Remedial Technology	Technology/Process Option
No Action	No Action	No Further Action
Access Restrictions	Institutional controls	Institutional controls
Physical Containment	Hydraulic Containment	Groundwater extraction
Removal	Enhanced Physical Removal	Steam enhanced extraction
In Situ Treatment	Physical/Chemical Treatment	In situ geochemical stabilization
	Physical/Biological	Natural attenuation Aerobic oxidation (biosparging)

ES3.0 DEVELOPMENT OF ALTERNATIVES

Upper Aquifer remediation areas were developed on the basis of COC concentrations in groundwater and the interpreted presence of NAPL in the Upper Aquifer (Figure ES-1). The rationale for selecting remediation areas in this manner allowed for evaluation of applying more rigorous treatment technologies to those areas that pose the greatest risk to human health (i.e., areas of the aquifer with the highest COC concentrations) and those areas that serve as a continuous source of groundwater contamination (i.e., areas of the aquifer with the greatest NAPL impacts). The following three remediation areas were identified:

- Area 1 (2.7 acres) encompasses the former waste pit source area and contains the highest groundwater concentrations and the residual NAPL saturations.
- Area 2 (33 acres) encompasses the former tank farm source area and NAPL that historically migrated away from the former sources. The Upper Aquifer in Area 2 is intermittently impacted by residual NAPL.
- Area 3 (98 acres) encompasses the area containing only dissolved phase COC contamination in the Upper Aquifer (beyond the extent of observed NAPL).

The technologies retained from the screening process were used to develop five remedial alternatives to address NAPL and COCs in Upper Aquifer groundwater at the Site, as summarized below. Overall, the alternatives employ an active remedy to Area 1, which has a higher concentration of contamination, but a more passive remedy to Area 2 due to the discontinuous and irregular distribution of contamination intermixed with “cleaner” lenses throughout Area 2. With the exception of Alternative 1, each of the alternatives share the same approach for Area 2 which involves active treatment at downgradient area boundary, but natural and passive remediation throughout the remainder of the area. Each alternative employs monitored natural attenuation (MNA) in Area 3.

Alternative 1 – No Further Action
This alternative is required for inclusion as a baseline for comparison with other alternatives and includes the implementation of institutional controls, as current remedial actions would cease. Existing or planned institutional controls are a component of each alternative and include continuing the current well drilling restrictions and deed restrictions, along with implementing a CGA. It is estimated that natural attenuation processes would occur for approximately 145 years until groundwater cleanup levels would be met. Limited groundwater monitoring would be conducted to check on the progress or changes in site conditions.

Alternative 2 – Hydraulic Containment (Area 1) and In Situ Biosparging (Area 2)
This alternative includes groundwater extraction, aboveground treatment, and re-injection of treated groundwater to hydraulically contain impacted groundwater in the former waste pit area (Area 1) and limit the mass flux from Area 1 into Area 2; in situ biosparging (ISB) near the downgradient extent of NAPL in Area 2; and MNA in Area 3. Institutional controls will also be a component of Alternative 2.

Although the primary objective is to prevent contaminant migration, mass will be gradually reduced through extraction and treatment of aqueous contamination, as well as in situ via natural source zone depletion (NSZD).

Hydraulic containment will be achieved by pumping groundwater from five extraction wells screened in the shallow subunit and one extraction well screened in the deep subunit. The aboveground treatment system for extracted groundwater consists of the existing coalescing oil-water separator (OWS), two trickling filter rotary distributor (bioreactor) units, a pressure filter, and three 20,000-lb granular activated carbon (GAC) units to achieve levels that meet Montana re-injection standards.

ISB will be applied in Area 2 as an aerobic treatment transect spanning the width of Area 2 oriented approximately perpendicular to groundwater flow along the northwestern edge of the 1994 revised mill property boundary. The transect will comprise two staggered rows of twelve injection wells that are spaced approximately 80 feet apart from one another. The injection wells will be installed in the base of the Upper Aquifer with screened intervals from approximately 72 to 75 feet bgs so that injected air distributes across the base of the Upper Aquifer prior to traveling upwards through the shallow subunit. Injections will be conducted via four zones, each containing six wells, operating for 6 hours per day at approximately 10 actual cubic feet per minute (acfm) per well supplied by one compressor. The ISB transect will increase dissolved oxygen in groundwater promoting contaminant degradation as contaminated groundwater passes through the transect. Anaerobic NSZD processes will occur in Area 2 upgradient of the ISB transect.

MNA would occur in Area 3 as part of a site-wide monitoring program during remediation. MNA is anticipated to begin with approximately 27 wells sampled annually followed by reductions in frequency and/or locations over time. The plume in Area 3 is anticipated to readily attenuate following implementation of the ISB transect in Area 2, which will significantly reduce contaminant migration from Area 2 to 3 and will also aerobically enhance biodegradation processes in portions of Area 3.

The hydraulic containment in Area 1 is estimated to operate for approximately 145 years until the cleanup levels are met while ISB in Area 2 will operate for approximately 41 years and MNA in Area 3 will be implemented for approximately 10 years.

Alternative 3 – In-situ Biosparging (Areas 1 and 2)
Alternative 3 includes ISB in Area 1 by injecting air through a network of shallow and deep wells to address impacted groundwater and deplete COCs from NAPL in the waste pit area, along with implementing ISB and NSZD in Area 2 and MNA in Area 3. ISB in Area 1 will be implemented by injecting compressed air through a network of approximately 44 shallow and 11 deep injection wells evenly spaced assuming shallow and deep radii of influence of 30 and 60 feet, respectively. Deep wells will be screened from 67 to 70 feet bgs and collocated with shallow wells screened from 27 to 30 feet bgs. Injections will be conducted via 8 shallow and 2 deep zones that operate for 2 and 4 hours, respectively, three times daily at approximately 10 acfm per well supplied by two compressors. The ISB system in Area 1 is estimated to operate until cleanup levels are met (estimated at 6 years), while ISB in Area 2 will operate for approximately 41 years, and MNA in Area 3 will be conducted for 10 years.

Alternative 4 – Steam Enhanced Extraction/In Situ Biosparging (Area 1) and In-situ Biosparging (Area 2)
Alternative 4 includes the application of steam enhanced extraction (SEE) followed by ISB to address NAPL and impacted groundwater in the waste pit area (Area 1), along with implementing ISB and NSZD in Area 2 and MNA in Area 3. SEE will remove contaminant

mass by increasing subsurface temperature to temporarily increase NAPL mobility and stripping COCs from the NAPL. Following completion of SEE, ISB will be implemented as detailed in Alternative 3 to accelerate degradation of the remaining contamination.

The SEE system will include a steam injection system, multi-phase extraction and above ground liquid and vapor treatment systems, a 40-foot deep slurry wall for hydraulic control, a surface cover for temperature control, and soil vapor extraction to recover volatized contamination. Steam will be injected through 55 triple nested wells (165 locations in total) using a well spacing of 50 feet. The target treatment temperature is approximately 247°F, which is assumed to be achieved in approximately 105 days. To reach this temperature, a cutoff wall will be installed to reduce the influx of cold groundwater derived from continuous infiltration of fire pond water. Vapor and liquids will be extracted from 54 multi-phase extraction wells and 30 horizontal soil vapor extraction wells, followed by above ground treatment. Liquids will be treated by GAC and reinjected into the subsurface, extracted vapor will be treated via thermal oxidation, and recovered NAPL from the OWS will be treated (by incineration) at an off-site facility.

In Area 1, SEE is assumed to remove approximately 20 percent of the NAPL, which represents a decrease in residual NAPL saturations of approximately 1 percent. Mass fractions of COCs in the remaining NAPL are assumed to be reduced by 50 to 90 percent for higher molecular weight PAHs and 95 to 99 percent for the more volatile NAPL constituents. SEE will be implemented in Area 1 over a 1 year period (not including installation) followed by approximately 4 years of ISB that will continue until cleanup levels are reached. The ISB system in Area 2 will operate for approximately 41 years and MNA in Area 3 will be implemented for 10 years.

Alternative 5 – In-situ Geochemical Stabilization (Area 1) and In-situ Biosparging (Area 2)

Alternative 5 includes the application of in situ geochemical stabilization (ISGS) by injecting a proprietary modified-permanganate solution into the three subunits in the waste pit (Area 1) followed by NSZD, along with implementing ISB and NSZD in Area 2 and MNA in Area 3. The injected stabilization solution will encapsulate NAPL and oxidize organics. The stabilization process results in the formation of a geochemical shell within several days of injection, thereby reducing the flux of dissolved phase COCs into groundwater. The residual mass formed from the various geochemical reactions is a birnessite-like crust formation around the NAPL.

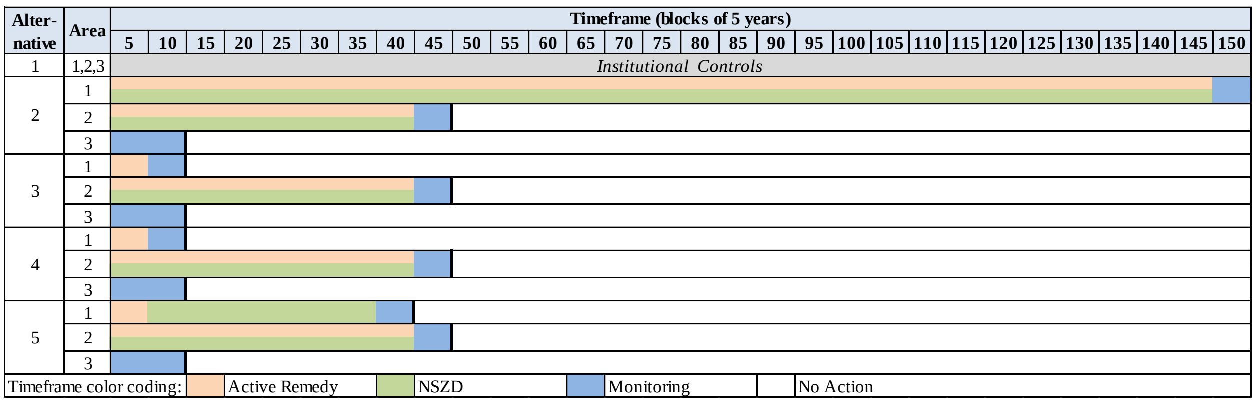
A 10-percent ISGS solution will be injected to target approximately 5 percent of the pore volume. The ISGS solution will be injected at approximately 398, 100, and 100 injection points in the shallow, middle, and deep subunits of Area 1, respectively, assuming radius of influence (ROI) values of approximately 10, 20, and 20 feet, respectively. Based on a complex heterogeneous distribution of NAPL and formation permeability, ISGS is expected to encapsulate approximately 80 percent of the NAPL in Area 1 over approximately 1 year. Following ISGS, NSZD will continue to deplete COCs from remaining NAPL for a period of approximately 29 years until cleanup levels are met. The ISB system in Area 2 will operate for approximately 41 years and MNA in Area 3 will be implemented for 10 years.

Remediation Timeframes

A spreadsheet-based NAPL depletion model was developed and used to estimate the time for each alternative to achieve preliminary revised groundwater cleanup levels in Areas 1 and 2. These timeframes were used to inform the development of alternative components, to evaluate effectiveness over time, and to establish the operational duration for preparing costs for the remedial alternatives. The model simulates the removal of COCs from NAPL and the remediation timeframe is determined as the point at which soluble COCs in the NAPL have been depleted such that the NAPL is no longer a source of COCs to groundwater at concentrations greater than the cleanup levels. The model provides an analytical-based approach to compare alternatives and reflects site-specific conditions (e.g., formation characteristics and contaminant mass and fractions) for the shallow and middle-deep subunits of Areas 1 and 2. Biodegradation rates used in the model vary per aquifer subunit, area, and remedial alternative and were derived from groundwater monitoring data (anaerobic) and field-scale study performance data (aerobic).

The approximate timeframes for the various components of each alternative are depicted in Table ES-2 below. The timeframes for remedial components applied to Areas 2 and 3 are identical across Alternatives 2, 3, 4, and 5, as they each share identical approaches for these two areas.

Table ES-2. Remedial Timeframes and Alternative Components



ES4.0 DETAILED ANALYSIS AND COMPARISON OF ALTERNATIVES

The National Contingency Plan (NCP), 40 CFR Part 300, requires remedial alternatives to be evaluated against nine criteria. Overall protection of human health and the environment and compliance with ARARs are two threshold criteria that any selected remedy must meet. Long term effectiveness and permanence; reduction in toxicity, mobility and volume; short-term effectiveness, implementability and costs are balancing criteria. State and public acceptance are modifying criteria. The alternatives were evaluated against seven of the nine NCP criteria to provide a basis for comparing the relative performance of the alternatives and to identify their advantages and disadvantages as part of selecting the most appropriate alternative to implement at the Site. The two remaining modifying criteria, State and community acceptance, will be addressed in the decision document.

The comparative analysis identifies significant differences and key issues between alternatives, helping highlight the tradeoffs and decision points. The comparative analysis results are visually depicted in Table ES-3 and briefly summarized below.

Table ES-3. Summary Evaluation of Alternatives

Alternative	Overall Protection of Human Health and the Environment	Compliance with ARARs	Long-Term Effectiveness and Permanence	Reduction of Toxicity, Mobility, or Volume through Treatment	Short-Term Effective-ness	Implement-ability	Cost Ranking	Sustain-ability
1. No Further Action	◐	◉	◐	○	◉	●	●	●
2. Area 1 Containment & Area 2 ISB	◉	◉	◉	◐	◐	◐	○	◐
3. Areas 1 & 2 ISB	●	●	●	●	◉	◉	◉	●
4. Area 1 SEE /ISB & Area 2 ISB	●	●	●	●	◐	○	○	○
5. Area 1 ISGS & Area 2 ISB	●	●	●	●	◉	◉	◐	◉

Ranking from lowest to highest performance: least desirable ○, next least desirable ◐, more desirable ◉, most desirable ●

- *Overall Protection of Human Health and the Environment*: Each alternative is adequately protective as institutional controls prevent the use of or exposure to contaminated groundwater. Alternatives 3, 4, and 5 are the most protective because NAPL and groundwater contamination are removed and/or treated so that RAOs and cleanup levels for groundwater can be achieved over a shorter period of time relative to Alternatives 1 and 2. Alternatives 3 and 4 will reach cleanup goals more rapidly than the other alternatives. Alternative 2 is marginally more protective than Alternative 1 as it controls contaminant migration and provides minor treatment.
- *Compliance with ARARs*: Each alternative complies with chemical, location and action-specific ARARs; however, Alternative 1 will not comply with chemical specific ARARs for a long period of time.
- *Long-Term Effectiveness and Permanence*: Alternatives 3, 4, and 5 provide a permanent remedy through in situ treatment or removal of NAPL and contaminants in groundwater. Following active treatment, NAPL that remains would be immobilized and relatively insoluble. Alternatives 3 and 4 will degrade and immobilize NAPL while NAPL will be encapsulated under Alternative 5. Alternative 2 includes limited treatment, but involves long-term management of an on-site facility. Alternative 1 is the least effective because no treatment will occur beyond natural attenuation over a long duration. Overall, Alternatives 3, 4, and 5 are anticipated to provide long-term effectiveness and permanence and are more effective than Alternative 2, which is slightly more effective than Alternative 1.
- *Reduction of Toxicity, Mobility, and Volume*: Alternatives 3, 4 and 5 provide the greatest reduction in toxicity, mobility, and volume, but differ in how they do so in Area 1. Alternatives 3 and 4 achieve the desired reduction in toxicity and mobility relatively quickly as ISB is complete at Year 6 for Alternative 3 and Year 5 for Alternative 4. Alternative 4 also provides the greatest immediate reduction in volume and a

considerable reduction in toxicity, by removing 20 percent of the NAPL volume and reducing mass fractions in approximately one year. Alternative 5 achieves the most rapid reduction in toxicity and mobility, addressing 80 percent of the NAPL mass in the first year, but then requires an additional 29 years of NSZD to adequately reduce toxicity and mobility. Alternative 2 takes considerably longer to reduce the toxicity, mobility and volume of the NAPL and impacted groundwater, and offers a marginal advantage over Alternative 1 (beyond natural attenuation) in that it reduces contamination via extraction in Area 1 and via ISB in Area 2.

- *Short-Term Effectiveness*: Alternative 1 has the fewest short-term impacts, followed by Alternative 3, Alternative 5, Alternative 2, and lastly by Alternative 4 with the most short-term impacts. With the exception of Alternative 1, each alternative has equal remediation timeframes in Areas 2 and 3. In Area 1, Alternative 4 is estimated to meet cleanup levels in the shortest timeframe at Year 5, closely followed by Alternative 3 at Year 6, then Alternative 5 at Year 30, and Alternatives 1 and 2 at Year 145.
- *Implementability*: Alternative 1 is the easiest to implement as no action is conducted except for limited groundwater monitoring and continuation of ICs. Alternative 3 is the next easiest to implement, involving approximately 79 ISB injection wells and operation of a simple system for 6 and 41 years in Areas 1 and 2, respectively. There will be some efficiencies shared in operating ISB in both Areas 1 and 2 as part of Alternative 3. Alternative 5 is slightly more complex than Alternative 3 as it requires approximately 600 ISGS injection points. The complexity increases with Alternative 2, which involves an extraction and above ground treatment system for 145 years in Area 1, in addition to 41 years of ISB in Area 2. Alternative 4 is the most complex involving the most equipment and specialized services to implement, as well as multiple extraction systems and above ground treatment components for vapor and liquids. Alternative 4 also involves implementing ISB upon completion of SEE, although the SEE injection points could be utilized for injecting air.
- *Cost*: Alternative 1 has no costs associated with active remediation but includes costs for limited groundwater monitoring and EPA reviews, Alternative 3 is the lowest cost alternative to implement. Alternative 5 provides similar levels of protection with moderately longer remediation timeframes to Alternative 3, but is estimated at over 3 times the cost of Alternative 3. Alternative 4 provides similar protection to Alternative 3, but is nearly 5 times more expensive. Alternative 2 is the most costly alternative and has the longest remediation timeframe.

Another factor involved in evaluating the remedial alternatives was the environmental effect of remedy implementation or sustainability. Alternative 3 is the most sustainable of the active remediation alternatives, having the lowest net environmental footprint. With respect to the five metrics considered under sustainability (materials used, waste generation, water usage, energy usage, and air emissions), Alternative 3 either had a smaller footprint than other alternatives or was similar to other alternatives in having the lowest impact.

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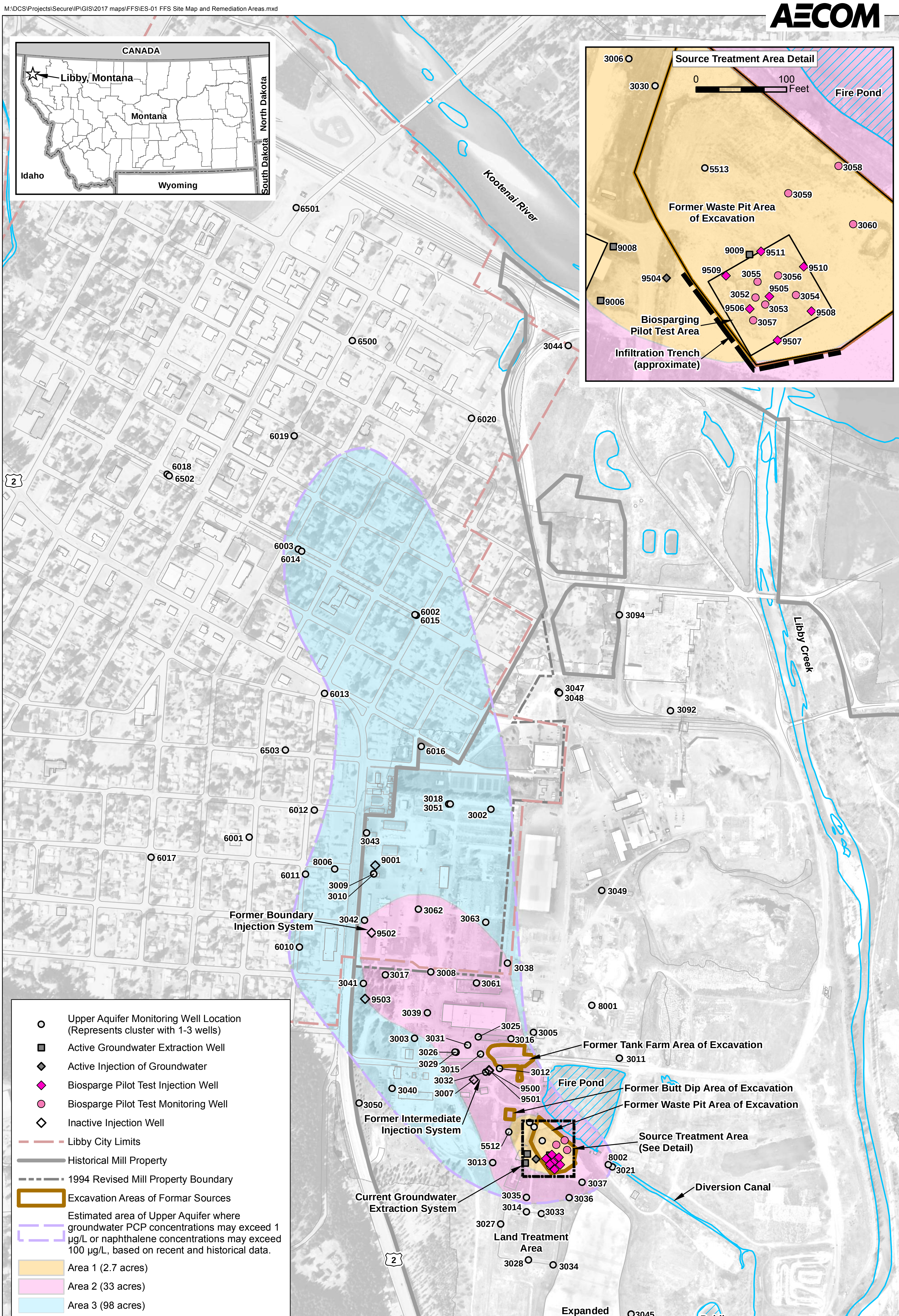

Site Location Map and Remediation Areas

FOCUSED FEASIBILITY STUDY FOR THE UPPER AQUIFER
LIBBY GROUNDWATER SITE, LIBBY, MONTANA

Job No.:	60514930
Designed By:	MCS
Drawn By:	JLC
Date:	2/14/2018

Fig. ES-1

1.1 PURPOSE OF REPORT

International Paper Company (IP) completed this feasibility study (FS) to develop and evaluate alternatives to remediate contaminants in the Upper Aquifer at the Libby Groundwater Site (Site). The FS process involved developing remedial action objectives (RAOs), screening remedial technologies, combining selected technologies into remedial alternatives, and evaluating the alternatives against the FS criteria (EPA 1988a) to identify the recommended remedial action. This FS is referred to as a focused FS (or FFS) in that it is focused on groundwater in the Upper Aquifer and newer remedial technologies that have been developed or further refined since the submittal of the original Libby Site FS (Woodward-Clyde Consultants [WCC] 1988b). Prior remedial efforts at the Site have not been successful in meeting cleanup goals in certain portions of the Upper Aquifer, in particular those that contain non-aqueous phase liquid (NAPL), and this FFS addresses NAPL-impacted portions of the Upper Aquifer. IP is performing this work in accordance with the Statement of Work (SOW) issued by the United States Environmental Protection Agency (EPA) (EPA 2012a) and agreed to by the Montana Department of Environmental Quality (MDEQ).

1.2 BACKGROUND

1.2.1 Site Description

The Site is a former lumber mill and wood treating operation located on Highway 2 in the City of Libby, Montana (Libby or City) (Figure 1-1). The Site consists of the excavated area shown on Figure 1-1, all surface areas which are contaminated with contaminants of concern in and around the excavated area including sub-strata material, all former or future treatment areas and the full extent of the contaminated groundwater plume emanating from the surface contamination. Historical releases of wood treating fluids resulted in impacts to soil and the underlying groundwater. Soil and groundwater remediation has been ongoing at the Site since the late 1980s under the direction of the EPA and MDEQ (the Agencies). IP acquired the Site remediation responsibilities upon its merger with Champion International Corporation on December 31, 2000.

Wood treating fluids were used at the Site from 1946 to 1969. These fluids consisted of complex mixtures of different blends of chemical products used over time, product process residues, and spent mixtures. The primary wood treating products used at the Site were creosote and pentachlorophenol (PCP). Creosote comprises predominantly polynuclear aromatic hydrocarbons (PAHs). PCP crystals were dissolved in a medium aromatic solvent similar to diesel fuel with five percent PCP and 95 percent carrier. In the mid-1960s, approximately ten percent of the treatment was a salt process believed to use fluoride, chrome, arsenic, dinitrophenol, zinc chloride, boric acid, and ammonium salt. A 50/50 mixture of one-half creosote and one-half fuel oil (PS400) was occasionally used for some wood treating orders. Production of treated wood products peaked sometime during the late 1950s and gradually decreased until the facility was shut down in 1969 (Alsid and Associates and J.R. Carr Associates [Alsid/Carr] 1985).

PCP and PAHs are the primary contaminants of concern (COCs) at the Site and they exist as both NAPL and dissolved phase constituents in the groundwater. The Site NAPL is predominantly a dense NAPL (DNAPL), NAPL that is denser than water, but some light NAPL (LNAPL) also exists.

Two aquifer units (the Upper Aquifer and Lower Aquifer) and a middle leaky aquitard (the Intermediate Zone) have been impacted by NAPL and dissolved phase COCs. A conceptual three-dimensional diagram of the impacted aquifers in relation to the current and historical remedial systems is presented on Figure 1-2. The Upper Aquifer is the subject of this FFS.

1.2.2 Site Regulatory History

EPA placed the Site on the final National Priorities List (NPL) in 1983. A remedial investigation (RI) and FS were completed in 1988 to establish the nature and extent of contamination and to evaluate alternatives for remediation of the Site. Current EPA decision documents for the Site include two Record of Decision (ROD) documents (EPA 1986, 1988b) and two Explanation of Significant Differences (ESD) documents (EPA 1993, 1997). These documents are listed in Table 1-1 with a summary of the key decisions made to address Site-related impacts to groundwater.

EPA initiated the Five-Year Review process for the Site in 1995. The purpose of a Five-Year Review is to determine whether a remedy remains protective of human health and the environment. Five-Year Review Reports were prepared by EPA in 1995, 2000, 2005, 2010, and 2015. IP implemented several actions to address issues EPA raised in the 2010 Five-Year Review Report (EPA 2010) regarding the protectiveness of the Upper Aquifer remedy. These actions are summarized in Sections 1.2.3.4 and 1.2.3.5. The 2015 Five-Year Review Report (EPA 2015) concluded that the groundwater remedy currently protects human health and the environment due to the City of Libby ordinance restricting groundwater use; however, for the remedy to be protective in the long-term it must include institutional controls (ICs) to prohibit groundwater use in areas outside the City limits, modify applicable or relevant and appropriate requirements (ARARs) and cleanup levels, and modify the groundwater remedy to achieve RAOs.

1.2.3 Previous Investigations

1.2.3.1 RI/FS (1985 to 1988)

An RI was performed in phases to evaluate the nature and extent of Site contamination, followed by a risk assessment to identify exposure pathways, COCs, and preliminary risk-based cleanup levels. Investigations included soil sampling, installation and sampling of wells, NAPL recovery tests, and surface water sampling (Alsid/Carr 1985 and WCC 1986, 1988a).

An FS was performed to develop and evaluate remedial alternatives to remove or reduce potential threats to human health and the environment (WCC 1988b). As part of the FS, a pilot-scale test was conducted in 1987 and 1988 to evaluate in situ bioremediation for treatment of the Upper Aquifer. Based on the pilot test results, the FS, the Proposed Plan, and public comment, EPA selected in situ bioremediation as the remedy for the Upper Aquifer, along with extraction of NAPL and contaminated groundwater in the former waste pit source area.

1.2.3.2 Addenda to RI/FS for the Lower Aquifer (1990 to 1993)

At the time the 1988 ROD (EPA 1988b) was issued, no remedial alternatives had been demonstrated to reduce contamination in the Lower Aquifer in a reasonable timeframe. The results of the following investigations formed the basis of EPA's decision to grant a technical impracticability (TI) waiver of ARARs for the Lower Aquifer (EPA 1993):

- A bench-scale study to evaluate bioremediation of DNAPL in the Lower Aquifer (WCC 1990).
- A field characterization study to evaluate the nature and extent of contamination in the Lower Aquifer (WCC 1993a).
- A focused risk assessment to evaluate potential risk to human health and the environment from Lower Aquifer contamination (WCC 1993b).
- An evaluation of technologies to remediate DNAPL in the Lower Aquifer (WCC 1993c).

1.2.3.3 Routine Groundwater Monitoring (1985 to Present)

Groundwater quality has been monitored in select wells since the mid-1980s. Locations of existing monitoring wells are presented on Figure 1-1. For the Libby Site, "well nest" generally refers to multiple wells installed at different depths in one boring and "well cluster" refers to a cluster of wells spaced 5 to 10 feet apart, with each well installed in a separate boring at a different depth. Each well nest or cluster has a parent name (e.g., well cluster 5513) and each well in the cluster (or nest) is assigned a unique name (e.g., wells 5513.1, 5513.2, and 5513.3). The results of Site-wide groundwater monitoring have been reported in annual reports submitted to the Agencies since 1992 (Arrowhead Engineering, Inc. [AEI] 2017b).

1.2.3.4 Post 2010 Five-Year Review Investigations (2010 to 2016)

In response to EPA's November 2009 SOW (EPA 2009), IP initiated planning for additional characterization work for the Upper Aquifer. Scoping of the characterization work was finalized following the completion of EPA's 2010 Five-Year Review Report (EPA 2010), and IP implemented the following tasks:

- Completed an extensive off-site investigation in 2010 to better delineate the extent of the dissolved phase plumes in the Upper Aquifer (URS 2011).
- Completed an extensive source area characterization investigation in 2011 to better understand the nature and extent of NAPL in the Upper Aquifer and initiated activities to evaluate remedial technologies for the Upper Aquifer (URS 2012).
- Developed a numerical groundwater flow and transport model to evaluate areas in Libby to restrict groundwater use to strengthen ICs (URS 2016).

1.2.3.5 July 2012 Statement of Work Investigations (2012 to 2014)

To gather information to support the FFS, as described in EPA's July 2012 SOW (EPA 2012), IP completed the following additional studies:

- Conducted a vapor intrusion investigation from 2011 to 2013 to further assess vapor as a potential exposure pathway (AEI 2013). The results indicated no evidence of any vapor intrusion under current conditions (EPA 2015).
- Re-evaluated groundwater cleanup levels based on current federal and state groundwater standards. The results were presented in the Final Remedial Action Objectives Technical Memorandum (URS 2013a). The Agency-approved RAOs and preliminary revised groundwater cleanup levels are presented in Section 2.1.
- Conducted a hot water/steam enhanced extraction (HW/SEE) bench-scale (laboratory) study to evaluate the ability of this technology to remove NAPL from the Upper Aquifer. A NAPL saturation reduction ranging from 0.9 to 2.7 percent pore volume (PV) was observed during the study, primarily due to dissolution of COCs, such as PCP, and non-COC chemicals (URS 2013b). An average 59 percent reduction of PCP mass in NAPL-impacted soil was observed in the bench test soil columns. Additional results of the HW/SEE bench-scale study are presented in the design basis in Section 3.1.1.1.
- Conducted an in situ biosparging (ISB) bench-scale study to evaluate the ability of this technology to reduce dissolved COC concentrations and to enhance the dissolution of NAPL. An average 70 percent reduction of PCP mass in NAPL-impacted soil was observed in the bench test soil columns (URS 2013c). Additional results of the ISB bench-scale study are presented in the design basis in Section 3.1.1.2.

1.2.3.6 Additional ISB Treatability Studies (2014 to 2017)

The 2012 SOW (EPA 2012) called for conducting pilot-scale (field) treatability studies to further evaluate a technology in the field, depending on the results of the bench-scale studies. Based on the results of the ISB bench-scale study, IP recommended an ISB pilot-scale study to further evaluate the ISB technology to treat COCs in the former waste pit area, the area most heavily impacted by NAPL.

The ISB pilot-scale scale test was designed to gather information to support development of an ISB alternative. The ISB pilot test was conducted to collect field data and evaluate the effectiveness and implementability of remediating COCs in the Upper Aquifer through a full-scale biosparging system. The ISB pilot-scale test was conducted in two phases, Phase 1 and Phase 2.

The objective of Phase 1 was to determine the achievable radius of influence (ROI) for the distribution of dissolved oxygen (DO) to the aquifer. ROI was determined in Phase 1 by monitoring air flow rate, pressure, water levels, and DO concentrations in the wells.

The objective of Phase 2 was to evaluate the effectiveness of biosparging in reducing the concentrations of COCs in the Upper Aquifer soil and groundwater. Phase 2 was initially planned to take place over a six-month period. After Phase 2 startup, IP submitted *Addendum One of the Biosparging Pilot-Scale Test Work Plan* on September 9, 2015 to the Agencies (AEI, 2015) to install three additional wells between the pilot test area and the fire pond (Figure 1-1) to evaluate the elevated pressure response observed during air injection and to extend the operation of the ISB pilot system for an additional six months (the test was actually extended for three additional months). *Addendum Two of the Biosparging Pilot-Scale Test Work Plan* was submitted on November 11, 2015 (AECOM, 2015) to evaluate the presence of NAPL near the fire pond.

Following completion of the ISB pilot test, the data from oxygen-demand tests indicated that air flow rates less than what was tested may be capable of meeting the oxygen demand. However, the complex lithology of the system required additional testing at alternate, lower air-flow rates to evaluate performance. *Addendum Three of the Biosparging Pilot-Scale Test Work Plan* (AECOM 2016a) was submitted to the Agencies on May 12, 2016. *Addendum Three* was designed to:

- Determine physical system parameters (e.g., air flow, radius of dissolved oxygen influence, and changes to hydraulic head) to evaluate alternative full-scale system designs,
- Compare the design parameters and estimates of respiration rates to results from the initial pilot test operations, and
- Evaluate spatial variability in ROI, hydraulic head, and respiration rates.

The additional tests were completed using the existing pilot study equipment, setup, and wells and was completed from May 22, 2016 through June 22, 2016. The activities focused on collecting data to evaluate design parameters under various operating conditions.

The results of the ISB Pilot Test and the additional low-flow testing described in Addendum Three are presented in Section 3.1.1.3.

1.2.3.7 FFS Data Gap Investigations

Several additional data collection activities were identified to support conceptual design and development of alternatives in the FFS in a June 21, 2016 meeting with IP and the Agencies. The data collection included the following activities:

- Conduct comprehensive groundwater sampling in 2016 for COC analysis to refine remediation areas and dissolved groundwater concentrations in areas where NAPL exists. The results of this sampling are presented in discussions on nature and extent of contamination (Section 1.2.7.1).
- Collect DNAPL and LNAPL samples for chemical analysis to estimate molecular weight and effective solubility. The results of this analysis are presented in AECOM (2017d) and they are summarized in Section 1.2.6.3.3.
- Measure LNAPL transmissivity in existing wells near former tank farm to evaluate LNAPL recoverability and appropriate recovery methods. The results of this evaluation were presented in AECOM (2017c) and they are summarized in Section 3.1.1.4.
- Drill 2 to 3 well nests in area where former mill buildings were located to further delineate and characterize Remediation Area 2. The results of this sampling are presented in discussions on the nature and extent of contamination (Section 1.2.7.1).
- Evaluate natural source zone depletion to identify and quantify NAPL mass depletion processes and support the estimation of remediation timeframes. The results of this assessment are presented in AECOM (2018).

1.2.4 Previous Remedial Actions

1.2.4.1 Soil Excavation and Treatment

The two primary historical contaminant source areas were the waste pit and the tank farm (Figure 1-1). Other smaller potential contaminant source areas were the butt dip, mineral spirits, and retort areas, located between the waste pit and tank farm areas.

Beginning in 1989 impacted soil above the water table, 7 to 17 feet below ground surface (bgs), was excavated from the former waste pit (1.5 acres), tank farm (0.83 acres), and butt dip (0.088 acres). The excavated soil was screened to a particle size less than 1 inch, and placed in the waste pit for biological pretreatment. Rock larger than 1 inch was placed on a rock pad and the rock surfaces were treated with bioreactor effluent. Approximately 45,000 cubic yards of soil and 31,000 cubic yards of rock (> 1 inch) were excavated (76,000 cubic yards total). Clean backfill was placed in the excavations of the former tank farm and butt dip areas.

The pretreated soil in the waste pit was transferred in stages to two land treatment units for biological treatment. In 1998, the majority of the remaining pretreated soil from the waste pit was placed on the newly constructed expanded land treatment unit. The former waste pit excavation was backfilled with the treated rock and a silty cover (about 3.5 feet thick). The land treatment areas are shown on Figure 1-1. Soil treatment is nearly completed.

1.2.4.2 Source Area Extraction and Treatment System

The source area extraction and treatment system (SAETS) has operated in varying configurations since 1991, and it is currently in operation. Three extraction wells were abandoned prior to 1997 due to poor NAPL recovery. The current configuration has been in operation since 2000 and includes three extraction wells (9006, 9008, and 9009), two oil/water separators, a bioreactor treatment system, an infiltration trench, and injection well 9504. The wells and infiltration trench are shown on Figure 1-1. The current SAETS system is shown in conceptual three-dimensional view on Figure 1-2.

In 2016, the three extraction wells pumped at an average (time-weighted) total rate of 25.4 gallons per minute (gpm), with individual average pumping rates of 10 gpm, 2.4 gpm, and 13 gpm for wells 9006, 9008, and 9009, respectively (AEI 2017a). The total average pumping rate from 2000 through 2016 is approximately 20 gpm.

Fluids pumped from extraction well 9006 is routed to a gravitational oil/water separator, while fluids pumped from extraction wells 9008 and 9009 is combined and routed to a coalescing oil/water separator. The NAPL in the oil/water separators is shipped off-site for incineration. The water phase from well 9006 (10 gpm in 2016) is treated in bioreactors and routed to the infiltration trench located on the south side of the former waste pit. The combined water phase from wells 9008 and 9009 (15.4 gpm in 2016) is re-injected into well 9504 screened in the Upper Aquifer.

Since inception of the source area extraction and treatment system in 1991 through 2016, an estimated 40,546 gallons of NAPL have been removed from the Upper Aquifer, which is approximately 0.02 percent of the total 211.99 million gallons of fluids pumped. An average of 1,600 gallons of NAPL have been removed per year (see Table 8 of AEI 2017a).

A NAPL recovery program separate from the SAETS has been implemented in the vicinity of the former tank farm area since the mid-1990s to monitor for NAPL presence/absence in monitoring wells and to remove NAPL from wells, if practical. Twenty-nine wells are part of this program. The results of NAPL monitoring and recovery are presented in the annual groundwater monitoring reports (AEI 2017a). A total of approximately 69 gallons (260 liters) of LNAPL has been recovered from two wells (3031.1 and 3039.1) from 1993 through 2015.

1.2.4.3 Former In Situ Bioremediation Systems

Two in situ bioremediation systems were formerly operated in the Upper Aquifer: the intermediate injection system and the boundary injection system. These systems were designed to aerobically treat the dissolved phase COCs in the Upper Aquifer by injecting clean, oxygenated water into the aquifer. The former bioremediation injection systems are shown in plan-view on Figure 1-1 and in conceptual three-dimensional view on Figure 1-2.

The intermediate injection system, located in the former tank farm area, was operated from 1987 to 1997 using wells 9500 and 9501, and well clusters 3004 and 3007, as injection wells. The typical total average injection rate for the intermediate system was about 70 gpm of oxygenated and nutrient-enriched water.

The boundary injection system, located approximately 1,000 feet downgradient of the intermediate system, was operated from 1993 to 2003 using well 9001.1, 9503.1, and 9503.2 as injection wells. The typical total average injection rate was about 230 gpm of oxygenated water.

Operation of these systems was discontinued because they were demonstrated to be no more effective in reducing dissolved phase PCP and PAHs to Site cleanup levels than natural attenuation, due to the presence of trapped NAPL in the Upper Aquifer (WCC 1999). Other factors that may have contributed to inefficient performance of the prior in situ bioremediation systems is that limited oxygen can be delivered to the aquifer through oxygenated water, there is a high oxidant demand in the aquifer, and the injected water tends to flow through preferential pathways in the aquifer. Other aquifer oxygenation methods are evaluated in the FFS, as detailed in Section 2.4.1.7.3.

1.2.5 Physical Characteristics

1.2.5.1 Geologic Setting

The Libby Site lies within a valley bordered by mountains. The valley has received deposits of both alluvial and glacial sediments, as well as erosional remnants from the surrounding mountains. The multiple sources of geologic materials have resulted in a complex stratigraphic system beneath the Site. Mountain valleys contain small streams, including Libby Creek and Flower Creek, which are recharged by high-country snowpack. These creeks flow into the regional river, the Kootenai River.

The Site directly overlies the Libby Valley deposits that consist of a complex stratigraphic sequence of discontinuous deposits of cobbles/boulders, gravel, sand, silt, and clay of alluvial and glacial origin. These heterogeneous deposits extend from the surface to approximately 140 to 190 feet bgs at the Site. It is these deposits that form the Upper Aquifer, the Intermediate Zone, and the Lower Aquifer (Figure 1-2).

Underlying the Lower Aquifer, is a glacial till predominately composed of clay and silt with varying content of gravel and sand, and occasional cobbles/boulders. Few borings have been drilled into the glacial till. The glacial till is expected to extend more than 500 feet deep to the Precambrian bedrock. The Precambrian rock beneath the Libby Valley was probably eroded by the advance of an ice sheet that moved up Libby Creek. Subsequently glacial till was deposited within this bedrock valley-shaped erosional feature.

Glacial lacustrine (lakebed) deposits form the cliffs along the east side of the Libby Valley. These deposits are visible from the former lumber mill.

1.2.5.2 Hydrogeologic Units

Two aquifers, the Upper Aquifer and Lower Aquifer, exist within the alluvial/glacial deposits beneath the Libby Valley. These two aquifers are separated by the Intermediate Zone, a unit of lower permeability materials, also referred to as the middle leaky aquitard. The depth and elevation of the three hydrogeologic units were interpreted from boring logs and geophysical logs. The three hydrogeologic units are shown in conceptual three-dimensional view on Figure 1-2.

1.2.5.2.1 Upper Aquifer

The Upper Aquifer is unconfined. The top of the Upper Aquifer is defined by the water table surface at a depth of approximately 6 feet bgs (near the fire pond) to 24 feet bgs (in the City of Libby), based on 2016 water table elevation data. The bottom of the Upper Aquifer is at a depth ranging from approximately 55 to 78 feet bgs across the Site. The Upper Aquifer consists of clean to silty/clayey gravel and sand with cobbles and boulders and occasional interbedded layers of clayey, silty, deposits approximately 2 to10 feet thick. The sand and gravel layers constitute about 80 percent of the total thickness of the Upper Aquifer (WCC 1999).

1.2.5.2.2 Intermediate Zone

The Intermediate Zone is a leaky aquitard that extends from approximately 70 feet bgs to 105 feet bgs. The deposits in this 35-foot-thick zone are similar to those in the Upper Aquifer, but contain a much higher content of silt and clay. Sand and gravel layers constitute only about 20 percent of the total thickness of the Intermediate Zone (WCC 1999). The transition from the Upper Aquifer to the Intermediate Zone can be subtle. Both units consist of interbedded water bearing and non-water bearing strata; however, the Upper Aquifer contains more water bearing strata than the Intermediate Zone.

1.2.5.2.3 Lower Aquifer

The Lower Aquifer underlies the Intermediate Zone and extends from approximately 105 to 160 feet bgs. It is a semi-confined aquifer. The transition from the Intermediate Zone to the Lower Aquifer is more subtle than the transition between the Upper Aquifer and the Intermediate Zone. The Lower Aquifer consists of clean to silty gravel and sand with cobbles and boulders interbedded with sandy, gravelly silt and clay layers, similar to the Upper Aquifer; however, the Lower Aquifer appears to have both higher silt and clay content and more silt and clay interbeds than the Upper Aquifer. The sand and gravel layers constitute about 70 percent of the total thickness of Lower Aquifer (WCC 1999). The undifferentiated glacial material that underlies the

Lower Aquifer serves as a barrier to downward groundwater movement from the alluvial deposits in the Libby Valley.

1.2.5.3 Hydraulic Conductivity

1.2.5.3.1 Upper Aquifer

Hydraulic testing, including slug and pumping tests, has been performed in the Upper Aquifer to estimate the spatial and vertical distribution of hydraulic conductivity in the aquifer. The hydraulic conductivity values derived from these tests are summarized in plan-view on Figure 1-3. Also, information collected during the recent ISB pilot test including well drilling, slug tests and aquifer responses to air injection, provided additional hydrogeological information on the Upper Aquifer in the former waste pit area (AECOM 2017b); and the calibrated numerical groundwater flow model provides hydraulic conductivity for the Upper Aquifer for on-site and off-site areas (URS 2016).

In the former waste pit area, there are three subunits of different hydrogeologic characteristics within the fluvial/glacial deposits of the Upper Aquifer. These subunits are referred to as the shallow, middle, and deep subunits. The shallow subunit extends from the water table to 36 feet bgs, the middle subunit extends from 36 to 54 feet bgs, and the deep subunit extends from 54 to 78 feet bgs (or deeper in localized areas). The three hydrogeologically contrasting subunits are difficult to distinguish in the field from soil boring lithology; however, results from slug tests and a pumping test performed during the source area characterization study in 2011 (URS 2012) revealed varying hydraulic conductivity vertically within the Upper Aquifer. These results are summarized on Figure 1-3. From these tests, the average hydraulic conductivity of the shallow, middle, and deep subunits is 46 feet per day (ft/d), 0.36 ft/d, and 5.0 ft/day, respectively, in the former waste pit area. Additional drilling and slug test data collected during the ISB pilot test (AECOM 2017b) confirmed the presence of three subunits. Pressure dissipation observations in the deep and middle subunits during air injection also provided evidence that the middle subunit is a semi-confining layer and the deep subunit is semi-confined, locally in the waste pit area.

The hydraulic conductivity of the Upper Aquifer increases to the north and hydraulically downgradient of the former waste pit, and less contrast and vertical variability in hydraulic conductivity has been observed. In the former tank farm area located 500 feet north of the former waste pit (Figure 1-3), the average hydraulic conductivity increases to 190 ft/d in the shallow subunit and 13 ft/d in both the middle and deep subunits, based on slug test results. Similar to the former waste pit area, semi-confining conditions may exist in the deep subunit in downgradient areas, but limited field data are available to date to confirm this.

Approximately 1,000 feet hydraulically downgradient of the former tank farm near the former boundary injection system, the hydraulic conductivity increases to approximately 800 ft/d based on historical aquifer testing at well 9001 (Figure 1-3) (URS 2009). No Upper Aquifer subunits have been distinguished in this area at this time. Hydraulic conductivity values estimated from the calibrated numerical model range from 200 to 400 ft/d for the full Upper Aquifer thickness in this area (URS 2016).

1.2.5.3.2 Intermediate Zone and Lower Aquifer

Hydraulic testing has not been extensively performed in the Intermediate Zone or the Lower Aquifer; therefore, the hydraulic conductivity of these zones has been estimated based on visual classification of the material and water production during drilling, limited pumping data, and professional judgment.

The Intermediate Zone hydraulic conductivity is expected to be low, based on lack of water production during drilling through this unit and the high content of fines (silt and clay) observed. A hydraulic conductivity value of 2.5 ft/d was estimated in the calibrated numerical groundwater model (URS 2016) for the Intermediate Zone, site-wide.

The Lower Aquifer hydraulic conductivity is estimated to range from 10 to 100 ft/d based on a low-yield pumping test, water production rates during drilling, electromagnetic (EM) conductivity measurements, and borehole sample descriptions. The low-yield pumping test was performed in Lower Aquifer well 9003 near the former boundary injection system. It provided limited data due to the difficulty in identifying and screening sufficient water bearing zones and maintaining a constant pumping rate and uniform drawdown curve (WCC1988a). Hydraulic conductivity values estimated from the calibrated numerical model range from 200 to 400 ft/d for the Lower Aquifer, site-wide (URS 2016).

1.2.5.4 Groundwater Flow in the Upper Aquifer

1.2.5.4.1 Upper Aquifer Shallow Subunit

Groundwater flow in the Upper Aquifer shallow subunit is unconfined. Groundwater elevation contours representing the water table surface are shown on Figure 1-4. The direction of groundwater flow is predominantly to the north toward the Kootenai River, following the slope of the ground surface topography. The average hydraulic gradient in the shallow subunit along the flow path from the former waste pit to near the Kootenai River is 0.006 foot/foot, based on the 2016 water table surface shown on Figure 1-4.

A strong localized hydraulic gradient exists around the fire pond as a result of surface water recharge into the shallow subunit of the Upper Aquifer. The fire pond is estimated to recharge up to 2,400 gpm to the shallow subunit of the Upper Aquifer (Section 1.2.5.5). The fire pond water level is typically maintained at an elevation of 2101 to 2102 feet above mean sea level (amsl) year round. The fire pond recharge causes groundwater to flow away from the former waste pit source area in a westward direction in the shallow subunit, under a relatively steep hydraulic gradient of 0.02 foot/foot (estimated between wells 5513.1 and 5512.1 on Figure 1-4).

During 2016 operations of the SAETS, treated groundwater was recharged into the shallow subunit in the former waste pit area at an average estimated rate of 10 gpm (Section 1.2.4.2); however this recharge would have little effect on the shallow subunit flow paths compared to the fire pond recharge.

Based on annual water level data from 2011 to 2016 and quarterly to bi-annual data in select wells from 2011 to 2013, the water table typically does not vary more than 5 feet throughout the Site, with some exceptions in local areas (e.g., west of the former tank farm and waste pit source areas toward Highway 2 and around the land treatment area). West of the former tank farm, the water table high in spring 2012 was up to 12 feet higher than the low water table in fall 2011. A rise in groundwater levels is observed each spring in the area of well nests 3013, 3040, and 3050 located west and northwest of the waste pit (personal communication AEI 2013), and a 14-foot rise in water level was observed in the shallow wells of these three nests in spring of 2012 compared to the low water level in fall 2011.

The water table surface shape has remained consistent from year to year, based on water table elevation maps prepared from 1992 through 2016 for the annual groundwater monitoring reports (AEI 2017b).

During former mill operations, log ponds were located in the eastern portion of the old mill property. These historical ponds may have recharged groundwater similarly to the fire pond and induced more westerly groundwater flow in the shallow subunit compared to today. Based on review of historical photographs, log ponds covered a large area of the former mill in the 1950s. By the 1960s, the log pond areas were smaller. In 1993, the last log pond was decommissioned, except for the former log pond that is now the fire pond (personal communication AEI 2016).

1.2.5.4.2 Upper Aquifer Middle/Deep Subunit

Groundwater flow in the Upper Aquifer deep subunit varies from unconfined to locally semi-confined in the former waste pit area by the low permeability middle subunit (Section 1.2.5.3.1). Downgradient of the former waste pit, the middle and deep subunits are indistinguishable and are considered one subunit (middle/deep).

A groundwater elevation (potentiometric) contour map for the Upper Aquifer deep subunit is shown on Figure 1-5. In the former waste pit area, a cone of depression in the potentiometric surface exists due to pumping extraction wells in the source area (Section 1.2.4.2). Although the extraction wells are designed to maximize the recovery of NAPL, they are providing some if not full hydraulic control of deep subunit groundwater in the former waste pit area.

In 2016, an average of 25.4 gpm of groundwater was extracted from the deep subunit and 15.4 gpm of groundwater from the source area extraction and treatment system was reinjected back into the deep subunit through injection well 9504, resulting in a net discharge rate of 10 gpm from the deep subunit.

Figure 1-5 shows the interpreted deep subunit groundwater elevation contour if the SAETS were turned off. It is estimated that a relatively flat hydraulic gradient of 0.005 (from the interpreted 2082- to 2086-foot contours on Figure 1-5) would naturally exist in the deep subunit beneath the former waste pit if the SAETS extraction and injection were not in operation.

The average hydraulic gradient in the deep subunit along the flow path from just downgradient of the former waste pit (at well 5512.3) to near the Kootenai River is 0.004 feet/feet based on the 2016 potentiometric surface shown on Figure 1-5.

Based on annual water level data from 2011 to 2016 and quarterly to bi-annual data in select wells from 2011 to 2013, the potentiometric surface in the middle/deep subunit typically varies less than 5 feet throughout the Site, with exceptions at wells 3013.2 (west of former waste pit), 3007.2 (west of former tank farm), and 5513.2 and 5513.3 (in the former waste pit); water levels in these wells were up to 8 to 14 feet higher in spring 2012 and 2013 compared to the water level low in fall 2011 and summer 2015/2016.

1.2.5.4.3 Vertical Groundwater Flow Paths

Vertical groundwater flow paths in the former waste pit area are highly complex due to recharge from the fire pond, pumping from extraction wells, and reinjection and infiltration of groundwater from the SAETS (Section 1.2.4.2).

Groundwater pumping and reinjection associated with the SAETS resulted in a net discharge from the middle/deep subunit of 10 gpm and a net recharge into the shallow subunit of 10 gpm in 2016. This combined with recharge from the fire pond has caused the hydraulic head in the deep subunit to be approximately 20 feet lower than the shallow subunit and a cone of depression to form in the deep subunit.

Vertical groundwater flow paths in the Upper Aquifer are shown along two flow paths in cross sectional view from the fire pond to the Kootenai River through the former tank farm source area (cross section A-A′ on Figure 1-6) and through the former waste pit source area (cross Section B-B′ on Figure 1-7). The vertical hydraulic gradient in the Upper Aquifer near the former waste pit area is complex (Figure 1-7), due to the high infiltration into the shallow subunit from the fire pond and operation of the SAETS as discussed above.

Generally, there is a downward vertical hydraulic gradient from the Upper Aquifer to the Lower Aquifer in the former mill area. Farther downgradient of the Site, at well nests 3018, 6002, and 6003 (Figure 1-1), there is a slight upward hydraulic gradient between the Lower Aquifer and the Upper Aquifer. Farther downgradient near the river, the upward hydraulic gradient diminishes and converts back to a downward gradient (Figures 1-6 and 1-7).

The vertical hydraulic gradients have remained consistent from year to year, based on groundwater elevation data collected from 1992 through 2016 and reported in the annual groundwater monitoring reports (AEI 2017b).

1.2.5.4.4 Estimated Groundwater Discharge Rates

Groundwater discharge rates were estimated for the Upper Aquifer shallow, middle and deep subunits along transects in the former waste pit area, downgradient of the former tank farm, and farther downgradient off-site to support the design basis for developing remedial alternatives in the FFS (Section 3.1.2). The groundwater discharge rates per unit width of aquifer were estimated using the following relationship:

$$Q = KIB$$

Q = groundwater discharge rate (cubic feet per day per unit width of the aquifer [(ft^3/d)/ft or ft2/d])

K = hydraulic conductivity (ft/d)

I = hydraulic gradient (feet/feet)

B = Upper Aquifer subunit thickness (feet)

Groundwater discharge transects were oriented perpendicular to groundwater flow in the shallow subunit (Figure 1-4) and in the middle/deep subunits combined (Figure 1-5). The transect lengths were selected based on the width of the contaminant plumes and selected remediation areas, discussed later in Section 1.2.6.1 and Section 3.1.2, respectively. Groundwater discharge rates for each transect were estimated by multiplying the transect length by the discharge rate per unit aquifer width. The estimated groundwater discharge rates and the parameters used in the estimation are provided in Table 1-2. The hydraulic conductivity values used in the estimate were from slug test results in the former waste pit and tank farm areas, shown on Figure 1-3, and from the calibrated numerical flow model (URS 2016) for the off-site area. Aquifer subunit thickness was estimated from boring logs. Year 2016 groundwater elevation contours were used to estimate a representative hydraulic gradient in the three areas for each subunit (Figures 1-4 and 1-5). Currently, the SAETS captures most or all of the groundwater discharge from the middle/deep subunits in the former waste pit area, as shown by the cone of depression on Figure 1-5, based on 2016 groundwater level measurements. Figure 1-5 also shows interpreted groundwater elevation contours without the SAETS were operating. Table 1-2 presents groundwater discharge from the middle/deep subunits in the former waste pit without the SAETS operating.

Average groundwater discharge through a unit width of Upper Aquifer in the former waste pit area is approximately 19 cubic feet per day per foot [(ft^3/d)/ft] (Transects 1S and 1D). The shallow subunit is estimated to contribute 95 percent of this flow because the middle/deep subunit has a lower hydraulic conductivity and gradient. Separate transects (1S and 1D) were developed for the shallow and deep subunits because groundwater flows westward in the shallow subunit and northward in the deep subunit. Average groundwater discharge through a unit width of Upper Aquifer downgradient of the former tank farm area is approximately 42 (ft^3/d)/ft (Transect 2), twice that of the waste pit discharge. The shallow subunit is estimated to contribute 95 percent of the flow compared to the middle/deep subunit, due to the middle/deep subunit's lower hydraulic conductivity and hydraulic gradient.

Average groundwater discharge through a unit width of Upper Aquifer farther downgradient and off-site is approximately 76 (ft^3/d)/ft (Transect 3), nearly twice that of the former tank farm area discharge. The assumed hydraulic conductivity values and the measured hydraulic gradients are similar in the shallow, middle, and deep subunits, thus the contribution of each unit to discharge is dependent on the subunit thickness.

Hydraulic conductivity is the most variable and uncertain parameter in the groundwater discharge estimate. There is uncertainty associated with incomplete knowledge of spatial variability in the aquifer, accuracy of the slug test method (order of magnitude), and accuracy in the geometric mean representing the average conditions of the aquifer subunit (appropriate sample size). Hence, groundwater discharge may vary locally or as bulk flow by an order of magnitude or more.

1.2.5.4.5 Average Linear Velocity

Average linear velocity for groundwater (groundwater velocity) was estimated for the Upper Aquifer subunits to support the estimation of remediation timeframes in the FFS, using the following relationship:

$$V = KI/n_e$$

V = average linear velocity for groundwater (ft/d)

K = hydraulic conductivity (ft/d)

I = hydraulic gradient (feet/feet)

n_e = effective porosity (unitless)

The estimated groundwater velocity and the parameters used in the estimation are presented in Table 1-2. In the former waste pit area, groundwater velocity is approximately 3.7 ft/d in the shallow subunit. A reversal of groundwater flow occurs in the middle/deep subunit due to the extraction wells, thus there is currently no flow in the direction of the natural hydraulic gradient. Based on the interpreted groundwater elevation contours without the SAETS operating, the estimated groundwater velocity would be 0.0091 ft/d in the middle subunit and 0.13 ft/d in the deep subunit under a natural hydraulic gradient.

Downgradient of the former tank farm area, the groundwater velocity is approximately 11 ft/d in the shallow subunit and 0.22 ft/d in the deep/middle subunit.

Farther downgradient and off-site, the groundwater velocity is approximately 9 ft/d in the shallow, middle, and deep subunits.

Similar to estimates of groundwater discharge discussed in Section 1.2.5.4.4, hydraulic conductivity is the most variable and uncertain parameter in the groundwater velocity estimate. Because hydraulic conductivity values may vary by an order of magnitude or more, groundwater velocity may vary by an order of magnitude or more.

1.2.5.5 Surface Water

The main surface water bodies near the Site are the fire pond, Libby Creek, and the Kootenai River (Figure 1-1).

The fire pond receives water from Libby Creek through an unlined diversion canal and stores water for fire protection. Both the canal and the pond lose water to the underlying aquifer. The surface water leakage from the pond to the aquifer was estimated on September 3, 1986 to be 5.2 cubic feet per second (cfs) (2,400 gpm) (WCC 1986). This was considered to be an over-estimation of fire pond seepage under normal operating conditions in WCC (1986); however, it provides a good order of magnitude estimate of pond water loss to the Upper Aquifer and it is similar to the estimated fire pond recharge rate of 1,700 gpm estimated during calibration of the numerical groundwater flow model.

Libby Creek is a perennial stream (Figure 1-1). Boetter and Wilke (1978) reported a measured stream flow of 85 cfs (39,000 gpm) south of the fire pond during the low flow season of 1974, and that the creek was gaining or losing along different segments of the creek. Immediately upstream of the fire pond, the creek is likely a losing stream but may become a gaining stream near its junction with the Kootenai River.

The Kootenai River is normally a gaining stream. The average monthly flow rate in the river varied from 5,000 cfs to 33,000 cfs over 80 years (1911 to 1991) (USGS 12303000 Kootenai River at Libby, MT).

1.2.5.6 Groundwater Recharge

The annual precipitation ranged from 12.04 to 25.56 inches from 1940 to 1970, with an average annual precipitation of 19.4 inches (Boettcher and Wilke 1978).

Precipitation in the mountains surrounding the Libby Valley enters mountain streams via surface and subsurface flow. The mountain streams then discharge to valley streams (e.g., Libby Creek, Flower Creek, and Parmenter Creek). Groundwater recharge to the Libby Valley aquifers results from infiltration of precipitation, losing valley streams and other surface water bodies (e.g., fire pond), and lawn irrigation water in the City of Libby.

1.2.5.7 Groundwater Withdrawal

A City ordinance prohibiting the use of water wells for domestic and irrigation purposes has been in place since the mid-1980s to limit human exposure to Site-related COCs. Therefore, there is limited groundwater withdrawal in the vicinity of the Site.

Limited groundwater withdrawal in the vicinity of the Site includes:

- Dewatering well 3092, located in the former mill area (Figure 1-1), has been operated intermittently for several decades to prevent groundwater from flowing into a manhole access to the sewer system. Although the well is thought to be capable of producing up to 150 gpm, the estimated average pumping rate in 2016 was 19 gpm.
- Groundwater extraction occurs during operation of the SAETS (Section 1.2.4.2). The processed groundwater is re-injected back into the Upper Aquifer via an injection well and an infiltration gallery.
- Temporary groundwater withdrawals for construction dewatering.

1.2.6 Nature and Extent of Contamination

1.2.6.1 Former and Current Sources

In the original Site feasibility study (WCC 1988b), three areas were identified as the primary sources of wood treating fluids to the Upper Aquifer: the former waste pit, the former tank farm, and the former butt dip area (Figure 1-1). As part of remedial actions that began in 1989, soil above the water table in these areas was excavated and biologically treated in land treatment units on Site (Section 1.2.4.1). These three areas are now referred to as “former source areas.”

Currently, the primary source of groundwater contamination is wood treating fluid and wastes that remain in the aquifer in the form of LNAPL and DNAPL. COCs adsorbed to the aquifer matrix or stored as dissolved COCs in finer-grained layers (diffuse mass) are also potential sources of COCs in groundwater. NAPL historically migrated both vertically downward and laterally downgradient away from the former source areas in a complex flow path dependent on the NAPL release volume, the physical properties of the various wood treating mixtures and wastes that seeped into the aquifer during different periods, and historical groundwater flow in the aquifer.

In the former waste pit area, condensate from the retort and other waste inputs increased the hydraulic head at the waste pit during its operation, inducing downward seepage of DNAPL vertically through the Upper Aquifer and deeper into the Lower Aquifer. It is possible that the LNAPL that seeped into the Upper Aquifer in the former waste pit migrated beneath the water table (downward and laterally) through preferential channels of higher hydraulic conductivity, pushed by the hydraulic head at the source.

Seepage of wood treating fluids from the former tank farm and butt dip likely occurred as intermittent spills and leaks with less head to force NAPL into the Upper Aquifer. This is supported by subsurface investigations conducted in 2011, where visible NAPL in aquifer soil was less frequently observed in the former tank farm compared to the former waste pit area, and even less NAPL was visible in the former butt dip area (URS 2012).

The source area extraction and treatment system, described previously in Section 1.2.4.2, has removed contaminant mass in the former waste pit area since it began operation in 1991. From 1991 through 2016, an estimated 40,546 gallons of NAPL has been extracted and an estimated 34,869 pounds of PAHs and 6,936 pounds of PCP have been degraded in the bioreactor system (AEI 2017a). Mass removal has primarily targeted the Upper Aquifer deep subunit.

1.2.6.2 NAPL Distribution in the Upper Aquifer

The extent of NAPL in the Upper Aquifer has been investigated and documented through drilling and well monitoring activities from 1984 to 2016. NAPL is easily observed during drilling due to the high visibility of creosote and its distinct odor, and NAPL observations were typically documented in Site boring logs. Each boring log for the Site has been thoroughly reviewed, and NAPL observed during drilling from 1984 to the present has been summarized in a database. Observations range from a slightly visible sheen to visible brown/black droplets on soil cuttings and core or in drilling water discharged to roll off bins. The thickness of intervals where NAPL was observed in borings ranges from less than an inch to more than 10 feet. Single to multiple observations at different depths may be observed in a single borehole. Due to the abundance of large gravel and cobbles in the subsurface, the drilling methods employed at the Site have been limited to sonic, air rotary, and historically cable tool. Soil samples collected by these methods are generally disturbed, although less so for those collected by sonic drilling.

Figure 1-8 shows the locations where NAPL was observed in the Upper Aquifer during drilling, including historical observations (1984 to 2009) and more recent observations (2010 to the present). These observations range from a single occurrence of slight sheen to multiple occurrences in a single boring with more visible NAPL; therefore, Figure 1-8 is a conservative display of where NAPL has been observed in borings.

In January 2016, the upgradient extent of NAPL was refined during drilling of six borings around the edge of the fire pond near the former waste pit. NAPL was observed in four soil borings drilled on the southwest edge of the fire pond, and no NAPL was observed in the two borings drilled on the north side of the fire pond (Figure 1-8). Based on these observations, NAPL likely extends underneath the southwest edge of the fire pond, possibly pushed by a historically high hydraulic head in the former waste pit (Section 1.2.6.1), and terminates somewhere under the fire pond.

In August and September of 2016, three well clusters (3061, 3062, and 3063) were installed in the area north of the tank farm to further delineate the extent of NAPL and dissolved COCs in this area. Each of the three well clusters included a shallow, middle, and deep individual well. The wells were installed and sampled in accordance with an Agency-approved work plan (AECOM 2016b). NAPL was observed in the soil core in two of the three wells, 3061 and 3062, as shown on Figure 1-8.

In 2014 and 2015, a comprehensive monitoring of NAPL presence/absence was performed in all accessible Upper Aquifer monitoring wells to provide updated information on NAPL extent for the FFS. Procedures for this monitoring event and the results were presented in the 2015 Annual Groundwater Monitoring Report (AEI 2016). The results are provided on Figure 1-9, which is a map view showing Upper Aquifer wells that contained visible NAPL in varying amounts (e.g., film, sheen, brown/black droplets, LNAPL layer, etc.) and wells that did not contain visible NAPL. For wells installed after 2015, NAPL presence/absence observations were recorded during development or sampling, and these results are shown on Figure 1-9. In general, the area where NAPL was observed in wells (Figure 1-9) is slightly smaller than the area where NAPL was observed in soil borings (Figure 1-8).

DNAPL and LNAPL presence/absence has been monitored quarterly in 29 wells located in the former tank farm area and hydraulically downgradient since 1993 as part of the annual monitoring for the Upper Aquifer. When recoverable LNAPL accumulates in a well, it is removed during the quarterly monitoring event. This occurs in only two of the 29 wells, 3031.1 and 3039.1, where one to two feet of LNAPL can accumulate in a quarter following the removal of LNAPL from the wells. From 1993 through 2015, 70 liters (18 gallons) of LNAPL was removed from well 3031.1 with LNAPL thickness ranging from a trace to 2 feet; and 187 liters (49 gallons) of LNAPL was removed from well 3039.1 with LNAPL thickness ranging from 1 to 5 feet. Six other wells in the quarterly NAPL monitoring program have much smaller amounts of LNAPL (less than 2 inches thick) and DNAPL (oil droplets in bottom of well).

In late 2016, an LNAPL transmissivity assessment was initiated in accordance with an Agency–approved work plan (AECOM 2016c) to further assess LNAPL recovery in these wells. New well 3061.1 was added to the assessment because approximately 1 foot of LNAPL accumulated in the well one month after installation in September 2015. The results of the LNAPL transmissivity assessment were presented in a draft technical memorandum (AECOM 2017c).

The northernmost observation of NAPL was in 1985 during drilling of well nest 3018 where NAPL sheen was observed in the lower half of the Upper Aquifer. In 2013, NAPL was not observed in soil cores from a confirmation well (3051) drilled adjacent to 3018. NAPL has not been observed in the wells at either location. Thus, it appears that the current extent of NAPL is south of wells 3018 and 3051.

1.2.6.3 NAPL Physical and Chemical Properties

Physical and chemical properties of NAPL were evaluated during the source area investigation in 2011 and again during investigations in 2016. The 2011 physical and chemical data were previously presented in the source area characterization report (URS 2012) and are summarized in this section. The 2016 physical and chemical data were collected in accordance with an Agency-approved sampling and analysis plan (IP 2016). The results were interpreted and discussed in a final technical memorandum (AECOM 2017d); a summary of the results are presented in this section.

1.2.6.3.1 Ultraviolet Photography and NAPL Saturation Tests

Soil cores were collected in 2011 from the Upper Aquifer in the former waste pit and tank farm source areas and sent to PTS Laboratories for ultraviolet (UV) and white light photography to identify soil sub-cores with higher NAPL content for further analysis. The selected sub-cores were analyzed for initial (field) and residual NAPL pore saturations using Dean Stark analysis. Centrifuge and water drive test methods were used to estimate residual (immobile) NAPL saturations.

At least two, 1-foot-long soil cores were collected from each former source area boring, targeting the most visibly impacted soil identified in the field. These soil cores were frozen in the field using dry ice and submitted to PTS Laboratories for core photography in accordance with protocol. Based on the review of UV photographs, the 28 most impacted soil cores (of 104 total cores) were selected for initial and residual NAPL saturation analysis. In each selected core, the most visibly impacted portion of the core was selected to sub-core for the analysis. Therefore, the NAPL saturation analysis was performed on Upper Aquifer samples with the highest NAPL impacts.

The initial and residual NAPL saturation results are presented in Table 1-3. The initial NAPL saturations in the former waste pit sub-core samples ranged from 1.7 to 17.1 percent pore volume, with an average of 6.5 percent. The initial NAPL saturations in the former tank farm sub-core samples were lower and ranged from 0.7 to 9.5 percent pore volume with an average of 4.8 percent. As shown in Table 1-3, the residual saturation is equivalent to the initial saturation in all water drive test samples and in all but four centrifuge test samples, indicating that NAPL is primarily present at residual (immobile) saturations in the source areas. For the four samples with a residual NAPL saturation less than initial saturation, the decrease in NAPL saturations was small, ranging from 0.3 to 2.7 percent.

Typical sub-core samples collected for NAPL saturation analysis and the results are presented on Figure 1-10. These sub-core samples represent some of the most visibly impacted samples from the former waste pit (top two samples) and former tank farm (bottom two samples).

At boring 5508 located within the former waste pit footprint, core samples were collected every 10 feet of the boring to obtain a profile at one location. The most visibly impacted soil from each 10-foot interval of boring was selected for core photography, shown on Figure 1-11. Much of the soil had visible sheen in the field based on sheen tests or noticeable sheen on the soil core, but UV photography shows very little NAPL present. This emphasizes the conservativism in NAPL presence/absence observations during drilling that are shown on Figure 1-8. Thus, observation of NAPL sheen in soil cores at the locations shown on Figure 1-8 likely represent residual NAPL saturations that are much lower than the saturations found in the most impacted samples from the former source areas.

1.2.6.3.2 NAPL Density, Viscosity, and Interfacial Tension

Most of the Site wells that contain visible NAPL (Figure 1-9) do not produce sufficient recoverable sample volume, thus physical property analysis in 2011 was limited to a DNAPL sample from extraction well 9006 (collected in the gravitational oil/water separator) and an LNAPL sample collected from well 3039.1. The two NAPL samples were submitted to PTS Laboratories for analysis of density and viscosity at five temperatures up to 150 degrees Fahrenheit (°F) and interfacial tension to support the evaluation of thermal technologies in the FFS. The laboratory results are provided in AECOM (2017a), Appendix C.

In 2016 additional NAPL samples were collected for analysis of physical properties, including samples from the two sampling locations in 2011 plus two new locations. DNAPL was collected again from extraction well 9006 (from the gravitational oil/water separator), plus another DNAPL sample was collected from extraction wells 9008 and 9009 combined (from the coalescing oil/water separator). LNAPL was collected again from well 3039.1, plus another LNAPL sample was collected from new monitoring well 3061.1 located north of the tank farm.

The 2016 samples were analyzed by Triton Analytics Corporation for viscosity, density, and specific gravity at a range of groundwater temperatures including 5 degrees Celsius (°C) (41 °F), 10 °C (50 °F), and 20 °C (68 °F); and interfacial tension at 25 °C (77 °F). The laboratory results are provided in AECOM (2017a), Appendix C.

Table 1-4 presents a summary of the 2011 and 2016 analyses of physical properties at a typical groundwater temperature of 10 °C (50 °F). The density of the DNAPL samples was similar for the two wells ranging from 1.0136 to 1.0190 grams per cubic centimeter (g/cm^3). The density of the LNAPL sample from new well 3061.1 (0.9370 g/cm^3) was slightly less dense than the samples from well 3039.1 (0.9616 to 0.9647 g/cm^3). The dynamic viscosity of the DNAPL samples ranged from 13.1 to 14.6 centipoise (cp). The viscosity of the LNAPL sample from new well 3061.1 (4.40 cp) was less viscous than the samples from well 3039.1 (7.84 to 8.0 cp).

1.2.6.3.3 Chemical Analysis of NAPL

NAPL samples were collected from extraction well 9006, monitoring well 3006.1, and monitoring well 3039.1 during the source area investigation (URS 2012) and analyzed for metals, volatile organic compounds (VOCs), and semi-volatile organic compounds (SVOCs). Four additional NAPL samples were collected in 2016 and analyzed for hydrocarbons, PAHs, PCP, and monocyclic aromatic hydrocarbons (MAHs).

The DNAPL samples had a chemical composition consistent with a mixture of coal tar creosote and PCP wood treating solutions. The fractions of priority pollutant PAHs (PAH16) in the DNAPL samples were 16 to 17.9 percent. Mass fractions of benzene, toluene, ethylbenzene, and xylenes (BTEX) were low (0.027 to 0.044 percent).

The LNAPL samples had a chemical composition consistent with a mixture of coal tar creosote and PCP wood treating fluids with diesel range hydrocarbons. The fractions of PAH16 were 2.9 to 5.2 percent. Mass fractions of BTEX were low (0.003 to 0.006 percent).

The complete NAPL analytical results are provided in AECOM (2017a), Appendix D. Table 1-5 summarizes PCP and naphthalene concentrations in the NAPL samples collected in 2011 and 2016, the two key COCs in the dissolved plume.

1.2.6.3.4 Chemical Analysis of Aquifer Soil

Soil samples of Upper Aquifer matrix were collected at various locations and depths across the Site from 2011 to 2016 during drilling of borings and monitoring wells. Table 1-6 summarizes the analytical results of Upper Aquifer soil concentrations (mass fractions) for select groundwater COCs in the south area (former waste pit), the middle area (former tank farm) and the north area (downgradient of the former sources) of the Site.

Soil concentrations in the former source areas provide both the NAPL mass in the pore space and the mass fraction of COCs in the NAPL in the pore space (if NAPL is present in the sample). To a lesser extent, the soil concentration represents adsorbed phase and dissolved phase COC mass in the samples. The source area soil sampling targeted both soil visibly impacted by NAPL and soil not visibly impacted by NAPL. The soil PCP concentration distribution in the source areas is presented on Figure 1-12. The full analytical results are presented in AECOM (2017a), Appendix E. Soil concentrations outside the extent of NAPL in the Upper Aquifer (north area) represent adsorbed and dissolved COC mass in the aquifer matrix.

Soil concentrations are generally highest in the former waste pit area (south area) and decrease to the north, as shown in Table 6-1. Soil PCP concentration ranges from 0.98 to 74 milligrams per kilogram (mg/kg), with an average of 19 mg/kg in the former waste pit area; 0.022 to 68 mg/kg, with an average of 4.5 in the former tank farm area; and soil PCP concentrations are generally below reporting limits (<0.005 to <1.8 mg/kg) in the northern area downgradient of the former sources.

1.2.7 Contaminant Fate and Transport

1.2.7.1 Current Distribution of COCs in Groundwater

Groundwater COCs were established in the 1988 ROD and the 1997 ESD. The preliminary revised groundwater cleanup levels for the Upper Aquifer are updated in this FFS from the Agency-approved Final Technical Memorandum: Remedial Action Objectives for the Upper Aquifer (URS 2013a) to reflect updated groundwater standards (Section 2.1, Table 2-1). The extent of COC concentrations above these cleanup levels was evaluated for the shallow and middle/deep subunits of the Upper Aquifer, using the 2016 comprehensive groundwater chemical data.

PCP groundwater concentrations in 2016 for the shallow and middle/deep subunits of the Upper Aquifer are displayed on Figures 1-13A and 1-13B, respectively, with NAPL observations in wells noted by an asterisk next to the concentration. A comparison of the PCP distribution in the shallow and middle/deep subunits shows that the extent of PCP is larger in the middle/deep subunit and the concentrations are generally higher throughout the subunit.

The 13 PAH COC concentrations in 2016 for the shallow and middle/deep subunits of the Upper Aquifer are displayed on Figures 1-14A/B through 1-26A/B. The extent of the 13 PAHs above their respective cleanup levels is within the extent of PCP contamination. Similar to PCP distribution, the extent of PAH concentrations is larger in the middle/deep subunit and the concentrations are generally higher throughout the subunit.

Possible explanations for higher COC concentrations in the middle/deep subunit include:

- Wells sampled where NAPL has been observed may not represent the dissolved phase concentration. A small amount of NAPL in the groundwater sample can increase the COC concentration in a groundwater sample [by up to an estimated 5,000 micrograms per liter (µg/L) for PCP].
- Deep subunit NAPL may have higher mass fractions of COCs than shallow subunit NAPL (Table 1-5).
- Biooxidation of COCs is likely greater in shallow groundwater because of the high recharge rate of surface water containing dissolved oxygen.

PCP concentrations are low (slightly above or below the cleanup level of 1µg/L) in wells surrounding the former tank farm area of excavation, including wells that contain NAPL (Figures 1-13A and 1-13B). Although the wood treating fluid source could have been a low PCP formulation, the decrease in PCP concentrations since the early 1990s (Section 1.2.7.2) supports that PCP may be dissolving from the NAPL in this area. Currently, groundwater flow from the former tank farm is along a separate flow path from the former waste pit. There is a high flux of clean groundwater flowing from the fire pond through the former tank farm, which may be contributing to PCP dissolution and depletion from the NAPL. Figure 1-27 presents a cross sectional view of PCP groundwater concentrations and NAPL occurrence along the flow path downgradient of the former tank farm. PCP concentrations along this flow path in both the shallow and deep subunit are currently below the cleanup goal of 1 µg/L. NAPL that remains in the Upper Aquifer beneath the eastern portion of the former tank farm area and along the flow path downgradient appears to no longer be a significant source of dissolved phase contamination in the Upper Aquifer.

PCP groundwater concentrations are highest in the former waste pit area in both the shallow and deep subunits, where concentrations are 5,000 µg/L or greater in several wells (Figures 1-13A and 1-13B). These concentrations are above the estimated effective solubility of PCP in Site DNAPL, which is estimated to be on the order of 1,000 µg/L (AECOM 2017d).

The vertical distribution of PCP groundwater concentrations and NAPL along the flow path downgradient of the former waste pit is shown on Figure 1-28. As shown on Figure 1-28, PCP concentrations attenuate by up to three orders of magnitude in the shallow subunit and one order of magnitude in the deep subunit just 500 feet downgradient of the former waste pit. Shallow subunit attenuation may be enhanced by biooxidation and less PCP mass in shallow subunit NAPL, as discussed above. Deep subunit attenuation may be related to hydraulic capture of deep subunit groundwater by the source area extraction wells (Section 1.2.5.4.2), which controls the PCP mass flux from the waste pit source area. Currently, residual NAPL downgradient of the former waste pit is likely maintaining the PCP plume downgradient of the former waste pit.

1.2.7.2 PCP and Naphthalene Trends in Groundwater

Historic trends for PCP and naphthalene concentrations from 1987 to 2016 were evaluated for each Upper Aquifer well cluster/nest. Graphs for each well nest are presented in Appendix A. PCP and naphthalene were selected for this evaluation because they are relatively soluble and mobile in groundwater compared to other COCs at the Site and they define the outermost extent of groundwater contamination above cleanup levels.

PCP concentration trend graphs are presented in map view on Figure A1 for the Upper Aquifer well clusters/nests outside the former waste pit and tank farm source areas, and the source area detail is provided at a larger scale on Figure A2. Naphthalene concentration trend graphs are presented in map view on Figure A3 for the well clusters/nests outside the former source areas, and the source area detail is provided at a larger scale on Figure A4.

The following are key observations related to PCP and naphthalene concentration trends:

- The highest PCP concentrations (1,000 to 10,000 µg/L) exist in the former waste pit area and directly downgradient to the west to well nest 5512 (Figure A2). These high concentrations have persisted in the shallow, middle, and deep subunits over the past six years, based on available analytical data at well clusters 5513 and 5512. Naphthalene concentrations are more variable, ranging from below the cleanup level of 100 µg/L to 100,000 µg/L (Figure A4).

- In three deep subunit wells located around the former tank farm (3012.1, 3015.1, and 3016.1), PCP has decreased at least two orders of magnitude from >1,000 to <10 µg/L (Figure A2) and naphthalene has decreased one order of magnitude from 10,000 to 1,000 µg/L and 1,000 to 100 µg/L (Figure A4) even in wells that contain DNAPL.
- There is higher variability in PCP and naphthalene concentrations over time in wells near the former source areas, especially in wells that historically contained NAPL. After 1992, the sampling of wells with observed NAPL (sheen, film, droplets, or accumulations) was discontinued because the concentrations represented the variable amount of NAPL in the samples, not dissolved phase concentrations. Select wells with NAPL were placed on quarterly monitoring for the presence/absence of NAPL, and monitoring for dissolved phase was focused on wells without NAPL. The wells with NAPL were sampled again in 2016, and some have been sampled annually since 2012.
- The historical sampling practice of purging three well volumes prior to sampling may have contributed to higher PCP variability in wells. Since March 2008, low flow purging and sampling techniques have been used for groundwater sampling.
- Highly variable PCP concentrations, from <1 to >1,000 µg/L, have been observed in wells 3013.1 (Figure A2) and 3040.1, (Figure A1) located to the west and northwest of the waste pit where high groundwater levels are observed each spring season (Section 1.2.5.4.1). Naphthalene concentrations at 3013.1 are typically near or below the cleanup level of 100 µg/L and at 3040.1 naphthalene is not detected.
- Overall, PCP concentrations downgradient of the former source areas have decreased from the early 1990s to 2016, based on the concentration trend graphs for well nests 3031 and 3039 in the tank farm area; and well nests 3002, 3018, 3041, 3042, 3043, 6001, and 8006, etc. in the middle portion of the plume downgradient from the tank farm (Figure A1). Naphthalene concentrations are near or below the cleanup level of 100 µg/L at these wells (Figure A3).
- PCP and naphthalene concentrations outside of the interpreted extent of the plumes have remained below cleanup levels, based on data collected from 1992 to 2016 in well nests 6500, 6501, and 6502 and supported by data collected from 2010 to 2016 in well clusters 6017, 6018, 6019, and 6020.

It can be concluded from the trend evaluations above that the COC plumes in the three subunits of the Upper Aquifer are stable, even where NAPL is present, and concentrations are decreasing in the outermost portions of the plume and in some wells in the former tank farm source area.

1.2.7.3 Dissolved COC Attenuation

The stability of the COC plumes downgradient of the NAPL sources is due to natural attenuation processes, mainly dispersion, adsorption, and natural biodegradation. First-order bulk attenuation rate constants for PCP and naphthalene were estimated using methods described in Newell et al. (2002). Groundwater concentration data from wells at various distances downgradient of the outermost extent of NAPL in the Upper Aquifer were used in the estimation. The bulk attenuation rate constants were used in the solubility modeling to evaluate remediation timeframes for each remedial alternative (Appendix B).

The estimated bulk attenuation rate and half-life for PCP and naphthalene in the shallow and middle/deep subunits are shown in Table 1-7. Attenuation in the Upper Aquifer is expected to be mostly related to biodegradation because soil-water distribution coefficients (K_d) for the COCs are relatively low due to the low organic carbon content in the aquifer matrix. For example, the K_d value for PCP is estimated to range from 0.125 to 0.99 L/kg, based on Site soil total organic carbon data and a literature value for the organic carbon-water partition coefficient (URS 2016). The corresponding retardation factor (R) for PCP in the Upper Aquifer ranges from approximately 2 to 7, based on the relationship:

$$R = 1 + (\text{soil dry bulk density/total porosity})K_d$$

This indicates that PCP solute travels in the Upper Aquifer at a rate 1/2 to 1/7 of the groundwater velocity.

1.2.8 Land Use

The former mill area (Figure 1-1) is currently used for light industrial or commercial purposes; businesses are located along US Highway 2, but most of this land is sparsely developed. Portions of the former mill property owned by Lincoln County Port Authority are currently being developed. The proposed future use of the former mill property is industrial and commercial, based on discussions with the former Executive Director, Kootenai River Development Council, Inc. in December 2012. A public fishing pond was recently constructed adjacent to the Libby Creek diversion canal in the southeast portion of the property for recreational purposes (Figure 1-1).

The Kootenai River bounds the former mill property to the north. Residential and commercial areas are located directly west and northwest of the former mill. Forest lands and rural residences are located east of the former mill property.

1.2.9 Summary of Baseline Risk Assessment

A baseline human health endangerment assessment was prepared in 1986 as part of the original feasibility study. It included an assessment of the current and future human health risks from contaminated groundwater in the Upper Aquifer.

No new Upper Aquifer groundwater risk assessment evaluation has been performed since the 1988 ROD was issued (EPA 1988b). Therefore, risks posed to human health and the environment by current conditions are expected to be comparable to those described in the 1988 ROD and the 1986 baseline risk assessment.

EPA determined that exposure to groundwater for domestic use would result in unacceptable risks under a residential scenario.

Soil vapor studies conducted by IP from 2011 to 2013 resulted in very low concentrations in samples collected from vapor monitoring points, sub-slab monitoring points, indoor air, and outdoor air. Based upon these results, a risk assessment to evaluate human health exposure to soil vapors is not required by the Agencies (EPA 2013).

1.2.10 NAPL Source Material as Principal or Low Level Threat Waste

Source material is defined in *A Guide to Principal Threat and Low Level Waste* (EPA 1991) as material that includes or contains hazardous substances, pollutants or contaminants that act as a reservoir for migration of contamination to groundwater, to surface water, to air, or acts as a source for direct exposure. Contaminated groundwater is generally not considered to be a source material although NAPL may be viewed as source material.

As discussed previously in Section 1.2.6.1, NAPL is currently the primary source of groundwater contamination in the Upper Aquifer. NAPL exists throughout the Upper Aquifer in the former waste pit and tank farm source areas, and where it historically migrated laterally and vertically away from these areas. NAPL and dissolved COCs in groundwater form a potentially complete exposure pathway to humans if pumping of contaminated groundwater occurs.

The concept of principal threat and low level threat was developed by EPA in the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) to be applied on a site-specific basis when characterizing source material for the purpose of developing cleanup options (EPA 1991). According to the NCP [40 CFR 300.430(a)(1)(iii)], EPA generally expects to use treatment to address principal threats posed by a site, wherever practicable; engineering controls, such as containment, for wastes that pose a relatively low long-term threat or where treatment is impracticable; and a combination of methods, as appropriate, to achieve protection of human health and the environment.

Principal and low level threat wastes are defined by EPA as follows (EPA 1991):

"Principal threat wastes are those source materials considered to be highly toxic or highly mobile that generally cannot be reliably contained or would present a significant risk to human health and the environment should exposure occur. They include liquids and other highly mobile materials (e.g., solvents) or materials having high concentrations of toxic compounds.

Low level threat wastes are those source materials that generally can be reliably contained and that would present only a low risk in the event of a release. They include source materials that exhibit low toxicity, low mobility in the environment, or are near health based levels."

According to EPA (1991) determinations as to whether a source material is a principal or low level threat should be based on the inherent toxicity as well as a consideration of the physical state of the material (e.g., liquid), the potential mobility of the wastes in the particular environmental setting, and the lability and degradation products of the material.

NAPL source material in the Upper Aquifer is difficult to categorize as either principal or low level threat waste. This is due to the complex distribution of NAPL in the aquifer and the variability in NAPL composition, NAPL saturation, and groundwater concentrations throughout the aquifer both laterally and vertically, as discussed previously in Section 1.2.6 and 1.2.7. The highest COC concentrations (and highest toxicity) in groundwater exist in the former waste pit area; partly a result of many of the wells containing small amounts of NAPL (typically a sheen) that increases the concentration in the groundwater sample. Groundwater in this area ranges in concentration from near or below groundwater quality standards to four orders of magnitude above standards. Groundwater collected from wells downgradient of the former waste pit area, including the former tank farm area, are generally lower in COC concentration. This is partly due to a lower NAPL saturation in the aquifer in these locations compared to the former waste pit area, and in some locations a NAPL composition that is lower in COC mass.

A key characteristic of the Upper Aquifer NAPL is that it is present predominantly as residual (immobile) saturations based on NAPL mobility testing (Section 1.2.6.3.1) and LNAPL transmissivity assessments (Section 3.1.1.4). However; a relatively small amount of NAPL can be recovered under an induced hydraulic gradient in extraction wells in the former waste pit area; this amount is estimated to be 0.02 percent of the total fluid volume pumped (Section 1.2.4.2)

Because the Site NAPL is not highly mobile, and it is naturally contained reliably at residual saturation, it is not considered principal threat waste. However; due to the high concentrations in groundwater at some locations where NAPL is present or near where NAPL is present, the Site NAPL is not considered to be a low level threat waste either.

In Section 3.1.2, remediation areas are developed based on the COC concentrations in groundwater and the interpreted presence of NAPL in the Upper Aquifer. Remedial alternatives are developed in Section 3.3 to address NAPL and dissolved COCs in groundwater by active treatment in areas of the Upper Aquifer with the highest COC concentrations, the highest potential for releasing dissolved COCs to the groundwater, and the greatest potential risk to human health.

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Table 1-1. EPA Decision Documents Related to Groundwater

Decision Document	Decisions Related to Groundwater
1986 ROD	Interim remedy of institutional controls was established including: (1) Buy Water Plan to provide monetary compensation to residents for using City water for human consumption and irrigation in lieu of private wells, and (2) City ordinance that prohibits drilling of water wells for the purpose of human consumption or irrigation.
1988 ROD	Cleanup levels for groundwater and remedial actions for the Upper Aquifer were established. Bioremediation was selected as the primary cleanup technology including: excavation and on-site biological treatment of source area soils (above the water table), source area extraction of contaminated groundwater and NAPL in the Upper Aquifer with biological treatment, and in-situ bioremediation of dissolved COCs in the Upper Aquifer.
1993 ESD	Waiver of ARARs granted for the Lower Aquifer due to the technical impracticability of removing NAPL from the Lower Aquifer and the improbability that Lower Aquifer contamination poses a risk to human health and the environment. Remedy of long-term monitoring and institutional controls was established for Lower Aquifer.
1997 ESD	Cleanup levels for the Upper Aquifer were modified to address updated federal MCLs and risk assessment practices.

Notes:
ARARs – Applicable or Relevant and Appropriate Requirements
ESD – Explanation of Significant Differences
MCL – maximum contaminant levels
NAPL – non-aqueous phase liquid
ROD – Record of Decision

Table 1-2. Groundwater Discharge and Average Linear Velocity for Upper Aquifer

Transect 1S and 1D (Former Waste Pit Area)

Parameters	Units	Shallow Subunit	Middle Subunit SAETS Off[1]	Deep Subunit SAETS Off[1]	Total
Depth to groundwater table (August 2016)	ft bgs	11			
Hydraulic conductivity range	ft/d	46	0.21 to 0.63	4.2 to 6.3	
Hydraulic conductivity geomean	ft/d	46	0.36	5.1	
Horizontal hydraulic gradient	ft/ft	0.016	0.0050	0.0050	
Aquifer subunit thickness	ft	25	18	20	63
Aquifer width	ft	1	1	1	
Effective porosity	unitless	0.20	0.20	0.20	
Discharge per unit width of aquifer	$(ft^3/d)/ft$	18	0.03	0.52	19
	gpm/ft	0.10	0.00017	0.0027	0.10
Transect length	ft	400	300	300	
Discharge across transect	gpm	38	0.051	0.81	39
Average linear velocity	ft/d	3.7	0.0091	0.13	

Transect 2 (Downgradient of Former Tank Farm)

Parameters	Units	Shallow Subunit	Middle Subunit	Deep Subunit	
Depth to groundwater table (August 2016)	ft bgs	21			
Hydraulic conductivity range	ft/d	95 to 360	1.5 to 107	18 to 30	
Hydraulic conductivity geomean	ft/d	190	13	13	
Hydraulic gradient	ft/ft	0.011	0.0035	0.0035	
Aquifer subunit thickness	ft	19	18	18	55
Aquifer width	ft	1	1	1	
Effective porosity	unitless	0.20	0.20	0.20	
Discharge per unit width of aquifer	$(ft^3/d)/ft$	40	0.81	0.79	42
	gpm/ft	0.21	0.0042	0.0041	0.22
Transect length	ft	1,100	1,100	1,100	
Discharge across transect	gpm	231	5	4	240
Average linear velocity	ft/d	11	0.22	0.22	

Transect 3 (Off-Site)

Parameters	Units	Shallow Subunit	Middle Subunit	Deep Subunit	
Depth to groundwater table (August 2016)	ft bgs	16			
Hydraulic conductivity range	ft/d	400	400	400	
Hydraulic conductivity geomean	ft/d	400	400	400	
Hydraulic gradient	ft/ft	0.0044	0.0045	0.0043	
Aquifer subunit thickness	ft	20	18	5.5	43
Aquifer width	ft	1	1	1	
Effective porosity	unitless	0.20	0.20	0.20	
Discharge per unit width of aquifer	$(ft^3/d)/ft$	34	32	9.4	76
	gpm/ft	0.18	0.17	0.049	0.40
Transect length	ft	1,200	1,200	1,200	
Discharge across transect	gpm	215	201	59	475
Average linear velocity	ft/d	8.8	9.0	8.6	

Table 1-2. Groundwater Discharge and Average Linear Velocity for Upper Aquifer

Notes:

[1] In the former waste pit area, groundwater in the middle and deep subunits is currently captured by the extraction wells in the SAETS. In Table 1-2 above, the groundwater discharge and average linear velocity are estimated assuming the SAETS is off, and groundwater flows under a natural hydraulic gradient downgradient of the former waste pit.

ft bgs - feet below ground surface

ft/d - feet per day

ft/ft - feet per feet

$(ft^3/d)/ft$ - cubic feet per day per foot

gpm - gallons per minute

gpm/ft - gallons per minute per foot

SAETS - source area extraction and treatment system

Table 1-3. Initial and Residual NAPL Saturation in Former Source Areas (2011)

Core Sample ID	Depth of Subsample (ft bgs)	Total Porosity (Percent)	Initial NAPL Saturation[1] (Percent Pore Volume)	Residual NAPL Saturation[1] After Centrifuge or Water Drive (Percent Pore Volume)	Potential Mobile NAPL (Percent Pore Volume)
Former Waste Pit Samples:					
5501 62-63	62.55	32.7	3.6	3.6	0.0
5501 62-63	62.7	26.4	4.9	4.9	0.0
5502 61-62	61.15	26.3	4.6	4.6	0.0
5502 61-62	61.15	23.8	1.7	1.7	0.0
5506 7-8	7.25	25.6	2.1	2.1	0.0
5507 11-12	11.45	32.2	4.6	4.4	0.3
5510 20-21	20.55	29.9	2.5	2.5	0.0
5511 65-66	65.3	38.2	11.3	10.8	0.4
5512/1 21-22	21.6	31.8	4.9	4.8	0.0
5512/1 21-22	21.75	26.2	5.0	5.0	0.0
5512/2 44-45	44.35	38.2	2.3	2.3	0.0
5512 65.5-66.5	66.2	38.0	8.6	8.6	0.0
5513/1 15.5-16.5	16.4	32.6	8.5	8.5	0.0
5513/2 45-46	45.15	30.0	2.5	2.5	0.0
5513/3 61-62	61.4	24.2	4.1	4.1	0.0
5513/3 61-62	61.4	30.4	5.7	5.7	0.0
5514 11-12	11.8	35.1	7.5	7.5	0.0
5516 32-33	32.2	12.3	9.2	9.2	0.0
5517 32-33	32.5	34.9	10.2	10.2	0.0
5519 51-52	51.75	46.0	17.2	14.5	2.7
5519 51-52	51.75	45.1	8.4	8.4	0.0
Former Tank Farm Samples:					
5520 14-15	14.32	12.6	7.4	7.4	0.0
5520 54-55	54.7	32.0	7.5	7.2	0.3
5520 54-55	54.7	30.8	8.0	8.0	0.0
5521 16-17	16.15	7.2	9.5	9.5	0.0
5522 37.5-38.5	37.9	31.9	0.7	0.7	0.0
5524 43-44	43.55	35.7	3.1	3.1	0.0
5525 41-42	41.77	33.3	3.8	3.8	0.0
5525 41-42	41.77	33.4	8.2	8.2	0.0
5526 33.5-34.5	34.05	33.1	3.8	3.8	0.0
5527 17-18	17.22	37.6	2.5	2.5	0.0
5528 16-17	16.54	29.8	4.6	4.6	0.0
5529 62-63	62.15	28.9	5.6	5.6	0.0
5529 62-63	62.15	35.6	6.7	6.7	0.0
5530 16-17	16.25	33.8	1.5	1.5	0.0
5531 23-24	23.35	34.6	4.8	4.8	0.0

Notes:

[1] Laboratory analysis of NAPL saturation was performed relative to the laboratory NAPL standard density of 0.86 g/cc. NAPL saturation values presented above were converted relative to the site specific NAPL density of 1 g/cc by reducing laboratory value by 14%.

Samples were analyzed by PTS Laboratories.

ft bgs – feet below ground surface

g/cc – grams per centimeter cubed

NAPL – non-aqueous phase liquid

Data presented in rows shaded grey are results from the water drive test. Data presented in unshaded cells are results from the Centrifuge test.

Table 1-4. Summary of NAPL Physical Properties in Upper Aquifer at Groundwater Temperature

NAPL Sample Location	Sample Date	Temperature		Dynamic Viscosity (mPa-s) (centipoise)	Kinematic Viscosity (mm^2/s) (centistoke)	Density (g/cm^3)	Specific Gravity (unitless)	Interfacial Tension (mN/m) (dyne/cm)	
		(°F)	(°C)	ASTM D445[a]/D7042[b]		ASTM D1481[a]/D4052[b]		ASTM D971	
Coalescing OWS (wells 9008 and 9009) DNAPL	2016	50	10	13.1	12.9	1.0174	1.0177	26.9	25°C
Gravitational OWS (well 9006) DNAPL	2011	50	10	14.6	14.3	1.0190	1.0190	24.2	21°C
	2016	50	10	14.0	13.9	1.0133	1.0136	24.6	25°C
Well 3039.1 LNAPL	2011	50	10	8.0	8.3	0.9644	0.9647	12.3	21°C
	2016	50	10	7.84	8.2	0.9613	0.9616	28.6	25°C
Well 3061.1 LNAPL	2016	50	10	4.40	4.7	0.9370	0.9373	23.5	25°C

Notes:

[a] Method used for 2011 analysis by PTS.

[b] Method used for 2016 analysis by Triton.

Additional laboratory results at other temperatures are provided in (AECOM 2017x), Appendix C.

2011 samples were analyzed by PTS Laboratories, Santa Fe Springs, California.

2016 samples were analyzed by Triton Analytics Corp., Houston, Texas.

Abbreviations:

ASTM – American Society for Testing and Materials
°C – degrees Celsius
°F – degrees Fahrenheit
cm – centimeter
DNAPL – dense non-aqueous phase liquid
g/cm^3 – gram per centimeter cubed
LNAPL – light non-aqueous phase liquid
mm^2/s – millimeter squared per second
mPa–s – milliPascal second
mN/s – milliNewton per second
NAPL – non-aqueous phase liquid
OWS – oil/water separator

Table 1-5. NAPL PCP and Naphthalene Concentrations

Well and Area	Upper Aquifer Subunit	Mass Fraction (mg/kg)	
		PCP	Naphthalene
9006 Waste Pit	Deep (DNAPL)	5,400 (2011) 5,020 (2016)	120,000 (2011) 72,400 (2016)
9008/9009 Waste Pit	Deep (DNAPL)	4,970 (2016)	95,000 (2016)
3006.1 Waste Pit	Shallow (LNAPL)	920 (2011)	41,800 (2011)
3039.1 Tank Farm	Shallow (LNAPL)	<750 (2011) 935 (2016)	22,000 (2011) 22,200 (2016)
3061.1 North of Tank Farm	Shallow (LNAPL)	135 (2016)	11,700 (2016)

Notes:
DNAPL – dense non-aqueous phase liquid
mg/kg – milligrams per kilogram
NAPL – non-aqueous phase liquid
PCP – pentachlorophenol

Table 1-6. Site-Wide Upper Aquifer Soil Concentrations (Mass Fractions)

Boring/Well Number	Sample Depth Interval (ft bgs)	Sample Date	Select Analytes (mg/kg) Acenaphthene	Benzo(a)pyrene	Fluoranthene	Fluorene	Naphthalene-svoc	Naphthalene-voc	Pentachlorophenol	Phenanthrene
SOUTH AREA SOIL SAMPLES (FORMER WASTE PIT)										
5503	10	6/9/2011	22	0.87	14	19	2.8	55	4	47
5503	36	6/9/2011	31	1.7	30	17	150	240	6.6	85
5503	40	6/9/2011	47	2.8	42	31	200	300	19	120
5504	16	6/10/2011	94	3.7	57	58	3200	5300	21	150
5504	47	6/10/2011	33	1.6	27	24	130	500	25	74
5504	64	6/10/2011	65	3	50	47	280	1300	23	140
5505	40	6/11/2011	65	4.7	47	39	210	84	31	110
5505	64	6/12/2011	67	3.8	53	46	240	1100	30	150
5505	75	6/12/2011	20	2.5	23	16	9	30	0.98	70
5506	12	6/12/2011	53	3.4	49	38	77	110	2.8	140
5506	45	6/12/2011	51	3.5	46	31	330	1500	12	130
5506	71	6/13/2011	4	0.29	5	3.3	30	240	1.4	14
5507	13	6/13/2011	62	3.6	46	43	170	610	31	120
5507	29	6/13/2011	65	3.5	50	44	170	310	74	140
5507	30	6/13/2011	4.5	0.17	3.6	3.6	17	24	6.6	9
5508	19	6/20/2011	110	6.6	82	70	2100	4000	32	260
5508	65	6/20/2011	11	0.69	8.8	7.5	40	270	1.8	31
		Minimum	4	0.17	3.6	3.3	2.8	24	0.98	9
		Maximum	110	6.6	82	70	3200	5300	74	260
		Geometric Mean	34.4	2.0	28.4	23.8	116.8	332.3	10.5	80.8
		Arithmetic Mean	47.3	2.7	37.3	31.6	432.7	939.6	19.0	105.3
MIDDLE AREA SOIL SAMPLES (FORMER TANK FARM)										
5509	32	6/21/2011	**0.023**	0.165	**0.13**	**0.036**	**0.11**	3.1	**0.88**	0.24
5510	28	6/21/2011	**0.022**	0.165	**0.065**	**0.027**	**0.063**	**2.2**	**0.73**	0.15
5520	40	10/5/2011	**1.5**	0.165	**2.7**	**1.4**	**2.6**	**180**	1	5.7
5521	35	10/06/2011	0.165	0.165	0.165	0.165	0.17	**3**	1	< 0.33
5521	60	10/06/2011	**3.3**	**0.69**	**12**	**4.2**	0.165	**0.099**	1	19
5522	27	10/6/2011	**56**	**3.4**	**55**	**32**	**190**	**310**	**5.8**	110
5522	36	10/6/2011	0.165	0.165	0.165	0.165	0.17	**950**	1	0.36
5523	31	10/7/2011	0.165	0.165	0.165	0.165	0.17	0.0085	1	0.165
5524	17	10/8/2011	**2.2**	**0.92**	**9.5**	**2.5**	**0.72**	0.115	**3**	8.9
5524	51	10/8/2011	**24**	**2.2**	**20**	**13**	**110**	**510**	5	49
5526	36	10/9/2011	**71**	**4.5**	**73**	**56**	**130**	**0.47**	**68**	180
5527	54	10/10/2011	0.165	0.165	0.165	0.165	0.17	**1.3**	1	0.5
3061.1	7-17	8/31/2016	12	0.18	4.3	8.8	4.9	Not Analyzed	1.3	13
3061.1	17-27	8/31/2016	0.0059	0.00315	0.018	0.0093	0.00315	Not Analyzed	0.028	0.024
3061.2	47-57	8/31/2016	32	1.8	25	23	130	Not Analyzed	4	76
3061.3	67-77	8/30/2016	41	1.9	27	28	210	Not Analyzed	7	86
3062.1	7-17	9/2/2016	7.9	0.15	3.2	5	4.1	Not Analyzed	0.76	9.7
3062.1	17-27	9/2/2016	0.036	0.0032	0.061	0.051	0.018	Not Analyzed	0.044	0.14
3062.2	37-47	9/2/2016	0.003	0.003	0.013	0.003	0.003	Not Analyzed	0.03	0.0077
3062.3	57-67	9/1/2016	0.00305	0.00305	0.0075	0.00305	0.00305	Not Analyzed	0.022	0.013
3063.1	17-32	9/7/2016	0.00305	0.00305	0.019	0.0074	0.00305	Not Analyzed	0.0305	0.026
3063.2	37-47	9/6/2016	0.00305	0.00305	0.00305	0.00305	0.00305	Not Analyzed	0.0305	0.00305
3063.3	57-67	9/6/2016	0.00305	0.003	0.003	0.003	0.003	Not Analyzed	0.031	0.003
		Minimum	0.003	0.003	0.003	0.003	0.003	Not Analyzed	0.022	0.003
		Maximum	71	4.5	73	56	210	Not Analyzed	68	180
		Geometric Mean	0.314	0.102	0.469	0.310	0.353	Not Analyzed	0.570	0.884
		Arithmetic Mean	11	0.736	10	7.6	34	Not Analyzed	4.5	25
NORTH AREA SOIL SAMPLES (DOWNGRADIENT OF FORMER SOURCES)										
3051.1	49.5	6/18/2013	0.16	0.16	0.013	0.16	0.16	0.01	1	0.033
3051.1	64.5	6/18/2013	0.15	0.15	0.15	0.15	0.15	0.009	0.9	0.15
6010.1	27-28	7/31/2010	0.0013	0.0013	0.0013	0.0013	0.0013		0.0027	0.0013
6010.2	37-38	7/30/2010	0.0037	0.0015	0.0059	0.0061	0.0062		0.01	0.0081
6010.3	36-37	7/30/2010	0.0035	0.0016	0.0047	0.0038	0.0044		0.0033	0.0079
6010.3	56-67	7/30/2010	0.0014	0.0014	0.0014	0.0014	0.0014		0.0028	0.0014
		Minimum	0.0013	0.0013	0.0013	0.0013	0.0013	0.009	0.0027	0.0013
		Maximum	0.0037	0.0016	0.013	0.0061	0.0062	0.01	0.01	0.033
		Geometric Mean	0.002	0.001	0.004	0.003	0.003	0.009	0.004	0.005
		Arithmetic Mean	0.002	0.001	0.005	0.003	0.003	0.010	0.005	0.010

Notes:

Soil samples in the South, Middle, and North areas above represent soil concentrations in Remediation Areas 1, 2, and 3, respectively, on Table 3-1 in Section 3.

Soil sample analytical results are from: URS. 2017. Final Technical Memorandum: Upper Aquifer Hydrogeologic Conceptual Site Model. Libby Groundwater Site, Libby, Montana, Revision 1. Prepared for International Paper Company. January 17. APPENDIX E, Table E1.

Soil sample locations selected in the Areas above are locations where soil chemical data are available, analyses is by ALS, and there is good spatial distribution of the data points. Field duplicates were omitted.

Analytical results in purple are below the laboratory reporting limit, and 1/2 the concentration of the reporting limit is shown.

Analytical results in red indicates the reporting limit was too high and the result was not used in the statistical summary.

Sample results that are shaded grey represent soil samples not visibly impacted by NAPL, as documented in the field.

Soil concentrations are reported on a dry weight basis.

Table 1-7. Bulk Attenuation Rate Constants for PCP and Naphthalene

COC	Subunit	Groundwater Flow Path (Well Data Used in Calculation)	Distance (ft)	k (1/d)	Half Life (d)
PCP	**US**	3003.3, 3008.1, 3062.1, 3010.1	950	0.03522	19.7
Naphthalene	**US**	3008.1, 3062.1, 3010.1, 3043.1	1100	0.03779	18.3
PCP	**UM/UD**	3061.3, 3002.2, 6014.3, 6019.3	3500	0.01109	62.5
Naphthalene	**UM/UD**	3061.3, 3010.2, 3051.1, 6016.3, 6013.3	2200	0.01675	41.4

Notes:
d - day
ft - feet
k - bulk attenuation rate constant
PCP - pentachlorophenol
US - Upper Aquifer shallow subunit
UM/UD - Upper Aquifer middle and deep subunit combined

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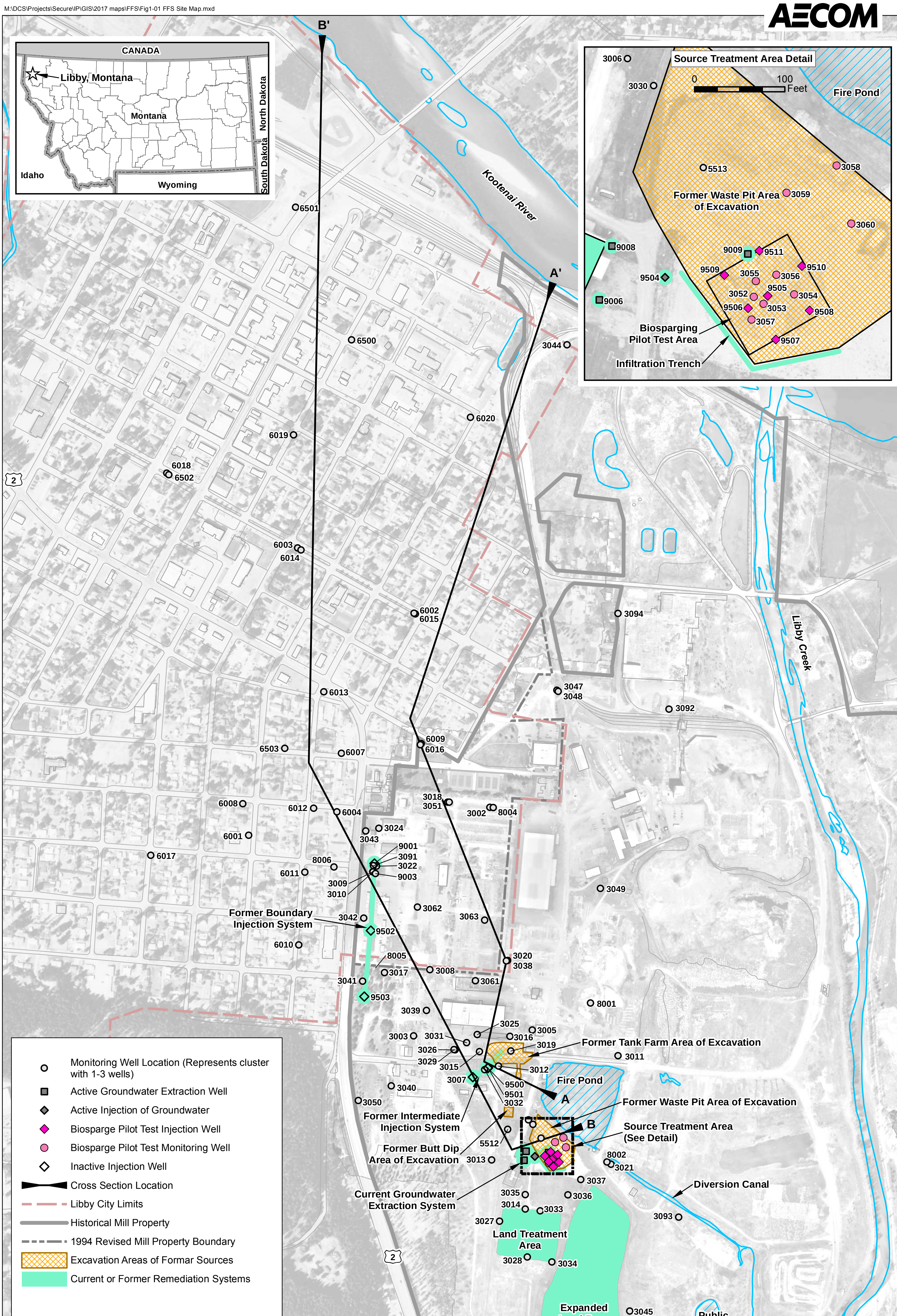


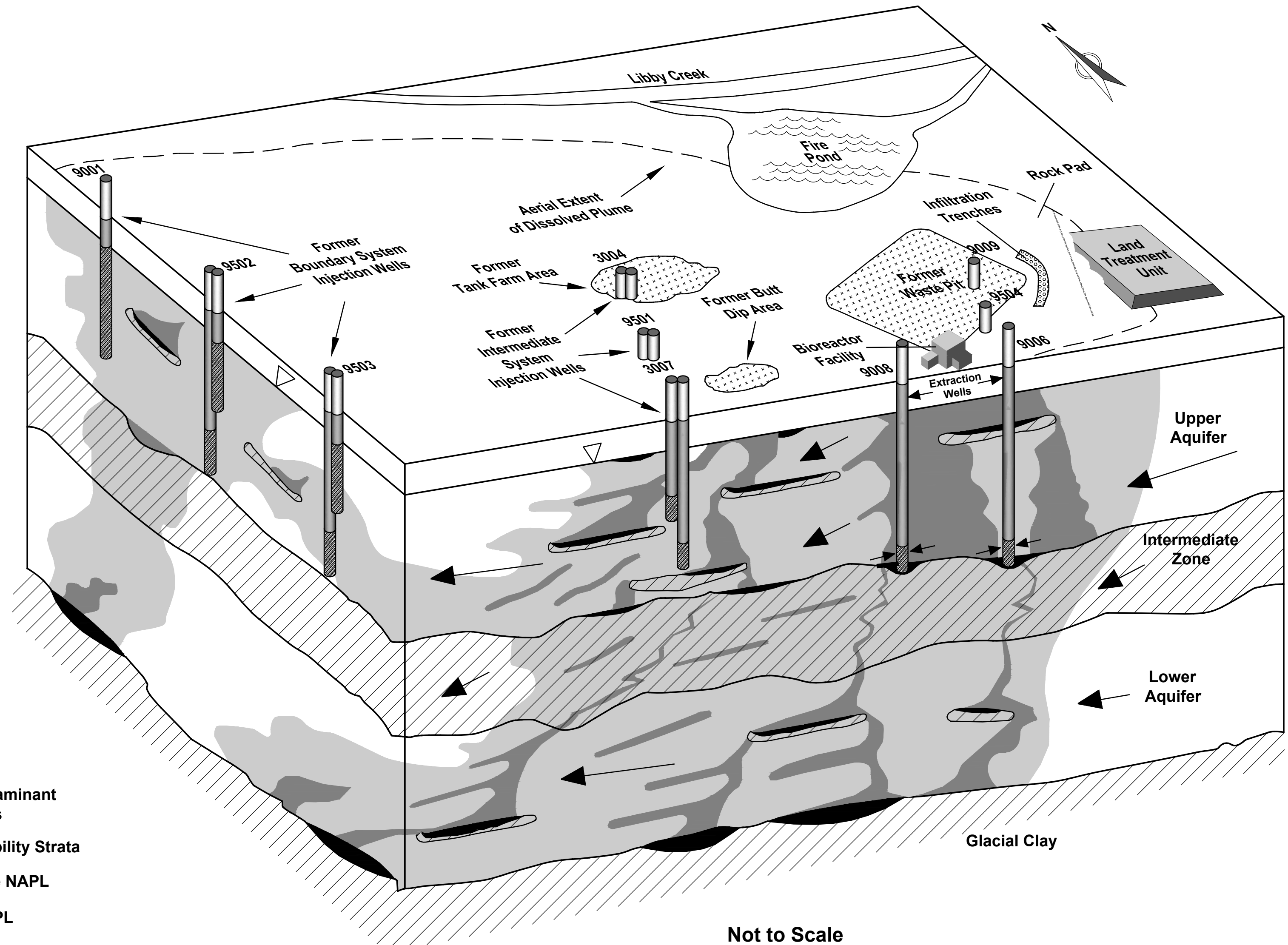
Site Map

FOCUSED FEASIBILITY STUDY FOR THE UPPER AQUIFER
LIBBY GROUNDWATER SITE, LIBBY, MONTANA

Job No.:	60514930
Designed By:	MCS
Drawn By:	JLC
Date:	2/14/2018

Fig. 1-1

AECOM



Not to Scale

LEGEND & NOTES:

- Former Contaminant Source Areas
- Low Permeability Strata
- Mobile Phase NAPL
- Residual NAPL
- Dissolved Phase Contamination
- Groundwater Table
- Groundwater Flow Lines

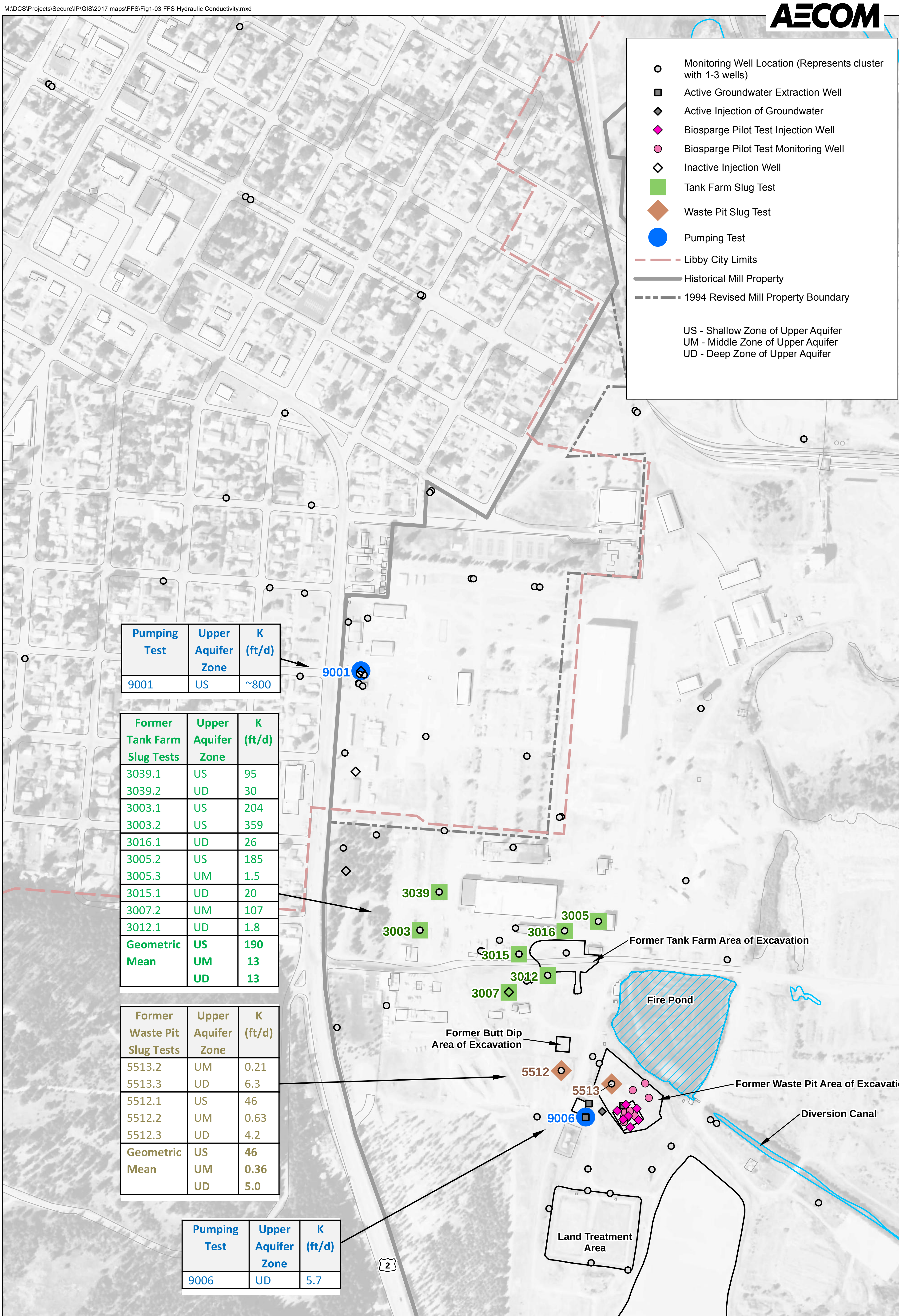
Job No. : 60514930	CONCEPTUAL DIAGRAM OF LIBBY AQUIFERS AND CURRENT/HISTORICAL REMEDIATION SYSTEMS
Prepared by : MCS	
Date : 7-24-17	

FIG 1-2

M:\DCS\Projects\Secure\IP\60514930_IP_ FFS_Det_An\7.0_CAD_GIS\CONAQUIFER_2.dwg

M:\DCS\Projects\Secure\IP\GIS\2017 maps\FFS\Fig1-03 FFS Hydraulic Conductivity.mxd

AECOM



Pumping Test	Upper Aquifer Zone	K (ft/d)
9001	US	~800

Former Tank Farm Slug Tests	Upper Aquifer Zone	K (ft/d)
3039.1	US	95
3039.2	UD	30
3003.1	US	204
3003.2	US	359
3016.1	UD	26
3005.2	US	185
3005.3	UM	1.5
3015.1	UD	20
3007.2	UM	107
3012.1	UD	1.8
Geometric Mean	US	190
	UM	13
	UD	13

Former Waste Pit Slug Tests	Upper Aquifer Zone	K (ft/d)
5513.2	UM	0.21
5513.3	UD	6.3
5512.1	US	46
5512.2	UM	0.63
5512.3	UD	4.2
Geometric Mean	US	46
	UM	0.36
	UD	5.0

Pumping Test	Upper Aquifer Zone	K (ft/d)
9006	UD	5.7

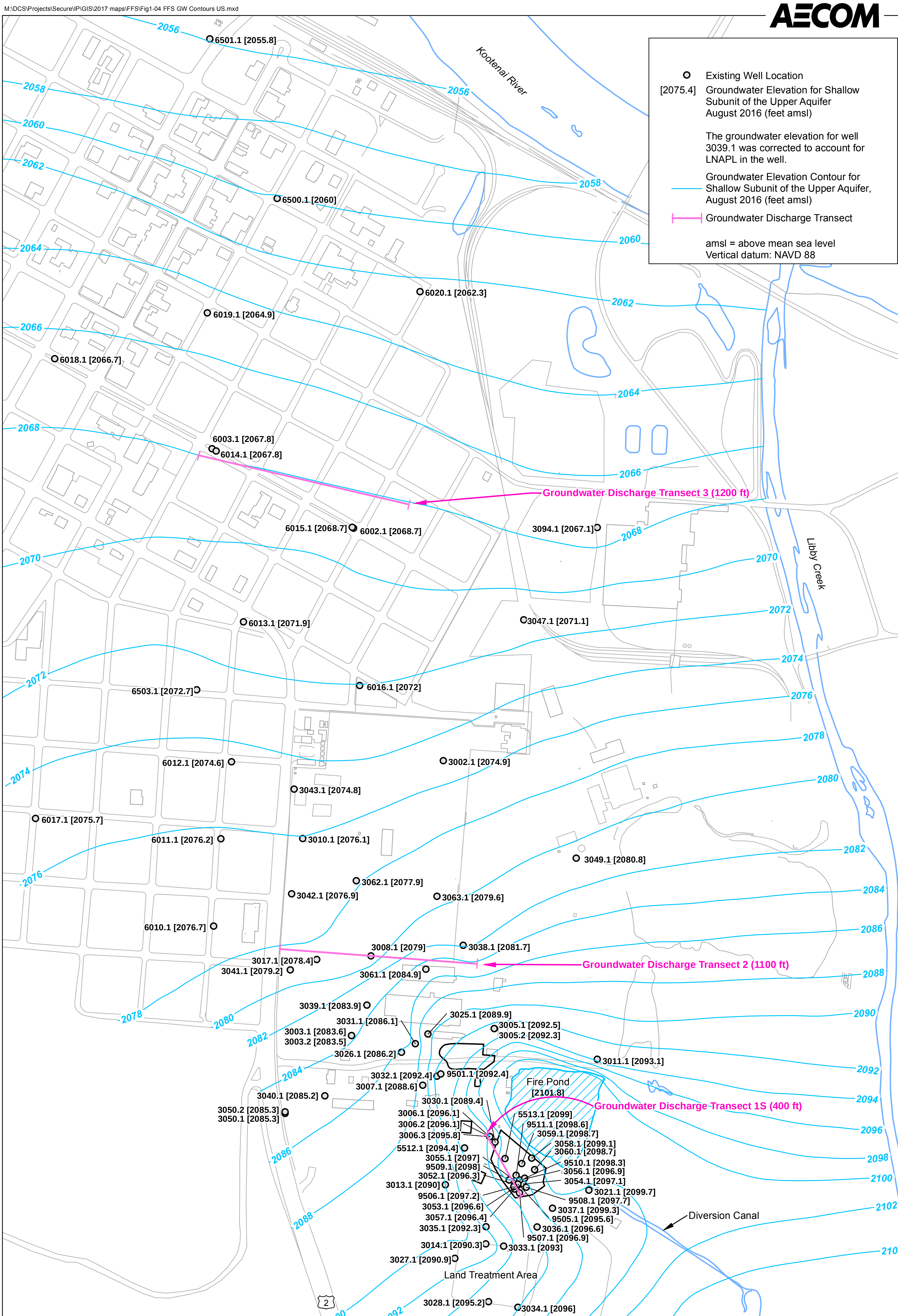
Hydraulic Conductivity Map
Upper Aquifer

FOCUSED FEASIBILITY STUDY FOR THE UPPER AQUIFER
LIBBY GROUNDWATER SITE, LIBBY, MONTANA

Job No.:	60514324
Designed By:	MCS
Drawn By:	JLC
Date:	8/8/2017

Fig. 1-3

AECOM



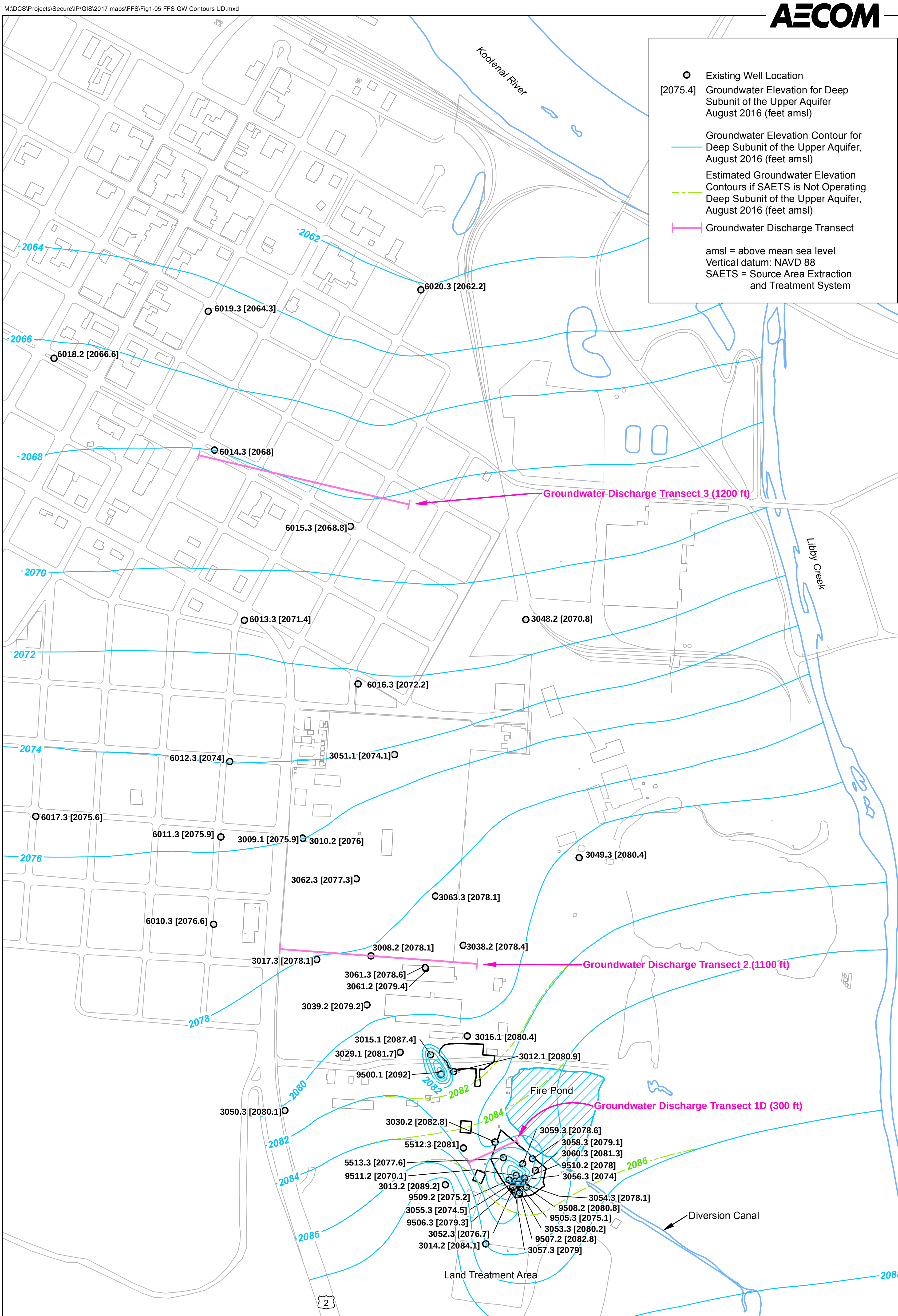
Groundwater Elevation Contours, Shallow Subunit of the Upper Aquifer (US) August 2016

FOCUSED FEASIBILITY STUDY FOR THE UPPER AQUIFER
LIBBY GROUNDWATER SITE, LIBBY, MONTANA

Job No.:	60514930
Designed By:	ARM
Drawn By:	JLC
Date:	7/26/2017

Fig. 1-4

M:\DCS\Projects\Secure\IP\GIS\2017 maps\FFS\Fig1-05 FFS GW Contours UD.mxd

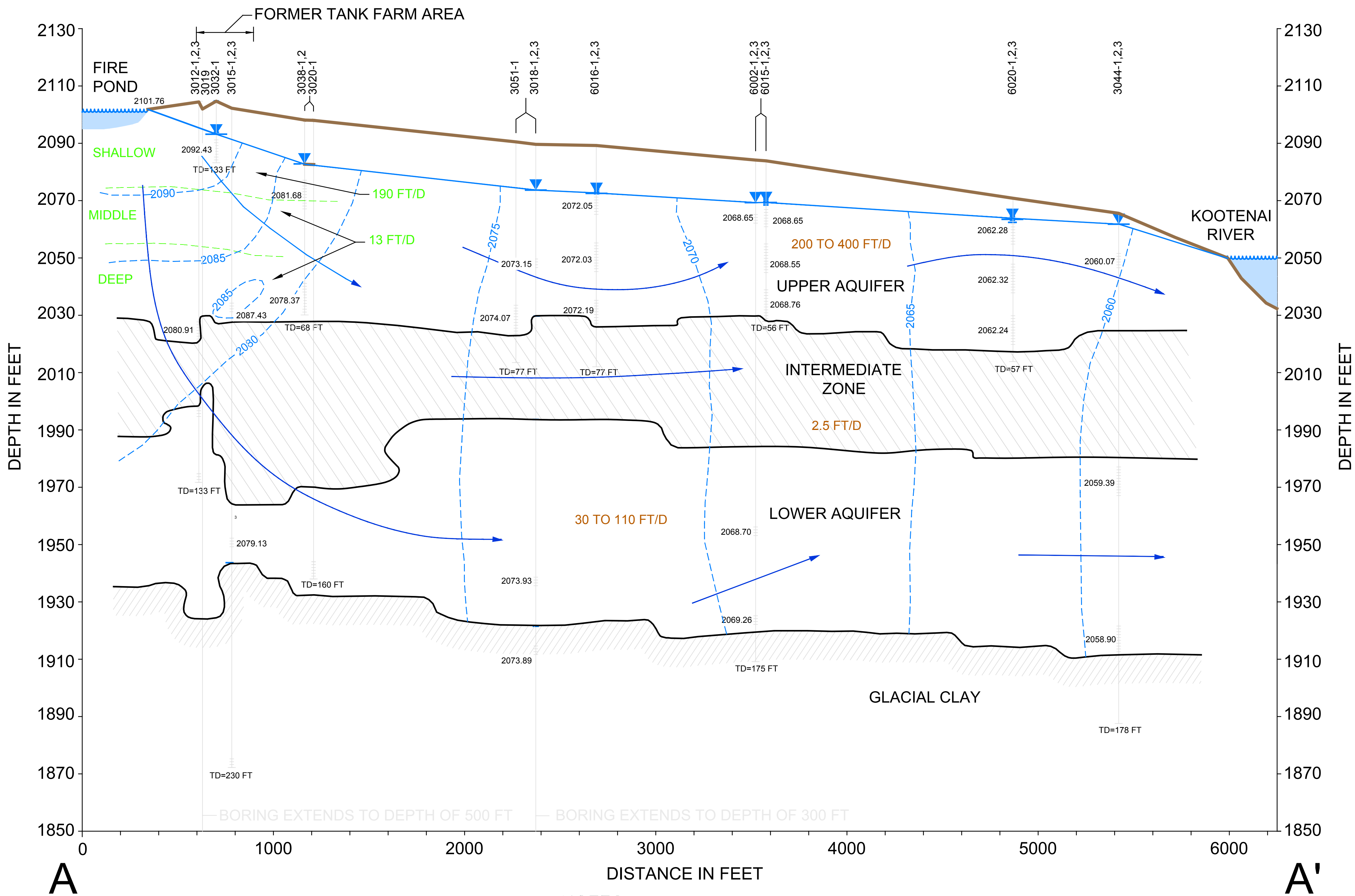


Groundwater Elevation Contours, Deep Subunit of the Upper Aquifer (UD) August 2016

FOCUSED FEASIBILITY STUDY FOR THE UPPER AQUIFER
LIBBY GROUNDWATER SITE, LIBBY, MONTANA

Job No.:	60514930
Designed By:	ARM
Drawn By:	JLC
Date:	7/26/2017

Fig. 1-5



LEGEND

GROUNDWATER FLOW LINE

APPROXIMATE WATER TABLE

2099.53 GROUNDWATER ELEVATION MEASURED IN WELL AUGUST 2016 (FT AMSL)

2070 POTENTIOMETRIC CONTOUR AUGUST 2016 (FT AMSL)

APPROXIMATE CONTACT BETWEEN SHALLOW, MIDDLE, AND DEEP SUBUNIT OF UPPER AQUIFER IN FORMER SOURCE AREAS

190 FT/D GEOMETRIC MEAN OF HYDRAULIC CONDUCTIVITY FOR UPPER AQUIFER SUBUNIT

2.5 FT/D HYDRAULIC CONDUCTIVITY VALUE ESTIMATED FROM CALIBRATED NUMERICAL MODEL.

NOTES:

1. WELL SPACING ALONG CROSS SECTION IS APPROXIMATE.
2. THE KOOTENAI RIVER STAGE OF 2050 FEET AMSL IS THE ESTIMATED AVERAGE RIVER STAGE BASED ON DATA COLLECTED FROM 1975 TO 1991 AT THE HISTORICAL GAUGE LOCATED APPROXIMATELY 1,700 FEET DOWNSTREAM OF THE HIGHWAY 37 BRIDGE.
3. CROSS SECTION LOCATION IS SHOWN ON FIGURE 1-1.
4. CROSS SECTION IS ORIENTED APPROXIMATELY PARALLEL TO HORIZONTAL GROUNDWATER FLOW.

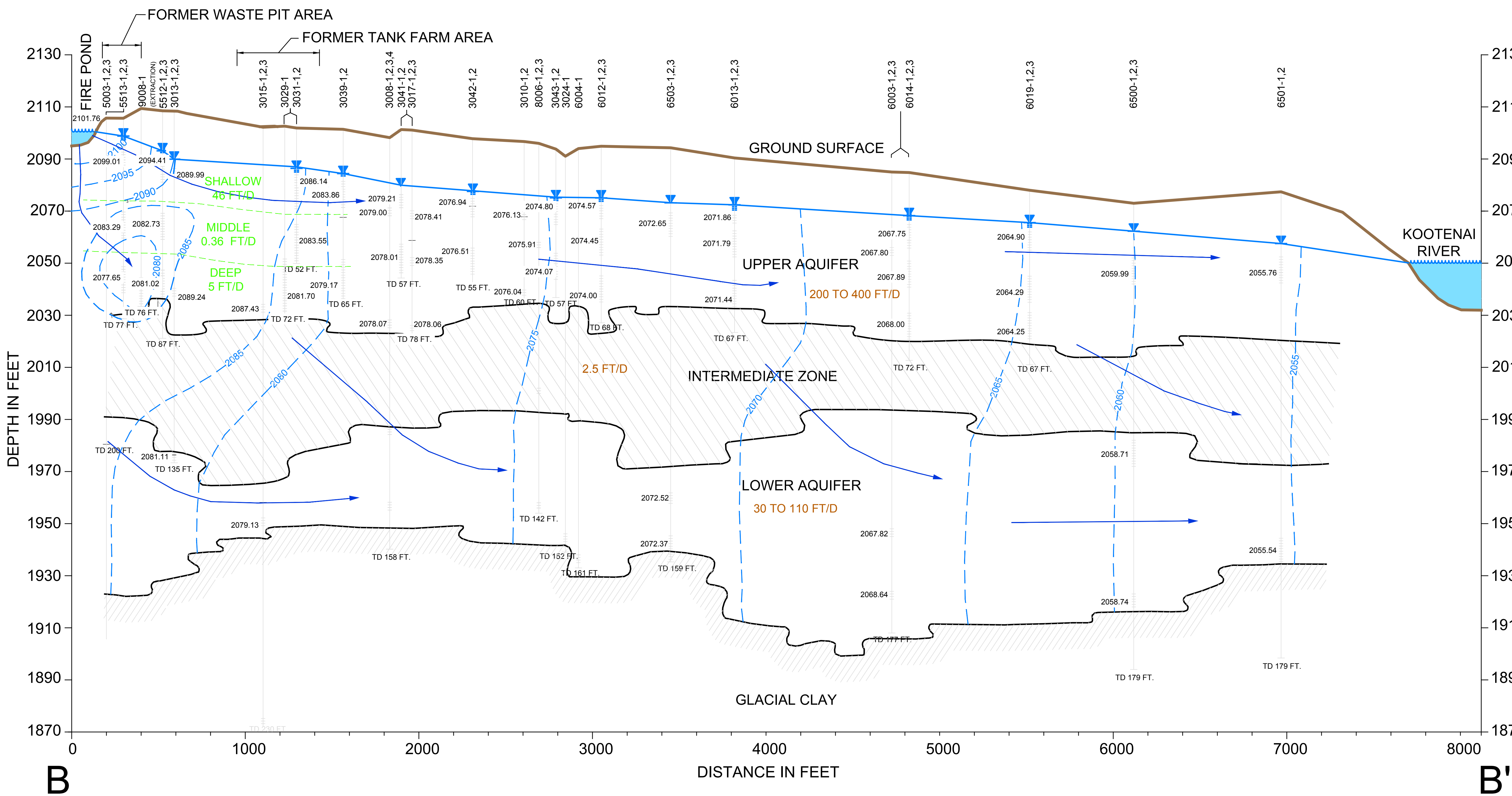
0 150 300 600 HORIZONTAL SCALE IN FEET

0 10 20 40 VERTICAL SCALE IN FEET

Job No. : 60514930	HYDROGEOLOGIC CROSS SECTION A–A'
Prepared By : MCS	
Date : 7/24/17	

FIG. 1-6

DRAWING PATH: M:\DCS\Projects\Secure\IP\60514930_IP_FFS_Det_Am7.0_CAD_GIS\HYDRO XS A-A.dwg



LEGEND

- GROUNDWATER FLOW LINE
- APPROXIMATE WATER TABLE
- 2099.53 GROUNDWATER ELEVATION MEASURED IN WELL AUGUST 2016 (FT AMSL)
- 2070 POTENTIOMETRIC CONTOUR AUGUST 2016 (FT AMSL)
- APPROXIMATE CONTACT BETWEEN SHALLOW, MIDDLE, AND DEEP SUBUNIT OF UPPER AQUIFER IN FORMER SOURCE AREAS
- 5 FT/D GEOMETRIC MEAN OF HYDRAULIC CONDUCTIVITY FOR AVERAGE GROUNDWATER UPPER AQUIFER SUBUNIT
- 2.5 FT/D HYDRAULIC CONDUCTIVITY VALUE ESTIMATED FROM CALIBRATED NUMERICAL MODEL

NOTES:

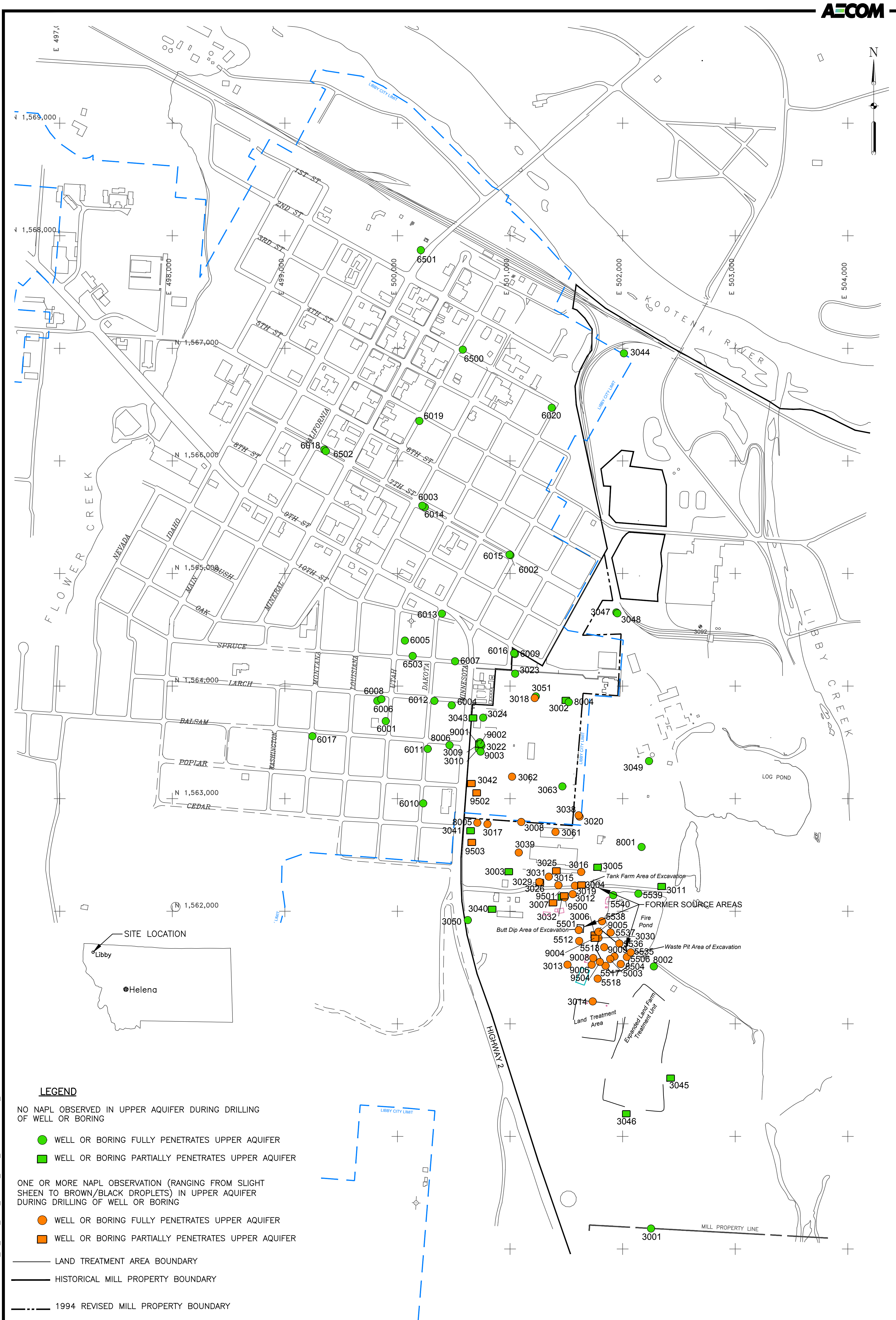
1. WELL SPACING ALONG CROSS SECTION IS APPROXIMATE.
2. THE KOOTENAI RIVER STAGE OF 2050 FEET AMSL IS THE ESTIMATED AVERAGE RIVER STAGE BASED ON DATA COLLECTED FROM 1975 TO 1991 AT THE HISTORICAL GAUGE LOCATED APPROXIMATELY 1,700 FEET DOWNSTREAM OF THE HIGHWAY 37 BRIDGE.
3. CROSS SECTION LOCATION IS SHOWN ON FIGURE 1-1.
4. CROSS SECTION IS ORIENTED APPROXIMATELY PARALLEL TO HORIZONTAL GROUNDWATER FLOW.

0 150 300 600 HORIZONTAL SCALE IN FEET

0 10 20 40 VERTICAL SCALE IN FEET

Job No. : 60514930	HYDROGEOLOGIC CROSS SECTION B–B'
Prepared By : MCS	
Date : 7/24/17	

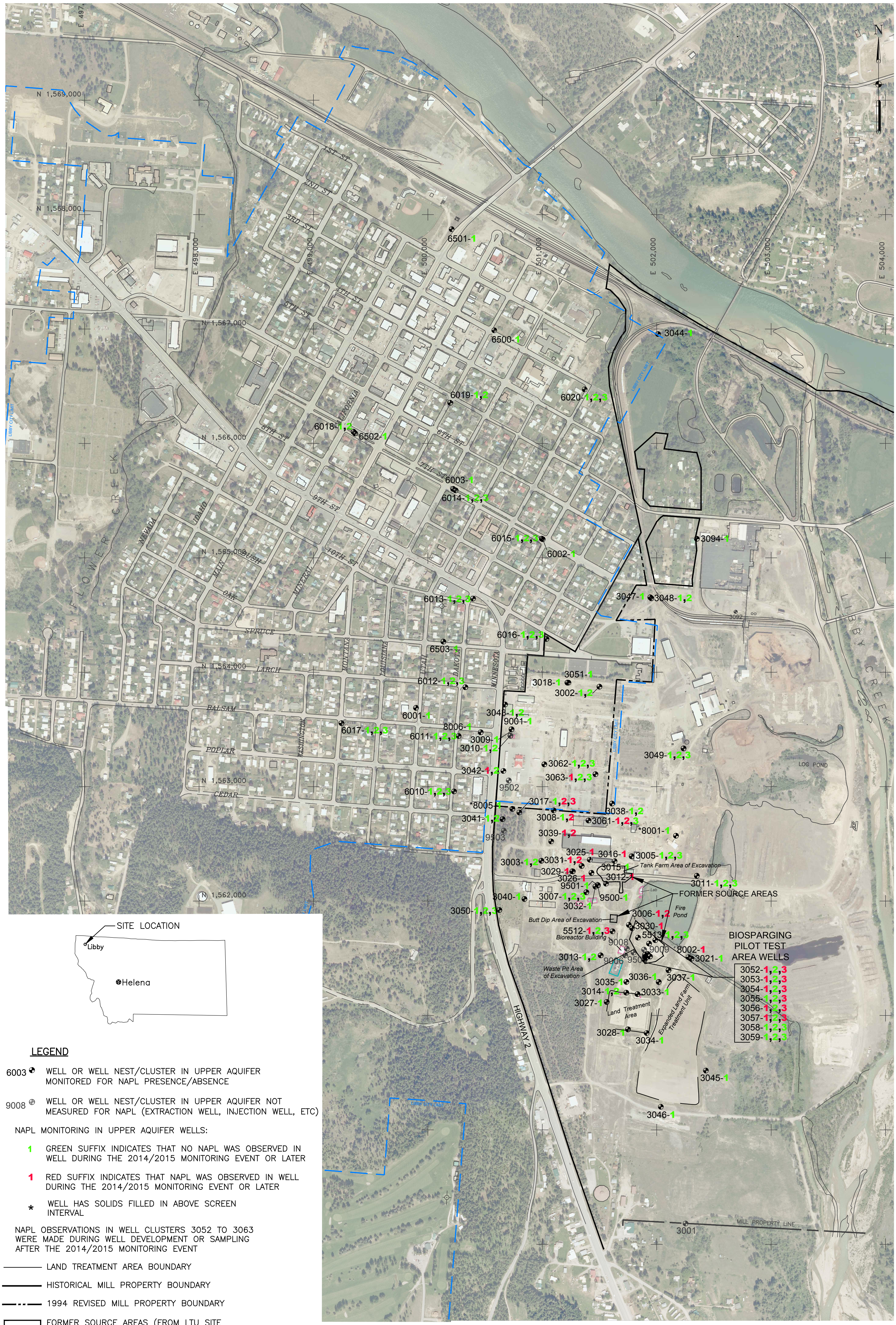
FIG. 1-7



Job No. : 60514930		NAPL OBSERVED DURING DRILLING IN THE UPPER AQUIFER
PREPARED BY: GG	DRAWN BY: RM	
DATE: 7-27-17		

FIG. 1-8

AECOM



LEGEND

6003 — WELL OR WELL NEST/CLUSTER IN UPPER AQUIFER MONITORED FOR NAPL PRESENCE/ABSENCE

9008 — WELL OR WELL NEST/CLUSTER IN UPPER AQUIFER NOT MEASURED FOR NAPL (EXTRACTION WELL, INJECTION WELL, ETC)

NAPL MONITORING IN UPPER AQUIFER WELLS:

1 — GREEN SUFFIX INDICATES THAT NO NAPL WAS OBSERVED IN WELL DURING THE 2014/2015 MONITORING EVENT OR LATER

1 — RED SUFFIX INDICATES THAT NAPL WAS OBSERVED IN WELL DURING THE 2014/2015 MONITORING EVENT OR LATER

* — WELL HAS SOLIDS FILLED IN ABOVE SCREEN INTERVAL

NAPL OBSERVATIONS IN WELL CLUSTERS 3052 TO 3063 WERE MADE DURING WELL DEVELOPMENT OR SAMPLING AFTER THE 2014/2015 MONITORING EVENT

LAND TREATMENT AREA BOUNDARY

HISTORICAL MILL PROPERTY BOUNDARY

1994 REVISED MILL PROPERTY BOUNDARY

FORMER SOURCE AREAS (FROM LTU SITE PLAN, DWG 2/11, WCC, APRIL 13, 1990)

LIBBY CITY LIMITS

0 400 800 1600

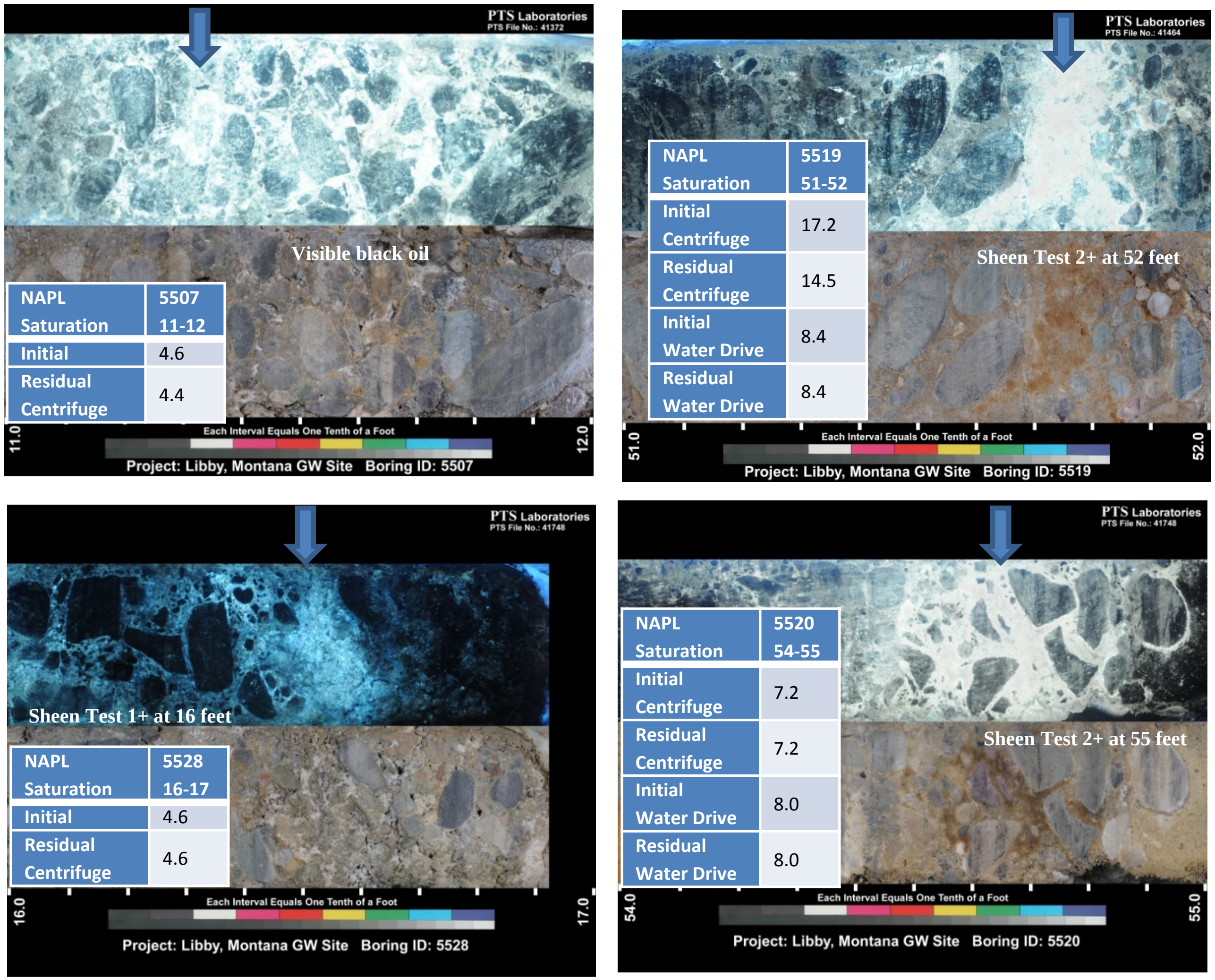
SCALE IN FEET

M:\DCS\PROJECTS\SECURE\IP\60514930_IP_FFS_DET_AN\7.0_CAD_GIS\OBS NAPL_12-16.DWG

Job No. : 60514930	NAPL OBSERVED IN UPPER AQUIFER WELLS
PREPARED BY: GG / DRAWN BY: RM	
DATE: 7-27-17	

FIG. 1-9

FIGURE 1-10
TYPICAL SUB-CORE SAMPLE ANALYZED FOR NAPL SATURATION

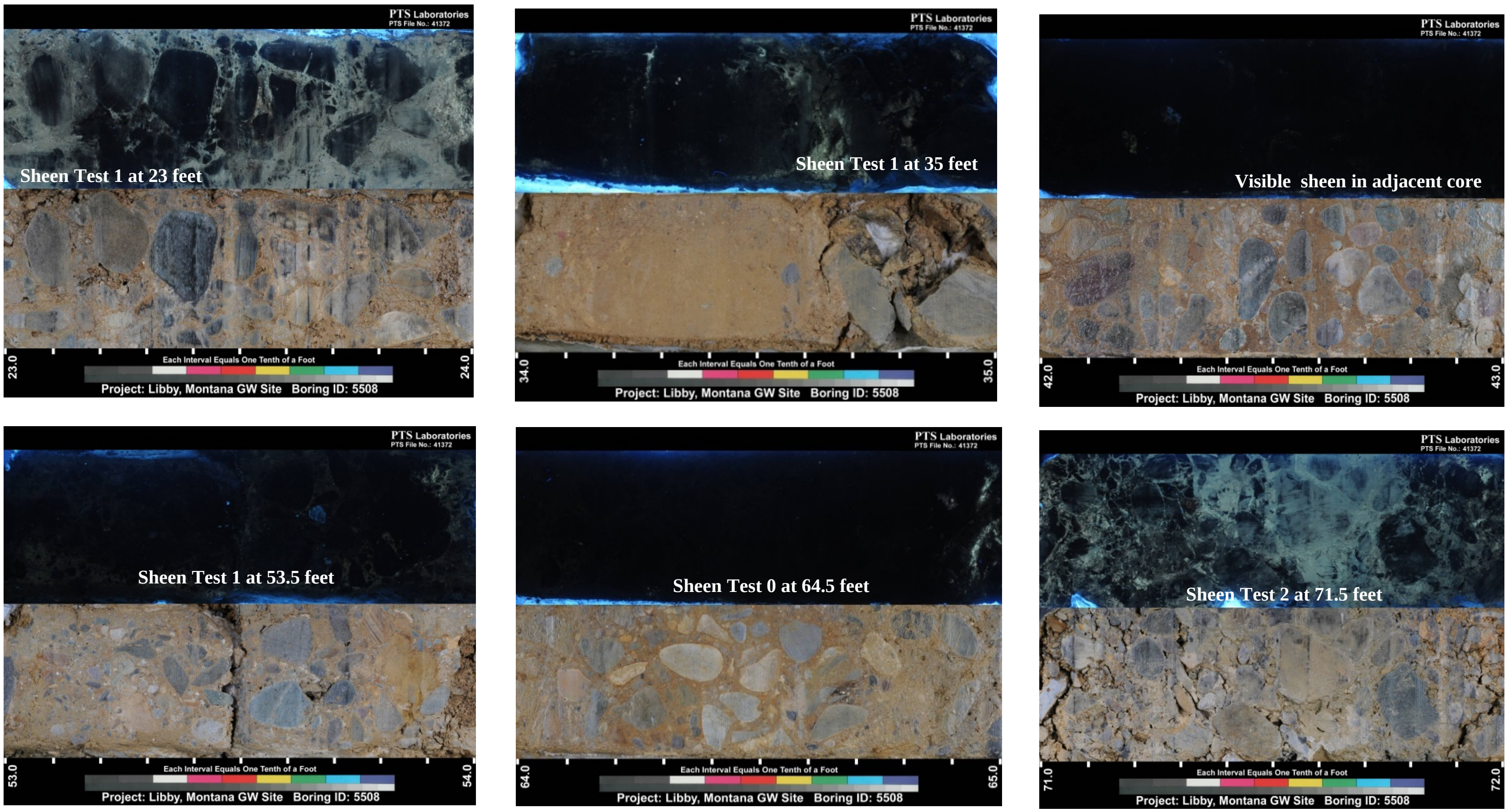


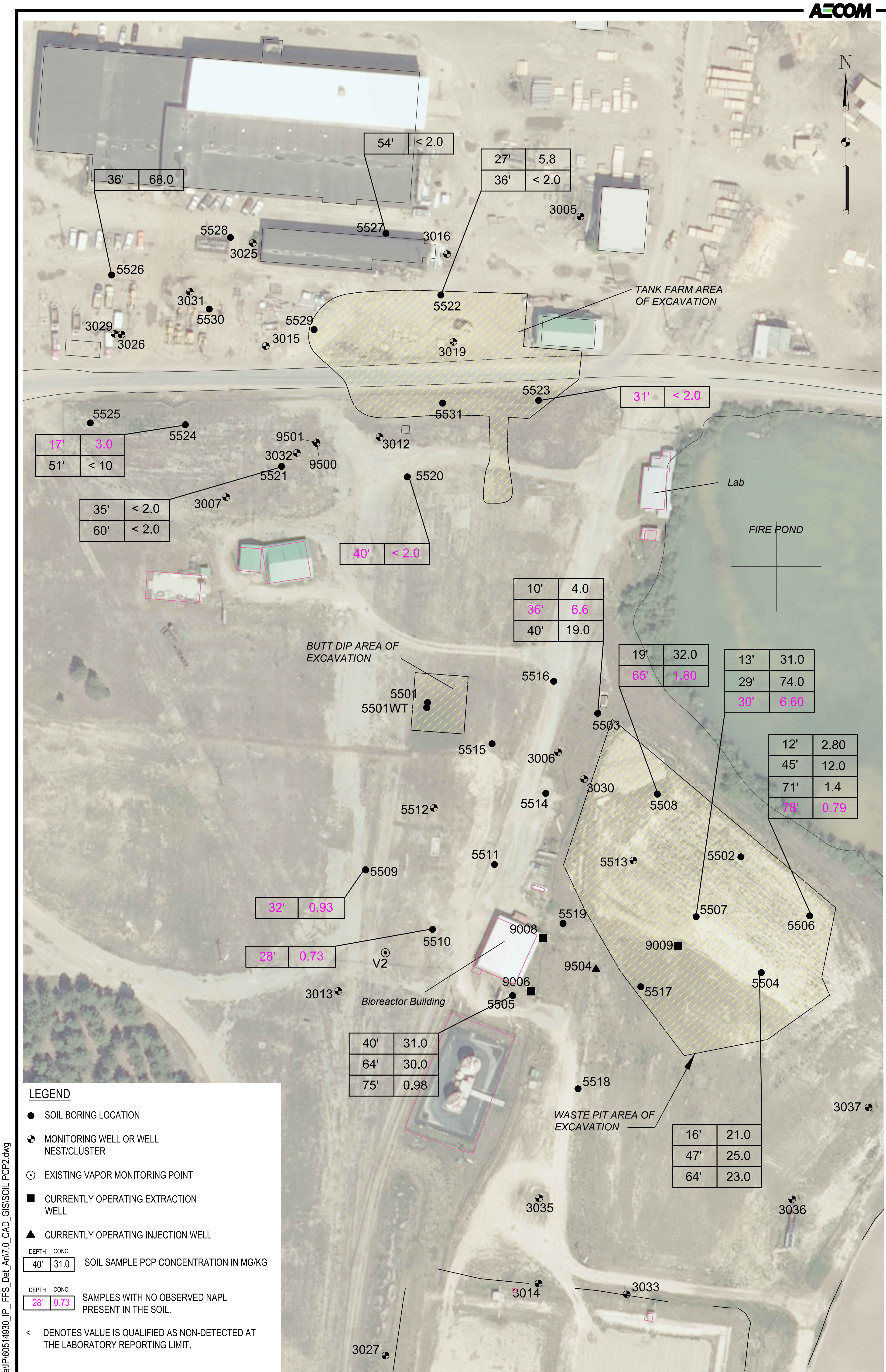
NOTES

NAPL Saturation values in tables are percent pore volume NAPL relative to specific gravity of 1

Sub-core location

FIGURE 1-11
CORE PHOTOGRAPHY AT BORING 5508 IN FORMER WASTE PIT AREA





Job No. : 60514930

Prepared by : JLC

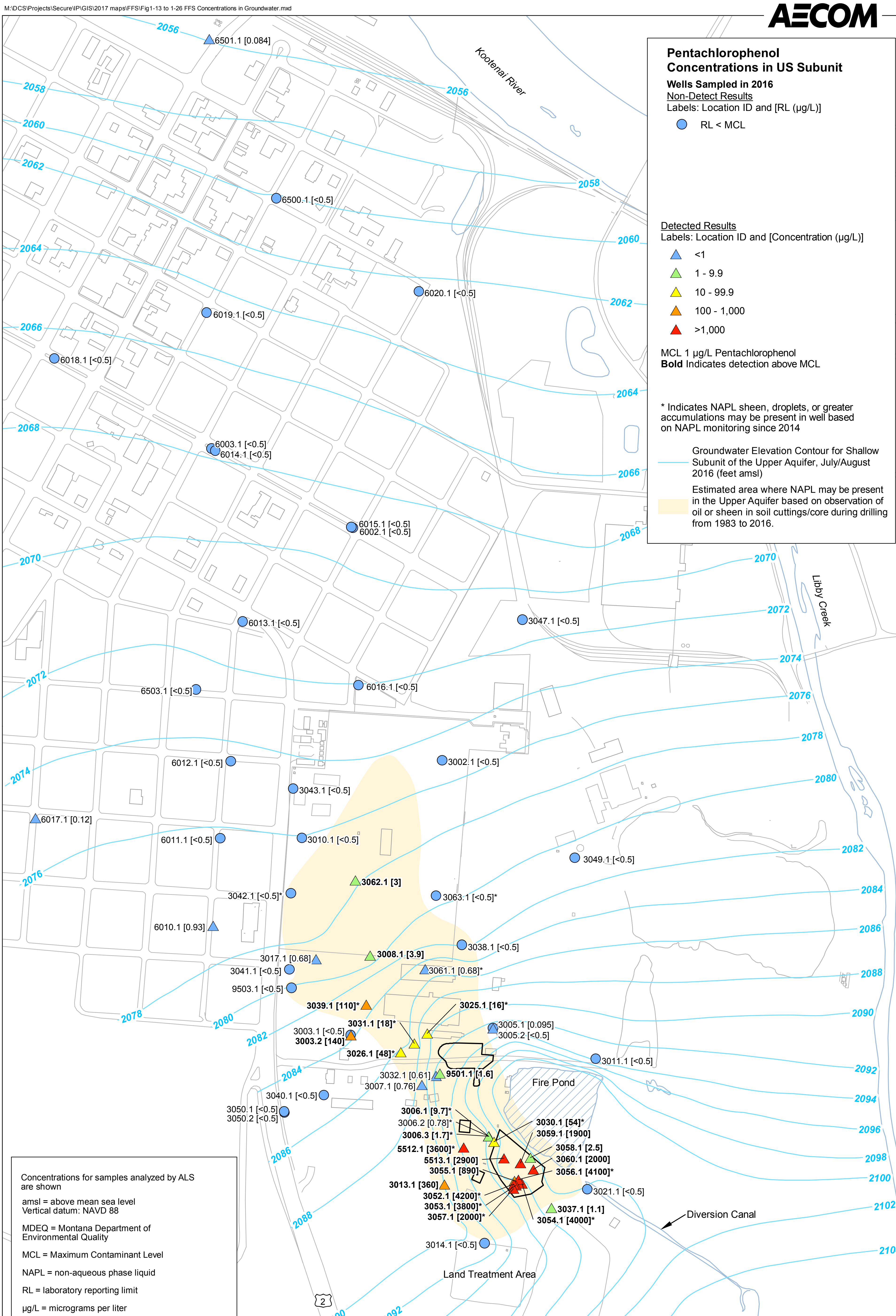
Date : 7-27-17

SOIL PCP CONCENTRATIONS IN FORMER SOURCE AREAS AND VICINITY

FIG. 1-12

M:\DCS\Projects\Secure\IP\GIS\2017 maps\FFS\Fig1-13 to 1-26 FFS Concentrations in Groundwater.mxd

AECOM



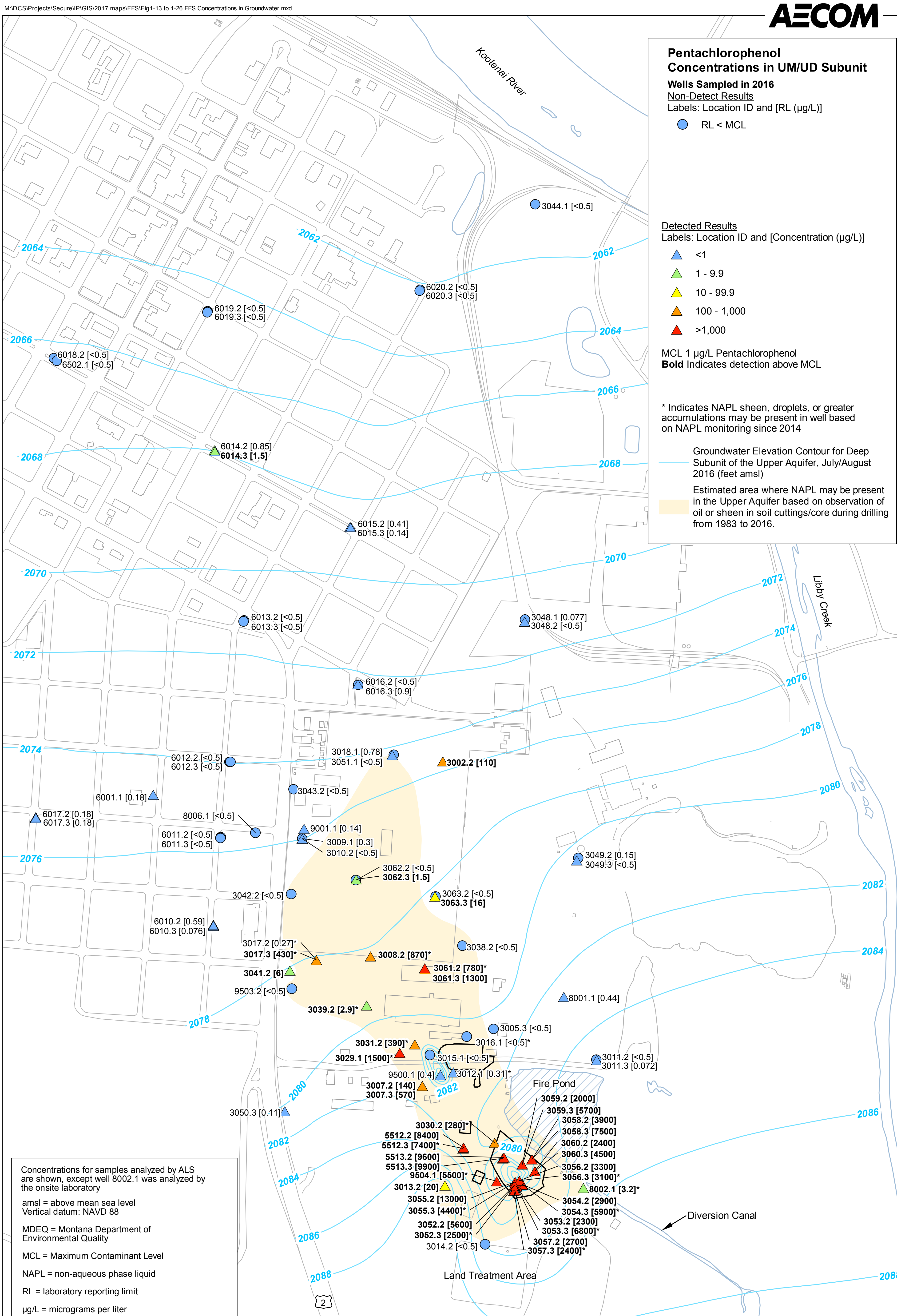
Pentachlorophenol Concentrations in Groundwater, Shallow Subunit of the Upper Aquifer (US) Summer 2016

FOCUSED FEASIBILITY STUDY FOR THE UPPER AQUIFER
LIBBY GROUNDWATER SITE, LIBBY, MONTANA

Job No.:	60514930
Designed By:	ARM
Drawn By:	JLC
Date:	2/12/2018

Fig. 1-13A

AECOM



Pentachlorophenol Concentrations in Groundwater, Middle/Deep Subunit of the Upper Aquifer (UM/UD) Summer 2016

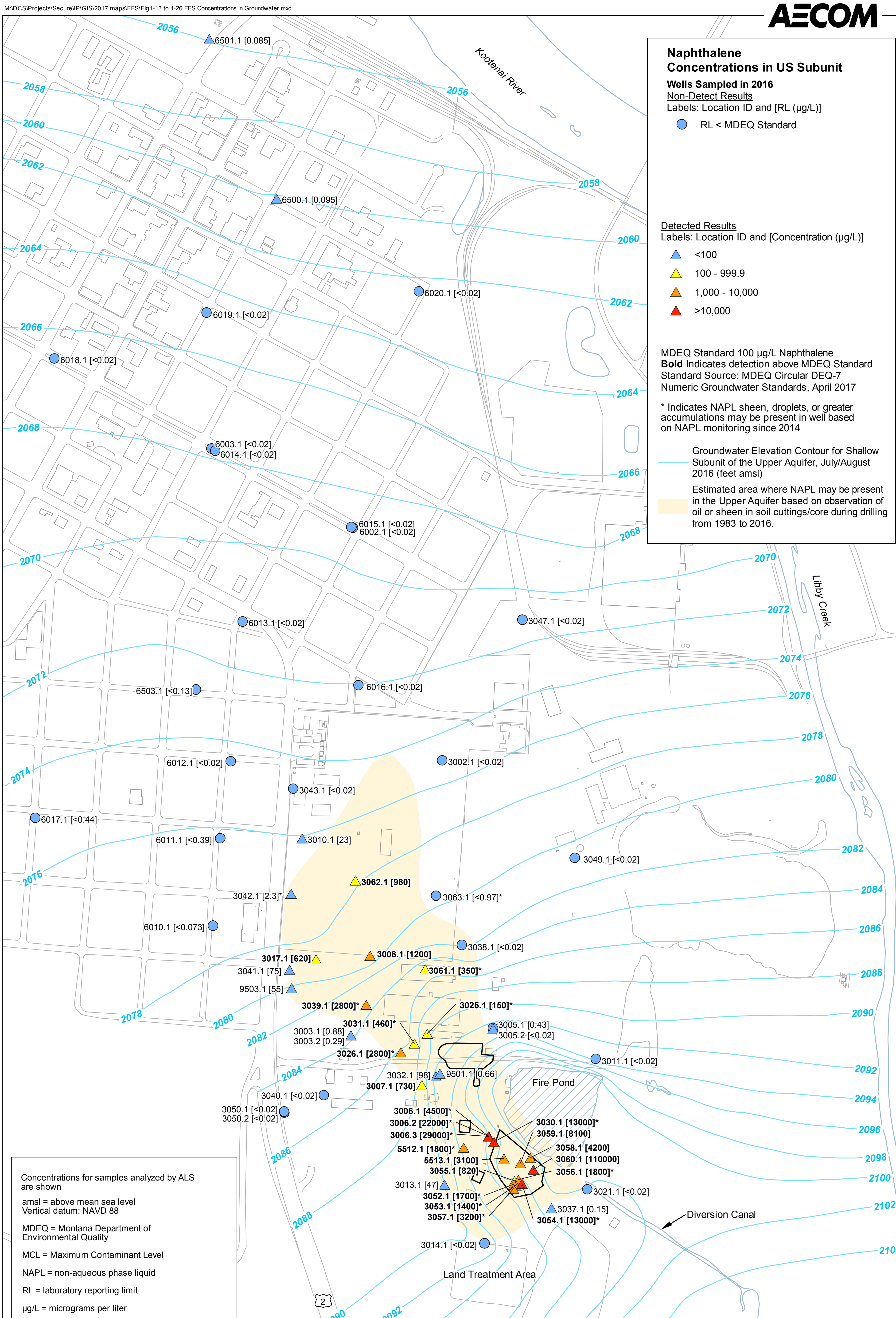
FOCUSED FEASIBILITY STUDY FOR THE UPPER AQUIFER
LIBBY GROUNDWATER SITE, LIBBY, MONTANA

Job No.:	60514930
Designed By:	ARM
Drawn By:	JLC
Date:	2/12/2018

Fig. 1-13B

M:\DCS\Projects\Secure\IP\GIS\2017 maps\FFS\Fig1-13 to 1-26 FFS Concentrations in Groundwater.mxd

AECOM



Naphthalene Concentrations in Groundwater, Shallow Subunit of the Upper Aquifer (US) Summer 2016

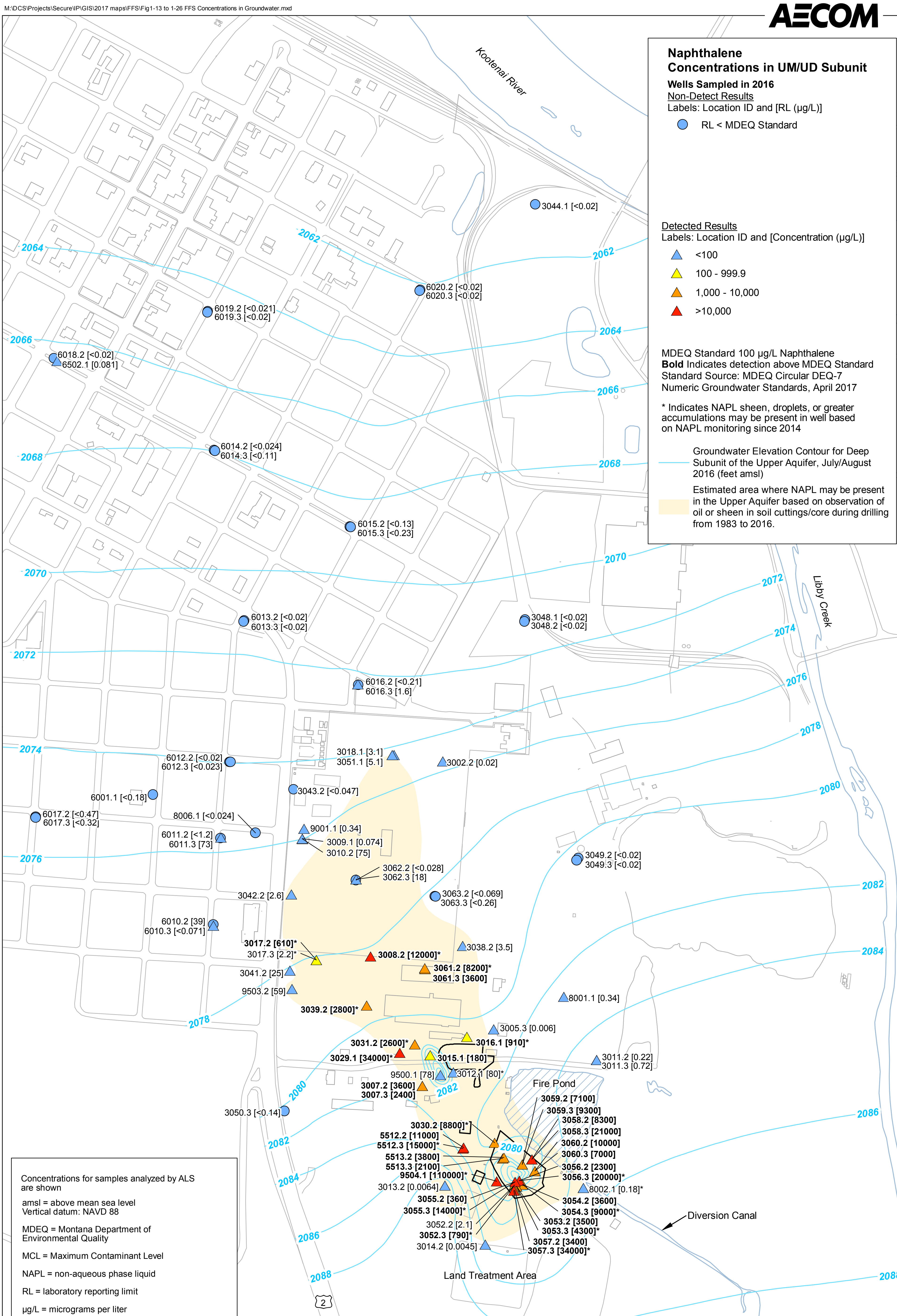
FOCUSED FEASIBILITY STUDY FOR THE UPPER AQUIFER
LIBBY GROUNDWATER SITE, LIBBY, MONTANA

Job No.:	60514930
Designed By:	ARM
Drawn By:	JLC
Date:	2/12/2018

Fig. 1-14A

M:\DCS\Projects\Secure\IP\GIS\2017 maps\FFS\Fig1-13 to 1-26 FFS Concentrations in Groundwater.mxd

AECOM



Naphthalene Concentrations in Groundwater, Middle/Deep Subunit of the Upper Aquifer (UM/UD) Summer 2016

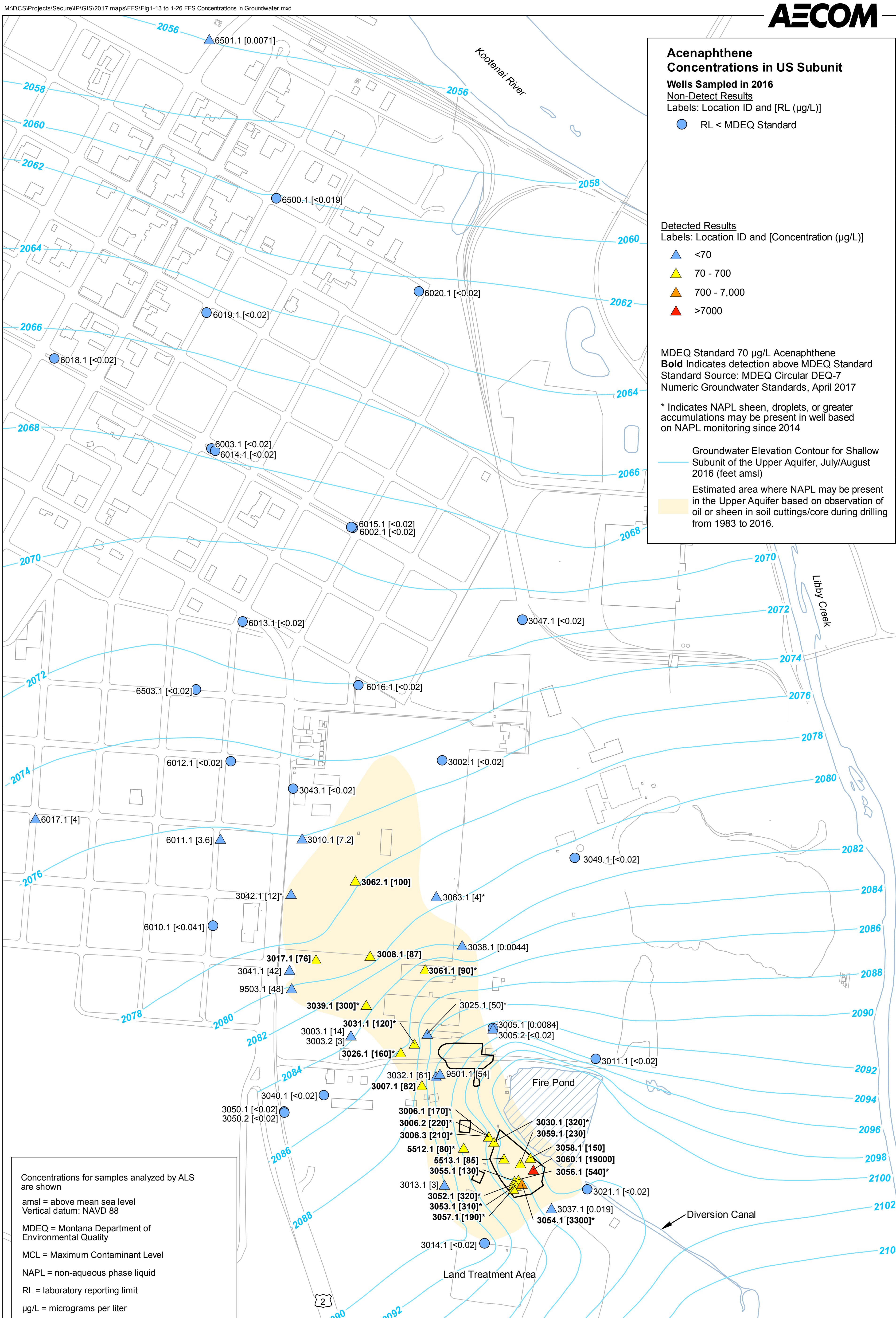
FOCUSED FEASIBILITY STUDY FOR THE UPPER AQUIFER
LIBBY GROUNDWATER SITE, LIBBY, MONTANA

Job No.:	60514930
Designed By:	ARM
Drawn By:	JLC
Date:	2/12/2018

Fig. 1-14B

M:\DCS\Projects\Secure\IP\GIS\2017 maps\FFS\Fig1-13 to 1-26 FFS Concentrations in Groundwater.mxd

AECOM



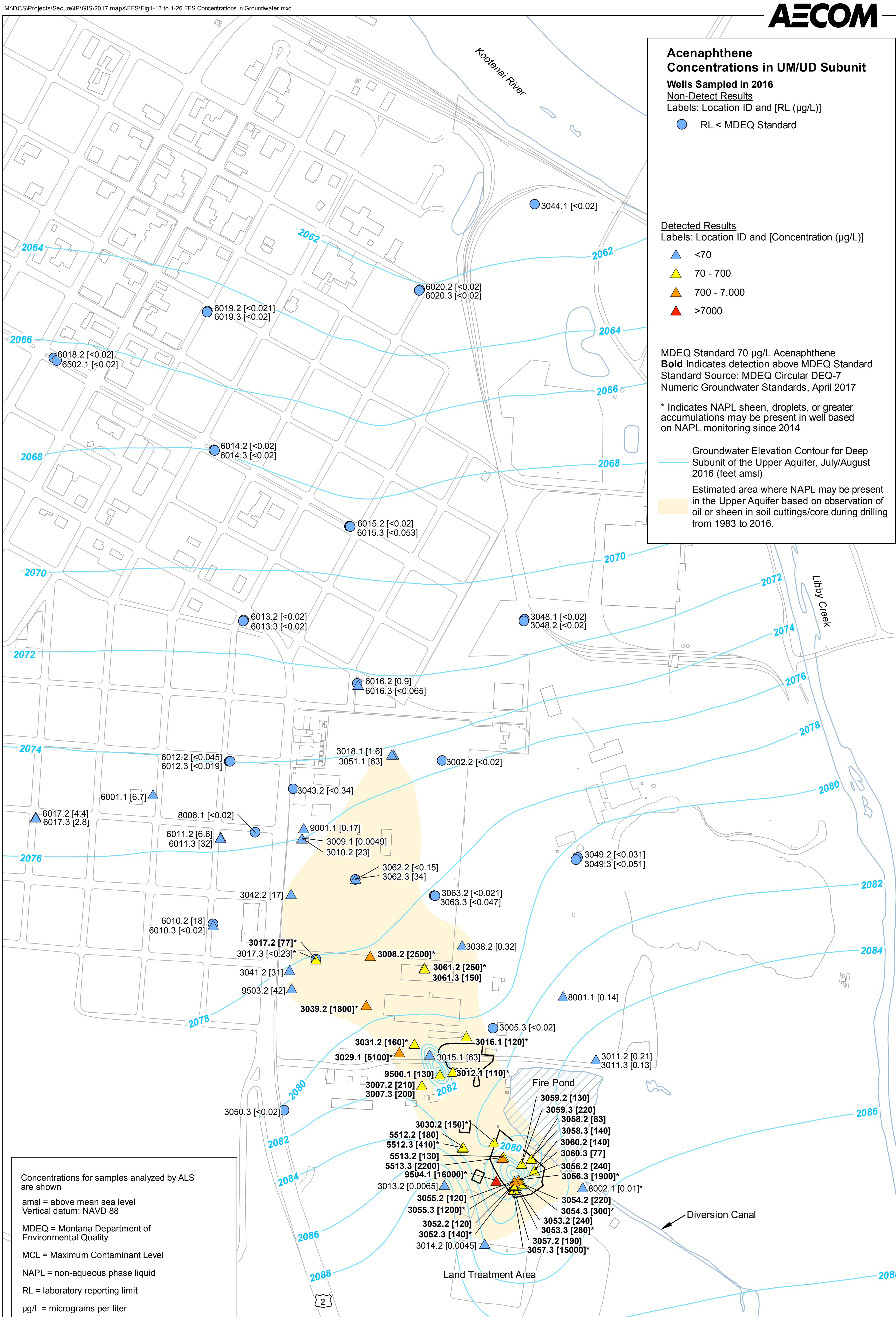
Acenaphthene Concentrations in Groundwater, Shallow Subunit of the Upper Aquifer (US) Summer 2016

FOCUSED FEASIBILITY STUDY FOR THE UPPER AQUIFER
LIBBY GROUNDWATER SITE, LIBBY, MONTANA

Job No.:	60514930
Designed By:	ARM
Drawn By:	JLC
Date:	2/12/2018

Fig. 1-15A

AECOM



Acenaphthene Concentrations in Groundwater, Middle/Deep Subunit of the Upper Aquifer (UM/UD) Summer 2016

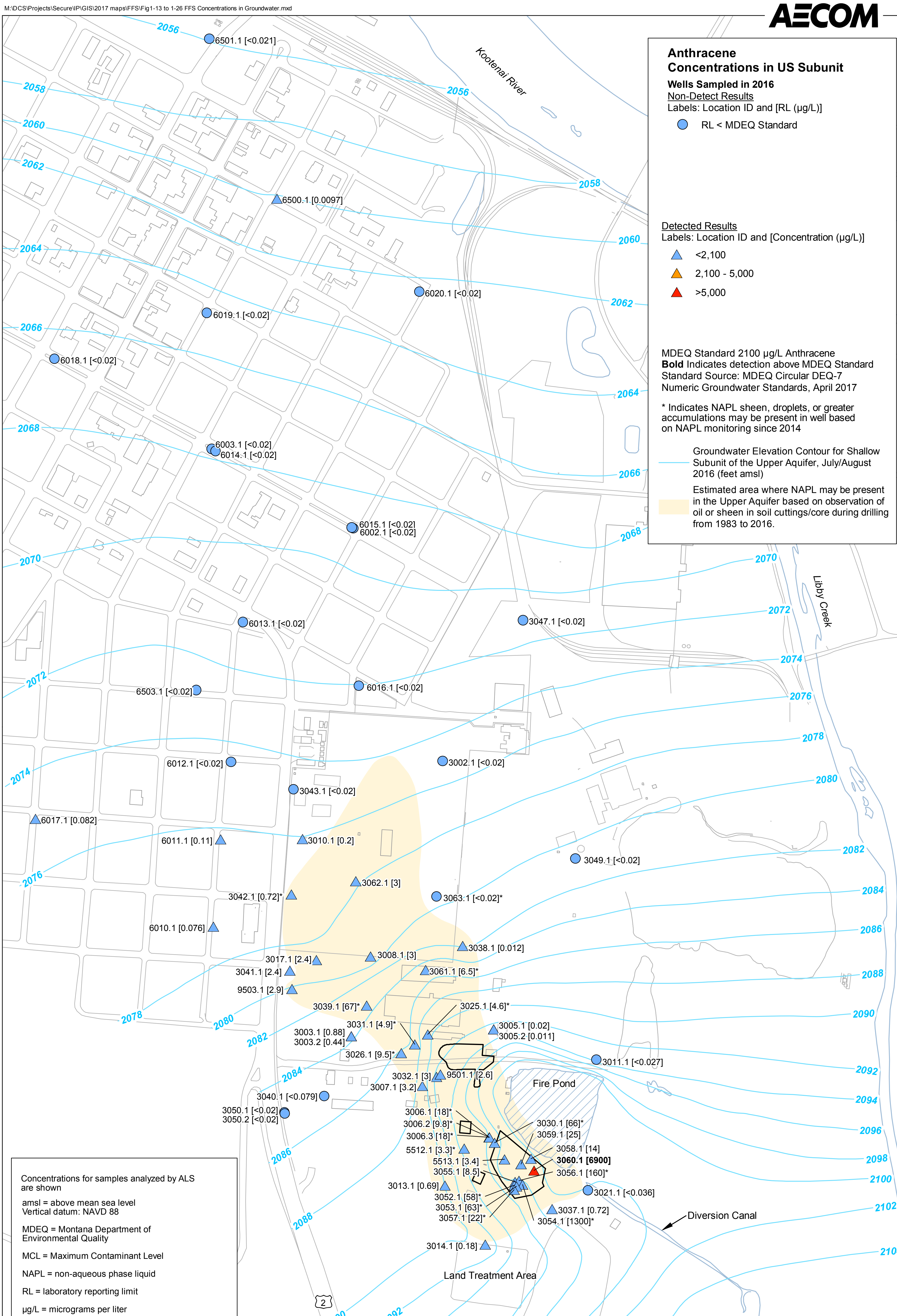
FOCUSED FEASIBILITY STUDY FOR THE UPPER AQUIFER
LIBBY GROUNDWATER SITE, LIBBY, MONTANA

Job No.:	60514930
Designed By:	ARM
Drawn By:	JLC
Date:	2/12/2018

Fig. 1-15B

M:\DCS\Projects\Secure\IP\GIS\2017 maps\FFS\Fig1-13 to 1-26 FFS Concentrations in Groundwater.mxd

AECOM



Anthracene Concentrations in Groundwater, Shallow Subunit of the Upper Aquifer (US) Summer 2016

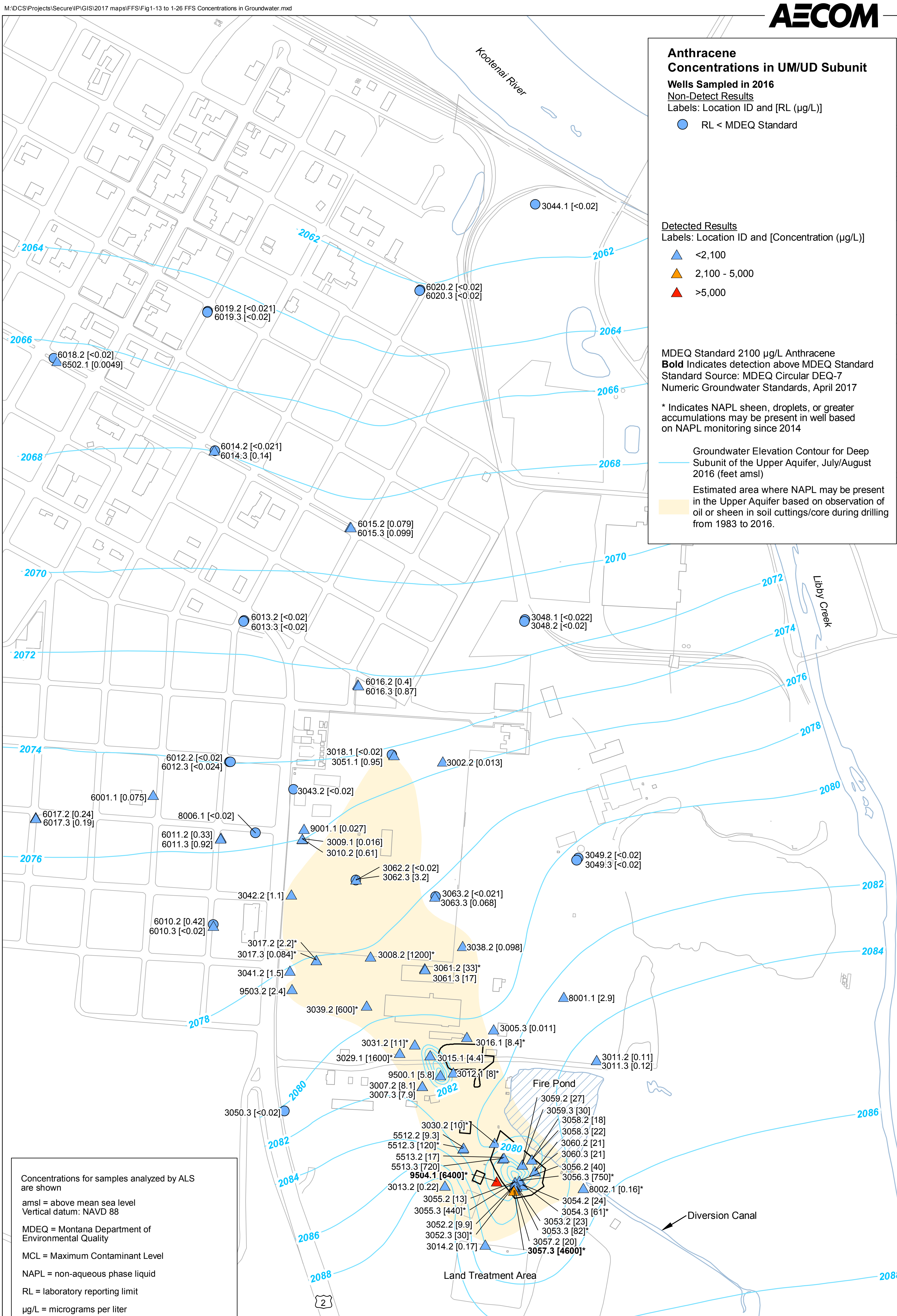
FOCUSED FEASIBILITY STUDY FOR THE UPPER AQUIFER
LIBBY GROUNDWATER SITE, LIBBY, MONTANA

Job No.:	60514930
Designed By:	ARM
Drawn By:	JLC
Date:	2/12/2018

Fig. 1-16A

M:\DCS\Projects\Secure\IP\GIS\2017 maps\FFS\Fig1-13 to 1-26 FFS Concentrations in Groundwater.mxd

AECOM



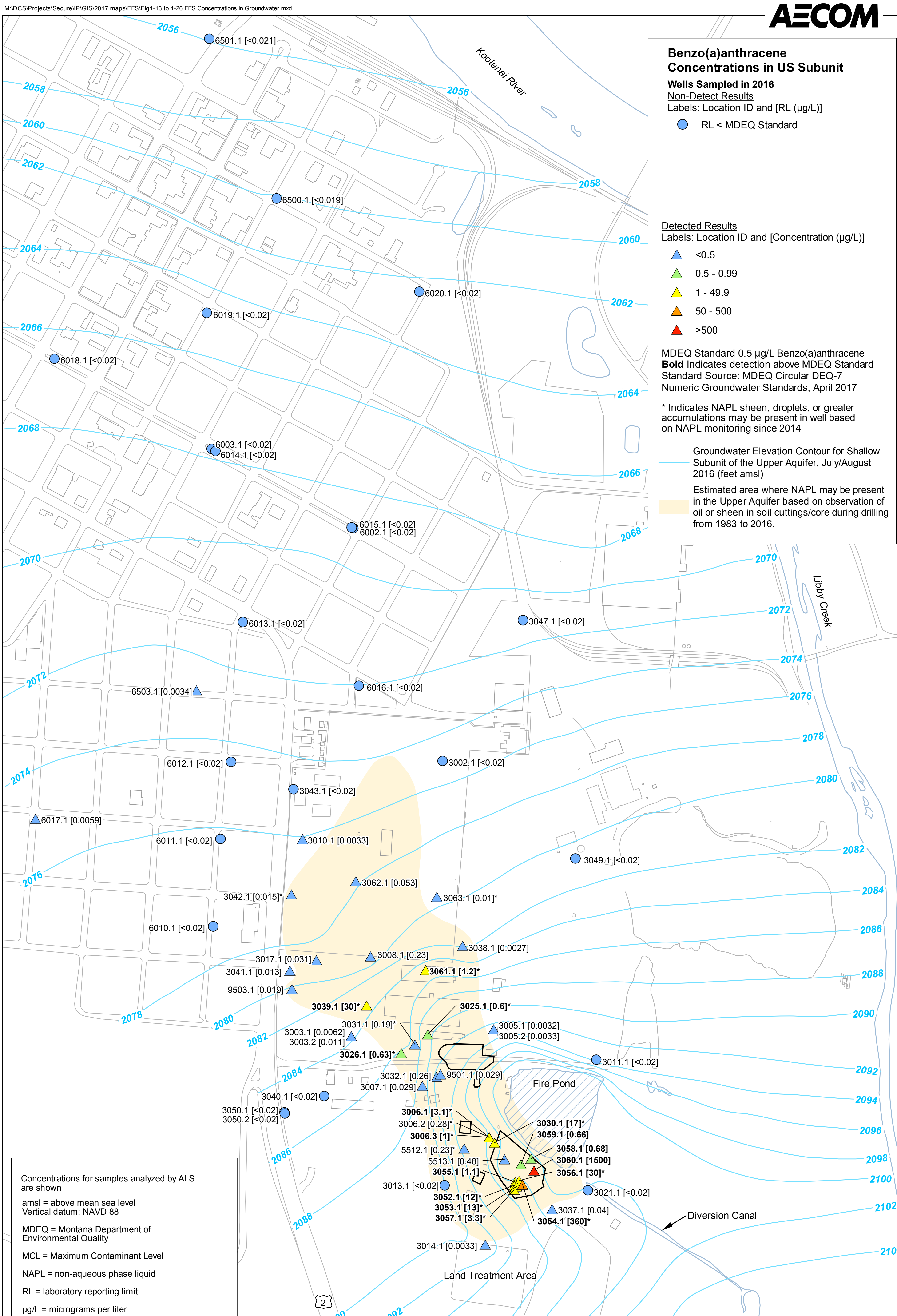
Anthracene Concentrations in Groundwater, Middle/Deep Subunit of the Upper Aquifer (UM/UD) Summer 2016

FOCUSED FEASIBILITY STUDY FOR THE UPPER AQUIFER
LIBBY GROUNDWATER SITE, LIBBY, MONTANA

Job No.:	60514930
Designed By:	ARM
Drawn By:	JLC
Date:	2/12/2018

Fig. 1-16B

AECOM



Benzo(a)anthracene Concentrations in Groundwater, Shallow Subunit of the Upper Aquifer (US) Summer 2016

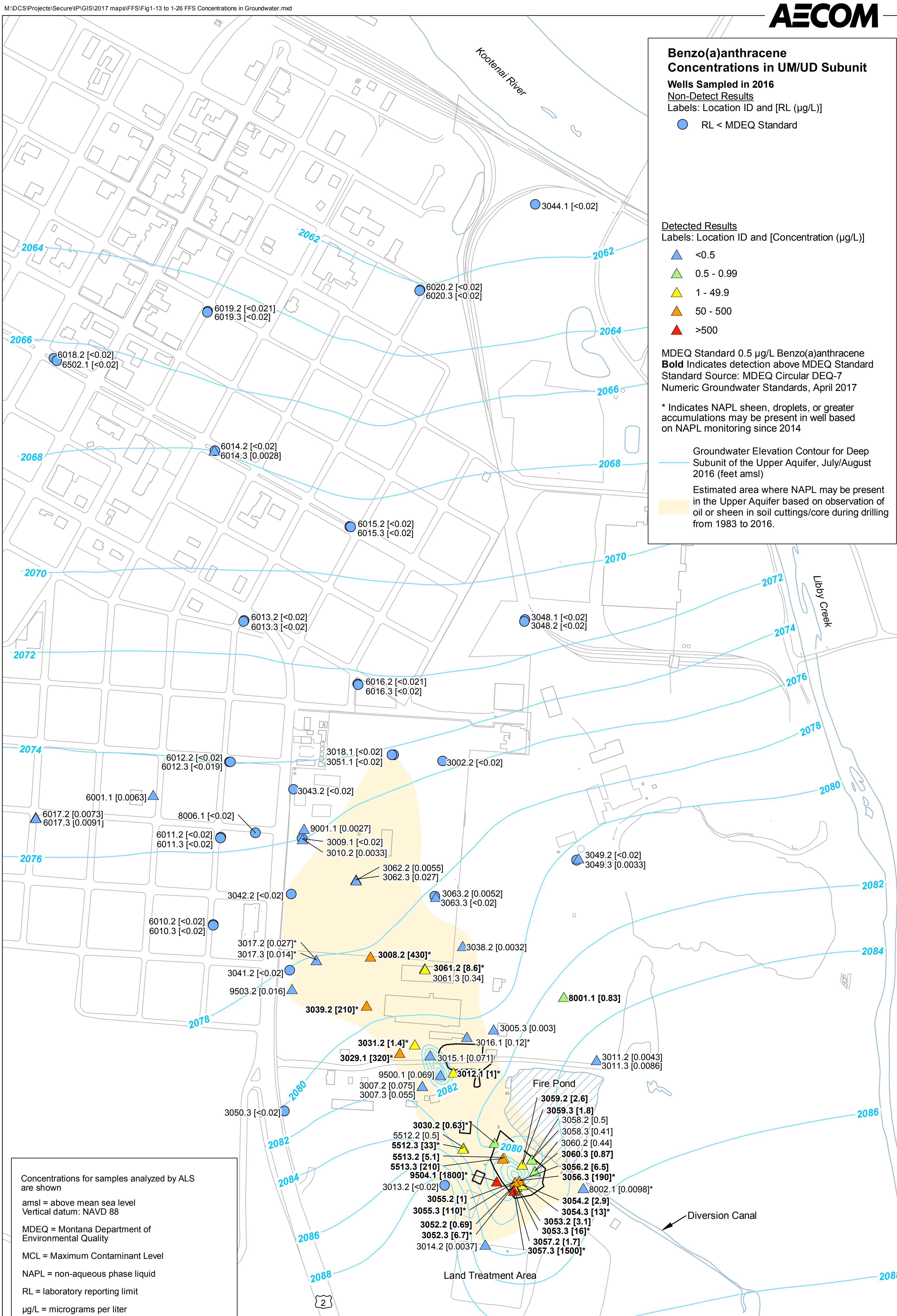
FOCUSED FEASIBILITY STUDY FOR THE UPPER AQUIFER
LIBBY GROUNDWATER SITE, LIBBY, MONTANA

Job No.:	60514930
Designed By:	ARM
Drawn By:	JLC
Date:	2/12/2018

Fig. 1-17A

M:\DCS\Projects\Secure\IP\GIS\2017 maps\FFS\Fig1-13 to 1-26 FFS Concentrations in Groundwater.mxd

AECOM



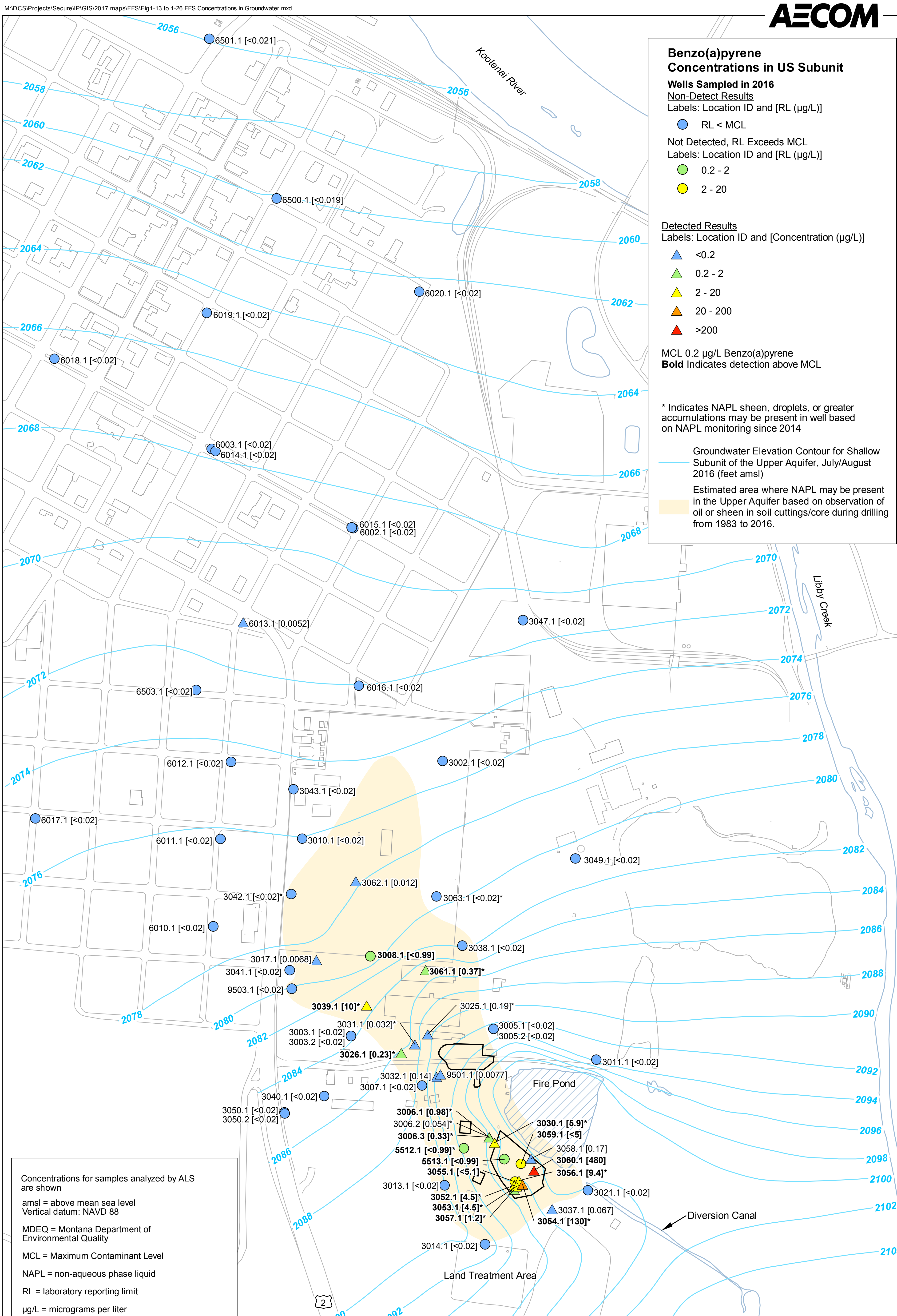
Benzo(a)anthracene Concentrations in Groundwater, Middle/Deep Subunit of the Upper Aquifer (UM/UD) Summer 2016

FOCUSED FEASIBILITY STUDY FOR THE UPPER AQUIFER
LIBBY GROUNDWATER SITE, LIBBY, MONTANA

Job No.:	60514930
Designed By:	ARM
Drawn By:	JLC
Date:	2/12/2018

Fig. 1-17B

AECOM



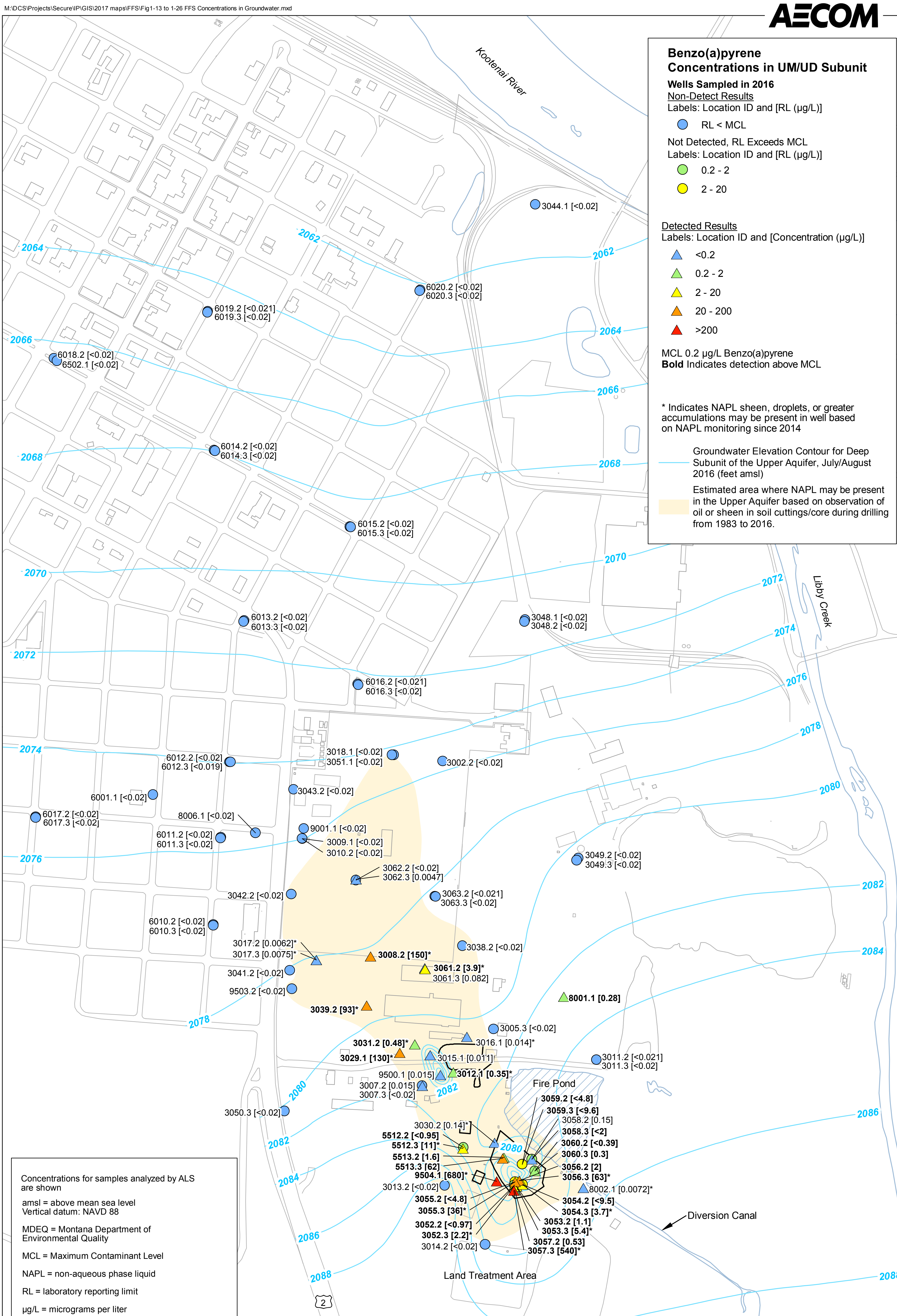
Benzo(a)pyrene Concentrations in Groundwater, Shallow Subunit of the Upper Aquifer (US) Summer 2016

FOCUSED FEASIBILITY STUDY FOR THE UPPER AQUIFER
LIBBY GROUNDWATER SITE, LIBBY, MONTANA

Job No.:	60514930
Designed By:	ARM
Drawn By:	JLC
Date:	2/12/2018

Fig. 1-18A

AECOM



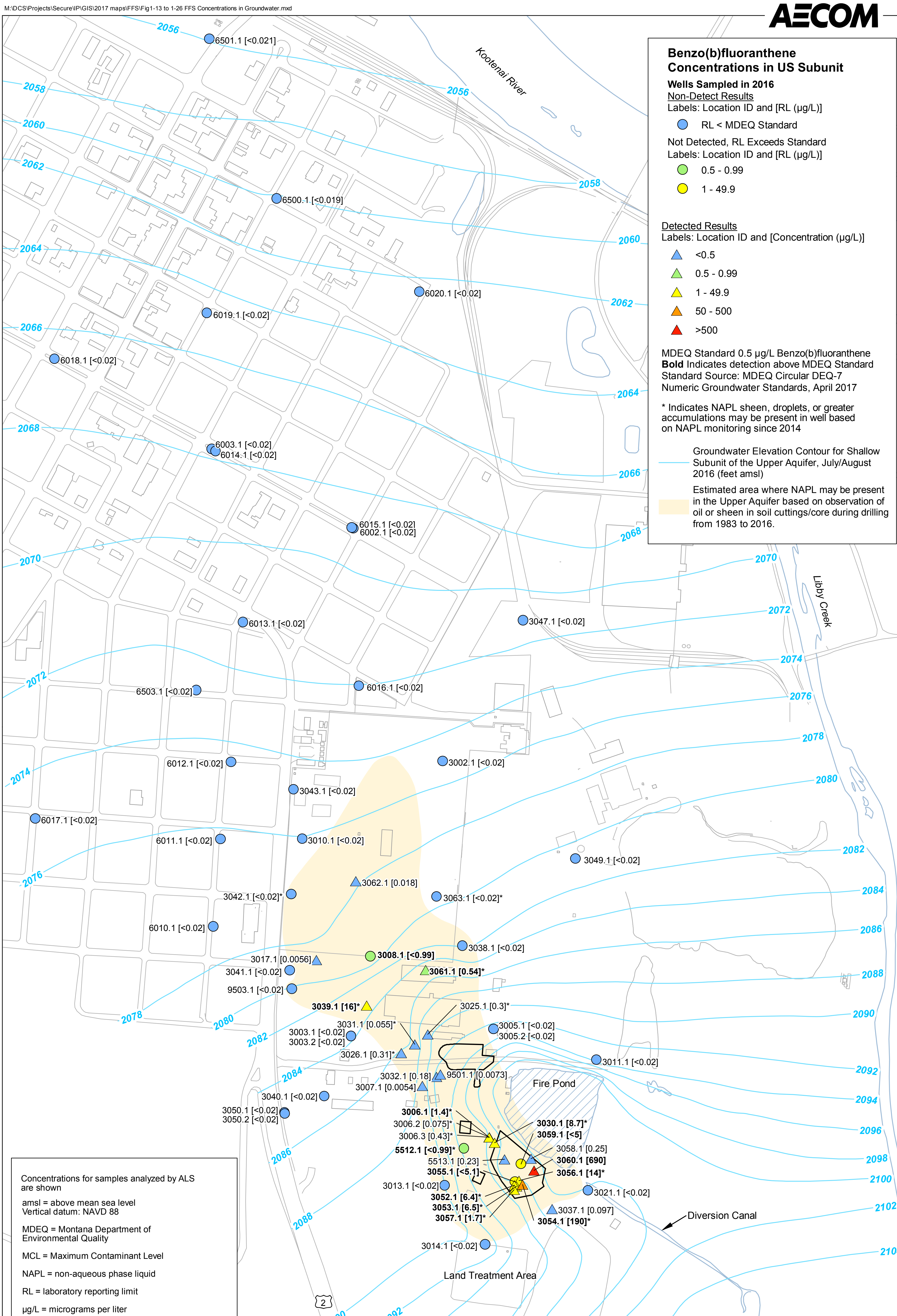
Benzo(a)pyrene Concentrations in Groundwater, Middle/Deep Subunit of the Upper Aquifer (UM/UD) Summer 2016

FOCUSED FEASIBILITY STUDY FOR THE UPPER AQUIFER
LIBBY GROUNDWATER SITE, LIBBY, MONTANA

Job No.:	60514930
Designed By:	ARM
Drawn By:	JLC
Date:	2/12/2018

Fig. 1-18B

AECOM



Benzo(b)fluoranthene Concentrations in Groundwater, Shallow Subunit of the Upper Aquifer (US) Summer 2016

FOCUSED FEASIBILITY STUDY FOR THE UPPER AQUIFER
LIBBY GROUNDWATER SITE, LIBBY, MONTANA

Job No.:	60514930
Designed By:	ARM
Drawn By:	JLC
Date:	2/12/2018

Fig. 1-19A

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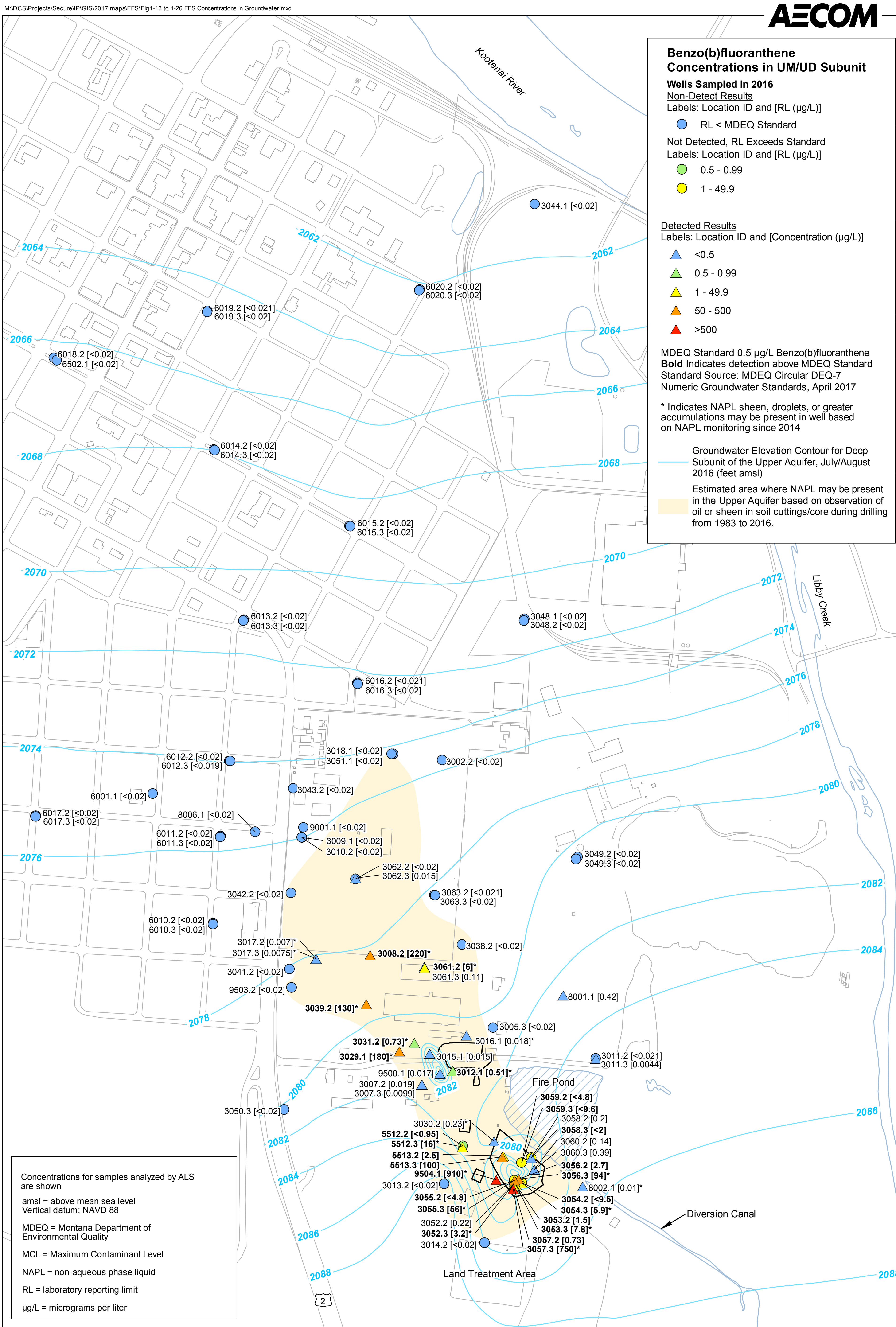
AECOM



Benzo(b)fluoranthene Concentrations in Groundwater, Middle/Deep Subunit of the Upper Aquifer (UM/UD) Summer 2016

FOCUSED FEASIBILITY STUDY FOR THE UPPER AQUIFER
LIBBY GROUNDWATER SITE, LIBBY, MONTANA

Job No.:	60514930
Designed By:	ARM
Drawn By:	JLC
Date:	2/12/2018

Fig. 1-19B

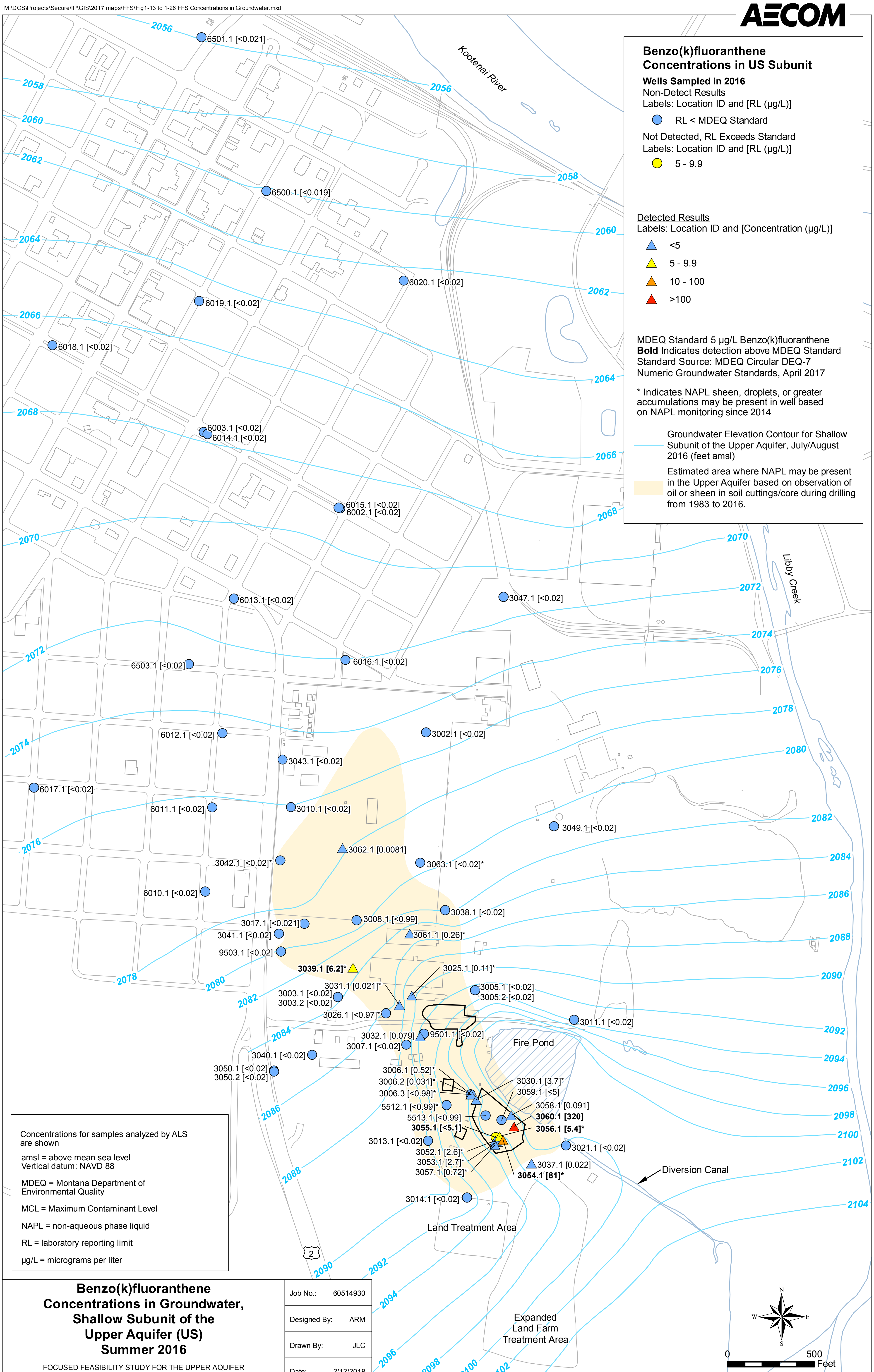

M:\DCS\Projects\Secure\IP\GIS\2017 maps\FFS\Fig1-13 to 1-26 FFS Concentrations in Groundwater.mxd
AECOM
Benzo(k)fluoranthene
Concentrations in US Subunit
Wells Sampled in 2016
Non-Detect Results
Labels: Location ID and [RL (µg/L)]
RL < MDEQ Standard
Not Detected, RL Exceeds Standard
Labels: Location ID and [RL (µg/L)]
5 - 9.9
Detected Results
Labels: Location ID and [Concentration (µg/L)]
<5
5 - 9.9
10 - 100
>100
MDEQ Standard 5 µg/L Benzo(k)fluoranthene
Bold Indicates detection above MDEQ Standard
Standard Source: MDEQ Circular DEQ-7
Numeric Groundwater Standards, April 2017
* Indicates NAPL sheen, droplets, or greater accumulations may be present in well based on NAPL monitoring since 2014
Groundwater Elevation Contour for Shallow Subunit of the Upper Aquifer, July/August 2016 (feet amsl)
Estimated area where NAPL may be present in the Upper Aquifer based on observation of oil or sheen in soil cuttings/core during drilling from 1983 to 2016.
Kootenai River
Libby Creek
Fire Pond
Diversion Canal
Land Treatment Area
Expanded Land Farm Treatment Area
6501.1 [<0.021]
6500.1 [<0.019]
6020.1 [<0.02]
6019.1 [<0.02]
6018.1 [<0.02]
6003.1 [<0.02]
6014.1 [<0.02]
6015.1 [<0.02]
6002.1 [<0.02]
6013.1 [<0.02]
3047.1 [<0.02]
6503.1 [<0.02]
6016.1 [<0.02]
6012.1 [<0.02]
3002.1 [<0.02]
3043.1 [<0.02]
6017.1 [<0.02]
6011.1 [<0.02]
3010.1 [<0.02]
3049.1 [<0.02]
3062.1 [0.0081]
3042.1 [<0.02]*
3063.1 [<0.02]*
6010.1 [<0.02]
3038.1 [<0.02]
3017.1 [<0.021]
3008.1 [<0.99]
3041.1 [<0.02]
3061.1 [0.26]*
9503.1 [<0.02]
3039.1 [6.2]*
3025.1 [0.11]*
3031.1 [0.021]*
3005.1 [<0.02]
3005.2 [<0.02]
3003.1 [<0.02]
3003.2 [<0.02]
3026.1 [<0.97]*
3011.1 [<0.02]
3032.1 [0.079]
9501.1 [<0.02]
3007.1 [<0.02]
3040.1 [<0.02]
3050.1 [<0.02]
3050.2 [<0.02]
3006.1 [0.52]*
3006.2 [0.031]*
3006.3 [<0.98]*
3030.1 [3.7]*
3059.1 [<5]
5512.1 [<0.99]*
3058.1 [0.091]
5513.1 [<0.99]
3060.1 [320]
3055.1 [<5.1]*
3056.1 [5.4]*
3013.1 [<0.02]
3021.1 [<0.02]
3052.1 [2.6]*
3053.1 [2.7]*
3057.1 [0.72]*
3037.1 [0.022]
3054.1 [81]*
3014.1 [<0.02]
2056
2058
2060
2062
2064
2066
2068
2070
2072
2074
2076
2078
2080
2082
2084
2086
2088
2090
2092
2094
2096
2098
2100
2102
2104
Concentrations for samples analyzed by ALS are shown
amsl = above mean sea level
Vertical datum: NAVD 88
MDEQ = Montana Department of Environmental Quality
MCL = Maximum Contaminant Level
NAPL = non-aqueous phase liquid
RL = laboratory reporting limit
µg/L = micrograms per liter
Benzo(k)fluoranthene Concentrations in Groundwater, Shallow Subunit of the Upper Aquifer (US) Summer 2016
FOCUSED FEASIBILITY STUDY FOR THE UPPER AQUIFER
LIBBY GROUNDWATER SITE, LIBBY, MONTANA
Job No.: 60514930
Designed By: ARM
Drawn By: JLC
Date: 2/12/2018
N
W
E
S
0
500
Feet
2

Fig. 1-20A

M:\DCS\Projects\Secure\IP\GIS\2017 maps\FFS\Fig1-13 to 1-26 FFS Concentrations in Groundwater.mxd

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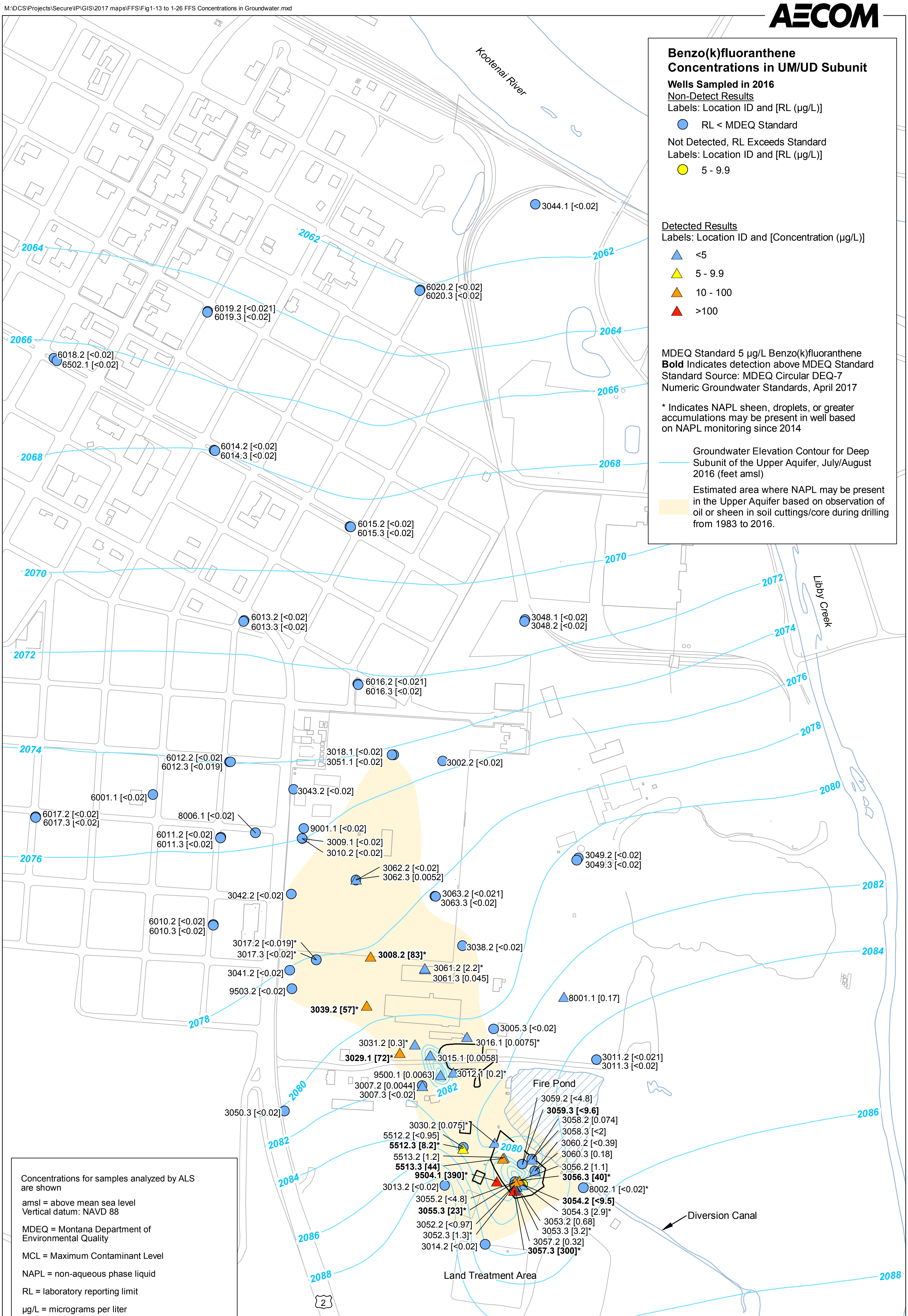


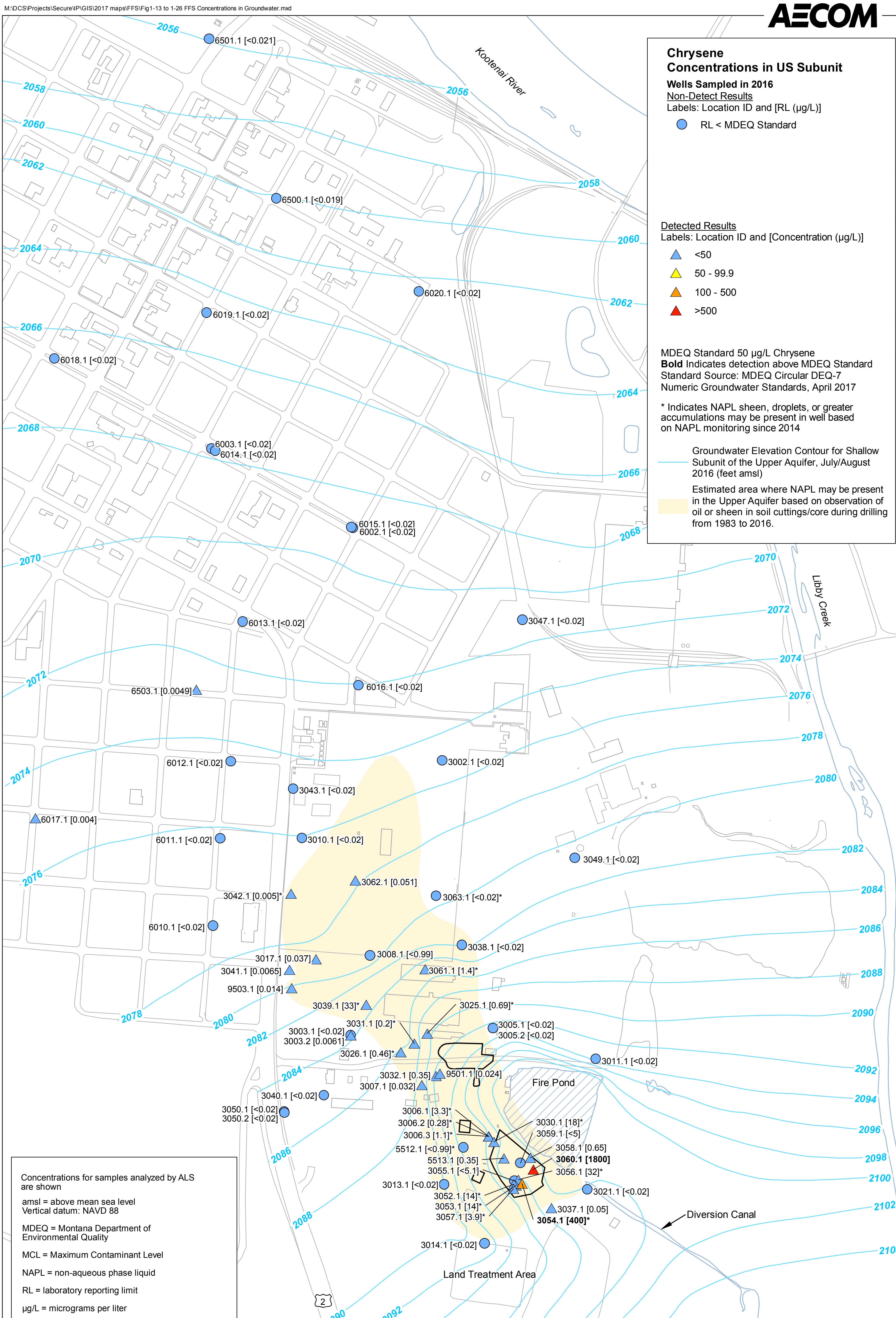
Benzo(k)fluoranthene Concentrations in Groundwater, Middle/Deep Subunit of the Upper Aquifer (UM/UD) Summer 2016

FOCUSED FEASIBILITY STUDY FOR THE UPPER AQUIFER
LIBBY GROUNDWATER SITE, LIBBY, MONTANA

Job No.:	60514930
Designed By:	ARM
Drawn By:	JLC
Date:	2/12/2018

Fig. 1-20B

AECOM

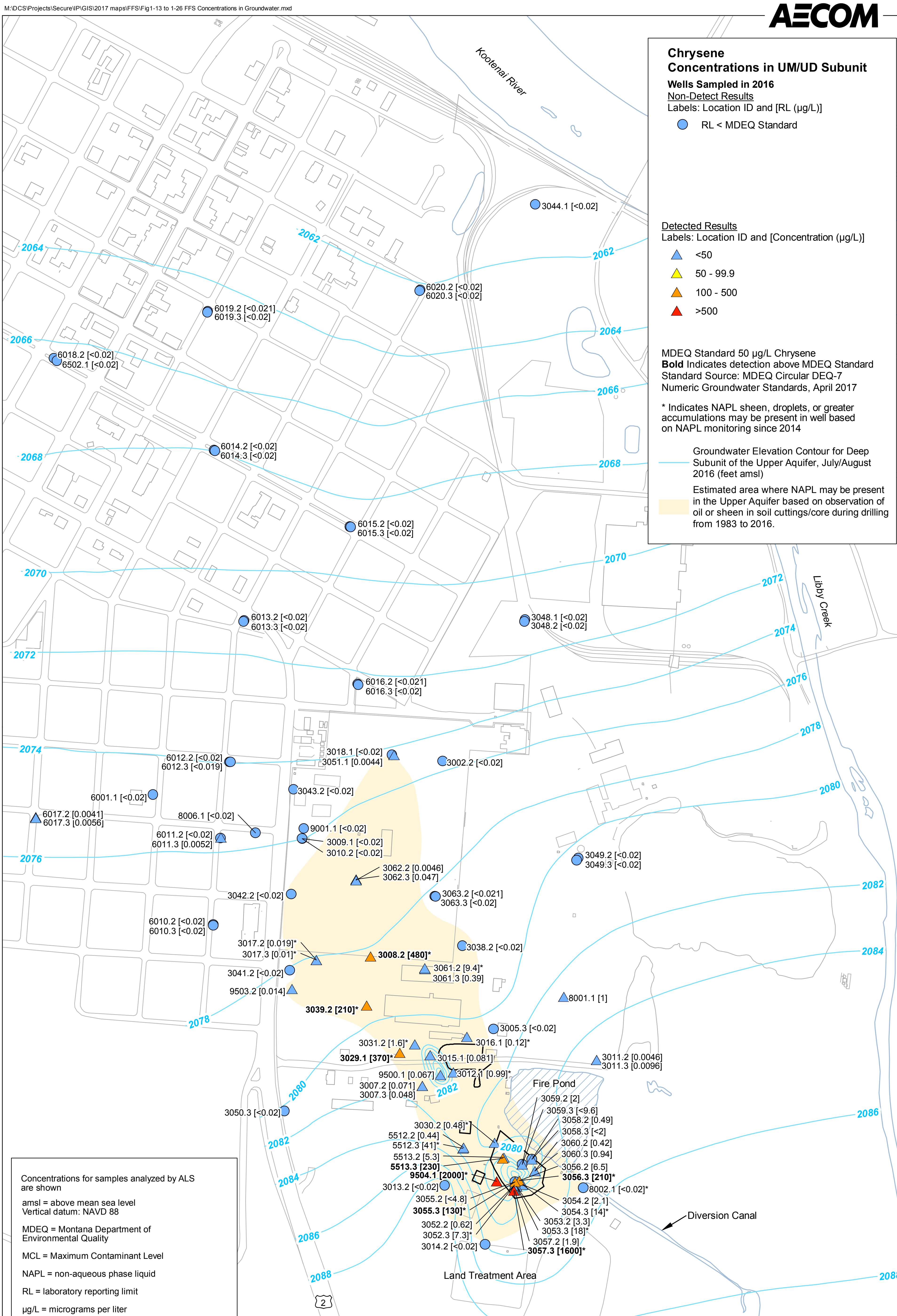


Chrysene Concentrations in Groundwater, Shallow Subunit of the Upper Aquifer (US) Summer 2016

FOCUSED FEASIBILITY STUDY FOR THE UPPER AQUIFER
LIBBY GROUNDWATER SITE, LIBBY, MONTANA

Job No.:	60514930
Designed By:	ARM
Drawn By:	JLC
Date:	2/12/2018

Fig. 1-21A



Chrysene
Concentrations in Groundwater, Middle/Deep Subunit of the Upper Aquifer (UM/UD)
Summer 2016

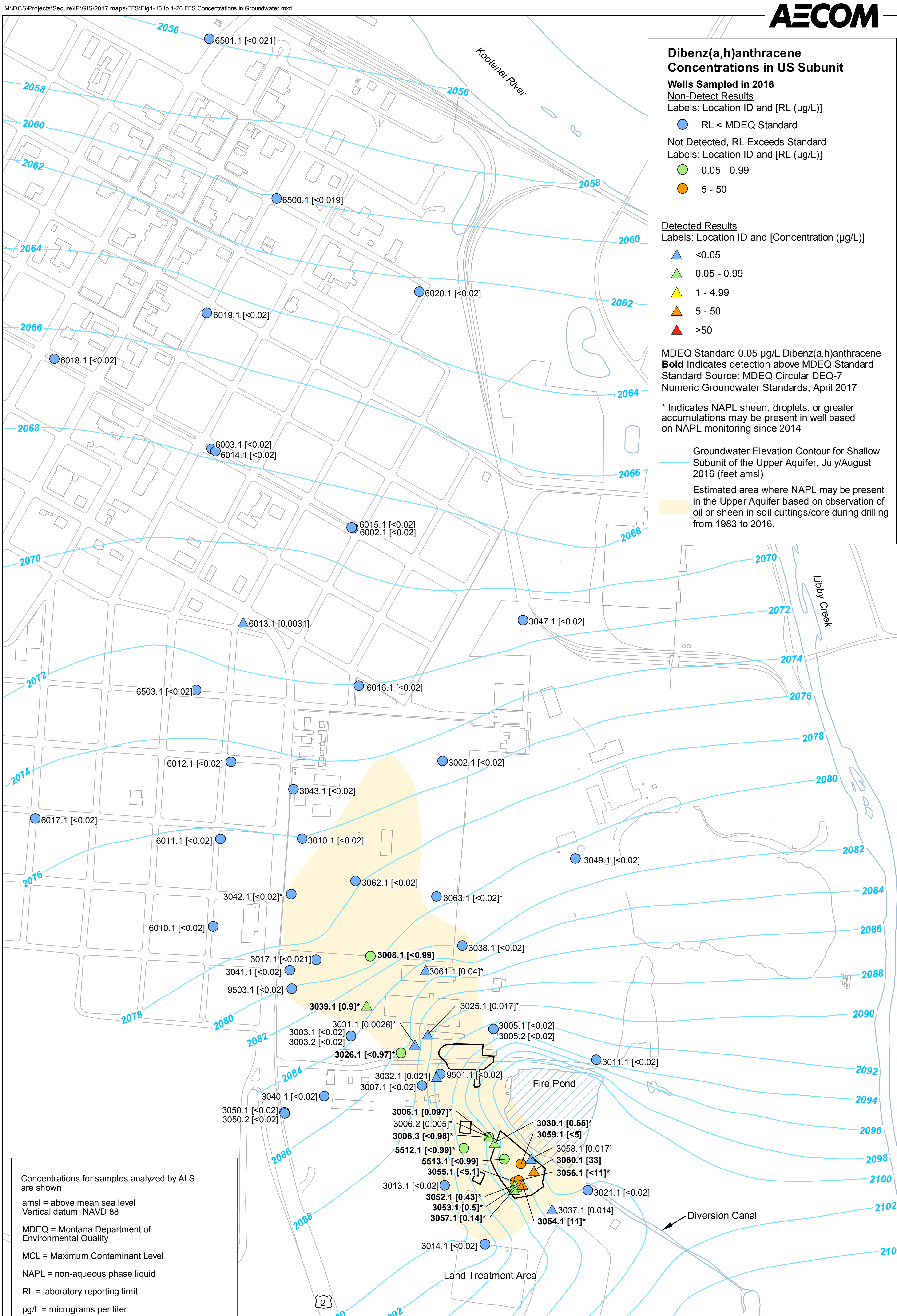
FOCUSED FEASIBILITY STUDY FOR THE UPPER AQUIFER
LIBBY GROUNDWATER SITE, LIBBY, MONTANA

Job No.:	60514930
Designed By:	ARM
Drawn By:	JLC
Date:	2/12/2018

Fig. 1-21B

M:\DCS\Projects\Secure\IP\GIS\2017 maps\FFS\Fig1-13 to 1-26 FFS Concentrations in Groundwater.mxd

AECOM



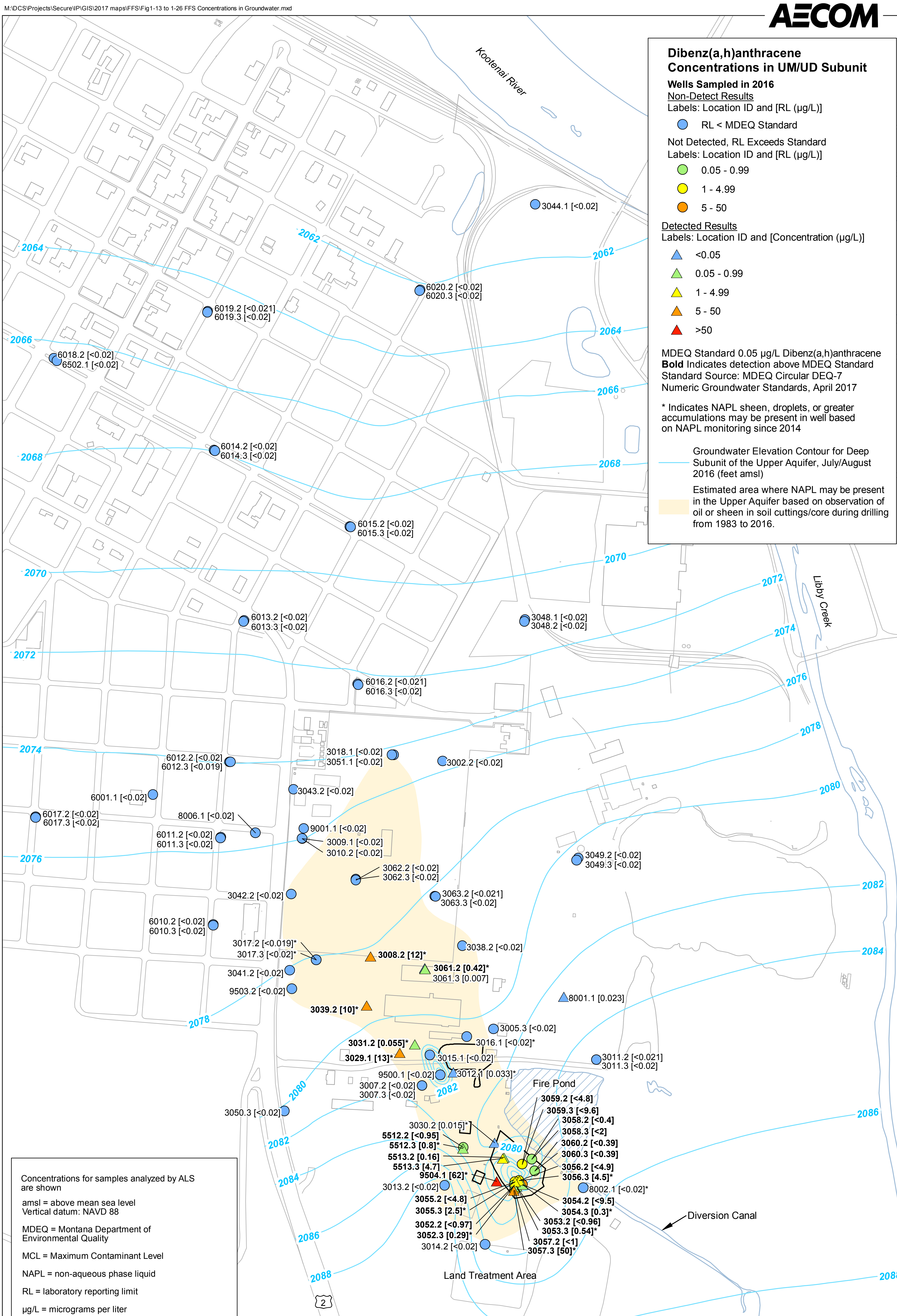
Dibenz(a,h)anthracene Concentrations in Groundwater, Shallow Subunit of the Upper Aquifer (US) Summer 2016

FOCUSED FEASIBILITY STUDY FOR THE UPPER AQUIFER
LIBBY GROUNDWATER SITE, LIBBY, MONTANA

Job No.:	60514930
Designed By:	ARM
Drawn By:	JLC
Date:	2/12/2018

Fig. 1-22A

AECOM



Dibenz(a,h)anthracene Concentrations in Groundwater, Middle/Deep Subunit of the Upper Aquifer (UM/UD) Summer 2016

FOCUSED FEASIBILITY STUDY FOR THE UPPER AQUIFER
LIBBY GROUNDWATER SITE, LIBBY, MONTANA

Job No.:	60514930
Designed By:	ARM
Drawn By:	JLC
Date:	2/12/2018

Fig. 1-22B

M:\DCS\Projects\Secure\IP\GIS\2017 maps\FFS\Fig1-13 to 1-26 FFS Concentrations in Groundwater.mxd

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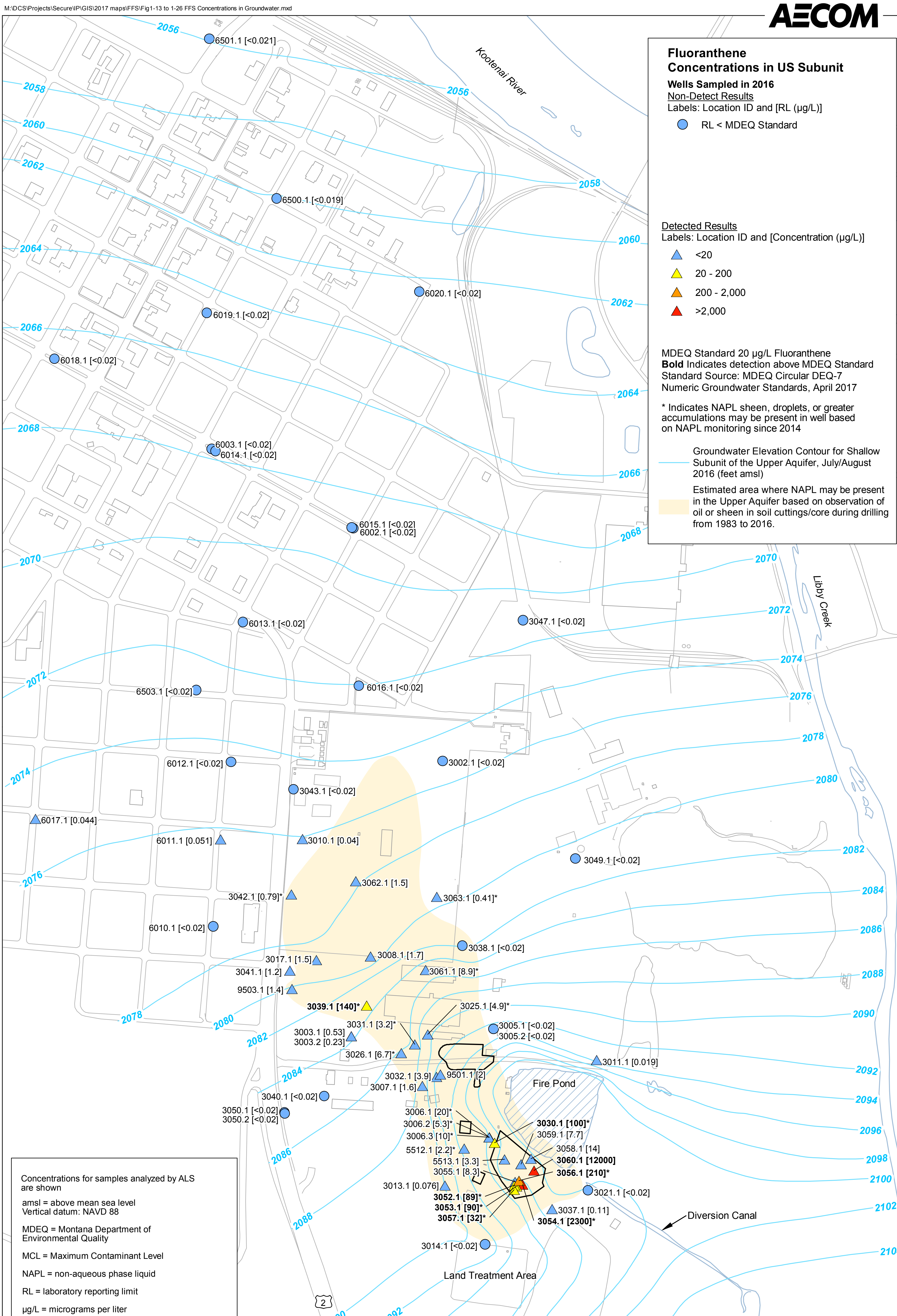


Fluoranthene Concentrations in Groundwater, Shallow Subunit of the Upper Aquifer (US) Summer 2016

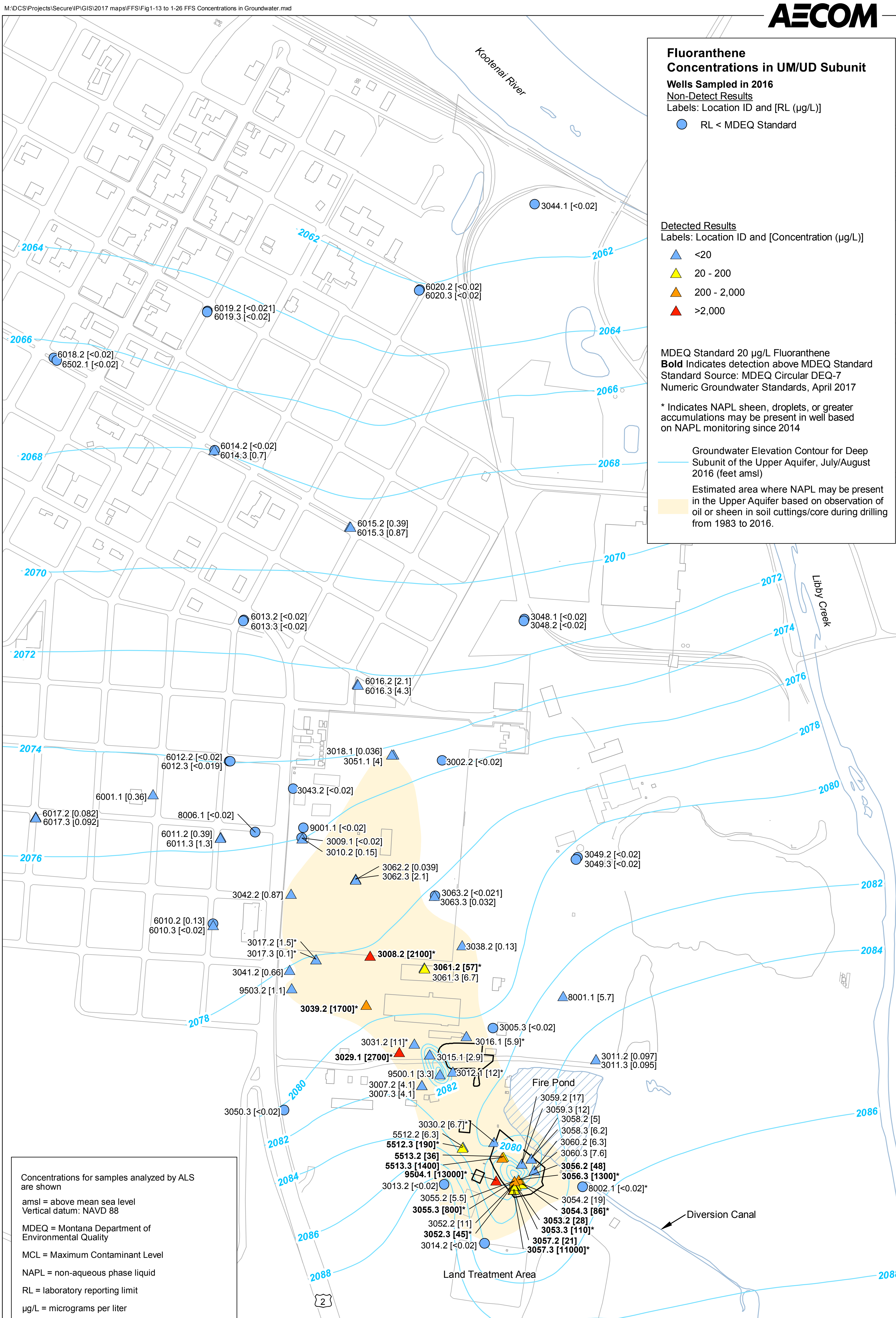
FOCUSED FEASIBILITY STUDY FOR THE UPPER AQUIFER
LIBBY GROUNDWATER SITE, LIBBY, MONTANA

Job No.:	60514930
Designed By:	ARM
Drawn By:	JLC
Date:	2/12/2018

Fig. 1-23A

M:\DCS\Projects\Secure\IP\GIS\2017 maps\FFS\Fig1-13 to 1-26 FFS Concentrations in Groundwater.mxd

AECOM



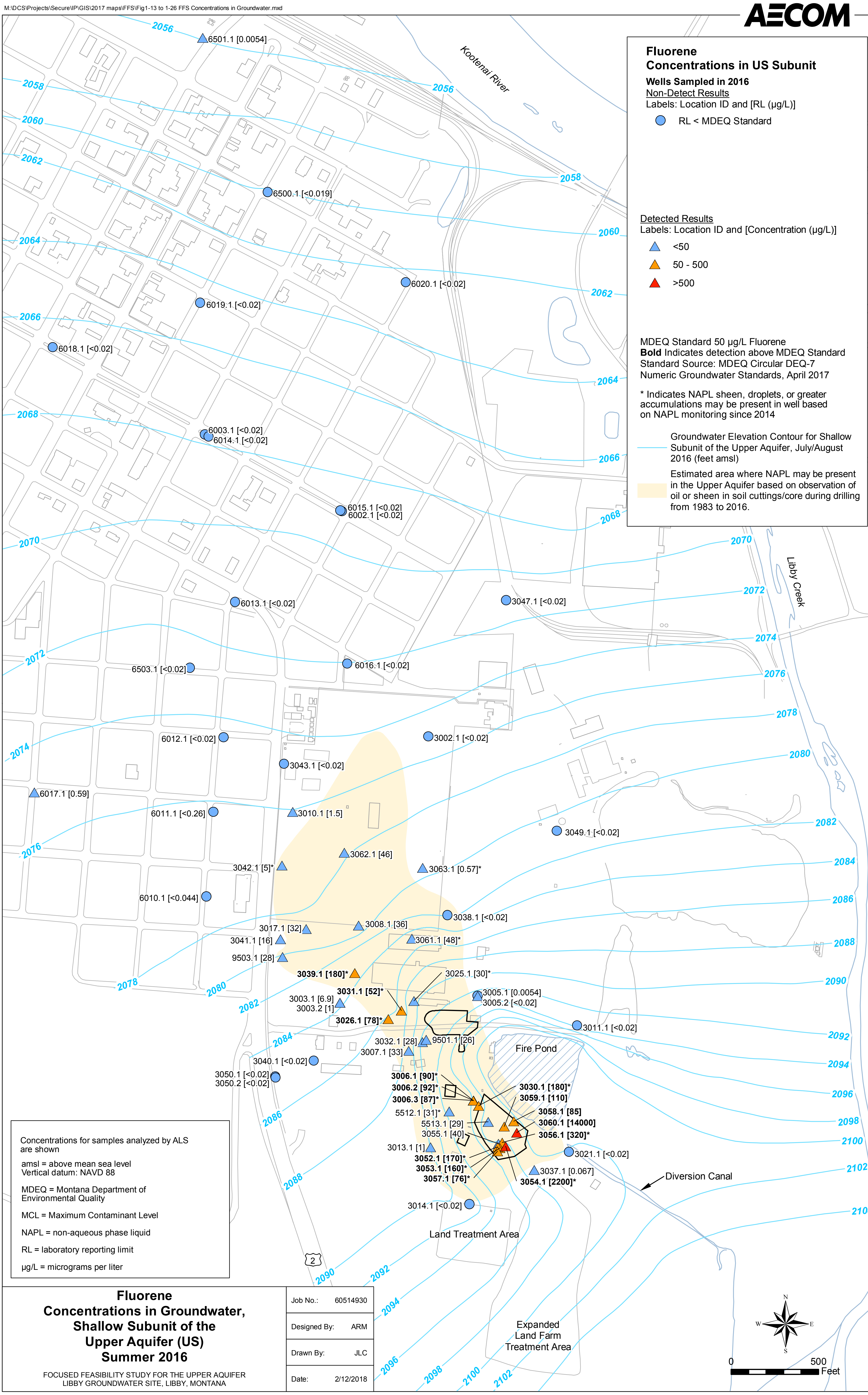
Fluoranthene Concentrations in Groundwater, Middle/Deep Subunit of the Upper Aquifer (UM/UD) Summer 2016

FOCUSED FEASIBILITY STUDY FOR THE UPPER AQUIFER
LIBBY GROUNDWATER SITE, LIBBY, MONTANA

Job No.:	60514930
Designed By:	ARM
Drawn By:	JLC
Date:	2/12/2018

Fig. 1-23B

AECOM



Fluorene Concentrations in US Subunit

Wells Sampled in 2016

Non-Detect Results

Labels: Location ID and [RL (µg/L)]

- RL < MDEQ Standard

Detected Results

Labels: Location ID and [Concentration (µg/L)]

- <50
- 50 - 500
- >500

MDEQ Standard 50 µg/L Fluorene
Bold Indicates detection above MDEQ Standard
Standard Source: MDEQ Circular DEQ-7 Numeric Groundwater Standards, April 2017

* Indicates NAPL sheen, droplets, or greater accumulations may be present in well based on NAPL monitoring since 2014

Groundwater Elevation Contour for Shallow Subunit of the Upper Aquifer, July/August 2016 (feet amsl)

Estimated area where NAPL may be present in the Upper Aquifer based on observation of oil or sheen in soil cuttings/core during drilling from 1983 to 2016.

Concentrations for samples analyzed by ALS are shown

amsl = above mean sea level
Vertical datum: NAVD 88

MDEQ = Montana Department of Environmental Quality

MCL = Maximum Contaminant Level

NAPL = non-aqueous phase liquid

RL = laboratory reporting limit

µg/L = micrograms per liter

Fluorene Concentrations in Groundwater, Shallow Subunit of the Upper Aquifer (US) Summer 2016

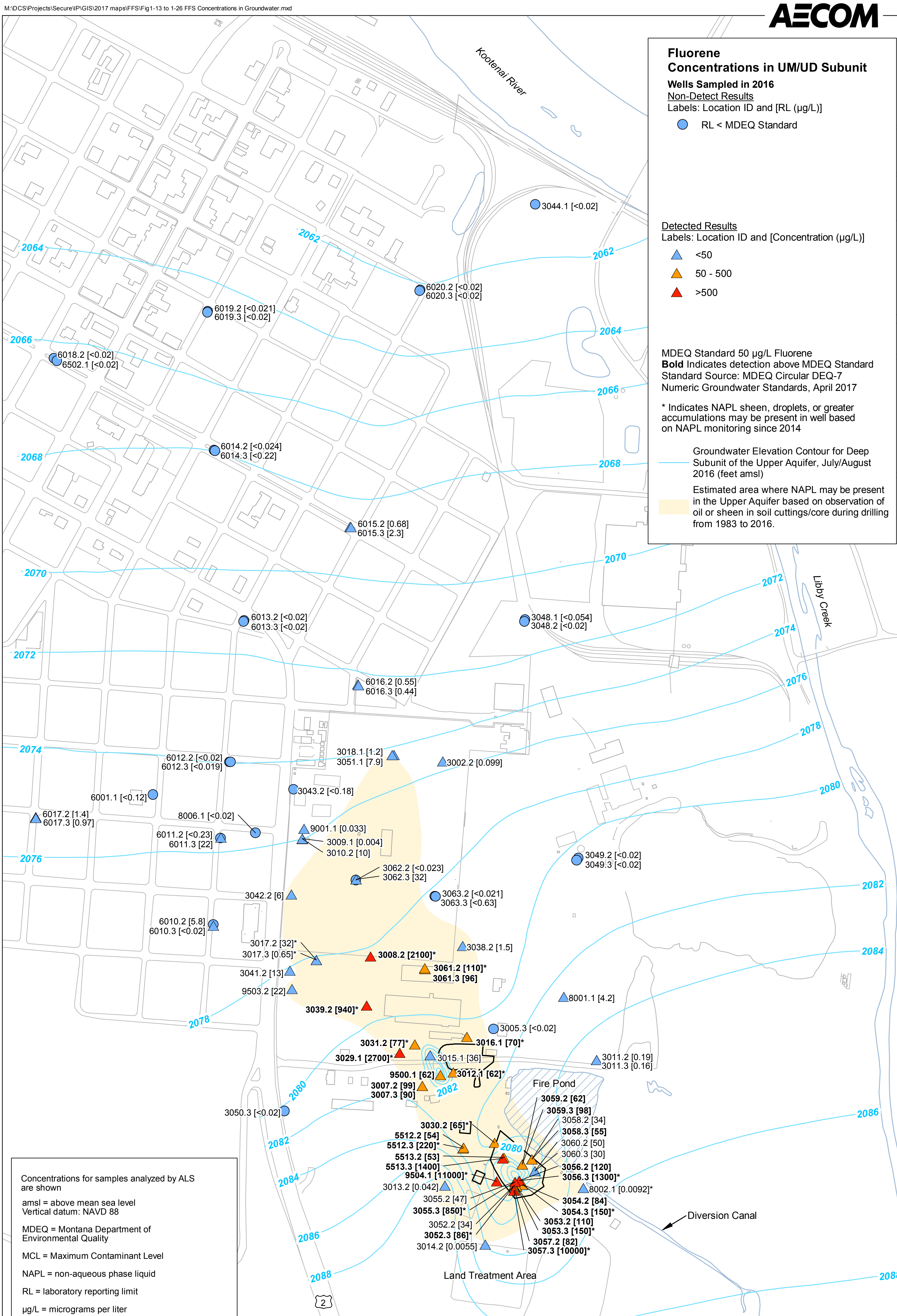
FOCUSED FEASIBILITY STUDY FOR THE UPPER AQUIFER
LIBBY GROUNDWATER SITE, LIBBY, MONTANA

Job No.:	60514930
Designed By:	ARM
Drawn By:	JLC
Date:	2/12/2018

Fig. 1-24A

M:\DCS\Projects\Secure\IP\GIS\2017 maps\FFS\Fig1-13 to 1-26 FFS Concentrations in Groundwater.mxd

AECOM



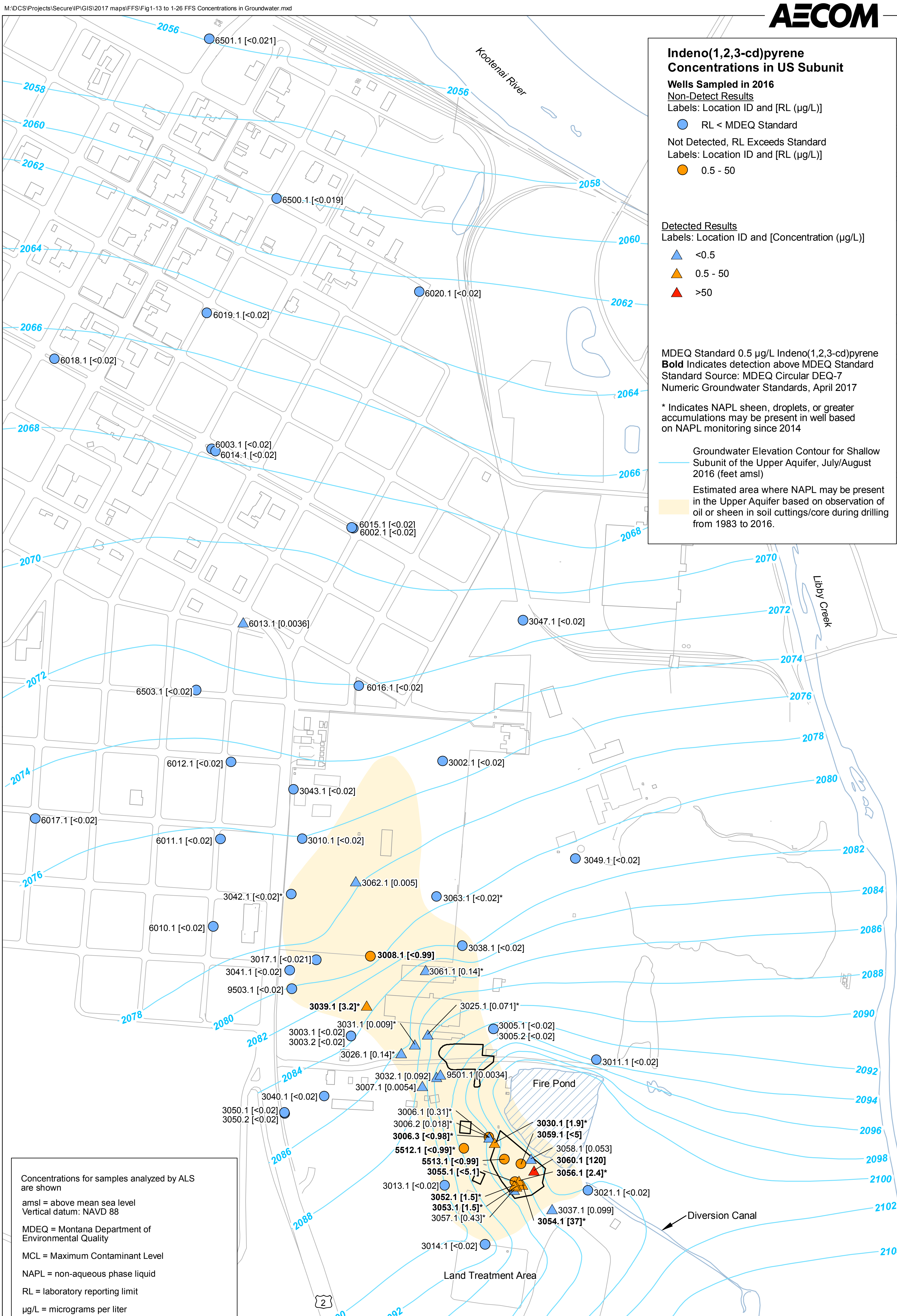
Fluorene Concentrations in Groundwater, Middle/Deep Subunit of the Upper Aquifer (UM/UD) Summer 2016

FOCUSED FEASIBILITY STUDY FOR THE UPPER AQUIFER
LIBBY GROUNDWATER SITE, LIBBY, MONTANA

Job No.:	60514930
Designed By:	ARM
Drawn By:	JLC
Date:	2/12/2018

Fig. 1-24B

M:\DCS\Projects\Secure\IP\GIS\2017 maps\FFS\Fig1-13 to 1-26 FFS Concentrations in Groundwater.mxd



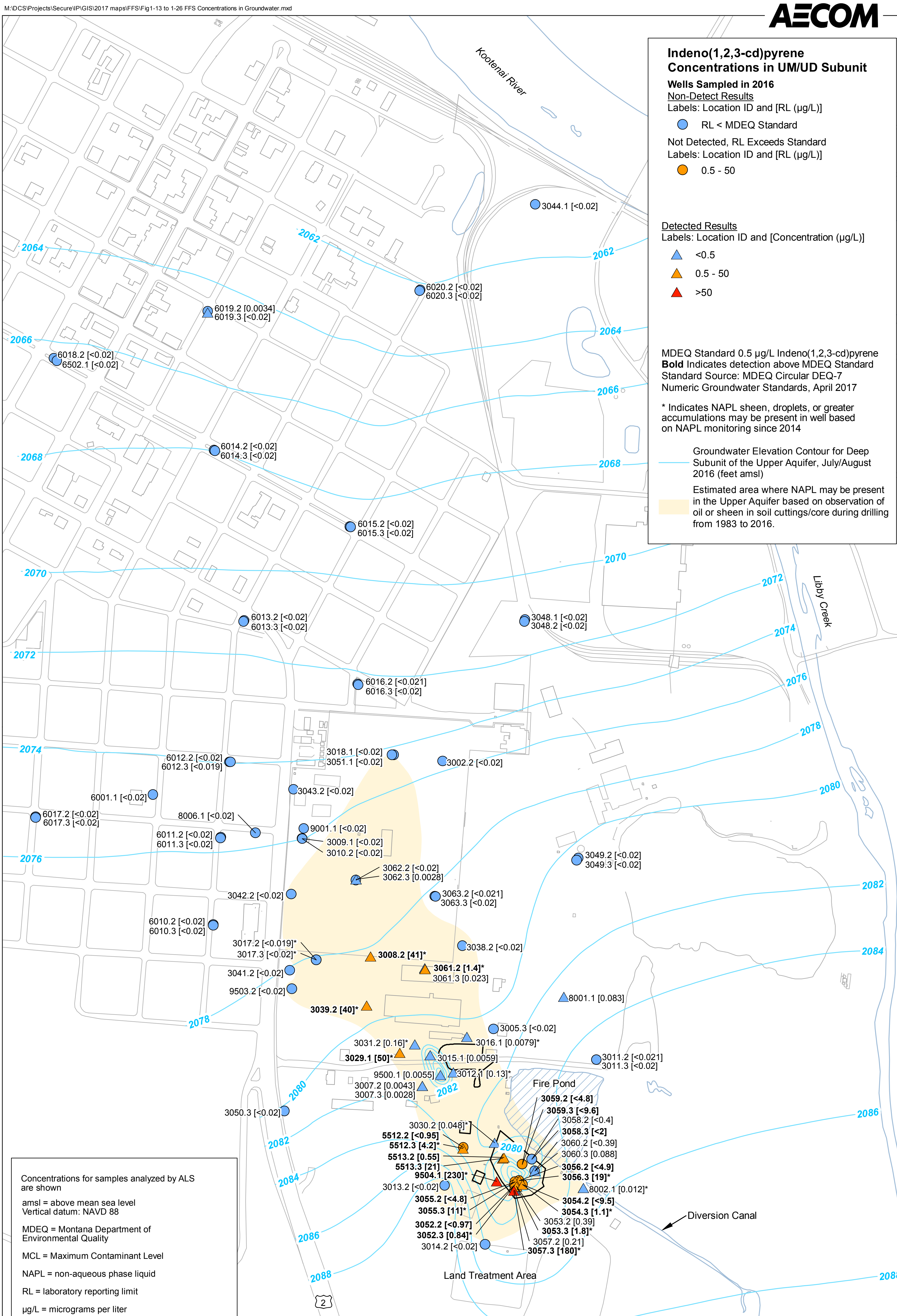
Indeno(1,2,3-cd)pyrene Concentrations in Groundwater, Shallow Subunit of the Upper Aquifer (US) Summer 2016

FOCUSED FEASIBILITY STUDY FOR THE UPPER AQUIFER
LIBBY GROUNDWATER SITE, LIBBY, MONTANA

Job No.:	60514930
Designed By:	ARM
Drawn By:	JLC
Date:	2/12/2018

Fig. 1-25A

AECOM



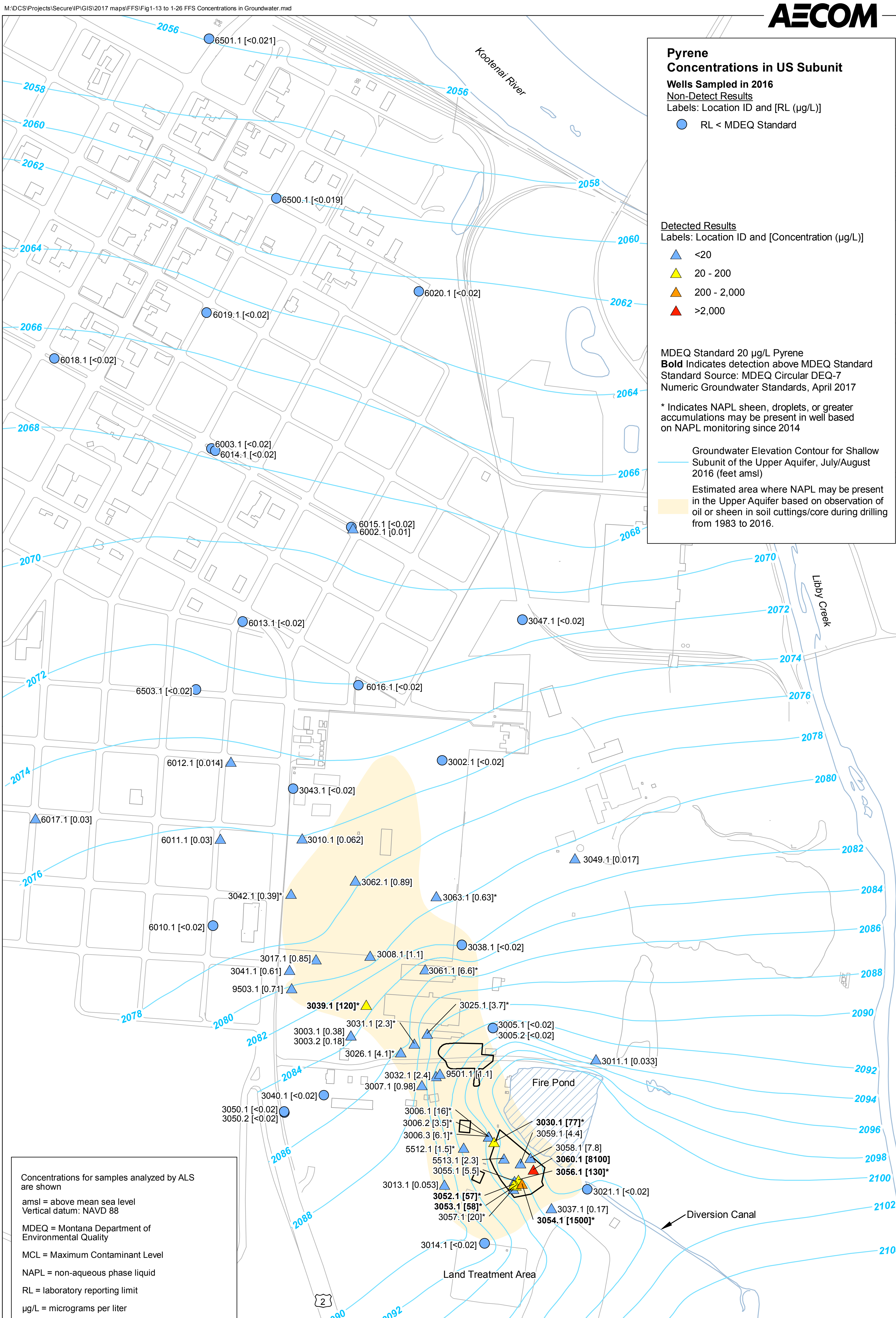
Indeno(1,2,3-cd)pyrene Concentrations in Groundwater, Middle/Deep Subunit of the Upper Aquifer (UM/UD) Summer 2016

FOCUSED FEASIBILITY STUDY FOR THE UPPER AQUIFER
LIBBY GROUNDWATER SITE, LIBBY, MONTANA

Job No.:	60514930
Designed By:	ARM
Drawn By:	JLC
Date:	2/12/2018

Fig. 1-25B

AECOM



Pyrene
Concentrations in US Subunit

Wells Sampled in 2016

Non-Detect Results

Labels: Location ID and [RL (µg/L)]

- RL < MDEQ Standard

Detected Results

Labels: Location ID and [Concentration (µg/L)]

- <20
- 20 - 200
- 200 - 2,000
- >2,000

MDEQ Standard 20 µg/L Pyrene
Bold Indicates detection above MDEQ Standard
Standard Source: MDEQ Circular DEQ-7
Numeric Groundwater Standards, April 2017

* Indicates NAPL sheen, droplets, or greater accumulations may be present in well based on NAPL monitoring since 2014

Groundwater Elevation Contour for Shallow Subunit of the Upper Aquifer, July/August 2016 (feet amsl)

Estimated area where NAPL may be present in the Upper Aquifer based on observation of oil or sheen in soil cuttings/core during drilling from 1983 to 2016.

Concentrations for samples analyzed by ALS are shown

amsl = above mean sea level
Vertical datum: NAVD 88

MDEQ = Montana Department of Environmental Quality

MCL = Maximum Contaminant Level

NAPL = non-aqueous phase liquid

RL = laboratory reporting limit

µg/L = micrograms per liter

Pyrene Concentrations in Groundwater, Shallow Subunit of the Upper Aquifer (US) Summer 2016

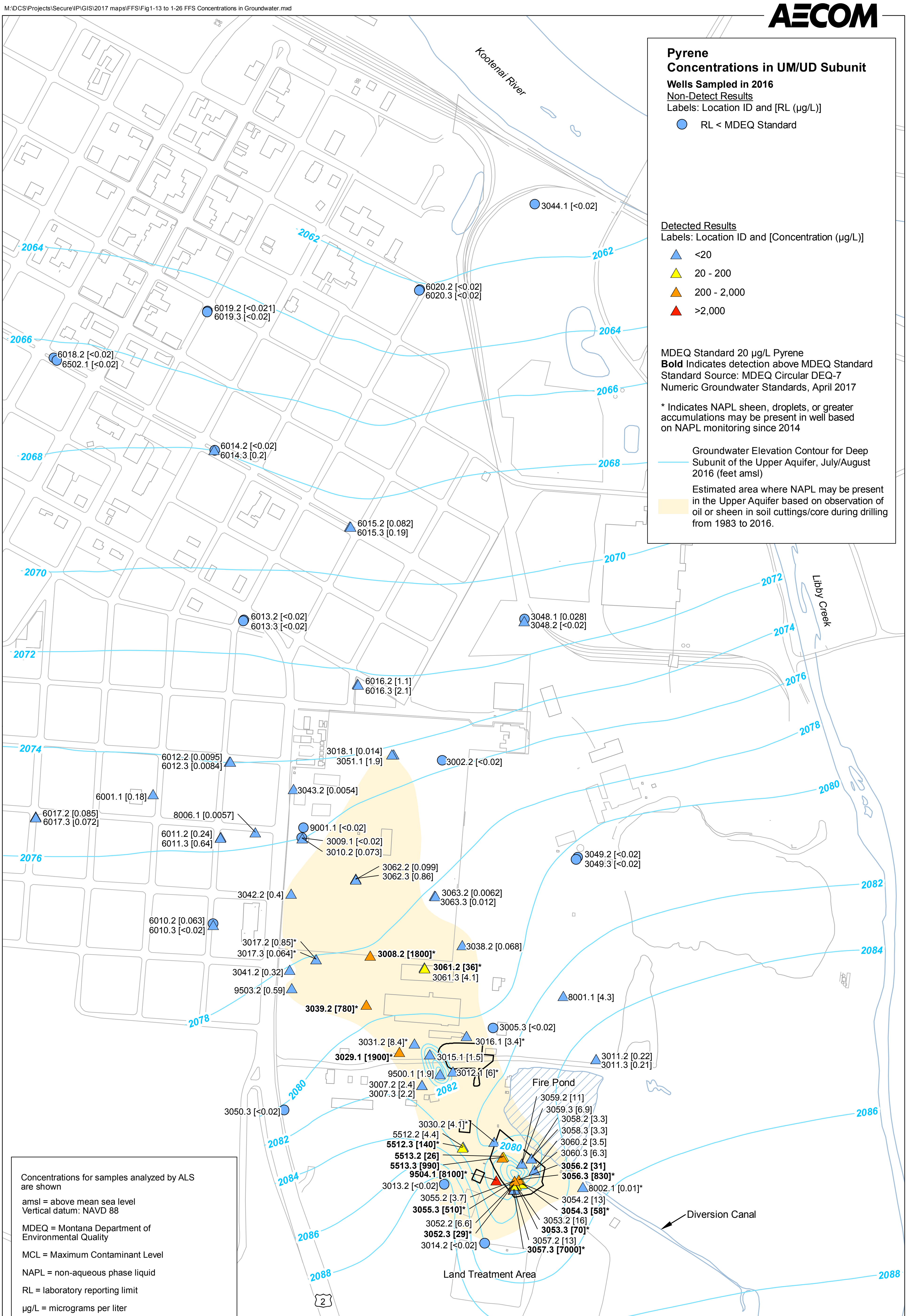
FOCUSED FEASIBILITY STUDY FOR THE UPPER AQUIFER
LIBBY GROUNDWATER SITE, LIBBY, MONTANA

Job No.:	60514930
Designed By:	ARM
Drawn By:	JLC
Date:	2/12/2018

Fig. 1-26A

M:\DCS\Projects\Secure\IP\GIS\2017 maps\FFS\Fig1-13 to 1-26 FFS Concentrations in Groundwater.mxd

AECOM

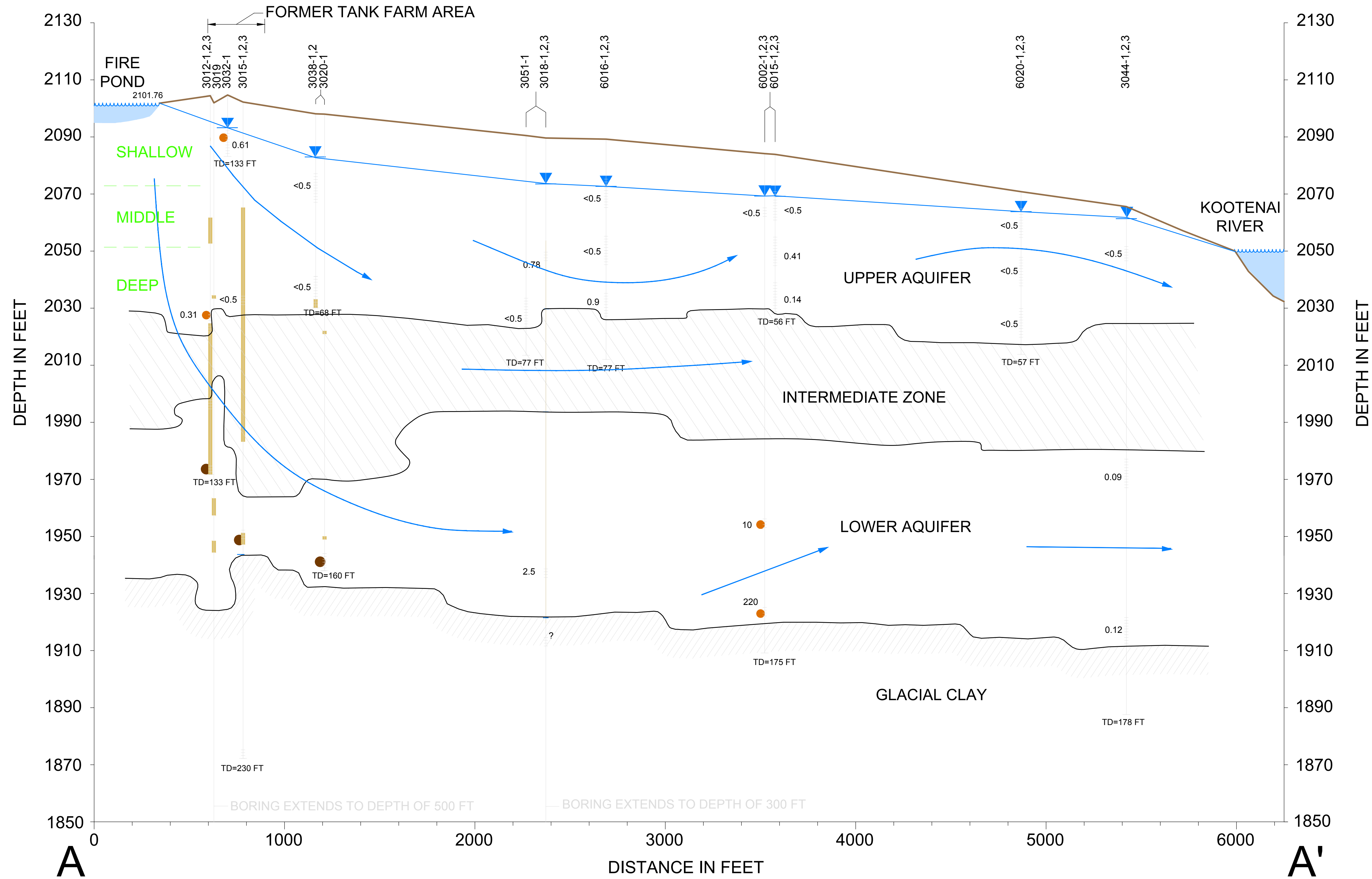


Pyrene
Concentrations in Groundwater,
Middle/Deep Subunit of the
Upper Aquifer (UM/UD)
Summer 2016

FOCUSED FEASIBILITY STUDY FOR THE UPPER AQUIFER
LIBBY GROUNDWATER SITE, LIBBY, MONTANA

Job No.:	60514930
Designed By:	ARM
Drawn By:	JLC
Date:	2/12/2018

Fig. 1-26B



AECOM

LEGEND

- APPROXIMATE WATER TABLE
- GROUNDWATER FLOW LINE
- 0.52 — PCP CONCENTRATION (ug/L) IN WELL FROM MAY - SEPTEMBER 2016 FOR SAMPLES ANALYZED BY ALS
- APPROXIMATE CONTACT BETWEEN SHALLOW, MIDDLE, AND DEEP SUBUNIT OF UPPER AQUIFER IN FORMER SOURCE AREAS
- NAPL SHEEN OR FILM OBSERVED IN WELL AT LEAST ONCE SINCE WELL WAS INSTALLED
- NAPL OF MEASURABLE THICKNESS (IN INCHES) OBSERVED AT LEAST ONCE SINCE WELL WAS INSTALLED
- NAPL (SHEEN OR OIL) OBSERVED IN SOIL DURING DRILLING

NOTES:

1. WELL SPACING ALONG CROSS SECTION IS APPROXIMATE.
2. THE KOOTENAI RIVER STAGE OF 2050 FEET AMSL IS THE ESTIMATED AVERAGE RIVER STAGE BASED ON DATA COLLECTED FROM 1975 TO 1991 AT THE HISTORICAL GAUGE LOCATED APPROXIMATELY 1,700 FEET DOWNSTREAM OF THE HIGHWAY 37 BRIDGE.

0 150 300 600 HORIZONTAL SCALE IN FEET

0 10 20 40 VERTICAL SCALE IN FEET

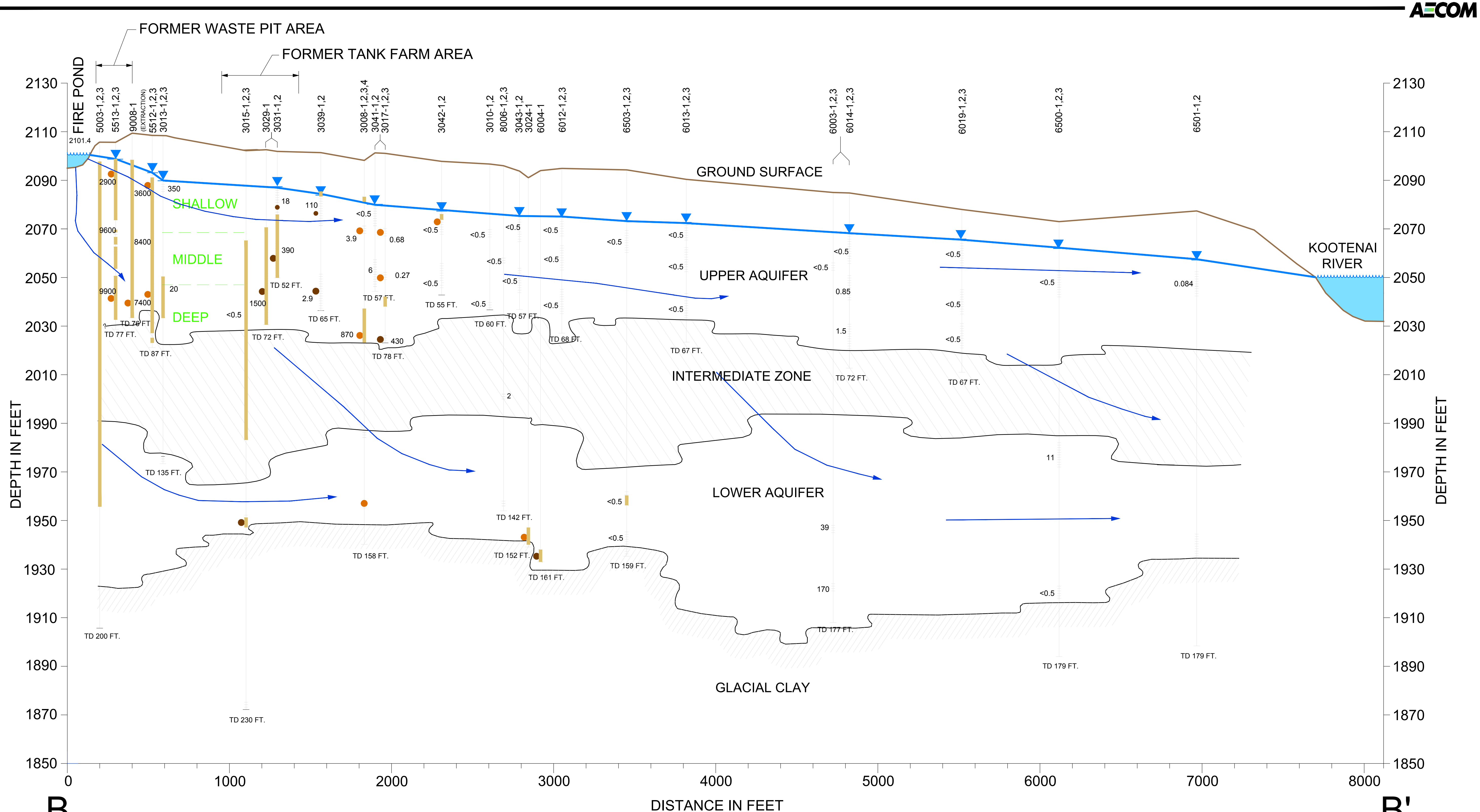
Job No. :	60409011
Prepared By :	MCS
Date :	1/13/17

HYDROGEOLOGIC CROSS SECTION A–A' WITH PCP CONCENTRATIONS AND NAPL OCCURRENCE

FIG. 1-27

DRAWING PATH: M:\DCS\Projects\Secure\IP\60514324_IP_FFS_DE_Sup\7.0_CAD_GIS\HYDRO XS NAPL (XS A-A').dwg

URS



LEGEND

- APPROXIMATE WATER TABLE
- GROUNDWATER FLOW LINE
- 12,000 — PCP CONCENTRATION (ug/L) IN WELL MAY - SEPTEMBER 2016 FOR SAMPLES ANALYZED BY ALS
- NAPL SHEEN OR FILM OBSERVED IN WELL AT LEAST ONCE SINCE WELL WAS INSTALLED
- NAPL OF MEASURABLE THICKNESS (IN INCHES) OBSERVED AT LEAST ONCE SINCE WELL WAS INSTALLED
- NAPL (SHEEN OR OIL) OBSERVED IN SOIL DURING DRILLING
- APPROXIMATE CONTACT BETWEEN SHALLOW, MIDDLE, AND DEEP SUBUNIT OF UPPER AQUIFER IN FORMER SOURCE AREAS

NOTES:

1. WELL SPACING ALONG CROSS SECTION IS APPROXIMATE.
2. THE KOOTENAI RIVER STAGE OF 2050 FEET AMSL IS THE ESTIMATED AVERAGE RIVER STAGE BASED ON DATA COLLECTED FROM 1975 TO 1991 AT THE HISTORICAL GAUGE LOCATED APPROXIMATELY 1,700 FEET DOWNSTREAM OF THE HIGHWAY 37 BRIDGE.
3. CROSS SECTION LOCATION IS SHOWN ON FIGURE 1-1.
4. CROSS SECTION IS ORIENTED APPROXIMATELY PARALLEL TO HORIZONTAL GROUNDWATER FLOW.

HORIZONTAL SCALE IN FEET: 0 150 300 600
VERTICAL SCALE IN FEET: 0 10 20 40

Job No. :	60514930
Prepared By :	MCS
Date :	7-27-17

HYDROGEOLOGIC CROSS SECTION B–B' WITH PCP CONCENTRATIONS AND NAPL OCCURRENCE

FIG. 1-28

This section presents a summary of the identification and screening of technologies. RAOs are presented along with the preliminary ARARs. General response actions to address COCs in the medium of concern, Upper Aquifer groundwater, are presented. Technologies and process options for each general response are identified and evaluated.

2.1 REMEDIAL ACTION OBJECTIVES

RAOs establish the degree to which a site requires control or remedial action to meet the objectives of protecting human health and the environment. These objectives are used to guide the identification and evaluation of remedial alternatives. In accordance with EPA guidelines (EPA 1988a), the RAOs reflect goals that specify media of concern, potential exposure routes and receptors, and acceptable contaminant levels or preliminary cleanup levels. Final cleanup levels will be determined when the remedy is selected and documented in a ROD amendment or ESD document.

As part of the FFS process, RAOs were updated for the Upper Aquifer, based on recent Site characterization information and recommendations in EPA's *2010 Five-Year Review Report* (EPA 2010). The updated RAOs were presented in the Agency-approved *Final Technical Memorandum, Remedial Action Objectives for the Upper Aquifer* (URS 2013a).

Development of the RAOs included consideration of EPA expectations codified in 40 CFR 300.430(a)(1)(iii)(F), which states:

> "EPA expects to return usable groundwaters to their beneficial uses wherever practicable, within a timeframe that is reasonable given the particular circumstances of the site. When restoration of groundwater to beneficial uses is not practicable, EPA expects to prevent further migration of the plume, prevent exposure to the contaminated groundwater, and evaluate further risk reduction."

The following RAOs were developed for the Upper Aquifer to address the Site-specific media and COCs:

- Prevent ingestion of Upper Aquifer groundwater with Site-related COCs that exceed preliminary revised groundwater cleanup levels.
- Protect human health and the environment by reducing Site-related COCs in Upper Aquifer groundwater to preliminary revised groundwater cleanup levels.

The preliminary revised groundwater cleanup levels for the Upper Aquifer are presented in Table 2-1. The Site groundwater COCs in Table 2-1 were established in the 1988 ROD and the 1997 ESD. The preliminary revised groundwater cleanup levels in Table 2-1 are federal maximum contaminant levels (MCLs) for the COCs that have MCLs; for those COCs without MCLs, Montana's Circular DEQ-7 numeric groundwater quality standards are listed. Table 2-1 was updated from URS (2013a) to reflect the current COCs and the 2017 updated DEQ-7 standards.

2.2 APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS

Three categories of potential ARARs were identified and reflect information collected during the FFS regarding current site conditions and Site-related COCs.

2.2.1 Overview of ARARs

Section 121(d) of CERCLA requires that on-site remedial actions be evaluated to determine if they meet laws, standards, requirements, regulations, criteria, or limitations under federal environmental laws that are determined to be ARARs. Requirements determined to be applicable or relevant and appropriate under state law must also be met if they are promulgated, consistently applied, and more stringent than federal requirements. If the state has primacy for a regulatory program and has adopted its own regulations that are at least as stringent as the federal regulations, then the state requirements are generally identified as ARARs and the federal requirements are not listed. The 1990 NCP requires compliance with ARARs during, and at completion of, remedial actions. Under limited circumstances, ARARs for on-site remedial actions may be waived.

ARARs are identified on a site-specific basis using a two-part analysis: 1) determination of whether a given requirement is applicable; and 2) determination of whether a requirement is relevant and appropriate if it is not applicable (EPA 1988a). Applicable requirements are cleanup standards, control standards, and other substantive environmental protection requirements, criteria, or limitations promulgated under federal or state law that specifically address a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance. Relevant and appropriate requirements are cleanup standards, control standards, and other substantive environmental protection requirements, criteria, or limitations promulgated under federal or state law that may not be applicable to a specific hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance, but address problems or situations sufficiently similar to those encountered to render them well suited for use at that particular site.

To determine whether a requirement is relevant and appropriate, characteristics of the remedial action, the hazardous substances present, and the physical characteristics of the site must be compared to those addressed in the statutory or regulatory requirement. In some cases, a requirement may be relevant, but not appropriate. In other cases, only part of a requirement will be considered relevant and appropriate. When it has been determined that a requirement is both relevant and appropriate, the requirement must be complied with to the same degree as if it were applicable (EPA 1988b).

Because the ARARs identified in the 1988 Record of Decision (ROD) have changed substantially since that time, as well as the risk-based science that form the basis for the ARARs, this document identified current ARARs for application to the remedial alternatives currently being analyzed.

Remedial actions may have to comply with the following requirements (EPA 1988b):

- *Chemical-Specific ARARs:* health- or risk-based standards that apply to a specific chemical. When applied to site-specific conditions, these result in the establishment of numerical values that determine the acceptable amount or concentration of a chemical that may be found in, or discharged to, the ambient environment. In general, chemical-specific requirements are set for a single chemical or closely-related group of chemicals. These requirements typically do not consider mixtures of chemicals that might be found at CERCLA sites. For this reason, cleanup goals set at levels of single chemical-specific requirements may not adequately protect human health or the environment at a site. When this occurs, cleanup goals are set below the chemical-specific requirements at more stringent levels and are based on information that may include human health or environmental risk assessment findings and/or health advisories.

- *Location-Specific ARARs:* restrictions placed on the concentrations of hazardous substances or the conduct of activities only because they occur in specific or sensitive locations, such as wetlands or areas of historical significance.
- *Action-Specific ARARs:* technology- or activity-based requirements of, or limitations on, actions taken with respect to the chemicals. These requirements are triggered by the specific remedial activities selected to accomplish a remedy. Action-specific requirements do not in themselves determine the remedial alternative; rather, they indicate how a selected alternative must be achieved. For example, emission standards for air strippers and incinerators, underground storage tank (UST) regulations, or land disposal restrictions.

To be considered items (TBCs) are nonpromulgated advisories, proposed rules, criteria, or guidance documents issued by the federal or state government that are not legally binding and do not have the status of potential ARARs. In many circumstances, these items are to be considered (i.e., TBC) material along with ARARs and may be used in determining the necessary level of cleanup for protection of health or the environment.

ARARs will define cleanup goals when they set an acceptable level with respect to site-specific factors. However, cleanup goals for some substances may have to be based on non-promulgated criteria and advisories rather than on ARARs because ARARs do not exist for those substances or because an ARAR alone would not be sufficiently protective in the given circumstances. To meet the cleanup goals in these situations, the cleanup requirements will not be based on ARARs alone but also on TBCs.

In accordance with EPA policy and guidance, ARARs (and TBCs necessary for protection) must be attained for contaminants remaining on-site at the completion of the remedial action, unless a waiver is justified. EPA also intends that the implementation of remedial actions should also comply with ARARs (and TBCs as appropriate).

The decision as whether to consider an item as a potential ARAR or TBC for the Libby Site was based on the assumption that the alternatives under consideration are limited to those described in Section 3. Those assumptions mean that none of the potential alternatives would involve: 1) discharge to a publicly owned treatment works; 2) release of any hazardous waste or hazardous constituents; or 3) on site disposal of any hazardous waste, or storage over 90 days on site of any hazardous waste (unless eligible for less stringent requirements available to waste generators for on-site accumulation of hazardous waste). Those requirements that were identified as preliminary ARARs and those items that are TBCs are listed in Table 2-2.

Preliminary is a qualifier that indicates that the current EPA position is that these conditions or sections are ARARs or TBCs, while a final determination by EPA has not been made.

2.2.2 Chemical-Specific ARARs

The preliminary chemical-specific ARARs are listed in Table 2-2. Preliminary federal chemical-specific ARARs include the following:

- The Safe Drinking Water Act (SDWA) regulations pertaining to MCLs of 40 CFR Part 141 are adopted by reference by the State of Montana (Administrative Rules of Montana [ARM] 17.38.203 – 17.38.207). 40 CFR Part 141 specifies MCLs for select chemicals in drinking water. Primary drinking water regulations are applicable only for drinking water at the tap. MCLs are enforceable for public drinking water systems that supply piped water to at least 15 service connections or at least 25 people. The groundwater at Libby currently does not meet the jurisdictional requirement, since the groundwater is not piped to 15 service connections or 25 people. However, MCLs are relevant and appropriate if groundwater is a current or potential source of drinking water. At the Libby Site, the MCLs (Table 2-9) and lead and copper action levels (Table 2-11) are relevant and appropriate.
- 40 CFR Part 141 specifies maximum contaminant level goals (MCLGs) for select chemicals in drinking water. Safe Drinking Water Act MCLGs are non-enforceable, health-based concentration levels that would result in no known adverse health effects given an adequate margin of safety. For probable human carcinogens, the MCLG is set at zero. For all other compounds, the MCLG is set at a level based on toxicity. Under the NCP, EPA requires that MCLGs set at levels above zero be attained by remedial actions for ground or surface waters that are current or potential sources of drinking water. If the MCLG is equal to zero, EPA determined under the NCP that the MCLG is not appropriate for setting cleanup levels. At the Libby Site, the non-zero MCLGs are relevant and appropriate. Table 2-12 lists the federal MCLGs.
- The Clean Water Act (CWA) water quality criteria address ambient surface water quality and are based on toxicity to human health and aquatic organisms. Usually, these are superseded by EPA-approved state water quality standards, but there are some federal criteria that have not been adopted or used by the state of Montana to set state standards, so it is necessary to consider the federal criteria in addition to the state standards (see below). The federal criteria for inorganics and organics are listed in Table 2-3. These criteria are relevant and appropriate for point source discharges into surface waters or for nonpoint source groundwater discharges into the Kootenai River, Libby Creek, and/or Flower Creek.

Preliminary chemical-specific Montana ARARs include the following:

- The Montana Water Act regulations (ARM 17.38.201 – 17.38.219) adopt the federal MCLs and are relevant and appropriate at the Libby Site (see Table 2-10).
- The Montana Water Quality regulations provide standards for protection of surface water and groundwater. The various standards are summarized in Tables 2-4, 2-5, 2-6, 2-7, and 2-8 and are applicable at the Libby Site. The Montana DEQ Circular DEQ-7 (DEQ-7) contains numeric water quality standards for Montana's surface and ground waters. The standards were developed in compliance with Section 75-5-301, Montana Code Annotated (MCA) of the Montana Water Quality Act, Section 80-15-201, the Montana

Agricultural Chemical Groundwater Protection Act, and Section 303(c) of the CWA. Numeric surface water quality standards that vary with each stream classification are specified in ARM 17.30.620 through 17.30.670. Narrative standards for both surface and ground waters are specified in ARM 17.30.620 through 17.30.670 and ARM 17.30.1001 through 17.30.1045. These standards are directly translated to protect beneficial uses from adverse effects, supplementing the existing numeric standards.

- The Montana Hazardous Waste regulations of ARM 17.53.101 through ARM 17.53.1502 establish a hazardous waste management program that is equivalent to the federal hazardous waste management regulations. These regulations set standards for the identification of hazardous wastes and include provisions for hazardous waste generation, treatment, storage and disposal. Because groundwater at the site has historically been managed as a listed hazardous waste under codes F032 and F034, and potentially also the characteristic hazardous waste codes D004 (arsenic), D018 (benzene), and D037 (pentachlorophenol), it is expected that regulated hazardous waste will be generated associated with the proposed action. Therefore, these standards are applicable at the Libby Site. The requirement to characterize solid wastes that are generated at the site to determine whether they are hazardous is an applicable requirement. Should regulated hazardous waste be generated as a part of remedial activities, it will be managed in accordance with the hazardous waste regulations and sent off site for treatment (if appropriate) and/or disposal. Table 2-17 summarizes land disposal restriction requirements for hazardous wastes expected to be generated at the Libby Site.
- The Montana Ambient Air Quality Standards of ARM 17.8.202 incorporating by reference 40 CFR Part 50 set forth National Ambient Air Quality Standards (NAAQS) for six priority pollutants, which are potential air quality ARARs (Table 2-15). The Montana Air Pollution Control Requirements of Lincoln County 75.1.206 and 75.1.305 control air pollution of particulate matter and dust (Table 2-15), which are identified as chemical-specific ARARs. ARM 17.8.309 contains particulate matter limits for fuel-burning equipment (Table 2-16), which are identified as chemical-specific ARARs. These standards are applicable at the Libby Site.

2.2.3 Location-Specific ARARs

The preliminary location-specific ARARs are listed in Table 2-2. Federal location-specific requirements that are preliminary ARARs include the following:

- The dredge and fill regulations under the CWA, which address discharges of dredged or fill material and work in or affecting navigable waters.
- Endangered Species Act. Threatened and endangered species are summarized in Table 2-13 and are applicable at the Libby Site. An assessment of endangered species at the site and determination of no effects is found in Appendix F.
- Fish and Wildlife Coordination Act (applicable at the Libby Site)
- Migratory Bird Treaty Act (applicable at the Libby Site)
- Bald Eagle Protection Act (applicable at the Libby Site)

- National Historic Preservation Act (NHPA), applicable at the Libby Site
- Archaeological and Historic Preservation Act (relevant and appropriate at the Libby Site)
- Executive Order 11988—Protection of Floodplains (applicable at the Libby Site)
- Executive Order 11990—Protection of Wetlands (applicable at the Libby Site)

The preliminary state location-specific ARARs include the following:

- The water quality regulations of ARM 17.30.101-109 (water quality standards, discharge permit requirements, maintenance of existing groundwater quality), relevant and appropriate at the Libby Site)
- Montana Antiquities Act (applicable at the Libby Site)
- Montana Nongame and Endangered Species Conservation Act (MCA 87-5-106), applicable at the Libby Site
- Montana Noxious Weed Control Law (MCA 7-22-2101, 2109, 2116, and 2152), applicable at the Libby Site

2.2.4 Action-Specific ARARs

Preliminary federal action-specific ARARs are listed in Table 2-2. Federal action-specific ARARs include the following:

- The NAAQS affect the existence of specific requirements for emission control for air pollutant sources and, therefore, potentially affect requirements that apply to remediation options. These standards are relevant to remediation options.
- Requirements for stationary sources of hazardous air pollutants apply to air emission sources that produce hazardous air pollutants (HAPs) in excess of applicable thresholds. These standards are applicable to remediation options.
- Standards of performance for small industrial-commercial-institutional steam generating units apply to steam generating units used for remediation with heat input capacities between 2.9 and 29 megawatts and may be relevant to units less than 2.9 megawatts. These standards are applicable to remediation options.
- Requirements for petroleum and oil storage in aboveground tanks and containers, which apply to cumulative aboveground storage equal to or greater than 1,320 gallons that have potential to release oil to navigable waters of the United States (40 CFR 112). These standards are applicable to remediation options.
- Substantive criteria associated with National Pollutant Discharge Elimination System (NPDES) permit requirements apply to proposed actions resulting in discharges to surface waters. These standards are applicable to remediation options.
- Compliance with substantive Underground Injection Control (UIC) permit requirements applies to the remediation if the proposed action involves installation and operation of a Class I, III, IV, or V UIC well. Injection of nonhazardous fluid into or above

underground sources of drinking water is subject to federal Class V UIC substantive requirements. These standards are applicable to remediation options.

- Requirements for hazardous waste generators, including waste characterization, on-site storage, and treatment before land disposal apply if the proposed action involves the generation, treatment, storage, and/or disposal of hazardous waste. Table 2-17 describes the specific land disposal restriction requirements for hazardous wastes that may be generated at the Libby Site. These standards are applicable to remediation options.

Preliminary Montana action-specific ARARs which are identified as applicable to remediation options, include the following:

- Substantive provisions of the regulations governing well drilling, repair, and plugging located at MCA 43-7-302, 85-2-516, and ARM 36.21 Subchapter 6 apply to new groundwater wells and/or the plugging of wells and boreholes.
- Substantive provisions governing permitting requirements for disposal of industrial waste into state waters, including groundwater, located at MCA 75-5-401 apply to-proposed actions involving the operation of a UIC well in which disposal of nonhazardous fluids occurs.
- Substantive provisions requiring a permit to discharge pollutants to state groundwaters in MCA 17.30.1023 apply to the proposed action that involves discharge to groundwater through a UIC well.
- Substantive provisions requiring a permit to discharge water associated with stormwater discharges in MCA 17.30.1105 apply to proposed actions involving ground disturbance of one or more acres or stormwater discharge associated with industrial activity.
- Montana Water Use Act requirements prohibiting waste and contamination of groundwater of MWUA 85-2-505 apply to the proposed actions involving the installation and/or operation of flowing and nonflowing wells.
- Montana Nondegradation Policy and Rules (75-5-303 MCA and ARM 17.30.701 through 717) apply to remedial actions that affect existing-uses of state waters and the level of water quality necessary to protect those uses must be maintained and protected.
- Montana Air Quality regulations. The laws and regulations at 75-2-102 MCA, ARM 17.8.1 through 17.8.230, ARM 17.8.301 through 17.8.342, ARM 17.8.604, ARM 17.8.610 through 17.8.612, ARM 17.8.802, and ARM 17.8.805 contain permitting requirements and restrictions on ambient air quality standards and monitoring, air emission standards, open burning, smoke, prevention of significant deterioration requirements, and other visible emissions. Substantive requirements associated with air pollutant sources that may be used during remediation apply to these sources.
- Montana Hazardous Waste regulations. These regulations provide standards for hazardous waste generators, transporters, and owners or operators of hazardous waste treatment, storage, and disposal facilities that also apply to short-term storage of hazardous waste. These will apply to regulated hazardous waste that is generated as a result of the proposed actions and treated, disposed of or stored.

- Montana Solid Waste Management Act and subsequent regulations. These requirements prohibit the dumping of solid waste, except as permitted, and provide standards that apply to the disposal of portable toilet waste.

2.2.5 TBCs

Preliminary TBC items are listed in Table 2-2. These include the following (see Table 2-2 for a complete list):

- The National Secondary Drinking Water regulations (NSDWRs or secondary standards) of 40 CFR Part 143 contain non-enforceable guidelines for drinking water for public drinking water systems. The secondary maximum contaminant levels (SMCLs) are drinking water standards developed to protect the aesthetic quality of drinking water. If groundwater is a current or potential source of drinking water, then SMCLs are TBCs. The State of Montana has adopted by reference 40 CFR Part 143 (20.7.10.101 NMAC), so SMCLs are TBCs for the Libby Site. SMCL values are listed in Table 2-2.
- Montana Nongame and Endangered Species Sage Grouse Habitat Conservation Program [Executive Order (EO) Nos. 10-2014 and 10-2015]
- Lincoln County, Montana Integrated Noxious Weed Management Plan

2.3 GENERAL RESPONSE ACTIONS

General response actions are broad classes of actions that may be implemented alone or in combination to satisfy the RAOs. For each general response action, technology types and process options are identified to address the medium and COC. General response actions may include treatment, containment, removal, institutional controls, or a combination of these.

Response actions identified for this Site include:

- No Action
- Access Restrictions
- Physical Containment
- Removal
- In situ Treatment

The general response actions and potentially applicable technologies for each response action are summarized on Table 2-18.

2.4 IDENTIFICATION AND SCREENING OF TECHNOLOGY TYPES AND PROCESS OPTIONS

This section presents the approach and results of the remedial technology screening. The technologies retained from the screening are assembled into a range of alternatives described in Section 3 and evaluated in Section 4 to assist in identifying a recommended alternative. RAOs and preliminary ARARs are presented prior to identifying general response actions and technologies.

2.4.1 Identification and Screening of Technologies

Identification of technologies and process options focused on a range of technologies applicable to wood-treating sites with an emphasis on treatment technologies that address NAPL and that are typically used for remediation of PCP and naphthalene in groundwater.

Technology types and process options were identified as being applicable to the Site to address the site COCs for each of the response actions. Multiple removal and in situ treatment technology types and process options were identified as being applicable to the Site and these were further evaluated. These technologies and process options were evaluated with respect to effectiveness, implementability, and cost.

The effectiveness evaluation focuses on the (1) ability to handle the anticipated volume of contamination and the size of the treatment area, as well as meeting the RAOs and cleanup levels, (2) potential impacts the process may have on human health and the environment, and (3) reliability of the process with respect to the constituents being addressed at the Site.

Implementability encompasses both the technical and administrative feasibility of implementing the technology. The evaluation of implementability commonly includes the ability to obtain necessary permits, availability of treatment/storage/disposal services, and procurement of necessary equipment and/or skilled workers to implement the technology.

Costs prepared during this portion of the evaluation play a limited role in the screening of process options. Relative costs (capital and operation and maintenance [O&M]) are used for screening. Costs for each process option are identified as high, medium, or low, relative to other options for a particular technology cost, and are based on engineering judgment.

The initial screening process was completed within professional guidelines to represent options generally considered applicable and technically feasible for use at the Site. Representative technology types and process options were selected to be carried forward for the development of alternatives. The screening evaluation is summarized in Table 2-18.

The range of technology types and process options was developed using several sources including: technologies previously or currently used at the Site, Site-specific documents that evaluated remedial technologies (Premier 2009b, CH2M Hill 2009), technologies used at sites with similar contaminants and media, and EPA resource documents. Process options identified as technically not implementable or not applicable to the Site are not listed in Table 2-18.

A summary of the response actions and the respective technologies and process options is provided below.

2.4.1.1 No Further Action

In accordance with the NCP, a No Action or in some cases a No Further Action (NFA) general response action is retained for consideration to provide a baseline against which other technologies can be compared. NFA indicates that no further actions or responses would be implemented at the Site; interim or current remedial actions would be stopped; and the sources would remain in place with no plans for future control or removal. In some instances, NFA includes limited monitoring (e.g., groundwater, vapor) of select areas.

This option was retained for use in the development of alternatives.

2.4.1.2 Institutional Controls

Institutional controls (ICs) include administrative or legal controls that limit land or resource use. Institutional controls are currently in place for the Site and include well drilling restrictions and deed restrictions, as described below.

A City ordinance that prohibits drilling water wells for the purpose of human consumption or irrigation has been in place since 1986. The City limit boundary is shown on Figure 1-1. Residents use City public water for human consumption and irrigation, and IP subsidizes a portion of the City water supply cost. City water can also be made available for businesses on the former mill property, which is outside the City limits, as redevelopment occurs in the future. Since 1986, the majority of domestic wells in the City have been taken out of service (by cap and lock or plugged and abandoned) in exchange for monetary compensation as part of a Buy Water Plan. Both the City ordinance and Buy Water Plan were part of the remedy in the 1986 ROD (EPA 1986).

The 1993 deed conveying the former mill property contained institutional control provisions that are intended to run with the land and bind future property owners to specific obligations. First, the deed informs future owners that the property is subject to the 1989 Consent Decree and that portions of the property (former source areas) were used for the disposal of hazardous substances. Second, the 1993 deed reserved a blanket easement providing access to the former mill property to perform work related to the Consent Decree and prohibiting future property owners from interfering with measures undertaken pursuant to the Consent Decree. Third, the deed requires that due care be exercised to not exacerbate any release from the property of a hazardous substance. Finally, a portion of the property is subject to specific restrictions prohibiting soil excavation or subsurface disturbance in former source areas unless approved in advance by EPA.

IP is currently working with the Agencies to consolidate and augment institutional controls to further reduce potential exposure to impacted groundwater. As part of this effort, a Controlled Groundwater Area (CGA) is being evaluated to restrict groundwater use where Site-related groundwater impacts to either the Upper Aquifer or Lower Aquifer have occurred, including certain areas outside the City limits that are not subject to the specific prohibitions of the well drilling restriction ordinance or the proprietary institutional controls established in the 1993 deed conveying the former mill property. Also, areas surrounding the Site-related contaminant plumes are being evaluated for inclusion in the CGA to minimize contaminant plume movement due to pumping.

Institutional controls have been effective in limiting exposure to groundwater COCs and are readily continued at the site.

This option was retained for use in the development of alternatives. It appears as a component of every alternative considered to eliminate exposure pathways and minimize contaminant plume exacerbation during the remediation timeframe of each alternative.

2.4.1.3 Hydraulic Containment

Hydraulic containment by means of groundwater extraction is a process option used as a containment technology to prevent further movement of a contaminant plume. Groundwater would be intercepted, pumped to the surface, and treated in an aboveground groundwater treatment system. The treated groundwater would be discharged to either surface water, land application/infiltration, or re-injected. An infiltration gallery currently exists on Site for the existing SAETS effluent. Potential aboveground treatment systems include:

- Bioreactors – Contaminants in extracted groundwater are contacted with microorganisms in biological reactors. The system circulates contaminated groundwater in an aeration basin. Contaminants are degraded via aerobic processes prior to discharge. An above ground bioreactor system currently treats extracted groundwater; therefore, biological treatment is a proven technology to address Site contaminants.
- Granular Activated Carbon (GAC) – Groundwater is pumped through a series of vessels or columns containing activated carbon. Dissolved organic contaminants in the groundwater are removed through adsorption. Periodic replacement or regeneration of saturated carbon is required. GAC treatment is a proven technology to address Site contaminants.

Groundwater extraction would primarily remove NAPL through dissolution, extracting the more soluble components first. Groundwater extraction is effective for capturing the dissolved plume and preventing further migration and can be readily implemented at the site. Extraction/treatment has a relatively low capital cost, but would require a long operational time period to reduce the NAPL composition of COCs to levels where monitored natural attenuation (MNA) would be sufficient to meet cleanup levels.

This option was retained for use in the development of alternatives.

2.4.1.4 Physical Removal

2.4.1.4.1 Skimming

Skimming is a physical method of hydraulic recovery of an LNAPL from the top of the groundwater column within a well using pumping or skimming equipment. LNAPL mass recovery using pumping or skimming is limited to reducing LNAPL saturation to residual saturation. At residual saturation, LNAPL will not flow and therefore hydraulic recovery is no longer possible.

Recovery technologies such as skimming are proven and cost effective technologies for LNAPL remediation and are easily implemented. However, Site data indicate that LNAPL mass is present mostly at residual saturation.

This option was not retained for use in the development of alternatives.

2.4.1.4.2 Large-Diameter Excavation

Excavation involves the use of industrial construction techniques using large-diameter augers to remove contaminated soil from the Site. The contaminated soil would be excavated and transported off Site to an approved hazardous waste incineration facility for treatment and disposal. The large boreholes would be subsequently backfilled with clean soil or slurry.

Excavation using large-diameter augers may be feasible but difficult based on the lithology of the Site given the target depths (e.g., up to 70 feet bgs) and large treatment area (e.g., over 2 acres). Cobbles and boulders may prove problematic for the augers and each boring would probably have to be cased during installation. Water production in the boring may also be problematic at depths, washing the soil from the augers back into the boring. Costs associated with the technology are high.

This option was not retained for use in the development of alternatives.

2.4.1.5 Enhanced Physical Removal

2.4.1.5.1 Steam Enhanced Extraction

Steam enhanced extraction (SEE) is a thermal technology in which steam is injected into an aquifer through injection wells to increase subsurface temperature. The process results in reducing the NAPL viscosity, specific gravity, and NAPL-water interfacial tension; and increasing the vapor pressure of the contaminants to enhance both liquid and vapor recovery. Soil vapor extraction (SVE) and multi-phase extraction (MPE) systems are generally operated with SEE systems. Extracted liquids are treated using conventional above ground treatment technologies such as air stripping and carbon adsorption. Extracted vapors are treated using conventional technologies such as condensation, carbon adsorption, and thermal oxidation. The steam temperatures decrease NAPL viscosity, specific gravity, and NAPL-water interfacial tension, which increase NAPL recoverability. Along with an increased pressure gradient, steam flushing enhances bulk recovery of NAPL present at saturations greater than residual saturation from the formation leaving the remaining treated soil with lower residual saturations of NAPL. In addition, SEE can decrease the mass fraction of the more volatile components in the remaining, residual NAPL by increasing vapor pressure and solubility.

The typical equipment required for SEE includes a boiler for steam generation and water softener to reduce the mineral content of the boiler feed water. A typical vapor extraction and treatment system consists of a knock-out tank, particulate filter, blower, condenser, and a vapor treatment system such as a thermal oxidizer or vapor phase GAC. The typical liquid treatment system consists of an equalization tank, liquid phase heat exchanger, oil-water separator, filter, and water treatment system such as GAC. A vapor cover over the treatment area is typically used to provide thermal insulation, prevent contaminants from condensing, prevent water infiltration, and provide a vapor seal for increasing vapor extraction. Hydraulic control by pumping using extraction wells or a subsurface barrier may be necessary for effective application.

SEE is an effective technology for treatment of NAPL and VOCs in source areas with extensive mobile and recoverable NAPL. In addition, SEE is effective for NAPL even at residual saturations that are primarily composed of compounds that can be volatilized at steam temperature. However, SEE is less efficient for sites with NAPL mostly at residual saturations and composed of semi- and nonvolatile compounds, as similar energy is required to achieve the same residual saturation endpoint irrespective of the initial saturations. Therefore, SEE provides less benefit for the cost at sites where the initial NAPL saturations are near residual saturations and the decrease is limited, specifically for semi- and nonvolatile NAPL like at the Libby Groundwater Site. A large complex steam generation and multiple above ground treatment systems, along with substantial subsurface infrastructure, would be needed to implement this technology. Costs associated with this technology would be high.

This option was retained for use in the development of alternatives.

2.4.1.5.2 Electrical Resistance Heating

Electrical resistance heating (ERH) is a thermal technology in which current is passed through the soil between two conductors to heat the subsurface. Heating of the soil increases the vapor pressure and vapors are typically removed via vapor extraction. ERH is often combined with extraction technologies such as SVE to capture and treat vapors that migrate into the vadose zone. Due to the limiting heat migration factors, the electrode wells would need to be spaced very closely to improve heating efficacy. As with any thermal treatment, the extraction design would need to account for capture of vapors that could potentially condense in the vadose zone to avoid treatment residuals and/or contaminant migration.

Electrical current only travels through moist or wet soil; therefore, the endpoint temperature reached will be limited to the boiling point of water that corresponds with the system pressure. For ERH to be effective, the influx of cold groundwater would need to be cut off from the NAPL impacted areas to reduce the heat load. A cutoff wall would have to be placed around the treatment area to the depth treated. A dewatering system would also be required to control the vertical upflow of cold groundwater from the Lower Aquifer. Installation of a deep cutoff wall and dewatering system may be feasible but technically challenging due to the depth and the cobbles and boulders in the subsurface material. A specialty contractor may be required for implementation. Costs associated with this technology would be high.

This option was not retained for use in the development of alternatives.

2.4.1.5.3 Thermal Conduction Heating

Thermal conduction heating (TCH) is a thermal technology in which heaters, operating at temperatures at and above 1000 to 1500ºF, are installed in wells to conduct heat to the subsurface. The extreme temperature boils groundwater and vaporizes NAPL. TCH is often combined with extraction technologies such as SVE to capture and treat vapors that migrate into the vadose zone. Due to the limiting heat migration factors, subsurface heaters are required in a minimal well spacing pattern to improve heating efficacy. As with any thermal treatment, the extraction design would need to account for capture of vapors that could potentially condense in the vadose zone to avoid treatment residuals and/or contaminant migration.

For TCH to be effective, the influx of cold groundwater would need to be cut off from the NAPL impacted areas to reduce the heat load. A cutoff wall would have to be placed around the treatment area to the treated depth. A dewatering system would also be required to control the vertical upflow of cold groundwater from the Lower Aquifer. Installation of a deep cutoff wall and dewatering system may be feasible but technically challenging. A specialty contractor may be required for implementation. Costs associated with this technology would be high.

This option was not retained for use in the development of alternatives.

2.4.1.6 In Situ Chemical Treatment

2.4.1.6.1 Surfactant Enhanced In Situ Chemical Oxidation (S-ISCO)

In situ chemical oxidation (ISCO) is a chemical treatment technology where an aqueous oxidizing agent is delivered to the subsurface to promote abiotic in situ oxidation. The oxidant is generally delivered via numerous injection points. Uniform distribution of the oxidant is dependent on formation uniformity. Oxidant distribution in heterogeneous formations typically results in uneven distribution of the oxidant, leaving portions of the formation untreated. Typical oxidizing agents include aqueous permanganate, persulfate, percarbonate, or ozone gas, along with Fenton's reagent (hydrogen peroxide and ferrous iron).

Surfactant enhanced in situ chemical oxidation (S-ISCO) adds a surfactant to ISCO. As chemical oxidation occurs in the aqueous phase, using a surfactant would increase the availability of contamination to be oxidized by enhancing the solubilization and desorption of the target contaminants. Surfactants are added through the same injection points as the oxidizing chemicals and are typically injected prior to the injection of the oxidizing chemical. Biodegradable surfactants are generally used. The addition of a surfactant does not decrease the amount of oxidizing chemical required. One potential concern with the injection of a surfactant is that it may also increase mobility of the NAPL and dissolved phase plume.

A large number of closely spaced injection wells would be required to achieve an effective distribution of the oxidizing agent and surfactant. An alternative approach would be surfactant injection with groundwater recirculation using a series of injection and extraction wells. Large or multiple doses are required when the oxidant demand is high, such as in the presence of NAPL.

Many in situ chemical oxidants leave a residual electron acceptor after breakdown. Ozone and Fenton's reagent leave residual dissolved oxygen, which may enhance aerobic biodegradation. Persulfate will leave sulfate, which may enhance anaerobic biodegradation. The creation of electron acceptors is a minor benefit of S-ISCO, since oxygen is more efficiently added through the injection of air or oxygen and sulfate is more easily added through the direct application of sulfate.

The effectiveness and implementability of S-ISCO for treatment of NAPL is considered low. S-ISCO is an emerging technology and effectiveness for treatment of NAPL is not well known. The implementability of S-ISCO is considered low. To achieve adequate coverage, chemical oxidation and surfactant injection wells would be required on about a 10-foot spacing, with short well screens. In addition, tens of millions of pounds of oxidant would be required to treat the entire plume.

This option was not retained for use in the development of alternatives.

2.4.1.6.2 In Situ Soil Stabilization (ISSS)

In situ soil stabilization or solidification is a technology where a chemical or other agent is added to physically bind or enclose contaminants within a stabilized mass. Stabilization involves chemical reactions that are induced between the stabilizing agent and contaminants to reduce contaminant mobility. Implementation involves the use of large diameter augers to mix stabilizing agents or install physical barriers. For proper implementation, the augers would need to reach to the base of the Upper Aquifer (approximately 70 feet bgs) to provide proper solidification or stabilization.

ISSS technology may be effective in containing or stabilizing the contaminants; however, implementability may be difficult or impractical due to encountering the cobbles and boulders during drilling to depths of 75 feet bgs. Costs may be high due to type of reagents required and implementation difficulties.

This option was not retained for use in the development of alternatives.

2.4.1.6.3 In Situ Geochemical Stabilization (ISGS)

In situ Geochemical Stabilization (ISGS) is a technology that consists of injecting modified permanganate solution into NAPL-impacted zones to achieve containment/stabilization, mass removal, and flux reduction (i.e., NAPL stabilization). As the oxidant migrates through the treatment area, various (bio)geochemical reactions destroy the targeted compounds present in the dissolved phase. Silica-based precipitates are deposited around NAPL ganglia and droplets following reagent injection, which leaves a mineral shell that reduces overall permeability in the treated area, thereby reducing the volumetric flux of upgradient groundwater into and through the impacted area. The oxidation of dissolved phase constituents also “hardens” or “chemical weathers” the NAPL as it steadily loses its more labile components. This causes a net increase in viscosity of the organic material, which yields a more stable, recalcitrant residual mass. In addition, both the insoluble MnO_2 precipitate that results from permanganate oxidation and other mineral species included in the ISGS formulation accumulate along the NAPL interface, physically coating the NAPL and thereby reducing the flux of dissolved-phase constituents into the groundwater.

ISGS is an effective stabilization technology forming a mineral crust around NAPL and can be cost effective. Limited equipment contained in transportable trailers facilitates an easy mobilization. However, implementation of ISGS requires specialized equipment and specific formulation protocols to generate the ISGS solution in the field by an exclusive licensee of the technology. ISGS has been implemented at sites with creosote, coal tars, and petroleum compounds.

This option was retained for use in the development of alternatives.

2.4.1.7 In Situ Biological Treatment

In situ biological treatment includes multiple processes that occur by natural physical, chemical, and biological processes, natural reduction, natural biological degradation or enhanced biological degradation.

In situ bioremediation is a process in which indigenous or inoculated microorganisms (i.e., fungi, bacteria, and other microbes) degrade (oxidize or use as an electron acceptor) organic contaminants found in soil and/or groundwater. Enhanced bioremediation is a process that attempts to accelerate the natural biodegradation process by providing nutrients, electron acceptors, and competent degrading microorganisms, the lack of which may otherwise be limiting the rapid conversion of organics to innocuous end products. Bioremediation can be implemented as aerobic or anaerobic depending on the Site conditions.

In situ biological treatment technologies evaluated for application at the Site are described below and include:

- Monitored natural attenuation/natural source zone depletion
- Anaerobic bio-oxidation
- Aerobic bio-oxidation

2.4.1.7.1 Monitored Natural Attenuation/Natural Source Zone Depletion

Monitored Natural Attenuation

MNA relies on natural processes to clean up or attenuate contaminants in groundwater. Natural attenuation occurs at most impacted sites. Monitoring and/or testing are performed at regular intervals to assess the effectiveness of natural attenuation.

Natural subsurface processes such as dilution, volatilization, biodegradation, adsorption, dissolution, and chemical reactions with subsurface materials are allowed to reduce contaminant concentrations to acceptable levels. Long-term monitoring must be conducted throughout the process to confirm that degradation is proceeding at rates consistent with meeting cleanup objectives. The primary natural attenuation processes at the Site are biodegradation, adsorption and dilution.

Biodegradation

Biodegradation describes the biological processes that act to degrade the hydrocarbons in the groundwater beneath the Site. Bacteria, like all organisms, require both nutrients and energy for survival. Energy is produced as a by-product of catabolism, where larger molecules are broken into smaller ones, resulting in a release of electrons. These electrons are passed from one carrier molecule to another in what is called the electron transport chain with the final molecule at the end of this chain called the terminal electron acceptor (TEA). There are different pathways by which PCP can biodegrade depending on the microbial community present and aquifer conditions (e.g., aerobic versus anaerobic) (Lopez et. al. 2016).

In aerobic organisms (or aerobes), oxygen is the TEA. In anaerobic organisms (or anaerobes), the TEA can be a wide variety of molecules other than oxygen such as nitrate (NO_3^-), ferric iron (Fe^{3+}), sulfate (SO_4^{2-}), or carbon dioxide (CO_2). In both processes, electron addition will transform the oxidized TEA substrate into its reduced form. Bacterial populations will always exploit the most energy-yielding pathways available. Therefore, if oxygen is present in sufficient concentrations, aerobic metabolism will dominate a system. However, if oxygen molecules become limited, NO_3^- reducing populations will take over because NO_3^- is the next-highest energy yielding TEA. This transition from one population to the next as TEAs are consumed (and it is assumed, not replenished) will continue until a microbial community is established that is in biogeochemical equilibrium with the environment. Under anaerobic conditions, PCP can be degraded as the TEA during the oxidation of other hydrocarbons (electron donors) through the reductive dechlorination process.

Biological activity can be monitored across a site either by watching for the depletion of TEAs and the accumulation of by-products over time in one well or by the changing geochemistry across a plume as TEAs are depleted. Often different portions of a contaminant plume are in different stages of degradation as the microbes adapt and deplete the more energy producing TEAs. Groundwater samples collected from monitoring wells provide snapshots of the area near each well at one point in time.

The majority of the natural attenuation parameters measured at the Site indicate that the groundwater within the impacted areas is anaerobic evidenced by low DO and oxidation reduction potential. Water flowing into the plume, especially from the fire pond, is assumed to contain dissolved oxygen, which is utilized by native microbes in degrading hydrocarbons in the shallow Upper Aquifer. Groundwater was found to contain very low levels of NO_3^- and SO_4^{2-}, limiting anaerobic degradation. Dissolved methane in several of the wells indicates some level of methanogenesis occurring at the Site (Premier 2009a).

Adsorption and Dissolution

Adsorption and dissolution are believed to play minor roles in the attenuation of the COCs in the groundwater. As groundwater flows through the impacted soil, it dissolves constituents of the source material and carries these compounds downgradient. As the compounds migrate they adsorb to organic matter within the soil, retarding their migration. In addition, the groundwater mixes with non-impacted groundwater, diluting the concentrations.

The low concentration of organic matter within the soil provides limited retardation of the dissolved phase compounds by adsorption (Section 1.2.7.3).

MNA is effective for reducing COC concentrations, but over a long period of time. MNA is easy to implement for a low cost associated with monitoring.

This option was retained for use in the development of alternatives.

<u>Natural Source Zone Depletion</u>

As described in the Interstate Technical and Regulatory Council (ITRC) technical guidance document (ITRC 2009a), natural source zone depletion (NSZD) is the combination of natural processes that decrease the mass of NAPL in the subsurface over time. The mechanisms responsible for NAPL depletion include volatilization, dissolution, and biodegradation. The significance of these mechanisms is related to the NAPL properties (e.g., the volatility and solubility of NAPL constituents) and the site setting. The site setting considerations are related to the movement of soil gas and groundwater within the source zone, geochemistry, and microbial ecology.

Biodegradation of NAPL constituents can occur through a number of microbially-facilitated reactions, depending on the availability of TEAs such as oxygen, nitrate, manganese and iron oxides, and sulfate. Within NAPL source zones, where electron acceptor demand and hydrocarbon concentrations are high, the above TEAs are depleted and methanogenesis may become the dominant degradation pathway. During each of these biodegradation reactions, carbon present in hydrocarbon NAPLs is converted to carbon dioxide and methane. Due to their limited solubility, carbon dioxide and methane partition into the gas phase and migrate upward into the vadose zone.

In the vadose zone, NAPL constituents may volatilize and redistribute into soil gas along with the methane and carbon dioxide generated through biodegradation. As these gases migrate upward through the soil column through diffusive or advective transport processes and come into contact with higher concentrations of atmospheric oxygen, methane and volatilized NAPL, constituents are aerobically degraded, and carbon transfer is dominated by the flux of carbon dioxide from the subsurface to atmosphere (Sihota et al. 2011; McCoy et al. 2014).

In addition to altering the composition of soil gas (e.g., oxygen utilization and/or carbon dioxide production), the biodegradation reactions responsible for NAPL depletion also release heat to surrounding soil and groundwater. The excess heat from biodegradation creates zones of increased temperature relative to the background soil temperature profile. These temperature anomalies (zones of warmer temperature) can be determined through subsurface temperature profiling within existing wells, or from dedicated sensors buried in soil (Sweeney and Ririe 2014; Warren and Bekins 2015).

NSZD is effective for reducing NAPL mass over a long period of time. It is easy to implement for a low cost associated with monitoring.

This option was retained for use in the development of alternatives.

2.4.1.7.2 Anaerobic Bio-oxidation

Enhanced Anaerobic Bioremediation with the Addition of Sulfate

Many organic compounds have been shown to degrade rapidly under aerobic conditions. Success of aerobic biodegradation is often limited by the inability to provide sufficient oxygen to the contaminated zones as a result of the low water solubility of oxygen and the rapid oxygen depletion due to the presence of organic compounds. In anaerobic conditions, sulfate can be an alternate electron acceptor used to enhance bioremediation. Sulfate is significantly more soluble in water than oxygen, and has a much higher biodegradation capacity than oxygen. Sulfate can be added to the surface and allowed to infiltrate to the subsurface or delivered to the subsurface as an injected solution, increasing the sulfate concentrations in the groundwater. Since the availability of sulfate is limited at most contaminated sites, the addition of sulfate to an aquifer would result in enhanced anaerobic biodegradation of dissolved hydrocarbons such as naphthalene from the NAPL. However, anaerobic degradation may be slow and multiple applications of sulfate may be required.

Biodegradation of PCP under anaerobic conditions occurs through reductive dechlorination where PCP provides chlorine as the TEA during the anaerobic biooxidation of other hydrocarbons. Biodegradation of PCP by reductive dechlorination could be enhanced by addition of an electron donor. However, other dissolved hydrocarbons at the Site are likely supporting PCP biodegradation; and, the addition of an electron donor may not increase PCP anaerobic biodegradation rates. The addition of sulfate to enhance biooxidation of other hydrocarbons could compete with the use of PCP as an electron acceptor and limit PCP reductive dechlorination. The effectiveness of this technology is considered low due to the lack of documented field applications, although it would be an easy technology to implement and costs would be low.

This option was not retained for use in the development of alternatives.

2.4.1.7.3 Aerobic Bio-oxidation

For aerobic bioremediation to be effective, sufficient oxygen must come into contact with the microbes and contaminants to allow degradation. Approximately 3.5 pounds of oxygen are required to degrade one pound of hydrocarbon. The NAPL contains PAH molecules of all sizes. PAHs with more than four rings are not very biodegradable; however, these higher molecular weight PAHs are also not very soluble and have limited impact to the groundwater.

Lower molecular weight compounds, including COCs that are above the cleanup levels (specifically PCP and naphthalene), are more soluble and impact the groundwater to a much greater degree. These compounds are also aerobically biodegradable, making aerobic bioremediation technically feasible. PCP can be degraded under both aerobic and anaerobic conditions, though the pathways differ and aerobic process occur more quickly (Lopez et. al. 2016).

Enhanced Bioremediation with Oxygen Addition

Enhancement of bioremediation using oxygen involves the addition of oxygen as the electron acceptor to enhance biodegradation and conversion of organic contaminants to CO_2 and water. Several options for adding oxygen include:

- Oxygen Release Compounds – Oxygen release compounds are typically solids with low water solubility. When hydrated, these compounds release their full amount of oxygen over a period of time (typically 1 year). This process enables aerobic microorganisms to accelerate degradation rates over the oxygen release period.
- Oxygen Injection – The addition of oxygen (or air) to groundwater increases the oxygen concentration and enhances the rate of biological degradation of organic contaminants by naturally-occurring microorganisms. This injection process also increases mixing in the saturated zone, which increases the mass transfer.

Both oxygen sources are readily available; however, addition at a site with elevated NAPL concentrations may require an impractical quantity of oxidizing reagent to achieve a complete reaction. In addition, an extensive delivery system would be required to supply the large quantity of oxygen to the area of concern. Costs for the chemical and delivery system would be high.

Based on the quantity of NAPL present within the aquifer and the estimated amount of oxygen that would be required to degrade the NAPL, oxygen addition was not retained in favor of a more cost-effective and readily implementable mechanism to add oxygen via compressed atmospheric air. Pure oxygen would require routine deliveries and introduces health and safety concerns because at high pressure (i.e. in an oxygen cylinder), it is highly reactive with other common organics. Therefore, oxygen addition was not retained as an option for developing alternatives.

Enhanced Bioremediation with Air Addition (Biosparging)

Biosparging is the injection of oxygen (in this case, in the form of ambient air) into the groundwater to stimulate biodegradation of the COCs by aerobic microorganisms, which consume oxygen to degrade the COCs. Injected air flows horizontally and vertically in channels through the soil column, increasing the dissolved oxygen content in the groundwater. The injected air partitions oxygen into the groundwater to (1) enhance aerobic biodegradation within the ROI of the injection points and (2) induce an oxygen-rich groundwater “front” that moves downgradient with groundwater flow. The injected air also aids in stripping dissolved-phase volatile contaminants from the groundwater into the vapor phase and transports the contaminants up into the vadose zone where they are often removed by a complementary technology such as SVE. For this Site, the use of a complementary technology (such as SVE) may not be required due to the low concentration of VOCs in NAPL.

As biological activity primarily occurs in the dissolved phase, the more soluble compounds continually dissolve from the residual NAPL, resulting in a compositional change or weathering of the NAPL. Eventually, NAPL weathering can result in the significant reduction of the soluble and biodegradable compounds in the NAPL and achieve cleanup levels in groundwater. The rate at which the oxygen-enriched groundwater front moves is dependent on groundwater flow velocity, the rate at which oxygen can be provided, and the oxygen utilization rate. In groundwater with high oxygen demand, the oxygen transport through the dissolved phase may be very limited. The effectiveness of biosparging relies on the permeability of the soil to disperse the air into the target treatment zone and on the biodegradation rates of the target compounds. In general, biosparging is more effective in permeable soils and for compounds that readily degrade under aerobic conditions.

A high natural oxidant demand could increase the amount of oxygen required to degrade the COCs. Based on sampling and analysis to assess natural attenuation (Premier 2009a) and natural source zone depletion (NSZD) (AECOM 2018), the Upper Aquifer is anaerobic with limited dissolved oxygen inside the contaminant plume, especially where NAPL is present. Outside the NAPL and dissolved COC area, the presence of dissolved oxygen and other oxidized electron acceptors (sulfate) indicates that the natural background oxidant demand of the Upper Aquifer is low. Biosparging with air involves a simple, effective, and less costly method of providing the electron acceptor to enhance aerobic biodegradation.

This option was retained for use in the development of alternatives.

2.4.2 Summary of Retained Technologies

Individual technologies and associated process options were evaluated with respect to effectiveness, implementability, and relative cost. The technology/process option screening results are summarized in Table 2-18. A representative process option within each general response action was retained for use in developing alternatives. The retained technology process options are summarized in Table 2-19.

Table 2-1. Preliminary Revised Groundwater Cleanup Levels for the Upper Aquifer

Contaminants of Concern[a]	Preliminary Revised Groundwater Cleanup Level for the Upper Aquifer[b]	Units	Basis[c]
PAHs			
Acenaphthene	70	µg/L	DEQ-7
Anthracene	2100	µg/L	DEQ-7
Fluoranthene	20	µg/L	DEQ-7
Fluorene	50	µg/L	DEQ-7
Naphthalene	100	µg/L	DEQ-7
Pyrene	20	µg/L	DEQ-7
Benzo (a) anthracene	0.5	µg/L	DEQ-7
Benzo (a) pyrene	0.2	µg/L	MCL
Benzo (b) fluoranthene	0.5	µg/L	DEQ-7
Benzo (k) fluoranthene	5	µg/L	DEQ-7
Chrysene	50	µg/L	DEQ-7
Dibenzo (a,h) anthracene	0.05	µg/L	DEQ-7
Indeno (1,2,3-c,d) pyrene	0.5	µg/L	DEQ-7
Other Compounds			
Pentachlorophenol	1	µg/L	MCL
Benzene	5	µg/L	MCL
Arsenic	10	µg/L	MCL
2,3,7,8-TCDD	30	pg/L	MCL

Notes:

[a] Groundwater COCs were established in the 1988 ROD and 1997 ESD.

[b] The preliminary revised groundwater cleanup levels are updated from the Final RAO Technical Memorandum (URS 2013a) to reflect updated ARARs for current COCs.

[c] MCLs are selected as the preliminary revised groundwater cleanup level where a MCL exists. MDEQ *Circular DEQ-7 Numeric Groundwater Standards*, April 2017, were selected for COCs that do not have a promulgated MCL.

ARAR – applicable or relevant and appropriate requirement

COC – contaminant of concern

MCL – maximum contaminant level

MDEQ – Montana Department of Environmental Quality

PAHs – polynuclear aromatic hydrocarbons

pg/L – picogram per liter

RAO – remedial action objective

TCDD – tetrachlorodibenzodioxin

µg/L – micrograms per liter

Table 2-2. Summary of Preliminary Federal and State ARARs and TBCs

<table>
<tr><th>Statute</th><th>Citation</th><th>Type</th><th>Requirement Description</th><th>Comments</th></tr>
<tr><td colspan="5">Chemical-Specific ARARs</td></tr>
<tr><td colspan="5">Federal</td></tr>
<tr><td colspan="5">SAFE DRINKING WATER ACT</td></tr>
<tr><td>SDWA</td><td>40 CFR Part 141 Subparts B, F, G, and I</td><td>Relevant and Appropriate</td><td>National Primary Drinking Water Regulations (40 CFR Part 141)

Below is a summary of contaminants of concern and corresponding MCLs (if present) associated with the Libby site. See Tables 2-9 and 2-12 for a complete listing of federal MCLs and MCLGs. See Table 2-11 for a summary of the Action Levels for lead and copper.

<u>MCLs</u>
Benzene (0.005 mg/L)
Pentachlorophenol (0.001 mg/L)
Arsenic 0.010 mg/L
Acenaphthene
Anthracene
Fluranthene
Fluorene
Naphthalene
Pyrene
Benzo (a) anthracene
Benzo (a) pyrene (0.0002 mg/L)
Benzo (b) fluoranthene
Benzo (k) fluoranthene
Chrysene
Dibenzo (a,h) anthracene
Indeno (1,2,3-c,d) pyrene
2,3,7,8-TCDD ($3x10^{-8}$ mg/L)</td><td>The NCP sets forth the following at 40 CFR §300.430(e)(2)(i)(B):

MCLGs, established under the SDWA, that are set at levels above zero, shall be attained by remedial actions for ground or surface waters that are current or potential sources of drinking water, where the MCLGs are relevant and appropriate under the circumstances of the release based on the factors in §300.400(g)(2). If an MCLG is determined not to be relevant and appropriate, the MCL shall be attained where relevant and appropriate to the circumstances of the release.

The NCP sets forth comparisons which shall be made in determining relevance and appropriateness in §§300.400(g)(2)(i) through (viii). Section 300.400(g)(2)(viii) requires that this comparison shall include consideration of use or potential use of affected resources at the CERCLA site.

Subparts B, F and G set forth MCLGs and MCLs. The non-zero MCLGs and MCLs are relevant and appropriate for surface water and groundwater, which is currently or may potentially be used as a source of drinking water.</td></tr>
</table>

Table 2-2. Summary of Preliminary Federal and State ARARs and TBCs

Statute	Citation	Type	Requirement Description	Comments
CLEAN WATER ACT				
CWA	33 USC §1251 - 1387	Applicable	Federal Water Pollution Control Act as amended by the CWA of 1977 and subsequent CWA amendments	33 USC §1251 sets forth goals of the Act, which include the following: • Restore and maintain the chemical, physical, and biological integrity of the Nation's waters • Prohibit the discharge of toxic pollutants in toxic amounts • Enable the goals of the Act through the control of both point and nonpoint sources of pollution
	33 USC §1311	Applicable	CWA Effluent Limitations	This section prohibits discharge of pollutants except as in compliance with the Act. This section includes the following: "Except as in compliance with this section and sections 1312, 1316, 1317, 1328, 1342, and 1344 of this Act, the discharge of any pollutant by any person shall be unlawful."
	33 USC §1314 and 40 CFR Part 131	Relevant and Appropriate	Water Quality Criteria See **Table 2-3**, Federal Recommended Water Quality Criteria for a listing of pollutants and associated water quality criteria.	Water quality criteria developed in accordance with 33 USC §1314 et seq. are relevant and appropriate for point source discharges into surface water from the site and for nonpoint source groundwater discharges into the Kootenai River, Libby Creek, and/or Flower Creek. When determining if CWA criteria are relevant and appropriate to surface water or groundwater, CERCLA §121(d)(2)(B)(i) requires consideration of the use of the surface or groundwater, the environmental media affected, the purposes for which such criteria were developed, and the latest information available.

Table 2-2. Summary of Preliminary Federal and State ARARs and TBCs

Statute	Citation	Type	Requirement Description	Comments
CWA	33 USC §1314 and 40 CFR Part 131	Relevant and Appropriate	See description above.	The purpose of the CWA criteria is set forth in 33 USC §1251(described previously). The CWA criteria address potential problems and pertain to circumstances that are similar to the Libby site if point source or nonpoint source pollutant discharges to the Kootenai River, Libby Creek, and/or Flower Creek occurred as a result of the proposed action. Point source or nonpoint source pollutant discharges as a result of the proposed action would degrade surface water quality, and would not be protective of human health and the environment. Therefore, the criteria are relevant and appropriate for point source discharges into surface water from the site and for nonpoint source groundwater discharges into the Kootenai River, Libby Creek, and/or Flower Creek if the source or non-point source is related to the Libby Groundwater Site or its remediation.
Chemical-Specific ARARs				
State of Montana				
MONTANA WATER QUALITY ACT				
§75-5-301, 302, MCA: Montana Water Quality Control Act ARM §17.30.601 through 641 – Surface Water Quality Standards and Procedures ARM §17.30.1001 through 1045 – Montana Groundwater Pollution Control System Establishes water quality standards and regulations to prevent or abate water pollution. If the Montana standards are more stringent or lower numerically than EPA MCLs, The Montana regulations must be met for the protection of the waters of the State of Montana. The substantive provisions of these regulations must be met as part of a reinjection program. The Montana standards also apply for constituents that have no federal standards.				
MWQA	§75-5-303, MCA	Applicable	State Waters Protection, General Requirements	Nondegradation Policy: Existing uses of state waters and the level of water quality necessary to protect those uses must be maintained and protected. "Degradation" means a change in water quality that lowers the quality of high-quality waters for a parameter. The term does not include those changes in water quality determined to be nonsignificant pursuant to §75-5-301(5)(c), MCA.

Table 2-2. Summary of Preliminary Federal and State ARARs and TBCs

Statute	Citation	Type	Requirement Description	Comments
	ARM §17.30.701 through 717	Applicable	Nondegradation Rules	The nondegradation rules apply to any activity of man resulting in a new or increased source that may cause degradation. If an activity will cause degradation, a person may request an authorization to degrade using the procedures given in ARM §17.30.707. The criteria for determining if changes in water quality are nonsignificant are given in ARM §17.30.715. Very simplistically these are as follows. For carcinogenic substances – any change would be significant. For toxic substances – any change that would be measurable or would result in an "instream" concentration that would exceed 15% of the lowest applicable standard would be significant. For harmful substances – any change that would result in an in stream concentration that would exceed 10% of the standard when ambient is less than 40% of the standard would be significant, while any change is generally considered significant if ambient is 40% or greater of the standard.
	ARM §17.30.601 through 17.30.670	Applicable	Surface Water Quality Standards and Procedures See **Table 2-7** and **Table 2-8** for surface water criteria applicable to the Libby site.	These regulations set forth surface water quality standards to conserve water by protecting, maintaining, and improving the quality and potability of water for public water supplies, wildlife, fish and aquatic life, agriculture, industry, recreation, and other beneficial uses. Standards are set according to stream and water-use classifications. The uses of the Kootenai River Drainage are classified as B-1 in the area of the Libby site except that the Flower Creek drainage to the Libby water supply intake (approximately at latitude 48.356, longitude-115.5676) is classified as A-1. (ARM §17.30.609) Affected environmental media include groundwater adjacent to the river and surface water within the Kootenai River, Libby Creek, and Flower Creek. The Kootenai River is currently impaired due to impacts from hydrostructure flow modification upstream impoundments (e.g., Pl-566 NRCS Structures) and does not fully support the standards for the designated use of aquatic life (temperature, water). Libby Creek from the Highway 2 bridge to the mouth of the Kootenai River is currently impaired due to physical substrate habitat alterations (land development) and streambank modifications/destabilization causing sedimentation/siltation and does not fully support the standard for the designated use of aquatic life (Montana Final 2016 Integrated Report and 303(d) List, Appendix A – Impaired Waters).

Table 2-2. Summary of Preliminary Federal and State ARARs and TBCs

Statute	Citation	Type	Requirement Description	Comments
	ARM §17.30.1001 through 17.30.1045	Applicable	Montana Groundwater Pollution Control System See **Table 2-6** for groundwater standards applicable to the Libby site.	These regulations set forth groundwater standards that are the maximum allowable changes in groundwater quality and are the basis for limiting discharges to groundwater as well as classifications of groundwater based on natural specific conductance.
	MDEQ Circular DEQ-7, developed in compliance with §75-5-301, MCA, §80-15-201, MCA, and Section 303(c) of the CWA	Applicable	Numeric water quality standards for Montana's surface and groundwaters. Below is a summary of numeric water quality standards for contaminants of concern associated with the Libby site in groundwater. See **Table 2-4** for a complete listing of numeric water quality standards (surface water and groundwater) applicable to the Libby site. <u>Numeric Water Quality Standards that surface and groundwater may not exceed (standard is for both surface and groundwater, unless otherwise noted)</u> Benzene: 5 µg/L Pentachlorophenol: 0.3 µg/L surface water and 1 µg/L groundwater Arsenic: 10 µg/L Acenaphthene: 70 µg/L Anthracene: 3,000 µg/L in surface water and 2,100 µg/L groundwater Fluranthene: 20 µg/L Fluorene: 50 µg/L Naphthalene: 100 µg/L Pyrene: 20 µg/L` Benzo (a) anthracene: 0.012 µg/L surface water and 0.5 µg/L groundwater Benzo (a) pyrene: 0.0012 µg/L surface water and 0.05 µg/L groundwater Benzo (b) fluoranthene: 0.0012 µg/L surface water and 0.05 µg/L groundwater Benzo (k) fluoranthene: 0.12 µg/L surface water and 5 µg/L groundwater Chrysene: 1.2 µg/L surface water and 50 µg/L ground water Dibenzo (a,h) anthracene: : 0.0012 µg/L surface water and 0.05 µg/L groundwater Indeno (1,2,3-c,d) pyrene: 0.012 µg/L surface water and 0.5 µg/L groundwater	These standards were adopted to protect the designated beneficial uses of state waters, such as growth and propagation of fishes and associated wildlife, waterfowl and furbearers use for drinking water, culinary and food processing purposes; recreation; agriculture; and industry and other commercial purposes.

Table 2-2. Summary of Preliminary Federal and State ARARs and TBCs

Statute	Citation	Type	Requirement Description	Comments
	MDEQ Circular DEQ-12A, developed in compliance with §75-5-103(2), MCA and adopted pursuant to §75-5-301(2), MCA	Applicable	Base numeric nutrients standards for Montana's surface waters. See **Table 2-5** for base numeric nutrients standards (flowing surface waters) applicable to the Libby site.	These standards for nitrogen and phosphorus were adopted to protect beneficial uses and prevent exceedences of other surface water quality standards which are commonly linked to nitrogen and phosphorus concentrations (e.g., pH and dissolved oxygen).
	ARM §17.38.201 through 17.38.207	Relevant and Appropriate	Montana MCLs See **Table 2-10** for Montana MCLs relevant to the Libby site.	These regulations were adopted to assure the safety of public water supplies with respect to bacteriological, chemical, and radiological quality and to promote efficient operation of public water supply systems.
ARM §17.30.103 Discharge Permits DPs are required before commencing construction for any activity requiring state water quality certification under 33 USC 1341 for the protection of waters of the State of Montana by controlling discharges onto or below the surface of the ground, The substantive requirements of the DPs are considered ARARs. The previous section of this table addresses applicable water quality standards.				
§17.30.103: Standards for Interstate and Intrastate Surface Waters				
MCA	§17.30.103, MCA	Relevant and Appropriate	Discharge permit with discharge limits to protect surface waters	The numerical limits that would apply if the discharge were not subject to administrative requirements because of CERCLA are relevant to surface water discharges from the site.
ARM §17.38: Montana Regulations for Public Drinking Water Systems				
	§17.38.203 §17.38.204 §17.38.205 §17.38.206	Relevant and Appropriate	Provides state with primary drinking water regulations based on federal MCLs for public water systems.	Relevant and appropriate standards are MCLs.
MONTANA HAZARDOUS WASTE ACT				
ARM §17.52.501: Montana Hazardous Waste Management Regulations				
MHWA	§17.53.501 and 17.53.502 §17.53.601 and 17.53.602 §17.53.801 and 17.53.802 §17.53.1001 and 17.53.1002 §17.53.1101 and 17.53.1102 §17.53.1301 and 17.53.1302 §17.53.1401 and 17.53.1402	Applicable	Establishes criteria for the classification of hazardous waste by incorporating by reference federal regulations, with the exception to the definition of a flammable gas noted in §17.53.502. See **Table 2-17** for specific land disposal restriction requirements pertaining to hazardous wastes expected to be generated at the Libby Site.	Applies to actions involving the generation and treatment, storage, and disposal of hazardous waste. Incorporates Federal Hazardous Waste Regulations by reference, with specified exceptions.

Table 2-2. Summary of Preliminary Federal and State ARARs and TBCs

Statute	Citation	Type	Requirement Description	Comments
CLEAN AIR ACT OF MONTANA				
ARM §17.8: Air Quality				
CAAM	§17.8, MCA	Applicable	Establishes ambient air quality standards, performance standards for specific sources of air pollutants, and specifies monitoring methods See **Table 2-15**	Applicable if remedial activities involve sources subject to regulation
CAAM	§17.8.309	Applicable	Particulate matter limits for fuel-burning equipment See **Table 2-16**	No person shall cause particulate matter from fuel combustion to be discharged into the outdoor atmosphere in excess of rates specified in ARM §17.8.309. Maximum Allowable Emissions in Pounds/MBtu for New Units 10 and below: 0.60 100: 0.35 1,000: 0.20 10,000 and above: 0.12
Location-Specific ARARs				
Federal				
CLEAN WATER ACT DREDGE AND FILL REQUIREMENTS				
CWA	40 CFR §230 and 33 CFR §§322/323	Applicable	Requirements for structures or work in or affecting navigable waters of United States and Requirements for discharges of dredged or fill material into waters of United States.	Substantive requirements of these sections are applicable
ENDANGERED SPECIES ACT				
ESA	16 USC §§1531, 1532, 1533, 1535, and 1536 50 CFR Part 17	Applicable	ESA Statute and Regulations See **Table 2-13**	The ESA requires that any action authorized, funded, or carried out by a federal agency is not likely to jeopardize the continued existence of any endangered species or threatened species or result in the destruction or adverse modification of critical habitat of such species. Substantive requirements of these regulations are applicable requirements.
MIGRATORY BIRD TREATY ACT				
MBTA	16 USC §703 to 712	Applicable	Provides protection for migratory bird species (including geese, ducks, raptors, many passerines). Prohibits killing or taking of bird or any part, nest, or egg of any such bird.	This requirement establishes a federal responsibility for the protection of the international migratory bird resource and requires consultation with the U.S. Fish and Wildlife Service to ensure that cleanup of the site does not unnecessarily impact migratory birds.
BALD EAGLE PROTECTION ACT				
BEPA	16 USC §668	Applicable	Bald Eagle Protection Act statute	

Table 2-2. Summary of Preliminary Federal and State ARARs and TBCs

Statute	Citation	Type	Requirement Description	Comments
NATIONAL HISTORIC PRESERVATION ACT				
NHPA	16 USC §470 et seq.	Applicable	NHPA statute.	This statute and implementing regulations require federal agencies to take into account the effect of the response action upon any district, site, building, structure, or object that is included in or eligible for the Register of Historic Places. Requires coordination with SHPO.
	36 CFR Parts 63, 65, and 800	Applicable	NHPA regulations	
ARCHEOLOGICAL (sic) AND HISTORIC PRESERVATION ACT (AHPA)				
AHPA	16 USC §469	Relevant and Appropriate	AHPA statute	This statute and implementing regulations establish requirements for the evaluation and preservation of historical and archaeological data, which may be destroyed through alteration of terrain as a result of a federal construction project or a federally licensed activity or program. This requires EPA or PRPs to survey the site for covered scientific, prehistorical or archaeological artifacts. The results of this survey will be reflected in the Administrative Record. Preservation of appropriate data concerning the artifacts is identified as an ARAR requirement to be completed during the implementation of a remedial action.
EXECUTIVE ORDER ON FLOODPLAIN MANAGEMENT				
	EO No. 11988, as amended	Applicable	This EO requires that actions be taken to avoid, to the extent possible, adverse effects associated with direct or indirect development of a floodplain, or to minimize adverse impacts if no practicable alternative exists.	
EXECUTIVE ORDER ON PROTECTION OF WETLANDS				
	EO No. 11990, as amended	Applicable	This EO requires federal agencies and the PRPs to avoid, to the extent possible, the adverse impacts associated with the destruction or loss of wetlands and to avoid support of new construction in wetlands if a practicable alternative exists. Wetlands are defined as those areas that are inundated or saturated by groundwater or surface water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions.	

Table 2-2. Summary of Preliminary Federal and State ARARs and TBCs

Statute	Citation	Type	Requirement Description	Comments
Location-Specific ARARs				
State of Montana				
MONTANA WATER QUALITY ACT				
ARM 17.30.101-109 Establishes water quality standards and regulations to prevent or abate water pollution. Compliance is necessary to protect the waters of the State of Montana. The substantive provisions of these regulations must be met as part of a reinjection program. The NM standards also apply for constituents that have no federal standard.				
MCA	§75-5-605, MCA	Applicable	Prohibits placement of wastes where they will cause pollution of any state water	It is unlawful to cause pollution of any state waters or to place or cause to be placed any wastes where they will cause pollution of any state waters, other than activities authorized by a permit.
	ARM §17.30.101-109	Relevant and Appropriate	Ensure that any activity requiring a federal license or permit that may result in discharge to state waters shall fulfill requirements of ARM Title 17.	It is the policy of the board that the department shall ensure that any activity that requires a federal license or permit and that may result in a discharge to state waters shall fulfill the requirements of ARM Title 17, Chapter 30. The substantive requirements that would otherwise be contained in a permit apply.
	ARM §17.30.1011	Applicable	Maintain existing groundwater quality	Any groundwater whose existing quality is higher than established groundwater quality standards for its classification must be maintained at that high quality.
ARM §17.30.103 Discharge Permits DPs are required before conducting or commencing construction for any activity requiring state water quality certification under 33 USC 1341 for the protection of waters of the State of Montana. Although a permit is not required, the substantive standards that would otherwise be part of a permit are ARARs.				
MONTANA STATE ANTIQUITIES ACT				
MSAA	§§22-3 Part 8	Applicable	Protection of human skeletal remains and burial sites	Prohibits knowingly disturbing or destroying grave, burial ground, or burial material without authorization and requires reporting discovery of such remains.
MONTANA NONGAME AND ENDANGERED SPECIES CONSERVATION ACT				
MCA	§87-5-106, MCA	Applicable	Protection of nongame species deemed to be in need of management	Except as provided in regulations issued by the department, it shall be unlawful for any person to take, possess, transport, export, sell, or offer for sale nongame wildlife deemed by the department to be in need of management. Subject to the same exception, it shall further be unlawful for any common or contract carrier knowingly to transport or receive for shipment nongame wildlife deemed by the department to be in need of management.

Table 2-2. Summary of Preliminary Federal and State ARARs and TBCs

Statute	Citation	Type	Requirement Description	Comments
MCA	ARM §12.5.201	Applicable	Montana Endangered Species List	Except as otherwise provided, it is unlawful for any person to take, possess, transport, export, sell or offer for sale, and for any common or contract carrier knowingly to transport or receive for shipment any species or subspecies of wildlife appearing on the following list: • Whooping crane (*grus americana*); • Northern Rocky Mountain wolf (*canis lupus irremotus*); and • Black-footed ferret (*mustela nigripes*).
MONTANA NOXIOUS WEED CONTROL LAW				
MNWCL	§7-22-2101(7)(a), MCA, §7-22-2109(2)(b), MCA, and ARM 4.5.201 through 4.5.210	Applicable	Definition of noxious weeds and weed management criteria.	Any exotic plant species established or that may be introduced in the state that may render land unfit for agriculture, forestry, livestock, wildlife, or other beneficial uses or that may harm native plant communities. Designated noxious weeds are listed in ARM 4.5.201 through 4.5.210 and must be managed consistent with weed management criteria under §7-22-2109(2)(b), MCA.
MNWCL	§7-22-2116, MCA	Applicable	Requires control of noxious weeds	It is unlawful for any person to allow any noxious weed to propagate or go to seed on the person's land, except as authorized. Owners must notify purchasers of the presence of noxious weeks when property is offered for sale.
MNWCL	§7-22-2152, MCA	Relevant and Appropriate	Notification to District Weed Board	Any person proposing certain actions including but not limited to a solid waste facility, a highway or road, a commercial, industrial, or government development, or any other development that needs state or local approval and that results in the potential for noxious weed infestation within a district must notify the district weed board at least 15 days prior to the activity and submit a written plan for approval specifying methods to accomplish revegetation.

Table 2-2. Summary of Preliminary Federal and State ARARs and TBCs

Statute	Citation	Type	Requirement Description	Comments
Action-Specific ARARs				
Federal				
CLEAN AIR ACT				
CAA	ARM §17.8: Air Quality		Refer to the CAA section of chemical-specific ARARs	
CAA	40 CFR Part 50	Relevant and appropriate	National ambient air quality standards, refer to **Table 2-14**	Establishes national ambient air quality standards, which affect restrictions on air pollution sources through operational requirements or permit standards.
CAA	40 CFR §61.01	Applicable	Requirements for stationary sources of hazardous air pollutants	The section sets forth provisions and permit requirements for operating stationary sources of hazardous air pollutants, including inorganic arsenic. Although the administrative process of obtaining a permit does not apply, the substantive requirements of Part 61 and a permit would apply if the source exceeds thresholds established in the regulation.
CAA	40 CFR Part 60 Subpart Dc	Applicable	Standards of performance for small industrial-commercial-institutional steam generating units	This regulation establishes emissions standards for industrial fossil-fuel fired steam generating units with heat input capacities between 2.9 and 29 megawatts
CLEAN WATER ACT				
CWA	40 CFR 112	Applicable	Requirements for petroleum storage in aboveground tanks. Requires preparation and implementation of a Spill Prevention, Control, and Countermeasure (SPCC) Plan.	40 CFR 112 applies to petroleum storage from which a release could reasonably be expected to discharge to a navigable water provided that aboveground storage cumulative above ground storage in contains of 55-gallon capacity or greater is more than 1,320 gallons.
	40 CFR Part 122	Applicable	National Pollution Discharge Elimination System program requirements for EPA administered permit programs	Although a permit is not required, substantive NPDES requirements that a permit would impose must be met.
	40 CFR Part 125	Applicable	Criteria and Standards for the National Pollutant Discharge Elimination System	Criteria and standards are considered substantive requirements of NPDES program
SAFE DRINKING WATER ACT				
SDWA	40 CFR Part 144	Applicable	Compliance with substantive UIC permit requirements	These regulations establish classes of UIC wells and permit controls based on the class of well. In Montana all classes of UIC other than Class II are EPA-regulated. Class II wells are those associated with oil and gas exploration. Compliance requirements depend on the Class of UIC. Although the administrative process of obtaining a permit does not apply, the substantive requirements determined through the permitting process would apply. A Class V well is for injection of nonhazardous fluids into or above underground sources of drinking water.

Table 2-2. Summary of Preliminary Federal and State ARARs and TBCs

Statute	Citation	Type	Requirement Description	Comments
RESOURCE CONSERVATION AND RECOVERY ACT				
RCRA	42 USC §6921(a) and (b)	Relevant and Appropriate	Law requiring that rules identifying and listing hazardous waste be developed.	42 USC §6921 requires developing and promulgating criteria for identifying the characteristics of hazardous waste and for listing specific chemicals as hazardous waste, taking into account toxicity, persistence, and degradability in nature, potential for accumulation in tissue, and other related factors such as flammability, corrosiveness, and other hazardous characteristics.
RCRA	40 CFR Part 261 including 261.3(c)(2)(i)	Applicable	Regulation defines hazardous waste characteristics and lists specific chemicals that are hazardous waste when discarded.	40 CFR Part 261 Subpart C identifies hazardous waste characteristics including ignitability and toxicity characteristic wastes (e.g., benzene, pentachlorophenol, arsenic); and 40 CFR Part 261 Part D identifies hazardous waste listings, including F032 and F034. 40 CFR 261.3(c)(2)(i) classifies solid waste generated from the treatment, storage, or disposal of a hazardous waste (including any sludge, spill residue, ash emission control dust, or leachate) as hazardous waste if the residue exhibits a characteristic or is listed waste that cannot be excluded from the listing.
RCRA	40 CFR Part 262	Applicable	Requirements for hazardous waste generators	40 CFR Part 262 defines substantive requirements for the on-site storage of hazardous waste. F032 and F034 waste and characteristic hazardous wastes stored onsite would be subject to these management standards.
RCRA	40 CFR Part 264	Relevant and Appropriate	Requirements for treatment, storage, and disposal facilities	40 CFR Part 264 establishes management requirements for treatment, storage, and disposal of hazardous waste and special provisions for cleanup, which may be relevant depending on specific circumstances.
RCRA	40 CFR Part 268	Applicable	Requirements for treatment before land disposal Refer to 40 CFR §268.40, Treatment Standards for Hazardous Waste, and 49 CFR 268.48, Universal Treatment Standards, where referenced. **See Table 2-17**	40 CFR Part 268 establishes treatment standards that must be met before hazardous waste can be disposed of in a landfill or other land-based unit. These requirements attach to the waste at the point of generation and affect offsite disposal and possibly onsite disposal.
OCCUPATIONAL SAFETY AND HEALTH ACT				
OSHA	29 CFR 1910	Applicable	Personnel working with hazardous waste must comply with health and safety standards	Requirements include health and safety training, protective equipment, proper handling of waste, monitoring of personnel health, and understanding emergency procedures.

Table 2-2. Summary of Preliminary Federal and State ARARs and TBCs

Statute	Citation	Type	Requirement Description	Comments
Action-Specific ARARs				
State of Montana				
MONTANA WATER QUALITY ACT				
ARM §17.30 Water Quality				
MCA	§75-5-401	Applicable	Permits required; compliance with substantive provision applies	Authorization establishing water quality standards required to dispose of industrial waste into state waters, including groundwaters.
MCA	§ 17.30.1023	Applicable	Permits required; compliance with substantive provision applies	A permit is required to discharge pollutants to state groundwaters. Sites must comply with the substantive requirements of a permit.
MCA	§17.30.1105	Applicable	A permit is required for discharge of water associated with stormwater discharges.	A general or specific MPDES permit is required for discharges associated with construction activity disturbing 1-acre or more, industrial activity, or that the Department of Environmental Quality determines is required to prevent a violation of water quality standards. Specific requirements depend on the type of permit the activity triggers. Although a permit is not required for CERCLA sites, the substantive permit requirements must be met unless otherwise waived.
MONTANA WATER USE ACT				
MWUA	85-2-505	Applicable	Waste and contamination of groundwater prohibited	No groundwater may be wasted. The department shall require all wells producing waters that contaminate other waters to be plugged or capped. It shall also require all flowing wells to be so capped or equipped with valves that the flow of water can be stopped when the water is not being put to beneficial use. Likewise, both flowing and nonflowing wells must be so constructed and maintained as to prevent the waste, contamination, or pollution of groundwater through leaky casings, pipes, fittings, valves, or pumps either above or below the land surface.
WATER WELL CONSTRUCTION				
MCA	43-37-302	Applicable	License requirements for well construction	It is unlawful for any water well contractor, water well driller, or monitoring well constructor to construct, alter, or rehabilitate water well or a monitoring well without first having obtained a valid license.
MCA	85-2-516	Applicable	Well Log Report	Within 60 days after any well is completed, a well log report must be filed by the driller with the Montana Bureau of Mines and Geology.

Table 2-2. Summary of Preliminary Federal and State ARARs and TBCs

Statute	Citation	Type	Requirement Description	Comments
MCA	ARM §36.21 Subchapter 6	Applicable	Construction standards for groundwater wells other than public drinking water and supply wells	ARM §36.21.634 -680 provide standards for construction of groundwater wells. §§36.21.671 and 672 provide requirements for well abandonment. (ARM §17.36.333, which would be Relevant and Appropriate as it applies to drinking water wells, references well construction standards in ARM §36.21 Subchapter 6.
MONTANA WATER QUALITY ACT				
ARM §17.30 Water Quality (refer to the nondegradation policy and rules under Montana Chemical-Specific ARARS)				
MONTANA AIR QUALITY ACT				
ARM §17.8 Air Quality				
CAAM	§75-2-102, MCA	Relevant and Appropriate	Intent, policy, and purpose of the CAAM	CAAM is intended to provide adequate remedies for the protection of the environmental life support system from degradation and provide adequate remedies to prevent unreasonable depletion and degradation of natural resources. It is the public policy to achieve and maintain levels of air quality that will protect human health and safety and, to the greatest degree practicable, prevent injury to plant and animal life and property, foster the comfort and convenience of the people, promote the economic and social development of this state, and facilitate the enjoyment of the natural attractions of this state. Specific rules that may apply depend on the types of air emissions sources that may be used at the site.
	ARM §17.8.201 through17.8.230	Applicable	Ambient Air Quality Standards and Monitoring	Specifies ambient air quality standards and provides that, generally, all ambient air monitoring, sampling and data collection, recording, analysis and transmittal must be in compliance with the Montana Quality Assurance manual except when MDEQ determines that more stringent requirements are necessary. **See Table 2-14** for specific requirements.
	ARM §17.8.301 through 17.8.342	Applicable	Air Emission Standards	Specifies emission standards for new stationary sources and modifications and hazardous air pollutants. **See Table 2-14** for specific requirements.
	ARM §17.8.604	Applicable	Materials prohibited from open burning	The regulation prohibits open burning a variety of materials including but not limited to food wastes, animal waste and materials, construction materials of certain types, and chemicals.
	ARM §17.8.610 through 17.8.612	Applicable	Open Burning Restrictions and Permit Requirements	Substantive aspects of restrictions and permits may apply, while the administrative aspect of obtaining a permit would not apply.

Table 2-2. Summary of Preliminary Federal and State ARARs and TBCs

Statute	Citation	Type	Requirement Description	Comments
	ARM §17.8.752	Applicable	Emission Control Requirements	The maximum air pollution control capability that is technically practicable and economically feasible must be installed on a new or modified facility or emitting unit for which a Montana air quality permit is required.
	ARM §17.8.802	Applicable	Prevention of Significant Deterioration Requirements	Incorporates by reference the air regulations in certain parts of 40 CFR regarding quality assurance requirements for prevention of significant deterioration air monitoring; standards of performance for new stationary sources; emission standards for hazardous air pollutants, and other standards and requirements.
	ARM §17.8.805	Applicable	Ambient Air Ceilings	Provides ambient air ceilings, and states that no concentrations of a pollutant may exceed concentrations allowed under either the applicable secondary or the primary national ambient air quality standard, whichever concentration is lowest for the pollutant for a period of exposure.
HAZARDOUS WASTE MANAGEMENT STATUTE AND REGULATIONS				
MONTANA HAZARDOUS WASTE ACT				
MHWA	§75-10-422, MCA	Applicable	Unlawful Disposal	It is unlawful to dispose of used oil or hazardous waste, as defined in this part or by rule, without a permit or, if a permit is not required under this part or rules adopted under this part, by any other means not authorized by law.
MHWA	ARM §17.53 Subchapters 6 and 8	Applicable	Hazardous Waste Generators Must Comply with Certain Requirements	Subchapter 6 establishes requirements for hazardous waste generators and Subchapter 8 establishes substantive requirements that apply to certain hazardous waste management activities related to treatment, storage, and disposal of hazardous waste. These requirements largely mirror federal hazardous waste requirements.
MONTANA SOLID WASTE MANAGEMENT ACT				
MSWMA	ARM §17.50..410	Applicable	Disposal in Unauthorized Area Prohibited	A person may not dispose of solid waste except as permitted.
MSWMA	ARM §17.50..410	Applicable	License Required	A license is required for any person disposing of solid waste or operating or maintaining a solid waste management system involved in the storage, treatment, recycling, recovery, or disposal of solid waste.
	ARM §17.50..816	Applicable	Disposal of Portable Toilet Waste	Portable toilet waste may only be disposed of in authorized facilities. Onsite disposal is prohibited unless specific pathogen reduction requirements are met.

Table 2-2. Summary of Preliminary Federal and State ARARs and TBCs

Statute	Citation	Type	Requirement Description	Comments
	ARM §17.50..816	Applicable	License Required for cleaning septic tanks, portable toilets, etc.	A person may not engage in the business of cleaning cesspools, septic tanks, portable toilets, privies, grease traps, car wash sumps, or similar treatment works, or disposal of septage and other wastes from these devices, unless licensed by the department.
MCA	ARM 24.122.501	Applicable	License required to operate boilers and steam engines	A person shall obtain the proper class of boiler operating engineer's license for operating a boiler
To Be Considered (Guidance, Non-Enforceable Guidelines, Criteria)				
SAFE DRINKING WATER ACT				
SDWA	40 CFR Part 143	TBC	Secondary Maximum Contaminant Levels (40 CFR 143.3) Aluminum 0.05 to 0.2 mg/L Chloride 250 mg/L Color 15 color units Copper 1.0 mg/L Corrosivity Non-corrosive Fluoride 2.0 mg/L Foaming agents 0.5 mg/L Iron 0.3 mg/L Manganese 0.05 mg/L Odor 3 threshold odor number pH 6.5-8.5 Silver 0.1 mg/L Sulfate 250 mg/L Total dissolved solids (TDS) 500 mg/L Zinc 5 mg/L	None of the parameters with Secondary Maximum Contaminant Levels are contaminants of concern.

Table 2-2. Summary of Preliminary Federal and State ARARs and TBCs

Statute	Citation	Type	Requirement Description	Comments
SDWA	40 CFR Part 141 Subparts B, F, G, and I	TBC	National Primary Drinking Water Regulations (40 CFR Part 141) Below is a summary of MCLGs for contaminants of concern associated with the Libby site. See **Table 2-12** for a complete listing of federal MCLGs. <u>MCLGs are zero for the following contaminants:</u> Benzene Pentachlorophenol Arsenic	The National NCP sets forth the following at 40 CFR Part 300.430(e)(2)(i)(B): MCLGs, established under the SDWA, that are set at levels above zero, shall be attained by remedial actions for ground or surface waters that are current or potential sources of drinking water, where the MCLGs are relevant and appropriate under the circumstances of the release based on the factors in Part 300.400(g)(2). If an MCLG is determined not to be relevant and appropriate, the MCL shall be attained where relevant and appropriate to the circumstances of the release. The NCP sets forth comparisons which shall be made in determining relevance and appropriateness in Parts 300.400(g)(2)(i) through (viii). Part 300.400(g)(2)(viii) requires that this comparison shall include consideration of use or potential use of affected resources at the CERCLA site. Subparts B, F and G set forth MCLGs and MCLs. The non-zero MCLGs and MCLs are relevant and appropriate for surface water and groundwater, which is currently or may potentially be used as a source of drinking water.
MONTANA NONGAME AND ENDANGERED SPECIES				
	EO No. 10-2014	TBC	Creating the Montana Sage Grouse Oversight Team and Montana Safe Grouse Habitat Conservation Program	Recommendations for managing sage grouse populations and protecting sage grouse habitat
	EO No. 10-2015		Creating the Montana Sage Grouse Oversight Team and Montana Safe Grouse Habitat Conservation Program	Amendments to EO No. 10-2014 to enhance protections
MCA	§79-22-104	TBC	Establish ongoing free-market mechanisms for voluntary conservation measures.	The legislature finds that allowing a project developer to provide compensatory mitigation for the debits of a project is consistent with the purpose of incentivizing voluntary conservation measures for sage grouse habitat and populations.
NOXIOUS WEEDS				
	NA	TBC	Lincoln County, Montana Integrated Noxious Weed Management Plan	The plan provides information on noxious weeds in the county and management strategies for them.

Notes:

§	–	Section
§§	–	Sections
Action	–	Action Specific ARAR
AHPA	–	Archeological and Historical Preservation Act
Appl	–	Applicable ARAR
ARAR	–	Applicable or Relevant and Appropriate Requirement
ARM	–	Administrative Rules of Montana
BEPA	–	Bald Eagle Protection Act
BMPs	–	Best Management Practices
CAA	–	Clean Air Act
CAAM	–	Clean Air Act of Montana
CERCLA	–	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	–	Code of Federal Regulations
Chem	–	Chemical Specific ARAR
CWA	–	Clean Water Act
DPs	–	Discharge Permits
EPA	–	US Environmental Protection Agency
ESA	–	Endangered Species Act
et acta.	–	And those pages or sections that follow
EO	–	Executive Order
Loc	–	Location specific ARAR
MBTA	–	Migratory Bird Treaty Act
MCA	–	Montana Code Annotated
MCL	–	Maximum Contaminant Level
MCLGs	–	Maximum Contaminant Level Goals
MDEQ	–	Montana Department of Environmental Quality
MHWA	–	Montana Hazardous Waste Act
MNWCL	–	Montana Noxious Weed Control Law
MPDES	–	Montana Pollutant Discharge Elimination System
MSAA	–	Montana State Antiquities Act
MSWMA	–	Montana Solid Waste Management Act
MWQA	–	Montana Water Quality Act
MWUA	–	Montana Water Use Act
NA	–	Not Applicable
NHPA	–	National Historic Preservation Act
No.	–	Number
NPDES	–	National Pollution Discharge Elimination System
NRCS	–	Natural Resources Conservation Services
P.L.	–	United States Public Law
PM10	–	Particulate matter 10 microns in size or smaller
PRPs	–	Potential responsible parties
TCDD	–	tetrachlorodibenzodioxin
TMDL	–	Total Maximum Daily Load
UIC	–	Underground Injection Control
USC	–	United States Code
USFWS	–	US Fish and Wildlife Service

Table 2-3. Federal Recommended Water Quality Criteria

Chemical	Freshwater Aquatic Life		Human Health	
	Acute µg/L	Chronic µg/L	Water and Organism µg/L	Organism Only µg/L
Inorganics				
Total Recoverable Aluminum	750	87	--	--
Dissolved Antimony	--	--	5.6	640
Dissolved Arsenic	340	150	0.018	0.14 (9[2])
Asbestos			7 million fibers/L	
Dissolved Barium	--	--	1,000	--
Dissolved Beryllium	NA		*	
Dissolved Boron	NA			
Dissolved Cadmium[1]	1.8	0.72	*	--
Dissolved Chromium III[1]	570/570/900/1800	74/74/120/230	*	--
Dissolved Chromium VI	16	11	*	--
Dissolved Cobalt	NA			
Dissolved Copper[1]	13/13/23/50	9.0/9/14/30	1,300	
Dissolved Lead[1]	65/65/120/280	2.5/2.5/4.6/11	--	--
Dissolved Molybdenum	NA			
Dissolved Mercury[7]	1.4	0.77	--	--
Methylmercury[7]	1.4	0.77		0.3 mg/kg
Dissolved Nickel[1]	470/470/750/1500	52/52/83/170	610	4,600
Total Recoverable Selenium	-- (20[2])	5.0	--	--
Dissolved Selenium	1.5/3.1	--	170*	4,200
Dissolved Silver[1]	3.2/3.2/9.0/37	--	--	--
Dissolved Thallium	--	--	0.24	0.47 (6.3[2])
Dissolved Zinc[1]	120/120/190/380	120/120/190/380	7,400	26,000
Chlorine	19	11	--	--
Cyanide	22 grams free cyanide (as Cn)/L	5.2 grams free cyanide (as Cn)/L	4* (total cyanide)	400* (total cyanide) (220,000[2])
Dissolved Nitrates	--	--	10,000	--
Total Ammonia[4,5,6]	32,600 - 885	6,670 - 389	--	--
Dissolved Iron	--	1,000	300	--
Hydrogen Sulfide	--	2.0	--	--
Dissolved Manganese	--	--	50	100
Organics				
Acenaphthene	--	--	70	90
Acrolein	--	3	3	400
Acrylonitrile	--	--	0.061	7.0
Aldrin	3.0	1.3	0.00000077[3]	0.00000077
Alpha-Hexachlorocyclohexane (HCH)	--	--	0.00036	0.00039
Anthracene	--	--	300	400
Benzene	--	--	0.58-2.1[3]	16-58[3]

Table 2-3. Federal Recommended Water Quality Criteria

Chemical	Freshwater Aquatic Life		Human Health	
	Acute µg/L	Chronic µg/L	Water and Organism µg/L	Organism Only µg/L
Benzidine	--	--	0.00014[3]	0.0011[3]
Benzo(a)anthracene	--	--	0.0012[3]	0.0013[3]
Benzo(a)pyrene	--	--	0.00012[3]	0.00013[3]
Benzo(b)fluoranthene	--	--	0.0012[3]	0.0013[3]
Benzo(k)fluoranthene	--	--	0.012[3]	0.013[3]
alpha-BHC	--	--	0.0026[3]	0.0049[3]
beta-BHC	--	--	0.0091[3]	0.017[3]
Beta-Hexachlorocyclohexane (HCH)	--	--	0.0080	0.014
gamma-BHC (Lindane)	-- (0.95[2])	--	0.98	1.8 (0.63[2])
Bis(2-Chloro-1-methylethyl) ether	--	--	200	4,000
Bis(2-chloroethyl) ether	--	--	0.030[3]	2.2[3]
Bis(2-chloroisopropyl) ether	--	--	1,400	65,000
Bis(2-ethyl-hexyl)phthalate	--	--	0.32[3]	0.37[3]
Bromoform	--	--	7.0[3]	120[3]
Butylbenzyl phthalate	--	--	0.10	0.10
Carbon tetrachloride	--	--	0.4[3]	5[3]
Carbyl	2.1	2.1		
Chlordane	2.4	0.0043	0.00031*[3]	0.00032[3]
Chlorobenzene	--	--	100*	800 (21,000[2])
Chlorodibromomethane	--	--	0.80[3]	21[3]
Chloroform	--	--	60*[3]	2,000[3]
2-Chloronaphthalene	--	--	800	1,000
2-Chlorophenol	--	--	30	800
Chlorophenoxy Herbicide (2,4-D)	--	--	1,300*	12,000*
Chlorophenoxy Herbicide (2,4,5-TP) (Silvex)	--	--	100*	400*
Chrysene	--	--	0.12*[3]	0.13*[3]
4,4'-DDT	1.1	0.001	0.00022[3]	0.00022[3]
Dibenzo(a,h)anthracene	--	--	0.00012[3]	0.00013[3]
Di-n-butyl phthalate	--	--	20	30
1,2-Dichlorobenzene	--	--	1,000*	3,000* (17,000[2])
1,3-Dichlorobenzene	--	--	7	10
1,4-Dichlorobenzene	--	--	300*	900* (2,600[2])
3,3'-Dichlorobenzidine	--	--	0.049[3]	0.15[3]
Dichlorobromomethane	--	--	0.95*[3]	27*[3]
1,2-Dichloroethane	--	--	9.9[3*]	650[3]
1,1-Dichloroethylene	--	--	300*	20,000* (32[2])
2,4-Dichlorophenol	--	--	77	290
1,2-Dichloropropane	--	--	0.90[3*]	31[3*]

Table 2-3. Federal Recommended Water Quality Criteria

Chemical	Freshwater Aquatic Life		Human Health	
	Acute µg/L	Chronic µg/L	Water and Organism µg/L	Organism Only µg/L
1,3-Dichloropropene	--	--	0.27[3]	12[3] (1,700[2])
Dieldrin	0.24	0.056	0.0000012[3]	0.0000012[3]
Diethyl phthalate	--	--	600	600
Dimethyl phthalate	--	--	2,000	2,000
Di-n-Butyl Phthalate	--	--	20	30
2,4-Dimethylphenol	--	--	100	3,000
2,4-Dinitrophenol	--	--	10	60
2,4-Dinitrotoluene	--	--	0.049[3]	1.7[3]
2,3,7,8-TCDD Dioxin	--	--	5.0E-9[3]	5.1E-9[3]
1,2-Diphenylhydrazine	--	--	0.03[3]	0.2[3]
Alpha-Endosulfan	0.22[8]	0.056[8]	20	30
Beta-Endosulfan	0.22[8]	0.056[8]	20	40
Endosulfan sulfate	--	--	20	40
Endrin	0.086	0.036[9]	0.03*	0.03*
Endrin aldehyde	--	--	1	1
Ethylbenzene	--	--	68*	130*
Fluoranthene	--	--	20	20
Fluorene	--	--	50	70
Gamma-Hexachlorocyclohexane (HCH) (Lindane)	--	--	4.2*	4.4*
Heptachlor	0.52	0.0038	0.0000059[3*]	0.0000059[3*]
Heptachlor epoxide	0.52	0.0038	0.000032[3*]	0.000032[3*]
Hexachlorobenzene (HCB)	--	--	0.000079[3*]	0.000079[3*]
Hexachlorobutadiene	--	--	0.01[3*]	0.01[3*]
Hexachlorocyclopentadiene	--	--	4*	4*
Hexachloroethane	--	--	0.1[3]	0.1[3]
Ideno(1,2,3-cd)pyrene	--	--	0.0012[3]	0.013[3]
Isophorone	--	--	34[3]	1,800[3]
Methoxychlor	--	0.03	0.02*	0.02*
Methyl bromide	--	--	100	10,000
2-Methyl-4,6-dinitrophenol	--	--	2	30
3-Methyl-4-Chlorophenol	--	--	500	2,000
Methylene chloride	--	--	20[3*]	1,000[3*]
Nitrobenzene	--	--	10	600
Nitrosamines	--	--	0.0008	1.24
N-Nitrosodimethylamine	--	--	0.00069[3]	3.0[3]
N-Nitrosodi-n-propylamine	--	--	0.0050[3]	0.51[3]
N-Nitrosodiphenylamine	--	--	3.3[3]	6.0[3]
Nonylphenol	28	6.6	--	--
PCBs (total)	--	0.014	0.000064[3]	0.000064[3]
Pentachlorophenol	19	15	0.03[3]	0.04[3]
Phenol	--	--	4,000	300,000
Pyrene	--	--	20	30
1,1,2,2-Tetrachloroethane	--	--	0.2[3]	3[3]

Table 2-3. Federal Recommended Water Quality Criteria

Chemical	Freshwater Aquatic Life		Human Health	
	Acute µg/L	Chronic µg/L	Water and Organism µg/L	Organism Only µg/L
Tetrachloroethylene	--	--	10[3*]	29[3*]
Toluene	--	--	57*	520*
Toxaphene	0.73	0.0002	0.00070[3*]	0.00071[3*]
1,2-Trans-dichloroethylene	--	--	100*	4,000* (140,000[2])
1,2,4-Trichlorobenzene	--	--	0.071*	0.076* (940[2])
1,1,2-Trichloroethane	--	--	0.55[3*]	8.9[3*]
Trichloroethylene	--	--	0.6[3*]	7[3*]
1,1,1-Trichloroethane	--	--	10,000*	200,000*
2,4,6-Trichlorophenol	--	--	1.5[3]	2.8[3]
Tributyltin (TBT)_	0.46	0.072	--	--
Vinyl chloride	--	--	0.022[3*]	1.6[3*] (5,300[2])
p,p-Dichlorodiphenyldichloroethylene (DDE)	--	--	0.000018[3]	0.000018[3]
p,p-Dichlorodiphenyldichloroethane (DDD)	--	--	0.00012[3]	0.00012[3]
p,p-Dichlorodiphenyltrichloroethane (DDT)	1.1	0.001	0.000030[3]	0.000030[3]
2,4,5-Trichlorophenol	--	--	300	600
Chlorpyrifos	0.083	0.041	--	--
Demeton	--	0.1	--	--
Bis(Chloromethyl) Ether	--	--	0.00015	0.017
Guthion	--	0.01	--	--
Hexachlorocyclo-hexane-technical	--	--	0.0066	0.010
Malathion	--	0.1	--	--
Methoxychlor	--	0.03	100	--
Mirex	--	0.001	--	--
Dinitrophenols	--	--	10	1,000
Nitrosodibutylamine	--	--	0.0063	0.22
Nitrosodiethylamine	--	--	0.0008	1.24
Nitrosopyrolidine	--	--	0.016	34
Pentachlorobenzene	--	--	0.1	0.1
1,2,4,5-Tetrachlorobenzene	--	--	0.03	0.03
Tributyltin TBT	0.46	0.072	--	--
2,4,5-Trichlorophenol	--	--	300	600

Notes:
Totals metals analyses may be needed for other aspects of the RI/FS.
*EPA has issued a MCL for this chemical which may be more stringent. See 40 CFR Part 141.
NA – No federal numeric criteria for this parameter
1 Freshwater acute and chronic hardness-dependent criteria calculated based on normalized hardness value of 100.
2 These are state water quality criterion for human health (organism only) standards that differ from the federal standards.
3 Based on a carcinogenicity of 10^{-6} risk.
4 Preliminary acute and chronic criteria calculated based on a pH range of 6.5 to 8.0. Although the chronic criterion is temperature-dependent, the calculated standard does not vary over the temperature range observed in the four surface water bodies (0-14ºC).
5 Standards are based on the presence of salmonids and fish early life stages.
6 Standard is inversely proportional to pH (i.e., as the pH decreases, the standard increases).

[7] This recommended water quality criterion was derived from data for inorganic mercury (II), but is applied here to total mercury. If a substantial portion of the mercury in the water column is methylmercury, this criterion will probably be under protective. In addition, even though inorganic mercury is converted to methylmercury and methylmercury bioaccumulates to a great extent, this criterion does not account for uptake via the food chain because sufficient data were not available when the criterion was derived.

[8] This value was derived from data for endosulfan and is most appropriately applied to the sum of alpha-endosulfan and beta-endosulfan.

[9] The derivation of the CCC for this pollutant (Endrin) did not consider exposure through the diet, which is probably important for aquatic life occupying upper trophic levels.

Additional Notes:

L	–	Liter
MCL	–	Maximum contaminant level
mg/kg	–	milligrams per kilogram
mg/L	–	milligrams per liter
Rl	–	Remedial Investigation
Rl/FS	–	Remedial Investigation/Feasibility Study
µg/L	–	micrograms per liter

References for This Table: EPA National Recommended Water Quality Criteria
https://www.epa.gov/wqc/national-recommended-water-quality-criteria

Table 2-4. MDEQ-Circular 7 (DEQ-7) Montana Numeric Water Quality Standards

Chemical	Freshwater Aquatic Life		Human Health (13) (14)	
	Acute (1) µg/L	Chronic (2) µg/L	Surface Water µg/L	Ground Water µg/L
Inorganics				
Dissolved Aluminum (6)	750	87	--	--
Total Ammonia Nitrogen	(4)(5)	(4)(5)	--	--
Ammonium Sulfamate	--	--	1,000 HA	1,000 HA
Antimony	--	--	5.6	6
Arsenic (29)	340	150	10	10
Asbestos	--	--	7 million fibers/L	7 million fibers/L
Barium	--	--	1,000	1,000
Beryllium	--	--	4	4
Cadmium	0.52 @ 25 mg/L hardness (9)	0.097 @ 25 mg/L hardness (9)	5	5
Chromium, all forms	--	--	100	100
Chromium, hexavalent	16	11	--	--
Chromium, trivalent	579 @ 25 mg/L hardness (9)	27.7 @ 25 mg/L hardness (9)	--	--
Chlorine, total residual	19	11	4,000	4,000
Cyanide, total	22	5.2	4	200
Copper	3.79 @ 25 mg/L hardness (9)	2.85 @ 25 mg/L hardness (9)	1,300	1,300
Escherichia coli (Bacteria)	--	--	(10)	Less than 1 (3)
Gases, dissolved, total pressure (16)	110% of saturation	--	--	--
Hydrogen Sulfide	--	2	--	--
Iron	--	1,000	--	--
Lead	13.98 @ 25 mg/L hardness (9)	0.545 @ 25 mg/L hardness (9)	15	15
Mercury	1.7	0.91	0.005	2
Nickel	145 @ 25 mg/L hardness (9)	16.1 @ 25 mg/L hardness (9)	100	100
Nitrate (as N)	(8)	(8)	$1x10^4$	$1x10^4$
Nitrate plus nitrite (as N)	(8)	(8)	$1x10^4$	$1x10^4$
Nitrite (as N)	(8)	(8)	1,000	1,000
Nitrogen, total inorganic (as N)	(8)	(8)	--	--
Oxygen, dissolved (16)	(12)	(12)	--	--
Phosphorus, inorganic (16)	(8)	(8)	--	--
Radium 226	--	--	5 picoC/liter	5 picoC/liter
Radium 228	--	--	5 picoC/Liter	5 picoC/Liter
Radon 222	--	--	300 picoC/Liter	300 picoC/Liter
Selenium	20	5	50	50
Silver	0.374 @ 25 mg/L hardness (9)	--	100	100
Stronium	--	--	4,000	4,000
Temperature	(10)	(10)	--	--
Thallium	--	--	0.24	2
Turbidity (16)	(10)	(10)	--	--
Uranium, natural	--	--	30	30

Table 2-4. MDEQ-Circular 7 (DEQ-7) Montana Numeric Water Quality Standards

Chemical	Freshwater Aquatic Life		Human Health (13) (14)	
	Acute (1) µg/L	Chronic (2) µg/L	Surface Water µg/L	Ground Water µg/L
Zinc	37 @ 25 mg/L hardness (18)	37 @ 25 mg/L hardness (18)	7,400	2,000
Organics				
Acenaphthene	--	--	70	70
Acetochlor (23)	--	--	100	100
Acifluorfen	--	--	9.4	9.4
Acrolein	3	3	3	3
Acrylamide	3	3	0.7	0.7
Acrlonitrile	--	--	61	61
Alachlor (24)	--	--	2	2
Aldacarb (37)	--	--	3	3
Aldicarb Sulfone (37)	--	--	2	2
Aldicarb Sulfoxide (37)	--	--	4	4
Aldrin	1.5	--	$7.7x10^{-6}$	0.02
Alpha Emitters (8)	--	--	15 picoC/liter	15 picoC/liter
Alpha-Chlordane	--	--	0.008	1
Alpha-Hexachlorocyclohexane (HCH)	--	--	0.0036	0.0036
Ametryn	--	--	60	60
Aminomethylphosphonic Acid (AMPA)	--	--	2,000	2,000
Aminopyralid	--	--	3,000	3,000
Anthracene	--	--	3,000	2,100
Atrazine (25)	--	--	3	3
Azinophos and degredate azinphos methyl oxon metriltriazotion	--	--	10	10
Azoxystrobin	--	--	1,200	1,200
Bentazon	--	--	210	210
Benzene	--	--	5	5
Benzidine	--	--	0.0014	0.0014
Benzo(g,h,i)perylenene	--	--	--	--
Benzo(a)anthracene	--	--	0.012	0.5 (22)
Benzo(a)pyrene	--	--	0.0012	0.05
Benzo(b)fluoranthene	--	--	0.012	0.5 (22)
Benzo(k)fluoranthene	--	--	0.12	5 (22)
Beta Emitters	--	--	4 mrem/yr	4 mrem/yr
Beta-Chloronaphthalene	--	--	800	800
Beta-Hexachlorocyclohexane	--	--	0.08	0.08
Bis(2-Chloroethoxy)Methane	--	--	--	--
Bis(2-chloroethyl) ether	--	--	0.3	0.3
Bis(2-chloroisopropyl) ether	--	--	200	200
Bis(Chloromethyl)ether	--	--	0.0015	0.0015
Bromacil	--	--	700	700
Bromate	--	--	10	10
Bromodichloromethane	--	--	9.5	10
Bromoform	--	--	70	80
Bromoxynil	--	--	3.2	3.2

Table 2-4. MDEQ-Circular 7 (DEQ-7) Montana Numeric Water Quality Standards

Chemical	Freshwater Aquatic Life		Human Health (13) (14)	
	Acute (1) µg/L	Chronic (2) µg/L	Surface Water µg/L	Ground Water µg/L
Butyl Benzyl Phthalate	--	--	1	1
Butylate	--	--	300	300
Carbon tetrachloride	--	--	4	3
Carbaryl	--	--	70	70
Carbofuran	--	--	40	40
Carboxin	--	--	700	700
Chloramben	--	--	100	100
Chlordane	1.2	0.0043	0.0031	1
Chlorimuron Ethyl	--	--	600	600
Chlorite	--	--	1,000	1,000
Chlorobenzene	--	--	100	100
Chlorodibromomethane	--	--	4	4
Chlorothalonil			14	14
Chloroethane	--	--	--	--
Chloroform	--	--	60	70
2-Chlorophenol	--	--	30	30
Chlorophenyl Phenyl Ether, 4-	--	--	--	--
Chlorsulfuran	--	--	100	100
Chlorpyrifos	0.083	0.041	2	2
Chrysene	--	--	1.2	50 (22)
cis-1,2-Dichloroethylene	--	--	70	70
cis-1,3-Dichloropropene	--	--	3.4	4
Clopyralid	--	--	1,000	1,000
Clothianidin			650	650
Cyanazine	--	--	10 HA	10 HA
Dacthal	--	--	70	70
Dalapon	--	--	200	200
Demeton	--	0.1	0.3	0.3
Di(2-Ethylhexyl)Phthalate	--	--	3.2	6
Di(2-Ethylhexyl)Adipate	--	--	280	280
Diazinon	0.17	0.17	1 HA	1 HA
Dibenzo(a,h)anthracene	--	--	0.0012	0.05 (22)
1,2-Dibromoethane	--	--	0.017	0.017
Dibutyl Phthalate	--	--	20	20
Dicamba	--	--	200	200
1,2-Dichlorobenzene	--	--	600	600
1,3-Dichlorobenzene	--	--	7	600
1,4-Dichlorobenzene	--	--	75	75
3,3'-Dichlorobenzidine	--	--	0.49	0.49
Dichlorodifluoromethane	--	--	1,000	1,000
1,2-Dichloroethane	--	--	5	4
1,1-Dichloroethylene	--	--	7	7
2,4-Dichlorophenol	--	--	10	10
2,4- Dichlorophenoxyacetic Acid	--	--	70	70
1,2-Dichloropropane	--	--	5	5
1,3-Dichloropropene	--	--	2.7	2.7

Table 2-4. MDEQ-Circular 7 (DEQ-7) Montana Numeric Water Quality Standards

Chemical	Freshwater Aquatic Life		Human Health (13) (14)	
	Acute (1) µg/L	Chronic (2) µg/L	Surface Water µg/L	Ground Water µg/L
Dichlorprop	--	--	300	300
Dieldrin	0.24	0.056	1.2×10^{-5}	0.02
Diethyl phthalate	--	--	600	600
Difenoconazole	--	--	70	70
Dimethenamid and degredate demethenamid OA	--	--	300	300
Dimethoate	--	--	15 HA	15 HA
Dimethrin	--	--	2,000	2,000
Dimethyl phthalate	--	--	2,000	2,000
2,4-Dimethylphenol	--	--	100	100
4,6-Dinitro-o Cresol	--	--	2	2
2,4-Dinitrophenol	--	--	10	10
2,4-Dinitrotoluene	--	--	0.49	0.49
2,6-Dinitrotoluene	--	--	0.5	0.5
Dinitrophenols	--	--	10	10
Dinoseb	--	--	7	7
Dioxin Chlorinated Dibenzo-p-dioxins and Chlorinated Dibenzofurans	--	--	5×10^{-8} (7)	2×10^{-6} (7)
Diphenamid	--	--	200	200
1,2-Diphenylhydrazine	--	--	0.3	0.3
Diquat	--	--	20	20
Disulfoton	--	--	0.3	0.3
Diuron	--	--	10	10
Endosulfan (39)	0.11	0.056	20	20
Endosulfan, I (the cis isomer of Endosulfan)	0.11	0.056	20	20
Endosulfan, II (the trans isomer of endosulfan)	0.11	0.056	20	20
Endosulfan Sulfate	--	--	20	20
Endothall	--	--	100	100
Endrin	0.086	0.036	0.03	2
Endrin aldehyde	--	--	1	1
Epichlorohydrin	--	--	10	10
Ethion	--	--	3	3
Ethofumesate	--	--	2,000	2,000
Ethylbenzene	--	--	68	700
Fenamiphos	--	--	1.7	1.7
Fenbuconazole	--	--	93	93
Fipronil	--	--	1	1
Flucarbazone	--	--	3,000	3,000
Flucarbazone sulfonamide	--	--	3,000	3,000
Flumeturon	--	--	83	83
Fluoranthene	--	--	20	20
Fluorene	--	--	50	50
Fluoride	--	--	4,000	4,000
Fluroxypyr	--	--	7,000	7,000

Table 2-4. MDEQ-Circular 7 (DEQ-7) Montana Numeric Water Quality Standards

Chemical	Freshwater Aquatic Life		Human Health (13) (14)	
	Acute (1) µg/L	Chronic (2) µg/L	Surface Water µg/L	Ground Water µg/L
Fonofos	--	--	10	10
Gamma-Hexachlorocyclohexane (HCH) (Lindane)	0.95	--	0.2	0.2
Glufosinate ammonium			40	40
Glyphosate	--	--	700	700
Glyphosate Isopropylamine Salt	--	--	700	700
Guthion	--	0.01	--	--
Haloacetic acids (38)	--	--	60	60
Heptachlor	0.26	0.0038	$5.9x10^{-5}$	0.08
Heptachlor epoxide	0.26	0.0038	$3.2x10^{-4}$	0.04
Hexachlorobenzene (HCB)	--	--	$7.9x10^{-4}$	0.2
Hexachlorobutadiene	--	--	0.1	5
Hexachlorocyclohexane	--	--	.066	.066
Hexachlorocyclopentadiene	--	--	4	50
Hexachloroethane	--	--	1	30
Hexazinone	--	--	300	300
Imazalil (Parent name Enilconazole)	--	--	5.5	5.5
Imazamethabenz-methyl ester (includes the metabolit imazamethabenz methyl acid) (2)	--	--	1,700	1,700
Imazamox	--	--	20,000	20,000
Imazapic	--	--	3,000	3,000
Imazapyr	--	--	$1.7x10^{4}$	$1.7x10^{4}$
Imazethapyr	--	--	$1.7x10^{4}$	$1.7x10^{4}$
Imidacloprid	--	--	380	380
Ideno(1,2,3-cd)pyrene	--	--	0.012	0.5 (22)
Isophorone	--	--	350	400
m-Xylene	--	--	10,000	10,000
Malathion	--	--	470	470
MCPA	--	--	3	3
MCPP	--	--	300	300
Metalaxyl	--	--	400	400
Methamidophos	--	--	2	2
Methomyl	--	--	170	170
Methoxychlor	--	0.03	0.02	40
Metsulfuron Methyl	--	--	1,700	1,700
Methyl bromide	--	--	100	10
Methyl chloride	--	--	600	600
Methylene chloride	--	--	5	5
Metolachlor (includes the metabolites metolachlor ESA and metolachlor OA) (27)	--	--	1,000	1,000
Metribuzin	--	--	170	170
Mirex	--	0.001	1	1
Monochlorodibromomethane			8	8
MTBE	--	--	30 (17)	30 (17)

Table 2-4. MDEQ-Circular 7 (DEQ-7) Montana Numeric Water Quality Standards

Chemical	Freshwater Aquatic Life		Human Health (13) (14)	
	Acute (1) µg/L	Chronic (2) µg/L	Surface Water µg/L	Ground Water µg/L
Myclobutanil	--	--	170	170
N-Nitrosodimethylamine	--	--	0.0069	0.0069
N-Nitrosodi-n-propylamine	--	--	0.05	0.05
N-Nitrosodiphenylamine	--	--	33	33
N-Nitrosopyrrolidine	--	--	0.16	0.16
n-Dioctyl Phthalate	--	--	--	--
Naphthalene	--	--	100	100
Nicosulfuron	--	--	8,500	8,500
Nitrobenzene	--	--	10	10
Nitrosamines	--	--	0.008	0.008
Nitrophenol, 4-	--	--	50	50
o-Nitrophenol	--	--	--	--
Nitrosodibutylamine, N	--	--	0.063	0.063
Nitrosodiethylamine, N	--	--	0.008	0.008
Nonylphenol	28	6.6	--	--
o-Xylene	--	--	10,000	10,000
Oxamyl	--	--	200	200
Oxydemeton Methyl	--	--	0.7	0.7
p,p-Dichlorodiphenyldichloroethylene	--	--	$1.8x10^{-4}$	$1.8x10^{-4}$
p,p-Dichlorodiphenyldichloroethane	--	--	0.0012	0.0012
p,p-Dichlorodiphenyltrichloroethane	0.5	0.001	$3x10^{-4}$	$3x10^{-4}$
p-Bromodiphenyl Ether	--	--	--	--
p-Chloro-m-Cresol	--	--	500	500
p-Xylene	--	--	10,000	10,000
Paraquat Dichloride	--	--	30	30
Parathion	0.065	0.013	--	--
Pentachlorobenzene	--	--	0.1	0.1
Pentachlorophenol	5.3 @ pH of 6.5 (11)	4 @ pH of 6.5 (11)	0.3	1
Phenanthrene (PAH)	--	--	--	--
Phenol	--	--	4,000	4,000
Picloram	--	--	500	500
Pinoxaden (NOA 407855)O (28)	--	--	2,000	2,000
Polychlorinated Biphenyls (all PCBs)	--	0.014	0.00064	0.5
Primisulfuron Methyl	--	--	1,700	1,700
Prometon	--	--	100	100
Pronamide	--	--	500	500
Propachlor	--	--	87	87
Propane, 1,2-Dibromo-3-Dhloro-	--	--	0.2	0.2
Propazine	--	--	100	100
Propham	--	--	100	100
Propioconazole	--	--	700	700
Propoxur	--	--	24	24
Prosulfuron	--	--	350	350
Pyrasulfotole	--	--	70	70
Pyrene	--	--	20	20

Table 2-4. MDEQ-Circular 7 (DEQ-7) Montana Numeric Water Quality Standards

Chemical	Freshwater Aquatic Life		Human Health (13) (14)	
	Acute (1) µg/L	Chronic (2) µg/L	Surface Water µg/L	Ground Water µg/L
Pyroxsulam	--	--	7,000	7,000
Simazine	--	--	4	4
Styrene	--	--	100	100
Sulfentrazone			700	700
Sulfometuron Methyl			1,800	1,800
Sulfosulfuron	--	--	1,600	1,600
Tebuconazole	--	--	190	190
Tebuthiuron	--	--	500	500
Terbacil	--	--	83	83
Terbufos	--	--	0.83	0.83
1,2,4,5-Tetrachlorobenzene	--	--	0.03	0.03
1,1,2,2-Tetrachloroethane	--	--	2	2.0
Tetrachloroethylene	--	--	5	5
Thiamethozxam			80	80
Thifensulfuron Methyl	--	--	290	290
Toluene	--	--	57	1,000
Toxaphene	0.73	0.0002	0.007	0.3
Tralkoxydim (21)	3,750	--	30	30
trans-1,2-dichloroethylene	--	--	100	100
trans-1,3-Dichloropropene	--	--	2	2
Trans-Nonachlor	--	--	2	2
Triallate	--	--	4.6	4.6
Triasulfuron	--	--	70	70
Tribenuron Methyl	--	--	50	50
Tributyltin (TBT)	0.46	0.0072	--	--
1,2,4-Trichlorobenzene	--	--	0.071	70
1,1,2-Trichloroethane	--	--	5	3
Trichloroethylene	--	--	5	5
1,1,1-Trichloroethane	--	--	200	200
Trichlorofluoromethane (HM)	--	--	2,000	2,000
2,4,5-Trichlorophenol	--	--	300	300
2,4,6-Trichlorophenol	--	--	15	30
Trichlorophenoxy Proprionic Acid, 2 (2,4,5-)	--	--	50	50
Trichlorophenoxyacetic Acid	--	--	70	70
Triclopyr	--	--	300	300
Trifluralin	--	--	43	43
Trihalomethanes, total	--	--	80	80
Triticonazole	--	--	1,100	1,100
Vinyl 2-Chloroethyl Ether	--	--	--	--
Vinyl chloride	--	--	0.22	0.2
Xylenes	--	--	10,000	10,000

Notes:
Reference for This Table: http://deq.mt.gov/Portals/112/Water/WQPB/Standards/SB235Rulemaking/DEQ-7_Final_April2017.pdf

-- = No Montana numeric criteria for this parameter

(1) The one-hour average concentration of these parameters in surface waters may not exceed these values more than once in any three year period, on average, with the exception of silver, which, at present, is interpreted as a “not to exceed” value.

(2) The 96 hour average concentration of these parameters in surface waters may not exceed these values more than once in any three year period, on average.

(3) The 24 hour geometric mean value must not exceed these values.

(4) Freshwater Aquatic Life Standards for total ammonia nitrogen (µg/L NH_3-N plus NH_4-N).

Because these formulas are non-linear in pH and temperature, the Standard is the average of separate evaluations of the formulas reflective of the fluctuations of pH and temperature within the averaging period; it is not appropriate to apply the formula to average pH and temperature. See https://deq.mt.gov/Portals/112/Water/WQPB/Standards/PDF/DEQ7/FinalApprovedDEQ7.pdf, Footnote 4 for details.

(5) A plant nutrient, excessive amounts of which may cause violations of Administrative Rules of Montana (ARM) 17.30.637 (1)(e).

(6) Approved methods of sample preservation, collection, and analysis for determining compliance with the standards set forth in DEQ-7 are found in the surface water quality standards (ARM17.30.601, et seq.) and the ground water rules (ARM 17.30.1001, et seq.).

Standards for metals (except aluminum) in surface water are based upon the analysis of samples following a "total recoverable" digestion procedure (EPA Method 200.2, Supplement I, Rev. 2.8, May, 1994).

Standards for alpha emitters, beta emitters and gamma emitters in surface waters are based upon the analysis of unfiltered samples and appropriate EPA approved analysis methods.

Standards for metals in ground water are based upon the dissolved portion of the sample (after filtration through a 0.45 µm membrane filter, as specified in "Methods for Analysis of Water and Wastes" 1983, Environmental Monitoring and Support Laboratory, U.S. Environmental Protection Agency, EPA-600/4-79-020, or equivalent). Standards for alpha emitters, beta emitters and gamma emitters in ground water are based upon the analysis of filtered samples and appropriate EPA approved analysis methods.

Standard for organic parameters in surface water and ground water are based on unfiltered samples.

(7) Calculation of an equivalent concentration of 2,3,7,8-TCDD is to be based on congeners of CDDs/CDFs and the toxicity equivalency factors (TEF) in van den Berg, M: et al. (2006) The 2005 World Health Organization Re-evaluation of Human and Mammalian Toxic Equivalency Factors for Dioxins and Dioxin-like Compounds. Toxicological Sciences 93(2):223-241. The analysis method to be used is EPA Method 1613, Revision B, Tetra- through Octa-Chlorinated Dioxins and Furans by Isotope Dilution HRGC/HRMS), EPA Method 8290, or other method approved by the department on case by case basis. The Required Reporting Value(s) (RRV) for Dioxin and congeners are to be the lowest detection level for the analysis method approved by the Department.

(8) Radionuclides consisting of alpha emitters, beta emitters and gamma emitters are classified as carcinogens. “Alpha emitters” means the total radioactivity due to alpha particle emission. “Beta emitters” means the total radioactivity due to beta particle emission. “Gamma emitters” means the total radioactivity due to gamma particle emission. The emitters covered under this Standard include but are not limited to: Cesium, radioactive Iodine, radioactive Strontium-89 and -90, radioactive Tritium Gamma photon emitters.

(9) Freshwater Aquatic Life Standards for these metals are expressed as a function of total hardness (mg/L, CaCO3). The values displayed in the chart correspond to a total hardness of 25 mg/L. The hardness relationships are:

	Acute = exp.{ma[ln(hardness)]+ba}		**Chronic = exp.{mc[ln(hardness)]+bc}**	
	ma	**ba**	**mc**	**Bc**
Cadmium	1.0166	-3.924	0.7409	-4.719
Copper	0.9422	-1.700	0.8545	-1.702
Chromium (III)	0.819	3.7256	0.819	0.6848
Lead	1.273	-1.46	1.273	-4.705
Nickel	0.846	2.255	0.846	0.0584
Silver	1.72	-6.52		
Zinc	0.8473	0.884	0.8473	0.884

Note: If the hardness is <25mg/L as CaCO3, the number 25 must be used in the calculation. If the hardness is greater than or equal to 400 mg/L as CaCO3, 400 mg/L must be used in the calculation.

(10) This standard is based upon Water-Use Classifications. See Administrative Rules of Montana (ARM), title 17, Chapter 30 - Water Quality, Sub-Chapter 6 - Surface Water Quality Standards.

(11) Freshwater Aquatic Life Standard for pentachlorophenol is dependent on pH. Values displayed in the chart correspond to a pH of 6.5 and are calculated as follows:

Acute = exp[1.005(pH) - 4.869] Chronic = exp[1.005(pH) - 5.134]

(12) Freshwater Aquatic Life Standards for dissolved oxygen in milligrams per liter are as follows:

	Standards for Waters Classified A-1, B-1, B-2, C-1, and C-2		**Standards for Waters Classified B-3, C-3, and I**	
	Early Life Stages[1,2]	**Other Life Stages**	**Early Life Stages[2]**	**Other Life Stages**
30 Day Mean	N/A[3]	6.5	N/A[3]	5.5
7 Day Mean	9.5 (6.5)	N/A[3]	6.0	N/A[3]
7 Day Mean Minimum	N/A[3]	5.0	N/A[3]	4.0
1 Day Minimum[4]	8.0 (5.0)	4.0	5.0	3.0

[1]These are water column concentrations recommended to achieve the required inter-gravel dissolved oxygen concentrations shown in parentheses. For species that have early life stages exposed directly to the water column, the figures in parentheses apply.

[2]Includes all embryonic and larval stages and all juvenile forms of fish to 30-days following hatching.

[3]N/A (Not Applicable).

[4]All minima should be considered as instantaneous concentrations to be achieved at all times.

(13) Surface or groundwater concentrations may not exceed these values.

(14) Source of the criteria used to derive the standard: PP = priority pollutant criteria

NPP = non-priority pollutant criteria
OL= organoleptic pollutant criteria

MCL = Maximum contaminant level from the drinking water regulations

HA = health advisory developed from EPA's "Drinking Water Standards and Health Advisories" (October 1996) guidance, using recent scientific evidence and verified by EPA Region VIII toxicologist

(15) The Narrative Standards are located in the Administrative Rules of Montana (ARM) 17.30.601 et seq. and ARM 17.30.1001 et seq.

Applicable to surface waters only.

(16) Based on taste and odor thresholds given in EPA 822-f-97-008 December 1997.

(17) Trigger Values are used to determine if a given increase in the concentration of toxic parameters is significant or non-significant as per the non-degradation rules ARM 17.30.701 et seq. The acronym "N/A" means "not applicable".

(18) The sum of the concentrations of tralkoxydim and its breakdown products shall not exceed the standards listed. For a list of known breakdown products, see EPA memorandum "EFED's Section 3 Review for Tralkoxydim (Chemical #121000; Case # 060780; DP Barcodes 0234682, 0234752, 0238697, 0235723 & 0239519)," and the associated "Environmental Fate Assessment for Tralkoxydim."

(19) Ground water human health standard is based on the relative potency for selected PAH compounds listed in Table 8 of the EPA "Provisional Guidance for Quantitative Risk Assessment of Polycyclic Aromatic Hydrocarbons" July 1993, EPA/600/R-93/089.

(20) The sum of the concentrations of acetochlor and the breakdown products, acetochlor ESA and acetochlor OA, shall not exceed the standards listed.

(21) The sum of the concentrations of alachlor and the breakdown products, alachlor ESA and alachlor OA, shall not exceed the standards listed.

(22) The sum of the concentrations of atrazine and the breakdown products, deethyl atrazine, deisopropyl atrazine, and deethyl deisopropyl atrazine, shall not exceed the standards listed.

(23) The sum of the concentrations of imazamethabenz-methyl ester and the breakdown product, imazamethabenz-methyl acid, shall not exceed the standards listed.

(24) The sum of the concentrations of metolachlor and the breakdown products, metolachlor ESA and metolachlor OA, shall not exceed the standards listed.

(25) The sum of the concentrations of pinoxaden (NOA 407855) and the breakdown products, pinoxaden NOA 407854 and pinoxaden NOA 447204, shall not exceed the standards listed.

(26) The human health criteria for arsenic is the more restrictive of the risk based level of 1 in 1000 [$1x10^{-3}$], or the MCL.

(27) The quantitative combination of two or more of Aldicarb, Aldicarb sulfone and Aldicarb sulfoxide shall not exceed 7 µg/L because each has a similar mode of action.

(28) The quantitative sum of all listed Haloacetic acids is used in determining the total Haloacetic acid concentration.

(29) The sum of the concentrations of Endosulfan and its isomers Endosulfan I and Endosulfan II shall not exceed the standards listed.

Additional Notes:

FFS – Final Feasibility Study
L – Liter
MCL – Maximum contaminant level
mg/kg – milligrams per kilogram
mg/L – milligrams per liter
µg/L – micrograms per liter

Table 2-5. MDEQ-Circular 12A (DEQ-12A) Montana Numeric Nutrient Water Quality Standards

Chemical	Period When Criteria Apply[3]	Ecoregion[1,2]	Numeric Nutrient Standard (ug/L)[4]
Total Phosphorus	July 1 to September 30	Northern Rockies (15)[5]	25
Total Nitrogen	July 1 to September 30	Northern Rockies (15)[5]	275

Notes:
Reference for This Table:
https://deq.mt.gov/Portals/112/Water/WQPB/Standards/PDF/NutrientRules/CircularDEQ12A_July2014_FINAL.pdf

[1] Ecoregions are based on the 2009 version (version 2) of the U.S. Environmental protection Agency maps.
2 Within and among the geographic regions or watersheds listed, base numeric nutrient standards of the downstream reaches or other downstream reaches or other downstream waterbodies must continue to be maintained.
[3] For the purposes of ambient surface water monitoring and assessment only, a ten-day window (plus/minus) on the beginning and ending dates of the period when the criteria apply is allowed in order to accommodate year-specific conditions (an early-ending spring runoff, for example).
[4] The average concentration during a period when the standards apply may not exceed the standards more than once in any five-year period, on average.
[5] The Libby site is within the Northern Rockies Ecoregion 15, according to the U.S. Environmental Agency maps.

Additional Notes:

FFS – Final Feasibility Study
L – Liter
MDEQ – Montana Department of Environmental Quality
µg/L – micrograms per liter

Table 2-6. Class I Groundwater Standards
ARM 17.30.1006

Parameter	Standard
Quality of Class I ground water must be maintained so that these waters are suitable for the following beneficial uses with little or no treatment: i. Public and private water supplies ii. Culinary and food processing purposes iii. Irrigation iv. Drinking water for livestock and wildlife v. Commercial and industrial purposes	No numeric standard
All toxic, carcinogenic, radioactive, nutrients, and harmful parameters listed in Circular DEQ-7 with human health criteria standards	Must meet Montana Numeric Water Quality Ground Water Standards, see Table 2-4
Parameters for which human health standards are not listed in Circular DEQ-7	No increase of a parameter to a level that renders the waters harmful, detrimental, or injurious to the beneficial uses listed for Class I water
Degradation of high-quality waters may not be authorized unless necessary because there are no economically, environmentally, and technologically feasible modifications to the proposed project that would result in no degradation	No numeric standard

Notes:

*Class I ground waters are those ground waters with a natural specific conductance less than or equal to 1,000 microSiemens/cm at 25 degrees C. Based on information in Section 4.3.5 of the 1988 Feasibility Study for Site Remediation, Libby Montana, the State of Montana has designated the ground water outside of the contaminant plume in Libby, Montana as Class 1.

**The ground water quality standards for metal parameters are based on the dissolved portion (after filtration through a 0.45 micron filter) of the contaminant in the ground water. The ground water quality standards for other parameters in Circular DEQ-7 are based upon unfiltered samples. For inorganic parameters, compliance with standards based on filtered samples must be assumed if analyses using the total recoverable method demonstrates compliance with the numerical standards.

Table 2-7. Montana Surface Water Criteria
A-1 Classification Standards, Includes Flower Creek Drainage to Libby Water Supply Intake (ARM 17.30.60)
(As Listed at ARM 17.30.622)

Parameter	Standard[7]
--	Suitable for drinking, culinary and food processing[1]
--	Suitable for bathing, swimming, and recreation, growth and progation of salmonid fishes and associated aquatic life, waterfowl, and furbearers, and agricultural and industrial water supply[2]
pH	6.5 - 8.5[4]
Temperature	≤ 67° F[5]
Dissolved Oxygen	See Table 2-3 for applicable MDEQ Circular DEQ-7 standard
Turbidity	No increase above naturally occurring turbidity or suspended sediment is allowed except as permitted in 75-5-318 MCA
Sediment, suspended sediment, settleable solids, oils, or floating solids	No increases are allowed above naturally occurring concentrations are allowed, which will or are likely to create a nuisance or render the waters harmful, detrimental, or injurious to public health, recreation, safety, welfare, livestock, wild animals, birds, fish, or other wildlife.
Color	True color must not be increased more than two color units above naturally-occurring color
Carcinogenic, bioconcentrating, toxic, radioactive, nutrient, or harmful parameters	Concentrations may not exceed the applicable standards set forth in MDEQ Circular DEQ-7 standard (see Table 2-3), and unless a variance has been granted, MDEQ Circular DEQ-12A (see Table 2-4)[6]
E. coli bacteria (10% of monthly geometric mean samples)[3]	≤ 64 cfu/100 mL
E. coli bacteria (monthly geometric mean)[3]	≤ 32 cfu/100 mL
--	
Dischargers issued permits under ARM 17.30.13	Must conform with nondegredation rules (ARM 17.30.7), and may not cause receiving water concentrations to exceed applicable MDEQ Circular DEQ-7 standards or MDEQ Circular DEQ-12A standards, unless a nutrient standards variance has been granted (when stream flows equal or exceed the design flows specified in ARM 17.30.635(2).

Notes:

[1]Waters classified A-1 are to be maintained suitable for drinking, culinary and food processing purposes after conventional treatment for removal of naturally present impurities.

[2] Water quality must be maintained suitable for bathing, swimming, and recreation; growth and propagation of salmonid fishes and associated aquatic life, waterfowl and furbearers; and agricultural and industrial water supply.

[3]The geometric mean number of E. coli bacteria may not exceed 32 colony forming units per 100 ml and 10% of the samples may not exceed 64 colony forming units per 100 ml during any 30-day period if resulting from domestic sewage. Criteria based on a pH range of 6.6 to 8.8, temperature of 0 to 20ºC, and fish early life stages present.

[4]Induced variation of hydrogen ion concentration (pH) within the range of 6.5-8.5 must be less than 0.5 pH unit. Natural pH outside this range must be maintained without change. Natural pH above 7.0 must be maintained above 7.0.

[5]A 1° F maximum increase above naturally occurring water temperature is allowed within the range of 32° F to 66° F; within the naturally range of 66° F to 66.5° F, no discharge is allowed which will cause the water temperature to exceed 67° F; and where the naturally occurring water temperature is >=66.5° F, the maximum allowable increase in water temperature is 0.5° F. A 2° F-per-hour maximum decrease below naturally occurring water temperature is allowed when the water temperature is > 55° F. A 2° F maximum decrease below naturally occurring water temperature is allowed within the range of 55° F to 32° F.

[6]If site-specific criteria for aquatic life are adopted using the procedures in 75-5-310 MCA, the criteria shall be used as water quality standards for the affected waters and as the basis for permit limits instead of the applicable standards in MDEQ Circular DEQ-7.

[7] In accordance with MCA 75-5-306, it is not necessary that wastes be treated to a purer condition than the natural condition of the receiving water as long as the minimum treatment requirements, adopted pursuant to MCA 75-5-305 are met .

ARM - Administrative Rules of Montana	mL - milliliter
cfu - Colony forming units	°F - Degrees Fahrenheit
MCA - Montana Code Annotated	≤ - Less than or equal to
MDEQ - Montana Department of Environmental Quality	≥ - Greater than or equal to

Table 2-8. Montana Surface Water Criteria
B-1 Classification Standards, Includes Kootenai River Drainage (ARM 17.30.609)
(As Listed at ARM 17.30.623)

Parameter	Standard[5]
--	Maintained suitable for drinking, culinary and food processing purposes, after conventional treatment, bathing, swimming, and recreation, growth and progation of salmonid fishes and associated aquatic life, waterfowl, and furbearers, and agricultural and industrial water supply
pH	6.5 - 8.5[1]
Temperature	$\leq$ 67° F[2]
Dissolved Oxygen	See Table 2-3 for applicable MDEQ Circular DEQ-7 standard
Turbidity	Maximum allowable increase above naturally occurring turbidity is 5 nephelometric turbidity units except as permitted in 75-5-318 MCA
Sediment, suspended sediment, settleable solids, oils, or floating solids	No increases are allowed above naturally occurring concentrations are allowed, which will or are likely to create a nuisance or render the waters harmful, detrimental, or injurious to public health, recreation, safety, welfare, livestock, wild animals, birds, fish, or other wildlife.
Color	True color must not be increased more than five color units above naturally-occurring color
Carcinogenic, bioconcentrating, toxic, radioactive, nutrient, or harmful parameters	Concentrations may not exceed the applicable standards set forth in MDEQ Circular DEQ-7 standard (see Table 2-3), and unless a nutrient standards variance has been granted, MDEQ Circular DEQ-12A (see Table 2-4)[4]
E. coli bacteria (10% of monthly geometric mean samples), April through October[3]	$\leq$ 252 cfu/100 mL
E. coli bacteria (monthly geometric mean), April through October[3]	$\leq$ 126 cfu/100 mL
E. coli bacteria (10% of monthly geometric mean samples), November through March[3]	$\leq$ 1,260 cfu/100 mL
E. coli bacteria (monthly geometric mean), November through March[3]	$\leq$ 630 cfu/100 mL
Dischargers issued permits under ARM 17.30.13	Must conform with nondegredation rules (ARM 17.30.7), and may not cause receiving water concentrations to exceed applicable MDEQ Circular DEQ-7 standards or MDEQ Circular DEQ-12A standards, unless a nutrient standards variance has been granted (when stream flows equal or exceed the design flows specified in ARM 17.30.635(2).

Notes:

[1]Induced variation of hydrogen ion concentration (pH) within the range of 6.5-8.5 must be less than 0.5 pH unit. Natural pH outside this range must be maintained without change. Natural pH above 7.0 must be maintained above 7.0.

[2]A 1° F maximum increase above naturally occurring water temperature is allowed within the range of 32° F to 66° F; within the naturally range of 66° F to 66.5° F, no discharge is allowed which will cause the water temperature to exceed 67° F; and where the naturally occurring water temperature is >=66.5° F, the maximum

[3]The geometric mean number of E. coli bacteria may not exceed 126 colony forming units per 100 ml and 10% of the samples may not exceed 252 colony forming units per 100 ml during any 30-day period (between April and October) or 630 colony forming units per 100 ml and 10% of the samples may not exceed 1260 colony forming units per 100 ml during any 30-day period (between November and March).

[4]If site-specific criteria for aquatic life are adopted using the procedures in 75-5-310 MCA, the criteria shall be used as water quality standards for the affected waters and as the basis for permit limits instead of the applicable standards in MDEQ Circular DEQ-7.

[5] In accordance with MCA 75-5-306, it is not necessary that wastes be treated to a purer condition than the natural condition of the receiving water as long as the minimum treatment requirements, adopted pursuant to MCA 75-5-305 are met

MDEQ - Montana Department of Environmental Quali	°F - Degrees Fahrenheit
ARM - Administrative Rules of Montana	$\leq$ - Less than or equal to
MCA - Montana Code Annotated	$\geq$ - Greater than or equal to
mL - milliliter	cfu - Colony forming units

Table 2-9. Federal MCLs
(40 CFR 141)

Contaminant	MCL (mg/L)	MCL (µg/L)
Primary Inorganics (40 CFR 141.62)		
Antimony	0.006	6
Asbestos	7 million fibers/liter (longer than 10 µm)	7 million fibers/liter (longer than 10 µm)
Arsenic	0.010	10
Barium	2	2,000
Beryllium	0.004	4
Cadmium	0.005	5
Chromium	0.1	100
Cyanide (as free cyanide)	0.2	200
Fluoride	4.0	4,000
Mercury	0.002	2
Nickel*	0.1*	100*
Nitrate (as N)	10	10,000
Nitrite (as N)	1	1,000
Total Nitrite and Nitrate (as N)	10	10,000
Selenium	0.05	50
Thallium	0.002	2
Primary Organics (40 CFR 141.61)		
Vinyl chloride	0.002	2
Benzene	0.005	5
Carbon tetrachloride	0.005	5
1,2-Dichloroethane	0.005	5
Trichloroethylene	0.005	5
para-Dichlorobenzene	0.075	75
1,1-Dichloroethylene	0.007	7
1,1,1-Trichloroethane	0.2	200
cis-1,2-Dichloroethylene	0.07	70
1,2-Dichloropropane	0.005	5
Ethylbenzene	0.7	700
Monochlorobenzene	0.1	100
o-Dichlorobenzene	0.6	600
Styrene	0.1	100
Tetrachloroethylene	0.005	5
Toluene	1	1,000
trans-1,2-Dichloroethylene	0.1	100
Xylenes (total)	10	10,000
Dichloromethane	0.005	5
1,2,4-Trichlorobenzene	0.07	70
1,1,2-Trichloroethane	0.005	5

Table 2-9. Federal MCLs
(40 CFR 141)

Contaminant	MCL (mg/L)	MCL (µg/L)
Primary Synthetic Organics (40 CFR 141.61)		
Alachlor	0.002	2
Aldicarb	0.003	3
Aldicarb sulfoxide	0.004	4
Aldicarb sulfone	0.002	2
Atrazine	0.003	3
Carbofuran	0.04	40
Chlordane	0.002	2
Dibromochloropropane	0.0002	0.2
2,4-D	0.07	70
Ethylene dibromide	0.00005	0.05
Heptachlor	0.0004	0.4
Heptachlor epoxide	0.0002	0.2
Lindane	0.0002	0.2
Methoxychlor	0.04	40
Polychlorinated biphenyls (PCBs)	0.0005	0.5
Pentachlorophenol	0.001	1
Toxaphene	0.003	3
2,4,5-TP	0.05	50
Benzo[a]pyrene	0.0002	0.2
Dalapon	0.2	200
Di(2-ethylhexyl) adipate	0.4	400
Di(2-ethylhexyl) phthalate	0.006	6
Dinoseb	0.007	7
Diquat	0.02	20
Endothall	0.1	100
Endrin	0.002	2
Glyphosate	0.7	700
Hexachlorobenzene	0.001	1
Hexachlorocyclopentadiene	0.05	50
Oxamyl (Vydate)	0.2	200
Picloram	0.5	500
Simazine	0.004	4
2,3,7,8-TCDD (Dioxin)	3×10^{-8}	3×10^{-5}
Turbidity (40 CFR 141.13)		
Turbidity (monthly average)	1 turbidity unit (TU)	1 TU
Turbidity (average for 2 consecutive days)	5 TUs	5 TUs

Table 2-9. Federal MCLs
(40 CFR 141)

Contaminant	MCL (mg/L)	MCL (µg/L)
Microbiological Contaminants (40 CFR 141.63)		
Systems collecting at least 40 samples per month: no more than 5.0 percent of samples during the month may be total coliform-positive.		
Systems collecting less than 40 samples per month: no more than one sample collected during a month may be total coliform-positive.		

Notes:

* The federal MCL and MCLG for nickel were remanded on February 9, 1995. All other rules pertaining to nickel, including monitoring requirements and best available treatment technology development, remain in effect.

µg/L – micrograms per liter
µm – micrometer
CFR – Code of Federal Regulations
Cl_2 – Chloride
ClO_2 – Chlorine dioxide
MCLG – Maximum contaminant level goal
MCLs – Maximum contaminant levels
mg/L – milligrams per liter
NMAC – New Mexico Administrative Code
pCi/L – picocuries per liter
TCDD – tetrachlorodibenzodioxin
TU – Turbidity Unit

Table 2-10. Montana MCLs
(ARM 17.38.201A – 17.38.219)

Contaminant	MCL
Maximum Inorganic Chemical Contaminant Levels (ARM 17.38.203)	
Arsenic	40 CFR 141.6(j) and 141.6(k) adopted and incorporated by reference
Inorganic Contaminants	40 CFR 141.1 and 141.62(b) adopted and incorporated by reference
Maximum Residual Disinfectant Levels	40 CFR 141.65 adopted and incorporated by reference
Action Levels for Lead and Copper	40 CFR 141.80(c) adopted and incorporated by reference
Maximum Organic Chemical Contaminant Levels (ARM 17.38.204)	
Synthetic Organic Contaminants, Volatile Organic contaminants, and Disinfection Byproducts	40 CFR 141.61(a), 141.61(c), 141.64(a) and (a)(1), 141.64(b)(1)(i), and 141.64(b)(2)(i) adopted and incorporated by reference
Maximum Turbidity Contaminant Levels (ARM 17.38.205)	
Turbidity	40 CFR 141.13, 141.73, 141.173, 141.550, and 141.551 adopted and incorporated by reference except for the following changes:
	"One turbidity unit" means 1.0 nephelometric turbidity unit and "five turbidity units" means 5.0 nephelometric turbidity units.
	40 CFR 141.73(a)(1) replaced with…
	40 CFR 141.73(a)(2) replaced with…
	First sentence in 40 CFR 141.551 replaced with….
	Turbidity measurements may be invalidated by MDEQ based on documentation that……
Maximum Microbiological Contaminant Levels (ARM 17.38.207)	
Microbiological Contaminants	40 CFR 141.63(a), 141.63(b), and 141.63(c0 adopted and incorporated by reference.

Notes:

CFR – Code of Federal Regulations
MCLs – Maximum contaminant levels
MCLG – Maximum contaminant level goal
ARM – Administrative Rules of Montana
µg/L – micrograms per liter

Table 2-11. Action Levels for Lead and Copper
[ARM 17.38.201A and 17.38.203(d), which adopts by reference 40 CFR Part 141.80(c)]

Contaminant	Action Level
Lead	0.015 mg/L (90^{th} percentile level)
Copper	1.3 mg/L (90^{th} percentile level)

Notes:
CFR – Code of Federal Regulations
mg/L – milligrams per liter
ARM – Administrative Rules of Montana

Table 2-12. Federal Maximum Contaminant Level Goals (MCLGs) (40 CFR 141.50 - 141.55)

Contaminant	MCLG (µg/L)
Maximum Contaminant Level Goals for Organic Contaminants [40 CFR 141.50(b)]	
1,1-Dichloroethylene	7
1,1,1-Trichloroethane	200
para-Dichlorobenzene	75
Aldicarb	1
Aldicarb sulfoxide	1
Aldicarb sulfone	1
Atrazine	3
Carbofuran	40
o-Dichlorobenzene	600
cis-1,2-Dichloroethylene	70
trans-1,2-Dichloroethylene	100
2,4-D	70
Ethylbenzene	700
Lindane	0.2
Methoxychlor	40
Monochlorobenzene	100
Styrene	100
Toluene	1,000
2,4,5-TP	50
Xylenes (total)	10,000
Dalapon	200
Di(2-ethylhexyl) adipate	400
Dinoseb	7
Diquat	20
Endothall	100
Endrin	2
Glyphosate	700
Hexachlorocyclopentadiene	50
Oxamyl (Vydate)	200
Picloram	500
Simazine	4
1,2,4-Trichlorobenzene	70
1,1,2-Trichloroethane	3

Table 2-12. Federal Maximum Contaminant Level Goals (MCLGs) (40 CFR 141.50 - 141.55)

Contaminant	MCLG (µg/L)
Maximum Contaminant Level Goals for Inorganic Contaminants (40 CFR 141.51)	
Antimony	6
Asbestos	7 million fibers/liter (longer than 10 µm)
Barium	2,000
Beryllium	4
Cadmium	5
Chromium	100
Copper	1,300
Cyanide (as free Cyanide)	200
Fluoride	4,000
Mercury	2
Nitrate	10,000 (as Nitrogen)
Nitrite	1,000 (as Nitrogen)
Total Nitrate+Nitrite	10,000 (as Nitrogen)
Selenium	50
Thallium	0.5

Notes:
CFR – Code of Federal Regulations
MCLG – maximum contaminant level goals
µg/L – micrograms per liter
µm – micrometer

Table 2-13. Threatened and Endangered Species in Montana

Common Name	Scientific Name	Federal Status	Montana State Status[1]
Animals			
Bat, Northern long-eared	*Myotis septentrionalis*	T	
Bear, Grizzly	*Ursus arctos horribilis*	T	
Black-footed ferret [1]	*Mustela nigripes*	E	E
Cuckoo, Yellow-billed	*Coccyzus americanus*	T	
Least tern, interior	*Sterna antillarum*	E	
Lynx, Canada Contiguous US DPS	*Lynx canadensis*	T	
Plover, piping	*Charadrius melodus*	T	
Red Knot	*Calidris canutus rufa*	T	
Stonefly, Meltwater Lednian	*Lednia tumana*	P	
Stonefly, Western Glacier	*Zapada glacier*	P	
Sturgeon, pallid	*Scaphirhynchus albus*	E	
Sturgeon, white	*Acipenser transmontanus*	E	
Trout, Bull	*Salvelinus confluentus*	T	
Whooping crane	*Grus americana*	E	E
Wolf, Northern Rocky Mountain[2]	*Canis lupus irremotus*	E	E
Wolverine	*Gulo gulo luscus*	P	
Plants			
Howellia, water	*Howellia aquatilis*	T	
Ladies'-tresses, Ute	*Spiranthes diluvialis*	T	
Pine, whitebark	*Pinus albicaulis*	C	
Spalding's Catchfly	*Silene spaldingii*	T	

Notes:

C – Candidate
E – Endangered
MFW&P – Montana Fish, Wildlife, and Parks
P – Proposed
T – Threatened
USFWS – U.S. Fish and Wildlife Service
USFWS Montana Federal species accessed 5/31/2017, memorandum dated at https://www.fws.gov/montanafieldoffice/Endangered_Species/Listed_Species/TEClist.pdf

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[1] Administrative Rules of Montana 12.5.201
[2] *Canis lupus* is federally listed, with no subspecies

Table 2-14. National Ambient Air Quality Standards
(40 CFR Part 50)

Pollutant		Averaging Time	Level	Form
Carbon Monoxide (CO)		8 hours	9 ppm	Not to be exceeded more than once per year
		1 hour	35 ppm	
Lead (Pb)		Rolling 3 month average	0.15 μg/m^3	Not to be exceeded
Nitrogen Dioxide (NO_2)		1 hour	100 ppb	98th percentile of 1-hour daily maximum concentrations, averaged over 3 years
		1 year	53 ppb	Annual Mean
Ozone (O_3)		8 hours	0.070 ppm	Annual fourth-highest daily maximum 8-hour concentration, averaged over 3 years
Particle Pollution (PM)	$PM_{2.5}$	1 year	12.0 μg/m^3	annual mean, averaged over 3 years
		1 year	15.0 μg/m^3	annual mean, averaged over 3 years
		24 hours	35 μg/m^3	98th percentile, averaged over 3 years
	PM_{10}	24 hours	150 μg/m^3	Not to be exceeded more than once per year on average over 3 years
Sulfur Dioxide (SO_2)		1 hour	75 ppb	99th percentile of 1-hour daily maximum concentrations, averaged over 3 years
		3 hours	0.5 ppm	Not to be exceeded more than once per year

Notes:
CFR – Code of Federal Regulations
PM_{10} – Particulate matter 10 microns in size or smaller
μg/m^3 – micrograms per cubic meter

Table 2-15. Montana Ambient Air Quality Standards and Air Pollution Control Requirements

Contaminant	Requirement	Description
NAAQS (refer to Table 2-13)	ARM 17.8.202	40 CFR Part 50 incorporated by reference
PM	ARM 17.8.220	Prohibits causing or contributing to concentrations of particulate matter in the ambient air such that the mass of settle particulate matter exceeds a 30-day average; 10 gm/m^2, 30-day average, not to be exceeded. A measurement method is also provided
PM	ARM 17.8.304 and 17.8.308	Emissions of airborne particulate matter must be controlled so that they do not "exhibit an opacity of 20% or greater average over six consecutive minutes
PM	ARM 17.8.308	No person shall cause or authorize the production, handling, transportation or storage of any material; or cause or authorize the use of any street, road, or parking lot; or operate a construction facility or demolition project, unless reasonable precautions to control emissions of airborne particulate matter are taken
Hydrocarbons	ARM 17.8.324	Contains certain standards regarding hydrocarbon emissions and the treatment, storage, and handling of petroleum products
NAAQS/MAAQS	Control of Air Pollution, Lincoln County 75.1.104	Actions to be taken to identify source(s) in Lincoln County that contribute to the NAAQS/MAAQS if the county fails to attain NAAQS/MAAQS
PM	Control of Air Pollution, Lincoln County 75.1.206 (40 CFR Part 50.6)	Air pollution alerts can be issued when particulate matter exceeds a level 20% below a state or federal standard for particulates
Dust	Control of Air Pollution, Lincoln County 75.1.305 (40 CFR 50.6)	Actions must be taken to prevent vehicular carry-on and windborne entrainment of dust on unpaved/untreated roads, parking lots or commercial lots

Notes:
ARM – Administrative Rules of Montana
MAAQS – Montana Ambient Air Quality Standards
NAAQS – National Ambient Air Quality Standards
PM – Particulate matter

Table 2-16. Montana Particulate Matter Requirements for Fuel Burning Equipment (ARM 17.8.309)

	Maximum Allowable Emissions of Particulate Matter in Pounds per MMbtu	
Heat Input in MMBtu/hour	**Existing Fuel Burning Equipment**	**New Fuel Burning Equipment**
10 and below	0.60	0.60
100	0.40	0.35
1,000	0.28	0.20
10,000 and above	0.19	0.12

Notes:
ARM – Administrative Rules of Montana
MMbtu – Million British Thermal Units
When heat input falls between any two consecutive heat input values, ARM 17.8.309 provides equations for calculating emissions.

Table 2-17. Land Disposal Standards for Hazardous Wastes of Concern

Waste Code	Regulated Hazardous Constituent	Treatment Standard for Wastewaters (mg/L) or Technology Code	Treatment Standard for Nonwastewaters (mg/kg unless noted as mg/L) or Technology Code	Treatment Standard/Disposal Requirements[5]
F032	Acenaphthene	0.059	3.4	Land disposal allowed if waste meets the identified treatment standards for regulated hazardous constituents and is treated using the technology, if specified (i.e., CMBST).
	Anthracene	0.059	3.4	
	Benz(a)anthracene	0.059	3.4	
	Benzo(b)fluoranthene (difficult to distinguish from benzo(k) fluoranthene)	0.11	6.8	
	Benzo(k)fluoranthene (difficult to distinguish from benzo(b) fluoranthene)	0.11	6.8	
	Benzo(a)pyrene	0.061	3.4	
	Chrysene	0.059	3.4	
	Dibenz(a,h) anthracene	0.055	8.2	
	2-4-Dimethyl phenol	0.036	14	
	Fluorene	0.059	3.4	
	Hexachlorodibenzo-p-dioxins	0.000063, or CMBST[1,2]	0.001, or CMBST[1,2]	
	Hexachlorodibenzofurans	0.000063, or CMBST[1,2]	0.001, or CMBST[1,2]	
F034	Acenaphthene	0.059	3.4	Land disposal allowed if waste meets the identified treatment standards for regulated hazardous constituents and is treated using the technology, if specified (i.e., CMBST).
	Anthracene	0.059	3.4	
	Benz(a)anthracene	0.059	3.4	
	Benzo(b)fluoranthene (difficult to distinguish from benzo(k) fluoranthene)	0.11	6.8	
	Benzo(k)fluoranthene (difficult to distinguish from benzo(b) fluoranthene)	0.11	6.8	
	Benzo(a)pyrene	0.061	3.4	
	Chrysene	0.059	3.4	
	Dibenz(a,h) anthracene	0.055	8.2	
	Fluorene	0.059	3.4	
	Ideno (1,2,3-c,d)pyrene	0.0055	3.4	
	Naphthalene	0.059	5.6	
	Phenanthrene	0.059	5.6	
	Pyrene	0.067	8.2	
	Arsenic	1.4	5.0 mg/L TCLP	
	Chromium (Total)	2.77	0.60 mg/L TCLP	

Table 2-17. Land Disposal Standards for Hazardous Wastes of Concern

Waste Code	Regulated Hazardous Constituent	Treatment Standard for Wastewaters (mg/L) or Technology Code	Treatment Standard for Nonwastewaters (mg/kg unless noted as mg/L) or Technology Code	Treatment Standard/Disposal Requirements[5]
D004[3]	Wastes that exhibit the characteristic of toxicity for arsenic	1.4 and meet 40 CFR 268.48 standards[4,6]	5.0 mg/L TCLP and meet 40 CFR 268.48 standards[4,6]	Land disposal allowed if waste meets the identified treatment standards for regulated hazardous constituents and is treated using the technology, if specified (i.e., CMBST).
D018[3]	Wastes that exhibit the characteristic of toxicity for benzene	0.14 and meet 40 CFR 268.48 standards[4,6]	10 and meet 40 CFR 268.48 standards[4,6]	Land disposal allowed if waste meets the identified treatment standards for regulated hazardous constituents and is treated using the technology, if specified (i.e., CMBST).
D037[3]	Pentachlorophenol	0.089 and meet 40 CFR 268.48 standards[4,6]	7.4 and meet 40 CFR 268.48 standards[4,6]	Land disposal allowed if waste meets the identified treatment standards for regulated hazardous constituents and is treated using the technology, if specified (i.e., CMBST).

Notes:
[1] Per 40 CFR 268.42 Table 1, CMBST = High temperature organic destruction technologies, such as combustion in incinerators, boilers, or industrial furnaces operated in accordance with the applicable requirements of 40 CFR part 264, subpart O, or 40 CFR part 265, subpart O, or 40 CFR part 266, subpart H, and in other units operated in accordance with applicable technical operating requirements; and certain non-combustive technologies, such as the Catalytic Extraction Process.
[2] For these wastes, the definition of CMBST is limited to (1) combustion units operating under 40 CFR 266, combustion units permitted under 40 CFR 264, Subpart O, or (3) combustion units operating under 40 CFR 265, Subpart O, which have obtained a determination of equivalent treatment under 268.42(b).
[3] These wastes, when rendered nonhazardous and then subsequently injected in a Class I Safe Drinking Water Act well, are not subject to treatment standards (see 40 CFR 148.1(d)).
[4] These wastes, when rendered nonhazardous and then subsequently managed in CWA or CWA-equivalent systems, are not subject to treatment standards (see 40 CFR 268.1(c)(3) and (4))
[5] A prohibited waste identified in this table may be land disposed only if it meets the requirements found in the table. For each waste, the table identifies one of three types of treatment standard requirements: (1) All hazardous constituents in the waste or in the treatment residue must be at or below the values for that waste; or (2) The hazardous constituents in the extract of the waste or in the extract (noted as mg/L) of the treatment residue must be at or below the values found in the table; or (3) The waste must be treated using the technology specified in the table.
[6] The 40 CFR 268.48 Standards are the UTS, which have been established for underlying hazardous constituents in 40 CFR 268.48(a) and the Universal Treatment Standards Table. The UTS of all contaminants of concern are the same as those identified for the F032 and F034 waste codes.

CFR – *Code of Federal Regulations*
CWA – Clean Water Act
mg/L – milligrams per liter
TCLP – toxicity characteristic leaching procedure
UTS – Universal Treatment Standards

Table 2-18. Identification and Screening of Technologies and Process Options

General Response Action	Potential Remedial Technology	Process Option	Description	Effectiveness	Implementability	Relative Cost	Retained (Yes/No) and Screening Comments
No Action	No Action	No further action	No further actions or responses will be implemented with the exception of groundwater monitoring. COCs will remain in place with no plans for future control, treatment, or removal.	**Low.** Will not further address concerns about protectiveness.	**High.** While technically implementable, no action does not address CERCLA threshold criteria.	**None.**	**Yes**, retained per the NCP.
Access Restrictions	Institutional Control (ICs)	Land Use Zoning, Deed Restrictions, Restrictive Covenant, Controlled Groundwater Area	Exposure pathway controlled with administrative measures.	**Moderate.** Relies on administrative measures to limit exposure to groundwater COCs. ICs effective in short term, but must be maintained and enforced to provide long-term protection.	**Moderate to High.** Readily implemented using existing guidance; however, requires offsite land-owner concurrence and compliance. Some uncertainty on enforcement tools and responsibility over long term.	**Low.**	**Yes**, ICs are retained as a component for each alternative.
Physical Containment	Hydraulic Containment	Groundwater Extraction	Extract groundwater to capture and contain impacted groundwater from sources. Extracted liquids would require treatment and/or disposal.	**Moderate.** Groundwater extraction would be effective in preventing dissolved COCs from migrating downgradient, but effectiveness on decreasing NAPL mass via dissolution is limited.	**Moderate to High.** Readily implementable with extraction wells. May require modification of the existing treatment system or a new system to treat the mass of COCs.	**Moderate to High.** Installation and capital costs are relatively low compared to other active options; however, the life cycle costs are high due to the long operational period.	**Yes**, retained technology to control flow of groundwater COCs from source areas.
Removal	Physical Removal	Skimming	Recover LNAPL hydraulically, from the top of the groundwater column within a well.	**Moderate to High.** Can effectively decrease LNAPL mass in areas with readily recoverable LNAPL and limit occurrence of LNAPL in wells. Not effective when LNAPL transmissivity is at or below the ITRC guidance endpoint.	**Moderate to High.** Readily implemented in existing wells and may require installation of new extraction wells. Existing structures may limit accessibility.	**Low to Moderate.** Implementation costs are relatively low. Operation and disposal life-cycle costs may be moderate depending on the time to achieve the endpoint.	**No**, not retained as technology for LNAPL removal.
		Large diameter auger (LDA) excavation	NAPL impacted soil is excavated with large diameter (4 to 6 feet) augers with casing. Flowable fill is placed in the LDA boreholes and limits groundwater flux. Excavated soil direct loaded or stockpiled for offsite treatment and disposal. Soil is not typically reused.	**Moderate.** NAPL in soil is removed; thus, mitigating the mass flux of COCs to groundwater. The low permeability flowable fill limits horizontal groundwater flux through treated area. Uncertainty in effectiveness is caused by ability to locate and excavate NAPL impacted soil. Depth of NAPL impacted soil may be greater than practical limits of LDA excavation.	**Moderate.** A flowable fill production plant will likely be required onsite to meet demand. Surface access is required for subsurface impacted soil. A field-scale test would be required to determine ability to achieve required treatment depth with or without casing in cobble lithology. Requires treatment or disposal of excavated soil.	**High.** Cost increases with depth and amount of flowable fill required. Excavated soil treatment and\or disposal costs would be high.	**No.** Not retained because not likely to achieve required depth in site lithology.
	Enhanced Physical Removal	Steam Enhanced Extraction (SEE)	Inject steam to increase NAPL recoverability (lower interfacial tension and viscosity) by hydraulic recovery. Increases volatility and removal of semi-volatile constituents from the NAPL. Requires multiphase extraction to recover fluids. Requires multiple above ground treatment systems.	**Moderate to High.** Site-specific SEE bench-scale testing results showed: - NAPL saturation reduction of 1 to 3% of pore volume (10 to 30% reduction of NAPL content) - 59% reduction of PCP in aquifer soil - inconclusive reduction of PAHs in aquifer soil Less effective in low permeability soil. COCs may not be adequately removed from the NAPL to meet groundwater criteria.	**Moderate.** Requires installation of extensive injection and extraction well network and infrastructure to inject steam, recover fluids, and treat recovered fluids. Existing structures will limit accessibility. High groundwater flux through treatment area requires management to optimize energy consumption.	**High.** Capital costs are high for wells and equipment. Operational costs are high for energy and fluid treatment.	**Yes.** Retained as a technology to decrease the mass of NAPL in moderately permeable aquifer soils.

Table 2-18. Identification and Screening of Technologies and Process Options

General Response Action	Potential Remedial Technology	Process Option	Description	Effectiveness	Implementability	Relative Cost	Retained (Yes/No) and Screening Comments
Removal	Enhanced Physical Removal	Electrical Resistance Heating (ERH)	An electrical current and the electrical resistance of the formation creates heat, which vaporizes water, creating steam that volatilizes semi-volatile constituents from the NAPL. NAPL mobility and recoverability is also increased. Volatilized COCs and mobilized NAPL captured by a multi-phase extraction system and treated ex situ. Requires periodic water injections to maintain electrical conductivity of the formation. Requires multiple above ground treatment systems.	**Low to Moderate.** Can effectively reduce the mass fraction of COCs in the NAPL (composition change) and reduce the mass of NAPL (saturation change). COCs not likely to be adequately removed from the NAPL to meet groundwater criteria. Effective in low permeability soil.	**Low to Moderate.** Requires installation of extensive electrode network to heat the treatment area. Incurs a high energy demand and requires infrastructure to recover fluids and treat recovered fluids. Existing structures will limit accessibility. High groundwater flux through treatment area requires management to optimize energy consumption. Higher permeability and groundwater flux decreases efficiency (longer heating time).	**High.** High cost for electrodes, equipment, operation, ex-situ treatment facility and electrical energy.	**No.** Not retained due to low effectiveness in permeable aquifer soil.
		Thermal Conduction Heating (TCH)	Heat is supplied to the subsurface through specially designed heater wells. Achieves higher temperatures than ERH and SEE. Increases volatilization of semi-volatile COCs from the NAPL and increases NAPL mobility and recoverability. Multiphase extraction is required to recover fluids and vapor. Requires multiple above ground treatment systems.	**Low to Moderate.** Can effectively reduce the semi-volatile mass fraction of COCs in the NAPL (composition change) and reduce the mass of NAPL (saturation change). TCH can achieve higher temperatures than other thermal methods and may remove more COCs from the NAPL. Effective in low permeability soil.	**Low to Moderate.** Requires installation of extensive heating element network to heat the treatment area. Incurs a high energy demand and requires infrastructure to recover fluids and treat recovered fluids. Existing structures (fire pond) will limit accessibility. High groundwater flux through treatment area requires management to optimize energy consumption. Higher permeability and groundwater flux decreases efficiency (longer heating time).	**High.** High cost for wells, heating elements, equipment, operation, ex-situ treatment facility and electrical energy.	**No.** Not retained due to less effectiveness in permeable aquifer soil.
In Situ Treatment	Chemical Treatment	Surfactant Enhanced In Situ Chemical Oxidation (S-ISCO)	An injected surfactant solution enhances solubilization of COCs from the NAPL to the aqueous phase. COCs in the aqueous phase are oxidized with subsequent injection of an oxidant.	**Low to Moderate.** Surfactant enhanced ISCO is an emerging technology. Semi-volatile treatment appears feasible but can be very site-specific; thus, site-specific effectiveness is unknown. Bench-scale testing is required.	**Low to Moderate.** A large number of injection points would be required to cover the NAPL treatment area. A large amount of surfactant and oxidant would be required to treat the NAPL. It is likely that multiple injections would be required to achieve NAPL reduction.	**Moderate to High.** High cost for wells, injection solutions, equipment, operation, and multiple injections.	**No.** Not retained because of uncertainty in effectiveness.
	Physical/Chemical Treatment	In Situ Soil Stabilization (ISSS)	Injection and mixing of solidifying reagents with the soil to form a monolithic, low-permeability, solid mass with high structural integrity. The resulting matrix reduces the mobility and solubility of COCs originally present in the soil. Reagents may include Portland cement, fly ash, blast furnace slag, and organic sorbents, such as GAC, Zeolite, and organophilic clay.	**Moderate.** The low permeability of the treated material will significantly reduce the mass flux of COCs to groundwater. Long-term integrity and reduction in leaching of COCs from the treated material is uncertain because of the complex physical and chemical properties of the NAPL. Uncertainty in effectiveness is caused by ability to locate and stabilize NAPL impacted soil. Depth of NAPL impacted soil may be greater than practical limits of soil mixing.	**Moderate.** Large mixing augers or jet injection equipment used to blend and homogenize reagents with soil. Specialty mixing equipment (augers) can be impeded at sites with debris or coarse granular material (cobbles). Implementation difficulty increases with depth. Surface access is required for subsurface impacted soil. A field-scale test would be required to determine ability to achieve required treatment depth in cobble lithology.	**High.** Costs vary widely according to materials or reagents used and their availability, project size, and chemical nature of COCs.	**No.** Not retained due to uncertainty to achieve the required treatment depth.

Table 2-18. Identification and Screening of Technologies and Process Options

General Response Action	Potential Remedial Technology	Process Option	Description	Effectiveness	Implementability	Relative Cost	Retained (Yes/No) and Screening Comments
In Situ Treatment	Physical/Chemical Treatment	In Situ Geochemical Stabilization (ISGS)	A proprietary mix of permanganate and mineral salts are injected in the treatment area that oxidize dissolved organics and forms a stable mineral precipitate that reduces soil permeability, forms a mineral crust around the NAPL, and reduces mass flux from the treatment area.	**Moderate.** Although COC mass reduction occurs via chemical oxidation, mass flux reduction primarily occurs via geochemical stabilization. Applications have been successfully tested and completed at creosote and coal tar sites. Site specific testing and geochemical modeling is required to evaluate the long-term stability of the mineral crust.	**Moderate to High.** The proprietary solution is typically delivered to the subsurface by direct-push or injection wells. Injection wells likely required for the Site because of the cobble lithology. Site hydraulic conductivity is favorable for implementation. Fresh water recharge from the fire pond may support long-term stability of the mineral crust.	**Moderate to High.** Primary costs are injection wells, proprietary chemical mix, and injection time. Estimated costs for one event is relatively less than ISSS and S-ISCO.	**Yes.** Retained because of effectiveness at other creosote sites.
	Physical/Biological Treatment	Monitored Natural Attenuation/Natural Source Zone Depletion	COCs attenuate over time through natural physical, chemical, and biological processes. Natural attenuation or natural source zone depletion (NSZD) is the reduction in NAPL mass from dissolution and volatilization followed by subsequent bio-attenuation of the COCs in soil gas and groundwater.	**Low.** The time required to achieve groundwater criteria through natural attenuation will be long without active remediation. Can slowly reduce the mass fraction of COCs in the NAPL (composition change) and reduce the aqueous solubility of COCs without significantly reducing the mass of NAPL.	**Moderate.** The rate of NSZD has not been evaluated and would require periodic geochemical monitoring of groundwater and measurement of carbon dioxide flux to the atmosphere.	**Low.** Long attenuation timeframe will require extended monitoring and reporting duration.	**Yes.** Natural attenuation is a component for each alternative.
		Anaerobic Bio-oxidation	Supply an alternative electron acceptor such as nitrate or sulfate to support anaerobic biodegradation of COCs, including the PAHs and PCP. Studies show that PAHs degrade under nitrate and sulfate reducing conditions.	**Low.** A bench-scale treatability study did not show PCP degradation or sulfate depletion with low levels of sulfate (7 mg/L). Literature review did not identify anaerobic bio-oxidation of PCP with sulfate as an effective treatment.	**Moderate to High.** Injection of sulfate can be readily implemented with existing and new wells. High sulfate solubility and significant dispersion/diffusion increases the ROI for injection wells and persistence of electron acceptor between injection events.	**Low.** The cost of anaerobic bioremediation through the application of sulfate is relatively low.	**No.** Not retained because of limited effectiveness for PCP bio-oxidation.
		Aerobic Bio-oxidation	Deliver oxygen via biosparging in treatment barriers or as arrays to promote aerobic biodegradation of dissolved NAPL constituents. In addition, biosparging can enhance removal of semi-volatile compounds from the NAPL.	**Moderate to High.** Site-specific bench- and field-scale testing indicates biosparging can remove COCs from aquifer soil impacted by NAPL. Although ISB does not physically remove bulk NAPL, ISB enhances dissolution and biooxidation of COCs and hydrocarbons from the NAPL, thus decreasing NAPL mass. The insoluble compounds in the NAPL will not be removed.	**Moderate to High.** Field-scale testing indicates biosparging is readily implemented. The testing also highlighted the effects of aquifer heterogeneity on system design and operation.	**Low.** Costs are relatively low, although operational period is longer than other technologies which may increase life cycle costs.	**Yes.** Bench and field-scale testing indicate that biosparging is a feasible technology.

Notes:

COCs – Contaminants of concern
ITRC – Interstate Technology Regulatory Council
LNAPL – Light non-aqueous phase liquid
NAPL – Non-aqueous phase liquids
PAH – Polynuclear aromatic hydrocarbons
PCP – Pentachlorophenol
ROI – Radius of influence
SVOC – Semi-volatile organic compound
VOC – Volatile organic compound

Table 2-19. Technologies/Process Options Retained

General Response Action	Potential Remedial Technology	Technology/Process Option
No Action	No Action	No Further Action
Access Restrictions	Institutional controls	Institutional controls
Physical Containment	Hydraulic Containment	Groundwater extraction
Removal	Enhanced Physical Removal	Steam enhanced extraction
In Situ Treatment	Physical/Chemical Treatment	In situ geochemical stabilization
	Physical/Biological	Natural attenuation Aerobic oxidation (biosparge)

This section presents the development of alternatives, beginning by summarizing information used as the basis of conceptual design including the division of the Site into three remediation areas. Five remedial alternatives are identified and their key components and processes are described by remediation area.

3.1 BASIS OF CONCEPTUAL DESIGN

This section summarizes key information used to develop the conceptual designs for the remedial alternatives. It includes findings from laboratory and field testing, the basis for selecting remediation areas, the selection of design parameters for each remediation area, and the basis for estimating remediation timeframes.

3.1.1 Laboratory and Field Tests

This section summarizes findings from prior laboratory and field tests that were considered in developing design parameters for the remedial alternatives. Prior testing included a SEE bench-scale test, ISB bench- and pilot-scale tests, and a LNAPL transmissivity assessment.

3.1.1.1 SEE Technology Bench-Scale Test

A SEE bench-scale test was performed to assess the effectiveness of SEE in enhancing NAPL recovery from five laboratory-prepared columns of Upper Aquifer soil (URS 2013b). The bench-scale test evaluated changes in NAPL saturation and COC mass that could be achieved with SEE in Upper Aquifer soil containing Site NAPL. The following are key findings from the SEE bench-scale test:

- No visible NAPL to a trace of visible NAPL (<0.01 mL) was produced in the fluid extracted from the five soil columns during the hot water flood and steam flood testing. However, NAPL saturations in the soil columns decreased from 0.9 to 2.7 percent of the soil column PV. The reduction of NAPL mass is most likely from dissolution and volatilization of a comparatively small mass of COCs and a larger mass of non-COC hydrocarbons. The initial NAPL saturations in the soil columns (7.8 to 10.2 percent of PV) were similar to maximum NAPL saturations observed in the field that are primarily at residual saturations.
- Monitoring data shows that the hot water flooding target temperature of 194°F and steam flooding target temperature of 250°F were achieved.
- The reduction in the PCP mass fraction in the NAPL remaining in the columns ranged from 1 percent (where pore volume flushes were limited by permeability) to 91 percent (where more than 20 pore volumes of hot water and steam were flushed through the column).
- The concentrations and mass fractions of naphthalene and other PAHs increased in the waste pit soil columns. In soil columns from the tank farm area, the naphthalene mass fractions decreased by approximately 70 percent in two of the three columns.
- Based on the decrease in NAPL saturations in the soil columns, SEE is expected to remove approximately 20 percent of the NAPL mass. In addition, SEE may remove up to 90 percent of the PCP and up to 70 percent of naphthalene from the NAPL.

- SEE as a single remedial technology is not expected to be capable of achieving Site cleanup levels for PCP and PAHs in the Upper Aquifer because even under optimal contact conditions in the bench-scale test, a residual NAPL saturation of 5.3 to 8.5 percent of PV remained.
- The ability of SEE technology to remove COCs from the remaining NAPL is uncertain, since both increases and decreases in COC concentrations were observed in the soil matrix during the tests.

3.1.1.2 ISB Bench-Scale Test

Bench-scale microcosm and column tests were conducted to assess ISB technology in reducing NAPL mass in Upper Aquifer soil to a level that PCP and PAH cleanup goals could be achieved in groundwater by ISB or natural attenuation (URS 2014). Also, the effects of using air versus high purity oxygen were evaluated.

The following are key findings from the microcosm tests:

- A mass balance indicates that 44 percent of the total PCP mass in the microcosms disappeared from the air treatments and 48 percent from the pure oxygen treatments during the first 8 weeks of treatment.
- PCP-degrading bacterial biomass grew by several orders of magnitude in the air and oxygen treatments, indicating that biosparging will create zones of high-efficiency PCP-degrading bacteria in the aquifer.
- Most of the PAH mass was removed by day 56 (69 percent and 75 percent for the air and pure oxygen treatments, respectively).

The following are key findings from column tests:

- Biodegradation of the COCs in aquifer conditions (11 °C, >10 milligrams per liter [mg/L] PCP) proceeded rapidly once DO was raised. Biodegradation of the COCs was so rapid that it occurred prior to entering the columns, even at 4 °C (in the stock solution) and 11 °C (in the column influent bottles).
- The tests indicated that after DO becomes reliably elevated in the aquifer, a competent biota should develop, forming an in situ bioreactor.
- The tests also showed that air or pure oxygen can be effectively used.

The bench-scale microcosm and column tests indicated that the Site is particularly suitable for ISB because the aquifer is deep and has heterogeneity in vertical permeability, maximizing the injection ROI, and the concentrations of dissolved metals that typically cause biofouling are low (e.g., total Fe of < 0.01 to 6.2 mg/L and total Mn of 0.05 to 3.1 mg/L), minimizing biofouling concerns (note that no evidence of biofouling was observed in the microcosm or column tests).

3.1.1.3 ISB Pilot-Scale Test

An ISB pilot-scale test was performed to further evaluate the effectiveness and implementability of remediating COCs in the Upper Aquifer with ISB and to develop a full-scale conceptual design for evaluation in the FFS (AECOM 2017b).

The key findings of the ISB pilot-scale test are summarized as follows:

The data collected during the pilot test support the assumption that ISB can effectively reduce source concentrations of PCP and naphthalene, as indicated by a reduction in both the average and relative concentrations to less degradable compounds in the post-biosparge soil samples. Continued operation of the ISB system is anticipated to further degrade target compounds. Pilot test observations also support that the well spacing of 42 feet used during the pilot test provided adequate coverage.

The groundwater sampling results indicate a reduction in dissolved phase concentrations (excluding samples with suspected NAPL droplets) of the target compounds. This reduction in concentration may result in a reduction of the mass flux of these compounds leaving the treatment area. Further treatment by the ISB system should further reduce source concentrations and dissolved phase concentrations, which will further reduce the mass flux from the impacted area.

In the shallow subunit, the following data were observed and used to develop design parameters for the conceptual design:

- Air injection rates that ranged from 2 to 13 actual cubic feet per minute (acfm) were achieved at relatively low injection pressures ranging from 9.5 to 13 pounds per square inch (psi).
- Changes in groundwater elevations were minimal and limited by the permeable, unconfined lithology of the shallow subunit.
- Air injection into the shallow subunit increased DO concentrations and resulted in bubbling in the surrounding monitoring network during Phase 1 pilot testing, suggesting a ROI of approximately 30 feet at an air flow rate of 10 acfm.

In the deep subunit, the following data were observed and used to form design parameters for the conceptual design:

- Air injection rates that ranged from 1 to 6.7 acfm were achieved at injection pressures ranging from 15.9 to 28.7 psi.
- The semi-confined nature of the middle and deep zones increases lateral pressure distribution and dissipation; thus, deep air injection affects groundwater pressure in the middle and deep zones at distances greater than 70 feet from the injection well even at low air injection rates.
- Air injection into deep groundwater increased DO concentrations in the monitoring network during the limited duration of the study.
- In the middle zone at both injection rates (1 and 3 acfm), the observed ROI varied across the Site and ranged from 35 to 50 feet.
- An ROI of 60 feet at 3 acfm is a conservative estimate for use in a conceptual design, as influences were observed up to 70 feet away.
- An ROI of at least 70 feet was achieved at 6.7 acfm in middle and deep groundwater and could also be used to develop a conceptual design.

- Based on pressure observations in the middle and deep subunits, a full-scale design should optimize air injection rates, injection pressures, and operation intervals to minimize in situ pressure accumulation and potential health and safety concerns related to pressure relief at well heads, which should be designed to manage expected pressures.

DO depletion rates ranged from 0.10 mg/L per hour (mg/L/hr) to 1.5 mg/L/hr.

3.1.1.4 LNAPL Transmissivity Assessment

The hydrogeologic conditions of LNAPL at three wells were assessed and two manual skimming tests were performed in 2016 to assess LNAPL transmissivity and recoverability near the former tank farm where NAPL thicknesses of several inches to several feet can accumulate in three wells (AECOM 2017c). Key findings of this assessment are as follows:

- LNAPL exists under confined (3061.1) and unconfined (3031.1 and 3039.1) aquifer conditions at the Site. The in-well measured LNAPL thickness at 3061.1 is not representative of the LNAPL thickness in the formation.
- LNAPL transmissivity estimates from manual skimming tests completed in 2016 were less than 0.01 square feet per day (ft^2/day) at both wells tested. LNAPL is not effectively recoverable using hydraulic methods when the LNAPL transmissivity is less than 0.1 to 0.8 ft^2/day (ITRC 2009b). LNAPL transmissivity estimates for each well are at least an order of magnitude less than the lower criterion, indicating LNAPL is not practicably recoverable at these wells.
- Sustainable LNAPL skimming rates are likely less than 0.02 and 0.0001 gallons per day (gpd) at 3039.1 and 3061.1, respectively, indicating hydraulic recovery is not practicable at the Site.

Based on the results, LNAPL recovery is not recommended at these locations and semi-annual gauging is adequate for the purpose of monitoring LNAPL stability at these locations.

3.1.2 Remediation Areas and Design Parameters

To assist in developing remedial alternatives, the impacted area of the Upper Aquifer was divided into remediation areas to which general response actions were assessed against. These remediation areas were developed based on COC concentrations in groundwater and the interpreted presence of NAPL in the Upper Aquifer. Identifying remediation areas in this manner allowed for scaled remediation with the application of more rigorous treatment technologies to those areas that pose the greatest risk to human health (areas of the aquifer with the highest COC concentrations) and to those areas that serve as a continuous source of groundwater contamination (areas of the aquifer with the greatest NAPL impacts). Furthermore, the manner in which contamination is distributed throughout the formation influences the suitability of various remedial approaches. The Upper Aquifer areas were divided into three separate remediation areas, as shown on **Figure 3-1** and as defined below.

<u>*Area 1*</u> encompasses the former waste pit source area and the surrounding area where there is predominantly residual LNAPL and DNAPL with small amounts of DNAPL recovered from extraction wells. The area is 2.7 acres in size with an average aquifer thickness of 63 feet extending from the average water table depth of 11 feet bgs to a total average aquifer depth of 74

feet. The Upper Aquifer in Area 1 has three subunits of different hydrogeologic characteristics (the shallow, middle, and deep subunits), as described in Section 1.2.5.3.1. Average aquifer parameters representing Area 1 are summarized in Table 1-2 (Transect 1S and 1D). Area 1 is the smallest of the three areas, but it has the highest average NAPL saturation and the highest concentrations in groundwater. The average estimated mass of select COCs, NAPL volume and saturations, and ranges of dissolved COC concentrations in Area 1 are summarized in Table 3-1. Parameters in Tables 1-2 and 3-1 were used in the conceptual design of remedial alternatives and to estimate remediation timeframes.

Area 2 directly surrounds Area 1 and extends approximately 1,600 feet downgradient to include NAPL that historically migrated from the former waste pit and tank farm. NAPL in Area 2 is predominantly residual NAPL. Area 2 is 33 acres in size with an average aquifer thickness of 57 feet, extending from the average water table depth of 17 feet bgs to a total average aquifer depth of 72 feet. There are three Upper Aquifer subunits characterized in Area 2 (the shallow, middle, and deep subunits), but the middle and deep subunits have similar properties and can be considered as one subunit (middle/deep). Average aquifer parameters representing Area 2 are summarized in Table 1-2 (Transect 2). Area 2 has lower average NAPL saturations and lower groundwater concentrations than Area 1. The average estimated mass of select COCs, NAPL volume and saturations, and ranges of dissolved COC concentrations in Area 2 are summarized in Table 3-1. Parameters in Tables 1-2 and 3-1 were used in the conceptual design of remedial alternatives and to estimate remediation timeframes.

Area 3 extends approximately 2,800 feet directly downgradient of Area 2 and includes the dissolved COC plume. No NAPL has been observed recently in Area 3 during drilling or in completed wells. Area 3 is 98 acres in size, and is the largest of the three areas. The average Upper Aquifer thickness in Area 3 is 43 feet, extending from the water table at an average of 16 feet bgs to approximately 59 feet bgs. The three Upper Aquifer subunits in Area 3 (shallow, middle, and deep) have similar properties and can be considered as one aquifer unit. Average aquifer parameters representing Area 3 are summarized in Table 1-2 (Transect 3). Groundwater concentrations in Area 3 are the lowest of the three areas. The average estimated mass of select COCs, NAPL volume and saturations, and ranges of dissolved COC concentrations in Area 3 are summarized in Table 3-1. Parameters in Tables 1-2 and 3-1 were used in the conceptual design of remedial alternatives and to estimate remediation timeframes.

3.1.3 Method for Estimating Remediation Timeframes

To support development and comparison of costs for the remedial alternatives, a model was developed and used to estimate the time for each alternative to achieve preliminary revised groundwater cleanup levels. The model simulates the removal of COCs from NAPL and the estimated time to deplete the COCs from NAPL such that the NAPL is not a source of COCs to groundwater at concentrations greater than the cleanup levels. The NAPL depletion model builds on the analytical solution used to estimate the effective aqueous solubility of COCs from Site NAPL presented in the NAPL Characterization Study for the Upper Aquifer (AECOM 2017d).

The mechanism that depletes COCs from the NAPL is the continuous partitioning (dissolution) of COCs from the NAPL to the effective solubility in groundwater as COCs are biodegraded in groundwater (Appendix B). The calculations use well-established equations from literature (e.g., not empirically derived) and utilize parameters derived from pilot testing or calibrated to site-specific conditions. Although the NAPL depletion model also includes dissolution of COCs to clean groundwater flowing into a remediation volume, simulations show that the biodegradation rate of COCs in groundwater primarily determines the time required to effectively deplete the COCs from NAPL. Thus, alternatives that significantly enhance biodegradation rates (e.g., biosparging) deplete COCs from the NAPL faster and provide shorter remediation timeframes.

As presented in Appendix B, the NAPL depletion model assumes ideal conditions including instantaneous dissolution and constant first-order biodegradation rates. Although these assumptions may provide optimistic estimates of remediation timeframes, the model provides an analytical-based approach to compare alternatives using site-specific characteristics and estimates of alternative performance from bench and/or field-scale studies.

3.2 IDENTIFICATION OF ALTERNATIVES

Following identification and screening of technologies and process options, the technologies retained from the screening process were used to develop preliminary remedial alternatives for the Site. These preliminary alternatives were presented to EPA during a meeting on June 21, 2016. EPA provided comments and agreed to the list of preliminary alternatives in February 2017. The preliminary alternatives developed in this FFS to address NAPL and COCs in Upper Aquifer groundwater at the Site include:

- Alternative 1 – No Further Action
- Alternative 2 – Hydraulic Containment (Area 1) and In Situ Biosparging (Area 2)
- Alternative 3 – In Situ Biosparging (Areas 1 and 2)
- Alternative 4 – Steam Enhanced Extraction/In Situ Biosparging (Area 1) and In Situ Biosparging (Area 2)
- Alternative 5 – In Situ Geochemical Stabilization (Area 1) and In Situ Biosparging (Area 2)

The alternatives above were modified slightly from the preliminary list approved by EPA. Shallow in situ biosparging and deep hydraulic containment (Area 1) proposed originally was eliminated because it was similar to Alternatives 2 and 3 and therefore redundant. LNAPL skimming in Area 2, proposed originally as a component of each active alternative, was not carried forward because the LNAPL transmissivity was estimated to be too low for practicable recovery based on a field assessment (Section 3.1.1.4). Also, ISB was included as a follow-on to SEE as part of Alternative 4 based on evaluation documented in Appendix B.

Overall, the alternatives employ a more active or rigorous treatment to Area 1 and a more passive remedy to Area 2. As previously discussed, Area 1 has a higher concentration of contamination, making it suitable to apply larger scale remedies somewhat uniformly across the area. However, the discontinuous and irregular distribution of contamination intermixed with "cleaner" lenses throughout Area 2 renders full-scale implementation of active remedies ineffective and impractical. Therefore, a more passive approach has been selected for Area 2 that involves active treatment at downgradient boundary of the area, but natural and passive remediation throughout the remainder of the area.

Each of the alternatives share institutional controls as a common component and Alternatives 2 through 5 share ISB in Area 2 and MNA in Area 3 as common components. These common components will be discussed in Section 3.3 at their first occurrence. The operation of the SAETS would cease under Alternatives 1, 3, 4, and 5, and it would be modified under Alternative 2. A plan view showing the technologies applied to Areas 1 and 2 for each alternative is shown on Figures 3-2 through 3-8, with supporting process flow diagrams for Alternatives 2 and 4 provided on Figure 3-4 and 3-7, respectively.

3.3 DEVELOPMENT OF ALTERNATIVES

This section describes the primary components and processes of the conceptual design for each of the five alternatives, which are also summarized in Table 3-2.

3.3.1 Alternative 1 – No Further Action

Alternative 1, the baseline alternative, prescribes ‘No Further Action’ with respect to the Upper Aquifer beyond implementing institutional controls. Remedial actions have been conducted at the Site during the past 25 years; therefore, the baseline alternative for comparing alternatives is No *Further* Action. Current remedial actions would be stopped and the impacted groundwater would not be actively treated. In situ treatment through natural attenuation and NSZD would continue at the site and the Upper Aquifer would be monitored to determine progress or changes in conditions. It is anticipated that cleanup goals would be met after approximately 145 years based on NAPL dissolution modeling conducted with natural attenuation rates (Appendix B).

Institutional controls would be implemented to include administrative or legal controls that limit land or resource use. Current institutional controls and additional institutional controls being considered (Section 2.4.1.2) would be retained. Institutional controls are a component of each remedial alternative. General maintenance components are also included in each alternative, involving the maintenance of fences, signs, roads, drainage, and/or structures. A CERCLA 5-year review is required whenever contaminants remain on site above levels that would allow for unrestricted use and unlimited exposure.

3.3.2 Alternative 2 – Hydraulic Containment (Area 1) and In Situ Biosparging (Area 2)

Alternative 2 includes groundwater extraction, aboveground treatment, and re-injection of treated groundwater to hydraulically contain impacted groundwater in the former waste pit area (Area 1) and limit the mass flux from Area 1 into Area 2; ISB near the downgradient extent of NAPL to treat contaminated groundwater in Area 2 and to propagate a dissolved oxygen rich zone that further reduces contaminant concentrations and prevents dissolved COC migration downgradient of Area 2; and MNA in Area 3. Institutional controls as described in Alternative 1 will also be a component of Alternative 2. Remediation areas are shown on Figure 3-1 and a plan view of the remediation systems for Alternative 2 is provided on Figures 3-3a and 3-3b.

3.3.2.1 Remedy Implementation in Area 1

The remedial technologies applied to Area 1 include groundwater extraction, treatment, and re-injection designed to hydraulically contain the flow through Area 1. During this hydraulic containment process, contaminant mass reduction will occur through extraction and treatment, as well as by NSZD. The NSZD rates will be quantified using a mass and/or energy balance approach by measuring the mass flux of electron acceptors into the NAPL source zone and mass flux of hydrocarbon and biodegradation products such as carbon dioxide out of the NAPL source zone. Performance monitoring for assessing NSZD rate includes groundwater sampling, soil gas screening, temperature profiling, and measuring carbon dioxide flux at the ground surface.

To accomplish hydraulic containment, groundwater will be pumped from five extraction wells screened in the shallow subunit of the Upper Aquifer (approximately 25 to 35 feet bgs) and one extraction well screened in the deep subunit of the Upper Aquifer (approximately 55 to 75 feet bgs) at a rate of 15 gpm per well and 2 gpm per well, respectively. The well spacing and location were designed to create a hydraulic barrier perpendicular to groundwater flow. The barrier was designed to hydraulically contain impacted groundwater flowing through both subunits in the former waste pit area (550 feet long for both subunits). The pumping rates and spacing were estimated using hydraulic conductivities estimated for each subunit and Darcy’s law to estimate the stagnation point, velocity divide, and the capture zone of each well using the method described in Keely and Tsang (1983).

The extraction wells pump extracted groundwater to an aboveground treatment system consisting of the existing coalescing oil-water separator (OWS), two trickling filter rotary distributor units, a pressure filter, and three 20,000-lb GAC units (Figure 3-4). The multicomponent treatment system will remove contaminants to levels that would meet Montana re-injection standards. An existing bioreactor facility is currently being utilized on site. However, the facility is reaching the end of its design life and does not have the capacity to treat the groundwater at the estimated flow rate of 80 gpm. Alternative 2 assumes a new treatment system will be designed. Use of components identified as salvageable and in acceptable operating condition would be evaluated during detailed design. The components that are anticipated to be re-used include the existing OWS and the existing NAPL storage tank.

Historically, NAPL has not been observed in extraction wells screened in the shallow subunit, and therefore, the extracted water from the five shallow subunit extraction wells (combined 75 gpm) will bypass the OWS and flow directly into the trickling filters. Groundwater pumped at a rate of 2 gpm from the deep subunit extraction well will flow through the OWS prior to the trickling filters. The influent piping to the OWS will be designed to route influent flow from the shallow subunit extraction wells through the OWS, if NAPL is observed in this flow, at which point the OWS may need to be upgraded to account for increased capacity.

The effluent from the trickling filters will flow through a pressure filter to three GAC units that will provide additional treatment and removal of COCs. Biological treatment alone is not expected to remove contaminants to meet Montana re-injection standards. Effluent from the GAC units will be injected into two existing re-injection wells (9500.1 screened in the shallow subunit, and 9501.1 screened in the deep subunit) and two newly installed re-injection wells (both screened in the shallow subunit). Cumulative re-injection rates will be the same as the total rates extracted for each subunit (i.e., 75 gpm in the shallow subunit and 2 gpm in the deep subunit). The aboveground treatment system will remove NAPL and dissolved COCs from groundwater. NAPL will be collected and disposed of off-site at a treatment storage and disposal facility (TSDF) capable of incineration. GAC units, when adsorption capacity has been reached, will be transported off site for treatment (incineration) and disposal. A process flow diagram of the conceptual design of the groundwater treatment system is shown on Figure 3-4.

A plan view of the remediation treatment systems for Alternative 2, including the extraction and re-injection well locations, and the planned conveyance piping are provided on Figure 3-3a. A potentiometric map of the shallow and deep subunit (interpreted without operation of the existing source area extraction system wells) was used as the basis for the placement of extraction wells, as shown on Figure 3-3b.

The following assumptions and durations are anticipated for hydraulic containment implementation:

- *Extraction well completion, system installation, and startup*: Approximately one year is assumed for drilling, completing extraction wells, installing aboveground treatment system components, startup, and optimizing system performance.
- *System O&M and monitoring*: The system will operate for approximately 145 years based on NAPL dissolution modeling (Appendix B). Monitoring of 12 wells will be performed semiannually for two years and monitoring of select wells annually for 150 years, until cleanup levels are confirmed. Additionally, the aboveground groundwater treatment system effluent will be monitored and sampled on a regular basis to verify that groundwater standards are met prior to reinjection of the effluent.
- *Post-remediation monitoring*: After treatment objectives have been achieved, groundwater extraction and treatment will cease and post-remediation monitoring will ensue until the treatment's longevity and effectiveness is sufficiently established.

Under this alternative, hydraulic containment pumping would remove NAPL with recovery rates steadily declining. NAPL is assumed to initially represent 0.015 percent of the total fluid volume extracted from the deep subunit based on historical recovery volumes, yielding approximately 0.43 gpd of NAPL at a continuous pumping rate of 2 gpm.

3.3.2.2 Remedy Implementation in Area 2

Residual NAPL is present throughout portions of Area 2, and is a source of dissolved COCs in Area 3. An ISB transect near the downgradient edge of NAPL in Area 2 will mitigate contaminant flux leaving Area 2 and cut off the source to Area 3, after which the groundwater plume in Area 3 would naturally attenuate. The contaminant mass in Area 2 upgradient of the ISB transect would decrease via NSZD, which would be monitored as discussed in Section 3.3.2.1. NZSD would be enhanced by the reinjection of oxygenated and treated water from the GAC effluent (from groundwater extracted in Area 1), which would stimulate aerobic biodegradation and increase dissolution with the influx of "clean" groundwater and with a steeper hydraulic gradient. The downgradient ISB transect will increase dissolved oxygen in groundwater promoting contaminant degradation as contaminated groundwater passes through the transect, as well as creating a dissolved oxygen-rich front migrating with groundwater from the transect. The operational processes for remediation by ISB are explained in Section 2.4.1.7.3.

ISB will be applied as a treatment transect oriented approximately perpendicular to groundwater flow that spans the width of Area 2. The transect will be implemented along the northwestern edge of the 1994 revised mill property boundary, just outside of the southeastern extent of the Libby City limits, as shown on Figure 3-3a. The transect will span approximately 960 feet in length and comprises two staggered rows of 12 injection wells that are spaced approximately 80 feet apart from one another (24 injection wells total). Although ISB was not pilot tested in the proposed location, a 40-foot ROI is assumed based on a comparison of formation permeability between Areas 1 and 2 relative to the ROIs achieved during pilot testing in Area 1 (described in Sections 3.1.1.3 and 3.3.3.1).

The treatment width required to achieve cleanup levels within the transect's active ISB area and propagate a DO-rich front is approximately 75 feet, as shown in Table 3-3. The assumptions presented in Table 3-3 are based on aquifer conditions (i.e., permeability, porosity, hydraulic gradient, contaminant concentrations) and anticipated half-lives of 1 day for PCP and 2 days for naphthalene under aerobic conditions stimulated by ISB based on pilot testing observations, as discussed in Appendix B. The calculated treatment width of 75 feet assumes that residual contamination within the treatment area has been largely treated and is not meaningfully contributing mass to the aqueous phase. This minimum treatment width can be easily achieved using two rows of staggered ISB injection wells (two rows are recommended to provide sufficient and overlapping coverage), each with anticipated 40-foot ROIs, to yield a net-sparged width of 150 to 160 feet followed by a DO-rich front propagating downgradient of the treatment transect.

Since the hydraulic conductivity and aquifer transmissivity within the biosparging treatment transect may decrease as air displaces water and decreases the water saturation within the treatment transect, the spatial difference in hydraulic conductivity and transmissivity may cause some flow of groundwater around the biosparge treatment transect. The effect of air sparging on groundwater mounding and flow is typically evaluated by groundwater elevation monitoring. Thus, the implementation and operation of the biosparging treatment transect will include monitoring of groundwater elevations using existing wells and new piezometers as needed to evaluate potential changes to groundwater flow gradients and directions near the biosparge treatment transect. In addition, the performance of the biosparge treatment transect will be evaluated by monitoring groundwater geochemistry and contaminant concentrations within and around the treatment transect. If monitoring data indicates the biosparge treatment transect performance is not adequate, the design (length) and operation of the biosparge barrier can be modified to improve performance and mitigate the potential for untreated groundwater to flow around the biosparge barrier.

Boreholes will be drilled with sonic drilling to install wells. Specific well construction details will be refined prior to implementation, but for now we assume that each injection well will be 2 inches in diameter, constructed of schedule 40 carbon steel casing and a 3-foot-long stainless steel, wire wrapped screen (0.020-inch slot size) surrounded by a sand pack sealed with overlying bentonite. The injection wells will be developed to remove fines after installation;

however, a 5-footlong sump will be placed below the well screen to capture fines that may enter the injection wells when off cycle (e.g., not injecting).

Injection wells will be installed in the base of the Upper Aquifer so that injected air distributes across the top of the Intermediate Zone. The well completion depths will vary, but are assumed to have an average depth of 80 feet bgs with screened intervals from approximately 72 to 75 feet bgs (assumes a 5-foot sump), based on the interpreted top of the Intermediate Zone depicted on Figure 1-28. Air will be injected only in the deep subunit to achieve treatment in both the shallow and deep subunits, as the sparged air is anticipated to readily travel upwards through the shallow subunit in the absence of a semi-confining middle subunit in Area 2.

The operational details of the injection wells forming the treatment transect will be refined through field testing; however, for the purposes of this FFS, the following assumptions are made based on observations from ISB pilot testing conducted in Area 1.

Airflow and Pressures: Ambient air will be injected at a flow rate that provides sufficient oxygen to enhance biological activity in groundwater. Although pure oxygen may slightly enhance the biodegradation performance, it introduces additional complexities and safety concerns that are avoided by compressing atmospheric air. Furthermore, bench-scale testing with air and oxygen shows that air is still very effective (see Section 3.1.1.2) and suggests that the incremental benefit to using oxygen is not worth the accompanying tradeoffs. Injection pressures will be field-adjusted using a series of valves based on field observations to achieve a target flowrate near 10 acfm per well. Based on observations from ISB pilot testing in Area 1 with consideration given to differences in formation characteristics between Areas 1 and 2, routine injection pressures are anticipated to range between 20 and 40 pounds per square inch gauge (psig), with initial injection pressures of 45 to 55 psig to establish the air passages. At these target injection rates and pressures, no monitoring or vapor collection system is anticipated to be required in the vadose zone.

Zoning and Cycles: This describes the anticipated zoning and injection duration cycling; however, these are subject to change based on field observations during field installation and system startup. Pulsing air flow (i.e., turning the system on and off at specified intervals) provides better distribution and mixing of the air in the contaminated saturated zone, thereby allowing for greater contact with the dissolved phase contaminants. During sparging, the presence of air channels and trapped air may decrease hydraulic conductivity within the treatment transect and affect groundwater flow near and through the treatment transect. Groundwater mounding during air sparging will be monitored to evaluate potential changes to groundwater flow. In addition, air injection and flow rates will be cycled through multiple zones to optimize system performance and minimize groundwater mounding. Cycling frequency is site-specific and depends on the characteristics of site soils and the oxygen depletion rate within the groundwater. The 24 ISB injection wells will be grouped into 4 zones containing 6 wells each, with each zone operating sequentially for 2 hours followed by 6 hours of downtime. These timeframes assume that dissolved oxygen saturation is reached after an hour of air injections and is consumed at rates between 1 and 2 mg/L/hr. Therefore, each zone would operate and alternate individually, having a daily operational duration of approximately 6 hours.

System Components and Operation: Individual components will be designed in detail prior to implementation; however, air flow is anticipated to be provided by one, 40-HP rotary screw air compressor with an inline flow regulator. The system will distribute flow through each zone using manifolds equipped with pressure, temperature, and flow indicators. The remediation system is assumed to be controlled by a supervisory control and data acquisition (SCADA) system for monitoring and control, as well as a programmable logic controller (PLC) that will enable adjustable injection cycle durations and frequencies by ISB zone. Ambient air will be filtered through a 5-micron particulate filter prior to entering the air compressor and compressed air will be filtered through an oil filter prior to injection into the subsurface. Conveyance piping (e.g., 1-inch high density polyethylene [HDPE]) will be installed within a shallow trench (e.g., 1.5 feet bgs) where possible and above ground piping will be completed with galvanized pipe or pressure-rated rubber airline hose.

The following assumptions and durations are anticipated for each different phase of ISB implementation:

- *Injection well completion, system installation, and startup*: Up to three months are assumed for drilling, completing injection wells, installing system components, starting ISB, and optimizing system performance (e.g., zoning, cycle durations, pressures, and air flow rates).
- *System O&M and monitoring*: The system will be operated until the mass discharge from NAPL in Area 2 is less than the attenuation capacity of groundwater and enhances attenuation of the downgradient groundwater plume into Area 3. Therefore, the operational timeframe of the ISB transect is governed by NSZD progress in upgradient portions of Area 2 and not by areas downgradient of the ISB transect, which are anticipated to naturally attenuate faster than contaminant mass upgradient of the ISB transect. Operation of the ISB transect will terminate based on performance monitoring and analytical data, which is anticipated to occur after approximately 41 years of operation based on NAPL depletion modeling (Appendix B). Although the shallow subunit in Area 2 is estimated to reach cleanup goals after only 12 years of system operation, the middle-deep subunit is not estimated to reach cleanup goals until after 41 years of operation. Because sparging only occurs in the deep subunit (and then bubbles upward through the shallow subunit), ISB will continue in the subunit for the duration necessary in the deep subunit, which is assumed to be 45 years (rounded up to be conservative).
- *Post-remediation monitoring*: After treatment objectives have been achieved, ISB will cease and post-remediation monitoring will ensue until the treatment's longevity and effectiveness is sufficiently established, which is assumed to occur after 5 additional years.

3.3.2.3 Remedy Implementation in Area 3

Mass discharge from residual NAPL in Area 2 is the source of the dissolved plume in Area 3. The extent of the groundwater plume in Area 3 has remained relatively stable for multiple decades, indicating natural attenuation is managing the mass discharge from Area 2. The plume is anticipated to readily naturally attenuate and shrink after contaminant discharge from Area 2 is mitigated by the ISB system. Under MNA, the groundwater plume in Area 3 will be monitored to verify natural attenuation is occurring and that the plume is stable or receding.

With time, treated and oxygenated groundwater exiting the ISB transect in Area 2 will migrate into Area 3, providing an oxygen source to enhance aerobic biodegradation and flushing with "clean" groundwater. Groundwater monitoring wells will be sampled routinely until cleanup levels are achieved, which is anticipated to occur within a short timeframe (e.g., 10 years) after the ISB transect becomes operational. Therefore, MNA in Area 3 is expected to achieve groundwater cleanup criteria long before ISB ceases in Area 2. A groundwater monitoring report evaluating effectiveness and progress would be prepared routinely.

3.3.2.4 Alternative Summary and Sequencing

The general sequence and duration of key activities under Alternative 2 include the following:

- Year 0: Install extraction and re-injection wells, conveyance piping, ISB transect wells, and groundwater treatment plant upgrades. System startup and begin operation. NSZD in Areas 1 and 2, and MNA in Area 3.
- Years 1 to10: NSZD and O&M of hydraulic containment in Area 1 and ISB in Area 2. MNA in Area 3.
- Years 11 to 41: NSZD and O&M of hydraulic containment in Area 1 and ISB in Area 2. NFA in Area 3.
- Years 41 to 46: NSZD and O&M of hydraulic containment in Area 1. Post-remediation monitoring in Area 2 and NFA in Area 3.
- Years 47 to 145: NSZD and O&M of hydraulic containment in Area 1. NFA in Areas 2 and 3.
- Years 146 to 150: Post-remediation monitoring in Area 1 and NFA in Areas 2 and 3.
- Year 150: Remedy Complete.

3.3.3 Alternative 3 – In Situ Biosparging (Areas 1 and 2)

Alternative 3 includes ISB in Area 1 by injecting air through a network of shallow and deep wells to address impacted groundwater and deplete COCs from NAPL in the waste pit area (Area 1), ISB near the downgradient extent of NAPL to treat contaminated groundwater in Area 2 and to propagate a dissolved oxygen rich zone that further reduces contaminant concentrations and prevents dissolved COC migration downgradient of Area 2, and MNA in Area 3. Institutional controls as described in Alternative 1 will also be a component of Alternative 3. A plan view of the remediation systems to Alternative 3 is provided on Figure 3-5.

3.3.3.1 Remedy Implementation in Area 1

Similar to ISB in Area 2, as described in Alternative 2 (Section 3.3.2.2), ISB in Area 1 will reduce contaminant mass by promoting contaminant biodegradation through increased dissolved oxygen in groundwater and accelerating NAPL weathering by increasing the rate of dissolution. A secondary benefit to treating the contaminant mass in Area 1 via ISB is that a portion of the treated and oxygenated groundwater will flow from Area 1 to Area 2, accelerating attenuation in Area 2 by enhancing aerobic biodegradation and "flushing" the formation with "clean" and oxygenated water.

ISB will be implemented via injecting compressed air into the shallow and deep subunits of the Upper Aquifer through a network of shallow and deep injection wells evenly spaced throughout Area 1 (Figure 3-5). Approximately 44 shallow and 11 deep injection wells will be used to oxygenate the groundwater, assuming shallow and deep radii of influence of 30 and 60 feet, respectively, based on observations from the ISB pilot testing (described in Section 3.1.1.3). It was observed during pilot testing that sparging in the deep subunit increased dissolved oxygen levels within the middle subunit as effectively as sparging directly in the middle subunit, which was attributed to the middle subunit functioning as a semi-confining layer that increased the distribution and injection ROI in the deep subunit. Therefore, no injection wells are proposed to be screened in the middle subunit.

Similar to the process described in Alternative 2 for installing ISB injection wells, boreholes will be advanced via sonic drilling and coring. Each of the 11 deep wells will be collocated with a shallow well in a shared 8-inch-diameter borehole. The remaining 33 shallow injection wells (without deep pairs) will be installed within a 6-inch-diameter boring. Injection well construction details are the same as those described in Alternative 2 for ISB in Area 2, except that the shallow wells will be screened from 27 to 30 feet bgs and deep wells will be screened from 67 to 70 feet bgs.

The following assumed operational details of the injection well network are based on pilot testing, but will be refined through field testing.

Airflow and Pressures: Injection pressures will be field-adjusted to provide sufficient oxygen to groundwater at a target flowrate near 10 acfm per well of ambient air. Routine injection pressures are anticipated to range between 6 and 12 psig in the shallow subunit and between 20 and 40 psig in the deep subunit. Initial injection pressures of 18 and 45 psig to establish the air passages are anticipated for the shallow and deep subunits, respectively. At these target injection rates and pressures, no monitoring or vapor collection system is anticipated to be required in the vadose zone.

Zoning and Cycles: This describes the anticipated zoning and injection duration cycling; however, these are subject to change based on field observations during field installation and system startup.

Shallow: The 44 shallow ISB injection wells will be grouped into 8 zones, with 4 containing 6 wells each and 4 containing 5 wells each. Two shallow zones (comprising 10 to 12 wells total) will operate concurrently for 2 hours followed by 6 hours of downtime while the other 6 zones operate (three sets of two zones). These timeframes are based on pilot testing observations, where maximum dissolved oxygen concentrations were reached after 20 minutes to 2 hours of air injections and were consumed at rates up to 1.1 mg/L/hr. Therefore, shallow zones will operate in pairs, each having a daily operational duration of approximately 6 hours per day.

Deep: The 11 deep ISB injection wells will be grouped into 2 zones, with one containing 6 wells and the other containing 5 wells. The two zones will alternate injections, with each operating individually for 4 hours followed by 4 hours of downtime, for a total operational duration of approximately 12 hours per day. These timeframes are based on pilot testing observations, where maximum dissolved oxygen concentrations in the deep subunit were reached after 2 to 3 hours of air injections and were consumed at rates up to 3.1 mg/L/hr. The longer injection duration is controlled by slower dissolved oxygen increases in the deeper subunit, whereas the faster dissolved oxygen consumption in the middle subunit necessitates more frequent injections (less downtime).

System Components: Individual components will be designed in detail prior to implementation; however, air flow is anticipated to be provided to the shallow zones via one, 40-HP rotary claw air compressor and to the deep zones via one, 40-HP rotary screw air compressor, both equipped with inline flow regulators. The system will distribute flow through each zone using manifolds equipped with pressure, temperature, and flow indicators. The remediation system is assumed to be controlled by a SCADA system for monitoring and control, as well as a PLC that will enable adjustable injection cycle durations and frequencies by ISB zone. Ambient air will be filtered through a 5-micron particulate filter prior to entering the air compressor and compressed air will be filtered through an oil filter prior to injection into the subsurface. Conveyance piping (e.g., 1-inch HDPE) will be installed within a shallow trench (e.g., 1.5 feet bgs) where possible, and above ground piping will be completed with galvanized pipe or pressure-rated rubber airline hose.

System O&M and Monitoring: The compressors will operate continuously and the system monitored and controlled remotely with occasional in-person visits for repairs and adjustments. O&M will be performed as necessary and its frequency will be established based on observed demands; however, it is assumed for the purpose of this FFS that quarterly maintenance events are conducted following system startup. Each visit assumes minor equipment replacement with infrequent larger replacements. Groundwater parameters (primarily dissolved oxygen) and depth to water will be measured at groundwater wells in the vicinity of the treatment area. Airflow velocity and pressures will be measured at injection wells on-cycle and off-cycle. Pressure will also be measured inside of the well casing at monitoring wells in the vicinity of the treatment area.

The following assumptions and durations are anticipated for each different phase of ISB implementation:

- *Injection well completion, system installation, and startup*: Up to three months are assumed for drilling, completing injection wells, installing system components, starting ISB, and optimizing system performance (e.g., zoning, cycle durations, pressures, and air flow rates).
- *System duration*: The system will operate until COC mass in NAPL has decreased such that the effective aqueous solubilities of COCs from the NAPL are less than cleanup goals. When cleanup goals are achieved, ISB would cease. NAPL solubility modeling (Appendix B) indicates that the desired effective solubilities would be reached within 6 years in each of the shallow, middle, and deep subunits of Area 1.
- *Post-remediation monitoring*: After treatment objectives have been achieved (desired effective solubilities), ISB will cease and post-remediation monitoring will ensue until

the treatment's longevity and effectiveness is sufficiently established, which is assumed to occur after 5 additional years (Year 11).

3.3.3.2 Remedy Implementation in Area 2

ISB will be implemented in Area 2, as described in Alternative 2, and likely with a similar remedial timeframe (the ISB duration was kept at 41 years for the purpose of cost estimating). The contaminant mass in Area 2 upgradient of the ISB transect will be reduced via NSZD, which will be monitored as discussed in Section 3.3.2.2. Similar to the effects of reinjecting treated groundwater from Area 1 into Area 2 under Alternative 2, treated and oxygenated groundwater will flow from Area 1 through Area 2 under Alternative 3, accelerating attenuation by enhancing aerobic biodegradation and "flushing" the formation with "clean" water. However, dissolution modeling suggests that the effects of "flushing" with clean water are minor when compared to in situ biodegradation processes as approximately 80 percent and over 99 percent of mass depletion simulated in the shallow and deep subunits, respectively, are attributed to biodegradation where the remaining 20 percent and less than 1 percent of mass depletion were simulated to occur from the flux of incoming "clean" groundwater.

3.3.3.3 Remedy Implementation in Area 3

MNA will be implemented in Area 3, as described in Alternative 2.

3.3.3.4 Alternative Summary and Sequencing

The general sequence and duration of key activities under Alternative 3 include the following:

- Year 0: Install ISB injection wells and implement ISB (system startup and begin operation) in Areas 1 and 2. NSZD in Area 2 and MNA in Area 3.
- Years 1 to 6: O&M of ISB in Areas 1 and 2. NSZD in Area 2 and MNA in Area 3.
- Years 6 to 10: O&M of ISB in Area 2. NSZD in Area 2 and MNA in Area 3. Post-remediation monitoring in Area 1.
- Year 11: O&M of ISB in Area 2 and NSZD. Post-remediation monitoring in Area 1 and NFA in Area 3.
- Years 12 to 41: NSZD and O&M of ISB in Area 2. NFA in Areas 1 and 3.
- Years 42 to 46: Post-remediation monitoring in Area 2 and NFA in Areas 1 and 3.
- Year 46: Remedy Complete.

3.3.4 Alternative 4 – Steam Enhanced Extraction/In situ Biosparging (Area 1) and In Situ Biosparging (Area 2)

Alternative 4 includes the application of SEE followed by ISB to address NAPL and impacted groundwater in the waste pit area (Area 1), ISB near the downgradient extent of NAPL to treat contaminated groundwater in Area 2, and MNA in Area 3. Institutional controls as described in Alternative 1 will also be a component of Alternative 4.

3.3.4.1 Remedy Implementation in Area 1

SEE will be applied in Area 1 to increase subsurface temperature that will temporarily increase NAPL recoverability by decreasing NAPL viscosity and strip COCs from the NAPL by increasing the vapor pressure of the COCs. Four main removal mechanisms employed during steam injection for contaminant recovery include (USACE 2009):

- Physical displacement of NAPL as steam migrates from injection to extraction wells.
- Volatilization of COCs and extraction as a vapor phase.
- Solubilization and condensation of contaminants with subsequent removal in the dissolved phase by groundwater extraction.
- In situ destruction by either chemical or biological reactions.

The SEE system applied to Area 1 includes the following multi-unit components:

- Steam generating and injection system
- Multi-phase extraction and above ground liquid and vapor treatment systems
- Hydraulic control system/barrier
- Surface barrier/cover
- Soil vapor extraction

Steam will be generated by a 50 million British thermal units per hour (BTU/hr) boiler using City water. The water will be pretreated using a water softener. Wastes associated with steam generation will include boiler blowdown and softener regeneration liquids. These liquids will be contained prior to appropriate disposal.

Steam will be injected through 55 triple nested wells (165 wells total) screened in the shallow, middle, and deep subunits, to treat a 2.7-acre area with a target depth of 67 feet bgs. A well spacing of 50 feet was assumed to target the boiling point of water and heat a specific volume of subsurface. The target treatment temperature is approximately 247 °F. Assuming a subsurface temperature of 50 °F and achieving a 1.9 degree F per day of heating, the target temperature could be achieved in approximately 105 days. A 3-inch vapor barrier of shotcrete with polyester carbon over the 2.7-acre area will be installed to minimize heat loss and contain vapor loss. The locations of the injection/extraction wells are shown on Figure 3-6. A process flow diagram showing the various treatment steps planned for the vapor and liquid treatment system is shown on Figure 3-7.

A total of approximately 45,400 pounds of steam per hour will be injected (275 lbs/hr/well). The range of injection pressures for each subunit is:

- 5 – 10 psig – Shallow
- 10 – 20 psig – Middle
- 20 – 40 psig – Deep

Vapor and liquids will be extracted from 54 multi-phase extraction wells and 30 horizontal soil vapor extraction wells.

The extracted liquids (steam, groundwater, and NAPL) will be treated in an above ground system consisting of a heat exchanger, oil/water separator, and liquid phase GAC. Treated liquids will be reinjected into the subsurface downgradient of Area 1. The extracted vapor will be treated via thermal oxidation following removal of entrained liquids. Recovered NAPL from the OWS will be stored in tanks prior to disposal off site. A process flow diagram of the conceptual design of the vapor and liquid treatment system is shown on Figure 3-7.

A utility upgrade for a connection to the City water line will be required prior to implementing SEE. The existing City water line is 1 inch in diameter, running about 500 feet from the main line. A 2- to 3-inch-diameter line will be installed to provide a continuous supply of clean water to the water softener and steam boiler. The electrical power to the Libby on-site laboratory (LOSL) and the bioreactor building has been upgraded. A service lateral will extend from the upgraded power line to provide power to the SEE equipment.

The high flow of cold groundwater recharging the shallow subunit from the fire pond was estimated to limit subsurface heating to target temperatures during SEE, based on site-specific groundwater modeling results. Therefore, a cutoff wall barrier is assumed to be installed as a hydraulic control prior to implementation of SEE so that reasonable steam injection rates can be used to heat the subsurface. The cutoff wall will be approximately 460 feet long, 40 feet deep, and two feet wide, constructed of sheet pile/soil/bentonite at a location between the former waste pit (Area 1) and the fire pond. Although the cutoff wall would significantly decrease the influx of fresh water and likely improve SEE performance, if left in place post-remedy the cutoff wall would decrease long-term NSZD of the NAPL in Area 2. Presently the fire pond provides oxygenated fresh water, which serves to decrease NAPL mass through dissolution and aerobic biodegradation. Therefore, upon completion of SEE the wall could be removed or a different hydraulic control could be temporarily employed so that the groundwater gradient returns to its pre-remedy conditions.

Baseline soil sampling and analysis will be conducted prior to SEE. Approximately 30 soil samples will be collected for chemical analysis from 10 borings drilled within Area 1. Groundwater samples will be collected prior to SEE from wells located within Area 1 to provide a baseline of groundwater concentrations prior to SEE. Wells located hydraulically upgradient of Area 1 and the SEE radius of influence will be sampled as part of the baseline monitoring. Baseline subsurface temperature data will also be collected. Static groundwater level elevations and presence/absence of NAPL will be monitored in 10 wells prior to SEE.

SEE System Components and Operation: Key components of Alternative 4 include the following (Table 3-2):

- A 50-million BTU/hr, natural gas fired, trailer mounted boiler to generate steam for injection. The SEE vendor proposed natural gas, however, natural gas is not available at the Site and propane is the available fuel source.
- Fifty-five triple-nested steam injection wells (five to seven feet apart per cluster). Shallow subunit wells will be screened approximately 33 to 38 feet bgs, middle subunit wells will be installed roughly 53 to 58 feet bgs, and deep subunit wells will be installed roughly 70 to 75 feet bgs. Wells will be installed in 6-inch-diameter borings with 2-inch

carbon steel casing and stainless steel screens. Steam injection wells will be connected to the steam injection system via 2-inch ductile iron pipe with Victaulic fittings.

- Twenty-seven double-nested MPE wells (five to seven feet apart, per cluster). Shallow subunit wells will be screened from approximately 2 to 42 feet bgs, and deep subunit wells will be screened from 40 to 75 feet bgs. Wells will be installed in 8-inch-diameter borings with 4-inch carbon steel casing and stainless steel screens. MPE wells will be equipped with pneumatic pumps that will extract groundwater at a rate of approximately 6 gpm per well cluster. MPE wells will be connected to 4-inch fiberglass reinforced pipe (vapor) and 1-inch ductile iron pipe (groundwater/NAPL) and delivered to above ground liquid and vapor treatment systems.
- A blower will extract soil vapor at a rate of 3,000 standard cubic feet per minute (scfm) from approximately 30 horizontal SVE wells trenched at shallow depths and completed with 2-inch polyvinyl chlorinated (PVC) pipe.
- The liquid treatment system will consist of a cone separator, OWS, and two GAC units. Treated liquids will be re-injected into existing injection wells located downgradient of Area 1 (wells 9500.1 and 9501.1). The vapor treatment system will consist of a cone separator and condenser skid via 4- to 8-inch fiberglass reinforced pipe to remove entrained liquids prior to treatment in a thermal/catalytic oxidizer.
- Twenty-five temperature monitoring points, and 10 pressure monitoring wells will be installed to support the SEE system.
- Existing engineering (access controls, fencing, and signage) and ICs would be maintained to prevent unauthorized land and groundwater use.

The following assumptions and durations are anticipated for SEE implementation:

- *Injection and extraction well completion, system installation, and startup:* Approximately one and a quarter year is assumed for drilling, completing injection and extraction wells, installing temperature and pressure monitoring points, installing aboveground treatment system components and boiler equipment, startup, and optimizing system performance.
- *System O&M and monitoring*: The system will be operated for approximately 460 days. Monitoring of six wells on a semiannual basis will be performed for two years after SEE is completed in Area 1. Approximately 25 temperature monitoring points and 10 pressure monitoring points will be monitored continuously during SEE operations. Treated liquids from the above ground treatment system will be sampled and analyzed prior to reinjection to confirm compliance with reinjection criteria.

  Air samples will be collected from the thermal oxidizer emissions stack to confirm VOCs, criteria pollutants, or hazardous air pollutants are below emission limits and do not trigger additional emissions control requirements.

  Soil sampling and testing will be performed to estimate the contaminant concentrations and mass remaining in the soil following SEE.

- *Post-remediation monitoring*: After treatment objectives have been achieved, treatment will cease and post-remediation monitoring will ensue until the treatment's longevity and effectiveness is sufficiently established.

Under this alternative, NAPL and dissolved phase contaminants will be removed via SEE, after which ISB will be implemented in Area 1 with a configuration/setup identical to that described in Alternative 3 with the exception of repurposing some of the SEE injection wells for injecting air. Assuming ISB would commence by the end of Year 1, remediation timeframe modeling estimates that cleanup levels would be reached by Year 5 with remedy complete by Year 10, assuming 5 years of MNA. Based on bench-scale testing, approximately 20 percent of the mostly residual NAPL mass present in Area 1 is assumed to be removed as NAPL, which amounts to approximately 75,000 gallons of NAPL. SEE is capable of achieving greater removal effectiveness at sites where higher NAPL saturations indicate mobile and recoverable NAPL. However, the mostly residual NAPL saturations observed at the Libby Site limit the potential for NAPL recovery with SEE. Bench-scale testing indicates that SEE could decrease residual NAPL saturations by approximately 1 percent of the PV.

As a result of SEE, reductions in the mass fraction of COCs in the remaining NAPL may range between 50 and 90 percent for higher molecular weight PAHs, whereas greater reductions of 95 to 99 percent are anticipated for the more volatile NAPL constituents.

3.3.4.2 Remedy Implementation in Area 2

ISB will be implemented in Area 2, as described in Alternative 2, and likely with a similar remedial timeframe (the ISB duration of 41 years was used for the purpose of cost estimating). The contaminant mass in Area 2 upgradient of the ISB transect will be reduced via NSZD, which will be monitored as discussed in Section 3.3.2.2. Similar to the effects of reinjecting treated groundwater from Area 1 into Area 2 under Alternative 2, treated and oxygenated groundwater will flow from Area 1 through Area 2 under Alternative 4, accelerating attenuation by enhancing aerobic biodegradation and "flushing" the formation with "clean" water. However, dissolution modeling suggests that the effects of "flushing" with clean water are minor when compared to in situ biodegradation processes as approximately 80 percent and over 99 percent of mass depletion simulated in the shallow and deep subunits, respectively, are attributed to biodegradation where the remaining 20 percent and less than 1 percent of mass depletion were simulated to occur from the flux of incoming "clean" groundwater.

3.3.4.3 Remedy Implementation in Area 3

MNA will be implemented in Area 3, as described in Alternative 2.

3.3.4.4 Alternative Summary and Sequencing

The general sequence and duration of key activities under Alternative 4 include the following:

- Years 0 to 1: Install SEE wells and implement SEE in Area 1. Install ISB transect wells and implement ISB in Area 2. NSZD in Area 2, and MNA in Area 3.
- Years 1 to 5: Install ISB in Area 1, then O&M of ISB in Areas 1 and 2. MNA in Area 3.
- Years 5 to 10: O&M of ISB and NSZD in Area 2. Post-remediation monitoring in Area 1 and MNA in Area 3.

- Years 11 to 41: O&M of ISB and NSZD in Area 2. NFA in Areas 1 and 3.
- Years 41 to 46: Post-remediation monitoring in Area 2. NFA in Areas 1 and 3.
- Year 46: Remedy Complete.

3.3.5 Alternative 5 – In Situ Geochemical Stabilization (Area 1) and In Situ Biosparging (Area 2)

Alternative 5 includes the application of ISGS by injecting a proprietary modified permanganate solution developed by Innovative Environmental Technologies, Inc. (IET) into the three subunits in the waste pit (Area 1) followed by NSZD, ISB near the downgradient extent of NAPL to treat contaminated groundwater in Area 2 and to propagate a dissolved oxygen rich zone that further reduces contaminant concentrations and prevents dissolved COC migration downgradient of Area 2, and MNA in Area 3. Institutional controls as described in Alternative 1 will also be a component of Alternative 5. A plan view of the remediation systems for Alternative 5 is provided on Figure 3-8.

3.3.5.1 Remedy Implementation in Area 1

Injection of the geochemical stabilization solution is used to encapsulate NAPL with chemical oxidation of organics as a secondary effect. As the solution migrates through the treatment area, the chemical oxidant (permanganate) destroys COCs present in the dissolved phase and at NAPL-water interfaces, resulting in the formation of a geochemical shell (that includes manganese oxide). The geochemical shell accumulates along the NAPL interface, physically coating and encapsulating the NAPL and reducing the flux of dissolved phase COCs into groundwater.

ISGS solution will be applied over a 125,000-square foot area of Area 1 at depths from 7 to 74 feet bgs into each subunit (shallow, middle and deep) of the Upper Aquifer. Approximately 600 injection points will be installed using sonic drilling to advance the injection screen to the target depths (see Figure 3-8).

ISGS solutions ranging from 3 to 10 percent concentration (amount of oxidant in the solution) have been applied and field tested and a 10 percent concentration solution was selected for application at the Site. Reagent injection volume from laboratory studies for other sites have demonstrated that a reagent volume of approximately 5 to 10 percent of the pore space was sufficient to treat impacted soil. Therefore, a 10 percent ISGS solution will be injected in concentrated form to displace 5 percent of the formation pore volume. The ISGS solution has a viscosity similar to water and will freely disperse and distribute throughout the formation, mixing with formation water and remaining active until contact with organic matter.

The shallow subunit will be treated at 398 injection points with an ROI of approximately 10 feet. The ISGS solution will be injected between 7 and 34 feet bgs at five injection intervals about every five feet within this zone. A 10 percent ISGS solution will be injected to target approximately 5 percent of the pore volume in the shallow subunit, assuming a 20 percent effective porosity. ISGS solution injection activities for the shallow subunit are estimated to be conducted over an 85-day period.

The middle subunit will be treated at 100 injection points with an ROI of approximately 20 feet. The ISGS solution will be injected between 34 and 54 feet bgs at four injection intervals about every five feet within this zone. A 10 percent ISGS solution will be injected to target approximately 5 percent of the pore volume in the middle subunit, assuming a 20 percent effective porosity. Injection activities for the middle subunit are estimated to be conducted over a 63-day period.

The deep subunit will be treated at 100 injection points with an ROI of approximately 20 feet. The ISGS solution will be injected between 54 and 74 feet bgs at four injection intervals, about every five feet within this zone. A 10 percent ISGS solution will be injected to target approximately 5 percent of the pore volume in the deep subunit, assuming a 20 percent effective porosity. Injection activities for the deep subunit are estimated to be conducted over a 63-day period.

The ISGS solution will be prepared on site in a self-contained trailer consisting of a liquid feed system with two, 120-gallon conical tanks equipped with mixers that will provide a capacity of maintaining up to 30 percent solids in suspension. The liquid and air injection systems contained in the trailer include a generator, stainless steel piping, pneumatic diaphragm pump, and compressor. Injection lines used to deliver the solution are 1-inch-diameter high pressure stainless steel braided rubber. IET proprietary injection rods with retractable injection zones and backflow protection will be used. Injection zones of 18 inches will be used in combination with 24-inch injection rods, where appropriate.

Compressed air will be delivered to the subsurface using the air injection system. Injecting air and monitoring pressure changes allows confirmation of open delivery routes. Injecting air also enhances horizontal injection pathways. At each point, a 10 percent solution will be injected at pressures between 15 to 120 psi and flow rates from 2 to 15 gpm. Water will be injected following the solution to rinse the injection equipment. Compressed air is then injected to clear the liquids from the lines and to assist solution distribution into the subunit. Injecting air also minimizes surfacing of the solution following release of injection pressure. Following the injection cycle, each injection point will be temporarily capped to allow the pressurized subunit to accept the solution.

Treatment of the waste pit (Area 1) would start downgradient and move cross-gradient toward the middle of the waste pit, thus maintaining hydraulic control during implementation. Application of ISGS would be completed in one year. It is expected that an encrusted material would be formed within up to five days after injection of ISGS chemicals.

The residual mass formed from the various geochemical reactions is a birnessite-like crust formation around the DNAPL. Birnessite is an oxide of manganese and magnesium along with sodium, calcium, and potassium with the following chemical composition:

$$(Na, Ca, K)\ (Mg, Mn)\ Mn_6\ O_{14} \bullet 5\ H_2O$$

As Birnessite is formed, NAPL is encapsulated, mass flux is reduced, and concentrations of COCs downgradient will be reducing. Reaction of NAPL with ISGS solution will occur within 3 to 7 days of injection.

The following assumptions and durations are anticipated for ISGS implementation:

- *Injection well completion, system installation, and startup:* Approximately one year is assumed for drilling, completing injection wells, mobilizing chemical mixing and injection system components, startup, and optimizing injection performance.
- *System O&M and monitoring*: The system will be operated for approximately one year. Monitoring of 12 wells on a semiannual basis for two years will be performed following completion of ISGS solution injection. Performance monitoring prior to and following injection and treatment will include:
  - Collection of subsurface core
  - Groundwater sampling of wells downgradient of Area 1

  Prior to injection of ISGS chemicals, groundwater will be sampled from existing wells upgradient and downgradient of the waste pit. Wells within the waste pit will also be sampled for NAPL levels. Following ISGS, 30 soil samples will be collected from 10 locations within the treated waste pit area. Soil samples will be collected from each of the treated intervals for thin section/microscopy.
- *Post-remediation monitoring*: After treatment objectives have been achieved, treatment will cease and post-remediation monitoring will continue until the treatment's longevity and effectiveness is sufficiently established.

Based on a complex heterogeneous distribution of NAPL and formation permeability, application of ISGS is expected to encapsulate approximately 80 percent of the NAPL in Area 1. The ability to deliver an ISGS solution to a target treatment area is very site-specific and depends on site-specific aquifer permeability heterogeneity and the distribution of NAPL within the heterogeneous aquifer lithology. Thus, a pilot test is typically required to estimate site-specific treatment effectiveness. Although uncertain, an 80% treatment effectiveness was assumed to complete remediation time frame modeling and allow comparison of alternatives. NSZD will continue to remove NAPL and COCs from NAPL that is not encapsulated. The estimated time for NSZD to achieve groundwater criteria based on the untreated NAPL in Area 1 ranges from 29 to 145 years and depends on how much of the pore volume in Area 1 is available for the remaining NAPL to enhance dissolution and biodegradation (Appendix B).

3.3.5.2 Remedy Implementation in Area 2

ISB will be implemented in Area 2, as described in Alternative 2, but likely with a slightly longer remedial timeframe; however, for the purposes of cost estimating, the ISB duration was kept at 41 years. The contaminant mass in Area 2 upgradient of the ISB transect would be reduced via NSZD, which would be monitored as discussed in Section 3.3.2.2. Under Alternative 2, treated and oxygenated water from Area 1 is reinjected into Area 2, enhancing aerobic degradation and flushing the formation with "clean" water. Under Alternative 5, groundwater flux from Area 1 through Area 2 is likely to be anaerobic and at reduced flows compared to pre-ISGS due to significant permeability decreases from oxidized material following ISGS injections.

3.3.5.3 Remedy Implementation in Area 3

MNA will be implemented in Area 3, as described in Alternative 2.

3.3.5.4 Alternative Summary and Sequencing

The general sequence and duration of key activities under Alternative 5 include the following:

- Year 0: Install and implement ISGS in Area 1 and ISB transect in Area 2. NSZD in Area 2, and MNA in Area 3.
- Years 1 to 10: O&M of ISB in Area 2. NSZD in Areas 1 and 2. MNA in Area 3.
- Years 11 to 29: NSZD and O&M of ISB in Area 2. NSZD in Area 1 and NFA in Area 3.
- Years 30 to 34: NSZD and O&M of ISB in Area 2. Post-remediation monitoring in Area 1 and NFA in Area 3.
- Years 34 to 41: NSZD and O&M of ISB in Area 2. NFA in Areas 1 and 3.
- Years 41 to 46: Post-remediation monitoring in Area 2. NFA in Areas 1 and 3.
- Year 46: Remedy Complete.

Table 3-1. Estimated Mass of Select COCs and NAPL Volume in Remediation Areas 1, 2, and 3

	Remediation Area			Total	Unit
	1	2	3		
Total Area	2.7	33	98	133.7	acres
Average Depth to Groundwater (August 2016)	11	17	16		ft bgs
Average Upper Aquifer Saturated Thickness	63	57	43		ft
Total Soil Volume in Upper Aquifer Saturated Zone	7,449,855	81,558,191	185,287,687		ft^3
	275,645	3,017,653	6,855,644		cy
Average Upper Aquifer Dry Bulk Density	1.87	1.87	1.87		g/cm^3
Average Upper Aquifer Wet Bulk Density	2.18	2.18	2.18		g/cm^3
Average Upper Aquifer Total Porosity	30.7	30.7	30.7		%
Total Mass of Soil PCP[1]	7,484	19,301	46	26,830	kg
	16,502	42,558	102	59,161	lbs
Total Mass of Soil Naphthalene[1]	170,863	147,241	33	318,136	kg
	376,752	324,665	72	701,490	lbs
Total Mass of Soil Fluoranthene[1]	14,713	43,734	52	58,498	kg
	32,442	96,433	114	128,988	lbs
Total Mass of Soil Fluorene[1]	12,483	32,837	31	45,350	kg
	27,525	72,405	68	99,998	lbs
Total Mass of Soil Benzo(a)pyrene[1]	1,078	3,180	14	4,272	kg
	2,378	7,011	31	9,420	lbs
Estimated DNAPL Volume[2]	385,126	993,244	0	1,378,370	gal
Estimated DNAPL Saturation[2]	2.25	0.529	0		% PV
Range of Dissolved PCP Concentrations (2016)					
Shallow Subunit	0.78 - 3,600	<0.5 - 360	<0.5 - 140		ug/L
Middle Subunit	5,500 - 9,700	<0.5 - 570	0.14 - 140		ug/L
Deep Subunit	280 - 9,900	0.31 - 1,500	0.14 - 16		ug/L
Range of Dissolved Naphthalene Concentrations (2016)					
Shallow Subunit	1,800 - 29,000	<0.02 - 2,800	<0.02 - 55		ug/L
Middle Subunit	3,800 - 110,000	<0.028 - 3,600	<0.013 - 39		ug/L
Deep Subunit	2,100 - 15,000	0.0064 - 34,000	0.11 - 75		ug/L

Notes:

[1] The total mass of select COCs in soil is based on the average of the available soil concentration data in each remediation area, as provided on Table 1-6. The soil concentrations represent NAPL in the pore space, if present, with smaller contributions from adsorbed and dissolved mass in the pore space.

[2] The estimated DNAPL volume is based on the average mass of each COC in each remediation area divided by the average concentration of the three available DNAPL samples collected from the oil/water separators. It is assumed that NAPL predominantly exists as DNAPL in the Upper Aquifer with negligible LNAPL.

[3] The estimated DNAPL saturation is based on the total estimated DNAPL volume divided by the total volume of saturated pore space in each remediation area.

Table 3-2. Summary of Key Components for Alternatives

Area	Alternative	Component	Description
All Areas	Alternative 1	Institutional Controls	o City ordinance that prohibits drilling of a water well for the purpose of human consumption or irrigation. o General maintenance activities including maintenance of fences, signs, roads, drainage, or structures. o Discontinue SAETS and Upper Aquifer monitoring activities. o Perform 5-year reviews and maintain CGA.
Area 1	Alternative 2	Five (5) Shallow Extraction Wells	o 110-foot spacing between extraction wells o Combined capture zone of 550 feet perpendicular to plume o 15 gpm pumping rate at each extraction well o 4-inch diameter carbon steel well casing and 4-inch diameter wire-wrapped SS 0.020-inch slotted screens o Well depths of approximately 35 ft bgs with screened intervals of approximately 25 – 35 ft bgs
		One (1) Deep Extraction Well	o Radius of 87.5 feet o Capture Zone of 550 feet o 2 gpm pumping rate o 4-inch carbon steel well casing with 4-inch SS wire-wrapped 0.020-inch slotted screens o Well depth of 75 feet bgs with screened interval of 54.5 – 74.5 ft bgs
		Coalescing Oil-Water Separator	o Use existing system component, which has sufficient capacity for deep extraction.
		Two (2) Trickling Filter Rotary Distributor Units	o Influent flow capacity of 125 gpm; average of 80 gpm
		Pressure Filter	o Removes bio solids that will break away into effluent from trickling filters prior to entering GAC vessels.
		Three (3) Granular Activated Carbon Vessels	o Three stages; 20,000 lb units each o Consumption rate of 210,000 lbs per year, changed out quarterly o Effluent to meet Montana Re-Injection Standards
		Re-Injection Wells	o 2 gpm re-injected into existing deep re-injection well 9501.1 o 25 gpm re-injected into existing shallow re-injection well 9500.1 o 25 gpm re-injected into two (2) new shallow re-injection wells screened 25-35 ft bgs. o New wells installed with 4-inch carbon steel casing and 4-inch SS wire-wrapped 0.020-inch slotted screens o HDPE conveyance piping from treatment system to re-injection wells
	Alternative 3	Shallow In-Situ Biosparging (ISB) Injection Point	o 44 shallow injection wells with estimated 30-foot ROIs o 3-foot screens; approximately 27 to 30 ft bgs o Targeted airflow of 10 acfm per injection well at injection pressures of 6 to 12 psig supplied by one 40-HP rotary claw compressor and HDPE piping from system manifold to wellhead

Table 3-2. Summary of Key Components for Alternatives

Area	Alternative	Component	Description
Area 1	Alternative 3	Deep ISB Injection Points	o 11 deep injection wells with estimated 60-foot ROIs o 3-foot screens; approximately 67 to 70 ft bgs o Targeted airflow of 10 acfm per injection well at injection pressures of 20 to 40 psig supplied by one 40-HP rotary screw compressor and HDPE piping from system manifold to wellhead
	Alternative 4	Cut-Off Wall	o Prevents cold water influx from Fire Pond o 460-feet long and 40-feet deep and a 2-foot wide trench o Vinyl sheet piling and back-filled with soil-bentonite mixture o Excavated soil disposed as hazardous waste
		Surface Seal	3-inch (maximum) layer of shotcrete mixed with polyester carbon fibers to reduce surface cracking and vapor short-circuiting during steam injection.
		Trailer-Mounted Boiler	o 50-million BTU/hour; natural gas fired o Water pre-treated with water softener
		Steam Injection Piping	2-inch ductile iron piping with Victaulic fittings
		Steam Injection Wells	o 55 triple-nested steam injection locations (165 wells total) installed approximately 5-7 feet apart per cluster with wells screened from 33-38, 58-63, and 75-80 ft bgs in the shallow, middle, and deep subunits, respectively. o Wells will be completed with 2-inch diameter stainless steel casing and screen o Average injection rate of 275 lbs/hr per steam injection well of 80% quality steam. o The approximate range of steam injection pressures will be between 5 and 10 psig, 10 and 20 psig, and 20 and 40 psig for the shallow, middle, and deep subunit injection wells, respectively.
		Multi-Phase Extraction (MPE) Wells	o 27 double-nested steam injection wells installed approximately 5-7 feet apart per cluster o Shallow Subunit wells screened from 2-42 ft bgs o Deep Subunit wells screened from 40-80 ft bgs o Wells will be completed with 4-inch diameter carbon steel casing and stainless steel screen o Pneumatic pumps installed in these wells will extract groundwater from the treatment zone at a rate of approximately 6 gpm per well cluster (shallow and deep)
		Conveyance Piping	o Liquid from MPE: 1-in ductile iron pipe o Vapor from MPE: 4-in fiberglass reinforced pipe (heat traced)
	Alternative 4	MPE Treatment Process - Liquid	o Pumped to cone separator then transferred to OWS (200 gpm capacity or more) via hazardous location centrifugal pump with SS housing. o Transferred from OWS to two liquid GAC units capable of 200 gpm (or more) via hazardous location centrifugal pump before discharge. o LNAPL transferred from OWS to 330-gallon totes via hazardous location centrifugal pump. o DNAPL Cone Separator pumped to 330-gallon totes via sliding vane action pump constructed using ductile iron. o All transfer piping constructed of 1 or 2-in ductile iron piping.

Table 3-2. Summary of Key Components for Alternatives

Area	Alternative	Component	Description
Area 1	Alternative 4	MPE Treatment Process - Vapor	o Extracted through cone separator and condenser skid o Conveyance piping stepped up from 4 to 8-in fiberglass reinforced pipe at manifold that feeds into cone separator o Condenser skid will house two 24-inch diameter condensate filter separators, an air-to-air heat exchanger, and a variable speed drive, hazardous location centrifugal pump o Remaining contaminants after condenser skid will be treated in oxidizer skid housing thermal/catalytic oxidizer system, knockout tank, and variable speed blower.
		Monitoring and Support Wells	o 30 horizontal soil-vapor extraction wells o 25 temperature monitoring points o 10 pressure monitoring wells
	Alternative 5	In-Situ Geochemical Stabilization Injection Points	o Shallow Subunit injection points: 398 points screened from 7-34 ft bgs, a ROI of 10 ft, and five injection intervals o Middle Subunit injection points: 100 points screened from 34-54 ft bgs, a ROI of 20 ft, and four injection intervals o Deep Subunit injection points: 100 points screened from 54-74 ft bgs, a ROI of 20 ft, and four injection intervals o 2-15 gpm injection rate for all wells with 10% solution at pressures between 15 to 120 psi
Area 2	Alternative 2 Alternative 3 Alternative 4 Alternative 5	ISB Transect	o 24 ISB wells at 80-foot spacing forming two rows having a net sparged length of 950 -960 feet o 3-foot screens; approximately 67 to 70 ft bgs o Targeted airflow of 10 acfm per well at injection pressures between 20 to 04 psig supplied by one 40-HP rotary screw compressor
Area 3	Alternative 2 Alternative 3 Alternative 4 Alternative 5	Monitored Natural Attenuation	o Sampling 27 wells for Alternatives 2, 3, and 5, and 20 wells for Alternative 4. Analyses include PAHs via EPA method 8270-SIM, PCP via EPA method 8151M, and dioxin via EPA method 8280A.

Notes:

bgs - below ground surface
EPA - Environmental Protection Agency
ft - feet
gpm - gallons per minute
in - inch
ISB - in-situ biosparging
lb - pound
MPE - multi-phase extraction
PAH - poly aromatic hydrocarbons
PCP - pentachlorophenol
psi - pounds per square inch
psig - pounds per square inch-gauge
ROI - Radius of Influence
SS - Stainless Steel

Table 3-3. Treatment Width Calculations for the Area 2 ISB Transect

Item	Symbol	Unit	Shallow Subunit		Middle-Deep Subunit		Data Source
			PCP	Naphthalene	PCP	Naphthalene	
Targeted Final Concentration	C_f	mg/L	0.001	0.1	0.001	0.1	Table 2-1
Maximum Influent Concentration	C_0	mg/L	0.004	1.2	1.3	13	Maximum concentration along transect in 2016
Estimated Half Life with ISB	$t_{1/2}$	d	1.0	2.0	1.5	3.0	Appendix B
1st Order Decay Rate	k	1/d	0.69	0.35	0.5	0.6	Appendix B
Hydraulic Conductivity	K_h	ft/d	190	190	13	13	Table 1-2
Hydraulic Gradient	i	ft/ft	0.011	0.011	0.0035	0.0035	Table 1-2
Darcy Flux	q	ft/d	2.09	2.09	0.046	0.046	q = Ki
Effective Porosity	n_e	-	0.2	0.2	0.2	0.2	Table 1-2
Groundwater Velocity	v	ft/d	10.5	10.5	0.23	0.23	Table 1-2
Required Treatment Timeframe	t	d	2.0	7.2	14.3	8.1	Calculated
Required Treatment Width	x	ft	21	75	3.3	1.8	Calculated

Notes:
d – day
ft – feet
ISB – in situ biosparging
mg/L – milligrams per liter
PCP – pentachlorophenol

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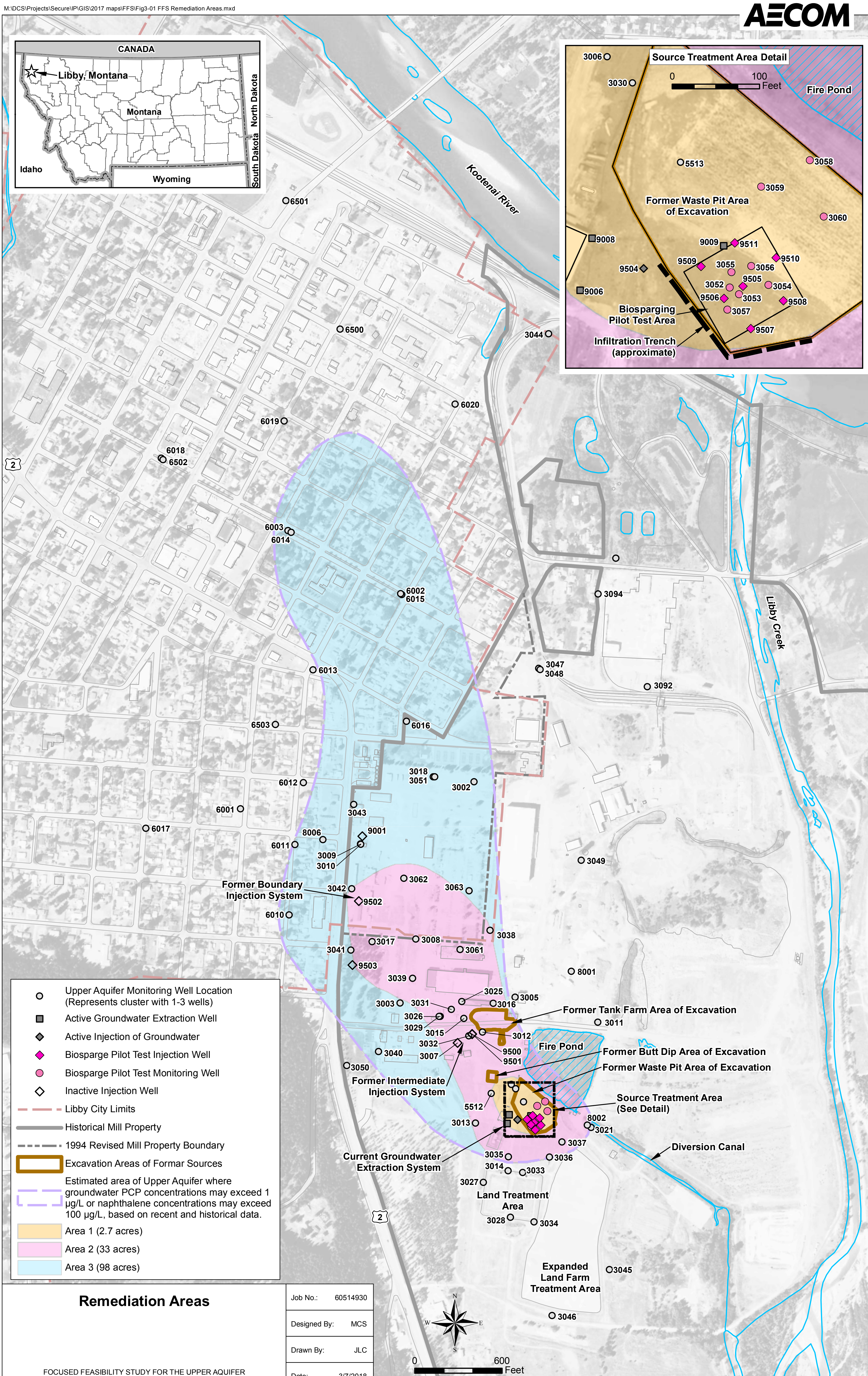

Remediation Areas

FOCUSED FEASIBILITY STUDY FOR THE UPPER AQUIFER
LIBBY GROUNDWATER SITE, LIBBY, MONTANA

Job No.:	60514930
Designed By:	MCS
Drawn By:	JLC
Date:	3/7/2018

Fig. 3-1

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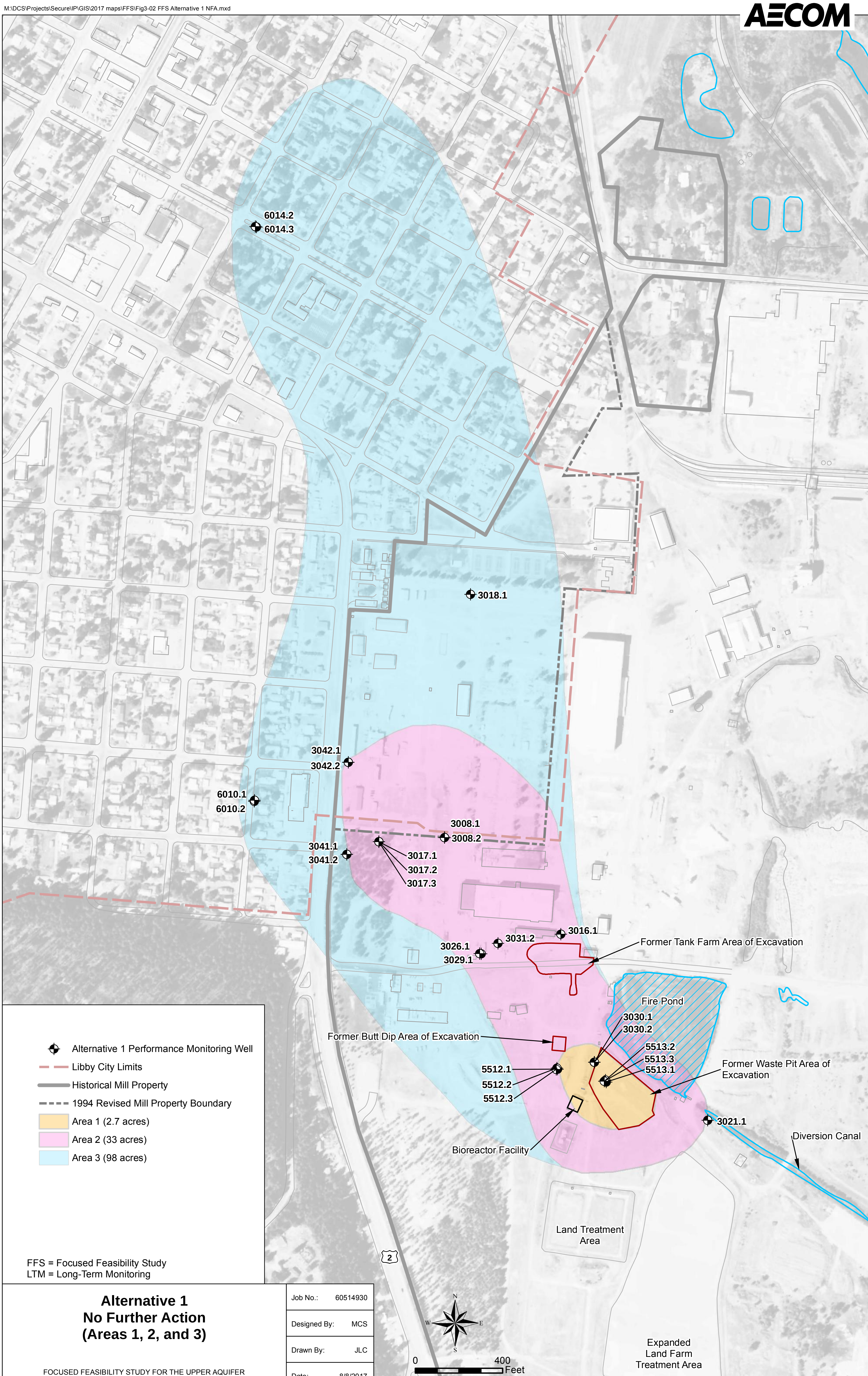

Alternative 1
No Further Action
(Areas 1, 2, and 3)

FOCUSED FEASIBILITY STUDY FOR THE UPPER AQUIFER
LIBBY GROUNDWATER SITE, LIBBY, MONTANA

Job No.:	60514930
Designed By:	MCS
Drawn By:	JLC
Date:	8/8/2017

Fig. 3-2

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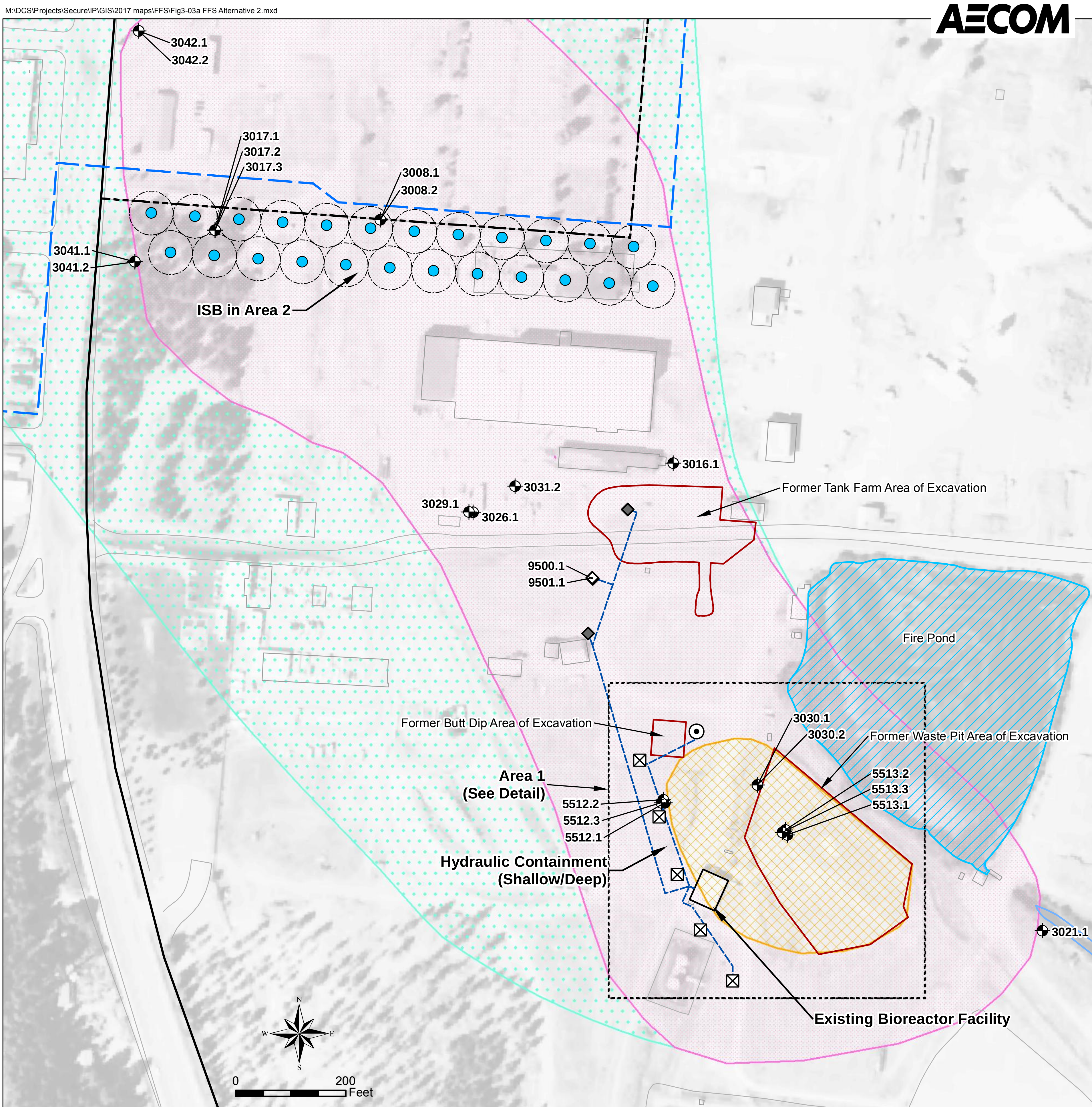


Alternative 2 Performance Monitoring Well

Area 1

Planned Shallow Subunit Groundwater Extraction Well

Planned Deep Subunit Groundwater Extraction Well

New Re-injection Well

Existing Re-injection Well

Extraction and Re-injection Well Conveyance Piping

Area 2 ISB Well

Radius of Influence (40')

Area 1 (2.7 acres)

Area 2 (33 acres)

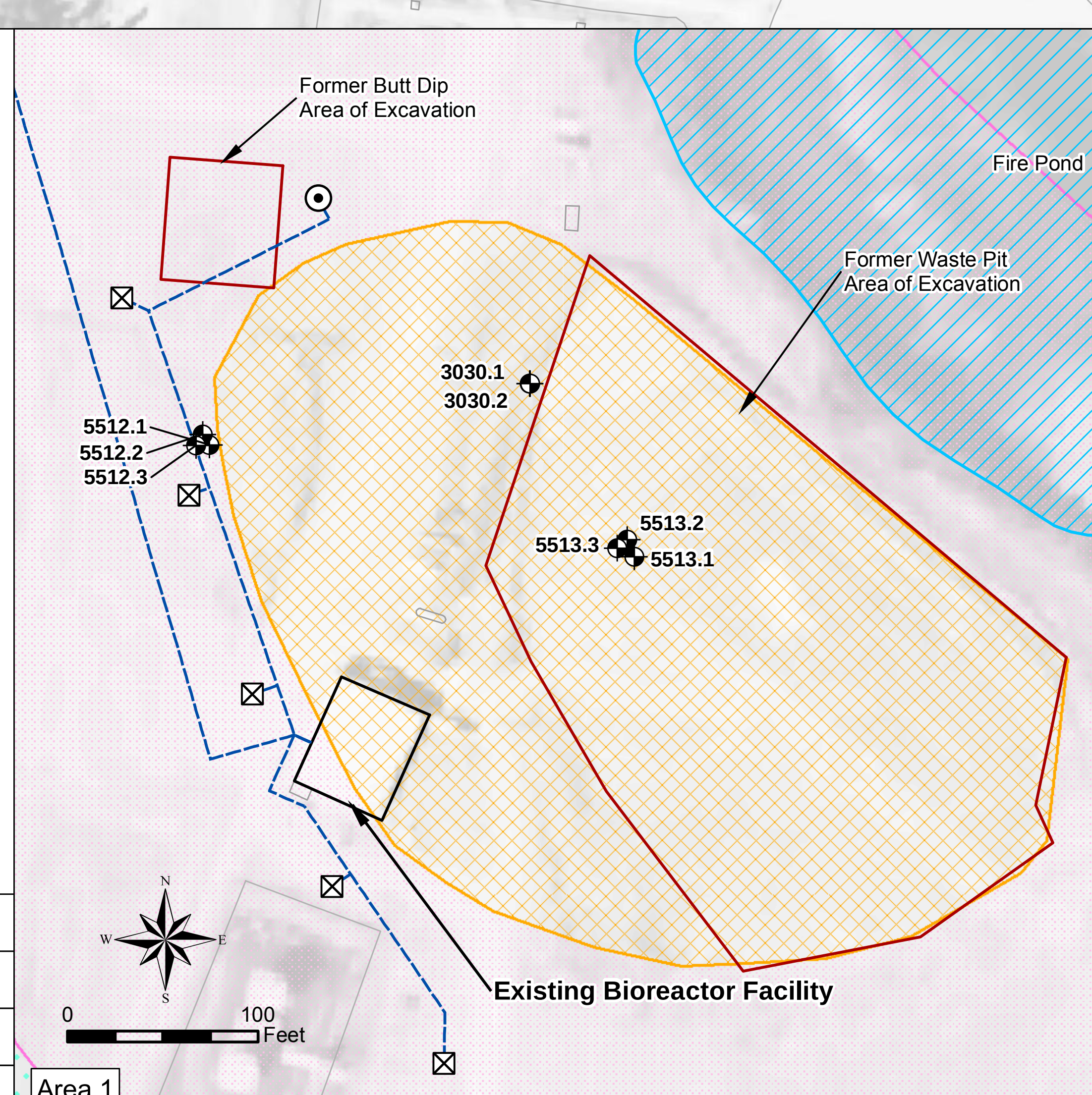
Area 3 (98 acres)

Historical Mill Property

1994 Revised Mill Property Boundary

Libby City Limits

FFS = Focused Feasibility Study
ISB = In Situ Biosparging
LTM = Long-Term Monitoring
MNA = Monitored Natural Attenuation

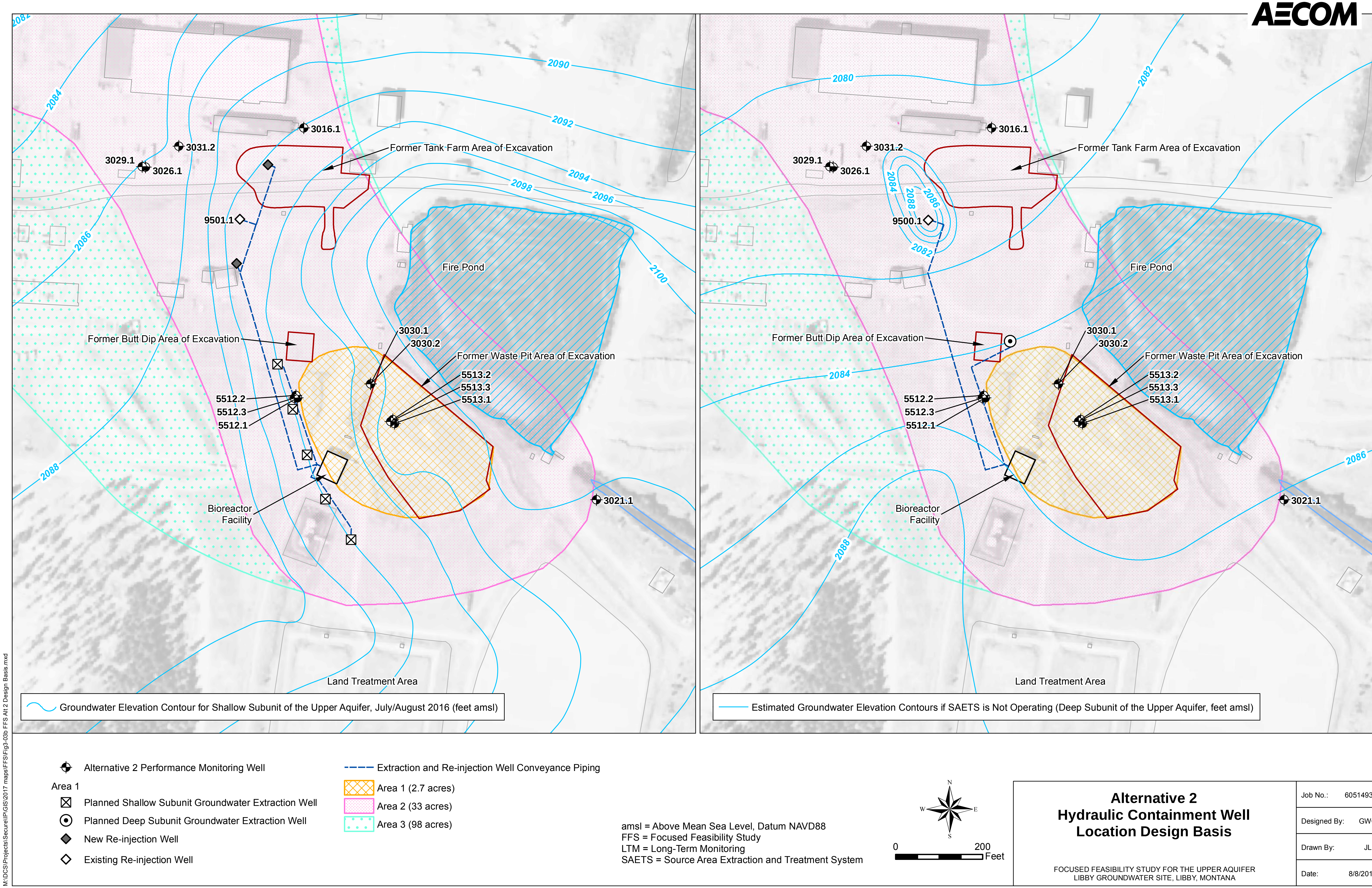


Alternative 2
Hydraulic Containment (Area 1),
ISB (Area 2),
and MNA (Area 3)

FOCUSED FEASIBILITY STUDY FOR THE UPPER AQUIFER
LIBBY GROUNDWATER SITE, LIBBY, MONTANA

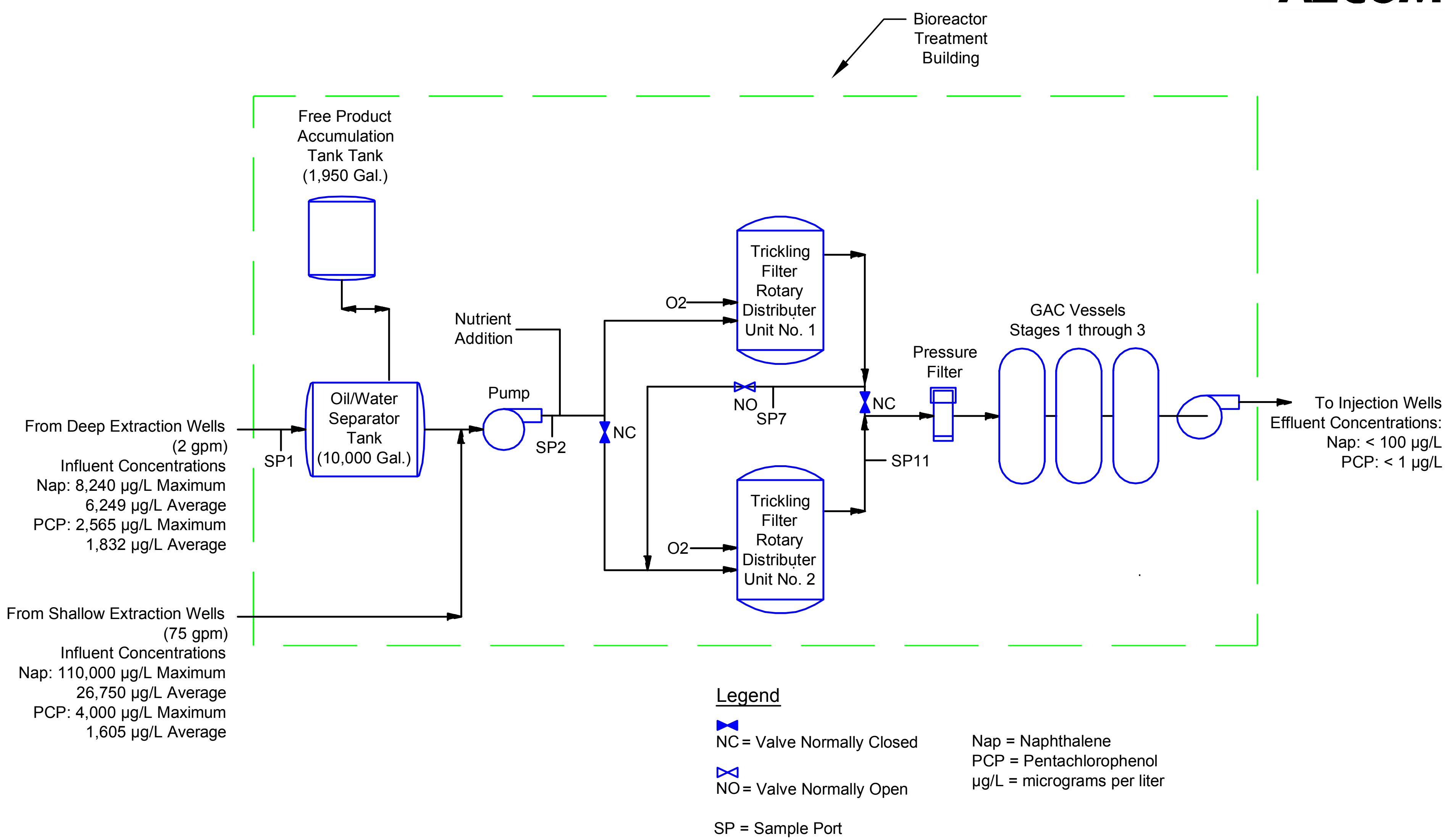
Job No.:	60514930
Designed By:	GWG
Drawn By:	JLC
Date:	8/8/2017

Fig. 3- 3a



Alternative 2 Hydraulic Containment Well Location Design Basis	Job No.:	60514930
	Designed By:	GWG
	Drawn By:	JLC
FOCUSED FEASIBILITY STUDY FOR THE UPPER AQUIFER LIBBY GROUNDWATER SITE, LIBBY, MONTANA	Date:	8/8/2017

Fig. 3-3b



Alternative 2
Groundwater Treatment Process Flow Diagram

FOCUSED FEASIBILITY STUDY FOR THE UPPER AQUIFER
LIBBY GROUNDWATER SITE, LIBBY, MONTANA

Job No.:	60514930
Designed By:	GWG
Drawn By:	JLC
Date:	7/27/2017

Fig. 3-4

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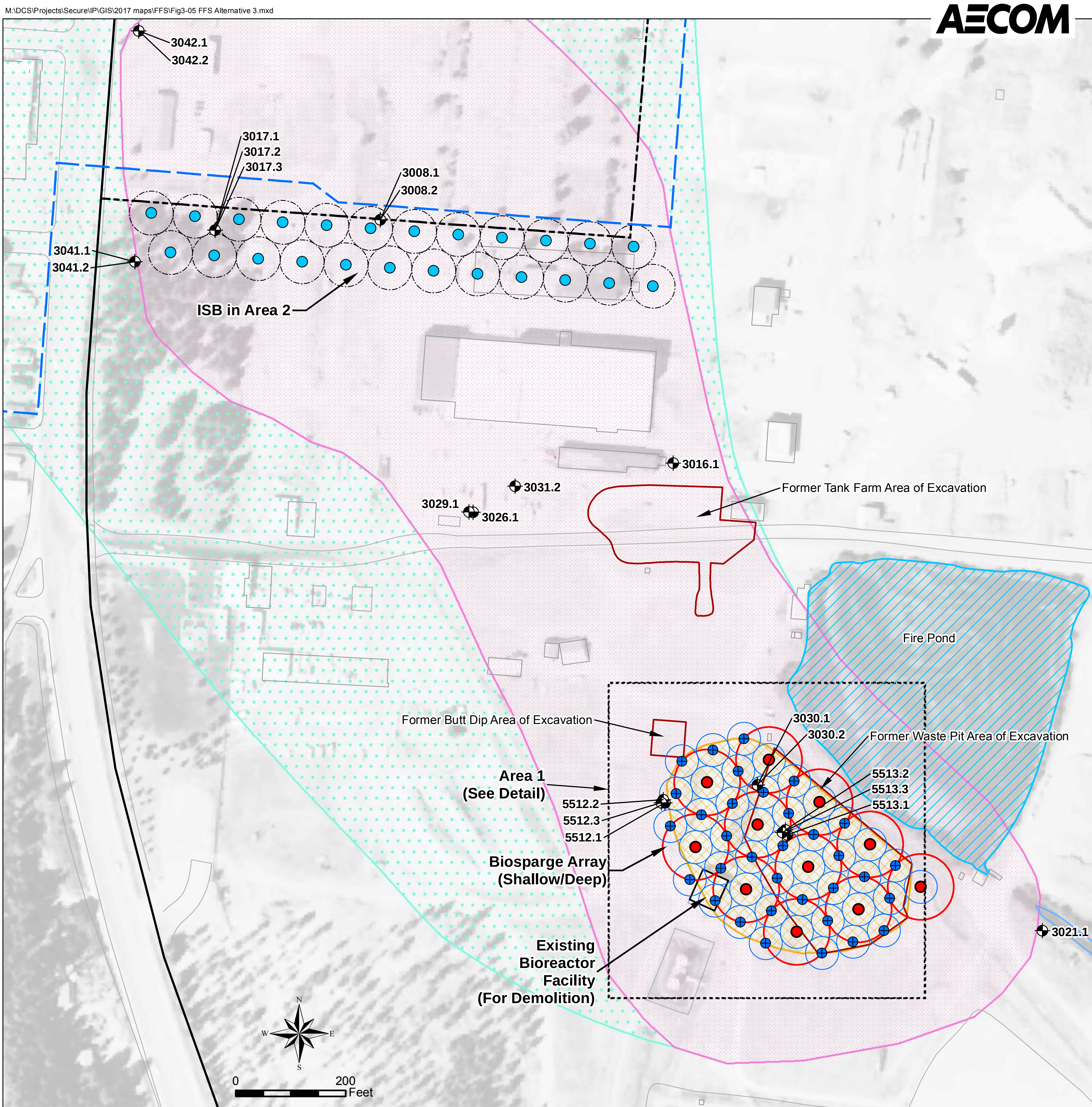
AECOM

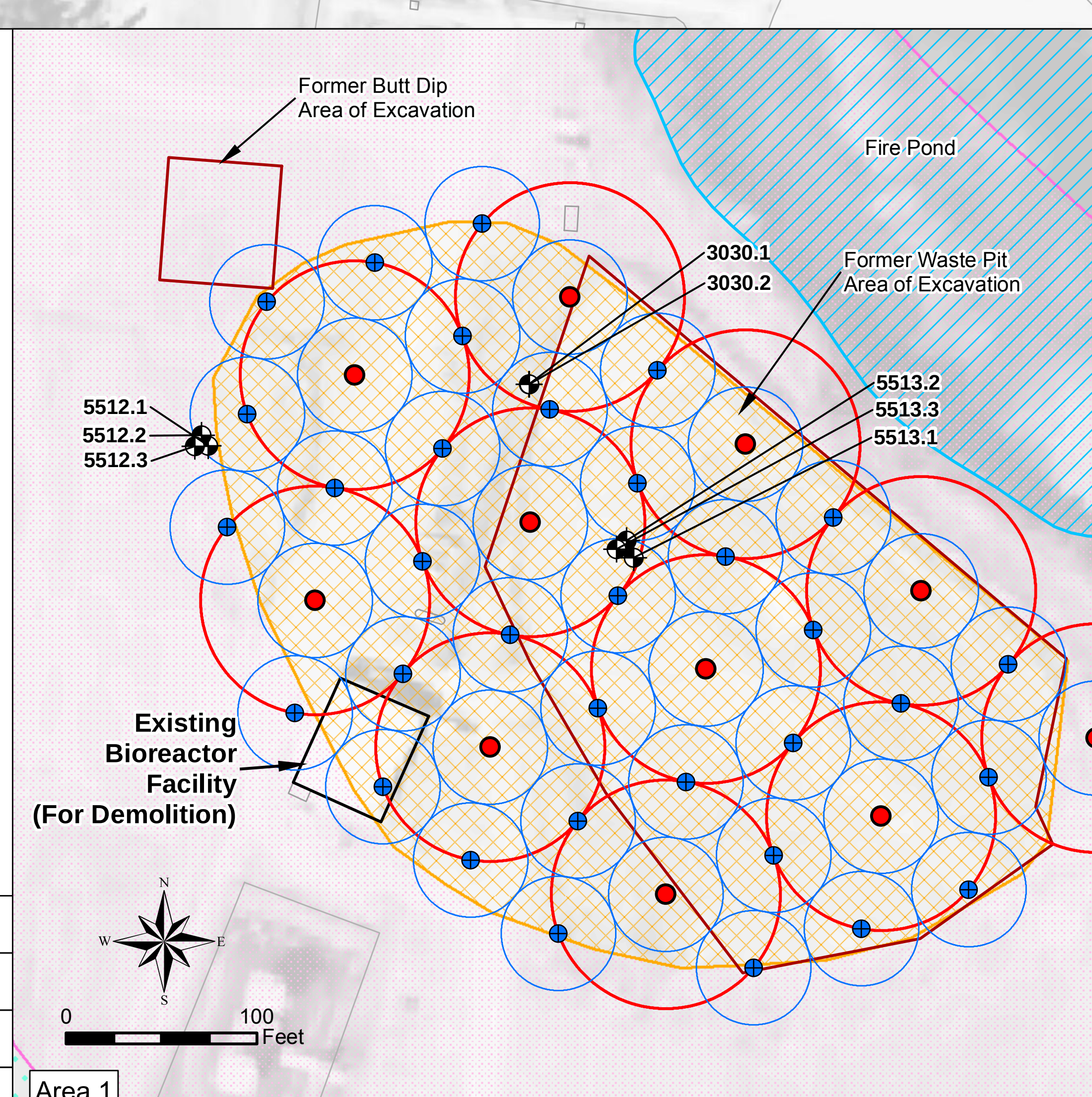


Alternative 3 Performance Monitoring Well

Area 1

- Shallow Subunit ISB Well
- Shallow and Deep Subunit ISB Well
- Area 2 ISB Well
- Radius of Influence (30')
- Radius of Influence (40')
- Radius of Influence (60')
- Area 1 (2.7 acres)
- Area 2 (33 acres)
- Area 3 (98 acres)
- Historical Mill Property
- 1994 Revised Mill Property Boundary
- Libby City Limits

FFS = Focused Feasibility Study
ISB = In Situ Biosparging
LTM = Long-Term Monitoring
MNA = Monitored Natural Attenuation



Alternative 3
ISB (Area 1),
ISB (Area 2),
and MNA (Area 3)

FOCUSED FEASIBILITY STUDY FOR THE UPPER AQUIFER
LIBBY GROUNDWATER SITE, LIBBY, MONTANA

Job No.:	60514930
Designed By:	GWG
Drawn By:	JLC
Date:	8/8/2017

Fig. 3-5

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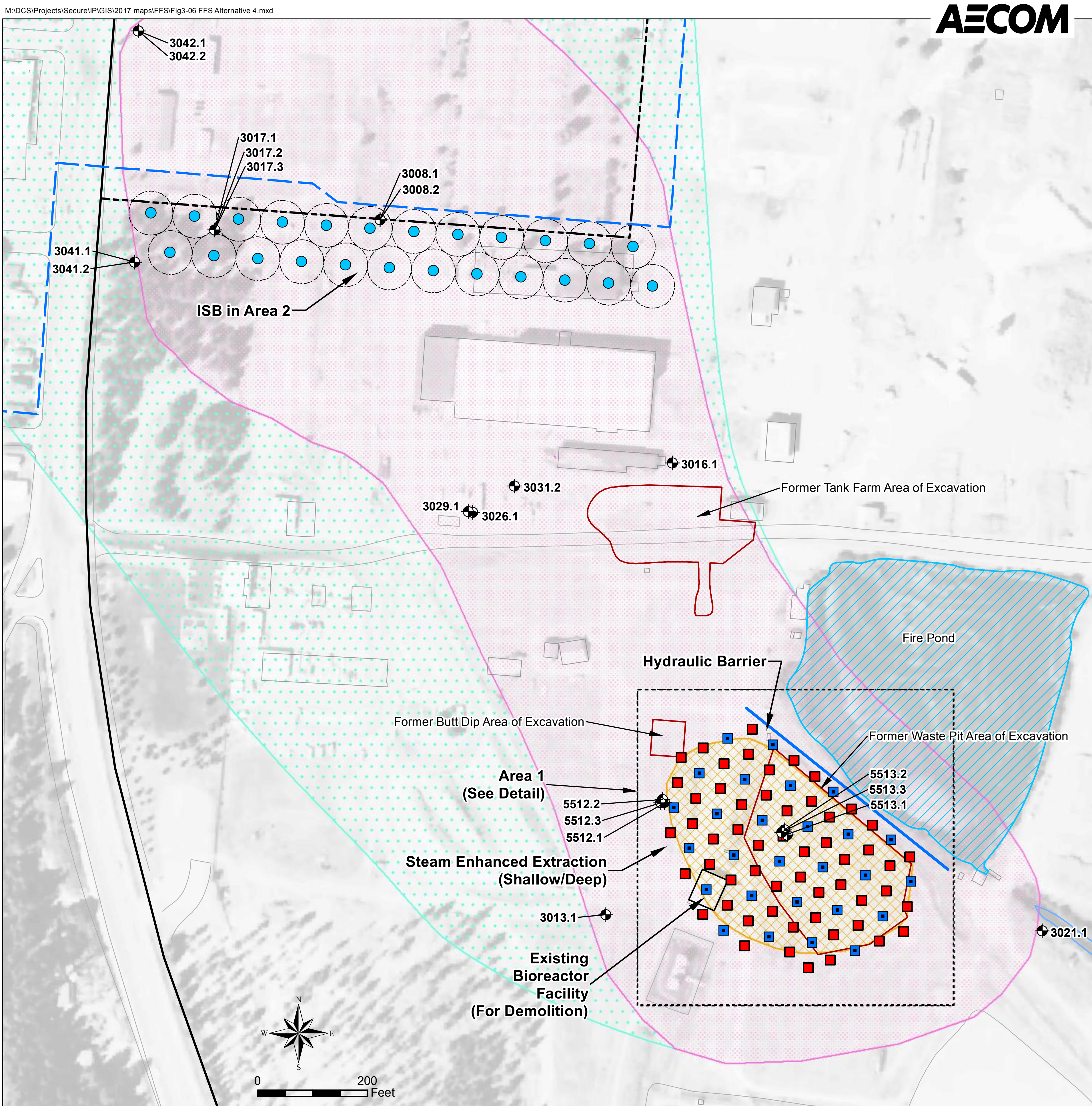


Alternative 4 Performance Monitoring Well

Area 1

Extraction Well Pair

Steam Injection Well Triplet and ISB Injection Wells

Hydraulic Barrier

Area 2 ISB Well

Radius of Influence (40')

Area 1 (2.7 acres)

Area 2 (33 acres)

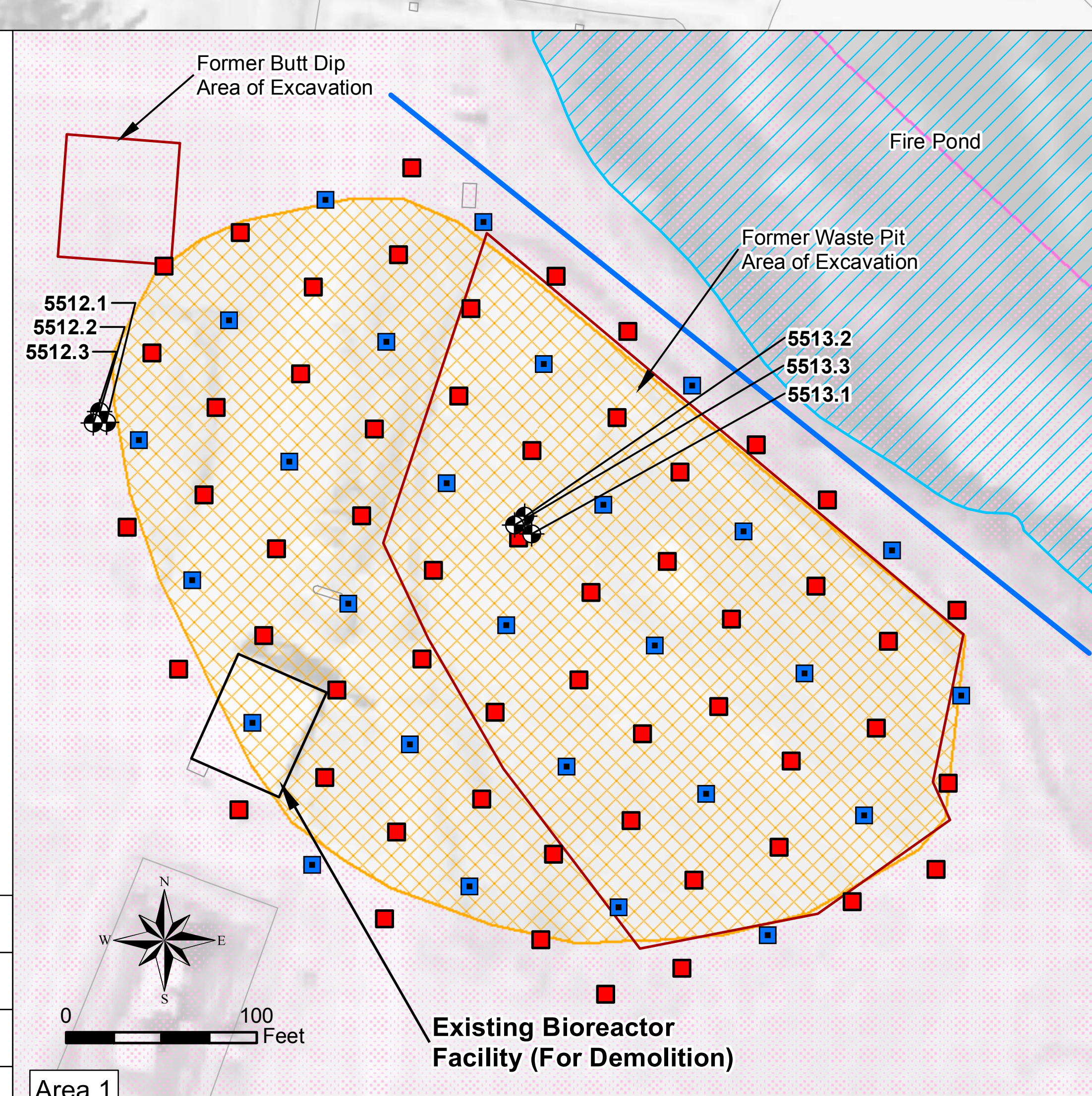
Area 3 (98 acres)

Historical Mill Property

1994 Revised Mill Property Boundary

Libby City Limits

FFS = Focused Feasibility Study
ISB = In Situ Biosparging
LTM = Long-Term Monitoring
SEE = Steam Enhanced Extraction
MNA = Monitored Natural Attenuation



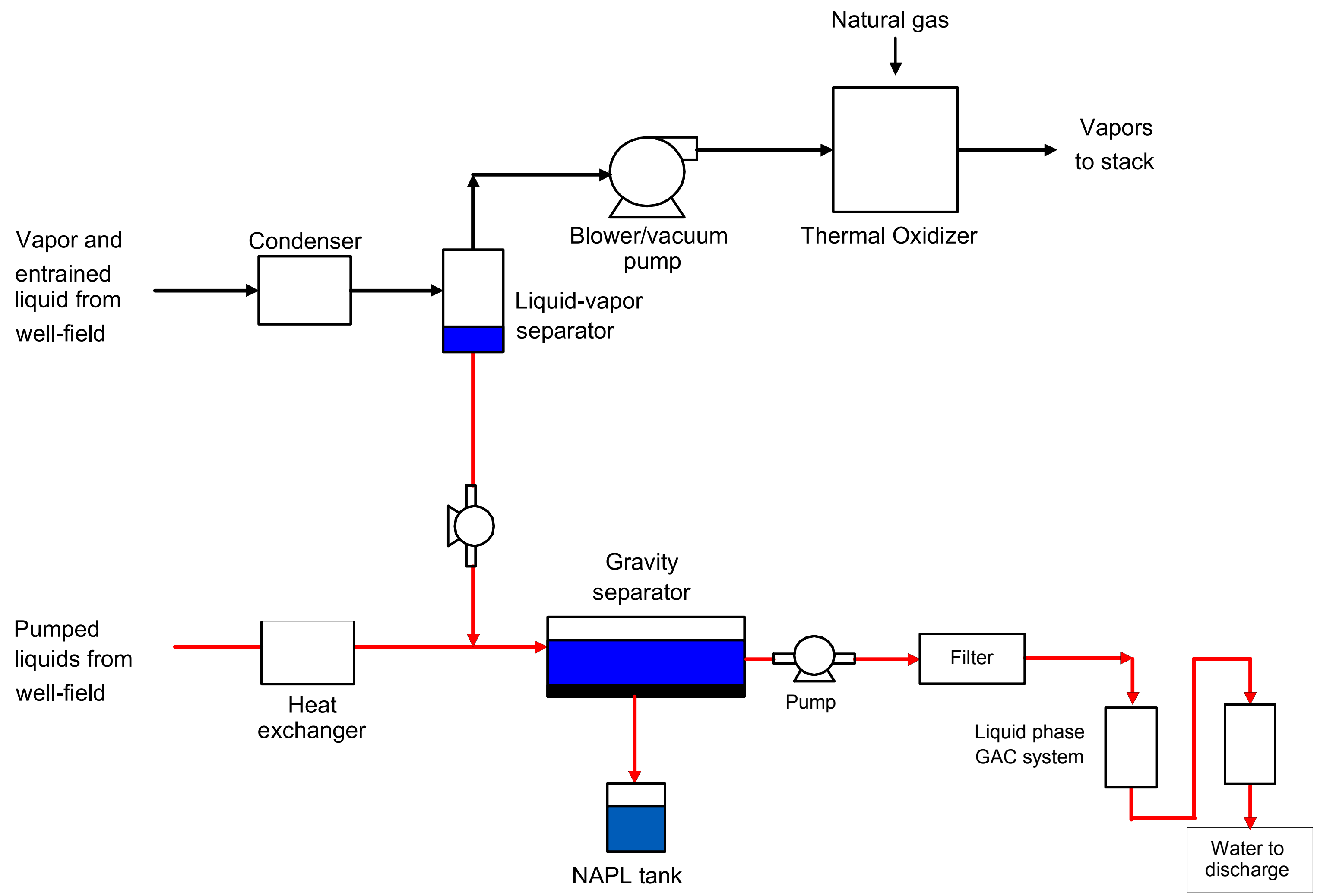
Alternative 4
SEE/ISB (Area 1),
ISB (Area 2),
and MNA (Area 3)

FOCUSED FEASIBILITY STUDY FOR THE UPPER AQUIFER
LIBBY GROUNDWATER SITE, LIBBY, MONTANA

Job No.:	60514930
Designed By:	GWG
Drawn By:	JLC
Date:	2/22/2018

Fig. 3-6

Conceptual Process Flow Diagram: Vapor and Liquid Treatment System



Alternative 4 Conceptual Process Flow Diagram: Vapor and Liquid System for SEE FOCUSED FEASIBILITY STUDY FOR THE UPPER AQUIFER LIBBY GROUNDWATER SITE, LIBBY, MONTANA	Job No.:	60514930
	Designed By:	GWG
	Drawn By:	JLC
	Date:	7/26/2017

SEE = Steam Enhanced Extraction

Fig. 3-7

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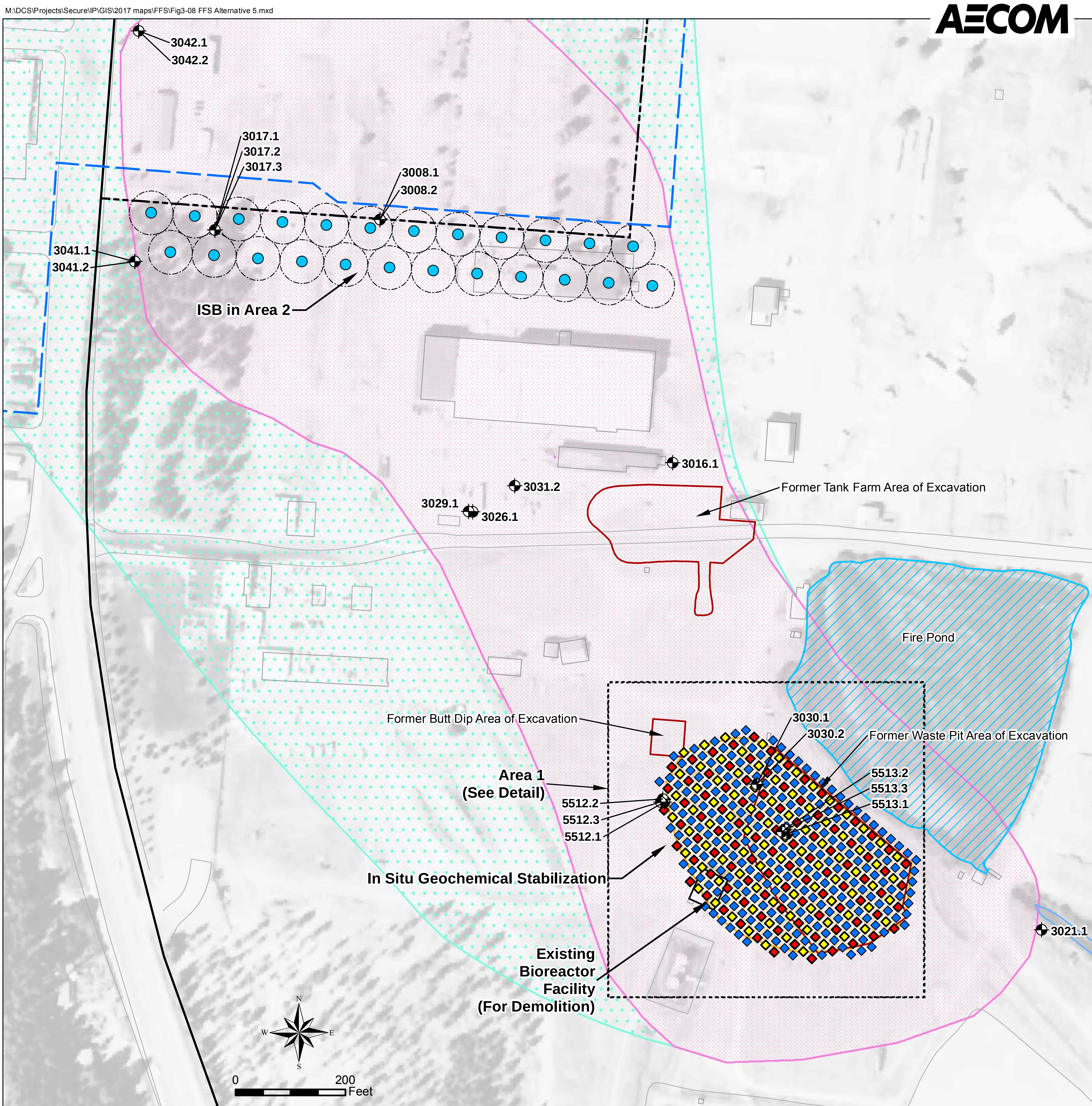


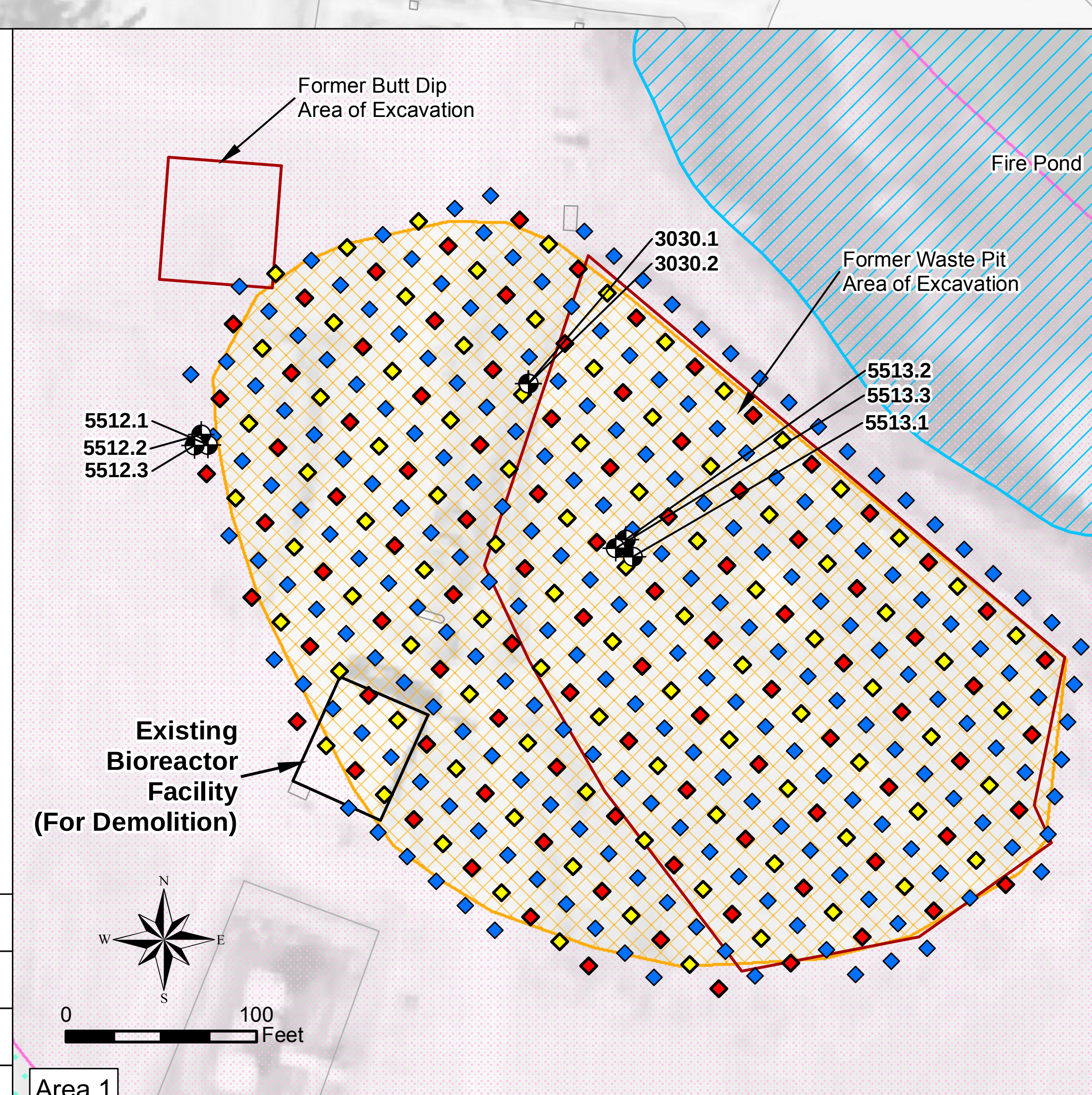
Alternative 5 Performance Monitoring Well

Area 1

- Shallow Subunit ISGS Point
- Colocated Medium and Shallow Subunit ISGS Point
- Colocated Deep and Shallow Subunit ISGS Point
- Area 2 ISB Well
- Radius of Influence (40')
- Area 1 (2.7 acres)
- Area 2 (33 acres)
- Area 3 (98 acres)
- Historical Mill Property
- 1994 Revised Mill Property Boundary
- Libby City Limits

Note: Colocated wells may be installed approximately 5 to 10 feet apart in the field

FFS = Focused Feasibility Study
ISB = In Situ Biosparging
ISGS = In Situ Geochemical Stabilization
LTM = Long-Term Monitoring
MNA = Monitored Natural Attenuation



Alternative 5
ISGS (Area 1),
ISB (Area 2),
and MNA (Area 3)

FOCUSED FEASIBILITY STUDY FOR THE UPPER AQUIFER
LIBBY GROUNDWATER SITE, LIBBY, MONTANA

Job No.:	60514930
Designed By:	GWG
Drawn By:	JLC
Date:	8/8/2017

Fig. 3-8

The detailed analysis of alternatives builds on the development of alternatives presented in Section 3 and provides additional information to further define the alternatives. The resulting analysis presents the necessary information for decision-makers to select an appropriate remedy. Each of the alternatives is assessed against the evaluation criteria and analyzed in terms of how well each one meets those criteria. The detailed analysis of alternatives consists of the following components:

- An individual analysis of each alternative using seven of the nine NCP criteria. The two modifying criteria, state and community acceptance, are evaluated by the EPA after the FS undergoes public comment and are not included in the FS.
- A comparative analysis of each of the alternatives within a single alternative area.

4.1 EVALUATION CRITERIA

The NCP contains provisions that require each alternative to be evaluated against nine criteria listed in 40 CFR § 300.430(e)(9). These criteria were published in the March 8, 1990 Federal Register (55 FR 8666) to provide a basis for comparing the relative performance of the alternatives and to identify their advantages and disadvantages. This evaluation is intended to provide sufficient information to adequately assess the alternatives and to select the most appropriate alternative for implementation as a remedial action at the Site. The nine evaluation criteria are summarized in Table 4-1 and described below:

Threshold Criteria:

(1) Overall protection of human health and the environment

(2) Compliance with ARARs

Balancing Criteria:

(3) Long-term effectiveness and permanence

(4) Reduction of toxicity, mobility, and volume through treatment

(5) Short-term effectiveness

(6) Implementability

(7) Cost

Modifying Criteria:

(8) State acceptance

(9) Community acceptance

The criteria are categorized into three groups: threshold criteria, balancing criteria, and modifying criteria. Unless a waiver can be obtained, a particular alternative must meet threshold criteria for it to be eligible for selection as a remedial action. A particular alternative must meet the threshold criteria or that alternative is considered unacceptable without a waiver. If ARARs cannot be met, a waiver may be obtained when one of the six exceptions listed in the NCP occur (40 CFR § 300.430 (f)(1)(ii)(C)(1 to 6)), which are listed below:

1. The remedial action selected is only a part of the total remedial action (interim remedy), and the final remedy will attain the ARAR upon its completion.
2. Compliance with the ARAR will result in a greater risk to human health and the environment than alternative options.
3. Compliance with the ARAR is technically impracticable from an engineering perspective.
4. An alternative remedial action will attain an equivalent standard of performance through the use of another method or approach.
5. The ARAR is a state requirement that the state has not consistently applied (or demonstrated the intent to apply consistently) in similar circumstances.
6. For Superfund-financed remedial action, compliance with the ARAR will not provide a balance between protecting human health and the environment and the availability of Superfund money for responses at other facilities.

Unlike the threshold criteria, the five balancing criteria assess the advantages and disadvantages among alternatives. A low rating on one balancing criterion can be compensated by a high rating on another. The two modifying criteria are evaluated after the FFS undergoes public comment and are used to modify the recommended alternative, as appropriate. Modifying criteria are not included in the individual or comparative analysis of alternatives in the FFS. In addition, each of the alternatives will be evaluated qualitatively with respect to sustainability metrics in the comparative analysis. The nine evaluation criteria and the sustainability metrics are described in further detail below.

4.1.1 Threshold Criteria

To be eligible for selection, an alternative must meet the two threshold criteria described below, or in the case of ARARs, must justify why a waiver is appropriate.

Overall protection of human health and the environment. Under this criterion, alternatives are assessed to determine whether they can adequately protect human health and the environment, in both the short- and long-term, from unacceptable risks posed by hazardous substances, pollutants, or contaminants present in the Upper Aquifer groundwater at the Site. Protection can be achieved by eliminating, reducing, or controlling exposures to levels established during development of remediation goals consistent with 40 CFR § 300.430(e)(2)(i) through treatment, engineering controls, or institutional controls. Overall protection of human health and the environment draws on the assessments of other evaluation criteria, especially long-term effectiveness and permanence, short-term effectiveness, and compliance with ARARs.

Compliance with ARARs. The alternatives are assessed to determine whether they attain ARARs under federal environmental laws and state environmental or facility siting laws, or provide grounds for invoking one of the waivers under paragraph (f)(1)(ii)(C) of 40 CFR § 300.430. Compliance with chemical-specific, location-specific, and action-specific ARARs is assessed for each alternative.

4.1.2 Balancing Criteria

The five criteria listed below represent the criteria upon which the detailed evaluation and comparative analysis of alternatives is based. The level of detail required to analyze each alternative under these NCP evaluation criteria depends on the nature and complexity of the site, the types of technologies and alternatives being considered, and other project-specific considerations. The analysis is performed in sufficient detail to understand the significant aspects of each alternative and to identify the uncertainties associated with the evaluation.

Long-term effectiveness and permanence. Alternatives are assessed for the long-term effectiveness and permanence they afford, along with the degree of certainty that the alternative will prove successful. Factors considered as appropriate include the following:

(a) The magnitude of residual risk remaining from untreated waste or treatment residuals remaining at the conclusion of the remedial activities. The characteristics of the residuals were considered to the degree that they remain hazardous, taking into account their volume, toxicity, mobility, and propensity to bioaccumulate.

(b) The adequacy and reliability of controls such as containment systems and institutional controls necessary to manage treatment residuals and untreated waste. In particular, this factor addresses the uncertainties associated with land disposal for providing long-term protection from residuals; the assessment of the potential need to replace technical components of the alternative such as a slurry wall, or treatment system; and the potential exposure pathways and risks posed should the remedial action need replacement.

Reduction of toxicity, mobility, or volume through treatment. The alternatives are assessed to determine the degree to which they employ recycling or treatment that reduces toxicity, mobility, or volume. In addition, the alternatives are assessed to determine how treatment is used to address the principal threats posed by the site. Factors that are considered as appropriate include the following:

(a) The treatment or recycling processes the alternatives employ and the materials they will treat.

(b) The amount of hazardous substances, pollutants, or contaminants that will be destroyed, treated, or recycled.

(c) The degree of expected reduction of the waste due to treatment or recycling and the specification to which reduction(s) is occurring.

(d) The degree to which the treatment is irreversible.

(e) The type and quality of residuals that will remain following treatment, considering the persistence, toxicity, mobility, and propensity to bioaccumulate hazardous substances and their constituents.

(f) The degree to which treatment reduces the inherent hazards posed by principal threats at the site.

Short-term effectiveness. The short-term impacts of alternatives assessed include the following:

(a) Short-term risks that might be posed to the community during implementation of an alternative.

(b) Potential impacts on workers during remedial action and the effectiveness and reliability of protective measures.

(c) Potential environmental effects of the remedial action and the effectiveness and reliability of mitigative measures during implementation.

(d) Time until protection is achieved.

Implementability. The ease or difficulty of implementing the alternatives is assessed by considering the following types of factors, as appropriate:

(a) Technical feasibility, including the technical difficulties and the unknowns associated with the construction and operation of a technology, the reliability of the technology, the ease of undertaking additional remedial actions, and the ability to monitor the effectiveness of the remedy.

(b) Administrative feasibility, including the activities needed to coordinate with other offices and agencies and the ability and time required to obtain any necessary approvals and permits from other agencies (for off-site actions).

(c) Availability of services and materials, including the availability of adequate off-site treatment; storage capacity, and disposal capacity and services; the availability of necessary equipment and specialists, and provisions to ensure any necessary additional resources; the availability of services and materials; and the availability of prospective technologies.

Cost. The types of costs that are assessed include the following:

(a) Capital (construction) costs, including both contingency and professional/technical services

(b) Annual O&M costs

(c) Periodic costs

(d) Net present value costs

CERCLA and the NCP require that every remedy selected in the ROD must be cost-effective (NCP 1990). In the context of CERCLA, the cost effectiveness finding is determined during the remedy selection phase, considering the long-term effectiveness and permanence afforded by the alternatives, the extent to which the alternative reduces the toxicity, mobility or volume of the hazardous substances through treatment, the short-term effectiveness of the proposed or selected alternative, and the proposed or selected alternative's costs. The detailed analysis develops, evaluates and compares the cost of the respective alternatives included in the detailed analysis, but draws no conclusion as to the cost-effectiveness of the alternatives. See 55 Fed. Reg. 8722 – 8723, and 40 CFR §§ 430.(e)(9)(G) and 430.(f)(5)(D). The balancing criteria provide the basis for the cost-effectiveness determination in the ROD. Additional detail on the types of information included in the detailed cost analysis is described in Section 4.1.5.

4.1.3 Modifying Criteria

The two modifying criteria are state and community acceptance. As previously discussed, evaluations of the alternatives under the modifying criteria are not used in the comparative analysis of alternatives described in this FFS; evaluation of these criteria is performed after the FFS is completed.

Community acceptance. This assessment includes determining which components of the alternatives interested persons in the community support, have reservations about, or oppose. Community acceptance of any of the alternatives will be evaluated as part of the public comment period during the remedy selection process.

State acceptance. The state concerns that are assessed include the following:

(a) The state's position and key concerns related to the preferred alternative and other alternatives.

(b) The state's comments on ARARs or the proposed use of waivers.

State acceptance of any of the alternatives will be evaluated as part of the remedy selection process.

4.1.4 Costing Components

4.1.4.1 Development of Alternative Costs

Cost estimates are developed during the FFS primarily for the purpose of comparing remedial alternatives during the remedy selection process and are not to be used for establishing project budgets or negotiating Superfund enforcement settlements. Since the RI/FFS cannot remove all uncertainty, irrespective of the data quality, the expected accuracy of cost estimates during the FFS is less than that of estimates developed during remedial design/remedial action (RD/RA). As a project moves from the planning stage into the design and implementation stage, the level of project definition increases, thus allowing a more accurate cost estimate. An "early" estimate of the project's life cycle costs is made during the FFS to assist in a remedy selection.

At the FFS stage, the design for the remedial action project is still conceptual, not detailed, and the cost estimate is considered to be "order-of-magnitude" (EPA 2000a). However, detailed assumptions must be made in developing the costs. These assumptions are subject to change and the expected level of accuracy of the cost estimates developed ranges from minus 30 percent to plus 50 percent. Furthermore, costs projected in the distant future (e.g., greater than 30 years from the present) have increasing uncertainty. Designs will be completed prior to remedial action implementation to refine and increase the level of accuracy of the cost estimate.

The NCP requires that the determination of cost-effectiveness be a component of the ROD, supported by this FFS report, and specifically a comparison of the NCP's balancing criteria. In the context of CERCLA, the cost effectiveness finding is determined during the remedy selection phase, considering the long-term effectiveness and permanence afforded by the alternatives, the extent to which the alternative reduces the toxicity, mobility or volume of the hazardous substances through treatment, the short-term effectiveness of the proposed or selected alternative, and the proposed or selected alternative's costs. The detailed analysis develops, evaluates and compares the cost of the respective alternatives included in the detailed analysis, but draws no conclusion as to the cost-effectiveness of the alternatives. See 55 Fed. Reg. 8722 – 8723, and 40 CFR §§ 430.(e)(9)(G) and 430.(f)(5)(D).

Detailed cost estimates are presented in Appendix C, with detailed individual estimates per alternative in Sheets 1 to 5 and estimated total costs compared between alternatives in Sheet 6. The cost estimates are prepared in accordance with *EPA Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA* (1988) at page 6-3. Vendor proposals were received for SEE and ISGS to support developing costs for those alternatives and are presented in Appendices D and E, respectively. A summary of the steps involved in developing the FFS cost estimates is presented below.

1. **Describe the alternative.**

   As the first step in the development of the cost estimate, the remedial alternative is described in general terms.

2. **Identify the cost elements of the remedial alternative for capital (e.g., construction), annual O&M, and periodic activities.**

   Cost elements associated with each alternative are identified, including mobilization/ demobilization; sampling and analysis; site work; and specific remedial activities such as collection, containment, treatment, and disposal of waste or contaminated media (e.g., NAPL). These cost elements serve to form line items for the alternative cost estimate.

   For each of the alternatives, the cost estimates are split into three major groups of costs: 1) capital (construction), 2) O&M, and 3) periodic. Each of these groups also includes: 1) contingency costs, and 2) project management (professional/technical services) costs. Most commonly, capital (construction) costs are those costs necessary to construct the remedial action and include labor, equipment, material, and mobilization/demobilization costs, including contractor markups (such as overhead and profit). Professional/technical services costs are those costs associated with administrative and other services necessary to implement the remedial action (such as engineering, permitting, project management, design, and construction management). Contingencies and professional/technical services are estimated as a percentage of the total construction activities. The individual cost groups are discussed further below.

   <u>Capital (Construction) Costs</u>

   Capital costs are those expenditures required to construct or install a remedial action. These costs consist primarily of expenditures initially incurred to build or install the remedial action, but exclude costs required to operate or maintain the action throughout its lifetime. Capital (construction) costs include labor, equipment, and material costs associated with activities such as mobilization/demobilization; site work; installation of wells or treatment systems; and waste management.

   The cost assumptions for construction of the remedial action in this FFS report are that all capital (construction) costs are assumed to occur in year zero (base year 2019). Although implementing SEE would extend beyond a year, all initial construction costs are assumed to occur in Year 0 so they sum up under capital costs.

O&M Costs

O&M costs are those post-construction/installation costs necessary to provide for or verify the continued effectiveness of a remedial action. These costs are estimated mostly on an annual basis. O&M costs occur over the entire period of analysis and are identified for both the remedial action and long-term O&M phases. O&M costs include labor, equipment, and material costs associated with activities such as monitoring; operating and maintaining extraction, containment, or treatment systems; and disposal of residuals.

Periodic Costs

Periodic costs are those costs that occur only once every few years or costs that occur only once during the entire O&M period of analysis. Periodic costs can occur at any time during the period of analysis (both short-term and long-term). Periodic costs include future costs, subject to a discount factor, for replacing components (e.g., new aboveground groundwater treatment plant), five-year reviews, site reports, and updates to institutional controls. Although periodic costs can be either capital or O&M costs, for the purposes of this FFS report, periodic and O&M costs have been captured on the same cost analysis worksheets, because these costs both occur subsequent to the initial construction phase. The frequency with which a periodic cost occurs is included on the cost analysis summary worksheets.

3. **Estimate construction/O&M activity costs.**

Quantities and unit costs were estimated for each line item associated with the identified cost elements. For each line item, a unit cost was selected from a source of cost data, including:

- Actual unit costs for activities from contractors/vendors
- Costs for similar activities reported in cost estimating guides/references
- Professional experience with similar activities

The cost of each element was determined by multiplying the unit cost by the estimated quantity. A subtotal of the cost elements for the primary activities associated with each of the alternatives was calculated.

4. **Apply contingency and estimate professional/technical services costs.**

Other costs were added after the line item costs were subtotaled, including contingencies and professional/technical support. Contingencies were used to cover unknowns, unforeseeable circumstances, or unanticipated conditions that are not possible to evaluate from the data available at the time the estimate is prepared. Professional/technical service costs encompass costs related to project management, remedial, design, construction management, and technical support.

There were many contributing factors in determining the contingencies and professional/ technical percentages applied to the cost estimate, which were assessed using EPA guidance and engineering judgment. Cost contingencies were applied to each alternative task at varying amounts based on the anticipated level of complexity and uncertainty, and ranged from 5 to 20 percent. Professional/technical services costs were estimated by applying percentages to the total construction activities plus contingency, and ranged from 5 to 12 percent based on the perceived oversight required.

5. **Conduct present worth analysis.**

   Present worth analyses are included in the cost estimates to discount current dollar costs to net present value (NPV) costs. Given a long-term project life (e.g., more than 30 years), this discounting effect can be very significant with NPV costs significantly lower than current costs. This is particularly true for alternatives that incur the majority of expenses later in their project life. The discount factor is calculated for each year over the project duration taking into account inflation and the expected return on investment. For costing purposes, the analysis assumes an annual inflation of 1.8 percent, based on average national inflation rates from May 2016 to May 2017 (US Inflation Calculator 2017), and a conservative return on investment rate of 2.8 percent based on the nominal interest rates forecast by the Office of Management and Budget (White House Administration 2017) for long-term (30 year) investments. At these rates, discount factors of 0.952, 0.907, 0.746, and 0.376 are applied at Years 5, 10, 30, and 100, respectively.

   These rates are assumed for the purposes of this FFS and can be altered upon remedy design, but overall result in conservatively low discount factors. According to a study by Forbes in 2014, average returns on investment for bonds from 2004 to 2013 was 4.6 percent (Forbes 2014), which would result in a higher discount rate. The EPA costing guidance cites a discount rate of 7 percent, which is based on a directive with the long-term investment rates forecasted by the Office of Management and Budget from 1993 (EPA and USACE 2000). Therefore, this FFS cost analysis is conservative by using lower interest rates that better reflect current market conditions. These lower interest rates yield higher discount factors and have less influence on the NPV calculation. For purposes of illustration, extremely low discount factors of 0.713, 0.508, 0.131, and 0.001 would be applied at Years 5, 10, 30, and 100, respectively, if a discount rate of 7 percent were used.

6. **Review estimate.**

   Independent peer reviews were conducted of the cost estimate, evaluating the reasonableness of estimated quantities, durations, and unit costs.

4.1.4.2 Present Worth Analysis

A present worth, or present value, analysis is a method used to evaluate expenditures that occur over different time periods. This standard methodology allows for a cost comparison of different remedial action alternatives, which may have capital and O&M costs that are incurred in different time periods, on the basis of a single cost figure for each alternative. Present value analysis consists of four major steps: 1) defining the period of analysis, 2) estimating actual cash outflows for each year of the project, 3) selecting a discount rate to use in the present value calculation, and 4) calculating the present value.

Only capital (construction) costs that occur in future years (i.e., after year 0) are subject to a net present value analysis. All other capital (construction) costs did not include a net present value analysis. Future costs involving construction related to replacing remedy components are considered to be periodic costs that are subject to a net present value analysis and sensitive to the discount rate, as are O&M costs.

4.1.4.3 Period of Analysis

The period of analysis is the period of time over which a present value is calculated and reflects the project duration, resulting in a complete life cycle cost estimate for implementing the remedial alternative. The period for detailed analyses of the alternatives within this FFS vary between 50 and 165 years based on the maximum remedial timeframe per remediation area for each alternative.

4.1.4.4 Discount Rate

A real discount rate is applied to expenditures that occur beyond the base year over the period of analysis. The real discount rate consists of the difference between the rate of inflation and the nominal discount rate. Therefore, the real discount rate takes into account cost increases (inflation) over time in addition to the discount applied (nominal discount) to adjust for future expenditures in current day dollars based on the anticipated rate of return on investment. Costs for the alternatives during the period of analysis are related to a common base year, which allows the cost of final remedial action to be compared on the basis of a single figure representing the amount of money that, if invested in the base year, should be sufficient to cover the costs associated with the remedial action over its planned life. Additional information on the discount rate is included in Section 4.1.4.1.

4.2 INDIVIDUAL ANALYSIS OF ALTERNATIVES

This section provides the evaluation of the remedial action alternatives, developed to address contamination in the Upper Aquifer groundwater at the Site, with respect to the seven threshold and balancing evaluation criteria defined in Section 4.1. A summary of the analysis is provided in Table 4-2.

4.2.1 Alternative 1 – No Further Action

Alternative 1, NFA, includes decommissioning and demolishing the SAETS, abandoning existing groundwater extraction wells and select monitor wells, continuing monitoring of groundwater, implementing institutional controls, and conducting 5-year reviews.

(1) Overall Protection of Human Health and the Environment

This alternative is protective of human health and the environment in the short-term as there are no exposure pathways to contaminated groundwater. Previous remedial actions conducted at the site along with deed restrictions and institutional controls prohibiting drilling of water wells for the purpose of human consumption or irrigation are protective of human receptors by eliminating/preventing direct contact or ingestion of groundwater. A proposed CGA would further restrict groundwater use and protect potential groundwater users outside the City limits.

Under Alternative 1, the extent of the Upper Aquifer groundwater plume has not changed since monitoring began in the mid-1980s. Contaminant reduction would continue to gradually occur via natural attenuation, primarily aerobic and anaerobic biodegradation, and its effectiveness would be assessed through limited groundwater monitoring. A NAPL depletion model simulated natural attenuation and natural source zone depletion of the NAPL and suggests that cleanup goals would be achieved and the Upper Aquifer groundwater could be restored to beneficial use with remedy completion after approximately 150 years (Appendix B). During this time period, ICs would remain in place and groundwater monitoring and 5-year reviews would be conducted.

(2) Compliance with ARARs
The chemical-specific ARARs include the Montana DEQ circular DEQ-7 water quality standards for groundwater and EPA MCLs. Alternative 1 will not comply with the chemical-specific ARARs for over 150 years, because the alternative relies on natural processes for contaminant reduction as no active remediation of NAPL and groundwater occurs.

Table 4-3 provides a summary of ARARs and an initial assessment of whether a specific ARAR is applicable, relevant and appropriate, or not applicable to the alternative.

(3) Long-Term Effectiveness and Permanence
Alternative 1 will not reduce identified risks or contaminant concentrations at the Site; however, contaminant concentrations will continue to naturally attenuate and are estimated to ultimately reach cleanup goals after approximately 150 years. Therefore, this alternative has limited long-term effectiveness and permanence.

Under NFA, NAPL in groundwater remains in the Upper Aquifer for over 150 years. Controlled access and institutional controls provide adequate control to reduce direct contact. Residual contamination remains and undergoes NSZD. Highly weathered and residual NAPL depleted of soluble components is anticipated to remain even after cleanup goals are achieved in groundwater (e.g., after 150 years).

(4) Reduction of Toxicity, Mobility, or Volume through Treatment
There is no active treatment in this alternative that will reduce toxicity, mobility, or volume; however, contaminant concentrations will continue to naturally attenuate, primarily through biodegradation. It is anticipated that NSZD will decrease toxicity, mobility, and volume over a long period of time.

(5) Short-Term Effectiveness
This alternative will have no short-term impacts on human health and the environment during implementation because it involves no activity except for limited groundwater monitoring and 5 year reviews. No actions will be implemented, therefore no additional risks to workers or the community would be observed. Although this alternative will be immediately protective based on implementing ICs, it is not anticipated to meet ARARs until Years 150, 46, and 46 for Areas 1, 2, and 3, respectively.

(6) Implementability
This alternative is readily implementable, in that there are no remediation activities except for limited groundwater monitoring and 5 year reviews to be implemented. Minimal administrative coordination may be required to implement institutional controls over a long period of time. The City ordinance prohibiting well drilling has been in effect since 1986 and it has been relatively easy to implement. The City ordinance does not prohibit groundwater use from residents who already have wells. The former mill property, where the highest groundwater concentrations exist, is not within the City and is not subject to the City ordinance. The proposed CGA provides for notifications to drillers of restrictions in the CGA and the State will not issue well permits inside the CGA; however, there is currently no penalty for violation of drilling a well or reopening a restricted well within a CGA.

(7) Cost
The capital costs associated with this alternative include decommissioning and demolishing the existing SAETS, abandoning existing extraction wells and select monitoring wells, and implementing additional ICs. O&M includes limited groundwater monitoring and 5 year reviews. The long-term costs associated with periodic reviews required every five years at a minimum, are estimated at $15,000 per review. Estimated detailed costs and associated assumptions for Alternative 1 are summarized in Sheet 1 of Appendix C. The total estimated cost for implementing Alternative 1 in the first year (Year 0) is approximately $400,000, with an anticipated total remedy cost of $1.5 million (current dollar) and $900,000 (NPV) by remedy completion at 150 years.

4.2.2 Alternative 2 – Hydraulic Containment (Area 1) and In Situ Biosparging (Area 2)

Alternative 2 includes hydraulic containment and aboveground groundwater treatment in Area 1, ISB and NSZD in Area 2, and MNA in Area 3.

(1) Overall Protection of Human Health and the Environment
This alternative is protective of human health and the environment in the short-term and long-term as there are no exposure pathways to contaminated groundwater. Previous remedial actions conducted at the site along with deed restrictions and institutional controls prohibiting drilling of water wells for the purpose of human consumption or irrigation are protective of human receptors by eliminating/preventing direct contact or ingestion of groundwater. A proposed CGA would further restrict groundwater use and protect potential groundwater users outside the City limits. Upon achieving and sustaining cleanup goals, groundwater in the Upper Aquifer could be restored to beneficial use.

Under this alternative, contaminants are contained in Area 1 by hydraulic containment and treated in situ via biosparging in Area 2, enabling attenuation of the plume in Area 3. The remediation is permanently effective as mass is depleted in situ by NSZD and groundwater extraction and aboveground treatment in Area 1, by in situ biosparging treatment and NSZD in Area 2, and by natural attenuation in Area 3. Contaminant mass removed from Area 1 as NAPL or removed by adsorption onto GAC would be permanently destroyed via offsite incineration. MNA in Area 3 would allow for natural degradation of contaminants and support a stable or shrinking plume.

To determine this alternative's long-term effectiveness and to lessen the uncertainty of reaching cleanup goals, performance monitoring would be conducted involving collecting system measurements and gauging and sampling groundwater monitoring wells to assess potentiometric control and capture effectiveness. System measurements and influent/effluent samples would be collected from the bioreactors and GAC vessels to assess treatment efficacy. Necessary modifications to pumping and system components would be made based on monitoring results to provide adequate hydraulic containment and treatment. Similarly, the efficacy of the ISB transect in Area 2 would be evaluated via monitoring and flowrates, cycling durations, and pressures would be adjusted as needed. The monitoring data will also be used to evaluate the ISB design and modifications to meet performance objectives.

Long-term management would be required of the various systems including:

- Annual sampling of Area 3's groundwater plume through Year 10.
- Quarterly performance monitoring and system O&M for the ISB injection wells and associated equipment (compressors are assumed to be replaced every 15 years) through Year 41.
- Quarterly performance monitoring and system O&M for the hydraulic containment system, including extraction wells and pumps (assumed to be replaced every 15 years), OWS and NAPL disposal, bioreactor components and sludge disposal, GAC monitoring and changeouts, and reinjection wells and associated equipment through Year 145.
- 5-year reviews and institutional controls until remedy completion at Year 150.

(2) Compliance with ARARs
Alternative 2 will comply with the chemical-specific, location-specific, and action-specific ARARs pertaining to the Site for protection of human health and the environment. Chemical-specific ARARs including EPA and MDEQ groundwater standards which address requirements for cleanup of groundwater are met through NSZD of residual NAPL, as well as contaminant extraction and ex situ treatment and off-site disposal.

During remedy implementation, management practices, construction techniques, and health and safety protocols will be implemented to comply with ARARs. Engineering controls, inspection and maintenance protocols, and post-construction monitoring will be readily implemented and effective in ensuring continued compliance with ARARs. Two ARARs pertinent to the long-term operation of this alternative are (1) oil storage requirements in aboveground tanks whose storage equals or exceeds 1,320 gal (40 CFR 112) as the free product accumulation tank capacity is 1,950 gal; and (2) UIC permit requirements for reinjection to groundwater.

Table 4-3 provides a summary of ARARs and an initial assessment of whether a specific ARAR is applicable, relevant and appropriate, or not applicable to the alternative.

(3) Long-Term Effectiveness and Permanence
Following completion of Alternative 2, groundwater cleanup goals will have been attained and there will be no unacceptable risk posed by residual contamination on site. The technologies are anticipated to meet performance specifications because they are proven technologies and the systems (groundwater extraction and treatment system in Area 1 and ISB transect in Area 2) will operate until performance criteria are met that indicate cleanup goals would be achieved and sustained in the long-term.

The anticipated residual contamination may include insoluble hydrocarbons that strongly sorb to soil and would remain in highly weathered NAPL, neither of which would pose a risk to groundwater receptors. The systems are designed to operate until the weathered residual NAPL is depleted of soluble components such that the effective solubilities of remaining components upon system shutdown would not result in aqueous concentrations above clean up goals under equilibrium conditions (Appendix B). Although most NAPL is currently at residual saturations and immobile, NAPL weathering will further decrease NAPL saturation and increase NAPL viscosity, which will make the remaining NAPL more immobile and not recoverable. Institutional controls will be applied to the site restricting intrusive activities to prevent direct contact with the weathered residual contamination in soil.

(4) Reduction of Toxicity, Mobility, or Volume through Treatment

Alternative 2 reduces the toxicity, mobility, and volume of contamination through different mechanisms, as described by remediation area below. As Alternatives 2, 3, 4, and 5 share the same components for Area 2 (ISB and NSZD) and Area 3 (MNA), they share the same levels of reductions as described in detail here for Alternative 2 and are not repeated in the respective subsections for Alternatives 3, 4, or 5.

Area 1: This area contains contaminant mass largely as NAPL, with sorbed and aqueous phase mass as a result of partitioning from the NAPL. A portion of contaminant mass will be destroyed in situ via NSZD; however, the majority of contaminant mass will be removed with groundwater from the subsurface in the aqueous and NAPL phases via extraction wells and undergo aboveground treatment. This treatment process is irreversible as contaminant mass is ultimately destroyed. There will be a portion of less soluble NAPL constituents that are not extracted nor treated; however, the overall NAPL volume and mobility will have decreased as the NAPL would be weathered such that only the insoluble components with high soil-sorption coefficients would remain.

Groundwater extraction and treatment will continue to operate until target effective solubilities are met that would not result in aqueous concentrations above cleanup goals under equilibrium conditions. Information on contaminant reductions via the treatment system is detailed below.

- NAPL will be separated in the OWS from groundwater extracted from the deep subunit and containerized for collection and offsite incineration. During the initial years of system operation, approximately 0.015 percent of extracted liquids are anticipated to be NAPL with diminishing portions over time. Approximately 25,300 gallons of NAPL are anticipated to be recovered and incinerated over the project life (145 years), which represents about 6.5 percent of the estimated 389,000 gallons of NAPL believed to be present in Area 1 (Appendix B), the remainder of which will be highly weathered.
- Aqueous contaminant mass will be biologically destroyed in the trickling filter (bioreactor) via enhanced aerobic biodegradation processes. Contaminant reductions achieved in the bioreactor will vary by constituent, but are assumed to decrease on average by 90 to 95 percent (comparing influent to effluent concentrations) based on the existing SAETS performance. Any biosolids (growth from the bioreactor) that accumulate during the process would be collected in the cartridge filters prior to entering the GAC vessels and would be periodically removed and disposed of accordingly.
- Aqueous contamination remaining in the bioreactor's effluent, estimated at PCP and naphthalene concentrations of 80 and 1,340 parts per billion (ppb), will be collected on carbon in the GAC treatment vessels to achieve cleanup goals of 1 and 100 ppb, respectively. At these concentrations, approximately 105 tons of GAC are anticipated to be consumed annually for a total consumption of 16,800 tons over the system lifetime (145 years). Approximately 27 and 420 lbs of PCP and naphthalene mass, respectively, are estimated to be collected on the carbon annually, which will ultimately be destroyed when the spent carbon is incinerated offsite. The effluent from the lag GAC vessel will meet cleanup levels and discharge requirements prior to reinjection.

Area 2: This area contains contaminant mass largely as NAPL, with sorbed and aqueous phase mass as result of partitioning from the NAPL in Area 2 and a portion as influx from Area 1. Contaminant mass in Area 2 will be destroyed in situ via biodegradation, both from the ISB transect installed near the City limits and from aerobically enhanced conditions downgradient of the reinjection wells that deliver treated and oxygenated water to the subsurface. The treatment achieved is irreversible as biodegraded contaminant mass is destroyed and results in innocuous compounds including carbon dioxide and water. There will be a portion of less soluble constituents that biodegrade and attenuate at a much slower rate and will not undergo as much treatment; however, the overall NAPL volume and mobility will have significantly decreased as the NAPL would be weathered such that only the insoluble components with high soil-sorption coefficients would remain. ISB and NSZD will continue until target effective solubilities are met that would not result in aqueous concentrations above cleanup goals under equilibrium conditions. Information on contaminant reductions via ISB and NSZD is detailed below.

- Aqueous contaminant mass will be biologically destroyed within the ISB transect and propagated downgradient dissolved-rich oxygen front via aerobic biodegradation processes. Contaminant reductions achieved via biodegradation will vary by constituent, but are anticipated to meet cleanup goals for PCP and naphthalene for groundwater entering the treatment area of the ISB transect in less than 15 days (Table 3-3) assuming influent concentrations of 1.3 and 13 mg/L for PCP and naphthalene, respectively. Approximately 10,950 lbs of TPH, 26 lbs of PCP, and 1060 lbs of naphthalene are anticipated to be treated by the transect within the first year based on estimated daily flux rates from current conditions of 30 lbs/day of TPH, 0.07 lbs/day of PCP, and 2.9 lbs/day of naphthalene entering the ISB transect.
- Contaminant mass will attenuate via NSZD, including aqueous phase mass destruction via natural biodegradation and increased dissolution of soluble constituents in the NAPL; thereby, weathering the NAPL and decreasing its mobility and toxicity. In each of the shallow, middle, and deep subunits, PCP and naphthalene are estimated to represent approximately 0.5 and 3.8 percent of the total contaminant mass present, respectively.
- **Shallow Subunit:** Approximately 1,720 tons of contaminant mass are estimated to be present in the shallow subunit of Area 2, of which approximately 17,230 lbs and 131,000 lbs are estimated to be represented by PCP and naphthalene, respectively. More than 99.9 percent of PCP and naphthalene mass are anticipated to be destroyed after 12 years when cleanup goals are simulated to be reached in the shallow subunit (Appendix B).
- **Middle-Deep Subunit:** Approximately 2,550 tons of contaminant mass are estimated to be present in the middle and deep subunits of Area 2, of which approximately 25,470 lbs and 193,600 lbs are estimated to be represented by PCP and naphthalene, respectively. More than 99.9 percent of PCP and naphthalene mass are anticipated to be destroyed after 41 years when cleanup goals are simulated to be reached in the middle and deep subunits (Appendix B).

Area 3: this area contains contaminant mass largely in the aqueous phase originating from aqueous mass influx from Area 2, with a portion of mass sorbed to soils as the plume has migrated. The downgradient edge of the groundwater plume in Area 3 appears to be stable, indicating an equilibrium of attenuation rates and mass influx rates. Therefore, once the contaminant influx has been eliminated, or significantly reduced, due to the ISB transect in Area 2, the aqueous phase mass in Area 3 is anticipated to readily attenuate and will be largely destroyed by biodegradation processes. The treatment achieved is irreversible as biodegraded contaminant mass is destroyed and results in innocuous compounds including carbon dioxide and water. Successful source elimination via the ISB transect is anticipated to result in complete treatment of Area 3, achieving a full reduction in volume. MNA will continue in Area 3 until the groundwater concentrations remain below cleanup goals for several years.

(5) Short-Term Effectiveness

This alternative requires the installation of a moderate number of injection/extraction wells. Sizable above ground equipment associated with extraction and treatment is required and will be partially housed in the existing SAETS building, whereas the ISB injection equipment is compact and contained in a single skid. Delivery of these materials and mobilization of installation equipment will result in minor impacts to the community from construction traffic, heavy equipment noise, and emissions. This alternative involves routine GAC changeouts where the spent GAC is retrieved for offsite disposal and replaced with new GAC, necessitating a few truck transports every couple to few months. Hazardous materials (i.e., spent GAC, NAPL, and biosolids) would be taken offsite by licensed transporters for disposal at permitted facilities and manifested accordingly.

Potential risks to construction workers may occur during implementation, but are expected to be limited by utilizing experienced and trained workers, appropriate personal protective equipment (PPE), and health and safety measures. Exposure to O&M workers will need to be controlled using qualified personnel and appropriate controls and PPE when changing out the GAC, removing biosolids, and draining accumulated NAPL.

The potential for short-term environmental impacts is small as ISB is a self-contained system requiring a small footprint and impacts to the environment would result from mobilization and drilling activities. This alternative is fairly power-intensive with operating extraction and injection pumps and a bioreactor system for 145 years to remediate Area 1, in addition to running one, 40-HP compressor continuously as part of ISB in Area 2 for 41 years that would annually consume approximately 260 megawatt hours of electricity.

Although this alternative will be immediately protective with the inclusion of ICs, it is not anticipated to be complete nor meet ARARs until Years 145, 41, and 10 for Areas 1, 2, and 3, respectively.

(6) Implementability

Alternative 2 is administratively and technically feasible and does not require significant coordination with agencies to perform the work. The technologies can be implemented with readily available materials and there are many vendors capable of implementing them. Hydraulic containment with above ground treatment and ISB are straightforward and well-proven technologies that have been successfully implemented at many other sites similar in characteristics. The existing SAETS infrastructure and ISB pilot testing wells can be leveraged. The performance of both technologies can be readily monitored and reliably assessed. If changes are needed to the treatment area or the footprint needs to be extended, both technologies are easily scalable and can be expanded to additional areas. The anticipated quantities requiring offsite disposal can be easily transported to and readily accommodated at existing treatment, storage, and disposal facilities (TSDFs).

(7) Cost
Estimated detailed costs and associated assumptions for Alternative 2 are summarized in Sheet 2 of Appendix C. The total estimated cost for implementing Alternative in the first year (Year 0) is approximately $5,120,000, with an anticipated total remedy cost of $181,340,000 (current dollar) and $99,800,000 (NPV) by remedy completion at 150 years.

4.2.3 Alternative 3 – In Situ Biosparging (Areas 1 and 2)

Alternative 3 includes ISB in Area 1, ISB and NSZD in Area 2, and MNA in Area 3.

(1) Overall Protection of Human Health and the Environment
This alternative is protective of human health and the environment in the short-term and long-term as there are no exposure pathways to contaminated groundwater. Institutional controls are in place and additional institutional controls are planned to prevent the use of impacted groundwater until deemed safe for consumption. Upon achieving and sustaining cleanup goals, groundwater in the Upper Aquifer could be restored to beneficial use.

Under this alternative, contamination is treated in place and further migration is prevented, enabling complete attenuation of the plume in Area 3. The remediation is permanently effective as the treatment destroys contaminant mass via biodegradation. MNA in Area 3 would ensure that contamination is delineated and is confined within the network and that the plume is stable or shrinking.

To determine this alternative’s long-term effectiveness and to lessen the uncertainty of reaching cleanup goals, performance monitoring would be conducted involving monitoring groundwater wells and adjusting injection flowrates, cycling durations, and pressures as needed. The monitoring data will also be used to evaluate the ISB design and modifications to meet performance objectives.

Long-term management would be required of the various systems including:

- Annual sampling of Area 3’s groundwater plume through Year 10.
- Quarterly performance monitoring and system O&M for the ISB injection wells and associated equipment through Year 6 and 41 in Areas 1 and 2, respectively.
- 5-year reviews and institutional controls until remedy completion at Year 46.

(2) Compliance with ARARs
Alternative 3 will comply with the chemical-specific, location-specific, and action-specific ARARs pertaining to the Site for protection of human health and the environment. Chemical-specific ARARs including EPA and MDEQ groundwater standards which address requirements for cleanup of groundwater are met through in situ treatment and natural source zone depletion of residual NAPL. During remedy implementation, management practices, construction techniques, and health and safety protocols will be implemented to ensure compliance with ARARs. Engineering controls, inspection and maintenance protocols, and post-construction

monitoring will be readily implemented and effective in assuring continued compliance with ARARs.

Table 4-3 provides a summary of ARARs and an initial assessment of whether a specific ARAR is applicable, relevant and appropriate, or not applicable to the alternative.

(3) Long-Term Effectiveness and Permanence
Following completion of Alternative 3, groundwater cleanup goals will have been attained and there will be no unacceptable risk posed by residual contamination on site. ISB is anticipated to meet performance specifications as it is a proven technology for treating dissolved phase contaminants and evidence of enhanced NAPL depletion was observed in treatability studies. ISB will operate until performance criteria are met. Cleanup goals would be achieved and sustained in the long-term.

The anticipated residual contamination after ISB ceases includes insoluble hydrocarbons that strongly sorb to soil and would remain in the highly weathered NAPL, neither of which would pose a risk to groundwater receptors. ISB will operate until the weathered residual NAPL is depleted of soluble components such that the effective solubilities of remaining components upon system shutdown would not result in aqueous concentrations above clean up goals under equilibrium conditions (Appendix B). Although most NAPL is currently at residual saturations and immobile, NAPL weathering will further decrease NAPL saturation and increase NAPL viscosity, which will make remaining NAPL more immobile and not recoverable. Institutional controls will be applied to the site restricting intrusive activities to prevent direct contact with the weathered residual contamination in soil.

(4) Reduction of Toxicity, Mobility, or Volume through Treatment
Alternative 3 reduces the toxicity, mobility, and volume of contamination through different mechanisms and are described for Area 1 below. The implementation and assumed operation of components for Area 2 (ISB and NSZD) and Area 3 (MNA) under Alternative 3 are identical to those for Alternative 2; therefore, their anticipated reductions are identical to those described in Section 4.2.2 and are not repeated here.

The contaminant mass in Area 1 is largely NAPL, with sorbed and aqueous phase mass present as result of partitioning from the NAPL. Aqueous phase mass will be destroyed by ISB through enhanced aerobic biodegradation and the sorbed and NAPL phase mass will be depleted through increased partitioning into the aqueous phase as the aqueous mass is biodegraded. The biological treatment achieved is irreversible as biodegraded contaminant mass is destroyed and results in innocuous compounds including carbon dioxide and water. There will be a portion of less soluble constituents that biodegrade and attenuate at a much slower rate and will not undergo as much treatment; however, the overall NAPL volume and mobility will have significantly decreased as the NAPL would be weathered such that only the insoluble components with high soil-sorption coefficients would remain. ISB and NSZD will continue until target effective solubilities are met that would not result in aqueous concentrations above cleanup goals under equilibrium conditions.

Contaminant mass will be reduced by both ISB and NSZD, including aqueous phase mass destruction via enhanced biodegradation and increased dissolution of soluble constituents in the NAPL; thereby, weathering the NAPL and decreasing its mobility and toxicity. In each of the shallow, middle, and deep subunits of Area 1, PCP and naphthalene are estimated to represent approximately 0.5 percent and 11.5 percent of the total contaminant mass present. In each subunit, more than 99.9 percent of PCP and naphthalene mass are anticipated to be destroyed after 6 years when cleanup goals are simulated to be reached (Appendix B). In the shallow subunit, approximately 700 tons of contaminant mass are estimated to be present, of which approximately 7,040 lbs and 162,000 lbs are estimated to be represented by PCP and naphthalene, respectively. In the middle and deep subunits, approximately 940 tons of contaminant mass are estimated to be present, of which approximately 9,400 lbs and 216,000 lbs are estimated to be represented by PCP and naphthalene, respectively.

(5) Short-Term Effectiveness

ISB application requires the installation of a moderate number of wells and injection system equipment that is compact and self-contained as multiple skid-mounted units resulting in little impact to the community from construction traffic, heavy equipment noise, or emissions. Potential risks to construction workers may occur during implementation, but are expected to be limited by utilizing experienced and trained workers, appropriate PPE, and health and safety measures. Exposure to O&M workers is minimal as nothing is extracted and ISB operation uses ambient compressed air, as opposed to highly reactive compressed oxygen.

The potential for short-term environmental impacts is small as ISB is a self-contained system requiring a small footprint and impacts to the environment would result from mobilization and drilling activities. This alternative is moderately power-intensive with running three, 40-HP compressors continuously during ISB in Areas 1 and 2 for 6 years, followed by running one, 40-HP compressor for ISB in Area 2 from Years 7 to 41, where each compressor would annually consume approximately 260 megawatt hours of electricity. One possible environmental impact is the potential for air to move beneath the fire pond during injection activities. This risk can be mitigated by monitoring pressures at locations near the fire pond to assess potential gradients toward the fire pond and modifying air injection rates, pressures, and durations as needed, to avoid inducing contaminant movement toward the fire pond.

Although this alternative will be immediately protective with the inclusion of ICs, it is not anticipated to be complete nor meet ARARs until Years 11, 46, and 10 for Areas 1, 2, and 3, respectively.

(6) Implementability

Alternative 3 is administratively and technically feasible and does not require significant coordination with agencies to perform the work. ISB can be implemented with readily available materials and there are many capable vendors to implement it. ISB is straightforward and well-proven, having been successfully implemented at many other sites with similar characteristics. The existing ISB pilot testing wells can be leveraged. ISB's performance can be readily monitored and reliably assessed. If changes are needed to the treatment area or the footprint needs to be extended, it is easily scalable and can be expanded to additional areas by installing additional ISB wells or transects. ISB in Area 2 is a common component to Alternatives 2 through 5; however, Alternative 3 can recognize some efficiency by implementing ISB in both Areas 1 and 2 in shared design efforts, contracting, planning, well and system installation, and performance monitoring programs and activities.

(7) Cost
Estimated detailed costs and associated assumptions for Alternative 3 are summarized in Sheet 3 of Appendix C. The total estimated cost for implementing Alternative in the first year (Year 0) is approximately $2,350,000, with an anticipated total remedy cost of $7,960,000 (current dollar) and $7,010,000 (NPV) by remedy completion at 46 years.

4.2.4 Alternative 4 – Steam Enhanced Extraction/In Situ Biosparging (Area 1) and In Situ Biosparging (Area 2)

Alternative 4 includes SEE followed by ISB in Area 1, ISB and NSZD in Area 2, and MNA in Area 3.

(1) Overall Protection of Human Health and the Environment
Alternative 4 (SEE and ISB) is protective of human receptors and eliminates the exposure to NAPL and contaminated groundwater through removal of NAPL and contaminated groundwater, offsite disposal (treatment by incineration), and in situ dissolution and biodegradation of the NAPL soluble fraction. Human health is protected in the near term as safe worker practices are in place to prevent exposure to extracted contaminated groundwater and NAPL and above ground treatment systems are designed with robust containment to eliminate direct contact. Institutional controls are in place and additional institutional controls are planned to prevent the use of impacted groundwater until deemed safe for consumption.

To determine this alternative's long-term effectiveness and to lessen the uncertainty of reaching cleanup goals, performance monitoring would be conducted involving collecting system measurements, and gauging and sampling groundwater monitoring wells would be performed to assess removal and treatment effectiveness.

Long-term management would be required of the various systems including:

- Annual sampling of Area 3's groundwater plume through Year 10.
- Quarterly performance monitoring and system O&M for Area 1 and 2 ISB injection wells and associated equipment through Year 5 for Area 1 and Year 41 for Area 2.
- Performance monitoring and system O&M during the implementation period for the SEE and associated treatment systems and ISB system, including injection and extraction wells and pumps OWS and NAPL disposal, GAC monitoring and changeouts, and reinjection wells and associated equipment.
- 5-year reviews and institutional controls until remedy completion at Year 46.

(2) Compliance with ARARs
Chemical-specific ARARs, EPA and MDEQ groundwater standards that address requirements for cleanup of groundwater are met by removal of NAPL and off-site disposal, and natural source zone depletion of residual NAPL.

Table 4-3 provides a summary of ARARs and an initial assessment of whether a specific ARAR is applicable, relevant and appropriate, or not applicable to the alternative.

(3) Long-Term Effectiveness and Permanence

Alternative 4 is effective in the long-term and provides a permanent treatment solution when SEE is followed by ISB. After implementation of SEE, residual NAPL will remain as not all of the NAPL will be recovered. SEE is anticipated to reduce the existing NAPL volume by 20 percent, which represents a decrease of approximately 1 percent in NAPL saturation, based on bench-scale testing. This limited decrease in saturation reflects that Site NAPL is already at residual conditions with limited recoverability.

Within the remaining residual NAPL, SEE is estimated to remove 90 percent of the mass of PCP and 70 percent of the mass of naphthalene from the NAPL in Area 1. After SEE has been completed, ISB will quickly degrade the remaining NAPL and COCs from Area 1 under aerobic conditions to achieve groundwater cleanup levels within an estimated few years. NAPL in Area 2 would biologically degrade with in situ biosparging, and contaminants in groundwater in Area 3 would naturally attenuate through degradation and other processes. Through removal and in situ treatment, groundwater cleanup levels would be achieved eliminating the need for long-term site management controls other than the IC during the time required for active remediation. Alternative 4 would achieve RAOs and cleanup levels within an estimated timeframe of 41 years.

In Area 1 following treatment using SEE for approximately one year, approximately 80 percent of the NAPL is anticipated to still remain in the subsurface. SEE will remove a portion of the NAPL, volatilize lighter fractions of COCs and solubilize compounds from NAPL into groundwater for subsequent degradation reactions under aerobic conditions at elevated temperature. The remaining majority of NAPL will be at residual saturations and immobile and contain lower mass fractions of COCs such as PCP and naphthalene. The NAPL characteristics would be less hazardous while the remaining NAPL will be further treated using ISB. ICs will be in place to manage the risk and eliminate potential for direct contact/ingestion by human receptors.

(4) Reduction of Toxicity, Mobility, or Volume through Treatment

SEE/ISB will permanently and significantly reduce the toxicity, mobility and volume of NAPL and COCs in groundwater. Alternative 4 provides a rapid initial reduction in volume and toxicity using SEE to remove NAPL, followed by degradation of the remaining NAPL mass using ISB until an adequate reduction in toxicity, mobility, and volume has been achieved.

SEE will remove NAPL as well as volatile and soluble contaminants from the NAPL that will be extracted and treated in above ground treatment systems. The above ground treatment systems will either remove or destroy the contaminants through separation, biological degradation and adsorption for liquids and thermal oxidation for vapor phase contaminants. Extracted NAPL will be collected, transported offsite and destroyed at an offsite incineration facility. ISB will provide for biological degradation of contaminants in Area 2. In Area 1 where SEE is applied, remaining NAPL will be further degraded through ISB. NAPL will be removed to the extent practicable and steam stripping will deplete most volatile and semi volatile constituents, which will decrease their effective aqueous solubility. The remaining, residual NAPL will have a higher viscosity and be immobile.

(5) Short-Term Effectiveness
Application of SEE in Area 1 requires the installation of multiple above ground treatment systems for liquids and vapors, a steam generating system for application of steam to the subsurface, installation of a shotcrete cover over Area 1, a subsurface soil/bentonite barrier between Area 1 and the fire pond, and installation of a large number of wells for injection extraction and monitoring. Potential risks to workers and the community may occur during implementation. Potential risks are expected to be minimal because the use of experienced workers will be used and appropriate PPE and health and safety measures will be employed during implementation. The short-term impact to the community will result from increased vehicle traffic, noise, and emissions. Potential for short-term environmental impacts from construction activity, thermal oxidation, steam generation, and vapor treatment system operations and emissions, and offsite transport of NAPL.

This alternative will be immediately protective with the inclusion of ICs and is anticipated to ARARs at Years 10, 46, and 10 for Areas 1, 2, and 3, respectively.

(6) Implementability
Alternative 4 is administratively and technically feasible but has limitations with respect to availability of vendors that can supply and implement the SEE technology. There are a limited number of vendors with direct experience applying SEE to NAPL at creosote/wood treating sites. The application of SEE technology involves a complex system including multiple treatment trains; water softening and steam generating equipment; a 2.7-acre shotcrete cover; a subsurface barrier; multiple injection, extraction and monitoring wells; and above ground conveyance piping to support the application of the SEE technology. SEE technology is energy intensive requiring on-site energy generation using a non-renewable energy source. Extracted NAPL requires transport to an offsite treatment facility (incineration) that can be provided by multiple suppliers. Utilities (water) will require upgrade to allow effective implementation of SEE.

Alternative 4 also involves implementing ISB as described in Alternative 3 upon completion of SEE. The level of effort required to implement ISB in Area 1 following SEE could be readily implemented by adding compressor equipment and using existing SEE injection wells.

(7) Cost
Estimated detailed costs and associated assumptions for Alternative 4 are summarized in Sheet 4 of Appendix C. The total estimated cost for implementing Alternative 4 in the first year (Year 0) is approximately $33,490,000, with an anticipated total remedy cost of $38,910,000 (current dollar) and $37,970,000 (NPV) by remedy completion at 46 years.

4.2.5 Alternative 5 – In Situ Geochemical Stabilization (Area 1) and In Situ Biosparging (Area 2)

Alternative 5 includes ISGS followed by NSZD in Area 1, ISB and NSZD in Area 2, and MNA in Area 3.

(1) Overall Protection of Human Health and the Environment
Alternative 5 (ISGS and ISB) is protective of human receptors and eliminates the exposure to NAPL and contaminated groundwater through in situ treatment. Treatment of NAPL by in situ geochemical stabilization and ISB protects human health and the environment by eliminating the

potential for NAPL dissolution of COCs to groundwater. Natural attenuation processes reduce dissolved phase contaminant concentrations. A mineralogical assay may be conducted to confirm formation of birnessite.

To determine this alternative's long-term effectiveness and to lessen the uncertainty of reaching cleanup goals, performance monitoring would be conducted involving collecting system measurements and gauging and sampling groundwater monitoring wells to assess ISGS effectiveness.

Long-term management would be required of the various systems including:

- Annual sampling of Area 3's groundwater plume through Year 10.
- Quarterly performance monitoring and system O&M for the Area 2 ISB injection wells and associated equipment through Year 41.
- Performance monitoring for ISGS, including soil sampling and mineralogical assays and groundwater sampling through Year 34.
- 5-year reviews and institutional controls until remedy completion at Year 46.

(2) Compliance with ARARs
Chemical-specific ARARs including EPA and MDEQ groundwater standards which address requirements for cleanup of groundwater are met through in situ treatment and stabilization and natural source zone depletion of residual NAPL. Action specific ARARs for injecting chemicals include compliance with UIC requirements.

Table 4-3 provides a summary of ARARs and an initial assessment of whether a specific ARAR is applicable, relevant and appropriate, or not applicable to the alternative.

(3) Long-Term Effectiveness and Permanence
Alternative 5 is anticipated to be effective in the long-term and provides a permanent treatment solution. NAPL is geochemically encapsulated forming a birnessite-like crust that is a durable, long-lasting and insoluble solid posing no risk to human health and the environment. Application of the ISGS solution requires excellent contact between reagent and contaminated material/ NAPL to result in a high degree of treatment effectiveness. In areas where insufficient contact and treatment occurs, NAPL that is not encapsulated will be depleted of mass and COCs by NSZD. ISGS reduces subsurface porosity, provides long-term stabilization and is not affected by changes in aquifer characteristics. Longevity will need to be evaluated; however birnessite mineral has a half-life of several hundred years under normal environmental conditions.

Long-term effectiveness and permanence has been demonstrated at a limited number of sites. The effectiveness of ISGS to encapsulate organic material could be uncertain as it requires good distribution into a heterogeneous subsurface and contact with NAPL. NAPL not contacted by the ISGS solution would remain in the subsurface, however, it would be stable (not mobile) and naturally degrade. Long-term monitoring would be required to monitor the stability and degradation. Monitoring and soil core sampling and testing would be required to assess permanence of the encapsulated NAPL.

(4) Reduction of Toxicity, Mobility, or Volume through Treatment
Within Area 1, approximately 80 percent of the NAPL is expected to be encapsulated. However, encapsulation is dependent on the ability to deliver and distribute the solution to a heterogeneous aquifer lithology and contact NAPL in the treatment area. The geochemical reaction is rapid and the residual birnessite-like crust surrounding the NAPL is not toxic. The toxicity is also reduced by eliminating the availability of contaminants in the NAPL to dissolve into groundwater. Mobility is reduced by physically and chemically encapsulating the NAPL making it immobile and insoluble. The encapsulated NAPL is a stable recalcitrant mass that maintains its integrity for long periods of time. Encapsulation of NAPL is primary mechanism with chemical oxidation of contaminants a secondary effect. The remaining NAPL would undergo degradation through natural source zone depletion.

(5) Short-Term Effectiveness
ISGS application requires installation of a large number of injection points and onsite mobilization of ISGS chemical mixing and injection system equipment that is compact and contained in two trailers and requires a small operational footprint. Transport of limited treatment equipment results in little impact to the community from construction traffic or heavy equipment noise. On site workers have training and experience that minimize potential risk to workers. The potential for short-term environmental impacts are minimal as the ISGS is a self-contained system requiring a small footprint. Most of the impacts to the environment would result from drilling activities.

Although this alternative will be immediately protective with the inclusion of ICs, it is not anticipated to be complete nor meet ARARs until Years 34, 46, and 10 for Areas 1, 2, and 3, respectively.

(6) Implementability
ISGS is a straightforward technology to use and is applicable to a wide range of organic contaminants. The chemical and injection systems are self-contained and easy to mobilize and operate with little waste disposal. However, implementation of ISGS requires specialized equipment and specific formulation protocols to generate the ISGS solution in the field by an exclusive licensee to the technology. The ISGS solution is a proprietary catalyzed solution provided by one vendor and must be manufactured on site. However, the ISGS solution could be applied/injected by multiple remediation companies. The ISGS solution has been used to remediate multiple sites with creosote, coal tars, and heavy ended petroleum compounds.

Injection of ISGS solution through sonic drilled boreholes could result in varied distribution of ISGS solution. Injection of air into the subsurface could potentially result in creation of horizontal or preferential pathways, potentially impact NAPL mobility and ISGS solution distribution. The overall formation permeability in the treated area could be reduced thereby reducing the volumetric flux of upgradient groundwater into and through the impacted area. Daylighting of ISGS solution could occur but can be captured and/or mitigated.

ISGS solution subsurface short circuiting within open boreholes or short circuiting to land surface via non-grouted boreholes could occur. ISGS reagent contains impurities (metals and inorganics) that are not prime constituents of the reagents, and concentrations of the impurities could exceed groundwater standards.

(7) Cost

Estimated detailed costs and associated assumptions for Alternative 5 are summarized in Sheet 5 of Appendix C. The total estimated cost for implementing Alternative in the first year (Year 0) is approximately $20,330,000, with an anticipated total remedy cost of $25,310,000 (current dollar) and $24,360,000 (NPV) by remedy completion at 46 years.

4.3 COMPARATIVE ANALYSIS OF ALTERNATIVES

In the comparative analysis, each of the alternatives is compared against one another with respect to each of the seven NCP criteria. Evaluation of the criteria generally identifies the significant differences and key issues between alternatives. The purpose of the analysis presented below is to identify the advantages and disadvantages of each alternative relative to one another so that the key tradeoffs and decision-makers can be identified (USEPA 1988b). The comparative analysis results are summarized in Table 4-4.

4.3.1 Overall Protection of Human Health and the Environment

Alternative 1 (NFA) is the least protective of human health, as indicated by the length of time to achieve RAOs and cleanup levels in Upper Aquifer groundwater without the implementation of any measures to contain or reduce contamination. Alternative 1 will be protective of human health because of restricted access and recorded institutional controls, such as City well drilling restrictions. Along with a proposed CGA, these controls restrict future human receptor exposure to groundwater.

Alternative 2 provides additional protection through containment of contaminants in Area 1 and in situ treatment in Area 2 to eliminate the exposure pathway to human receptors. However, implementing Alternative 2 does not meaningfully expedite the timeframe to achieve RAOs and cleanup levels over Alternative 1, requiring long-term management while contamination remains in Area 1.

Alternatives 3, 4, and 5 are the most protective of human receptors because NAPL and contaminants in Upper Aquifer groundwater are either removed and/or treated so that RAOs and cleanup levels for groundwater can be achieved over a shorter period of time relative to Alternatives 1 and 2. Until cleanup levels are met, ICs prohibit drilling of wells and use of the groundwater for drinking or irrigation. Alternatives 3 and 4 will meet cleanup levels in Area 1 considerably faster than other alternatives.

Overall, Alternatives 3, 4, and 5 are more protective of human health and the environment than Alternative 2, which is marginally more protective than Alternative 1.

4.3.2 Compliance with ARARs

Each of the alternatives will comply with the applicable and relevant and appropriate ARARs summarized in Section 2.2. Alternatives 1 and 2 will take the longest to meet chemical ARARs. Alternatives 2 and 4 will have the most action-specific ARARs to comply with. Alternatives 2, 4, and 5 will require compliance with substantive UIC requirements for injection of nonhazardous fluids into the subsurface, Alternative 3 will comply with ARARs most readily. Implementation of Alternative 1 is eventually expected to comply with applicable ARARs but not for a long period of time.

4.3.3 Long-Term Effectiveness and Permanence

Alternative 1 is the least effective in the long-term because no treatment occurs beyond natural attenuation and residual NAPL will continue to remain in place for a very long time. Alternative 1 includes recorded ICs to restrict human receptor exposure to impacted groundwater. In Alternative 2, aqueous and NAPL phase contamination are anticipated to remain in place in Area 1 for nearly the same duration as under Alternative 1, but will be contained and a portion treated ex situ. A portion of Area 2 contamination will be actively treated in situ via the ISB transect under Alternative 2, limiting contaminant migration and enabling the groundwater plume in Area 3 to remediate more quickly.

Alternatives 3, 4, and 5 provide a permanent remedy through in situ treatment or removal of NAPL and contaminants in groundwater. Residual NAPL following remedy completion for Alternatives 3, 4, and 5 would be immobilized and relatively insoluble due to significant weathering under Alternatives 3 and 4 and encapsulation under Alternative 5. A degraded and immobilized NAPL would remain under Alternatives 3 and 4, while an encapsulated NAPL would remain under Alternative 5. Longevity and effectiveness of the encapsulation would require sampling, analysis, and testing of soil cores. Alternative 4 could have less residual NAPL, as treatment with SEE could initially remove a greater amount. Remaining NAPL would require further treatment or degradation by ISB prior to meeting clean up goals. Alternative 5 would require NSZD for remaining NAPL that has not been contacted by ISGS solution. Therefore, Alternatives 2 through 5 have similar treatment residuals, but Alternatives 3 and 4 have the least intermediate treatment residuals following active treatment.

Alternatives 2 and 4 include off-site disposal of NAPL. Alternative 2 includes long-term management of an on-site facility. Off-site facilities have established reliable controls for treatment/management of NAPL. Institutional controls are included in each alternative to restrict drilling of wells and human receptor exposure to NAPL and contaminated groundwater.

Overall, Alternatives 3, 4, and 5 are nearly equal in long-term effectiveness and permanence and are more effective than Alternative 2, which is slightly more effective than Alternative 1.

4.3.4 Reduction of Toxicity, Mobility, and Volume

There is no reduction of toxicity, mobility, or volume through active treatment under Alternative 1 (NFA), although contamination is gradually reduced via natural attenuation and NSZD. Active treatment under an Alternative 2 provides reduction in toxicity, mobility, or volume in small amounts via groundwater extraction and aboveground treatment in Area 1 and in considerable amounts via ISB in Area 2.

Alternatives 3, 4, and 5 provide greater reduction in toxicity, mobility, and volume through in situ treatment or removal and treatment of NAPL and contaminants in groundwater (i.e., incineration of NAPL at a TSDF), but differ in how they do so in Area 1. Alternative 3 rapidly weathers the NAPL, removing the more soluble compounds and increasing its viscosity. Alternative 4 removes a portion of the existing NAPL, the remainder of which undergoes rapid weathering via ISB similar to Alternative 3. Alternative 4 reduces the overall NAPL volume more than any other alternative, removing an estimated 20 percent of NAPL volume in the first year; however, Alternatives 3 and 4 reach the same endpoint reduction in similar timeframes.

Although Alternative 5 does not decrease the volume of the NAPL, Alternative 5 significantly reduces NAPL toxicity and mobility through long-term encapsulation.

Alternative 4 achieves the desired reduction in toxicity and mobility the fastest as ISB is complete at Year 5, closely followed by Alternative 3 at Year 6. Alternative 5 achieves the most rapid reduction in toxicity and mobility, addressing 80 percent of the NAPL mass in the first year assuming adequate distribution of ISGS solution, but then requires 29 more years prior to adequately reducing toxicity and mobility.

Overall, Alternatives 3, 4, and 5 each share similar performance for reduction in toxicity, mobility, and volume. Alternative 2 reduces the toxicity, mobility and volume of the NAPL and impacted groundwater more than Alternative 1 (beyond natural attenuation) in that it reduces contamination via extraction in Area 1 and via ISB in Area 2.

4.3.5 Short-Term Effectiveness

Overall, Alternative 1 has the least short-term impacts, followed by Alternative 3, then by Alternative 5, then by Alternative 2, and lastly by Alternative 4 with the greatest short-term impacts. With the exception of Alternative 1, each alternative has equal remediation timeframes in Areas 2 and 3. In Area 1, Alternative 4 is estimated to meet cleanup levels in the shortest timeframe at Year 5, closely followed by Alternative 3 at Year 6, then later by Alternative 5 at Year 29, and Alternatives 1 and 2 at Year 145. Considering impacts and timeframes, Alternative 3 has the highest performance in short-term effectiveness by a considerable margin.

Alternative 1 (NFA) provides no increased short-term risks because no construction-related actions will be implemented that would create additional risks to workers or the community. Alternative 3 involves a small potential for increased risks from mobilization, drilling, and O&M activities associated with ISB in Areas 1 and 2. Alternative 5 involves a slightly increased potential for risk from mobilization, drilling, and injection activities associated with ISGS in Area 1, and working with the chemicals used for stabilization.

Larger potential risks are posed to workers and the community for Alternative 2 and most notably for Alternative 4. Risks to workers may occur during installation of wells and operation of injection and extraction systems and aboveground treatment systems under Alternative 2. Risks associated with truck haulage on local roads may slightly increase the potential for traffic hazards in the community. Alternative 4 includes increased truck traffic due to the multiple pieces of equipment required for the steam generation, aboveground liquid and vapor treatment systems, storage of removed NAPL, and frequent delivery of a fuel source (e.g., propane) for power generation. There will be increased risks to workers during the operation of the SEE thermal treatment system and management of byproducts and emissions under Alternative 4. Alternative 4 includes the import of a surface barrier (shotcrete) material from off-site sources and installation of a subsurface barrier constructed of soil/bentonite. This will increase truck traffic and thereby potential risks to the community.

4.3.6 Implementability

Alternative 1 (NFA) does not include construction activities and is the easiest to implement. Alternative 1 also includes recorded ICs that are in place for the property. Although more complex than Alternative 1, Alternative 3 is the next easiest to implement and includes the installation of injection wells and minor aboveground infrastructure to inject air, closely followed by Alternative 5 that is slightly more complex to implement. The additional complexity of Alternative 5 is associated with injection of ISGS solution at approximately 600 injection points in Area 1 compared to 55 air injection points for ISB in Area 1. Furthermore, ISB will be implemented in Area 2 as a common component to Alternatives 2 through 5; therefore, expansion of the ISB approach in Area 1 does not add significant complexity to Alternative 3, making Alternative 3 easier to implement than Alternative 5. Alternative 5 requires specialized equipment and specific formulation protocols to generate the ISGS solution in the field, thus limiting the number of suppliers to one with an exclusive license. Injection of solution and air could create preferential pathways and negatively impact solution distribution and possibly NAPL mobility.

Alternatives 2 and 4 are both more difficult to implement, but for different reasons. They both employ aboveground treatment systems and involve transporting and disposing NAPL, though in small and sustained quantities for Alternative 2 compared to large but brief quantities in Alternative 4. Alternative 2 is readily implementable, but involves long-term O&M (estimated at 145 years) of the extraction and treatment system. Alternative 2 can also be readily expanded, easily adjusted, and reliably monitored. Alternative 4 is the most difficult to implement because it involves the most complex system, requires multiple treatment systems, the most construction equipment to complete, necessitates specialized services offered by limited contractors, requires onsite water pretreatment (softening) and steam generation, includes transport of the largest quantity of NAPL to an off-site TSDF, and includes importing materials from off-site locations (bentonite, soil, and shotcrete). Alternative 4 is difficult to scale and would involve a complex process of similar magnitude to later expand its footprint. It is also more difficult to monitor its performance.

Alternative 4 involves the greatest construction activities and includes construction of a surface barrier, installation of a subsurface groundwater barrier and installation of multiple wells and construction of multiple aboveground treatment systems. Following application of SEE additional in situ treatment (ISB) using existing wells is necessary to treat remaining NAPL. Alternative 4 includes on-site thermal treatment; however, thermal treatment contractors are limited and the technology requires multiple treatment trains (i.e., liquid treatment, vapor treatment, water pretreatment, and steam generation), resulting in the on-site transport of complex equipment and use of by specially trained operators. Utilities require upgrade to provide sufficient power to operate the systems properly and efficiently. Collection/management of treatment byproducts (i.e., NAPL, spent carbon, air emissions) results in additional sampling and monitoring activities.

Overall, Alternative 1 is the easiest to implement followed by Alternative 3 and then Alternative 5. The complexity increases with Alternative 2, but Alternative 2 is still notably easier to implement than Alternative 4, which is the most complex.

4.3.7 Cost

Alternative 1 (NFA) does not include construction activities and has the lowest cost. For an additional cost of approximately $103 million (present value), containment and limited treatment in Areas 1 and 2 is included (Alternative 2), which is the second-least protective, but the most expensive option. For approximately $93 million (net present value) less than Alternative 2, treatment via ISB (Alternative 3) can be implemented in Area 1 in lieu of hydraulic containment. Implementing SEE or ISGS to more aggressively treat NAPL in Area 1 would cost approximately $31 million or $17 million (net present value) over Alternative 3 for Alternatives 4 and 5, respectively. Although Alternative 5 provides similar levels of protection with identical total timeframes (46 years) as Alternative 3, it is estimated at 3.2 times the cost of Alternative 3. Alternative 4 provides similar protection to Alternative 3 and achieves cleanup goals one year sooner in Area 1, but is nearly 5 times more expensive.

Estimated cost subtotals are summarized in the Table 4-5 for the five alternatives, presented to the nearest $100,000 ($0.1 M).

Table 4-1. Evaluation Criteria

Balancing Criteria	Description
Overall Protection of Human Health and the Environment	Alternatives will be assessed to determine whether a specific alternative achieves adequate protection and how site risks posed through each pathway are eliminated, reduced or controlled through treatment engineering or institutional controls.
Compliance with Applicable or Relevant and Appropriate Requirements (ARARs)	Alternatives will be assessed to determine whether the alternative attains Federal and State chemical-, location- and action-specific ARARs, or other criteria, advisories and guidance's agreed upon as "to be considered", or whether justification exists for invoking one of the six waivers allowed as identified in CFR Title 40 Section 300.430.
Long-Term Effectiveness and Permanence	Alternatives will be assessed with respect to the magnitude of risk remaining at the site after response objectives have been met or remedial activities are concluded, the effectiveness of the controls required to manage the risk posed by treatment residuals or untreated wastes. The characteristics of the residuals should be considered to the degree that they remain hazardous taking into account their volume, toxicity, mobility, and propensity to bioaccumulate. The adequacy and suitability of controls such as containment systems or institutional controls that are used to manage treatment residuals or untreated waste.
Reduction of Toxicity, Mobility and Volume through Treatment	Alternatives will be evaluated with respect to whether an alternative uses a treatment technology(ies) that permanently and significantly reduce toxicity, mobility or volume of the hazardous substance. Treatment includes reducing principal threats through destruction of toxic contaminants, reduction of total mass of contaminants, irreversible reduction in contaminant mobility or reduction of total volume of contaminated media. Evaluation factors include: • Treatment process used and materials treated. • Amount of hazardous materials destroyed or treated. • Degree of reduction in mobility, toxicity or volume. • Permanence/degree to which it is irreversible. • Type and amount of treatment residuals remaining.
Short-term Effectiveness	Alternatives will be evaluated to assess effects of the alternative during implementation until response objectives are met. Response objectives include meeting cleanup values in groundwater. Factors to be assessed include: • Protection of community during implementation of the remedial action, risks resulting from implementation and measures to mitigate risks. • Potential impacts to workers and effectiveness and reliability of protective measures. • Potential impacts to the environment and effectiveness and reliability of protective measures. • Time until response objectives are achieved, <30 years, 31-99 years, >100 years

Table 4-1. Evaluation Criteria

Balancing Criteria	Description
Implementability	Alternatives are evaluated with respect to the technical and administrative feasibility of implementing an alternative and availability of technology equipment/service. Factors addressed include: • Technical Feasibility – Technical difficulties and unknowns associated with construction and operation of an alternative. – Reliability of the technology used. – Ease of implementing additional remedial actions at a later time. – Ability to monitor effectiveness of remedial action. – Availability of services and materials needed for alternative. • Administrative Feasibility – Level of coordination with other agencies.
Cost	Alternatives will be evaluated with respect to Capital and Operation and Maintenance (O&M) costs, periodic cost and present worth cost. Capital Costs include: • Direct costs • Construction • Equipment • Services (utilities) • Disposal of waste Indirect Costs include: • Engineering • License costs • Startup and shake down • Contingency O&M Costs include: • Operating labor costs • Maintenance materials and labor • Chemicals, materials and energy • Disposal of treatment residuals • Sampling and analysis • Administrative costs • Insurance, taxes, and licensing fees for certain technologies • Maintenance reserve and contingency funds for equipment replacement • Cost of 5 year site reviews

Table 4-2. Individual Analysis of Alternatives Summary

Alternative	1. Overall Protection of Human Health and the Environment	2. Compliance with ARARs	3. Long-Term Effectiveness and Permanence	4. Reduction of Toxicity, Mobility, or Volume through Treatment	5. Short-Term Effectiveness	6. Implementability	7. Cost	
							Ranking Comment	Current Dollar Totals (*in millions*)
1 No Further Action	**Moderate** Protective of human health exposure to contaminated groundwater in short term through restrictions on drilling wells and use of groundwater.	**Moderately High** Does not meet chemical-specific ARARs for groundwater quality standards until natural processes occur for over 150 years.	**Moderate** Effectiveness and permanence not attained as residual risk from NAPL remaining in groundwater occurs for over 150 years. Natural processes are slow and lengthy.	**Moderately Low** No active treatment to reduce toxicity, mobility or volume; however, natural processes over a long period of time should reduce contaminant concentrations, thus, reducing toxicity, mobility, and volume.	**Moderately High** Effective in the short term in the sense that there are no actions being implemented that could pose risks to workers, community or the environment. Has an estimated 150-year timeframe until cleanup goals are met.	**High** Easy to implement as no actions are proposed. Administration of ICs over a long period of time requires agency coordination. Small effort is associated with limited long-term monitoring.	**Low** Very low capital, minor O&M.	**Capital (Yr 0)** $0.4 M **O&M/Periodic** $1.1 M **NPV** $0.9 M
2 Hydraulic Containment (Area 1) & ISB (Area 2)	**Moderately High** Protective of human health and the environment by restricting the exposure pathway to contaminated groundwater and by containing and partially treating aqueous contamination while the NAPL naturally attenuates.	**Moderately High** Complies with ARARs; however, chemical-specific groundwater quality standards are not achieved in each area of the site until 150 years. Action- and location-specific ARARs are met during implementation through system and engineering controls.	**Moderately High** Is effective at eliminating or reducing exposure to human receptors as contamination is effectively contained until the NAPL and contaminants naturally attenuate in situ and system operation continues until cleanup goals are reached. Extracted NAPL is incinerated and extracted impacted water is treated biologically and polished with GAC to meet cleanup goals before being reinjected to the Upper Aquifer.	**Moderate** Reduction in contaminant toxicity, mobility, and volume primarily occurs through in situ natural attenuation, but also partially through extraction and treatment in aboveground systems. Approximately 6.5% of existing NAPL is estimated to be extracted and incinerated. 90 to 95% mass reduction is expected from the bioreactor, followed by GAC polishing resulting in approximately 105 tons of annual GAC consumption. In Area 2, over 99.9% of PCP and naphthalene mass is anticipated to be naturally degraded in situ within 12 and 41 years in the shallow and middle-deep subunits, respectively.	**Moderate** Potential risks to workers and community occur from mobilization and operation of multiple treatment systems/equipment. Potential risks to workers and the environment from management and operation of above ground treatment systems and handling of treatment residuals/byproducts (e.g., biosolids, spent GAC, NAPL). Has an estimated 150-year timeframe until cleanup goals are met, of which 145 and 41 years involve active treatment in Areas 1 and 2, respectively.	**Moderate** Technically and administratively easy to implement, without requiring much coordination. Supplies and capable vendors are readily available. The effectiveness of containment can be easily monitored and reliably assessed. Extraction and treatment is easily scalable and can be readily expanded to additional areas. However, this alternative does require long-term O&M of the system.	**High** Low capital, very high O&M.	**Capital (Yr 0)** $4.5 M **O&M/Periodic** $176.9 M **NPV** $99.8 M
3 ISB (Area 1 & 2)	**High** Protective of human health and the environment by eliminating exposure pathway to contaminated groundwater through degradation and destruction of aqueous contamination and by immobilization and weathering of NAPL.	**High** Complies with ARARs. Chemical-specific groundwater quality standards are achieved in each area of the site within 46 years. Action- and location-specific ARARs are met during implementation through system and engineering controls.	**High** Is effective at eliminating or reducing exposure to human receptors as NAPL and contaminants are degraded in situ and the NAPL is stripped of soluble components and becomes highly weathered resulting in a viscous and less mobile residual, which provides a permanent solution to address site contamination and achieve cleanup goals. System operation continues until cleanup goals are reached.	**High** Reduction in contaminant toxicity, mobility, and volume occurs through in situ enhanced aerobic degradation whereby aqueous mass is destroyed and the NAPL is stripped of soluble components and becomes highly weathered. Over 99.9% of PCP and naphthalene mass is anticipated to be naturally degraded in situ within 6 years in Area 1 and within 12 and 41 years in the shallow and middle-deep subunits of Area 2, respectively.	**Moderately High** Minor potential risks to workers and community occur from mobilization and installing injection wells. No risk is anticipated from system operation as nothing is extracted and the system utilized compressed ambient air. Has an estimated 46-year timeframe until cleanup goals are met, of which 6 and 41 years involve active treatment in Areas 1 and 2, respectively.	**Moderately High** Technically and administratively easy to implement, without requiring much coordination. Supplies and capable vendors are readily available. ISB's performance can be easily monitored and reliably assessed. ISB is easily scalable and can be readily expanded to additional areas.	**Moderately Low** Low capital, moderately low O&M.	**Capital (Yr 0)** $2.2 M **O&M/Periodic** $5.7 M **NPV** $7.0 M

Table 4-2. Individual Analysis of Alternatives Summary

Alternative	1. Overall Protection of Human Health and the Environment	2. Compliance with ARARs	3. Long-Term Effectiveness and Permanence	4. Reduction of Toxicity, Mobility, or Volume through Treatment	5. Short-Term Effectiveness	6. Implementability	7. Cost	
							Ranking Comment	Current Dollar Totals (*in millions*)
4 SEE/ISB (Area 1) & ISB (Area 2)	**<u>High</u>** Protective of human health and the environment by eliminating exposure pathway to contaminated groundwater through removal of contaminants, onsite treatment of extracted liquids and vapors and offsite treatment (incineration) and disposal of NAPL.	**<u>High</u>** Complies with ARARs. Chemical-specific groundwater quality standards are achieved in each area of the site within 46 years. Action- and location-specific ARARs are met during implementation through system and engineering controls.	**<u>High</u>** Is effective at eliminating or reducing exposure to human receptors as NAPL and contaminants are removed from the groundwater. NAPL and contaminants are further treated or destroyed providing a permanent solution to address site contamination and achieve cleanup goals. Following SEE in Area 1 some NAPL remains in groundwater for a short period of time until ISB reduces concentrations.	**<u>High</u>** Reduction in contaminant toxicity, mobility, and volume occurs through removal from the subsurface and treatment in aboveground systems followed by in situ treatment (biodegradation).	**<u>Moderate</u>** Potential risks to workers and community occur from mobilization and operation of multiple treatment systems/equipment. Potential risks to workers and the environment from management and operation of steam generation (boilers), thermal oxidation systems and handling of treatment residuals/byproducts. Has an estimated 46-year timeframe until cleanup goals are met, of which 5 and 41 years involve active treatment in Areas 1 and 2, respectively.	**<u>Moderately Low</u>** SEE is technically implementable; however, there are a limited number of contractors who can implement SEE. SEE requires multiple aboveground systems for steam generation and liquid and vapor treatment. Boiler operation requires trained personnel who meet State requirements. Liquid treatment systems are standard and readily available. Vapor treatment system is complex, but available. Additional biosparging treatment could use existing wells. Utilities (electrical, water) are required to be upgraded to operate efficiently. Operation of multiple systems increases the complexity of this alternative, increases resource usage (electricity, water, and fuel), and generates more treatment residuals to manage and dispose offsite. Involves offsite transport of NAPL to incineration facility. This alternative is difficult to scale, monitor, and expand or repeat.	**<u>High</u>** Very high capital, moderately low O&M.	**<u>Capital (Yr 0)</u>** $33.4 M **<u>O&M/Periodic</u>** $5.5 M **<u>NPV</u>** $38.0 M
5 ISGS (Area 1) & ISB (Area 2)	**<u>High</u>** Protective of human health and the environment by eliminating exposure pathway to contaminated groundwater through encapsulation of NAPL and organic contaminants.	**<u>Moderately High</u>** Complies with ARARs. Chemical-specific groundwater quality standards are achieved in each area of the site within 46 years. Action- and location-specific ARARs are met during implementation through system and engineering controls.	**<u>Moderately High</u>** Is effective at eliminating or reducing exposure to human receptors as NAPL and contaminants are encapsulated resulting in a viscous and less mobile residual providing a permanent solution to address site contamination and achieve cleanup goals. Requires good distribution in subsurface and contact with NAPL to be effective. Following ISGS in area 1 some NAPL remains in groundwater for a period of time until NSZD reduces concentrations.	**<u>Moderately High</u>** Reduction in contaminant toxicity, mobility, and volume occurs through in situ geochemical treatment and encapsulation of NAPL and organics.	**<u>Moderately High</u>** Minor potential risks to workers and community occur from mobilization and operation of chemical mixing and injection systems/equipment. Has an estimated 46-year timeframe until cleanup goals are met, of which 1 and 41 years involve active treatment in Areas 1 and 2, respectively.	**<u>Moderately High</u>** ISGS is technically implementable, but there is only one supplier licensed to generate the geochemical solution though there are multiple contractors who could implement (inject/apply) ISGS solution. Mobilization of ISGS system involves two self-contained trailers with chemical mixing/injection systems. Less complex system to operate and requires fewer resources, such as electricity and water, and results in no generation of treatment residuals to manage and dispose offsite. Injection of solution and distribution to contact NAPL could be impacted by generation of preferential pathways, NAPL movement or short-circuiting.	**<u>Moderately High</u>** High capital, moderately low O&M.	**<u>Capital (Yr 0)</u>** $20.3 M **<u>O&M/Periodic</u>** $5.0 M **<u>NPV</u>** $24.4 M

Notes:
ARAR – applicable or relevant and appropriate requirements; GAC – granular activated carbon; ISB – in-situ biosparging; ISGS – in-situ geochemical stabilization; NAPL – non-aqueous phase liquids; NPV – net present value
NSZD – natural source zone depletion; O&M – operations and maintenance; PCP – pentachlorophenol; SEE – steam enhanced extraction

Table 4-3. Potential ARARs for Alternatives

Standard, Requirement, Criteria or Limitation	Citation	Requirement Description	Alternatives				
			Alternative 1 No Further Action	Alternative 2 Hydraulic Containment & ISB	Alternative 3 ISB	Alternative 4 SEE & ISB	Alternative 5 ISGS & ISB
Chemical-Specific ARARS							
Federal							
SAFE DRINKING WATER ACT							
National Primary Drinking Water Standards	40 CFR Part 141 Subparts B, F, G, and I	National Primary Drinking Water Regulations (40 CFR Part 141) See **Tables 2-9** and **2-12** for a listing of federal MCLs and MCLGs. See Table **2-11** for a summary of the Action Levels for lead and copper.	R&A	R&A	R&A	R&A	R&A
CLEAN WATER ACT							
Federal Water Pollution Control Criteria	33 USC §1251 - 1387	Federal Water Pollution Control Act as amended by the CWA of 1977 and subsequent CWA amendments.	A	A	A	A	A
	33 USC §1311	CWA Effluent Limitations	A	A	A	A	A
	33 USC §1314 and 40 CFR Part 131	Water Quality Criteria See **Table 2-3**, Federal Recommended Water Quality Criteria for a listing of pollutants and associated water quality criteria.	NA	R&A	NA	R&A	R&A
	33 USC §1314 and 40 CFR Part 131	CWA criteria See description above	R&A	R&A	NA	R&A	R&A
Chemical-Specific ARARs							
State of Montana							
MONTANA WATER QUALITY ACT							
State water pollution control criteria	§75-5-303, MCA	State Waters Protection, General Requirements	A	A	A	A	A
Nondegradation of Water Quality	ARM §17.30.701 through 717	Nondegradation Rules	A	A	A	A	A

Table 4-3. Potential ARARs for Alternatives

Standard, Requirement, Criteria or Limitation	Citation	Requirement Description	Alternatives				
			Alternative 1 No Further Action	Alternative 2 Hydraulic Containment & ISB	Alternative 3 ISB	Alternative 4 SEE & ISB	Alternative 5 ISGS & ISB
Surface Water Quality Standards and Procedures	ARM §17.30.601 through 17.30.670	Surface Water Quality Standards and Procedures See **Table 2-7** and **Table 2-8** for surface water criteria applicable to the Libby site.	A	A	A	A	A
Montana Groundwater Pollution Control System	ARM §17.30.1001 through 17.30.1045	Montana Groundwater Pollution Control System See **Table 2-6** for groundwater standards applicable to the Libby site.	A	A	A	A	A
Montana Numeric Water Quality Standards	MDEQ Circular DEQ-7, developed in compliance with §75-5-301, MCA, §80-15-201, MCA, and Section 303(c) of the CWA	Numeric water quality standards for Montana's surface and groundwaters. See **Table 2-4** for a listing of numeric water quality standards (surface water and groundwater) applicable to the Libby site.	A	A	A	A	A
Montana Numeric Nutrients Standards	MDEQ Circular DEQ-12A, developed in compliance with §75-5-103(2), MCA and adopted pursuant to §75-5-301(2), MCA	Base numeric nutrients standards for Montana's surface waters. See **Table 2-5** for base numeric nutrients standards (flowing surface waters) applicable to the Libby site.	A	A	A	A	A
Montana Maximum Contaminant Levels	ARM §17.38.201 through 17.38.207	Montana MCLs See **Table 2-10** for Montana MCLs relevant to the Libby site.	R&A	R&A	R&A	R&A	R&A
MCA	§17.30.103, MCA	Discharge permit with discharge limits to protect surface waters.	R&A	R&A	R&A	R&A	R&A
ARM §17.38: Montana Regulations for Public Drinking Water Systems	§17.38.203 §17.38.204 §17.38.205 §17.38.206	Provides state with primary drinking water regulations based on federal MCLs for public water systems.	R&A	R&A	R&A	R&A	R&A

Table 4-3. Potential ARARs for Alternatives

Standard, Requirement, Criteria or Limitation	Citation	Requirement Description	Alternatives				
			Alternative 1 No Further Action	Alternative 2 Hydraulic Containment & ISB	Alternative 3 ISB	Alternative 4 SEE & ISB	Alternative 5 ISGS & ISB
MONTANA HAZARDOUS WASTE ACT							
MHWA	§17.53.501 and 17.53.502 §17.53.601 and 17.53.602 §17.53.801 and 17.53.802 §17.53.1001 and 17.53.1002 §17.53.1101 and 17.53.1102 §17.53.1301 and 17.53.1302 §17.53.1401 and 17.53.1402	Establishes criteria for the classification of hazardous waste by incorporating by reference federal regulations, with the exception to the definition of a flammable gas noted in §17.53.502. See **Table 2-17** for specific land disposal restriction requirements pertaining to hazardous wastes expected to be generated at the Libby Site.	NA	A	NA	A	NA
CLEAN AIR ACT MONTANA							
CAAM	§17.8, MCA	Establishes ambient air quality standards, performance standards for specific sources of air pollutants, and specifies monitoring methods. See **Table 2-15**	NA	A	NA	A	NA
	§17.8.309	Particulate matter limits for fuel-burning equipment. See **Table 2-16**	NA	NA	NA	A	NA
Location-Specific ARARs							
Federal							
CLEAN WATER ACT DREDGE AND FILL REQUIREMENTS							
CWA	40 CFR §230 and 33 CFR §§322/323	Requirements for structures or work in or affecting navigable waters of United States and Requirements for discharges of dredged or fill material into waters of United States.	NA	NA	NA	NA	NA

Table 4-3. Potential ARARs for Alternatives

Standard, Requirement, Criteria or Limitation	Citation	Requirement Description	Alternatives				
			Alternative 1 No Further Action	Alternative 2 Hydraulic Containment & ISB	Alternative 3 ISB	Alternative 4 SEE & ISB	Alternative 5 ISGS & ISB
ENDANGERED SPECIES ACT							
ESA	16 USC §§1531, 1532, 1533, 1535, and 1536 50 CFR Part 17	ESA Statute and Regulations See **Table 2-13**	A	A	A	A	A
MIGRATORY BIRD TREATY ACT							
MBTA	16 USC §703 to 712	Provides protection for migratory bird species (including geese, ducks, raptors, many passerines). Prohibits killing or taking of bird or any part, nest, or egg of any such bird.	A	A	A	A	A
BALD EAGLE PROTECTION ACT							
BEPA	16 USC §668	Bald Eagle Protection Act statute	A	A	A	A	A
NATIONAL HISTORIC PRESERVATION ACT							
NHPA	16 USC §470 et seq.	NHPA statute	A	A	A	A	A
	36 CFR Parts 63, 65, and 800	NHPA regulations					
ARCHEOLOGICAL (sic) AND HISTORIC PRESERVATION ACT (AHPA)							
AHPA	16 USC §469	AHPA statute	A	A	A	A	A
EXECUTIVE ORDER ON FLOODPLAIN MANAGEMENT							
	EO No. 11988, as amended	This EO requires that actions be taken to avoid, to the extent possible, adverse effects associated with direct or indirect development of a floodplain, or to minimize adverse impacts if no practicable alternative exists.	NA	NA	NA	NA	NA
EXECUTIVE ORDER ON THE PROTECTION OF WETLANDS							
	EO No. 11990, as amended	This EO requires federal agencies and the PRPs to avoid, to the extent possible, the adverse impacts associated with the destruction or loss of wetlands and to avoid support of new construction in wetlands if a practicable alternative exists.	NA	NA	NA	NA	NA

Table 4-3. Potential ARARs for Alternatives

Standard, Requirement, Criteria or Limitation	Citation	Requirement Description	Alternatives				
			Alternative 1 No Further Action	Alternative 2 Hydraulic Containment & ISB	Alternative 3 ISB	Alternative 4 SEE & ISB	Alternative 5 ISGS & ISB
		Wetlands are defined as those areas that are inundated or saturated by groundwater or surface water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions.					
Location-Specific ARARs							
State of Montana							
MONTANA WATER QUALITY ACT							
MCA	§75-5-605, MCA	Prohibits placement of wastes where they will cause pollution of any state water.	NA	A	A	A	A
	ARM §17.30.101-109	Ensure that any activity requiring a federal license or permit that may result in discharge to state waters shall fulfill requirements of ARM Title 17.	NA	A	A	A	A
	ARM §17.30.1011	Maintain existing groundwater quality.	A	A	A	A	A
MONTANA STATE ANTIQUITIES ACT							
MSAA	§§22-3 Part 8	Protection of human skeletal remains and burial sites.	A	A	A	A	A
MONTANA NONGAME AND ENDANGERED SPECIES CONSERVATION ACT							
MCA	§87-5-106, MCA	Protection of nongame species deemed to be in need of management.	A	A	A	A	A
	ARM §12.5.201	Montana Endangered Species List	A	A	A	A	A

Table 4-3. Potential ARARs for Alternatives

Standard, Requirement, Criteria or Limitation	Citation	Requirement Description	Alternatives				
			Alternative 1 No Further Action	Alternative 2 Hydraulic Containment & ISB	Alternative 3 ISB	Alternative 4 SEE & ISB	Alternative 5 ISGS & ISB
MONTANA NOXIOUS WEED CONTROL LAW							
MNWCL	§7-22-2101(7)(a), MCA, §7-22-2109(2)(b), MCA, and ARM 4.5.201 through 4.5.210	Definition of noxious weeds and weed management criteria.	A	A	A	A	A
	§7-22-2116, MCA	Requires control of noxious weeds.	A	A	A	A	A
	§7-22-2152, MCA	Notification to District Weed Board	NA	R&A	R&A	R&A	R&A
ACTION-SPECIFIC ARARS							
Federal							
CLEAN AIR ACT							
Air Pollution Control	ARM §17.8: Air Quality	Refer to the CAA section of chemical-specific ARARs.					
	40 CFR Part 50	National ambient air quality standards, refer to **Table 2-14**	NA	NA	NA	R&A	NA
	40 CFR §61.01	Requirements for stationary sources of hazardous air pollutants.	NA	NA	NA	A	NA
	40 CFR Part 60 Subpart Dc	Standards of performance for small industrial-commercial-institutional steam generating units.	NA	NA	NA	A	NA
CLEAN WATER ACT							
Water Pollution Control Requirements	40 CFR 112	Requirements for petroleum storage in aboveground tanks. Requires preparation and implementation of a SPCC Plan.	NA	A	NA	A	NA
	40 CFR Part 122	National Pollution Discharge Elimination System program requirements for EPA administered permit programs.	NA	A	A	A	A

Table 4-3. Potential ARARs for Alternatives

Standard, Requirement, Criteria or Limitation	Citation	Requirement Description	Alternatives				
			Alternative 1 No Further Action	Alternative 2 Hydraulic Containment & ISB	Alternative 3 ISB	Alternative 4 SEE & ISB	Alternative 5 ISGS & ISB
	40 CFR Part 125	Criteria and Standards for the National Pollutant Discharge Elimination System.	NA	A	A	A	A
SAFE DRINKING WATER ACT							
Underground Injection Control	40 CFR Part 144	Compliance with substantive UIC permit requirements.	NA	A	A	A	A
RESOURCE CONSERVATION AND RECOVERY ACT							
Hazardous waste requirements	42 USC §6921(a) and (b)	Law requiring that rules identifying and listing hazardous waste be developed.	NA	R&A	NA	R&A	NA
	40 CFR Part 261 including 261.3(c)(2)(i)	Regulation defines hazardous waste characteristics and lists specific chemicals that are hazardous waste when discarded.	A	A	A	A	A
	40 CFR Part 262	Requirements for hazardous waste generators.	A	A	A	A	A
	40 CFR Part 264	Requirements for treatment, storage, and disposal facilities.	A	A	A	A	A
	40 CFR Part 268	Requirements for treatment before land disposal Refer to 40 CFR §268.40, Treatment Standards for Hazardous Waste, and 49 CFR 268.48, Universal Treatment Standards, where referenced. **See Table 2-17.**	A	A	A	A	A
OCCUPATIONAL SAFETY AND HEALTH ACT							
OSHA	29 CFR 1910	Personnel working with hazardous waste must comply with health and safety standards.	NA	A	A	A	A

Table 4-3. Potential ARARs for Alternatives

Standard, Requirement, Criteria or Limitation	Citation	Requirement Description	Alternatives				
			Alternative 1 No Further Action	Alternative 2 Hydraulic Containment & ISB	Alternative 3 ISB	Alternative 4 SEE & ISB	Alternative 5 ISGS & ISB
Action-Specific ARARS							
State of Montana							
MONTANA WATER QUALITY ACT							
MCA	§75-5-401	Permits required; compliance with substantive provision applies.	NA	A	A	A	A
	§ 17.30.1023	Permits required; compliance with substantive provision applies.	NA	A	A	A	A
	§17.30.1105	A permit is required for discharge of water associated with stormwater discharges.	NA	A	A	A	A
MONTANA WATER USE ACT							
MWUA	85-2-505	Waste and contamination of groundwater prohibited.	NA	A	A	A	A
WATER WELL CONSTRUCTION							
MCA	43-37-302	License requirements for well construction.	NA	A	A	A	A
MCA	85-2-516	Well Log Report		A	A	A	A
	ARM §36.21 Subchapter 6	Construction standards for groundwater wells other than public drinking water and supply wells.	NA	A	A	A	A
MONTANA AIR QUALITY ACT							
ARM §17.8 Air Quality							
CAAM	§75-2-102, MCA	Intent, policy, and purpose of the CAAM. Specific rules that may apply depend on the types of air emissions sources that may be used at the site.	NA	R&A	NA	R&A	R&A
	ARM §17.8.201 through 17.8.230	Ambient Air Quality Standards and Monitoring. See Table 2-14 for specific requirements.	NA	A	A	A	A

Table 4-3. Potential ARARs for Alternatives

Standard, Requirement, Criteria or Limitation	Citation	Requirement Description	Alternatives				
			Alternative 1 No Further Action	Alternative 2 Hydraulic Containment & ISB	Alternative 3 ISB	Alternative 4 SEE & ISB	Alternative 5 ISGS & ISB
	ARM §17.8.301 through 17.8.342	Air Emission Standards. See Table 2-14 for specific requirements.	NA	NA	NA	A	NA
	ARM §17.8.604	Materials prohibited from open burning.	NA	NA	NA	NA	NA
	ARM §17.8.610 through 17.8.612	Open Burning Restrictions and Permit Requirements	NA	NA	NA	NA	NA
	ARM §17.8.752	Emission Control Requirements. The maximum air pollution control capability that is technically practicable and economically feasible must be installed on a new or modified facility or emitting unit for which a Montana air quality permit is required.	NA	NA	NA	A	NA
	ARM §17.8.802	Prevention of Significant Deterioration Requirements	NA	NA	NA	A	NA
	ARM §17.8.805	Ambient Air Ceilings		A	A	A	A
HAZARDOUS WASTE MANAGEMENT STATUTE AND REGULATIONS							
MONTANA HAZARDOUS WASTE ACT							
MHWA	§75-10-422, MCA	Unlawful Disposal	A	A	A	A	A
MHWA	ARM §17.53 Subchapters 6 and 8	Hazardous Waste Generators Must Comply with Certain Requirements	A	A	A	A	A
MONTANA SOLID WASTE MANAGEMENT ACT							
MSWMA	ARM §17.50..404	Disposal in Unauthorized Area Prohibited.	NA	NA	NA	NA	NA
	ARM §17.50..404	License Required	NA	NA	NA	NA	NA
	ARM §17.50..816	Disposal of Portable Toilet Waste	NA	A	A	A	A
	ARM §17.50..816	License Required for cleaning septic tanks, portable toilets, etc.	NA	A	A	A	A
MCA	ARM 24.122.501	License required to operate boilers and steam engines.	NA	NA	NA	A	NA

Table 4-3. Potential ARARs for Alternatives

Notes:

§	–	Section	MBTA	–	Migratory Bird Treaty Act
§§	–	Sections	MCA	–	Montana Code Annotated
A	–	Applicable	MCL	–	Maximum Contaminant Level
Action	–	Action Specific ARAR	MCLGs	–	Maximum Contaminant Level Goals
AHPA	–	Archeological and Historical Preservation Act	MDEQ	–	Montana Department of Environmental Quality
ARAR	–	Applicable or Relevant and Appropriate Requirement	MHWA	–	Montana Hazardous Waste Act
ARM	–	Administrative Rules of Montana	MNWCL	–	Montana Noxious Weed Control Law
BEPA	–	Bald Eagle Protection Act	MSAA	–	Montana State Antiquities Act
CAA	–	Clean Air Act	MSWMA	–	Montana Solid Waste Management Act
CAAM	–	Clean Air Act of Montana	MWUA	–	Montana Water Use Act
CFR	–	Code of Federal Regulations	NA	–	Not Applicable
CWA	–	Clean Water Act	NHPA	–	National Historic Preservation Act
DEQ		Department of Environmental Quality	No.	–	Number
EPA	–	US Environmental Protection Agency	PRPs	–	Potential responsible parties
ESA	–	Endangered Species Act	R&A	–	Relevant & Appropriate
EO	–	Executive Order	SEE	–	Steam Enhanced Extraction
ISB	–	In Situ Biosparging	SPCC		Spill Prevention, Control, and Countermeasure
ISGS		In-situ Geochemical Stabilization	UIC	–	Underground Injection Control

Table 4-4. Comparative Analysis of Alternatives Summary

<table>
<tr><th>Criteria</th><th>Alternative 1
No Further Action</th><th>Alternative 2
Hydraulic Containment (Area 1) & ISB (Area 2)</th><th>Alternative 3
ISB (Areas 1 & 2)</th><th>Alternative 4
SEE/ISB (Area 1) & ISB (Area 2)</th><th>Alternative 5
ISGS (Area 1) & ISB (Area 2)</th></tr>
<tr><td>1. Overall Protection of Human Health and the Environment[1]</td><td colspan="5">Alternative 1 is the least protective of human health because of the length of time to achieve clean up levels and no active treatment to reduce contaminant concentrations. An increased level of protection occurs under Alternative 2 with institutional controls and containment. Alternatives 3, 4, and 5 are the most protective as treatment and/or removal of NAPL and contaminants in groundwater is performed to achieve cleanup levels in a shorter period of time.
Summary (most protective to least): 3 = 4 = 5 > 2 > 1</td></tr>
<tr><td>2. Compliance with ARARs</td><td colspan="5">Implementation of Alternatives 1 and 2 comply with applicable ARARs, except that the groundwater clean up levels would not be met for an extended length of time. Alternatives 3, 4, and 5 achieve cleanup levels in a shorter time period. Alternatives 2 and 4 must comply with more action specific ARARs applicable to aboveground treatment systems.
Summary (most compliant to least): 3 = 4 = 5 > 2 > 1</td></tr>
<tr><td>3. Long-Term Effectiveness and Permanence</td><td colspan="5">Alternative 1 is the least effective in the long-term because no active treatment is included. Alternative 2 includes institutional controls and containment to restrict human receptor exposure, but NAPL and contaminants remain for a long period of time. Alternatives 3, 4, and 5 provide a permanent remedy through treatment and/or removal of NAPL and contaminants in groundwater. Alternatives 2 and 4 include off-site treatment (incineration) of NAPL and GAC, along with reinjection of treated groundwater. Alternatives 3, 4 and 5 are more effective than 2 in the long term because Alternative 2 includes long-term management of an on-site facility.
Summary (most effective to least): 3 = 4 > 5 > 2 > 1</td></tr>
<tr><td>4. Reduction of Toxicity, Mobility, or Volume through Treatment</td><td colspan="5">There is no reduction of toxicity, mobility, or volume through active treatment of groundwater under Alternative 1. Alternatives 2 , 3 ,4, and 5 include treatment either in situ or ex situ. Alternatives 3, 4, and 5 achieve reduction of toxicity, mobility or volume in a shorter period of time through active treatment or removal of NAPL and dissolved contaminants, with Alternatives 3 and 4 having the shortest timeframes.
Summary (most reduction to least): 3 = 4 > 5 > 2 > 1</td></tr>
<tr><td rowspan="2">5. Short-Term Effectiveness
Impacts
Remedial Timeframes (years)</td><td colspan="5">Alternative 1 provides no short-term impacts because no construction-related actions will be implemented; however, its duration to achieve cleanup goals reduces its effectiveness. Potential risks to workers and the community may occur during the implementation of the removal and/or treatment activities in Alternatives 2, 3, 4, and 5. Alternative 4 includes increased truck traffic due to the greater number of pieces of equipment needed for steam generation and liquid and vapor treatment systems associated with implementation of SEE. There will be increased impacts to workers during the operation of the boiler system and vapor thermal treatment system and management of byproducts in Alternative 4.
Summary (most effective [less short-term impacts] to least): 1 > 3 > 5 > 2 > 4</td></tr>
<tr><td>Active: Areas 1, 2, 3 = 0
NSZD or MNA: Areas 1, 2, 3 = 145
Total[1]: Areas 1, 2, 3 = 150</td><td>Active: Area 1 = 145, 2 = 41, 3 = 0
NSZD or MNA: Area 1 = 0, Area 2 = 0, Area 3 = 10
Total[1]: Area 1 = 150, 2 = 46, 3 = 10</td><td>Active: Area 1 = 6, 2 = 41, 3 = 0
NSZD or MNA: Area 1 = 0, Area 2 = 0, Area 3 = 10
Total[1]: Area 1 = 11, 2 = 46, 3 = 10</td><td>Active: Area 1 = 5, 2 = 41, 3 = 0
NSZD or MNA: Area 1 = 0, Area 2 = 0, Area 3 = 10
Total[1]: Area 1 = 10, 2 = 46, 3 = 10</td><td>Active: Area 1 = 1, 2 = 41, 3 = 0
NSZD or MNA: Area 1 = 29, Area 2 = 0, Area 3 = 10
Total[1]: Area 1 = 35, 2 = 46, 3 = 10</td></tr>
<tr><td>6. Implementability</td><td colspan="5">Alternative 1 does not include construction activities and is easiest to implement, but includes long-term groundwater monitoring and institutional controls that require administrative coordination and enforcement. Alternatives 2, 3, 4, and 5 include installation of injection and/or extraction wells, which is a common practice. Alternative 3 requires a shorter construction period and uses less construction equipment than Alternatives 4 and 5, and does not require any ex situ treatment. Alternatives 2 and 4 include transport of NAPL and GAC to an off-site treatment facility. Alternative 4 includes on-site liquids, GAC, and vapor thermal treatment where there are multiple treatment trains and generation of treatment byproducts.
Summary (easiest to difficult): 1 > 3 > 5 > 2 > 4</td></tr>
<tr><td>7. Cost Ranking (least to most expensive)</td><td>$
Lowest NPV Cost
Lowest Capital & O&M Costs</td><td>$$$$$
Highest NPV Cost
Highest O&M Costs</td><td>$$
Lowest NPV Cost</td><td>$$$$
Moderately High NPV Cost
Highest Capital Cost</td><td>$$$
Moderate NPV Cost</td></tr>
</table>

Notes:

There are two other evaluation criteria, state and community acceptance, which will be addressed in the ROD once comments on the RI/FS report and proposed plan have been received.

[1] Total Remedial Timeframes include 5 years of post remediation monitoring for Areas 1 and 2.

ARAR - Applicable or Relevant and Appropriate Requirement
GAC - Granular Activated Carbon
NAPL - Non-aqueous phase liquid
SEE - Steam Enhanced Extraction

Table 4-5. Summary of Costs by Alternative

Alternative	Cost in Current Dollars (shown in millions)			NPV
	Capital (Year 0)	O&M/Periodic	Total	
1	$0.4	$1.1	$1.5	$0.9
2	$4.5	$176.9	$181.4	$99.8
3	$2.2	$5.7	$7.9	$7.0
4	$33.4	$5.5	$38.9	$38.0
5	$20.3	$5.0	$25.3	$24.4

Notes:

O&M – operation and maintenance

NPV – net present value

EPA recognizes that many factors are involved in evaluating remedial alternatives including the environmental effects of remedy implementation. Greener or sustainable cleanup activities can be evaluated in the context of a complete balancing criteria analysis for evaluating alternatives after determining that the alternative meets the threshold criteria of protectiveness and compliance with ARARs. Sustainability metrics can be used to help determine relative benefits versus negative impacts of remedial actions.

5.1 SUSTAINABILITY METRICS

Sustainability metrics are not unique criteria and could be addressed with one of the existing CERCLA criteria. However, in this FFS a qualitative evaluation with respect to the sustainability metrics will be presented independent of the comparative analysis of alternatives against the CERCLA threshold and balancing criteria. The sustainability metrics considered in this evaluation include:

- Materials Used
- Waste Generated
- Water Usage
- Energy Usage
- Air Emission

These metrics are similar to EPA's metrics for conducting an environmental footprint analysis of site clean-up activities and are described in the EPA document, *Methodology for Understanding and Reducing a Project's Environmental Footprint (EPA 2012b)*.

Materials Metrics. The materials metrics consider the amount of materials used onsite. In general, manufactured or significantly processed materials used onsite and come from offsite sources include chemicals, nutrients, food grade amendments, metals, plastics, and cement.

Waste Metrics. The waste metrics consider the waste generated onsite and whether the waste is hazardous or nonhazardous or can be recycled or reused. Onsite hazardous waste includes waste generated onsite and disposed of at an offsite hazardous waste facility or a regulated onsite disposal unit. This includes excavated soil, treatment plant residuals and recovered product. Onsite nonhazardous waste is generated onsite, disposed of offsite, and can include soil, concrete, metal, vegetation, and treatment plant residues.

Water Metrics. This metric considers the amount of water used onsite during remediation and the sources and fate of the used water. This includes water used for equipment decontamination, extraction and treatment, and chemical blending. Water sources include potable water supplies, extracted groundwater, surface water and reclaimed water. The fate of water includes reuse, use in a process or for irrigation, discharge to groundwater, surface water or a publically owned treatment works (POTW) or sewer system.

Energy Metrics. The energy metrics consider the amount of energy used by the remedy (onsite and offsite). This energy for electricity generation, transportation, materials manufacturing, and other offsite activities that support the remedy.

Air Emissions Metrics. The air emission metrics consider emissions of greenhouse gases (GHGs), nitrogen oxides (NOx), sulfur oxides (SOx), particulate matter (PM) and hazardous air pollutants (HAPs).

A conceptual level of design conducted for each alternative may not define quantities for items considered under each sustainability metric, therefore the evaluation will be qualitative and a relative comparison among alternatives.

5.2 SUSTAINABILITY EVALUATION

An analysis of alternatives with respect to the sustainability metrics was conducted to identify aspects of a remedy that causes the greatest impacts for each of the metrics. Table 5-1 provides a summary of the activities under each metric associated with each alternative. Table 5-2 provides a qualitative evaluation of each alternative with respect to each metric and identifies the relative impact and impact drivers. Alternative 1 No Further Action involves decommissioning the SAETS, abandonment of wells, and demolition of the building. This activity would also be conducted under Alternatives 3, 4 and 5. For Alternative 2 existing equipment will be evaluated for reuse in the above ground groundwater treatment system. Therefore, this activity will not be included in the sustainability evaluation and Alternative 1 will not be evaluated as there will be no remediation activities associated with Alternative 1 except for limited groundwater monitoring once the SAETS, wells, and building are decommissioned and removed. The sustainability evaluation will focus on the alternatives employing active remediation.

Materials Used. Alternative 3 has the lowest impact with respect to materials used. The remediation involves the lowest number of installed wells (55+24), lowest amount of steel casing used, and fewest pieces of equipment used in the remediation system. Alternative 5 also involves the use of less equipment for treatment but has the added use of a chemical, ISGS solution, and a greater number of drill holes (598). Alternative 2 has fewer wells but includes an above ground groundwater treatment system with tanks, pumps, reactors, oil/water separator, piping and GAC. Alternative 4 has the highest impact with respect to materials used as it includes multiple above ground treatment systems for liquid (GAC) and vapor (thermal oxidizer), steam boiler, shotcrete surface cover over 2.7 acres, excavation and installation of a sheet pile wall (460 ft x 40 ft x 2 ft), a horizontal soil vapor extraction system, and 192 wells.

Onsite Waste Generation. Alternatives 3 and 5 have the lowest impact with respect to onsite waste generation. Only soil IDW from well installation is anticipated. Alternatives 2 and 4 will generate the most waste from above ground groundwater treatment systems that recover NAPL and use GAC for liquid treatment. Alternative 4 is anticipated to remove more NAPL than Alternative 2. Alternative 2 will also generate soil IDW from well installation and biomass from the above ground biological treatment system. Alternative 4 will generate a greater amount of soil waste from well installation and from excavation for the sheet pile wall installed between Area 1 and the fire pond. Alternative 4 will also generate waste from water pretreatment (softening) and steam generation (boiler blowdown).

Water Usage. Alternatives 2 and 3 have the lowest water usage and impact, as water is used for drilling, well installation, and equipment decontamination. Alternative 5 uses water in the implementation process for onsite chemical mixing of the ISGS solution. Alternative 4 requires the most continuous supply of water for steam generation. Alternatives 2 and 4 will reinject treated groundwater to the Upper Aquifer.

Energy Usage. Alternative 3 has the lowest impact on energy usage as power is required for operation of 2 compressors in Area 1 for about 6 years and 1 compressor in Area 2 for about 41 years. Alternative 5 has a low to medium impact as fuel (diesel or gasoline) is needed to operate a self-contained system for chemical mixing and injection for about a year. Alternative 5 also requires power for 1 compressor in Area 2 for about 41 years. Energy usage for Alternative 2 is higher as power is needed for groundwater extraction and above ground treatment equipment for about 145 years and fuel for offsite transportation of NAPL and spent GAC to an offsite TSD facility. Alternative 4 has the highest energy usage and requirement (fuel and electricity) for steam generation, water softening, steam injection, groundwater and vapor extraction, groundwater treatment, and vapor treatment by thermal oxidation for over 1 year, fuel for equipment used for soil excavation and installation of a sheet pile wall, and fuel for offsite transport of NAPL and spent GAC to an offsite TSD facility.

Air Emissions. Each of the alternatives will generate air emissions from vehicles/trucks transporting equipment and supplies during implementation of the alternative. Alternatives 3 and 5 have the lowest impact and lowest potential to generate emissions from the treatment system. Alternative 2 uses more equipment (tanks, vessels) with a potential for venting and emissions. Alternative 4 has the highest impact and potential for emissions from multiple pieces of equipment used in the treatment process (steam boiler, thermal oxidizer, condenser, heat exchanger).

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Table 5-1. Summary of Sustainability Metrics for Each Alternative

Alternatives	Materials Used	Onsite Waste Generation	Water Usage	Energy Usage	Air Emissions
2. Hydraulic Containment and In Situ Biosparging	Area 1: 8 perm wells, approx. 320 ft steel casing Area 2: 24 wells, approx. 1,700 ft steel casing 3 Granular Activated Carbon (GAC) 20,000 lb units 2 trickling filter units Nutrients Pressure filter Steel tanks/vessels Oil water separator Pumps 1 -40 hp Compressor HDPE Piping	Spent GAC-about 210,000lbs per year hazardous waste Biomass-hazardous waste NAPL-about 160 gallons per year hazardous waste Soil IDW-nonhazardous/ hazardous waste	Well drilling Equipment decontamination O&M	Pumps for groundwater extraction Pumps for aboveground treatment system Building HVAC & lighting Fuel for drilling equipment	Vessels & tanks venting Vehicle emissions Truck emissions Drilling equipment emissions
3. In Situ Biosparging	Area 1: 55 air injection wells, approx. 2,100 ft steel casing Area 2: 24 wells, approx. 1,700 ft steel casing 3- 40 hp Compressors HDPE Piping	Soil IDW-nonhazardous/ hazardous waste	Well drilling Equipment decontamination	Compressors Building HVAC Fuel for drilling equipment	Vehicle emissions Truck emissions Drilling equipment emissions
4. Steam Enhanced Extraction and In Situ Biosparging	Area 1: 192 wells, approx. 13,250 ft steel casing Area 1: 30 horizontal wells, approx. 8,000 ft steel pipe Area2: 24 wells, approx. 1700 ft steel casing Fuel (natural gas or propane) for steam generation(boiler), water softener Thermal oxidizer GAC units Shotcrete with polyester carbon fibers for cover over 2.7 acres Bentonite & Vinyl sheet pile for subsurface wall	Spent GAC NAPL about 80,000 gallons hazardous waste Boiler blowdown and softener regeneration liquid Soil IDW-nonhazardous/ hazardous waste Soil from wall excavation - nonhazardous/hazardous waste	90 gpm for steam generation and treatment system Well drilling Equipment decontamination	Total Power Need: 400 kW Total Electric Load: 500 kVA Total Power Usage: 3.4 M kWh Total Gas Usage: 426,000 MM BTU Steam generation Water softener Thermal oxidizer Multiple pumps for aboveground treatment system Multiple pumps for liquid & vapor extraction system Steam injection system Compressor	Boiler emissions Oxidizer emissions Tanks venting Vehicle emissions Truck emissions Drilling equipment emissions

Table 5-1. Summary of Sustainability Metrics for Each Alternative

Alternatives	Materials Used	Onsite Waste Generation	Water Usage	Energy Usage	Air Emissions
	Tanks & vessels/oil water separator/ cone separator/condenser/air to air heat exchanger Pumps Ductile iron, fiberglass reinforced, and HDPE pipe Compressor			Fuel for excavation equipment Fuel for drilling equipment Generation of shotcrete	
5. In Situ Geochemical Stabilization and In Situ Biosparging	Area 1: 598 drill holes Area 2: 24 wells, approx. 1,700 ft steel casing ISGS solution Tanks/mixers Pumps Piping Generator Compressor	Soil IDW-nonhazardous/ hazardous waste	8-30 gpm for mixing ISGS solution Borehole drilling Equipment decontamination	Generator Compressor Pumps/mixer Fuel for drilling equipment	Vehicle emissions Truck emissions Generator emissions Drilling equipment emissions

Notes:

GAC – granular activated carbon
gpm – gallons per minute
HDPE – high density polyethylene
hp – horse power
HVAC – heating, ventilation and air conditioning
IDW – investigation derived waste
ISB – in situ biosparging
ISGS – in situ geochemical stabilization
NAPL – non-aqueous phase liquid
O&M – operation and maintenance

Table 5-2. Evaluation Based on Sustainability Metrics

Alternatives	Active Treatment Timeframe (Years)	Impact Assessment	Materials Used	Onsite Waste Generation	Water Usage	Energy Usage	Air Emissions
2. Hydraulic Containment and In Situ Biosparging		**Relative Impact**	**High**	**High**	**Low**	**High**	**Low**
	Area 1 160 Area 2 45	Impact Drivers	Well construction. Aboveground groundwater extraction, treatment and reinjection system equipment. Aboveground air injection system.	Hazardous waste-NAPL, Spent GAC, Biomass from treatment system operation. Hazardous & non-hazardous waste-soil IDW from well installation.	Decontamination of equipment Well drilling.	Electrical power for aboveground groundwater extraction, treatment and reinjection system equipment and building HVAC and lighting. Electrical power for 1 compressor for air injection. Fuel for drilling equipment.	Transportation of equipment to site. Drilling equipment used during well installation.
3. In Situ Biosparging		**Relative Impact**	**Low**	**Low**	**Low**	**Low**	**Low**
	Area 1 10 Area 2 45	Impact Drivers	Well construction. Aboveground air injection system.	Hazardous & non-hazardous waste-soil IDW from well installation.	Decontamination of equipment. Well drilling.	Electrical power for 3 compressors for air injection. Fuel for drilling equipment.	Transportation of equipment (compressors, piping) to site. Drilling equipment used during well installation.
4. Steam Enhanced Extraction and In Situ Biosparging		**Relative Impact**	**High**	**High**	**High**	**High**	**High**
	Area 1 1+ Area 2 45	Impact Drivers	Well construction. Steam generating equipment. Aboveground liquid extraction & treatment system. Aboveground vapor extraction & treatment system. Shotcrete cover over 2.7 acres. Vinyl sheet pile and bentonite subsurface wall. Aboveground air injection system.	Hazardous waste-NAPL, Spent GAC, from treatment system operation. Non-hazardous waste-liquid from water softening and steam generation system operation. Hazardous & non-hazardous waste-soil IDW from well installation. Hazardous & non-hazardous waste-soil IDW from wall installation.	Steam generation Decontamination of equipment. Well drilling.	Electrical power for aboveground groundwater extraction, treatment and reinjection system equipment. Electrical power for aboveground vapor extraction and thermal oxidizer treatment system equipment. Fuel for steam generation Fuel for excavation equipment. Fuel for drilling equipment. Electrical power for 1 compressor for air injection.	Potential emissions from steam generating equipment and thermal oxidizer. Transportation of equipment to site. Drilling equipment used during well installation. Excavation equipment during removal of soil and installation of sheet pile for wall.

Table 5-2. Evaluation Based on Sustainability Metrics

Alternatives	Active Treatment Timeframe (Years)	Impact Assessment	Materials Used	Onsite Waste Generation	Water Usage	Energy Usage	Air Emissions
5. In Situ Geochemical Stabilization and In Situ Biosparging		**Relative Impact**	**Medium**	**Low**	**Medium**	**Low**	**Low**
	Area 1 1+ Area 2 45	Impact Drivers	Chemicals for ISGS solution. Self-contained aboveground mixing and injection system. Aboveground air injection system.	Hazardous & non-hazardous waste-soil IDW from drill holes.	Water for solution mixing. Decontamination of equipment. Area 1: ISGS borehole drilling. Area 2: ISB well installation.	Electrical power for generator for ISGS solution mixing. Fuel for compressor. Fuel for drilling equipment. Electrical power for 1 compressor for air injection.	Transportation of equipment to site. Equipment used during ISGS injection (generator, mixing).

Notes:

Green – low impact /usage
Yellow – medium impact/usage
Red – high impact/usage

GAC – granular activated carbon
HVAC – heating, ventilation and air conditioning
IDW – investigation derived waste
ISB – in situ biosparging
ISGS – in situ geochemical stabilization
NAPL – non-aqueous phase liquid

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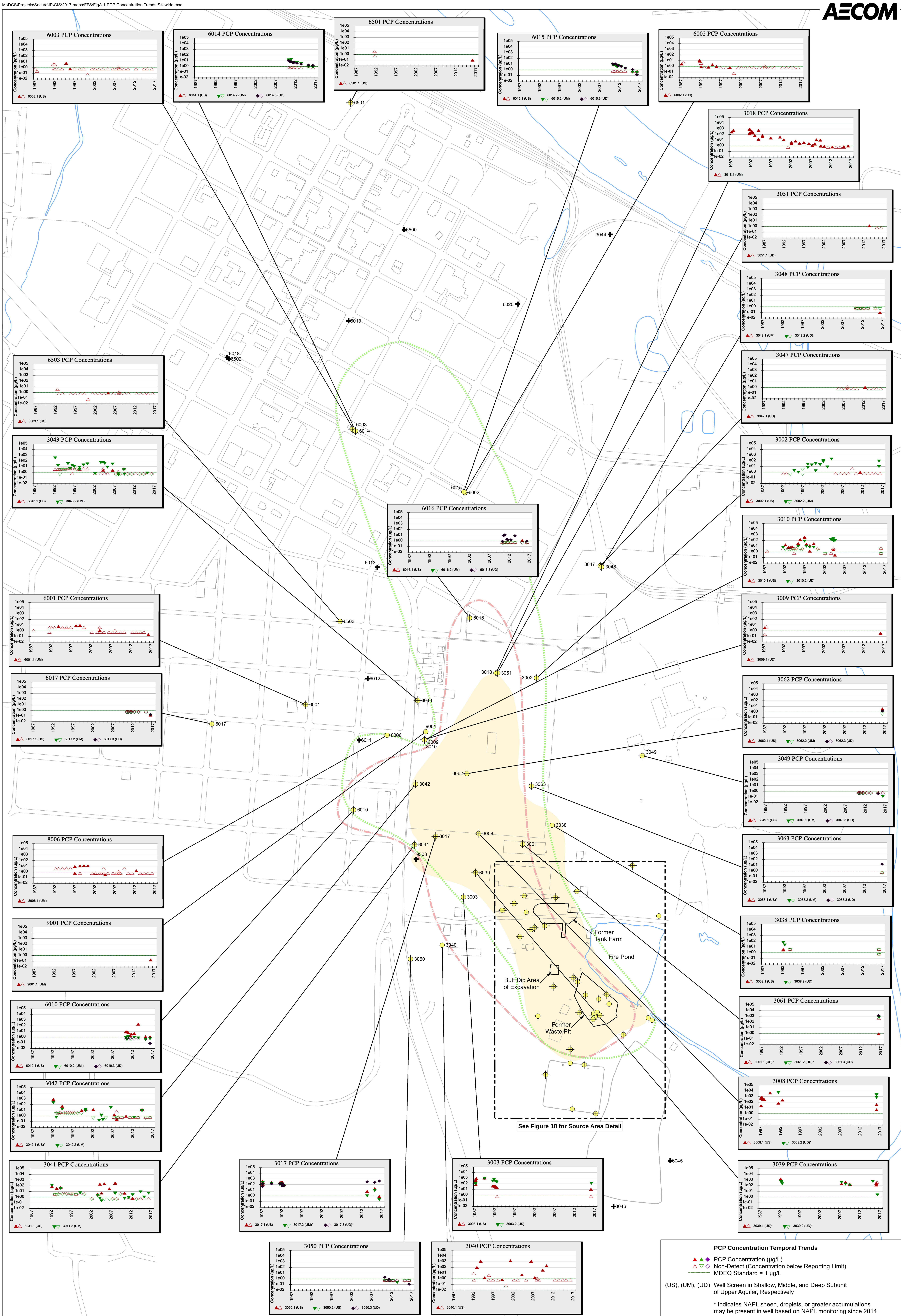
Appendix A

Concentration versus Time Graphs in Map View

Table of Contents

M:\DCS\Projects\Secure\IP\GIS\2017 maps\FFS\FigA-1 PCP Concentration Trends Sitewide.mxd



PCP Concentration Temporal Trends

- PCP Concentration (µg/L)
- Non-Detect (Concentration below Reporting Limit)
- MDEQ Standard = 1 µg/L

(US), (UM), (UD) Well Screen in Shallow, Middle, and Deep Subunit of Upper Aquifer, Respectively

* Indicates NAPL sheen, droplets, or greater accumulations may be present in well based on NAPL monitoring since 2014

- PCP Sampling Location
- Non-Detect Sampling Location (All results below reporting limit)
- **US Impacted Groundwater:** Estimated area of impacted groundwater in the shallow subunit of the Upper Aquifer based on one or more observed exceedance of PCP and/or naphthalene MDEQ standards from 2012 to 2016.
- **UM/UD Impacted Groundwater:** Estimated area of impacted groundwater in the middle/deep subunit of the Upper Aquifer based on one or more exceedance of PCP and/or naphthalene MDEQ standards from 2012 to 2016.
- Estimated area where NAPL may be present in the Upper Aquifer based on observation of oil or sheen in soil cuttings/core during drilling from 1983 to 2016.

Groundwater Pentachlorophenol (PCP) Concentration Trends in the Upper Aquifer (1987 to 2016)

FOCUSED FEASIBILITY STUDY FOR THE UPPER AQUIFER
LIBBY GROUNDWATER SITE, LIBBY, MONTANA

Job No.:	60514930
Designed By:	ARM
Drawn By:	JLC
Date:	7/27/2017

Fig. A-1

M:\DCS\Projects\Secure\IP\GIS\2017 maps\FFS\FigA-2 PCP Concentration Trends Source Area.mxd

AECOM

PCP Concentration Temporal Trends

▲▲◆ PCP Concentration (µg/L)
△▽◇ Non-Detect (Concentration below Reporting Limit)
MDEQ Standard = 1 µg/L

(US), (UM), (UD) Well Screen in Shallow, Middle, and Deep Subunit of Upper Aquifer, Respectively

* Indicates NAPL sheen, droplets, or greater accumulations may be present in well based on NAPL monitoring since 2014

PCP Sampling Location

Non-Detect Sampling Location (All results below reporting limit)

US Impacted Groundwater: Estimated area of impacted groundwater in the shallow subunit of the Upper Aquifer based on one or more observed exceedance of PCP and/or naphthalene MDEQ standards from 2012 to 2016.

UM/UD Impacted Groundwater: Estimated area of impacted groundwater in the middle/deep subunit of the Upper Aquifer based on one or more exceedance of PCP and/or naphthalene MDEQ standards from 2012 to 2016.

Groundwater Pentachlorophenol (PCP) Concentration Trends in the Upper Aquifer (1987 to 2016) Source Area Detail

FOCUSED FEASIBILITY STUDY FOR THE UPPER AQUIFER
LIBBY GROUNDWATER SITE, LIBBY, MONTANA

Job No.: 60514930

Designed By: ARM

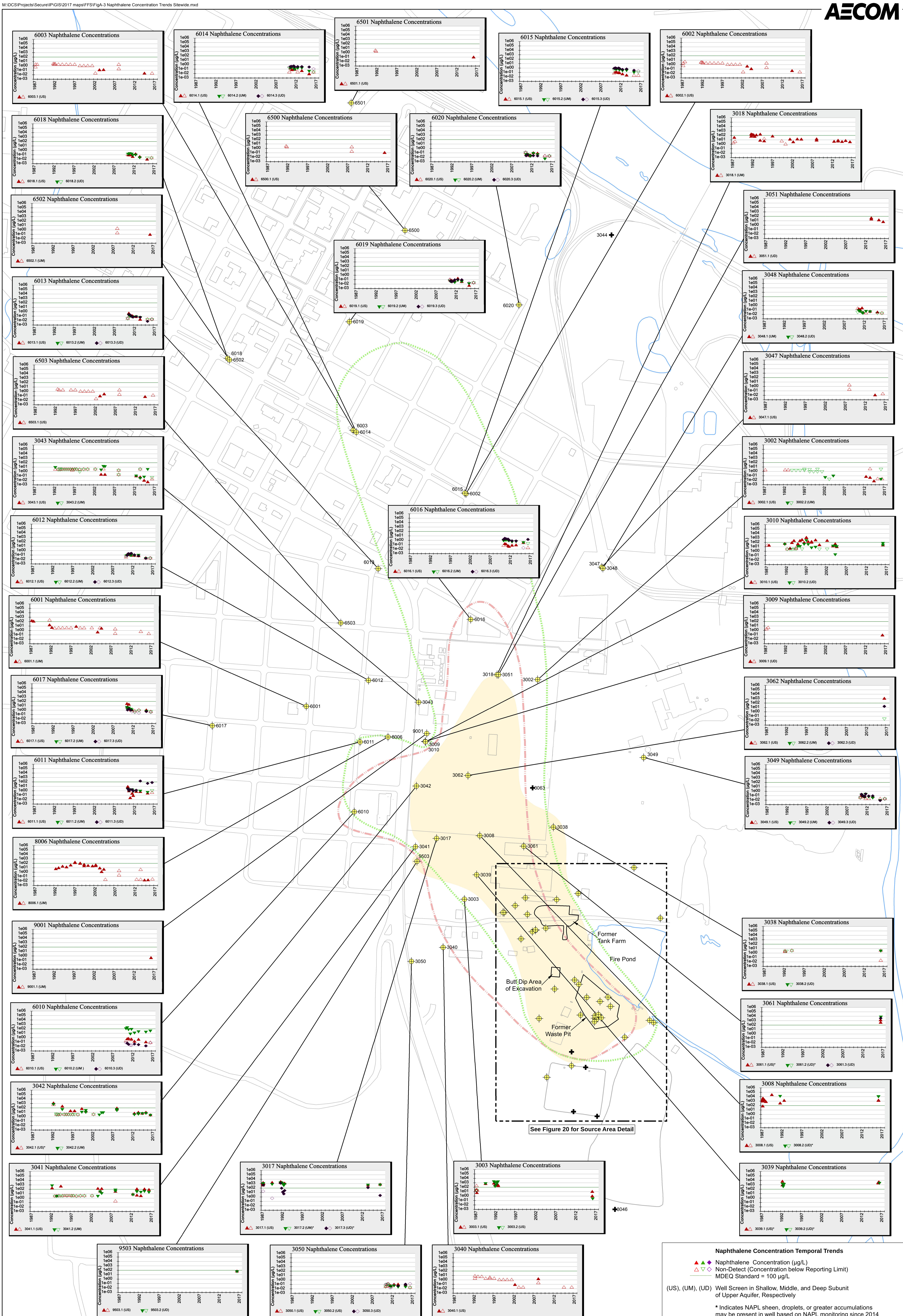
Drawn By: JLC

Date: 7/27/2017

Fig. A-2

M:\DCS\Projects\Secure\IP\GIS\2017 maps\FFS\FigA-3 Naphthalene Concentration Trends Sitewide.mxd

AECOM



Naphthalene Concentration Temporal Trends

- Naphthalene Concentration (µg/L)
- Non-Detect (Concentration below Reporting Limit)
- MDEQ Standard = 100 µg/L

(US), (UM), (UD) Well Screen in Shallow, Middle, and Deep Subunit of Upper Aquifer, Respectively

* Indicates NAPL sheen, droplets, or greater accumulations may be present in well based on NAPL monitoring since 2014

- Naphthalene Sampling Location
- Non-Detect Sampling Location (All results below reporting limit)
- **US Impacted Groundwater:** Estimated area of impacted groundwater in the shallow subunit of the Upper Aquifer based on one or more observed exceedance of PCP and/or naphthalene MDEQ standards from 2012 to 2016.
- **UM/UD Impacted Groundwater:** Estimated area of impacted groundwater in the middle/deep subunit of the Upper Aquifer based on one or more exceedance of PCP and/or naphthalene MDEQ standards from 2012 to 2016.
- Estimated area where NAPL may be present in the Upper Aquifer based on observation of oil or sheen in soil cuttings/core during drilling from 1983 to 2016.

Groundwater Naphthalene Concentration Trends in the Upper Aquifer (1987 to 2016)

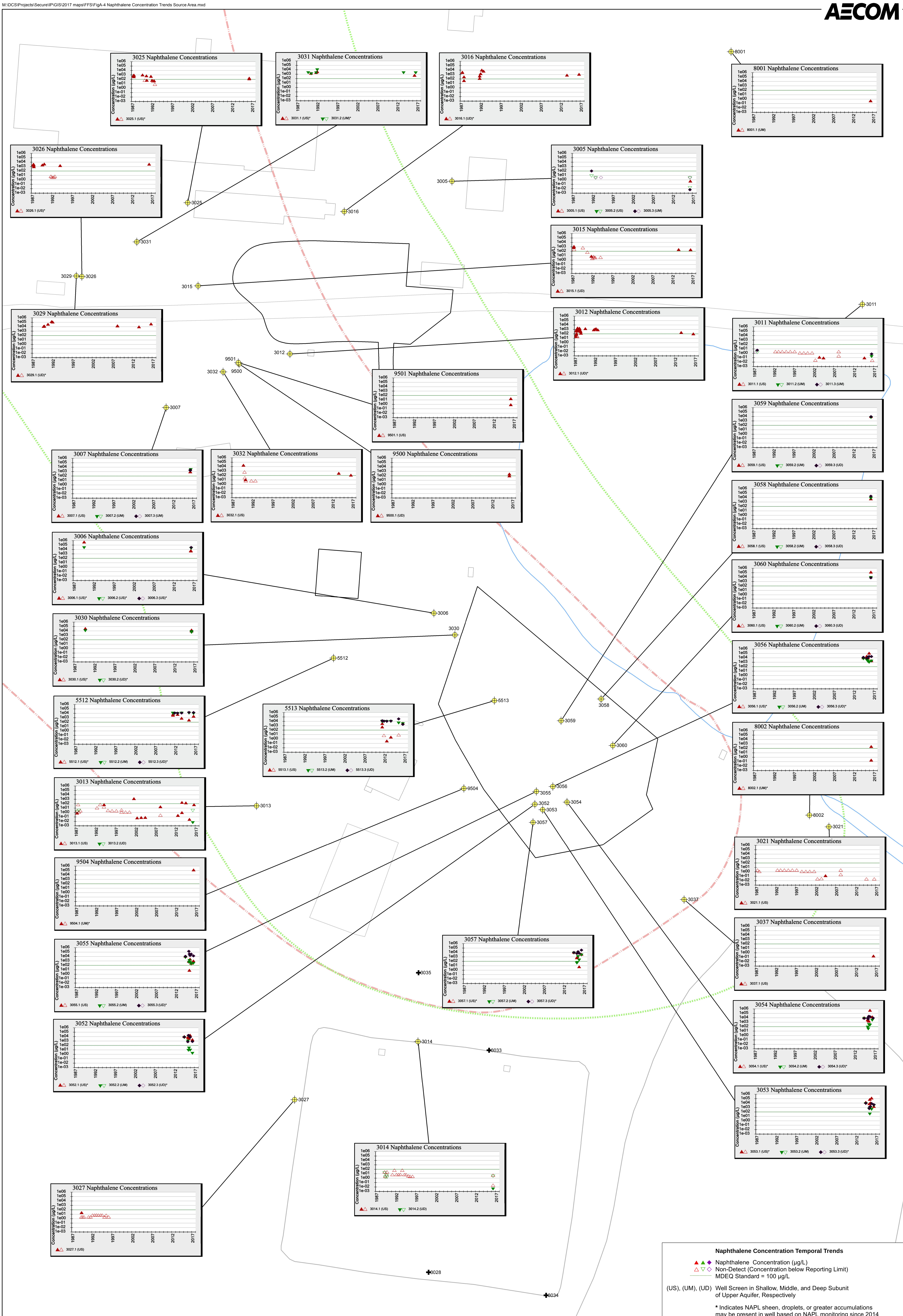
FOCUSED FEASIBILITY STUDY FOR THE UPPER AQUIFER
LIBBY GROUNDWATER SITE, LIBBY, MONTANA

Job No.:	60514930
Designed By:	ARM
Drawn By:	JLC
Date:	7/27/2017

Fig. A-3

M:\DCS\Projects\Secure\IP\GIS\2017 maps\FFS\FigA-4 Naphthalene Concentration Trends Source Area.mxd

AECOM



Naphthalene Concentration Temporal Trends

▲▲◆ Naphthalene Concentration (µg/L)
△▽◇ Non-Detect (Concentration below Reporting Limit)
MDEQ Standard = 100 µg/L

(US), (UM), (UD) Well Screen in Shallow, Middle, and Deep Subunit of Upper Aquifer, Respectively

* Indicates NAPL sheen, droplets, or greater accumulations may be present in well based on NAPL monitoring since 2014

Naphthalene Sampling Location

Non-Detect Sampling Location (All results below reporting limit)

US Impacted Groundwater: Estimated area of impacted groundwater in the shallow subunit of the Upper Aquifer based on one or more observed exceedance of PCP and/or naphthalene MDEQ standards from 2012 to 2016.

UM/UD Impacted Groundwater: Estimated area of impacted groundwater in the middle/deep subunit of the Upper Aquifer based on one or more exceedance of PCP and/or naphthalene MDEQ standards from 2012 to 2016.

0 60 120 Feet

Groundwater Naphthalene Concentration Trends in the Upper Aquifer (1987 to 2016) Source Area Detail

FOCUSED FEASIBILITY STUDY FOR THE UPPER AQUIFER
LIBBY GROUNDWATER SITE, LIBBY, MONTANA

Job No.:	60514930
Designed By:	ARM
Drawn By:	JLC
Date:	7/27/2017

Fig. A-4

Appendix B

Draft-Final Technical Memorandum: NAPL Depletion Modeling

Environment

Prepared for
International Paper Company
Memphis, Tennessee

Submitted by
AECOM
Greenwood Village, Colorado
303-694-2770
March 9, 2018

Technical Memorandum: NAPL Depletion Modeling

Libby Groundwater Site, Libby, Montana

Revision 1

DRAFT FINAL

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1 Introduction

On behalf of International Paper, AECOM is submitting this technical memorandum (Memo) to present the methodology and results of modeling the depletion of contaminants of concern (COCs) that are in the form of non-aqueous phase liquid (NAPL) at the Site. The NAPL depletion model was developed as part of the focused feasibility study (FFS) to estimate the time period necessary to deplete select groundwater COCs from the NAPL under various remedial alternatives such that preliminary groundwater cleanup levels would be met and sustained as a result of reduced effective solubilities from NAPL weathering. A key component of the NAPL depletion model is the effective aqueous solubility model that was previously presented in the *Technical Memorandum: NAPL Characterization Study for the Upper Aquifer* (AECOM 2017a).

This Memo describes the concepts and equations forming the NAPL depletion model and summarizes how the model was used to simulate NAPL weathering for remedial alternatives applied to Remediation Areas 1 and 2 (see Section 3.1.3 of the FFS Report). The model simulations provide estimated remedial timeframes to achieve groundwater cleanup goals (Table 2-1 of the FFS) for the specified remedial alternatives that are used to evaluate the remedial alternatives developed in Section 3.3 of the FFS.

2 Methods

A spreadsheet-based NAPL depletion model was developed to simulate the partitioning of COCs from NAPL to groundwater via dissolution to equilibrium concentrations (effective solubilities) in groundwater. The processes simulated in the model are equilibrium dissolution primarily by the biooxidation of COCs in groundwater within the remediation volume, as well as by clean groundwater flux through the remediation volume (i.e., NAPL source area). During each simulation time step, instantaneous dissolution (partitioning) to groundwater (flowing into the remediation volume and within the pore volume of the remediation volume) is assumed to occur to the aqueous equilibrium concentrations of the COCs from the NAPL. As COCs are depleted from the NAPL over time, the composition of the NAPL changes and the equilibrium concentrations of COCs in groundwater change according to an effective solubility model for the NAPL. The assumptions and calculations for the effective solubility model and the NAPL depletion model are detailed below.

2.1 Effective Solubility Model

As presented in the NAPL Characterization Study (AECOM 2017a), the effective aqueous solubility and equilibrium concentration in groundwater (C_{eq}^{i}) of a compound i in the NAPL is estimated with Raoult's Law (Lee et al. 1992), as shown in Equation 1:

$$C_{eq}^{i} = C_{s}^{i} \frac{\chi_i}{FR_i} \tag{1}$$

where C_{s}^{i} is the aqueous solubility limit [milligrams per liter (mg/L)] of the pure compound i; χ_i is the mole fraction of compound i in the NAPL (mole per mole); and FR_i is the solid-liquid reference fugacity ratio of compound i in the NAPL (unitless). The solid-liquid fugacity ratios are provided by Brown et al. (2005) or were calculated as presented in Peters et al. (1997, 2000). The mole fraction (χ_i) of compound i in a NAPL is estimated from the average molecular weight of the NAPL, as shown in Equation 2:

$$\chi_i = C_{ct}^{i} \frac{MW_{ct}}{MW_i} \tag{2}$$

where C_{ct}^{i} is the mass fraction of compound i in the NAPL, MW_{ct} is the average molecular weight [grams per mole (g/mole)] of the NAPL, and MW_i is the molecular weight (g/mole) of compound i. The mole fraction (χ_i) of compound i in a NAPL is also defined by Equation 3 as:

$$\chi_i = \frac{n_i}{n_T} \tag{3}$$

where n_i is the number of moles of compound i in the NAPL and n_T is the total number of moles of all compounds in the NAPL.

2.2 NAPL Depletion Model

The NAPL depletion model is an Excel spreadsheet-based model that simulates the removal of NAPL constituents via dissolution from the total NAPL mass. Inputs to the model include the following:

- Treatment volume, $V_T = W \cdot L \cdot H$, where
  - W is the width of the treatment volume orthogonal to groundwater flow
  - L is the length of the treatment volume parallel to groundwater flow
  - H is the height of the treatment volume's saturated thickness
- Groundwater discharge through the treatment volume, $Q_w = K \cdot i \cdot A$, where
  - K is the average hydraulic conductivity of the treatment volume
  - i is the average hydraulic gradient across the treatment volume in the direction of groundwater flow
  - A is the area of the transect orthogonal to groundwater flow through the treatment volume and is estimated as $A = W \cdot H$
- Average porosity $\boldsymbol{\theta}$ of the treatment volume is used to estimate the groundwater pore volume $V_w = \theta \cdot V_T$ in the treatment volume assuming saturated flow conditions.
- Total initial trapped NAPL mass $m_{T,0}$ in the treatment volume
- The mass fraction C_{ct}^i of each compound i in the NAPL that will be modeled and used to estimate the initial mass of the compound i in the treatment volume $m_{i,0} = C_{ct}^i \cdot m_{T,0}$
- Solubility model parameters:
  - The initial average NAPL molecular weight MW_{ct}
  - The molecular weight MW_i of each compound i in the NAPL mixture that will be modeled
  - The pure phase solubility C_S^i of each compound i in the NAPL mixture that will be modeled
  - The solid-liquid fugacity ratio FR_i of each compound i in the NAPL mixture that will be modeled
- The attenuation half-life $t_{1/2,i}$ of each compound i in the NAPL that will be modeled and used to estimate the first-order decay rate constant $k_i = \frac{Log_n(0.5)}{-t_{1/2,i}}$ for each compound

The NAPL depletion model assumes that compounds in the NAPL that are not being modeled are not removed and are insoluble (generally the higher molecular weight components); thus, the number of moles of insoluble compounds in the NAPL does not change with time. Since the initial average molecular weight of the NAPL (MW_{ct}) includes modeled and insoluble compounds, the average molecular weight of the insoluble (non-modeled) compounds MW_{non} is calculated and used to estimate the number of insoluble moles in the NAPL. The mass (m_{non}), average molecular weight (MW_{non}), and number of moles (n_{non}) of the insoluble fraction of the NAPL in the model is estimated using Equations 4, 5, and 6 below:

$$m_{non} = m_{T,0} \cdot \left(1 - \sum_{i=1}^{j} C_{ct}^i\right) \tag{4}$$

$$MW_{non} = \frac{1 - \sum_{i=1}^{j} C_{ct}^i}{{}^1/_{MW_{ct}} - \sum_{i=1}^{j} {}^{C_{ct}^i}/_{MW_i}} \tag{5}$$

where j is the number of NAPL compounds i that are being depleted from the NAPL in the model.

$$n_{non} = \frac{m_{non}}{MW_{non}} \tag{6}$$

Initially, the effective aqueous solubility ($C^i_{eq,0}$) for each modeled compound i is calculated with Equations 1 and 3 where the number of moles (n_i) of compound i and the total number of moles in the NAPL (n_T) are calculated with Equations 7 and 8, respectively.

$$n_{i,0} = \frac{m_{i,0}}{MW_i} \tag{7}$$

$$n_{T,t=0} = n_{non} + \sum_{i=1}^{j} n_{i,t=0} \tag{8}$$

During each time step (Δt), the NAPL depletion model removes the mass of compound i from the NAPL caused by partitioning (dissolution) of compound i from the NAPL to the equilibrium concentration (effective solubility) in the aqueous phase as clean groundwater flows through the remediation volume and biooxidation removes dissolved compounds from the pore volume within the remediation volume. The model time step varies based on the half-lives and is typically 1/10th the minimum half-life of the modeled COCs for reasons described in Section 2.2.1. The mass of compound i at each time step is calculated per Equations 9 and 10 as follows:

$$m_{i,t} = m_{i,t-\Delta t} - \Delta m_{i,t} \tag{9}$$

$$\Delta m_{i,t} = \Delta t \cdot Q_w \cdot C^i_{eq,t-\Delta t} + V_w \cdot \left(C^i_{eq,t-\Delta t} - C^i_t\right) \tag{10}$$

where $C^i_{eq,t-\Delta t}$ and $m_{i,t-\Delta t}$ are the equilibrium aqueous concentration (or effective solubility) and mass, respectively, of compound i at the end of the prior time step (same as beginning of current time step). C^i_t is the concentration of compound i at the end of the current time step after mass is degraded via biooxidation. The first part of Equation 10 [$\Delta t \cdot Q_w \cdot C^i_{eq,t-\Delta t}$] represents aqueous phase mass leaving the remediation volume with exiting groundwater flux and assumes that incoming groundwater flux is “clean” (has a concentration of zero). The second part of Equation 10 [$V_w \cdot \left(C^i_{eq,t-\Delta t} - C^i_t\right)$] represents the portion of mass destroyed by biooxidation as represented by the change in concentrations during the time step. Assuming 1st-order attenuation, the estimated concentration of compound i at the end of the time step is calculated by Equation 11.

$$C^i_t = C^i_{eq,t-\Delta t} \cdot e^{-k_i \cdot \Delta t} \tag{11}$$

Upon combining Equations 10 and 11, Equation 10 can be represented by Equation 12.

$$\Delta m_{i,t} = C^i_{eq,t-\Delta t} \cdot \left(\Delta t \cdot Q_w + V_w \cdot \left(1 - e^{-k_i \Delta t}\right)\right) \tag{12}$$

In the Excel spreadsheet, the mass of compound i in the NAPL decreases during each time step and is estimated with Equations 9 and 12. For each compound, the mole fraction is estimated using Equation 13,

$$\chi_i = \frac{\frac{m_{i,t}}{MW_i}}{n_{T,t-\Delta t}} \tag{13}$$

where $n_{T,t-\Delta t}$ is the total number of moles in the NAPL at the beginning of the time step (end of prior time step). The equilibrium aqueous concentration of compound i at the new mole fraction is calculated using Equation 1. The NAPL depletion model estimates the change in the equilibrium aqueous concentration of COCs from the NAPL over time as the COCs are removed from the NAPL. The time period that is takes for the simulated equilibrium aqueous concentrations (effective solubilities) in the model to decrease below groundwater cleanup levels is used as the assumed remediation timeframes for an alternative to achieve cleanup goals and be complete.

2.2.1 Model Time Step

Since the calculations in the NAPL depletion model at each time step numerically estimate dissolution and attenuation processes that are continuous, the length of the modeling time step (Δt) affects the remediation time estimated by the model. If the time step is too long relative to the attenuation half-life, the estimated mass removal rate from attenuation is less and the remediation time increases (Figure 1). The mass removal rate from constant groundwater flux through the remediation volume (first half of Equation 10) is not affected by the time step duration because the model assumes instantaneous partitioning to the equilibrium aqueous concentration. As shown in Figure 1 for a given initial mass of pentachlorophenol (PCP) and naphthalene, the estimated remediation time by the model does not significantly change for time step durations that are less than 1/10th of the attenuation half-life of the COC. Thus, time steps used in the simulations were selected such that the ratio of the attenuation half-life to the time step duration was equal to or greater than 10. Although ratios greater than 10 (shorter time steps) better simulate continuous processes, shorter time steps increase the number of calculations and do not meaningfully influence the estimated remediation timeframe.

2.2.2 Average Molecular Weight

A NAPL characterization study estimated the average molecular weight of NAPL collected from two oil-water separators that treat groundwater from three extraction wells (9006, 9008, and 9009) in Remediation Area 1 (AECOM 2017a). An average NAPL molecular weight of 295 g/mole (average of 272 and 318 g/mole for the two NAPL samples) was used to calculate the effective solubility (equilibrium aqueous concentration) in the NAPL depletion model per Section 2.1. Although the NAPL depletion model assumes that compounds in the NAPL that are not being modeled are not removed and are insoluble, many other hydrocarbons in the NAPL are soluble and being depleted from the NAPL. The depletion of other hydrocarbons from the NAPL would increase the NAPL average molecular weight at a faster rate with time, since lower molecular weight hydrocarbons are generally more soluble than higher molecular weight hydrocarbons in the NAPL. Thus, the mole fraction and effective solubility of PCP and naphthalene would be greater than currently modeled at each time step as other soluble hydrocarbons are depleted from the NAPL. By only including a few soluble hydrocarbons, the NAPL depletion model estimates longer remediation times than a more complex model that includes more soluble hydrocarbons. The difference in remediation times is expected to be minimal, but depends on the initial fraction of soluble hydrocarbons in the NAPL.

2.2.3 Equilibrium Dissolution

The solid-liquid reference fugacity ratios for PCP (0.085) and naphthalene (0.31), as well as the pure-phase aqueous solubilities used in the solubility model (Equation 1), are from the NAPL characterization study (AECOM 2017a). Although partitioning (dissolution) to the equilibrium aqueous concentration is typically a rate-limited process, the NAPL depletion model assumes instantaneous partitioning to groundwater to the effective aqueous solubility (equilibrium aqueous concentration). NAPL morphology (NAPL surface area relative to NAPL volume) is known to significantly affect dissolution behavior. The effect of non-ideal, rate-limited NAPL partitioning behavior would be to decrease the rate of NAPL depletion and increase remediation time relative to the assumption of instantaneous partitioning to the equilibrium aqueous concentration. NAPL morphology and its effect on dissolution rates at this Site are unknown and beyond the scope of the model. However, the NAPL depletion model is primarily used to evaluate and support comparison of the remedial alternatives; therefore, any bias of shorter remedial timeframes would be equally integrated into each alternative’s simulation allowing the relative comparison against one another.

3 Simulations

NAPL depletion models were developed for Remediation Areas 1 and 2 to estimate the remediation time for the remedial alternatives in the FFS. Within both remediation areas, the models were setup to simulate NAPL depletion in the Shallow and Middle-Deep subunits of the Upper Aquifer separately based on differences in hydraulic properties, groundwater flow, and observed attenuation rates. Properties of the remediation areas and inputs to the NAPL depletion model are summarized in Table 1. Within the volume of the remediation areas, the mass of NAPL and the mass fractions of PCP and naphthalene in the NAPL used in the model were estimated from average soil sample concentrations in the saturated zone of each remediation area separately (Table 3-1 of the FFS).

3.1 Remediation Area 1

The dimensions of Remediation Area 1 in the model are approximately 450 ft by 260 ft at the surface (approximately 2.7 acres) with an average saturated thickness of 63 ft. The pore volume (V_w) of Remediation Area 1 (6.26×10^7 Liters) was estimated assuming a porosity of 30%. Within the pore volume of Remediation Area 1, the initial volume of NAPL in the model is 388,000 gallons (1.47×10^6 average Liters). Using a NAPL specific gravity of 1.015, the initial mass of NAPL in Remediation Area 1 is approximately 1.49×10^6 kilograms (kg), which the model assumes is evenly distributed in the remediation volume.

The initial mass fractions of PCP and naphthalene in the NAPL are 0.5% and 11.5%, respectively, based on average soil concentrations (mass fractions) in Remediation Area 1. Using an average NAPL molecular weight (MW_{ct}) of 295 grams per mole (g/mole) and the initial mass fractions of PCP and naphthalene, the estimated average molecular weight of the insoluble NAPL fraction (MW_{non}) from Equation 5 is 356 g/mole, which was used to estimate the total number of moles of assumed insoluble components in the NAPL (Equation 6).

For each subunit of the upper aquifer (shallow and middle-deep), the length of Remediation Area 1 that is orthogonal to groundwater flow is 450 ft. The Shallow subunit was assumed to have a saturated thickness of 27 ft. Using an average hydraulic conductivity of 46 feet per day (ft/d) and a hydraulic gradient of 0.016, the volumetric groundwater flow rate (Q_w) through the Shallow subunit of Remediation Area 1 is 2.53×10^5 Liters per day (L/d) or 6.69×10^4 gallons per day (gpd). The estimated saturated thickness of the Middle-Deep subunit is 36 ft. Using an average hydraulic conductivity of 5 ft/d and a hydraulic gradient of 0.005, the volumetric groundwater flow rate (Q_w) through the Middle-Deep subunit of Remediation Area 1 is 1.15×10^4 L/d or 3,030 gpd.

3.2 Remediation Area 2

The dimensions of Remediation Area 2 in the model are approximately 750 ft by 1,915 ft at the surface (approximately 33 acres) with an average saturated thickness of 57 ft. Within the pore volume (6.95×10^8 Liters) of Remediation Area 2, the initial volume of NAPL in the model is 1.01×10^6 gallons (3.83×10^6 Liters). The initial mass of NAPL in Remediation Area 2 is approximately 3.88×10^6 kg, which the model assumes is evenly distributed in the remediation volume.

The initial mass fractions of PCP and naphthalene are 0.5% and 3.8%, respectively, based on average soil concentrations in Remediation Area 2. Using an average NAPL molecular weight (MW_{ct}) of 295 g/mole and the initial mass fractions of PCP and naphthalene, the estimated average molecular weight of the insoluble NAPL fraction (MW_{non}) from Equation 5 is 311 g/mole, which was used to estimate the total number of moles of assumed insoluble components in the NAPL (Equation 6).

For each subunit of the upper aquifer (shallow and middle-deep), the length of Remediation Area 2 that is orthogonal to groundwater flow is 750 ft. The Shallow subunit was assumed to have a saturated thickness of 23 ft. Using an average hydraulic conductivity of 190 ft/d and a hydraulic gradient of 0.02, the volumetric groundwater flow rate (Q_w) through the Shallow subunit of Remediation Area 2 is 1.86×10^6 L/d or 4.90×10^5 gpd. The estimated saturated thickness of the Middle-Deep subunit is 34 ft. Using an average hydraulic conductivity of 13 ft/d and a hydraulic gradient of 0.0035, the volumetric groundwater flow rate (Q_w) through the Middle-Deep subunit of Remediation Area 2 is 3.29×10^4 L/d or 8,680 gpd.

3.3 Natural Source Zone Depletion

The NAPL depletion model was used to simulate natural source zone depletion (NSZD) of the NAPL in Remediation Areas 1 and 2. In addition to the solubility model and the properties of the Remediation Areas discussed in Sections 3.1 and 3.2, the key parameters required to simulate NSZD is the first-order decay rate (k_i) or half-life ($t_{1/2,i}$) of the NAPL compounds in groundwater. Site-specific attenuation rates for PCP and naphthalene were estimated from attenuation behavior in Remediation Area 3 groundwater using a method presented in Newell et. al. (2002) (Section 1.2.7.3 of the FFS). In the Shallow subunit, the half-lives of PCP and naphthalene were estimate to be 19.7 and 18.3 days, respectively. In the Middle-Deep subunit, which is expected to be more anaerobic (limited potential oxygen diffusion from the ground surface), the half-lives of PCP and naphthalene were estimate to be 62.5 and 41.4 days, respectively.

3.3.1 Mass Depletion from Groundwater Flux versus Attenuation

As described in Section 2.2 and represented in Equation 10, the estimated mass removed from the NAPL during each time step occurs from two processes: 1) partitioning of COCs to fresh groundwater flow through the remediation volume ($\Delta t \cdot Q_w \cdot C^i_{eq,t-\Delta t}$) and 2) partitioning of COCs to the equilibrium aqueous concentration in the remediation pore volume after COCs are removed from the pore volume by biooxidation ($V_w \cdot \left(C^i_{eq,t-\Delta t} - C^i_t\right)$). To evaluate the importance and fraction of mass removed by biooxidation ($x_{i,b}$), the following equation is used:

$$x_{i,b} = \frac{V_w \cdot \left(C^i_{eq,t-\Delta t} - C^i_{\Delta t}\right)}{\Delta t \cdot Q_w \cdot C^i_{eq,t-\Delta t} + V_w \cdot \left(C^i_{eq,t-\Delta t} - C^i_{\Delta t}\right)} \tag{14}$$

After substituting in Equation 11 and assuming the time step duration (Δt) is 1/10th the half-life of compound i, Equation 14 is revised as follows:

$$x_{i,b} = \frac{\left(1-e^{-k_i \Delta t}\right)}{\left(1-e^{-k_i \Delta t}\right) + \Delta t \cdot {}^{Q_w}/_{V_w}} \text{ where } \Delta t = \frac{t_{1/2,i}}{10} = \frac{Log_n(0.5)}{-10k_i} = \frac{0.0693}{k_i}$$

$$x_{i,b} = \frac{0.067}{0.067 + 0.069 \cdot \frac{{}^{Q_w}/_{V_w}}{k_i}} \tag{15}$$

Thus, the fraction of mass depleted from the NAPL by biooxidation in the remediation area pore volume is a function of the fresh groundwater pore volume flow rate through the treatment volume (${}^{Q_w}/_{V_w}$) and the 1st-order attenuation rate (k_i). In most scenarios, the fraction of mass depleted from the NAPL by biooxidation processes is significantly greater than through fresh groundwater flow through the remediation volume, even under anaerobic conditions with slow attenuation rates.

3.4 In Situ Biosparging

The NAPL depletion model was used to simulate in situ biosparging (ISB) of the NAPL in Remediation Area 1. In situ biosparging injects air into the remediation volume to increase dissolved oxygen concentrations and enhance aerobic biooxidation of COCs in groundwater. Aerobic biooxidation is the primary aboveground treatment system at the Site to treat groundwater extracted from the Waste Pit area. A review of performance data shows that half-lives of PCP and total polycyclic aromatic hydrocarbons (PAHs) are 0.10 and 0.08 days, respectively, in the aboveground groundwater treatment system.

Since in situ conditions are likely less ideal than the aboveground treatment system for promoting aerobic biooxidation, the half-lives of PCP and naphthalene in the Remediation Area 1 treatment volume are expected to be greater than in the aboveground treatment system. Half-lives for PCP and naphthalene to evaluate the remediation time for ISB were estimated by calibrating the NAPL depletion model to changes in the NAPL composition that were observed during the ISB pilot-scale test completed in 2016 (AECOM 2017b).

3.4.1 Calibration to ISB Pilot-Scale Test

To calibrate the NAPL depletion model to the ISB pilot-scale test results and estimate half-lives for PCP and naphthalene, the following steps were completed:

a. Estimate NAPL mass in the pilot test volume from baseline soil sample analytical results

b. Estimate the initial mass fractions of COCs in the NAPL from baseline soil sample analytical results

c. Estimate the decrease in mass fractions of COCs in the NAPL from the 270-day soil sample analytical results

d. Calibrate NAPL depletion model by adjusting half-lives to match decrease in mass fractions over 270 days

Descriptions of the soil sampling and analytical procedures for the baseline and 270-day samples are provided in the test report (AECOM 2017b). To account for spatial variability in soil concentrations caused by variability in the NAPL saturation, soil concentrations were normalized to the concentrations of phenanthrene and fluoranthene to estimate the change in the mass fraction of COCs in the NAPL. Since effective aqueous solubilities of phenanthrene and fluoranthene are very limited and are significantly less than the COCs, phenanthrene and fluoranthene concentrations in soil are used to normalize soil concentrations of other NAPL compounds because their mass fractions in the NAPL were stable during the ISB test.

3.4.1.1 Initial NAPL Mass and Mass Fractions

Prior to implementing the ISB pilot-scale test, soil samples were collected from the ISB test volume within Remediation Area 1 and analyzed for PCP and PAH concentrations. The soil analytical results for PCP, naphthalene, phenanthrene, and fluoranthene are summarized in Table 2. The average soil concentrations ($C_{s,i}$) of phenanthrene and fluoranthene were calculated and used to estimate the initial average NAPL mass per unit volume:

$$\frac{m_{T,0}}{V_T} = \frac{C_{s,i} \cdot \rho_b}{C_{ct}^i} \tag{16}$$

where ρ_b is the soil bulk density (1,848 kilograms per cubic meter) and C_{ct}^i is the average mass fraction of phenanthrene (0.0266) and fluoranthene (0.0095) in NAPL samples from Remediation Area 1 (AECOM 2017a). The average NAPL mass per unit volume ($\frac{m_{T,0}}{V_T}$) was also used to estimate the average NAPL saturation (S_n) within the test volume:

$$S_n = \frac{\frac{m_{T,0}}{V_T}}{\theta \cdot \rho_n} \tag{17}$$

where ρ_n is the average density of the NAPL (1.015 grams per cubic centimeter) and the average porosity (θ) of the treatment volume is 0.30.

Equation 16 and the data for phenanthrene and fluoranthene are used to estimate the average NAPL mass per unit volume for the treatment volume. As discussed previously, phenanthrene and fluoranthene were used to estimate NAPL mass because their mass fractions are relatively stable in the NAPL compared to PCP and naphthalene. Using Equation 16, the mass fractions (C_{ct}^i) of PCP and naphthalene in the NAPL are estimated from their average soil concentrations ($C_{s,i}$) and the NAPL mass per unit volume estimated from phenanthrene and fluoranthene data:

$$C_{ct}^i = \frac{C_{s,i} \cdot \rho_b}{\frac{m_{T,0}}{V_T}} \tag{18}$$

Using pilot-scale treatment volume dimensions of 140 ft by 140 ft, the estimated NAPL mass and mass fractions for PCP and naphthalene in the Shallow (saturated interval of 26 ft) and Middle-Deep (saturated interval of 37 ft) subunits were estimated with Equations 16 and 18 and are provided in Table 3. The initial NAPL mass and mass fractions for PCP and naphthalene were used in the NAPL depletion model to simulate performance of the ISB pilot-scale test. In addition, these initial mass fractions of PCP and naphthalene were compared to the mass fractions after 270 days of ISB operation to estimate removal performance.

3.4.1.2 Decrease in Mass Fractions after 270 Days

To estimate the change in NAPL composition during the 270-day operation of the ISB pilot-scale test, initial average soil sample concentrations were compared to average soil concentrations in samples collected after completion of the test. Before comparing concentrations, PCP and naphthalene concentrations were normalized by the concentrations of phenanthrene and fluoranthene. The normalized soil concentrations represent the ratio of mass fractions in the NAPL. For example, the average ratio of PCP to phenanthrene concentrations in soil samples is the also the ratio of the PCP to phenanthrene mass fractions (concentrations) in the NAPL. Thus, a comparison of normalized soil concentrations before and after the test represents the changes in mass fractions in the NAPL.

The average soil concentration ratios are provided in Table 3. In the Shallow subunit, the PCP and naphthalene mass fractions in the NAPL decreased by 68% and 37%, respectively. Similarly, the PCP and naphthalene mass fractions in the NAPL decreased by 64% and 41%, respectively, in the Middle-Deep subunit. Thus, the decrease in the mass fractions indicates that the ISB pilot-scale test effectively removed PCP and naphthalene from the NAPL.

3.4.1.3 Calibrated Attenuation Rates

To estimate the aerobic first-order decay rates of PCP and naphthalene during the pilot-scale ISB test, NAPL depletion model simulations were completed separately for the Shallow and Middle-Deep subunits in the test volume that included the initial NAPL masses and mass fractions in Table 3. The NAPL depletion models for each subunit were setup using the hydraulic properties for Remediation Area 1 (Table 1). First-order decay rates were adjusted to calibrate the models in each subunit to the mass of PCP and naphthalene removed from the NAPL after 270 days of ISB operation (Figures 2 and 3). The fitted first-order decay rates for PCP are 0.92 per day (1/d, half-life of 0.75 days) in the Shallow subunit and 0.49/d (half-life of 1.42 days) in the Middle-Deep subunit (Figure 2). For naphthalene, the fitted first-order decay rates are 0.40/d (half-life of 1.74 days) in the Shallow subunit and 0.24/d (half-life of 2.84 days) in the Middle-Deep subunit (Figure 3).

Based on these attenuation rates from the ISB pilot-scale test, simulations to estimate remediation time for ISB in Remediation Area 1 used half-lives of 1 day and 1.5 days for PCP in the Shallow and Middle-Deep subunits, respectively, and half-lives of 2 and 3 days for naphthalene in the Shallow and Middle-Deep subunits, respectively.

3.5 Steam Enhanced Extraction

The NAPL depletion model was used to estimate remediation time following implementation of steam enhanced extraction (SEE) in Remediation Area 1. Implementation of SEE is expected to increase recovery of the mostly residual NAPL in the treatment volume and enhance removal of COCs and change the composition of the remaining NAPL. A bench-scale study was completed to evaluate the performance of steam enhanced extraction (SEE) on Site soil and NAPL (URS 2013). Bench-scale study results from two soil columns constructed to represent the soil and NAPL saturation conditions in Remediation Area 1 (Waste Pit) indicate that NAPL saturation and mass could be decrease approximately 20% from initial NAPL saturations, which are mostly at residual saturations. In regards to changes in NAPL composition, the PCP mass fraction in the NAPL decreased by 90% in a Waste Pit soil column after 15 pore volumes of hot water and 5 pore volumes of steam. The concentrations and mass fractions of naphthalene and other PAHs increased in the Waste Pit soil columns. In soil columns from the Tank Farm area, the naphthalene mass fractions decreased by approximately 70% in two of the three columns.

NAPL depletion simulations were performed for the Shallow and Middle-Deep subunits in Remediation Area 1 and assumed that the initial NAPL mass would decrease by 20%. In addition, the simulations assumed that the mass fractions of PCP and naphthalene would decrease by 90% and 70%, respectively. Two remedial alternatives for SEE were evaluated. The first SEE alternative assumed NSZD is the primary mechanism for composition change of the remaining NAPL following implementation of SEE; thus, the natural attenuation rates presented in Section 3.3 were used in the NAPL depletion model. The second SEE alternative assumed that ISB will be implemented after SEE to complete the required composition change of the remaining NAPL. Thus, the SEE and ISB alternative uses the ISB attenuation rates presented in Section 3.4.1.3. For both alternatives, SEE operation was assumed to be one year prior to NSZD or ISB. Although implementation of SEE requires hydraulic control (cutoff wall used in conceptual design for costs), the NAPL depletion simulations assumed groundwater flux through Remediation Area 1 is restored to historic, background conditions after SEE.

3.6 In Situ Geochemical Stabilization

To evaluate the remediation time for in situ geochemical stabilization (ISGS) relative to the other alternatives, the performance of ISGS was assumed to contain and prevent dissolution of COCs from approximately 80% of the NAPL in Remediation Area 1. The 80% treatment effectiveness assumes that injection and distribution of the remediation fluid will contact 80% of the NAPL since complete treatment (100% effectiveness) is typically limited by the inability to uniformly deliver remedial solutions in heterogeneous aquifers with heterogeneous NAPL distributions. Thus, the NAPL depletion model evaluated NSZD of the NAPL following an initial 80% reduction in the NAPL mass with no change to the mass fraction of COCs in the remaining NAPL. Natural attenuation rates presented in Section 3.3 were used in the NAPL depletion model following implementation of ISGS. In addition, it is assumed in the model that the remaining NAPL mass (20% of the initial mass) is uniformly distributed throughout the treatment volume, which optimizes NSZD and weathering of the NAPL by anaerobic biooxidation. Thus, the estimated NAPL depletion rate following ISGS using the model may be higher than the actual depletion rate if the remaining NAPL is more heterogeneously distributed following ISGS.

4 Results

The results from the NAPL depletion simulations including the estimated remediation time and fraction of mass removed by biooxidation are summarized in Table 4 by remedial alternative, remediation area, Upper Aquifer subunit, and COC (PCP or naphthalene). Figures 4 through 9 show the NAPL dissolution behavior with time for the remedial alternatives evaluated with the NAPL depletion model.

4.1 Natural Source Zone Depletion

In Remediation Area 1, the estimated time for NSZD to weather PCP from the NAPL in the Middle-Deep subunit (145 years) is significantly greater than the remediation time for PCP in the Shallow subunit (37 years) because of less groundwater flow and a longer half-life (62.5 days) in the Middle-Deep subunit. Within the Shallow subunit, NAPL depletion by relatively high fresh groundwater flux removes approximately 20% of the COCs from the NAPL. In the Middle-Deep subunit, greater than 97% of the COCs are depleted from the NAPL by biooxidation indicating that biooxidation and estimates of attenuation rates primarily control NAPL depletion and estimates of remediation time.

In Remediation Area 2, the maximum estimated remediation time for NSZD is 41 years for PCP in the Middle-Deep subunit. Although more NAPL mass is present in Remediation Area 2, the NSZD remediation times are less than Remediation Area 1 because Remediation Area 2 has less NAPL mass per volume and a much larger pore volume for biooxidation to occur. In addition, the estimated mass fraction of naphthalene in the NAPL is less for Remediation Area 2.

4.2 In Situ Biosparging

Using the aerobic attenuation rates from calibrating the NAPL depletion model to the performance of the ISB pilot-scale test, the estimated time for ISB to weather PCP and naphthalene from the NAPL in Remediation Area 1 ranged from 3 to 6 years. Because of the fast attenuation rates (half-lives less than 3 days) in the NAPL depletion model, greater than 97% of the COCs are depleted from the NAPL by biooxidation. The NAPL depletion model and simulations in Remediation Area 1, support the results of the ISB pilot-scale test that indicate ISB is a feasible remedial alternative.

4.3 Steam Enhanced Extraction

The NAPL depletion model indicates that SEE decreases the remediation time compared to NSZD because of the reduction in NAPL mass and mass fractions of PCP and PAHs in the NAPL by implementation of SEE. Remediation times range from 21 to 95 years in Remediation Area 1 if SEE is followed by NSZD as anaerobic biooxidation during NSZD is required to remove the remaining mass of COCs from the NAPL. However, remediation times are likely to be less for SEE and NSZD because NSZD rates may be higher as a result of higher groundwater temperatures for several years following SEE. In comparison, SEE followed by ISB depletes the COCs from the NAPL in a much shorter time (3 to 5 years) because aerobic biooxidation is significantly faster than anaerobic biooxidation.

4.4 In Situ Geochemical Stabilization

By encapsulating NAPL mass and mitigating dissolution of COCs from the NAPL, the NAPL depletion model indicates that ISGS can decrease the time required for NSZD to weather COCs from the remaining, untreated NAPL. Estimated remediation times for ISGS ranged from 6 to 7 years in the Shallow subunit and 16 to 29 years in the Middle-Deep subunit. In comparison to SEE followed by NSZD, the shorter remediation times for ISGS indicates that an initial decrease in NAPL mass from remedial activity decreases remediation time more than an initial decrease in the mass fractions of COCs in the NAPL. Note that reductions in the pore volume and hydraulic conductivity may be caused by ISGS, which would increase remediation time. In addition, the time to deplete COCs from the NAPL under anaerobic biooxidation and NSZD after ISGS would be underestimated by the model in areas where untreated NAPL is similar to initial saturations (i.e. the distribution of remaining NAPL is less uniform and more heterogeneous).

5 Conclusions

The NAPL depletion model provided a simple analytical tool to compare remedial alternatives and the effect the remedial alternatives have on remediation time, which is the time required to decrease the mass fraction and effective aqueous solubility of COCs to groundwater concentration targets. The NAPL depletion model shows that enhancing dissolution of the COCs from the NAPL by biooxidation of the COCs in groundwater is the primary removal process controlling remediation time. Thus, significantly increasing the attenuation rates of the COCs with ISB estimated the shortest remediation times in comparison to slower attenuation rates and longer remediation times for NSZD and ISGS. The combination of SEE and ISB provides the shortest estimated remediation times (3 to 5 years). However, the NAPL depletion simulations indicate that ISB alone can remove the COCs from the NAPL with remediation times (3 to 6 years) similar to but slightly longer than the combined remedial alternative of SEE and ISB.

6 References

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Tables

Table 1. Remediation Area Properties and NAPL Depletion Model Inputs

Remediation Area	Model Input	Symbol	Shallow Subunit	Middle-Deep Subunit
Remediation Area 1	Width (ft) x Length (ft)	$W \bullet L$	450 x 260	
	Saturated Thickness (ft)	H	27	36
	Flux Transect Area (ft^2)	A	12,150	16,200
	Porosity	$\boldsymbol{\theta}$	0.30	
	Pore Volume (L)	V_w	2.68E+07	3.58E+07
	Hydraulic Conductivity (ft/d)	K	46	5
	Hydraulic Gradient	i	0.016	0.005
	Groundwater Discharge Rate (L/d)	Q_w	2.53E+05	1.15E+04
	Groundwater Discharge Rate (Pore Volumes/d)	Q_w/V_w	0.0094	0.0003
	Initial NAPL Mass (kg)	$m_{T,0}$	640,000	853,000
	Initial Mass Fraction of PCP	C_{ct}^{i}	0.005	
	Initial Mass Fraction of Naphthalene		0.115	
Remediation Area 2	Width (ft) x Length (ft)	$W \bullet L$	740 x 1,950	
	Saturated Thickness (ft)	H	23	34
	Transect Area (ft^2)	A	17,250	25,500
	Porosity	$\boldsymbol{\theta}$	0.30	
	Pore Volume (L)	V_w	2.81E+08	4.15E+08
	Hydraulic Conductivity (ft/d)	K	190	13
	Hydraulic Gradient	i	0.011	0.0035
	Groundwater Discharge Rate (L/d)	Q_w	1.02E+06	3.29E+04
	Groundwater Discharge Rate (Pore Volumes/d)	Q_w/V_w	0.0036	0.0001
	Initial NAPL Mass (kg)	$m_{T,0}$	1,567,000	2,316,000
	Initial Mass Fraction of PCP	C_{ct}^{i}	0.005	
	Initial Mass Fraction of Naphthalene		0.038	

Notes:
ft = feet
L = liters
ft/d = feet per day
L/d = Liters per day
kg = kilograms

Table 2. Soil Concentrations from ISB Pilot-Scale Test

Time	Upper Aquifer Subunit	Location	Soil Sample Depth (ft bgs)	Soil Concentration PCP (mg/kg)	Naphthalene (mg/kg)	Phenanthrene (mg/kg)	Fluoranthene (mg/kg)
Baseline	Shallow	3052.1	12	160	1188	286	103
		9505.1	12	168	741	167	67.9
		3053.1	12.5	132	782	205	77.9
		3054.1	13	129	688	185	75.5
		3052.1	22	259	1632	267	129
		3056.1	22	282	822	335	141
		9505.1	22	51.8	276	65.7	26.5
		3053.1	23	131	631	156	62.8
		3054.1	23	121	511	138	57
		3055.1	23	93	534	151	59.2
		3052.1	32	160	600	184	83.3
		9505.1	32	56.6	131	86	32.5
		3053.1	33	158	581	214	88.4
		3054.1	33	162	728	215	95.1
	Middle-Deep	3052.1	42	90	152	90.6	33
		3056.1	42	404	950	357	135
		9505.1	42	90.7	198	155	66.3
		3053.1	43	69.2	141	67.7	27.5
		3054.1	43	202	562	197	78.8
		3055.1	43	99.2	337	123	44.5
		3052.1	52	73.6	190	83.1	30.3
		9505.1	52	111	395	126	47.6
		3053.1	53	7	13	7.2	<2.6
		3054.1	53	29.6	58	27.2	10.7
		3052.1	62	98.5	285	115	46.2
		3056.1	62	270	1301	427	162
		9505.1	62	111	410	145	59.6
		3053.1	63	75.3	265	81.4	29
		3054.1	63	30.1	48	34.1	14.7
		3055.1	63	147	492	186	77.6
		3052.1	72	40.1	170	53.4	22.9
		9505.1	72	20.6	71.7	26.5	10.9
		3053.1	73	28	106	38	16.1
270-Day	Shallow	5541	13	32.5	97.9	97.5	48.6
		5542	13	30	483	131	62
		5543	13	22.6	363	100	49.8
		5544	13	37.4	494	214	92
		5542	22	55.1	822	226	104
		5541	23	30.7	162	94.9	47.8
		5543	23	37.9	350	94.7	46.2
		5544	23	40.7	272	90.6	69.1
		5541	33	19.1	283	118	56.6
		5542	33	11.6	46	61.2	25.3
		5543	33	19	110	62.2	27.1
		5544	33	13.7	123	56.9	22.4
	Middle-Deep	5541	43	78	252	148	64
		5542	43	39.7	20.6	76.1	42.5
		5543	43	15.5	18	72.4	33.5
		5544	43	2.7	21	13.6	5.3
		5541	53	11.1	93.9	62.3	26.6

Table 2. Soil Concentrations from ISB Pilot-Scale Test

Time	Upper Aquifer Subunit	Location	Soil Sample Depth (ft bgs)	Soil Concentration PCP (mg/kg)	Naphthalene (mg/kg)	Phenanthrene (mg/kg)	Fluoranthene (mg/kg)
270-Day	Middle-Deep	5542	53	30.7	176	109	53.6
		5543	53	8.9	13.3	17.6	7.7
		5544	53	26.3	137	60	21.7
		5541	63	31.6	357	119	57.9
		5542	63	45.8	160	93.7	46.5
		5543	63	31.3	114	67.5	28.6
		5541	72.5	24	329	121	56.8
		5543	72.5	31.4	174	99	50.4
		5542	73	23.1	113	79	40.8

Notes:

Baseline samples were collected from 5/12/14 through 5/20/14.

270-Day soil samples were collected from 1/25/16 through 1/29/16.

Analytical data is from Table 3A in Biosparging Pilot-Scale Test Report (AECOM 2017b).

ft bgs = feet below ground surface

mg/kg = milligrams per kilogram

PCP = pentachlorophenol

Table 3. NAPL Depletion Model Calibration to ISB Pilot-Scale Test

Property or Calculation	Symbol	Shallow Subunit	Middle-Deep Subunit
Initial Average Soil Concentration (mg/kg) - Phenanthrene	$C_{s,i}$	190	123
NAPL Mass per unit Volume (kg/m^3) - Phenanthrene	$m_{T,0}/V_T$	13.2	8.6
Average NAPL Saturation (%) - Phenanthrene	S_n	4.3%	2.8%
Initial Average Soil Concentration (mg/kg) - Fluoranthene	$C_{s,i}$	79	48
NAPL Mass per unit Volume (kg/m^3) - Fluoranthene	$m_{T,0}/V_T$	15.3	9.4
Average NAPL Saturation (%) - Fluoranthene	S_n	5.0%	3.1%
NAPL Mass per unit Volume (kg/m^3)	$m_{T,0}/V_T$	14.2	9.0
Average NAPL Saturation (%)	S_n	4.7%	2.9%
Pilot-Scale Test Volume (m^3)	V_T	14,430	20,535
Pilot-Scale Test Initial NAPL Mass (kg)	$m_{T,0}$	205,000	184,000
Initial Average Soil Concentration (mg/kg) - PCP	$C_{s,i}$	147	105
Initial Average PCP Mass Fraction (%)	C_{ct}^{i}	1.92%	2.17%
Initial Average Soil Concentration (mg/kg) - Naphthalene	$C_{s,i}$	703	323
Initial Average Naphthalene Mass Fraction (%)	C_{ct}^{i}	9.14%	6.67%
Initial PCP Mass Fraction in NAPL			
Average Ratio of PCP/Phenanthrene		0.78	0.87
Average Ratio of PCP/Fluoranthene		1.88	2.36
270-Day PCP Mass Fraction in NAPL			
Average Ratio of PCP/Phenanthrene		0.27	0.35
Average Ratio of PCP/Fluoranthene		0.56	0.77
PCP Mass Fraction Change (%)			
PCP/Phenanthrene		-65%	-60%
PCP/Fluoranthene		-70%	-68%
Average PCP Mass Fraction Change (%)		-68%	-64%
Initial Naphthalene Mass Fraction in NAPL			
Average Ratio of Naphthalene/Phenanthrene		3.65	2.47
Average Ratio of Naphthalene/Fluoranthene		8.86	6.57
270-Day Naphthalene Mass Fraction in NAPL			
Average Ratio of Naphthalene/Phenanthrene		2.48	1.59
Average Ratio of Naphthalene/Fluoranthene		5.14	3.53
Naphthalene Mass Fraction Change (%)			
Naphthalene/Phenanthrene		-32%	-36%
Naphthalene/Fluoranthene		-42%	-46%
Average Naphthalene Mass Fraction Change (%)		-37%	-41%

Notes:

mg/kg = milligrams per kilogram

kg/m^3 = kilograms per cubic meter

Table 4. NAPL Depletion Model Results

Alternative	Remediation Area	Upper Aquifer Subunit	Contaminant of Concern	Fraction of Mass Removed by Biooxidation[1] (%)	Remediation Time (years)
NSZD	Remediation Area 1	Shallow	PCP	78%	37
			Naphthalene	80%	28
		Middle-Deep	PCP	97%	**145**
			Naphthalene	98%	78
	Remediation Area 2	Shallow	PCP	90%	12
			Naphthalene	91%	7
		Middle-Deep	PCP	99%	**41**
			Naphthalene	100%	17
ISB	Remediation Area 1	Shallow	PCP	99%	3
			Naphthalene	97%	4
		Middle-Deep	PCP	100%	4
			Naphthalene	100%	**6**
SEE & NSZD	Remediation Area 1	Shallow	PCP	78%	25
			Naphthalene	80%	21
		Middle-Deep	PCP	97%	**95**
			Naphthalene	98%	58
SEE & ISB	Remediation Area 1	Shallow	PCP	99%	3
			Naphthalene	97%	4
		Middle-Deep	PCP	100%	3
			Naphthalene	100%	**5**
ISGS & NSZD	Remediation Area 1	Shallow	PCP	78%	7
			Naphthalene	80%	6
		Middle-Deep	PCP	97%	**29**
			Naphthalene	98%	16

Notes:

[1] Fraction of mass removed by biooxidation is after implementation of SEE or ISGS during NSZD or ISB.

Figures

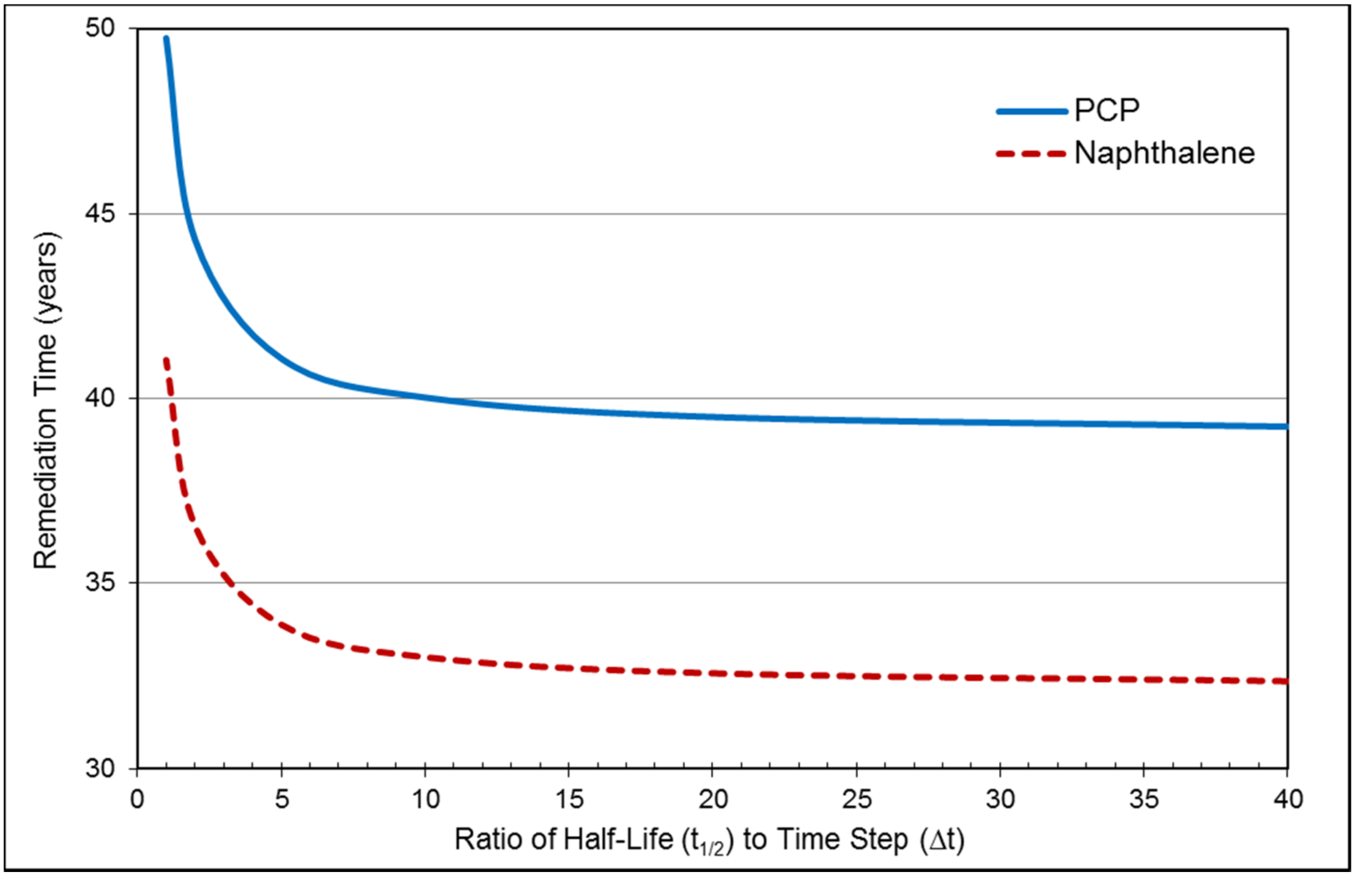

Figure 1. The effect of the modeling time step (Δt) on remediation time.

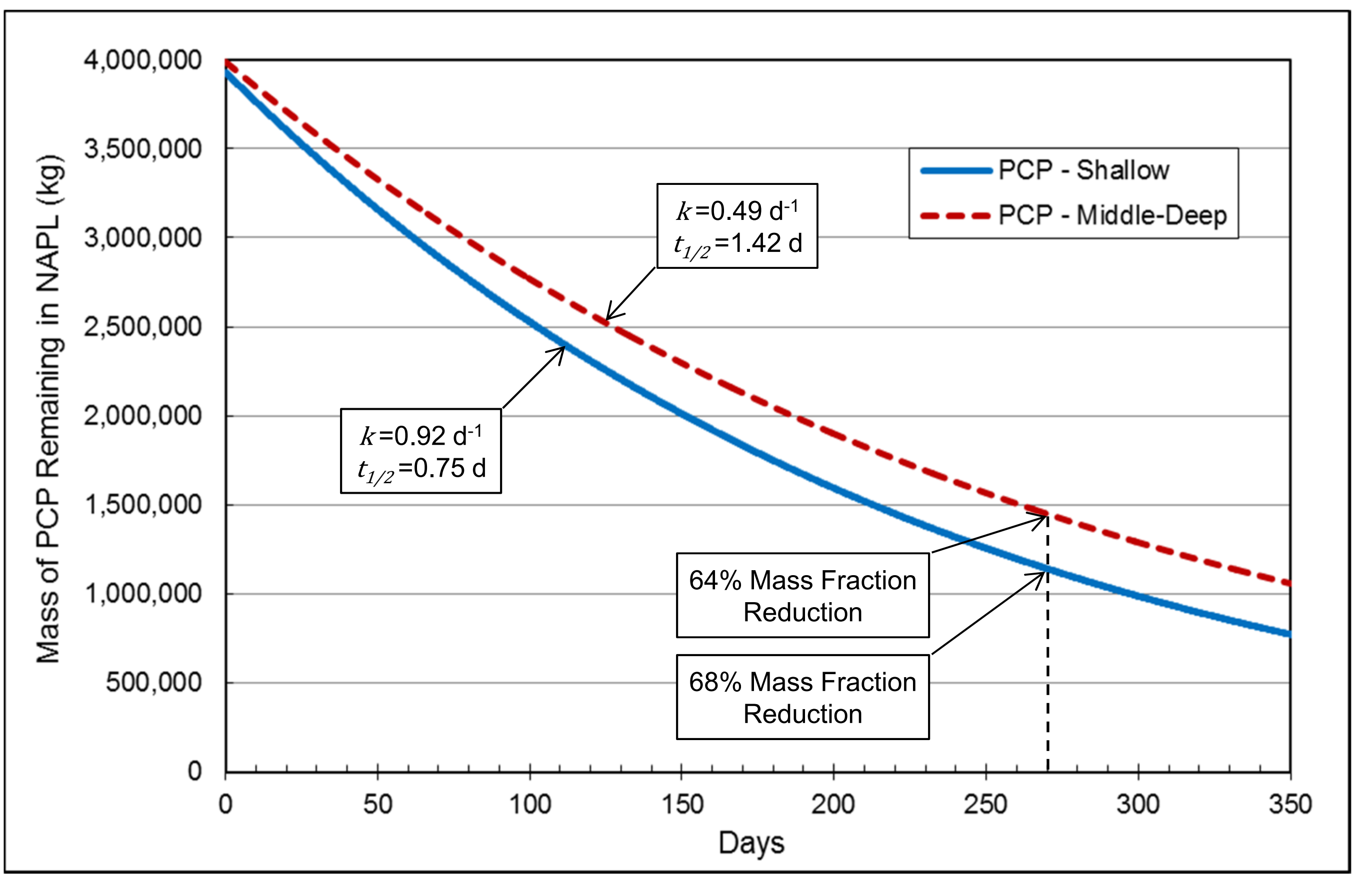

Figure 2. Modeled mass of PCP removed from NAPL during pilot-scale ISB test.

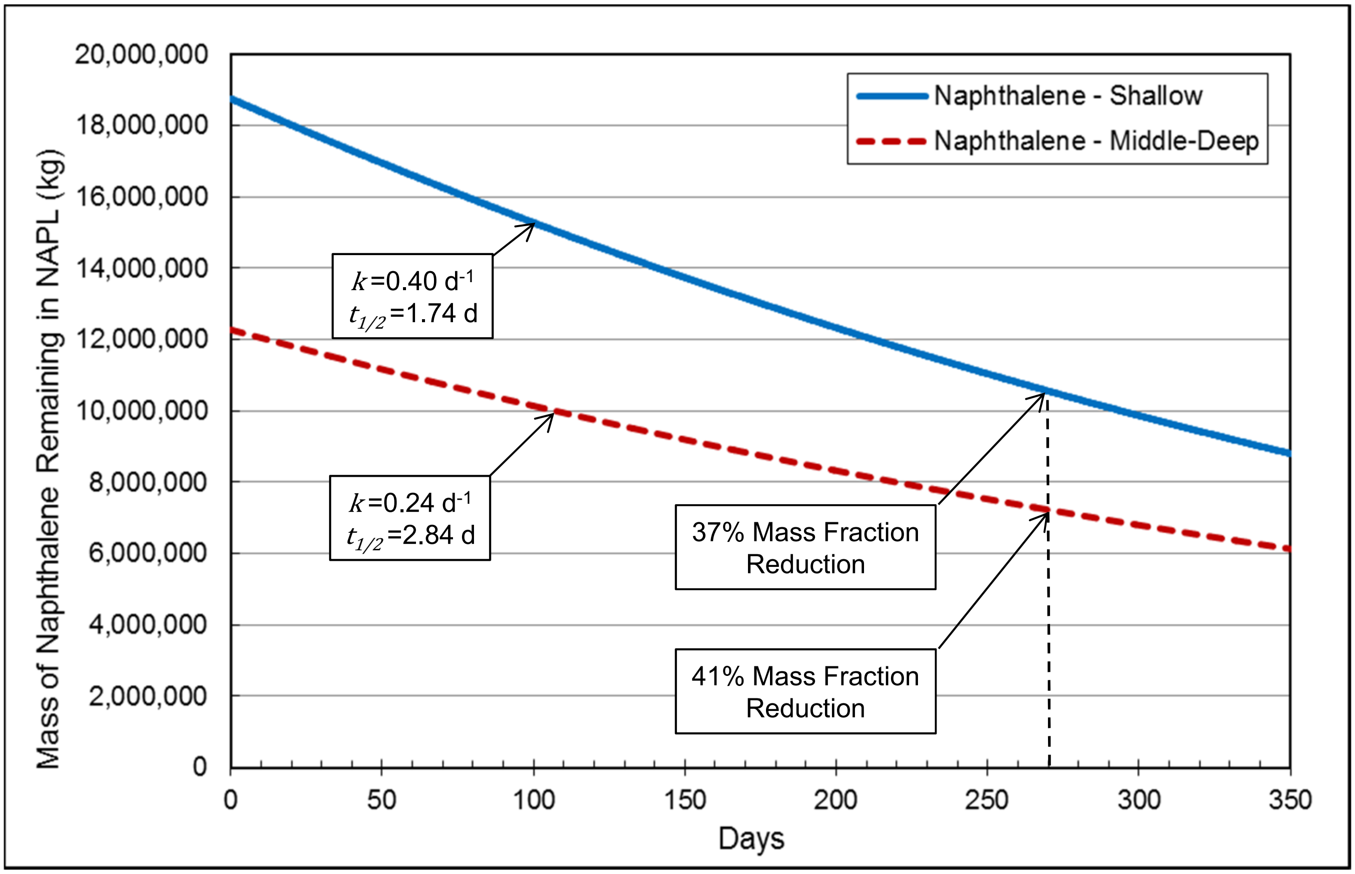

Figure 3. Modeled mass of Naphthalene removed from NAPL during pilot-scale ISB test.

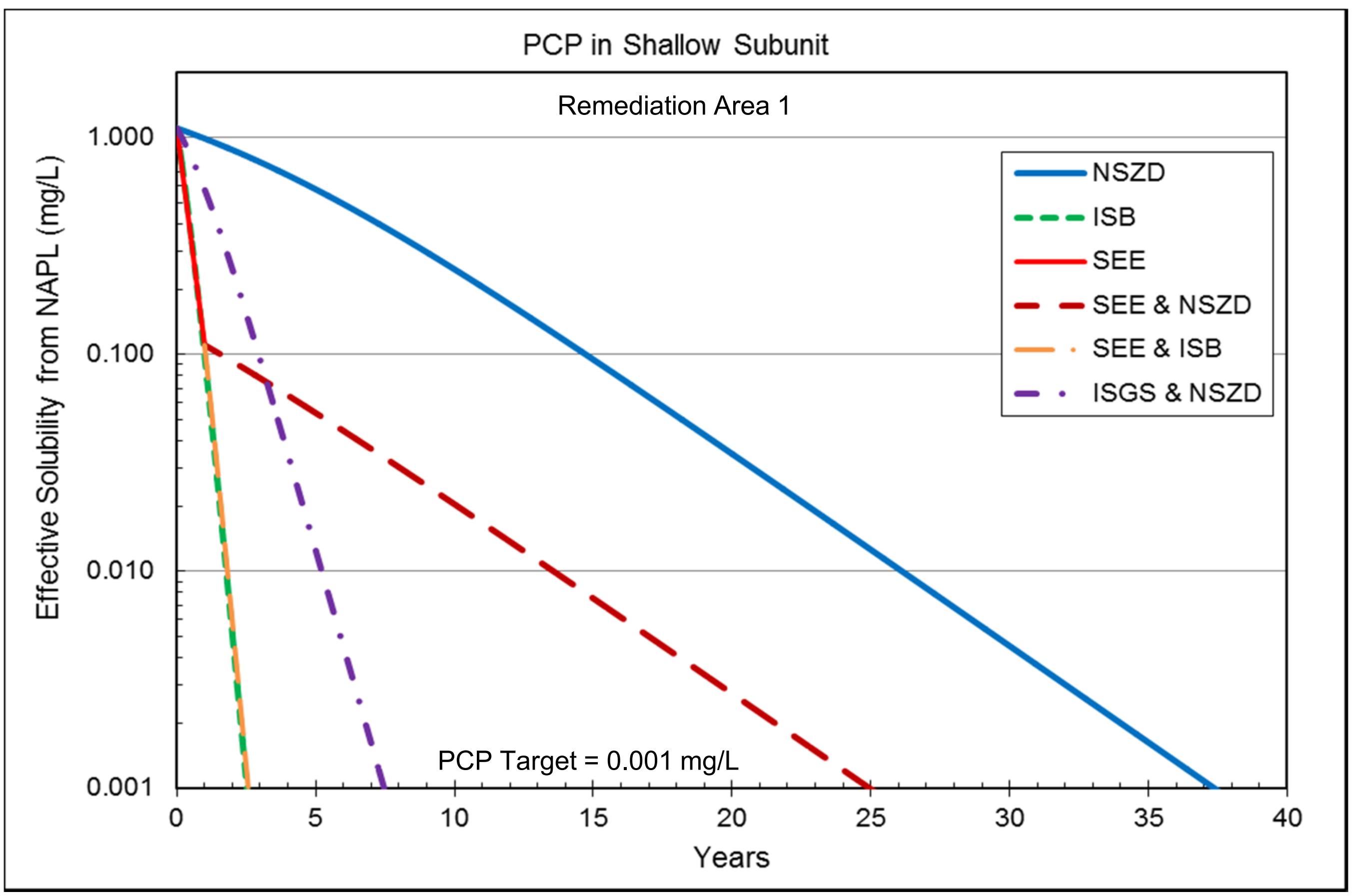

Figure 4. PCP depletion and effective solubility from NAPL in Shallow subunit.

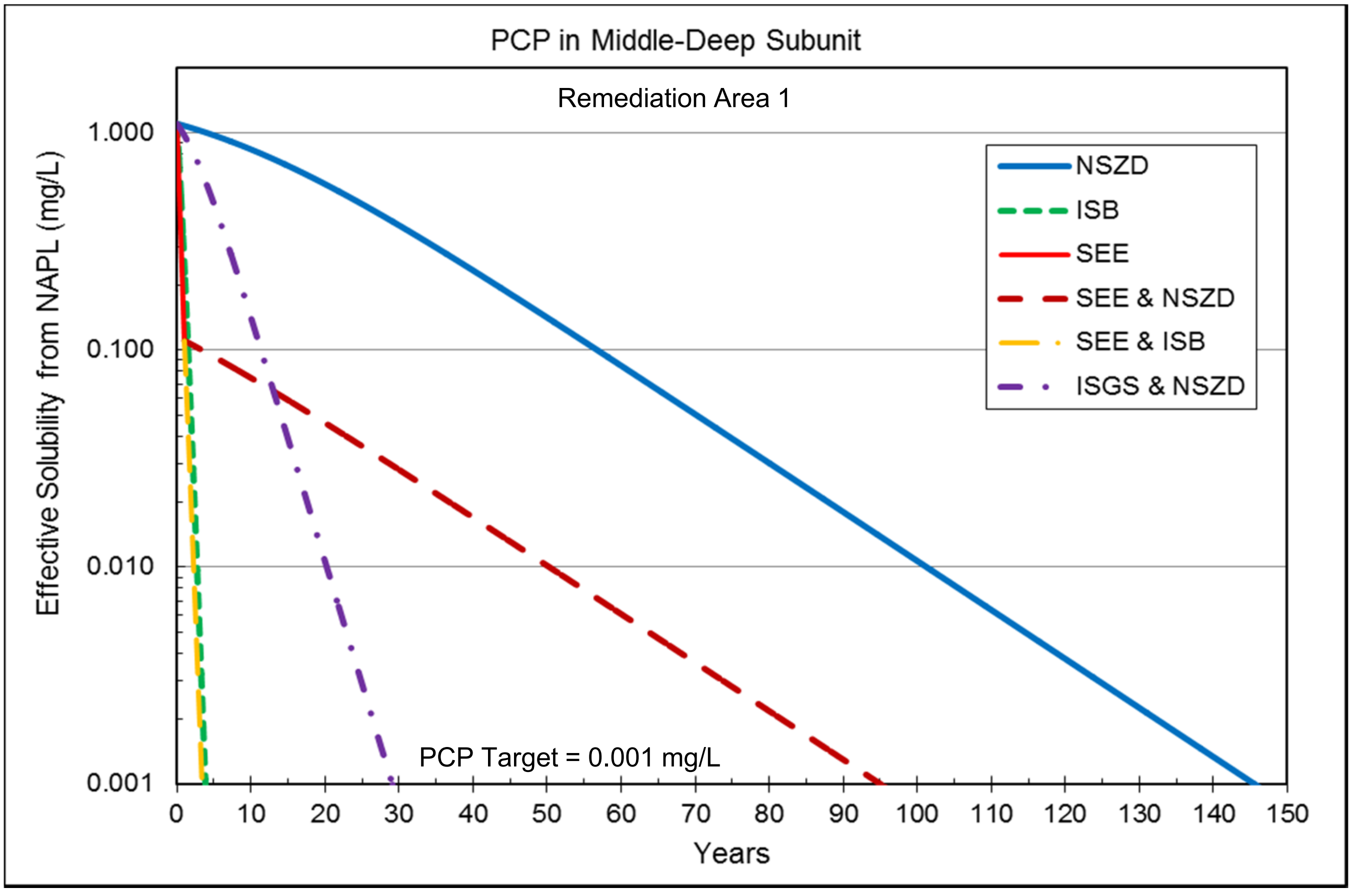

Figure 5. PCP depletion and effective solubility from NAPL in Middle-Deep subunit.

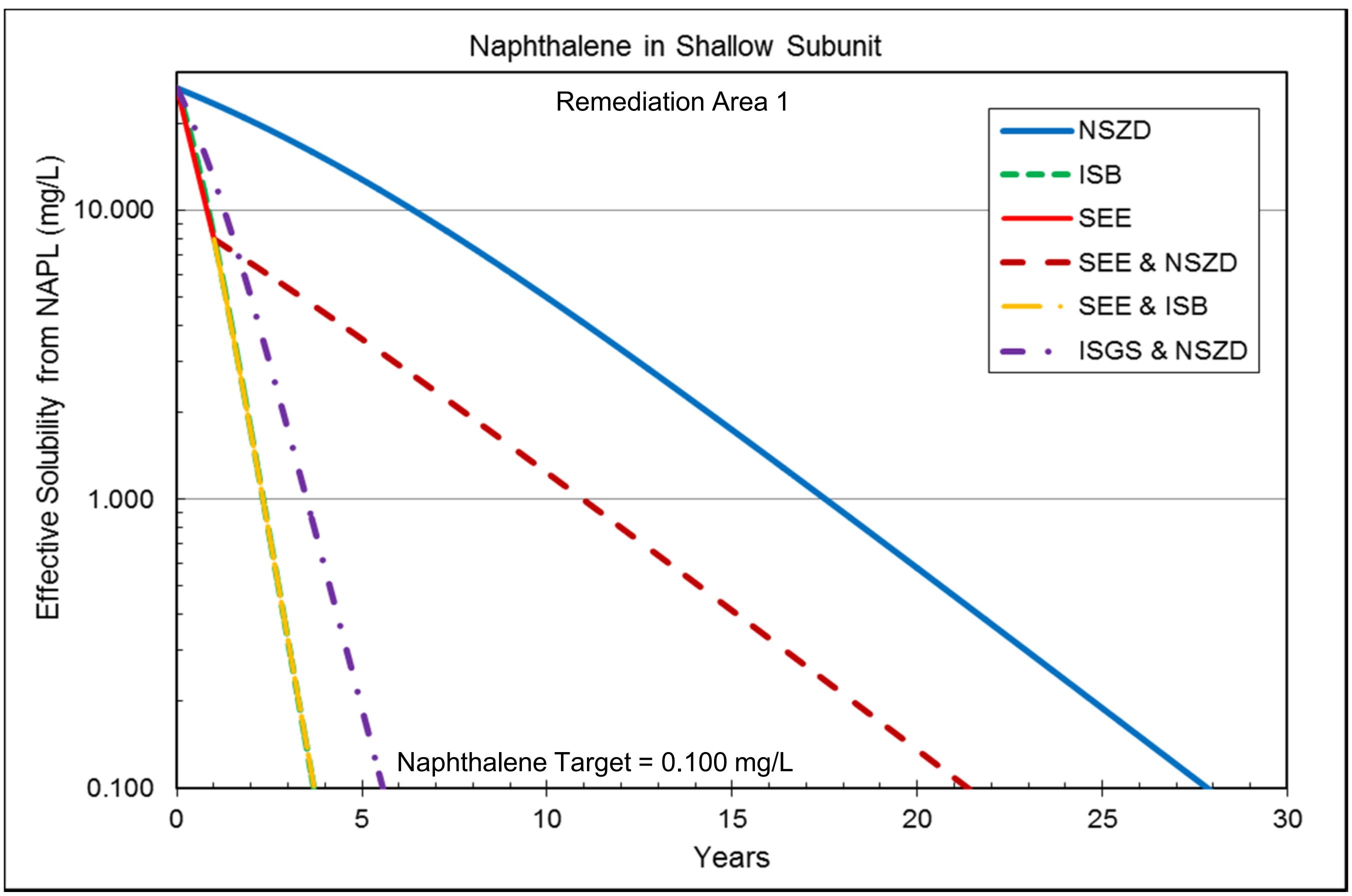

Figure 6. Naphthalene depletion and effective solubility from NAPL in Shallow subunit.

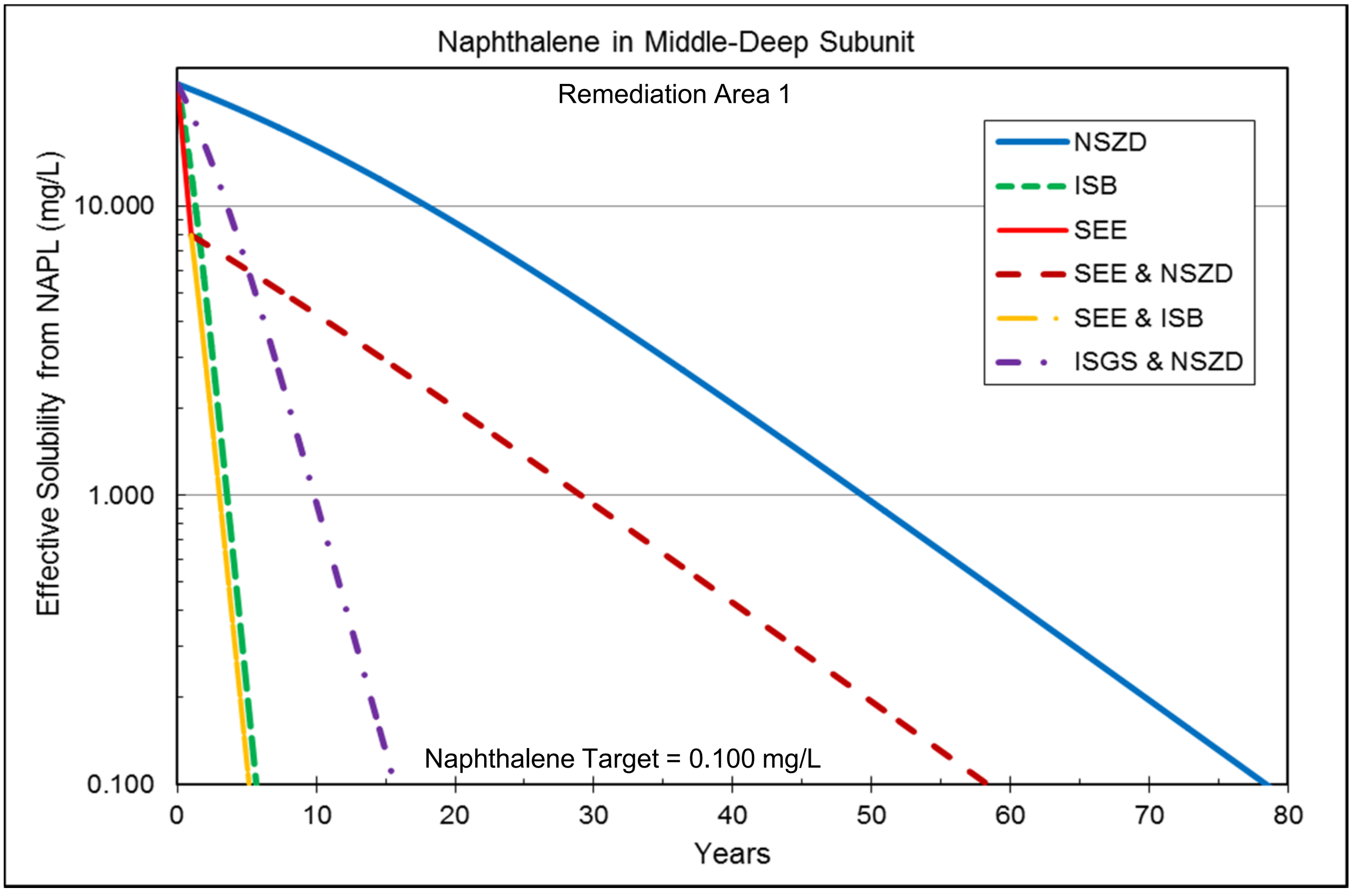

Figure 7. Naphthalene depletion and effective solubility from NAPL in Middle-Deep subunit.

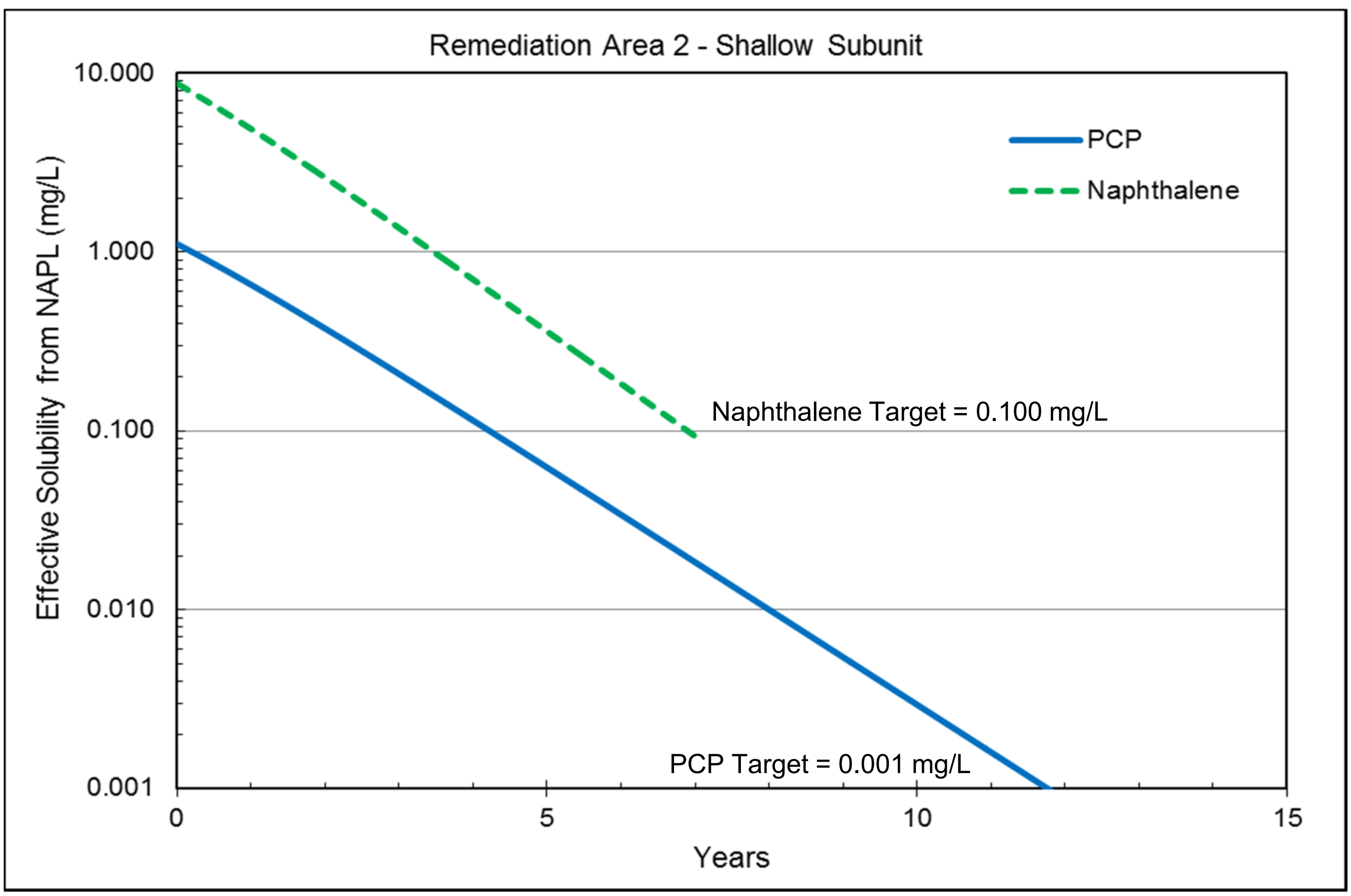

Figure 8. NAPL depletion and effective solubility in Shallow subunit of Remediation Area 2.

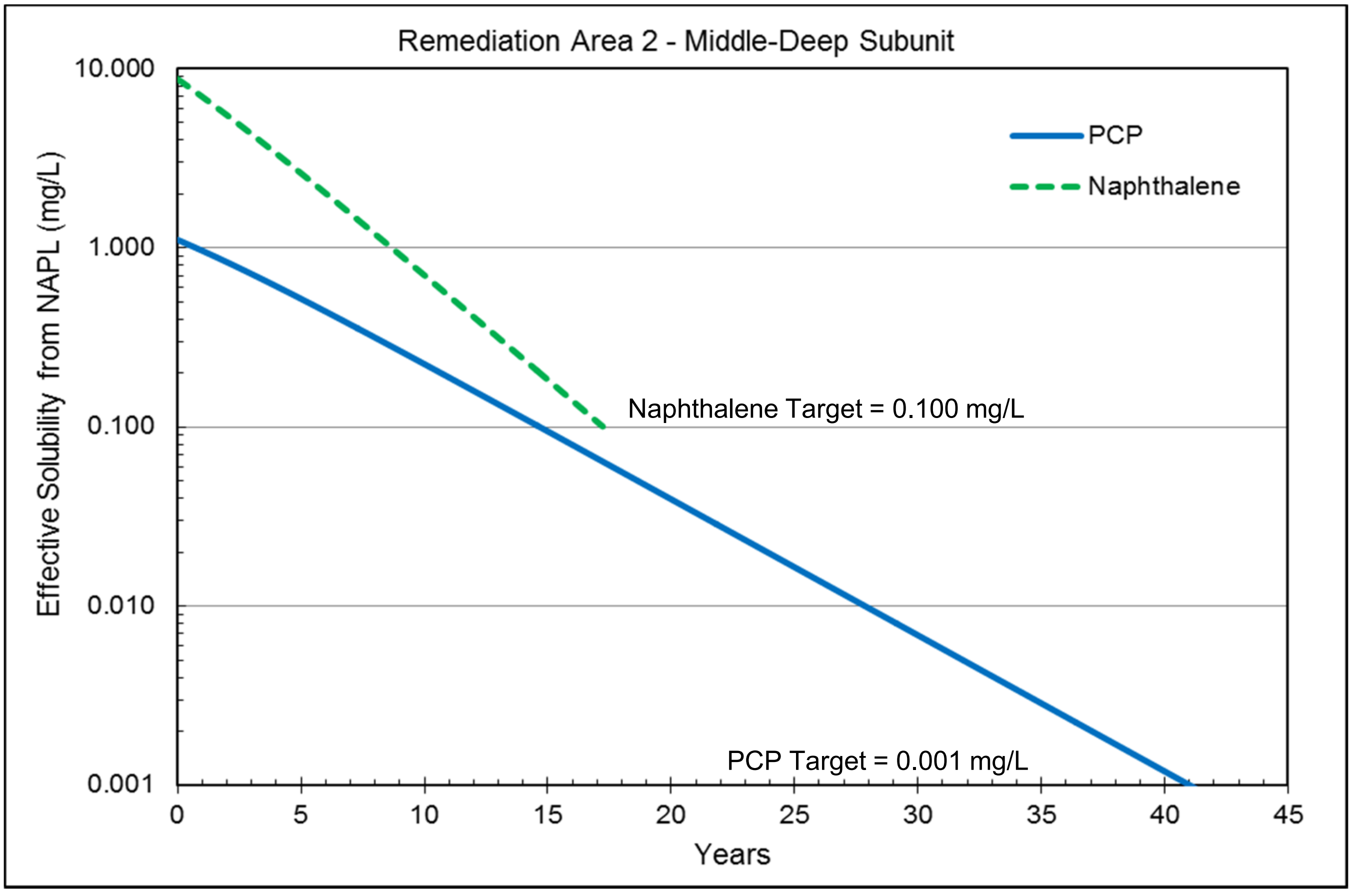

Figure 9. NAPL depletion and effective solubility in Middle-Deep subunit of Remediation Area 2.

Appendix C

Cost Estimates for Remedial Alternatives

ALTERNATIVE 1 COST ESTIMATE SUMMARY
No Further Action with Institutional Controls Appendix C - Sheet 1

Site: Libby Groundwater Site **Phase:** FFS Costing **Base Year:** 2019
Location: Libby, MT **Date:** February 2018 **Duration:** 150 Years

Description: no action would be taken in the Upper Aquifer beyond implementing institutional controls and 5-year reviews with groundwater monitoring. Current remedial actions would be stopped, inlcuding operation of the SAETS. Natural attenuation would continue at the site, which would be evaluated during the 5-year reviews based on results from UA monitoring. The duration of this alternative is based on natural attentuation rates, but ultimately would be determined by monitoring aquifer conditions.

CAPITAL COSTS (YEAR 0):

Item No.	DESCRIPTION & NOTES	UNIT	UNIT COST	QUANTITY	TOTAL (ROUNDED)
1.00	**SAETS Decommissioning**				**$328,230**
1.01	Decommission Treatment System	LS	$202,000	1	$202,000
1.02	Demo Bioreactor Facility Building (offset by salvage)	LS	$8,000	1	$8,000
1.03	Remove Tanks, Towers, Piping at Bioreactor Facility	LS	$35,000	1	$35,000
1.04	Decomission Infiltration Gallery	LS	$0	1	$0
1.05	Abandon/Remove Existing Conveyance Piping	ft	$15	370	$5,550
1.06	Abandon Existing Wells	ft	$15	594	$8,910
1.07	*Project Management*	*%*		*10*	*$25,950*
1.08	*Contingency*	*%*		*15*	*$42,820*
2.00	**Implement ICs**				**$22,050**
2.01	Mob/Demob	LS	$5,000	1	$5,000
2.02	Implement Additional ICs	LS	$15,000	1	$15,000
2.03	*Project Management*	*%*		*5*	*$1,000*
2.04	*Contingency*	*%*		*5*	*$1,050*
3.00	**TOTAL CAPITAL COST**				**$350,280**

PERIODIC COSTS:

Item No.	DESCRIPTION & NOTES	UNIT	UNIT COST	QUANTITY	TOTAL (ROUNDED)
4.00	**Recurring 5-Year Expenditures**				**$15,000**
4.01	Five Year Review Report	EA	$10,000	1	$10,000
4.02	Update Institutional Controls Plan	EA	$4,000	1	$4,000
4.03	*Project Management*	*%*		*5*	*$700*
4.04	*Contingency*	*%*		*2*	*$300*
5.00	**Groundwater Monitoring & Reporting - (once every 5 years)**				**$19,523**
5.01	Sampling Upper Aquifer Wells	well	$250	15	$3,750
5.02	Groundwater analytical	sample	$196	17	$3,332
5.03	Evaluation and Reporting	report	$10,000	1	$10,000
5.04	Liquid IDW (decon & purged groundwater)	drum	$131	1	$131
5.05	*Project Management*	*%*		*8*	*$1,380*
5.06	*Contingency*	*%*		*5*	*$930*
6.00	**Remedy Complete (Year 150)**				**$63,290**
6.01	Mob/Demob	LS	$7,000	1	$7,000
6.02	Monitoring Well Abandonment	well	$990	40	$39,600
6.03	Oversight, Documentation, & Per Diem	day	$1,350	8	$10,800
6.04	*Project Management*	*%*		*5*	*$2,870*
6.05	*Contingency*	*%*		*5*	*$3,020*
7.00	**TOTAL PERIODIC COSTS**				**$1,098,980**

PROJECT COST SCHEDULE & PRESENT VALUE ANALYSIS

Item No.	DESCRIPTION	YEAR	PERIOD COST	CUMULATIVE COST	DISCOUNT FACTOR	PERIOD NET PRESENT VALUE
8.00	**O&M Cost**					
8.00	Site Decommissioning & Controls	0	$350,280	$350,280	1.000	$350,280
8.01	No Action	1	$0	$350,280	0.990	$0
8.02	No Action	2	$0	$350,280	0.981	$0
8.03	No Action	3	$0	$350,280	0.971	$0
8.04	No Action	4	$0	$350,280	0.962	$0
8.05	Monitoring & 5-year Review	5	$34,523	$384,803	0.952	$32,876
8.06	No Action	6	$0	$384,803	0.943	$0
8.07	No Action	7	$0	$384,803	0.934	$0
8.08	No Action	8	$0	$384,803	0.925	$0
8.09	No Action	9	$0	$384,803	0.916	$0
8.10	Monitoring & 5-year Review	10	$34,523	$419,326	0.907	$31,308
8.11	No Action	11	$0	$419,326	0.898	$0
8.12	No Action	12	$0	$419,326	0.889	$0
8.13	No Action	13	$0	$419,326	0.881	$0
8.14	No Action	14	$0	$419,326	0.872	$0
8.15	Monitoring & 5-year Review	15	$34,523	$453,849	0.864	$29,815
8.16	No Action	16	$0	$453,849	0.855	$0
8.17	No Action	17	$0	$453,849	0.847	$0
8.18	No Action	18	$0	$453,849	0.839	$0
8.19	No Action	19	$0	$453,849	0.830	$0
8.20	Monitoring & 5-year Review	20	$34,523	$488,372	0.822	$28,392
8.21	No Action	21	$0	$488,372	0.814	$0
8.22	No Action	22	$0	$488,372	0.806	$0
8.23	No Action	23	$0	$488,372	0.799	$0
8.24	No Action	24	$0	$488,372	0.791	$0
8.25	Monitoring & 5-year Review	25	$34,523	$522,895	0.783	$27,038
8.26	No Action	26	$0	$522,895	0.776	$0
8.27	No Action	27	$0	$522,895	0.768	$0
8.28	No Action	28	$0	$522,895	0.761	$0
8.29	No Action	29	$0	$522,895	0.753	$0
8.30	Monitoring & 5-year Review	30	$34,523	$557,418	0.746	$25,748
8.31	No Action	31	$0	$557,418	0.739	$0
8.32	No Action	32	$0	$557,418	0.731	$0
8.33	No Action	33	$0	$557,418	0.724	$0
8.34	No Action	34	$0	$557,418	0.717	$0
8.35	Monitoring & 5-year Review	35	$34,523	$591,941	0.710	$24,520
8.36	No Action	36	$0	$591,941	0.703	$0
8.37	No Action	37	$0	$591,941	0.697	$0
8.38	No Action	38	$0	$591,941	0.690	$0
8.39	No Action	39	$0	$591,941	0.683	$0
8.40	Monitoring & 5-year Review	40	$34,523	$626,464	0.676	$23,350
8.41	No Action	41	$0	$626,464	0.670	$0
8.42	No Action	42	$0	$626,464	0.663	$0
8.43	No Action	43	$0	$626,464	0.657	$0
8.44	No Action	44	$0	$626,464	0.650	$0
8.45	Monitoring & 5-year Review	45	$34,523	$660,987	0.644	$22,237
8.46	No Action	46	$0	$660,987	0.638	$0
8.47	No Action	47	$0	$660,987	0.632	$0
8.48	No Action	48	$0	$660,987	0.625	$0
8.49	No Action	49	$0	$660,987	0.619	$0
8.50	Monitoring & 5-year Review	50	$34,523	$695,510	0.613	$21,176
8.51	No Action	51	$0	$695,510	0.607	$0
8.52	No Action	52	$0	$695,510	0.602	$0
8.53	No Action	53	$0	$695,510	0.596	$0
8.54	No Action	54	$0	$695,510	0.590	$0
8.55	Monitoring & 5-year Review	55	$34,523	$730,033	0.584	$20,166
8.56	No Action	56	$0	$730,033	0.578	$0
8.57	No Action	57	$0	$730,033	0.573	$0
8.58	No Action	58	$0	$730,033	0.567	$0
8.59	No Action	59	$0	$730,033	0.562	$0
8.60	Monitoring & 5-year Review	60	$34,523	$764,556	0.556	$19,204
8.61	No Action	61	$0	$764,556	0.551	$0
8.62	No Action	62	$0	$764,556	0.545	$0
8.63	No Action	63	$0	$764,556	0.540	$0

8.64	No Action	64	$0	$764,556	0.535	$0
8.65	Monitoring & 5-year Review	65	$34,523	$799,079	0.530	$18,288
8.66	No Action	66	$0	$799,079	0.525	$0
8.67	No Action	67	$0	$799,079	0.519	$0
8.68	No Action	68	$0	$799,079	0.514	$0
8.69	No Action	69	$0	$799,079	0.509	$0
8.70	Monitoring & 5-year Review	70	$34,523	$833,602	0.504	$17,415
8.71	No Action	71	$0	$833,602	0.500	$0
8.72	No Action	72	$0	$833,602	0.495	$0
8.73	No Action	73	$0	$833,602	0.490	$0
8.74	No Action	74	$0	$833,602	0.485	$0
8.75	Monitoring & 5-year Review	75	$34,523	$868,125	0.480	$16,585
8.76	No Action	76	$0	$868,125	0.476	$0
8.77	No Action	77	$0	$868,125	0.471	$0
8.78	No Action	78	$0	$868,125	0.467	$0
8.79	No Action	79	$0	$868,125	0.462	$0
8.80	Monitoring & 5-year Review	80	$34,523	$902,648	0.457	$15,794
8.81	No Action	81	$0	$902,648	0.453	$0
8.82	No Action	82	$0	$902,648	0.449	$0
8.83	No Action	83	$0	$902,648	0.444	$0
8.84	No Action	84	$0	$902,648	0.440	$0
8.85	Monitoring & 5-year Review	85	$34,523	$937,171	0.436	$15,040
8.86	No Action	86	$0	$937,171	0.431	$0
8.87	No Action	87	$0	$937,171	0.427	$0
8.88	No Action	88	$0	$937,171	0.423	$0
8.89	No Action	89	$0	$937,171	0.419	$0
8.90	Monitoring & 5-year Review	90	$34,523	$971,694	0.415	$14,323
8.91	No Action	91	$0	$971,694	0.411	$0
8.92	No Action	92	$0	$971,694	0.407	$0
8.93	No Action	93	$0	$971,694	0.403	$0
8.94	No Action	94	$0	$971,694	0.399	$0
8.95	Monitoring & 5-year Review	95	$34,523	$1,006,217	0.395	$13,640
8.96	No Action	96	$0	$1,006,217	0.391	$0
8.97	No Action	97	$0	$1,006,217	0.387	$0
8.98	No Action	98	$0	$1,006,217	0.384	$0
8.99	No Action	99	$0	$1,006,217	0.380	$0
9.00	Monitoring & 5-year Review	100	$34,523	$1,040,740	0.376	$12,989
9.01	No Action	101	$0	$1,040,740	0.373	$0
9.02	No Action	102	$0	$1,040,740	0.369	$0
9.03	No Action	103	$0	$1,040,740	0.365	$0
9.04	No Action	104	$0	$1,040,740	0.362	$0
9.05	Monitoring & 5-year Review	105	$34,523	$1,075,263	0.358	$12,369
9.06	No Action	106	$0	$1,075,263	0.355	$0
9.07	No Action	107	$0	$1,075,263	0.351	$0
9.08	No Action	108	$0	$1,075,263	0.348	$0
9.09	No Action	109	$0	$1,075,263	0.345	$0
9.10	Monitoring & 5-year Review	110	$34,523	$1,109,786	0.341	$11,779
9.11	No Action	111	$0	$1,109,786	0.338	$0
9.12	No Action	112	$0	$1,109,786	0.335	$0
9.13	No Action	113	$0	$1,109,786	0.331	$0
9.14	No Action	114	$0	$1,109,786	0.328	$0
9.15	Monitoring & 5-year Review	115	$34,523	$1,144,309	0.325	$11,217
9.16	No Action	116	$0	$1,144,309	0.322	$0
9.17	No Action	117	$0	$1,144,309	0.319	$0
9.18	No Action	118	$0	$1,144,309	0.316	$0
9.19	No Action	119	$0	$1,144,309	0.312	$0
9.20	Monitoring & 5-year Review	120	$34,523	$1,178,832	0.309	$10,682
9.21	No Action	121	$0	$1,178,832	0.306	$0
9.22	No Action	122	$0	$1,178,832	0.303	$0
9.23	No Action	123	$0	$1,178,832	0.300	$0
9.24	No Action	124	$0	$1,178,832	0.298	$0
9.25	Monitoring & 5-year Review	125	$34,523	$1,213,355	0.295	$10,173
9.26	No Action	126	$0	$1,213,355	0.292	$0
9.27	No Action	127	$0	$1,213,355	0.289	$0
9.28	No Action	128	$0	$1,213,355	0.286	$0
9.29	No Action	129	$0	$1,213,355	0.283	$0
9.30	Monitoring & 5-year Review	130	$34,523	$1,247,878	0.281	$9,688
9.31	No Action	131	$0	$1,247,878	0.278	$0
9.32	No Action	132	$0	$1,247,878	0.275	$0

9.33	No Action	133	$0	$1,247,878	0.273	$0
9.34	No Action	134	$0	$1,247,878	0.270	$0
9.35	Monitoring & 5-year Review	135	$34,523	$1,282,401	0.267	$9,225
9.36	No Action	136	$0	$1,282,401	0.265	$0
9.37	No Action	137	$0	$1,282,401	0.262	$0
9.38	No Action	138	$0	$1,282,401	0.260	$0
9.39	No Action	139	$0	$1,282,401	0.257	$0
9.40	Monitoring & 5-year Review	140	$34,523	$1,316,924	0.254	$8,785
9.41	No Action	141	$0	$1,316,924	0.252	$0
9.42	No Action	142	$0	$1,316,924	0.250	$0
9.43	No Action	143	$0	$1,316,924	0.247	$0
9.44	No Action	144	$0	$1,316,924	0.245	$0
9.45	Monitoring & 5-year Review	145	$34,523	$1,351,447	0.242	$8,366
9.46	No Action	146	$0	$1,351,447	0.240	$0
9.47	No Action	147	$0	$1,351,447	0.238	$0
9.48	No Action	148	$0	$1,351,447	0.235	$0
9.49	No Action	149	$0	$1,351,447	0.233	$0
9.50	Monitoring, 5-year Review, & Remedy Complete	150	$97,813	$1,449,260	0.231	$22,573
TOTAL PROJECT COSTS			**$1,449,260**			**$895,043**

COST SUMMARIES	**CURRENT DOLLAR**	**NPV**
Costs through Year 10	**$420,000**	**$415,000**
Costs through Year 30	**$558,000**	**$526,000**
Costs through Project Closeout	**$1,450,000**	**$896,000**

ALTERNATIVE 2 COST ESTIMATE SUMMARY

Containment (Area 1), ISB (Area 2) and MNA (Area 3) Appendix C - Sheet 2

Site: Libby Groundwater Site **Phase:** FFS Costing **Base Year:** 2019

Location: Libby, MT **Date:** February 2018 **Duration:** 150 Years

Description: Hydraulic containment in Area 1 includes 6 new extraction wells, 4 re-injection wells (2 new and 2 existing), and large-scale upgrades to the existing bioreactor facility to hydraulically contain groundwater in Area 1. Hydraulic containment in Area 1 is anticipated to occur from Year 0 to 150 based on mass reduction rates via NSZD. ISB in Area 2 utilizes a transect of 24 deep injection points (formed by two rows and 4 zones) that operate for 2 hours three times daily. ISB in Area 2 is assumed to occur from Year 0 to 41 based on contaminant reduction rates. MNA in Area 3 is anticipated to occur from Year 0 to 10 assuming source cutoff.

CAPITAL COSTS (YEAR 0):

Item No.	DESCRIPTION & NOTES	UNIT	UNIT COST	QUANTITY	TOTAL (ROUNDED)
1.00	**Mobilization / Demobilization**				**$73,210**
1.01	Drill Rigs & Supporting Equipment	LS	$12,500	1	$12,500
1.02	Work & Implementation Plans (SAP, QAPP, SWP)	LS	$20,000	1	$20,000
1.03	Coordination - Access Agreements	LS	$4,000	1	$4,000
1.04	Temporary Facilities & Utilities (fence, roads, signs, trailers)	month	$2,000	6	$12,000
1.05	Completion Report	EA	$12,000	1	$12,000
1.06	*Project Management*	*%*		*10*	*$6,050*
1.07	*Contingency*	*%*		*10*	*$6,660*
2.00	**Bioreactor Facility Upgrade**				**$2,868,580**
2.01	Decommission Existing Treatment System	LS	$202,000	1	$202,000
2.02	Concrete Tank	LS	$62,500	1	$62,500
2.03	Oil-water separator	LS	$225,000	0	$0
2.04	Trickling Filter Rotary Distributor (excludes tank)	EA	$46,500	2	$93,000
2.05	Media Filter	EA	$117,500	2	$235,000
2.06	GAC Treatment Train (three 20,000-lb vessels)	LS	$1,500,000	1	$1,500,000
2.07	Reconnect Utilities	LS	$15,000	1	$15,000
2.08	Abandon/Remove Existing Conveyance Piping	ft	$15	370	$5,550
2.09	Abandon Existing Wells	ft	$15	600	$9,000
2.10	Oversight, Documentation, & Per Diem	day	$1,350	20	$27,000
2.11	System Testing/Startup	EA	$20,000	1	$20,000
2.12	*Project Management*	*%*		*15*	*$325,360*
2.13	*Contingency*	*%*		*15*	*$374,170*
3.00	**Hydraulic Containment System Construction**				**$351,660**
3.01	35-ft 4" Extraction Well Installation	well	$5,550	5	$27,750
3.02	75-ft 4" Extraction Well Installation	well	$11,875	1	$11,875
3.03	35-ft 2" Re-Injection Well Installation	well	$5,060	2	$10,120
3.04	Well Development	well	$800	8	$6,400
3.05	Trenching and Conveyance Pipe Installation	ft	$25	1,280	$32,000
3.06	Pump cost, installation, and testing/startup	well	$13,000	6	$78,000
3.07	Utility connection & electrical controls	LS	$45,000	1	$45,000
3.08	Subcontractor Crew Per Diem & Lodging	day	$525	25	$13,125
3.09	Oversight, Documentation, & Per Diem	day	$1,350	25	$33,750
3.10	Evaluation and Reporting	report	$15,000	1	$15,000
3.11	*Project Management*	*%*		*12*	*$32,770*
3.12	*Contingency*	*%*		*15*	*$45,870*
4.00	**ISB Injection Well Installation - Area 2**				**$460,470**
4.01	Install Deep Injection Well (80 ft bgs)	well	$11,600	24	$278,400
4.02	Well Development	well	$800	24	$19,200
4.03	Subcontractor Crew Per Diem & Lodging	day	$525	24	$12,600
4.04	Oversight, Documentation, & Per Diem	day	$1,350	24	$32,400
4.05	*Project Management*	*%*		*12*	*$41,120*
4.06	*Contingency*	*%*		*20*	*$76,750*
5.00	**ISB System Setup & Testing - Area 2**				**$137,630**
5.01	Remedial Skid - Area 2 (1 compressor, 4 zones)	EA	$50,000	1	$50,000
5.02	Electrical Hookup & Controls	skid	$17,000	1	$17,000
5.03	Piping & Connections	ft	$10	1,920	$19,200
5.04	Field Testing/Startup	day	$1,350	12	$16,200
5.05	*Project Management*	*%*		*12*	*$12,290*
5.06	*Contingency*	*%*		*20*	*$22,940*

6.00	**IDW Management & Disposal**				**$30,216**
6.01	Solid IDW (soil cuttings)	drum	$200	72	$14,400
6.02	Liquid IDW (decon & purged groundwater)	drum	$131	0	$0
6.03	NAPL IDW	gal	$2.60	10	$26
6.04	Soil Analysis & Profiling	EA	$730	8	$5,840
6.05	Liquid Analysis & Profiling	EA	$605	0	$0
6.06	NAPL Analysis & Profiling	EA	$600	1	$600
6.07	Transportation to TSDF	drum	$60	76	$4,560
6.08	*Project Management*	*%*		*8*	*$2,040*
6.09	*Contingency*	*%*		*10*	*$2,750*
7.00	**SUBTOTAL**				**$3,921,766**
8.00	**Additional Costs**				
8.01	Remedial Design	%		8	$313,750
8.02	Construction Management	%		6	$235,310
8.03	Institutional Controls	LS	$12,000	1	$12,000
9.00	**TOTAL CAPITAL COST**				**$4,482,826**
ANNUAL O&M COSTS:					
10.00	**Groundwater Monitoring & Reporting - Areas 1, 2, & 3 (Years 0-10)**				**$28,091**
10.01	Sampling Upper Aquifer Wells	well	$250	27	$6,750
10.02	Groundwater analytical	sample	$196	30	$5,880
10.03	Evaluation and Reporting	report	$12,000	1	$12,000
10.04	Liquid IDW (decon & purged groundwater)	drum	$131	1	$131
10.05	*Project Management*	*%*		*8*	*$1,990*
10.06	*Contingency*	*%*		*5*	*$1,340*
11.00	**Groundwater Monitoring & Reporting - Areas 1 & 2 (Years 11-46)**				**$23,915**
11.01	Sampling Upper Aquifer Wells	well	$250	21	$5,250
11.02	Groundwater analytical	sample	$196	24	$4,704
11.03	Evaluation and Reporting	report	$11,000	1	$11,000
11.04	Liquid IDW (decon & purged groundwater)	drum	$131	1	$131
11.05	*Project Management*	*%*		*8*	*$1,690*
11.06	*Contingency*	*%*		*5*	*$1,140*
12.00	**Groundwater Monitoring & Reporting - Area 1 (Years 47-150)**				**$15,775**
12.01	Sampling Upper Aquifer Wells	well	$250	8	$2,000
12.02	Groundwater analytical	sample	$196	9	$1,764
12.03	Evaluation and Reporting	report	$10,000	1	$10,000
12.04	Liquid IDW (decon & purged groundwater)	drum	$131	1	$131
12.05	*Project Management*	*%*		*8*	*$1,120*
12.06	*Contingency*	*%*		*5*	*$760*
13.00	**Containment-P&T System Operation - Area 1 (Years 0-145)**				**$1,163,052**
13.01	System O&M & Annualized Replacements	qtr	$4,100	4	$16,400
13.02	GAC Consumption (dispose & replace)	lb	$3.40	210,000	$714,000
13.03	NAPL Disposal (price ajdusted to include transportation)	gal	$3.70	160	$592
13.04	Performance Monitoring	qtr	$6,000	4	$24,000
13.05	Annual Reporting	yr	$8,000	1	$8,000
13.06	System Utilities (reactor & pumps)	mo	$18,000	12	$216,000
13.07	*Project Management*	*%*		*8*	*$78,320*
13.08	*Contingency*	*%*		*10*	*$105,740*
14.00	**ISB Operation - Area 2 (Years 0-41)**				**$83,650**
14.01	System O&M & Annualized Replacements	qtr	$5,200	4	$20,800
14.02	Performance Monitoring & Evaluation	qtr	$3,400	4	$13,600
14.03	O&M Annual Report	rpt	$7,200	1	$7,200
14.04	Annual Utilities	yr	$28,800	1	$28,800
14.05	*Project Management*	*%*		*8*	*$5,640*
14.06	*Contingency*	*%*		*10*	*$7,610*
15.00	**TOTAL O&M COSTS** (*through project closeout*)				**$175,492,037**

PERIODIC COSTS:

16.00	**Recurring Five Year Expenditures (Years 5-145)**				**$20,950**
16.01	Five Year Review Report	EA	$15,000	1	$15,000
16.02	Update Institutional Controls Plan	EA	$4,000	1	$4,000
16.03	*Project Management*	*%*		*5*	*$950*
16.04	*Contingency*	*%*		*5*	*$1,000*
17.00	**Area 1 Decommissioning (Year 145)**				**$467,715**
17.01	Mob/Demob	LS	$10,000	1	$10,000
17.02	Subcontractor Crew Per Diem & Lodging	day	$525	21	$11,025
17.03	Soil Confirmation Borings	boring	$6,400	12	$76,800
17.04	Laboratory Analysis	sample	$119	40	$4,760
17.05	Decommission P&T and Bioreactor System	LS	$250,000	1	$250,000
17.06	Extraction & Re-Injection Well Abandonment	LS	$5,600	1	$5,600
17.07	Oversight, Documentation, & Per Diem	day	$1,350	21	$28,350
17.08	*Project Management*	*%*		*10*	*$38,660*
17.09	*Contingency*	*%*		*10*	*$42,520*
18.00	**Area 2 Decommissioning (Year 41)**				**$205,075**
18.01	Mob/Demob	LS	$10,000	1	$10,000
18.02	Subcontractor Crew Per Diem & Lodging	day	$525	15	$7,875
18.03	Soil Confirmation Borings	boring	$8,500	9	$76,500
18.04	Laboratory Analysis	sample	$119	30	$3,570
18.05	Decommission ISB System	EA	$16,000	1	$16,000
18.06	80-ft Injection Well Abandonment	well	$1,470	24	$35,280
18.07	Oversight, Documentation, & Per Diem	day	$1,350	15	$20,250
18.08	*Project Management*	*%*		*10*	*$16,950*
18.09	*Contingency*	*%*		*10*	*$18,650*
19.00	**Remedy Complete (Year 150)**				**$80,160**
19.01	Mob/Demob	LS	$7,000	1	$7,000
19.02	Monitoring Well Abandonment	well	$990	40	$39,600
19.03	Oversight, Documentation, & Per Diem	day	$1,350	8	$10,800
19.04	Reporting	EA	$12,000	1	$12,000
19.05	*Project Management*	*%*		*10*	*$6,940*
19.06	*Contingency*	*%*		*5*	*$3,820*
20.00	**TOTAL PERIODIC COSTS** (*through project closeout*)				**$1,360,500**

PROJECT COST SCHEDULE & PRESENT VALUE ANALYSIS

Item No.	DESCRIPTION	YEAR	PERIOD COST	CUMULATIVE COST	DISCOUNT FACTOR	PERIOD NET PRESENT VALUE
21.00	**O&M Cost**					
21.00	Implement P&T and ISB & 6-mo Operation	0	$5,120,223	$5,120,223	1.000	$5,120,223
21.01	P&T in Area 1, ISB in Area 2, MNA Area 3	1	$1,274,793	$6,395,016	0.990	$1,262,392
21.02	P&T in Area 1, ISB in Area 2, MNA Area 3	2	$1,274,793	$7,669,809	0.981	$1,250,112
21.03	P&T in Area 1, ISB in Area 2, MNA Area 3	3	$1,274,793	$8,944,602	0.971	$1,237,952
21.04	P&T in Area 1, ISB in Area 2, MNA Area 3	4	$1,274,793	$10,219,395	0.962	$1,225,909
21.05	P&T in Area 1, ISB in Area 2, MNA Area 3 & 5-yr Review	5	$1,295,743	$11,515,138	0.952	$1,233,935
21.06	P&T in Area 1, ISB in Area 2, MNA Area 3	6	$1,274,793	$12,789,931	0.943	$1,202,175
21.07	P&T in Area 1, ISB in Area 2, MNA Area 3	7	$1,274,793	$14,064,724	0.934	$1,190,481
21.08	P&T in Area 1, ISB in Area 2, MNA Area 3	8	$1,274,793	$15,339,517	0.925	$1,178,900
21.09	P&T in Area 1, ISB in Area 2, MNA Area 3	9	$1,274,793	$16,614,310	0.916	$1,167,432
21.10	P&T in Area 1, ISB in Area 2, MNA Area 3	10	$1,295,743	$17,910,053	0.907	$1,175,075
21.11	P&T in Area 1, ISB in Area 2	11	$1,270,617	$19,180,670	0.898	$1,141,080
21.12	P&T in Area 1, ISB in Area 2	12	$1,270,617	$20,451,287	0.889	$1,129,980
21.13	P&T in Area 1, ISB in Area 2	13	$1,270,617	$21,721,904	0.881	$1,118,988
21.14	P&T in Area 1, ISB in Area 2	14	$1,270,617	$22,992,521	0.872	$1,108,103
21.15	P&T in Area 1, ISB in Area 2 & 5-yr Review	15	$1,291,567	$24,284,088	0.864	$1,115,416
21.16	P&T in Area 1, ISB in Area 2	16	$1,270,617	$25,554,705	0.855	$1,086,649
21.17	P&T in Area 1, ISB in Area 2	17	$1,270,617	$26,825,322	0.847	$1,076,078
21.18	P&T in Area 1, ISB in Area 2	18	$1,270,617	$28,095,939	0.839	$1,065,611
21.19	P&T in Area 1, ISB in Area 2	19	$1,270,617	$29,366,556	0.830	$1,055,245
21.20	P&T in Area 1, ISB in Area 2 & 5-yr Review	20	$1,291,567	$30,658,123	0.822	$1,062,210
21.21	P&T in Area 1, ISB in Area 2	21	$1,270,617	$31,928,740	0.814	$1,034,815
21.22	P&T in Area 1, ISB in Area 2	22	$1,270,617	$33,199,357	0.806	$1,024,748
21.23	P&T in Area 1, ISB in Area 2	23	$1,270,617	$34,469,974	0.799	$1,014,780
21.24	P&T in Area 1, ISB in Area 2	24	$1,270,617	$35,740,591	0.791	$1,004,909
21.25	P&T in Area 1, ISB in Area 2 & 5-yr Review	25	$1,291,567	$37,032,158	0.783	$1,011,541
21.26	P&T in Area 1, ISB in Area 2	26	$1,270,617	$38,302,775	0.776	$985,453
21.27	P&T in Area 1, ISB in Area 2	27	$1,270,617	$39,573,392	0.768	$975,867
21.28	P&T in Area 1, ISB in Area 2	28	$1,270,617	$40,844,009	0.761	$966,374
21.29	P&T in Area 1, ISB in Area 2	29	$1,270,617	$42,114,626	0.753	$956,973
21.30	P&T in Area 1, ISB in Area 2 & 5-yr Review	30	$1,291,567	$43,406,193	0.746	$963,290
21.31	P&T in Area 1, ISB in Area 2	31	$1,270,617	$44,676,810	0.739	$938,446
21.32	P&T in Area 1, ISB in Area 2	32	$1,270,617	$45,947,427	0.731	$929,317
21.33	P&T in Area 1, ISB in Area 2	33	$1,270,617	$47,218,044	0.724	$920,277
21.34	P&T in Area 1, ISB in Area 2	34	$1,270,617	$48,488,661	0.717	$911,325
21.35	P&T in Area 1, ISB in Area 2 & 5-yr Review	35	$1,291,567	$49,780,228	0.710	$917,340
21.36	P&T in Area 1, ISB in Area 2	36	$1,270,617	$51,050,845	0.703	$893,681
21.37	P&T in Area 1, ISB in Area 2	37	$1,270,617	$52,321,462	0.697	$884,988
21.38	P&T in Area 1, ISB in Area 2	38	$1,270,617	$53,592,079	0.690	$876,379
21.39	P&T in Area 1, ISB in Area 2	39	$1,270,617	$54,862,696	0.683	$867,854
21.40	P&T in Area 1, ISB in Area 2 & 5-yr Review	40	$1,291,567	$56,154,263	0.676	$873,582
21.41	P&T in Area 1, ISB and Decommission Area 2	41	$1,475,692	$57,629,955	0.670	$988,410
21.42	P&T in Area 1, MNA in Area 2	42	$1,186,967	$58,816,922	0.663	$787,290
21.43	P&T in Area 1, MNA in Area 2	43	$1,186,967	$60,003,889	0.657	$779,631
21.44	P&T in Area 1, MNA in Area 2	44	$1,186,967	$61,190,856	0.650	$772,047
21.45	P&T in Area 1, MNA in Area 2, & 5-yr Review	45	$1,207,917	$62,398,773	0.644	$778,031
21.46	P&T in Area 1, MNA in Area 2	46	$1,186,967	$63,585,740	0.638	$757,100
21.47	P&T in Area 1	47	$1,178,827	$64,764,567	0.632	$744,594
21.48	P&T in Area 1	48	$1,178,827	$65,943,394	0.625	$737,350
21.49	P&T in Area 1	49	$1,178,827	$67,122,221	0.619	$730,178
21.50	P&T in Area 1 & 5-yr Review	50	$1,199,777	$68,321,998	0.613	$735,925
21.51	P&T in Area 1	51	$1,178,827	$69,500,825	0.607	$716,041
21.52	P&T in Area 1	52	$1,178,827	$70,679,652	0.602	$709,076
21.53	P&T in Area 1	53	$1,178,827	$71,858,479	0.596	$702,178
21.54	P&T in Area 1	54	$1,178,827	$73,037,306	0.590	$695,347
21.55	P&T in Area 1 & 5-yr Review	55	$1,199,777	$74,237,083	0.584	$700,821
21.56	P&T in Area 1	56	$1,178,827	$75,415,910	0.578	$681,885
21.57	P&T in Area 1	57	$1,178,827	$76,594,737	0.573	$675,252
21.58	P&T in Area 1	58	$1,178,827	$77,773,564	0.567	$668,683
21.59	P&T in Area 1	59	$1,178,827	$78,952,391	0.562	$662,179
21.60	P&T in Area 1 & 5-yr Review	60	$1,199,777	$80,152,168	0.556	$667,391
21.61	P&T in Area 1	61	$1,178,827	$81,330,995	0.551	$649,359
21.62	P&T in Area 1	62	$1,178,827	$82,509,822	0.545	$643,042
21.63	P&T in Area 1	63	$1,178,827	$83,688,649	0.540	$636,787

21.64	P&T in Area 1	64	$1,178,827	$84,867,476	0.535	$630,592
21.65	P&T in Area 1 & 5-yr Review	65	$1,199,777	$86,067,253	0.530	$635,556
21.66	P&T in Area 1	66	$1,178,827	$87,246,080	0.525	$618,383
21.67	P&T in Area 1	67	$1,178,827	$88,424,907	0.519	$612,368
21.68	P&T in Area 1	68	$1,178,827	$89,603,734	0.514	$606,411
21.69	P&T in Area 1	69	$1,178,827	$90,782,561	0.509	$600,512
21.70	P&T in Area 1 & 5-yr Review	70	$1,199,777	$91,982,338	0.504	$605,239
21.71	P&T in Area 1	71	$1,178,827	$93,161,165	0.500	$588,886
21.72	P&T in Area 1	72	$1,178,827	$94,339,992	0.495	$583,157
21.73	P&T in Area 1	73	$1,178,827	$95,518,819	0.490	$577,485
21.74	P&T in Area 1	74	$1,178,827	$96,697,646	0.485	$571,867
21.75	P&T in Area 1 & 5-yr Review	75	$1,199,777	$97,897,423	0.480	$576,369
21.76	P&T in Area 1	76	$1,178,827	$99,076,250	0.476	$560,795
21.77	P&T in Area 1	77	$1,178,827	$100,255,077	0.471	$555,340
21.78	P&T in Area 1	78	$1,178,827	$101,433,904	0.467	$549,938
21.79	P&T in Area 1	79	$1,178,827	$102,612,731	0.462	$544,589
21.80	P&T in Area 1 & 5-yr Review	80	$1,199,777	$103,812,508	0.457	$548,875
21.81	P&T in Area 1	81	$1,178,827	$104,991,335	0.453	$534,045
21.82	P&T in Area 1	82	$1,178,827	$106,170,162	0.449	$528,850
21.83	P&T in Area 1	83	$1,178,827	$107,348,989	0.444	$523,705
21.84	P&T in Area 1	84	$1,178,827	$108,527,816	0.440	$518,611
21.85	P&T in Area 1 & 5-yr Review	85	$1,199,777	$109,727,593	0.436	$522,693
21.86	P&T in Area 1	86	$1,178,827	$110,906,420	0.431	$508,570
21.87	P&T in Area 1	87	$1,178,827	$112,085,247	0.427	$503,623
21.88	P&T in Area 1	88	$1,178,827	$113,264,074	0.423	$498,724
21.89	P&T in Area 1	89	$1,178,827	$114,442,901	0.419	$493,873
21.90	P&T in Area 1 & 5-yr Review	90	$1,199,777	$115,642,678	0.415	$497,760
21.91	P&T in Area 1	91	$1,178,827	$116,821,505	0.411	$484,311
21.92	P&T in Area 1	92	$1,178,827	$118,000,332	0.407	$479,600
21.93	P&T in Area 1	93	$1,178,827	$119,179,159	0.403	$474,935
21.94	P&T in Area 1	94	$1,178,827	$120,357,986	0.399	$470,315
21.95	P&T in Area 1 & 5-yr Review	95	$1,199,777	$121,557,763	0.395	$474,017
21.96	P&T in Area 1	96	$1,178,827	$122,736,590	0.391	$461,209
21.97	P&T in Area 1	97	$1,178,827	$123,915,417	0.387	$456,723
21.98	P&T in Area 1	98	$1,178,827	$125,094,244	0.384	$452,280
21.99	P&T in Area 1	99	$1,178,827	$126,273,071	0.380	$447,880
22.00	P&T in Area 1 & 5-yr Review	100	$1,199,777	$127,472,848	0.376	$451,406
22.01	P&T in Area 1	101	$1,178,827	$128,651,675	0.373	$439,209
22.02	P&T in Area 1	102	$1,178,827	$129,830,502	0.369	$434,936
22.03	P&T in Area 1	103	$1,178,827	$131,009,329	0.365	$430,705
22.04	P&T in Area 1	104	$1,178,827	$132,188,156	0.362	$426,516
22.05	P&T in Area 1 & 5-yr Review	105	$1,199,777	$133,387,933	0.358	$429,873
22.06	P&T in Area 1	106	$1,178,827	$134,566,760	0.355	$418,258
22.07	P&T in Area 1	107	$1,178,827	$135,745,587	0.351	$414,189
22.08	P&T in Area 1	108	$1,178,827	$136,924,414	0.348	$410,160
22.09	P&T in Area 1	109	$1,178,827	$138,103,241	0.345	$406,171
22.10	P&T in Area 1 & 5-yr Review	110	$1,199,777	$139,303,018	0.341	$409,368
22.11	P&T in Area 1	111	$1,178,827	$140,481,845	0.338	$398,307
22.12	P&T in Area 1	112	$1,178,827	$141,660,672	0.335	$394,432
22.13	P&T in Area 1	113	$1,178,827	$142,839,499	0.331	$390,595
22.14	P&T in Area 1	114	$1,178,827	$144,018,326	0.328	$386,796
22.15	P&T in Area 1 & 5-yr Review	115	$1,199,777	$145,218,103	0.325	$389,840
22.16	P&T in Area 1	116	$1,178,827	$146,396,930	0.322	$379,307
22.17	P&T in Area 1	117	$1,178,827	$147,575,757	0.319	$375,617
22.18	P&T in Area 1	118	$1,178,827	$148,754,584	0.316	$371,964
22.19	P&T in Area 1	119	$1,178,827	$149,933,411	0.312	$368,345
22.20	P&T in Area 1 & 5-yr Review	120	$1,199,777	$151,133,188	0.309	$371,245
22.21	P&T in Area 1	121	$1,178,827	$152,312,015	0.306	$361,214
22.22	P&T in Area 1	122	$1,178,827	$153,490,842	0.303	$357,700
22.23	P&T in Area 1	123	$1,178,827	$154,669,669	0.300	$354,220
22.24	P&T in Area 1	124	$1,178,827	$155,848,496	0.298	$350,775
22.25	P&T in Area 1 & 5-yr Review	125	$1,199,777	$157,048,273	0.295	$353,536
22.26	P&T in Area 1	126	$1,178,827	$158,227,100	0.292	$343,984
22.27	P&T in Area 1	127	$1,178,827	$159,405,927	0.289	$340,637
22.28	P&T in Area 1	128	$1,178,827	$160,584,754	0.286	$337,324
22.29	P&T in Area 1	129	$1,178,827	$161,763,581	0.283	$334,042
22.30	P&T in Area 1 & 5-yr Review	130	$1,199,777	$162,963,358	0.281	$336,672
22.31	P&T in Area 1	131	$1,178,827	$164,142,185	0.278	$327,575
22.32	P&T in Area 1	132	$1,178,827	$165,321,012	0.275	$324,389

22.33	P&T in Area 1	133	$1,178,827	$166,499,839	0.273	$321,233
22.34	P&T in Area 1	134	$1,178,827	$167,678,666	0.270	$318,108
22.35	P&T in Area 1 & 5-yr Review	135	$1,199,777	$168,878,443	0.267	$320,612
22.36	P&T in Area 1	136	$1,178,827	$170,057,270	0.265	$311,949
22.37	P&T in Area 1	137	$1,178,827	$171,236,097	0.262	$308,915
22.38	P&T in Area 1	138	$1,178,827	$172,414,924	0.260	$305,910
22.39	P&T in Area 1	139	$1,178,827	$173,593,751	0.257	$302,934
22.40	P&T in Area 1 & 5-yr Review	140	$1,199,777	$174,793,528	0.254	$305,319
22.41	P&T in Area 1	141	$1,178,827	$175,972,355	0.252	$297,069
22.42	P&T in Area 1	142	$1,178,827	$177,151,182	0.250	$294,179
22.43	P&T in Area 1	143	$1,178,827	$178,330,009	0.247	$291,318
22.44	P&T in Area 1	144	$1,178,827	$179,508,836	0.245	$288,484
22.45	P&T in Area 1, Decommision Area 1, & 5-yr Review	145	$1,667,492	$181,176,328	0.242	$404,101
22.46	MNA in Area 1	146	$15,775	$181,192,103	0.240	$3,786
22.47	MNA in Area 1	147	$15,775	$181,207,878	0.238	$3,749
22.48	MNA in Area 1	148	$15,775	$181,223,653	0.235	$3,712
22.49	MNA in Area 1	149	$15,775	$181,239,428	0.233	$3,676
22.50	MNA in Area 1 & Remedy Complete	150	$95,935	$181,335,363	0.231	$22,140
TOTAL PROJECT COSTS			**$181,335,363**			**$99,799,065**

COST SUMMARIES	CURRENT DOLLAR	NPV
Costs through Year 10	**$17,911,000**	**$17,245,000**
Costs through Year 30	**$43,407,000**	**$38,143,000**
Costs through Project Closeout	**$181,336,000**	**$99,800,000**

ALTERNATIVE 3 COST ESTIMATE SUMMARY

ISB (Areas 1 & 2) and MNA (Area 3) Appendix C - Sheet 3

Site: Libby Groundwater Site **Phase:** FFS Costing **Base Year:** 2019

Location: Libby, MT **Date:** February 2018 **Duration:** 46 Years

Description: ISB in Area 1 utilizes 44 shallow and 11 deep (collocated) injection points comprising 8 shallow and 2 deep zones that operate for 2 and 4 hours three times daily, respectively. ISB in Area 1 is anticipated to occur from Year 0 to 6 based on source degradation, after which MNA is performed until Year 11. ISB in Area 2 utilizes a transect of 24 deep injection points (formed by two rows and 4 zones) that operate for 2 hours three times daily. ISB in Area 2 is assumed to occur from Year 0 to 41 based on contaminant reduction rates. MNA in Area 3 is anticipated to occur from Year 0 to 10 assuming source cutoff.

CAPITAL COSTS (YEAR 0):

Item No.	DESCRIPTION & NOTES	UNIT	UNIT COST	QUANTITY	TOTAL (ROUNDED)
1.00	**Mobilization / Demobilization**				**$73,210**
1.01	Drill Rigs & Supporting Equipment	LS	$12,500	1	$12,500
1.02	Work & Implementation Plans (SAP, QAPP, SWP)	LS	$20,000	1	$20,000
1.03	Coordination - Access Agreements	LS	$4,000	1	$4,000
1.04	Temporary Facilities & Utilities (fence, roads, signs, trailers)	month	$2,000	6	$12,000
1.05	Completion Report	EA	$12,000	1	$12,000
1.06	*Project Management*	*%*		*10*	*$6,050*
1.07	*Contingency*	*%*		*10*	*$6,660*
2.00	**SAETS Decommissioning**				**$361,120**
2.01	Decommission Treatment System	LS	$202,000	1	$202,000
2.02	Demo Bioreactor Facility Building (offset by salvage)	LS	$8,000	1	$8,000
2.03	Remove Tanks, Towers, Piping at Bioreactor Facility	LS	$35,000	1	$35,000
2.04	Abandon/Remove Existing Conveyance Piping	ft	$15	370	$5,550
2.05	Abandon Existing Wells	ft	$15	600	$9,000
2.06	Oversight, Documentation, & Per Diem	day	$1,350	10	$13,500
2.07	*Project Management*	*%*		*15*	*$40,960*
2.08	*Contingency*	*%*		*15*	*$47,110*
3.00	**ISB Injection Well Installation - Areas 1 & 2**				**$1,106,895**
3.01	Install Shallow Injection Well (35 ft bgs)	well	$5,200	44	$228,800
3.02	Install Collocated Shallow-Deep Injection Well (35 & 75 ft bgs)	well	$13,300	11	$146,300
3.03	Install Deep Injection Well (80 ft bgs)	well	$11,600	24	$278,400
3.04	Well Development	well	$800	79	$63,200
3.05	Subcontractor Crew Per Diem & Lodging	day	$525	57	$29,925
3.06	Oversight, Documentation, & Per Diem	day	$1,350	57	$76,950
3.07	*Project Management*	*%*		*12*	*$98,830*
3.08	*Contingency*	*%*		*20*	*$184,490*
4.00	**ISB System Setup & Testing - Areas 1 & 2**				**$358,720**
4.01	Remedial Skid - Area 1 (2 compressors, 10 zones)	EA	$90,000	1	$90,000
4.02	Remedial Skid - Area 2 (1 compressor, 4 zones)	EA	$50,000	1	$50,000
4.03	Electrical Hookup & Controls	skid	$17,000	2	$34,000
4.04	Piping & Connections	ft	$10	6,320	$63,200
4.05	Field Testing/Startup	day	$1,350	22	$29,700
4.06	*Project Management*	*%*		*12*	*$32,030*
4.07	*Contingency*	*%*		*20*	*$59,790*
5.00	**IDW Management & Disposal**				**$59,777**
5.01	Solid IDW (soil cuttings)	drum	$200	146	$29,200
5.02	Liquid IDW (decon & purged groundwater)	drum	$131	0	$0
5.03	NAPL IDW	gal	$2.60	214	$557
5.04	Soil Analysis & Profiling	EA	$730	15	$10,950
5.05	Liquid Analysis & Profiling	EA	$605	0	$0
5.06	NAPL Analysis & Profiling	EA	$600	1	$600
5.07	Transportation to TSDF	drum	$60	150	$9,000
5.08	*Project Management*	*%*		*8*	*$4,030*
5.09	*Contingency*	*%*		*10*	*$5,440*
6.00	**SUBTOTAL**				**$1,959,722**
7.00	**Additional Costs**				
7.01	Remedial Design	%		8	$156,780
7.02	Construction Management	%		6	$117,590
7.03	Institutional Controls	LS	$12,000	1	$12,000
8.00	**TOTAL CAPITAL COST**				**$2,246,092**

ANNUAL O&M COSTS:

9.00	**Groundwater Monitoring & Reporting - Areas 1, 2, & 3 (Years 0-10)**				**$29,431**
9.01	Sampling Upper Aquifer Wells	well	$250	27	$6,750
9.02	Groundwater analytical	sample	$196	30	$5,880
9.03	Evaluation and Reporting	report	$12,000	1	$12,000
9.04	Liquid IDW (decon & purged groundwater)	drum	$131	1	$131
9.05	*Project Management*	*%*		*8*	*$1,990*
9.06	*Contingency*	*%*		*10*	*$2,680*
10.00	**Groundwater Monitoring & Reporting - Areas 1 & 2 (Year 11)**				**$25,055**
10.01	Sampling Upper Aquifer Wells	well	$250	21	$5,250
10.02	Groundwater analytical	sample	$196	24	$4,704
10.03	Evaluation and Reporting	report	$11,000	1	$11,000
10.04	Liquid IDW (decon & purged groundwater)	drum	$131	1	$131
10.05	*Project Management*	*%*		*8*	*$1,690*
10.06	*Contingency*	*%*		*10*	*$2,280*
11.00	**Groundwater Monitoring & Reporting - Area 2 (Years 12-46)**				**$19,401**
11.01	Sampling Upper Aquifer Wells	well	$250	13	$3,250
11.02	Groundwater analytical	sample	$196	15	$2,940
11.03	Evaluation and Reporting	report	$10,000	1	$10,000
11.04	Liquid IDW (decon & purged groundwater)	drum	$131	1	$131
11.05	*Project Management*	*%*		*8*	*$1,310*
11.06	*Contingency*	*%*		*10*	*$1,770*
12.00	**ISB Operation - Areas 1 & 2 (Years 1-6)**				**$174,530**
12.01	System O&M & Annualized Replacements	qtr	$8,600	4	$34,400
12.02	Performance Monitoring & Evaluation	qtr	$5,200	4	$20,800
12.03	O&M Annual Report	rpt	$9,600	1	$9,600
12.04	Annual Utilities	yr	$86,300	1	$86,300
12.05	*Project Management*	*%*		*5*	*$7,560*
12.06	*Contingency*	*%*		*10*	*$15,870*
13.00	**ISB Operation - Area 2 (Years 7-41)**				**$81,320**
13.01	System O&M & Annualized Replacements	qtr	$5,200	4	$20,800
13.02	Performance Monitoring & Evaluation	qtr	$3,400	4	$13,600
13.03	O&M Annual Report	rpt	$7,200	1	$7,200
13.04	Annual Utilities	yr	$28,800	1	$28,800
13.05	*Project Management*	*%*		*5*	*$3,520*
13.06	*Contingency*	*%*		*10*	*$7,400*
14.00	**TOTAL O&M COSTS** (*through project closeout*)				**$4,993,761**

PERIODIC COSTS:

15.00	**Recurring Five Year Expenditures (Years 5-45)**				**$20,950**
15.01	Five Year Review Report	EA	$15,000	1	$15,000
15.02	Update Institutional Controls Plan	EA	$4,000	1	$4,000
15.03	*Project Management*	*%*		*5*	*$950*
15.04	*Contingency*	*%*		*5*	*$1,000*
16.00	**Area 1 Decommissioning (Year 6)**				**$247,435**
16.01	Mob/Demob	LS	$10,000	1	$10,000
16.02	Subcontractor Crew Per Diem & Lodging	day	$525	21	$11,025
16.03	Soil Confirmation Borings	boring	$6,400	12	$76,800
16.04	Laboratory Analysis	sample	$119	40	$4,760
16.05	Decommission ISB System	EA	$18,000	1	$18,000
16.06	35-ft Injection Well Abandonment	well	$730	55	$40,150
16.07	75-ft Injection Well Abandonment	well	$1,400	11	$15,400
16.08	Oversight, Documentation, & Per Diem	day	$1,350	21	$28,350
16.09	*Project Management*	*%*		*10*	*$20,450*
16.10	*Contingency*	*%*		*10*	*$22,500*

17.00	**Area 2 Decommissioning (Year 41)**				**$205,075**
17.01	Mob/Demob	LS	$10,000	1	$10,000
17.02	Subcontractor Crew Per Diem & Lodging	day	$525	15	$7,875
17.03	Soil Confirmation Borings	boring	$8,500	9	$76,500
17.04	Laboratory Analysis	sample	$119	30	$3,570
17.05	Decommission ISB System	EA	$16,000	1	$16,000
17.06	80-ft Injection Well Abandonment	well	$1,470	24	$35,280
17.07	Oversight, Documentation, & Per Diem	day	$1,350	15	$20,250
17.08	*Project Management*	*%*		*10*	*$16,950*
17.09	*Contingency*	*%*		*10*	*$18,650*
18.00	**Remedy Complete (Year 46)**				**$80,160**
18.01	Mob/Demob	LS	$7,000	1	$7,000
18.02	Monitoring Well Abandonment	well	$990	40	$39,600
18.03	Oversight, Documentation, & Per Diem	day	$1,350	8	$10,800
18.03	Reporting	EA	$12,000	1	$12,000
18.04	*Project Management*	*%*		*10*	*$6,940*
18.05	*Contingency*	*%*		*5*	*$3,820*
19.00	**TOTAL PERIODIC COSTS** (*through project closeout*)				**$721,220**

PROJECT COST SCHEDULE & PRESENT VALUE ANALYSIS

Item No.	DESCRIPTION	YEAR	PERIOD COST	CUMULATIVE COST	DISCOUNT FACTOR	PERIOD NET PRESENT VALUE
20.00	**O&M Cost**					
20.00	Implement ISB & 6-mo Operation in Areas 1+2, MNA in Area 3	0	$2,348,073	$2,348,073	1.000	$2,348,073
20.01	ISB in Areas 1+2, MNA in Area 3	1	$203,961	$2,552,034	0.990	$201,977
20.02	ISB in Areas 1+2, MNA in Area 3	2	$203,961	$2,755,995	0.981	$200,012
20.03	ISB in Areas 1+2, MNA in Area 3	3	$203,961	$2,959,956	0.971	$198,067
20.04	ISB in Areas 1+2, MNA in Area 3	4	$203,961	$3,163,917	0.962	$196,140
20.05	ISB in Areas 1+2, MNA in Area 3 & 5-yr Review	5	$224,911	$3,388,828	0.952	$214,183
20.06	ISB in Areas 1+2, Decommission Area 1 ISB, MNA in Area 3	6	$451,396	$3,840,224	0.943	$425,682
20.07	ISB in Area 2, MNA in Areas 1+3	7	$110,751	$3,950,975	0.934	$103,426
20.08	ISB in Area 2, MNA in Areas 1+3	8	$110,751	$4,061,726	0.925	$102,420
20.09	ISB in Area 2, MNA in Areas 1+3	9	$110,751	$4,172,477	0.916	$101,424
20.10	ISB in Area 2, MNA in Areas 1+3 & 5-yr Review	10	$131,701	$4,304,178	0.907	$119,436
20.11	ISB in Area 2, MNA in Area 1	11	$106,375	$4,410,553	0.898	$95,530
20.12	ISB in Area 2	12	$100,721	$4,511,274	0.889	$89,573
20.13	ISB in Area 2	13	$100,721	$4,611,995	0.881	$88,701
20.14	ISB in Area 2	14	$100,721	$4,712,716	0.872	$87,839
20.15	ISB in Area 2 & 5-yr Review	15	$121,671	$4,834,387	0.864	$105,077
20.16	ISB in Area 2	16	$100,721	$4,935,108	0.855	$86,138
20.17	ISB in Area 2	17	$100,721	$5,035,829	0.847	$85,300
20.18	ISB in Area 2	18	$100,721	$5,136,550	0.839	$84,470
20.19	ISB in Area 2	19	$100,721	$5,237,271	0.830	$83,649
20.20	ISB in Area 2 & 5-yr Review	20	$121,671	$5,358,942	0.822	$100,065
20.21	ISB in Area 2	21	$100,721	$5,459,663	0.814	$82,029
20.22	ISB in Area 2	22	$100,721	$5,560,384	0.806	$81,231
20.23	ISB in Area 2	23	$100,721	$5,661,105	0.799	$80,441
20.24	ISB in Area 2	24	$100,721	$5,761,826	0.791	$79,658
20.25	ISB in Area 2 & 5-yr Review	25	$121,671	$5,883,497	0.783	$95,291
20.26	ISB in Area 2	26	$100,721	$5,984,218	0.776	$78,116
20.27	ISB in Area 2	27	$100,721	$6,084,939	0.768	$77,356
20.28	ISB in Area 2	28	$100,721	$6,185,660	0.761	$76,604
20.29	ISB in Area 2	29	$100,721	$6,286,381	0.753	$75,859
20.30	ISB in Area 2 & 5-yr Review	30	$121,671	$6,408,052	0.746	$90,746
20.31	ISB in Area 2	31	$100,721	$6,508,773	0.739	$74,390
20.32	ISB in Area 2	32	$100,721	$6,609,494	0.731	$73,666
20.33	ISB in Area 2	33	$100,721	$6,710,215	0.724	$72,950
20.34	ISB in Area 2	34	$100,721	$6,810,936	0.717	$72,240
20.35	ISB in Area 2 & 5-yr Review	35	$121,671	$6,932,607	0.710	$86,417
20.36	ISB in Area 2	36	$100,721	$7,033,328	0.703	$70,842
20.37	ISB in Area 2	37	$100,721	$7,134,049	0.697	$70,152
20.38	ISB in Area 2	38	$100,721	$7,234,770	0.690	$69,470
20.39	ISB in Area 2	39	$100,721	$7,335,491	0.683	$68,794
20.40	ISB in Area 2 & 5-yr Review	40	$121,671	$7,457,162	0.676	$82,295
20.41	ISB in Area 2, Decommision Area 2 ISB	41	$305,796	$7,762,958	0.670	$204,820
20.42	MNA in Area 2	42	$19,401	$7,782,359	0.663	$12,868
20.43	MNA in Area 2	43	$19,401	$7,801,760	0.657	$12,743

20.44	MNA in Area 2	44	$19,401	$7,821,161	0.650	$12,619
20.45	MNA in Area 2 & 5-yr Review	45	$40,351	$7,861,512	0.644	$25,990
20.46	MNA in Area 2 & Remedy Complete	46	$99,561	$7,961,073	0.638	$63,504
TOTAL PROJECT COSTS			**$7,961,073**			**$7,008,275**

COST SUMMARIES	**CURRENT DOLLAR**	**NPV**
Costs through Year 10	**$4,305,000**	**$4,211,000**
Costs through Year 30	**$6,409,000**	**$5,935,000**
Costs through Project Closeout	**$7,962,000**	**$7,009,000**

ALTERNATIVE 4 COST ESTIMATE SUMMARY

SEE + ISB (Area 1), ISB (Area 2) and MNA (Area 3) Appendix C - Sheet 4

Site: Libby Groundwater Site **Phase:** FFS Costing **Base Year:** 2019

Location: Libby, MT **Date:** February 2018 **Duration:** 46 Years

Description: SEE in Area 1 employs 55 triple-nested (shallow, middle, and deep) steam injection wells in conjunction with 27 double-nested shallow and deep multi-phase extraction (MPE) wells. SEE in Area 1 is anticipated to occur from Year 0 to 1 , after which ISB is implemented until Year 5 based on estimated mass reduction rates. ISB in Area 2 utilizes a transect of 24 deep injection points (formed by two rows and 4 zones) that operate for 2 hours three times daily. ISB in Area 2 is assumed to occur from Year 0 to 41 based on contaminant reduction rates. MNA in Area 3 is anticipated to occur from Year 0 to 10 assuming source cutoff.

CAPITAL COSTS (YEAR 0):

Item No.	DESCRIPTION & NOTES	UNIT	UNIT COST	QUANTITY	TOTAL (ROUNDED)
1.00	**Mobilization / Demobilization**				**$73,210**
1.01	Drill Rigs & Supporting Equipment	LS	$12,500	1	$12,500
1.02	Work & Implementation Plans (SAP, QAPP, SWP)	LS	$20,000	1	$20,000
1.03	Coordination - Access Agreements	LS	$4,000	1	$4,000
1.04	Temporary Facilities & Utilities (fence, roads, signs, trailers)	month	$2,000	6	$12,000
1.05	Completion Report	EA	$12,000	1	$12,000
1.06	*Project Management*	*%*		*10*	*$6,050*
1.07	*Contingency*	*%*		*10*	*$6,660*
2.00	**SAETS Decommissioning**				**$517,170**
2.01	Decommission Treatment System	LS	$202,000	1	$202,000
2.02	Demo Bioreactor Facility Building (offset by salvage)	LS	$8,000	1	$8,000
2.03	Remove Tanks, Towers, Piping at Bioreactor Facility	LS	$35,000	1	$35,000
2.04	Abandon/Remove Existing Conveyance Piping	ft	$15	370	$5,550
2.05	Overdrill Wells & Abandon with Heat-Resistant Grout	ft	$65	1,850	$120,250
2.06	Oversight, Documentation, & Per Diem	day	$1,350	15	$20,250
2.07	*Project Management*	*%*		*15*	*$58,660*
2.08	*Contingency*	*%*		*15*	*$67,460*
3.00	**Steam Enhanced Extraction Implementation**				**$26,812,877**
3.01	SEE Design (TerraTherm)	LS	$330,000	1	$330,000
3.02	Construction, Operation, and Demob (TerraTherm)	LS	$14,200,000	1	$14,200,000
3.03	Firepond Cutoff Wall Installation	LS	$882,400	1	$882,400
3.04	Upgrade Water Line to 3-inch	LS	$150,000	1	$150,000
3.05	35-ft 2" Re-Injection Well Installation	well	$5,060	2	$10,120
3.06	Well Development	well	$800	167	$133,600
3.07	Utilities	LS	$2,930,000	1	$2,930,000
3.08	Soil Confirmation Borings	boring	$8,500	10	$85,000
3.09	Laboratory Analysis	sample	$119	33	$3,927
3.10	Subcontractor Crew Per Diem & Lodging	day	$525	640	$336,000
3.11	Oversight, Documentation, & Per Diem	day	$1,350	640	$864,000
3.12	Evaluation & Reporting	report	$25,000	1	$25,000
3.13	*Project Management*	*%*		*12*	*$2,394,010*
3.14	*Contingency*	*%*		*20*	*$4,468,820*
4.00	**ISB Injection Well Installation - Area 2 [*Area 1 repurposes SEE wells*]**				**$460,470**
4.01	Install Deep Injection Well (80 ft bgs)	well	$11,600	24	$278,400
4.02	Well Development	well	$800	24	$19,200
4.03	Subcontractor Crew Per Diem & Lodging	day	$525	24	$12,600
4.04	Oversight, Documentation, & Per Diem	day	$1,350	24	$32,400
4.05	*Project Management*	*%*		*12*	*$41,120*
4.06	*Contingency*	*%*		*20*	*$76,750*
5.00	**ISB System Setup & Testing - Areas 1 & 2**				**$358,720**
5.01	Remedial Skid - Area 1 (2 compressors, 10 zones)	EA	$90,000	1	$90,000
5.02	Remedial Skid - Area 2 (1 compressor, 4 zones)	EA	$50,000	1	$50,000
5.03	Electrical Hookup & Controls	skid	$17,000	2	$34,000
5.04	Piping & Connections	ft	$10	6,320	$63,200
5.05	Field Testing/Startup	day	$1,350	22	$29,700
5.06	*Project Management*	*%*		*12*	*$32,030*
5.07	*Contingency*	*%*		*20*	*$59,790*

6.00	**IDW Management & Disposal**				**$1,091,736**
6.01	Solid IDW (soil cuttings)	drum	$200	618	$123,600
6.02	Solid IDW (excavated from wall installation)	ton	$186	1,680	$312,480
6.03	Liquid IDW (decon & purged groundwater)	drum	$131	0	$0
6.04	NAPL IDW	gal	$2.60	77,810	$202,306
6.05	Soil Analysis & Profiling	EA	$730	62	$45,260
6.06	Liquid Analysis & Profiling	EA	$605	0	$0
6.07	NAPL Analysis & Profiling	EA	$600	236	$141,600
6.08	Transportation to TSDF	drum	$60	1,562	$93,720
6.09	*Project Management*	*%*		*8*	*$73,520*
6.10	*Contingency*	*%*		*10*	*$99,250*
7.00	**SUBTOTAL**				**$29,314,183**
8.00	**Additional Costs**				
8.01	Remedial Design	%		8	$2,345,140
8.02	Construction Management	%		6	$1,758,860
8.03	Institutional Controls	LS	$12,000	1	$12,000
9.00	**TOTAL CAPITAL COST**				**$33,430,183**

ANNUAL O&M COSTS:

10.00	**Groundwater Monitoring & Reporting - Areas 1, 2, & 3 (Years 0-10)**				**$28,091**
10.01	Sampling Upper Aquifer Wells	well	$250	27	$6,750
10.02	Groundwater analytical	sample	$196	30	$5,880
10.03	Evaluation and Reporting	report	$12,000	1	$12,000
10.04	Liquid IDW (decon & purged groundwater)	drum	$131	1	$131
10.05	*Project Management*	*%*		*8*	*$1,990*
10.06	*Contingency*	*%*		*5*	*$1,340*
11.00	**Groundwater Monitoring & Reporting - Area 2 (Years 11-46)**				**$19,651**
11.01	Sampling Upper Aquifer Wells	well	$250	13	$3,250
11.02	Groundwater analytical	sample	$196	15	$2,940
11.03	Evaluation and Reporting	report	$11,000	1	$11,000
11.04	Liquid IDW (decon & purged groundwater)	drum	$131	1	$131
11.05	*Project Management*	*%*		*8*	*$1,390*
11.06	*Contingency*	*%*		*5*	*$940*
12.00	**ISB Operation - Areas1 & 2 (Years 1-5)**				**$174,530**
12.01	System O&M & Annualized Replacements	qtr	$8,600	4	$34,400
12.02	Performance Monitoring & Evaluation	qtr	$5,200	4	$20,800
12.03	O&M Annual Report	rpt	$9,600	1	$9,600
12.04	Annual Utilities	yr	$86,300	1	$86,300
12.05	*Project Management*	*%*		*5*	*$7,560*
12.06	*Contingency*	*%*		*10*	*$15,870*
13.00	**ISB Operation - Area 2 (Years 5-41)**				**$81,320**
13.01	System O&M & Annualized Replacements	qtr	$5,200	4	$20,800
13.02	Performance Monitoring & Evaluation	qtr	$3,400	4	$13,600
13.03	O&M Annual Report	rpt	$7,200	1	$7,200
13.04	Annual Utilities	yr	$28,800	1	$28,800
13.05	*Project Management*	*%*		*5*	*$3,520*
13.06	*Contingency*	*%*		*10*	*$7,400*
14.00	**TOTAL O&M COSTS** (*through project closeout*)				**$4,843,222**

PERIODIC COSTS:

15.00	**Recurring Five Year Expenditures (Years 5-45)**				**$20,950**
15.01	Five Year Review Report	EA	$15,000	1	$15,000
15.02	Update Institutional Controls Plan	EA	$4,000	1	$4,000
15.03	*Project Management*	*%*		*5*	*$950*
15.04	*Contingency*	*%*		*5*	*$1,000*
16.00	**Area 1 Decommissioning (Year 5)**				**$162,245**
16.01	Mob/Demob	LS	$10,000	1	$10,000
16.02	Subcontractor Crew Per Diem & Lodging	day	$525	21	$11,025
16.03	Soil Confirmation Borings	boring	$6,400	12	$76,800
16.04	Laboratory Analysis	sample	$119	40	$4,760
16.05	Decommission ISB System	EA	$18,000	1	$18,000
16.06	Oversight, Documentation, & Per Diem	day	$1,350	10	$13,500
16.07	*Project Management*	*%*		*10*	*$13,410*
16.08	*Contingency*	*%*		*10*	*$14,750*
17.00	**Area 2 Decommissioning (Year 41)**				**$205,075**
17.01	Mob/Demob	LS	$10,000	1	$10,000
17.02	Subcontractor Crew Per Diem & Lodging	day	$525	15	$7,875
17.03	Soil Confirmation Borings	boring	$8,500	9	$76,500
17.04	Laboratory Analysis	sample	$119	30	$3,570
17.05	Decommission ISB System	EA	$16,000	1	$16,000
17.06	80-ft Injection Well Abandonment	well	$1,470	24	$35,280
17.07	Oversight, Documentation, & Per Diem	day	$1,350	15	$20,250
17.08	*Project Management*	*%*		*10*	*$16,950*
17.09	*Contingency*	*%*		*10*	*$18,650*
18.00	**Remedy Complete (Year 46)**				**$80,160**
18.01	Mob/Demob	LS	$7,000	1	$7,000
18.02	Monitoring Well Abandonment	well	$990	40	$39,600
18.03	Oversight, Documentation, & Per Diem	day	$1,350	8	$10,800
18.03	Reporting	EA	$12,000	1	$12,000
18.04	*Project Management*	*%*		*10*	*$6,940*
18.05	*Contingency*	*%*		*5*	*$3,820*
19.00	**TOTAL PERIODIC COSTS** (*through project closeout*)				**$636,030**

PROJECT COST SCHEDULE & PRESENT VALUE ANALYSIS

Item No.	DESCRIPTION	YEAR	PERIOD COST	CUMULATIVE COST	DISCOUNT FACTOR	PERIOD NET PRESENT VALUE
20.00	**O&M Cost**					
20.00	Implement SEE & 6-mo ISB Operation in Area 2	0	$33,484,889	$33,484,889	1.000	$33,484,889
20.01	Implement ISB in Area 1, ISB in Areas 1 & 2, MNA Area 3	1	$202,621	$33,687,510	0.990	$200,650
20.02	ISB in Areas 1 & 2, MNA Area 3	2	$202,621	$33,890,131	0.981	$198,698
20.03	ISB in Areas 1 & 2, MNA Area 3	3	$202,621	$34,092,752	0.971	$196,765
20.04	ISB in Areas 1 & 2, MNA Area 3	4	$202,621	$34,295,373	0.962	$194,851
20.05	ISB Area 1&2, MNA Area 3, Decommission Area 1, 5-yr Review	5	$385,816	$34,681,189	0.952	$367,412
20.06	ISB in Area 2, MNA in Areas 1 & 3	6	$109,411	$34,790,600	0.943	$103,178
20.07	ISB in Area 2, MNA in Areas 1 & 3	7	$109,411	$34,900,011	0.934	$102,175
20.08	ISB in Area 2, MNA in Areas 1 & 3	8	$109,411	$35,009,422	0.925	$101,181
20.09	ISB in Area 2, MNA in Areas 1 & 3	9	$109,411	$35,118,833	0.916	$100,197
20.10	ISB in Area 2, MNA in Areas 1 & 3, & 5-yr Review	10	$130,361	$35,249,194	0.907	$118,221
20.11	ISB in Area 2	11	$100,971	$35,350,165	0.898	$90,677
20.12	ISB in Area 2	12	$100,971	$35,451,136	0.889	$89,795
20.13	ISB in Area 2	13	$100,971	$35,552,107	0.881	$88,922
20.14	ISB in Area 2	14	$100,971	$35,653,078	0.872	$88,057
20.15	ISB in Area 2 & 5-yr Review	15	$121,921	$35,774,999	0.864	$105,293
20.16	ISB in Area 2	16	$100,971	$35,875,970	0.855	$86,352
20.17	ISB in Area 2	17	$100,971	$35,976,941	0.847	$85,512
20.18	ISB in Area 2	18	$100,971	$36,077,912	0.839	$84,680
20.19	ISB in Area 2	19	$100,971	$36,178,883	0.830	$83,856
20.20	ISB in Area 2 & 5-yr Review	20	$121,921	$36,300,804	0.822	$100,270
20.21	ISB in Area 2	21	$100,971	$36,401,775	0.814	$82,233
20.22	ISB in Area 2	22	$100,971	$36,502,746	0.806	$81,433
20.23	ISB in Area 2	23	$100,971	$36,603,717	0.799	$80,641
20.24	ISB in Area 2	24	$100,971	$36,704,688	0.791	$79,856
20.25	ISB in Area 2 & 5-yr Review	25	$121,921	$36,826,609	0.783	$95,487
20.26	ISB in Area 2	26	$100,971	$36,927,580	0.776	$78,310
20.27	ISB in Area 2	27	$100,971	$37,028,551	0.768	$77,548
20.28	ISB in Area 2	28	$100,971	$37,129,522	0.761	$76,794
20.29	ISB in Area 2	29	$100,971	$37,230,493	0.753	$76,047
20.30	ISB in Area 2 & 5-yr Review	30	$121,921	$37,352,414	0.746	$90,932
20.31	ISB in Area 2	31	$100,971	$37,453,385	0.739	$74,575
20.32	ISB in Area 2	32	$100,971	$37,554,356	0.731	$73,849
20.33	ISB in Area 2	33	$100,971	$37,655,327	0.724	$73,131
20.34	ISB in Area 2	34	$100,971	$37,756,298	0.717	$72,419
20.35	ISB in Area 2 & 5-yr Review	35	$121,921	$37,878,219	0.710	$86,595
20.36	ISB in Area 2	36	$100,971	$37,979,190	0.703	$71,017
20.37	ISB in Area 2	37	$100,971	$38,080,161	0.697	$70,327
20.38	ISB in Area 2	38	$100,971	$38,181,132	0.690	$69,642
20.39	ISB in Area 2	39	$100,971	$38,282,103	0.683	$68,965
20.40	ISB in Area 2 & 5-yr Review	40	$121,921	$38,404,024	0.676	$82,464
20.41	ISB and Decommision Area2	41	$306,046	$38,710,070	0.670	$204,988
20.42	MNA in Area 2	42	$19,651	$38,729,721	0.663	$13,034
20.43	MNA in Area 2	43	$19,651	$38,749,372	0.657	$12,907
20.44	MNA in Area 2	44	$19,651	$38,769,023	0.650	$12,782
20.45	MNA in Area 2 & 5-yr Review	45	$40,601	$38,809,624	0.644	$26,151
20.46	MNA in Area 2 & Remedy Complete	46	$99,811	$38,909,435	0.638	$63,664
TOTAL PROJECT COSTS			**$38,909,435**			**$37,967,422**

COST SUMMARIES	CURRENT DOLLAR	NPV
Costs through Year 10	**$35,250,000**	**$35,169,000**
Costs through Year 30	**$37,353,000**	**$36,891,000**
Costs through Project Closeout	**$38,910,000**	**$37,968,000**

ALTERNATIVE 5
ISGS (Area 1), ISB (Area 2), and MNA (Area 3)

Site: Libby Groundwater Site | **Phase:** FFS Costing | **Base Year:** 2019
Location: Libby, MT | **Date:** February 2018 | **Duration:** 46 Years

Description: ISGS in Area 1 injects a geochemical stabilizing solution into approximately 398 shallow, 100 middle, and 100 deep injection points. ISGS in Area 1 is anticipated to occur from Year 0 to 1 based the anticipated drilling activities and quantity of solution injected, after which NSZD is assumed to occur until Year 29 ISB in Area 2 utilizes a transect of 24 deep injection points (formed by two rows and 4 zones) that operate for 2 hours three times daily. ISB in Area 2 is assumed to occur from Year 0 to 41 based on contaminant reduction rates. MNA in Area 3 is anticipated to occur from Year 0 to 10 assuming source cutoff.

CAPITAL COSTS (YEAR 0):

Item No.	DESCRIPTION & NOTES	UNIT	UNIT COST	QUANTITY	TOTAL (ROUNDED)
1.00	**Mobilization / Demobilization**				**$73,210**
1.01	Drill Rigs & Supporting Equipment	LS	$12,500	1	$12,500
1.02	Work & Implementation Plans (SAP, QAPP, SWP)	LS	$20,000	1	$20,000
1.03	Coordination - Access Agreements	LS	$4,000	1	$4,000
1.04	Temporary Facilities & Utilities (fence, roads, signs, trailers)	month	$2,000	6	$12,000
1.05	Completion Report	EA	$12,000	1	$12,000
1.06	*Project Management*	*%*		*10*	*$6,050*
1.07	*Contingency*	*%*		*10*	*$6,660*
2.00	**SAETS Decommissioning**				**$370,040**
2.01	Decommission Treatment System	LS	$202,000	1	$202,000
2.02	Demo Bioreactor Facility Building (offset by salvage)	LS	$8,000	1	$8,000
2.03	Remove Tanks, Towers, Piping at Bioreactor Facility	LS	$35,000	1	$35,000
2.04	Abandon/Remove Existing Conveyance Piping	ft	$15	370	$5,550
2.05	Abandon Existing Wells	ft	$15	600	$9,000
2.06	Oversight, Documentation, & Per Diem	day	$1,350	15	$20,250
2.07	*Project Management*	*%*		*15*	*$41,970*
2.08	*Contingency*	*%*		*15*	*$48,270*
3.00	**In-Situ Geochemical Stabilization Implementation**				**$16,555,256**
3.01	ISGS Pilot Study	LS	$515,000	1	$515,000
3.02	ISGS Design and Application in Shallow Subunit (10' ROI)	LS	$4,529,219	1	$4,529,219
3.03	ISGS Design and Application in Middle Subunit (20' ROI)	LS	$3,357,375	1	$3,357,375
3.04	ISGS Design and Application in Deep Subunit (20' ROI)	LS	$3,357,375	1	$3,357,375
3.05	Soil Confirmation Borings	boring	$8,500	10	$85,000
3.06	Laboratory Analysis	sample	$119	33	$3,927
3.07	Subcontractor Crew Per Diem & Lodging	day	$525	240	$126,000
3.08	Oversight, Documentation, & Per Diem	day	$1,350	240	$324,000
3.09	Evaluation and Reporting	report	$20,000	1	$20,000
3.10	*Project Management*	*%*		*12*	*$1,478,150*
3.11	*Contingency*	*%*		*20*	*$2,759,210*
4.00	**ISB Injection Well Installation - Area 2**				**$460,470**
4.01	Install Deep Injection Well (80 ft bgs)	well	$11,600	24	$278,400
4.02	Well Development	well	$800	24	$19,200
4.03	Subcontractor Crew Per Diem & Lodging	day	$525	24	$12,600
4.04	Oversight, Documentation, & Per Diem	day	$1,350	24	$32,400
4.05	*Project Management*	*%*		*12*	*$41,120*
4.06	*Contingency*	*%*		*20*	*$76,750*
5.00	**ISB System Setup & Testing - Area 2**				**$137,630**
5.01	Remedial Skid - Area 2 (1 compressor, 4 zones)	EA	$50,000	1	$50,000
5.02	Electrical Hookup & Controls	skid	$17,000	1	$17,000
5.03	Piping & Connections	ft	$10	1,920	$19,200
5.04	Field Testing/Startup	day	$1,350	12	$16,200
5.05	*Project Management*	*%*		*12*	*$12,290*
5.06	*Contingency*	*%*		*20*	*$22,940*
6.00	**IDW Management & Disposal**				**$177,206**
6.01	Solid IDW (soil cuttings)	drum	$200	444	$88,800
6.02	Liquid IDW (decon & purged groundwater)	drum	$131	0	$0
6.03	NAPL IDW	gal	$2.60	10	$26
6.04	Soil Analysis & Profiling	EA	$730	45	$32,850
6.05	Liquid Analysis & Profiling	EA	$605	0	$0
6.06	NAPL Analysis & Profiling	EA	$600	1	$600
6.07	Transportation to TSDF	drum	$60	448	$26,880
6.08	*Project Management*	*%*		*8*	*$11,940*
6.09	*Contingency*	*%*		*10*	*$16,110*
7.00	**SUBTOTAL**				**$17,773,812**

8.00	**Additional Costs**				
8.01	Remedial Design	%		8	$1,421,910
8.02	Construction Management	%		6	$1,066,430
8.03	Institutional Controls	LS	$12,000	1	$12,000
9.00	**TOTAL CAPITAL COST**				**$20,274,152**
ANNUAL O&M COSTS:					
10.00	**Groundwater Monitoring & Reporting - Areas 1, 2, & 3 (Years 0-10)**				**$28,091**
10.01	Sampling Upper Aquifer Wells	well	$250	27	$6,750
10.02	Groundwater analytical	sample	$196	30	$5,880
10.03	Evaluation and Reporting	report	$12,000	1	$12,000
10.04	Liquid IDW (decon & purged groundwater)	drum	$131	1	$131
10.05	*Project Management*	*%*		*8*	*$1,990*
10.06	*Contingency*	*%*		*5*	*$1,340*
11.00	**Groundwater Monitoring & Reporting - Areas 1 & 2 (Years 11-34)**				**$23,915**
11.01	Sampling Upper Aquifer Wells	well	$250	21	$5,250
11.02	Groundwater analytical	sample	$196	24	$4,704
11.03	Evaluation and Reporting	report	$11,000	1	$11,000
11.04	Liquid IDW (decon & purged groundwater)	drum	$131	1	$131
11.05	*Project Management*	*%*		*8*	*$1,690*
11.06	*Contingency*	*%*		*5*	*$1,140*
12.00	**Groundwater Monitoring & Reporting - Area 2 (Years 35-46)**				**$18,521**
12.01	Sampling Upper Aquifer Wells	well	$250	13	$3,250
12.02	Groundwater analytical	sample	$196	15	$2,940
12.03	Evaluation and Reporting	report	$10,000	1	$10,000
12.04	Liquid IDW (decon & purged groundwater)	drum	$131	1	$131
12.05	*Project Management*	*%*		*8*	*$1,310*
12.06	*Contingency*	*%*		*5*	*$890*
13.00	**ISB Operation - Area 2 (Years 0-41)**				**$83,650**
13.01	System O&M & Annualized Replacements	qtr	$5,200	4	$20,800
13.02	Performance Monitoring & Evaluation	qtr	$3,400	4	$13,600
13.03	O&M Annual Report	rpt	$7,200	1	$7,200
13.04	Annual Utilities	yr	$28,800	1	$28,800
13.05	*Project Management*	*%*		*8*	*$5,640*
13.06	*Contingency*	*%*		*10*	*$7,610*
14.00	**TOTAL O&M COSTS** (*through project closeout*)				**$4,562,643**
PERIODIC COSTS:					
15.00	**Recurring Five Year Expenditures (Years 5-45)**				**$20,950**
15.01	Five Year Review Report	EA	$15,000	1	$15,000
15.02	Update Institutional Controls Plan	EA	$4,000	1	$4,000
15.03	*Project Management*	*%*		*5*	*$950*
15.04	*Contingency*	*%*		*5*	*$1,000*
16.00	**Area 2 Decommissioning (Year 41)**				**$205,075**
16.01	Mob/Demob	LS	$10,000	1	$10,000
16.02	Subcontractor Crew Per Diem & Lodging	day	$525	15	$7,875
16.03	Soil Confirmation Borings	boring	$8,500	9	$76,500
16.04	Laboratory Analysis	sample	$119	30	$3,570
16.05	Decommission ISB System	EA	$16,000	1	$16,000
16.06	80-ft Injection Well Abandonment	well	$1,470	24	$35,280
16.07	Oversight, Documentation, & Per Diem	day	$1,350	15	$20,250
16.08	*Project Management*	*%*		*10*	*$16,950*
16.09	*Contingency*	*%*		*10*	*$18,650*
17.00	**Remedy Complete (Year 46)**				**$80,160**
17.01	Mob/Demob	LS	$7,000	1	$7,000
17.02	Monitoring Well Abandonment	well	$990	40	$39,600
17.03	Oversight, Documentation, & Per Diem	day	$1,350	8	$10,800
17.03	Reporting	EA	$12,000	1	$12,000
17.04	*Project Management*	*%*		*10*	*$6,940*
17.05	*Contingency*	*%*		*5*	*$3,820*
18.00	**TOTAL PERIODIC COSTS** (*through project closeout*)				**$473,785**

PROJECT COST SCHEDULE & PRESENT VALUE ANALYSIS

Item No.	DESCRIPTION	YEAR	PERIOD COST	CUMULATIVE COST	DISCOUNT FACTOR	PERIOD NET PRESENT VALUE
19.00	**O&M Cost**					
19.00	Implement ISGS 6-mo ISB Operation in Area 2	0	$20,330,022	$20,330,022	1.000	$20,330,022
19.01	NSZD in Area 1, ISB in Area 2, MNA in Area 3	1	$111,741	$20,441,763	0.990	$110,654
19.02	NSZD in Area 1, ISB in Area 2, MNA in Area 3	2	$111,741	$20,553,504	0.981	$109,578
19.03	NSZD in Area 1, ISB in Area 2, MNA in Area 3	3	$111,741	$20,665,245	0.971	$108,512
19.04	NSZD in Area 1, ISB in Area 2, MNA in Area 3	4	$111,741	$20,776,986	0.962	$107,456
19.05	NSZD in Area 1, ISB in Area 2, MNA in Area 3 & 5-yr Review	5	$132,691	$20,909,677	0.952	$126,362
19.06	NSZD in Area 1, ISB in Area 2, MNA in Area 3	6	$111,741	$21,021,418	0.943	$105,376
19.07	NSZD in Area 1, ISB in Area 2, MNA in Area 3	7	$111,741	$21,133,159	0.934	$104,351
19.08	NSZD in Area 1, ISB in Area 2, MNA in Area 3	8	$111,741	$21,244,900	0.925	$103,336
19.09	NSZD in Area 1, ISB in Area 2, MNA in Area 3	9	$111,741	$21,356,641	0.916	$102,330
19.10	NSZD in Area 1, ISB in Area 2, MNA in Area 3 & 5-yr Review	10	$132,691	$21,489,332	0.907	$120,334
19.11	NSZD in Area 1, ISB in Area 2	11	$107,565	$21,596,897	0.898	$96,599
19.12	NSZD in Area 1, ISB in Area 2	12	$107,565	$21,704,462	0.889	$95,659
19.13	NSZD in Area 1, ISB in Area 2	13	$107,565	$21,812,027	0.881	$94,729
19.14	NSZD in Area 1, ISB in Area 2	14	$107,565	$21,919,592	0.872	$93,807
19.15	NSZD in Area 1, ISB in Area 2 & 5-yr Review	15	$128,515	$22,048,107	0.864	$110,987
19.16	NSZD in Area 1, ISB in Area 2	16	$107,565	$22,155,672	0.855	$91,991
19.17	NSZD in Area 1, ISB in Area 2	17	$107,565	$22,263,237	0.847	$91,096
19.18	NSZD in Area 1, ISB in Area 2	18	$107,565	$22,370,802	0.839	$90,210
19.19	NSZD in Area 1, ISB in Area 2	19	$107,565	$22,478,367	0.830	$89,333
19.20	NSZD in Area 1, ISB in Area 2 & 5-yr Review	20	$128,515	$22,606,882	0.822	$105,693
19.21	NSZD in Area 1, ISB in Area 2	21	$107,565	$22,714,447	0.814	$87,603
19.22	NSZD in Area 1, ISB in Area 2	22	$107,565	$22,822,012	0.806	$86,751
19.23	NSZD in Area 1, ISB in Area 2	23	$107,565	$22,929,577	0.799	$85,907
19.24	NSZD in Area 1, ISB in Area 2	24	$107,565	$23,037,142	0.791	$85,071
19.25	NSZD in Area 1, ISB in Area 2 & 5-yr Review	25	$128,515	$23,165,657	0.783	$100,652
19.26	NSZD in Area 1, ISB in Area 2	26	$107,565	$23,273,222	0.776	$83,424
19.27	NSZD in Area 1, ISB in Area 2	27	$107,565	$23,380,787	0.768	$82,613
19.28	NSZD in Area 1, ISB in Area 2	28	$107,565	$23,488,352	0.761	$81,809
19.29	NSZD in Area 1, ISB in Area 2	29	$107,565	$23,595,917	0.753	$81,013
19.30	MNA in Area 1, ISB in Area 2 & 5-yr Review	30	$128,515	$23,724,432	0.746	$95,850
19.31	MNA in Area 1, ISB in Area 2	31	$107,565	$23,831,997	0.739	$79,445
19.32	MNA in Area 1, ISB in Area 2	32	$107,565	$23,939,562	0.731	$78,672
19.33	MNA in Area 1, ISB in Area 2	33	$107,565	$24,047,127	0.724	$77,907
19.34	MNA in Area 1, ISB in Area 2	34	$107,565	$24,154,692	0.717	$77,149
19.35	ISB in Area 2 & 5-yr Review	35	$123,121	$24,277,813	0.710	$87,447
19.36	ISB in Area 2	36	$102,171	$24,379,984	0.703	$71,861
19.37	ISB in Area 2	37	$102,171	$24,482,155	0.697	$71,162
19.38	ISB in Area 2	38	$102,171	$24,584,326	0.690	$70,470
19.39	ISB in Area 2	39	$102,171	$24,686,497	0.683	$69,785
19.40	ISB in Area 2 & 5-yr Review	40	$123,121	$24,809,618	0.676	$83,276
19.41	ISB and Decommision Area 2	41	$307,246	$25,116,864	0.670	$205,792
19.42	MNA in Area 2	42	$18,521	$25,135,385	0.663	$12,285
19.43	MNA in Area 2	43	$18,521	$25,153,906	0.657	$12,165
19.44	MNA in Area 2	44	$18,521	$25,172,427	0.650	$12,047
19.45	MNA in Area 2, & 5-yr Review	45	$39,471	$25,211,898	0.644	$25,424
19.46	MNA in Area 2 & Remedy Complete	46	$98,681	$25,310,579	0.638	$62,943
19.47	NA	47	$0	$25,310,579	0.632	$0
19.48	NA	48	$0	$25,310,579	0.625	$0
19.49	NA	49	$0	$25,310,579	0.619	$0
19.50	NA	50	$0	$25,310,579	0.613	$0
TOTAL PROJECT COSTS			**$25,310,579**			**$24,356,936**

COST SUMMARIES	CURRENT DOLLAR	NPV
Costs through Year 10	**$21,490,000**	**$21,429,000**
Costs through Year 30	**$23,725,000**	**$23,260,000**
Costs through Project Closeout	**$25,311,000**	**$24,357,000**

SUMMARY OF ESTIMATED COSTS

Comparison by Remedial Alternative

Site: Libby Groundwater Site
Location: Libby, MT
Phase: FFS Costing
Base Year: 2019
For: 200 Years
Date: February 2018

Alternative Descriptions
1) No Further Action through Year 150
2) Containment (Area 1), ISB (Area 2) and MNA (Area 3) through Year 150
3) ISB (Areas 1 & 2) and MNA (Area 3) through Year 46
4) SEE+ISB (Area 1), ISB (Area 2) and MNA (Area 3) through Year 46
5) ISGS (Area 1), ISB (Area 2), and MNA (Area 3) through Year 46

PROJECT COST SCHEDULE & PRESENT VALUE ANALYSIS

YEAR	DISCOUNT FACTOR	PERIOD CURRENT COSTS BY ALTERNATIVE					CUMULATIVE NPV BY ALTERNATIVE				
		1	2	3	4	5	1	2	3	4	5
0	1.000	$350,280	$5,120,223	$2,348,073	$33,484,889	$20,330,022	$350,280	$5,120,223	$2,348,073	$33,484,889	$20,330,022
5	0.952	$34,523	$1,295,743	$224,911	$385,816	$132,691	$383,156	$11,330,523	$3,358,451	$34,643,265	$20,892,583
15	0.864	$34,523	$1,291,567	$121,671	$121,921	$128,515	$444,279	$22,858,150	$4,677,559	$35,630,960	$21,920,091
30	0.746	$34,523	$1,291,567	$121,671	$121,921	$128,515	$525,457	$38,142,693	$5,934,512	$36,890,911	$23,259,107
50	0.613	$34,523	$1,199,777	$0	$0	$0	$616,740	$54,966,435	$7,008,275	$37,967,422	$24,356,936
75	0.480	$34,523	$1,199,777	$0	$0	$0	$708,398	$70,981,301	$7,008,275	$37,967,422	$24,356,936
100	0.376	$34,523	$1,199,777	$0	$0	$0	$780,183	$83,523,968	$7,008,275	$37,967,422	$24,356,936
150	0.231	$97,813	$95,935	$0	$0	$0	$895,043	$99,799,065	$7,008,275	$37,967,422	$24,356,936
Total	-	$1,449,260	$181,335,363	$7,961,073	$38,909,435	$25,310,579	$895,043	$99,799,065	$7,008,275	$37,967,422	$24,356,936

Appendix D

TerraTherm SEE Proposal

Appendix D
TerraTherm SEE Proposal

AECOM

Libby Groundwater Site

Libby, Montana

Preliminary Site Evaluation

March 13, 2017

TERRATHERM
a Cascade Company

About TerraTherm

- A U.S. based company offering all major methods of subsurface heating:
  - In Situ Thermal Desorption (ISTD) via Thermal Conductive Heating (TCH)
  - Steam Enhanced Extraction (SEE)
  - Electrical Resistance Heating (ERH)
- Completed 50 thermal projects worldwide either directly or through a Licensee
- Meets treatment goals 100% of the time
- TerraTherm Experience Modification Rating (EMR) history:
  - 2016: 0.70
  - 2015: 0.69
  - 2014: 0.91
  - 2013: 0.89
  - 2012: 0.90

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Site Background

Site Name: Libby Groundwater Site

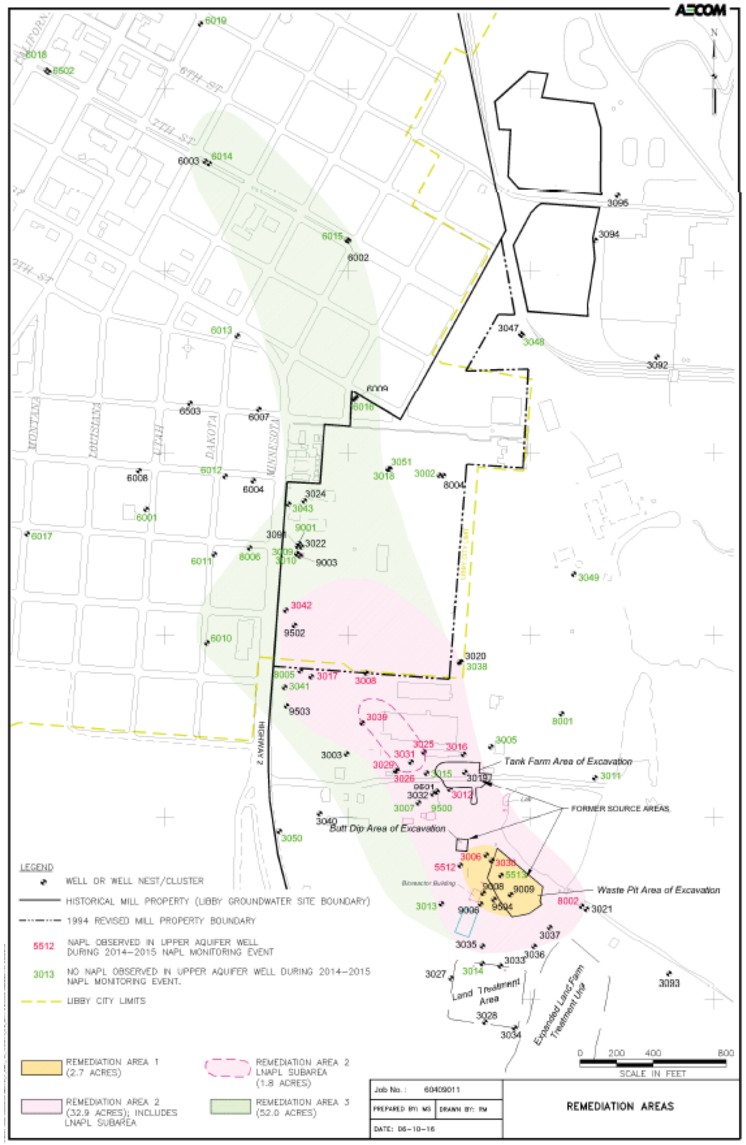
Site Location: Libby, Montana

Site/Environmental Consultant: AECOM, Mary Stauffer

Objective: Obtain a conceptual cost to implement thermal remediation at the site

Contaminants of Concern: Creosote. Acenaphthene, Anthracene, Fluoranthene, Fluorene, Naphthalene, Pyrene, Benzo (a) anthracene, Benzo (a) pyrene, Benzo (b) fluoranthene, Benzo (k) fluoranthene, Chrysene, Dibenzo (a,h) anthracene, Indeno (1,2,3-c,d) pyrene, Pentachlorophenol, Benzene, Arsenic and TCDD.

Site Location Map



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Geology and Hydrogeology

Geology:

- 0.0 to 34.0 ft bgs: Gravel/Sand/Silt/Clay – Layer 1
- 34.0 to 54.0 ft bgs: Gravel/Sand/Silt/Clay – Layer 2
- 54.0 to 74.0 ft bgs: Gravel/Sand/Silt/Clay – Layer 3

Hydrogeology: Water surface elevation varies and is impacted by existing Pump and Treat System. A water surface elevation of 18.0 ft bgs was used for this evaluation.

Hydrogeology: Hydraulic conductivity values were provided as follows,

- Layer 1: 45 ft/day (1.59x10^{-2} cm/sec)
- Layer 2: 0.42 ft/day (1.48x10^{-4} cm/sec)
- Layer 3: 5.3 ft/day (1.87x10^{-3} cm/sec)

A hydraulic conductivity value representative to the entire site is of 14.2 ft/day (5.0x10^{-3} cm/sec) and was used for this evaluation.

Hydraulic gradient: Hydraulic gradient varies and is impacted by existing Pump and Treat System. A gradient representative to the entire site of 0.005 ft/ft was used for this evaluation.

Conceptual Treatment Scenario

Treatment Technology	Treatment Area	Target Area (ft^2)	Target Depth (ft bgs)	Target Volume (CY)
Steam Enhanced Extraction **(SEE)**	**Area 1**	117,600 (L: 294 ft – W: 400 ft)	0.0 – 67.0	291,822

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Contaminants of Concern, Mass Estimate, and Remediation Goals

Contaminants of Concern: Creosote. Acenaphthene, Anthracene, Fluoranthene, Fluorene, Naphthalene, Pyrene, Benzo (a) anthracene, Benzo (a) pyrene, Benzo (b) fluoranthene, Benzo (k) fluoranthene, Chrysene, Dibenzo (a,h) anthracene, Indeno (1,2,3-c,d) pyrene, Pentachlorophenol, Benzene, Arsenic and TCDD.

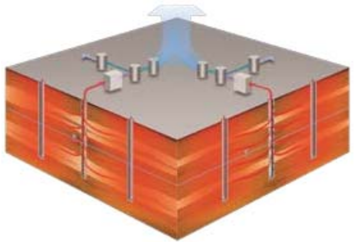
Mass Estimate: The mass used for this evaluation is 250,000 lbs and was calculated by its respective volume and an approximate average concentration of ~660 mg/kg (this is a best guess number).

Remediation Goals: To mobilize and remove NAPL to the extent practicable. Attempt to reach the goals in the table below to the extent practicable, based on our experience with these types of COCs

Chemical Name	Groundwater (ug/L)		Soil (mg/kg)	
	Max level Detected	Target Level	Max Level Detected	Target Level
Acenaphthene		670		None (all COCs)
Anthracene		2100		
Fluoranthene		130		
Fluorene		1100		
Naphthalene	36,000	100	3,200	
Pyrene		830		
Benzo (a) anthracene		0.5		
Benzo (a) pyrene	170	0.05	6.6	
Benzo (b) fluoranthene		0.5		
Benzo (k) fluoranthene		5		
Chrysene		50		
Dibenzo (a,h) anthracene		0.05		
Indeno (1,2,3-c,d) pyrene		0.5		
Pentachlorophenol	21,000	1	74	
Benzene		5		
Arsenic		10		
TCDD		2E-06		

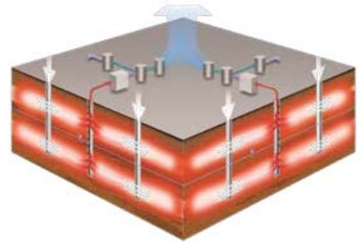
Thermal Technologies Evaluated

Thermal Conduction Heating (TCH / ISTD)



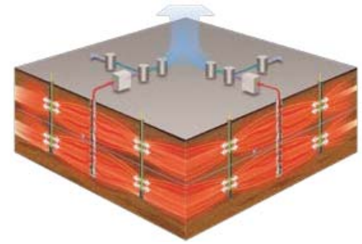
For all sites with low to moderate groundwater flow rates and either Volatile Organic Compounds (VOCs) or Semi-Volatile Organic Compounds (SVOCs).

Steam Enhanced Extraction (SEE)

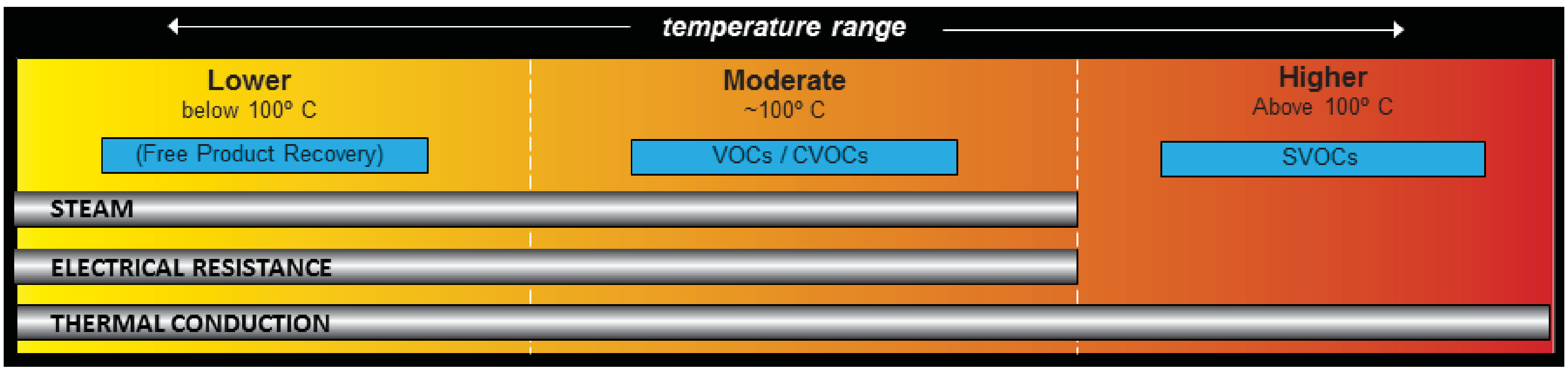


For permeable sites with significant groundwater flow rates and for sites with either volatile or moderately volatile contaminants.

Electrical Resistance Heating (ERH)



For all sites with low to moderate groundwater flow rates and either volatile or moderately volatile contaminants.



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Thermal Technologies Evaluated

Characteristics	TCH	SEE	ERH
Heating Method	Conduction	Steam injection, convection	Resistance
Factors Governing Heating	Thermal conductivity Groundwater flow	Permeability injection rates and pressure	Electrical resistivity Groundwater flow
Maximum Temperature	325-400°C (once dewatered)	100°C (boiling point)	100°C (boiling point)
Sensitivity to Water Content and Flow	Works in wet and dry conditions Water flow can remove heat faster than is added	Not Sensitive	Does not work in dry conditions Water flow can remove heat faster than it is added
Sensitivity to Contrasts between Layers	Differences in water content and flow may affect heating rate	Aquitards not heated directly	Resistivity contrasts may lead to uneven and incomplete heating – long electrodes may be inefficient
Sensitivity to Buried Objects	Not sensitive	Low-permeable layers may interfere with stream migration	Metal debris and pipes may prevent uniform heating
Heat Input Governed By	Soil thermal conductivity (varies by a factor of 1 to 3 between most common geologies)	Hydraulic conductivity	Soil resistivity (varies by a factor of more than 200 for most common geologies)
Fluids Added to Ground	None	Steam	Water

Note:

- *TerraTherm has succesfully completed soil remedies at similar sites in the past, using the SEE technology.*

Conceptual Treatment Approach/Methodology

Conceptual Treatment Approach:

- SEE using a well spacing of 50 feet to target the boiling point of water.
- Soil vapor and steam extraction from multi-phase extraction wells used to extract the vaporized contaminants and steam, and to maintain pneumatic and hydraulic control. Horizontal SVE wells may be utilized to optimize vapor extraction from the shallow soils.
- A hydraulic barrier would be used to limit inflow of groundwater on the east side.

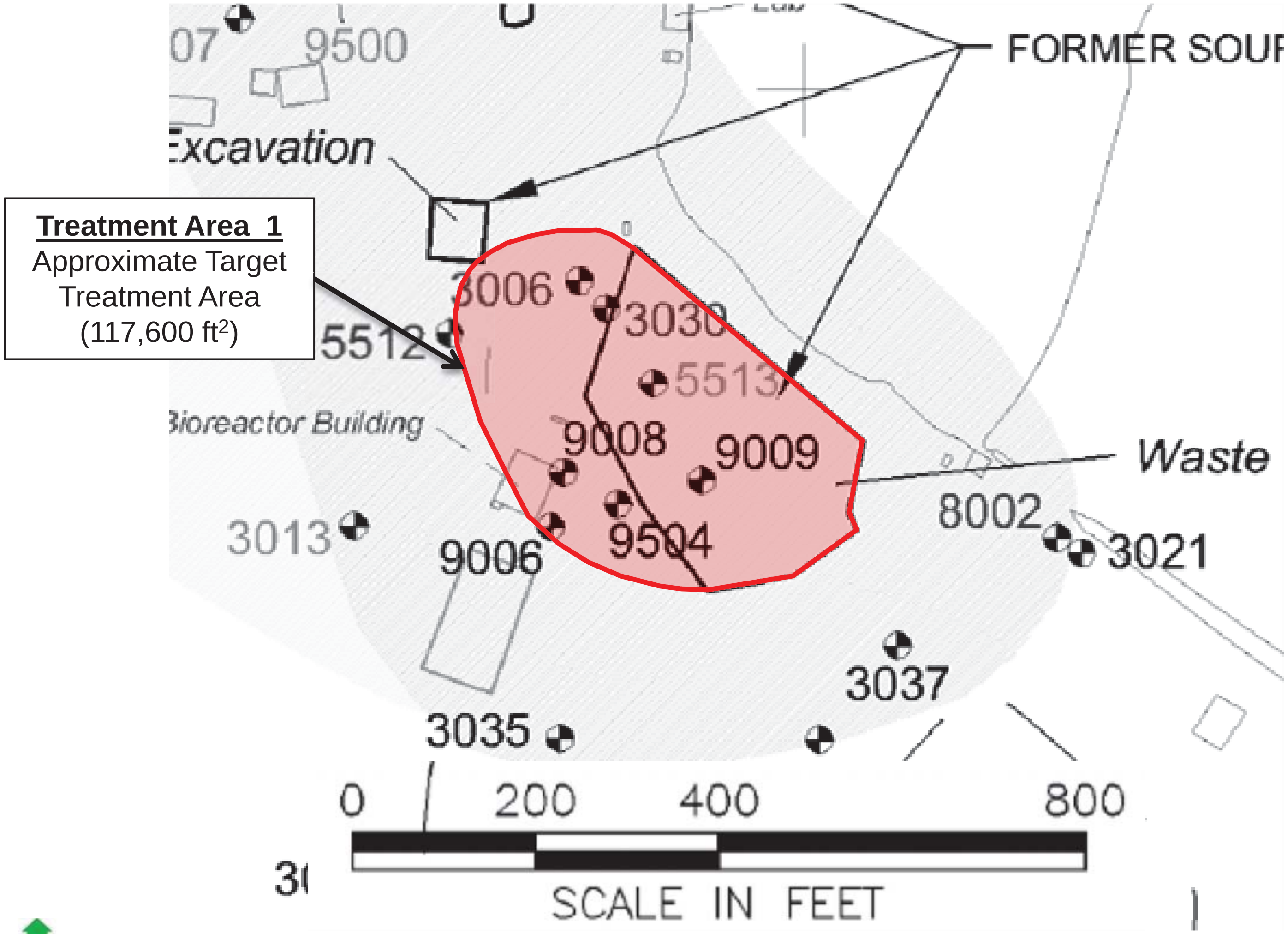
Vapor and Liquid Treatment Approach:

- Extracted liquid (condensate) treated using gravity separation and Granular Activated Carbon (GAC).
- Vapors treated in a thermal oxidizer due to the expected high mass present at the site.

Monitoring:

- Temperature monitoring to track subsurface heating, pneumatic, and hydraulic control.
- Vapor and liquid treatment system monitoring for mass removal and discharge compliance.

Treatment Area Map



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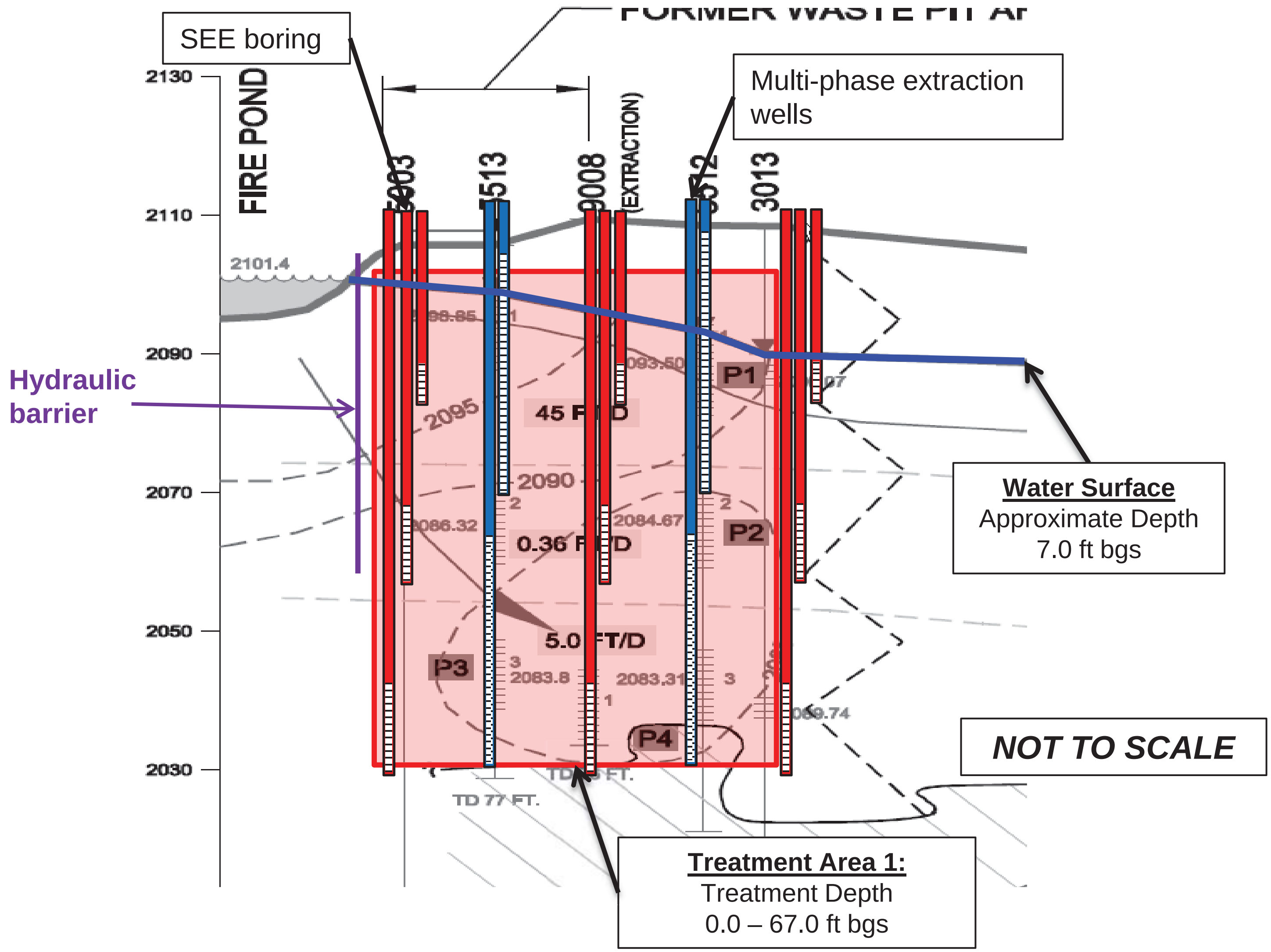
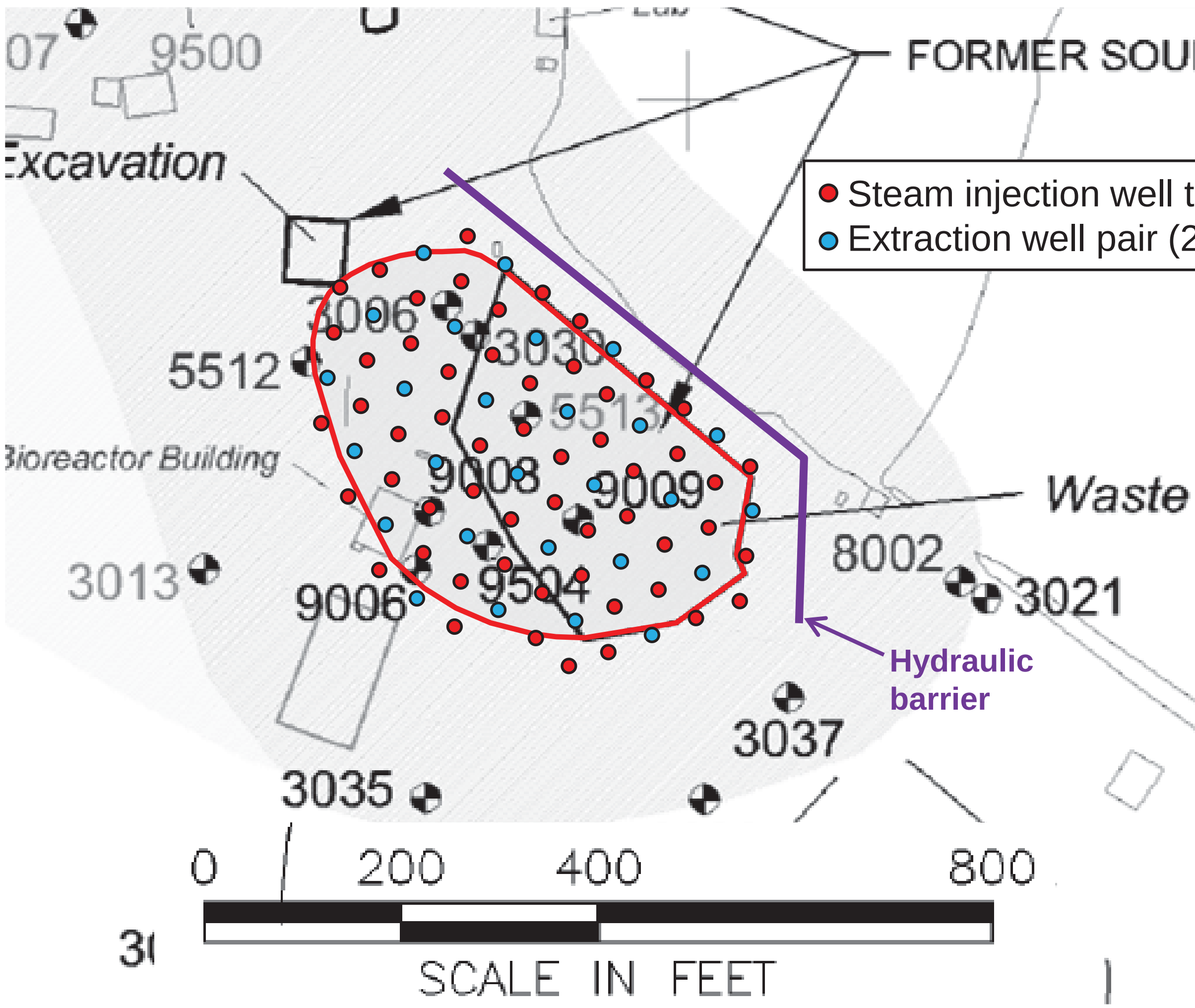
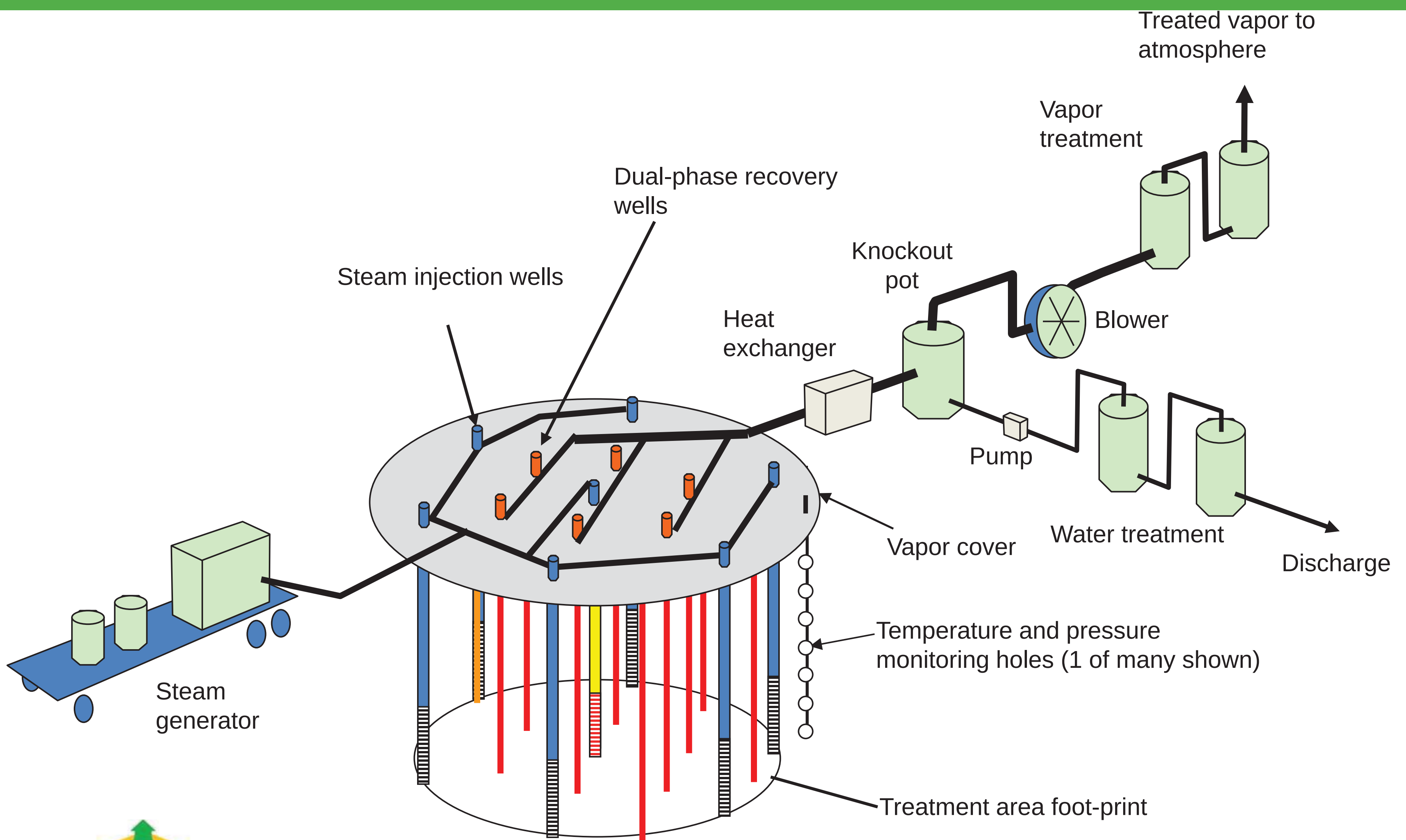
Conceptual Cross Section



Conceptual Wellfield Layout



Schematic of Typical SEE Site



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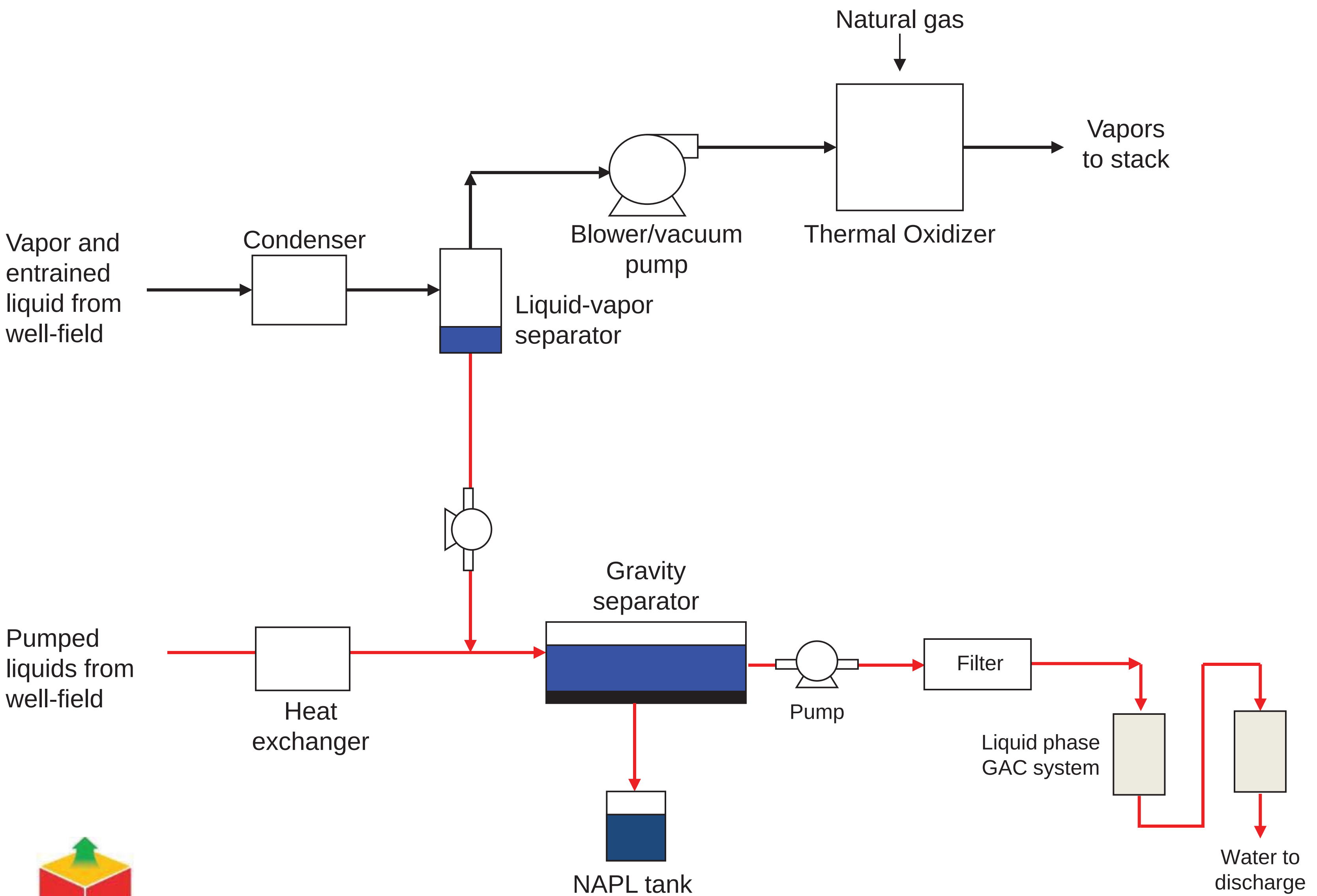
Conceptual Process Flow Diagram: Vapor and Liquid Treatment System



Conceptual Design Parameters/Treatment Outputs

Libby Groundwater Site		AECOM
Volume and heat capacity	***Area 1***	***Unit***
Treatment area	117,600	ft^2
Upper depth of treatment	-	ft bgs
Lower depth of treatment	67	ft bgs
Volume, TTZ	291,822	yd^3
Solids volume	189,684	yd^3
Porosity	0.35	-
Porosity volume	102,138	yd^3
Initial saturation	97	percent
Soil weight	846,999,537	lbs soil
Water weight	166,941,276	lbs water
Soil heat capacity	211,749,884	BTU/F
Water heat capacity	166,941,276	BTU/F
Total heat capacity, whole TTZ	378,691,160	BTU/F

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Conceptual Design Parameters/Treatment Outputs (Continued)

Libby Groundwater Site		AECOM
Energy balance	***Area 1***	***Unit***
Steam injection rate	45,375	lbs/hr
Water extraction rate during heatup	143.3	gpm
Average extracted water temperature	190	F
Percent of injected energy extracted as steam	10	%
Steam extracted, average	4,538	lbs/hr
Energy flux into treatment volume	44,059,125	BTU/hr
Energy flux in extracted groundwater	10,048,360	BTU/hr
Energy flux in extracted steam	4,405,913	BTU/hr
Net energy flux into treatment volume	29,604,853	BTU/hr
Heating per day	1.9	F/day
Start temperature	50	F
Target temperature	247	F
Estimated heat loss, worst case	30	%
Operating time		
Shake-down	10	days
Heating to boiling point	112	days
Boiling and drying	287	days
Heating to target temperature	9	days
Sampling/analysis phase	10	days
Post treatment vapor extraction	30	days
Total operating time	459	days

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Conceptual Design Parameters/Treatment Outputs (Continued)

Libby Groundwater Site	**AECOM**
Numbers of wells	***Area 1***
Multiphase extraction well, pumping	54
Horizontal SVE wells	30
Steam injection wells	165
Temperature monitoring holes	25
Pressure monitoring wells	10

Libby Groundwater Site	**AECOM**	
Process equipment	***Value***	***Unit***
Treatment system power supply	320	kW
Total power need to site	400	kW
Estimated total electric load	500	kVA
Water softener feed rate	90.8	gpm
Steam generator capacity	45,375.0	lbs/hr
Vapor extraction rate, total	3,240	scfm
Non-condensable vapor	1,620	scfm
Estimated steam extraction	1,620	scfm
Liquid extraction rate	143.3	gpm
Condensed liquid rate	9.1	gpm
Water treatment rate	152.3	gpm
Vapor treatment type	Thermal Oxidizer w/ heat recovery	-
Dominant contaminant of concern	Creosote	-
Estimated COC mass	250,000	lbs
Estimated COC mass treated by vapor system	32,500	lbs
Estimated COC mass treated by water system	5,000	lbs
Estimated COC mass generated as NAPL	212,500	lbs
Estimated max mass removal rate, vapor system	161	lbs/day

Conceptual Utility Requirements & Budgetary Costs

Libby Groundwater Site	AECOM	
Utility estimates	***Value***	***Unit***
Steam usage, total	284,451,000	lbs
Power usage, treatment system	2,059,000	kWh
Power usage, total	3,412,000	kWh
Gas usage, total	425,961	MM BTU
Discharge water, total	20,051,000	gallons
Discharge vapor, total	1,073	mill scf

AECOM Libby Groundwater Site	
Design and Procurement	$330,000
Construction and Operation	$14,190,000
Utilities, paid by client	$2,930,000
Total	**$17,450,000**

Notes/Assumptions

Assumptions:

- **Price:**
    - +/- 30% price accuracy based on current understanding of preliminary Conceptual Site Model (CSM) as stated in this treatment concept
    - Unit power cost assumed: $0.11/kWh
    - Unit gas cost assumed: $6.0/mm BTU
    - Following items were not included in this cost estimate:
        - Installation of a hydraulic barrier
        - Drill cutting disposal
        - Disposal of extracted NAPL
        - Disposal of Investigation-Derived Waste (IDW)
- **Turn-Key services:**
    - Design/procurement/permitting (permitting managed by AECOM, TerraTherm supports the process)
    - Construction
    - Operations (site and office support)
    - Demobilization
    - Reporting
- **Construction:**
    - 100 ft/day drilling production assumed
    - Electrical and mechanical connections above grade
- **Operations**
    - Standard:
        - Field Crew (4.0 persons on average) housed within 30 minute drive to the site
        - Office support: Project Management and Engineering
- **Demobilization**
    - Bringing site back to as near to starting conditions as possible:
        - Grouting up wells
        - Removal of all equipment
        - Overdrilling of wells is excluded

Possible Next Step

Basis of Design Report (BODR):

TerraTherm would be pleased to provide a proposal for preparation of the BODR (or alternatively for preparation of the detailed design effort as described below) for the project.

The BODR includes the following:

- Site visit and meeting
- Thermal modeling and refinement of thermal treatment concept(s)
- Evaluation of data gaps
- Risk/uncertainty evaluation
- Define exact scope of work for key project tasks (responsibility matrix)
- Comparison of multiple treatment scenarios (if applicable)
- Firm price cost estimate

The price for this deliverable can range from $15,000 to $25,000.

For further information, please contact Alejandro Daza at (978) 730-1200, Ext. 2638

Additional Information

TERRATHERM
a Cascade Company

ISTD and SEE Case Study:
Arnold Air Force Base, Tennessee
(Approved for public release, distribution unlimited AEDC2011-262)

Project Information: A combined In Situ Thermal Remediation approach utilizing In Situ Thermal Desorption (ISTD) and Steam Enhanced Extraction (SEE) was implemented at a former vapor degreasing facility and leach pit at Arnold Air Force Base in Tullahoma, TN (Solid Waste Management Unit 10 [SWMU-10]). An estimated 31,000 gallons of chlorinated solvents (primarily PCE) were disposed of at SWMU-10, posing a regional risk to groundwater.

Subsurface Geology/Hydrogeology: Permeability in the target treatment zone (TTZ) differed by at least three orders of magnitude. The shallow aquifer consists of a silty sand/silty gravel layer encountered roughly 15 to 20 ft bgs and extending to approximately 40 ft bgs. The intermediate aquifer is a source of drinking water in the region and consists of gravely clay/clayey gravel, with the gravel content increasing with depth, including a highly permeable rubble layer approximately 5-10 ft thick above the bedrock surface. The intermediate aquifer is present from approximately 40 ft bgs, and extends to the top of the limestone bedrock located at approximately 85 ft bgs.

Project Goals: The primary goals of the remedial action were to remove dense non-aqueous phase liquid (DNAPL) from the source zone, and to reduce solvent-based contaminant mass flux from the source area to the downgradient intermediate aquifer.

Project Approach: Shallow aquifer heating was accomplished with thermal conduction heaters installed to depths of 50 to 65 ft bgs, while intermediate aquifer heating was achieved by steam injection in the basal gravel/upper bedrock zone at 80-90 ft bgs. Extraction wells completed between 45 and 90 ft bgs in and around the TTZ maintained hydraulic and pneumatic control. The TTZ encompassed an area of approximately 27,360 ft^2 and a volume of 66,700 yd^3 with various treatment depths ranging from 50 to 90 ft bgs.

Project Results: After 7 months of operation, soil and groundwater sample results showed that PCE concentrations in the eastern portion of the Site were below the performance standards. However, in the western portion of the Site, sample results were above the performance standards due to an unidentified water source creating cooling in the shallow zone. The project team enhanced the western zone treatment system by intercepting the water inflow with extraction sumps and boundary trenches, reconfiguring heating to target the cooler shallow soils, and by adding insulation to the vapor cap to minimize surface heat loss. After a total of 16 months of system operation, approximately 165,000 pounds of chlorinated VOCs (primarily PCE) were removed from the TTZ.

Visit our Website! www.terratherm.com

Southern California Edison Co. (Visalia Poleyard)

Link:
https://yosemite.epa.gov/r9/sfund/r9sfdocw.nsf/vwsoalphabetic/Southern+California+Edison+Co.+(Visalia+Poleyard)?OpenDocument

Appendix E
IET ISGS Proposal

Appendix E
IET ISGS Proposal

Proposal to Address NAPL Contamination via Chemical Immobilization

using

In-Situ Geochemical Stabilization (ISGS)

for

The Libby Groundwater Site

Site Location:
Libby, Montana

April 2017

Innovative Environmental Technologies, Inc.
6071 Easton Road
Pipersville, PA 18947
(888) 721-8283
IET-INC.NET

April 12, 2017

Elaine Reilly

AECOM

Dear Ms. Reilly:

Innovative Environmental Technologies Inc. (IET) has completed a remedial design and cost estimate regarding the Libby Groundwater site located in Libby, Montana. The site has been identified as having soils and groundwater impacted by the historical release of wood preserving compounds. As a result of IET's evaluation of the provided data, a design which will stabilize the present NAPL via *In-Situ Geochemical Stabilization* (ISGS) is proposed. The proposed remedial program is designed to geochemically bind NAPL contamination in-situ. The ISGS solution will be applied via IET's patented mixing and injection equipment, as found in the following patent: United States Apparatus Patent Number 7,044,152.

The following estimate sets forth a lump sum price for the design, implementation and follow up of this process and is presented for budgetary consideration. All costs included in the lump sum price are listed below.

Included in the lump sum prices are:

- All materials necessary to complete the proposed plan
- All equipment and personnel required to execute the proposed plan
- Handling and Management of materials on site
- Mobilization/Demobilization of the injection crews
- All per diem for the required crews
- Site Restoration
- Final field injection report
- Final plot of injection points
- Six quarterly data analysis reports based on data provided to IET from AECOM, provided as a value added service for no charge

Table of Contents

OBJECTIVE

It shall be the objective of IET to conduct a stabilization of present free product at the site located in Libby, Montana. *In-Situ Geochemical Stabilization* (ISGS) entails the use of modified permanganate solutions for the purposes of mass removal and flux reduction (i.e., NAPL stabilization). As the oxidant migrates through the treatment area, various (bio)geochemical reactions destroy the targeted compounds present in the dissolved phase. This causes a “hardening” or "chemical weathering” of the NAPL as it steadily loses its more labile components. This causes a net increase in viscosity of the organic material, which yields a more stable, recalcitrant residual mass. In addition, both the insoluble MnO_2 precipitate that results from permanganate oxidation and other mineral species included in the ISGS formulation accumulate along the NAPL interface, physically coating the NAPL and thereby reducing the flux of dissolved-phase constituents of interest (COI) into the groundwater as below (Photograph 1).

Unlike the typical application of In Situ Chemical Oxidation (ISCO) reagents, ISGS is used to encapsulate NAPL, with chemical oxidation of COI’s being a secondary affect. As a result, the overall oxidant dosing is often substantially less than with typical ISCO applications, resulting in rapid, highly effective treatment at a much lower cost.

Photograph 1: Untreated Soil Core and ISGS treated soil core

TREATMENT AREA

The treatment area will target a 125,000 square foot area from 7-74' below grade surface (bgs). This area will be divided into 3 subunits based upon physical and chemical similarities.

AREA A SHALLOW

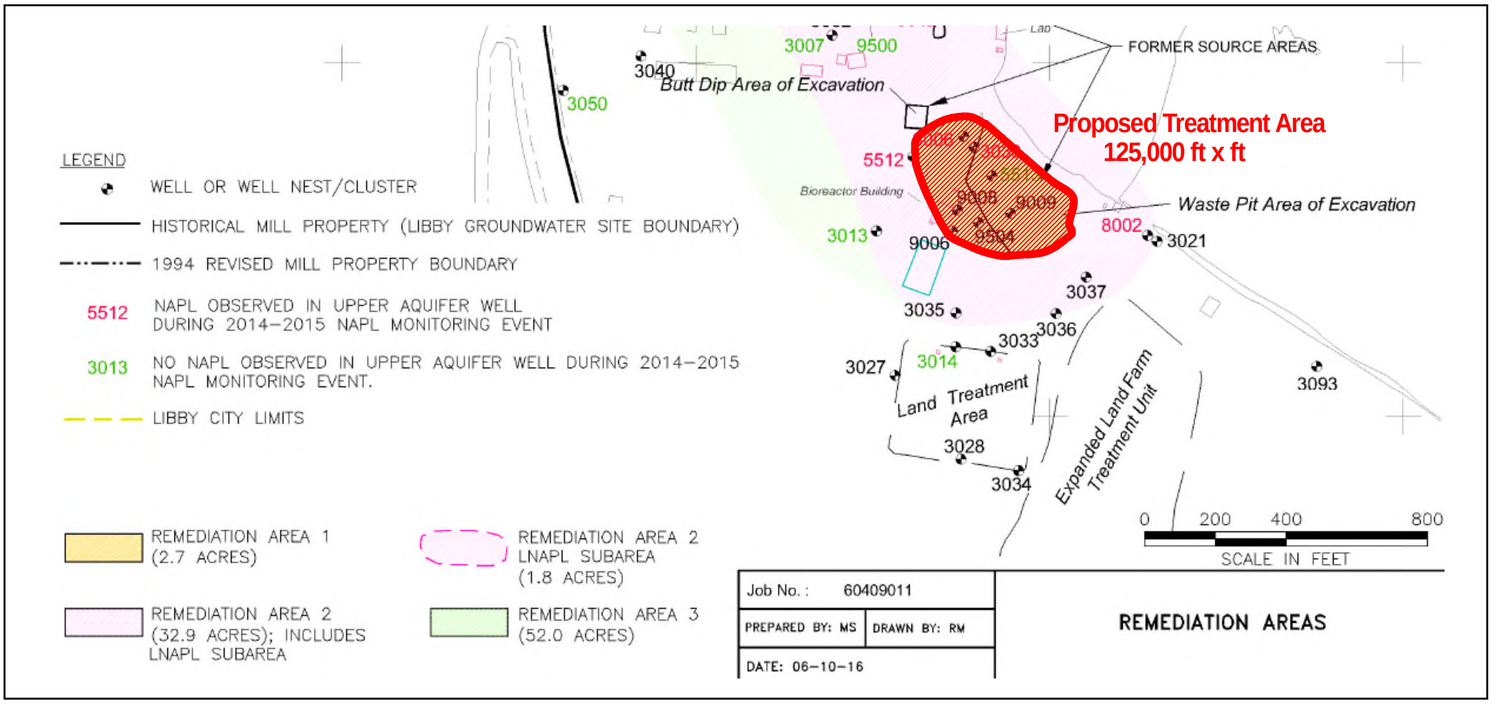
The subunit, Area A Shallow, will require 398 injection points based on a radius of influence of 10 feet. The ISGS solution will treat between 7 and 34 feet below ground surface (bgs) with five injection intervals evenly spaced within this zone. A sonic rig will be used to advance the injection screen to the target depths. A 10% ISGS solution is proposed for the area and the solution will target approximately 5% of the pore volume in the treatment area, assuming a 20% effective porosity. Area A Shallow is estimated to take 85 day(s) to complete.

AREA A MIDDLE

The subunit, Area A Middle, will require 100 injection points based on a radius of influence of 20 feet. The ISGS solution will treat between 34 and 54 feet below ground surface (bgs) with four injection intervals evenly spaced within this zone. A sonic rig will be used to advance the injection screen to the target depths. A 10% ISGS solution is proposed for the area and the solution will target approximately 5% of the pore volume in the treatment area, assuming a 20% effective porosity. Area A Middle is estimated to take 63 day(s) to complete.

AREA A DEEP

The subunit, Area A Deep, will require 100 injection points based on a radius of influence of 20 feet. The ISGS solution will treat between 54 and 74 feet below ground surface (bgs) with four injection intervals evenly spaced within this zone. A sonic rig will be used to advance the injection screen to the target depths. A 10% ISGS solution is proposed for the area and the solution will target approximately 5% of the pore volume in the treatment area, assuming a 20% effective porosity. Area A Deep is estimated to take 63 day(s) to complete.



SCOPE OF WORK

The injection event will require 598 injection points, which will encompass 125,000 square feet. IET estimates that this event will take 211 days to implement.

Subsurface Pathway Development

Initially, compressed air shall be delivered to the subsurface via IET proprietary injection trailer system. This process step allows for confirmation of open delivery routes while enhancing horizontal injection pathways. The confirmation of open and viable subsurface delivery pathways insures that upon introduction of the oxidizer(s) injections will occur freely thus minimizing health and safety risks associated with oxidant full injection lines and injection tooling when no subsurface delivery route has been established. Confirmation of open and free pathways is accomplished via observed pressure drops and fee moving compressed gases to the subsurface.

ISGS Emplacement

A 10% solution of In Situ Geochemical Stabilization will then be introduced at pressures between 15 and 120 psi and flow rates between 2-15 gpm. A small amount of water follows this step in order to rinse the injection equipment.

Post Liquid Injection – Compressed Air Injection

Lastly, the injection lines are cleared of liquids and all injectants are forced into the created formation and upward into the vadose zone. This step insures that all material is injected outward into the formation and minimizes any surface excursions of injectants following the release of the injection pressure. Once the injection cycle is complete, the injection point is temporarily capped to allow for the pressurized subsurface to accept the injectants.

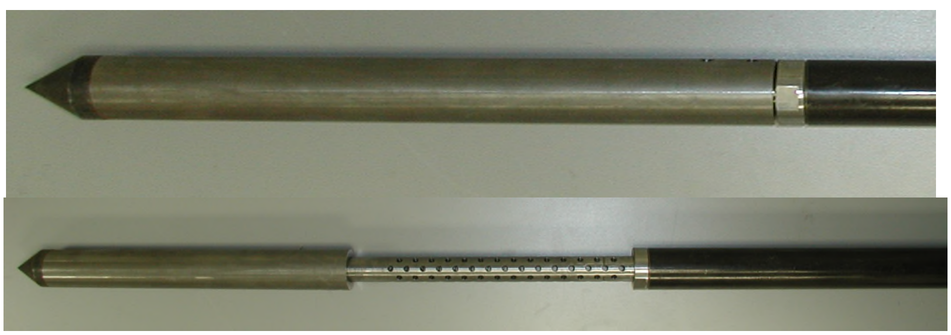
Equipment Description

The injections small occur via IET's mobile oxidation injection trailer and IET's direct-push equipment as described:

Injection Lines: High Pressure Stainless steel Braided Rubber one inch diameter hoses

Injection Trailer: IET Self-contained injection trailer, consisting of: two 120 gallon conical tanks capable of maintaining unto 30% solids as a suspension via lightning mixers; on-board generator, all stainless steel piping system, 2" pneumatic diaphragm pump with an operating pressure of 110 psi.; on-board 25 CFM/175 psig compressor with 120 gallons of air storage; self contained eye wash and safety shower.

Injection Rods: IET proprietary injection rods with retractable injection zones and backflow protection Injection zones of 18 inches are to be used in combination with 24" injection AWJ-Rods where appropriate.



IET INJECTION SYSTEM
UNITED STATES PATENT 7,044,152

Injection Trailers Include: Multiple Liquid Feed Systems, Stainless Steel Piping, Isolated Compressed Gas Containment, Safety Shower, Eyewash Station, Onboard Generator, Chemical Resistant Construction, Mobile Office Space

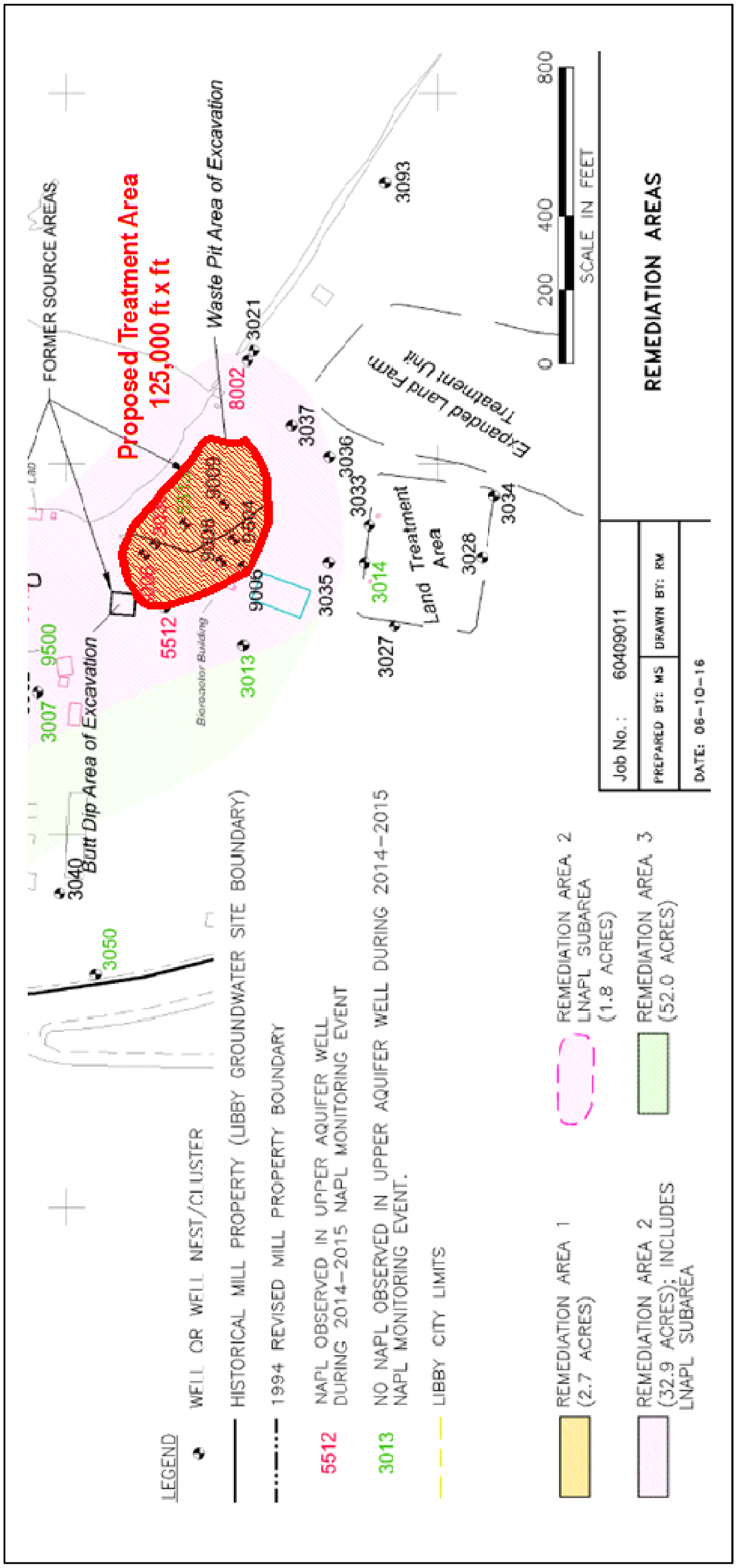
SUMMARY

Innovative Environmental Technologies, Inc. presents this cost estimate for the stabilization of NAPL onsite for the defined treatment area. It is estimated to cost **$11,243,968.75** to treat the site utilizing ISGS. IET has estimated that it will take **211** days to complete the remedial program.

	Area (FtXFt)	Number of Injection Pts	Number of Intervals	Targeted Zone (Ft bgs)	Gls ISGS/Interval	Total Gallons ISGS	Number of Days	Cubic Yards	Price	Price per Cubic Yard
ISGS Injection: Area A-Shallow Subunit	125000	398	5.00	7-34'	127.1984925	253125	85	125000	$4,529,218.75	$36.23
ISGS Injection: Area A-Middle Subunit	125000	100	4.00	34-54'	469	187500	63	92592.59259	$3,357,375.00	$36.26
ISGS Injection: Area A-Deep Subunit	125000	100	4.00	54-74'	468.75	187500	63	92592.59259	$3,357,375.00	$36.26
						628125	211		$11,243,968.75	

APPENDICES:

APPENDIX 1 – SITE MAP



APPENDIX 2 – DOSAGE CALCULATIONS

AREA A SHALLOW

Libby, Montana		**FULL SCALE ESTIMATE**						
ISGS Injection: Area A-Shallow Subunit								
Parameters	**Units**	**Assumptions**						
Target Area	Ft.X Ft.	125000						
Area of influence of Remediation Injection(s)	Sq. Ft.	314.159						
Estimated Number of Injections to Treat Area	# Injections	398						
vertical impacted zone	Ft.	27						
Total Volume Targeted	Cu. Yd.	125000						
Porosity	%	20.00%						
Injection Parameters								
Antcipated Radius of Influence	Ft	10						
Pore Volume	Gal	5062500						
ISGS Concentration in Pore Volume	%	5.0%						
Required Volume of ISGS	Gal	**253125**						
Required CaCl	pounds	57510		$0.50				
Required 37.5% NaSi	Gallons	10125		$10.00				
Required 40% NaMnO2	Gallons	25312.5		$33.00				
Required Ferrous Carbonate	pounds	57510		$2.20				
Cost of ISGS -		$3,164,062.50						
Intervals Per Point	**7-34'**	**5.00**						
Required Volume of ISGS/interval		127.1984925						
INJECTION/ROI EVALUATION								
Days of Sonic Rig	85.00	$6,500.00		$552,500.00		84.375		
IET Trailer - Injection System	85.00	$4,500.00		$382,500.00				
Days IET Supervision/coordination	85.00	$1,250.00		$106,250.00				
Report and data evaluation	1	$1,500.00		$1,500.00				
Days IET Admin	1	$2,500.00		$2,500.00				
Mob/demob	1	$3,500.00		$3,500.00				
						Cost per cubic yard		36.23375
TOTAL LUMP SUM ESTIMATE - FULL SCALE				**$4,529,218.75**		Cost per ton		24.15583

AREA A MIDDLE

Libby, Montana		**FULL SCALE ESTIMATE**						
ISGS Injection: Area A-Middle Subunit								
Parameters	**Units**	**Assumptions**						
Target Area	Ft.X Ft.	125000						
Area of influence of Remediation Injection(s)	Sq. Ft.	1256.636						
Estimated Number of Injections to Treat Area	# Injections	100						
vertical impacted zone	Ft.	20						
Total Volume Targeted	Cu. Yd.	92592.59259						
Porosity	%	20.00%						
Injection Parameters								
Antcipated Radius of Influence	Ft	20						
Pore Volume	Gal	3750000						
ISGS Concentration in Pore Volume	%	5.0%						
Required Volume of ISGS	Gal	**187500**						
Required CaCl	pounds	42600		$0.50				
Required 37.5% NaSi	Gallons	7500		$10.00				
Required 40% NaMnO2	Gallons	18750		$33.00				
Required Ferrous Carbonate	pounds	42600		$2.20				
Cost of ISGS -		$2,343,750.00						
Intervals Per Point	**34-54'**	**4.00**						
Required Volume of ISGS/interval		468.75						
INJECTION/ROI EVALUATION								
Days of Sonic Rig	63.00	$6,500.00		$409,500.00		62.5		
IET Trailer - Injection System	63.00	$4,500.00		$283,500.00				
Days IET Supervision/coordination	63.00	$1,250.00		$78,750.00				
Report and data evaluation	1	$1,500.00		$1,500.00				
Days IET Admin	1	$2,500.00		$2,500.00				
Mob/demob	1	$3,500.00		$3,500.00				
						Cost per cubic yard		36.25965
TOTAL LUMP SUM ESTIMATE - FULL SCALE				**$3,357,375.00**		Cost per ton		24.1731

AREA A DEEP

Libby, Montana		**FULL SCALE ESTIMATE**						
ISGS Injection: Area A-Deep Subunit								
Parameters	**Units**	**Assumptions**						
Target Area	Ft.X Ft.	125000						
Area of influence of Remediation Injection(s)	Sq. Ft.	1256.636						
Estimated Number of Injections to Treat Area	# Injections	100						
vertical impacted zone	Ft.	20						
Total Volume Targeted	Cu. Yd.	92592.59259						
Porosity	%	20.00%						
Injection Parameters								
Antcipated Radius of Influence	Ft	20						
Pore Volume	Gal	3750000						
ISGS Concentration in Pore Volume	%	5.0%						
Required Volume of ISGS	Gal	**187500**						
Required CaCl	pounds	42600		$0.50				
Required 37.5% NaSi	Gallons	7500		$10.00				
Required 40% NaMnO2	Gallons	18750		$33.00				
Required Ferrous Carbonate	pounds	42600		$2.20				
Cost of ISGS -		$2,343,750.00						
Intervals Per Point	**54-74'**	**4.00**						
Required Volume of ISGS/interval		468.75						
INJECTION/ROI EVALUATION								
Days of Sonic Rig	63.00	$6,500.00		$409,500.00		62.5		
IET Trailer - Injection System	63.00	$4,500.00		$283,500.00				
Days IET Supervision/coordination	63.00	$1,250.00		$78,750.00				
Report and data evaluation	1	$1,500.00		$1,500.00				
Days IET Admin	1	$2,500.00		$2,500.00				
Mob/demob	1	$3,500.00		$3,500.00				
						Cost per cubic yard		36.25965
TOTAL LUMP SUM ESTIMATE - FULL SCALE				**$3,357,375.00**		Cost per ton		24.1731

APPENDIX 3: TECHNOLOGY DISCUSSION

ISGS TECHNOLOGY DISCUSSION

In Situ Geochemical Stabilization (ISGS) entails the use of modified permanganate solutions for the purposes of mass removal and flux reduction (*i.e.,* NAPL stabilization). As the oxidant migrates through the treatment area, various geochemical reactions destroy the targeted compounds present in the dissolved phase. This causes a "hardening" or "chemical weathering" of the NAPL as it steadily loses its more labile components. This causes a net **increase in viscosity** of the organic material, which yields a more stable, recalcitrant residual mass. In addition, both the insoluble MnO_2 precipitate that results from permanganate oxidation and other mineral species included in the ISGS formulation accumulate along the NAPL interface, physically coating the NAPL and thereby reducing the flux of dissolved-phase constituents of interest (COI) into the groundwater as seen in the pictures below.

Summary – LNAPL Application: The primary objectives of the piloted technology are to demonstrate both mass removal and mass stabilization. To achieve these objectives the delivery of the ISGS material must effectively distribute the material to the targeted zone(s) and the formation of the Birnessite-like crust must be confirmed. Birnessite (**Photo 1**) is an oxide of Mn and Mg, along with Na, Ca and K with the composition:

$$(Na,Ca,K)(Mg,Mn)Mn_6O_{14} \cdot 5H_2O$$

Photo 1: Birnessite

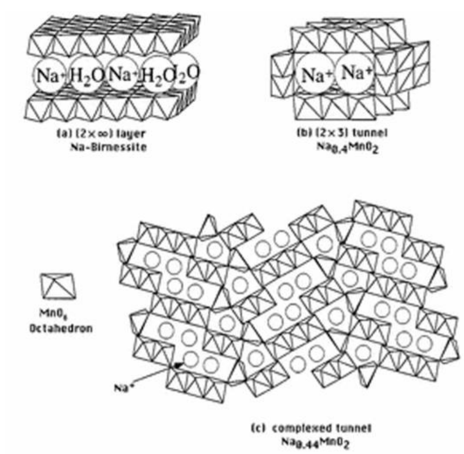
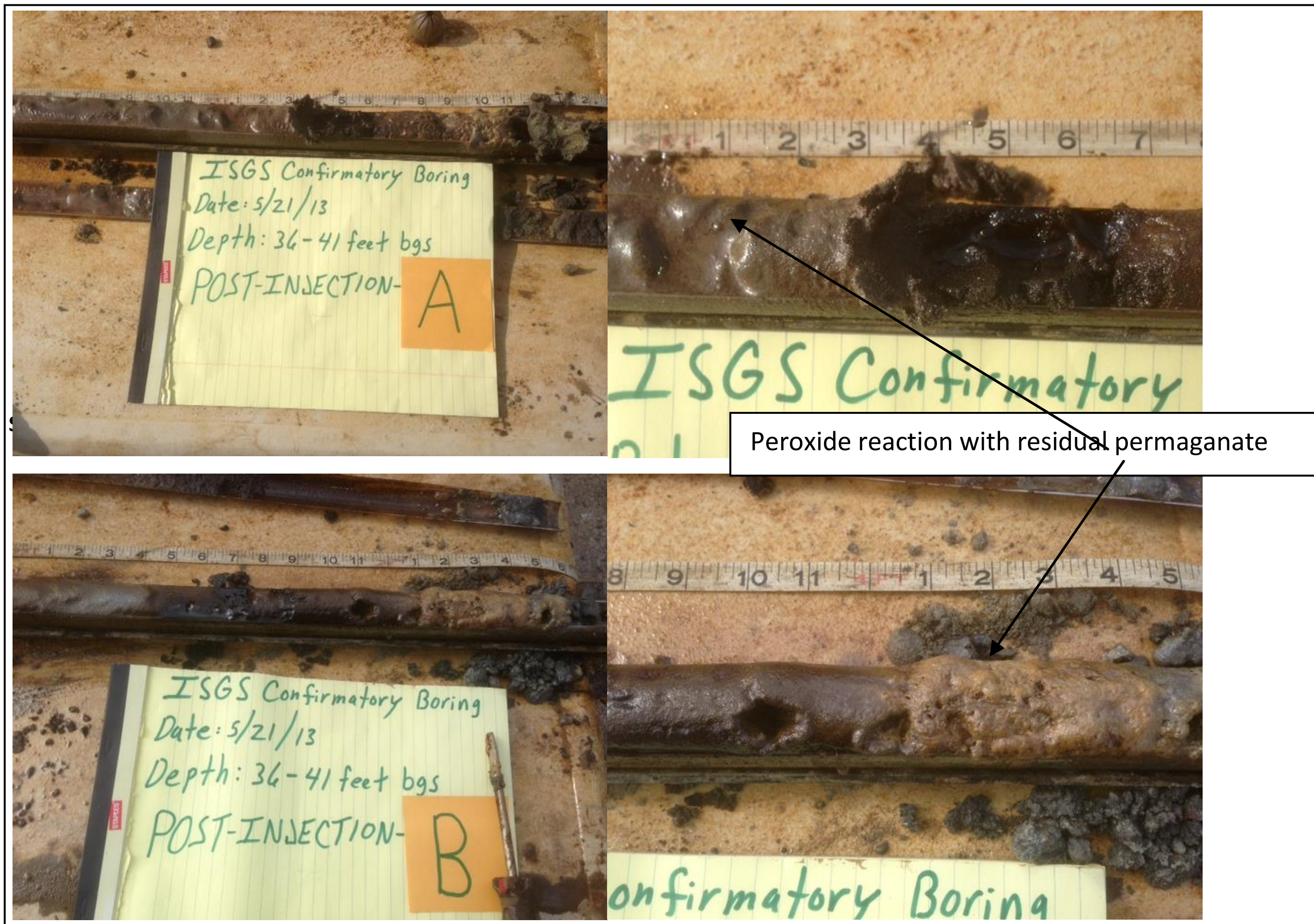


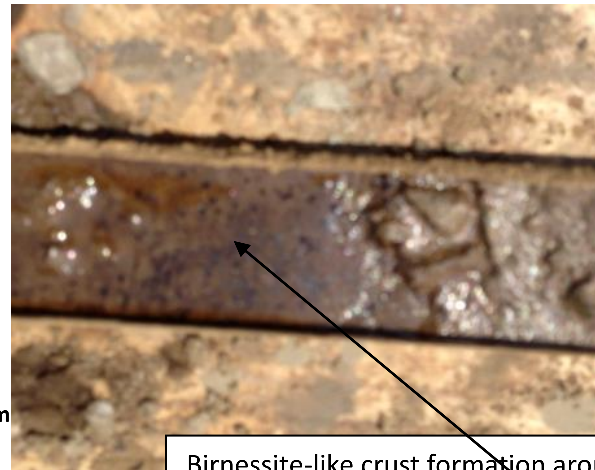
Figure 2 Schematic diagram of the structure of layered and tunnel manganese oxides.

The field sampling techniques one day following the injection event (traditional acetate liner advancement) proved ineffective in its ability to obtain characteristic samples below approximately 38’ bgs. It was the opinion of IET that the residual hydrostatic pressure in the primary injection zone resulted in a “heaving” of the unconsolidated sands into the tooling. A consequence of this “heaving” was the inability of the acetate liner sampling tooling to overcome the hydrostatic head pressure. Samples down to 38’ bgs were obtained and evaluated in the field. Photos of the day one sampling event are provided below in **Photo 2**. The day one sampling event provided evidence to support the 10’ radius design basis of the pilot in the 35-38’ injection zone, however without the benefit of the deeper injection zone samples a modification to the sampling technique was required. The day five sampling event utilized a discrete sampling method which allowed for the sampling of the entire injection profile (35-41’ bgs). Photos of the day five sampling event are provided below in **Photo 3**.

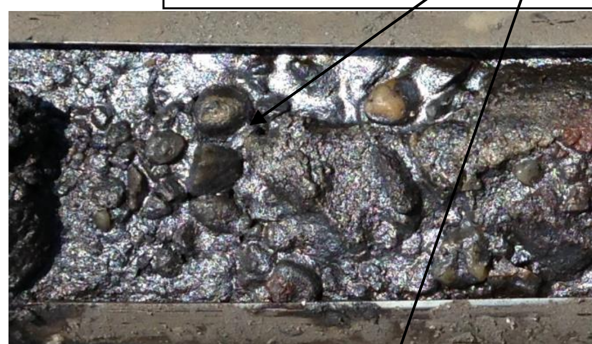


Sample “B” Location – Day 1

Day One sampling occurred so as to confirm delivery and the presence of the ISGS injectant. Day Five was used to evaluate the geotechnical formation.



Birnessite-like crust formation around “globels” of free-phase DNAPL and Saturated soil



In September 2013, a creosote site was injected by IET, prior to injection creosote was seen in samples and a strong odor was noted. Following injection the creosote that was observed above the peat layer was seen to have “solidified”, with no associated odor (15 days following injection). In the picture below the peat layer is easily seen and the ISGS formation immediately above it.

Peat Layer

Close-up of ISGS

APPENDIX 4 – CASE STUDY

Summary – DNAPL Application

The primary objectives of the technology are to demonstrate both mass removal and mass stabilization. To achieve these objectives the delivery of the ISGS material must effectively distribute the material to the targeted zone(s) and the formation of the Birnessite-like crust must be confirmed. Birnessite (**Photo 1**) is an oxide of Mn and Mg, along with Na, Ca and K with the composition:

$$(Na,Ca,K)(Mg,Mn)Mn_6O_{14} . \cdot 5H_2O$$

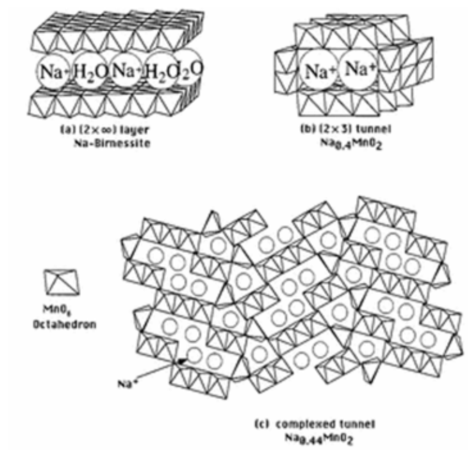
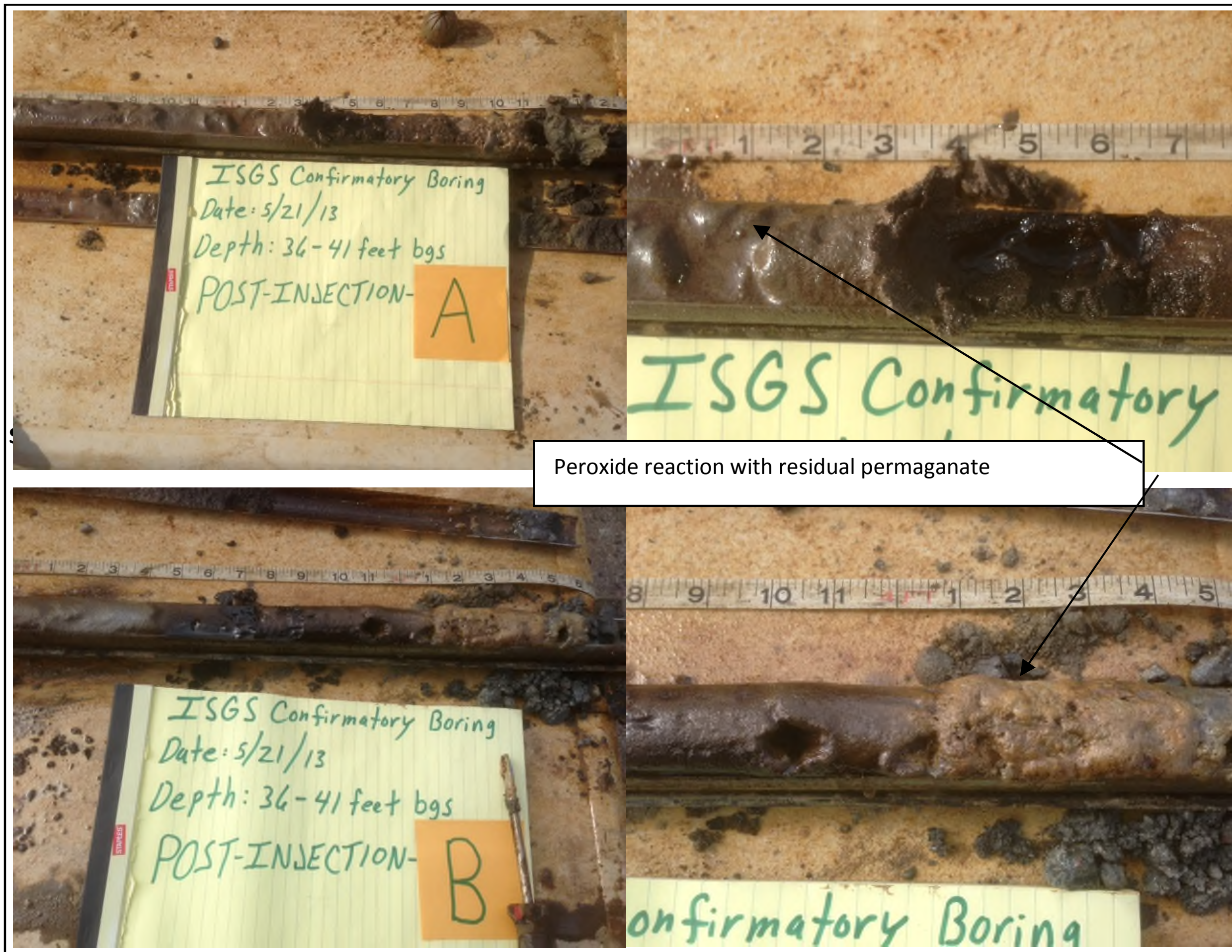


Figure 2 Schematic diagram of the structure of layered and tunnel manganese oxides.

Photo 1: Birnessite

The field sampling techniques one day following the injection event (traditional acetate liner advancement) proved ineffective in its ability to obtain characteristic samples below approximately 38' bgs. It was the opinion of IET that the residual hydrostatic pressure in the primary injection zone resulted in a "heaving" of the unconsolidated sands into the tooling. A consequence of this "heaving" was the inability of the acetate liner sampling tooling to overcome the hydrostatic head pressure. Samples down to 38' bgs were obtained and evaluated in the field. Photos of the day one sampling event are provided below in **Photo 2**. The day one sampling event provided evidence to support the 10' radius design basis of the pilot in the 35-38' injection zone, however without the benefit of the deeper injection zone samples a modification to the sampling technique was required. The day five sampling event utilized a discrete sampling method which allowed for the sampling of the entire injection profile (35-41' bgs). Photos of the day five sampling event are provided below in **Photo 3**.



Sample "B" Location – Day 1

Day One sampling occurred so as to confirm delivery and the presence of the ISGS injectant. Day Five was used to evaluate the geotechnical formation.

Innovative Environmental Technologies, Inc.

Proposal to Conduct a Pilot to Address NAPL Contamination via Chemical Immobilization

using

In-Situ Geochemical Stabilization (ISGS)

for

The Libby Groundwater Site

Site Location:
Libby, Montana

June 2017

Innovative Environmental Technologies, Inc.
6071 Easton Road
Pipersville, PA 18947
(888) 721-8283
IET-INC.NET

June 13, 2017

Elaine Reilly

AECOM

Dear Ms. Reilly:

Innovative Environmental Technologies Inc. (IET) has completed a remedial pilot design and cost estimate regarding the Libby Groundwater site located in Libby, Montana. The site has been identified as having soils and groundwater impacted by the historical release of wood preserving compounds. As a result of IET's evaluation of the provided data, a design which will stabilize the present NAPL via *In-Situ Geochemical Stabilization* (ISGS) is proposed. The proposed remedial program is designed to geochemically bind NAPL contamination in-situ. The ISGS solution will be applied via IET's patented mixing and injection equipment, as found in the following patent: United States Apparatus Patent Number 7,044,152.

The following estimate sets forth a lump sum price for the design, implementation and follow up of this process and is presented for budgetary consideration. All costs included in the lump sum price are listed below.

Included in the lump sum prices are:

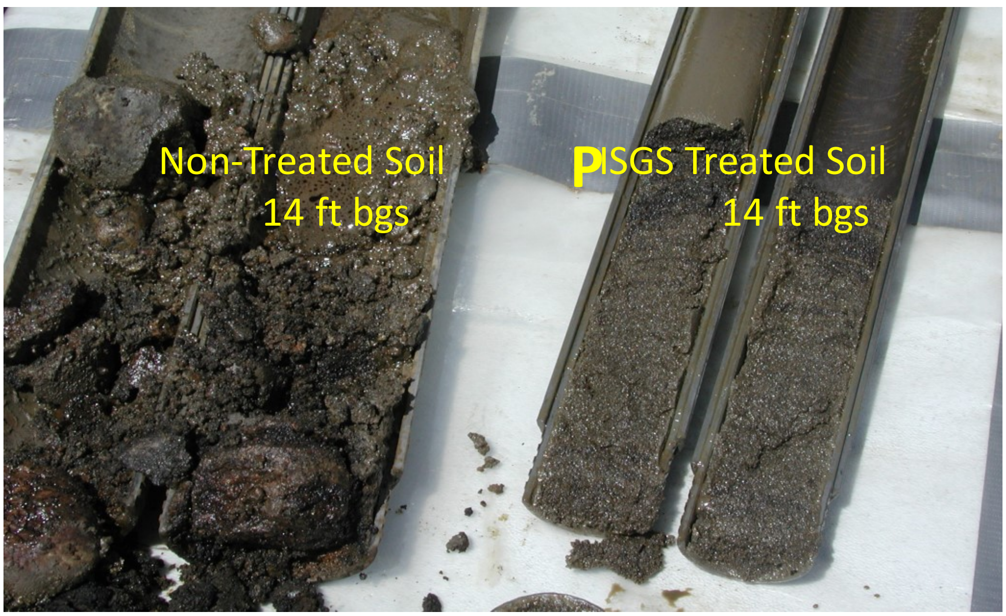
- All materials necessary to complete the proposed plan
- All equipment and personnel required to execute the proposed plan
- Handling and Management of materials on site
- Mobilization/Demobilization of the injection crews
- All per diem for the required crews
- Site Restoration
- Final field injection report
- Final plot of injection points
- Six quarterly data analysis reports based on data provided to IET from AECOM, provided as a value added service for no charge

Table of Contents

OBJECTIVE

It shall be the objective of IET to conduct a stabilization of present free product at the site located in Libby, Montana. *In-Situ Geochemical Stabilization* (ISGS) entails the use of modified permanganate solutions for the purposes of mass removal and flux reduction (i.e., NAPL stabilization). As the oxidant migrates through the treatment area, various (bio)geochemical reactions destroy the targeted compounds present in the dissolved phase. This causes a “hardening” or "chemical weathering” of the NAPL as it steadily loses its more labile components. This causes a net increase in viscosity of the organic material, which yields a more stable, recalcitrant residual mass. In addition, both the insoluble MnO_2 precipitate that results from permanganate oxidation and other mineral species included in the ISGS formulation accumulate along the NAPL interface, physically coating the NAPL and thereby reducing the flux of dissolved-phase constituents of interest (COI) into the groundwater as below (Photograph 1).

Unlike the typical application of In Situ Chemical Oxidation (ISCO) reagents, ISGS is used to encapsulate NAPL, with chemical oxidation of COI’s being a secondary affect. As a result, the overall oxidant dosing is substantially less than with typical ISCO applications, resulting in rapid, highly effective treatment at a much lower cost.



Photograph 1: Untreated Soil Core and ISGS treated soil core

TREATMENT AREAS

The exact location of the treatment areas has yet to be determined but the specifics of the shallow, middle and deep target treatment designs can be applied nevertheless. These areas are divided into 3 subunits based upon physical and chemical similarities in the subsurface.

AREA A SHALLOW

The subunit, Area A Shallow, will require 16 injection points based on a radius of influence of 10 feet. The ISGS solution will treat between 7 and 34 feet below ground surface (bgs) with five injection intervals evenly spaced within this zone. A direct push rig will be used to advance the injection screen to the target depths. A 10% ISGS solution is proposed for the area and the solution will target approximately 5% of the pore volume in the treatment area, assuming a 20% effective porosity. Area A Shallow is estimated to take 4 day(s) to complete.

AREA A MIDDLE

The subunit, Area A Middle, will require 4 injection points based on a radius of influence of 20 feet. The ISGS solution will treat between 34 and 54 feet below ground surface (bgs) with four injection intervals evenly spaced within this zone. A sonic rig will be used to advance the injection screen to the target depths. A 10% ISGS solution is proposed for the area and the solution will target approximately 5% of the pore volume in the treatment area, assuming a 20% effective porosity. Area A Middle is estimated to take 4 day(s) to complete.

AREA A DEEP

The subunit, Area A Deep, will require 4 injection points based on a radius of influence of 20 feet. The ISGS solution will treat between 54 and 74 feet below ground surface (bgs) with four injection intervals evenly spaced within this zone. A sonic rig will be used to advance the injection screen to the target depths. A 10% ISGS solution is proposed for the area and the solution will target approximately 5% of the pore volume in the treatment area, assuming a 20% effective porosity. Area A Deep is estimated to take 4 day(s) to complete.

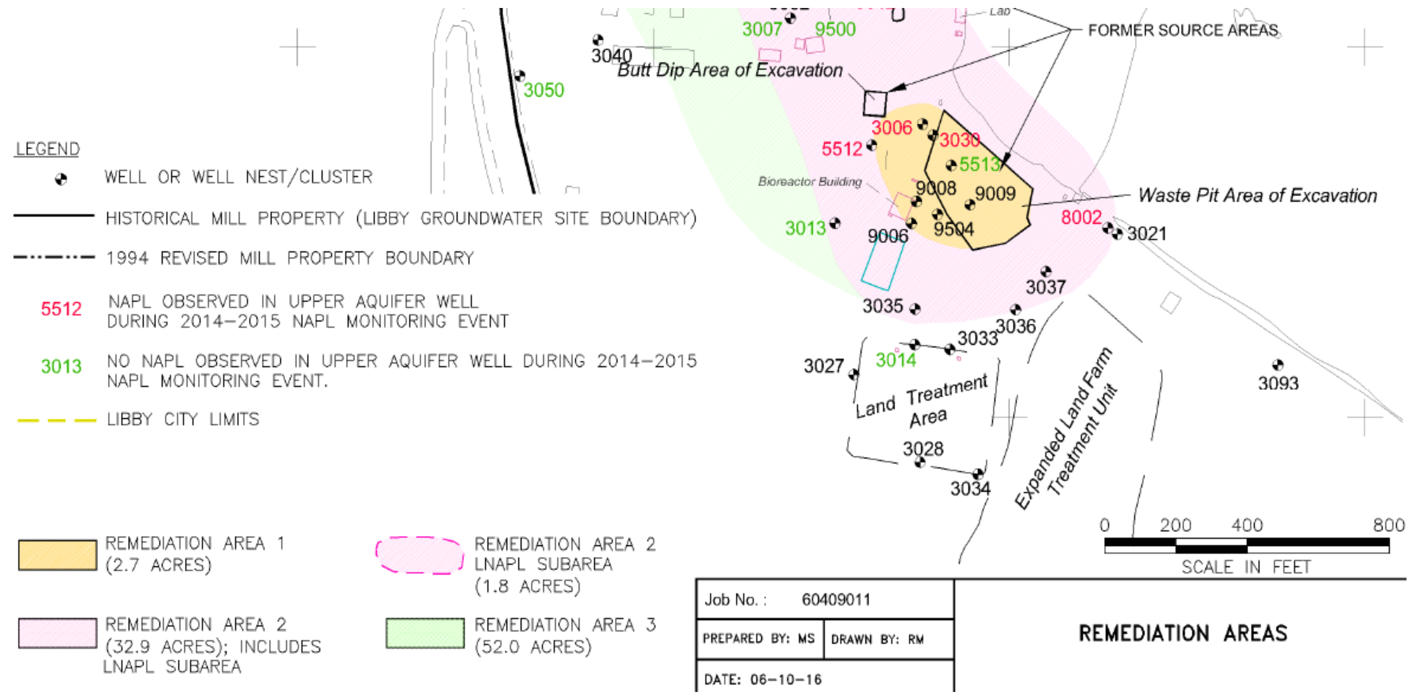


Figure 1. Site Map

SCOPE OF WORK

The injection event will require up to 24 injection points, which will encompass 5,026 square feet. IET estimates that this event will take 12 days to implement.

Subsurface Pathway Development

Initially, compressed air shall be delivered to the subsurface via IET proprietary injection trailer system. This process step allows for confirmation of open delivery routes while enhancing horizontal injection pathways. The confirmation of open and viable subsurface delivery pathways insures that upon introduction of the oxidizer(s) injections will occur freely thus minimizing health and safety risks associated with oxidant full injection lines and injection tooling when no subsurface delivery route has been established. Confirmation of open and free pathways is accomplished via observed pressure drops and fee moving compressed gases to the subsurface.

ISGS Emplacement

A 10% solution of In Situ Geochemical Stabilization will then be introduced at pressures between 15 and 120 psi and flow rates between 2-15 gpm. A small amount of water follows this step in order to rinse the injection equipment.

Post Liquid Injection – Compressed Air Injection

Lastly, the injection lines are cleared of liquids and all injectants are forced into the created formation and upward into the vadose zone. This step insures that all material is injected outward into the formation and minimizes any surface excursions of injectants following the release of the injection pressure. Once the injection cycle is complete, the injection point is temporarily capped to allow for the pressurized subsurface to accept the injectants.

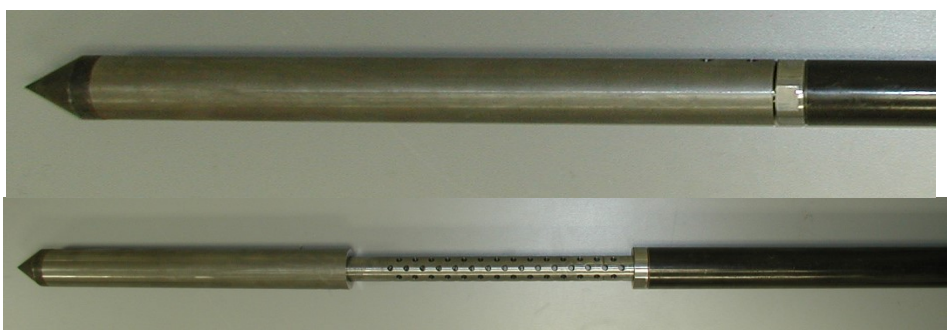
Equipment Description

The injections small occur via IET's mobile oxidation injection trailer and IET's direct-push equipment as described:

Injection Lines: High Pressure Stainless steel Braided Rubber one inch diameter hoses

Injection Trailer: IET Self-contained injection trailer, consisting of: two 120 gallon conical tanks capable of maintaining unto 30% solids as a suspension via lightning mixers; on-board generator, all stainless steel piping system, 2" pneumatic diaphragm pump with an operating pressure of 110 psi.; on-board 25 CFM/175 psig compressor with 120 gallons of air storage; self contained eye wash and safety shower.

Injection Rods: IET proprietary injection rods with retractable injection zones and backflow protection Injection zones of 18 inches are to be used in combination with 24" injection AWJ-Rods where appropriate.



IET INJECTION SYSTEM
UNITED STATES PATENT 7,044,152

Injection Trailers Include: Multiple Liquid Feed Systems, Stainless Steel Piping, Isolated Compressed Gas Containment, Safety Shower, Eyewash Station, Onboard Generator, Chemical Resistant Construction, Mobile Office Space

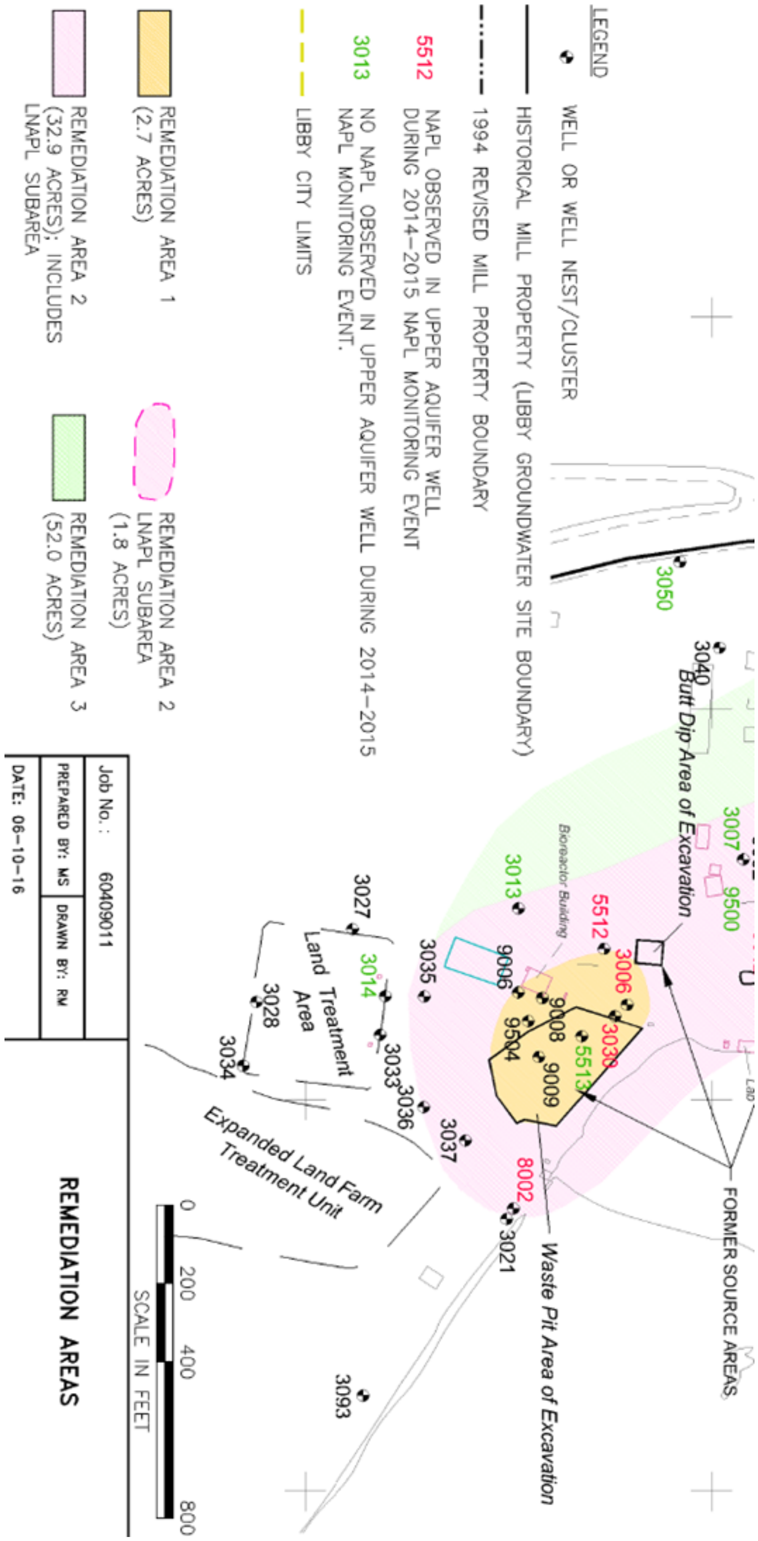
SUMMARY

Innovative Environmental Technologies, Inc. presents this pilot cost estimate for the stabilization of NAPL onsite for the defined treatment area. It is estimated to cost **$513,802.77** to treat the pilot areas utilizing ISGS. IET has estimated that it will take **12** days to complete the remedial program.

Area ID	Area (FtXFt)	Number of Injection Pts	Number of Intervals	Targeted Zone (Ft bgs)	Gls ISGS/Interval	Total Gallons ISGS	Number of Days	Cubic Yards	Price	Price per Cubic Yard
ISGS Injection: Area A-Shallow Subunit	5027	16	5	7-34'	127	10179	4	5027	$178,457.83	$35.50
ISGS Injection: Area A-Middle Subunit	5027	4	4	34-54'	471	7540	4	3723	$160,172.47	$43.02
ISGS Injection: Area A-Deep Subunit	5027	4	4	54-74'	471	7540	4	3723	$160,172.47	$43.02
Totals		24		7-74'		25258	12	12473		
								Mob/Demob	$15,000	
									$513,802.77	

APPENDICES:

APPENDIX 1 – SITE MAP



APPENDIX 2 – DOSAGE CALCULATIONS

AREA A SHALLOW

Libby, Montana		**PILOT SCALE ESTIMATE**	
ISGS Injection: Area A-Shallow Subunit			
Parameters	**Units**	**Assumptions**	
Target Area	Ft.X Ft.	5026.544	
Area of influence of Remediation Injection(s)	Sq. Ft.	314.159	
Estimated Number of Injections to Treat Area	# Injections	16	
vertical impacted zone	Ft.	27	
Total Volume Targeted	Cu. Yd.	5026.544	
Porosity	%	20.00%	
Injection Parameters			
Antcipated Radius of Influence	Ft	10	
Pore Volume	Gal	203575.032	
ISGS Concentration in Pore Volume	%	5.0%	
Required Volume of ISGS	Gal	**10178.7516**	
Cost of ISGS -		$127,234.40	
Intervals Per Point	**7-34'**	**5.00**	
Required Volume of ISGS/interval		127.234395	
INJECTION/ROI EVALUATION			
Days of DPT Rig	4.00	$2,000.00	$8,000.00
IET Trailer - Injection System	4.00	$4,500.00	$18,000.00
Days IET Supervision/coordination	4.00	$1,250.00	$5,000.00
Report and data evaluation	1	$1,500.00	$1,500.00
Days IET Admin	1	$2,500.00	$2,500.00
Mob/demob	1	$3,500.00	$3,500.00
TOTAL LUMP SUM ESTIMATE - FULL SCALE			**$178,457.83**

AREA A MIDDLE

Libby, Montana		**PILOT SCALE ESTIMATE**	
ISGS Injection: Area A-Middle Subunit			
Parameters	**Units**	**Assumptions**	
Target Area	Ft.X Ft.	5026.544	
Area of influence of Remediation Injection(s)	Sq. Ft.	1256.636	
Estimated Number of Injections to Treat Area	# Injections	4	
vertical impacted zone	Ft.	20	
Total Volume Targeted	Cu. Yd.	3723.365926	
Porosity	%	20.00%	
Injection Parameters			
Antcipated Radius of Influence	Ft	20	
Pore Volume	Gal	150796.32	
ISGS Concentration in Pore Volume	%	5.0%	
Required Volume of ISGS	Gal	**7539.816**	
Cost of ISGS -		$94,247.70	
Intervals Per Point	**34-54'**	**4.00**	
Required Volume of ISGS/interval		471.2385	
INJECTION/ROI EVALUATION			
Days of Sonic Rig	4.00	$6,500.00	$26,000.00
IET Trailer - Injection System	4.00	$4,500.00	$18,000.00
Days IET Supervision/coordination	4.00	$1,250.00	$5,000.00
Report and data evaluation	1	$1,500.00	$1,500.00
Days IET Admin	1	$2,500.00	$2,500.00
Mob/demob	1	$3,500.00	$3,500.00
TOTAL LUMP SUM ESTIMATE - FULL SCALE			**$160,172.47**

AREA A DEEP

Libby, Montana		PILOT SCALE ESTIMATE		
ISGS Injection: Area A-Deep Subunit				
Parameters	**Units**	**Assumptions**		
Target Area	Ft.X Ft.	5026.544		
Area of influence of Remediation Injection(s)	Sq. Ft.	1256.636		
Estimated Number of Injections to Treat Area	# Injections	4		
vertical impacted zone	Ft.	20		
Total Volume Targeted	Cu. Yd.	3723.365926		
Porosity	%	20.00%		
Injection Parameters				
Antcipated Radius of Influence	Ft	20		
Pore Volume	Gal	150796.32		
ISGS Concentration in Pore Volume	%	5.0%		
Required Volume of ISGS	Gal	**7539.816**		
Cost of ISGS -		$94,247.70		
Intervals Per Point	**54-74'**	**4.00**		
Required Volume of ISGS/interval		471.2385		
INJECTION/ROI EVALUATION				
Days of Sonic Rig	4.00	$6,500.00		$26,000.00
IET Trailer - Injection System	4.00	$4,500.00		$18,000.00
Days IET Supervision/coordination	4.00	$1,250.00		$5,000.00
Report and data evaluation	1	$1,500.00		$1,500.00
Days IET Admin	1	$2,500.00		$2,500.00
Mob/demob	1	$3,500.00		$3,500.00
TOTAL LUMP SUM ESTIMATE - FULL SCALE				**$160,172.47**

APPENDIX 3 – TECHNOLOGY DISCUSSION

Innovative Environmental Technologies, Inc.

ISGS TECHNOLOGY DISCUSSION

In Situ Geochemical Stabilization (ISGS) entails the use of modified permanganate solutions for the purposes of mass removal and flux reduction (*i.e.,* NAPL stabilization). As the oxidant migrates through the treatment area, various geochemical reactions destroy the targeted compounds present in the dissolved phase. This causes a “hardening” or "chemical weathering” of the NAPL as it steadily loses its more labile components. This causes a net **increase in viscosity** of the organic material, which yields a more stable, recalcitrant residual mass. In addition, both the insoluble MnO_2 precipitate that results from permanganate oxidation and other mineral species included in the ISGS formulation accumulate along the NAPL interface, physically coating the NAPL and thereby reducing the flux of dissolved-phase constituents of interest (COI) into the groundwater as seen in the pictures below.

Summary – LNAPL Application: The primary objectives of the piloted technology are to demonstrate both mass removal and mass stabilization. To achieve these objectives the delivery of the ISGS material must effectively distribute the material to the targeted zone(s) and the formation of the Birnessite-like crust must be confirmed. Birnessite (**Photo 1**) is an oxide of Mn and Mg, along with Na, Ca and K with the composition:

$$(Na,Ca,K)(Mg,Mn)Mn_6O_{14} \cdot 5H_2O$$

Photo 1: Birnessite

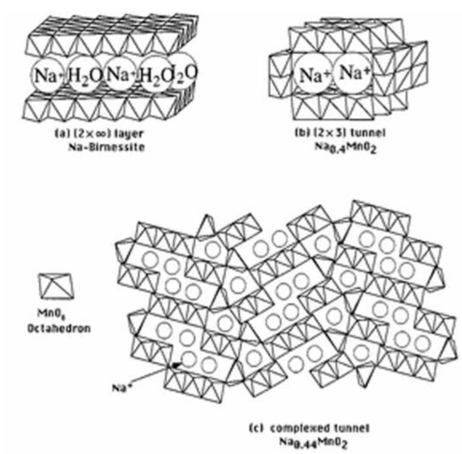
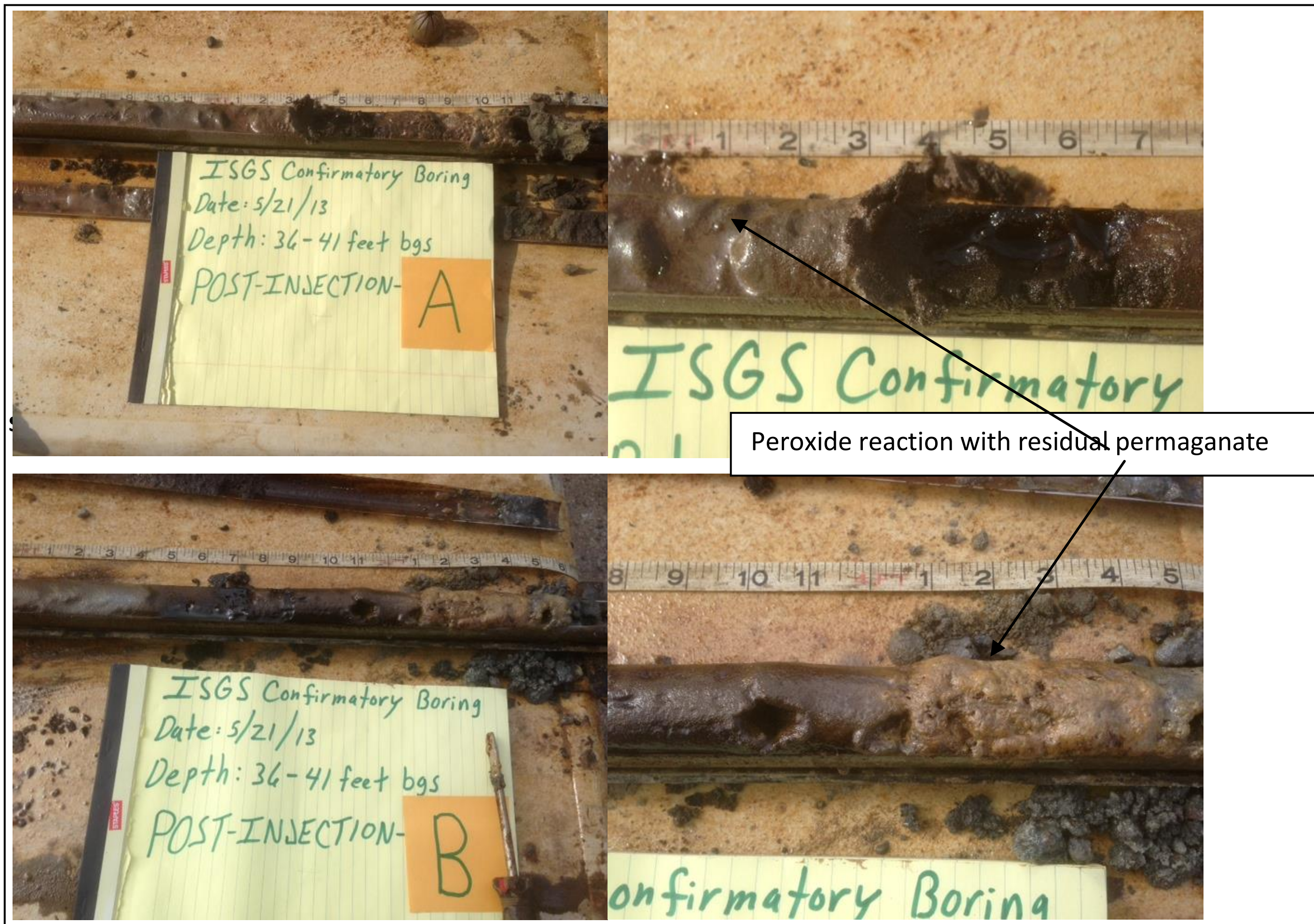


Figure 2 Schematic diagram of the structure of layered and tunnel manganese oxides.

The field sampling techniques one day following the injection event (traditional acetate liner advancement) proved ineffective in its ability to obtain characteristic samples below approximately 38’ bgs. It was the opinion of IET that the residual hydrostatic pressure in the primary injection zone resulted in a “heaving” of the unconsolidated sands into the tooling. A consequence of this “heaving” was the inability of the acetate liner sampling tooling to overcome the hydrostatic head pressure. Samples down to 38’ bgs were obtained and evaluated in the field. Photos of the day one sampling event are provided below in **Photo 2**. The day one sampling event provided evidence to support the 10’ radius design basis of the pilot in the 35-38’ injection zone, however without the benefit of the deeper injection zone samples a modification to the sampling technique was required. The day five sampling event utilized a discrete sampling method which allowed for the sampling of the entire injection profile (35-41’ bgs). Photos of the day five sampling event are provided below in **Photo 3**.



Sample “B” Location – Day 1

Day One sampling occurred so as to confirm delivery and the presence of the ISGS injectant. Day Five was used to evaluate the geotechnical formation.


Birnessite-like crust formation around “globels” of free-phase DNAPL and Saturated soil
Sample “B” - Day 5 (37’ bgs)
Birnessite-like crystallization Day 5

In September 2013, a creosote site was injected by IET, prior to injection creosote was seen in samples and a strong odor was noted. Following injection the creosote that was observed above the peat layer was seen to have “solidified”, with no associated odor (15 days following injection). In the picture below the peat layer is easily seen and the ISGS formation immediately above it.

APPENDIX 4 – CASE STUDY

Summary – DNAPL Application

The primary objectives of the technology are to demonstrate both mass removal and mass stabilization. To achieve these objectives the delivery of the ISGS material must effectively distribute the material to the targeted zone(s) and the formation of the Birnessite-like crust must be confirmed. Birnessite (**Photo 1**) is an oxide of Mn and Mg, along with Na, Ca and K with the composition:

$$(Na,Ca,K)(Mg,Mn)Mn_6O_{14} \cdot 5H_2O$$

Photo 1: Birnessite

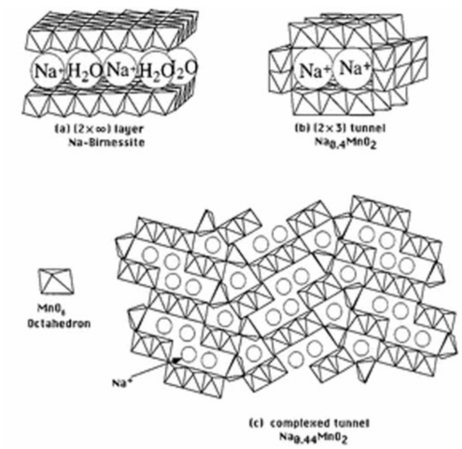


Figure 2 Schematic diagram of the structure of layered and tunnel manganese oxides.

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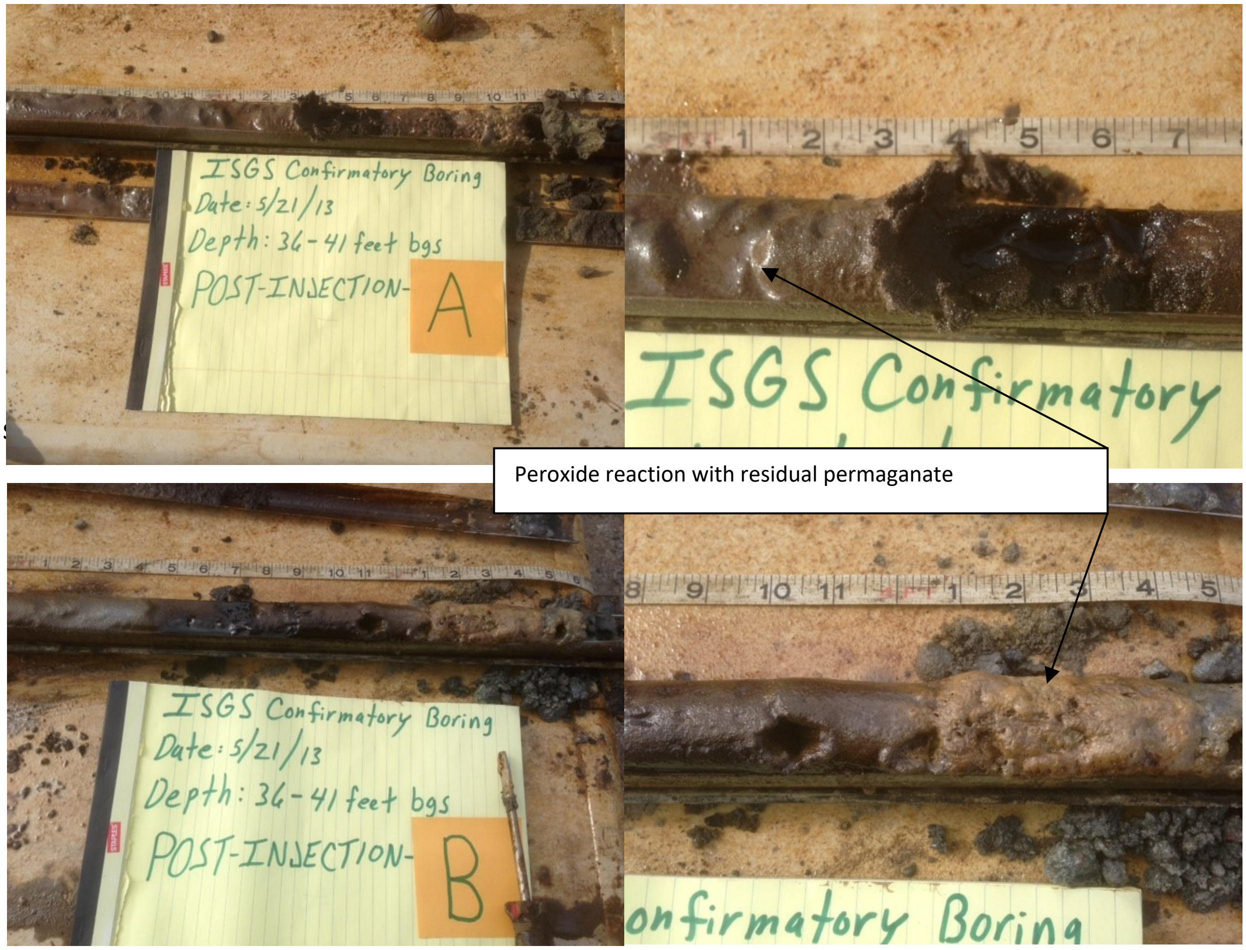


Sample "B" Location – Day 1

Day One sampling occurred so as to confirm delivery and the presence of the ISGS injectant. Day Five was used to evaluate the geotechnical formation.

Appendix F

Threatened and Endangered Species Assessment for the Libby Groundwater Site

Appendix F
Threatened and Endangered Species Assessment for the Libby Groundwater Site

An evaluation of the potential to adversely affect federally listed endangered and threatened species was conducted by comparing ranges and habitats of listed species to the location and habitats present within the project area. Based on the following analysis, proposed activities within the Libby Groundwater Site remediation areas will have no effect to federally listed species.

The project area includes portions of Areas 1 and 2 within the Libby Groundwater Site. Area 1 occupies about 2.7 acres and the portion of Area 2 where in-situ bioremediation activities will occur occupies less than 1 acre. Both areas are located on the southeast side of the Town of Libby, Montana, within the historical mill property. The former mill area is currently used for light industrial or commercial purposes; businesses are located along US Highway 2, but most of former mill site is sparsely developed. Area 1 is mostly a former waste pit area and includes graveled and grassy areas. The property in which Area 1 is located is surrounded by a 6-foot chain-line fence. Activities in Area 2 will occur in an industrial/commercial area near U.S. Highway 2 that includes unvegetated areas, buildings, grass and some woody vegetation. The project areas and the land within a quarter mile radius have been previously disturbed. Residential and commercial areas are located directly west and northwest of the former mill. Forest lands and rural residences are located east of the former mill property. The elevation of the site is about 2,100 feet and elevations in the surrounding mountains are 4,000 to 6,000 feet high. Native habitats in the surrounding areas are Rocky Mountain Dry-Mesic Montane conifer forest on the lower mountains, and Northern Rocky Mountain lower montane riparian woodland and shrubland in the river valleys and along streams. Libby Creek is located about 1,500 feet east of the project area and the Kootenai River is about 1 mile to the north.

There are 19 federally listed endangered, threatened, proposed and candidate species in Montana (Table 1) (USFWS 2017a), of which 8 species have ranges that overlap Lincoln County (USFWS 2017b). Six species may occur in the project area (USFWS 2018).

Table 1. Federally Listed, Proposed and Candidate Species Potentially Present in the Libby Area

Common Name	Scientific Name	Status	Habitat and Range in Montana	Potential for Occurrence in Project Area (USFWS 2018)
Mammals				
Black-footed ferret	*Mustela nigripes*	E/XN, SE	Prairie dog complexes in eastern Montana. Not expected to occur in Lincoln County.	No. Project area is not in species range.
Canada Lynx	*Lynx canadensis*	T	Present in western Montana including Lincoln County. West of the Continental Divide, generally occurs in subalpine forest between 4,000 and 7,000 feet, mostly in lodgepole pine forest.	Possible, see text.
Grizzly bear	*Ursus arctos horribilis*	T	Alpine and subalpine coniferous forest in western Montana, including Lincoln County.	Possible, see text.
Wolverine	*Gulo gulo luscus*	P	High elevation alpine and boreal forests that reliably maintain deep persistent snow late into the warm season. Expected to occur in Lincoln County. Project area is within current range.	Possible, see text.

Table 1. Federally Listed, Proposed and Candidate Species Potentially Present in the Libby Area

Common Name	Scientific Name	Status	Habitat and Range in Montana	Potential for Occurrence in Project Area (USFWS 2018)
Northern long-eared bat	*Myotis septentrionalis*	T	Eastern Montana, caves, abandoned mines, roosts in live trees and snags. Not expected to occur in Lincoln County.	No. Project area is not in species range.
Birds				
Least tern	*Sterna antillarum*	E	Yellowstone River and Missouri River sandbars and beaches in eastern Montana. Not expected to occur in Lincoln County.	No. Project area is not in species range.
Piping plover	*Charadrius melodus*	T	Missouri and Yellowstone River sandbars and alkali beaches, northeastern Montana. Not expected to occur in Lincoln County.	No. Project area is not in species range.
Red knot	*Califris canutus rufa*	T	Migrant, eastern Montana plains along shorelines. Not expected to occur in Lincoln County.	No. Project area is not in species range.
Whooping crane	*Grus americana*	E, SE	Wetlands, migrates through eastern Montana. Not expected to occur in Lincoln County.	No. Project area is not in species range.
Yellow-billed cuckoo	*Coccyzus americanus*	T	Population west of the Continental Divide. Riparian areas with cottonwoods and willows. Proposed critical habitat does not occur in Montana (USFWS 2018).	Possible, see text.
Fish				
Bull trout	*Salvelinus confluentus*	T	Occurs in cold water rivers, streams, lakes and reservoirs in Clark Fork, Flathead, St. Mary and Belly river basins. Libby Creek and Kootenai River are designated critical habitat.	Possible. See text.
Pallid sturgeon	*Scaphirhynchus albus*	E	Rivers, bottom dwelling: Missouri, Yelllowstone, Marias, Milk, Poplar, Power, Tongue Rivers. Not expected to occur in Lincoln County.	No. Project area is not in species range
White sturgeon (Kootenai River population	*Acipenser transmontanus*	E	Kootenai River, bottom dwelling. Occurs in the Kootenai River from Kootenai Falls 31 river miles below Libby dam downstream for 167.7 miles into Canada (USFWS 2018d).	No. Project area is not in current species range.

Table 1. Federally Listed, Proposed and Candidate Species Potentially Present in the Libby Area

Common Name	Scientific Name	Status	Habitat and Range in Montana	Potential for Occurrence in Project Area (USFWS 2018)
Plants				
Whitebark pine	*Pinus albicaulis*	C	High-elevation upper montane forested habitat near treeline, in central and western Montana.	No. Project area does not have suitable habitat.
Spalding's catchfly	*Silene spaldingii*	T	Known from Upper Flathead River and Fisher River drainages; and Tobacco Valley. Occurs in open grasslands with rough fescue or bluebunch wheatgrass.	Possible, see text.
Ute ladies'-tresses orchid	*Spiranthes diluvialis*	T	River meander wetlands. Known to occur in Jefferson, Madison, Beaverhead, Gallatin, and Broadwater Counties, in southwest and south-central Montana. Not expected to occur in Lincoln County.	No. Project Area is not in current species range.
Water Howellia	*Howellia aquatilis*	T	Wetlands, Swan Valley in Lake and Missoula Counties. Not expected to occur in Lincoln County.	No. Project area is not in current species range.
Insects				
Meltwater Lednian Stonefly	*Lednia tumana*	P	High elevation meltwater streams in Glacier, Flathead and Lake Counties. Not expected to occur in Lincoln County.	No. Project area is not in current species range.
Western glacier Stonefly	*Zapada glacier*	P	Clean, cold, running waters that have a high oxygen content. Not expected to occur in Lincoln County.	No. Project area is not in current species range.

Notes:
E = endangered
T = threatened
C = candidate for listing
PT = proposed threatened
XN = experimental, non-essential

Listed species that may occur within the project area include the following (USFWS 2018):

- Grizzly bear (*Ursus arctos horribilis*) - Threatened
- Canada lynx (*Lynx canadensis*) - Threatened
- Wolverine (*Gulo gulo luscus*) – Proposed threatened
- Yellow-billed cuckoo (*Coccyzus americanus*, western population) - Threatened
- Bull trout (*Salvelinus confluentus*) - Threatened

- Spalding's catchfly (Silene spaldinii) 0threatened

Grizzly bear occur within alpine and subalpine coniferous forest in western Montana, including Lincoln County. The project area at Libby is not within current range of the threatened population, according to range information in the ECOS species profile (USFWS 2018b). The current range includes areas within 2 to 4 miles south and west of Libby. Habitats used in Montana primarily include meadows, seeps, riparian areas, shrub field, closed and open timber, sidehill parks, snow chutes and alpine areas (Montana Natural Heritage Program and Montana Fish, Wildlife and Parks 2018a). The project area is on the edge of the Town of Libby, is below the elevational range of typical habitats used by this species, and does not have natural habitats. Most of the project area is fenced. Grizzly bears are unlikely to occur, and any occurrence is likely to be of short duration because of the unsuitable habitat and human activity in the area. Wandering individuals could result in an incidental occurrence. If a grizzly bear is observed during project activities, activities should stop until the grizzly bear has left the area and the Fish and Wildlife Service should be contacted. With this mitigation, the proposed project is expected to have *no effect* to grizzly bear.

Canada lynx generally occur in subalpine forest between 4,000 and 7,000 feet in Montana, mostly in lodgepole pine forest but also mixed stands of subalpine fir, lodgepole pine, Douglas-fir, grand fir, western larch and hardwoods (Montana Natural Heritage Program and Montana Fish, Wildlife and Parks 2018b). They avoid large openings but hunt along edges in dense cover. They may be transient in other habitats. The project area is within current species range but not within critical habitat (USFWS 2018c). The project area is on the edge of the Town of Libby, is below the elevation range of typical habitats used by this species, and does not have natural habitats. Most of the project area is fenced. Canada lynx are unlikely to occur, and any occurrence is likely to be of short duration because of the unsuitable habitat and human activity in the area. Wandering individuals could result in an incidental occurrence. If a Canada lynx is observed during project activities, activities should stop until the lynx has left the area and the Fish and Wildlife Service should be contacted. With this mitigation, the proposed project is expected to have *no effect* to Canada lynx.

Wolverines typically occur in alpine tundra and boreal and mountain forests, especially in large wilderness areas (Montana Natural Heritage Program and Montana Fish, Wildlife, and Parks 2018c). They occupy high elevations in summer but occur at lower elevations in winter. They mostly occur in areas of medium to scattered timber and avoid clear-cuts and burned areas. Dispersing individuals may occur far outside of typical habitat. Wolverines avoid areas of human activity and are unlikely to occur in the project area. Any occurrence would be of short duration. Wandering individuals could result in an incidental occurrence. If a wolverine is observed during project activities, activities should stop until the animal has left the area and the Fish and Wildlife Service should be contacted. With this mitigation, the proposed project is expected to have *no effect* to wolverine.

Yellow-billed cuckoo occur in riparian areas with cottonwoods and willows. Western subspecies require patches of at least 25 acres of dense riparian forest with a canopy cover of at least 50 percent in both the overstory and understory (Montana Natural Heritage Program and Montana Fish, Game and Parks 2018d). The Libby area is not within the current known range of this species, and the closest records are near Kalispell (USFWS 2018e). Suitable habitat does not occur within or adjacent to the project area. The proposed project is expected to have *no effect* to yellow-billed cuckoo.

Bull trout occurs in cold water rivers, streams, lakes and reservoirs in the Clark Fork, Flathead, St. Mary and Belly river basins. Bull trout have more specific habitat requirements than other trout, including cold water, stable stream channels, clean spawning and rearing gravel, complex and diverse cover (such as large woody debris, undercut banks, boulders, and pools), and unblocked migratory corridors (USFWS 2018f). Resident bull trout remain in the same stream their entire lives, while migratory bull trout move to larger bodies of water in the winter. Critical habitat has been designed for this species and both Libby

Creek and Kootenai River are designated critical habitat within Recovery Unit 30 Kootenai River Basin (USFWS 2010). The project area is located more than 1,500 feet away from Libby Creek and nearly a mile from the Kootenai River. The only surface water features within or adjacent to the project area are the fire pond and a portion of the diversion canal. These water bodies are unlikely to support bull trout. The proposed activities will have no effect to these waterbodies, and the proposed project will have *no effect* to bull trout.

Spalding's catchfly is a regional endemic restricted to remnant Palouse Prairie grasslands (Montana Natural Heritage Program 2018). Extant populations occur in the Tobacco Plains area in northeast Lincoln County, Lost Trail National Wildlife Refuge west of Kalispell, Niarada area west of Flathead Lake and Wild Horse Island in Flathead Lake. They occur in open, mesic grasslands in the valleys and foothills with rough fescue, needlegrasses, and Idaho fescue, and occasionally with scattered ponderosa pine or broadleaf shrubs. The project area does not have suitable habitat and the proposed project will have *no effect* to Spalding's catchfly.

References:

Montana Natural Heritage Program. 2018. Spalding's Catchfly – Silene spaldingii. Montana Field guide. Retrieved on February 15, 2018 from http://FieldGuide.mt.gov/speciesDeail.aspx?elcode=PDCAR0U150

Montana Natural Heritage Program and Montana Fish, Wildlife and Parks. 2018a. Grizzly Bear -Ursus arctos. Montana Field Guide. Retrieved on February 21, 2018, from http://FieldGuide.mt.gov/speciesDetail.aspx?elcode=AMAJB01020

Montana Natural Heritage Program and Montana Fish, Wildlife and Parks 2018b. Canada lynx -Lynx canadensis. Montana Field Guide. Retrieved on February 21, 2018, from http://FieldGuide.mt.gov/speciesDetail.aspx?elcode=AMAJH03010

Montana Natural Heritage Program and Montana Fish, Wildlife and Parks 2018c. Wolverine -Gulo gulo. Montana Field Guide. Retrieved on February 21, 2018, from http://FieldGuide.mt.gov/speciesDetail.aspx?elcode=AMAJF03010

Montana Natural Heritage Program and Montana Fish, Wildlife and Parks 2018d. Yellow-billed cuckoo – Coccyzus americanus. Montana Field Guide. Retrieved on February 21, 2018, from http://FieldGuide.mt.gov/speciesDetail.aspx?elcode=ABNR0202

U.S. Fish and Wildlife Service. 2010. Endangered and Threatened Wildlife and Plants; Revised Designation of Critical Habitat for Bull Trout in the Coterminous United States; Final Rule. Federal Register 75 (200): 63897-64070.

U.S. Fish and Wildlife Service. 2017a. Threatened, Endangered, and Candidate Species in Montana. Endangered Species Act. Fish and Wildlife Service, Ecological Services, Montana Field Office, Helena, Montana. November 17, 2017

U.S. Fish and Wildlife Service. 2017b. Endangered, Threatened, Proposed and Candidate Species. Montana Counties. Endangered Species Act. Fish and Wildlife Service, Ecological Services, Montana Field Office, Helena, Montana. November 17, 2017

U.S. Fish and Wildlife Service. 2018a. Species List Letter from Fish and Wildlife Service, Montana Ecological Service Field Office, Helena, Montana. February 21, 2018

USFWS. 2018b. Grizzly bear (*Ursus arctos horribilis*). ECOS Species Profile. Environmental Conservation Online System. https://ecos.fws.gov/ecp0/profile/speciesProfile?spcode=A001

USFWS. 2018c. Canada lynx (Lynx canadensis). ECOS Species Profile. Environmental Conservation Online System. https://ecos.fws.gov/ecp0/profile/speciesProfile?sId=3652

USFWS 2018d. White Sturgeon (Acipenser transmontanus) ECOS Species Profile. Environmental Conservation Online System. https://ecos.fws.gov/ecp0/profile/speciesProfile?spcode=E087

USFWS. 2018e. Yellow-billed cuckoo (Coccyzus americanus) ECOS Species Profile. Environmental Conservation Online System. https://ecos.fws.gov/ecp0/profile/speciesProfile?spcode=B06R

USFWS. 2018e. bull trout (*Salvelinus confluentus*) ECOS Species Profile. Environmental Conservation Online System. https://ecos.fws.gov/ecp0/profile/speciesProfile?spcode=EO65

United States Department of the Interior

FISH AND WILDLIFE SERVICE
Montana Ecological Services Field Office
585 Shepard Way, Suite 1
Helena, MT 59601-6287
Phone: (406) 449-5225 Fax: (406) 449-5339

In Reply Refer To:
Consultation Code: 06E11000-2018-SLI-0227
Event Code: 06E11000-2018-E-00331
Project Name: Libby Groundwater Site

February 21, 2018

Subject: List of threatened and endangered species that may occur in your proposed project location, and/or may be affected by your proposed project

To Whom It May Concern:

The enclosed species list identifies threatened, endangered, proposed and candidate species, as well as proposed and final designated critical habitat, that may occur within the boundary of your proposed project and/or may be affected by your proposed project. The species list fulfills the requirements of the U.S. Fish and Wildlife Service (Service) under section 7(c) of the Endangered Species Act (Act) of 1973, as amended (16 U.S.C. 1531 *et seq.*).

New information based on updated surveys, changes in the abundance and distribution of species, changed habitat conditions, or other factors could change this list. Please feel free to contact us if you need more current information or assistance regarding the potential impacts to federally proposed, listed, and candidate species and federally designated and proposed critical habitat. Please note that under 50 CFR 402.12(e) of the regulations implementing section 7 of the Act, the accuracy of this species list should be verified after 90 days. This verification can be completed formally or informally as desired. The Service recommends that verification be completed by visiting the ECOS-IPaC website at regular intervals during project planning and implementation for updates to species lists and information. An updated list may be requested through the ECOS-IPaC system by completing the same process used to receive the enclosed list.

The purpose of the Act is to provide a means whereby threatened and endangered species and the ecosystems upon which they depend may be conserved. Under sections 7(a)(1) and 7(a)(2) of the Act and its implementing regulations (50 CFR 402 *et seq.*), Federal agencies are required to utilize their authorities to carry out programs for the conservation of threatened and endangered species and to determine whether projects may affect threatened and endangered species and/or designated critical habitat.

A Biological Assessment is required for construction projects (or other undertakings having similar physical impacts) that are major Federal actions significantly affecting the quality of the human environment as defined in the National Environmental Policy Act (42 U.S.C. 4332(2)(c)). For projects other than major construction activities, the Service suggests that a biological evaluation similar to a Biological Assessment be prepared to determine whether the project may affect listed or proposed species and/or designated or proposed critical habitat. Recommended contents of a Biological Assessment are described at 50 CFR 402.12.

If a Federal agency determines, based on the Biological Assessment or biological evaluation, that listed species and/or designated critical habitat may be affected by the proposed project, the agency is required to consult with the Service pursuant to 50 CFR 402. In addition, the Service recommends that candidate species, proposed species and proposed critical habitat be addressed within the consultation. More information on the regulations and procedures for section 7 consultation, including the role of permit or license applicants, can be found in the "Endangered Species Consultation Handbook" at:

http://www.fws.gov/endangered/esa-library/pdf/TOC-GLOS.PDF

Please be aware that bald and golden eagles are protected under the Bald and Golden Eagle Protection Act (16 U.S.C. 668 *et seq.*), and projects affecting these species may require development of an eagle conservation plan (http://www.fws.gov/windenergy/eagle_guidance.html). Additionally, wind energy projects should follow the wind energy guidelines (http://www.fws.gov/windenergy/) for minimizing impacts to migratory birds and bats.

Guidance for minimizing impacts to migratory birds for projects including communications towers (e.g., cellular, digital television, radio, and emergency broadcast) can be found at: http://www.fws.gov/migratorybirds/CurrentBirdIssues/Hazards/towers/towers.htm; http://www.towerkill.com; and http://www.fws.gov/migratorybirds/CurrentBirdIssues/Hazards/towers/comtow.html.

We appreciate your concern for threatened and endangered species. The Service encourages Federal agencies to include conservation of threatened and endangered species into their project planning to further the purposes of the Act. Please include the Consultation Tracking Number in the header of this letter with any request for consultation or correspondence about your project that you submit to our office.

Attachment(s):

- Official Species List

Official Species List

This list is provided pursuant to Section 7 of the Endangered Species Act, and fulfills the requirement for Federal agencies to "request of the Secretary of the Interior information whether any species which is listed or proposed to be listed may be present in the area of a proposed action".

This species list is provided by:

Montana Ecological Services Field Office
585 Shepard Way, Suite 1
Helena, MT 59601-6287
(406) 449-5225

Project Summary

Consultation Code: 06E11000-2018-SLI-0227

Event Code: 06E11000-2018-E-00331

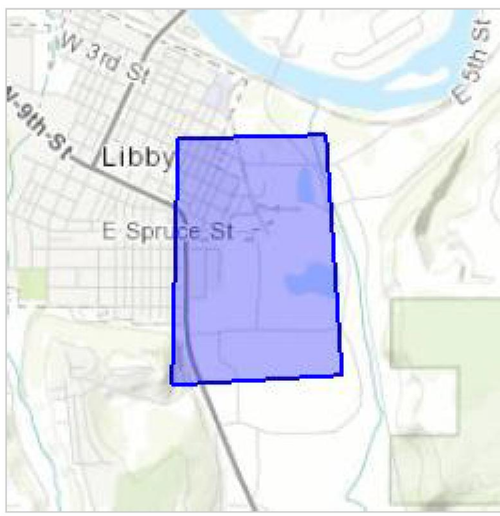
Project Name: Libby Groundwater Site

Project Type: Superfund Site Remediation

Project Description: Bioremediation activities, including In Situ Biosparging to treat contaminated groundwater, by injecting air through a network of shallow and deep wells.

Project Location:

Approximate location of the project can be viewed in Google Maps: https://www.google.com/maps/place/48.38341246355339N115.5428184858321W



Counties: Lincoln, MT

Endangered Species Act Species

There is a total of 6 threatened, endangered, or candidate species on this species list. Species on this list should be considered in an effects analysis for your project and could include species that exist in another geographic area. For example, certain fish may appear on the species list because a project could affect downstream species. See the "Critical habitats" section below for those critical habitats that lie wholly or partially within your project area under this office's jurisdiction. Please contact the designated FWS office if you have questions.

Mammals

NAME	STATUS
Canada Lynx *Lynx canadensis* Population: Wherever Found in Contiguous U.S. There is **final** critical habitat for this species. Your location is outside the critical habitat. Species profile: https://ecos.fws.gov/ecp/species/3652	Threatened
Grizzly Bear *Ursus arctos horribilis* Population: U.S.A., conterminous (lower 48) States, except where listed as an experimental population or delisted There is **proposed** critical habitat for this species. The location of the critical habitat is not available. Species profile: https://ecos.fws.gov/ecp/species/7642	Threatened
North American Wolverine *Gulo gulo luscus* No critical habitat has been designated for this species. Species profile: https://ecos.fws.gov/ecp/species/5123	Proposed Threatened

Birds

NAME	STATUS
Yellow-billed Cuckoo *Coccyzus americanus* Population: Western U.S. DPS There is **proposed** critical habitat for this species. Your location is outside the critical habitat. Species profile: https://ecos.fws.gov/ecp/species/3911	Threatened

Fishes

NAME	STATUS
Bull Trout *Salvelinus confluentus* Population: U.S.A., conterminous, lower 48 states There is **final** critical habitat for this species. Your location overlaps the critical habitat. Species profile: https://ecos.fws.gov/ecp/species/8212	Threatened

Flowering Plants

NAME	STATUS
Spalding's Catchfly *Silene spaldingii* No critical habitat has been designated for this species. Species profile: https://ecos.fws.gov/ecp/species/3681	Threatened

Critical habitats

There is 1 critical habitat wholly or partially within your project area under this office's jurisdiction.

NAME	STATUS
Bull Trout *Salvelinus confluentus* https://ecos.fws.gov/ecp/species/8212#crithab	Final