Lead-Rich Sediments, Coeur d'Alene River Valley, Idaho: Area, Volume, Tonnage, and Lead Content

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Contents

Tables

Illustrations

Plates

Figures

Abstract

In north Idaho, downstream from the Coeur d'Alene (CdA) silver-lead-zinc mining district, lead-rich sediments, containing at least 1,000 ppm of lead, cover approximately 61 km^2 (or 73 percent) of the 84-km^2 floor of the CdA River valley, from the confluence of its North and South Forks to the top of its delta-front slope, in CdA Lake. Concentrations of lead (Pb) in surface sediments range from 15 to about 38,500 ppm, and average 3,370 ppm, which is 112 times the mean background concentration (30 ppm) of Pb in uncontaminated sediments of the CdA and St. Joe River valleys.

Most of the highest concentrations of Pb are in sediments within or near the river channel, or near the base of the stratigraphic section of Pb-rich sediments. Ranges of Pb concentration in Pb-rich sediments gradually decrease with increasing distance from the river and its distributaries. Ranges of thickness of Pb-rich sediments generally decrease abruptly with increasing distance from the river, from about 3 ± 3 m in the river channel to about 1 ± 1m on upland riverbanks, levees and sand splays, to about 0.3 ± 0.3 m in back-levee marshes and lateral lakes. Thickness of Pb-rich dredge spoils (removed from the river and deposited on Cataldo-Mission Flats) is mostly in the range 4 ± 4 m, thinning away from an outfall zone north and west of the river, near the formerly dredged channel reach near Cataldo Landing. We attribute lateral variation in ranges of thickness and Pb content of Pb-rich sediments to the dynamic balance between decreasing floodwater flow velocity with increasing distance from the river and the quantity, size, density, and Pb content of particles mobilized, transported, and deposited.

We present alternative median- and mean-based estimates of the volume of Pb-rich sediments, their wet and dry tonnage, and their tonnage of contained Pb. We calculate separate pairs of estimates for 23 Estimation Units, each of which corresponds to a major depositional environment, divided into down-valley segments. We favor median-based estimates of the thickness and thickness-interval weighted-average Pb concentration, because uncommonly thick and Pb-rich sections may excessively influence mean estimates. Nevertheless, data from partial sections of Pb-rich sediments are included in most estimates, and these tend to reduce both median- and mean-based estimates.

Median-based estimates indicate a volume of 32 M m^3 of Pb-rich sediments in the CdA River valley, with a dry tonnage of 47 ± 4 M t, containing 250 ± 75 kt of Pb (considering analytical uncertainties only). An equivalent tonnage of dry CdA River valley sediments of the pre-mining era, with the mean background concentration of 30 ppm of Pb, would contain about 1.4 kt of Pb. Thus, the amount of Pb added to CdA River valley sediments deposited since the onset of mining is estimated as 249 ± 75 kt of Pb, or about 99.5 percent of the estimated Pb contained. Of an estimated 850 ± 10 kt of Pb lost to streams as a result of mining-related activities, an estimated total of 739 ± 319 kt of Pb has been deposited in sediments of the South Fork drainage basin, the CdA River valley, and the bottom of CdA Lake (combined). Based on mid-range values from a set of preferred estimates with uncertainty ranges up to ± 50 percent, roughly 24 percent of the 850 ± 10 kt of mining-derived Pb lost to streams has been added to sediments of the South Fork drainage basin, 29 percent to sediments of the CdA River valley floor, and 34 percent to sediments on the bottom of CdA Lake. This amounts to roughly 87 percent of the Pb lost to streams, not including Pb contained in sediments of the North Fork

drainage basin and the Spokane River valley, the tonnages of which have not yet estimated.

Introduction

Background of Study

In 1998 we were asked to provide preliminary estimates of the volume and tonnage of Pb-enriched sediments in the CdA River valley for a National Resource Damage Assessment, being conducted by the U.S. Fish and Wildlife Service (USFWS) and the Coeur d'Alene Tribe. We had been collecting data with the goal of doing such estimates, so we rapidly did preliminary estimates, which were reported by Ridolfi Engineers (2000). Here we present revised estimates, describe the data on which they are based, and explain our estimation methods and results.

Purpose of Report

The primary purpose of this report is to present estimates of the areas, volumes and tonnages of Pb-rich sediments present in the Coeur d'Alene (CdA) River valley, and to explain how those estimates were made. Such estimates are needed to quantify the baseline distribution of Pb-rich sediments in the CdA River valley, and to provide the basis for planning and estimating the costs and effects of alternative suggested remedies.

A subordinate purpose of this report is to present estimates of the tonnage of Pb contained in Pb-rich sediments of the CdA River valley, and of the amount of Pb added by deposition of waste products from upstream mining and milling. Such estimates contribute to a preliminary assessment of the mass balance of Pb lost to streams, versus Pb deposited in sediments. This provides an overall check on the reasonableness of estimates of tonnages of Pb present in the CdA drainage basin.

Location of Study Area

The CdA River drains a large part of the north Idaho panhandle (figure 1). The North and South Forks of the CdA River join near Enaville, Idaho to form the main stem of the CdA River, which meanders about 58 km (36 mi) southwesterly, to CdA Lake (figure 2). The St. Joe River enters CdA Lake south of Harrison, and the Spokane River exits CdA Lake at its northwestern end.

The main body of this report concerns the CdA River valley, which extends from the confluence of its North and South Forks to the mouth of the CdA River, where it enters CdA Lake (figure 2). However, the last part of this report concerns much of the CdA drainage basin, including the southern part of the North Fork drainage basin, all of the South Fork drainage basin, the CdA River valley, and CdA Lake.

Figure 1. Index and location maps showing the Coeur d'Alene River and other major tributary rivers and streams of the Spokane River Basin

Figure 2. Index and location maps, showing selected features of the Coeur d'Alene drainage basin

Hydrologic Infrastructure

Post Falls Dam is on the Spokane River, about 11 km (7 mi) west of the outlet of CdA Lake into the Spokane River at the northwest end of the lake. The existing dam was built in 1906 to supply power for the nearby mines and cities (Woods and Beckwith, 1996). In 1940 the dam was raised 1.5 ft (0.45 m), (Parker, 1942), and since then summer water level has been held at the 2,125 ft (647.7 m) elevation from June until late September. During the summer, therefore, the reservoir impounded by the Post-Falls dam extends from CdA Lake, up the CdA River valley to Cataldo Landing (a river distance of about 47 km, or 29 mi). Thus, there is little or no downstream current in the CdA River during the summer, and summer water level is held artificially high in lateral marshes and lakes that are connected to the river by distributary streams or artificial canals (Bookstrom and others, 1999). Drainage ditches and pumps are used locally to return floodwater to the river from seasonally flooded agricultural fields in the floodplain. Railroad and highway embankments locally enhance natural levees or provide artificial levees, set back from the natural levees.

Disposal and Dispersal of Mining-Derived Wastes

Pb-rich sediments on the floor of the CdA River valley are downstream from the CdA silver-Pb-zinc mining district, most of which lies within an area drained by the South Fork of the CdA River and its tributaries, but part of which extends northward to Prichard Creek and its tributaries, which flow into the North Fork (figure 2). The CdA mining district, which is one of the giant silver-lead-zinc mining districts in the world, has produced about 7 million metric tons (or Megatons, Mt) of Pb (Pb), 3 Mt of zinc (Zn), and 30 thousand t (or kilotons, kt) of silver (Ag), (Long, 1998a). To recover these metals, the mills produced about 109 M t of crushed and pulverized mill tailings, containing over 1 Mt of Pb, and 1 Mt of Zn. About 56 Mt of these tailings, containing an estimated 800 kt of Pb, were discarded directly into creeks that are tributary to the CdA River (Long, 1998b).

Early jig mills recovered only about 50 to 80 percent of the Pb, and none of the zinc contained in the mill feed. Therefore, jig-mill tailings commonly contained up to 5 weight percent of Pb and Zn. The slime fraction of jig tailings, which contained high percentages of ore minerals, was discarded directly into streams, and rapidly washed away. The coarse fraction was discarded separately, and tended to collect near the mill until episodes of high stream flow, when it also was washed down-stream.

Metal-enriched sediments had reached the floodplain of the lower CdA River valley by 1903, when homesteaders near Thompson Lake filed the first lawsuit alleging damages from river disposal of tailings (Long, 2000). Since mining began in 1886, thirteen major floods have inundated the floodplain of the CdA River valley, 26 lesser floods have covered much of the valley floor, and annual spring floods cover much of the lower reach of the valley floor (Stephen Box, unpublished compilation from USGS records). Annual spring snowmelt run-off floods tend to be relatively gradual and prolonged, as CdA Lake over-fills and back-floods the lower valley. By contrast, winter rain-on-snow floods are less frequent but more abrupt. Winter floods are aggressively erosive, because they peak rapidly, when lake level is low, and hydraulic gradient is high.

Progressive adoption and improvement of flotation milling techniques between about 1912 and 1934 gradually increased metal recoveries, which allowed mines to produce larger tonnages of lower-grade ores. As a result, flotation mills discarded increasing quantities of finer-grained tailings with decreasing metal concentrations. Beginning in about 1928 the Bunker Hill and Page mills used tailings-settling ponds, and in 1949 the Dayrock mine, followed by other mine-mill complexes, began to use the sand-sized fraction of tailings as underground stope fill (Long, 1998b). Some mills continued to discard the fine-grained fraction of tailings directly into creeks until 1968, when that practice was prohibited. Before 1968 metal-bearing mill slimes were being discarded into streams at an estimated rate of 2,000 t/day (Hoffmann, 1995), and the South Fork ran "the color of 'dirty dough'" with suspended mill tailings (Rabe and Flaherty, 1974). Below the confluence, muddy South-Fork water mixed with about 4 times its volume of relatively clear North-Fork water to form the CdA River, which ran turbid with suspended sediment contributed mostly by the South Fork.

From 1932 to 1967 a dredge removed metal-enriched sediments from the bottom of the river-channel near Cataldo Landing, and placed it on Cataldo Flats and Mission Flats, forming extensive deposits of dredge spoils. Each summer the dredge excavated an area of about 10 hm^2 (25 acres to a depth of about 6.7 m (22 ft), (Grant, 1952).

Metal-Enriched Sediments

The history of mining, milling, smelting, transportation, and disposal of wastes in the CdA mining district, and the history of flooding in the CdA River valley, have combined to effect dispersal of metal-enriched sediments, which cover most of the floor of the CdA River valley. These metal-enriched sediments are highly enriched in lead, zinc, silver, arsenic, antimony, and mercury, and moderately enriched in copper, cadmium, iron and manganese, relative to median concentrations of those metals in normal sediments of the region, not contaminated by mining wastes (Fousek, 1996).

Metal-enriched sediments of the CdA River valley have alternatively been called *sediment, sediments, soil, or slickens*. The Glossary of Geology (Bates and Jackson, 1978) defines *sediments* as solid materials that have settled down from a state of suspension in a liquid. The singular term "*sediment*" is usually applied to material held in suspension in water or recently deposited from suspension. In the plural, the term "*sediments*" indicates deposits of essentially unconsolidated materials. Soil is the natural growth medium for land plants, the lower limit of which generally coincides with the common rooting of native perennial plants. *Slickens* are defined as extremely fine-grained materials, such as finely pulverized tailings discharged from hydraulic mines, or extremely fine silt deposited by a stream during flood. We prefer the general terms *metal-enriched sediments,* or *Pb-rich sediments.* Locally, metal-enriched sediments are relatively barren of plants (either because they are toxic to plants, or because annual additions of sediment bury small plants). Metal-enriched sediments also are locally thicker than the rooting depths of common native perennial land plants, and they are commonly present in underwater environments, where they are the natural growth medium for water plants. *Metal-enriched sediments* do not fit the definition *slickens* as extremely fine-grained tailings, because they generally consist of mixtures of fine-grained tailings and natural sediments, which locally include sand and gravel.

Metal-enriched sediments are present in a variety of depositional settings in the CdA River valley, as indicated by a digital map of surficial geology, wetlands, and deepwater habitats of the CdA River valley, by Bookstrom and others (1999). Plate 6 of that report shows the extent of the floodplain. Nearly all of the geochemical samples on which we base our estimates of the area, volume, and tonnage of Pb-rich sediments were taken from within that area of recurrent flooding and dispersal of flood-borne sediment. Plate 7 shows water regimes, which indicate predominantly sub-aqueous, sub-aerial, and seasonally sub-aqueous depositional environments. Plate 8 characterizes predominant grain sizes of sediments in different depositional environments. Plates 9 and 10 characterize redox and pH conditions predominant in different environments of sedimentary deposition, storage, and weathering.

Sandy metal-enriched riverbed sediments, analyzed by X-Ray Diffraction (XRD) and Scanning Electron Microscopy (SEM) by Robert Hooper and Brian Mahoney (written communication, 1996) consist of detrital grains of rock-forming minerals (such as quartz, feldspar and mica), accessory minerals (such as pyroxene, magnetite and rutile), non-metallic vein minerals (such as siderite and dolomite), and traces of detrital metallic vein minerals (sulfides such as sphalerite, pyrite, galena and tetrahedrite), and their weathering products, which include cerrussite (lead carbonate), and iron- and manganese-oxy-hydrides in the CdA River valley, but also anglesite (lead sulfate), and traces of plattnerite (lead dioxide, probably from smelter fallout) in sediments of the South Fork, as identified by XRD (Stephen Sutley, written communication, 1996). Freshly deposited over-bank sediment closely resembles riverbed sediments. However, as over-bank sediment weathers in the predominantly oxidizing upland environment of the riverbanks and levees, detrital ore minerals become etched, pitted and dissolved, while clay minerals form by weathering of feldspars and micas, and the resulting sediments become progressively coated and partially cemented by reddish iron- and black manganese-oxy-hydrides, which tend to adsorb Pb as a major component, and Zn as a minor component.

By contrast, metal-enriched sediments deposited and stored under-water, in transitional to reducing environments, such as lateral marshes and lakes, or the riverbed (beneath the uppermost oxidized layer), contain a wide variety of microcrystalline to nano-crystalline Pb- and Zn-bearing phases. Thornburg and Hooper (2001) used Transmission Electron Microscopy (TEM) analysis of grain-coatings and bio-coatings, to identify microcrystalline Pb sulfide, Zn sulfide, and amorphous bio-coatings with highly variable metal sulfide compositions (complex Pb-Zn-Cu sulfides) in samples from transitional and reducing environments. Harrington and others (1998) identified similar sulfides in metal-enriched sediments of CdA Lake, and suggested that they form in-place, as metallic ions, released by reduction of iron- and manganese-oxy-hydrides, react with H_2S, released by sulfate-reducing bacteria. Deposition of these authigenic sulfides removes metal ions from pore water, and retains them in sludge-like sediments. The authigenic sulfides are so fine-grained and poorly crystalline that they have enormous internal and external surface areas, and are much more chemically reactive than detrital sulfides. Therefore, the metals contained in authigenic sulfides probably are significantly more bio-available than the metals in detrital sulfides (Brian Mahoney and Robert Hooper, personal communication, 2001).

Pb-Rich Sediments

We define Pb-rich sediments as sediments that contain at least 1,000 ppm of Pb. That is the threshold Pb concentration for removal of soil from residential areas to protect human health in the Bunker Hill Superfund Site. The 1,000-ppm cutoff concentration for Pb-rich sediment is higher than the 530 ppm-Pb threshold concentration shown to cause observable effects of Pb poisoning in waterfowl that ingest Pb-bearing sediment from the CdA river valley, but lower than the 1,800 ppm-Pb threshold shown to cause waterfowl mortality by Pb poisoning (Beyer and others, 2000). Of the 998 surface samples analyzed, 77.5 percent contain at least 1,000 ppm of Pb.

Normal sediments of the CdA and St. Joe River valleys, deposited before the beginning of large-scale mining and milling, or outside the area covered by mining-derived sediments, contain an average of 30 ppm of Pb ($\pm$ 12 ppm at one standard deviation, based on 96 samples, with Pb concentrations ranging from 7 to 61 ppm). Basal mining-derived sediment of the jig-milling era commonly contains between 5,000 and 30,000 ppm of Pb (figure 13). Pb concentrations of generally decrease up-section, to a rounded average of 3,400 ppm at the surface.

Preliminary Estimates of Quantities of Pb-Rich Sediments

Preliminary estimates of the distribution, volume and tonnage of Pb-rich sediments on the floor of the CdA River valley were needed in the summer of 1998 as the starting point for a Restoration Alternatives Plan (RAP) for the Coeur d'Alene Basin Natural Resource Assessment (NRDA). That plan was prepared by Gearheart and others (1999) for the Natural Resource Trustees, which include the Coeur d'Alene Tribe, the U.S. Department of Agriculture – Forest Service (USFS), and the U.S. Department of the Interior – Fish and Wildlife Service (USFWS), and Bureau of Land Management (USBLM).

The number and spacing of surface samples of CdA River valley sediments, analyzed for Pb, was sufficient to support hand contouring or geo-statistical estimation of surface Pb concentration (Box, unpublished contour maps, 1998; Kern, unpublished geo-statistical map, 1999). However, the number and distribution of thickness and Pb-concentration determinations for stratigraphic sections of Pb-rich sediment were insufficient to support hand contouring or geo-statistical estimation of the thickness, volume, tonnage, and lead content of Pb-rich sediments. We therefore chose a polygonal method of estimation. Available data were not evenly distributed across the floodplain, so we decided that estimation polygons based on depositional settings would be preferable to estimation polygons based on the distribution of data points.

We used the Wetland System Derivative Map, Coeur d'Alene River Valley (plate 3 of Bookstrom and others, 1999) as the basis of a polygonal method for estimation of thickness, volume, and tonnage of Pb-rich sediments. Map units represent generalized depositional settings, which broadly relate to patterns of distribution, deposition and accumulation of Pb-rich sediments. We therefore compiled and averaged data from sites within polygons defined by System-level geologic and wetland map units (plates 1 and 2).

To distinguish down-valley changes in the thickness and lead content of Pb-rich sediments along the river channel, we divided the river channel into eight longitudinal reaches (numbered 0 to 7), most of which are roughly centered on drill transects. To represent along-valley differences in the character of the floodplain and its deposits of Pb-rich sediments, we divided the valley into upper, middle, and lower parts, and the floodplain into 9 segments, as marked on plates 1 and 2, and labeled on figures 3 to 5.

We defined estimation polygons as map-unit polygons (or parts thereof) that are within the area of Pb-rich surface sediments, as defined by a hand-digitized 1,000-ppm-Pb contour, based on geochemical data for about 800 samples of surface sediment. We defined 23 Estimation Units, each comprised of estimation polygons of a given map unit, within a specified river reach, longitudinal part of the valley, or segment of the floodplain. We measured the area of each Estimation Unit within each river reach and floodplain segment. Based on thickness-data points within each Estimation Unit, we calculated the mean thickness and volume of Pb-rich sediments within it. Based on published densities for wet and dry unconsolidated sand and soil, we calculated preliminary estimates of tonnage of wet and dry Pb-rich sediment. We averaged thickness-interval weighted-average Pb-concentration data from within each Estimation Unit, and multiplied it by the corresponding dry tonnage of Pb-rich sediments to estimate tonnage of contained Pb. We added the estimates for each Estimation Unit to estimate the total area, volume, tonnage, and Pb content of Pb-rich sediments in the CdA River valley. Our overall preliminary estimate was that 42 M m^3 of Pb-rich sediments, containing about 350 kt of Pb, are present on the floor of the CdA River valley (Gearheart and others, 1999).

This report includes the data on which the preliminary estimate was based (Gearheart and others, 1999; Ridolfi Engineers, 2000), augmented by additional data gathered later. In the text that follows, we describe methods of sample collection and analysis, and present summaries of statistical data on thickness and Pb content of surface samples and stratigraphic sections of Pb-rich sediment. We describe estimation methods more-fully, and present summaries of revised estimates of the area, thickness, volume, and tonnage of wet and dry Pb-rich sediments in the CdA River valley, and of the tonnage of Pb contained in, and added to those sediments, as a result of mining-related activities in the CdA mining region.

Figure 3. Location map, upper CdA River valley

Figure 4. Location map, middle CdA River valley

Figure 5. Location map, lower CdA River valley

Data Collection Methods

Datasets, Sources and Methods

We compiled sample locations, geochemical data, and measurements of thickness of Pb-rich sediments from several datasets, including those of Bender (1991), Rabbi (1994), Hoffmann (1995), Lejeune and others (1995), Fousek (1996), USEPA (1998), USEPA (1999a, 1999b), Campbell and others (1999), Balistrieri and others (2000), and Box and others (2001). Table 1 identifies each dataset, lists the number of sample sites included, summarizes the sample site location method, sampling method, sample type, sample preparation and digestion procedures, specifies the analytical techniques used, and identifies the laboratory where the chemical analyses were performed. Recognition of these differences makes it possible to judge their possible effects on estimation of the volume and tonnage of Pb-rich sediments, and the tonnage of Pb contained in those sediments.

Table 1. Geochemical Data Sets and Methods of Sampling and Analysis

Sample-Site Location Methods

From 1993 to 1996 Box and others (2001) visually identified field locations of sample sites on 1:24,000-scale USGS topographic maps, referenced to the 1927 North American Datum (NAD 1927). Coordinates of latitude and longitude were manually measured from those maps in degrees, minutes and seconds, arithmetically converted to decimal degrees (to 4 decimal places). We used ARC/INFO® to convert latitude-longitude coordinates to metric Universal Transverse Mercator (UTM) coordinates for zone 11. Locations determined in this way are considered accurate to within about 50 to 150 ft (about 15 to 45 m), depending on the distinctiveness of the site and its distance from features recognized on the ground and on the map.

Bender (1991), Rabbi (1994), and Hoffmann (1995) presented 1:6,250- to 1:25,000-scale maps of their sample locations in lateral lakes. A summary article by Sprenke and others (2000) also included a small-scale map showing their sample locations. We transferred locations of sample sites from the paper maps to on-screen images derived from USGS topographic maps, by measuring proportional distances between corresponding mapped features. We measured coordinates for each site identified on-screen, using ArcView® software, set to meters, Universal Transverse Mercator (UTM), zone 11, 1927 North American Datum (NAD 1927).

USEPA (1999b) included large-scale maps of sample transects across the railroad embankment. The maps indicate distances of transects from railroad mile markers, and distances of samples from the centerline between the railroad tracks. We transferred locations of mile-markers and sample sites to 1:24,000-scale USGS topographic maps (NAD 1927), and measured UTM coordinates from topographic-map grids.

Beginning in 1996 Balistrieri and others (2000), and Box and others (2001) located sample sites with the NAVSTAR Global Positioning System (GPS), Precise Positioning Service (PPS), then available only to US Governmental Agencies. Coordinates of latitude and longitude (referenced to NAD 1927) were measured in degrees and minutes, to three decimal places. Locations determined in this way are considered accurate to within about 10 m (33 ft). USGS drill sites in the river channel had been located previously by tape-and-compass measurement from mapped and marked reference sites on riverbanks. Locations of those reference sites were checked by GPS (PPS) measurement in 1997. Box and others (2001) converted coordinates expressed in decimal minutes to decimal degrees (to decimal 4 places). We used ARC/INFO® to convert these latitude-longitude coordinates to UTM zone 11 coordinates.

LeJeune and others (1995), USEPA (1998), and Campbell and others (1999), determined sample-site coordinates using commercial GPS receivers, differentially corrected for random variations introduced by the military, by comparison with fixed-station receivers. Locations of these sites are considered accurate to within about 15 m (50 ft). LeJeune and others (1995) and Campbell and others (1999) referenced coordinates to NAD 1927. At our request, USEPA (1998) converted UTM coordinates, measured relative to the 1983 North American Datum, to UTM coordinates referenced to NAD 1927.

Fousek (1996) used a commercial GPS receiver, not corrected for random variations introduced by the military, to measure latitude-longitude coordinates of sample sites, which he reported in decimal degrees, to four decimal places, as referenced to NAD 1927. We used ARC/INFO® to convert latitude-longitude to UTM zone-11 coordinates. Most of those locations appeared accurate to within about 100 m (300 ft), but some apparently are less accurate, based on comparisons of sample sample-site locations with sample descriptions or classifications.

Preliminary sample-location maps, plotted from sample coordinates, superimposed on a digital map of surficial geology and wetlands (Bookstrom and others, 1998), showed that many sample coordinates did not match their sample-site descriptions or classifications. For example, some sites within the floodplain, had coordinates that placed them just outside the floodplain. Some samples from sites along the riverbanks, had coordinates that placed them in the river or on the floodplain. We were able to revise misfit coordinates by checking them against a field map or by comparing them to original GPS Coordinates. In some cases it was obvious that one coordinate was correct but the other was not, so we moved the location along its correct coordinate to the nearest site that fit would fit its field description or classification. In other cases, we simply moved the misfit location to the nearest site that would fit its field description or wetland-unit classification. Then we used ArcView® to revise UTM coordinates for the revised locations.

Sampling Methods

Different sampling tools, methods, sampling intervals, and sample sizes were used in different studies, and this can affect the comparability of the resulting data. In most studies, a single sample of surface sediment was collected at each site, from the upper few centimeters (or inches) of mineral sediment, after removing surface vegetation (table 1). However, in studies by LeJeune and others (1995) and USEPA (1999b) a composite sample, consisting of 5 or more sub-samples, was collected from a small area (about 10 m^2) at each site. Composite samples tend to suppress extreme local variations.

Concentration of Pb in sediments commonly increases downward to the base of the section of Pb-rich sediments, beneath which it decreases sharply. Therefore the depth range of a sample interval can seriously affect its Pb content. If a sample interval crosses the contact between Pb-rich sediments and underlying Pb-poor sediments of the pre-mining era, the sample is diluted, and will under-represent the Pb content of the Pb-rich sediment. Thus, in large parts of the floodplain where Pb-rich sediments are less than 1 ft thick, the 2 ft sample intervals used by USEPA (1998) may seriously under-represent the concentration of Pb in the uppermost surface sediments.

Where possible, vertically contiguous depth-interval channel samples were scraped (bottom-to-top) from shovel-cleaned exposures along riverbanks, or on the walls of hand-dug pits on the floodplain. Exposures provide access to sediments in place, which can be seen as they are sampled from bottom to top, so that there is no question of sample loss, or down-section contamination. However, exposures are limited to eroded outcrops along riverbanks and to relatively dry areas, where test pits can be dug and sampled without collapsing. The 1998 USGS sampling was designed to obtain information data on thickness and Pb content of floodplain sediments at minimum cost. To minimize the time spent drying and preparing samples, relatively small samples were taken at about 20 cm depth intervals, starting at the surface (Box and others, 2001).

University of Idaho (U of I) students Bender (1991), Rabbi (1994), and Hoffmann (1995) used either a gravity-drop freeze box, or a piston coring device to sample lateral lake sediments. Box and others (2001) pushed and pounded core tubes into floodplain sediments to obtain many core samples from floodplain sediments. A truck-mounted percussion core drill was used to sample floodplain sediments in Strobl Marsh. A vibro-coring device or a vibrated piston-corer was used to obtain samples of river-channel and lake sediments. In some deep holes, a bucket auger was used to remove sediment samples from the vibro-core tube, so that the tube could be vibrated deeper. USEPA (1998) used a percussion-driven coring device with a secondary vibrator to collect samples from the river channel, floodplain and lateral lakes. Penetration was better than with strongly vibrated vibro- or piston-coring devices, but core recovery was much lower, especially in soft, water-rich lake sediments. By measuring penetration versus recovery, depth corrections were made for core loss. However USEPA (1998) lake-core recovery was poor, and their sample intervals were excessively large. Where their corrected data are drastically different from those from nearby U of I freeze-box or piston-core sites, the U of I data are preferred, because the U of I workers achieved excellent sample recovery.

Ground-penetrating radar (GPR) soundings provide over 330 measurements of thickness of Pb-rich sediments in the river channel (USEPA, 1998). GPR transects were made along previously drilled transects to identify the GPR response of the contact between metal-enriched and underlying pre-mining-era sediments, and to calibrate the GPR instrument for determination of depth to that contact. Near each of seven drill transects, five additional GPR transects were made, two upstream, two downstream, and one along the axis of the river channel. For each GPR transect (across the river channel) we calculated a mean and median thickness of Pb-rich sediments.

Sample Preparation Methods

In several studies, each sample was dried, sieved to < 2 mm (very coarse-grained sand size and smaller), mostly to remove vegetation, such as sticks, grass, and roots. Campbell and others (1999) sieved to < 1 mm (coarse-grained sand size and smaller), to insure elimination of Pb shot. Samples collected in 1993 by Fousek (1996) were sieved to < 180 microns (medium-grained silt size and smaller), to focus on the relatively bio-available size fraction. The chosen size fraction of each sample was homogenized, split to a sub-sample of about 100 g, and pulverized.

Differences in size fractions analyzed can misrepresent the bulk composition if the Pb content of the size-fraction analyzed is much different from that of the bulk sample. For example, most of the Pb in gravel is in its fine-grained fraction. Therefore, the Pb content of a sample of the fine-grained fraction of gravel from the river channel upstream from Cataldo Landing will greatly over-represent the overall concentration of Pb in the bulk of the gravel. However, downstream from Cataldo Landing, nearly all sediment of the CdA River valley is sand-sized or smaller. RCG/Hagler Bailly (now Stratus Consulting) compared analyses of the < 2 mm and < 180-micron fractions of 12 samples from the lateral lakes area of the lower Coeur d'Alene River valley. The finer fraction assayed only 1.7 percent higher even though a stronger digestion was used (Kate

LeJeune, written communication, 2,000). Most of the Fousek (1996) samples that were sieved to < 180 microns are from the floodplain, where silt is a common to abundant component of Pb-rich sediments. It is therefore likely that Pb concentrations of the < 180-micron fraction are similar to that of the corresponding bulk sediment, except perhaps in samples from relatively sandy upland areas along natural levees adjacent to the river.

Sample Digestion Methods

Concentrated nitric acid was a major component of all digestions reported. Perchloric acid, or hydrochloric acid, or both were used in some procedures to promote full digestion of primary detrital sulfide minerals. Hydrofluoric acid was used in 4-acid "total" digestion procedures to promote digestion of silicate minerals. If a significant fraction of the lead in Pb-rich sediments of the CdA River valley were held sulfide or silicate minerals, resistant to digestion by concentrated nitric acid, then assays based on 4-acid digestions would be significantly higher than those based on nitric-acid digestions. To test this possibility, Box and others (2001) compared assays of 29 CdA River-valley samples, analyzed by both ACZ, Inc., using concentrated nitric acid digestion, and by XRAL, Inc., using 4-acid digestion. Both laboratories used the same method to analyze the samples for Pb. Assays from the nitric acid digestion were slightly higher than those from the 4-acid digestion, as shown by a linear regression of ACZ versus XRAL assays ($y = 1.036\ x$, with $R^2 = 0.998$). However, that minor difference was within the range of variation for analyses of duplicate samples of some of the same samples by XRAL, Inc. ($y = 1.049\ x$, and $R^2 = 0.994$). Therefore, no significant difference was found between analyses for Pb based on digestion by concentrated nitric acid versus analyses for Pb based 4-acid digestion. This indicates that nearly all of the lead in Pb-rich sediments of the CdA River valley is in forms that are digested by concentrated nitric acid, which suggests that detrital galena is uncommon, and that silicate minerals, which are abundant in the sediments, have very low Pb concentrations.

Chemical Analytical Methods

Bender (1991), and Rabbi (1994) used Flame Atomic Absorption Spectroscopy (FAAS) to analyze CdA sediment samples for Pb and other metals. Arthur Horowitz also used FAAS to analyze sediment samples collected in 1992 by Fousek (1996), and samples collected by Balistrieri and others (2000). James Lindsay and Bi-Shea King used Energy Dispersive X-Ray Fluorescence Spectroscopy (EDXRF) to analyze the 1993 USGS samples of Box and others (2001) for Pb. Mohammed Ikramuddin, of Eastern Washington University (EWU) used 4-acid digestion and Inductively Coupled Plasma – Mass Spectroscopy (ICP-MS) to analyze most of the USGS samples of Box and others (2001). XRAL Laboratories used 4-acid digestion and ICP- Atomic Emission Spectroscopy (ICP-AES) to analyze USGS samples taken in 1998 (Box and others, 2001). ACZ Laboratories, Inc. used concentrated nitric acid digestion and ICP-AES to analyze USFWS samples (Campbell and others, 1999).

Accurate analyses for Pb can be done by any of these methods, provided the Pb is completely digested, and the analytical devices are properly calibrated for the range of concentrations present in the samples. Box and others (2001) compared analytical results for Standard Reference Materials (SRMs) analyzed by EWU, USGS (EDXRF), XRAL, and ACZ laboratories to mean total values certified by the National Institute of Standards and Technology (NIST) for those materials. Mean Pb recoveries by EWU for two NIST SRMs with certified Pb concentrations of 1162 and 5532 ppm were 98.9 and 101.6 percent, with precisions (variations from the mean at the 95 percent confidence level) of 3.2 to 4.3 percent for analyses of 8 splits of each material. Mean Pb recoveries by XRAL for the same two NIST SRMs were 99.0 and 94.8 percent. XRAL precision was 9.7 to 12.4 percent for analyses of 15 to 16 splits of two USGS SRMs. Mean ACZ recoveries for the same two NIST SRMs were 83.7 and 92.4 percent. Although Pb recoveries by ACZ were significantly lower for NIST samples, they slightly exceeded XRAL recoveries for splits of samples from the CdA River valley. This indicates that the concentrated nitric acid digestion used by ACZ did not digest 8 to 16 percent of the Pb in the NIST samples, but it did digest essentially all of the lead in samples of Pb-rich sediment from the CdA River valley.

Lead in Surface Sediments

Frequency Distribution of Lead in Surface Sediments

As shown by the frequency diagram in figure 6, Pb concentrations in 998 samples of surface sediment from the floor of the CdA River valley range from 15 to 38,500 ppm Pb, and average 3,371 ppm Pb. About 78 percent of the samples contain over 1,000 ppm Pb and average 4,245 ppm Pb, which is about 141 times the mean background concentration (30 ppm Pb). The remaining 22 percent of the samples contain less than 1,000 ppm Pb and average 347 ppm Pb, which is about 12 times the mean background concentration (30 ppm Pb).

Spatial Distribution of Lead in Surface Sediments

Plate 1 shows the spatial distribution of 998 samples of surface sediment in the context of depositional environments, represented by Wetland System map units. A circular marker for each sample is coded by size and color to indicate its Pb concentration by ppm class (for example, 1,000 to 1,999 ppm Pb). ArcView® software can be used to identify any sample point and find its Pb concentration in the database table that accompanies the map.

Area of Pb-Rich Surface Sediments

A 1,000-ppm-Pb contour was hand-digitized to include sample sites with at least 1,000 ppm of Pb in surface sediment, and exclude sample sites with less than 1,000 ppm of Pb in surface sediment. The stippled area on plate 1 represents the area of Pb-rich surface sediments (within the 1,000-ppm-Pb contour). That area is 61.20 km^2, as measured digitally from the map, using ArcView® software, or 61.27 km^2, as estimated by kriging (John Kern, unpublished data, 1999). The total area of the floodplain is approximately 85 km^2. Thus, about 72 percent of the surface area of the floodplain is covered by Pb-rich sediment, containing at least 1,000 ppm of Pb.

Figure 6. Frequency diagram for concentration of lead in surface sediments

Lateral Variation of Lead Concentration in Surface Sediments

Figure 7 represents the lateral distribution of lead in surface sediments as a function of lateral distance from the river. The shape of each symbol indicates the wetland-system map unit, or depositional environment of the sample site it represents. Sample sites from the entire study area appear in one diagram, the horizontal axis of which represents distance from either side of the river. In general, the range of concentrations of Pb in surface sediment decreases gradually with increasing distance from the river and its distributaries. Similarly, the range of Pb-concentrations in surface sediment generally decreases from riverine, to upland, to palustrine and lacustrine depositional environments, which generally lie or extend progressively farther from the river in that order.

A least-squares linear regression for Pb concentration versus distance from the river intercepts the river at 4,023 ppm, and decreases toward 0 at about 3 km from the river, but its coefficient of determination ($R^2 = 0.0945$) indicates that it accounts for only about 9.5 percent of the variation. An exponential curve, which intercepts the river at 2,880 ppm, and decreases asymptotically toward about 500 ppm at 2.7 km from the river, accounts for about 13 percent of the data. These trends were fitted using Excel® software.

We attribute most lateral changes in the concentration of lead in Pb-rich sediments to the dynamic interplay between decreasing floodwater flow velocity with increasing distance from the river, and the quantity, size, density, and lead content of particles mobilized, transported, and deposited during floods. Local differences in hydrologic setting (between the outside and inside margins of meanders, for example), and differences between rising and falling stages of spring and winter floods (of different magnitudes and durations) increase the randomness of Pb distribution within any given range of distance from the river. Current velocity, grain size, and density are particularly important in separating sand- and silt-sized particles, carried over levees as suspended bed-material load, in the lower part of the water column, and settling in order of decreasing hydraulic equivalency, as current slackens. Powdery sediment, carried in wash-load suspension throughout the water column, settles more gradually and ubiquitously, leaving a fine coating of muddy (to dusty) Pb-rich sediment, as floodwaters recede. After flooding, such coatings are easily redistributed by wind or rainwater runoff. Along the outer margins of the floodplain, clean suspended sediment, delivered by tributary streams and slope-wash from hillsides bordering the floodplain, may mix with flood-borne Pb-rich sediment, diluting Pb concentrations in sediment deposited there.

Figure 7. Scatter diagram, showing ppm Pb in surface sediments vs. distance from river

Thickness of Pb-Rich Sediments

Thickness Determination

Semi-quantitative Pb-determination methods were sometimes used in the field to indicate to samplers whether they had reached the base of the section of Pb-rich sediments. Merckoquant® (10077) Pb-test kits for the detection and semi-quantitative determination of Pb ions were used successfully to identify the base of the section of Pb-rich sediments in wet environments, but were less dependable in sediments of dry, oxidizing environments. Field XRF instruments were used successfully to identify the base of the section of Pb-rich sediments in all environments. However, because of matrix effects (such as grain-size mineralogy, and water content), Pb concentrations estimated by field XRF generally are lower than those measured by laboratory methods, including XRF on dried and pulverized samples. In the 1994 XRF dataset, field XRF measurements were used to estimate thickness of Pb-rich sediments, without determination of thickness-interval weighted-average Pb concentration for the section of Pb-rich sediments.

To determine the thickness of a section of Pb-rich sediments, we first compiled results of analyses for Pb in successive depth intervals sampled. Then we marked the 1,000-ppm cutoff at the base of the deepest interval of a vertically continuous group of sample intervals containing at least 1,000 ppm Pb. In the rare situation where a sample contained less than 1,000 ppm of Pb, but the next-deeper sample or samples contained a sufficient excess (over 1,000 ppm) to exceed the deficit, we included the Pb-deficient interval, and marked the cutoff at the base of the deeper sample interval(s), containing at least 1,000 ppm of Pb. The total thickness of sediments above the cutoff concentration was taken to indicate the thickness of Pb-rich sediments at the site. Full thickness was determined for sites where the base of the section of Pb-rich sediments was reached and sampled. Partial thickness was determined for sites where the base of the section of Pb-rich sediments was not reached or sampled.

The exactness of measurements of thickness of Pb-rich sediments is limited by the sample interval used in sample collection and analysis. The 2-cm assay interval used by Bender (1991), Rabbi (1994), and Hoffmann (1995), of the University of Idaho, provides the most exact thickness data, whereas the large sample intervals used by USEPA (2 to 4 ft) provide the least exact data on thickness of Pb-rich sediments. In addition to being inexact, such large intervals may be misleading, in that a thinner layer of Pb-rich sediments may be diluted, so that the entire interval appears to contain less than 1,000 ppm of Pb, whereas its upper part may contain over 1,000 ppm of Pb.

The accuracy of measurements of thickness of Pb-rich sediments made from drill core is limited by the percentage of core recovery, as indicated by the difference between core recovered and depth penetrated. Incomplete core intervals can be corrected to equal penetration intervals, however the exactness of the correction depends on the correct correlation of recovery intervals with depth intervals. Where the recorded penetration intervals are larger than the thickness of Pb-rich sediments, the “corrected” recovery intervals exaggerate the thickness of Pb-rich sediments.

Dredge-spoil deposits at Cataldo Flats are so thick at their eastern end that they were not penetrated by available drilling methods. Hand-level traverses from the river were used to measure the elevation of the upper surface of the dredge spoil deposits with respect to summer water level of the river. The bottom surface of the dredge spoils was assumed to be at about summer water level, so dredge-spoil thickness was estimated as the difference between their top-surface elevation and the summer water-surface elevation of the river. At the thin down-valley edge of the dredge-spoil deposits, we measured dredge-spoil thickness from core holes and test pits. In intermediate areas, we estimated dredge-spoil thickness by interpolation.

Bank-wedge deposits of Pb-rich sediments extend from the riverbank the crest of the natural levee on each side of the river. These deposits generally thin from riverbanks toward levee tops. Most thickness measurements were made at riverbank exposures, but a few were made where the riverbank had eroded nearly to the crest of its natural levee, or in test pits near the crest of the natural levee. Where both riverbank and levee-top measurements are available, the average thickness of the bank-wedge deposit is about 70 percent of the thickness at the riverbank. We therefore multiplied riverbank thickness measurements by 0.70 to estimate average the average thickness of corresponding bank-wedge deposits.

Measurements of partial-thickness were made where the bottom of the section of Pb-rich sediments was not exposed, or was not penetrated by drilling. Nearly all river-channel sections used in the estimation represent total thickness of Pb-rich sediments. However, 49 percent of the sections measured along riverbanks represent partial thickness, as do 40 percent of the dredge-spoil sections, and 31 percent of the floodplain sections. Measurements of partial thickness were included in the data on which estimates of volume and tonnage of Pb-rich sediments are based, because their exclusion would eliminate many of the thickest measured sections, which were not completely exposed or penetrated. Fousek (1996) only sampled to 15 cm at most floodplain sites, but these measurements were included, because they indicate that Pb-rich sediments are at least that thick at those sites.

Plate 2 shows the spatial distribution of sites where thickness of Pb-rich sediments was determined or estimated. Symbol shapes indicate whether the full or partial thickness is represented, and how the section was measured or estimated. Symbol sizes and colors indicate thickness of Pb-rich sediments by class (30 to 59 cm, for example). ArcView® software can be used to identify any sample site in the database table that accompanies the map, and indicate the thickness of Pb-rich sediments at that site.

Across-Valley Variation in Thickness of Pb-Rich Sediments

Figure 8 is a scatter diagram showing variation in thickness of full sections of Pb-rich sediments with increasing lateral distance from the river. Symbol shapes indicate depositional settings, as represented by the wetland system map units in which they are located. The range of thickness of Pb-rich sediments generally decreases abruptly with increasing distance from the river. Distance from the river channel generally increases from riverbanks, to levee uplands, to back-levee marshes and lateral lakes. Thus, ranges of thickness of Pb-rich sediments generally decrease from mostly 3 $\pm$ 3 m in the river channel, to mostly 1 $\pm$ 1 m on proximal riverbanks, and upland levees and sand splays, to mostly 0.3 $\pm$ 0.3 m in distal lateral marshes and lakes. We attribute most lateral decreases in ranges of thickness of Pb-rich sediments to the dynamic balance between decreasing floodwater flow velocity with increasing distance from the river, and the quantity, size, and density of particles mobilized, transported, and deposited.

Within each of these depositional environments, however, thickness variation is mostly random. Nevertheless, figures 9 to 12 display least-squares regression lines, and alternative logarithmic, exponential, or polynomial curves that best fit the highly random data. Although they account for small percentages variation, they hint at weak patterns of distribution of thickness of Pb-rich sediments versus distance from the river.

Figure 9 indicates that the thickness of sandy, Pb-rich dredge spoils decreases exponentially with distance from the river -- from about 7 m thick at about 130 m from the river, to 24 cm thick at about 1 km from the river. An exponential curve explains almost 90 percent of the variation in data for dredge-spoil thickness versus distance from the river. The thickest part of the dredge-spoil deposit probably indicates the zone of maximum outfall from a moveable radial dredge pipe, with multiple outlets, which probably moved across a broad arc, mostly between about 50 and 250 m from the river.

Figure 10 shows that thickness of predominantly sandy, Pb-rich sediments in upland environments such as levee back-slopes, sand splays and distributary levees, tends to decrease logarithmically with increasing distance from the river. However, the fitted logarithmic curve accounts for only about 19 percent of the variation in thickness of upland Pb-rich sediments, the rest of which appears quite random.

Figure 11 indicates that thickness of predominantly silty Pb-rich sediments deposited in palustrine environments of lateral marshes shows mostly random variation with increasing distance from the river. Thickness varies mostly between 15 and 70 cm. Linear and logarithmic trends show gradually decreasing thickness with increasing distance from the river. However, each of the fitted trends accounts for only about 1 percent of the data, and the rest appear quite randomly distributed with respect to distance from the river.

Figure 12 indicates that thickness of Pb-rich sediments in lacustrine environments of lateral lakes shows mostly random variation with increasing distance from the river. Thickness varies mostly between 8 and 67 cm. A linear regression only accounts for about 9 percent of the variation. A convex polynomial curve accounts for about 15 percent of the variation. This hints that thickness of Pb-rich sediments in lateral lakes may tend to increase from riverward shores to about 1 km from the river, and decrease from there to surrounding shores. As shown in plate 2, relatively thick sections of Pb-rich sediments are present near the ends of some inlet channels, which connect the river to most lateral lakes. These thick sections probably represent inlet deltas, which commonly are as much as 1 km of the river, as mapped and described by Bookstrom and others (1999).

The randomness of thickness of Pb-rich sediments within proximal riverbanks and uplands probably results from wide range of locally and temporally variable currents during rising and falling limbs of relatively gradual and prolonged spring floods and relatively sudden and erosive winter floods. By contrast, the highly random distribution of thickness of Pb-rich sediments versus distance from the river in relatively distal back-levee marshes and lateral lakes probably results from widely and randomly distributed fallout of very fine-grained wash-load sediment, which gradually settles out of suspension and ubiquitously coats surfaces with muddy Pb-rich sediment as floodwaters recede. This thin muddy coating is very susceptible to post-flood redistribution, by wind, after it dries to dust, or by rainwater runoff.

Figure 8. Scatter diagram, showing thickness of Pb-rich sediments vs. distance from river

Figure 9. Scatter diagram, showing thickness of Pb-rich dredge spoils vs. distance from river

Figure 10. Scatter diagram, showing thickness of upland Pb-rich sediments vs. distance from river

Figure 11. Scatter diagram, showing thickness of palustrine Pb-rich sediments vs. distance from river

Figure 12. Scatter diagram, showing thickness of lacustrine Pb-rich sediments vs. distance from river

Down-Valley Variation in Thickness of Pb-Rich Sediments

Vertical sections of Pb-rich sediments vary in thickness down-valley within each major wetland-system map unit, as shown in table 2, which lists summary statistics for thickness of Pb-rich sediments on the floor of the CdA River valley. The summary statistics in table 2 are based on 660 measurements or estimates of full or partial (minimum) thickness of Pb-rich sediments, in depositional settings represented by Estimation Units of river reaches and floodplain segments of the upper, middle and lower parts of the CdA River valley.

Thickness of sandy Pb-rich sediments in the river channel varies widely (from 0 to 836 cm), both across the channel and down the river. Across-channel variation in thickness of Pb-rich sediments varies relative to meander bends. Point-bar deposits of Pb-rich sediments are present along the lower inside margins of meander bends, whereas Pb-rich sediments are absent from the lower outside margins of meander bends. Along relatively straight reaches, Pb-rich sediments partially fill the river channel, forming a relatively flat bottom, with steep sides of pre-mining era sediment, capped by bank-wedge deposits of Pb-rich sediments. Dunes up to about 1 m high are present in Pb-rich sand on the river bottom, along reaches where flow is relatively rapid during some floods.

Median thickness of Pb-rich sediments varies down-river by reach, from 3.00 m in reach 1, increasing to a maximum of 3.84 m in reach 2, and then decreasing down-river to 3.21 m in reach 3, to 2.84 m in reach 4, to 2.26 m in reach 5, and to 1.65 m in reach 6. Corresponding mean thickness values for each river reach are given in table 2. Median values for thickness of Pb-rich sediments in the river channel range from 89 to 114 percent of mean values. The maximum thickness of Pb-rich sediments in river reach 2 may represent an excess accumulation of sediments, which are being scoured and transported farther down-valley. We observed several examples of scoured exposures of stratified Pb-rich sediments along river reach 2 after the 100-year flood of February 1996. At the river-mouth bar thickness of Pb-rich sediments increases to 574 cm, where a plume of thermally buoyant river enters CdA Lake, and begins to spread, and lose velocity.

Thickness of Pb-rich sand and silt of riverbank-wedge deposits ranges from 4 to 216 cm, depending on how much was deposited between the riverbank and the levee top, and how much of it has subsequently been removed by lateral erosion. Mean thickness of bank-wedge deposits generally decreases down-river, from 103 cm for reaches 0 and 1, to 49 cm for reaches 5 and 6. Median values for thickness of Pb-rich sediments in bank-wedge deposits are 78 to 96 percent of mean values, which indicates that the distribution of thickness is somewhat skewed, and that relatively thick sections have somewhat disproportionate influence on the mean of thickness.

Thickness of sandy Pb-rich dredge-spoils generally varies from 15 to 702 cm, but is up to 1,100 cm thick along narrow dikes and highway embankments, where dredge spoils have been used as construction fill. Excluding dikes and embankments, the median of dredge-spoil thickness is 1.61 m, whereas the mean thickness is 2.25 m. This significant difference between the median and mean dredge-spoil thickness indicates that the distribution of thickness of dredge-spoil deposits is significantly skewed, and that relatively thick sections excessively influence the mean of thickness.

Table 2. Thickness of Pb-Rich Sediments, Summary Statistics

Thickness of Pb-rich sand and silt in upland deposits (levees of the river and its distributaries, and crevasse splays), varies from 10 cm to > 210 cm. Mean thickness of upland deposits is 65 cm for the upper valley segment, 62 cm for the middle valley, and 39 cm for the lower valley segment. Median values are 47 to 75 percent of mean values, which indicates that upland deposits of Pb-rich sediments have strongly skewed distributions, and that relatively thick sections excessively influence the mean of thickness.

Thickness of organic-rich silty, Pb-rich sediments in palustrine deposits of back-levee marshes varies from 1 to 200 cm. Mean values for thickness of Pb-rich sediments in palustrine environments decrease from 44 cm in the upper valley, to 15 cm in the middle and lower valley segments. Median values are 68 to 83 percent of mean values. This indicates that distributions of thickness of palustrine deposits are skewed, and that relatively thick sections disproportionately influence the mean of thickness.

Thickness of Pb-rich sediments in lacustrine deposits of lateral lakes varies from 1 cm to 122 cm. Thickest accumulations of sandy to silty sediments are in and around inlet deltas mapped by Bookstrom and others (1999). Elsewhere, thinner deposits of silty to muddy Pb-rich sediments are widely distributed across the bottoms of lateral lakes. Median thickness of Pb-rich sediments in lateral lakes varies from 18 cm in the upper valley, to 34 cm in the middle valley, and 14 cm for the lower valley. Median thickness values are 99 percent of mean values in the upper valley, indicating normal distributions in lakes that are far from the river, and relatively disconnected from it. Median thickness values are 89 percent of mean values in the middle valley, and 71 percent of mean values in the lower valley. Thus, thickness distributions in lateral lakes are progressively more skewed with increasing distance down-valley, where lateral lakes are progressively closer to the river. This suggests that relatively distal lakes in the upper valley receive much of their Pb-rich sediment as wash load, which settles more-or-less randomly over the bottom surface of the lake. By contrast, relatively proximal lakes of the lower valley probably receive a greater proportion of their Pb-rich sediment via distributaries, as bed-material load, which settles progressively with increasing distance from the river or the distributary mouth and its inlet delta.

Lead Concentration Profiles in Sedimentary Sections

Vertical profiles of lead concentration in sedimentary sections of Pb-rich sediments commonly have a Pb-rich basal zone, deposited early in the history of mining and milling, when jig-mill recoveries of Pb were poor, and tailings were Pb-rich. Basal Pb-rich sediments commonly contain between 5,000 and 30,000 ppm of Pb (figure 13). As the flotation process was adopted, metal recoveries improved with time, concentrations of Pb in tailings decreased, but the output of tailings increased, as larger tonnages of lower-grade ore were processed. Thus, Pb concentrations generally decrease up-section (figure 13) to an average of about 3,400 ppm in surface sediments (figure 6).

Figure 13. Lead-concentration profiles for sedimentary sections of Pb-rich sediments

Figure 14. Frequency diagram of thickness-weighted-average lead concentration

Figure 15. Scatter diagram, showing thickness-weighted-average ppm Pb vs. distance from river

Thickness-Weighted-Average Lead Concentration

We calculated the thickness-interval weighted-average concentration of lead in each section of Pb-rich sediments by multiplying the Pb concentration of sediments in each depth interval by the thickness of the interval sampled, and then dividing the total of the resulting products by the total thickness of Pb-rich sediments in the section. Weighted average concentration of Pb in full sections of Pb-rich sediments ranges from 1,000 to 22,103 ppm, and averages 5,101 ppm, as shown by the frequency diagram and summary statistics in figure 14. Thus, the mean of weighted average Pb concentration of full sections of Pb-rich sediments is about 170 times the mean background concentration of lead (30 ppm) in uncontaminated sediments of the CdA and St. Joe River valleys.

Across-Valley Variation of Thickness-Weighted-Average Lead Concentration

Figure 15 illustrates that the range of thickness-interval weighted-average Pb concentration in full sections of Pb-rich sediments generally decreases with increasing lateral distance from the river (figure 15). A linear regression slopes gradually with increasing distance from the river, but only accounts for about 2 percent of the variation. A sub-parallel but somewhat lower exponential trend accounts for only marginally more of the variation (about 4 percent), most of which is random. Nevertheless, plots of thickness-interval weighted- average Pb concentration for sections of Pb-rich sediments versus distance from the river in upland, palustrine, and lacustrine environments hint at subtle patterns.

Figure 16 indicates that in upland deposits, thickness-weighted average Pb concentration (in full sections of Pb-rich sediments) ranges from about 1,000 to 10,000 ppm and is quite randomly distributed with respect to distance from the river. Nevertheless, an upward convex polynomial curve accounts for about 5 percent of the variation, which is nearly 9 times as much of the variation as a linear regression that slopes away from the river. This hints that thickness-weighted average Pb concentrations may tend to increase with increasing distance from the river to about 100 m from the river, beyond which they tend to decrease. This apparent tendency may result from a complex interplay between floodwater velocity and the quantity, size, density, and Pb content of mineral grains transported in and deposited from bed-material load, as floodwater spreads onto the floodplain and loses velocity. Only three full sections of Pb-rich sediments were sampled outside the 200-m wide belt of levee back-slope deposits. One section on a low alluvial terrace in the floodplain upper valley averaged nearly 8,000 ppm of Pb. A section in a distributary levee averaged about 22,000 ppm of Pb, and a section in a sand splay averaged about 5,000 ppm of Pb.

Figure 17 indicates that in palustrine deposits of back-levee marshes, the highest weighted-average Pb concentrations (in full sections of Pb-rich sediments) tend to decrease with increasing distance from the river, from about 13,000 ppm at 120 m from the river to about 5,400 ppm at about 2.5 km from the river. A linear regression slopes gradually away from the river, but explains about 11 percent of the variation. A power regression, which explains 24 percent of the variation, slopes steeply from 7,000 ppm at 100 m from the river, but flattens progressively with increasing distance from the river, and asymptotically approaches 2,200 ppm at about 2.5 km from the river.

Figure 18 indicates that in lacustrine deposits of lateral lakes, weighted average Pb concentrations of full sections of Pb-rich sediments vary from about 2,000 ppm to 15,000 ppm, and are nearly randomly distributed with respect to distance from the river. A linear regression, which slopes almost imperceptibly away from the river, accounts for only about 0.5 percent of the variation. A slightly sagging polynomial curve accounts for only about 3 percent of the variation, but the sag of this curve generally corresponds to the high part of the sediment-thickness curve, which probably represents deltaic deposits at the mouths of inlet distributaries and canals. These relatively sandy deposits may have somewhat lower concentrations of Pb than finer-grained lake-bottom sediments, which consist mostly of silty mud.

Figure 16. Scatter diagram, showing thickness-weighted Pb concentration in upland Pb-rich sediments, vs. distance from river

Figure 17. Scatter diagram, showing thickness-weighted Pb concentration in palustrine Pb-rich sediments, vs. distance from river

Figure 18. Scatter diagram, showing thickness-weighted Pb concentration in lacustrine Pb-rich sediments, vs. distance from river

Down-Valley Variation of Thickness-Weighted-Average Lead Concentration

River-channel deposits of Pb-rich sediments have medians of thickness-interval weighted-average Pb concentrations that vary down-valley from 2,315 ppm in reach 1, to 9,221 ppm in reach 2, to 5,286 ppm in reach 3, to 9,138 ppm in reach 4, to 6,608 ppm in reach 5, and to 7,404 ppm in reach 6 (table 3). Medians are 91 to 99 percent of means, indicating nearly normal distributions, in which the means are only slightly unduly influenced by uncommonly high Pb concentrations.

The relatively low 2,215-ppm median Pb concentration of river-channel sediments of reach 1 corresponds to relatively coarse sand, which has filled the former dredge pond. This occurred after dredging ceased in about 1967, but before aerial photographs were taken in 1975, which show a large central sand bar at the site of the former dredge pond. Drill cores from the sand bar indicate about 2.5 to 5 m of Pb-rich sand, with no basal zone of very high Pb concentration, probably because basal jig-era sediments were removed by dredging, and replaced with flotation-era sand. Dredging removed sand that settled where the river gradient flattens. However, most finer-grained sediment probably was transported farther down the river. Much of it apparently was deposited in reach 2, where thickest section of Pb-rich sediments (836 cm) and the section with the maximum thickness-weighted Pb concentration (20,844 ppm of Pb) are both located.

Riverbank-wedge deposits have weighted-average Pb concentrations for sections of Pb-rich sediments that range from 1,563 ppm to 16,212 ppm. Median weighted-average Pb concentrations for bank-wedge sections maximize at 5,495 ppm Pb along reach RBW 2, and decrease down-valley to 4,571 ppm for reaches RBW 5 and 6. Ratios of medians to means increase down-river, from between 0.66 and 0.69 for reaches RBW 0 to 2 (where bank-wedge deposits are high, narrow, abruptly tapered, variably complete, and variably eroded) to 0.78 for reaches RBW 3 and 4, and 1.08 for reaches RBW 5 and 6 (where bank-wedge deposits are progressively lower, wider, more gradually tapered, less incomplete, and less variably eroded).

Table 3. Thickness-Weighted-Average Lead Concentration in Pb-Rich Sediments, Summary Statistics

Upland deposits have median weighted-average Pb concentrations of 3,820 ppm in the upper valley, 5,408 ppm in the middle valley, and 3,633 ppm in the lower valley Medians range from 83 to 93 percent of means, and are lowest relative to the highest mean, suggesting that a few high values strongly influence the middle-valley mean.

Palustrine deposits have median weighted-average Pb concentrations that decrease down-valley of 5,083 ppm in the upper valley, 4,417 ppm in the middle valley, and 2,875 ppm in the lower valley. Medians range from 67 to 95 percent of means, and are lowest relative to the highest mean, suggesting that a few high values strongly influence the mean for the middle valley.

Lacustrine deposits of lateral lakes have median weighted-average Pb concentrations of 2,815 ppm in the upper valley, 6,663 ppm in the middle valley, and 5,386 ppm in the lower valley. Medians are 96 to 100 percent of means, indicating nearly normal distributions in the sub-aqueous depositional environments of lateral lakes.

Revised Estimation of Volume, Tonnage, and Lead Content of Pb-Rich Sediments

We have revised our preliminary estimates of the volume, tonnage, and Pb content of Pb-rich sediments on the floor of the CdA River valley. We have used the definitions of Estimation Units that we used in making our preliminary estimates, but we have changed some of the areas included, based on additional data. We have based estimates of sediment density on measured characteristics of sediments in representative depositional settings of the CdA River valley, rather than on published densities for generally similar materials. Our preliminary estimates were based entirely on mean (average) values for thickness and thickness-weighted average Pb concentration. In our revised estimation scheme, we calculated median (50th percentile) as well as mean values for thickness, density, and thickness-weighted average Pb concentration, in order to provide alternative median-based and mean-based estimates of the volume, wet and dry tonnage, and lead content of Pb-rich sediments.

Differences between medians and means indicate skewed distributions. For example, in deposits where thickness decreases asymptotically with increasing distance from the river (as in dredge-spoil and upland deposits), the mean may be strongly influenced by very thick sections close to the river, and the mean therefore exceeds the median. Similarly, in deposits where weighted-average Pb concentration decreases asymptotically with increasing distance from the river (as in palustrine deposits), the mean exceeds the median. Means and medians for thickness of Pb-rich sediments can also be biased as a result of uneven sampling. For example, in any Estimation Unit where observations of thick deposits near the river are more abundant than those of thinner, less Pb-rich deposits farther from the river, the resulting means, and to a lesser extent, medians will tend to be positively biased.

Inclusion of data from basally truncated partial sections of Pb-rich sediments tends to negatively bias means, and to a lesser extent, medians of thickness and weighted average Pb concentration of Pb-rich sediments. Summary statistics in table 2 indicate partial thickness determinations at 2 percent of river-channel sites, 49 percent of bank-wedge sites and 31 percent of floodplain sites. Summary statistics in table 3 indicate determination of weighted-average Pb concentration from partial sections at 29 percent of river-channel sites, 26 percent of riverbank sites, and 34 percent of floodplain sites.

Further improvement of estimation accuracy would require substantially more determinations of the full thickness and thickness-weighted average Pb concentration of sections of Pb-rich sediments. These should be pervasively and evenly distributed. With sufficient data distribution, geo-statistical methods such as kriging could be applied to optimize estimation accuracy, and estimate variance at chosen confidence intervals (Barnes, 1980).

Estimation Equations

Estimation of volume and tonnage of Pb-rich sediments, and tonnage of contained Pb is based on three equations:

1. Volume of sediments (m_{sed}^3) = area (m_{sed}^2) x thickness of sediments (m_{sed});
2. Tonnage of dry sediments (t_{sed}) = volume (m_{sed}^3) x density (t_{sed}/m_{sed}^3) of dry sediments;
3. Tonnage of Pb (tPb) = tonnage of dry sediments (t_{sed}) x Pb concentration in dry sediments (t_{Pb}/Mt_{sed}).

Into these equations, we substituted measurements of areas of Pb-rich sediments, medians and means of thickness, density, and depth-weighted average Pb concentrations. In this way, we calculated median and mean estimates of volumes and tonnages of Pb-rich sediments, and tonnages of lead in Pb-rich sediments of the CdA River valley.

Area of Pb-Rich Sediments

To define the area of Pb-rich surface sediments, we manually revised a previously digitized 1,000-ppm Pb contour to separate additional data points representing samples that contain at least 1,000 ppm of Pb from those that contain less. The area enclosed by the 1,000-ppm-Pb contour is represented by the stippled pattern in plate 1, which also shows sample sites, sized and color-coded to indicate Pb-concentration class, superimposed on the Wetland System Map by Bookstrom and others (1999).

We excluded the gravel bed of the braided river channel (upstream from Cataldo Landing) from the area of Pb-rich sediments, as defined for the preliminary estimate. Although several samples of the fine-grained fraction of the gravel contain over 1,000 ppm of Pb, the fine fraction comprises only a small percentage of the bulk of the gravel, so the bulk concentration of Pb in the gravel is less than 1,000 ppm. We expanded the area of Pb-rich sediments at Lead Flats, near Kingston, on the basis of data acquired after the preliminary estimate was made. We excluded a large part of the Bare Marsh area, which had been mistakenly included in the preliminary estimate. After these revisions, the total area included in our revised estimation is 99.9 percent of the total area of Pb-rich sediments containing at least 1,000 ppm, as depicted by a geo-statistical map Pb concentration in surface sediments by John Kern and others (unpublished data, 1999).

As before, we defined each Estimation Unit to include polygons (or parts thereof) of a given wetland-system map unit, inside the 1,000-ppm-Pb contour, and within a given river reach or valley segment. We used ArcView® Geographic Information System (GIS) software to “clip” map-unit polygons along intersections with the 1,000 ppm contour and river-reach or floodplain-segment boundaries, and to measure areas of Estimation Units. We summed the areas of Pb-rich sediments in all Estimation Units to indicate a total area of 61 km^2 of Pb-rich surface sediments in the CdA River valley (table 4).

Thickness and Volume of Pb-Rich Sediments

Our revised estimation of the total volume of Pb-rich sediments in the CdA River valley is represented by a median of 32 M m^3, and a mean of 40 M m^3 (table 4). We calculated mean and median thickness of Pb-rich sediments for each Estimation Unit from results of thickness determinations within it (table 2). We calculated median- and mean-based estimates of the volume of Pb-rich sediments in each Estimation Unit by multiplying its area of Pb-rich surface sediments by the median and mean of thickness of Pb-rich sediments within it.

Table 4. Estimated Area, Thickness, and Volume of Pb-Rich Sediments

Density of Pb-Rich Sediments (Wet and Dry)

In our revised estimations, we use median and mean calculated densities for wet and dry sediments from each depositional setting, rather than published densities for generally similar materials. Median and mean densities are calculated from 160 measurements of weight-percent solids, and 140 measurements of density of solids in sediments containing at least 1,000 ppm of Pb from Wetland-System Map units, representative of major depositional environments of the CdA River valley.

Densities of wet and dry sediments were estimated from measurements of weight (wt) fraction of solids, and specific gravity of solids, according to the following equations:

1. Weight fraction of solids = (sample dry wt)/(sample wet wt);
2. Weight fraction of water = 1 – wt fraction of solids;
3. Specific gravity of solids = density of solids (g/cm^3)/density of water (g/cm^3);
4. Density of water = 1 g/cm^3;
5. Density of air = 0 g/cm^3;
6. Sediment volume (cm^3) = wt fraction of solids (g)/density of solids (g/cm^3);
7. Water volume (cm^3) = wt fraction of water (g)/density of water (g/cm^3);
8. Porosity (water volume fraction) = cm^3 water/(cm^3 water + cm^3 sediment);
9. Density of wet sediments = (water volume fraction)(water density) + (sediment volume fraction)(density of solids);

10. Density of dry sediments = (water volume fraction)(air density) + (sediment volume fraction)(density of solids).

Table 5 summarizes data on specific gravity and weight percent of solids, used to estimate densities of Pb-rich and Pb-poor sediments in depositional environments represented by Wetland-System Map units. Tables 6 and 7 summarize median and mean porosities (volume percentages of water) and volume percentages of solids in sediments. Tables 8 and 9 summarize median and mean densities of wet and dry sediments of Wetland-System Map units, representative of major depositional environments of the CdA River valley.

Table 5. Weight-Percent and Specific Gravity of Solids in Sediments

Table 6. Median Porosity and Volume Percent of Solids in Sediments

Table 7. Mean Porosity and Volume Percent of Solids in Sediments

Table 8. Median Density of Wet and Dry Sediments

Table 9. Mean Density of Wet and Dry Sediments

Tonnage of Pb-Rich Sediments (Wet and Dry)

Our revised estimation of the total tonnage of wet Pb-rich sediments in the CdA River valley is represented by a median of 63 M t, and a mean of 77 M t. Tonnages of water-saturated sediments were estimated to indicate the tonnages of sediments and contained pore water that would be involved if water-saturated Pb-rich sediments were removed without de-watering.

Our revised estimation of the total tonnage of dry Pb-rich sediments is represented by a median of 47 M t, and a mean of 57 M t. Tonnages of dry sediments were estimated, because they are required for estimation of contained Pb, since assays for Pb are performed on dried samples, and analytical results are expressed as parts of Pb per million parts of dry sediment (ppm, g/Mg, or g/t).

Tables 10 and 11 summarize median and mean estimates of tonnages of wet and dry Pb-rich sediments in major depositional environments, represented by system-level map units of the CdA River valley.

Table 10. Estimated Tonnage of Water-Saturated Pb-Rich Sediments

Table 11. Estimated Tonnage of Dry Pb-Rich Sediments

Tonnage of Lead in Pb-Rich Sediments of the CdA River valley

Median- and Mean-Based Estimates

The overall tonnage of lead contained in Pb-rich sediments on the floor of the CdA River valley is bracketed by a median-based estimate of 250 kt of Pb, and a mean-based estimate of 324 kt of Pb (table 12). We calculated a median-based estimate of Pb tonnage in each Estimation Unit by multiplying its median tonnage of dry Pb-rich sediments (from table 11) by its median weighted-average Pb concentration (from table

3). Then we summed the median-based estimates for all Estimation Units to provide a median-based estimate of total tonnage of lead in Pb-rich sediments. Likewise, we calculated a mean-based estimate of Pb tonnage in each Estimation Unit by multiplying its mean tonnage of dry Pb-rich sediments by its mean weighted- average Pb concentration. Then we summed the mean-based estimates for all Estimation Units to provide a mean-based estimate of total tonnage of lead in Pb-rich sediments. Estimates are reported to three significant figures, because the data on which they are based were recorded and reported to at least three significant figures (table13).

Table 12. Estimated Tonnage of lead in Pb-Rich Sediments, CdA River valley

Table 13. Summary of Estimation Uncertainties

Estimation Uncertainties

For such a large area, available measurements of thickness and weighted-average Pb concentration are too few, irregularly distributed, and incomplete (some are vertically limited) to support complete and rigorous statistical estimation uncertainties. Nevertheless, uncertainty ranges can be estimated for some factors, such as the area of Pb-rich sediments (within - 0.1 percent of that estimated by kriging), the weight percent of solids (within ± 5.9 percent error in the mean), specific gravity of solids in Pb-rich sediments (within ± 2.5 percent error in the mean). To estimate uncertainty ranges for median- and mean-based estimates of the wet and dry tonnages of Pb-rich sediments, we multiplied the total of maximum relative uncertainties in density (8.4 percent) by estimated tonnages of wet and dry Pb-rich sediments (tables 10 and 11).

Analytical precisions of Pb determinations from different laboratories are within ±12 percent), and percentages of Pb recovery from Standard Reference Materials are between 95 and 102 percent. Maximum relative errors for estimation of both sediment density and Pb concentration add to a rounded total uncertainty of about ± 30 percent (table 13). We multiplied by our estimates of Pb tonnage by 30 percent, to indicate analytical uncertainty ranges for estimated tonnages of Pb contained in Pb-rich sediments of the CdA River valley (table 12). Thus, our mean-based estimate is 324 ± 97 kt of Pb. However, uncommonly thick and Pb-rich sections near the river may unduly influence the mean-based estimate. We therefore favor the median-based estimate of 250 ± 75 kt of Pb in Pb-rich sediments of the CdA River valley.

Preliminary Mass Balance for Lead

Inasmuch as Pb tends to associate strongly with transported sediment and deposited sediments, the tonnage of Pb added to sediments down-valley from sources of mill tailings should approximately balance the tonnage of lead contained in tailings that were lost to streams. Lead is geochemically immobile in most natural near-surface environments, where Pb^{+2} ions either form stable compounds, such as sulfides, sulfates, carbonates or phosphates (Blanchard, 1968), or adsorb onto commonly associated manganese- or iron-oxy-hydrides, hydroxides, or oxides (Smith, 1991). In seven water samples taken from the CdA River near Harrison during the 1997 water year, dissolved Pb comprised an average of only 1.7 percent of total recoverable Pb (where dissolved is defined as that portion of a sample that passes through a 0.45 micrometer membrane filter). The remaining 98.3 percent of the total recoverable Pb was contained in or associated with suspended particles, trapped by the filter (Brennan and others, 1997). Similarly, in a water sample taken from the CdA River near Harrison during the February 1996 flood, dissolved Pb comprised 1.5 percent of total recoverable Pb, whereas suspended particles, trapped by the filter contained 98.5 percent of the total recoverable Pb (Beckwith, 1996). Thus, about 98.4 percent of the Pb transported by the river was associated with suspended particles during both the 1997 water year and the February 1996 flood (By contrast, dissolved Zn comprised 94 percent of recoverable Zn in the water samples taken throughout 1997, and 12.4 percent of total recoverable Zn in the sample taken during the February 1996 flood, indicating that in CdA River water dissolved Zn predominates over particulate Zn, except during major, particularly erosive winter floods).

As tailings-rich sediment is transported down-valley, it mingles with metal-poor sediment, also in transport, to form increasing volumes (and tonnages) of mixed and diluted metal-enriched sediments. Nevertheless, since about 98.4 percent of total recoverable Pb is associated with sedimentary particles, the tonnage of Pb added to down-valley sediments as a result of tailings loss should approximately balance the tonnage of Pb in tailings that were lost to tributary streams.

Tonnage of Lead Lost to Streams

Javorka (1991) reported preliminary estimates that 115 M t of mine tailings were produced in the South Fork drainage basin, and that 72 Mt (or 62 percent) of tailings were discharged into the river. However, those estimates did not distinguish between tailings discarded directly into streams and those stockpiled in unprotected dumps. Furthermore, Javorka (1991) did not estimate the tonnage of Pb contained in tailings produced or released, so his estimates cannot be used in a mass balance for Pb. Long (1998b) made an exhaustive inventory of production data from every mine and mill in the CdA mining region, including data from all sources available to USGS. He estimated that 109 M t of mill tailings were produced in the CdA mining district from 1884 to 1997 (95 percent of the amount estimated by Javorka, 1991).

Long (1998b) estimated that 56 Mt of tailings, containing approximately 800 kt of Pb, were discarded directly into tributaries of the CdA River. Uncontrolled jig tailings, stockpiled along the various tributaries to the South Fork, but subsequently eroded away, were counted as tailings discarded into creeks. However, a few large uncontrolled dumps, which are partly intact, were categorized as uncontrolled tailings dumps. Thus, Long (1998b) estimated that 13 Mt of tailings, containing 200 kt of Pb were placed in stockpiles that were not protected against loss by erosion. Most of that (164 kt of Pb) was from the Bunker Hill complex. According to milling statistics given by Rickard (1920) about 45 percent of the Pb in jig tailings from the Bunker Hill mill was contained in the slime fraction, which comprised about 14 percent of the tailings. Most of that slime-fraction Pb probably was lost to the South Fork. After 1915, when flotation was introduced, about 13 percent of the Pb in tailings was contained in the slime fraction, most of which probably was lost to the South Fork. Applying these percentages to annual tailings production through 1928 (when the Central Impoundment was built), Keith Long (written communication, 2001) estimated that about 52 $\pm$ 5 kt of Pb was contained in slimes lost indirectly lost to the South Fork. Adding the 800 kt of Pb lost directly to streams and the 52 ± 5 kt of Pb in slimes lost indirectly to the South Fork indicates a total loss of 852 ± 5 kt of Pb lost to streams. In addition, a relatively small but unknown tonnage of Pb was lost by erosion of the Central Impoundment during the 1933 flood. Rounding 852 to 850 kt, and doubling to the uncertainty range to reflect uncertainty as to whether all of the slime fraction reached the stream, and how much Pb was lost by erosion of the Central Impoundment, we represent the total tonnage of Pb lost directly and indirectly to streams as approximately 850 ± 10 kt of Pb in table 15.

Tonnages of Lead in Sediments

South Fork Drainage Basin

The volume, tonnage, and lead content of Pb-rich sediments present in the South Fork drainage basin have not yet been estimated in a complete and thorough way. However, Stephen Box and others (unpublished data, 2000) have mapped the distribution of Pb-rich sediments deposited during the eras of jig and flotation milling, and of sediments deposited since the cessation of direct disposal of tailings into streams. They also have compiled available data on the thickness and concentration of lead in Pb-rich jig-era sediments. Before recent removal projects in Canyon and Ninemile Creeks, and the South Fork near Osburn and at Smelterville Flats, jig-era over-bank sediments (Jos) covered an area of approximately 5.7 Mm^2 in the South Fork drainage basin. Although thickness of jig-era over-bank sediments varies widely, its average thickness, calculated from measurements of full and partial thickness at 115 sites, was 98 cm, or approximately 1 m, and its average Pb concentration in jig-era sediments, calculated from 786 measurements, was 19,070 ppm, or approximately 19,000 ppm (Stephen Box, unpublished data, 2000). Assuming a dry density for jig-era over-bank sediments similar to that of bank-wedge sediments of the CdA River valley (1.58 t/m^3), the estimated tonnage of jig-era over-bank sediments would be about 9 Mt, which would contain approximately 171 kt of Pb (table 14).

In addition, jig-era gravels cover about 0.6 Mm^2, jig-flotation-era mill-site areas cover about 0.7 Mm^2, and wet jig-flotation-era over-bank sediments cover about 0.5 Mm^2 (Stephen Box and others, unpublished data, 2000). Average thickness, density, and Pb concentration of these Pb-rich sediments, which cover a total area of about 1.8 Mm^2, has not yet been determined. To roughly approximate the volume, tonnage, and Pb content of these sediments, we make the following assumptions:

1. Thickness of over-bank and mill-site deposits is similar to that of jig-era over-bank sediments -- about 1 m.
2. Thickness of channel deposits is at least double that of jig-era over-bank sediments – at least 2 m.
3. Bulk density of dry over-bank sediments is similar to that of bank-wedge sediments of the CdA River valley – about 1.58 g/cm^3 (or 1.58 kt/Mm^3).
4. Bulk density of dry gravel is similar to that of loose, dry gravel, as indicated in USBLM (undated) – about 1.19 g/cm^3 (or 1.19 kt/Mm^3).
5. Pb concentration of jig-flotation-era over-bank sediments is about 50 percent of that of jig-era over-bank sediments (about 10,000 ppm, or 10 kt/Mt).
6. Bulk Pb concentration of jig-era and flotation-era gravel is about 10 percent of Pb concentration in over-bank sediments of the corresponding era (about

2,000 ppm, or 2 kt/M t) in jig-era gravels, and about 1,000 ppm (or 1 kt/Mt in flotation-era gravels.

7. Bulk Pb concentration of post-disposal-era gravels is about 50 percent of Pb concentration in flotation-era gravels.

Based on these assumptions and the measured areas covered by different types of Pb-enriched sediments, we suggest that in addition to the approximately 171 kt of Pb estimated to be contained in jig-era over-bank sediments, other Pb-enriched sediments of the South Fork drainage basin probably contain approximately 33 kt of Pb. Therefore, Pb-enriched sediments of the South Fork drainage basin probably contain approximately 204 kt, or a rounded total of 200 kt of Pb (table 14). The uncertainty of this estimate is large, probably about ± 50 percent, so the tonnage of Pb in sediments of the South Fork drainage basin is approximated as 200 ± 100 kt of Pb (table 15).

Table 14. Tonnage of Lead in Sediments, South Fork Drainage Basin (Preliminary Estimate)

North Fork Drainage Basin

Mines and mills in tributaries to the North Fork of the CdA River, such as Prichard and Beaver Creeks, also added Pb-enriched sediment to the CdA River drainage basin. Long (1998b) classified tailings of the Jack Waite mill as impounded, but classified the tailings of other mills as lost to tributaries. Partly eroded remnants of several jig- and flotation-tailings impoundments remain within the Prichard Creek drainage basin, but exact amounts of tailings remaining in impoundments, versus tailings originally released, or subsequently eroded, are uncertain. Nevertheless, tonnages of Pb added to the North Fork drainage basin probably are relatively small, compared to those added to the South Fork drainage basin, where most of the mining and milling occurred.

CdA River Valley

From the median-based estimate of 250 ± 75 kt contained in Pb-rich sediments of the CdA River valley, we subtracted the 1.4 kt of lead that would be contained in an equivalent tonnage (47 ± 4 M t) of dry pre-mining-era sediments, with the mean background lead concentration (30 ppm Pb). In this way, we estimated that 148.6 (or 149 ± 75 kt) of the 250 ± 75 kt of lead contained in Pb-rich sediments of the CdA River valley were added as a result of upstream mining-related activities in the CdA mining district or region (table 15). Thus, about 99.5 percent of the lead in Pb-rich sediments of the CdA River valley was added as a result of mining-related activities.

Delta Front of the CdA River

The delta front of the CdA River slopes gently from the mouth of the river and its adjacent levees and wetlands, to the floor of CdA Lake. Core hole DEL-1, which was drilled at the crest of the river-mouth bar, which is about 6 river widths beyond the river mouth, recovered a full section of Pb-rich sediments, 5.74 m thick, with a thickness-weighted average Pb concentration of 5,955 ppm (USEPA, 1998). Core hole 123, near the northwestern base of the delta front, recovered a full section of Pb-rich sediments, 1.10 m thick (Horowitz and others, 1995). By analogy, Pb-rich sediments near the southwestern base of the delta front probably also are about 1.10 m thick.

We estimate the thickness of Pb-rich sediments at the mouth of the river as 1.6 m, which is the midpoint between median and mean thickness of Pb-rich sediment in the lower river. We estimate the thickness of Pb-rich sediment at the mouths of Harrison Slough and Harrison Marsh (along the top of the delta-front slope, northwest and southeast of the river mouth) as 0.17 m, which is the midpoint between the median and mean thickness of Pb-rich sediment in lateral lakes of the lower valley. Based on the two thickness measurements and four thickness estimates described above, we estimate that Pb-rich sediments of the delta front average about 1.65 m thick.

The map area of the delta front is 1.4 km^2, as measured from plate 1, which we multiplied by an average thickness of 1.65 m, to estimate the volume of Pb-rich sediments in the delta front as 2.31 Mm^3. The midpoint between the median and mean dry densities of sediment samples from DEL-1 is 1.44 g/cm^3 (or t/m^3), which we multiplied 2.31 Mm^3 to estimate the dry tonnage of Pb-rich sediment as 3.3 M t. The thickness-weighted average concentration of Pb in DEL-1 is 5,955 ppm (or t/Mt), which we multiplied by 3.3 Mt, to estimate that Pb-rich sediments of the delta-front contain 19.8 kt of Pb. An equivalent tonnage of sediments with the background concentration of 30 ppm of Pb would contain 0.1 kt of Pb. We therefore estimate that 19.7 kt of Pb was added to delta-front sediments as a result of upstream disposal of mining-related wastes. In table 15 we round the tonnage of Pb added to 20 kt and suggest an uncertainty range of about $\pm$ 50 percent ($\pm$ 10 kt of Pb) because of analytical uncertainties, scarcity of data, and uncertainties in assumptions involved.

CdA Lake

Horowitz and others (1995) estimated that 75 M t of metal-enriched sediments cover about 85 percent of 127.8-km^2 area of the CdA Lake bottom to an area-weighted average thickness of 35 cm. They estimated that these sediments contain 470 kt of Pb, of which 468 kt (or 99.6 percent) was added as a result of mining-related activities. These estimates represent totals of estimates for 12 separate lake-bottom zones, each centered on a core hole, drilled near the central axis of the lake or one of its major bays. As Horowitz and others (1995) wrote, "the estimated mass of trace element-rich sediments, as well as the estimated masses of excess trace elements, are a function of the assumptions used in calculating them. If the assumed sediment bulk density was too high, then the calculated masses would decrease (e.g. a bulk density of 1.4 g/cm^3 would reduce the estimated mass of trace element-rich sediments to about 50 x 10^6 tonnes)." Assuming equivalent Pb concentrations, that 50 Mt of sediment would contain 313 kt of Pb.

The 127.8-km^2 area of CdA Lake, reported by Horowitz and others (1995) includes the delta front and the Harrison Arm of CdA Lake. This area includes the Harrison Slough, Harrison Marsh, and the western part of Thompson Marsh, and lower 2/3 of river reach 6, and its adjacent levees, which we include in the lower CdA River valley, and for which we provide subsequent estimates, based on additional data. To eliminate double counting, we reconstructed estimates for the overlapping area, based on data available to Horowitz and others (1995), and we subtracted them from the previous total estimates for CdA Lake. We multiplied the overlap area by the 1.1 m thickness of metal-enriched sediments in drill core 123 to calculate an overlap volume of 5.5 Mm^3. Based on alternative densities of 2.0 and 1.4 g/cm^3 for the metal-enriched sediments of CdA Lake, we calculated alternative tonnages of dry Pb-rich sediments in the overlap area as 11.0 or 7.7 kt. From data displayed in figure 3 of Horowitz and others (1995), we estimated the median concentration of Pb in drill core 123 as 5,300 ppm, which we used to calculate alternative estimates of 58 or 41 kt of Pb in metal-enriched sediments of the overlap area.

Subtracting 58 kt of Pb from a total of 470 kt of Pb in sediments with an assumed density of 2.0 g/cm^3 indicates an estimated 412 kt of Pb in metal-enriched sediments on the floor of CdA Lake beyond the delta-front of the CdA River. Alternatively, subtracting 41 kt of Pb from a total of 313 kt of Pb in sediments with an assumed density of 1.4g/cm^3 indicates an estimated of 272 kt of Pb in metal-enriched sediments on the floor of CdA Lake, beyond the delta front of the CdA River. Assuming that 99.6 percent of that lead was added as a result of mining-related activities (as above), the tonnage of Pb added to metal-enriched sediments on the floor of CdA Lake as a result of mining-related activities is estimated alternatively as 410 or 271 kt of Pb (table 15).

We favor the lower estimate of 271 kt of Pb, for the tonnage of Pb in metal-enriched sediments on the floor of CdA Lake beyond the delta front of the CdA River. That estimate is based on 1.4 g/cm^3 as the density of metal-enriched sediments on the floor of CdA Lake. This preferred density of 1.4 g/cm^3 is close to the dry density of Pb-rich sediments from the CdA River and its delta (1.4 to 1.5 g/cm^3). Chemical analytical results express Pb concentration in parts-per-million of Pb in dry sediment, which is multiplied by the tonnage of dry sediment to calculate the tonnage of contained Pb. The higher assumed density of 2.0 g/cm^3 is close to that of water-saturated Pb-rich sediments from the CdA River and its delta (1.9 to 2.1 g/cm^3).

Because of uncertainties described by Horowitz and others (1995), estimates based on those data and assumptions are assigned an uncertainty range of about $\pm$ 50 percent, as suggested by Arthur Horowitz (written communication, 2001). We therefore assign $\pm$ 50 percent uncertainty ranges to both the higher and lower estimates (table 15). Inasmuch as these wide uncertainty ranges overlap, the higher and lower estimates can be considered to be indistinguishable, and both are generally consistent with previous estimates by Horowitz and others (1995).

Nevertheless, for reasons explained above, we favor the lower estimated tonnage of Pb in metal-enriched sediments of CdA Lake (272 $\pm$ 135 kt of Pb), based on an assumed density of 1.4 g/cm^3. Adding the estimated 20 $\pm$ 10 kt of Pb in metal-enriched sediments of the delta front, this indicates a total of 292 $\pm$ 145 kt of Pb in metal-enriched sediments of CdA Lake, beyond the mouth of the CdA River and the top of its delta-front slope (table 15).

Spokane River Valley

During spring snowmelt-runoff events, a buoyant plume of relatively warm river water carries suspended metal-enriched sediment into a much larger, deeper, and colder CdA Lake. The thermally buoyant plume of river water carries metal-enriched suspended sediment into and across the lake, toward the outlet of CdA Lake, and into the Spokane River (P.F. Woods, unpublished data, 1999; S.E. Box and A.A. Bookstrom, unpublished data, 1997). During the 1999 runoff event, total Pb concentrations in water samples taken from the upper part of the buoyant plume decreased from 31 micrograms/liter at the mouth of the CdA River to 10.5 micrograms/liter at the outlet of the CdA River into the Spokane River (P.F. Woods, unpublished data, 1999).

Recent sampling indicates anomalous concentrations of Pb in local accumulations of fine-grained sediments in the channel of the Spokane River, as well as along its banks, and especially on the bottoms of dammed reservoirs along its course. (USEPA, 2000, 2001; S.E. Box, unpublished data, 2000; C.A. Grobois, A.A. Horowitz, J.J. Smith, and K.A. Elrick, unpublished data, 2000; and M.A. Beckwith, unpublished data, 2001). This suggests that most of the 111 kt of Pb "missing" from the preferred mass-balance estimation is present in sediments of the Spokane River valley. However, estimation of the tonnage of Pb added to mining-era sediments of the Spokane River valley awaits additional data and analysis.

Table 15. Preliminary Alternative Mass Balances for Lead

Lead Mass-Balance Calculations

If approximately 850 $\pm$ 10 kt of Pb were lost to drainages of the South and North Fork drainage basins, then approximately 850 $\pm$ 10 kt of Pb should have been added to downstream sediments as a result of the release of that lead. The sum of the favored lower set of estimates of Pb added to downstream sediments is 739 kt of Pb, and the sum of the uncertainties involved in the component estimates is $\pm$ 319 kt of Pb (table 15). Based on mid-range values from the preferred lower set of estimates with uncertainty ranges up to $\pm$ 50 percent, we suggest that about 24 percent of the Pb lost to streams is in sediments of the South Fork drainage basin, 29 percent is in sediments of the CdA River valley, and 34 percent is CdA Lake-bottom sediments. This accounts for a total of 87 percent of the Pb lost to streams, not including the tonnages of mining-derived Pb added to sediments of the North Fork drainage basin or the Spokane River valley, which have not yet been estimated.

The sum of an alternative set of higher estimates is 952 $\pm$ 410 kt of Pb, which exceeds the midrange of the estimated 850 $\pm$ 10 kt of Pb released by 102 $\pm$ 420 kt of Pb, or 12 percent (table 15). The wide uncertainty ranges of the lower and higher total estimates overlap broadly, and both agree in general with the tonnage of Pb estimated to have been released. Thus, preliminary mass-balance considerations generally corroborate the estimates of Horowitz and others (1995), as well as those presented here. Nevertheless, we favor the lower, median-based estimate of Pb added to the CdA River valley, because it does not give undue influence to uncommonly high values, and we favor the lower estimate of Pb added to CdA Lake, based on a density of 1.4 g/cm^3 for Pb-rich lake bottom sediments.

To further test the preliminary mass-balance model presented here, rigorous estimates of Pb added to sediments of the South Fork, North Fork, and Spokane River valleys would be required. Substantially more data also would be needed to support geo-statistical estimation of the tonnage and Pb content of metal-enriched sediments in the CdA River valley, which would provide corresponding estimates of minimum variance. Substantially more data on the spatial distribution of thickness, density, and concentration of Pb in metal-enriched sediments in CdA Lake also would be needed to test present assumptions of consistency of thickness, and homogeneity of density and Pb concentration in metal-enriched sediments in twelve large lake-bottom zones, each of which is currently represented by a single drill core near its center.

Summary of Conclusions

The mean background concentration of lead in uncontaminated sediments of the CdA and St. Joe River valleys is 30 ppm of Pb. Concentrations of lead in 998 samples of surface sediments from the floor of the CdA River valley range from 15 to 38,500 ppm Pb, and average 3,371 ppm Pb. We define Pb-rich sediments as sediments that contain at least 1,000 ppm of Pb. About 78 percent of the samples of surface-sediments contain over 1,000 ppm Pb, and average 4,245 ppm Pb. The remaining 22 percent contain less than 1,000 ppm Pb and average 347 ppm Pb. Thickness-weighted average concentrations of Pb in full sections of Pb-rich sediments range from 1,000 to 22,103 ppm, and average 5,101 ppm. Thus, the mean of thickness-weighted average Pb concentration of full sections of Pb-rich sediments is about 170 times the mean background concentration of Pb in uncontaminated sediments of the CdA and St. Joe River valleys.

Lead-rich sediments, containing at least 1,000 ppm of Pb, cover approximately 61 km^2, or 72 percent of the 85-km^2 floor of the CdA River valley. Most of the highest concentrations of Pb are in sediments within or near the river channel, or near the base of the stratigraphic section of Pb-rich sediments. Ranges of Pb concentration in Pb-rich sediments gradually decrease with increasing distance from the river and its distributaries.

Ranges of thickness of Pb-rich sediments generally decrease abruptly with increasing distance from the river, from about 3 $\pm$ 3 m in the river channel to about 1 $\pm$ 1m on upland riverbanks, levees and sand splays, to about 0.3 $\pm$ 0.3 m in back-levee marshes and lateral lakes. Thickness of Pb-rich dredge spoils (removed from the river and deposited on Cataldo-Mission Flats) is mostly in the range 4 $\pm$ 4 m, thinning away from an outfall zone north and west of the river, near the formerly dredged channel reach near Cataldo Landing.

Lateral and longitudinal variation in ranges of thickness and Pb content of Pb-rich sediments probably result from the time-integrated dynamic balance between decreasing floodwater flow velocity with increasing distance from the river, and the quantity, size, density, and Pb content of particles mobilized, transported, and deposited.

We calculated alternative median- and mean-based estimates of the thickness, volume, wet and dry density, and wet and dry tonnage of Pb-rich sediments, and the tonnage of Pb contained in dry Pb-rich sediments in major depositional environments of seven river reaches and three longitudinal parts of the floodplain, each of which was subdivided into three segments. We prefer the median-based set of estimates, because the mean-based estimates probably are unduly influenced by unusually thick and Pb-rich sections of Pb-rich sediments near the river.

Median-based estimates indicate a volume of about 32 Mm^3 of Pb-rich sediments in the CdA River valley. Median densities of wet Pb-rich sediments range from 1.63 g/cm^3 for palustrine sediments (with 63.7 volume percent of pore water) to 2.18 g/cm^3 for dredge-spoils (with 38.7 volume percent of pore water). Median densities of dry Pb-rich sediments range from 1.00 g/cm^3 for porous organic-bearing palustrine sediments to 1.79 g/cm^3 for sandy dredge-spoils. Median-based estimates of total tonnages of Pb-rich sediments indicate 63 $\pm$ 5 Mt of wet sediments, or 47 $\pm$ 4 Mt of dry sediments (with equivalent porosities). Our median-based estimate of the total tonnage of lead in Pb-rich sediments of the CdA River valley is 250 $\pm$ 75 kt of Pb.

If equivalent tonnages of sediments contained the background concentration of lead (30 ppm), total median-based tonnage of Pb would be about 1.4 kt. This indicates that about 99.5 percent of the 249 ± 75 kt of Pb contained in Pb-rich sediments of the CdA River valley was added as a result of mining-related activities in the CdA mining region, upstream.

Preferred estimates of tonnages of Pb in metal-enriched sediments of the CdA drainage basin indicate about 200 ± 100 kt in the South Fork drainage basin, 250 ± 75 kt in the CdA River valley, 20 ± 10 kt in the delta front, and 292 ± 145 kt in CdA Lake, for a total of 742 ± 320 kt. About 99.6 percent of that, or 739 ± 319 kt of Pb probably was added as a result of mining-related activities, which is 13 percent short of the estimated 850 ± 10 kt of Pb lost to streams as a result of tailings-disposal practices. Much of the remaining 111 kt of lost Pb probably resides in sediments of the Spokane River. Recent water sampling shows that during spring snowmelt-runoff events, a thermally buoyant plume of river water transports Pb-enriched suspended sediment across CdA Lake and into the Spokane River (P.F. Woods, unpublished data, 1999). Anomalously high concentrations of Pb are present in fine-grained sediments on the banks of the Spokane River, as well as in the river channel, and on the bottoms of reservoirs along its course (USEPA, 2000, 2001; S.E. Box, unpublished data, 2000; and C.A. Grobois and others, unpublished data, 2,000). However, estimation of the tonnage of Pb contained in such sediment awaits additional data and analysis.

Significant refinement of this preliminary mass-balance model would require a substantial amount of additional data on the distribution, thickness, density, and Pb content of metal-enriched sediments, especially for the South and North Fork drainage basins and the Spokane River valley, but also for the main stem of the CdA River valley, and the bottom of CdA Lake.

Acknowledgements

Eastern Washington University student, Scott Prevatte, calculated thickness-interval weighted-average Pb concentrations using data from geo-chemical profiles of sedimentary sections sampled. Scott also helped with the preparation of ArcView® GIS files used in our preliminary estimation. We thank USGS-WRD, USFWS, USEPA, and the University of Idaho for making their data available to us, and the Coeur d’Alene Tribe for digital computing support. John Wallis wrote the metadata. We thank Keith Long for reviewing the manuscript and its accompanying illustrations, Arthur Horowitz for his comments on a working draft of the preliminary mass-balance model, and Gary Raines for reviewing the digital files included with this report.

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Appendix 1. Digital Documentation for ArcView data sets

List of Files

ArcView project cdapbofp.apr consists of the files listed below:

File Name	Size(KB)	Type	Description
alsampb.avl	11	AVL	points, ppm Pb in surface sediment
alsamPb.dbf	161	DBF	points, ppm Pb in surface sediment
cdapbofp.apr	116	APR	ArcView project file
cdasurf4.avl	4	AVL	polygons, wetland system units (wsu)
cdasurf4_utm.dbf	197	DBF	polygons, wetland system units
cdasurf4_utm.shp	2,402	SHP	polygons, wetland system units
cdasurf4_utm.shx	14	SHX	polygons, wetland system units
fldpln2.avl	1	AVL	polygons, floodplain wsu
fldpln2.dbf	167	DBF	polygons, floodplain wsu
fldpln2.sbn	22	SBN	polygons, floodplain wsu
fldpln2.sbx	2	SBX	polygons, floodplain wsu
fldpln2.shp	1,690	SHP	polygons, floodplain wsu
fldpln2.shx	13	SHX	polygons, floodplain wsu
fpaream2.avl	1	AVL	polygon, study area
fpaream2.dbf	1	DBF	polygon, study area
fpaream2.shp	150	SHP	polygon, study area
fpaream2.shx	1	SHX	polygon, study area
pb1000.avl	1	AVL	polygons, 1000 ppm Pb in surface sed.
pb1000.dbf	13	DBF	polygons, 1000 ppm Pb in surface sed.
pb1000.sbn	21	SBN	polygons, 1000 ppm Pb in surface sed.
pb1000.sbx	2	SBX	polygons, 1000 ppm Pb in surface sed.
pb1000.shp	1,357	SHP	polygons, 1000 ppm Pb in surface sed.
pb1000.shx	12	SHX	polygons, 1000 ppm Pb in surface sed.
rivreach.avl	2	AVL	lines, river-reach boundaries
rivreach.dbf	1	DBF	lines, river-reach boundaries
rivreach.shp	1	SHP	lines, river-reach boundaries
rivreach.shx	1	SHX	lines, river-reach boundaries
segments.avl	2	AVL	lines, valley-segment boundaries
segments.dbf	1	DBF	lines, valley-segment boundaries
segments.shp	6	SHP	lines, valley-segment boundaries
segments.shx	1	SHX	lines, valley-segment boundaries
thkpb11.avl	11	AVL	points, thickness Pb-rich sediment
thkpb11.dbf	59	DBF	points, thickness Pb-rich sediment

Plot files in Encapsulated PostScript (*.eps)
P1surpb2.eps
P2thkpb3.eps

Metadata files in Text (*.txt)
readme.txt
cdafldpl.met
Pbsamthk.met
pbrchseg.met

Obtaining Digital Data Online

To obtain copies of the digital data, do one of the following:

1. Download the digital files from the USGS public access World Wide Web site on the Internet: **URL = http://geopubs.wr.usgs.gov/open-file/of01-140**.
2. Anonymous FTP from geopubs.wr.usgs.gov, in the directory **pub/open-file/of01-140/**

Table1. Geochemical Data Sets and Methods of Sampling, Preparation, Digestion, and Analysis of Sediments

Data Set	n	Location Method	Sampling Method	Surface Interval	Depth Intervals	Sample Prep	Digestion	Analytical Technique	Lab
Bender (1991), Rabbi (1994), and Hoffmann (1995), of University of Idaho	20	unspecified	freeze-box and piston-core from lake bottoms	uppermost 2-cm sample (from < 6 cm depth)	contiguous depth-intervals	dried at low T	concentrated nitric acid, plus perchloric acid; digestate refluxed by hydrochloric acid	FAAS - Flame Atomic Absorbtion spectroscopy; ICP in Hoffmann study	University of Idaho
LeJeune and others (1995), of Hagler Bailly Consulting, Inc., for Natural Resource Trustees	35	GPS, commercial, with differential correction	5-part composite surface samples from systematically random sites	surface grab	no	dried, seived to < 2 mm	concentrated nitric acid	ICP-AES	ACZ, Inc.
Fousek (1996), for USGS-WRD	155	GPS, commercial, uncorrected	1992 samples from riverbanks; 1993 core samples from 150 floodplain sites (chain of custody)	upper 5 cm, or above 1980 marker	contiguous depth-intervals	homogenized, seived to <2mm, freeze dried. 1993 samples sieved to < 180 micron for analysis.	4-acid (aqua regia, perchloric acid, and hydrofluoric acid, digestate refluxed by hydrochloric acid)	1992 samples by AAS (atomic absorption spectrometry); 1993 samples by ICP-AES; Sb, Hg by cold-vapor AAS	USGS-WRD, Atlanta, GA, A. Horowitz
USEPA (1998), by URS Greiner, Inc.	61	GPS, commercial, with differential correction	core samples from tube, vibrated and hammered into river-channel and floodplain sediment (chain of custody)	upper 61 cm	contiguous depth-intervals	dried, pulverized, homogenized	nitric acid and hydrogen peroxide, digestate refluxed by HCl (EPA method 3050)	ICP-AES	Chemtech
USEPA (1999a), by McCully, Frick and Gilman, Inc.	41	measured from railroad mile-markers and tracks	inorganic sediment samples from pits dug along segments of the railroad	upper 15 cm	contiguous depth-intervals	homogenized 5 subsamples, then split for analysis	nitric acid and hydrogen peroxide, digestate refluxed by HCl (EPA method 3050)	ICP-AES	American Analytical Services
USEPA (1999b)	32	plotted on base map	5-part composite samples	top 2.54 cm below veg.	no	not specified	not specified	not specified	not specified
Campbell and others (1999), for USFWS	542	GPS, commercial, with differential correction	surface samples from core tube forced into marsh sediment (chain of custody)	upper few cm of mineral sediment	no	air dried, sieved to < 1mm to eliminate shot	concentrated nitric acid (microwave)	ICP-AES (inductively coupled plasma - atomic-emission spectrometry)	ACZ, Inc.
Balistrieri and others (2000)	12	GPS, US govt., uncorrected	core samples from plastic tube, forced into river and floodplain sediment	top core interval	contiguous depth-intervals	not specified	nitric, perchloric, and hydrofluoric acids	FAAS - Flame Atomic Absorbtion spectroscopy, and (or) ICP-AES	USGS-WRD, Atlanta, GA, A. Horowitz
Box and others (2001) USGS-GD, 1993 data set	25	locations visually identified on maps at 1:24k-scale	samples from riverbanks, dug pits, and core tube forced into floodplain sediment	upper few cm, or above 1980 marker	contiguous depth-intervals	homogenized, seived to <2mm, oven dried, pulverized	no digestion for XRF analyses; 4-acid digestion for ICP analyses	XRF (X-ray flourescence), followed by ICP analyses of most samples	XRF by USGS-GD, ICP by Chemex, Inc, and (or) EWU
Box and others (2001) USGS-GD, 1994 to 1997 data sets	20	drill sites tape-measured from on-shore sites, visually identified on maps at 1:24k scale	core samples from tube, vibrated into river-channel sediment	upper few cm, or above 1980 marker	contiguous depth-intervals	homogenized, split, seived to <2mm, oven dried, pulverized	4-acid	ICP-AES or ICP-MS (inductively coupled plasma atomic-emission or mass spectrometry), calibrated to NIST standards 2710, and 2711	Eastern Washington University (EWU), M. Ikramuddin
Box and others (2001), USGS-GD, 1998 data set	52	GPS, US govt., uncorrected	samples from dug pits, and core tube forced into sediment	surface, or upper few cm	non-contiguous depth levels	seived to <2mm, freeze dried, pulverized, seived to < 200 microns	4-acid	ICP-AES	XRAL, Inc.

* NIST is the National Institute of Standards and Technology

Table 2. Thickness of Pb-Rich Sediments, Summary Statistics, CdA River and Floodplain

Estimation Unit	River Reach or Valley Part	Depositional Setting	Dominant Type of Mining-Era Sediments	Summary Statistics for Thickness of Pb-Rich Sediments											
				min (cm)	max (cm)	median (cm)	**mean (cm)**	md/mn[a]	std dev (cm)	**n[b]**	sq rt n	std error[c] (cm)	pct error[d]	**n_{part}[e]**	**n_{part}/n_{total}**
Riverbed Sediments															
R1	Upper valley	River channel	sand	128	714	300	337	0.89	137	56	7.48	18	5	1	0.02
R2	Upper valley	River channel	sand	0	836	384	378	1.02	190	69	8.31	23	6	4	0.06
R3	Middle valley	River channel	sand	0	531	321	273	1.18	165	63	7.94	21	8	3	0.05
R4	Mid to Lower	River channel	sand	0	514	284	251	1.13	172	53	7.28	24	9	0	0.00
R5	Lower valley	River channel	sand	0	604	226	198	1.14	162	48	6.93	23	12	0	0.00
R6	Lower valley	River channel	sand	0	397	162	158	1.02	118	47	6.86	17	11	0	0.00
Riverbed (R1-6)							***266***			***336***				***8***	***0.02***
Riverbank Sediments															
RBW0 & 1	Upper valley	Riverbank wedge	sand & silt	23	188	99	103	0.96	56	9	3.00	19	18	6	0.67
RBW2	Upper valley	Riverbank wedge	sand & silt	11	210	79	85	0.93	51	33	5.74	9	10	15	0.45
RBW3 & 4	Mid to Lower	Riverbank wedge	sand & silt	7	216	58	63	0.92	51	23	4.80	11	17	10	0.43
RBW5 & 6	Lower valley	Riverbank wedge	sand & silt	4	122	38	49	0.78	40	17	4.12	10	20	9	0.53
Riverbank (Rbw0-6)							***75***			***82***				***40***	***0.49***
Dredge-Spoil Sediments															
Udr dike	Upper valley	Dredge-spoil fill	sand	700	1100	700	833	0.84	207	6	2.45	84	10	0	0.00
Udr pile	Upper valley	Dredge outflow	sand	15	702	161	225	0.71	191	20	4.47	43	19	8	0.40
Dredge pile							***225***			***20***				***8***	***0.40***
Floodplain Sediments															
UU	Upper valley	Upland (levee)	sand & silt	10	210	31	65	0.47	65	33	5.74	11	9	16	0.48
UP	Upper valley	Palustrine (marsh)	silt	1	200	44	59	0.74	50	18	4.24	12	7	6	0.33
UL	Upper valley	Lacustrine (lake)	silty mud	1	40	17.5	18	0.99	13	6	2.45	5	14	1	0.17
MU	Middle valley	Upland (levee)	sand & silt	14	211	30.5	62	0.49	60	28	5.29	12	19	10	0.36
MP	Middle valley	Palustrine (marsh)	silt	1	64	15	22	0.68	19	44	6.63	3	15	10	0.23
ML	Middle valley	Lacustrine (lake)	silty mud	1	122	34	38	0.89	36	27	5.20	7	19	3	0.11
LU	Lower valley	Upland (levee)	sand & silt	15	92	29	39	0.75	30	7	2.65	11	29	3	0.43
LP	Lower valley	Palustrine (marsh)	silt	1	69	15	18	0.83	14	27	5.20	3	15	12	0.44
LL	Lower valley	Lacustrine (lake)	silty mud	1	67	14	20	0.71	23	25	5.00	5	23	5	0.20
Floodplain (Upper to Lower valley)							***38***			***215***				***66***	***0.31***

a. median/mean, b. number of observations, c. standard error of the mean = mean / sq rt n,
d. percent error = 100* (std error / mean), e. number of measurements of partial thickness.

Table 3. Thickness-Weighted Average Pb Concentration in Pb-Rich Sediments, Summary Statistics, CdA River and Floodplain

Estimation Unit	River Reach or Valley Part	Depositional Setting	Dominant Type of Mining-Era Sediments	Summary Statistics for Thickness-Weighted Average ppm Pb in Pb-Rich Sediments											
				min (g/t)	max (g/t)	median (g/t)	**mean (g/t)**	md/mn[a]	std dev (g/t)	**n[b]**	sq rt n	std error[c] (g/t)	pct error[d]	n_{part}[e]	n_{part}/n_{tot}
Riverbed Sediments															
R1	Upper valley	River channel	sand	1948	2695	2315	2362	0.98	303	5	2.24	136	6	1	0.20
R2	Upper valley	River channel	sand	3921	20844	9221	9919	0.93	4958	8	2.83	1753	18	5	0.63
R3	Middle Valley	River channel	sand	4574	7453	5286	5650	0.94	1296	4	2.00	648	11	3	0.75
R4	Mid to Lower valley	River channel	sand	6243	15719	9138	10060	0.91	4014	4	2.00	2007	20	0	0.00
R5	Lower valley	River channel	sand	2481	11998	6608	7136	0.93	3568	5	2.24	1595	22	0	0.00
R6	Lower valley	River channel	sand	2804	12174	7404	7446	0.99	4037	4	2.00	2018	27	0	0.00
			Riverbed (R1-6)				***7095***			***31***				***9***	***0.29***
Riverbank Sediments															
RBW 0-1	Upper valley	Riverbank wedge	sand & silt	1794	14980	4335	6557	0.66	5098	8	2.83	1802	27	7	0.88
RBW 2	Upper valley	Riverbank wedge	sand & silt	4523	16212	5495	7931	0.69	5589	4	2.00	2794	35	0	0.00
RBW 3-4	Mid to Lower valley	Riverbank wedge	sand & silt	1650	13117	4955	6367	0.78	3564	10	3.16	1127	18	0	0.00
RBW 5-6	Lower valley	Riverbank wedge	sand & silt	1563	5612	4571	4246	1.08	1568	5	2.24	701	17	0	0.00
			Riverbank (Rbw0-6)				***6275***			***27***				***7***	***0.26***
Dredge-Spoil Sediments															
Udr	Upper valley	Dredge Spoils	sand	2050	6347	3271	3754	0.87	1260	10	3.16	398	11	8	0.80
			Dredge Spoils				***3754***			***10***				***8***	***0.80***
Floodplain Sediments															
UU	Upper valley	Upland (levee)	sand & silt	1500	8347	3820	4463	0.86	2160	13	3.61	599	13	2	0.15
UP	Upper valley	Palustrine (marsh)	silt	1366	13369	5083	5960	0.85	4685	9	3.00	1562	26	2	0.22
UL	Upper valley	Lacustrine (lake)	silty mud	1000	4630	2815	2815	1.00	2567	2	1.41	1815	64	0	0.00
MU	Middle valley	Upland (levee)	sand & silt	3003	22103	5408	6545	0.83	4092	19	4.36	939	14	5	0.26
MP	Middle valley	Palustrine (marsh)	silt	1030	14500	4417	6595	0.67	2844	22	4.69	606	9	6	0.27
ML	Middle valley	Lacustrine (lake)	silty mud	1700	14711	6663	6638	1.00	3969	12	3.46	1146	17	3	0.25
LU	Lower valley	Upland (levee)	sand & silt	1330	6313	3633	3888	0.93	1653	7	2.65	625	16	6	0.86
LP	Lower valley	Palustrine (marsh)	silt	1000	7021	2875	2998	0.96	1912	10	3.16	605	20	5	0.50
LL	Lower valley	Lacustrine (lake)	silty mud	3100	9387	5386	5629	0.96	2137	9	3.00	712	13	1	0.11
			Floodplain (Upper to Lower valley)				***5059***			***103***				***38***	***0.37***

a. median/mean b. number of observations, c. standard error of the mean = mean/sq rt n,
d. percent error = 100*(std error/mean), e. number of measurements of partial thickness

Table 4. Estimated Area, Thickness, and Volume of Lead-Rich Sediments, Coeur d'Alene River Valley

Estimation Unit	**Area of Pb-Rich Sediments (km^2)**	Median Thickness, Pb-Rich Sediments (m)	Mean Thickness, Pb-Rich Sediments (m)	**Median Volume, Pb-Rich Sediments (M m^3)**	**Mean Volume, Pb-Rich Sediments (M m^3)**
Riverbed Sediments					
R0 gravel (<1000 ppm Pb)	1.74	ND[a]	ND	NE[b]	NE
R0 sand	0.03	ND	ND	NE	NE
R1	0.16	3.00	3.37	0.49	0.55
R2	0.88	3.84	3.78	3.37	3.32
R3	0.87	3.21	2.73	2.78	2.36
R4	0.58	2.84	2.51	1.64	1.45
R5	0.72	2.26	1.98	1.63	1.43
R6	0.61	1.62	1.58	0.98	0.96
Riverbed total (R1-6)	***3.81***			***10.90***	***10.07***
Riverbank Sediments					
Rbw0-1	0.15	0.99	1.03	0.15	0.15
Rbw2	0.40	0.79	0.85	0.32	0.34
Rbw3-4	0.94	0.58	0.63	0.55	0.59
Rbw5-6	0.65	0.38	0.49	0.25	0.32
Riverbank total (Rbw0-6)	***2.15***			***1.26***	***1.41***
Dredge-Spoils					
Dredge outfall	3.42	1.61	2.25	5.51	7.70
Dredge-spoil dikes, road fill	0.29	7.00	8.33	2.01	2.40
Dredge-Spoil total	***3.71***			***7.52***	***10.09***
Floodplain Sediments					
Upper valley floodplain					
Upland	6.67	0.31	0.65	2.07	4.34
Palustrine	4.92	0.44	0.59	2.16	2.90
Lacustrine	0.30	0.18	0.18	0.05	0.05
Upper valley floodplain total	*11.89*			*4.29*	*7.29*
Middle valley floodplain					
Upland	4.71	0.31	0.62	1.44	2.92
Palustrine	10.21	0.15	0.22	1.53	2.25
Lacustrine	5.95	0.34	0.38	2.02	2.26
Middle valley floodplain total	*20.87*			*4.99*	*7.43*
Lower valley floodplain					
Upland	2.61	0.29	0.39	0.76	1.02
Palustrine	4.46	0.15	0.18	0.67	0.80
Lacustrine	11.69	0.14	0.20	1.64	2.34
Lower valley floodplain total	*18.76*			*3.06*	*4.16*
Floodplain Total	***52***			***12***	***19***
CDA RIVER VALLEY TOTAL	***61***			***32***	***40***

a. Not Determined.
b. Not Estimated.

Table 5. Weight Percent Solids, and Specific Gravity of Solids in Sediments, Coeur d'Alene River Valley

Wetland Unit	Unit Code	weight percent of solids								specific gravity of solids							
		n	min	max	**median**	**mean**	stdev	std error	% error	n	min	max	**median**	**mean**	stdev	std error	% error
Mining-Era Sediment																	
River[1,2]	**R**	79	60.3	82.4	**78.1**	**75.4**	4.8	0.5	0.72	74	2.56	3.47	**2.94**	**2.96**	0.20	0.02	0.78
Riverbank wedge[1]	**Rbw**	7	65.8	90.2	**76.2**	**78.2**	8.3	3.1	4.02	7	2.54	3.09	**2.87**	**2.82**	0.19	0.07	2.59
Artif. dredge spoils[1]	**Ads**	10	69.4	92.2	**82.2**	**82.6**	6.9	2.2	2.63	10	2.81	3.00	**2.92**	**2.92**	0.08	0.02	0.82
Upland[1]	**U**	23	52.9	82.1	**72.6**	**71.6**	6.7	1.4	1.95	23	2.44	3.23	**2.73**	**2.74**	0.18	0.04	1.34
Palustrine[1,2]	**P**	23	46.6	74.9	**61.0**	**60.9**	7.9	1.6	2.69	13	2.49	3.45	**2.74**	**2.81**	0.25	0.07	2.48
Lacustrine[1] (lateral)	**L**	17	29.5	73.8	**64.9**	**58.0**	14.1	3.4	5.89	16	2.50	2.74	**2.93**	**2.80**	0.26	0.07	2.35
Delta[1] (river to lake)	**RLD**	5	72.2	75.1	**74.8**	**72.7**	2.8	1.2	1.71	5	2.81	2.95	**3.01**	**2.91**	0.10	0.04	1.54
Pre-Mining-Era Sediment																	
River[1]	R	42	59.3	81.7	74.0	73.6	5.0	0.8	1.05	43	2.34	3.14	2.68	2.71	0.20	0.03	1.12
Riverbank[1]	Rb	7	74.5	86.8	80.1	80.0	4.5	1.7	2.13	6	2.42	2.64	2.55	2.54	0.10	0.04	1.55
Upland[1]	U	21	60.2	82.7	74.9	73.5	5.0	1.1	1.47	19	2.29	2.65	2.59	2.56	0.10	0.02	0.92
Palustrine[1]	P	36	36.7	81.6	69.2	65.7	12.1	2.0	3.07	36	1.93	3.53	2.53	2.51	0.27	0.04	1.78
Lacustrine[1]	L	21	9.6	80.6	27.6	28.9	17.3	3.8	13.06	18	1.37	2.74	2.23	2.16	0.40	0.09	4.36
Delta[1] (river to lake)	RLD	1	65.2	65.2	65.2	65.2				1	2.63	2.63	2.63	2.63			

1. based on data from USEPA (1998),
2. based on data from Balistrieri and others (2000)

Table 6. Median Porosity and Volume Percent of Solids in Sediments, Coeur d'Alene River Valley

Wetland Unit	**Unit Code**	Predominant Sediments	wt fraction solids (g)	wt fraction water (g)	solid density (g/cm^3)	water density	air density	vol solids per g sed (cm^3)	vol water per g sed (cm^3)	**median volume percent water (porosity)**	**median volume percent solids**
Mining-Era Sediment											
River	**R**	sand	0.781	0.219	2.94	1.00	0.00	0.266	0.219	**45.2**	**54.8**
Riverbank wedge	**Rbw**	sand, silt	0.762	0.238	2.87	1.00	0.00	0.266	0.238	**47.3**	**52.7**
Artif. dredge spoils	**Ads**	sand	0.822	0.178	2.92	1.00	0.00	0.282	0.178	**38.7**	**61.3**
Upland	**U**	sand, silt	0.726	0.274	2.73	1.00	0.00	0.266	0.274	**50.7**	**49.3**
Palustrine	**P**	muddy silt	0.610	0.390	2.74	1.00	0.00	0.223	0.390	**63.7**	**36.3**
Lacustrine (lateral)	**L**	silty mud	0.649	0.351	2.93	1.00	0.00	0.222	0.351	**61.3**	**38.7**
Delta (river to lake)	**RLD**	sand, silt	0.748	0.252	3.01	1.00	0.00	0.249	0.252	**50.3**	**49.7**
Pre-Mining-Era Sediment											
River	R	sand	0.740	0.260	2.68	1.00	0.00	0.276	0.260	48.5	51.5
Riverbank	Rb	silty mud	0.801	0.199	2.55	1.00	0.00	0.314	0.199	38.8	61.2
Upland	U	soil	0.749	0.251	2.59	1.00	0.00	0.289	0.251	46.5	53.5
Palustrine	P	peat	0.692	0.308	2.53	1.00	0.00	0.274	0.308	53.0	47.0
Lacustrine (lateral)	L	organic mud	0.276	0.724	2.23	1.00	0.00	0.124	0.724	85.4	14.6
Delta (river to lake)	RLD	sand, silt	0.652	0.348	2.63	1.00	0.00	0.248	0.348	58.4	41.6

Table 7. Mean Porosity and Volume Percent of Solids in Sediments, Coeur d'Alene River Valley

Wetland Unit	**Unit Code**	wt fraction solids (g)	wt fraction water (g)	solid density (g/cm^3)	water density (g/cm^3)	vol solids per g sed (cm^3)	vol water per g sed (cm^3)	**mean volume percent water (porosity)**	**mean volume percent solids**
Mining-Era Sediment									
River	**R**	0.754	0.246	2.96	1.00	0.255	0.246	**49.1**	**50.9**
Riverbank wedge	**Rbw**	0.782	0.218	2.82	1.00	0.277	0.218	**44.0**	**56.0**
Artif. dredge spoils	**Ads**	0.826	0.174	2.92	1.00	0.283	0.174	**38.1**	**61.9**
Upland	**U**	0.716	0.284	2.74	1.00	0.261	0.284	**52.1**	**47.9**
Palustrine	**P**	0.609	0.391	2.81	1.00	0.217	0.391	**64.3**	**35.7**
Lacustrine (lateral)	**L**	0.580	0.420	2.80	1.00	0.207	0.420	**67.0**	**33.0**
Delta (river to lake)	**RLD**	0.727	0.273	2.91	1.00	0.250	0.273	**52.2**	**47.8**
Pre-Mining-Era Sediment									
River	R	0.736	0.264	2.71	1.00	0.272	0.264	49.3	50.7
Riverbank	Rb	0.800	0.200	2.54	1.00	0.315	0.200	38.8	61.2
Upland	U	0.735	0.265	2.56	1.00	0.287	0.265	48.0	52.0
Palustrine	P	0.657	0.343	2.51	1.00	0.262	0.343	56.7	43.3
Lacustrine (lateral)	L	0.289	0.711	2.16	1.00	0.134	0.711	84.2	15.8
Delta (river to lake)	RLD	0.652	0.348	2.63	1.00	0.248	0.348	58.4	41.6

Table 8. Median Density of Wet and Dry Sediments, Coeur d'Alene River Valley

Wetland Unit	**Unit Code**	pore space in sediments (volume percent)	solids in sediments (volume percent)	approx. density, water (g/cm^3)	approx. density, air (g/cm^3)	density, solids in sediment (g/cm^3)	**median density, wet sediments (g/cm^3)**	**median density, wet sediments (g/cm^3)**
Mining-Era Sediments								
River	**R**	45.2	54.8	1.00	0.00	2.94	**2.06**	**1.61**
Riverbank wedge	**Rbw**	47.3	52.7	1.00	0.00	2.87	**1.99**	**1.51**
Artif. dredge spoils	**Ads**	38.7	61.3	1.00	0.00	2.92	**2.18**	**1.79**
Upland	**U**	50.7	49.3	1.00	0.00	2.73	**1.85**	**1.34**
Palustrine	**P**	63.7	36.3	1.00	0.00	2.74	**1.63**	**1.00**
Lacustrine (lateral)	**L**	61.3	38.7	1.00	0.00	2.93	**1.75**	**1.13**
Delta (river to lake)	**RLD**	50.3	49.7	1.00	0.00	3.01	**2.00**	**1.49**
Pre-Mining-Era Sediments								
River	R	48.5	51.5	1.00	0.00	2.68	1.87	1.38
Riverbank	Rb	38.8	61.2	1.00	0.00	2.55	1.95	1.56
Upland	U	46.5	53.5	1.00	0.00	2.59	1.85	1.39
Palustrine	P	53.0	47.0	1.00	0.00	2.53	1.72	1.19
Lacustrine (lateral)	L	85.4	14.6	1.00	0.00	2.23	1.18	0.33
Delta (river to lake)	RLD	58.4	41.6	1.00	0.00	2.63	1.68	1.09

Table 9. Mean Density of Wet and Dry Sediments, Coeur d'Alene River Valley

Wetland Unit	**Unit Code**	pore space in sediments (volume percent)	solids in sediments (volume percent)	approx. density of water (g/cm^3)	approx. density of air (g/cm^3)	density, solids in sediments (g/cm^3)	**mean density, wet sediments (g/cm^3)**	**mean density, wet sediments (g/cm^3)**
Mining-Era Sediments								
River	**R**	49.1	50.9	1.00	0.00	2.96	**2.00**	**1.51**
Riverbank wedge	**Rbw**	44.0	56.0	1.00	0.00	2.82	**2.02**	**1.58**
Artif. dredge spoils	**Ads**	38.1	61.9	1.00	0.00	2.92	**2.19**	**1.81**
Upland	**U**	52.1	47.9	1.00	0.00	2.74	**1.83**	**1.31**
Palustrine	**P**	64.3	35.7	1.00	0.00	2.81	**1.65**	**1.00**
Lacustrine (lateral)	**L**	67.0	33.0	1.00	0.00	2.80	**1.59**	**0.92**
Delta (river to lake)	**RLD**	52.2	47.8	1.00	0.00	2.91	**1.91**	**1.39**
Pre-Mining-Era Sediments								
River	R	49.3	50.7	1.00	0.00	2.71	1.87	1.37
Riverbank	Rb	38.8	61.2	1.00	0.00	2.54	1.94	1.55
Upland	U	48.0	52.0	1.00	0.00	2.56	1.81	1.33
Palustrine	P	56.7	43.3	1.00	0.00	2.51	1.65	1.09
Lacustrine (lateral)	L	84.2	15.8	1.00	0.00	2.16	1.18	0.34
Delta (river to lake)	RLD	58.4	41.6	1.00	0.00	2.63	1.68	1.09

Table 10. Estimated Tonnage of Water-Saturated Lead-Rich Sediments, Coeur d'Alene River Valley

Estimation Unit	Median Volume, Pb-Rich Sediments (Mm^3)	Mean Volume, Pb-Rich Sediments (Mm^3)	Median Density, Wet Pb-Rich Sediments (t/m^3)	Mean Density, Wet Pb-Rich Sediments (t/m^3)	**Median Tonnage, Wet Pb-Rich Sediments (Mt)**	± 8.4 pct (Mt)	**Mean Tonnage, Wet Pb-Rich Sediments (Mt)**	± 8.4 pct (Mt)
Riverbed Sediments								
R1	0.49	0.55	2.06	2.00	1.01		1.10	
R2	3.37	3.32	2.06	2.00	6.95		6.64	
R3	2.78	2.36	2.06	2.00	5.72		4.73	
R4	1.64	1.45	2.06	2.00	3.38		2.90	
R5	1.63	1.43	2.06	2.00	3.36		2.85	
R6	0.98	0.96	2.06	2.00	2.02		1.92	
Riverbed total	*10.90*	*10.07*			***22.45***	*± 1.88*	***20.14***	*± 1.69*
Riverbank Sediments								
Rbw 0-1	0.15	0.15	1.99	2.02	0.29		0.31	
Rbw 2	0.32	0.34	1.99	2.02	0.63		0.69	
Rbw 3-4	0.55	0.59	1.99	2.02	1.09		1.20	
Rbw 5-6	0.25	0.32	1.99	2.02	0.49		0.65	
Riverbank total	*1.26*	*1.41*			***2.51***	*± 0.21*	***2.85***	*± 0.24*
Dredge-Spoils	*7.52*	*10.09*	*2.18*	*2.19*	*16.40*		*22.10*	
Dredge-spoils total	*7.52*	*10.09*	*2.18*	*2.19*	***16.40***	*± 1.38*	***22.10***	*± 1.86*
Floodplain Sediments								
Upper valley								
Upland	2.07	4.34	1.85	1.83	3.83		7.94	
Palustrine	2.16	2.90	1.63	1.65	3.53		4.79	
Lacustrine	0.05	0.05	1.75	1.59	0.09		0.09	
Upper valley total	*4.29*	*7.29*			*7.45*	*± 0.63*	*12.81*	*± 1.08*
Middle valley								
Upland	1.44	2.92	1.85	1.83	2.66		5.35	
Palustrine	1.53	2.25	1.63	1.65	2.50		3.71	
Lacustrine	2.02	2.26	1.75	1.59	3.54		3.60	
Middle valley total	*4.99*	*7.43*			*8.69*	*± 0.73*	*12.65*	*± 1.06*
Lower valley								
Upland	0.76	1.02	1.85	1.83	1.40		1.86	
Palustrine	0.67	0.80	1.63	1.65	1.09		1.32	
Lacustrine	1.64	2.34	1.75	1.59	2.87		3.72	
Lower valley total	*3.06*	*4.16*			*5.36*	*± 0.45*	*6.91*	
Floodplain total					***21***	*± 2*	***32***	*± 3*
CDA RIVER VALLEY TOTAL					***63***	*± 5*	***77***	*± 6*

Table 11. Estimated Tonnage of Dry Lead-Rich Sediments, Coeur d'Alene River Valley

Estimation Unit	Median Volume, Pb-Rich Sediments (Mm^3)	Mean Volume, Pb-Rich Sediments (Mm^3)	Median Density, Dry Pb-Rich Sediments (t/m^3)	Mean Density, Dry Pb-Rich Sediments (t/m^3)	**Median Tonnage, Dry Pb-Rich Sediments (Mt)**	± 8.4 percent (Mt)	**Mean Tonnage, Dry Pb-Rich Sediments (Mt)**	± 8.4 percent (Mt)
Riverbed Sediments								
R1	0.49	0.55	1.61	1.51	0.79		0.83	
R2	3.37	3.32	1.61	1.51	5.43		5.02	
R3	2.78	2.36	1.61	1.51	4.47		3.57	
R4	1.64	1.45	1.61	1.51	2.64		2.19	
R5	1.63	1.43	1.61	1.51	2.62		2.16	
R6	0.98	0.96	1.61	1.51	1.58		1.45	
Riverbed total	*10.90*	*10.07*			***17.54***	*± 1.47*	***15.21***	*± 1.28*
Riverbank Sediments								
Rbw 0-1	0.15	0.15	1.51	1.58	0.22		0.24	
Rbw 2	0.32	0.34	1.51	1.58	0.48		0.54	
Rbw 3-4	0.55	0.59	1.51	1.58	0.83		0.94	
Rbw 5-6	0.25	0.32	1.51	1.58	0.38		0.51	
Riverbank total	*1.26*	*1.41*			***1.90***	*± 0.16*	***2.23***	*± 0.19*
Dredge-Spoils	7.52	10.09	1.79	1.81	13.46		18.27	
Dredge-spoils total	*7.52*	*10.09*			***13.46***	*± 1.13*	***18.27***	*± 1.53*
Floodplain Sediments								
Upper valley								
Upland	2.07	4.34	1.34	1.31	2.77		5.68	
Palustrine	2.16	2.90	1.00	1.00	2.16		2.90	
Lacustrine	0.05	0.05	1.13	0.92	0.06		0.05	
Upper valley total	*11.81*	*17.39*			*18.46*	*± 1.55*	*26.90*	*± 2.26*
Middle valley								
Upland	1.44	2.92	1.34	1.31	1.93		3.83	
Palustrine	1.53	2.25	1.00	1.00	1.53		2.25	
Lacustrine	2.02	2.26	1.13	0.92	2.29		2.08	
Middle valley total	*4.99*	*7.43*			*5.74*	*± 0.48*	*8.15*	*± 0.68*
Lower valley								
Upland	0.76	1.02	1.34	1.31	1.01		1.33	
Palustrine	0.67	0.80	1.00	1.00	0.67		0.80	
Lacustrine	1.64	2.34	1.13	0.92	1.85		2.15	
Lower valley total	*3.06*	*4.16*			3.53	*± 0.30*	4.29	*± 0.36*
Floodplain total					***28***	*± 2*	***39***	*± 3*
CDA RIV. VAL. TOTAL					***47***	*± 4*	***57***	*± 5*

Table 12. Estimated Tonnage of Lead in Lead-Rich Sediments, Coeur d'Alene River Valley

Estimation Unit	Median Tonnage, Dry Pb-Rich Sediments (Mt)	Mean Tonnage, Dry Pb-Rich Sediments (Mt)	Median, Thickness-Weighted Average Pb (t/Mt)	Mean, Thickness-Weighted Average Pb (t/Mt)	**Median Tonnage, Pb in Pb-Rich Sediments (kt Pb)**	± 30 percent (kt Pb)	**Mean Tonnage, Pb in Pb-Rich Sediments (kt Pb)**	± 30 percent (kt Pb)
Riverbed Sediments								
R1	0.79	0.83	2315	2362	1.8		2.0	
R2	5.43	5.02	9221	9919	50.1		49.8	
R3	4.47	3.57	5286	5650	23.6		20.2	
R4	2.64	2.19	9138	10060	24.1		22.0	
R5	2.62	2.16	6608	7136	17.3		15.4	
R6	1.58	1.45	7404	7446	11.7		10.8	
Riverbed total					*129*		*120*	
Riverbank Sediments								
Rbw 0-1	0.22	0.24	4335	6557	1.0		1.6	
Rbw 2	0.48	0.54	5495	7931	2.6		4.3	
Rbw 3-4	0.83	0.94	4955	6367	4.1		6.0	
Rbw 5-6	0.38	0.51	4571	4246	1.7		2.2	
Riverbank total					*9*		*14*	
Riverbed and banks					***138***	*± 41*	***134***	*± 40*
Dredge Spoils	13.46	18.27	3271	3754	44.0		68.6	
Dredge-spoils total	*13.46*	*18.27*			***44***	*± 13*	***69***	± 21
Floodplain Sediments								
Upper valley								
Upland	2.77	5.68	3820	4463	10.6		25.4	
Palustrine	2.16	2.90	5083	5960	11.0		17.3	
Lacustrine	0.06	0.05	2815	2815	0.2		0.1	
Upper valley total					*22*		*43*	
Middle valley								
Upland	1.93	3.83	5408	6545	10.4		25.0	
Palustrine	1.53	2.25	4417	6595	6.8		14.8	
Lacustrine	2.29	2.08	6663	6638	15.2		13.8	
Middle valley total					*31*		*54*	
Lower valley								
Upland	1.01	1.33	3633	3888	3.7		5.2	
Palustrine	0.67	0.80	2875	2998	1.9		2.4	
Lacustrine	1.85	2.15	5386	5629	10.0		12.1	
Lower valley total					*16*		*20*	
Flooplain total					***68***	*± 20*	***116***	*± 35*
CDA RIV. VAL. TOTAL					***250***	*± 75*	***324***	*± 97*
minus background Pb	*-43*	*-56*	*27*	*30*	*-1*		*-2*	
CDA R.V., PB ADDED					***249***	*± 75*	***322***	*± 97*

Table 13. Summary of Estimation Uncertainties

Factor	Study/Lab	Method	Data Units	Signif. Figures in Data	Percent of Standard	Relative Error (percent)	Error in Mean (± percent)	Maximum Error (percentage)	Reference
Area of Pb-rich Sediments	USFWS	Krig	m^2	4	100.0				John Kern (unpub. data (1999)
	USGS	Hand Contour	m^2	4	99.88	0.1			this report
Thickness of Pb-Rich Sediment	USGS-GD, USGS-WRD, U. of Idaho, USEPA	direct measurement of full and partial sections	m, ft (m)	3		variable (includes interval-limited data and incomplete sections)	not determined		Box and others (2001), Balistrieri and others (2000), Fousek (1996), Bender (1991), Rabbi (1994), Hoffmann (1995), USEPA (1998)
	USEPA	Ground-Penetrating Radar	ft (m)	3		in close agreement with drilled sections	not determined		USEPA (1998)
Weight Percent Solids			weight percent	3			0.72 to 5.89		USEPA (1998),
Specific Gravity, Solids				3			0.78 to 2.48		Balistrieri and others
density, total error								± 8.4	
Analytical Precision (at 95 percent confidence level)	USGS-GD/EWU		percent				3.2 to 4.3		Box and others (2001)
	USGS-GD/XRAL		percent				9.7 to 12.4		Box and others (2001)
precision, total error								± 16.7	
density and precision, total error								± 25.1	
Pb Recovery (vs NIST certif. value)	USGS-GD/EWU	4-acid ICP-MS	ppm	3	99 to 102	-1 to +2			Box and others (2001)
	USGS-GD/XRAL	4-acid ICP-AES	ppm	3	95 to 98	-5 to -2			Box and others (2001)
Pb Recovery (vs XRAL for CdA test samples)	USFWS/ACZ	conc. Nitric ICP-AES	ppm	3	98 to 101	-2 to +1			calculated from Box and others (2001)
Pb recovery, total error								-8 to + 1	
Error-Range Total								- 33 to + 26.1	
Rounded Error-Range Total								± 30	

Table 14. Tonnage of Lead in Sediments of the South Fork Drainage Basin (Preliminary Estimate)

Deposital Era	Unit Symbol	Deposit Setting	Predominant Type of Pb-Rich Sediments	Total Mapped Area (Mm^2)	Average Thickness (m)	Volume (Mm3)	Dry Bulk Density (kt/Mm^3)	Tonnage of Pb-Rich Sediments (Mt)	Pb Concentration of Bulk Sediments (kt/Mt)	Pb Tonnage (kt Pb)	Rounded Pb Tonnage (kt Pb)	Uncertainty Range (kt Pb)
Post-Disposal	Pcg	channel	gravel, sand	3.7	2	7.4	1.19	8.8	0.5	4		
Flotation	Fcgos	channel	gravel, sand	2.8	2	5.6	1.19	6.7	1	7		
post-jig total				*6.5*		*13*		*15.5*		*11*		
Jig-Flotation	JFosw	over-bank	sand, silt (in wetlands)	0.5	1	0.5	1.58	0.8	10	8		
Jig-Flotation	JFms	millsite	tailings	0.7	1	0.7	1.58	1.1	10	11		
jig-flot. total				*1.2*		*1.2*		*1.9*		*19*		
Jig	Jcgos	channel	gravel	0.6	2	1.2	1.19	1.4	2	3		
Jig	Jos	over-bank	sand, silt	5.7	1	5.7	1.58	9.0	19	171		
jig total				*6.3*		*6.9*		*10.4*		*174*		
TOTAL				*21.7*		*35.3*		*45.2*		*204*	***200***	*± 100*

Table 15. Preliminary Alternative Mass Balances for Lead Lost to Streams vs. Lead Deposited in Sediments

Area	Reference	CdA Lake: Tonnage of Lead in Sediments (Horowitz and others, 1995) (kt)	CdA Lake: Tonnage of Lead in Zone of Overlap with River Valley and Delta Front (kt)	**Lower Estimated Tonnage of Lead (corrected for overlap) (kt)**	Uncertainty Range	Lead Tonnage as Percentage of Mining-Derived Lead Lost to Streams (based on mid-range of lower estimates)	**Higher Estimated Tonnage of Lead (corrected for overlap) (kt)**	Uncertainty Range	Lead Tonnage as Percentage of Mining-Derived Lead Lost to Streams (based on mid-range of higher estimates)
South Fork Drainage Basin	this report, table 14			200	± 100		200	± 100	
S. Fk. basin total				***200***	*± 100*	***24%***	***200***	*± 100*	***24%***
CdA River Valley									
CdA River and banks	this report, table 12								
	median			138	± 41	16%			
	mean						134	± 40	16%
CdA River Floodplain + Dredge Spoils	this report, table 12								
	median			112	± 33	13%			
	mean						190	± 56	22%
CdA River valley total				***250***	*± 75*	***29%***	***324***	*± 96*	***38%***
CdA Lake									
CdA Delta Front	this report			20	± 10	2%	20	+ 10	2%
CdA Lake	Horowitz and others (1995)								
	density 1.4 g/cm^3 assumed	313	-41	272	± 135	32%			
	density 2.0 g/cm^3 assumed	470	-58				412	± 206	49%
CdA Lake total				***292***	*±145*	***34%***	***432***	*± 216*	***51%***
Tonnage of Lead in Metal-Enriched Sediments, South Fork to CdA Lake Outlet				*742*	*± 320*	*87%*	*956*	*± 412*	*112%*
Tonnage of Mining-Derived Lead (99.6 percent of Total Lead)				***739***	*± 319*	***87%***	***952***	*± 410*	***112%***
Tonnage of Mining-Derived Lead Lost to Streams (Long, 1998b)				*-850*	*'± 10*		*-850*	*'± 10*	
Mass Balance, South Fork to CdA Lake Outlet				***-111***	*± 329*	***-13%***	***+ 102***	*± 420*	***+12%***

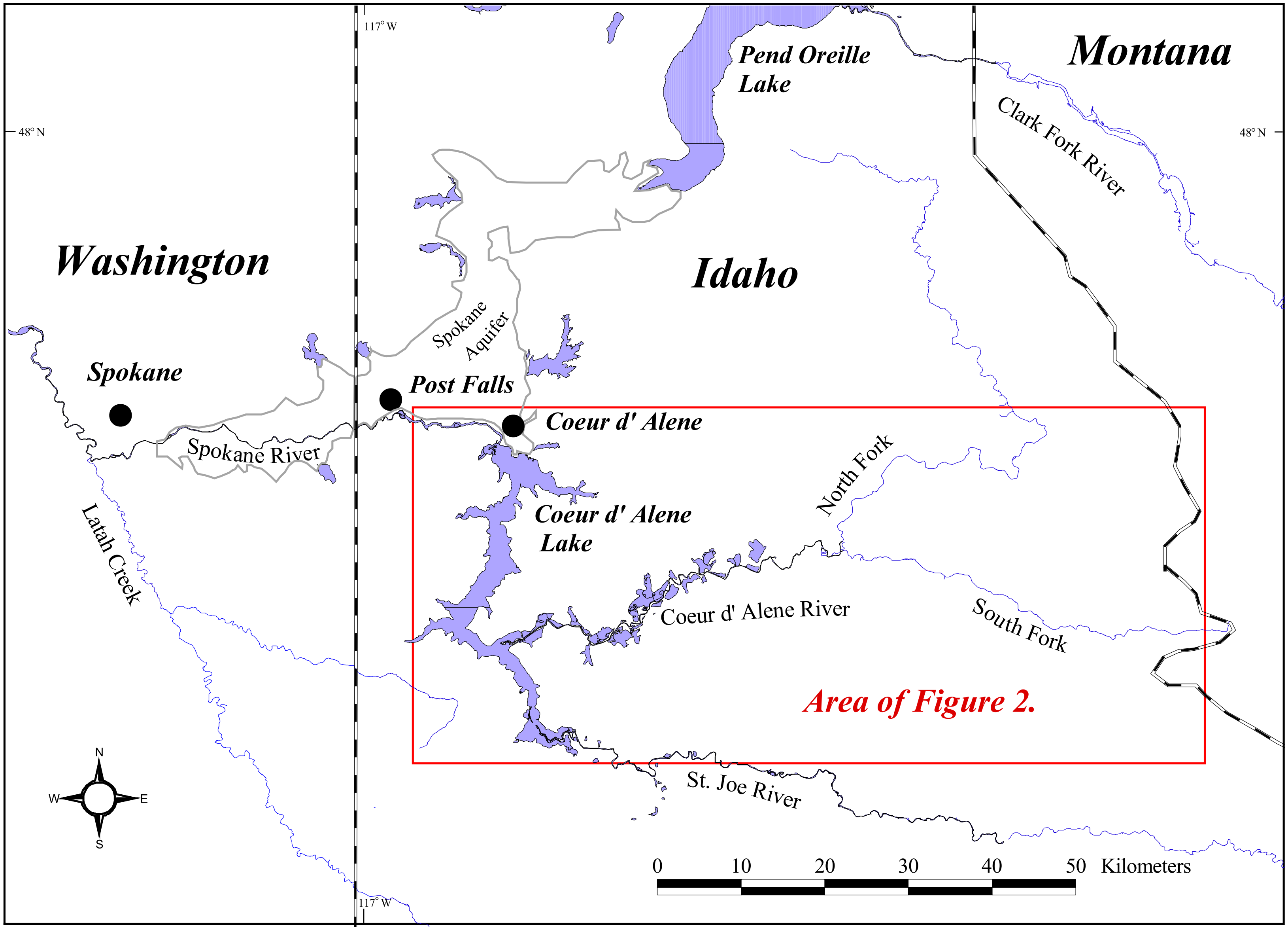

Figure 1. Location map showing the Coeur d'Alene River and other major tributary streams of the Spokane River Basin.

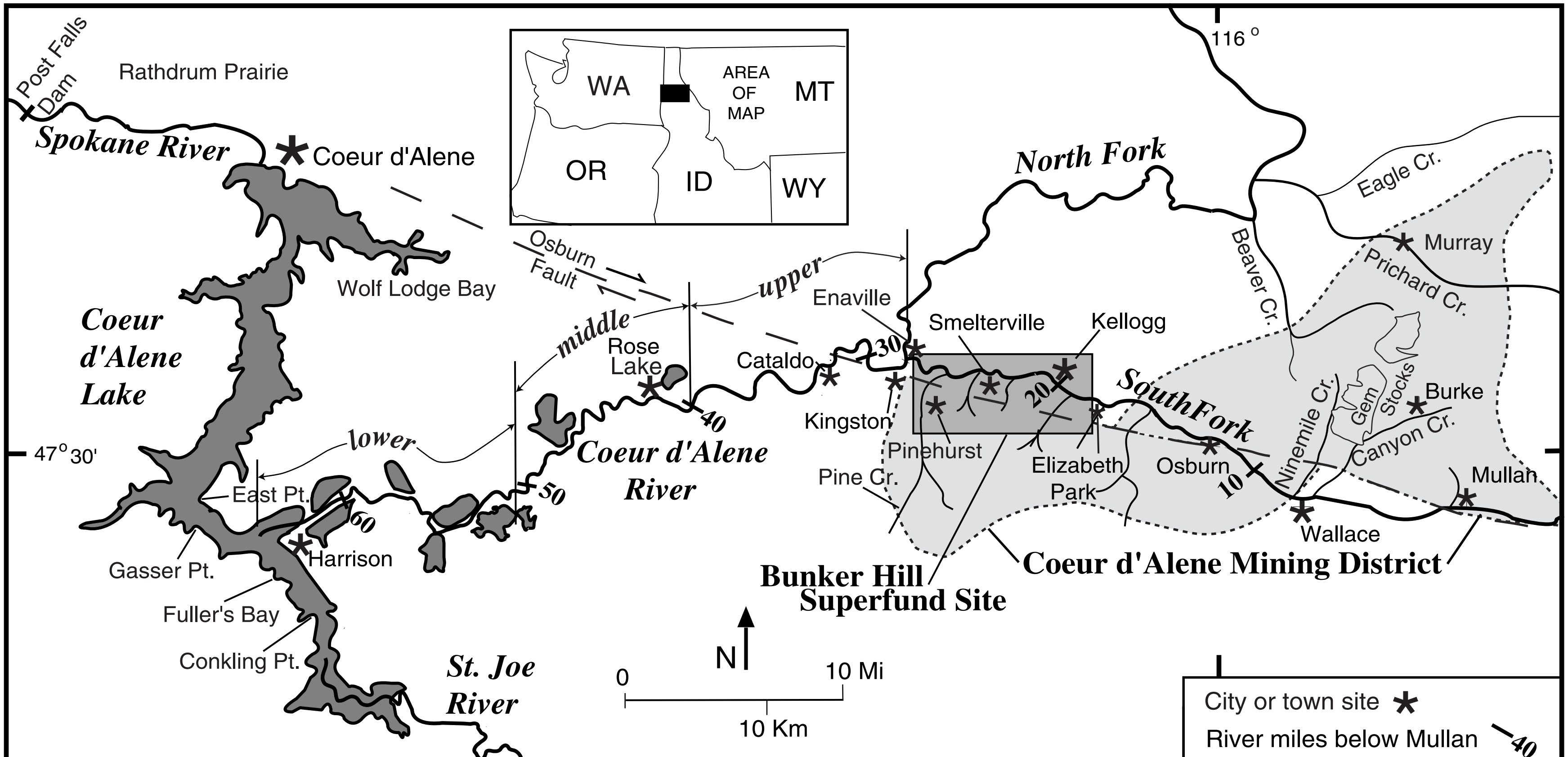

Figure 2. Index and location maps, showing selected features of the Coeur d'Alene (CdA) mining district, the Bunker Hill Superfund Site, the South and North Forks, the CdA River and its lateral lakes, the lower St. Joe River, CdA Lake, and the upper Spokane River.

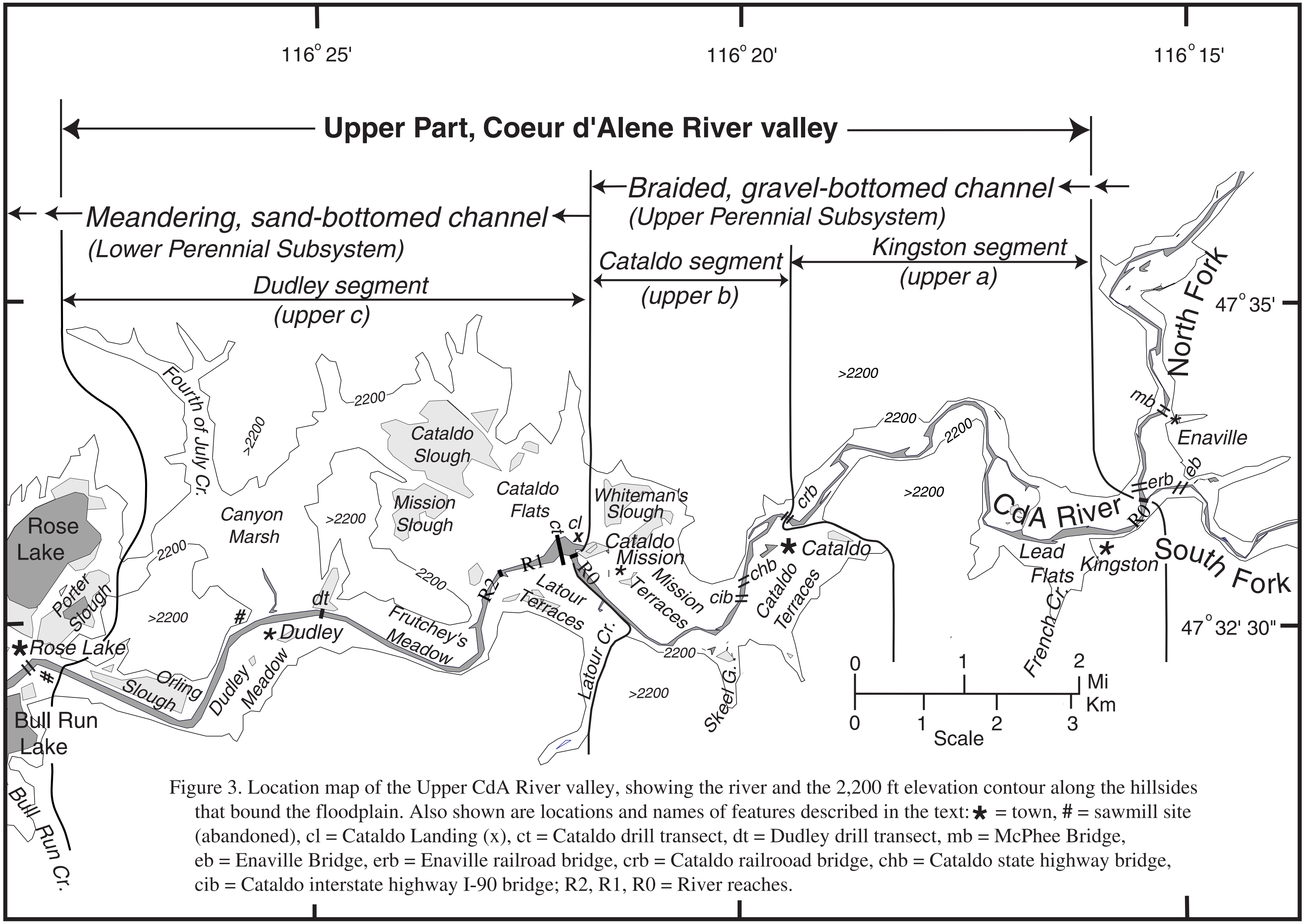

Figure 3. Location map of the Upper CdA River valley, showing the river and the 2,200 ft elevation contour along the hillsides that bound the floodplain. Also shown are locations and names of features described in the text: ★ = town, # = sawmill site (abandoned), cl = Cataldo Landing (x), ct = Cataldo drill transect, dt = Dudley drill transect, mb = McPhee Bridge, eb = Enaville Bridge, erb = Enaville railroad bridge, crb = Cataldo railrooad bridge, chb = Cataldo state highway bridge, cib = Cataldo interstate highway I-90 bridge; R2, R1, R0 = River reaches.

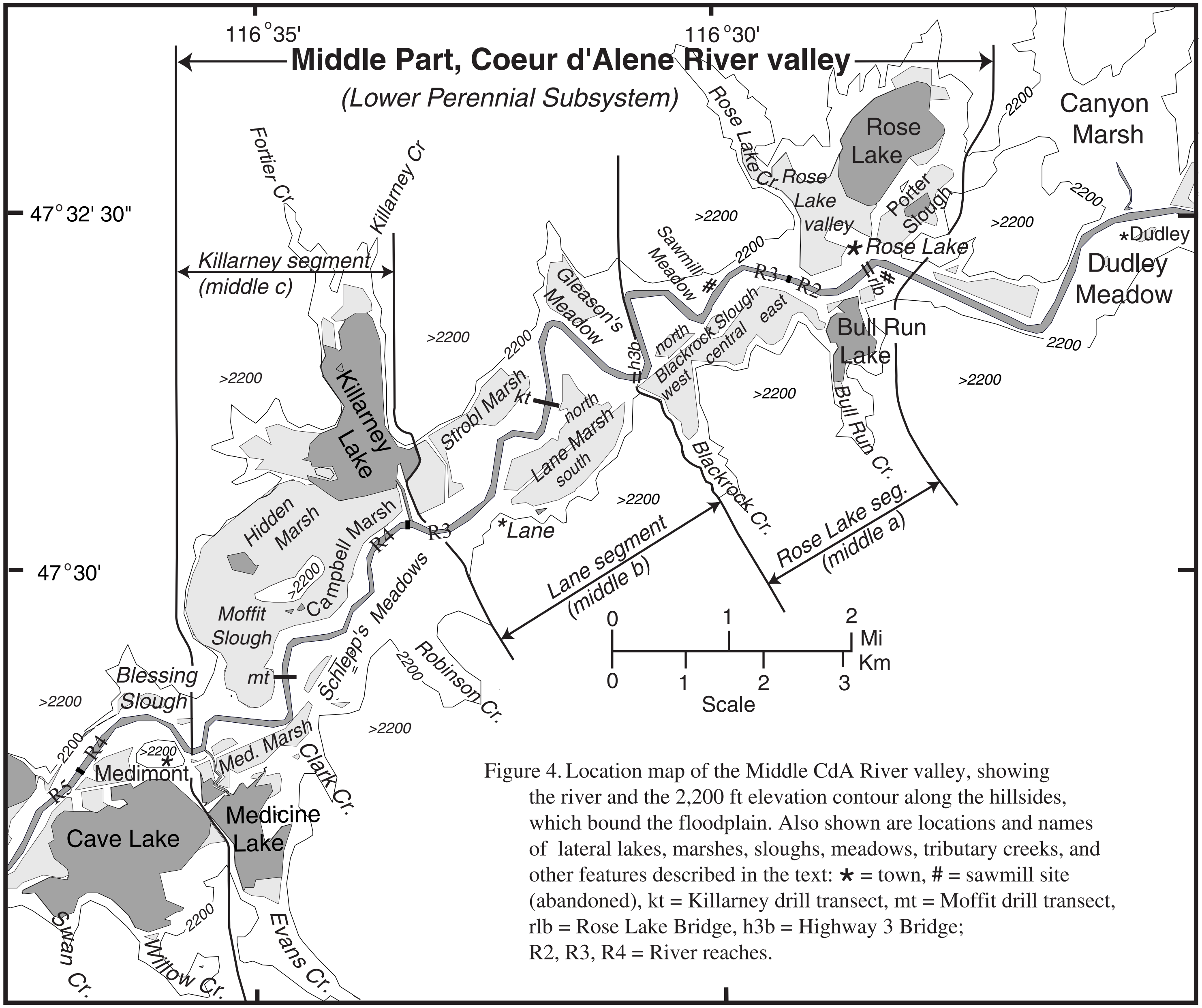

Figure 4. Location map of the Middle CdA River valley, showing the river and the 2,200 ft elevation contour along the hillsides, which bound the floodplain. Also shown are locations and names of lateral lakes, marshes, sloughs, meadows, tributary creeks, and other features described in the text: ★ = town, # = sawmill site (abandoned), kt = Killarney drill transect, mt = Moffit drill transect, rlb = Rose Lake Bridge, h3b = Highway 3 Bridge; R2, R3, R4 = River reaches.

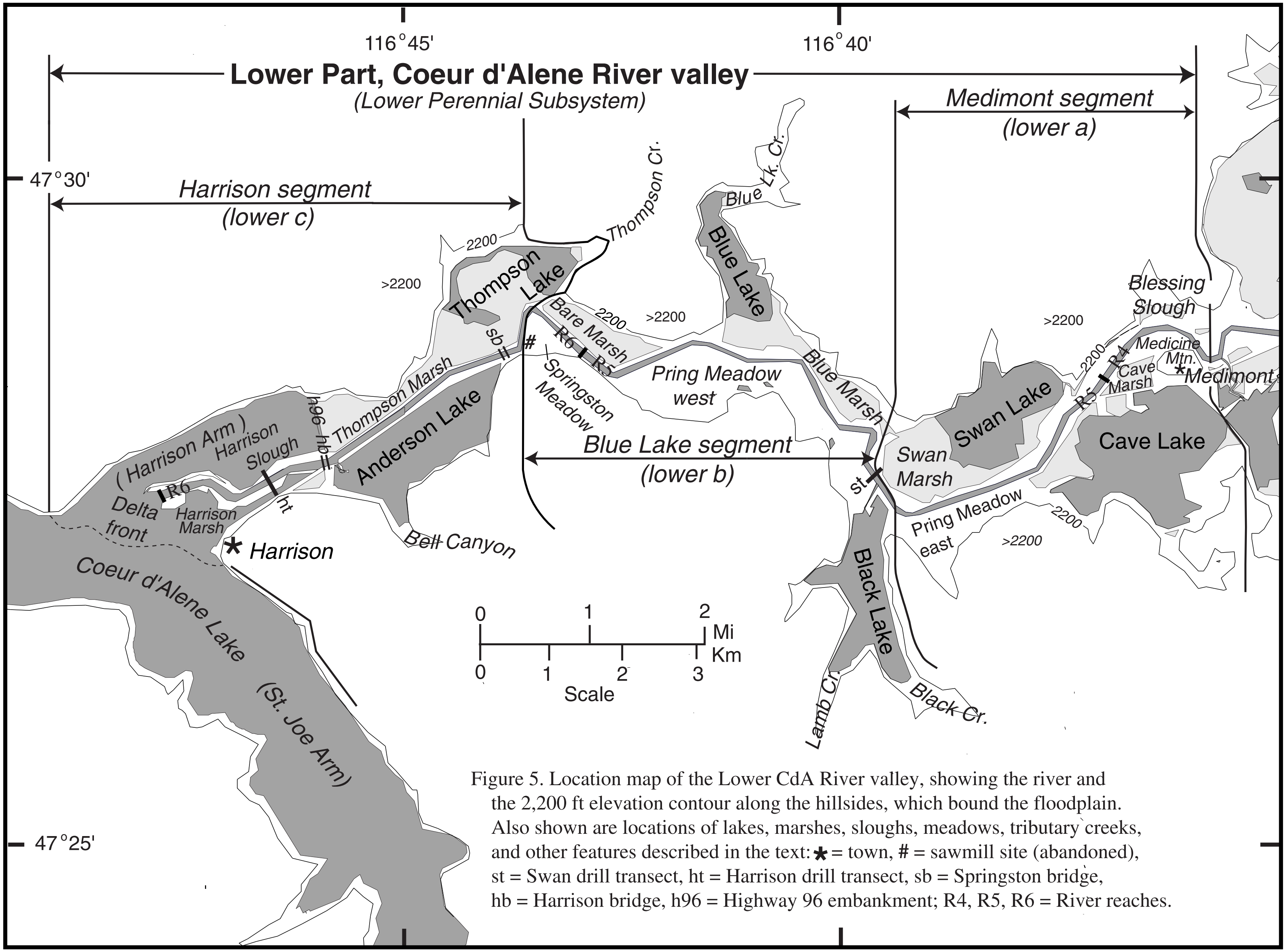

Figure 5. Location map of the Lower CdA River valley, showing the river and the 2,200 ft elevation contour along the hillsides, which bound the floodplain. Also shown are locations of lakes, marshes, sloughs, meadows, tributary creeks, and other features described in the text: ★ = town, # = sawmill site (abandoned), st = Swan drill transect, ht = Harrison drill transect, sb = Springston bridge, hb = Harrison bridge, h96 = Highway 96 embankment; R4, R5, R6 = River reaches.

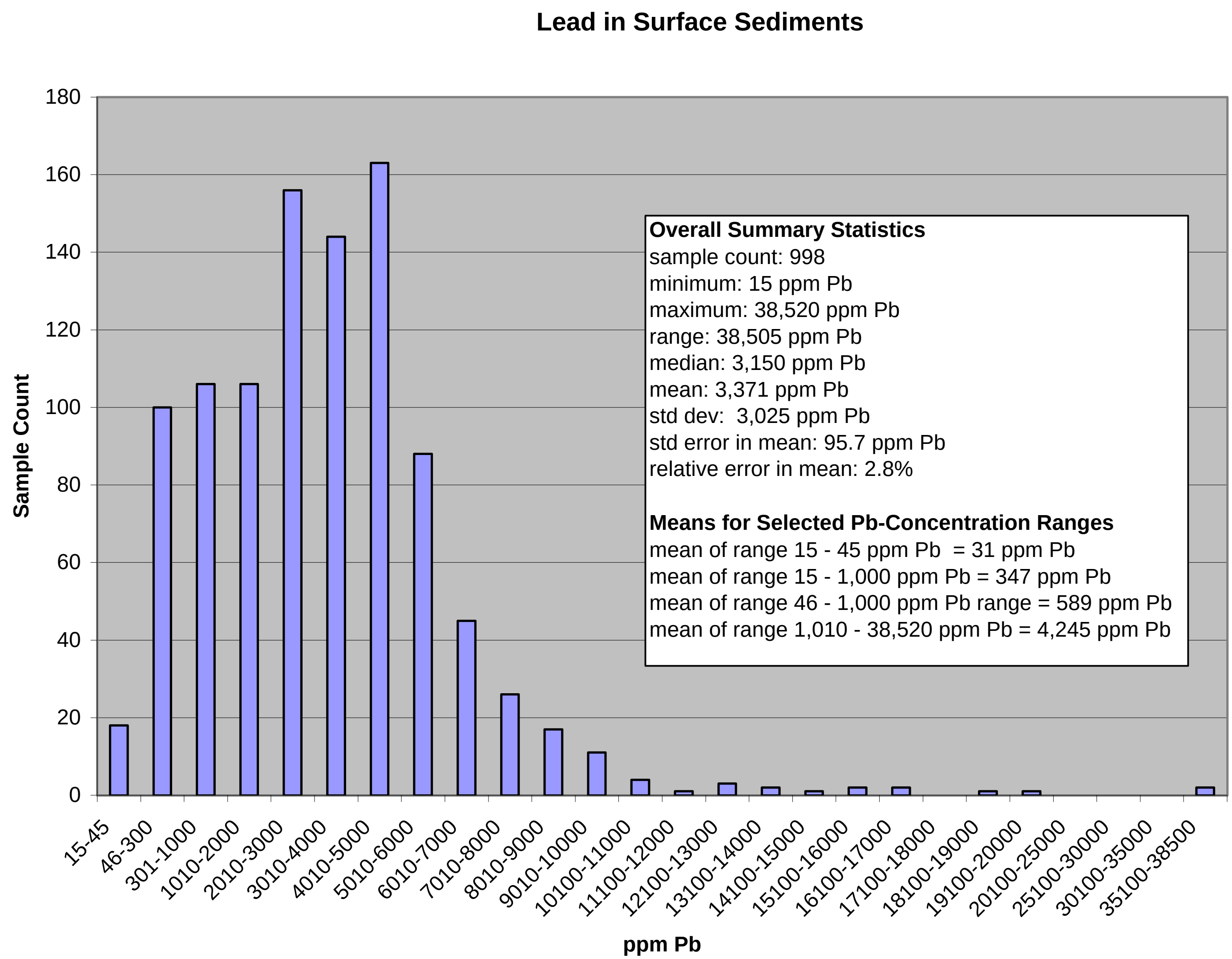

Figure 6. Frequency diagram for concentration of lead (ppm Pb) in samples of surface sediments, CdA River valley.

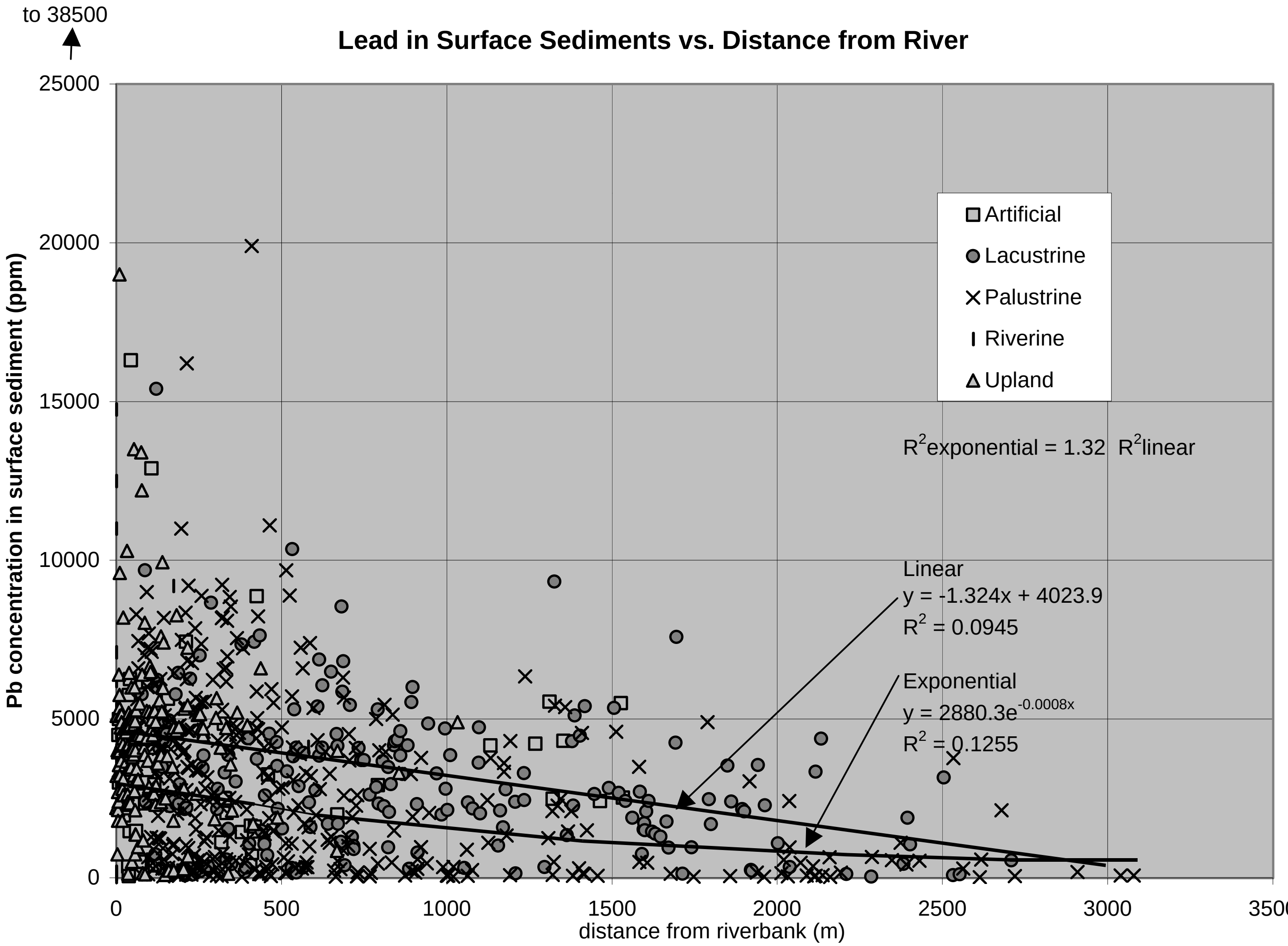

Figure 7. Scatter diagram showing lead concentration in surface sediments (by depostional setting), versus shortest distance (m) from nearest riverbank.

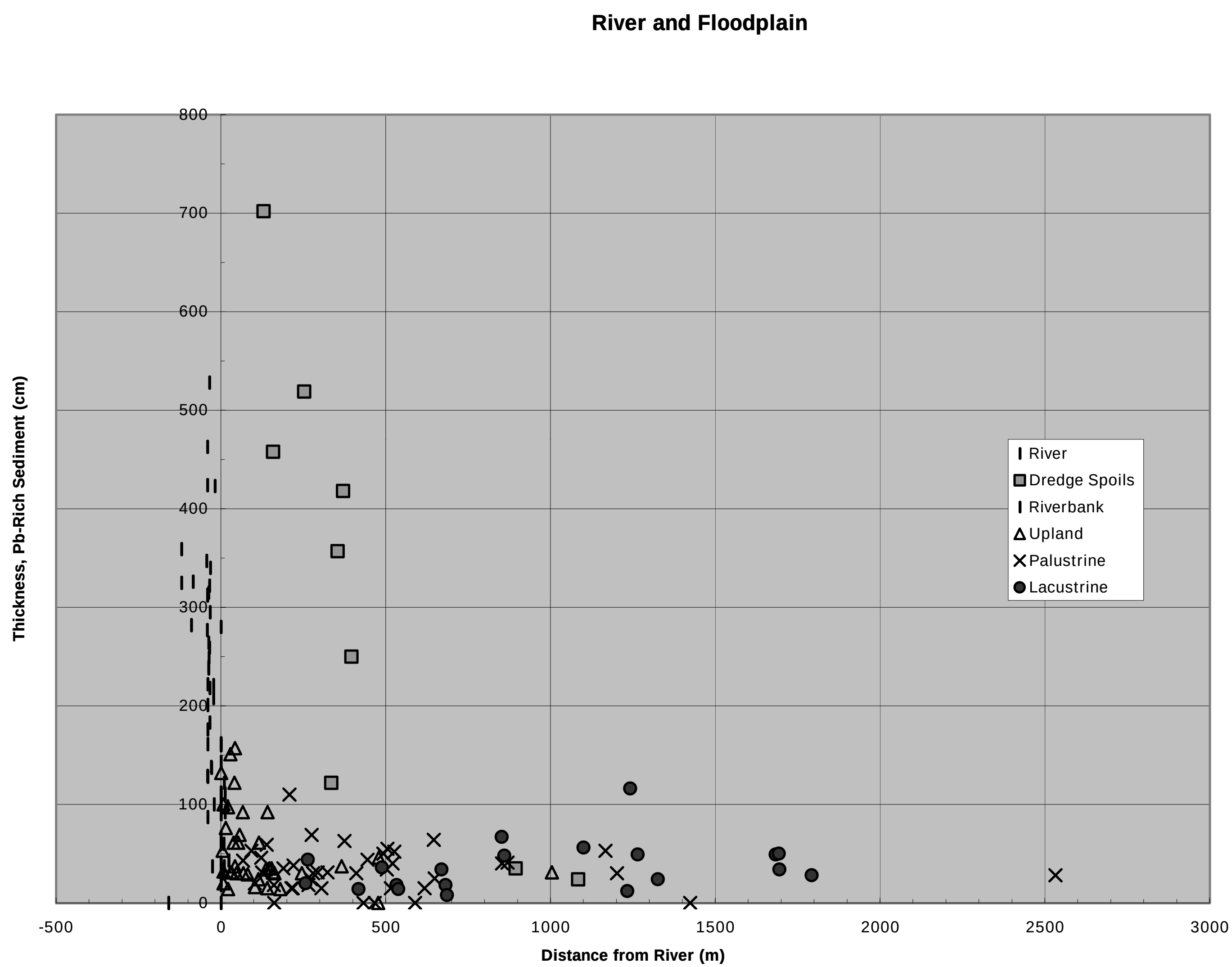

Figure 8. Scatter diagram, showing thickness (cm) of Pb-rich sediments (by depositional setting), versus shortest distance (m) from nearest riverbank.

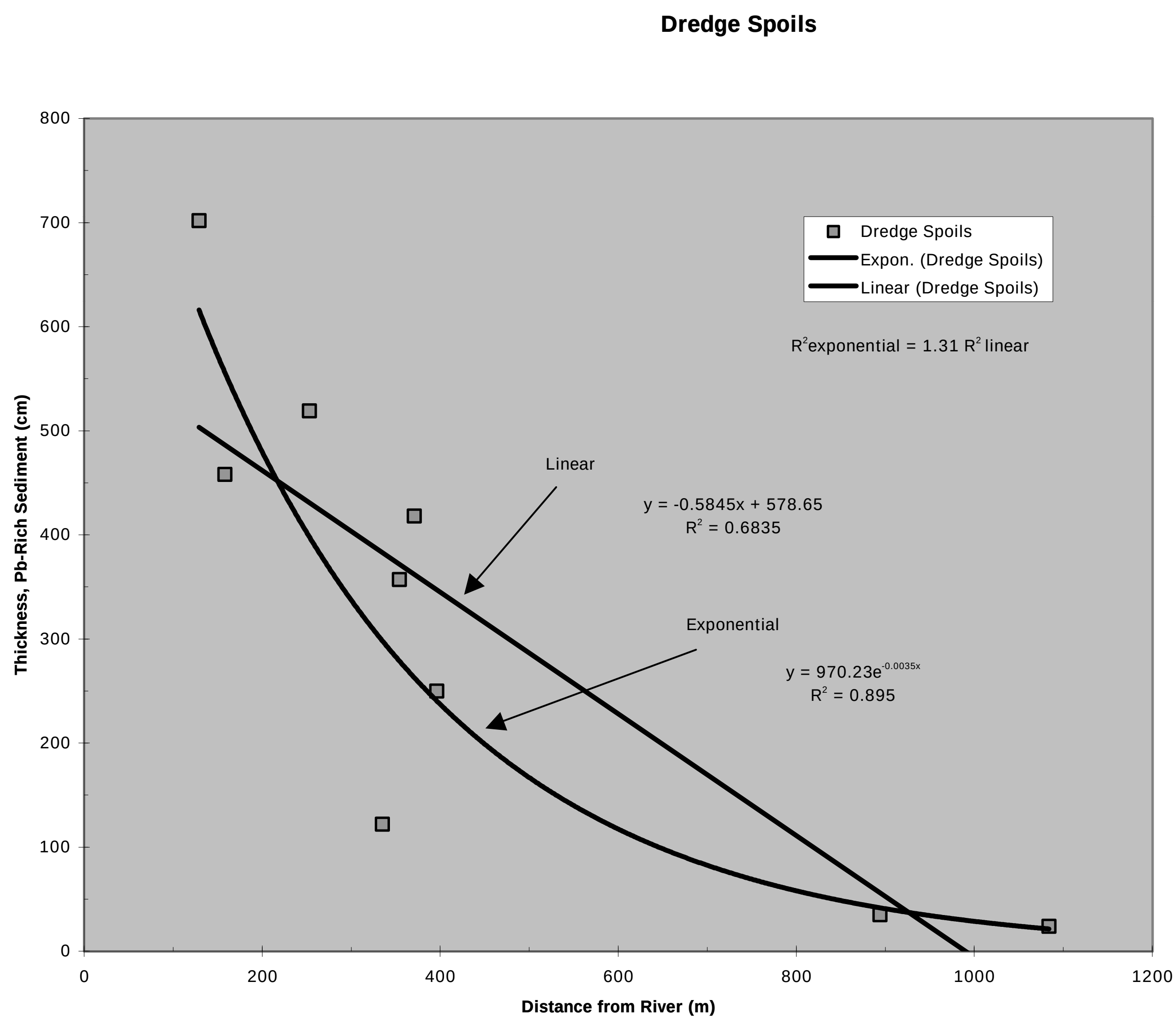

Figure 9. Scatter diagram, showing thickness of dredge spoils (cm), versus shortest distance (m) from the nearest riverbank.

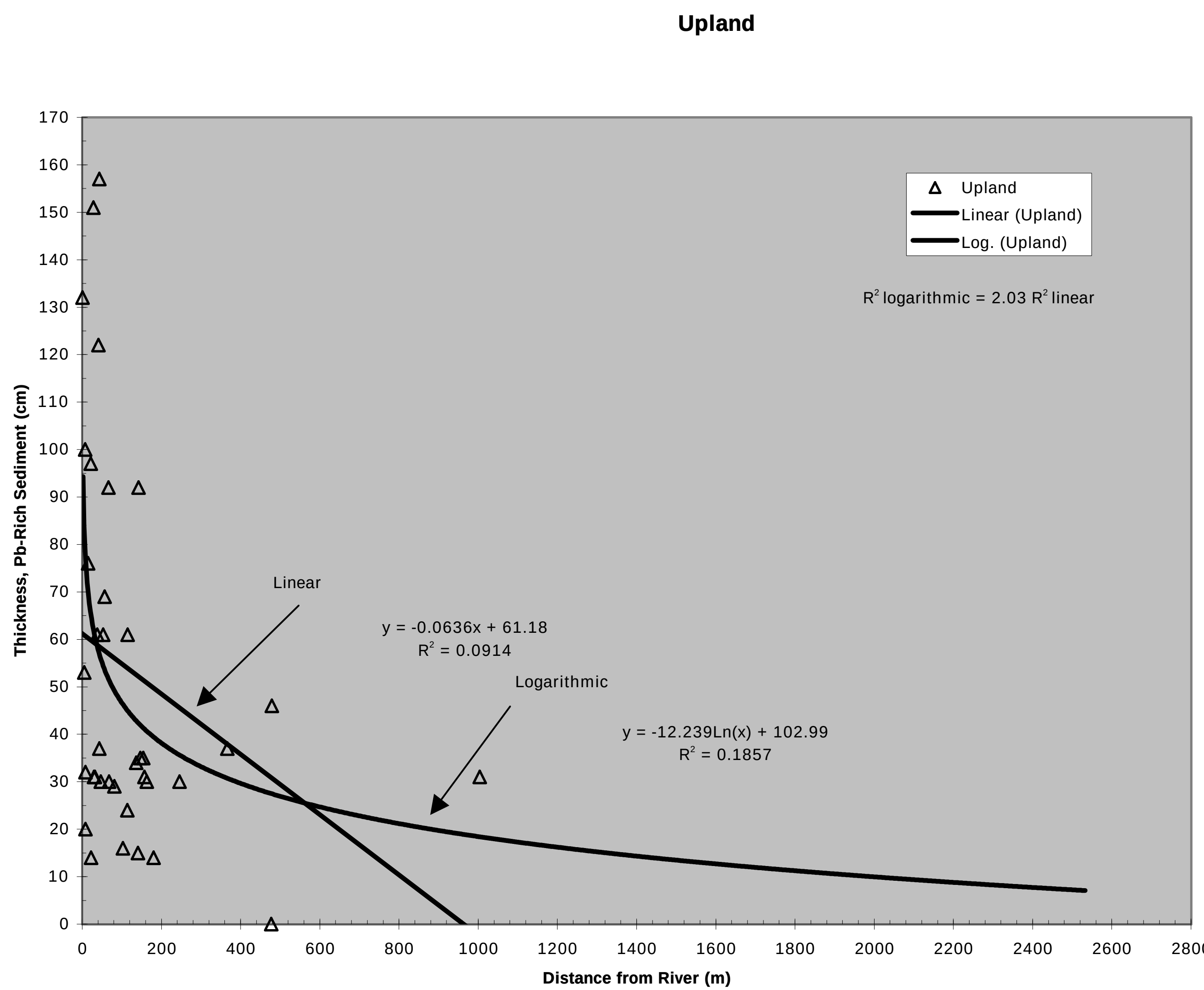

Figure 10. Scatter diagram, showing thickness of upland Pb-rich sediments (cm), versus shortest distance (m) from nearest riverbank.

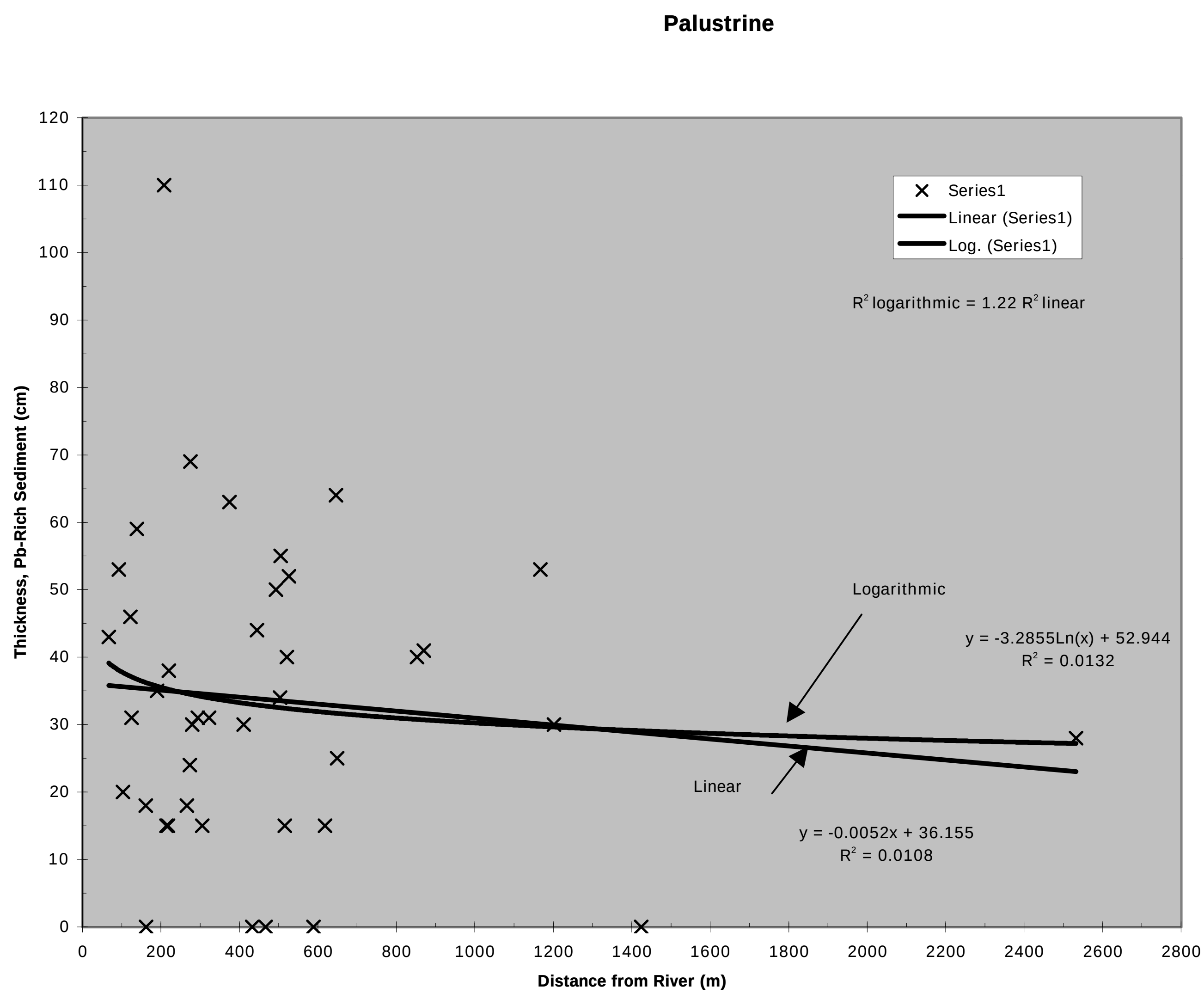

Figure 11. Scatter diagram, showing thickness (cm) of palustrine Pb-rich sediments, versus shortest distance (m) from nearest riverbank.

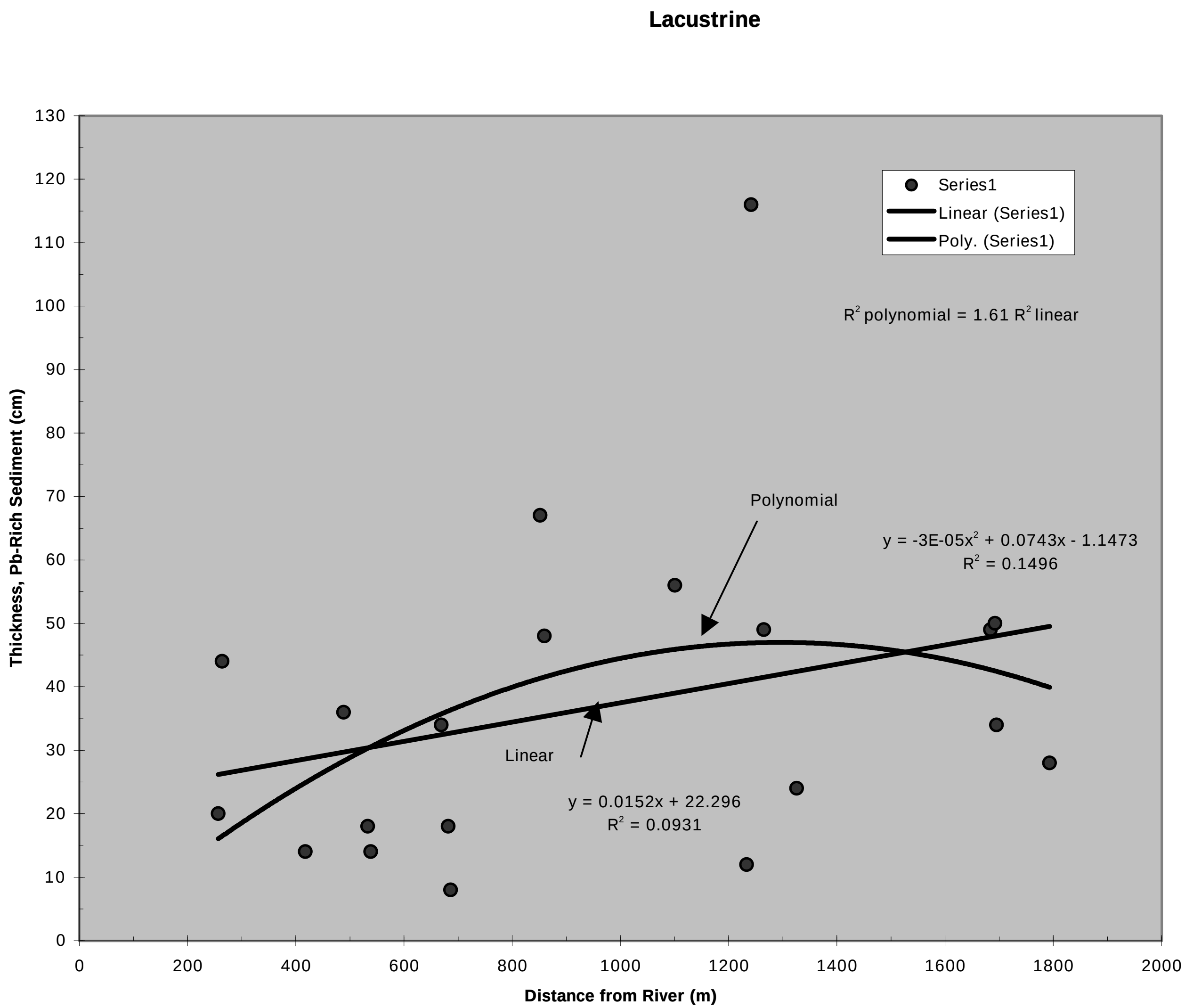

Figure 12. Scatter diagram, showing thickness (cm) of lacustrine Pb-rich sediments, versus shortest distance from the nearest riverbank.

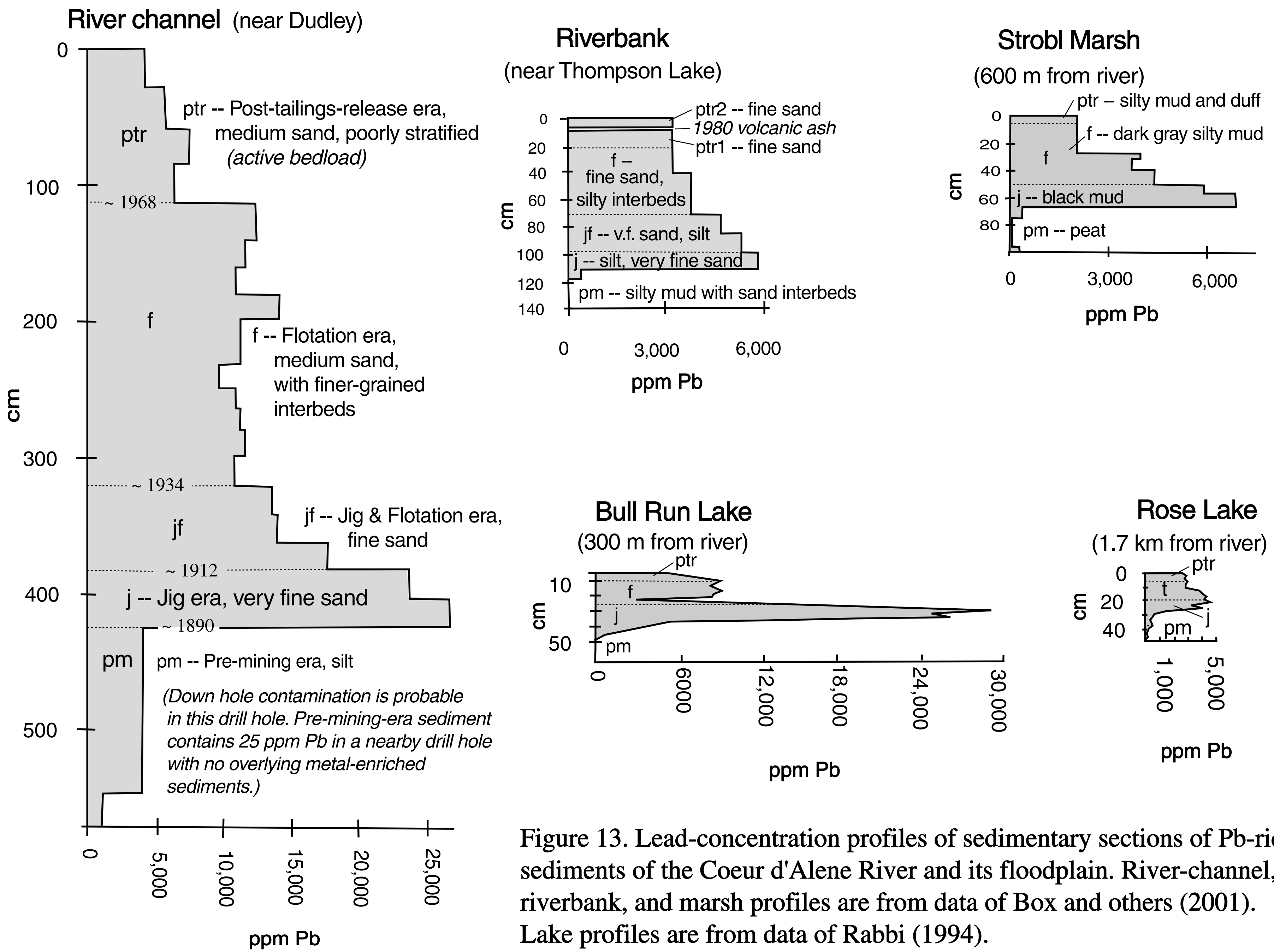

Figure 13. Lead-concentration profiles of sedimentary sections of Pb-rich sediments of the Coeur d'Alene River and its floodplain. River-channel, riverbank, and marsh profiles are from data of Box and others (2001). Lake profiles are from data of Rabbi (1994).

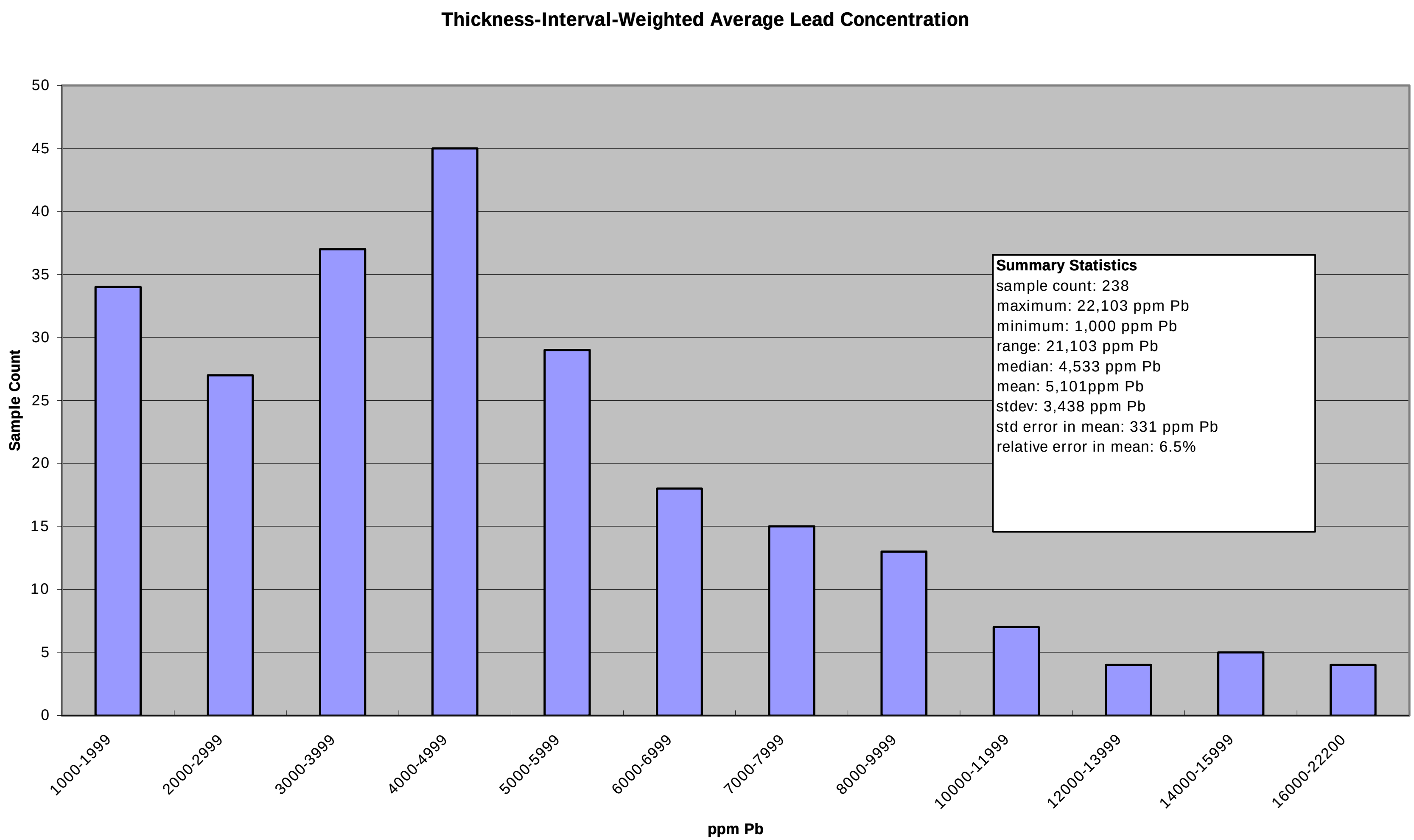

Figure 14. Frequency diagram for thickness-interval-weighted average lead concentration in full sections of lead-rich sediments.

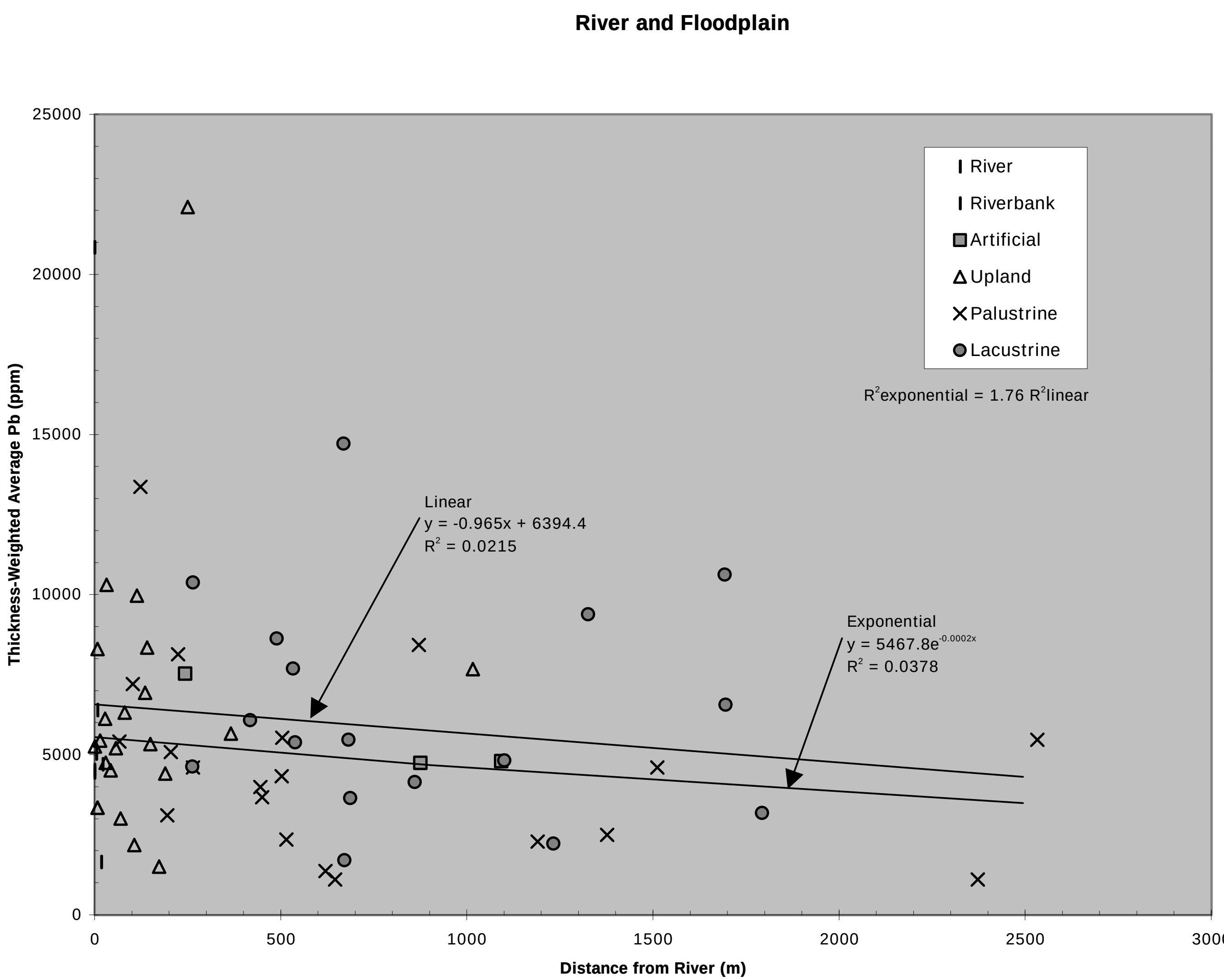

Figure 15. Scatter diagram, showing thickness-interval-weighted average Pb (ppm) in Pb-rich sediments, versus shortest distance (m) from the nearest riverbank.

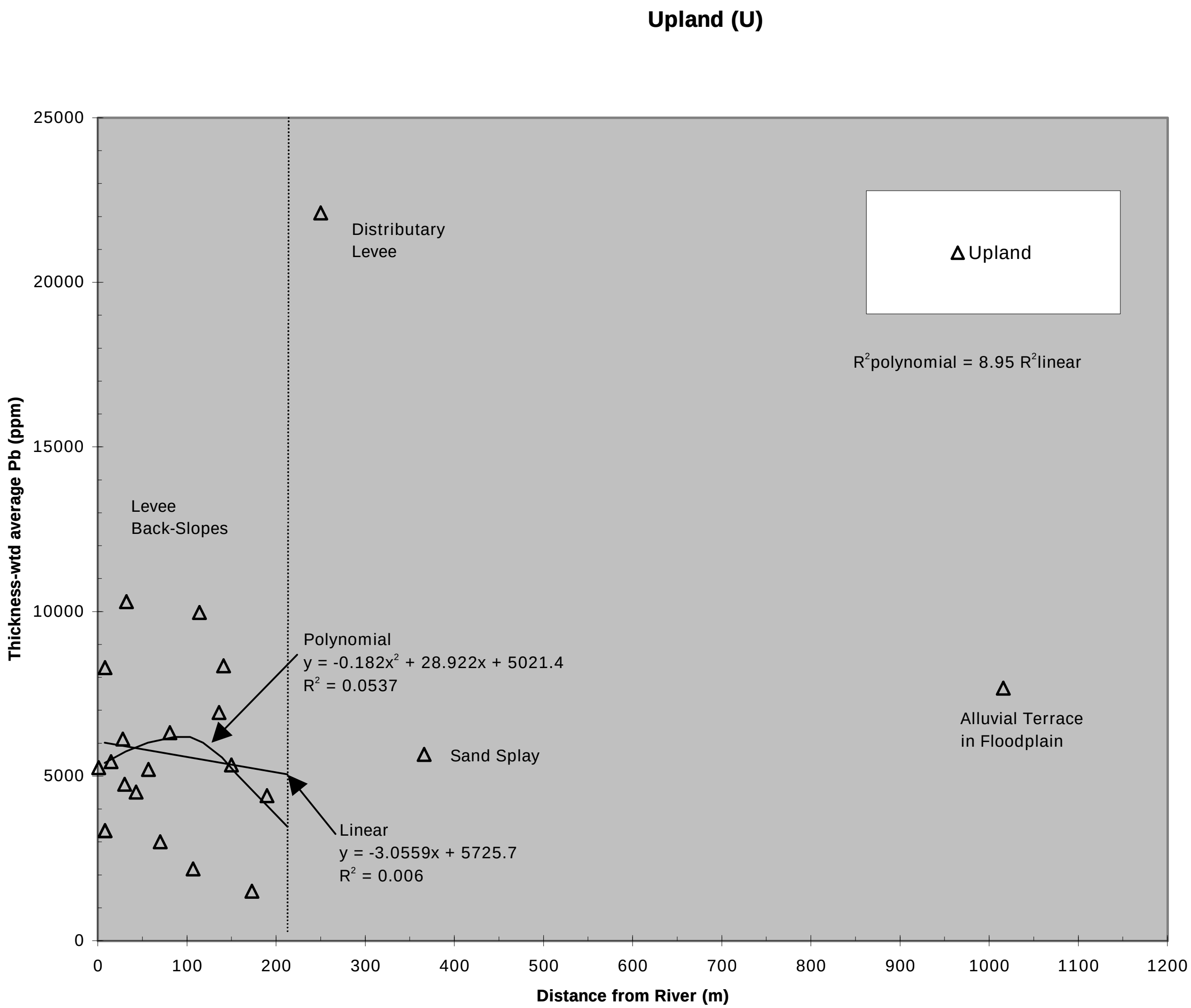

Figure 16. Scatter diagram, showing thickness-weighted average ppm Pb in upland sediments vs. shortest distance (m) from the nearest riverbank.

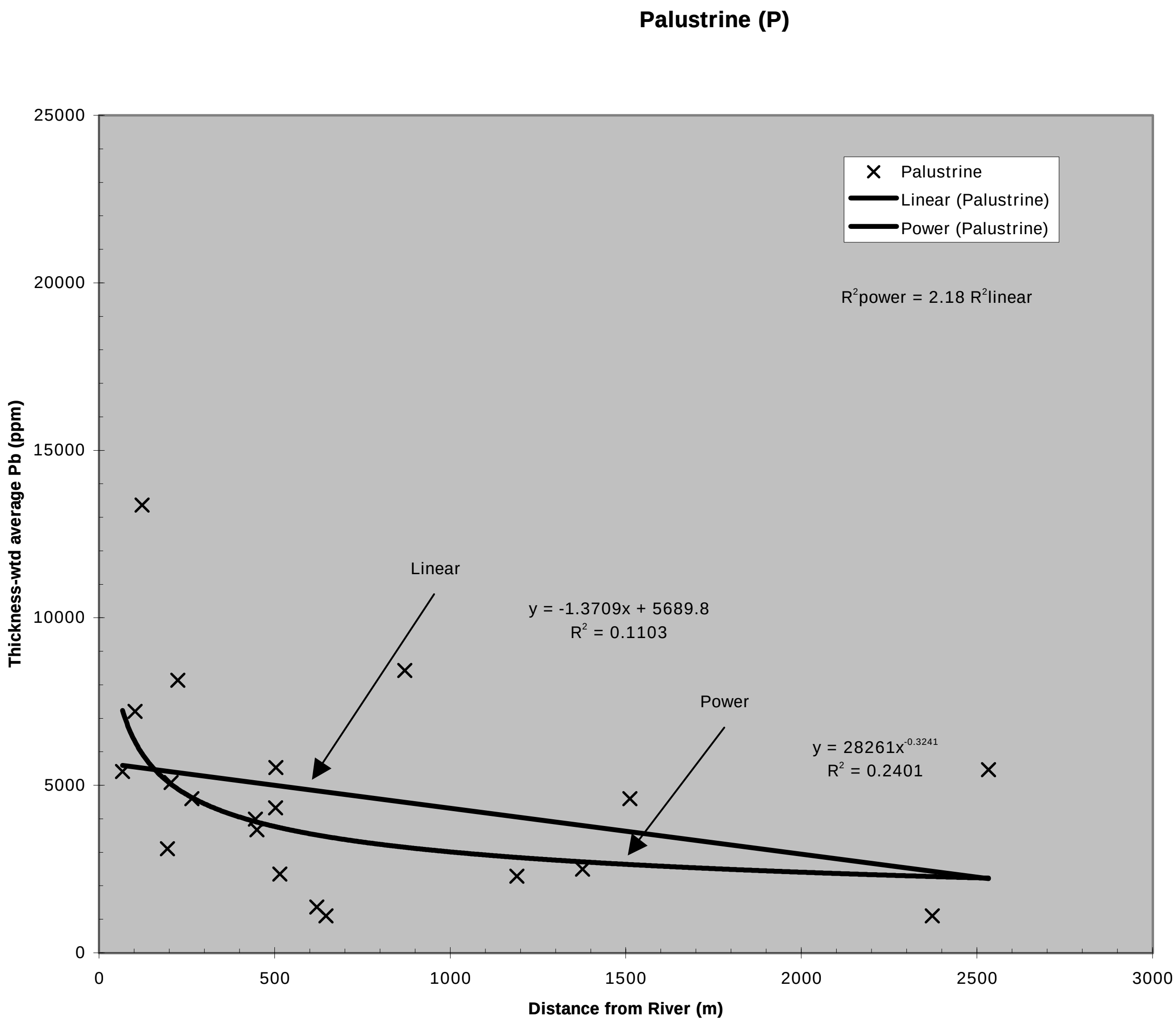

Figure 17. Scatter diagram, showing thickness-weighted average ppm Pb in palustrine sediments, vs. shortest distance (m) from the nearest riverbank.

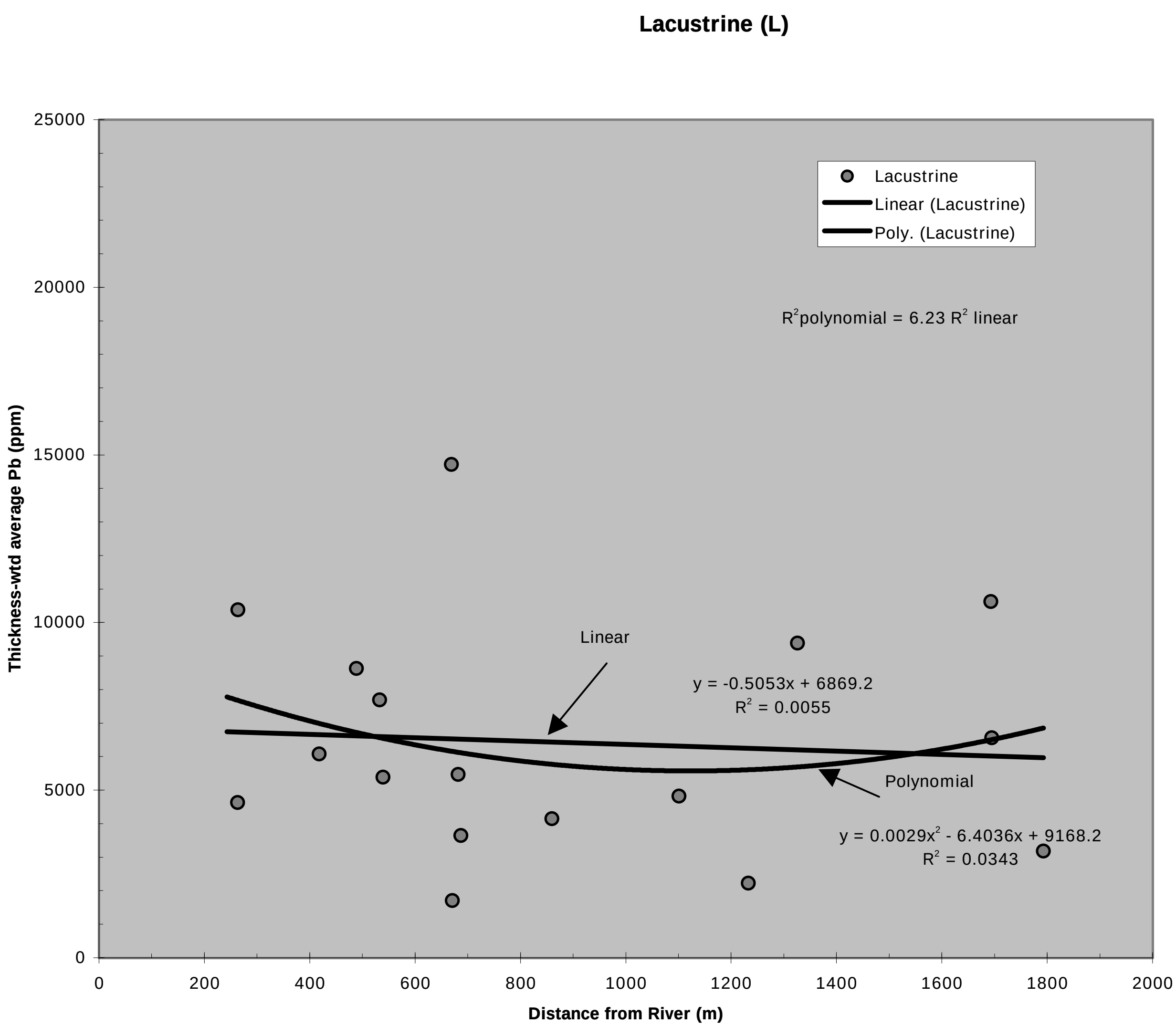

Figure 18. Scatter diagram, showing thickness-weighted average ppm Pb in lacustrine sediments, vs. shortest distance (m) from the nearest riverbank.

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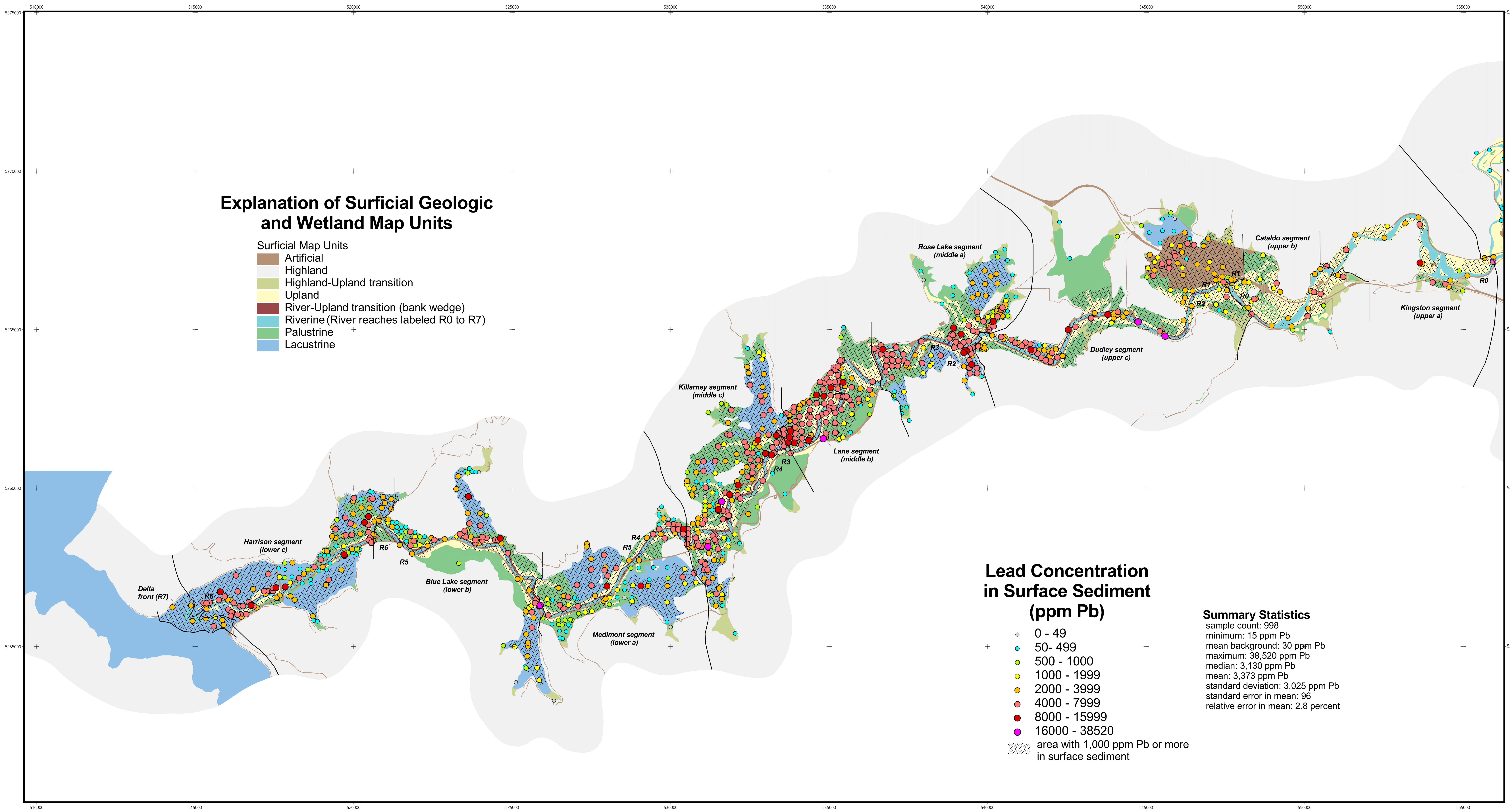

Map Projection and 5,000-meter grid
UTM, zone 11, 1927 North American Datum

2 0 2 4 6 8 10 Kilometers

scale 1:50,000

This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey standards or with the North American Stratigraphic Code. Any use of trade, firm, or product names in this publication is for descriptive purposes only and does not imply endorsement by the U.S. Government. This map was printed on an electronic plotter directly from digital files. Dimensional calibration may vary between electronic plotters and between X and Y directions on the same plotter, and paper may change size due to atmospheric conditions; therefore, scale and proportions may not be true on plots of this map.

Map of Surficial Geology and Wetlands, Showing Concentrations of Lead (ppm Pb) in Samples of Surface Sediment, Coeur d'Alene River Valley, Idaho

By Arthur A. Bookstrom, Stephen E. Box, Julie K. Campbell, and Berne L. Jackson
2001

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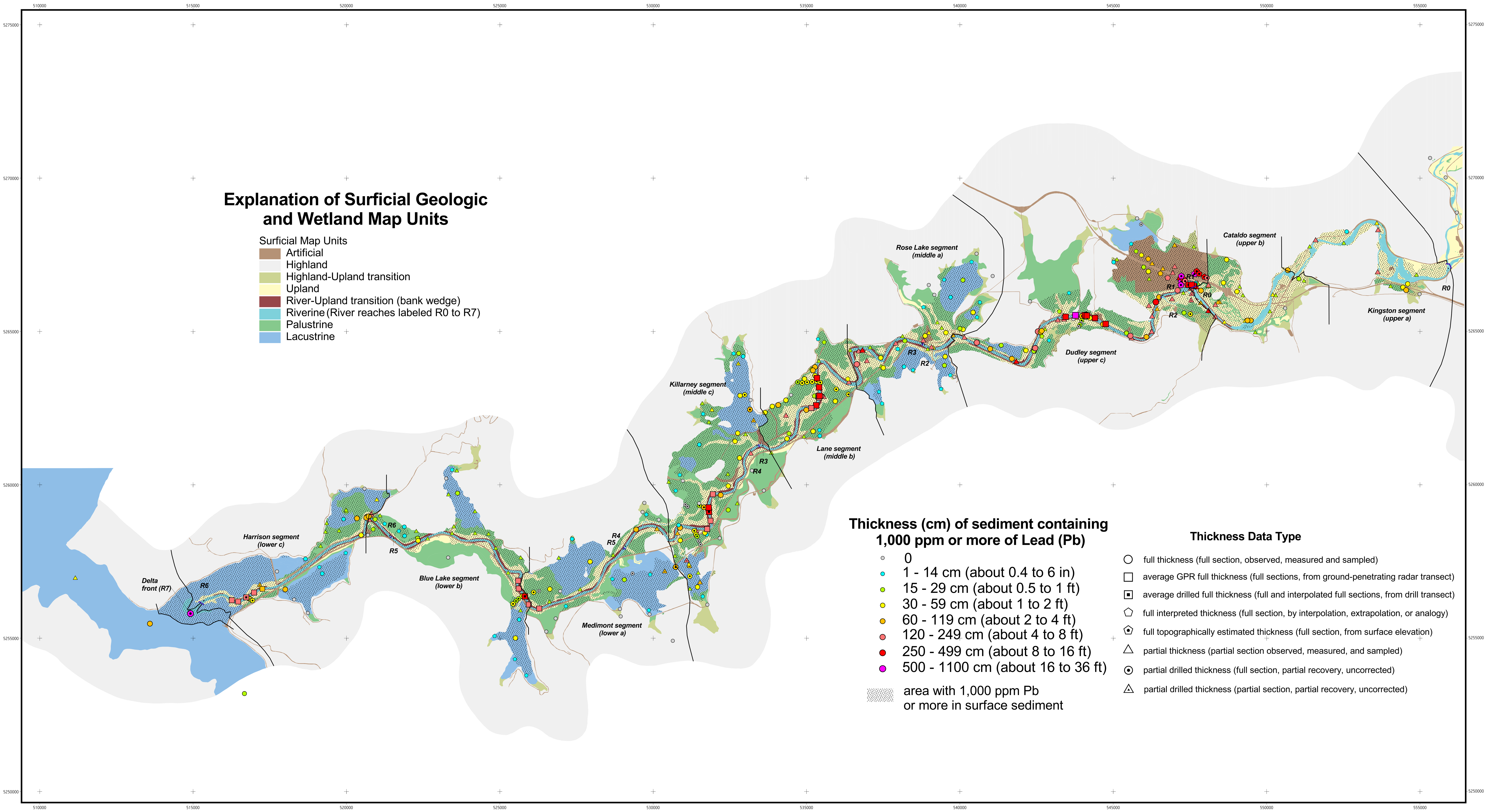
with the Coeur d'Alene Tribe

Open File Report 01-140
Plate 2 , Version 1.0



Map Projection and 5,000-meter grid
UTM, zone 11, 1927 North American Datum

scale 1:50,000

Map of Surficial Geology and Wetlands, Showing Thickness Measurements (cm) of Surficial Sediments, containing 1,000 ppm or more of Lead (Pb), Coeur d'Alene River Valley, Idaho

By Arthur A. Bookstrom, Stephen E. Box, Kathryn Foster, and Berne L. Jackson

2001