SECTION 319 NONPOINT SOURCE POLLUTION CONTROL PROGRAM

WATERSHED PROJECT FINAL REPORT

Sugarloaf Mountain Mine Waste Erosion Mitigation

by

Colorado Mountain College
Natural Resource Management Field Institute

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0.0 EXECUTIVE SUMMARY

PROJECT TITLE: Sugarloaf Mountain Mine Waste Erosion Mitigation

PROJECT START DATE: June, 2015 PROJECT COMPLETION DATE: April, 2019

FUNDING:	TOTAL ORIGINAL BUDGET (NPS + Non-Fed Match):	$770,837.09
	TOTAL ORIGINAL EPA GRANT:	$461,476
	TOTAL AMENDED BUDGET (NPS + Non-Fed Match):	$533,290
	TOTAL AMENDED EPA GRANT:	$319,974
	TOTAL EXPENDITURES OF EPA FUNDS:	$319,974
	TOTAL SECTION 319 MATCH ACCRUED:	$260,909.13

BUDGET REVISIONS:

May 18, 2017 – EPA Funding decreased by $141,502
In-kind match increased by $43,746 to meet the minimum match requirement of $213,316 after original project scope changes (loss of cash and in-kind match associated with original Task 1 – mine waste pile removal).

TOTAL EXPENDITURES: $580,883.13

SUMMARY OF ACCOMPLISHMENTS:

1. We constructed four sediment basins along Little Frying Pan Gulch and observed active deposition throughout the project. As the remediated channel re-equilibrates, we hope the basins will continue functioning to prevent downstream transport of sulfide-rich decomposing granite that was disturbed during construction.

2. We implemented log erosion barriers, enhanced channel roughness, erosion control matting, and revegetation techniques to reduce channel flow velocity and encourage deposition, primarily during the spring freshet and high intensity rain events.

3. A network of storm water diversion channels were established in Sugarloaf Gulch to mitigate erosion of mine waste pile SLD-06, which remains in situ.

4. Surface water quality data collected in the field include stream discharge, in situ field parameters, and grab samples for laboratory analysis. In addition to traditional in situ surveys, our team estimated the total volume of mine waste excavated from the gulch with photogrammetry methods using an Unmanned Aerial Vehicle (UAV). During construction of the repository, we collected composite mine waste samples for metals analysis.

5. The Headwaters of the Arkansas Working Group provided multiple opportunities for scientific collaboration and public education specifically pertaining to this project, as well as, water quality issues resulting from abandoned mines in general. Examples of outreach activities include field trips to the project site for students and professionals, scientific presentations local and national conferences, and experiential STEM education for Rockies Rocks!, SENDA, and the High Mountain Institute.

6. We curated a database of all data that is included in this report. Water quality data were uploaded to EPA's national Water Quality Portal.

1.0 INTRODUCTION

Historic mining in the Sugarloaf mining district west of Leadville, Colorado, continues to degrade water quality of the Lake Fork Creek and headwaters of the Arkansas River (HUC 110200010103). Downstream impairment of water quality (e.g. Nelson and Roline, 2003; Walton-Day et al., 2005) led to targeted remediation efforts of abandoned mine workings throughout the Sugarloaf Mining District and water quality monitoring of the Lake Fork Creek watershed. Relocation of mine working with the Nelson Tunnel was completed in 2001.Tailings piles below the Dinero wetland were removed in 2003 and a hydraulic bulkhead was installed in the Dinero Tunnel in 2009. During 2012, mine tailings at the Tiger Mine complex were relocated to a local repository and settling ponds with neutralizing media were installed. Remediation efforts of this project built on previous work aiming to reduce the negative effects of legacy mining to the Lake Fork Creek and the upper the Arkansas River.

The Sugarloaf Mining District operated from ~1880 until the 1920s producing primarily silver, and to a lesser extent gold, lead and zinc (Singewald, 1955). Mining occurred along metal-sulfide rich veins in Precambrian granite, schist, and gneiss (Singewald, 1955). Subsequently, Little Frying Pan and Sugarloaf gulches (Figure 1) are significant sources of acid rock drainage (ARD), acid mine drainage (AMD), and sulfide-rich sediment to the watershed. The Lake Fork Watershed Plan (CMC NRM, 2012) identifies Sugarloaf Gulch and Little Frying Pan Gulch (the main tributary to Colorado Gulch; Figure 1.) as the two greatest sources of metal loading to the Lake Fork Creek. Low pH conditions and elevated concentrations of metals characterize both these tributaries (Walton-Day et al., 2005, 2009, 2015; Rasmussen and Hallnan, 2017, and this study). Both of these streams exceed Colorado chronic Table Value Standards (TVS) for aluminum, arsenic, cadmium, iron, lead, manganese, and zinc (CDPHE, 2017).

Subsequently, Lake Fork Creek (segment COARUA05_B from Sugarloaf dam to the confluence with the Arkansas River) is listed on the Colorado Department of Public Health and Environment's (CDPHE) Monitoring and Evaluation list for macroinvertebrates and lead (aquatic life) and impaired waters §303(d) list for cadmium, zinc, manganese, arsenic and copper (aquatic life and water supply; CDPHE, 2018). Segment 2c of the Arkansas River (COARUA02c) is bounded to the north by the confluence with Lake Fork Creek and extends south to the confluence with Lake Creek. This reach of the Arkansas River is §303(d) listed for total arsenic and has an established Total Maximum Daily Load (TMDL) for cadmium and zinc (CDPHE, 2018). Metal loading in this segment of the Arkansas River is largely attributed to input from Lake Fork Creek (Walton-Day et al., 2005).

We addressed sources contributing to downstream water quality impairment through remediation in Sugarloaf and Little Frying Pan gulches. Both gulches have similar geomorphic conditions. The upper reach of Sugarloaf Gulch is a first order stream originating at ~10,200 ft and flows ~0.8 mi to the confluence with Little Sugarloaf Gulch, becoming second order, and enters the Lake Fork Creek. The total drainage area is ~0.52 mi^2. Little Frying Pan Gulch is a second order stream beginning at the confluence of Little Frying Pan East and Little Frying Pan West and is the former location of the Venture Mine. Little Frying Pan flows from ~10,200 ft downstream ~0.5 mi to the confluence with Colorado Gulch draining ~0.45 mi^2. Single-threaded entrenched channels with low width-depth ratio, low sinuosity, and steep gradient characterize both streams. Channels are bedrock controlled with cobble to sand size sediment that originates locally from eroding tailings piles and outcrops of decomposing granite. Stream banks have sparsely developed vegetation.

Sugarloaf and Little Frying Pan gulches are ephemeral streams. Melting snowpack during the spring freshet controls streamflow in both gulches. Streamflow typically peaks during the end of May or early June. Mean annual precipitation in the Sugarloaf Mining District is ~20 inches (Capesius and Stephens, 2009). High intensity summer rainstorms are also an important control on streamflow in this area. The Tiger Tunnel mine adit contributes perennial flow to Little Frying Pan Gulch via Little Frying Pan East. Often, though, Tiger adit discharge quickly infiltrates and flows subsurface for much of the year (July-April). Similarly, the Nelson and Dinero mine adits contribute perennial flow to the lower reach of Sugarloaf Gulch, but also flow subsurface for much of the year.

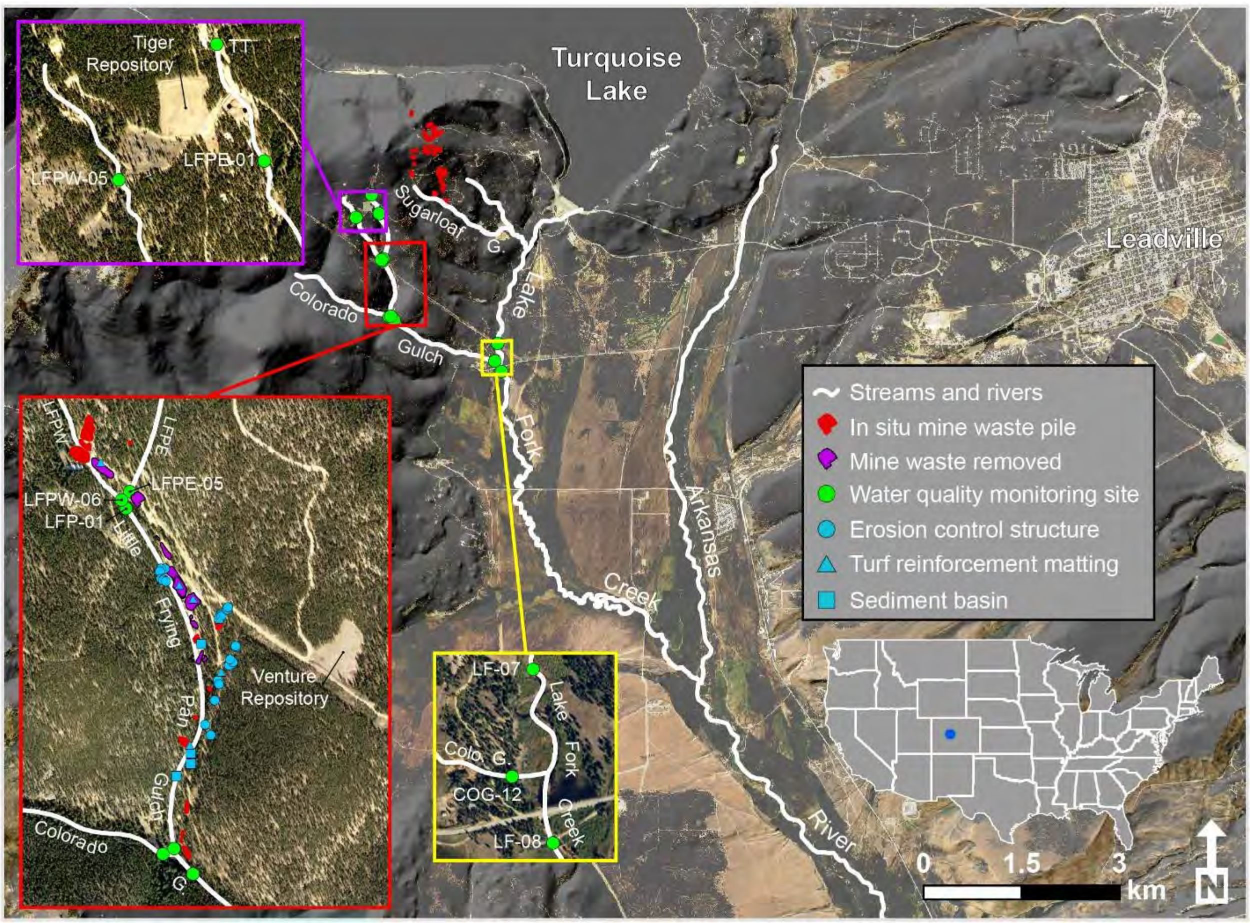

Figure 1. Site overview of the Sugarloaf Mining District near Leadville, Colorado including BMPs, monitoring locations, and surface waterways where this 319 project occurred.

2.0 PROJECT GOALS, OBJECTIVES, AND ACTIVITIES

The following goals and objectives were approved in the original project proposal and through the project scope amendment process. Here we describe the tasks completed to implement these goals tied to each objective. Project outcomes, evaluation methods, and successes are summarized in Figure 2.

Environmental Goal: Improve the water quality of the Lake Fork by reducing mobilization of sediment and mine waste, metals loading, and acidity in Sugarloaf Gulch and Little Frying Pan Gulch.

Environmental Goal: Improve aquatic habitat and water quality for trout below the confluence of Little Frying Pan on Colorado Gulch and in the Lake Fork.

Programmatic Goal: Continue the collaborative approach to watershed restoration in the Lake Fork Watershed.

Task	Products and Outcomes	Evaluation Methods	Measure of success
Task 1: Sediment basins	1) Capture and remove all sediment retained in controls following complimentary construction. 2) Estimate of final sediment and metal load reduction.	1) Total volume of sediment traps	1) Reduction of total metals (Ag, Al, Ba, Cr, Cd, Mo, Rb, Sb, Sn, Sr, Ti, Zr, Pb, Fe, Mn, Zn) in Colorado Gulch during construction activities
Task 2: Erosion control structures	1) Maximize roughness, decrease velocities, and encourage sediment deposition. 2) Estimate of final sediment reduction.	1) Reduction of erosion in gullies will be measured through annual monitoring of photo points and sediment reduction will be calculated by measuring the storage capacity of each in-channel and tributary structure. 2) Final sediment reduction will be calculated during the final field season of the grant	1) Visible sediment deposition in-channel structures
Task 3: Sugarloaf storm water channels	1) Divert storm water around mine waste pile. 2) Estimate of final sediment and metal load reduction.	1) Photo points and erosion pins	1) Visual reduction in erosion of mine waste pile with photo documentation.
Task 4: Monitoring	1) On-site weekly and final closeout reports 2) SAPP Document 3) Pre- and post- project data sets	1) Timely submittal of reports following requested templates 2) Approval of the SAPP 3) CDPHE SOP for WQ collection	1) Acceptance of reports by EPA Project Officer and NPS Project Coordinator 2) SAPP implementation over the life of the project with minimal modifications
Task 5: Community outreach	1) Organize meetings and develop partnerships with watershed stakeholders, present findings at watershed conferences.	1) Meeting minutes, attendance rolls, and public presentations	Increased public support through 15 meetings and 5 conferences
Task 6: Data analysis, reporting, and storage	1) Documentation of water quality trends. 2) Water quality storage tool (CDSN, STORET)	1) CDPHE water quality analysis tables 2) Proof of upload to DSN or STORET	1) Data that indicate trends in water quality toward attainment of TVS 2) All environmental data uploaded prior to end of contract
Task 7: Technical oversight and reporting	1) Quarterly Financial Reports 2) Semi-annual Reports 3) Final Reports	1) Submittal of Reports	1) Submittal of Reports

Figure 2. Task summary of products and outcomes, evaluation methods, and measures for success. Green cells indicate successful evaluation while orange cells indicate areas this project fell short of the anticipated success metric.

Objective 1: *Construct Best Management Practices to reduce impairment of stream segments (see environmental goals).*

Task 1. We constructed four sediment basins along Little Frying Pan Gulch during this project. Capacity of these basins ranges from ~50-350 m^3 and we observed active deposition throughout the project. As the remediated channel re-equilibrates, we hope the basins will continue functioning to prevent downstream transport of sulfide-rich decomposing granite that was disturbed during construction.

Product: Successful capture of sediment during and after channel excavation (Discussion in section 4.1). See Task 1 photos in Appendix 1 – Photographs.

Task 2. Several types of erosion control treatments were applied in both Little Frying Pan Gulch and adjacent gullies. We implemented log erosion barriers, enhanced channel roughness, erosion control matting, and revegetation techniques to reduce channel flow velocity and encourage deposition, primarily during the spring freshet and high intensity rain events.

Product: Visible sediment deposition at erosion control structures indicates localized increases of roughness and decreased flow velocity. See Task 2 photos in Appendix 1 – Photographs and Appendix 2 – *Lake Fork Watershed Sediment Mitigation* (Schoonover and Warner, 2017).

Task 3. Two storm water diversion channels in Sugarloaf Gulch were established to mitigate erosion of mine waste pile SLD-06, which remains in situ. We established photo-monitoring points to evaluate the stability of SLD-06. However, high intensity runoff and rainstorm events have not been observed since the installation of these diversion channels. We cannot evaluate the effectiveness of this Best Management Practice (BMP) at this time.

Product: See Task 3 photos in Appendix 1 – Photographs.

Objective 2: *Monitor Best Management Practice effectiveness (see environmental goals).*

Task 4. Monitoring for this project occurred from June 2015 to October 2018. Surface water quality data collected in the field include stream discharge and in situ field parameters. Laboratory analyses include concentrations of dissolved and total metals, as well as, major anions. 14 mine waste piles along Little Frying Pan Gulch were surveyed in situ as well as the newly constructed repository. We also estimated the total volume of mine waste excavated from the gulch using UAV photogrammetry methods. During construction of the repository, we also collected composite mine waste samples for metals analysis.

Products: Task 4 of Appendix 1 – Photographs contains images of water quality sampling locations. Appendix 2 – Applied *UAV Photogrammetry as an Integrative Mine Reclamation Tool* (Rasmussen and Mohrmann, 2017) contains details about our photogrammetry analysis. Appendix 3 contains all data we collected during this project. Appendix 4 is the Lake Fork Sampling and Analysis Plan (SAP) created in collaboration with the Bureau of Land Management (BLM) SAP developed in coordination with the BLM.

Objective 3: *Strengthen existing partnerships and community outreach through Headwaters of the Arkansas Working Group (HAWG) meetings and distribution of project accomplishment documents (see programmatic goals).*

Task 5. Figure 3 summarizes community outreach activities for this project that occurred from 2015-2018. The Headwaters of the Arkansas Working Group provided multiple opportunities for scientific collaboration and public education specifically pertaining to this project, as well as, water quality issues resulting from abandoned mines in general. Examples of outreach activities include field trips to the project site for students and professionals, scientific presentations local and national conferences, and experiential STEM education for Rockies Rocks!, SENDA, and the High Mountain Institute.

Products: Appendix 1 has photographs from community outreach events and conferences where this project was highlighted. Appendix 2 contains notes and attendance rolls from HAWG meetings.

Outreach Partner/ Event	Description of Involvement	2015			2016				2017				2018				2019	
Colorado Mountain College NRM classes	NRM course work, data collection, applied student learning outcomes		■	■			■	■		■	■			■	■			
Colorado Public Lands Day Leadville Community Clean Up	Annual event promoting a clean and healthy local watershed								■	■								
Geological Society of America (GSA) Annual Meeting	Presentation of research at annual Geologic Society of America conference			■				■				■						
Headwaters of the Arkansas Watershed Group (HAWG)	Headwaters of the Arkansas Watershed Group meetings			■		■				■								
High Mountain Institute	High school experiential learning program helped install erosion barriers													■	■			
Lake County Intermediate School Science Club	Facilitated after school science activites for 4-8th graders		■	■	■	■	■	■										
Leadville Boom Days	Watershed science presentation and project booth at well-attended annual summer festival		■				■				■				■			
Rockies Rock!	Experiential summer field camps for 1-6th graders in Lake County		■			■	■			■	■							
SENDA	Environmental education partnership with Lake County High School										■	■	■	■	■	■		
Sustaining Colorado Watersheds Conference	Presentation of research and project collaboration at annual Colorado Watershed Assembly			■				■				■						

Figure 3. Quarterly summary of community outreach activities conducted during this project. Green cell indicate quarters when CMC conducted community outreach.

Objective 4: *Transfer technology and project effectiveness (see environmental and programmatic goals).*

Task 6. All data collected during this project supported efforts to evaluate trends in water quality resulting from remediation treatments and Best Management Practices undertaken in this project. We curated a database of all data that is included in this report. Water quality data were uploaded to EPA's national Water Quality Portal since STORET was decommissioned.

Products: Water quality data were uploaded to EPA's national Water Quality Portal on July 1, 2019 (see Appendix 5 for upload receipt). Appendix 6 contains plots of water quality trends by site.

Task 7. 319 semi-annual reports and reimbursement requests were provided regularly during this project.

> **Product:** In addition to this final report, CDPHE received construction reports and semi-annual reports on a regular basis

2.1 PLANNED AND ACTUAL MILESTONES, PRODUCTS, AND COMPLETION DATES

Figure 4 provides a summary of the timelines for completion of project objectives for this 319 grant. Green cells are quarters when CMC completed work on this project. Grey cells indicate periods when BMP implementation and monitoring related to Objectives 1 and 2 was not feasible due to mountainous winter conditions.

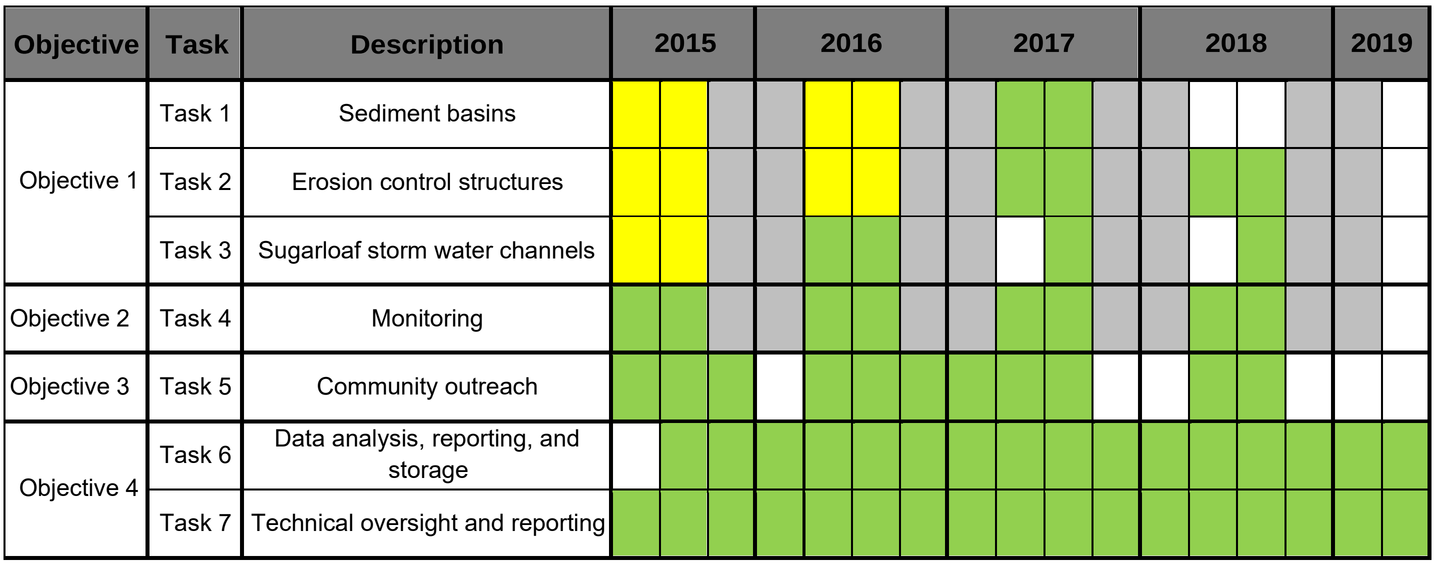

Figure 4. Quarterly summary of project milestones. Green cells indicate quarters CMC completed work. Grey cells indicate quarters with mountainous winter conditions when Objectives 1 and 2 work was not possible. Yellow cells indicates delays due to the Gold King spill (discussed below).

Implementation of Objective 1 was significantly different from that anticipated in the original Project Implementation Plan (PIP) due to the Gold King mine waste spill that occurred in August 2015. These delays are noted by the yellow quarters. CMC was originally contracted to excavate mine waste piles (originally Task 1) from Little Frying Pan Gulch, however, a stop work order was issued shortly after the Gold King spill. Objective 1 project work halted until to 9/15/16. During that period, the PIP, budget and scope of work were renegotiated with CDPHE. Subsequently, mine waste removal (originally CMC Task 1) was removed from CMC's scope of work and the budget was reduced accordingly by $141,502 and CMC's in-kind match requirement increased by $43,746 to meet the minimum match requirement of $213,316. Removal of mine waste piles was subsequently completed by the Colorado Division of Reclamation and Mining Safety (DRMS) during this period using non-319 funds. In an email on 9/15/16, Tammy Allen (CDPHE Restoration and Protection Unit Manager) communicated to, "proceed with work on all tasks as re-defined in the PIP/budget". Shortly thereafter, DRMS commenced removal of mine waste piles and completed this work during the fall of 2016. Pile removal by DRMS was part of the overall project, but 319 funds were not used. These revisions to the project were formalized in a letter dated 5/22/17 from April Haynes (CDPHE Water Quality Control Division Grants Manager) to Jake Mohrmann (CMC's acting Project Manager).

2.2 EVALUATION OF GOAL ACHIEVEMENT

The Colorado Nonpoint Source Program Management Plan (CDPHE, 2012) identifies abandoned mine drainage as one of the targeted NPS categories for the five-year period following the release of the plan. Metals and sediment loading associated with abandoned mine lands are considered nonpoint sources "because they are related to runoff and drainage from Abandoned Mine Lands (AML) sites for which there are no remaining financially viable 'responsible parties.'" Appendix C of the Colorado Nonpoint Source Program Management Plan (CDPHE, 2012) lists the Arkansas River Basin as one of the high priority abandoned hardrock mine sites in Colorado. Specifically, the 2012 plan states, "The Venture Mine is located in the Little Frying Pan drainage, a tributary to Colorado Gulch and the Lake Fork of the Arkansas. This segment is listed as impaired for not meeting the applicable Zinc and Cadmium standards. … The Venture Mine waste piles are some of the most significant remaining sources of pollutants in the Little Frying Pan drainage. The removal of the waste piles from the creek should significantly reduce the Zinc and Cadmium loads over the next five years and will complement the other work that has been completed in the watershed. " The goals listed below reflect the priorities of the 2012 Plan.

Environmental Goal 1: *Improve the water quality of the Lake Fork by reducing mobilization of sediment and mine waste, metals loading, and acidity in Sugarloaf Gulch and Little Frying Pan Gulch.*

BMPs were implemented by CMC and DRMS throughout Little Frying Pan Gulch from 2016-2018. Most significantly, DRMS constructed a new mine waste repository in the Sugarloaf Mining District and excavated ~12,300 m^3 (conservatively ~20,000 metric tons) of mine waste and decomposing granite from Little Frying Pan Gulch and sequestered this material in the repository. The mine waste repository was critical to the overall success of this project, but was a DRMS extension completed without NPS 319 funds. The material contained in the repository is no longer available for downstream sediment transport and was the single most effective BMP for reducing downstream transport of mine waste from this area.

Efforts to improve acidic water conditions and reduce metal concentrations towards attainment of Table Value Standards in Little Frying Pan and Sugarloaf gulches have been largely unsuccessful up to this point. Improvements in water quality may become more apparent in the future as BMP disturbances and channel processes equilibrate. See section 7.0 for additional discussion.

Environmental Goal 2: *Improve aquatic habitat and water quality for trout below the confluence of Little Frying Pan on Colorado Gulch and in the Lake Fork.*

Most trout populations can tolerate a pH range of 5.5 to 9.0, with an optimal range of 6.5 to 8.0 (Hartman and Gill 1968; Behnke and Zarn 1976; Raleigh 1984). Site COG-12 is located on Colorado Gulch directly upstream of the confluence with Lake Fork Creek. Over the past decade, there has been significant seasonal and annual variation in pH at COG-12, with pH field measurements ranging from 4.06 to 7.27. Post-remediation (2017 and 2018) pH levels at COG-12 have not been observed below 6.3. However, pH may still be limiting aquatic life along Colorado Gulch below the confluence of Little Frying Pan Gulch. COG-07 is the site directly below the confluence of Little Frying Pan Gulch and Colorado Gulch, with COG-06 upstream on Colorado Gulch, and LFP-05 upstream on Little Frying Pan (Figure 1). Water entering Colorado Gulch from Little Frying Pan has a pH that typically ranges from 3.0 to 3.5. The pH at COG-07 tends to have significant seasonal and annual variation, with field observations of pH ranging from 3.6 to 7.4. The low pH levels on Colorado Gulch below Little Frying Pan are likely impeding the establishment and long-term success of aquatic life along this reach.

Programmatic Goal 1: *Continue the collaborative approach to watershed restoration in the Lake Fork Watershed.*

A summary of the education and outreach efforts that kept the public and stakeholders informed about mining remediation as part of this project is provided in Figure 3. Appendix 2 contains these outreach materials.

3.0 IMPLEMENTATION OF BEST MANAGEMENT PRACTICES

Figure 5. Images of active site remediation by DRMS and post-remediation outcomes at the Gertrude-Venture Mine and completed storm intercept system at SLD-06 in Sugarloaf Gulch.

Figure 1 is a map of implemented BMPs and locations of water quality monitoring sites. Figure 5 shows before and after images of remediation at the Venture Mine. Additional pictures of the BMP construction, before, and after images are contained in Appendix 1.

Throughout the BMP implementation and design phase of this project we collaborated with Applegate Group, Inc. Applegate brought expertise in sediment transport and fluvial geomorphology relevant to the remediation work being completed during this project. Specifically, we leveraged Applegate's recent experience managing erosion in other areas with steep exposures of decomposing granite, similar to the Sugarloaf Mining District.

We implemented two main BMP treatment strategies during this project: 1) divert runoff away from and around mine waste piles remaining in situ (i.e. SLD-06), and 2) stabilize areas where waste material was removed to prevent continued erosion. The first strategy was primarily implemented at SLD-06 by the CMC Heavy Equipment Operations class following the design plan developed by CMC and Applegate staff.

While this BMP does not prevent erosion caused by water that falls or melts directly on the pile, it will likely prevent continued erosion caused by flowing surface water that is now being diverted around both sides of the pile. In the future, Turf Reinforcement Matting (TRM) treatments on the pile itself could additional stabilize the waste material.

In Little Frying Pan Gulch we implemented many small scale BMPs such as log erosion barriers (LEBs), TRM treatments, small check dams, revegetation, root wad/ log jams, and adding channel roughness wherever possible. These methods have the advantage of using locally available materials including logs, root wads, and rocks. Additionally, these BMPs are easily implemented by small foot crews using hand tools in areas where use of trucks and heavy equipment is not feasible. Applegate has seen high cumulative effectiveness using these sorts of BMP treatments in conjunction with one another. We expect similar effectiveness, primarily in terms of slope stabilization and flow velocity reductions, where these BMP treatments were implemented throughout the project site.

4.0 MONITORING

4.1 REDUCTION OF SEDIMENT SOURCES

One of the primary project objectives was removing several piles of mine waste and tailings from Little Frying Pan Gulch, relocating, and burying these materials in a newly constructed waste rock repository. This was completed during late summer and fall of 2016 in coordination with DRMS without 319 funding. Mine waste pile were surveyed in situ and using UAV photogrammetry techniques. Initial in situ estimates indicated ~4,100 m^3 of mine workings to be excavated, however, significantly more material was present than initially thought. In total, ~12,300 m^3 of material was excavated from the project reach in Little Frying Pan Gulch and buried in the repository. Using a range of density values (p = 1,800 – 2,200 kg/m^3), we conservatively estimate the mass of mine waste and decomposing granite sequestered in the repository at >20,000 metric tons. Details of this analysis are in Appendix 2.

	Estimated Volume	**Estimated Sediment Mass***	**Capacity Remaining**
Location	*cubic meters*	*metric tons*	*Percent*
Little Frying Pan Repository	>12,300	>20,000	0%
Sediment Basin 1	350	630	100%
Sediment Basin 2	50	90	~40%
Sediment Basin 3	50	90	~0%
Sediment Basin 4	150	270	~75%
In-channel structures (total)	200	360	-
SLD-06 Stabilization	4,500	4,500	-
PROJECT TOTAL	***~17,600***	***~25,940***	-

*Figure 6. Summary of estimated volumes, sediments mass, and remaining capacity of the main repository, constructed sediment basins, and BMP treatments. *Assumed p = 1,800 kg/m^3 for all mass calculations.*

Additionally, sediment basins, in-channel structures, and stabilization of SLD-06 will contribute to the cumulative reeducation of sediment to Lake Fork Creek. Estimates of these reductions for summarized in Figure 6. Sediment basins account for ~600 m^3 of sediment retention capacity (~1080 metric tons of local sediment). Sediment Basin 1 was constructed farthest downstream on Little Frying Pan Gulch to catch as much sediment as possible during DRMS excavation. As of October 2018, ~480 m^3 (~80%) of total sediment basin capacity remains. We anticipate that the remaining sediment basins will fill during subsequent seasons as the remediated channels equilibrate.

The exact sediment trapping capacity of in-channel strictures is difficult to quantify. Sedimentation capacity of individual structures ranges from ~0.25 to 5 m^3. We conservatively estimate the cumulative sediment capacity of newly constructed in-channel structures at ~200 m^3. More importantly, these types of BMPs promote local stabilization and prevent significant additional erosion. This is most notable at SLD-06 where storm intercept channels established during this project have prevented additional head cutting at this site.

During excavation of waste rock piles, composite samples were obtained from individual haul dumps for analysis of whole rock composition by X-ray Fluorescence (Figure 7 and Appendix 3). Using the metal concentration values from these samples, combined with volumetric estimates of individual haul dumps, we estimated the mass of metal sequestered in the repository. Our analysis indicates that a minimum of ~37,000 kg metals were removed as metal loading sources from Little Frying Pan Gulch and sequestered into the waste rock repository. Details of this analysis are in Appendix 2 (see Rasmussen and Mohrmann, 2017).

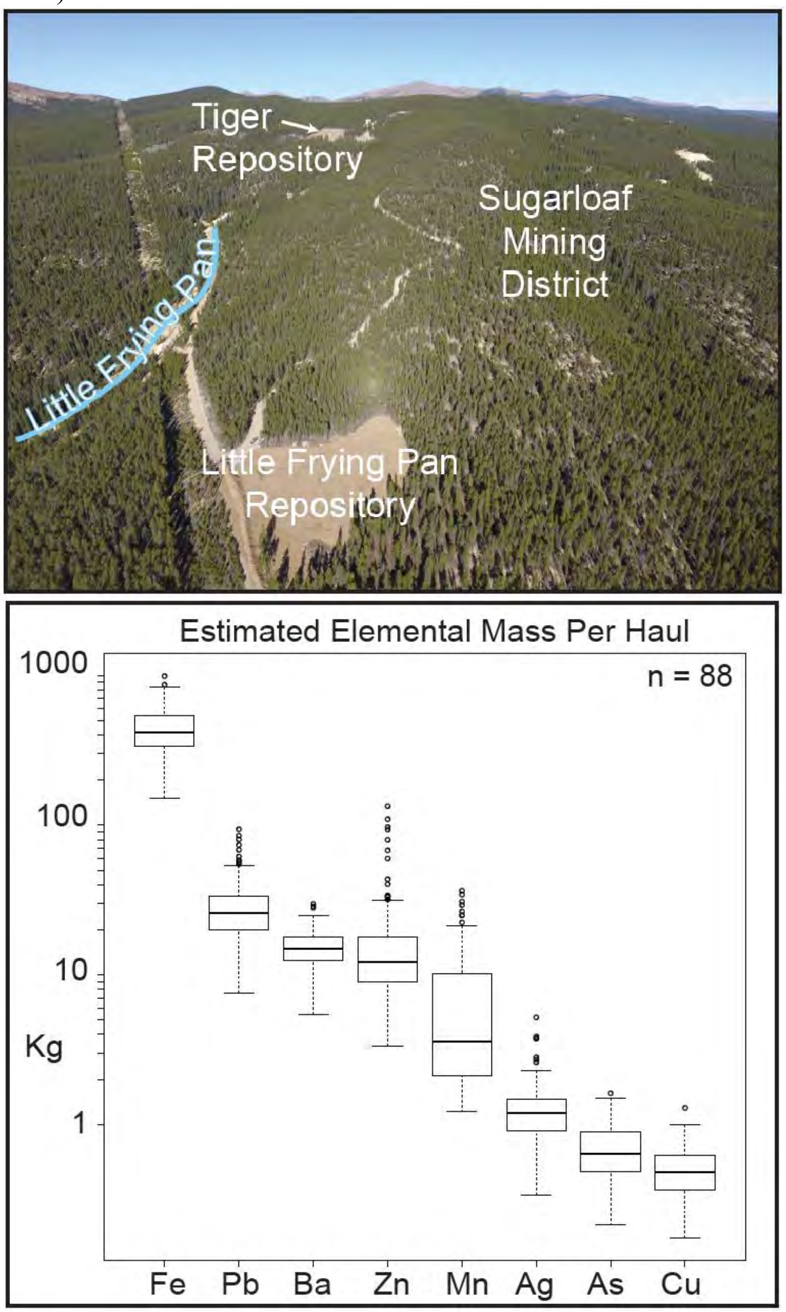

Figure 7. A) Aerial overview of the 319 project site in the Sugarloaf Mining District. B) Estimate of metal mass per excavation load derived from UAV photogrammetry analysis and XRF results.

4.2 WATER QUALITY TRENDS

Previously established water quality monitoring locations throughout the Sugarloaf Mining District were utilized to maximize comparison of pre-project datasets. The network of monitoring sites used during this project are intended to bracket BMPs and evaluate the effectiveness of the project. Figure 8 is a summary of the sites used in Little Frying Pan Gulch and the rational for these sites.

Site ID	Description and Rational
COG-06	*Description:* Colorado Gulch water located ~40 m above confluence with Little Frying Pan. *Rational:* Assess water quality upstream of Little Frying Pan Gulch.
COG-07	*Description:* Colorado Gulch water located ~30 m below confluence with Little Frying Pan. *Rational:* Assess water quality downstream of input from Little Frying Pan Gulch.
COG-12	*Description:* Located ~60 m above confluence with Lake Fork between private culvert and CR-5A culvert. *Rational:* Assess water quality immediately upstream of Lake Fork Creek.
LF-07	*Description:* Located directly below power lines downstream of input from Siwatch tunnel, ~200 m upstream from input from Colorado Gulch. *Rational:* Assess water quality upstream of Colorado Gulch.
LF-08	*Description:* Located on south side of CR-5A on Lake Fork Ranch ~150 m downstream of wooden bridge. *Rational:* Assess cumulative effects on Lake Fork Creek water quality after input from of Colorado Gulch.
LFP-01	*Description:* Located ~200 m down gradient of power line road, ~20 m downstream of confluence of the East and West fork of Little Frying Pan. *Rational:* Assess water quality immediately upstream of BMPs.
LFP-05	*Description:* Located ~40 m above confluence with Colorado Gulch. *Rational:* Assess water quality immediately downstream of BMPs.
LFPE-01	*Description:* Located in forest ~100 m downstream of Tiger Mine remediation area. *Rational:* Evaluate effectiveness of previously implemented Tiger Mine complex remediation BMPs.
LFPE-05	*Description:* Located on Little Frying Pan East upslope of power line road ~20 m upstream of confluence with Little Frying Pan West. *Rational:* Characterized water quality at the former site of the Venture Mine.
LFPW-05	*Description:* Located just above a logging road, just to the west of the Tiger area, on Little Frying Pan West. Sampled before water travels through culvert under the road. *Rational:* Monitor background water quality conditions upstream of Little Frying Pan Gulch that are independent of the Tiger Mine complex.
LFPW-06	*Description:* Located upslope of power line road at the former Venture area, just upstream of the confluence with the Little Frying Pan East at base of boulders in reclamation channel. *Rational:* Assess water quality flowing from the Tiger Mine complex into Little Frying Pan Gulch.
TT	*Rational: Description:* Tiger Tunnel discharge adit, located above Little Frying Pan East, and sampled at the discharge culvert. Monitor background water quality conditions of discharge from the Tiger Tunnel adit.

Figure 8. Water quality monitoring sites, site descriptions, and rationale for monitoring.

Overall, there are not clear improvements towards attainment of TVS. In some cases, the most elevated metal concentrations occur *after* implementation of BMPs (2008-2018). Given the limited post-BMP water quality data at this time compared with the pre-BMP data, caution should be exercised when interpreting water quality trends. As semi-annual water quality monitoring continues in the Sugarloaf Mining District, a more clear interpretation of BMP effectiveness will emerge. Appendix 3 contains a complete record of water quality data and Figure 7 contains plots of estimated masses of selected metals removed form Little Frying Pan Gulch. More detailed analysis including scientific methods, assumptions, and conclusions will be in a forthcoming publication (Rasmussen and Hallnan, in preparation).

Despite the lack of observed water quality improvement, it may still be too early to capture the full benefits of the BMP treatments. As the stream equilibrates and disturbed sulfide-rich sediment is flushed through, water quality may change. Additionally, the BMPs are intended to be most helpful during the spring freshet and large flooding events and will likely be helpful during these events.

5.0 COORDINATION EFFORTS

Activities on Sugarloaf Mountain, including Little Frying Pan Gulch, have been the subject of several long-standing collaborations, including participation by a wide range of local, state, and federal stakeholders. The Headwaters of the Arkansas Working Group (HAWG) contributed to this project by bringing many stakeholders together at meetings and outreach events. Staff from Colorado Mountain College facilitated HAWG meetings that included local land owners, other local community members, state agency representatives, and federal agency partners (see Appendix 2). In addition to providing technical advice, the Colorado Division of Reclamation, Mining and Safety (DRMS) conducted key aspects of this project, including the excavation of the soil repository for the project, tailing pile removal from Little Frying Pan Gulch, and capping of the repository. The Bureau of Land Management and the United States Geological Survey were both instrumental in water quality monitoring efforts associated with this project.

5.1 COORDINATION FROM OTHER STATE AGENCIES

DRMS was a key player in the implementation of this project. DRMS was responsible for improving access to the site through road grading, and they installed the first sediment basin prior to the removal of any tailings piles. DRMS was also instrumental in designing and constructing the required soil repository for this project. Additionally, DRMS implemented the removal of the in-channel tailings piles, installed rip rap and channel reinforcement, and installed erosion control matting in key areas after pile removal. This project would not have been possible without the significant efforts of DRMS.

5.2 OTHER STATE ENVIRONMENTAL PROGRAM COORDINATION

CDPHE’s Restoration & Protection Unit provided excellent support for this project. The Natural Resource Management Department at Colorado Mountain College experienced staff turnover during this project, and CDPHE contacts helped the new staff develop a deeper understanding of the complex issues related to the Sugarloaf Mountain project.

5.3 FEDERAL COORDINATION

The BLM funded the development of the Lake Fork Watershed Sampling and Analysis Plan (SAP) in 2017. Of the 20 sites in the Lake Fork SAP, twelve overlap with sites in this project. The Lake Fork SAP was designed with significant technical input from the BLM Royal Gorge Field Office, experts at the USGS Denver Federal Center, and the support of a post-graduate intern from the Geological Society of America GeoCorps program.

5.4 USDA PROGRAMS

No special USDA programs were involved in this project.

5.5 ACCOMPLISHMENTS OF AGENCY COORDINATION MEETINGS

The Headwaters of the Arkansas Watershed Group (HAWG) was actively involved in agency coordination and outreach (see Appendix 2 for HAWG meeting agendas and attendance rolls). CMC staff and faculty facilitated HAWG meetings, and CMC NRM Project Managers conducted additional agency coordination. Key agency partners included BLM, DRMS, CDPHE, and CMC.

5.6 RESOURCES/COORDINATION FROM FEDERAL LAND MANAGEMENT AGENCIES

The BLM and the USGS have been collecting water quality samples and monitoring water quality on the Lake Fork, including sites in Little Frying Pan Gulch and on Sugarloaf Mountain, for approximately 20 years. Both of these agencies contributed to this project through trainings on water quality sampling, funding to support water quality monitoring downstream of this project, and funding for the Lake Fork Watershed Sampling and Analysis Plan (see section 5.7 for additional detail).

5.7 OTHER SOURCES OF FUNDS

Summary of matches
The BLM provided water quality monitoring and sample laboratory analysis valued at ~$37,000 but was not eligible as a match on this grant.

Other in-kind match sources include:
Colorado Division of Mining, Safety and Reclamation (DRMS): ~$211,000
Colorado Mountain College: ~$49,000

6.0 SUMMARY OF PUBLIC PARTICIPATION

Over the course of this project, HAWG meetings were open to the public, and over 75 individuals were on the HAWG mailing list. Regular project updates were presented at HAWG meetings, and these meetings also helped facilitate inter-agency coordination. Representatives from city and county government attended HAWG meetings, along with state and federal agencies, and many interested community members and stakeholders. Dinero Mining Properties, LLC, was supportive of this project, and granted access through private property to the work sites on Little Frying Pan Gulch.

In addition to HAWG meetings, outreach events in the community highlighted this project along with other watershed health activities. Figure 3 and Appendix 2 summarizes public outreach, education, and community events.

7.0 ASPECTS OF THE PROJECT THAT DID NOT WORK WELL

1. The BMP measures undertaken in Objective 1 (Tasks 1-3) were not adequate to address the Environmental Goals to improve water quality set forth in this project. The only perennial flow into Little Frying Pan Gulch, the focus of this grant, originates from the Tiger Mine complex near the top of the Sugarloaf Mining District. Despite similar remediation efforts to this project at the Tiger complex finished in 2012, the flowing Tiger adit continually discharges acidic (~2 pH) metal saturated groundwater into the surface system. Discharge from the Tiger effectively controls water quality from the adit to the confluence with Colorado Gulch. The cumulative downstream effect on water quality by removing small mine waste piles (including the Venture complex) is negligible given the toxicity of inflow from the Tiger. Future projects need to evaluate the relative water quality of upstream tributaries and how that relates to potential (or even chemically possible) downstream improvements. Existing BMPs for AML where inflow are already impaired are probably not effective treatments and development of alternative BMPs should be considered.

2. Little Frying Pan Gulch exists at a complex intersection of geologic structures, zones of mineralization and intense weathering, and anthropogenic deposits. As DRMS excavated mine waste, it became apparent that the boundary between mine waste tailings at the surface and near-surface sulfide-rich zones of decomposing granite is ambiguous. In general, this resulted in excavating more material from deeper in the gulch and a significant underestimate of the required repository capacity. We recommend that future projects working in mineral rich zones of

Abandoned Mine Lands consider specific criteria for distinguishing between naturally occurring and anthropogenic materials, as this boundary is often enigmatic.

8.0 FUTURE ACTIVITY RECOMMENDATIONS

To assess the benefits of this 319 project and develop more effective remediation strategies for the Sugarloaf Mining District, long term water quality monitoring should continue. Macroinvertebrate sampling and monitoring was not undertaken as part of this project but should be considered as a future evaluation metric. Over time, the cumulative effects of remediation in the Sugarloaf Mining District (this project and others) may yield detectable changes in macroinvertebrate communities in the Lake Fork Creek due to reduction of contaminated sediment. Specific recommendations for future monitoring are specified in the Lake Fork Sampling and Analysis Plan (CMC NRM, 2018) maintained by CMC in collaboration with the BLM.

Given the lack of short-term water quality improvements after implementation of passive BMPs, future water quality improvement projects should consider the feasibility of bulkhead treatments or active water treatment strategies.

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Appendix 1

Task 1—Sediment Basins

Basin 2 Under Construction

Basin 2 Near Completion, prior to rain events

Basin 2 Contractor Walk-through with Applegate

Appendix 1

Task 1—Sediment Basins

Basin 2 Under Construction

Basin #2 Post-Construction

Basin #2 Post-Construction—Rain Event

Basin #2 Post-Construction—Rain Event

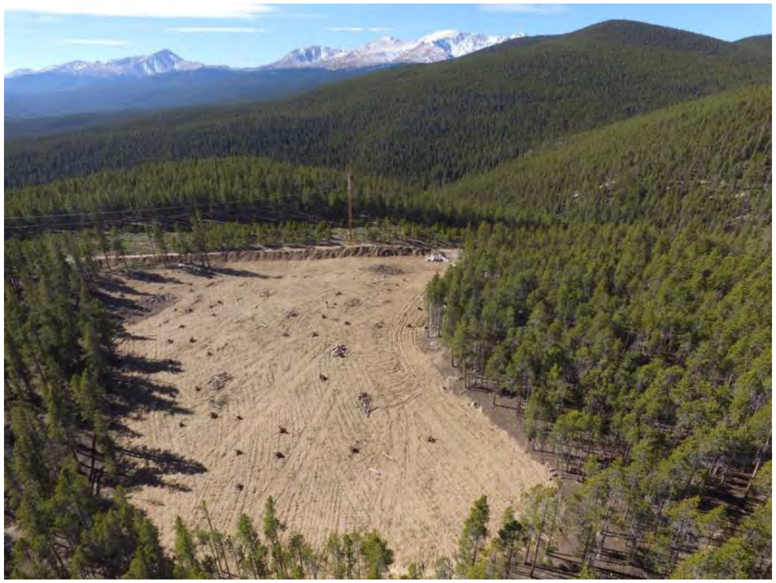
Appendix 1

Task 1—Sediment Basins

Basin #1 Post-Construction

Repository Construction—2016

Repository Walk-through with DRMS



Repository Post-Construction

Appendix 1

Task 2—In-Channel Structures

Venture Mine

Venture Pile Removed—New Channel Construction

TRM Matting Installation above Little Frying Pan

TRM Matting and Stabilization Finalized

Appendix 1

Task 2—In-Channel Structures


Proposed Log Erosion Barrier (LEB) site #6


LEB #6 Construction


LEB #6 Finalization

Appendix 1

Task 2—In-Channel Structures

LEB #6 Complete

LEB #6 Complete

LEB Series above Little Frying Pan

LEB and Channel Roughness Installation Below Powerline Road

Appendix 1

Task 2—In-Channel Structures

Road Damage above Little Frying Pan on Powerline Road

LEB Installation West of Little Frying Pan

Channel Roughness Modification above Little Frying Pan

Channel Roughness Modification above Little Frying Pan

Appendix 1

Task 2—In-Channel Structures

Field Classroom Discussion

Coconut Husk Matting Installation above Basin #2

Appendix 1

Task 3—Stormwater Intercepts

Heavy Equipment Class Building Interceptor Ditch

Continued Construction

Continued Construction

Channel Finalization

Appendix 1

Task 4—Sampling and Monitoring

COG-06

COG-07

COG-12

LF-07

Appendix 1

Task 4—Sampling and Monitoring

LF-08

LFP-01

LFP-05

LFPE-01

Appendix 1

Task 4—Sampling and Monitoring

LFPE-05

LFPW-06

TT

Flow Measurement at LFP-05

Appendix 1

Task 4—Sampling and Monitoring

Flow Measurement at COG-06

Grain Size Analysis—Hydrometer Testing

Grain Size Analysis—Sample Collection

Appendix 1

Task 5—Public Outreach

Community Cleanup and Outreach Event

HMI Students Constructing Sediment Basin

HMI Students Constructing Sediment Basin

Boom Days Outreach Table

Appendix 1

Task 5—Public Outreach

Photo 5a—Rockies Rock at 319 Site

Photo 5b—Outreach Table at Boom Days

Photo 5d—HMI Students at 319 Site

Photo 5c—Community Cleanup Event and Outreach

Watershed group expands

The Lake Fork Watershed Working Group elected to expand the group to focus on a larger geographic area, include additional stakeholders and prioritize additional watershed issues. The decision was made at the group's Nov. 14 meeting.

The Lake Fork Watershed Working Group was created in 2000 by approximately 30 stakeholders to address water-quality issues associated with historic mining in the Lake Fork Watershed, focusing on the Sugarloaf Mining District located just southwest of Turquoise Reservoir.

Since the group's formation, roughly $5 million, largely grant funds, have been spent on projects that have measurably improved water quality in the Lake Fork.

The newly expanded watershed group will focus on the entire headwaters of the Arkansas River upstream of Granite, including the Twin Lakes area. The next steps for the group will be to create a watershed plan document that analyzes watershed issues affecting this area and then prioritize projects that will further improve overall watershed health. The plan will address issues that could impact the watershed, such as forest health, water quality, water quantity, sedimentation and erosion, development, open space, climate, wetlands, riparian, education and recreation.

Citizens or organizations that have an interest in watershed issues or would like further information are encouraged to contact the watershed group by emailing nrm@coloradomtn.edu.

January 1, 2015 - Leadville Harold

HAWG

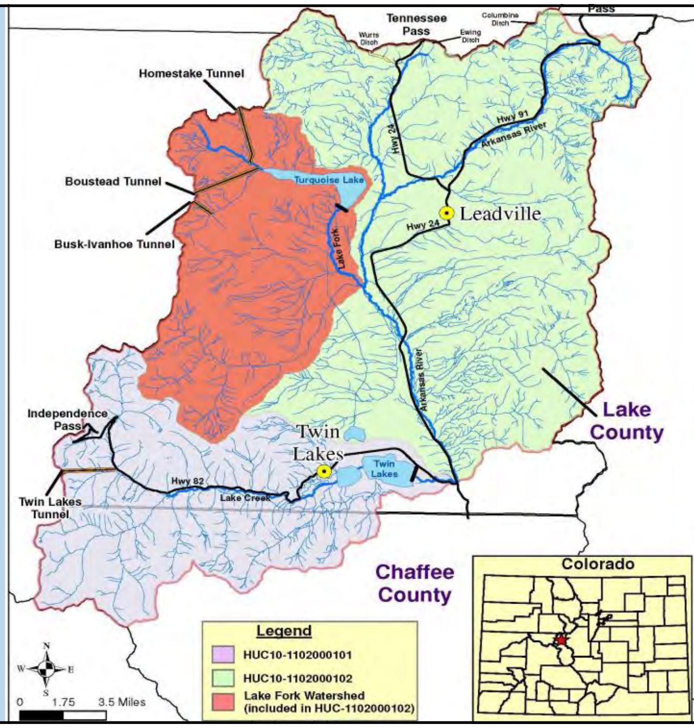
Headwaters of the Arkansas Watershed Group

April 15, 2015

NRM Advisory Board Meeting

Headwaters of the Arkansas Watershed Group H.A.W.G.

- **Facilitated by CMC NRM**
- **Recently approved for $30k of funding to create a Watershed Plan**
- **Watershed Plan will identify and prioritize watershed projects throughout the Headwaters**
- **Students will work with NRM Staff and Watershed Stakeholders to write the Watershed Plan and conduct education and public outreach events**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Boustead Tunnel
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Turquoise Lake
Lake Fork
Hwy 24
Hwy 91
Arkansas River
Leadville
Independence Pass
Twin Lakes Tunnel
Hwy 82
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Twin Lakes
Lake County
Chaffee County
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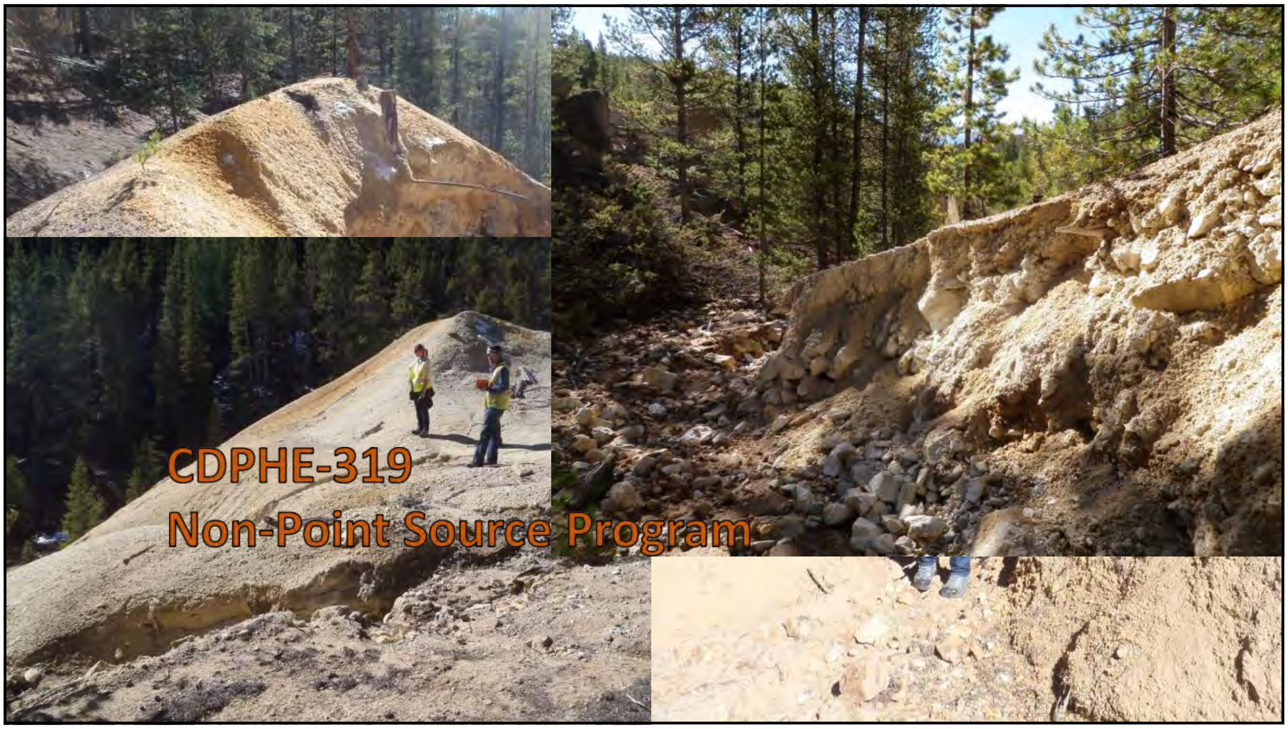
CDPHE-319
Non-Point Source Program

Headwaters of the Arkansas Watershed Group

May 15, 2015

9:30-9:35 Welcome and introductions

9:35-9:50 Update from the Arkansas Watershed Collaborative

9:50-10:10 Kick off of the Climax Grant and the comprehensive HAWG Watershed Plan

10:10-11:45 Updates on 2015 Summer Watershed Projects Throughout the Headwaters including:

*USFS Leadville- Tennessee Creek project update and "State of the Forest"
*USFS Gunnison- Forest Entomology talk
*Cloud City Conservation – Update on school and community compost project and Household Hazardous Waste program
*LCOSI- Update on Lake County open space and conservation projects
*Colorado Mountain College-Update on Sugarloaf Mountain Mine Waste Erosion Mitigation Project
*USGS- Update on Dinero Bulkhead Project and Aquatic Geochemistry
*Colorado 14ers Initiative- Recreation impacts on the 14ers & 2015 Lake County 14er projects

11:45-12:30 2015 Outreach Opportunities and Collaborations

*Outreach conversation regarding local summer "events"
*Co-Sponsoring of the fall Wild and Scenic Film Festival
*Brainstorm potential for volunteer events
*Pressing issues and late business

12:30-1:30 Lunch and networking

Headwaters of the Arkansas Watershed Group

October 23, 2015

9:30-9:35 Welcome and introductions

9:35-10:50 Project Updates

- Park County Stream and Wetland Inventory/Prioritization Project - Mark B.
- BLM/HAWG Geological Society of America Presentation - Kerri S.
- Update on Didymo in the Headwaters - Jenn M.
- Update on Sugarloaf Mining District Projects, Little Frying Pan Gulch projects - CMC/CDRMS

**10 Minute Networking Break*

11:00-12:00 Special Presentations

- PhD Dissertation Presentation - Kato D.
    - Dissolved Organic Carbon Characteristics in Metal-Rich Waters and the Implications for Copper Aquatic Toxicity
- Update on HAWG Watershed Plan and areas for collaboration and "data gaps" - Kerri S.

12:00-1:00 Lunch and networking

Headwaters of the Arkansas Watershed Group

Wednesday May 4, 2016

In room 401 – This is the KW room in the Climax building (the gym)

9:30-10:30 Project Updates

*-Evans Gulch – Jason Willis (Trout Unlimited)
*-Tiger Mine—Jason Willis (Trout Unlimited)
*-Venture/Welsh Mine—Craig Bissonnette (Col. Div. of Reclamation Mining and Safety)
-Dinero Bulkhead—Katie Walton-Day (USGS)
*-USFS Projects—Jeni Windorski (USFS)
*-Rocky Mountain Fen Research Project—Mike Conlin (Conlin Associates)
~~-California Gulch Superfund Site update—Alissa Schultz (CDPHE)~~
*-Clear Creek Bathymetry Project—Jake Mohrmann (CMC-NRM)
-California Gulch Superfund Monitoring—Jord Gertson (Sourcewater Consulting)
-Box Creek—Sam Sherwood (Aurora Water)
-Snow/Water runoff forecasting and Implications for upper and lower basin—Aurora Water? Pueblo?
-Escondido Ranch—Pueblo
-Ski Recreation Update from 2015/16—Ski Cooper
-GSA Field Trips hosted in Leadville, Mining Bike Tour Short Course
-CMC non credit classes

Brief Break

10:45-11:45 Breakout sessions

-Watershed Outreach, Summer Events Planning

- BBQ Fest- ask for volunteers, any partners want to donate giveaways, ask for suggestions on creating survey
- HAWG Newspaper section

-Watershed Plan, Pulling the pieces together

11:45-12:45 Lunch and Networking (Fiesta Taco Bar since it's Quatro de Mayo)

HAWG Meeting 5/4/16 Sign in Sheet

Name	Organization	E-mail (if not already on file)
Taylor Pearman	CMC (non paid student)	taparman@outlook.com
Maddalena Blondell	CMC (non paid student)	mblondell14@gmail.com
Adrienne Stanley	CMC (non paid student)	stanleyl@colorado.edu
Jim Gusek	Sovereign Consulting	on file
Bruce Hix	Lake County	bhix@co.lake.co.us
Ed Perko	Pueblo Water	eperko@pueblowater.org
Chad Blake	Arkansas Headwaters Recreation Area	Chad.Blake@state.co.us
David Gilbert	BLM	dgilbert@blm.gov
Kati Jj"t-	Ld 5	,n 'ford@usgs s'ilf0!
Melina Smell --+1,,,,, :l...:...t.0i. -=--:....:...;;;.:;; 0	___. ...:;..+- - - - - -	-=.:.. 6'(
Craig Bissonnette	CDRMS	Craig.b17 <::o n n t!-'-& _ k .co.us
Sam Sherwood	Aurora Water	
Rego E. Omerfgfc	Parkville Water	
Greg Teter	Parkville Water	gteter@pa.r, v / ,0
Mike Conlin	LCOSI	Co,vu fu-A550Ci A1c'& @ VA\Ja:,. C0vvi
Kerri Souller		
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Andrew Mackie	L-ruA	andrewjmackie@itva.org
Greg Brunjak	WARRP	sgbrunjak@aol.com
Mazi Dasleving	HMI	
Hannah Black	HMI	
Kathryn Hardgrave	CSFS	
Nick Gerich	USFS	ngerich@fs.fed.us
Jeni Windorski	USFS	
Lisa Corbin	USFS	

HAWG Meeting 5/4/16 Sign in Sheet

Name	Organization	E-mail (if not already on file)
Vince Matthews	LeadvilleGeologyLLC	LeadvilleGeology@gmail.co
Cathy Patti	CMC	
Jake Mohrmann	CMC	
Kato Dee	CMC	
Parker Simpson	student	

HAWG Meeting 5/4/16

Agenda

9:30-11:00 Project Updates/Presentations

-Evans Gulch – Jason Willis (Trout Unlimited)
-Tiger Mine—Jason Willis (Trout Unlimited)
-Venture/Welsh Mine—Craig Bissonnette (DRMS)
-Dinero Bulkhead—Katie Walton-Day (USGS)
-USFS Projects—Jeni Windorski (USFS)
-Rocky Mountain Fen Research Project—Mike Conlin (Conlin Associates)
-California Gulch Superfund Site update—Written update Alissa Schultz (CDPHE)
-Clear Creek Bathymetry Project—Jake Mohrmann (CMC-NRM)
-Snow/Water runoff forecasting and Implications for upper and lower basin—Aurora
-Escondido Ranch—Pueblo
-Winter Recreation Update from 2015/16—Ski Cooper written update

Brief Break

11:15-11:45 Breakout sessions

-Watershed Outreach, Summer Events Planning
-Watershed Plan, Pulling the pieces together

11:45-12:45 Lunch and Networking

HAWG Meeting Agenda
Feb. 3rd, 2017
KW Room (401)

9:00-9:15 Welcome and Intros

9:15-10:30 Project Updates

-New Lake County Commissioner introduction - Sarah Mudge

*-Venture/ Little Frying Pan 319 Project - Craig B. + Jake M.

*-UAV 3D Modeling - Dirk Rasmussen

-USFS project updates; Jeni Windorski & Lisa Corbin

-Wetland Focus Group Meeting - Feb 8 - Mark Beardsley

-Upper Ark Land Trust to Central Colorado Conservancy-Buffy Lenth

*-Sugarloaf BMP Monitoring (Dinnero Bulkhead) - Katie Walton-Day

*-CAIC State of the Snowpack Update - Ethan Greene

10:30-10:45 Break

10:45-11:45 HAWG 2017 Outreach event(s) - Jake Mohrmann

HAWG Watershed Plan Update - Jake Mohrmann

HAWG Watershed Plan Project Breakout - Katy Warner

11:45-12:30 Lunch / Networking

total 2

Sign In Sheet

Craig Bissonette
Sarah Mudge

HAWG 2/3/17

Name	Org.	E-mail (if not on file)
Mohrmann		
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HAWG meeting agenda 5-4-17

9:30-9:40 Welcome and introductions

9:40-11:15 Project and Stakeholder Updates

- -Dinero Mine Bulkhead- Sugarloaf Mining District - Katie Walton-Day and Joe Mills USGS (30min)
- -Lake County Office of Emergency Management- Hazard Identification Vulnerability Analysis - Mike McHargue (15min)
- -Snowpack Update and Spring High Flow outlook – Jake Mohrmann CMC (6 min)
- -Decomposed Granite Stabilization Short Course – FREE – July 10-14th – Steve Smith Applegate Group (5min)
  - *Implications for post fire sediment stabilization and erosion mitigation
- -Other Project and Agency Updates from stakeholders present (15min)
- -HAWG Outreach Event Update (15min)

11:15 Meeting Adjourn – Next meeting to be held in October 2017

*plan on sticking around a bit after the meeting for snacks and networking

LeadvHle & Lake County

Com ity lea p

In Celebration Of

Colorado Public Lands Day

Saturday May 20th!

Clean up our community

TOGETHER!

Time: 10am-3:00pm

Meet Where Your Group Captain Told You at 10am OR Meet At The CMC Gazebo at 10am To Join A Team!''

Colorado Mountain College
From 3:30-6:00pm

Beer Garden!
All PUBLIC WELCOME & ENCOURAGED TO ATTEND!

WIN!!! THOOS N S O DOLL RS O P IZ S O R E AWARDED!

PROUD SPONSORS

Leadville & El Condado de Lake

Limpieza Comunitaria

Para Celebrar el Primer

Día de Los Terrenos Públicos de Colorado

sábado, 20 de mayo

¡Limpiemos nuestra comunidad

JUNTOS!

De 10am a 3pm

Unase donde le indique su "capitan" del grupo a las 10am O vayase a las 10am a la glorieta de Colorado Mountain College para unir con un grupo.

Despues de limpiar... ¡UNA FIESTA! en Colorado Mountain College

De 3:30pm a 6pm

¡Cerveceria al Aire Libre!

TODO EL PUBLICO BIENVENIDO

¡Más de $5000 en premios!

PATROCINADORES ORGULLOSOS

Pb Periodic Brewing Leadville - Colorado

HAWG

Leadville Trail 100 Legacy Foundation

INDEPENDENCE REALTY & PROPERTY MANAGEMENT

LEADVILLE, CO GREAT LIVING AT ELEVATION 10,152'

Climax Molybdenum A Freeport-McMoRan Company

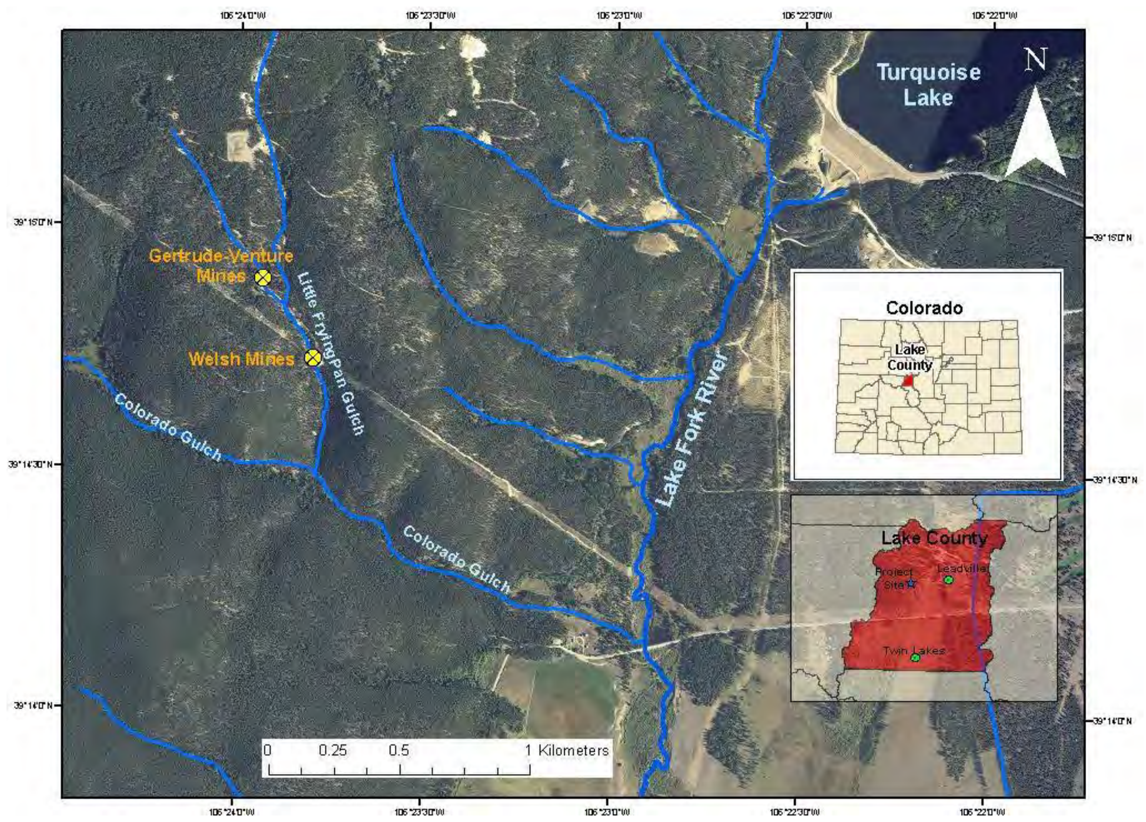
COLORADO MOUNTAIN COLLEGE 50TH ANNIVERSARY

COLORADO PUBLIC LANDS DAY

Lake Fork Watershed Sediment Mitigation
Leadville, Colorado

Thomas Schoonover*+; Katy Warner, PhD*

*Colorado Mountain College, NRM Field Institute, +Presenting



Background

Little Frying Pan Gulch (LFPG) is located in the Sugarloaf Mining District in Lake County, Colorado, approximately five miles west of Leadville. LFPG discharges into Colorado Gulch, then into the Lake Fork River, and ultimately into the Arkansas River. Field observations indicated that mine waste piles along LFPG were eroding, causing acid mine drainage, heavy metals loading, and mobilization of mine waste sediment. In the fall of 2016, several large tailings piles from the Gertrude-Venture and Welsh Mine complexes were removed from LFPG and deposited in a nearby soil repository. As with any earth-moving disturbance, there is potential for a short-term increase in sediment mobilization. This project was designed to mitigate the effects of sediment mobilization in the areas immediately downstream from the former Gertrude-Venture and Welsh Mine complex sites.


Gertrude-Venture tailings pile before (left) and after removal (right). Water from Little Frying Pan Gulch was interacting with the pile prior to removal. The Gertrude-Venture and Welsh Mine complex sites were immediately upstream from the sediment mitigation efforts.

Sediment Mitigation Goals

To reduce sediment mobilization through the implementation of in-channel velocity reductions structures and sediment sequestration structures along Little Frying Pan Gulch.

Training – Sediment Mitigation Short Course

In July of 2017, students and staff at the NRM Field Institute participated in a five day short-course on sediment mitigation, presented by the Applegate Group, Inc. This short-course included classroom discussion of mitigation techniques, followed by several days of on-the-ground implementation. The course covered four sediment mitigation techniques, and the NRM Field Institute crew continued applying these techniques along Little Frying Pan Gulch throughout the 2017 field season.

Sediment Mitigation Techniques

1. Sediment Basins
2. Log erosion barriers
3. Increased channel roughness
4. Erosion control matting

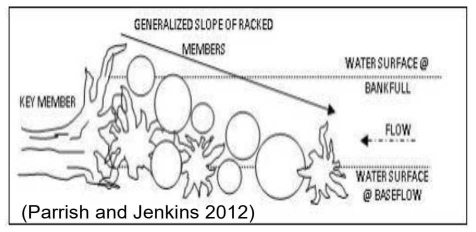
1. Sediment basins


Three sediment basins were installed along Little Frying Pan Gulch. The sediment basin in the photo on the left was built in the fall of 2016, and filled with sediment in under one year. The basin on the right w as constructed by NRM Field Institute field technicians in the in the summer of 2017. These basins were designed to allow water to flow through the rock face, while slowing velocity and sequestering sediment on-site.

2. Log erosion barriers


Log erosion barriers (LEBs) can be installed to intercept water running downslope or along a small channel. One the left, a series of LEBs were installed below an access road to prevent roadside erosion and trap sediment. On the right, the LEB spans a small channel and is reinforced with rocks to help hold it in place.

3. Increased channel roughness




Hydraulic roughness is the measure of the amount of frictional resistance water experiences when passing over land and channel features. Increasing roughness reduces water velocity, which helps reduce erosion. The NRM Field Institute team installed root balls, rock, and other woody material to increase channel roughness.

4. Erosion control matting


Two types of erosion control matting were used on this project. Disturbed soil was seeded and coconut husk matting (right) was installed above the recently constructed sediment basin in an attempt to establish vegetation and increase bank stability. Coconut husk matting is biodegradable, and can help hold seed and moisture in place as plants reestablish and stabilize the soil. We also installed Excelsior brand heavy duty turf reinforcement matting (left) to help prevent erosion of a small tailings pile, and along a steep road-side slope above Little Frying Pan Gulch. Excelsior TRM matting is made from woven polypropylene fibers, and is designed for use on challenging slopes and environments.

Project Accomplishments

- ✓ Installed 40 LEBs to reduce the water velocity during runoff events and prevent additional erosion in key areas
- ✓ Seeded with a native seed mix and installed approximately 50 sq. yds. of coconut husk matting above the recently constructed sediment basin to establish vegetation and increase bank stability
- ✓ Installed 75 sq. yds. of heavy duty turf reinforcement matting to prevent future erosion of a small tailings pile
- ✓ Added channel roughness above and below the LFPG access road to reduce water velocity during runoff events, and prevent additional erosion
- ✓ Installed 3 sediment basins on the main channel of Little Frying Pan Gulch to sequester mobilized sediment

Acknowledgements

This work was funded by a Clean Water Act section 319 grant through the Colorado Department of Public Health & Environment. Other project partners include the Bureau of Land Management, Colorado Division of Reclamation, Mining, and Safety, and the Headwaters of the Arkansas Watershed Group.

Special thanks to Steve Smith at Applegate Group for teaching the sediment mitigation short course: stevesmith@applegategroup.com

References

Parrish, R.M. and Jenkins, P.B. 2012. Natural Log Jams in the White River: Lessons for Geomimetic Design of Engineered Log Jams. U.S. Fish and Wildlife Service, Leavenworth, WA.

Excelsior Sediment Control Products
http://www.westernexcelsior.com/

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Applied UAV Photogrammetry as an Integrative Mine Reclamation Tool: Little Frying Pan Gulch, Leadville, Colorado

Dirk Rasmussen*⁺ and Jake Morhmann*

*Colorado Mountain College, NRM Field Institute; ⁺Presenting Author

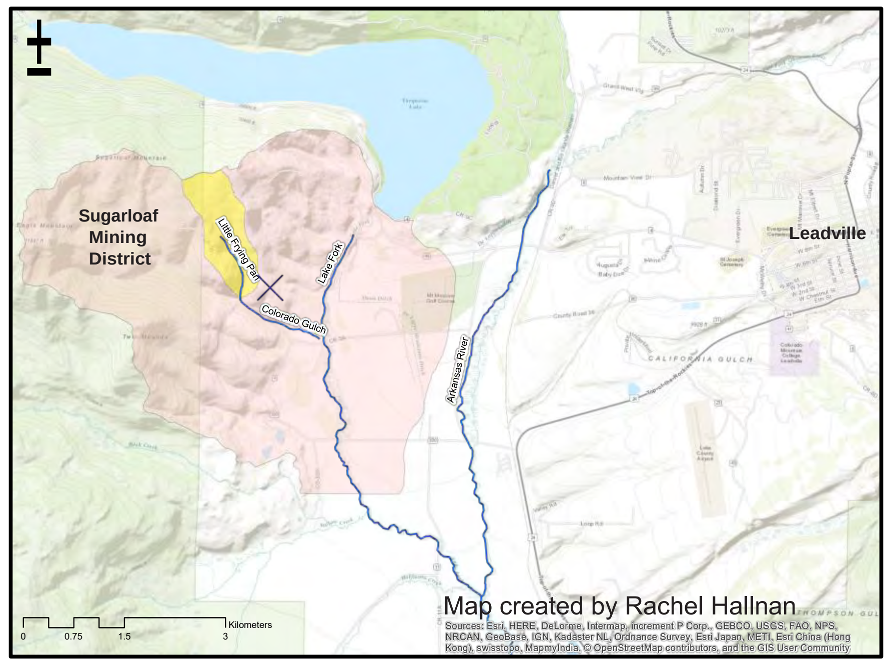
COLORADO MOUNTAIN COLLEGE

Flying Marmot

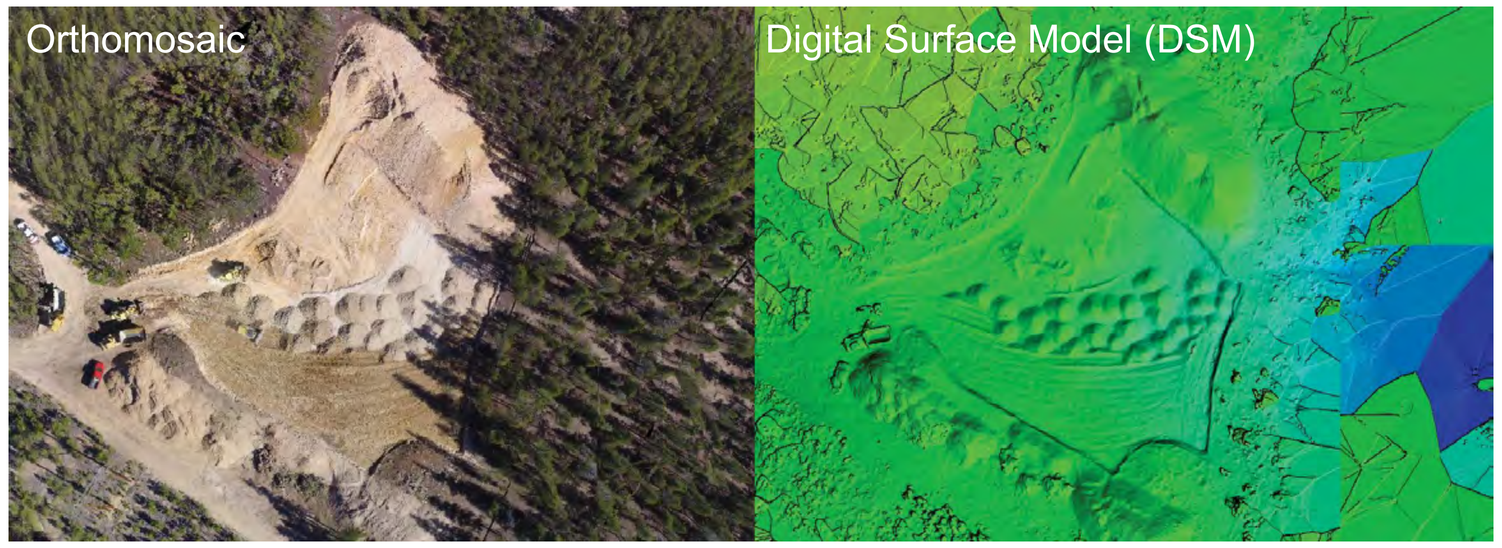
Natural Resource Management Program

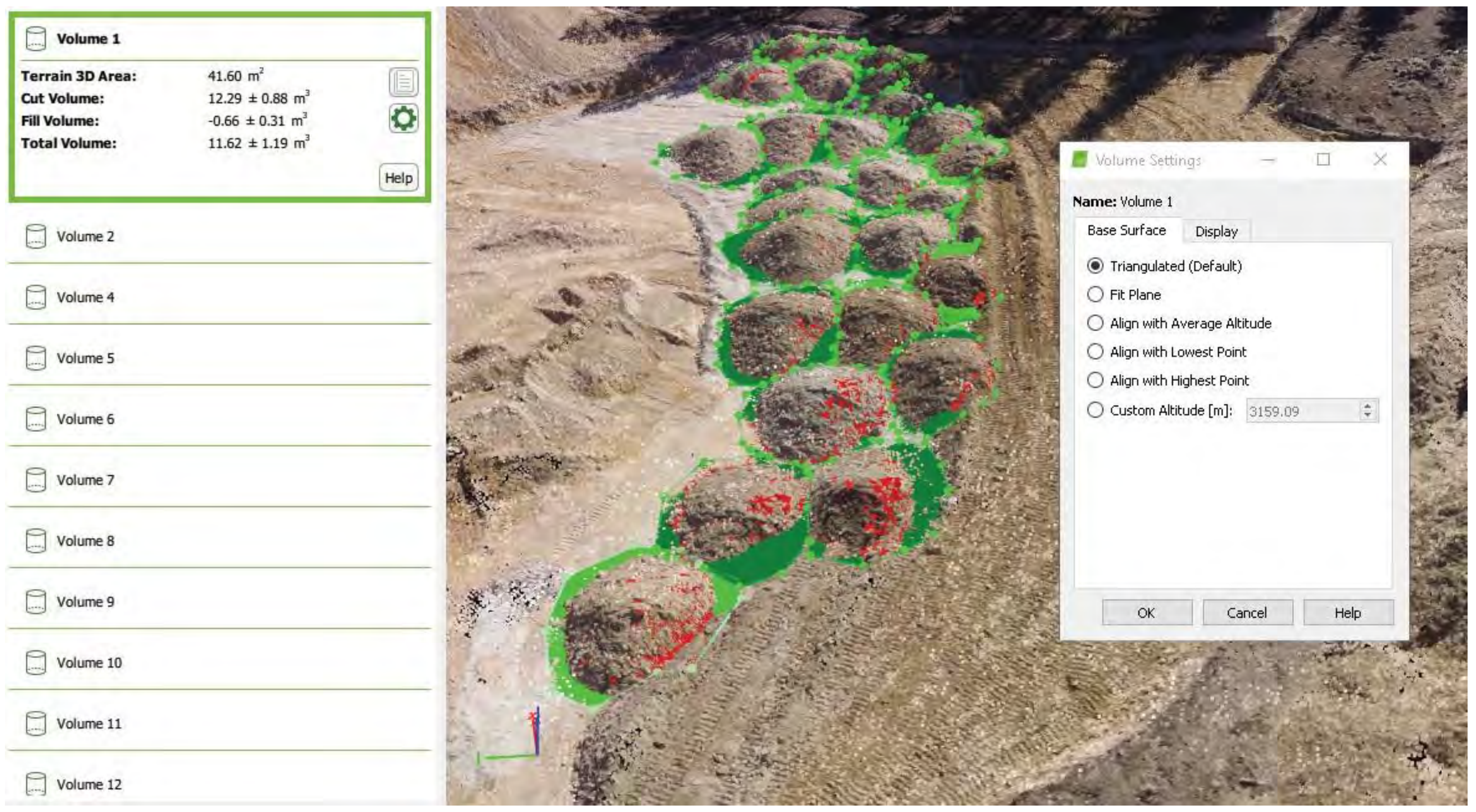
BACKGROUND: Historic mining in the Sugarloaf mining district near Leadville, Colorado, contributes to impaired water quality in the Lake Fork Creek and Arkansas River. Abandoned mines in Little Frying Pan Gulch have been significant contributors of metals and contaminated sediment to the watershed. Negative impacts on downstream water quality and aquatic ecosystems have led to targeted remediation of abandoned mine workings in this area. As part of the remediation in Little Frying Pan Gulch several piles of mine waste and tailings were excavated from the drainage and buried in a repository.

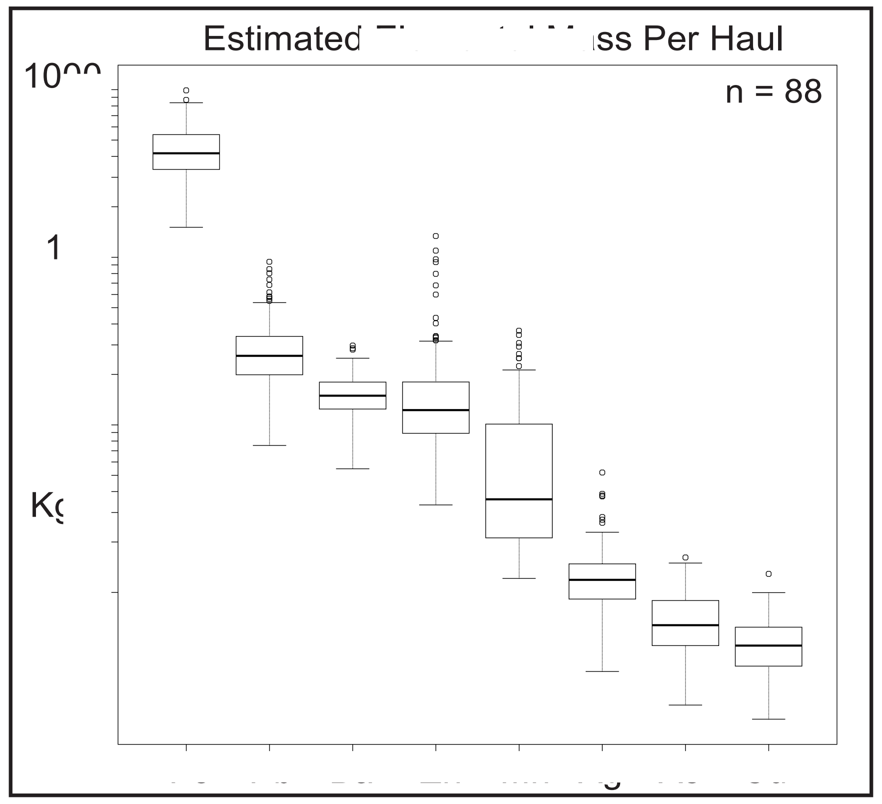
PROJECT GOAL: Estimate the volume of sediment and mass of contaminants removed from Little Frying Pan Gulch into the waste repository.

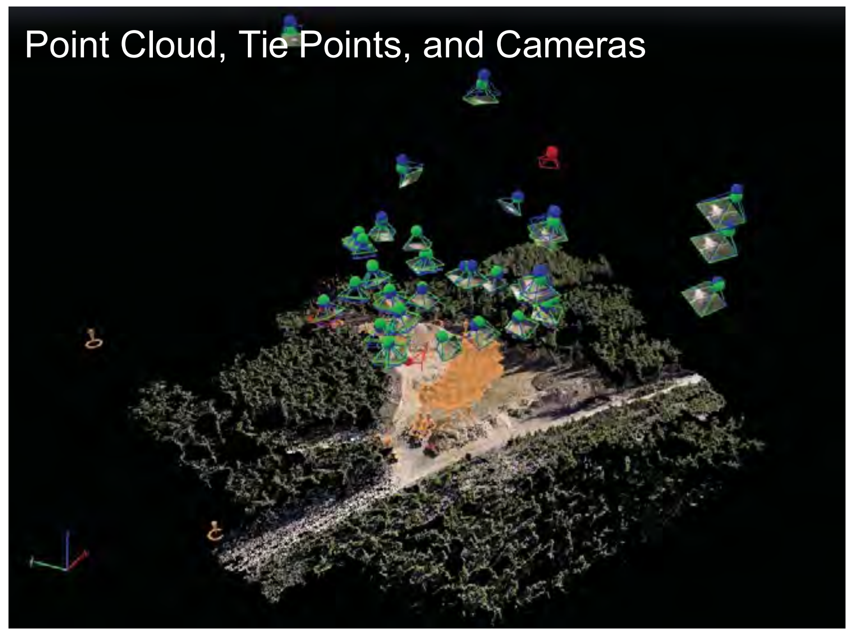


METHODS: We used a small-unmanned aerial vehicle (UAV) to monitor progress and collect photogrammetry datasets. Photographs were analyzed using Pix4D spatial modeling software. Composite samples of tailings and waste rock were collected from material placed into the repository, and analyzed using a field portable XRF. We combined volumetric estimates from UAV photogrammetry with XRF data to estimate a minimum mass of metals and contaminated sediment sequestered into the repository.









Estimated in situ waste volume	~4100 m³
Toal excavated waste material	~12300 m³
Estimated minimum metal mass removed	> 10⁴ kg
Estimated total metal mass removed	~10⁵ kg

$$Mass_{kg\ element} \approx Concentration_{mg/kg\ element} \times Volume_{m^3\ sediment} \times \rho_{1.6-2.2\ kg/m^3\ sediment}$$

CONCLUSIONS: ~12,300 cubic meters of mine waste were removed from Little Frying Pan Gulch into the waste repository during this project, four times the surveyed estimate. Our analysis indicates that a minimum of ~37,000 kg Fe, Pb, Ba, Zn, Mn, Ag, As, and Cu were sequestered into repository. The total mass of these metals in the repository is likely on the order of 10^5 kg. Unmanned aerial systems (UAS) are an effective tool for gathering detailed land surface information necessary for mine remediation projects and a complimentary workflow to more traditional methods.

ACKNOWLEDGEMENTS: This work was funded by a Clean Water Act section 319 grant through the Colorado Department of Public Health & Environment. Other project partners include the Bureau of Land Management, Colorado Division of Reclamation, Mining, and Safety, and the Headwaters of the Arkansas Watershed Group.

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GSA Annual Meeting in Seattle, Washington, USA - 2017

Paper No. 354-8
Presentation Time: 9:00 AM-6:30 PM

APPLIED UAV PHOTOGRAMMETRY AS AN INTEGRATIVE MINE RECLAMATION TOOL

RASMUSSEN, Dirk, Colorado Mountain College, Natural Resource Management, 901 South US-24, Leadville, CO 80461 and MOHRMANN, Jacob, Colorado Mountain College, Natural Resource Management, 901 South Hwy 24, Leadville, CO 80461, dmrasmussen@coloradomtn.edu

Unmanned aerial systems are an effective tool for gathering detailed spatiotemporal land surface information necessary for mine remediation projects. Data-driven approaches to quantifying the sources and magnitude of metal loading in a watershed are crucial for the success of remediation efforts. Historic mining in the Sugarloaf mining district near Leadville, Colorado, contributes to impaired water quality in the Lake Fork Creek and headwaters of the Arkansas River. Several abandoned mines in Little Frying Pan Gulch have been significant contributors of metals and contaminated sediment to the watershed. Negative impacts on downstream water quality and aquatic ecosystems have led to targeted remediation of abandoned mine workings in this area. As part of the remediation in Little Frying Pan Gulch several piles of mine waste and tailings were excavated from the drainage and buried in a waste rock repository. Throughout this process, we used a small-unmanned aerial vehicle (UAV) to monitor progress and collect photogrammetry datasets. Photographs were analyzed using Pix4D spatial modeling software to create orthomosaic imagery, digital elevation surfaces, and three-dimensional models of the site. Composite samples of tailings and waste rock were collected from material placed into the repository, and analyzed using a field portable XRF to determine metal content. We combined volumetric estimates from UAV photogrammetry with XRF data to estimate a minimum mass of metals and contaminated sediment sequestered into the repository. Unmanned aerial systems are a complimentary workflow to more traditional methods, and can serve as a cost-effective tool aiding a breadth of future project applications.

Session No. 354--Booth# 74

T144. Drones in Geoscience (Posters)
Wednesday, 25 October 2017: 9:00 AM-6:30PM

Halls 4EF (Washington State Convention Center)

Geological Society of America *Abstracts with Programs.* Vol. 49, No. 6
doi: 10.1130/abs/2017AM-307228

Back to: T144. Drones in Geoscience (Posters)

<< Previous Abstract | Next Abstract >>

GSA Annual Meeting in Seattle, Washington, USA - 2017

Paper No. 349-11
Presentation Time: 9:00 AM-6:30 PM

GEOSPATIAL CHARACTERIZATION OF SURFACE WATER QUALITY FOR WATERSHEDS WITH ABANDONED MINE LANDS: A CASE STUDY FROM THE SUGARLOAF MINING DISTRICT, LEADVILLE, COLORADO, USA

HALLNAN, Rachel, Bureau of Land Management, Colorado, 3028 E Main St, Cañon City, CO 81212; Bureau of Land Management, 3028 East Main Street, Canon City, CO 81212, RASMUSSEN, Dirk, Colorado Mountain College, Natural Resource Management, 901 South US-24, Leadville, CO 80461; Natural Resource Management Program, Colorado Mountain College, 901 US-24, Leadville, CO 80461 and SMEINS, Melissa, Bureau of Land Management, 3028 East Main Street, Canon City, CO 81212, rmhallnan@gmail.com

Abandoned mine lands span across the western United States and are often located in mountainous areas forming watershed headwaters. Resultant acid mine drainage from these areas impairs downstream water quality and habitat and poses significant health risks to humans and animals. With estimates of over 500,000 abandoned mines in the U.S. alone, it is important to address water quality degradation associated with these sites. The Sugarloaf mining district near Leadville Colorado underwent high impact historic metals mining during the late 1800s and early 1900s. Throughout the district there are numerous test pits, mine shafts and adits, and abandoned tailings and waste rock piles which have since impacted local water quality in the Lake Fork Creek and upper Arkansas River. High metal concentrations and low pH are common in the watersheds throughout the district. We characterize spatial and temporal trends of water quality within the Lake Fork watershed using Python, ArcGIS, and statistical analysis tools with a long-term water quality dataset. The workflow employed may be used at similar sites elsewhere to examine the relationships between legacy mining, water quality, and reclamation efforts. The integration of multiple analytical methods for long-term spatial and temporal water quality datasets presented here greatly enhances data driven remedial design planning and implementation.

Session No. 349--Booth# 37

D7. Environmental Geoscience (Posters)
Wednesday, 25 October 2017: 9:00 AM-6:30PM

Halls 4EF (Washington State Convention Center)

Geological Society of America *Abstracts with Programs.* Vol. 49, No. 6
doi: 10.1130/abs/2017AM-307074

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Geospatial characterization of surface water quality for watersheds with abandoned mine lands: a Case Study from the Sugarloaf mining district, Leadville, Colorado, USA

Rachel Hallnan[1*], Dirk Rasmussen[2], and Melissa Smeins[1]
[1]Bureau of Land Management; [2]Colorado Mountain College, Natural Resource Management Field Institute; *Presenting Author

ABSTRACT

Abandoned mine lands span across the western United States and are often located in mountainous areas forming watershed headwaters. Resultant acid mine drainage from these areas impairs downstream water quality and habitat and poses significant health risks to humans and animals. With estimates of over 500,000 abandoned mines in the U.S. alone, it is important to address water quality degradation associated with these sites. The Sugarloaf mining district near Leadville Colorado underwent high impact historic metals mining during the late 1800s and early 1900s. Throughout the district there are numerous test pits, mine shafts and adits, and abandoned tailings and waste rock piles which have since impacted local water quality in the Lake Fork Creek and upper Arkansas River. High metal concentrations and low pH are common in the watersheds throughout the district. We characterize spatial and temporal trends of water quality within the Lake Fork watershed using Python, ArcGIS, and statistical analysis tools with a long-term water quality dataset. The workflow employed may be used at similar sites elsewhere to examine the relationships between legacy mining, water quality, and reclamation efforts. The integration of multiple analytical methods for long-term spatial and temporal water quality datasets presented here greatly enhances data driven remedial design planning and implementation.

BACKGROUND

Sugarloaf Mining District

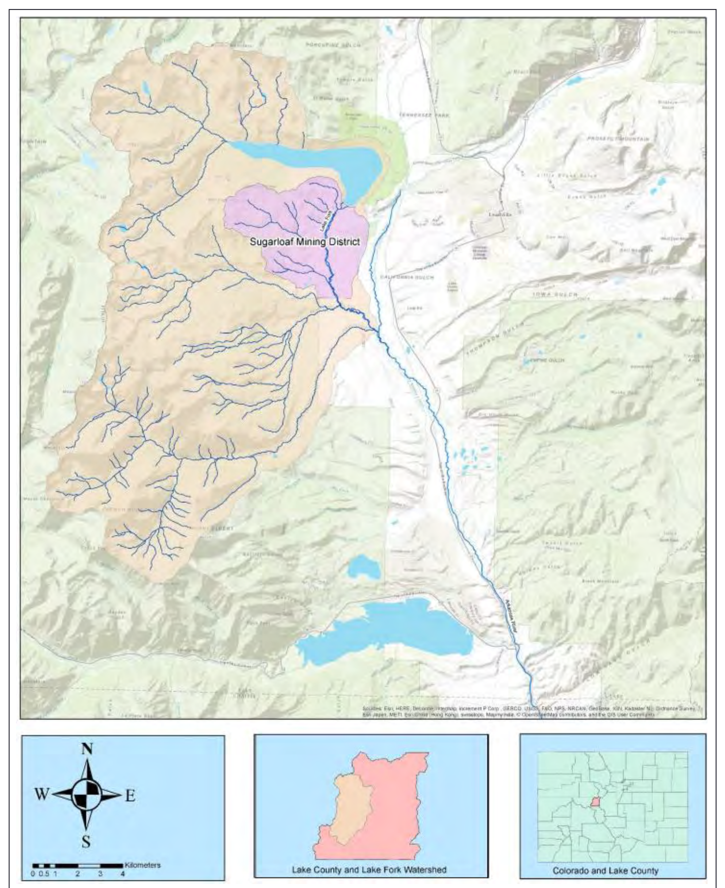
- Four miles west of Leadville in Lake County, Colorado
- Historic placer and hardrock mining – late 1800's through 1920's

Geology

- Mineralized veins cut through decomposing Granitic bedrock
- Sphalerite, Pyrite, Quartz, Galena, Calcopyrite, Tetrahedrite, Argenite, and Rhodochrosite

Hydrology

- Acid mind drainage from abandoned mines negatively impacts local water quality
- Low pH and metals loading, predominantly of Zn, Pb, Mn, Cd, and Fe
- Long-term monitoring
  - 15 year dataset
  - Over 30 sites across the district
  - Sampled semi-annually for high flow and low flow
  - Includes field parameters and metal concentrations



Acid mine drainage from the Tiger Tunnel post-remediation in the Sugarloaf Mining District

OBJECTIVES

- Compile and consolidate existing monitoring data into a simple, comprehensive, and queryable database
- Link comprehensive database into a geospatial database in ArcGIS that is easily transferable between users at CMC and the BLM
- Develop new Sample Analysis Plan for water quality monitoring in the Lake Fork Watershed that supports data-driven evaluation of remediation efforts in the watershed

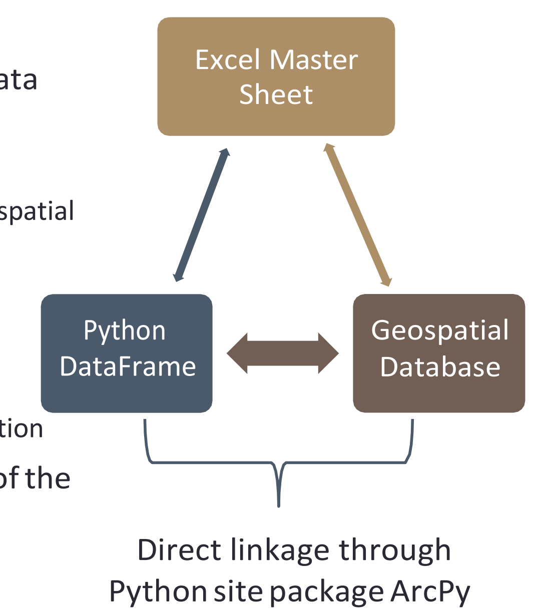
METHODS

Data Cleaning

- Issues in this dataset include: inconsistent site names, duplicate entries, inconsistent abbreviations, missing data, and inconsistent units.
- Uniform site-IDs and abbreviations, removed duplicate entries, missing data points, and standardized units

Database Development

1. RE-formatted excel datasheet for user friendly data entry
   - Serves as master data sheet
   - Used for input into both python dataframe and geospatial databases
2. Compiled data into python database
   - Pandas Dataframe
   - Updated directly from Excel mastersheet
   - Allows for easy temporal analysis and data visualization
3. Compiled ArcGIS geodatabase for the Lake Fork of the Arkansas
   - Updated directly from Excel mastersheet
   - Easy spatial analysis



New Sample Analysis Plan Development

- Investigated spatial and temporal data coverage across all sample locations
  - Used heatmaps and clustermaps to group important sites together
- Focused on sites located near remediation efforts:
  - Tiger and Venture Mine Areas

Venture mine site pre-remediation and tailings removal

Venture post-remediation with tailings pile removed

ACKNOWLEDGEMENTS

This work is funded by the Bureau of Land Management Royal Gorge Field Office through the GeoCorp program, and is part of an ongoing collaboration with Colorado Mountain College Natural Resource Management Field Institute.

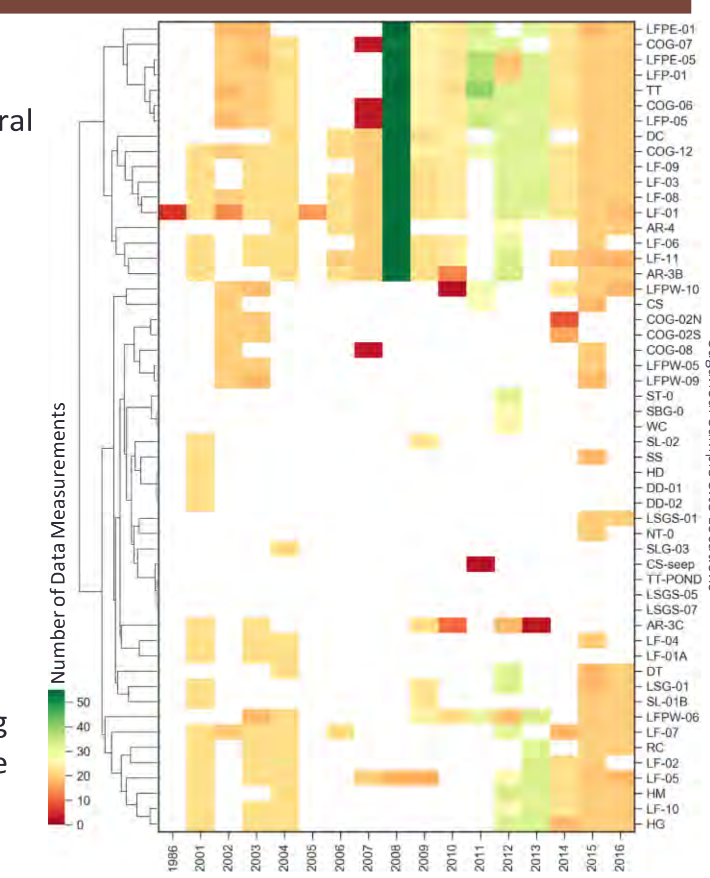
RESULTS

New Sample Analysis Plan

- Identified 20 sites with high temporal data coverage

Sites with the most temporal data coverage	
COG-06	LF-01
COG-07	LF-03
COG-12	LF-05
DC	LF-06
TT	LF-08
LFPE-01	LF-09
LFPE-05	LF-11
LFPW-06	AR-3B
LFP-01	AR-3C
LFP-05	AR-4

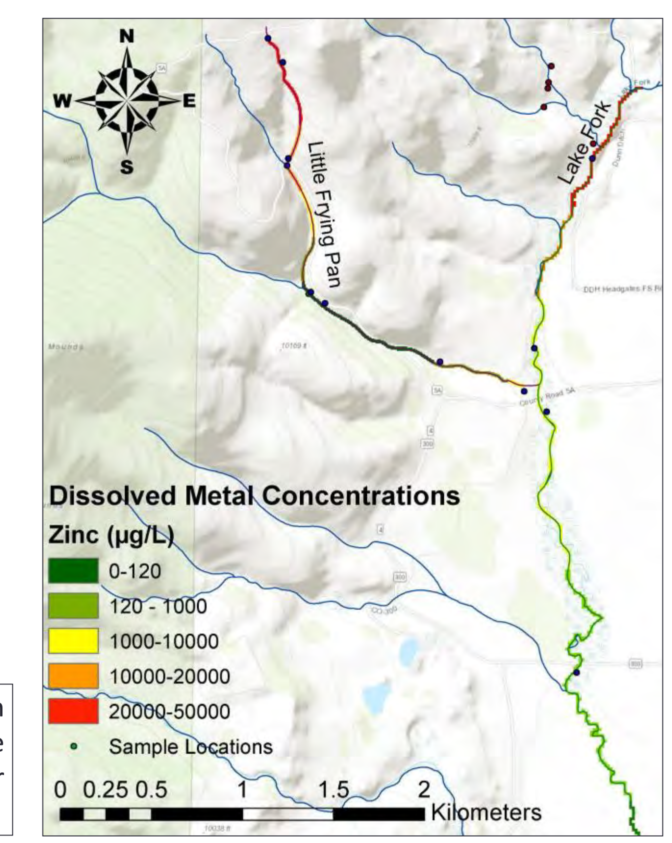
- New locations focus on Little Frying Pan Gulch and the Lake Fork of the Arkansas



Analysis and Ongoing Work

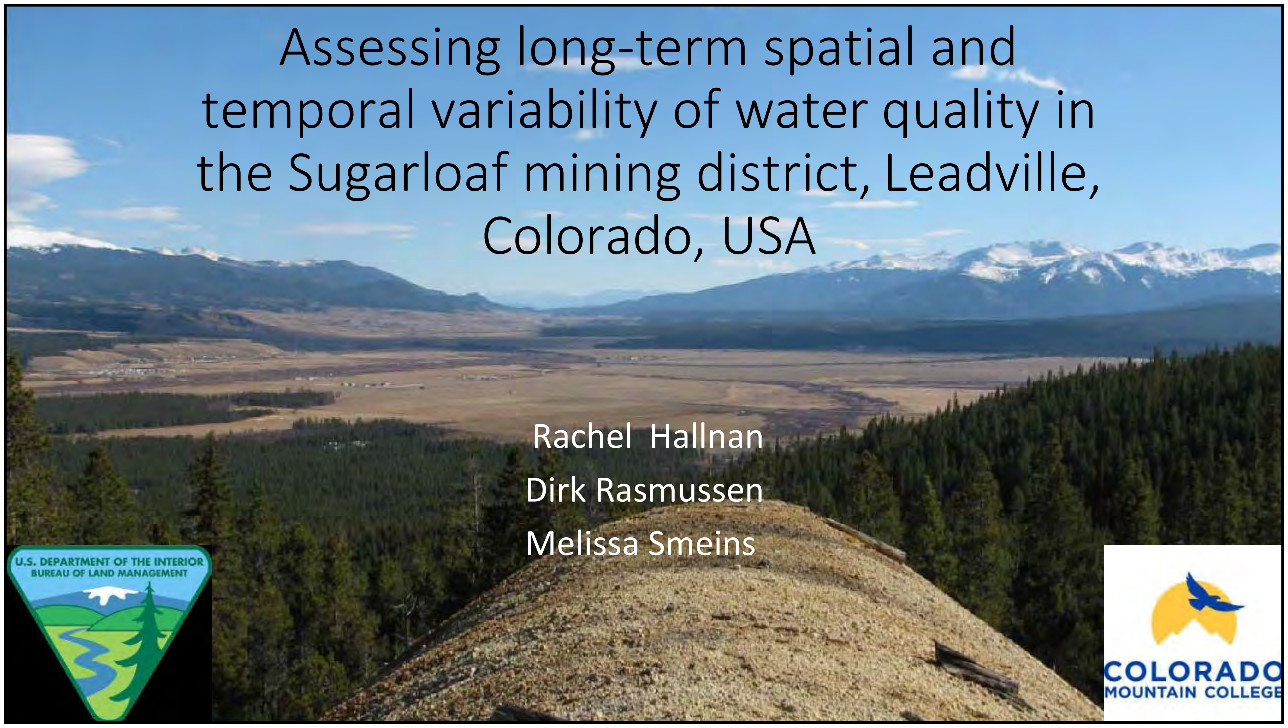
- Using ArcGIS Spatial Analyst Kriging tool to interpolate metal concentrations along stream reaches
- Visual representation of water quality across the mining district
- Future Work: Automate this visualization tool through the use of ArcPy:
  - Krige metal concentrations for all metals, across all sites, through time from 2002 - present
  - Animate temporal trends

Right: Zinc Concentrations from kriging between sample locations along the Lake Fork of the Arkansas River and Little Frying Pan Gulch for High Flow of 2016.



CONCLUSIONS

- A consolidated, clean, and consistent database is key for long-term analysis of water quality data
- Such analysis can allow for data-driven assessment of remediation efforts in the Sugarloaf Mining District and possible financial savings in the future
- Continued water quality monitoring is important for both locations with high density temporal data, as well as locations surrounding remediation efforts or with poor water quality.
  - Long-term trend analysis
  - Assessment of remediation success
- Future work includes constructing a new Sample Analysis Plan based on the important sites identified in this analysis with a smaller scope

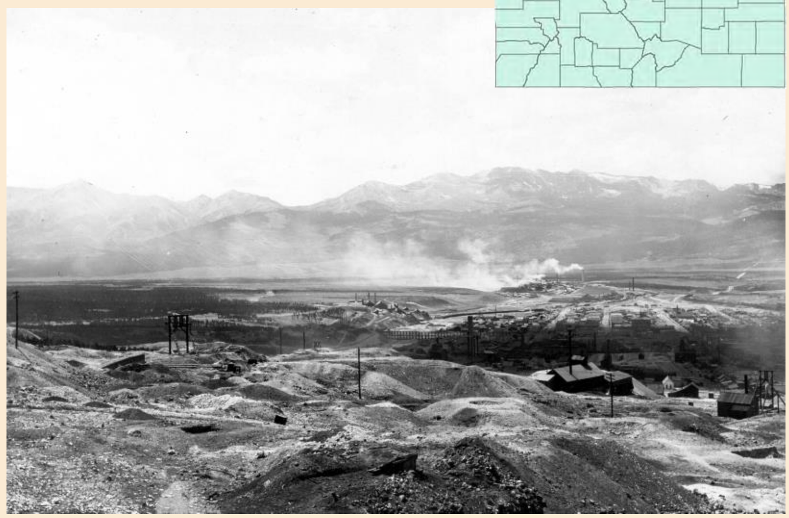


Abstract: Paper No. 299-4

Data-driven approaches to characterizing the magnitude of metal loading sources and resulting water quality trends in a watershed is crucial for successful remediation. Historic mining in the Sugarloaf mining district near Leadville, Colorado, has resulted in degraded water quality of the Lake Fork Creek, and subsequently upper headwaters of the Arkansas River. Negative impacts on downstream aquatic ecosystems have led to remediation of abandoned mine workings and water quality monitoring in the Lake Fork watershed since the 1980s. Several decades of water quality data provide a unique opportunity to analyze long-term spatial trends of water quality and assess the effects of acid mine drainage mitigation efforts within the watershed. We are presenting a long-term dataset including water quality field parameters and metals concentrations from twenty-five sites in the Lake Fork watershed. The distribution of metals across Lake Fork sub-basins is governed primarily by the presence or absence of abandoned mine workings, but display secondary spatial and temporal trends associated with sub-basin area and season.

Legacy Mining in Leadville, Colorado

- Leadville Mining District
- St. Kevin Mining District
- Sugarloaf Mining District
  - 1880s – 1920s[1]
  - Ag, Au, Zn, and Pb[1]
  - Placer and Hardrock
  - Crystalline Granite and Gneiss Bedrock
  - Mined mineralized veins along fault lines
  - Abandoned mining works



[1]Singwald, 1955

Acid Mine/Rock Drainage

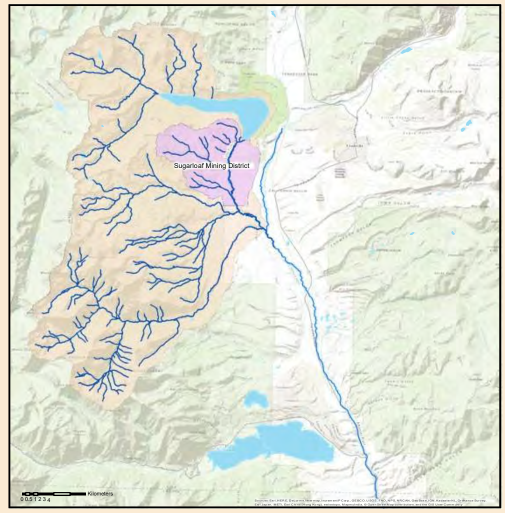
- Left over tailings, mine shafts and adits, and drainage tunnels
- Water Quality degradation of local surface waters
  - Acidification from sulfide oxidation
  - Heavy metals loading – Mn, Zn, Cd, Cu, Fe, and Pb[1]

Photo Credit: Colorado Mountain College

[1]Walton-day et al. 2005

Geographical Significance

- Headwaters of the Arkansas River



- Important fishery, water source, and recreational destination
- Monitoring and Remediation within the Lake Fork of the Arkansas River

Remediation

Year	Remediation
2002	Nelson Mine Pile – Removal and Cap
2004	Dinero Mine Piles – Removal and Cap
2009	Dinero Bulkhead emplacement
2009/ 2010	Tiger Mine Piles – Removal and Cap
2016	Venture Mine Piles – Removal and Cap

Photo Credits: Colorado Mountain College

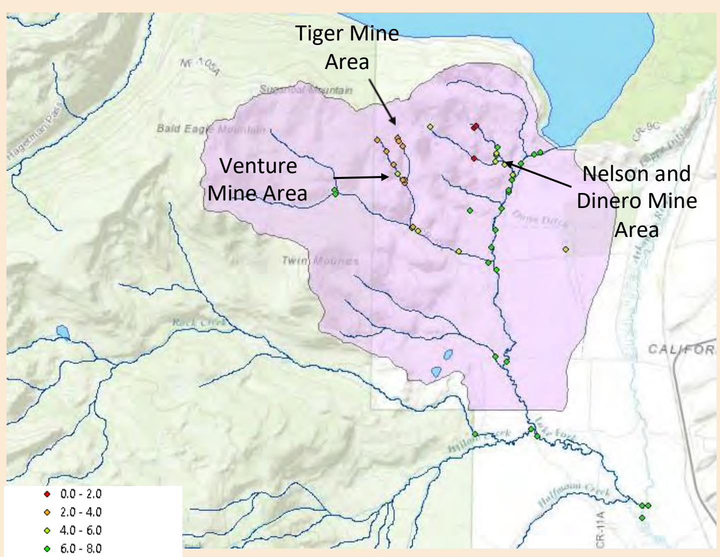
Tiger: Pre-Remediation

Tiger: Post-Remediation

Lake Fork Water Quality Monitoring

- Over 30 sites across the District
- Timeframe: 1986, 2002 – present
- Highflow / Lowflow sample events annually
- Field Parameters
  - pH, Conductivity, Alkalinity, ect.
- Total and Dissolved Metals

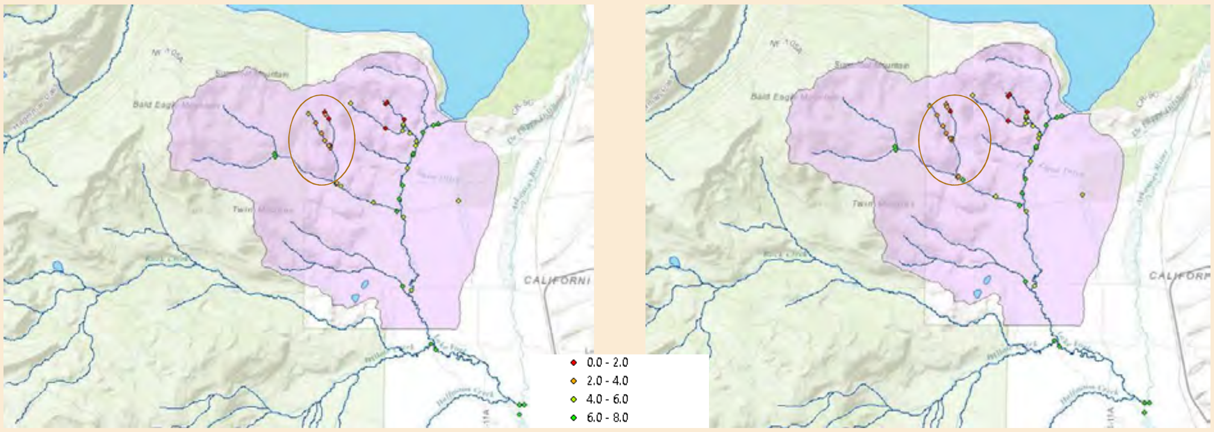
Spatial Distribution of pH – Average for 2013



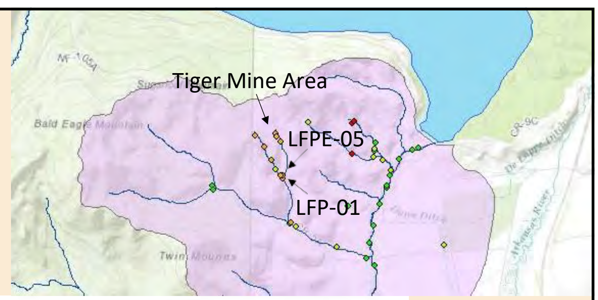
Little Frying Pan – Pre and Post Tiger Remediation

June (High Flow) 2009

September (Low Flow) 2009

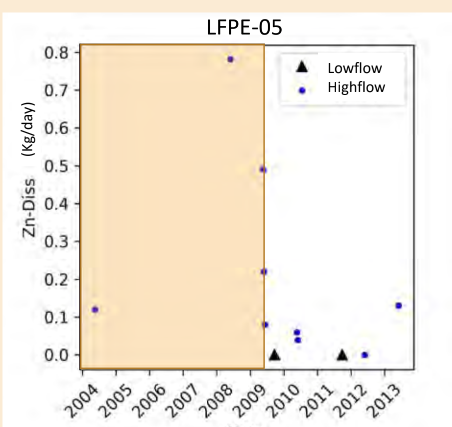


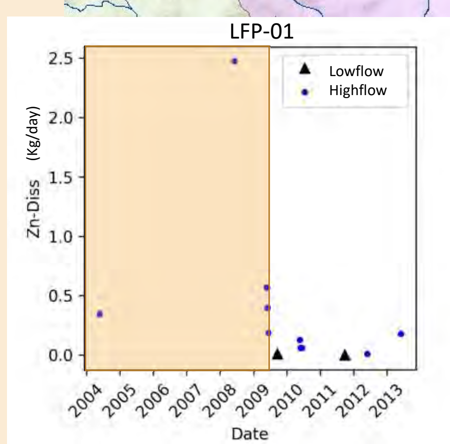
Little Frying Pan - Zn Loading



Pre-Tiger Remediation

Post-Tiger Remediation

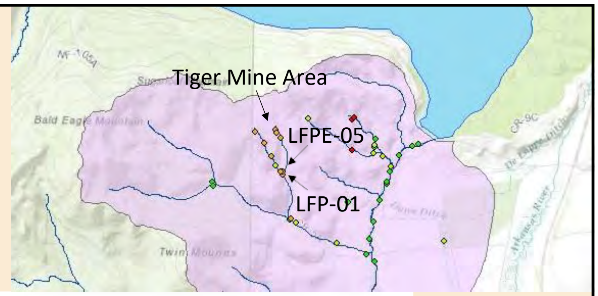


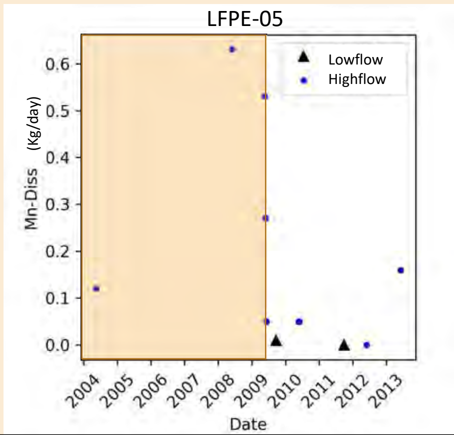


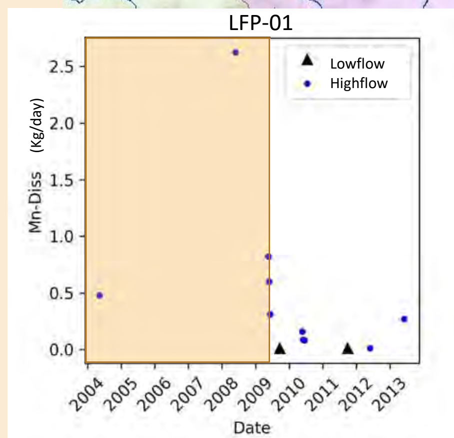
Little Frying Pan - Mn Loading

Pre-Tiger Remediation

Post-Tiger Remediation



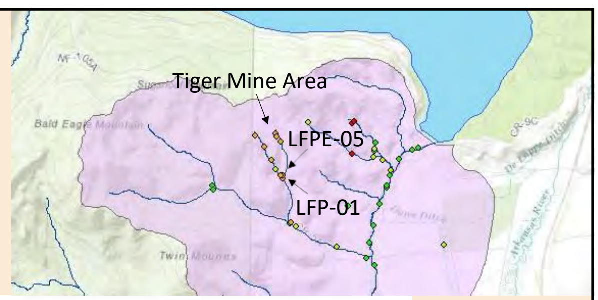


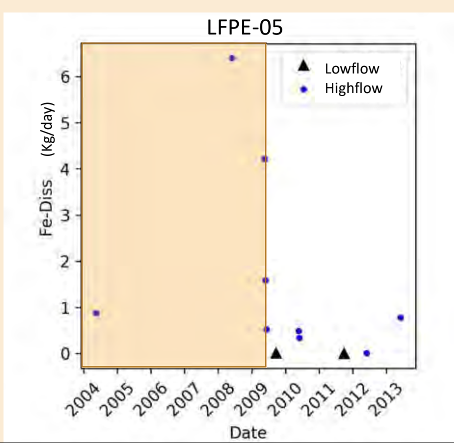


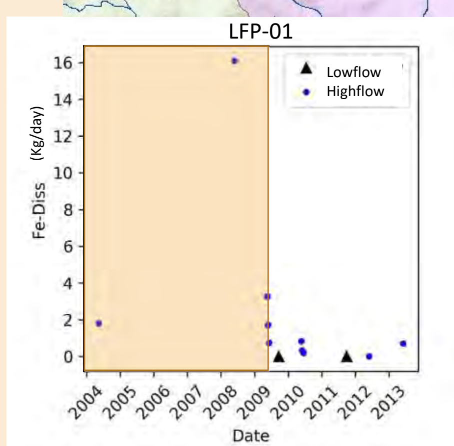
Little Frying Pan - Fe Loading

Pre-Tiger Remediation

Post-Tiger Remediation



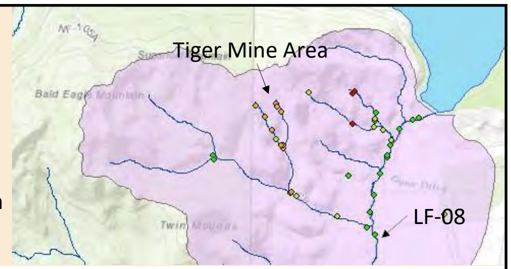


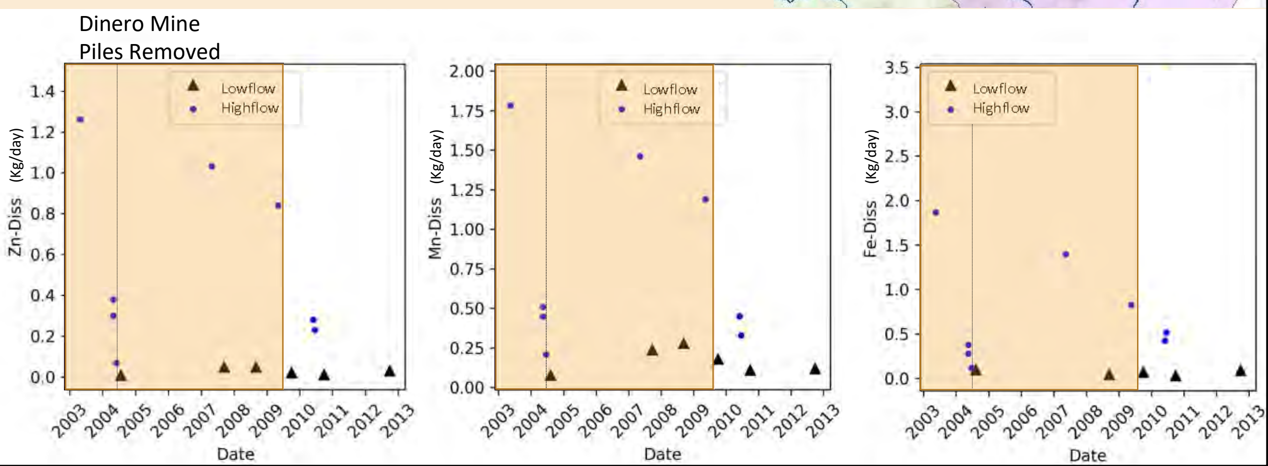


Lake Fork – Metals Loading
LF-08

Pre-Tiger Remediation

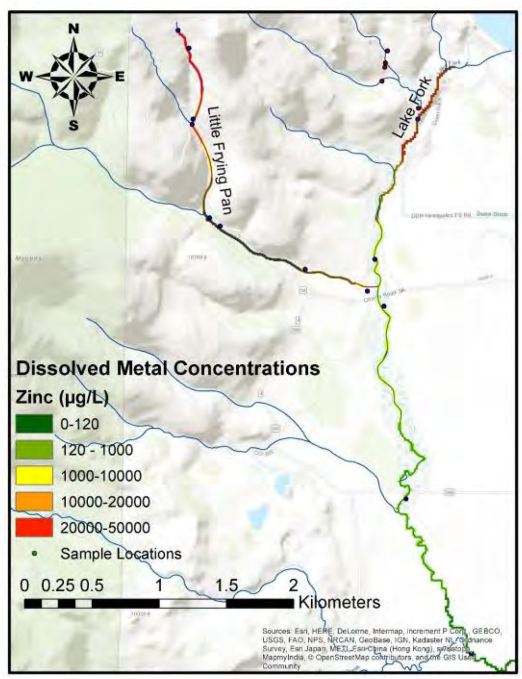
Post-Tiger Remediation





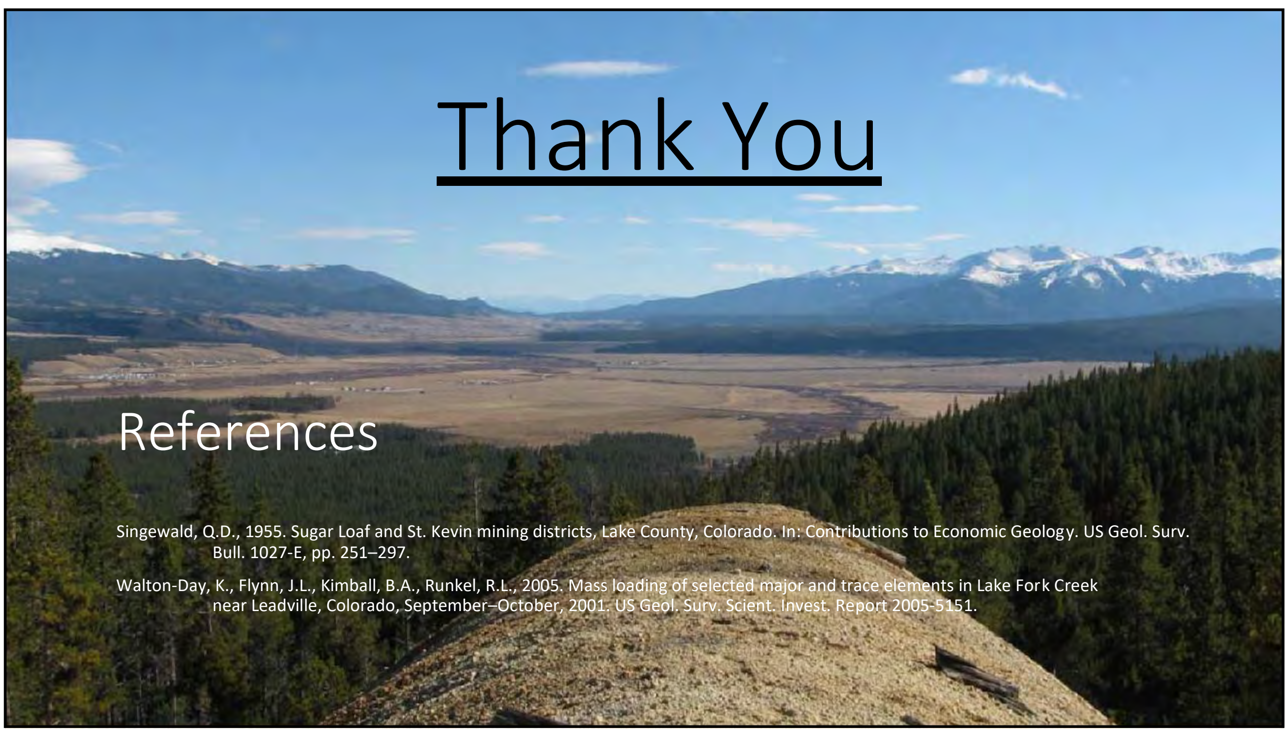
Spatial Distribution of Zinc – Low Flow 2016

- High Zinc Concentrations in Little Frying Pan and Sugarloaf – Locations of Mine Remediation
- Dilution occurs downstream on Lake Fork
- Upper Reaches of Little Frying Pan cannot sustain Fish Populations



Conclusions and Future Work

- The Tiger Mine Remediation project did result in reduced metal loading into Little Frying Pan Gulch
- However metal loads are still above standards for many aquatic species in the upper reaches of Little Frying Pan Gulch
- Analysis of 2017 data and beyond will help inform the efficacy of the Venture mine remediation efforts in Little Frying Pan Gulch
- Continued and consistent monitoring, and efficient data management in areas where remediation has taken place will help drive data-driven decision making on remediation efforts in the future



Thank You

References

Singewald, Q.D., 1955. Sugar Loaf and St. Kevin mining districts, Lake County, Colorado. In: Contributions to Economic Geology. US Geol. Surv. Bull. 1027-E, pp. 251–297.

Walton-Day, K., Flynn, J.L., Kimball, B.A., Runkel, R.L., 2005. Mass loading of selected major and trace elements in Lake Fork Creek near Leadville, Colorado, September–October, 2001. US Geol. Surv. Scient. Invest. Report 2005-5151.

Acknowledgements

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Bureau of Land Management
- Melissa Smeins

Colorado Mountain College
- Dirk Rasmussen
- Kato Dee
- Katy Warner
- Katie MacKnight

Lake Fork Watershed
Sampling and Analysis Plan (SAP)

1.0 Introduction

This Sampling and Analysis Plan (SAP) is for the continued monitoring of the Lake Fork Watershed and the remediation efforts by the Bureau of Land Management (BLM) in the Sugarloaf Mining District near Leadville, Colorado. The plan describes site locations, samples types, protocols, and analyses to be performed semiannually within the Lake Fork and several of its tributaries. Future projects may require amendments to this SAP to satisfy specific project needs. All supporting documentation and manuals referenced in this document is achieved with this document on the CMC NRM server.

2.0 Background

The BLM as a member of the Lake Fork Watershed Working Group (LFWWG) has participated in the remediation of abandoned mine features within the Lake Fork Watershed since 2001. Major efforts include remediation of mine waste dumps and tunnels associated with the Dinero, Nelson, Tiger, and Gertrude-Venture mines all located in the Sugarloaf Mining District. This SAP is part of a long-term monitoring plan evaluating the effectiveness of respective remedies to improve downstream water quality. Historically, a combination of ~60 sites were monitored within the Lake Fork Watershed. This document presents a sub-set of twenty sites for continued monitoring. The sub-set includes sites which have abundant historic data (i.e. those that were visited repeatedly and have good data coverage through time), and sites that bracket confluences where remediation efforts are completed in the watershed. At each site, water quality will be monitored by analyzing for major metals and measuring field parameters to assess water quality trends. Discharge measurements will also be measured at each site for metal loading analysis. Collectively, these data are used to assess the effectiveness of remediation efforts and continued impact from abandoned mine features in the watershed. Lastly, this analysis will inform how water from the Lake Fork Watershed influences downstream water quality of the Arkansas River.

3.0 Site Locations

The following 20 sites (Table 1 and Appendix A) within the Lake Fork Watershed should be sampled semiannually: once during high flow conditions in the spring (late May-early June), and once during low flow during the fall (September). Ensure to visit the same sites for high flow and low flow events (even if not all sites can be reached).

Site Name Abbreviations:

Lake Fork	-	*LF*
Little Sugarloaf Gulch	-	*LSG*
Dinero Tunnel	-	*DT*
Nelson Tunnel	-	*NT*
Sugarloaf Gulch	-	*SL*
Dinero Channel	-	*DC*

Tiger Tunnel	-	*TT*
Little Frying Pan East	-	*LFPE*
Little Frying Pan West	-	*LFPW*
Little Frying Pan	-	*LFP*
Colorado Gulch	-	*COG*

Table 1: Lake Fork sample locations and a brief description of each site.

Sample ID	Latitude	Longitude	Coverage Area	Description
LF-01	39.251157°	-106.374638°	Lake Fork Creek	Below Turquoise Reservoir at gauging station. Flow track along the concrete spillway.
LF-03	39.247577°	-106.378482°	Lake Fork Creek	Located just below the Dinero Channel input, ~25 m downstream of foot bridge on main stem of the Lake Fork.
LF-07	39.238128°	-106.381976°	Lake Fork Creek	Located directly below power lines downstream of input from Siwatch tunnel, ~200 m upstream from input from Colorado Gulch.
LF-08	39.235003°	-106.381135°	Lake Fork Creek	Located on south side of CR-5A on Lake Fork Ranch ~150 m downstream of wooden bridge.
LSG-01	39.251310°	-106.381346°	Dinero/ Nelson Area	Little Sugarloaf Gulch water, located just above the Dinero Tunnel to north in meadow of skunk cabbage.
DT	39.251015°	-106.381377°	Dinero/ Nelson Area	Dinero Tunnel water, located directly outside of the locked adit closure at the entrance to the Dinero Tunnel
NT	39.250540°	-106.385325°	Dinero/ Nelson Area	Nelson Tunnel discharge water, located just below the Nelson Tunnel discharge
SL-02	39.249666°	-106.379873°	Dinero/ Nelson Area	Collapsed adit outflow, located northwest of the Lake Fork foot bridge at the southwest corner of the meadow with the Dinero retention ponds.
DC	39.248312°	-106.378435°	Dinero/ Nelson Area	Dinero Channel water; a small channel that discharges into the Lake Fork from its west bank ~5 m upstream of the footbridge; sampled ~5 m above it discharges into the Lake Fork.
TT	39.253274°	-106.399227°	Tiger Area	Tiger Tunnel discharge adit, located above Little Frying Pan East, and sampled at the discharge culvert.
TT-Post	39.252641°	-106.398610°	Tiger Area	Tiger Mine water, located at the base of the passive treatment area, below the settling ponds.
LFPE-01	39.252098°	-106.374638°	Tiger Area	Located in forest ~100 m downstream of Tiger Mine remediation area

LFPE-05	39.247347°	-106.378482°	Tiger Area	Located on Little Frying Pan East upslope of power line road ~20 m upstream of confluence with Little Frying Pan West
LFPW-05	39.251352°	-106.381976°	Tiger Area	Located just above a logging road, just to the west of the Tiger area, on Little Frying Pan West. Sampled before water travels through culvert under the road.
LFPW-06	39.247346°	-106.381135°	Tiger Area	Located upslope of power line road at the former Venture area, just upstream of the confluence with the Little Frying Pan East at base of boulders in reclamation channel
LFP-01	39.246988°	-106.381346°	Tiger Area	Located ~200 m down-gradient of power line road, ~20 m downstream of confluence of the East and West fork of Little Frying Pan
LFP-05	39.240740°	-106.381377°	Tiger Area	Located ~40 m above confluence with Colorado Gulch
COG-06	39.240654°	-106.385325°	Tiger Area	Colorado Gulch water located ~40 m above confluence with Little Frying Pan
COG-07	39.240197°	-106.379873°	Tiger Area	Colorado Gulch water located ~30 m below confluence with Little Frying Pan
COG-12	39.235990°	-106.378435°	Tiger Area	Located ~60 m above confluence with Lake Fork between private culvert and CR-5A culvert

4.0 Sample Collection and Handling

4.1 Sample Kit Preparation

A minimum of 30 kits should be prepared prior to both the high flow and low flow field events. A sample kit consists of the following items: one 1 L HDPE sample bottle (acid washed), one 125 mL HDPE unacidified bottle (ESS quality certified), two 125 mL HDPE pre-acidified bottles (Lab acidified and ESS quality certified), one 45 micron low capacity disc filter, and ~18 inches of silicone tubing. Sample kit materials for each site should be sealed in a plastic zip lock bag together for transport and use in the field (Figure 1). See Table 2 pertaining to purchase information for these materials.

Table 2: Lake Fork sample kit items and purchasing details.

Item	Company	Item Number	Notes
Tubing	GeoTech	#87050000	
Low capacity disc filter	GeoTech	#73050002	0.45 micron
1 L HDPE sample bottle	ESS	0950-1060-QC	unacidified
125 mL HDPE unacidified bottle*	ESS	0125-1060-QC	unacidified
125 mL HDPE acidified bottle*	ESS	0125-1060-QC	3 mL Nitric Acid (1:1)

*Same item number, specify to ESS how many need to be acidified.

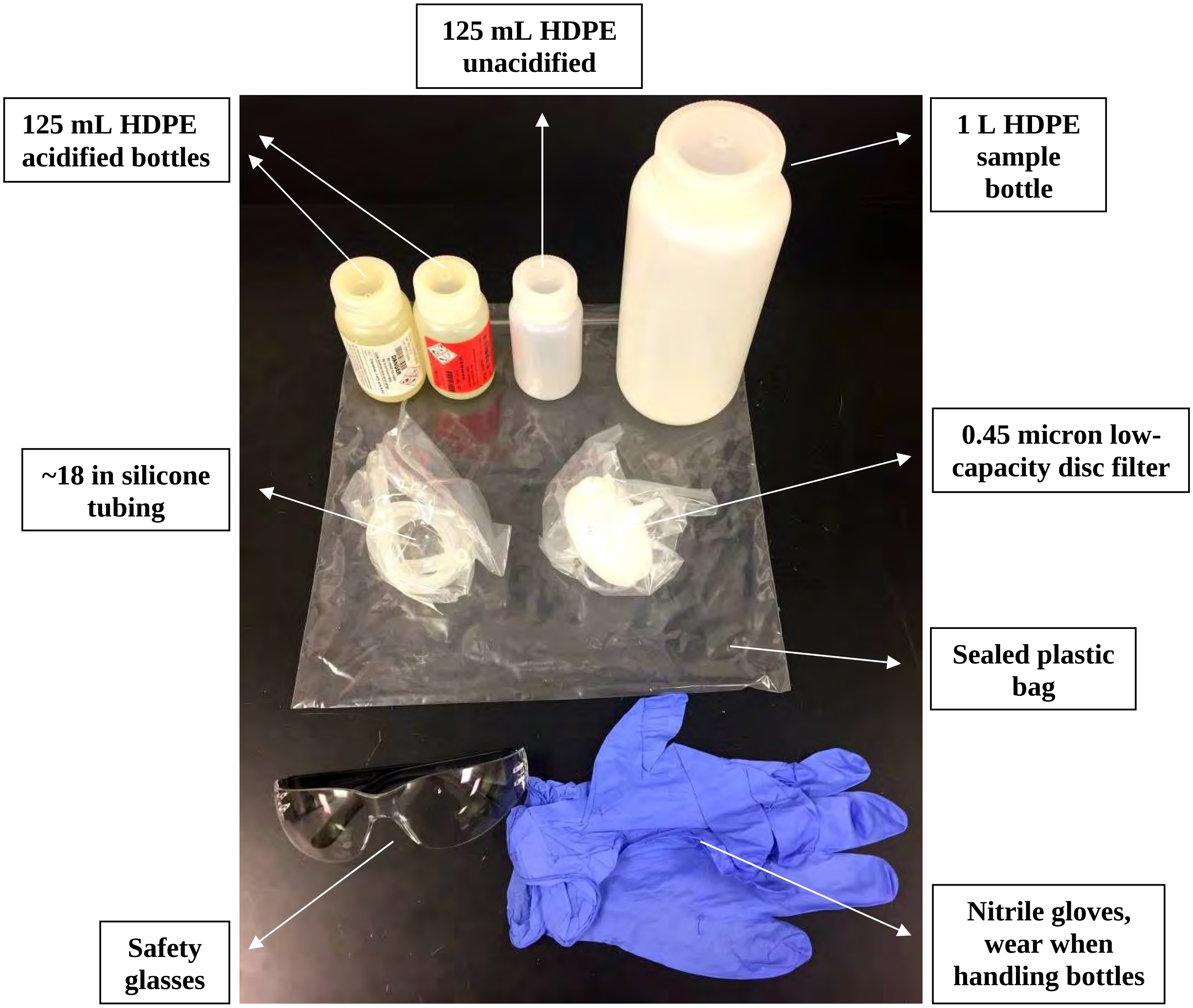


Figure 1: Lake Fork sample kit items and personal protection equipment (PPE).

4.2 Sample Collection

Four samples are required at each sampling locality, and are summarized in Table 3. Use the 1 L sample bottle to collect the bulk grab sample from the source. For samples collected on the Lake Fork, an isokinetic depth-integrating sampling device is necessary to retrieve a well-mixed representative sample across the channel (USGS, Instructions for DH-81). Divide water from the 1 L bottle between the three remaining sample bottles. The following instructions are abridged from the EPA SW-864 Manual Method 3005A (EPA, 1992), and modified specifically for this project. The primary difference is that bottles pre-acidified with nitric acid are used for the Lake Fork sampling event while the SW-864 manual outlines field acidification with nitric acid. The full manual is located at https://www.epa.gov/hw-sw846/sw-846-compendium. Methods concerning Anions follow EPA Method 300 (Pfaff, 1993).

Table 3: Details for the four samples collected at each Lake Fork site

	Sample Type	Filtered/Unfiltered	Bottle Type
1	Bulk sample collection and alkalinity/acidity titrations	Unfiltered	1 L sample bottle
2	Dissolved metals	Filtered	125 mL acidified bottle
3	Anions	Filtered	125 mL unacidified bottle
4	Total metals	Unfiltered	125 mL acidified bottle

In addition to the sites outlined above in Table 1, at least two field duplicates, and two DI blank samples should be collected and processed as well. Ideally, one field blank and one duplicate sample should be collected by each sampling team for every day of the event. Assuming one team samples for two days, a total of 20 samples, 2 field blanks, and 2 duplicate samples are required for the sampling event in both the spring high flow and in the fall low flow events.

Supplies and equipment per sample:

- Sample kit (see Table 2)
- Nitrile gloves
- Peristaltic pump and batteries
- Isokinetic depth-integrating sampling device (larger channels only)

Field Instructions:

I. Labeling
   1. Wearing clean gloves, use a permanent marker to clearly label each of the four bottles outlined in Table 3 as follows:

Format	Example
Site Name	*LF-01*
Date	*10/1/17*
Time	*13:45*
Sample Type	*Tot Met*

II. Sample Collection – 1 L bottle
   1. Wear clean gloves+ and only use them to touch the sample bottles and the sample water.
   2. Triple rinse the 1 L unacidified sample bottle (and lid threads) with sample water.
   3. Fill the 1 L unacidified bottle with sample water and close the lid.

III. Dissolved Metals (in-line filter method)
   1. Wearing clean gloves+, safety glasses, and long sleeves assemble tubing and filter with the portable field peristaltic pump, ensuring that filter is facing the correct direction for flow.
   2. Rinse the both ends of the tubing with sample water.
   3. Place the intake end of the tubing into the 1 L bottle with sample water. Triple rinse the tubing by purging sample water for three times the duration it takes water to

initially flow through the system. For example, if it takes 2 seconds for water to discharge from the tubing, purge for 6 seconds.
4. Open the first 125 mL acidified bottle labeled for dissolved metals. Use caution as the bottle is pressurized at high elevation. Since pre-acidified bottle are used, do not triple rinse the bottle or add additional acid.
5. Set the pump to its lowest setting to prevent splashing acid out of the bottle when filling begins. Fill the bottle to the neck with sample water outflow from the filter, and screw on the lip.
6. Place filled sample bottle back into a large Ziploc bag.

IV. Anions
1. Continue wearing clean gloves+.
2. Use the in-line filter setup outlined for dissolved metals in part III. It is not necessary to re-purge the tubing between samples. If for some reason the in-line filter is not setup with the peristaltic pump, follow steps 1-3 in part IV – Dissolved Metals (in-line filter method) above.
3. Open the 125 mL unacidified sample bottle labeled for anions.
4. Triple rinse the sample bottle (and lid threads) with filtered sample water.
5. Fill the 125 mL sample bottle labeled for anions to the neck with sample water outflow from the filter, and screw on the cap.
6. Place sample bottle back into the large Ziploc bag.

V. Total Metals – 125 mL acidified bottle
1. Continue to wear clean gloves+ and remove the filter from the peristaltic pump so that sample water discharges unfiltered.
2. Open the second 125 mL acidified bottle labeled for total metals. Use caution as the bottle is pressurized at high elevation. Since pre-acidified bottle are used, do not triple rinse the bottle or add additional acid.
3. Set the pump to its lowest setting to prevent splashing acid out of the bottle when filling begins. Fill the bottle to the neck with unfiltered sample water outflow directly from the tubing, and screw on the lip.
4. Place sample bottle back into the large Ziploc bag.

VI. Sample Preservation and Trash Disposal
1. Once Parts I – V are complete, ensure all four samples are contained in large zip lock bags (Bulk sample, Dissolved Metals, Anions, and Total Metals), and place the bags in a cooler on ice (double bagged ice cubes or sealed ice packs) for the duration of the field day. Refrigerate in the laboratory after returning from the field.
2. Disassemble the peristaltic pump place into its storage case between sites to avoid damage. Dispose of all tubing, gloves, and the filter used for each site. Do not reuse any of these items between multiple sites.

+If gloves become contaminated during any portion of sample collection and processing (touch the ground, sunscreen, face, etc.), change gloves before proceeding.

VII. Post-Field Chain of Custody Forms (COC)

1. Upon returning from the field, cross-reference the field notebook with all sample bottles. Complete an end of day sampling summary (EODSS) in the field notebook. Ziploc like samples together and refrigerate all samples.
2. Complete COC forms for total metals, dissolved metals, and anion samples*. Transfer all samples to the CMC Timberline Analytical Laboratory or ship to an alternative approved laboratory+. COC forms should accompany samples to the lab.

*Note that holding times can be as short as 48 hours for nitrite, nitrate, and phosphate, 7 days for sulfide, while fluoride, chloride, bromide, and sulfate have a holding period of 28 days (EPA, 2014).

+Historically, the following labs have been used to process Lake Fork water quality data: CMC Timberline Analytical Laboratory, Colorado Department of Wildlife, Evergreen Analytical Laboratory, and EPA Region 8 ESAT Laboratory

3. The typical metals and anions suite to be performed is outlined in Table 4:

Table 4: Summary of metals and cations/anions analyzed for the Lake Fork Sampling events and holding times for Anions (Pfaff, 1993). Holding times for all metals and cations are 6 months. (EPA, 2014).

Total Metals	Dissolved Metals	Cations	Anions	Holding Time
Aluminum	Aluminum	Calcium	Bromide	28 days
Arsenic	Arsenic	Magnesium	Chloride	28 days
Cadmium	Cadmium	Potassium	Fluoride	28 days
Copper	Copper	Sodium	Nitrate	48 hours
Iron	Iron		Nitrite	48 hours
Lead	Lead		Phosphate	48 hours
Manganese	Manganese		Sulfate	28 days
Selenium	Selenium			
Zinc	Zinc			

5.0 Field Parameter Measurements

Field parameters should be measured at each site outlined in
Table **1** using a YSI water quality sonde. Measurements (with accompanying units) of temperature, pH, conductivity, dissolved oxygen, oxidation reduction potential, and barometric pressure should be recorded in the field notebook. In the case that another instrument is used, or not all of the above parameters cannot be measured, a minimum of temperature, pH, and conductivity need to be measured. Prior to use, become familiar with instrument operations by consulting the manual (YSI, 2016).

Before each field event, equipment should be pre-checked and results recoded in the field notebook. For pH, use 10.0, 7.0, and 4.0 standard pH solutions. For conductivity, use 100, 500, and 1000 µS standard solutions. The threshold for pH is 0.1 unit and 10% of the conductivity standard. If the measurements are outside these ranges for any parameters, perform a three-point calibration according to the instrument manual. Post-check equipment after returning from the field and record results in the field notebook.

6.0 Stream Discharge Measurements

Discharge measurements are measured at each site identified in
Table ***1***. In the case that discharge is not measured due to lack of flow, note this in the field notebook. Three methods of measuring discharge are outlined below in Sections 4.1 to 4.3. Section 4.4 provides a recommended method of measuring discharge in both high flow and low flow for each sampling locality.

6.1 Flow Tracker

A SonTek Flow Tracker Handheld ADV should be used to measure discharge at sites with higher flows (Table 5). Please refer to the user manual for specific directions on using this instrument (SonTek Inc., 2007).

6.2 Baski Cutthroat Flumes

A Baski Cutthroat Flume (Figure 2) should be used for stream flows that are too low for the use of the Flow Tracker and too high for the use of volumetric measurements (Table 5). Please follow the detailed instructions from CDPHEs Standard Operating Procedures for Flow Measurements using a Cutthroat Flume (CDPHE, 2016).

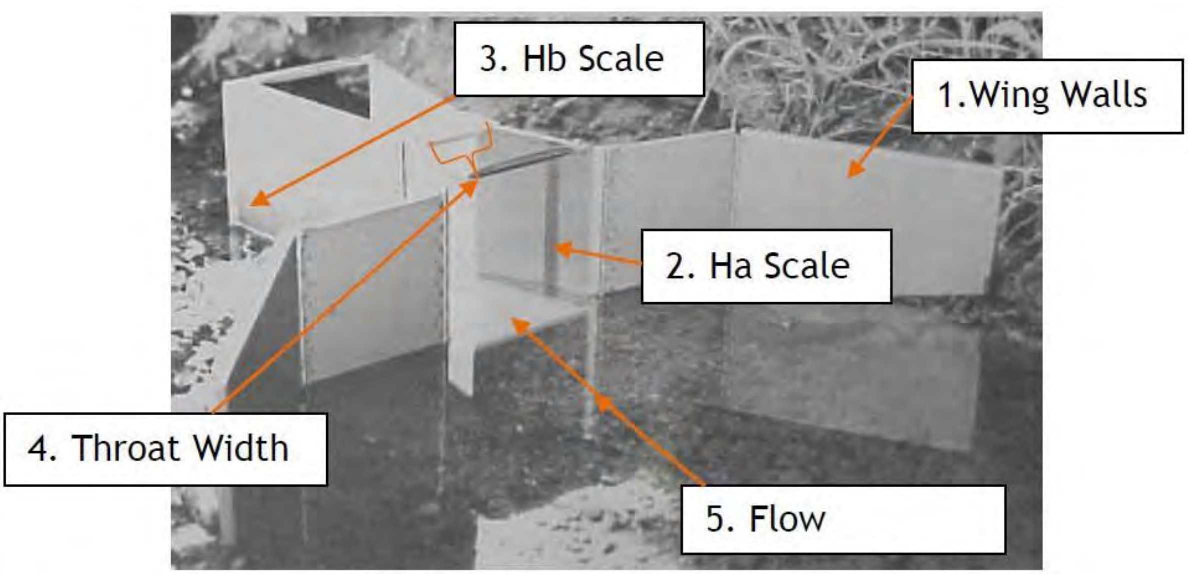


Figure 2: 8 in Cutthroat Flume with annotations (CDPHE, 2016)

6.3 Volumetric

This method is necessary for seeps and springs with flows that are insufficient for the use of an electronic flow sensor or a flume.

Equipment:

- English or Metric volume containers
- 4 in or 8 in diameter PVC pipes
- Round point shovels
- Timing device (i.e. stop-watch or smart phone)

Procedure:

1. Record container volume.
2. Channelize the flow through the pipe by temporarily modifying the channel with soil levees.
3. Collect 100% of stream flow into a container of specific volume.
4. Record time required to fill the container.
5. Repeat the previous measurement least 5 times, recording all times.

6.4 Recommended method for each site

Table 5: Recommended method for measuring discharge for both high flow and low flow sampling events based on flows from previous years.

Sample ID	Recommended Method		Notes
	High Flow	Low Flow	
LF-01	Flow Tracker	Flow Tracker	Gauging station LFCBSLCO+ - Record gauge staff height
LF-03	Flow Tracker	Flow Tracker	
LF-07	Flow Tracker	Flow Tracker	
LF-08	Flow Tracker	Flow Tracker	
LSG-01	4 in Baski	1 in Baski	Possible volumetric for low flow
DT	1 in Baski	1 in Baski	Possible 4 in for extremely high flows
NT	1 in Baski	1 in Baski	Possible 4 in for extremely high flows
SL-02	1 in Baski	1 in Baski	
DC	1 in Baski	Volumetric	Possible 4 in for high flow
TT	Large Volumetric	Volumetric	
TT-Post	Volumetric	Volumetric	
LFPE-01	1 in Baski	1 in Baski	Possible volumetric
LFPE-05	8 in Baski	1 in Baski	
LFPW-05	4 in Baski	1 in Baski	
LFPW-06	Large Volumetric	Volumetric	Multiple pipes and large Baski during high flow
LFP-01	8 in Baski	1 in Baski	
LFP-05	8 in Baski	1 in Baski	Possibly use two Baskis during high flow
COG-06	Flow Tracker	Flow Tracker	
COG-07	Flow Tracker	Flow Tracker	

COG-12	Flow Tracker	Flow Tracker	
+Website for LFCBSLCO gauge station: http://www.dwr.state.co.us/SurfaceWater/data/detail_graph.aspx?ID=LFCBSLCO&MTYPE=DISCHRG			

7.0 Laboratory Alkalinity and Acidity Titrations

Titrations should be performed on each sample collected for alkalinity or for acidity depending on the pH of the solution. The HACH Ecology Combination Test Kit Manuals (Hach Company, 2013) should be followed (method 8203 for alkalinity and methods 8201 and 8202 for acidity) Titrations should be performed within 24 hours of sample collection and kept at or below 6°C for preservation. Let the sample temperature increase to room temperature before analysis. Each titration should be performed at least twice to ensure that results are within 10% of each other.

8.0 References

PDFs of all references are achieved with this document on the CMC NRM server.

CDPHE. (2016). Standard Operating Procedures for Flow Measurements Using a Cutthroat Flume.

EPA. (1992). Method 3005A - Acid Digestion of Waters for Total Recoverable or Dissolved Metals for Analysis by FLAA or ICP Spectroscopy. *1992*, (July), 1–5.

EPA. (2014). SW-846 3000 Series: Inorganic Sample Preparation, (July), 0–27.

Hach Company. (2013). Colorimeter Procedures Manual.

Pfaff, J. D. (1993). Method 300.0 Determination of Inorganic Anions By Ion Chromatography. *Standard Methods*, (August), 28.

SonTek Inc. (2007). SonTek/YSI FlowTracker ADV Technical Manual, (858).

USGS, Operator's Manual for the US DH-81 Depth-Integrating Suspended-Sediment Sampler, (https://water.usgs.gov/fisp/docs/Instructions_US_DH-81_010612.pdf)

YSI. (2016). Pro DSS Sonde User Manual.

Appendix A: Context photos for each site location.

DT

NT

TT-POST

LFPW-05


DIRECTION
356 deg(T)
13S 379369
4345116
ACCURACY 10 m
DATUM WGS84
LFP-01
2017-06-07
14:07:21-06:00


DIRECTION
326 deg(T)
13S 379543
4344379
ACCURACY 5 m
DATUM WGS84
LFP-05
2017-06-07
13:23:00-06:00


DIRECTION
318 deg(T)
13S 379537
4344371
ACCURACY 5 m
DATUM WGS84
COG-06
2017-06-07
13:24:04-06:00


DIRECTION
322 deg(T)
13S 379620
4344337
ACCURACY 5 m
DATUM WGS84
COG-07
2017-06-07
13:19:44-06:00


DIRECTION
107 deg(T)
13S 380677
4343877
ACCURACY 5 m
DATUM WGS84
COG-12
2017-06-07
10:17:47-06:00

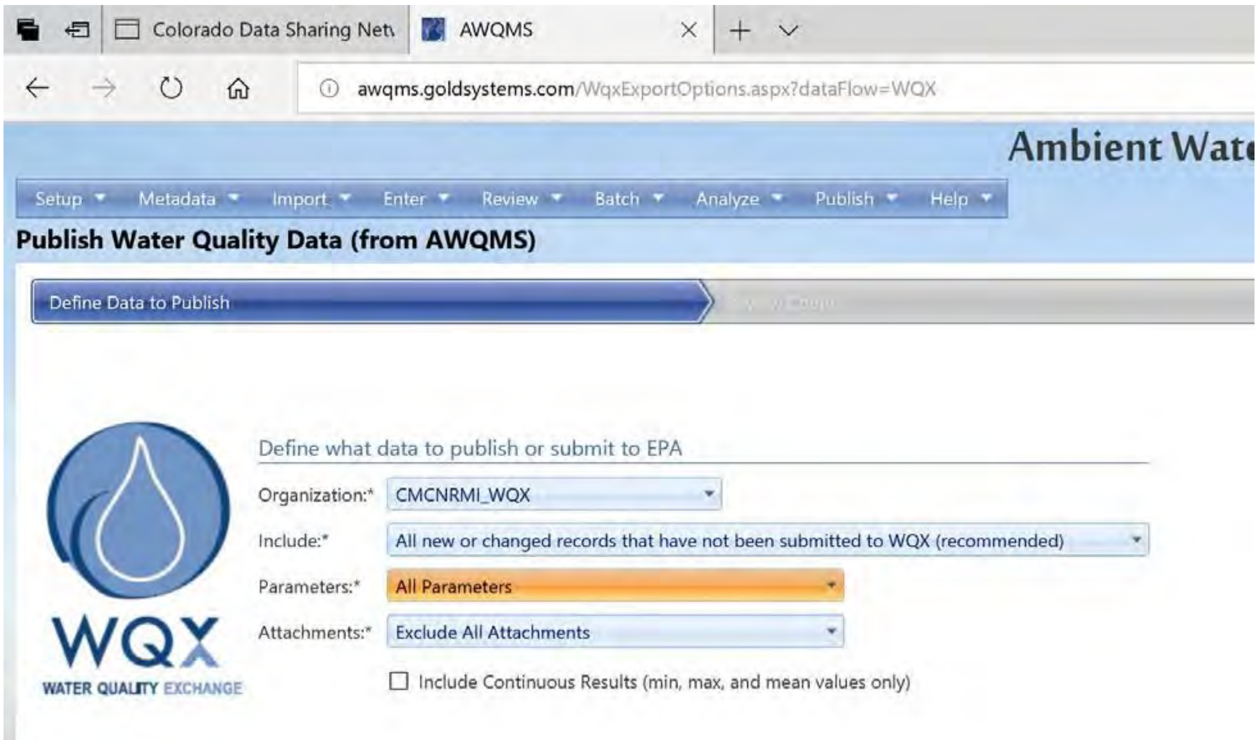
x

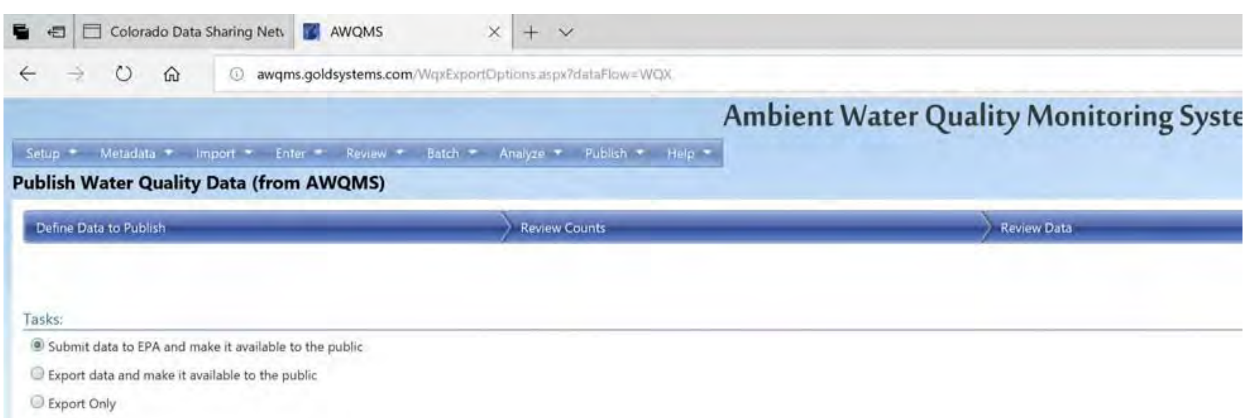
Summary of Upload & Submission to EPA:

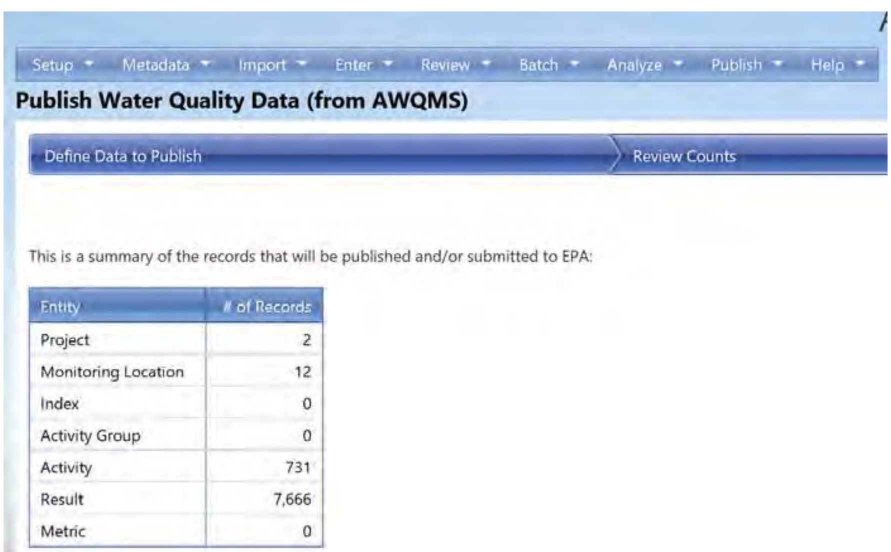
7666 Results

2 Projects

12 Monitoring Locations







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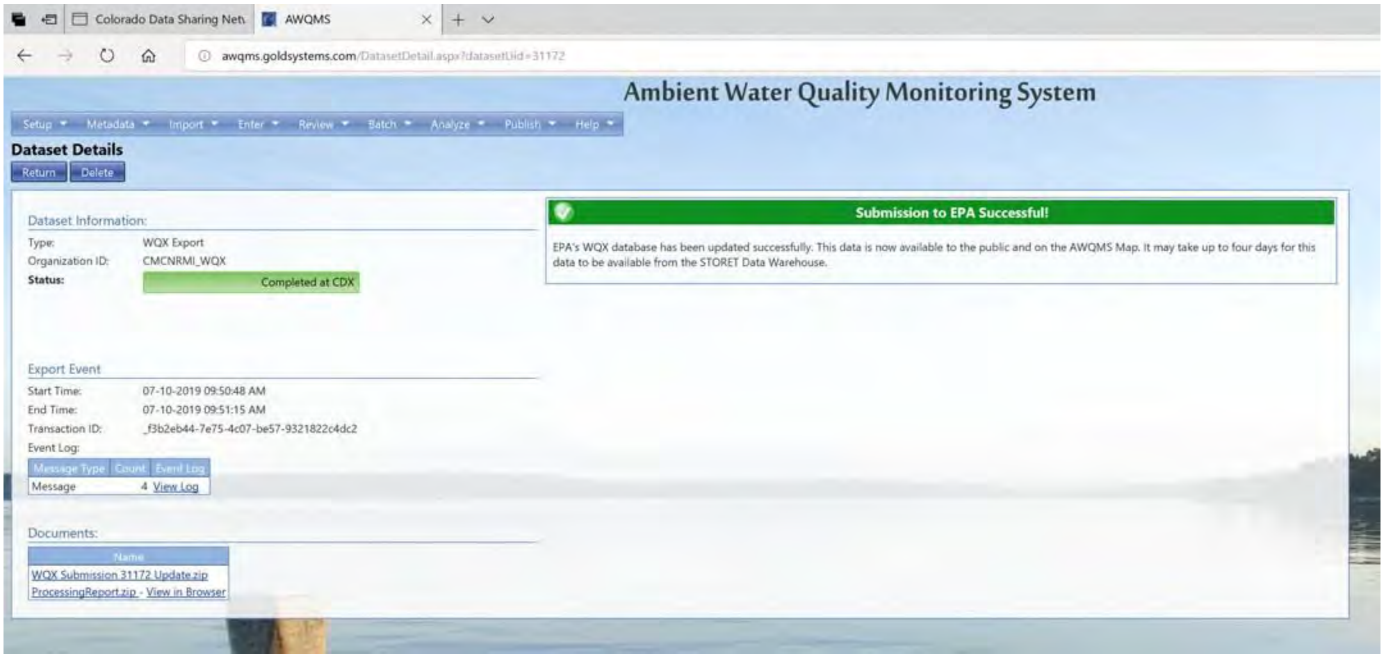
Activity Group	0
Activity	731
Result	7,666
Metric	0



To whom it may concern,

Colorado Data Sharing Network at the direction of DIRK RASMUSSEN uploaded water quality data and other water quality data that may or may not be part of a regulatory program to the Colorado Data Sharing Network's WQX-compatible data management system known as AWQMS and to the EPA National Data Warehouse known as WQX or STORET.

As a courtesy, we are summarizing the following data has been uploaded BETWEEN JUNE 6 AND JULY1, 2019 to AWQMS by CDSN Contractor MtnGeoGeek, LLC:

Items Successfully Processed AND SUBMITTED TO EPA WQX:

7,666 Results
2 Projects
12 Monitoring Locations

All uploads were accomplished without errors and without warnings.

- Attached is an Excel workbook containing the data template uploaded with above described modifications. Also attached are the Project, Monitoring Location, Activity, and Activity/Results Standard export files downloaded from AWQMS to demonstrate the data is present in AWQMS and accessible.

CDSN and Contractor MtnGeoGeek, LLC, can only provide this summary to demonstrate that data was uploaded into AWQMS. We cannot guarantee that any contractual requirements between CDPHE, EPA or any other entity that may have required certain data to be uploaded to AWQMS or WQX is in fact the data that was uploaded. We are attempting to demonstrate that data provided to CDSN and MtnGeoGeek, LLC by DIRK RASMUSSEN was indeed uploaded, with copies of the data provided as attachments. Any issues with accuracy or completeness of the data referenced in this report are the responsibility of DIRK RASMUSSEN AND COLORADO MOUNTAIN COLLEGE.

Primary CMCNRMI_WQX contact information is:

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Project Manager -- Natural Resource Management
719.486.4239 / dmrasmussen@coloradomtn.edu

Colorado Mountain College Leadville
901 South Highway 24 / Leadville, CO 80461
ColoradoMtn.edu

At any time, you may read, query and download data from AWQMS by using our public login:

http://cdsn.awqms.com
username: cdsnpublic
password: cdsnpublic

You may also use your dedicated **CMCNRMI_WQX** login.

For information on using AWQMS and tutorials, please visit http://www.coloradowaterdata.org/cdsnawqms_cdsn.html.

At any time, you may interact with data at the EPA National Data Warehouse by visiting http://www.epa.gov/storet/dw_home.html.

Sincerely,

Lynn Padgett, Colorado Data Sharing Network, MtnGeoGeek, LLC

(Please sign and return)

I certify that I have reviewed the AWQMS Project, Monitoring Location, and Activity/Results export files provided to me by the CDSN and MtnGeoGeek, LLC, and that these files accurately and completely represent the data I requested CDSN to upload to (check lines that apply)________AWQMS and/or________WQX for my organization and to satisfy any specific regulatory or grant/contract requirements such as REG85 or Non-Point Source Program. I certify that CDSN and MtnGeoGeek, LLC, correctly uploaded the data I provided to them and is not responsible for any issues regarding accuracy or completeness.

Signature/Title of Authorized Representative of Data Organization:

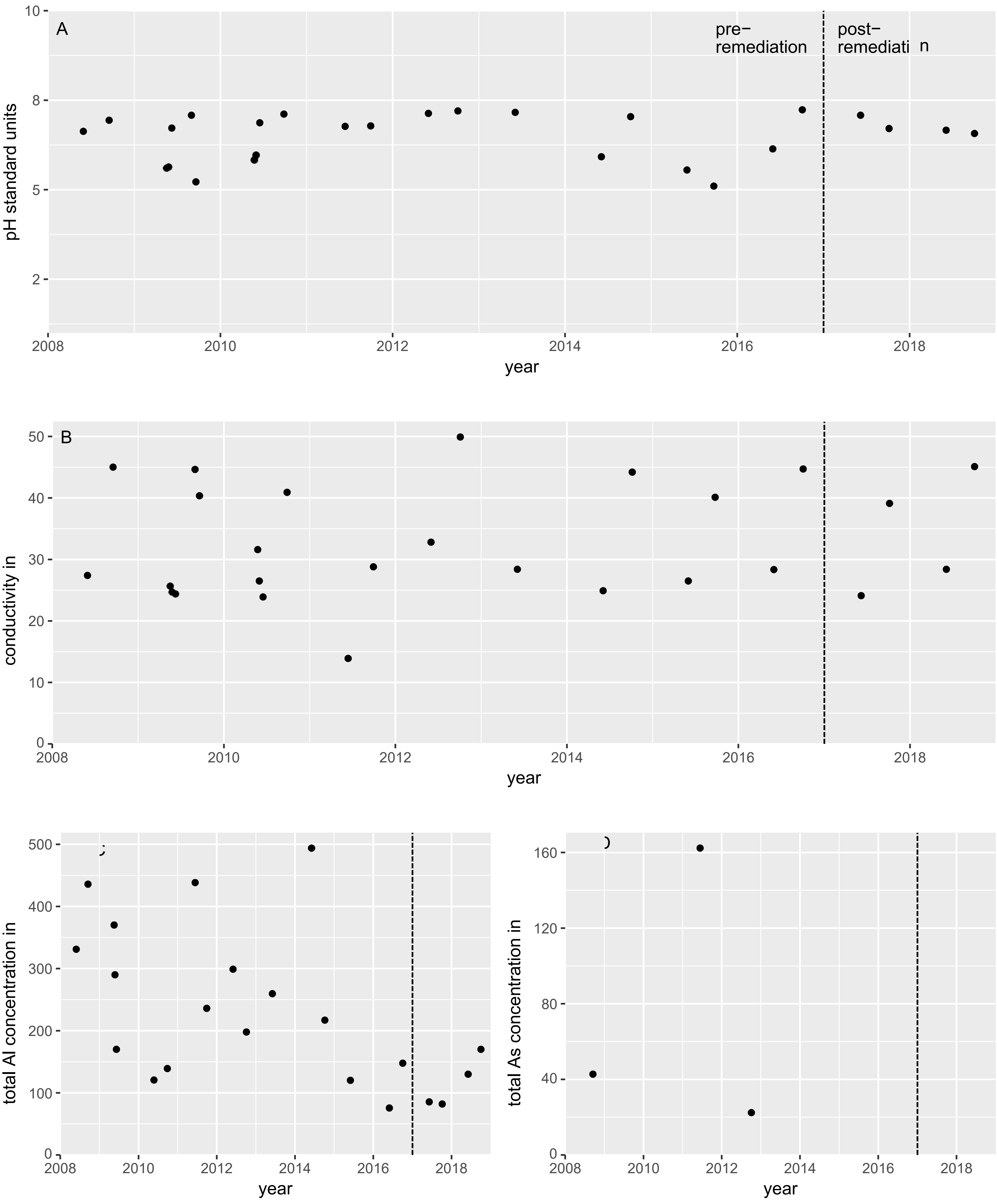
Dirk Rasmussen Digitally signed by Dirk Rasmussen
Date: 2019.07.11 12:02:59 -06'00'

Signature & Date	Printed Name	Title

Organization Name:

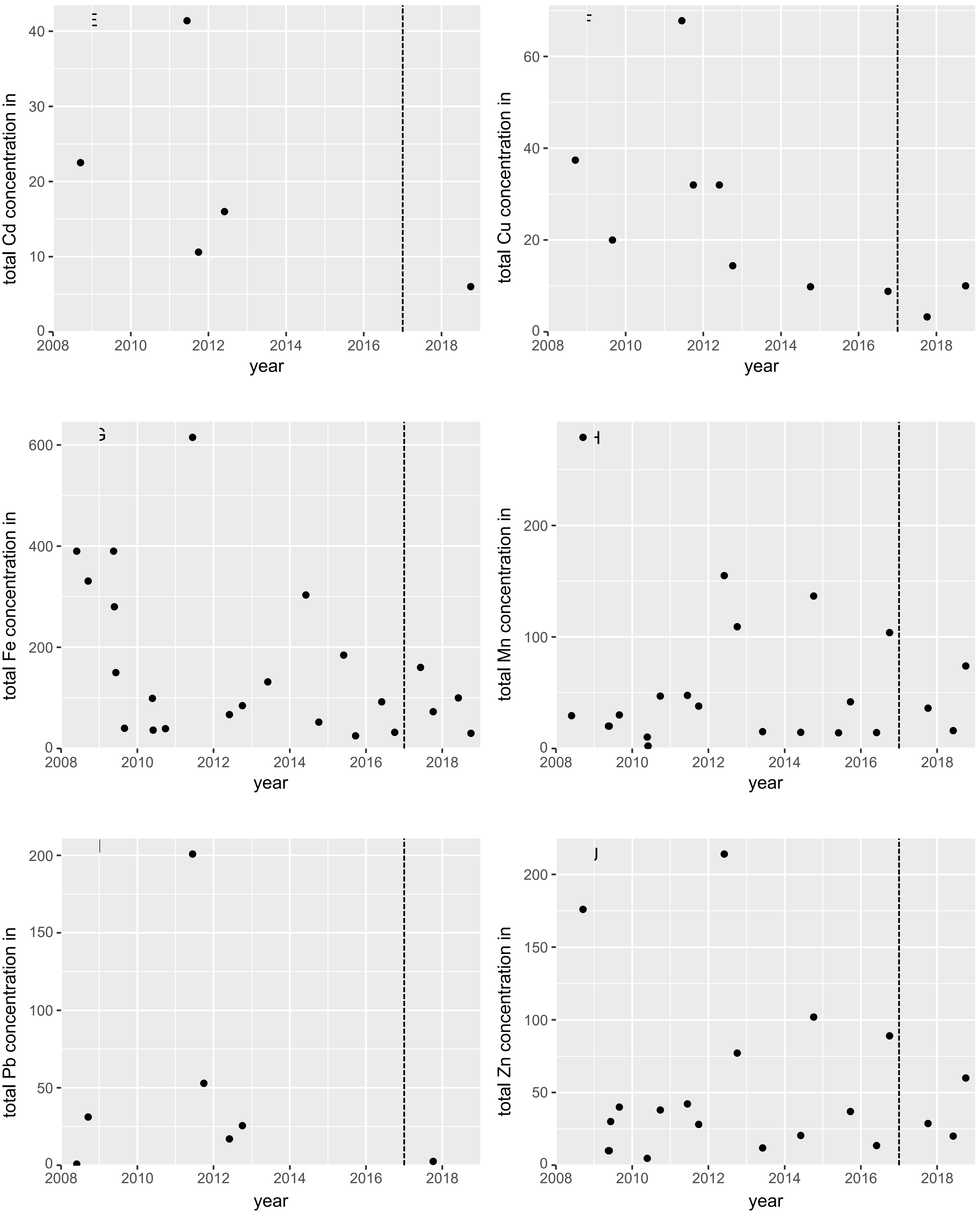
Regulatory or Program Name
(if fulfilling requirements):

COG−06

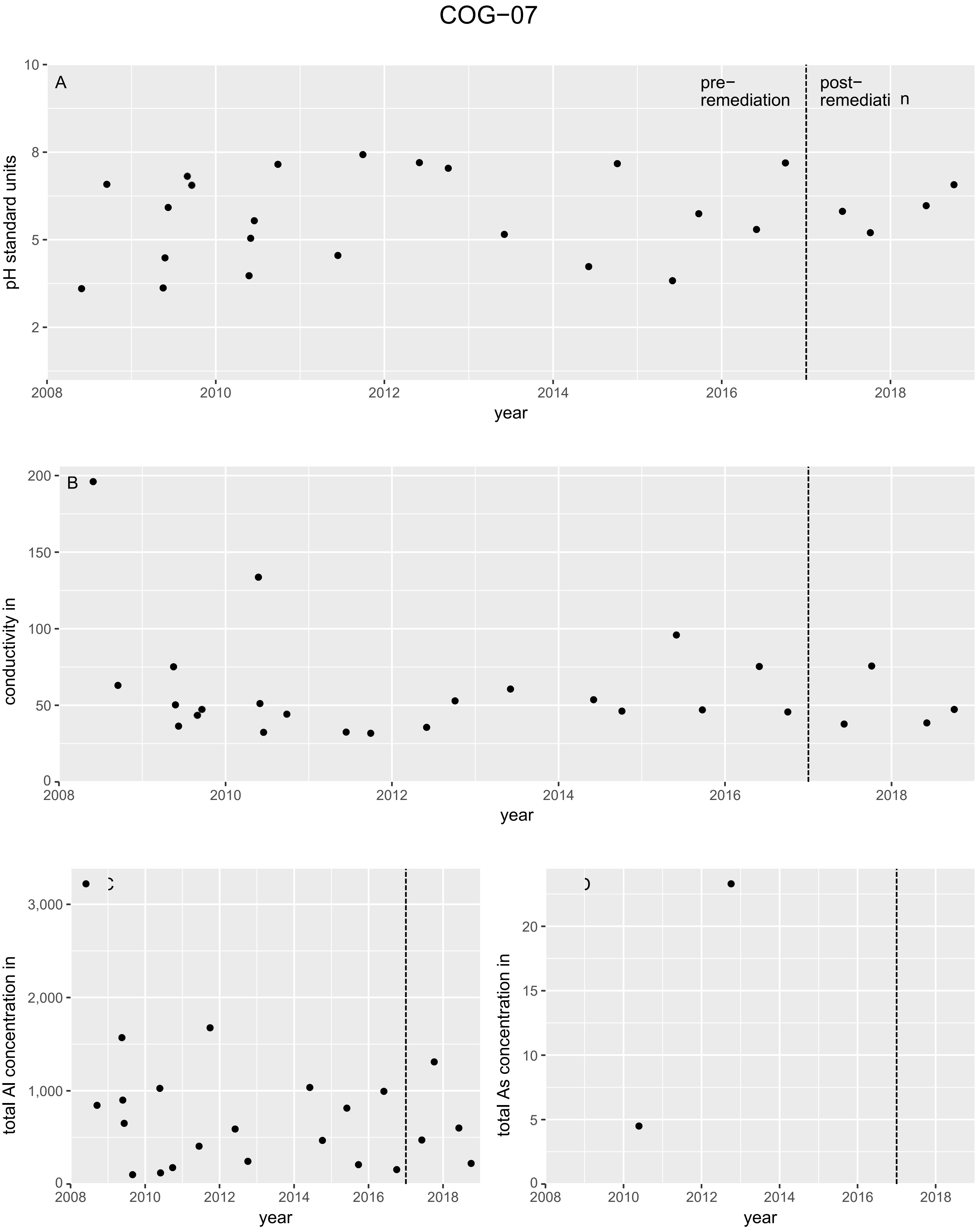


A
pre−
remediation
post−
remediati n
pH standard units
year
B
conductivity in
year
total Al concentration in
year
total As concentration in
year

COG−06

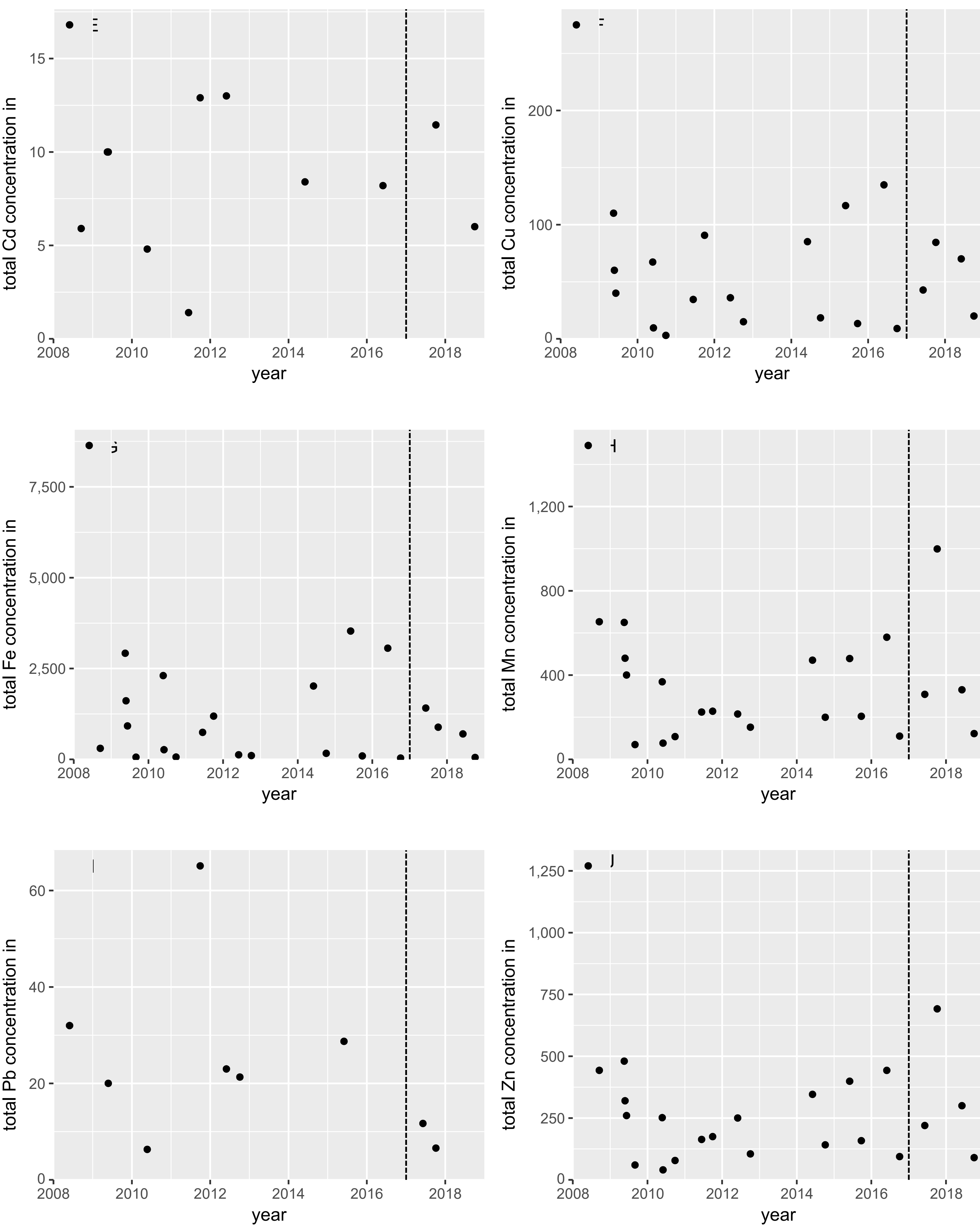


total Cd concentration in
total Cu concentration in
total Fe concentration in
total Mn concentration in
total Pb concentration in
total Zn concentration in
year
2008
2010
2012
2014
2016
2018

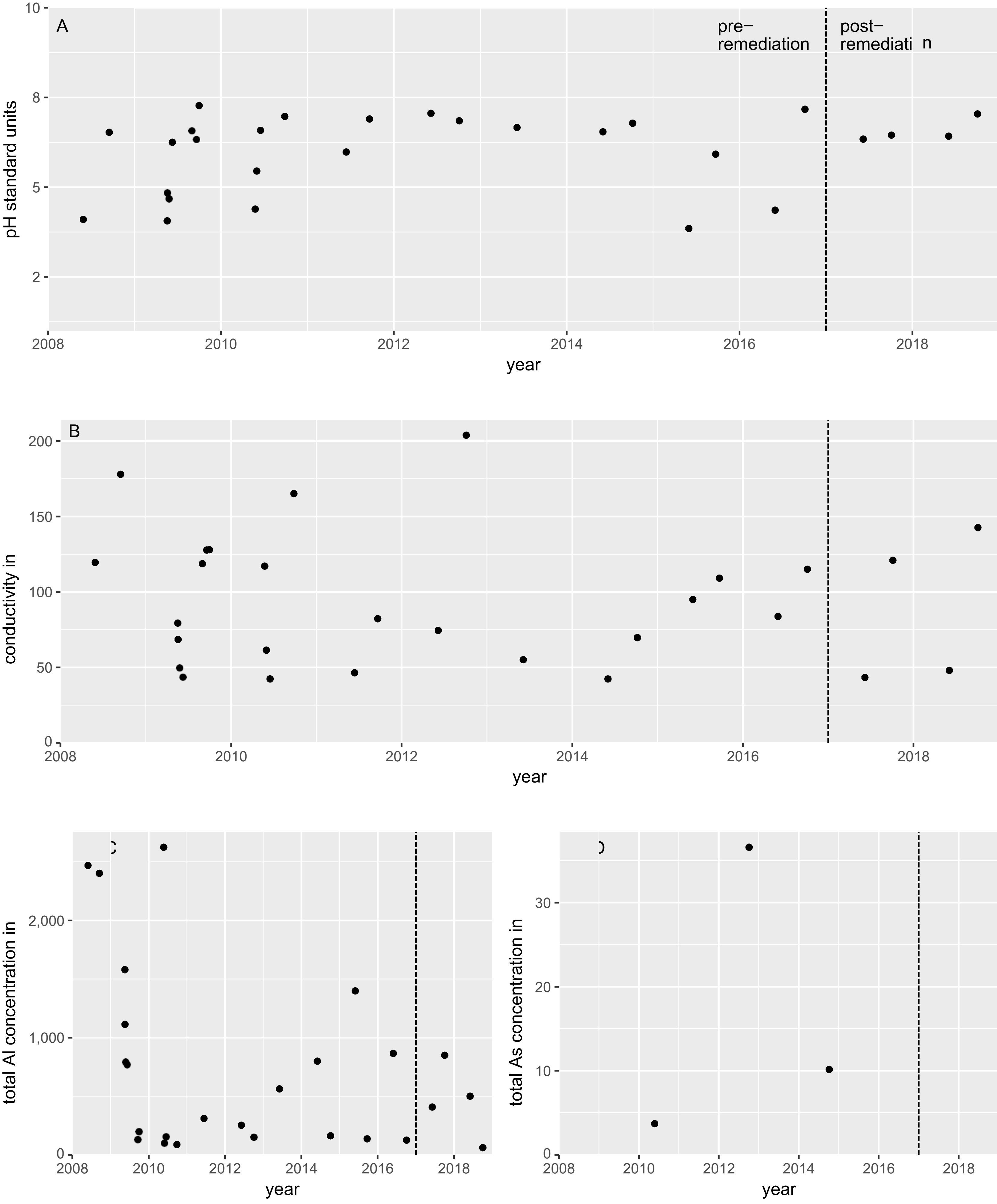


COG−07
A
pre−
remediation
post−
remediati n
pH standard units
year
B
conductivity in
year
total Al concentration in
year
total As concentration in
year

COG−07

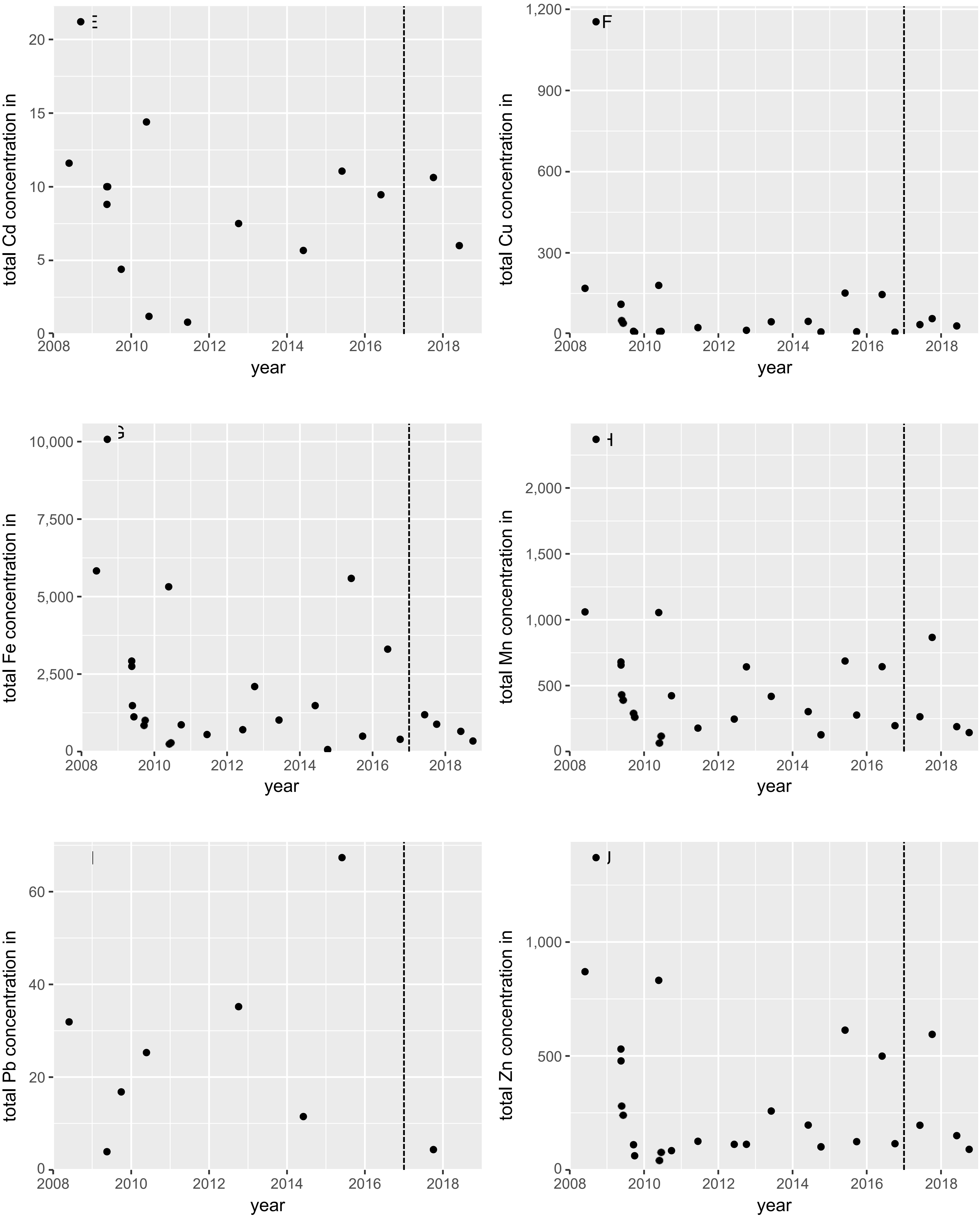

total Cd concentration in
total Cu concentration in
total Fe concentration in
total Mn concentration in
total Pb concentration in
total Zn concentration in
year
2008
2010
2012
2014
2016
2018

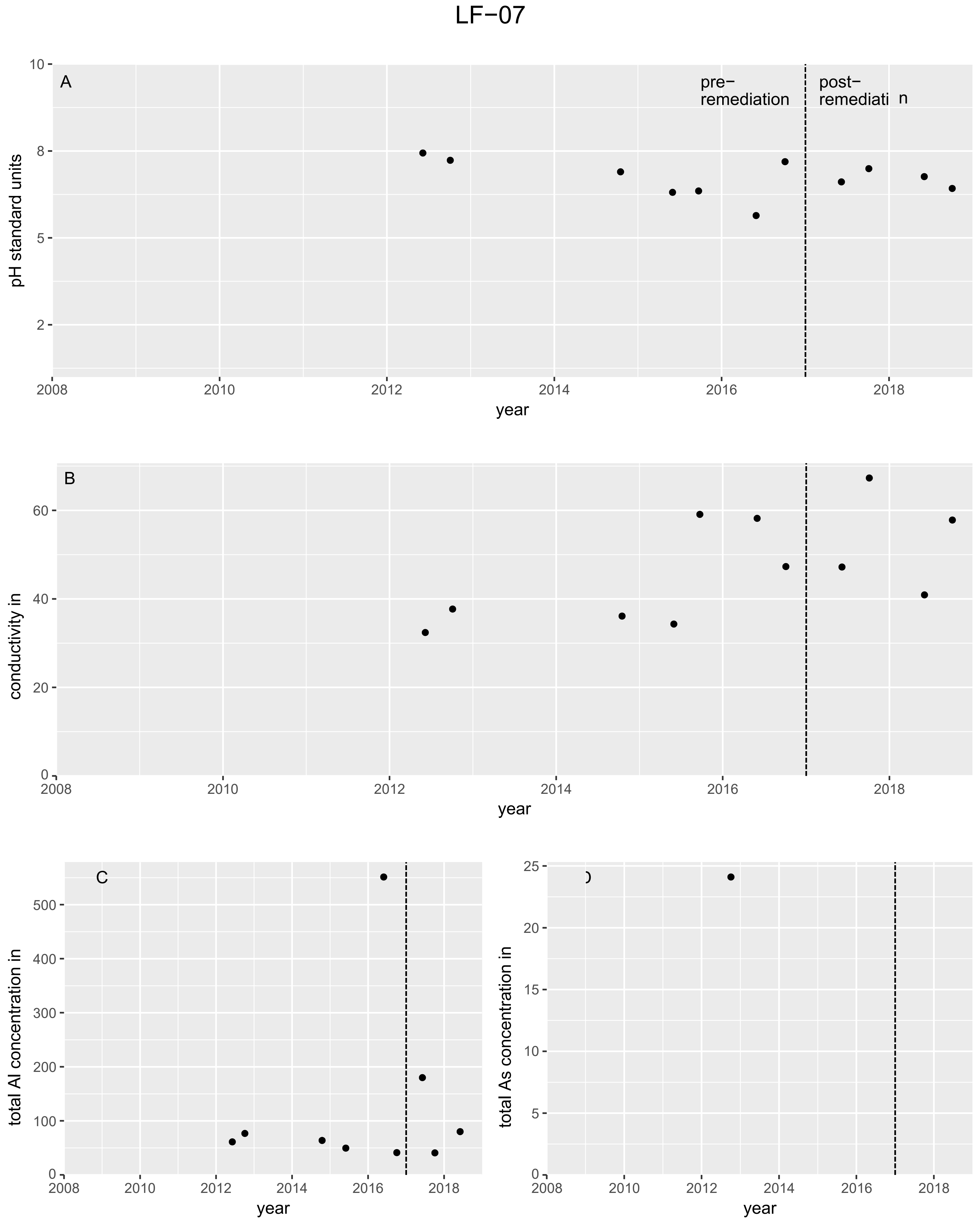
COG−12



A
pre−
remediation
post−
remediati n
pH standard units
year
B
conductivity in
year
C
total Al concentration in
year
D
total As concentration in
year

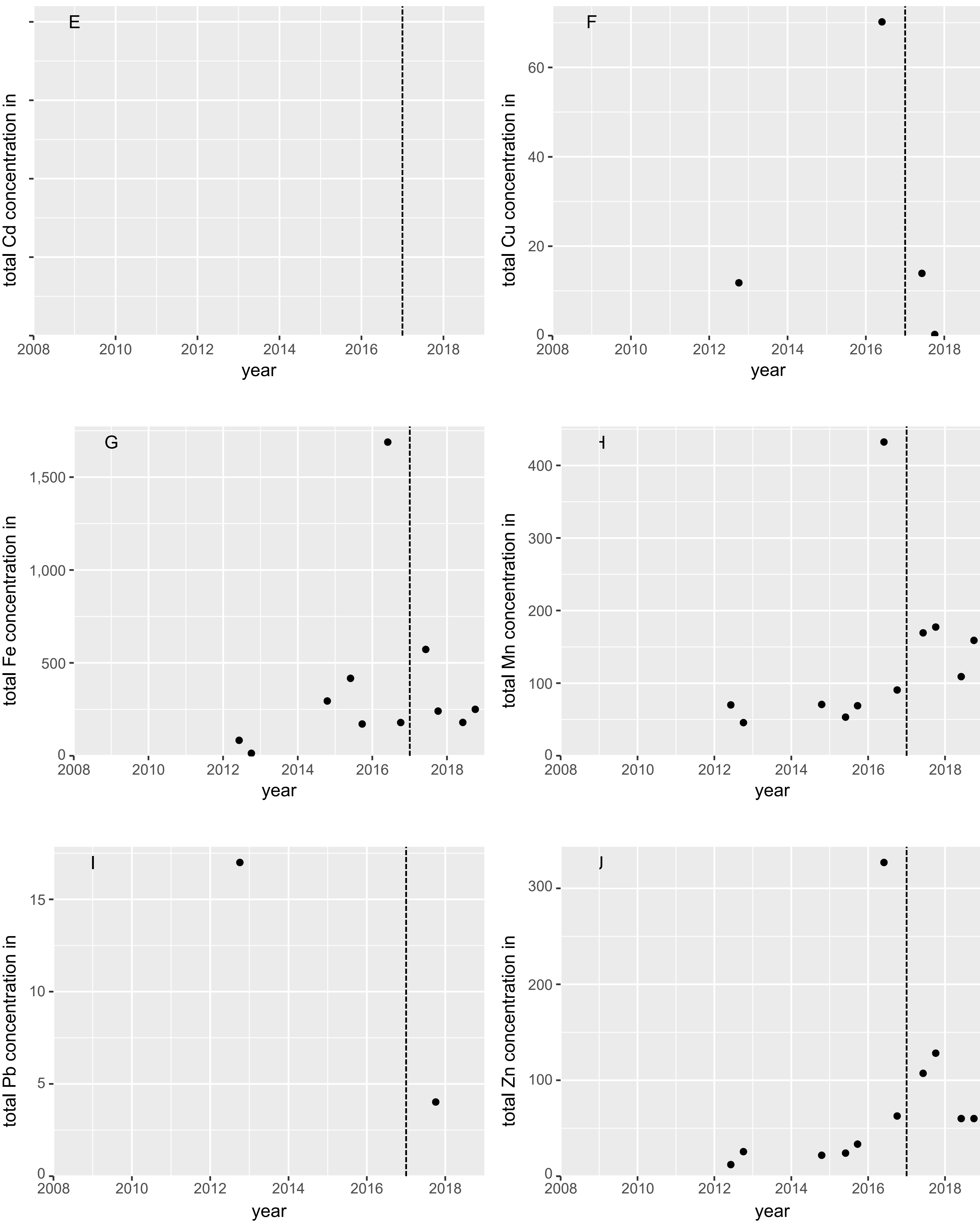
COG−12

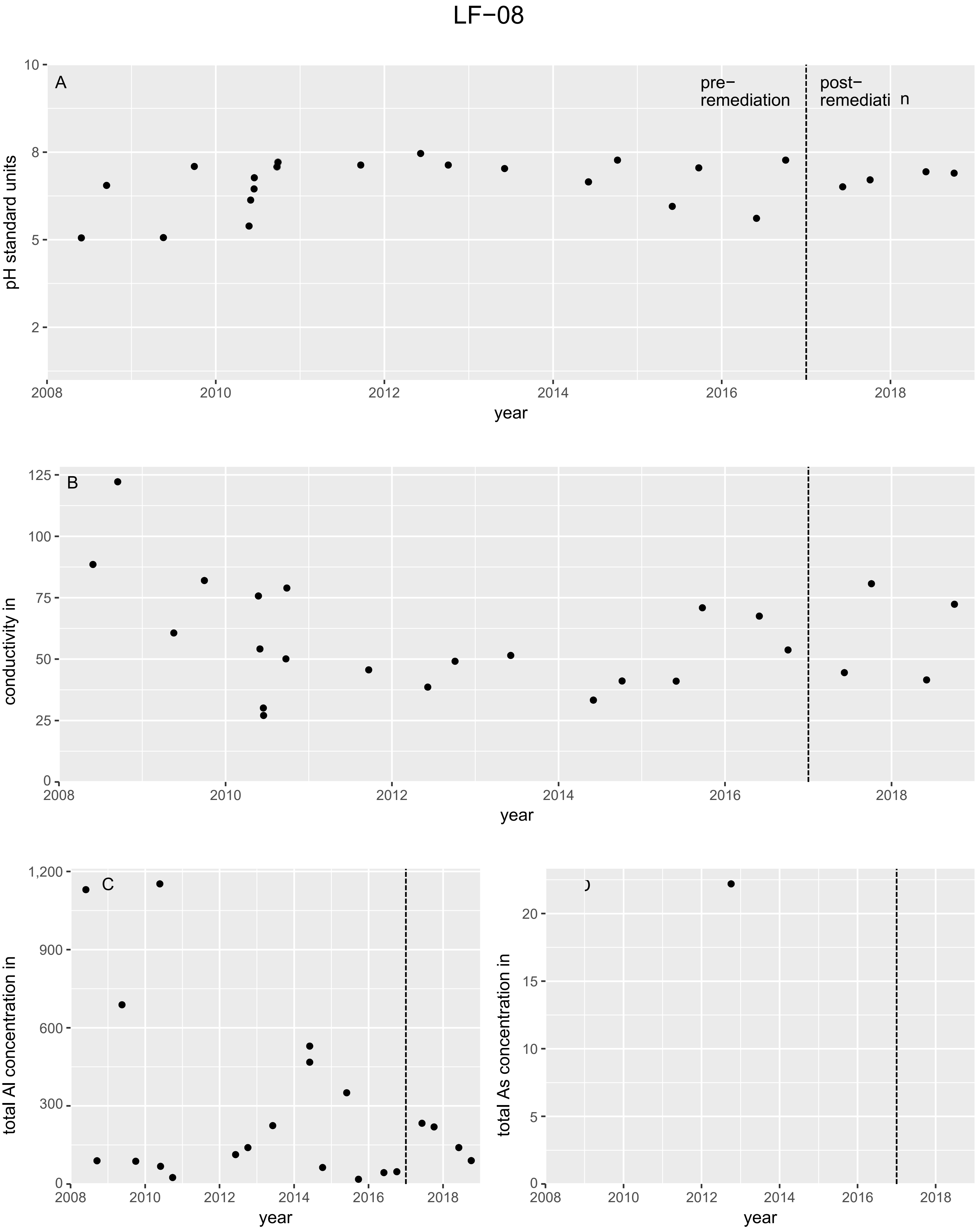

E
F
G
H
I
J
total Cd concentration in
total Cu concentration in
total Fe concentration in
total Mn concentration in
total Pb concentration in
total Zn concentration in
year
0
5
10
15
20
300
600
900
1,200
2,500
5,000
7,500
10,000
500
1,000
1,500
2,000
40
60
2008
2010
2012
2014
2016
2018



LF−07
A
pre−
remediation
post−
remediati n
pH standard units
year
B
conductivity in
year
C
total Al concentration in
year
total As concentration in
year

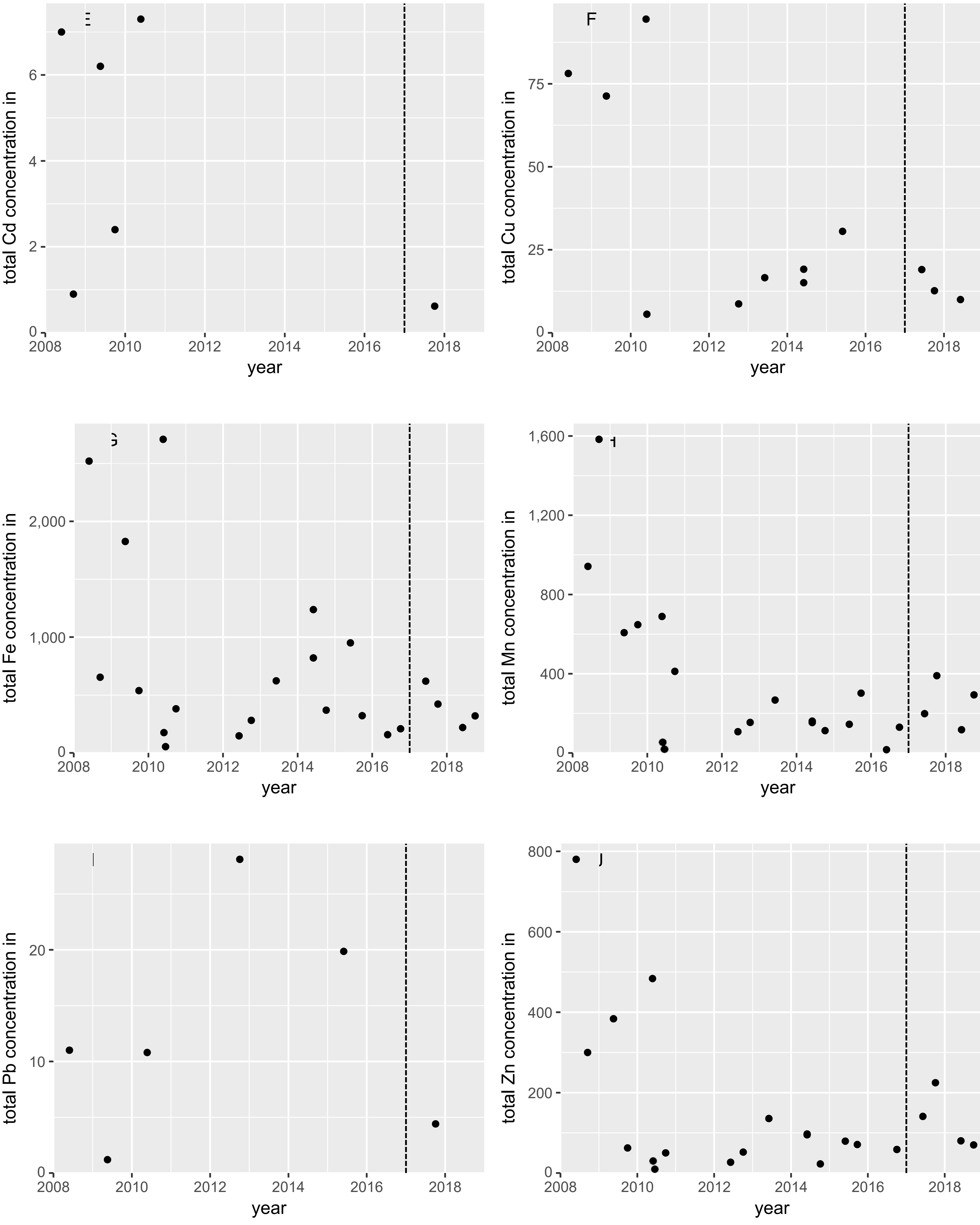
LF−07


E
total Cd concentration in
year
F
total Cu concentration in
year
G
total Fe concentration in
year
H
total Mn concentration in
year
I
total Pb concentration in
year
J
total Zn concentration in
year



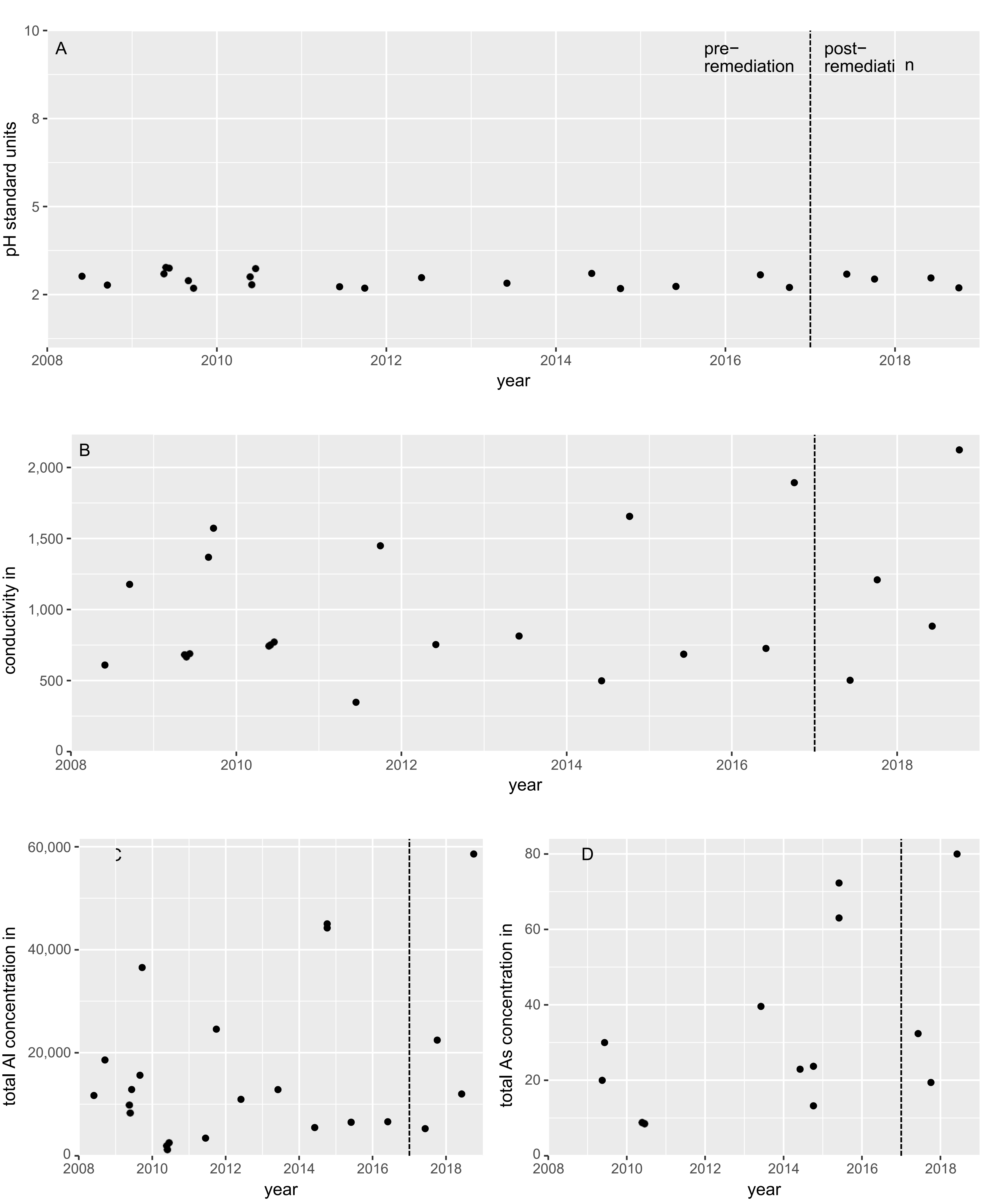
LF−08
A
pre−
remediation
post−
remediati n
pH standard units
10
8
5
2
2008
2010
2012
2014
2016
2018
year
B
conductivity in
125
100
75
50
25
0
2008
2010
2012
2014
2016
2018
year
C
total Al concentration in
1,200
900
600
300
0
2008
2010
2012
2014
2016
2018
year
total As concentration in
20
15
10
5
0
2008
2010
2012
2014
2016
2018
year

LF−08

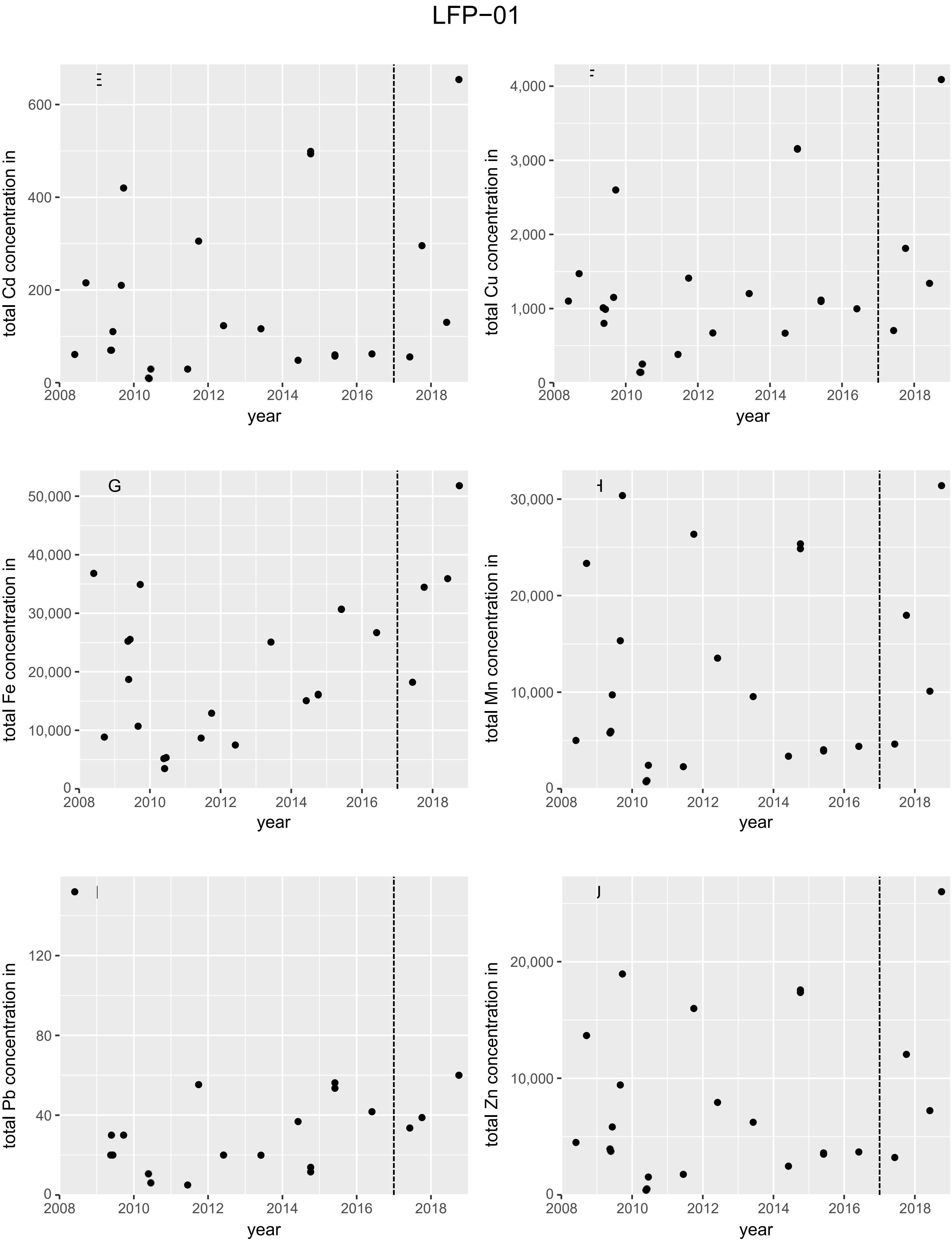


E
F
G
H
I
J
total Cd concentration in
total Cu concentration in
total Fe concentration in
total Mn concentration in
total Pb concentration in
total Zn concentration in
year
0
2
4
6
25
50
75
1,000
2,000
400
800
1,200
1,600
10
20
200
600
2008
2010
2012
2014
2016
2018

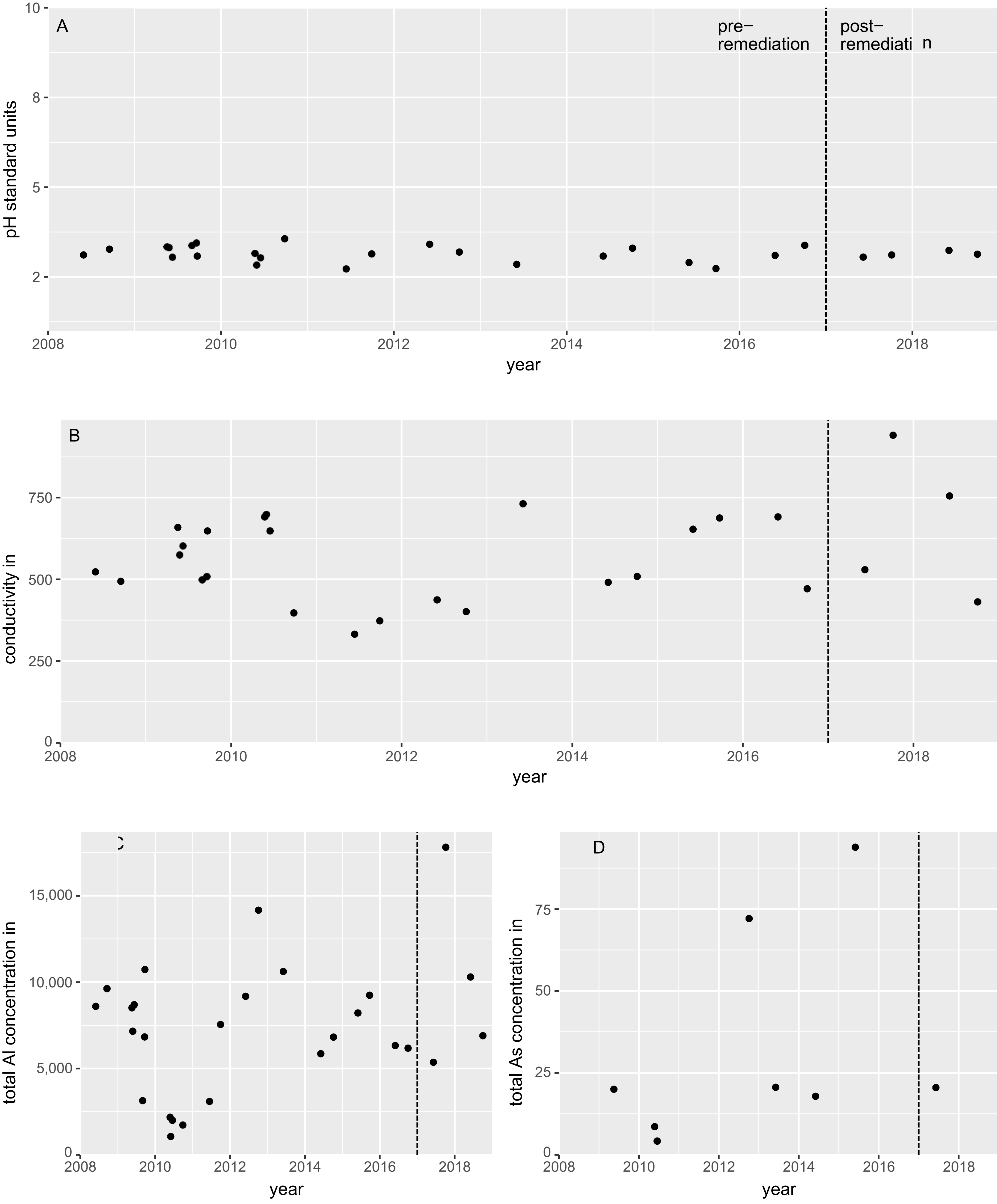
LFP−01



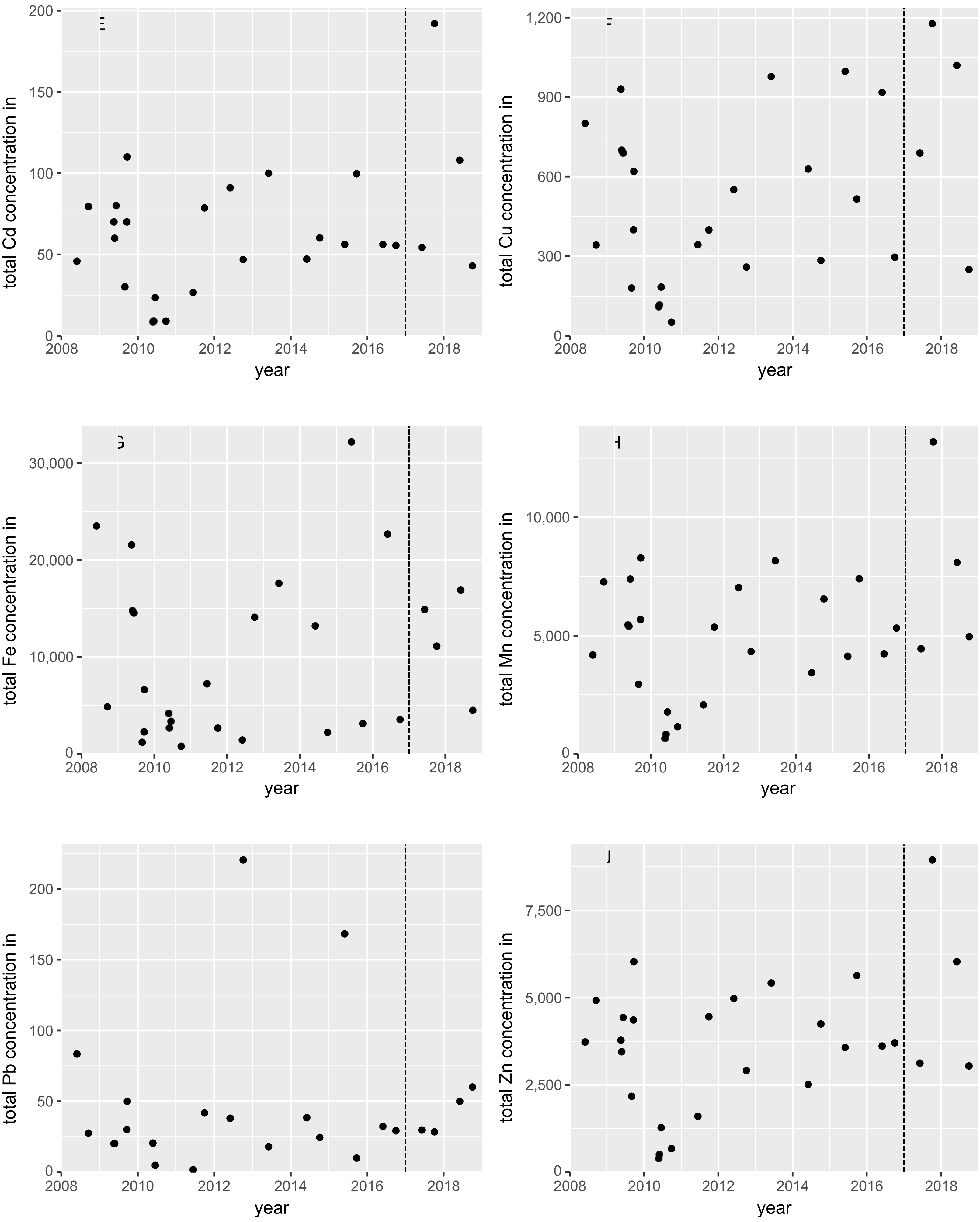
A
pre−
remediation
post−
remediati n
pH standard units
year
B
conductivity in
year
C
total Al concentration in
year
D
total As concentration in
year


LFP−01
E
total Cd concentration in
year
F
total Cu concentration in
year
G
total Fe concentration in
year
H
total Mn concentration in
year
I
total Pb concentration in
year
J
total Zn concentration in
year

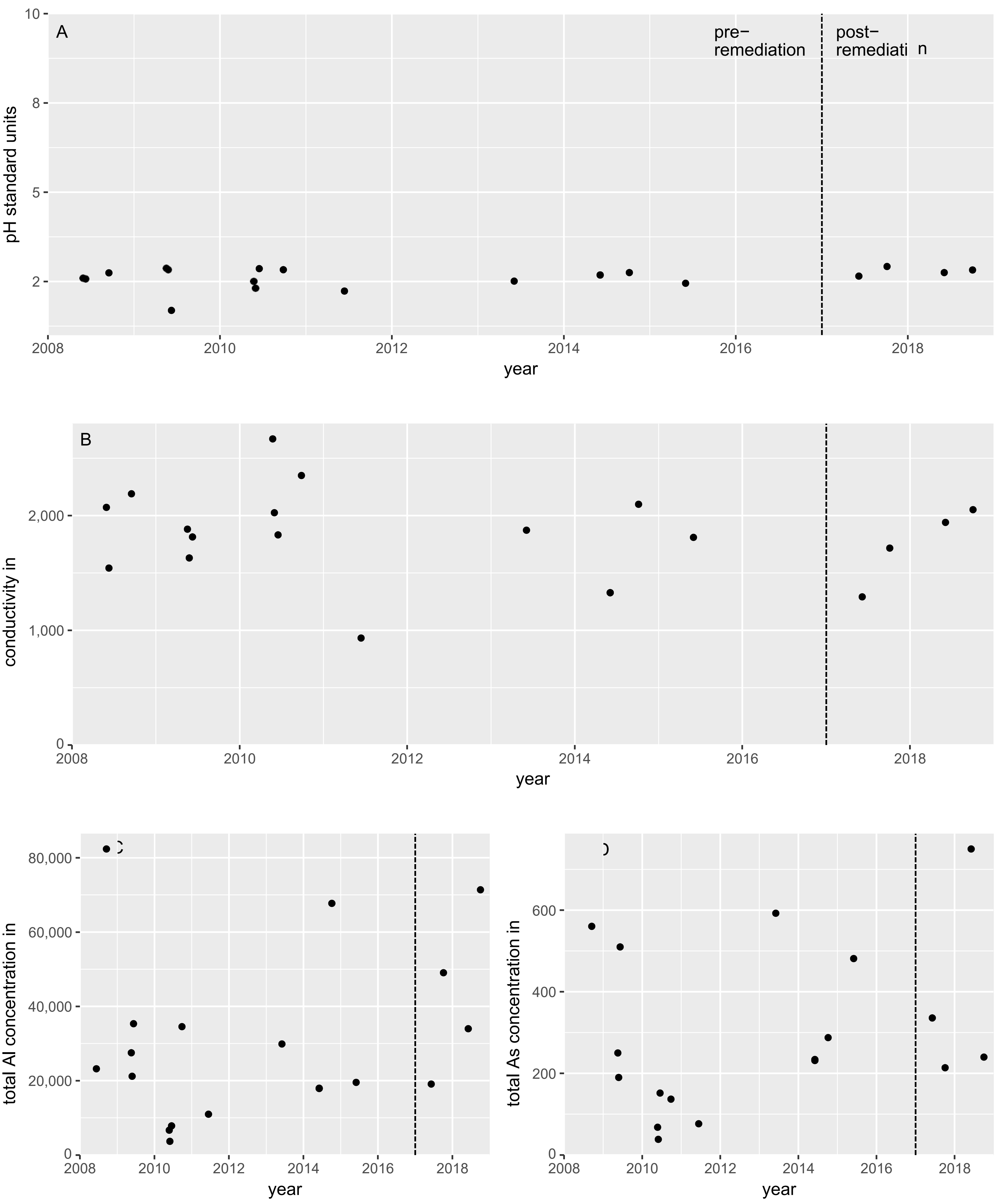
LFP−05


A
pre−
remediation
post−
remediati n
pH standard units
year
B
conductivity in
year
C
total Al concentration in
year
D
total As concentration in
year

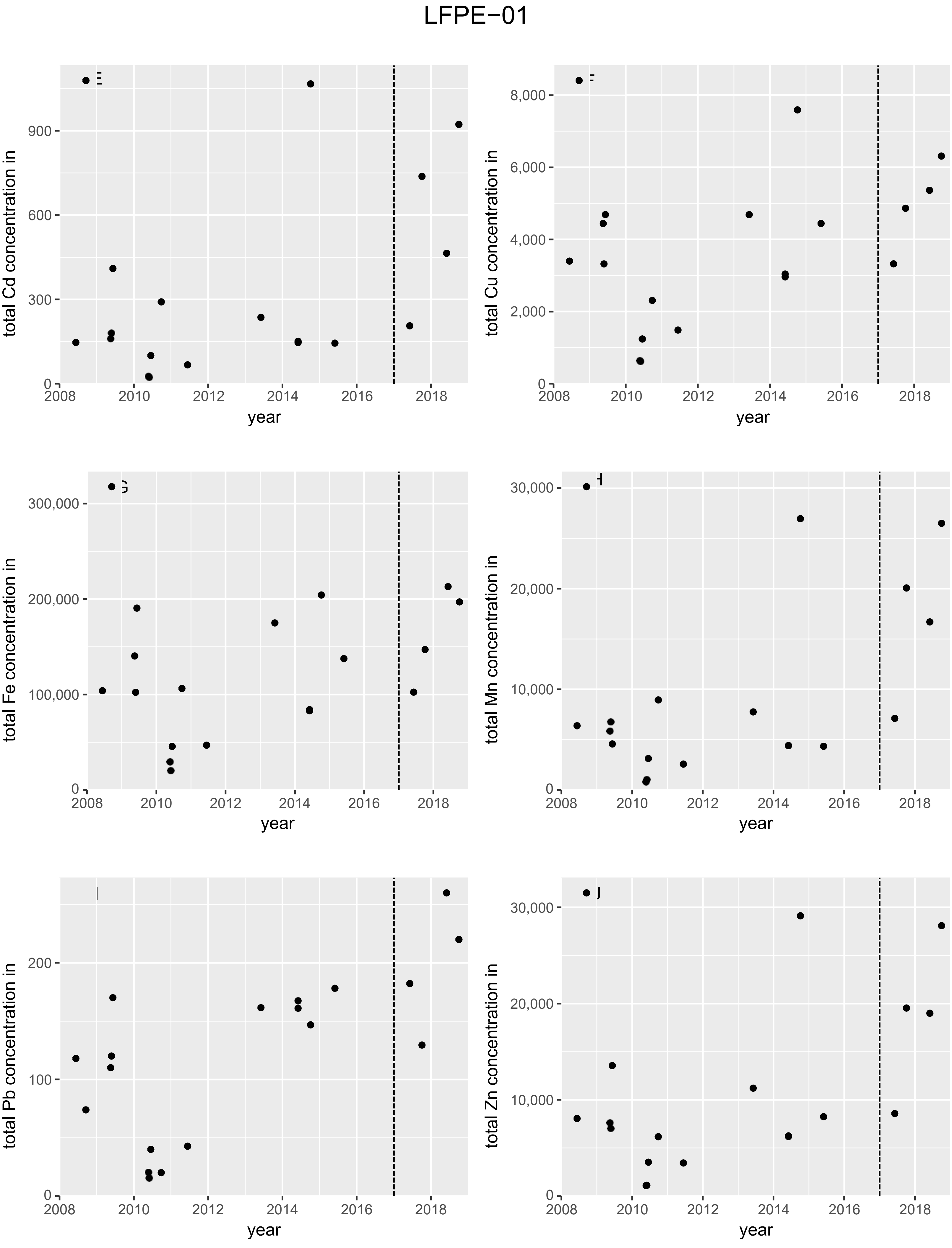
LFP−05


E
total Cd concentration in
F
total Cu concentration in
G
total Fe concentration in
H
total Mn concentration in
I
total Pb concentration in
J
total Zn concentration in
year

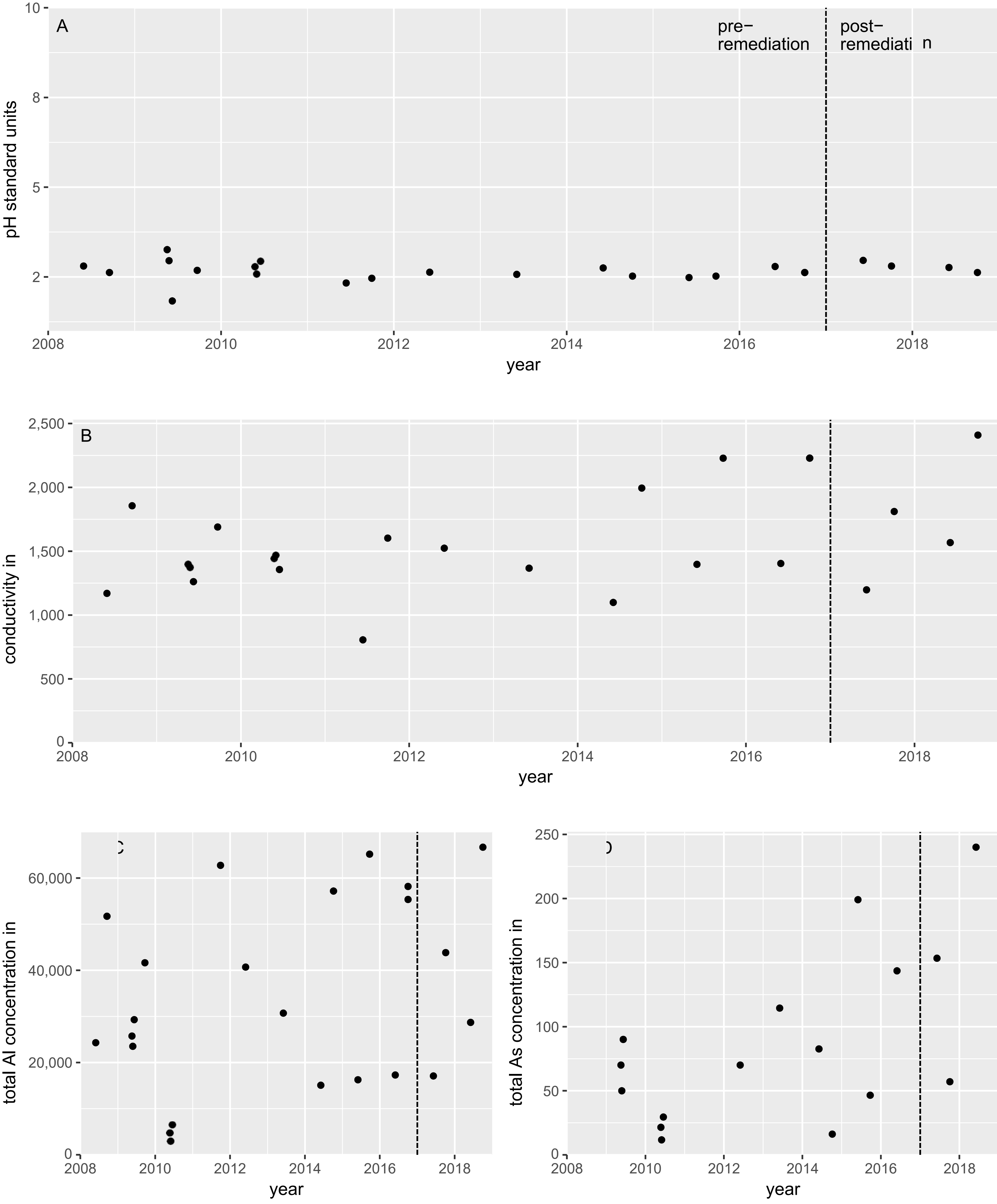
LFPE−01



A
pre−
remediation
post−
remediati n
pH standard units
year
B
conductivity in
year
total Al concentration in
year
total As concentration in
year

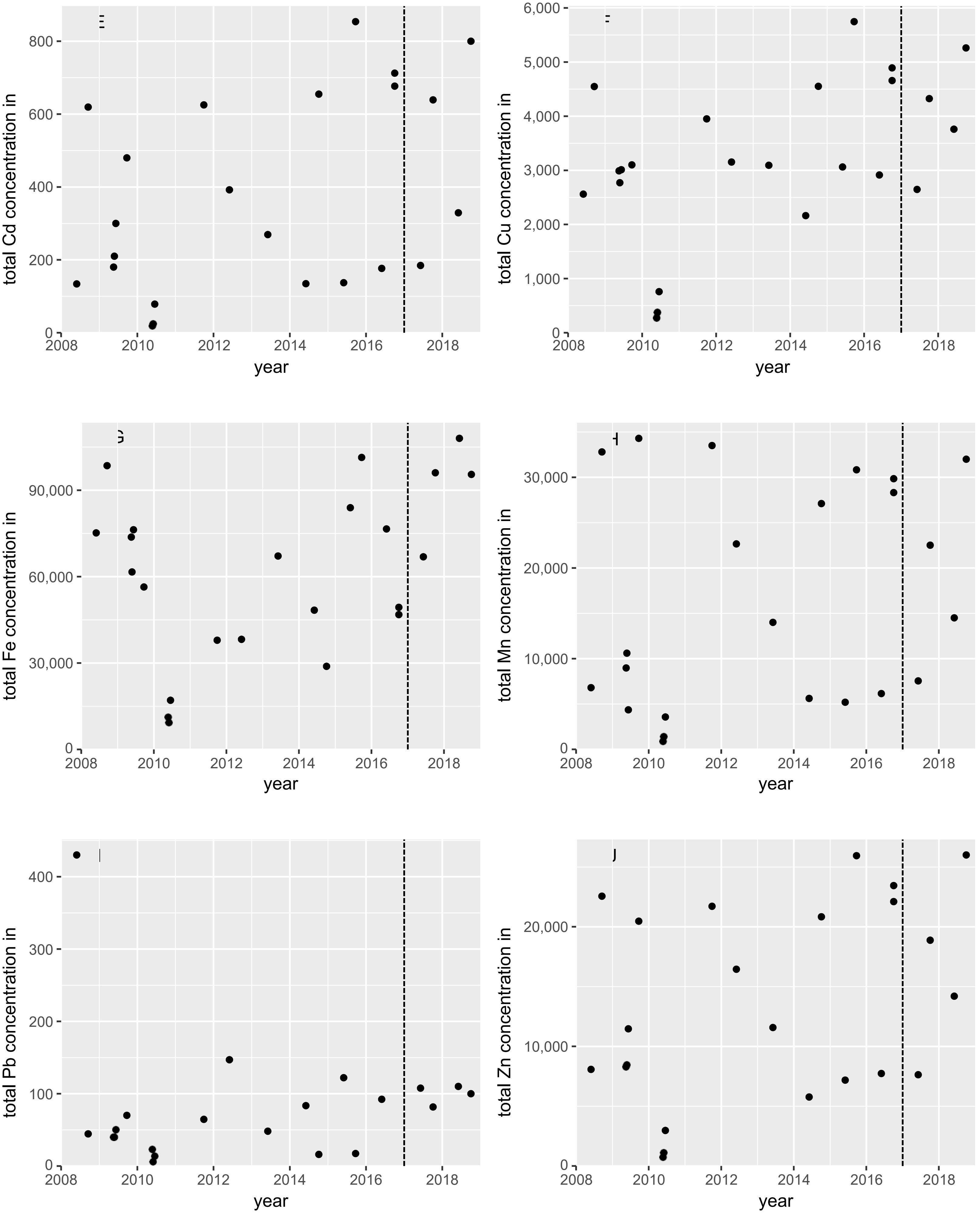

LFPE−01
E
total Cd concentration in
0
300
600
900
F
total Cu concentration in
0
2,000
4,000
6,000
8,000
G
total Fe concentration in
0
100,000
200,000
300,000
H
total Mn concentration in
0
10,000
20,000
30,000
I
total Pb concentration in
0
100
200
J
total Zn concentration in
0
10,000
20,000
30,000
2008
2010
2012
2014
2016
2018
year

LFPE−05



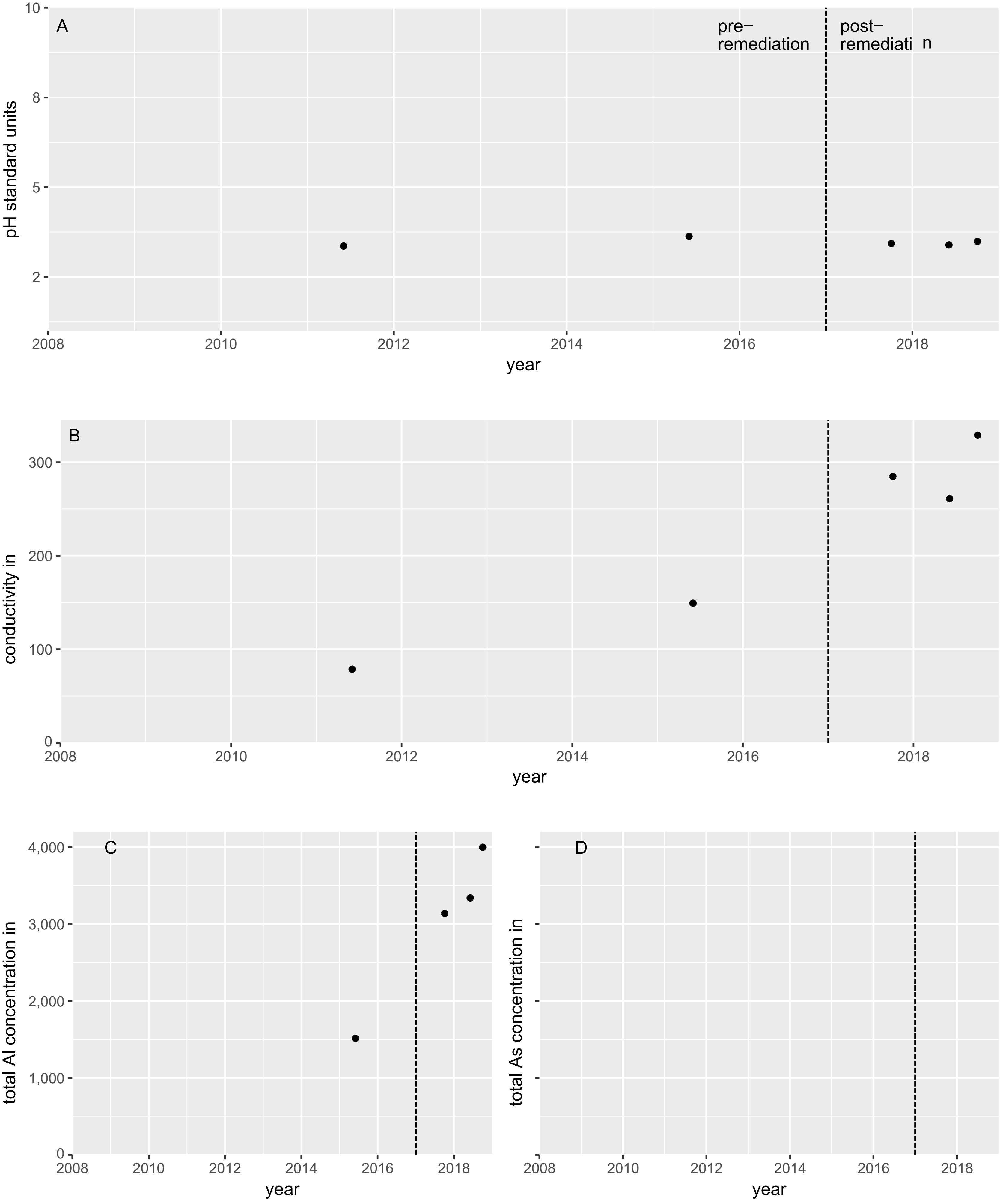
A
pre−
remediation
post−
remediati n
pH standard units
10
8
5
2
2008
2010
2012
2014
2016
2018
year
B
conductivity in
2,500
2,000
1,500
1,000
500
0
2008
2010
2012
2014
2016
2018
year
total Al concentration in
60,000
40,000
20,000
0
2008
2010
2012
2014
2016
2018
year
total As concentration in
250
200
150
100
50
0
2008
2010
2012
2014
2016
2018
year

LFPE−05

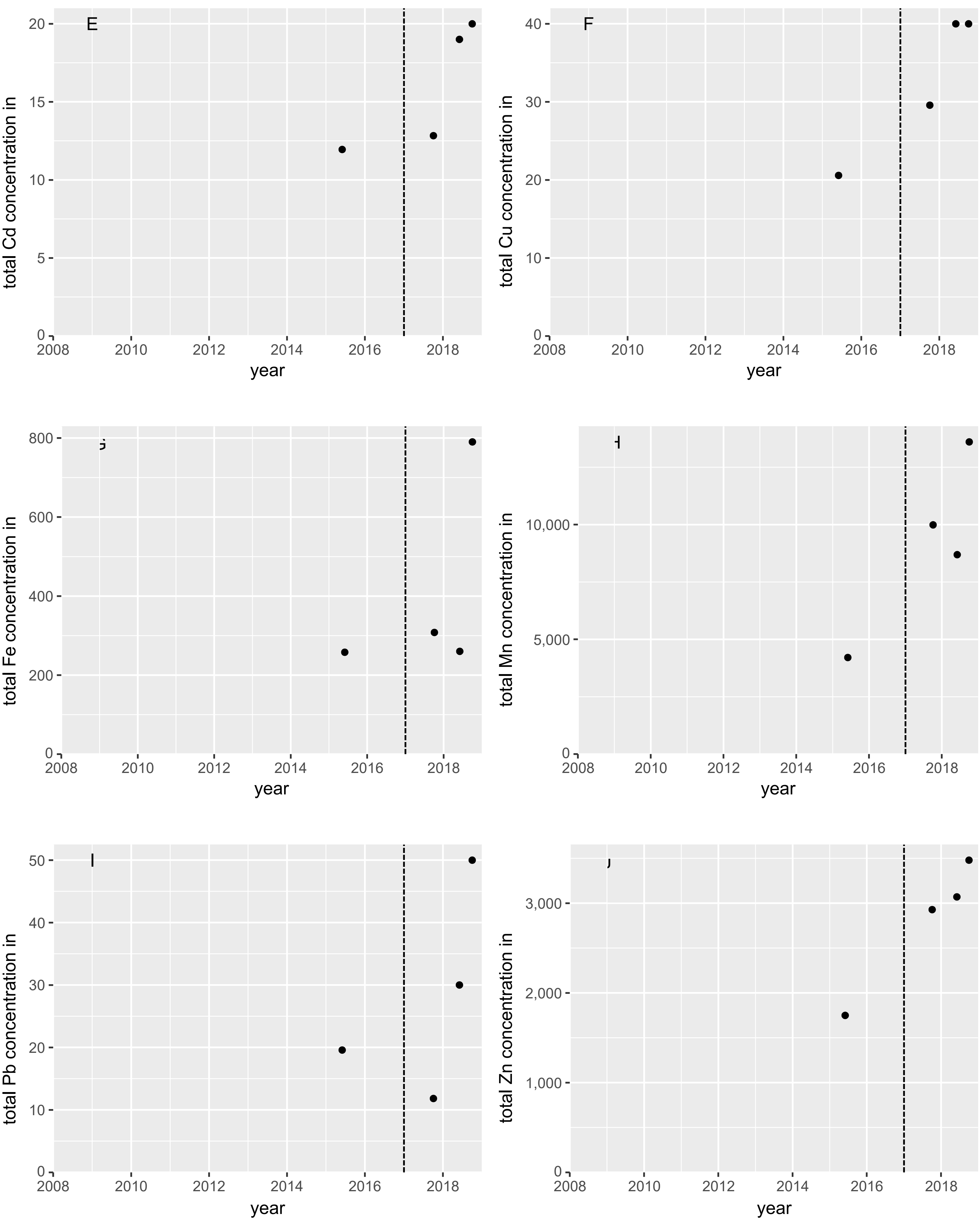


total Cd concentration in
total Cu concentration in
total Fe concentration in
total Mn concentration in
total Pb concentration in
total Zn concentration in
year
2008
2010
2012
2014
2016
2018
0
200
400
600
800
1,000
2,000
3,000
4,000
5,000
6,000
30,000
60,000
90,000
10,000
20,000
100
300

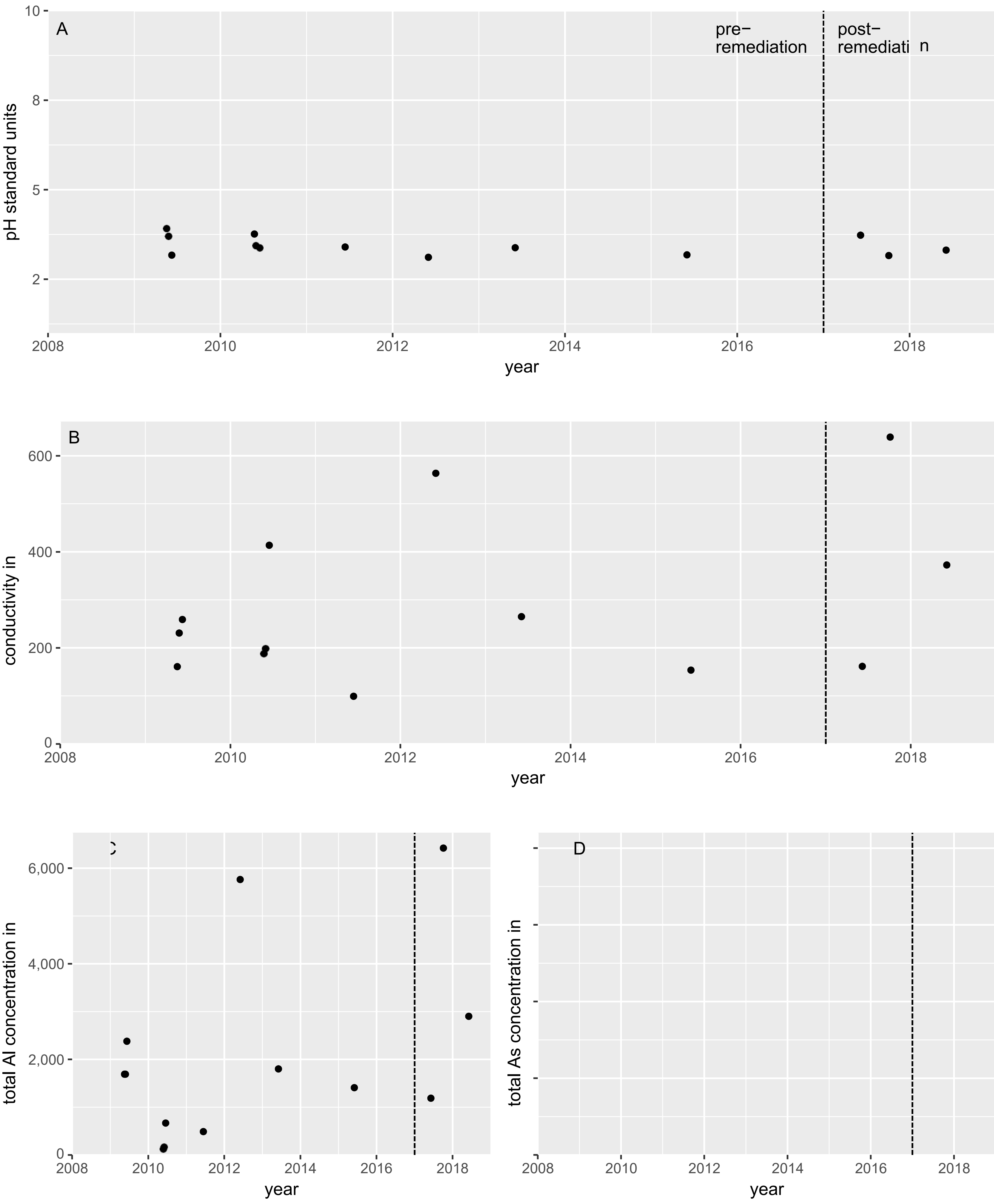
LFPW−05


A
pre−
remediation
post−
remediati n
pH standard units
10
8
5
2
2008
2010
2012
2014
2016
2018
year
B
conductivity in
300
200
100
0
2008
2010
2012
2014
2016
2018
year
C
total Al concentration in
4,000
3,000
2,000
1,000
0
2008
2010
2012
2014
2016
2018
year
D
total As concentration in
2008
2010
2012
2014
2016
2018
year

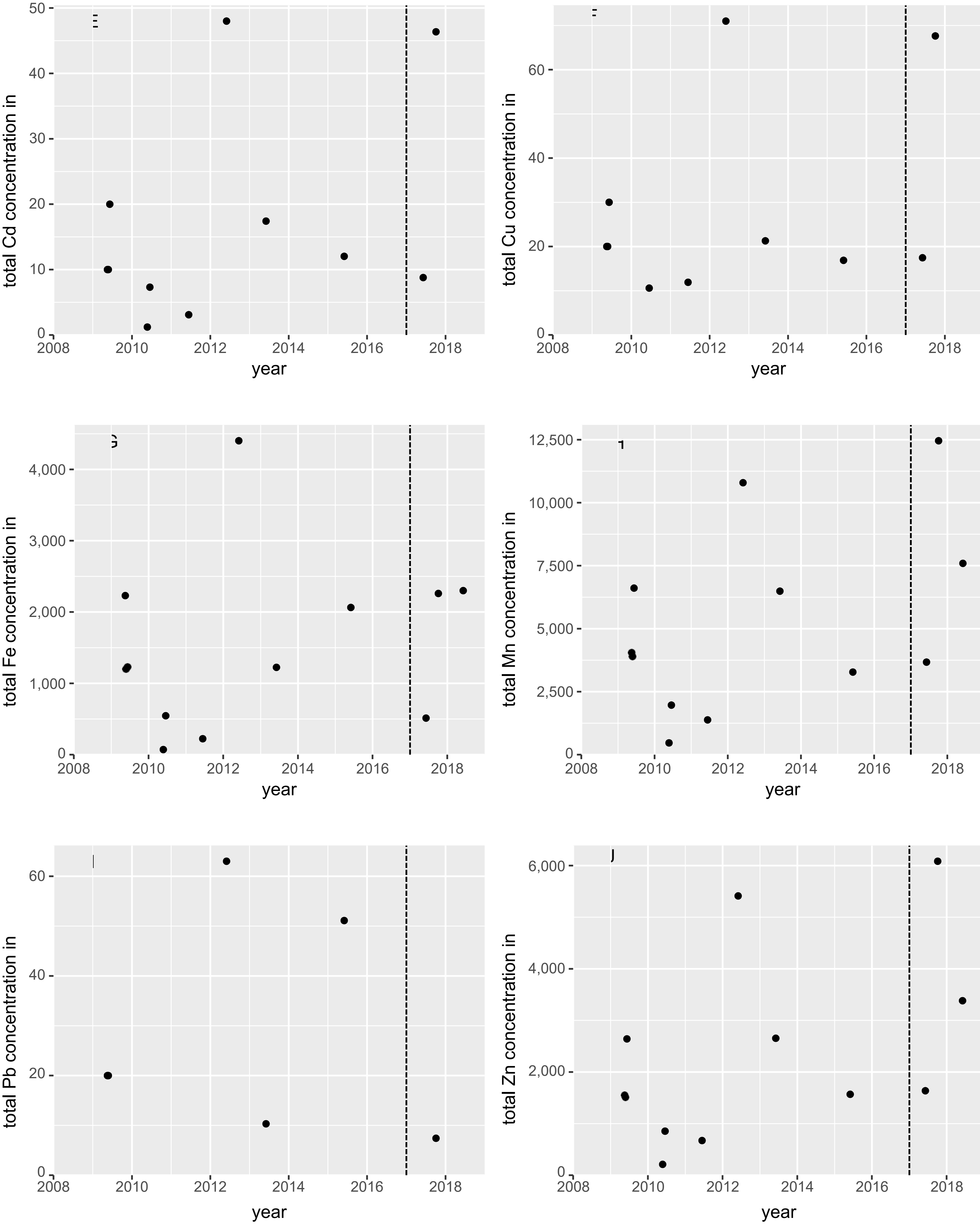
LFPW−05


E
total Cd concentration in
year
F
total Cu concentration in
year
G
total Fe concentration in
year
H
total Mn concentration in
year
I
total Pb concentration in
year
J
total Zn concentration in
year

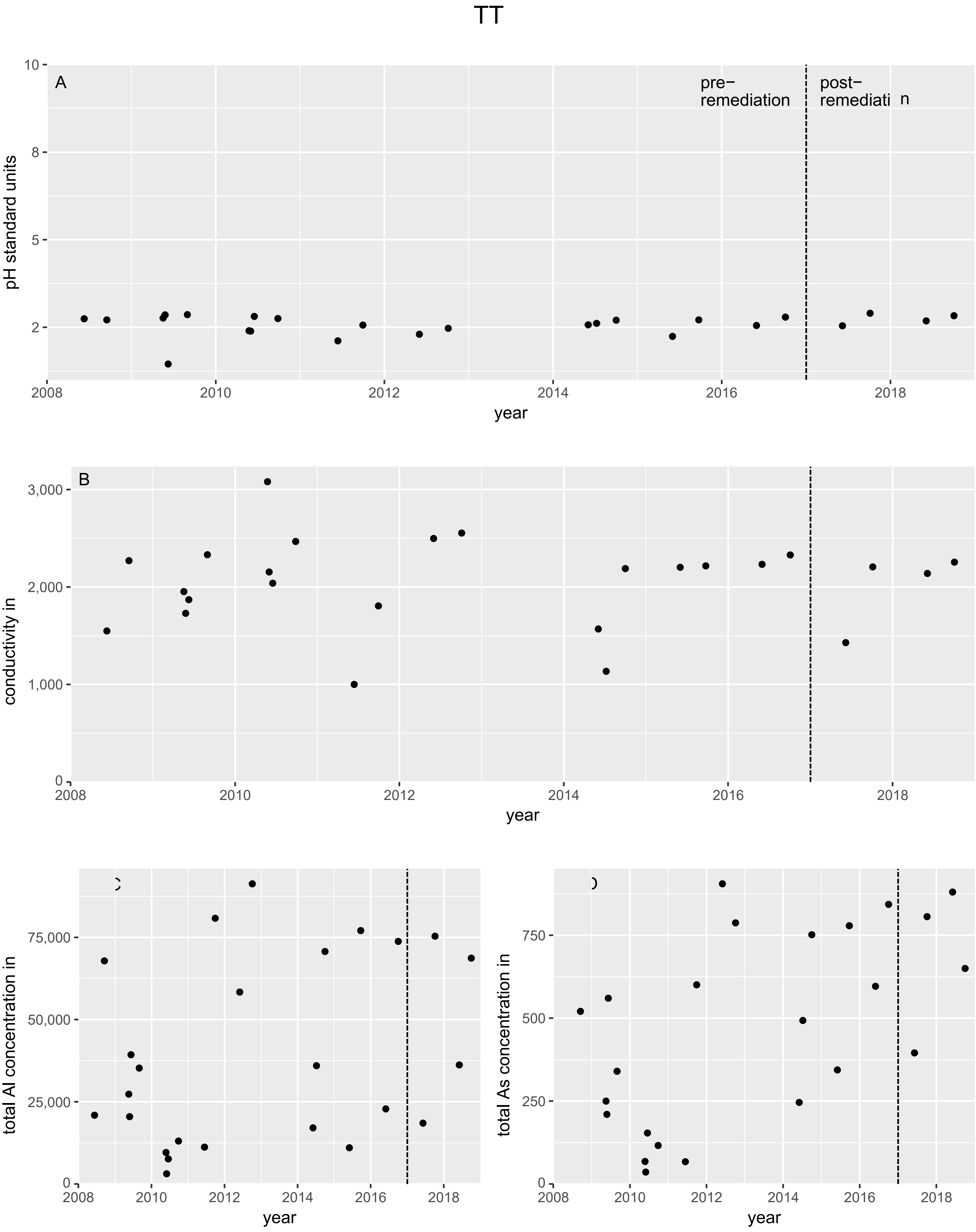
LFPW−06

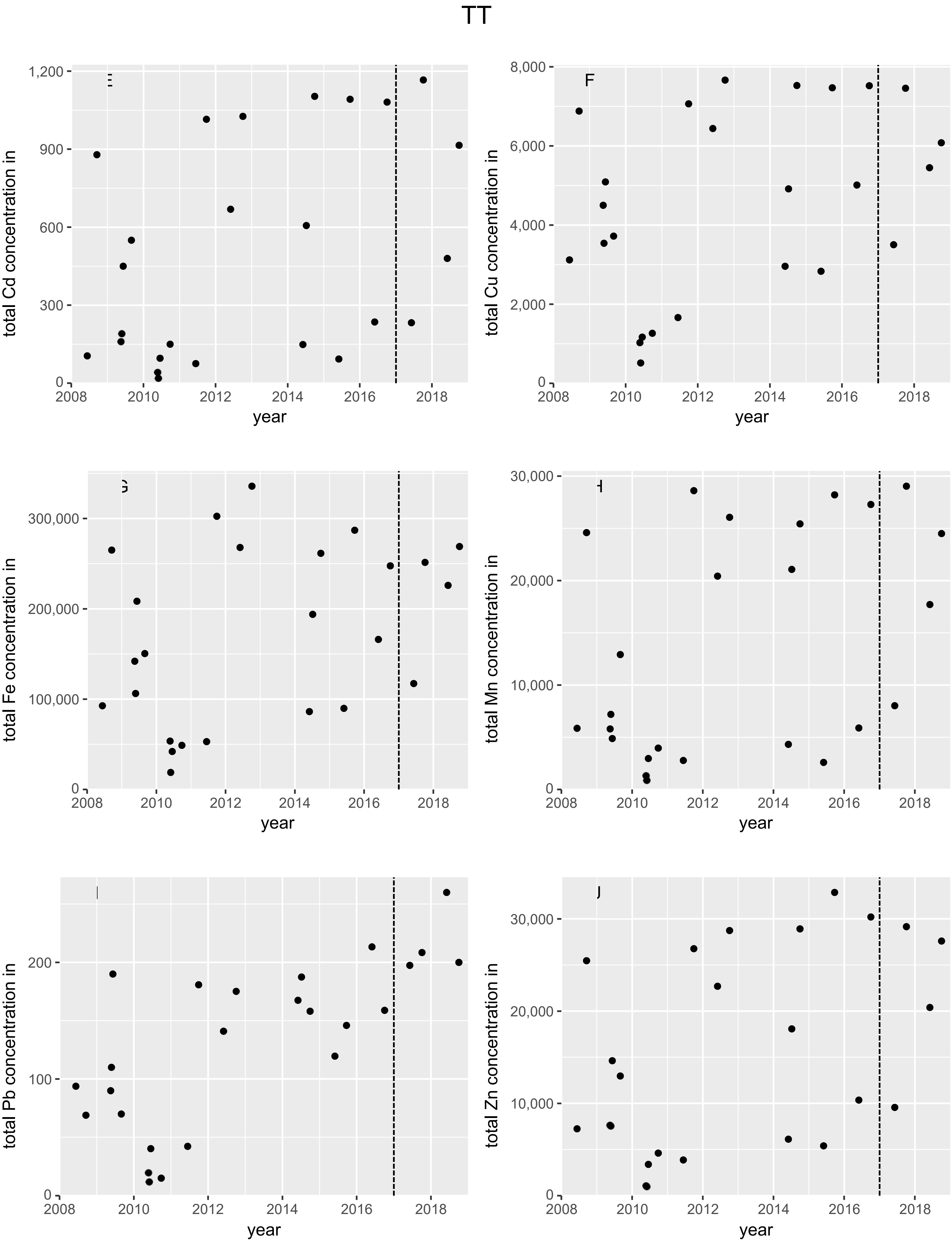

A
pre−
remediation
post−
remediati n
pH standard units
year
B
conductivity in
year
C
total Al concentration in
year
D
total As concentration in
year

LFPW−06



total Cd concentration in
year
total Cu concentration in
year
total Fe concentration in
year
total Mn concentration in
year
total Pb concentration in
year
total Zn concentration in
year


TT
A
pre–
remediation
post–
remediati n
pH standard units
year
B
conductivity in
year
C
total Al concentration in
year
D
total As concentration in
year


TT
total Cd concentration in
total Cu concentration in
total Fe concentration in
total Mn concentration in
total Pb concentration in
total Zn concentration in
year
2008
2010
2012
2014
2016
2018
0
300
600
900
1,200
2,000
4,000
6,000
8,000
100,000
200,000
300,000
10,000
20,000
30,000
100
200
F