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Environment

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Technical Memorandum: Numerical Modeling to Evaluate a Proposed Controlled Groundwater Area

Libby Groundwater Site, Libby, Montana

Revision 3

DRAFT-FINAL

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1 Introduction

AECOM prepared this Technical Memorandum on behalf of International Paper Company (IP) to present the results of numerical modeling to evaluate a proposed Controlled Groundwater Area (CGA) for the Libby Groundwater Site (Site). A CGA is proposed as an institutional control to restrict groundwater use to minimize changes to the Site-related groundwater plumes and potential exposure of groundwater contaminants of concern (COCs) to human health and the environment.

The groundwater plumes are defined in this document as portions of the Libby valley alluvial aquifers (i.e., the Upper and Lower Aquifers) where Site groundwater COCs exceed State groundwater quality standards due to historical wood treating operations at the Site. Pentachlorophenol (PCP) is the COC that exceeds the groundwater quality standard of 1 microgram per liter (µg/L) over the largest area in the Upper and Lower Aquifers (Figure 1). Wood treating fluids in the form of non-aqueous phase liquid (NAPL) also exist within the Upper and Lower Aquifer plume extents. The numerical modeling was used to assist in evaluating the proposed CGA boundary by simulating the effects of pumping outside the proposed CGA on the groundwater plumes.

2 Proposed CGA

2.1 Proposed CGA Boundaries

The proposed CGA is 1,123 acres in size (Figure 1). It encompasses the existing groundwater plumes and areas of historic and current activities that may have affected groundwater quality, such as historic landfills and ongoing soil treatment operations. The proposed CGA includes a buffer area surrounding the plumes to include where pumping wells could induce plume movement and alter the plumes' current configuration or potentially draw contaminated groundwater into wells. The buffer zone is sufficiently large to include uncertainty in the plumes' extent and in the predicted effects of pumping on the existing and future plume configuration.

The proposed horizontal CGA boundaries coincide with features that are relatively easy to identify at the ground surface. These features include legal property lines, regional and local surface water drainages, and geologic features that form barriers to groundwater flow, such as the low permeability lakebed deposits that form bluffs on the east and west sides of the valley. The proposed CGA boundaries are described below:

- The proposed north CGA boundary is Kootenai River, a regional river.
- The proposed west CGA boundary is Flower Creek, a tributary to Kootenai River.
- The proposed east CGA boundary is the former lumber mill property line, located on the east side of Libby Creek, a tributary to Kootenai River. The east boundary encompasses historic landfills trending north to south on the east side of Libby Creek (Figure 1). The historic landfills lay against the low permeability lakebed deposits that bound the alluvial aquifers on the east.
- The proposed south CGA boundary is formed by the former mill property line and low permeable lakebed deposits. The boundary follows the former mill property line on the south and along the east side of Highway 2 north for 0.6 miles. Then the boundary turns westward toward Flower Creek along the valley wall of low permeability lakebed deposits (Figure 1). The south boundary encompasses historic landfills and IP's land treatment areas where contaminated soils from the Site are currently biologically treated in above ground cells.

The proposed vertical CGA boundaries encompass the Libby valley alluvial deposits, from the water table to the glacial till at approximately 160 feet deep. The alluvial deposits comprise the Upper Aquifer, Lower Aquifer, and Intermediate Zone, a leaky aquitard that lies between the Upper and Lower Aquifers. These three alluvial units are difficult to distinguish during drilling.

Ultimately the CGA will be of sufficient size and depth to be protective of human health and the environment, while minimizing groundwater use restrictions to property owners.

2.2 Criteria for Establishing a CGA

A permanent CGA designation is proposed for the 1,123 acre area shown in Figure 1, based on meeting three of the five criteria in MCA 85-2-506 for designating a permanent CGA. The three criteria and basis for meeting the criteria are as follows:

MCA 85-2-506 (5)(e): Groundwater within the proposed CGA is not suited for beneficial use

Groundwater within the Upper and Lower Aquifer plumes (Figure 1) exceed State drinking water standards and is not suitable for human consumption, domestic use, or irrigation. Also, other areas within the proposed CGA that may not be suitable for unrestricted groundwater use include the historical landfills, the existing land treatment units, and areas of uncertainty surrounding the currently mapped extent of the groundwater plumes.

The historical landfills located along the south and east proposed CGA boundary (Figure 1) contain log yard waste, such as ash and debris. Although these landfills are not suspected to be sources of Site groundwater COCs, the groundwater underlying these landfills is likely to contain high total organic carbon and total dissolved solids. The eastern landfills lie against low permeable lakebed deposits that are unlikely to yield very much groundwater to wells.

The existing land treatment area and expanded land farm treatment area (Figure 1) has been used since 1989 to treat soil contaminated by historical wood treating operations. COC concentrations in the underlying groundwater are routinely monitored and found to be low, but occasionally exceed the State groundwater standards for some COCs.

The extent of groundwater contamination in the Upper and Lower Aquifers (Figure 1) is defined based on extensive subsurface investigations performed since the mid-1980s and routine sampling of the groundwater monitoring network installed to date. Groundwater COC concentrations above State groundwater standards have not been detected outside the plume extent shown on Figure 1 for the past five years or more. However; the distribution of NAPL and dissolved COCs in the Upper and Lower Aquifers is highly complex, causing some uncertainty in the mapped extent. NAPL and dissolved COCs historically migrated away from the former waste pit and tank farm source areas through discrete layers, resulting in high variability in COC concentrations vertically within the aquifers. Although there are multiple monitoring points vertically at each monitoring location, COCs above State groundwater standards may occur outside the mapped extent. To address this uncertainty, the proposed CGA includes a conservative buffer zone surrounding the plumes.

MCA 85-2-506 (5)(c): Projected groundwater withdrawals from the aquifer(s) in the proposed CGA will induce or alter contaminant migration exceeding relevant water quality standards

Pumping wells located hydraulically downgradient of the plumes have the potential to increase the groundwater velocity and move the plumes northward toward the Kootenai River or into pumping wells. The Kootenai River forms the northern boundary for the proposed CGA to prevent future pumping directly downgradient of the groundwater plumes.

Pumping wells located hydraulically cross-gradient of the plumes may also move the plumes. Numerical groundwater flow modeling and particle tracking was used to evaluate the suitability of the east and west proposed CGA boundaries by pumping wells outside of the CGA boundary (Sections 3 and 4).

MCA 85-2-506 (5)(f): Public health, safety, or welfare will become at risk

Groundwater use within the identified Upper and Lower Aquifer plumes (Figure 1) poses an unacceptable risk to human health. Pumping near the plumes may alter the plumes' configuration such that previously non-impacted groundwater becomes impacted, enters a well or surface water body, and poses a potential unacceptable risk to human health and the environment.

2.3 Proposed CGA Restrictions

The proposed groundwater use restriction within the CGA is to prevent the installation of wells for the purpose of human consumption, irrigation, or commercial/industrial use. Monitoring and remediation wells approved by the United States Environmental Protection Agency (EPA) and the Montana Department of Environmental Quality (MDEQ) would be allowed within the CGA.

3 Modeling Approach

The suitability of the proposed east and west CGA boundaries was evaluated using the existing calibrated numerical groundwater flow model (MODFLOW) developed for the Site (URS 2016). Pumping wells were simulated in the model just outside the proposed CGA boundary at locations shown in Figure 1 to evaluate the potential for pumping to draw contaminated groundwater into the well, or to induce plume movement and alter the plumes' current configuration. The pumping wells were simulated using the MODFLOW well package. Hydraulic heads in the Upper and Lower Aquifers were simulated in the model under steady state pumping conditions. Particle tracking (MODPATH) was used to display groundwater flow paths under non-pumping steady state flow conditions compared to simulated changes in groundwater flow paths under the different pumping scenarios. For the non-pumping and pumping scenarios, particles were allowed to flow under the steady state pumping flow field for 100,000 days (the model default value) or until the particle reached a groundwater discharge point, such as a well or surface water body. This provided a display of the maximum potential change to groundwater flow paths within the contaminant plumes and downgradient to the discharge point.

A total of 8 pumping wells were simulated in the model at 4 locations, with one well pumping the Upper and Lower Aquifers (modeled separately) at each of the 4 locations. One of the pumping locations was near the eastern CGA boundary (near Libby Creek) and three pumping locations were near the western CGA boundary (near Flower Creek) (Figure 1). The wells were placed in the model 500 feet on the east side Libby Creek and 500 feet on the west side of Flower Creek, outside the CGA boundary. Unsuitable pumping locations were avoided, such as within the historic landfills and the low permeable lakebed deposits east of Libby Creek and around the south CGA boundary and locations directly downgradient of the current plumes near the Kootenai River.

The pumping rates selected for model simulations were the estimated maximum yield for each Upper Aquifer and Lower Aquifer pumping well, based on the optimum well design for the maximum available drawdown. According to Driscoll (1986), screening the bottom one-third to one-half of an unconfined aquifer (e.g., Upper Aquifer) provides the optimum design, when the aquifer thickness is less than about 150 feet. A well in an unconfined aquifer is usually pumped so that at maximum capacity, the pumping water level is maintained slightly above the top of the screen. The well screen is positioned in the lower portion of the unconfined aquifer because the upper part is dewatered during pumping. In a confined aquifer (e.g., the Lower Aquifer), 80 to 90 percent of the aquifer thickness should be screened, assuming that the pumping water level will not drop below the top of the aquifer. Maximum available drawdown for confined conditions should be the distance from the potentiometric surface to the top of the aquifer.

The maximum available drawdown for each pumping well was initially estimated analytically using the Jacob's distance-drawdown method, for pumping durations up to 10 years (an assumed time to reach near steady state conditions). The aquifer transmissivity used in the calculation was based on the model calibrated horizontal hydraulic conductivity and aquifer thickness at each pumping well model cell. Figures 2A and 2B show the calibrated horizontal hydraulic conductivity values used in the model for the Upper Aquifer and Lower Aquifers, respectively.

The maximum yield for the Upper Aquifer pumping wells was assumed to be the pumping rate that produces a drawdown in the aquifer adjacent to the pumping well approximately one-half the aquifer thickness (i.e., drawdowns of 20 to 30 feet, depending on the pumping well location). The maximum yield for the Lower Aquifer pumping wells was assumed to be the pumping rate that produces a drawdown in the aquifer adjacent to the pumping well approximately 10 to 20 feet above the top of the Lower Aquifer (i.e., drawdowns of 50 to 80 feet, depending on the pumping well location). Table 1 provides the estimated maximum pumping rates that were simulated in the model for the Upper and Lower Aquifers.

Table 1. Pumping Rates Used in the Model to Evaluate the East and West CGA Boundaries

Simulated Pumping Well Location		Model Pumping Rates (gpm)	
		Upper Aquifer	Lower Aquifer
Near Libby Creek	Northeast	1,000	250
Near Flower Creek	Northwest	800	600
	Midwest	400	200
	Southwest	600	200

gpm = gallons per minute

Each well was pumped separately in the model simulations. One well pumping at the estimated maximum yield has a similar effect as multiple wells pumping in the area at lower rates. For example, a pumping rate of 800 gpm in the Upper Aquifer near Flower Creek has a similar effect as pumping 40 residential properties in that area at an average rate of 20 gpm each, or four commercial/industrial wells pumping in that area at an average rate of 200 gpm each.

The average drawdown in the model cell containing the pumping well was reviewed for reasonableness (i.e., that not too little or too much drawdown was simulated and that the calculated pumping rate reasonably represents the maximum potential well yield at that location).

4 Modeling Results

The model results of pumping Upper and Lower Aquifer wells near Libby Creek in the northeast pumping area are shown on Figure 3. The model results of pumping Upper and Lower Aquifer wells near Flower Creek are shown on Figure 4 (for the northwest pumping area), Figure 5 (for the midwest pumping area), and Figure 6 (for the southwest pumping area). The particle flow paths on Figures 3 through 6 show the cumulative travel time and distance from the particle release point to the CGA boundary to allow comparison of groundwater flow path direction, travel time, and travel distance under non-pumping and pumping scenarios.

At least one particle was released for each pumping scenario at an existing well location within the NAPL-impacted area where PCP is expected to be near the effective solubility of 1,000 µg/L (AECOM 2017) and closest to the simulated pumping well. Thus, particles were released at locations with maximum PCP concentrations and most sensitive to a change in groundwater flow path due to pumping outside the CGA.

The model results are discussed in Sections 4.1 through 4.5 below.

4.1 Northeast Pumping Near Libby Creek

Figure 3, left panel, shows the model simulated effects of pumping the Upper Aquifer 1,000 gpm in the northeast area outside the CGA. Two particles were released in this simulation, at wells 3061 and 3002. Well 3061 is the eastern-most location were NAPL exists in the Upper Aquifer and groundwater concentrations are approximately at the PCP effective solubility of 1,000 µg/L. A particle also was released in the model at well 3002. Although well 3002 is outside the estimated NAPL extent in the Upper Aquifer, PCP concentrations in this well are anomalously high (approximately 100 µg/L) compared to nearby wells.

Pumping the northeast well outside the CGA in the Upper Aquifer causes only a small change in groundwater flow direction within the plume (less than 200 feet), and the groundwater velocity under pumping conditions is similar to non-pumping conditions (i.e., particle travel time in days is similar along both the pumping and non-pumping flow paths). Based on these results, minimal Upper Aquifer plume movement would be expected with pumping outside the CGA.

Figure 3, right panel, shows the model simulated effects of pumping the Lower Aquifer 250 gpm in the northeast area outside the CGA. One particle was released at well 8001, the eastern-most location where NAPL has been observed in the Lower Aquifer. Well 8001 is a 1-inch diameter well, originally installed for geotechnical purposes, thus it has not been sampled for chemical analysis.

Pumping the northeast well outside the CGA in the Lower Aquifer has the potential to divert groundwater flow from within the NAPL-impacted source area toward the pumping well, as shown in Figure 3 (right panel). However; the PCP plume is estimated to remain well within the boundaries of the CGA, due to natural attenuation of PCP along the groundwater flow path caused by adsorption, dispersion, and biodegradation. Assuming a maximum PCP concentration of 1,000 µg/L PCP at well 8001 and an estimated bulk attenuation half-life of 217 days for PCP in the Lower Aquifer (Appendix A), PCP will reduce from 1,000 µg/L to the State standard of 1 µg/L along the groundwater flow path in 10 half-lives (or 2,170 days), or just beyond the 2,000 day time step location 1,618 feet downgradient of well 8001.

Due to natural attenuation along the flow path and groundwater pumping restrictions within the CGA boundary, there should be no exposure to the low concentrations in the Lower Aquifer that could be shifted eastward.

4.2 Northwest Pumping Near Flower Creek

Figure 4, left panel, shows the model simulated effects of pumping the Upper Aquifer 800 gpm in the northwest area outside the CGA. One particle was released in this simulation, at well 3057, located in the former waste pit source area where NAPL is present and groundwater concentrations are approximately at the PCP effective solubility of 1,000 µg/L. The flow path from well 3057 is west of all other flow paths originating in the NAPL-impacted area in the Upper Aquifer, thus it is the most sensitive to changes in flow path due to pumping on the west side of the plume.

Pumping the northwest well outside the CGA in the Upper Aquifer causes only a small change in groundwater flow direction within the plume (100 feet or less), and the groundwater velocity under pumping conditions is similar to non-pumping conditions (i.e., particle travel time in days is similar along both the pumping and non-pumping flow paths). Based on these results, minimal Upper Aquifer plume movement would be expected with pumping outside the CGA.

Figure 4, right panel, shows the model simulated effects of pumping the Lower Aquifer 600 gpm in the northwest area outside the CGA. One particle was released at well 6004, the western-most location where dense NAPL (DNAPL) accumulations have been observed multiple times in the bottom of the well. Although the well has not been sampled for a number of years, the groundwater concentrations are expected to be at the PCP effective solubility of 1,000 µg/L.

Pumping the northwest well outside the CGA in the Lower Aquifer has the potential to divert groundwater flow from within the NAPL-impacted source area toward the pumping well, as shown in Figure 4 (right panel). However; the PCP plume is estimated to remain well within the boundaries of the CGA, due to natural attenuation of PCP along the groundwater flow path caused by adsorption, dispersion, and biodegradation. Assuming a maximum PCP concentration of 1,000 µg/L PCP at well 6004 and an estimated bulk attenuation half-life of 217 days for PCP in the Lower Aquifer (Appendix A), PCP will reduce from 1,000 µg/L to the State standard of 1 µg/L along the groundwater flow path in 10 half-lives (or 2,170 days), or just beyond the 2,000 day time step location 3,150 feet downgradient of well 6004.

Due to natural attenuation along the flow path and groundwater pumping restrictions within the CGA boundary, there should be no potential exposure to the low concentrations in the Lower Aquifer that could be shifted westward.

4.3 Midwest Pumping Near Flower Creek

Figure 5, left panel, shows the model simulated effects of pumping the Upper Aquifer 400 gpm in the midwest area outside the CGA. Consistent with the northwest Upper Aquifer pumping location, one particle was released for the midwest pumping simulation, at well 3057, located in the former waste pit source area. Pumping the midwest well outside the CGA in the Upper Aquifer causes only a small change in groundwater flow direction within the plume (less than 200 feet), and the groundwater velocity under pumping conditions is similar to non-pumping conditions (i.e., particle travel time in days is similar along both the pumping and non-pumping flow paths). Based on these results, minimal Upper Aquifer plume movement would be expected with pumping outside the CGA.

Figure 5, right panel, shows the model simulated effects of pumping the Lower Aquifer 200 gpm in the midwest area outside the CGA. Consistent with the northwest Lower Aquifer pumping location, one particle was released at well 6004, the western-most location where DNAPL accumulations have been observed in the Lower Aquifer. Pumping the midwest well outside the CGA in the Lower Aquifer causes only a small change in groundwater flow direction within the plume (less than 200 feet), and the groundwater velocity under pumping conditions is similar to non-pumping conditions. Based on these results, minimal Lower Aquifer plume movement would be expected with pumping outside the CGA.

4.4 Southwest Pumping Near Flower Creek

Figure 6, left panel, shows the model simulated effects of pumping the Upper Aquifer 600 gpm in the southwest area outside the CGA. Consistent with the northwest and midwest Upper Aquifer pumping locations, one particle was released for the southwest pumping simulation, at well 3057, located in the former waste pit source area. Pumping the southwest well outside the CGA in the Upper Aquifer causes a shift in the groundwater flow path up to 450 feet westward along the western edge of the plume. The maximum change is in the most downgradient portion of the plume where concentrations are the lowest, thus the PCP plume would remain well within the boundary of the CGA. The groundwater velocity under pumping conditions is similar to non-pumping conditions up to the 1,300 day time step location near the downgradient edge of the Upper Aquifer plume.

Based on these results, the western edge of the Upper Aquifer PCP plume may move up to 450 feet west due to pumping the southwest well at the estimated maximum yield. However; due to natural attenuation along the flow path and groundwater pumping restrictions within the CGA boundary, there should be no potential exposure to the low concentrations that could be shifted westward.

Figure 6, right panel, shows the model simulated effects of pumping the Lower Aquifer 200 gpm in the southwest area outside the CGA. Consistent with the northwest and midwest Lower Aquifer pumping locations, one particle was released at well 6004, the western-most location where DNAPL accumulations have been observed in the Lower Aquifer. Pumping the southwest well outside the CGA in the Lower Aquifer causes only a small change in groundwater flow direction within the plume (200 feet or less), and the groundwater velocity under pumping conditions is similar to non-pumping conditions. Based on these results, minimal Lower Aquifer plume movement would be expected with pumping outside the CGA.

4.5 Other Model Simulations

Other model simulations were performed to confirm that the model scenarios discussed above were appropriately conservative for assessing the CGA boundaries. Particles were released in the model at multiple locations within the NAPL source areas in the Upper and Lower Aquifers to confirm that the particle tracking simulations shown on Figures 3 to 6 represent the most sensitive flow paths to pumping outside the proposed CGA.

Also, particle tracking in the Lower Aquifer was evaluated to assess potential changes due to pumping in the Upper Aquifer and particle tracking in the Upper Aquifer was evaluated to assess potential changes due to pumping in the Lower Aquifer. In general, the Lower Aquifer flow paths are affected by pumping the estimated maximum yield in the Upper Aquifer, but generally the effect is less than pumping directly in the Lower Aquifer at the maximum estimated yield. The Upper Aquifer flow paths were minimally changed (e.g., less than 150 feet) by pumping the estimated maximum yield in the Lower Aquifer.

5 Uncertainty

There are inherent uncertainties in modeling subsurface conditions, thus assumptions were made to develop a conservative yet reasonable delineation of a proposed CGA to restrict groundwater use for the protection of human health and the environment. Groundwater monitoring will be ongoing over the coming years and changes to the CGA boundary or the restrictions within the CGA may be recommended based on the results of future monitoring.

Key uncertainties in this evaluation are as follows:

- The extent of NAPL and PCP in the Upper and Lower Aquifers is based on monitoring data collected to date. Precise delineation of aquifer contamination is not feasible and groundwater impacts may extend beyond the extent shown in the figures.
- Aquifer hydraulic properties are estimates based on available field testing data and groundwater flow model calibration. Actual hydraulic properties may deviate from those used in the evaluation, and actual groundwater flow path direction, travel time, and travel distance under non-pumping and pumping scenarios may vary from that shown in this evaluation.
- Future land and water use inside and outside the CGA boundary is unknown. Potential changes in current and future remedial systems, drainage, surface water bodies, etc. may alter the future groundwater flow paths.

Some conservative assumptions used in this evaluation are as follows:

- The CGA includes a large buffer area in some locations to account for uncertainty in the extent of NAPL and COCs in the aquifers and in the hydraulic properties used to assess the effects of pumping outside the CGA.
- The maximum estimated well yield was used as the pumping rate in the model because the areas outside the CGA will not have limits on pumping rates, number of wells, or well locations other than those required by current water use laws. The future groundwater withdrawal rates may be lower than those simulated.
- Pumping affects groundwater flow paths in the Lower Aquifer more than the Upper Aquifer because the Lower Aquifer is confined, it has larger available drawdown (and may be subject to greater stress), and it has a lower hydraulic conductivity than the Upper Aquifer. It is unlikely that the Lower Aquifer will be used when the Upper Aquifer, a shallow aquifer with a higher hydraulic conductivity, is available to pump.
- Steady state pumping conditions were simulated in the evaluation, resulting in maximum groundwater drawdown and flow path modification. Intermittent pumping may cause less drawdown and flow path modification.

6 Summary and Conclusions

The proposed CGA is 1,123 acres in size (Figure 1) and includes the Upper Aquifer, Intermediate Zone, and Lower Aquifer to a total depth of approximately 160 feet. Groundwater modeling (Section 4) revealed that pumping outside the CGA in either the Upper or Lower Aquifer can cause some changes in groundwater flow paths within the plumes (typically less than 200 feet), and in some cases, flow paths can be redirected from the plumes to the pumping wells. However; due to natural attenuation along the flow path and groundwater pumping restrictions within the CGA boundary, there should be no potential exposure to COC concentrations in the Upper or Lower Aquifer plumes.

If pumping were to occur outside the CGA at the maximum estimated yield and if pumping were also to occur inside the CGA, then additional plume movement may occur and possible exposure to impacted groundwater may occur. Therefore the proposed groundwater use restriction within the CGA is to prevent the installation of wells for the purpose of human consumption, irrigation, or commercial/industrial use. Monitoring and remediation wells approved by the United States Environmental Protection Agency (EPA) and the Montana Department of Environmental Quality (MDEQ) would be allowed within the CGA.

7 References

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Figures

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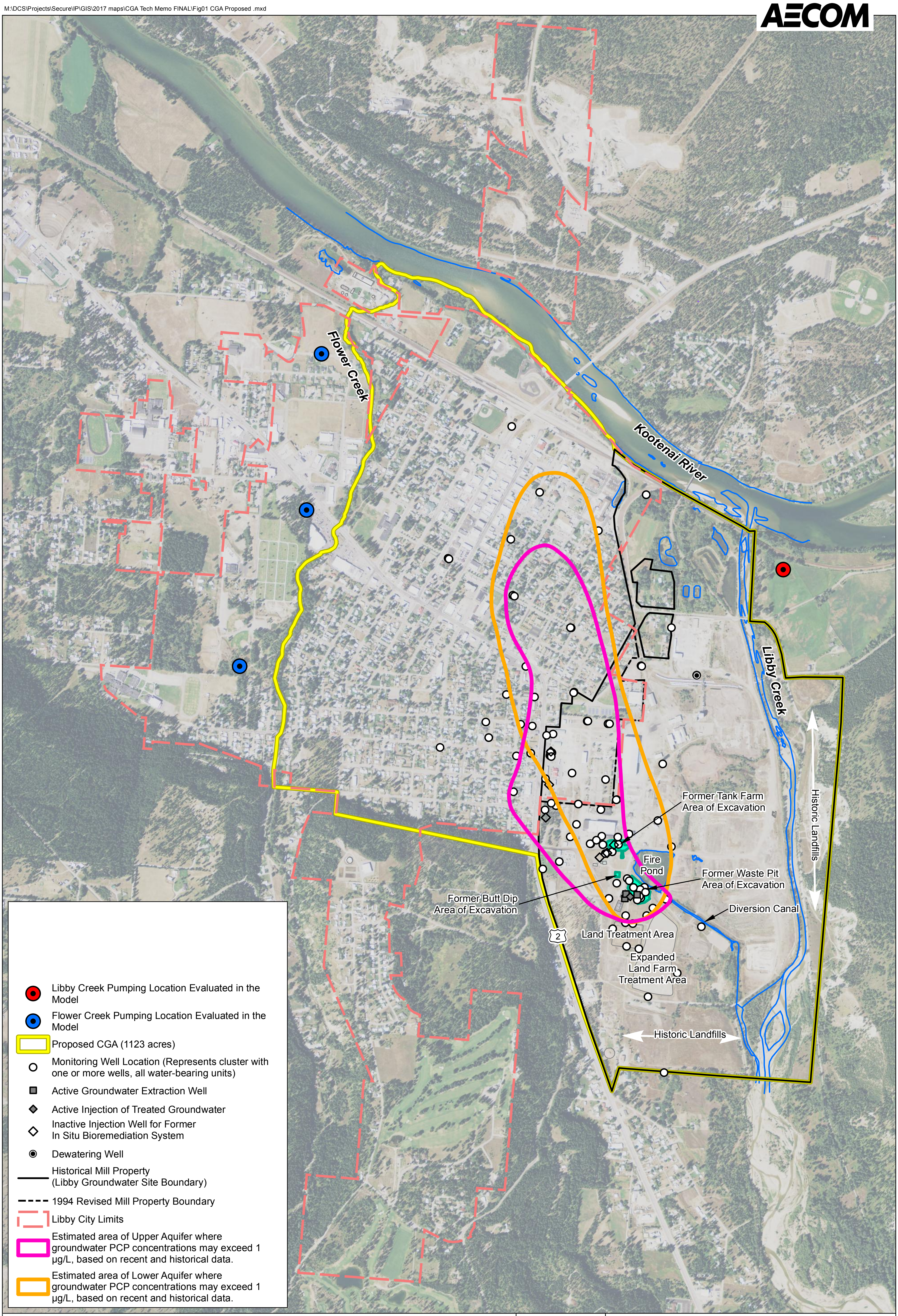

amsl = above mean sea level
Vertical datum: NAVD 88

Aerial Photo Source:
National Agricultural Imagery Program (NAIP)
USDA, 2013

N W E S

0 1,200 Feet

Job No.:	60542657
Designed By:	MCS
Drawn By:	JLC
Date:	9/8/2017

Proposed Controlled Groundwater Area (CGA)

NUMERICAL MODELING
TO EVALUATE A CONTROLLED GROUNDWATER AREA
LIBBY GROUNDWATER SITE, LIBBY, MONTANA

Fig. 1

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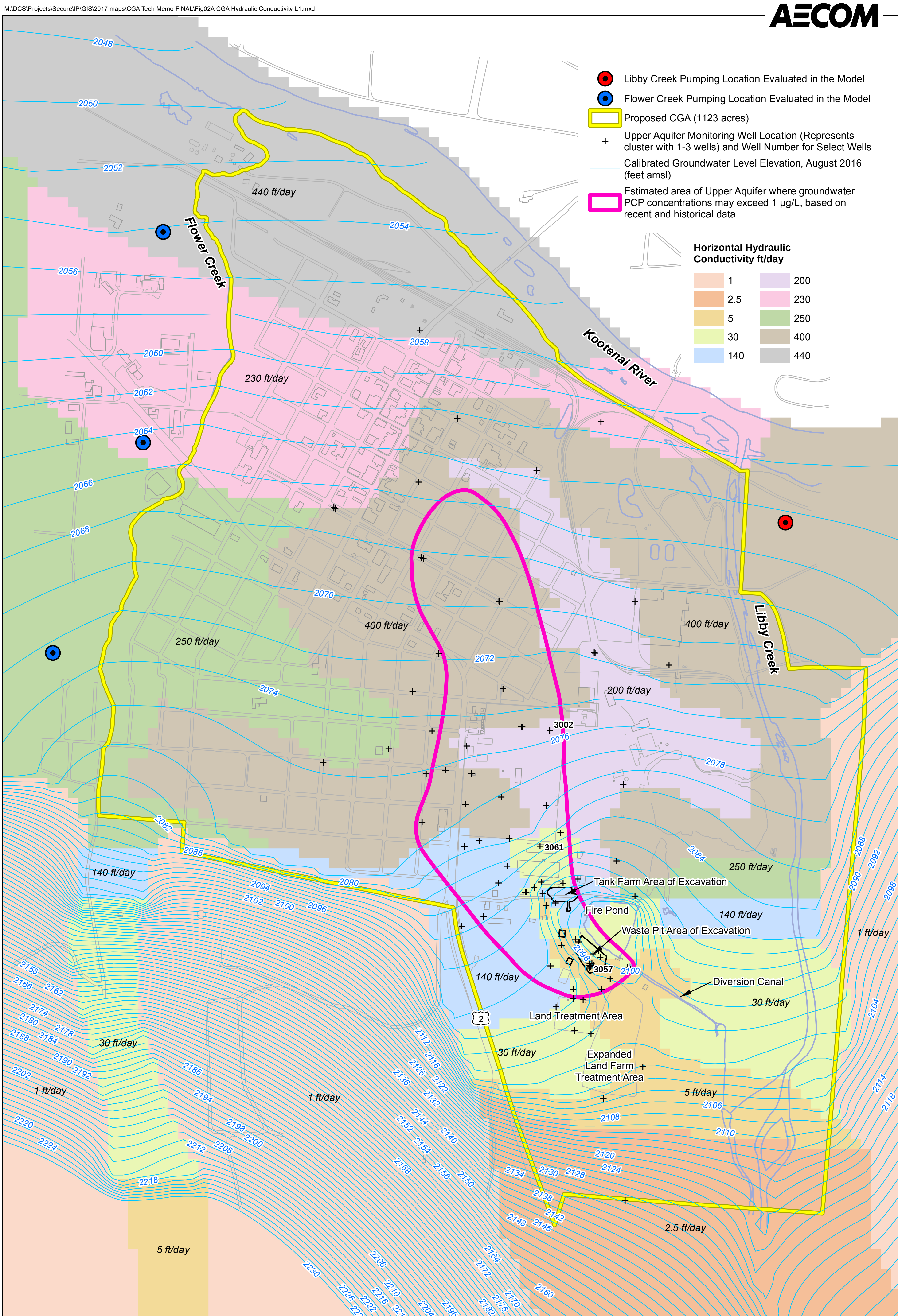

amsl = above mean sea level
Vertical datum: NAVD 88

Job No.:	60542657
Designed By:	MCS
Drawn By:	JLC
Date:	9/26/2017

Calibrated Horizontal Hydraulic Conductivity Distribution Upper Aquifer

NUMERICAL MODELING
TO EVALUATE A CONTROLLED GROUNDWATER AREA
LIBBY GROUNDWATER SITE, LIBBY, MONTANA

Fig. 2A

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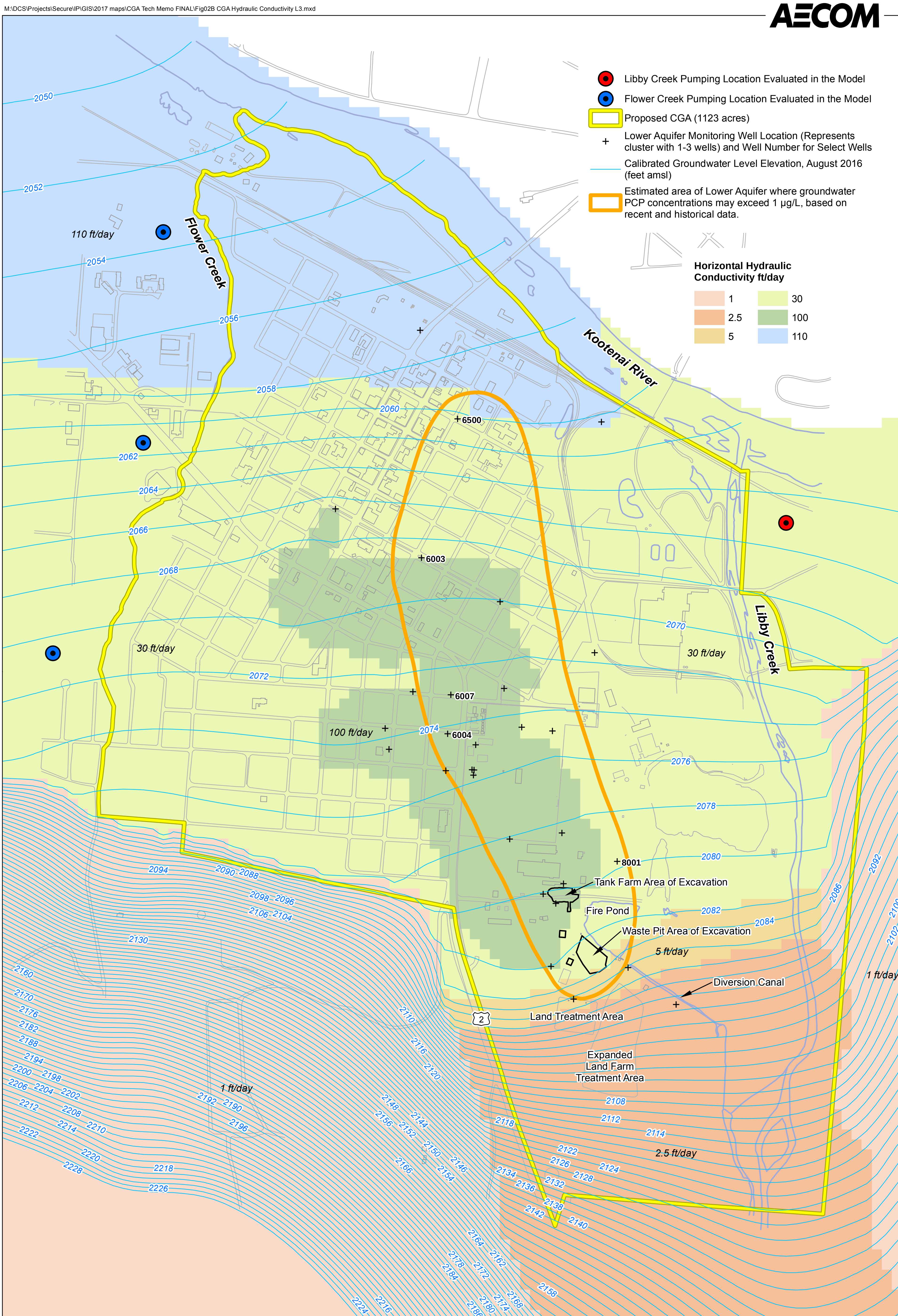

amsl = above mean sea level
Vertical datum: NAVD 88

0 900 Feet

Job No.:	60542657
Designed By:	MCS
Drawn By:	JLC
Date:	9/26/2017

Calibrated Horizontal Hydraulic Conductivity Distribution Lower Aquifer

NUMERICAL MODELING
TO EVALUATE A CONTROLLED GROUNDWATER AREA
LIBBY GROUNDWATER SITE, LIBBY, MONTANA

Fig. 2B

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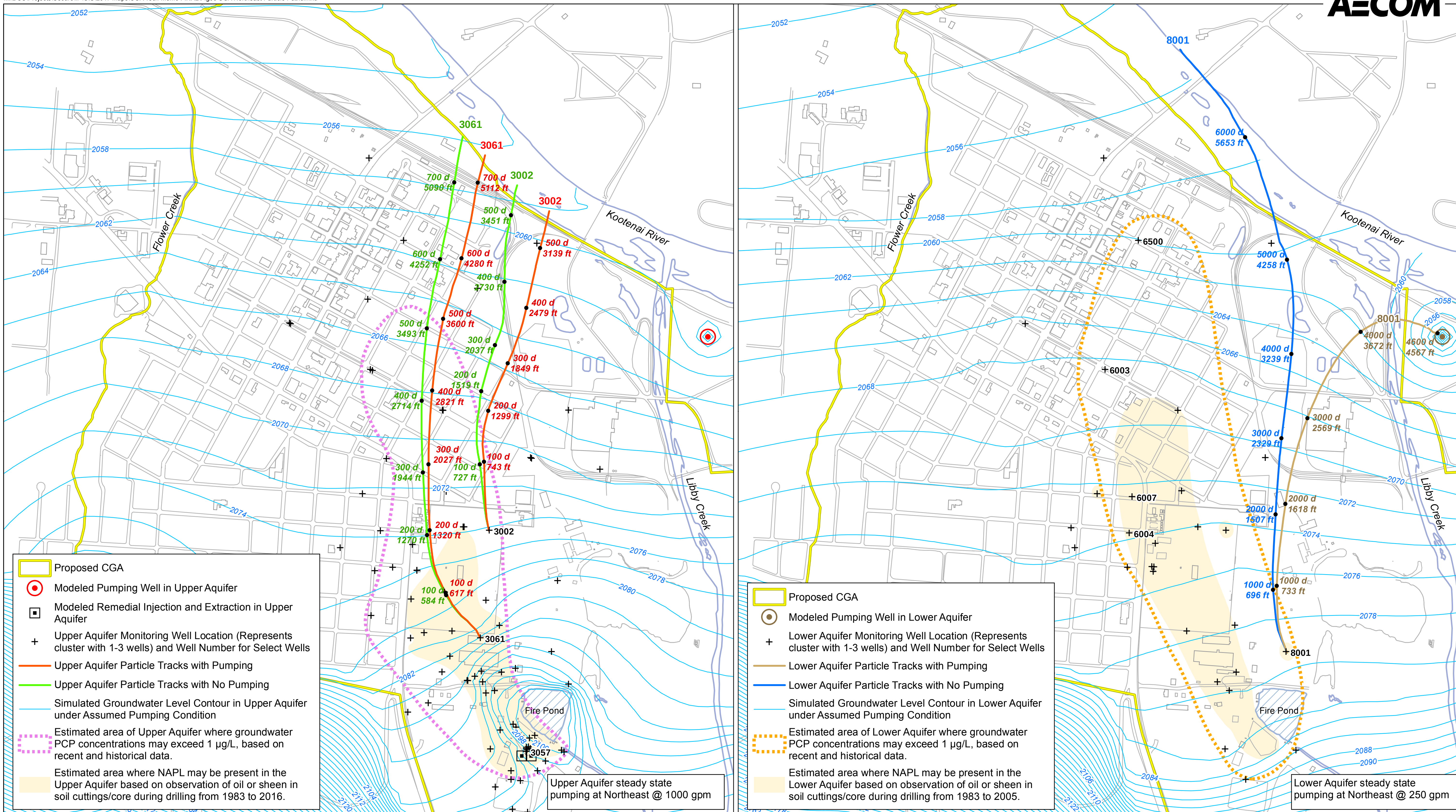

2000 d Particle Tracking Total Time (days)
3200 ft Particle Tracking Total Distance (feet)

N / S / E / W

0 — 1,000 Feet

gpm = gallons per minute
amsl = above mean sea level
Vertical datum: NAVD 88

Job No.:	60542657
Designed By:	CMZ
Drawn By:	JLC
Date:	9/19/2017

Northeast Pumping Outside the Proposed CGA Near Libby Creek

NUMERICAL MODELING
TO EVALUATE A CONTROLLED GROUNDWATER AREA
LIBBY GROUNDWATER SITE, LIBBY, MONTANA

Fig. 3

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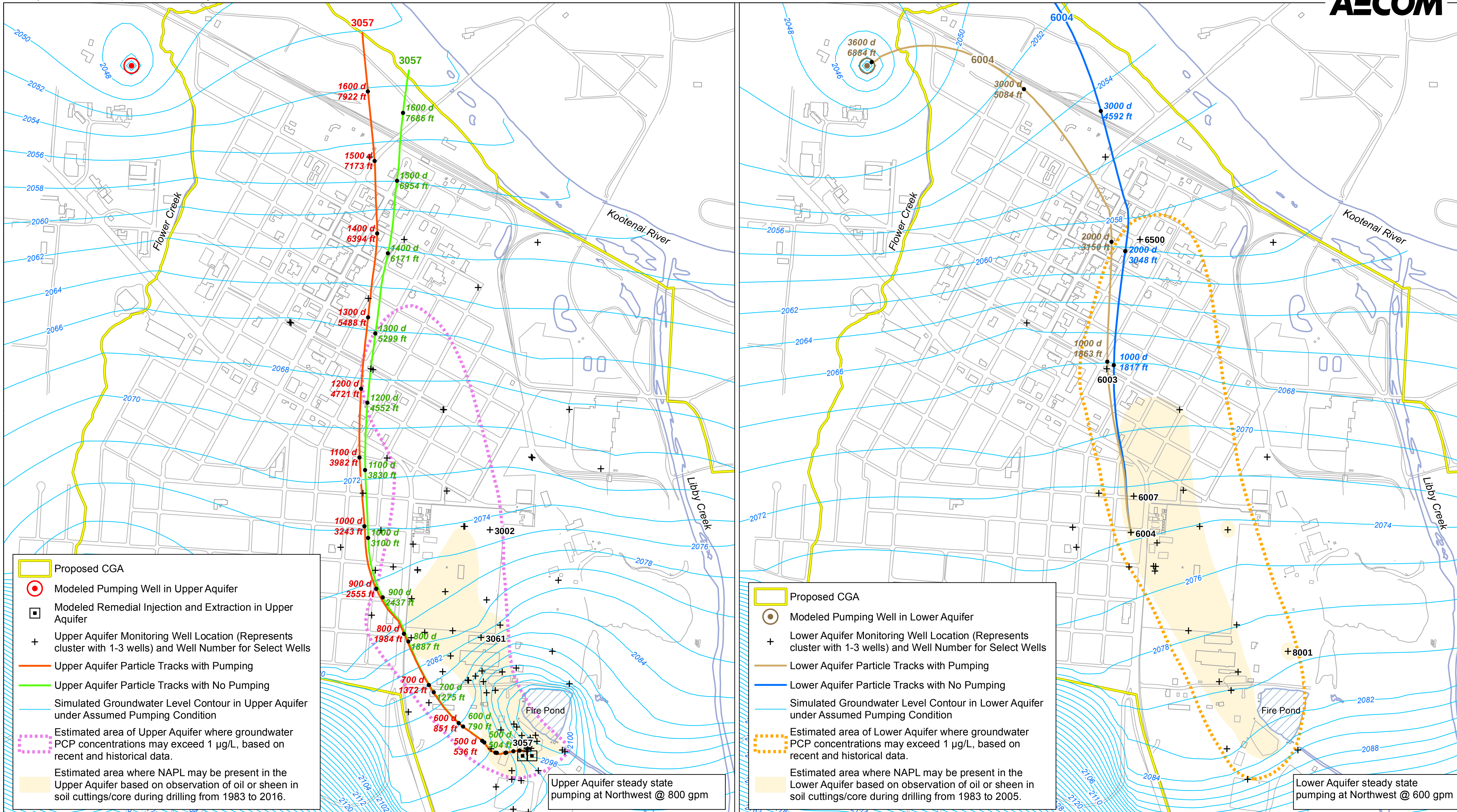

2000 d Particle Tracking Total Time (days)
3200 ft Particle Tracking Total Distance (feet)

N S W E

0 1,000 Feet

gpm = gallons per minute
amsl = above mean sea level
Vertical datum: NAVD 88

Job No.:	60542657
Designed By:	CMZ
Drawn By:	JLC
Date:	9/19/2017

Northwest Pumping Outside the Proposed CGA Near Flower Creek

NUMERICAL MODELING
TO EVALUATE A CONTROLLED GROUNDWATER AREA
LIBBY GROUNDWATER SITE, LIBBY, MONTANA

Fig. 4

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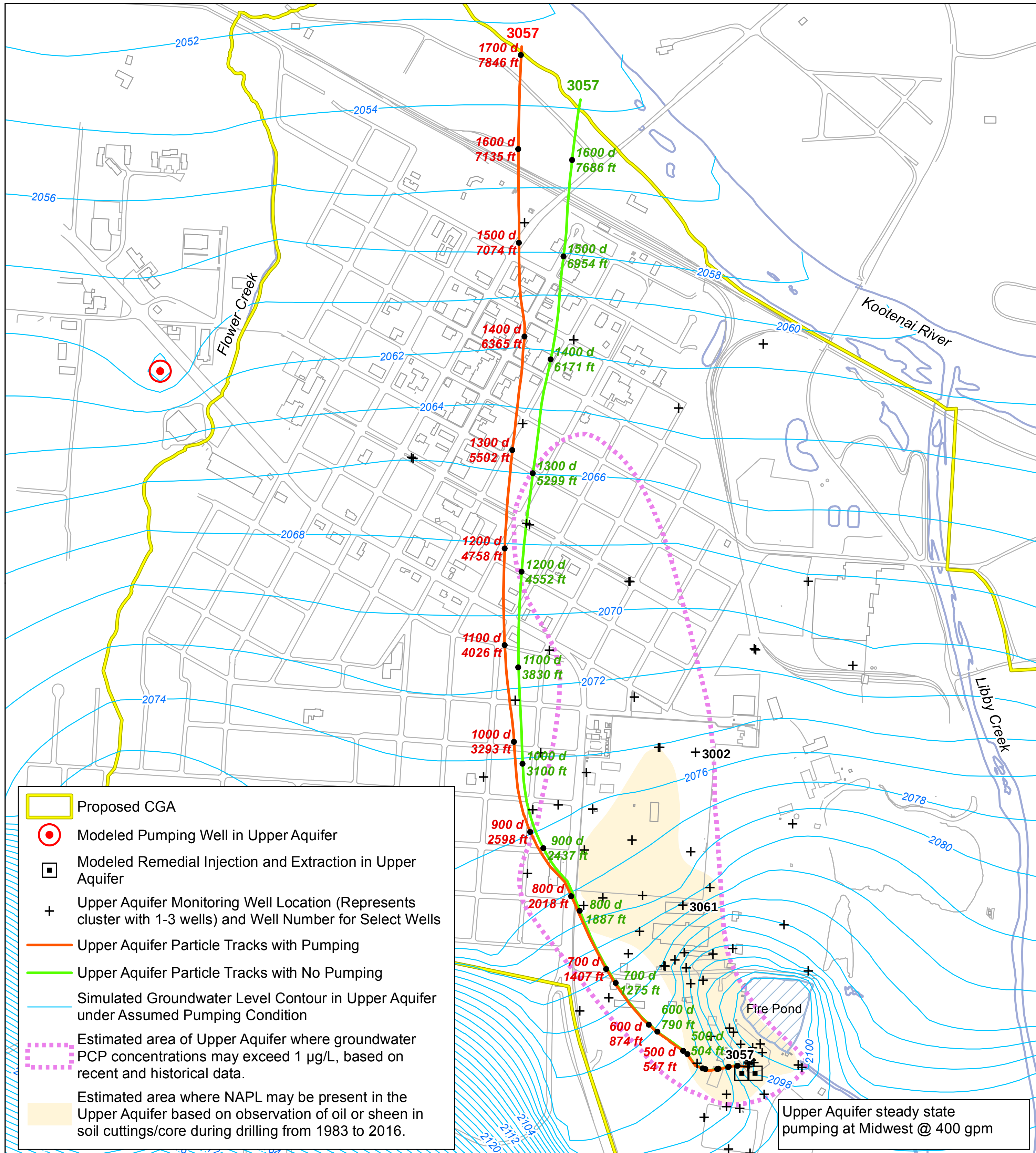

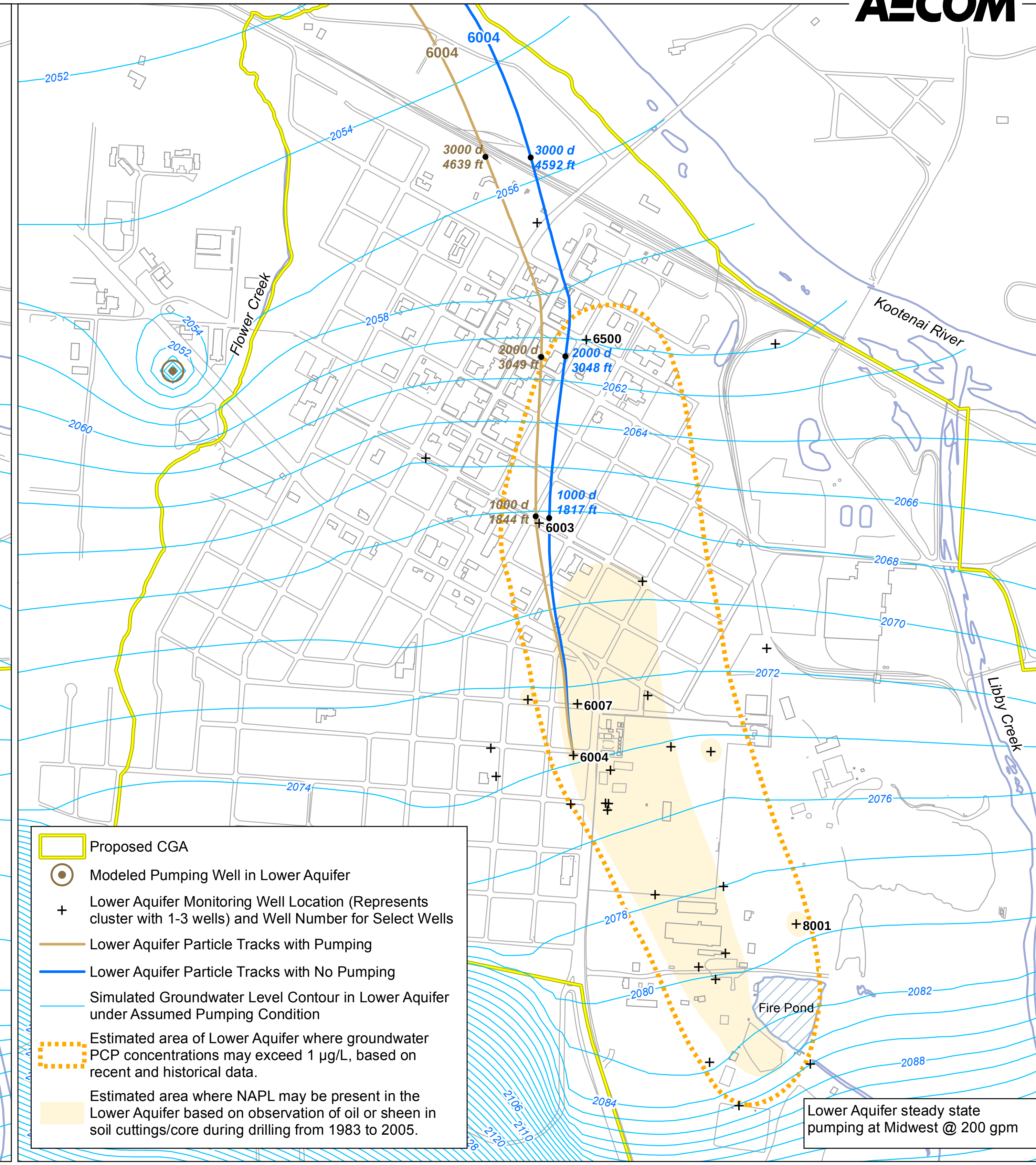

2000 d Particle Tracking Total Time (days)
3200 ft Particle Tracking Total Distance (feet)

0 1,000 Feet

gpm = gallons per minute
amsl = above mean sea level
Vertical datum: NAVD 88

Job No.:	60542657
Designed By:	CMZ
Drawn By:	JLC
Date:	9/19/2017

Midwest Pumping Outside the Proposed CGA Near Flower Creek

NUMERICAL MODELING
TO EVALUATE A CONTROLLED GROUNDWATER AREA
LIBBY GROUNDWATER SITE, LIBBY, MONTANA

Fig. 5

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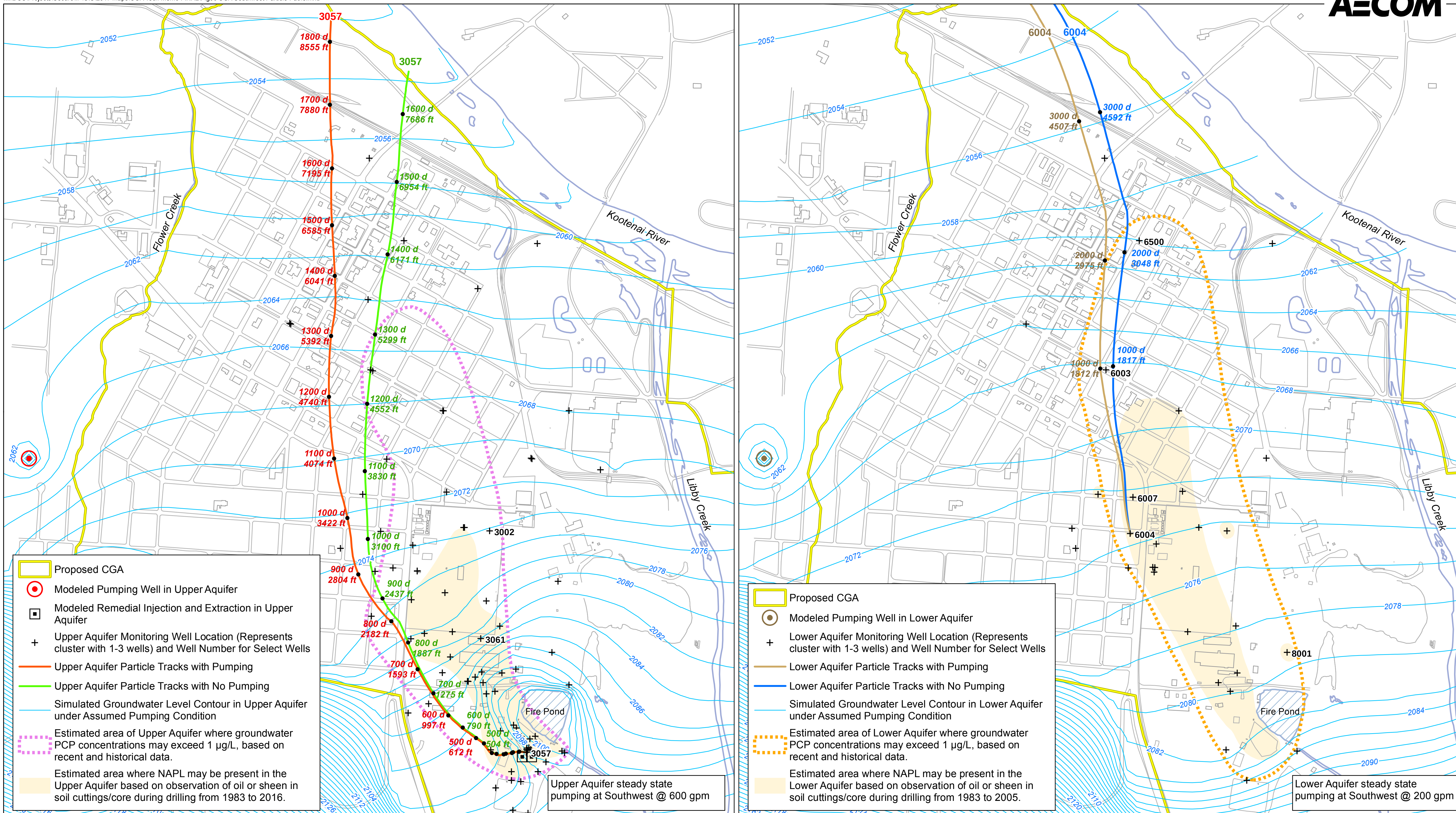
AECOM



2000 d Particle Tracking Total Time (days)
3200 ft Particle Tracking Total Distance (feet)

N S E W

0 1,000 Feet

gpm = gallons per minute
amsl = above mean sea level
Vertical datum: NAVD 88

Job No.:	60542657
Designed By:	CMZ
Drawn By:	JLC
Date:	9/19/2017

Southwest Pumping Outside the Proposed CGA Near Flower Creek

NUMERICAL MODELING
TO EVALUATE A CONTROLLED GROUNDWATER AREA
LIBBY GROUNDWATER SITE, LIBBY, MONTANA

Fig. 6

Appendix A. PCP Bulk Attenuation Estimates

The stability of the PCP plumes downgradient of the NAPL sources in the Upper and Lower Aquifers is due to natural attenuation processes, mainly adsorption, dispersion, and natural biodegradation. The effect of adsorption on PCP transport is expressed by a retardation factor. The estimated retardation factor for PCP in the Upper and Lower Aquifers is 1.77 (Table A-1). This means that PCP travels in the aquifers at a rate that is 1/1.77 (or 0.56) the rate of the groundwater velocity. Dissolved PCP is also dispersed (diluted) and biodegraded along its transport flow path, which further attenuates PCP transport in the aquifers. The combined effects of PCP adsorption (retardation), dispersion, and biodegradation can be estimated using a bulk attenuation half-life.

The first-order bulk attenuation half-life for dissolved PCP in the Upper and Lower Aquifers was 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 and Lower Aquifers were used in the estimation. The bulk attenuation half-lives were applied to the model simulated groundwater flow paths that reach pumping wells to assess whether or not PCP could potentially migrate beyond the proposed CGA due to pumping outside the CGA.

The bulk attenuation half-lives for PCP in the Upper Aquifer (shallow and middle/deep subunits) and the Lower Aquifer were estimated using solute transport data shown in Table A-1. Based on these estimates, PCP attenuates the fastest in the Upper Aquifer shallow subunit (half-life of 19.7 days), followed by the Upper Aquifer middle/deep subunit (half-life of 62.5 days), and PCP attenuates the slowest in the Lower Aquifer (half-life of 217.2 days). Attenuation in the Upper and Lower Aquifers is expected to be mostly related to biodegradation because soil-water distribution coefficients for PCP are relatively low due to the low organic carbon content in the aquifer matrix, thus causing adsorption to be low.

Based on the model simulations presented in the *Technical Memorandum: Numerical Modeling to Evaluate a Controlled Groundwater Area*, pumping the northeast and northwest wells outside the CGA in the Lower Aquifer has the potential to divert groundwater flow from within the NAPL-impacted source area toward the pumping wells. This is illustrated along particle flow paths from well 8001 to the northeast pumping well (Figure 3 of the Technical Memorandum) and from well 6004 to the northwest pumping well (Figure 4 of the Technical Memorandum). Table A-2 provides a summary of the flow path distances, the range of groundwater average linear velocities along the flow paths, travel time to the pumping wells, and the distance along the flow path for PCP to attenuate to the State standard of 1 ug/L. Based on these estimations, PCP above the State standard will remain well inside the proposed CGA boundary and will not migrate to pumping wells outside the CGA.

Appendix A References

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URS. 2012. Report: Investigation to Further Characterize the Upper Aquifer in the Former Source Areas, Libby Groundwater Site, Libby, Montana, Revision 1. Prepared for International Paper Company. May 14.

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Table A-1. Solute Transport Parameter Values for the Upper and Lower Aquifers

Parameter	Value	Unit	Notes
Bulk mass density of porous media (ρ_b)	1.89	g/cm^3	Upper Aquifer soil samples collected from former waste pit and tank farm (URS 2012); assumed that values are similar in the Lower Aquifer
Total porosity (n)	0.307	unitless	Upper Aquifer soil samples collected from former waste pit and tank farm (URS 2012); assumed that values are similar in the Lower Aquifer
Upper Aquifer effective porosity (ne)	0.2	unitless	Numerical model calibrated value (URS 2016)
Lower Aquifer effective porosity (ne)	0.15	unitless	Numerical model calibrated value (URS 2016)
Distribution coefficient (K_d)	0.125	L/kg or mL/g	$K_d = K_{oc}*f_{oc}$
Retardation factor (R)	1.77	unitless	$R = 1 + (\rho_b/n)*K_d$
Fraction organic carbon (f_{oc})	1.4E-04	g/g	Geomean of total organic carbon (140 mg/kg) for various saturated soil samples collected from mid 1980's to early 1990's collected from Upper and Lower Aquifers (lower bound for soil organic carbon)
Organic carbon partition coefficient ($K_{oc)}$	891	L/kg	Literature value from Knox et. al. (1993)
Upper Aquifer shallow subunit bulk attenuation half-life ($t_{1/2}$)	19.7	days	Estimated using method in Newell et. al. (2002), assuming first order decay of 2016 PCP concentrations at wells 3003.3, 3008.1, 3062.1, and 3010.1 (from AECOM 2017, Section 1.2.7.3, Table 1-7)
Upper Aquifer middle/deep subunit bulk attenuation half-life ($t_{1/2}$)	62.5	days	Estimated using method in Newell et. al. (2002), assuming first order decay of 2016 PCP concentrations at wells 3061.3, 3002.2, 6014.3, and 6019.3 (from AECOM 2017, Section 1.2.7.3, Table 1-7)
Lower Aquifer bulk attenuation half-life ($t_{1/2}$)	217.2	days	Estimated using method in Newell et. al. (2002), assuming first order decay of 2016 PCP concentrations at wells 6007.1 (390 ug/L), 6003.3 (170 ug/L), and 6500.3 (<0.5 ug/L)

Notes:
g/cm^3 = grams per cubic centimeters
g/g = grams per gram
L/kg = liters per kilogram
mg/kg = milligrams per kilogram
mL/g = milliliter per gram
PCP = pentachlorophenol

Table A-2. Travel Time and Distances for Particle Flow in the Lower Aquifer to Simulated Wells

Model Simulated Flowpath		Distance Along Particle Flowpath (ft)	Average Linear Velocity Range Along Flow Path (ft/d)[a]	Travel Time to Pumping Wells (yrs)		Assumed PCP Concentration at Monitoring Well (µg/L)[b]	Distance Along Flow Path for PCP to Attenuate to 1 µg/L (ft)[c]
From Monitoring Well	To Pumping Well			Water Particle	PCP Solute Particle		
8001	NE	4,600	0.7 - 1	12.6	22.3	1,000	1,800
6004	NW	6,900	1 - 2	9.9	17.5	1,000	3,400
Attenuation Applied to Particle Travel Along Flowpaths		none		none	adsorption		adsorption, dispersion, and biodegradation (bulk attenuation)

Notes:

[a] The average linear velocity range for Lower Aquifer flow paths from wells 8001 and 6004 is the range of average velocities estimated between the 1,000 day time steps in the model (see Technical Memorandum Figures 3 and 4).

[b] Wells 8001 and 6004 are not routinely sampled. NAPL was detected in the Lower Aquifer during drilling at these locations. The PCP concentration at these well locations is conservatively assumed to be 1,000 ug/L, the estimated effective solubility of PCP in groundwater at Libby.

[c] It takes an estimated 10 half-lives (2,172 days or 6 years) to reduce dissolved PCP in the Lower Aquifer from 1,000 ug/L to the State standard of 1 ug/L. The distance along the flowpath for PCP to attenuate to 1 ug/L was estimated by measuring the flow path distance to the 2,000 day time step, then estimating the distance to travel an additional 172 days using the average linear velocity near 2,000 days.

ft = feet

ft/d = feet per day

NAPL = non-aqueous phase liquid

PCP = pentachlorophenol

µg/L = micrograms per liter