Prepared in cooperation with the U.S. Fish and Wildlife Service

Assessment of Sediments in the Riverine Impoundments of National Wildlife Refuges in the Souris River Basin, North Dakota

Scientific Investigations Report 2014–5018

U.S. Department of the Interior
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Conversion Factors

SI to Inch/Pound

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Area	
hectare (ha)	2.471	acre
square centimeter (cm^2)	0.1550	square inch (ft^2)
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
cubic centimeter (cm^3)	0.06102	cubic inch (in^3)
liter (L)	61.02	cubic inch (in^3)
	Flow rate	
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)
	Mass	
gram (g)	0.03527	ounce, avoirdupois (oz)

Horizontal coordinate information is referenced to the World Geodetic System 1984 (GCS WGS84) and North American Datum of 1983 (NAD 83).

Assessment of Sediments in the Riverine Impoundments of National Wildlife Refuges in the Souris River Basin, North Dakota

By Brian A. Tangen,[1] Murray K. Laubhan,[2] and Robert A. Gleason[1]

Abstract

Accelerated sedimentation of reservoirs and riverine impoundments is a major concern throughout the United States. Sediments not only fill impoundments and reduce their effective life span, but they can reduce water quality by increasing turbidity and introducing harmful chemical constituents such as heavy metals, toxic elements, and nutrients. U.S. Fish and Wildlife Service national wildlife refuges in the north-central part of the United States have documented high amounts of sediment accretion in some wetlands that could negatively affect important aquatic habitats for migratory birds and other wetland-dependent wildlife. Therefore, information pertaining to sediment accumulation in refuge impoundments potentially is important to guide conservation planning, including future management actions of individual impoundments. Lands comprising Des Lacs, Upper Souris, and J. Clark Salyer National Wildlife Refuges, collectively known as the Souris River Basin refuges, encompass reaches of the Des Lacs and Souris Rivers of northwestern North Dakota. The riverine impoundments of the Souris River Basin refuges are vulnerable to sedimentation because of the construction of in-stream dams that interrupt and slow river flows and because of post-European settlement land-use changes that have increased the potential for soil erosion and transport to rivers. Information regarding sediments does not exist for these refuges, and U.S. Fish and Wildlife Service personnel have expressed interest in assessing refuge impoundments to support refuge management decisions.

Sediment cores and surface sediment samples were collected from impoundments within Des Lacs, Upper Souris, and J. Clark Salyer National Wildlife Refuges during 2004–05. Cores were used to estimate sediment accretion rates using radioisotope (cesium-137 [^{137}Cs], lead-210 [^{210}Pb]) dating techniques. Sediment cores and surface samples were analyzed for a suite of elements and agrichemicals, respectively. Examination of core characteristics along the depth profile suggests that there has been regular sediment mixing and removal, as well as non-uniform sediment deposition with time. Estimated mean accretion rates based on the three methods of determination (two time markers for ^{137}Cs, ^{210}Pb) ranged from 0.22–0.35 centimeters per year, and approximately 70 percent of cores had less ^{137}Cs than expected. Concentrations of sediment-associated elements generally were within reported reference ranges, and all agrichemicals analyzed were below detection limits. Results suggest that there does not appear to be widespread sediment accumulation in impoundments of the Souris River Basin refuges. In addition, there were no identifiable patterns among sedimentation rates from the upstream (Des Lacs, Upper Souris) to the downstream (J. Clark Salyer) refuges. There were, however, apparent upstream to downstream patterns of increased concentrations of some elements (for example, aluminum, boron, and vanadium) that may warrant further exploration. Future related monitoring and research efforts should focus on areas with high potential for sediment accumulation, such as upstream areas adjacent to dams, to identify potential sediment problems before they become too severe. Further, assessments of suspended sediments transported in the Des Lacs and Souris Rivers would augment interpretation of sedimentation data by identifying potential sediment sources and areas with the greatest potential for accumulation.

Introduction

During the extreme drought in the mid-1930s, the U.S. Fish and Wildlife Service (USFWS) established numerous national wildlife refuges (NWR) with the purpose of providing dependable habitats for migratory birds and other wildlife (U.S. Fish and Wildlife Service, 2007). In North and South Dakota, many of these refuges were established in river corridors that previously had been modified to enhance agricultural production. To create and restore floodplain habitats,

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[1] U.S. Geological Survey.

[2] U.S. Fish and Wildlife Service.

the USFWS constructed levees and dams to facilitate water retention and management of specific river reaches, essentially creating in-stream impoundments. A primary purpose of management was to provide breeding and stopover habitat for migratory waterfowl and other wetland-dependent species.

Impoundments created by obstructing river flows, however, often have a finite life span because they accumulate sediments that result in loss of water storage capacity (Smith and others, 1960; Gleason and others, 2003a; Juracek, 2004; Lee and others, 2008; Graf and others, 2010; Juracek, 2010; Juracek, 2011). Sedimentation is a natural process, but infrastructure that slows and impounds water flows tends to accelerate sedimentation rates in localized areas upstream from structures (for example, levees, dams) and accelerate erosion downstream from structures. The extent to which sediment processes are disrupted depends on channel morphology, flow characteristics (for example, frequency, magnitude, duration), type of infrastructure design (for example, stoplog as compared to radial gate water-control structure), and water-management strategies implemented.

In terms of quantity, sediment is the major pollutant of wetlands, lakes, estuaries, and reservoirs in the United States (Baker, 1992). The potential environmental effects of increased sedimentation are numerous and include water-quality degradation (Goldman and Horne, 1983; U.S. Environmental Protection Agency, 1986; Salomons and others, 1987; Wetzel, 2001) because sediments act as both a sink and source for constituents such as heavy metals, trace elements, nutrients, and agrichemicals (Martin and Hartman, 1987; Schwarz and others, 2004; Sando and others, 2007; Juracek and Becker, 2009; Juracek, 2010; Juracek, 2011; Belden and others, 2012). Once in the food chain, bioaccumulation of sediment-derived constituents may pose a risk to fish, wetland-dependent wildlife, and humans (Knezovich and others, 1987; Reynoldson, 1987; Willford and others, 1987; Ingersoll and others, 1994; U.S. Environmental Protection Agency, 1994; Morel and others, 1998; Hamilton and Buhl, 2004). Additionally, unconsolidated sediments can increase turbidity, reduce dissolved oxygen concentrations, alter nutrient availability, reduce sunlight penetration, bury invertebrate egg and plant seed banks, and affect aquatic biota (Ellis, 1936; McCabe and O'Brien, 1983; Dieter, 1991; Newcombe and MacDonald, 1991; Jurik and others, 1994; Gleason and Euliss, 1998; Gleason and others, 2003b). If sufficient, these changes can eliminate or reduce growth of submerged aquatic vegetation that provides foods and structure for fish, invertebrates, and wildlife (Robel, 1961; Kullberg, 1974).

Recent (circa 2000) research on Mud Lake, an impoundment on the James River managed by Sand Lake NWR in South Dakota, estimated that maximum pool depth has been reduced by as much as 55 centimeters (cm) because of sedimentation since approximately 1959 (Gleason and others, 2003a). Gleason and others (2003a) also estimated annual sedimentation rates and projected that wildlife habitats in Mud Lake (not shown) could be severely compromised in as few as 20 years if rates remained unchanged. Likewise, Schottler and Engstrom (2011) reported an average water depth loss of 15 cm from 1940 to 2008 for Agassiz Pool of Agassiz NWR (not shown) in northwest Minnesota. During that 68-year timeframe, an estimated 1,196,000 metric tons of inorganic sediment was eroded from the watershed and trapped within the 4,047-hectare (ha) Agassiz Pool. Similar studies also have demonstrated sedimentation in wetlands of off-channel refuges (Heimann and Richards, 2003; Elliot and others, 2006; Fitzpatrick and others, 2007).

Information pertaining to sediment accumulation in refuge impoundments is important to guide conservation planning, including future management actions of individual impoundments. Various strategies such as flushing, dredging, or upland management to reduce erosion and runoff can be used to remove sediments or reduce rates of accumulation; however, management options and success will vary among sites depending on watershed or wetland size, amount of sediment accumulation, and practical constraints associated with removal of materials from aquatic systems, including cost, partnership cooperation, and regulatory requirements. Therefore, effectively addressing environmental issues caused by sedimentation often requires site-specific information on the location and magnitude of sediment loads.

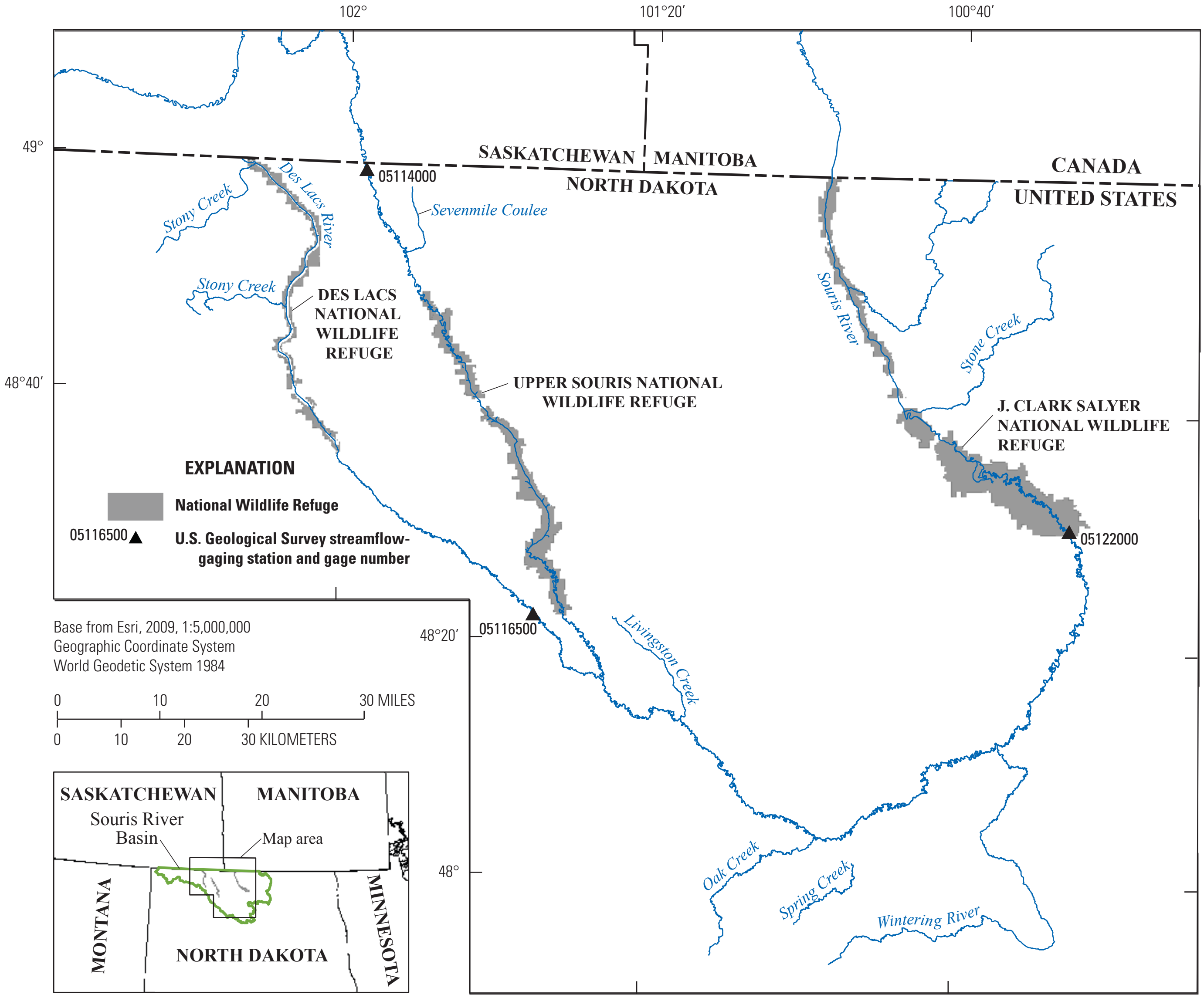
Riverine impoundments of Des Lacs, Upper Souris, and J. Clark Salyer NWRs (collectively known as the Souris River Basin refuges; fig. 1) may be particularly vulnerable to sediment accumulation because changes in land use (for example, conversion of grassland to agricultural production) have increased the potential for soil erosion and surface runoff of sediment to rivers; however, information regarding sediment dynamics currently (2013) does not exist for these refuges. Further, understanding how sedimentary dynamics vary with respect to the unique watershed characteristics of each refuge may assist refuge personnel in identifying alternative management or mitigation strategies. For example, management actions implemented to reduce surface runoff and sedimentation in the upstream tributaries (Des Lacs NWR) and mainstem impoundments (Upper Souris NWR) may affect sedimentary dynamics and proposed management actions in the lower reaches (J. Clark Salyer NWR). Given these considerations, USFWS personnel from the Souris River Basin refuges expressed interest in quantifying sedimentation rates in refuge impoundments to determine if potential problems are developing so any issues could be addressed cost-effectively before thresholds that compromise management goals are surpassed.

Purpose and Scope

The purpose of this report is to assess sedimentation and present sediment chemistry data of riverine impoundments within Des Lacs, Upper Souris, and J. Clark Salyer NWRs, located in the Souris River Basin of North Dakota. The objectives of the study were to gather baseline information on sediment dynamics (location, depth, accretion rates) and concentrations of sediment-associated trace elements and agrichemicals in a subset of impoundments on each refuge. To accomplish this task, sediment cores and surface sediment samples were collected from 31 sites distributed among the 3 refuges during 2004–05.

Study Area

The Souris River Basin encompasses approximately 63,700 square kilometers (km^2) of north-central North Dakota in the United States and southeast Saskatchewan and southwest Manitoba in Canada. The Souris River, the primary river in the basin, flows south from Saskatchewan into North Dakota where it then turns north and eventually flows into the Assiniboine River (not shown) in Manitoba (Vecchia, 2000). Recent water-quality assessments in the Souris River basin suggest that concentrations of various trace elements generally are within limits established by state water-quality standards; however, habitat degradation (for example, channelization, bank stabilization), nutrient inputs, siltation, and stream-flow modification have been identified as factors affecting aquatic life (North Dakota Department of Health, 1998; North Dakota Department of Health 2000; Wax, 2006a; Wax, 2006b).



Base from Esri, 2009, 1:5,000,000
Geographic Coordinate System
World Geodetic System 1984

Figure 1. Location of Des Lacs, Upper Souris, and J. Clark Salyer National Wildlife Refuges in North Dakota.

National wildlife refuges in the basin are located in northwestern North Dakota and consist of Des Lacs, Upper Souris, and J. Clark Salyer (fig. 1). Des Lacs NWR extends south from the Canada-North Dakota border and encompasses approximately 79 km^2 along a 45-kilometer (km) reach of the Des Lacs River, the primary tributary to the Souris River. Upper Souris NWR encompasses 130 km^2 along a 56-km reach of the west arm of the Souris River. J. Clark Salyer NWR encompasses 238 km^2 and extends southeast from the Canada-North Dakota border along 121 km of the east arm of the Souris River. Refuge habitats include riverine impoundments and reservoirs, prairie wetlands, native and tame grasslands, and wooded coulees (U.S. Fish and Wildlife Service, 2007). River impoundments are formed by low-head dams, dikes, and road beds equipped with a variety of water-control structures including stop-log structures, screw gates, and radial gates.

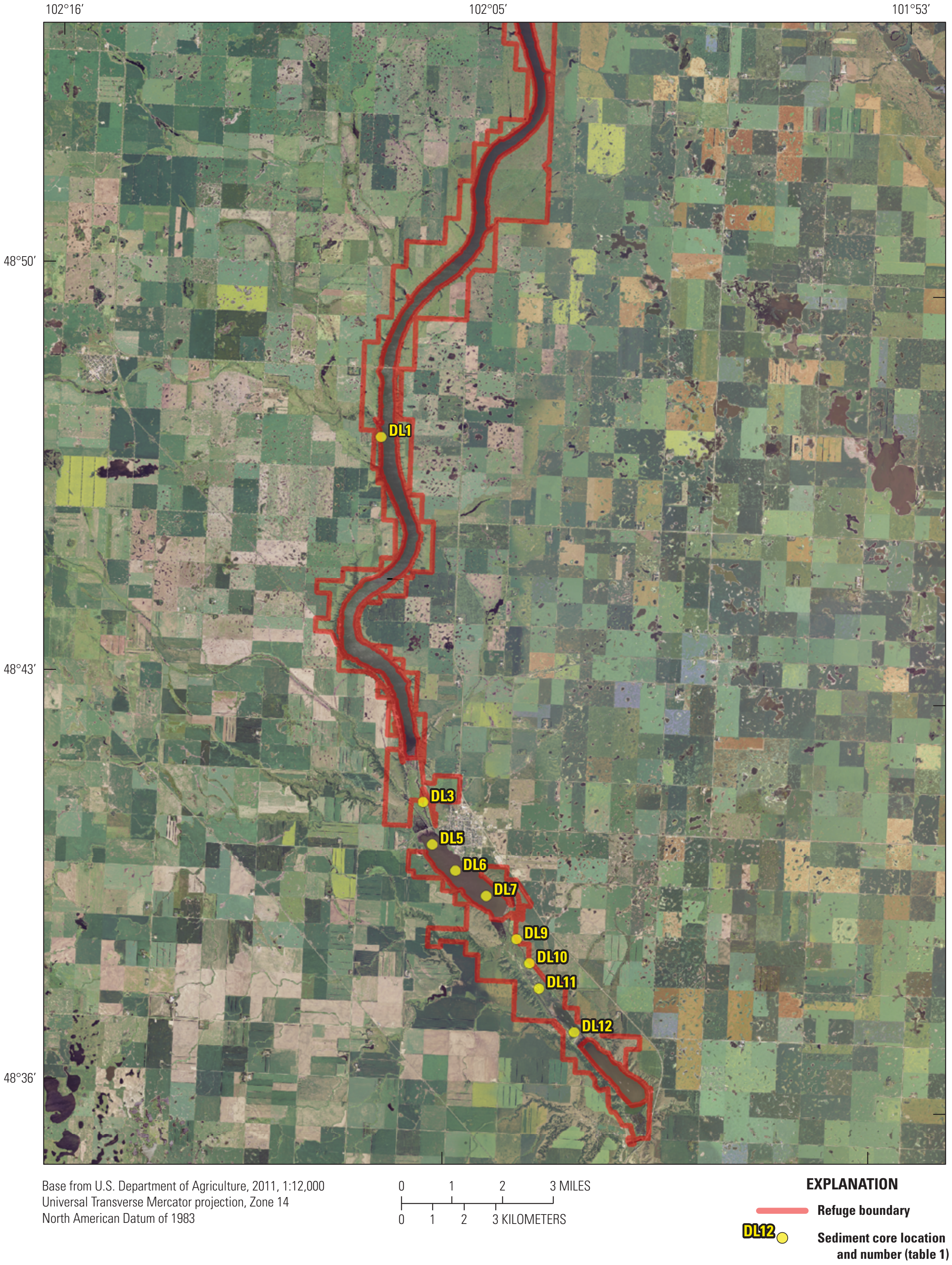
Sample Locations

Sediment cores were collected from impoundments on the Souris River Basin refuges for age-dating and determination of trace-element concentrations. Cores were sampled at strategic locations based on map reconnaissance and consultation with refuge staff. In selecting sites, areas were included that would likely span a gradient of potential sedimentation rates to provide USFWS staff with comprehensive information on their respective refuges that could be used to inform future management decisions. For example, cores were collected from impoundments that directly interrupt river flows or receive direct inputs from tributaries that were expected to have greater sediment accumulation. Conversely, impoundments located directly downstream from other impoundments also were sampled because sediment accumulation in these areas is expected to be lower because of decreased water flows in upstream sites that would facilitate sediment deposition. Cores were collected from locations that were not affected by the river channel to avoid variability associated with in-channel processes that could affect determination of sediment accretion rates. Nine cores were collected from 5 impoundments at Des Lacs NWR, 10 cores from 4 impoundments at Upper Souris NWR, and 10 cores from 3 impoundments at J. Clark Salyer NWR. Surface sediments also were collected at the 29 core sites, as well as an additional site at Upper Souris (US11) and J. Clark Salyer (JC5) NWRs. Core and sediment sample locations are depicted in figures 2, 3, and 4 for Des Lacs, Upper Souris, and J. Clark Salyer NWRs, respectively, and core and site descriptions are presented in table 1.

Soil Core Collection and Analysis

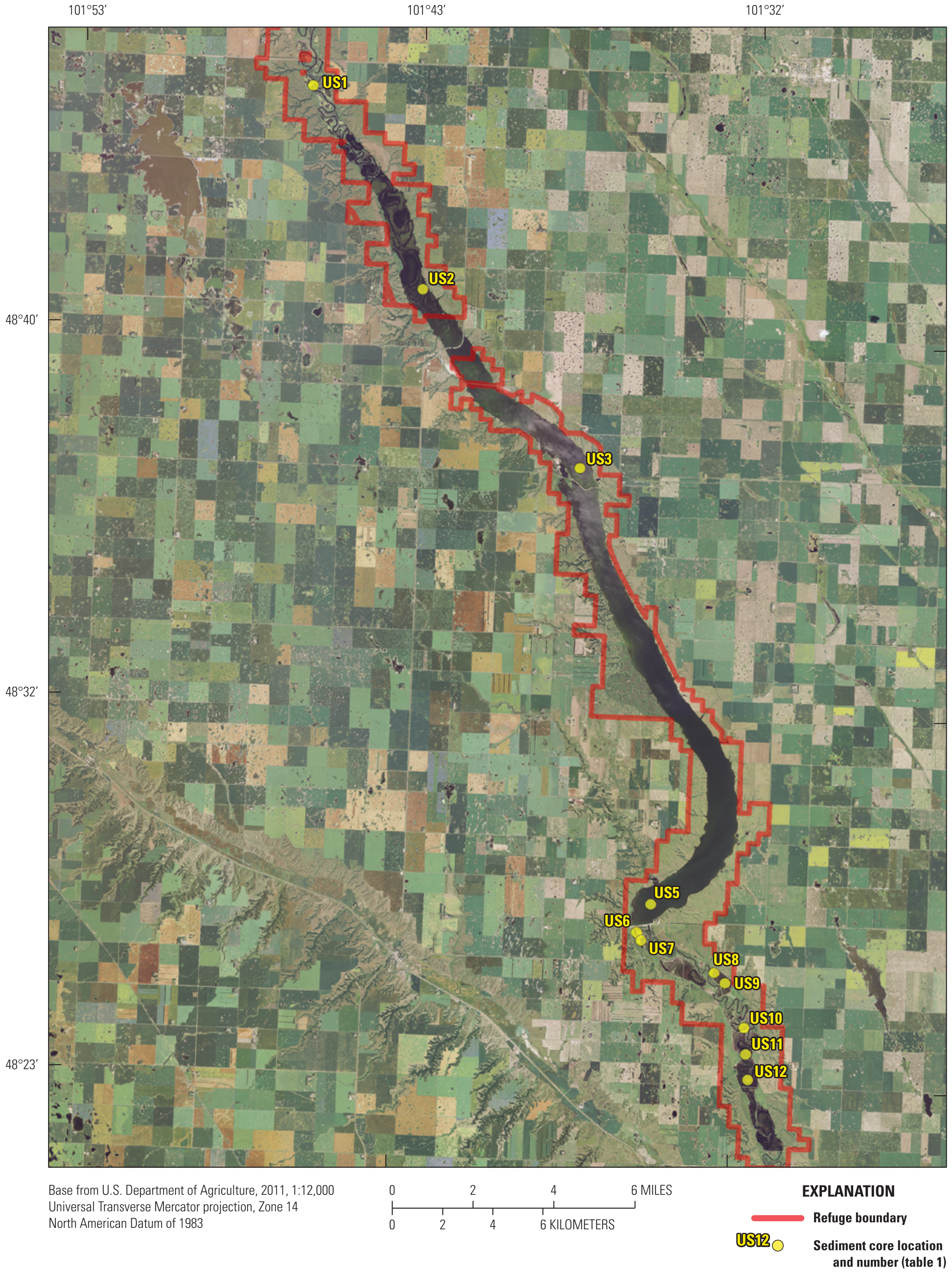
When conditions allowed, sediment cores were collected from a boat using a piston corer (Rowley and Dahl, 1956). Samples from the deep-water locations (fig. 3, Cores US3 and US5) of Lake Darling (not labeled on fig. 3) were collected during the winter months by drilling through the ice. The 10.8-cm diameter collection tube was manually inserted as far into the substrate as possible. Lengths (sediment depth) and compaction of individual cores differed among sites (table 1) because of variability in substrates. Cores were shipped to the U.S. Geological Survey St. Petersburg Coastal and Marine Science Center for processing and analysis. Each core was segmented into 1-cm (upper 20 cm) or 2-cm (depths greater than 20 cm) segments and analyzed for cesium-137 (^{137}Cs), lead-210 (^{210}Pb), and radium-226 (^{226}Ra) specific activity, bulk density (wet and dry), particle size, loss on ignition (LOI), and water content. Laboratory methods follow those of Robbins and others (2000), Marot and Smith (2012), and Gleason and others (2003a). For a subset of 14 cores (table 1), one-half of the segments were analyzed for 62 trace elements using inductively coupled plasma mass spectrometry (ICP-MS) and inductively coupled plasma optical emission spectrometry (ICP-OES). Additionally, surface sediments were collected near 31 core sampling locations (only 29 cores were analyzed for isotopes) and analyzed for 59 agrichemicals commonly used in the region. The North Dakota Department of Health Division of Laboratory Services analyzed soils for agrichemicals following analytical methods referenced in the Index to Environmental Protection Agency (EPA) Test Methods (EPA Web site, accessed October 1, 2012, at *http://www.epa.gov/region1/info/testmethods/pdfs/testmeth.pdf*).

Supported ^{210}Pb activity was approximated as the activity of ^{226}Ra and unsupported ^{210}Pb activity was calculated as the difference between total ^{210}Pb activity and ^{226}Ra activity (Binford, 1990; Holmes, 1998). Total ^{137}Cs inventory for each core was calculated as the sum of bulk density adjusted ^{137}Cs activity (Ritchie and McHenry, 1990). Bulk density was not determined for 11 segments of 7 cores. For these segments, bulk density was estimated by averaging the segments directly above and below the segment that was missing bulk density. For example, if a value was missing from the 8-cm segment, a mean value from the 7-cm and 9-cm segment was applied. Bulk density also was not determined for cores US3 and US5. To allow for a rough estimation of the total ^{137}Cs inventory, bulk density was estimated for these two cores using data from the nearby core US2. A mean bulk density was calculated for core US2 by 5-cm increments, and these estimates were applied to cores US3 and US5 by depth. Radium-226 often was determined only for every other segment deeper than 10–20 cm. Similar to methods for estimating bulk density, the missing values were estimated by calculating an average of the segments directly above and below the segment that was not analyzed.



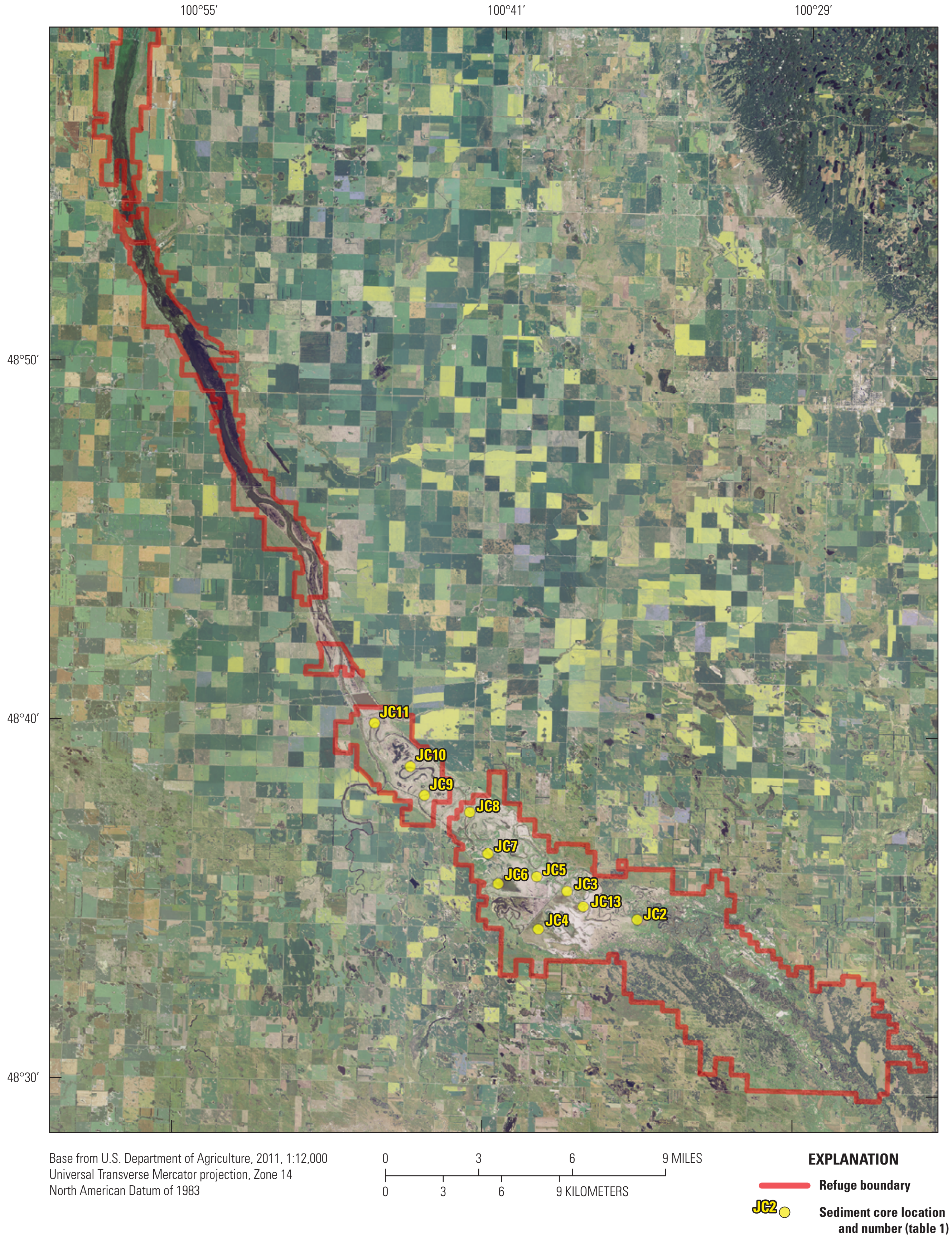
Base from U.S. Department of Agriculture, 2011, 1:12,000
Universal Transverse Mercator projection, Zone 14
North American Datum of 1983

Figure 2. Location of sample sites within Des Lacs National Wildlife Refuge.



Base from U.S. Department of Agriculture, 2011, 1:12,000
Universal Transverse Mercator projection, Zone 14
North American Datum of 1983

Figure 3. Location of sample sites within Upper Souris National Wildlife Refuge.



Base from U.S. Department of Agriculture, 2011, 1:12,000
Universal Transverse Mercator projection, Zone 14
North American Datum of 1983

Figure 4. Location of sample sites within J. Clark Salyer National Wildlife Refuge.

Table 1. Inventory and description of sample locations and sediment cores collected from impoundments within Des Lacs, Upper Souris, and J. Clark Salyer National Wildlife Refuges.

[Cores that were analyzed for trace element concentrations are marked with an asterisk (*). Cores JC5 and US11 were not analyzed for isotopes; however, sediment samples from these locations were analyzed for agrichemicals. Compaction is the difference between the depth of sediment penetration by the sample tube and the actual length of the sediment core. NWR, National Wildlife Refuge; ID, identifier; cm, centimeters, --, no data]

NWR	Site	Core ID	Description	Collection date	Core length, cm	Compaction, cm	Latitude	Longitude
Des Lacs	Pool 2	DL1*	in-channel impoundment; reference site just above dam near major coulee input	8/14/2004	55	--	48.7873	-102.1224
Des Lacs	Pool 4	DL3*	non-functional in-channel impoundment; middle hump area. Core site located in an area that historically received sediment from major coulee system, that since has been diverted towards Des Lacs Lake. This is also a reference core to better understand the sedimentary history of the hump.	8/14/2004	56	5	48.6834	-102.1008
Des Lacs	Pool 4	DL5	in-channel impoundment; upper reach, area that receives diverted sediment	8/13/2004	54	6	48.6715	-102.0931
Des Lacs	Pool 4	DL6*	in-channel impoundment; middle reach	8/13/2004	52	0	48.6642	-102.0827
Des Lacs	Pool 4	DL7	in-channel impoundment; lower reach	8/13/2004	53	3	48.6574	-102.0690
Des Lacs	Pool 4A	DL9*	mix of in- and off-channel impoundment; secondary sediment pond, secondary coulee dump site (in channel)	8/14/2004	63	10	48.6453	-102.0579
Des Lacs	Pool 5	DL10	mix of in- and off-channel impoundment; tertiary sediment pond, tertiary coulee dump site (in channel)	8/14/2004	53	13	48.6386	-102.0516
Des Lacs	Pool 6	DL11	in-channel impoundment; upper reach	8/13/2004	58	12	48.6316	-102.0433
Des Lacs	Pool 6	DL12*	in-channel impoundment; lower reach	8/13/2004	65	12	48.6194	-102.0290
Upper Souris	Lake Darling	US1*	in-channel impoundment; least impacted riverine wetland system	8/9/2004	39	6	48.7549	-101.7777
Upper Souris	Lake Darling	US2	in-channel impoundment; transition from riverine to lactustrine wetland system	8/10/2004	32	--	48.6826	-101.7168
Upper Souris	Lake Darling	US3*	in-channel impoundment; transition from lacustrine wetland to lake system	2/9/2005	48	--	48.6206	-101.6254
Upper Souris	Lake Darling	US5	in-channel impoundment; lake system	2/9/2005	20	--	48.4653	-101.5791
Upper Souris	Pool A	US6	off-channel impoundment; inlet	8/9/2004	36	--	48.4551	-101.5863
Upper Souris	Pool A	US7*	off-channel impoundment; outlet	8/9/2004	40	--	48.4522	-101.5837
Upper Souris	Pool 87A	US8	off-channel impoundment; inlet	8/9/2004	26	5	48.4413	-101.5438
Upper Souris	Pool 87A	US9*	off-channel impoundment; outlet	8/9/2004	40	5	48.4377	-101.5379
Upper Souris	Pool 96	US10*	in-channel impoundment; upper reach	8/9/2004	40	12	48.4230	-101.5280
Upper Souris	Pool 96	US11	in-channel impoundment; middle reach	8/9/2004	55	12	48.4133	-101.5255
Upper Souris	Pool 96	US12	in-channel impoundment; lower reach	8/9/2004	43	--	48.4034	-101.5239

Table 1. Inventory and description of sample locations and sediment cores collected from impoundments within Des Lacs, Upper Souris, and J. Clark Salyer National Wildlife Refuges.—Continued

[Cores that were analyzed for trace element concentrations are marked with an asterisk (*). Cores JC5 and US11 were not analyzed for isotopes; however, sediment samples from these locations were analyzed for agrichemicals. Compaction is the difference between the depth of sediment penetration by the sample tube and the actual length of the sediment core. NWR, National Wildlife Refuge; ID, identifier; cm, centimeters, --, no data]

NWR	Site	Core ID	Description	Collection date	Core length, cm	Compaction, cm	Latitude	Longitude
J. Clark Salyer	Pool 320	JC2*	in-channel impoundment; middle reach	8/11/2004	62	17	48.5798	-100.5979
J. Clark Salyer	Pool 320	JC3	in-channel impoundment; lower reach near dike	8/11/2004	40	6	48.5924	-100.6441
J. Clark Salyer	Pool 320	JC4	in-channel impoundment; back-water reach near dike	8/11/2004	46	8	48.5745	-100.6637
J. Clark Salyer	Pool 320	JC13*	in-channel impoundment; middle reach	8/12/2004	68	14	48.5855	-100.6328
J. Clark Salyer	Pool 326	JC5	in-channel impoundment; old floodplain reference site	8/11/2004	51	20	48.5992	-100.6647
J. Clark Salyer	Pool 326	JC6	in-channel impoundment; upper impoundment near water inlet	8/11/2004	56	9	48.5952	-100.6925
J. Clark Salyer	Pool 326	JC7	in-channel impoundment; middle impoundment (appeared highly disturbed)	8/11/2004	52	12	48.6089	-100.7002
J. Clark Salyer	Pool 326	JC8*	in-channel impoundment; lower impoundment near dam	8/11/2004	58	16	48.6280	-100.7154
J. Clark Salyer	Pool 332	JC9	in-channel impoundment; upper impoundment	8/12/2004	53	25	48.6353	-100.7454
J. Clark Salyer	Pool 332	JC10	in-channel impoundment; middle impoundment	8/12/2004	54	15	48.6487	-100.7560
J. Clark Salyer	Pool 332	JC11*	in-channel impoundment; lower impoundment	8/12/2004	57	6	48.6700	-100.7819

Determination of Sediment Accretion Rates

The ^{137}Cs and ^{210}Pb isotopes have been determined to be ideal for dating sedimentary dynamics during the past 100 years (DeLaune and others, 1989; Ritchie and McHenry, 1990; Callender and Robbins, 1993; Holmes, 1998; Gleason and others, 2003a; Van Metre and others, 2004; Wingard and others, 2007; Ritchie and Ritchie, 2008; Schottler and Engstrom, 2011). Isotopic data for each core were analyzed along the depth profile to identify key time markers and to estimate sediment accretion rates following standard methods described elsewhere (for example, Binford, 1990; Holmes, 1998; Gleason and others, 2003a). A general overview of these methods is provided below.

^{137}Cs is a product of nuclear testing and has a half-life of 30.3 years. Atmospheric fallout of ^{137}Cs began in the early 1950s, with detectable levels in soils beginning in 1954 and peak quantities in 1963–64 (Ritchie and McHenry, 1990). In general, the vertical distribution of ^{137}Cs in the sediment profile can be related to these time markers; hence, it can be used to estimate the amount of sediment that has accumulated since 1954 (Holmes, 1998). The ^{137}Cs profile of each core was inspected visually to identify key time markers that could be used to estimate accretion rates. It was assumed that the first detection (greatest depth) of ^{137}Cs activity in each core approximated the initial date of detectable fallout from the nearest monitoring site [Vermillion, S. Dak. (not shown)] in 1957. Ideal (undisturbed) sediment cores are expected to have a well-defined ^{137}Cs peak that is associated with maximum fallout that took place around 1963; thus, attempts to identify this time marker also were made. Once these time markers were identified, sediment accretion rates were calculated by dividing the associated depth by the number of years between deposition and collection of the core (that is, years from deposition to sample collection in 2004 or 2005).

The total measured ^{137}Cs inventory from the soil cores was compared to the expected ^{137}Cs inventory to assess potential sediment accretion. The expected ^{137}Cs inventory was calculated by adjusting annual fallout for radioactive decay (fig. 5). Strontium-90 (^{90}Sr) fallout data were obtained for Vermillion, S. Dak. (U.S. Department of Energy, Environmental Measurements Laboratory Web site, accessed February 21, 2014, at *http://www.wipp.energy.gov/NAMP/EMLLegacy/*), and ^{137}Cs was calculated by multiplying ^{90}Sr by 1.65 (Robbins, 1985).

^{210}Pb is naturally found in the atmosphere and has a half-life of 22.3 years. It is a member of the uranium decay series and is the daughter of radon-222. Radon-222, a daughter of ^{226}Ra, diffuses from the Earth's crust into the atmosphere where it decays to ^{210}Pb, which is subsequently entrapped in rainfall and returned to earth. Atmospheric residence time of ^{210}Pb is about 10 days and the concentration of ^{210}Pb in rainwater is believed to have remained constant with time (DeLaune and others, 1989; Holmes, 1998). The activity of ^{210}Pb returned to Earth (unsupported) is greater than that of background activity in the soil (supported); thus, it is possible to estimate the age of sediments by examining the distribution of unsupported ^{210}Pb. Most of the sediment cores were characterized by unsupported ^{210}Pb profiles that do not conform to the monotonic decrease in activity with depth as described for an ideal profile (Binford, 1990; Holmes, 1998). Because of the apparent variability in sedimentation with time, the age of each core segment was estimated using the Constant Rate of Supply (CRS) model (Appleby and Oldfield, 1978; Binford, 1990). Once cores were dated, vertical accretion rates were calculated by dividing depth of each segment by age.

Assessment of Trace Elements and Agrichemicals

Raw data and generalized summary statistics are provided for the sediment chemistry data. Although no statistical analyses were done, boxplots representing surface sediment concentrations of trace elements and agrichemicals collected near each core sample (boxplots represent core depth segments) were constructed to assess whether concentrations of chemical constituents changed noticeably along the general upstream to downstream gradient.

Radioisotopes and Physical Characteristics of Sediment Cores

Radioisotope specific activity, bulk density, particle size, LOI, and water content are presented by depth for each core in *appendix 1*. General patterns of these variables indicate that refuge impoundments for the Souris River Basin are characterized by episodes of sediment accretion, mixing, and removal. For example, the proportions of sands and silts often vary greatly along the depth profile (for example, cores DL6, DL10, US3, and JC2; fig. 6), suggesting high variability in factors, such as river flows, that affect the volume of fluvial material that can be moved and the distribution of this material. This conclusion is supported by the variability of other soil characteristics, such as LOI and bulk density, within and among cores (for example, cores US10, JC2, JC9, and JC10; fig. 7), which indicates variability in the depth of organic and other depositional materials. Further, some cores display uniform ^{137}Cs and ^{210}Pb profiles (figs. 8–18) that are indicative of mixing [for example, cores DL12 (fig. 11), US2 (fig. 12), and US6 (fig. 13)], whereas others are characterized by ideal ^{137}Cs profiles with near-surface peaks indicative of sediment transport or removal [for example, cores US1 (fig. 12), JC8 (fig. 17), and JC11 (fig. 18)]. Moreover, transport of sediments likely is variable throughout the system because of differences in sediments contributed from the watershed, river flows, and water-control structures. For example, areas above a stop-log structure would likely accumulate sediments, whereas areas associated with a radial gate would likely be characterized by greater sediment transport. Collectively, the general inference of episodic riverine environments also is supported by highly variable observed stream flows for the Des Lacs and Souris Rivers (fig. 19). For example, figure 19 shows low peak flows for the Des Lacs and Souris Rivers during the 1960s followed by extremely high peak flows during the 1970s.

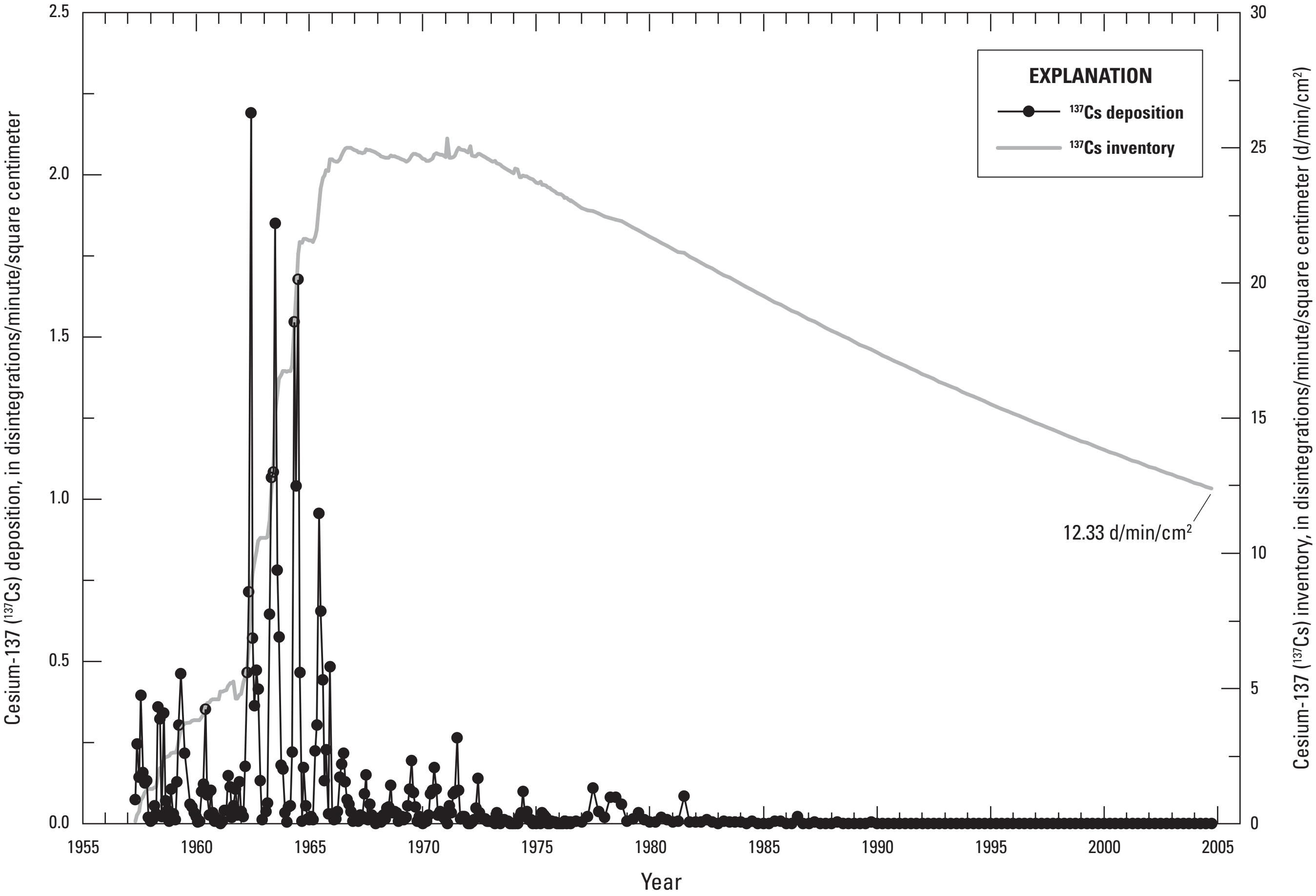


Figure 5. Annual fallout and estimated inventory of cesium-137 for Vermillion, South Dakota.

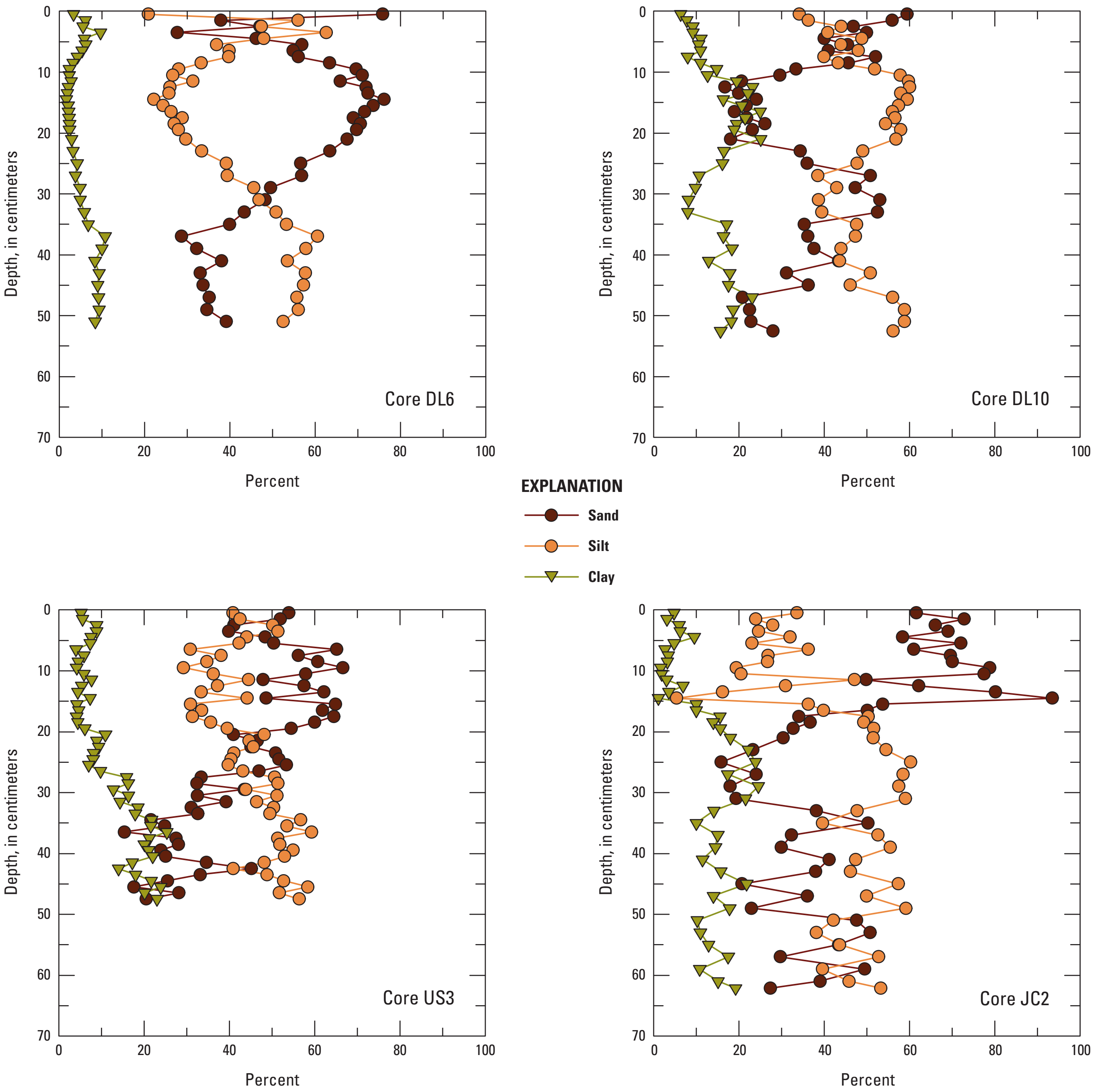


Figure 6. Percent sand, silt, and clay by depth for four sediment cores.

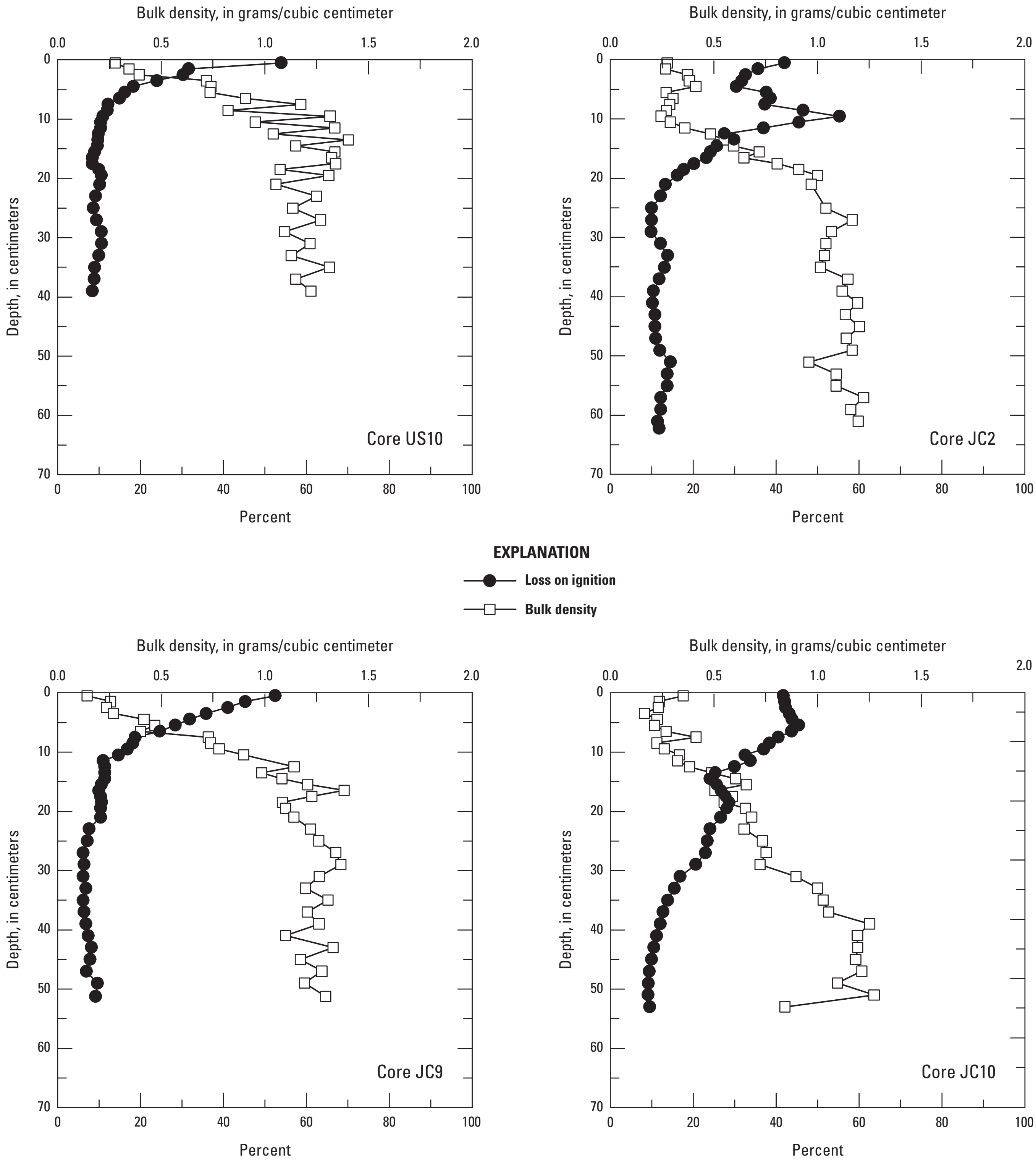


Figure 7. Loss on ignition and bulk density by depth for four sediment cores.

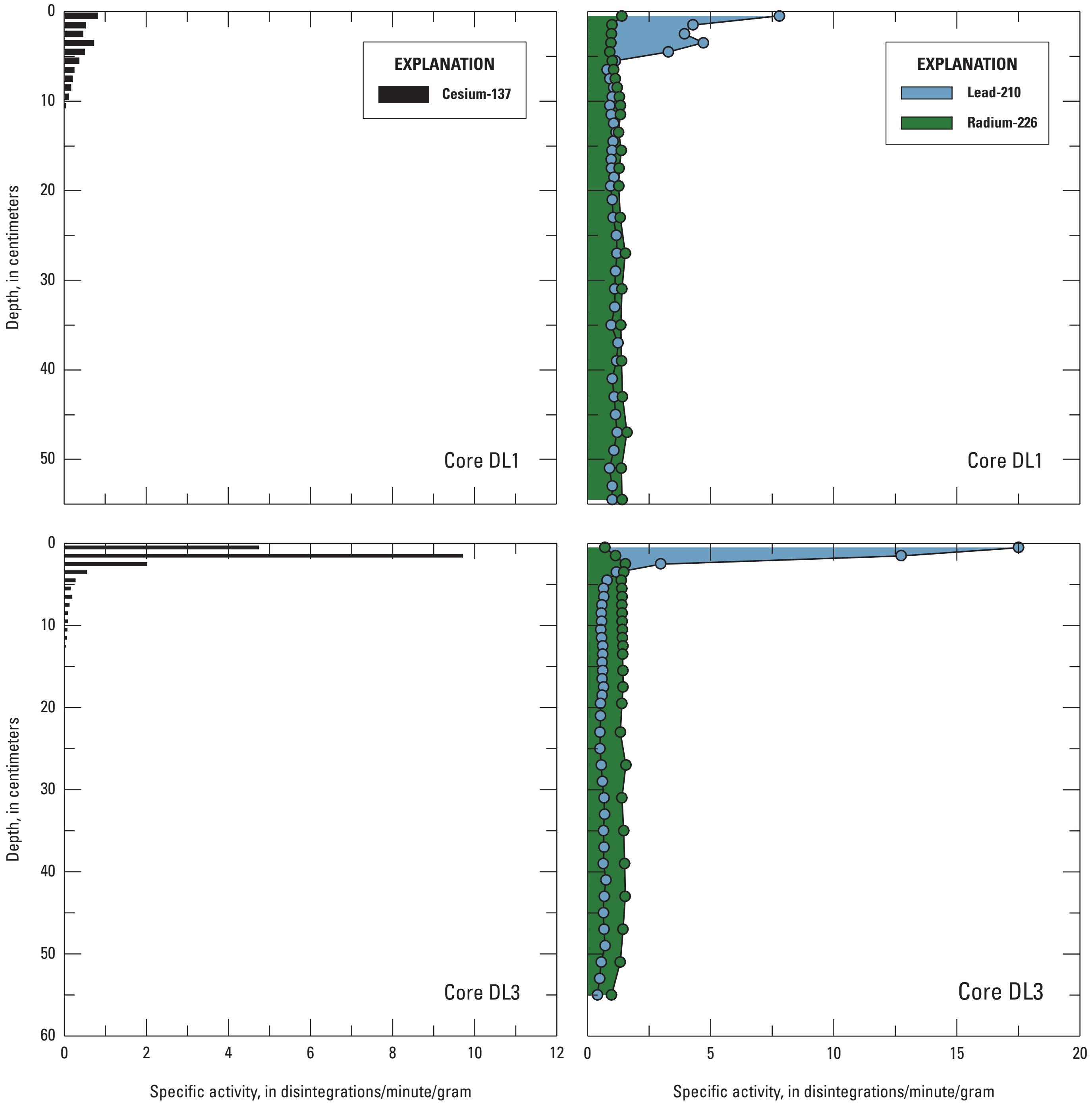


Figure 8. Radioisotope profiles for cores from Pool 2 and the north end of Pool 4 within Des Lacs National Wildlife Refuge. The difference between total lead-210 (^{210}Pb) and radium-226 approximates unsupported ^{210}Pb.

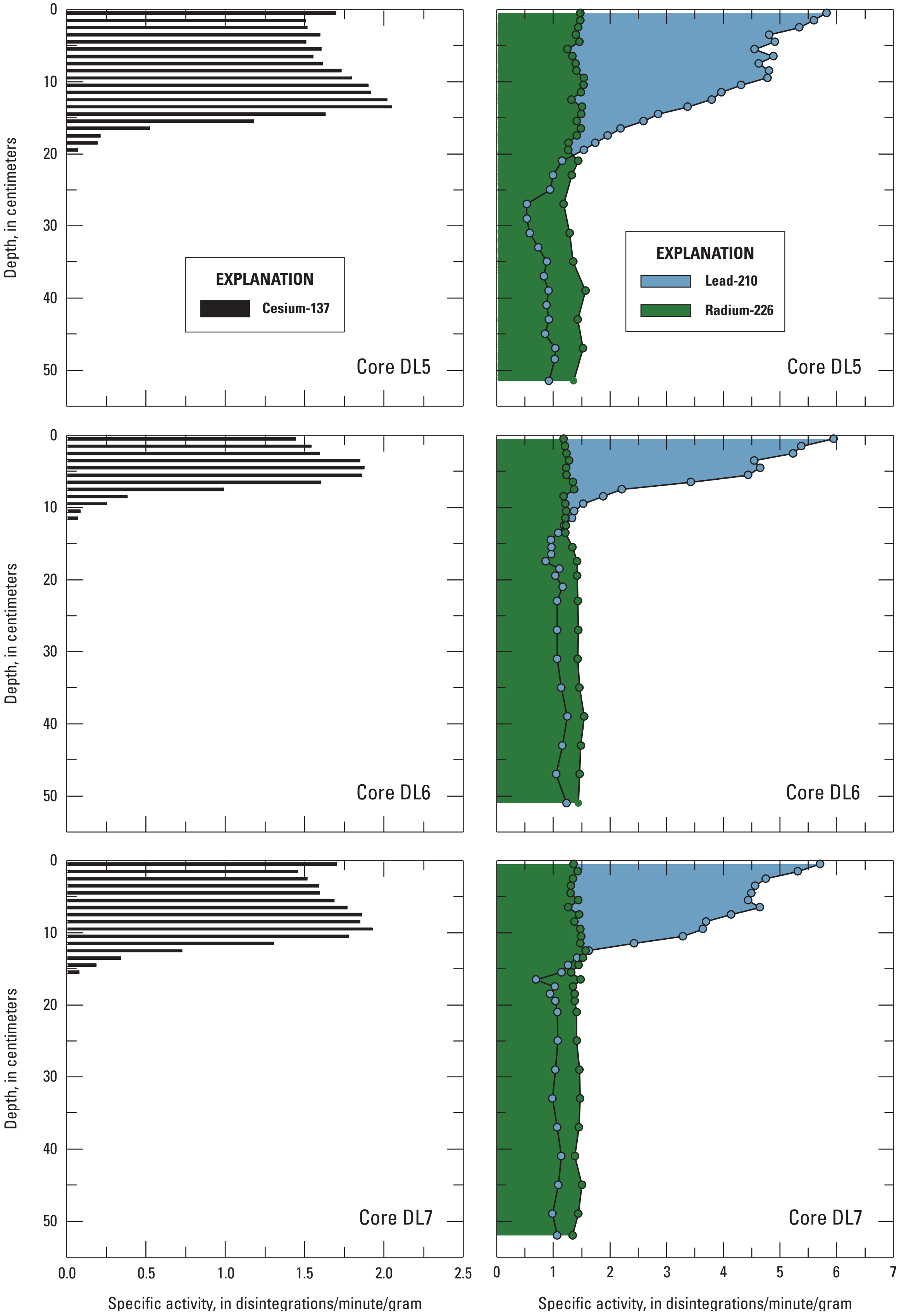


Figure 9. Radioisotope profiles for cores from main body of Pool 4 within Des Lacs National Wildlife Refuge. The difference between total lead-210 (^{210}Pb) and radium-226 approximates unsupported ^{210}Pb.

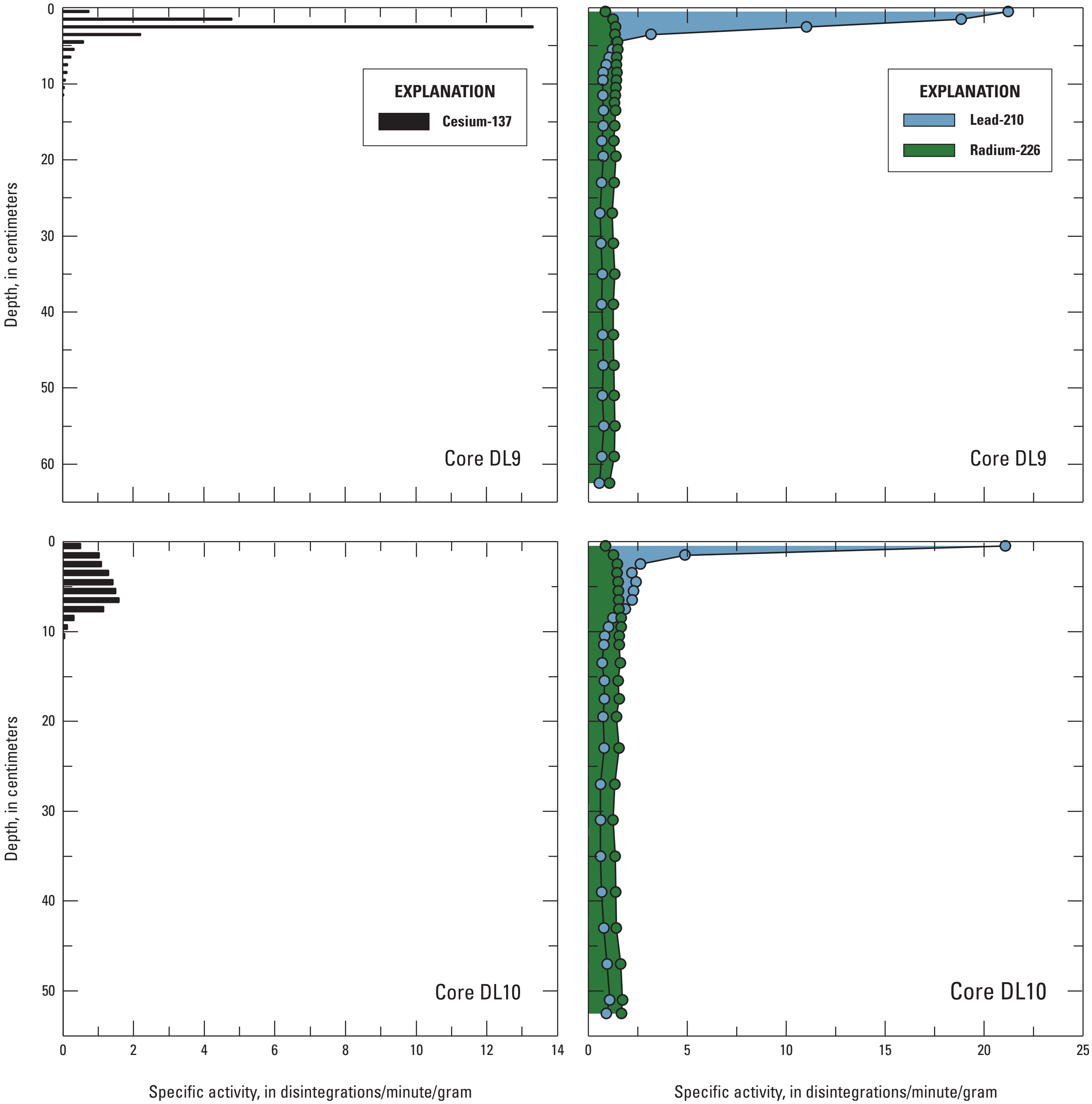


Figure 10. Radioisotope profiles for cores from Pool 4A and Pool 5 within Des Lacs National Wildlife Refuge. The difference between total lead-210 (^{210}Pb) and radium-226 approximates unsupported ^{210}Pb.

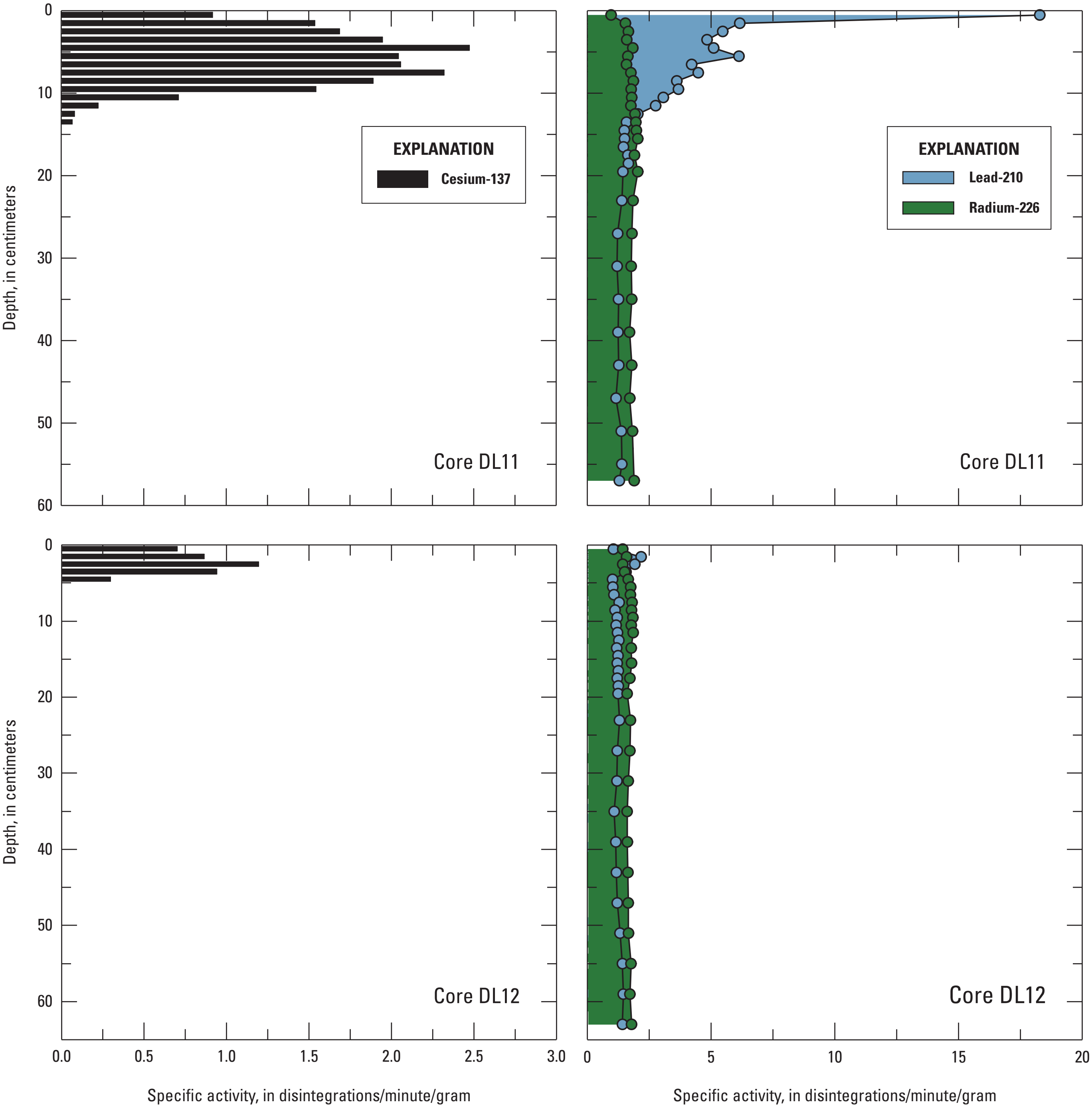


Figure 11. Radioisotope profiles for cores from Pool 6 within Des Lacs National Wildlife Refuge. The difference between total lead-210 (^{210}Pb) and radium-226 approximates unsupported ^{210}Pb.

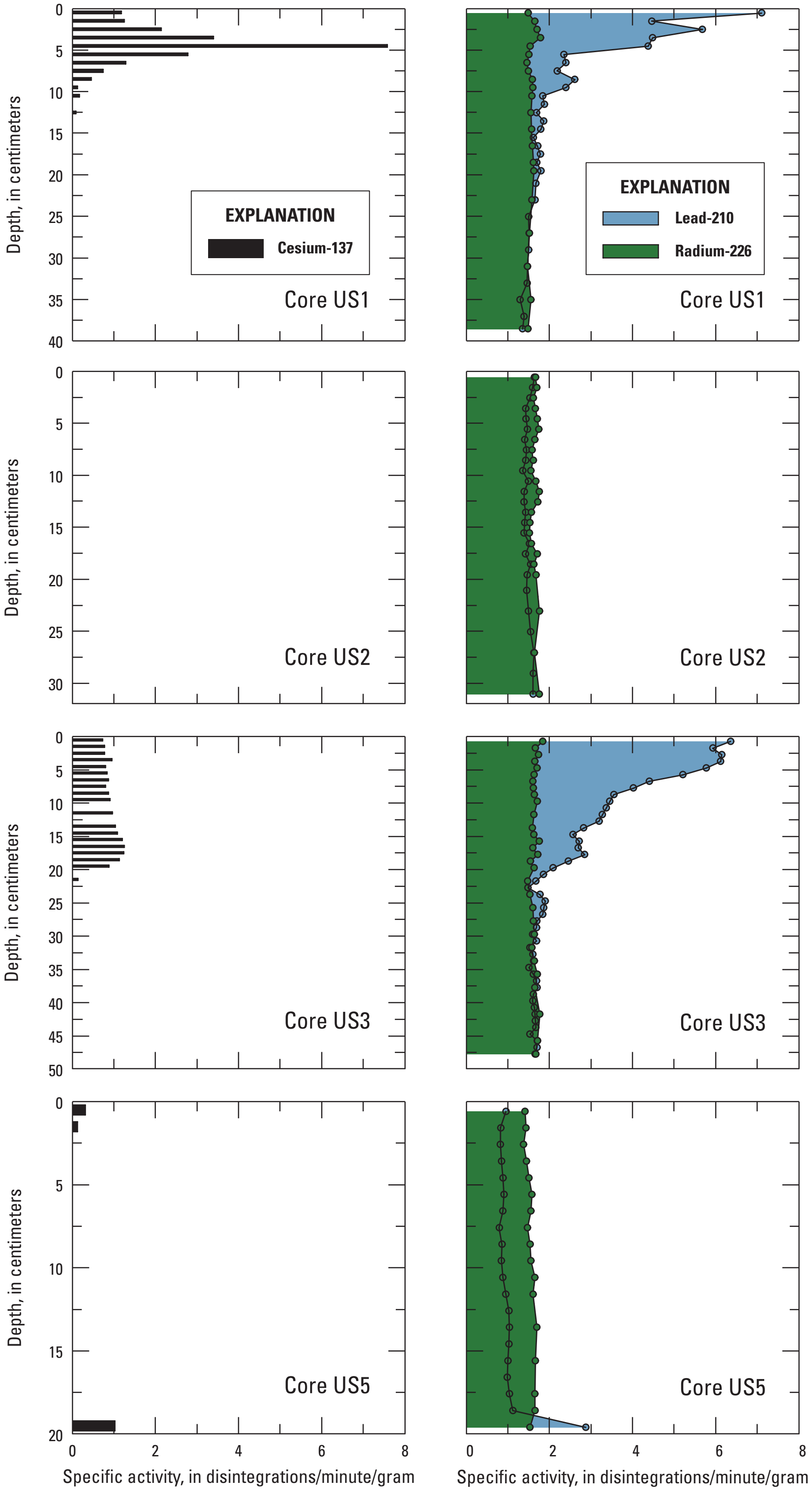


Figure 12. Radioisotope profiles for cores from Lake Darling within Upper Souris National Wildlife Refuge. The difference between total lead-210 (^{210}Pb) and radium-226 approximates unsupported ^{210}Pb.

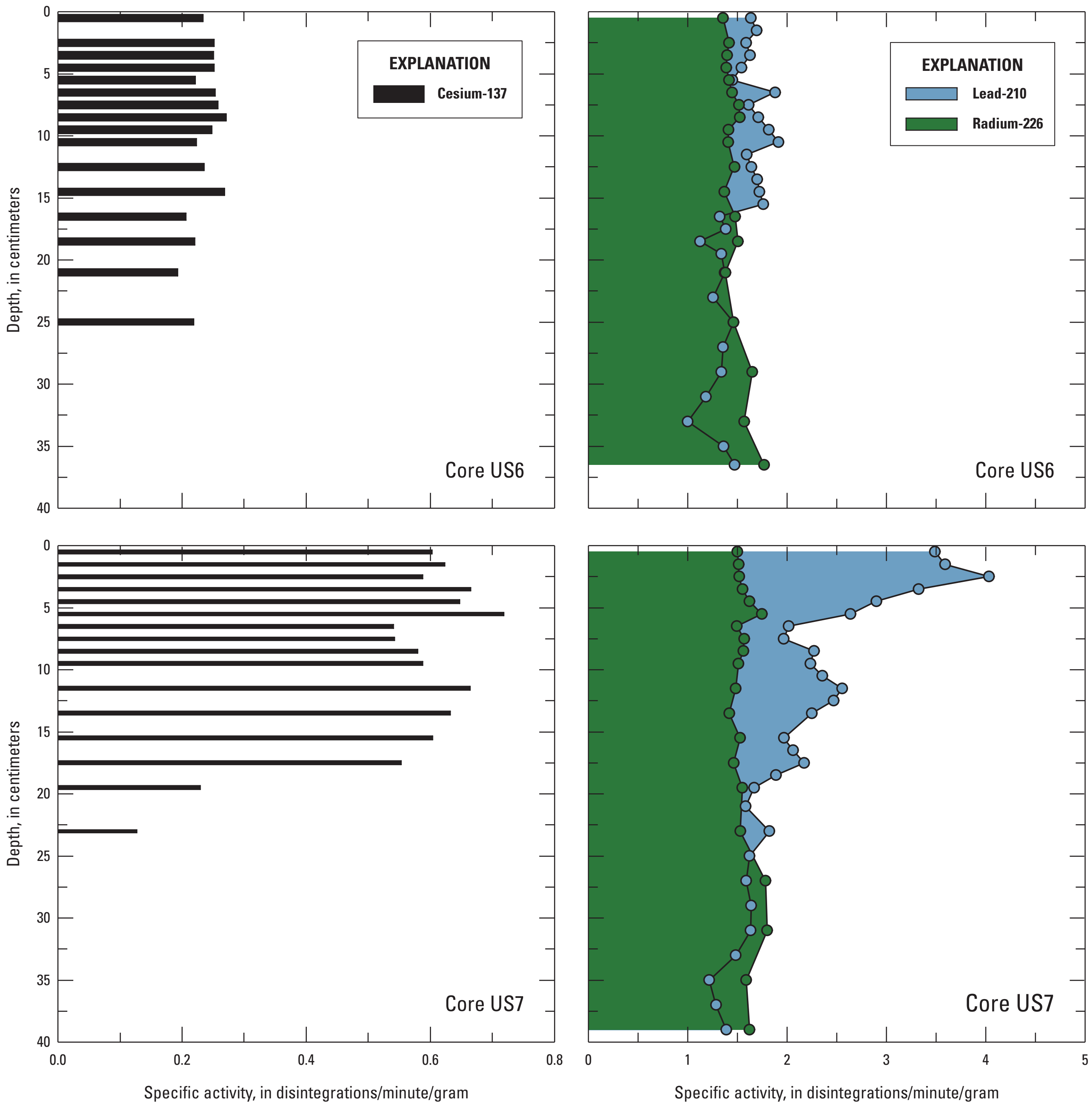


Figure 13. Radioisotope profiles for cores from Pool A within Upper Souris National Wildlife Refuge. The difference between total lead-210 (^{210}Pb) and radium-226 approximates unsupported ^{210}Pb.

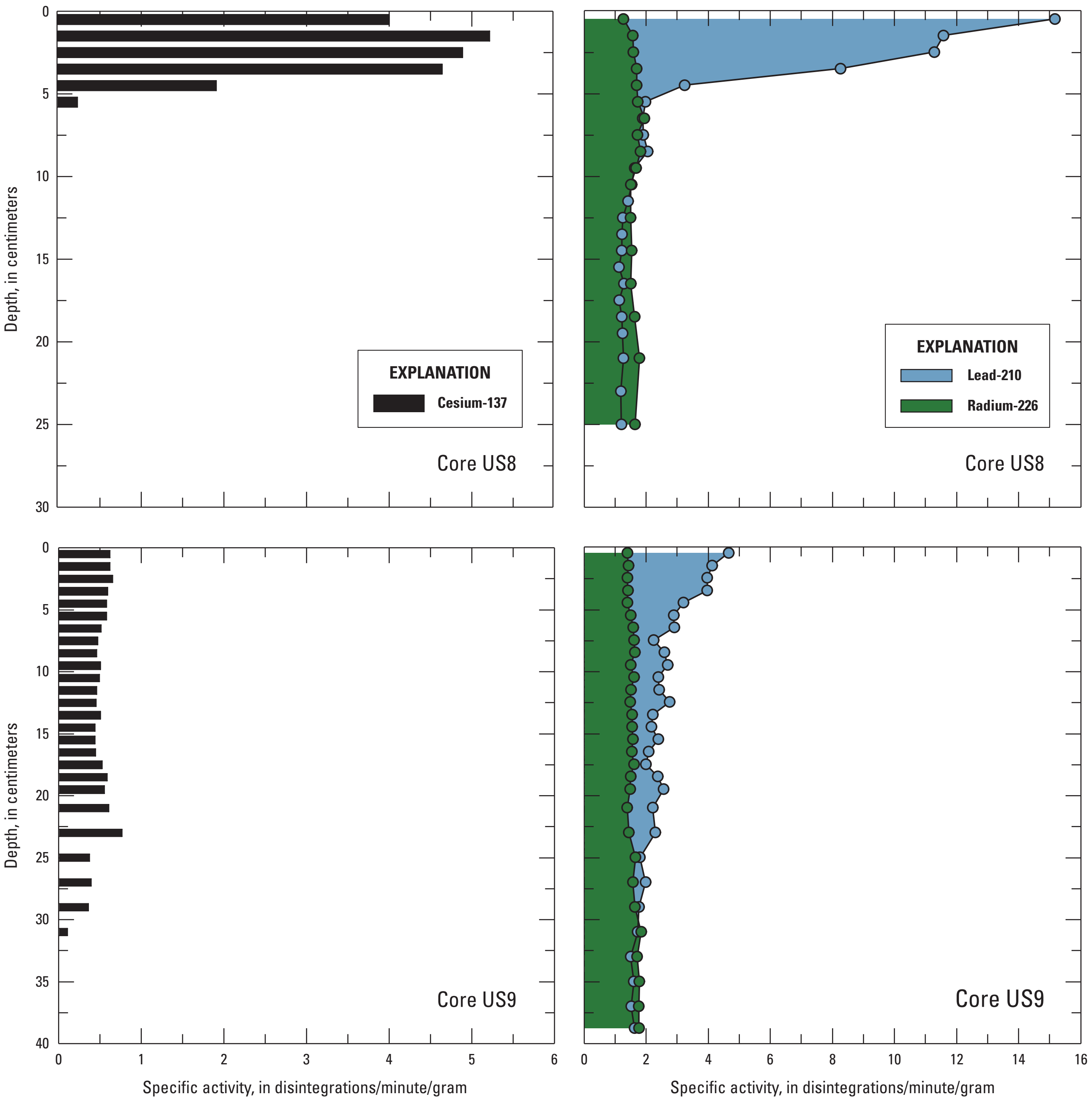


Figure 14. Radioisotope profiles for cores from Pool 87A within Upper Souris National Wildlife Refuge. The difference between total lead-210 (^{210}Pb) and radium-226 approximates unsupported ^{210}Pb.

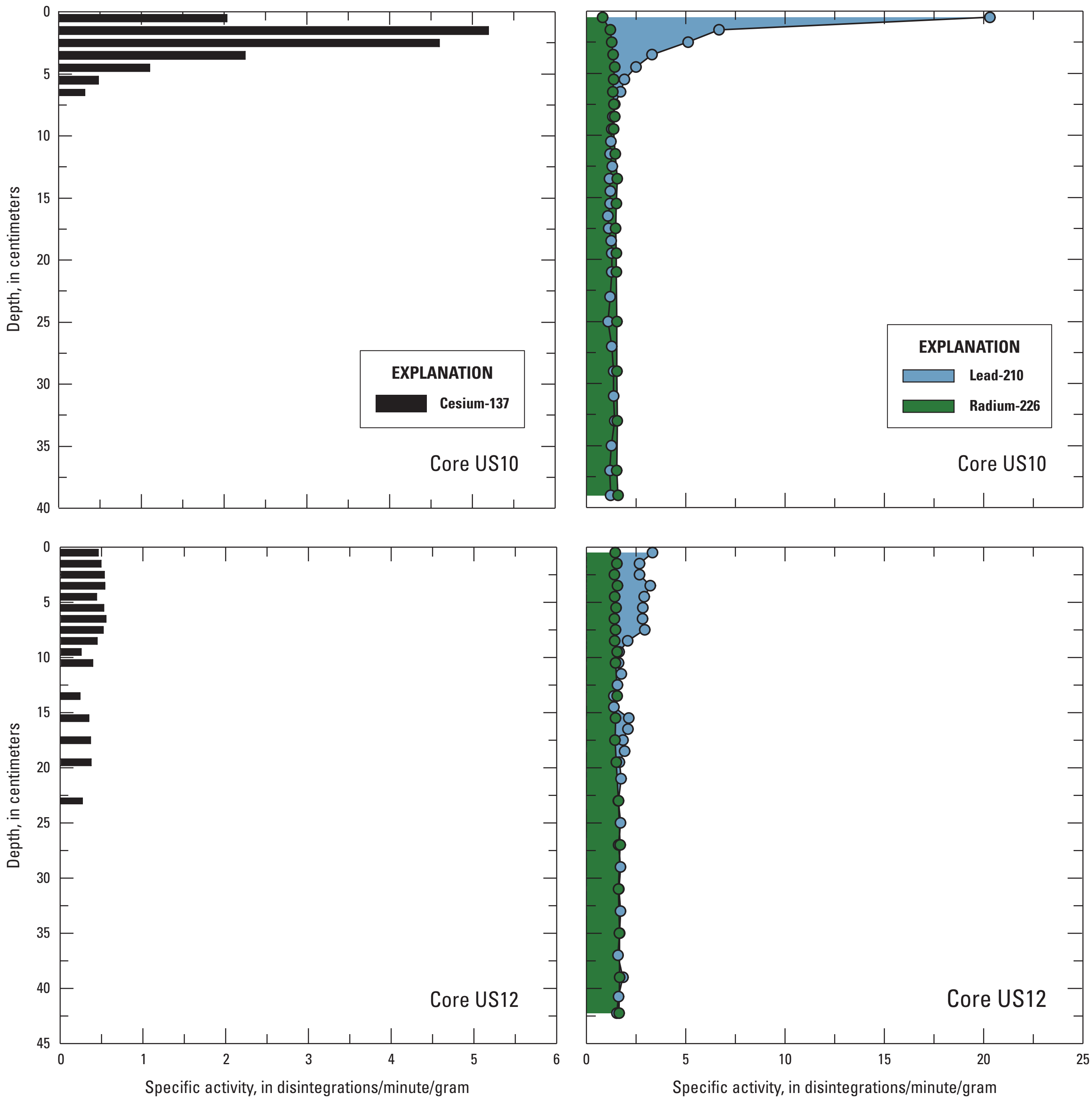


Figure 15. Radioisotope profiles for cores from Pool 96 within Upper Souris National Wildlife Refuge. The difference between total lead-210 (^{210}Pb) and radium-226 approximates unsupported ^{210}Pb.

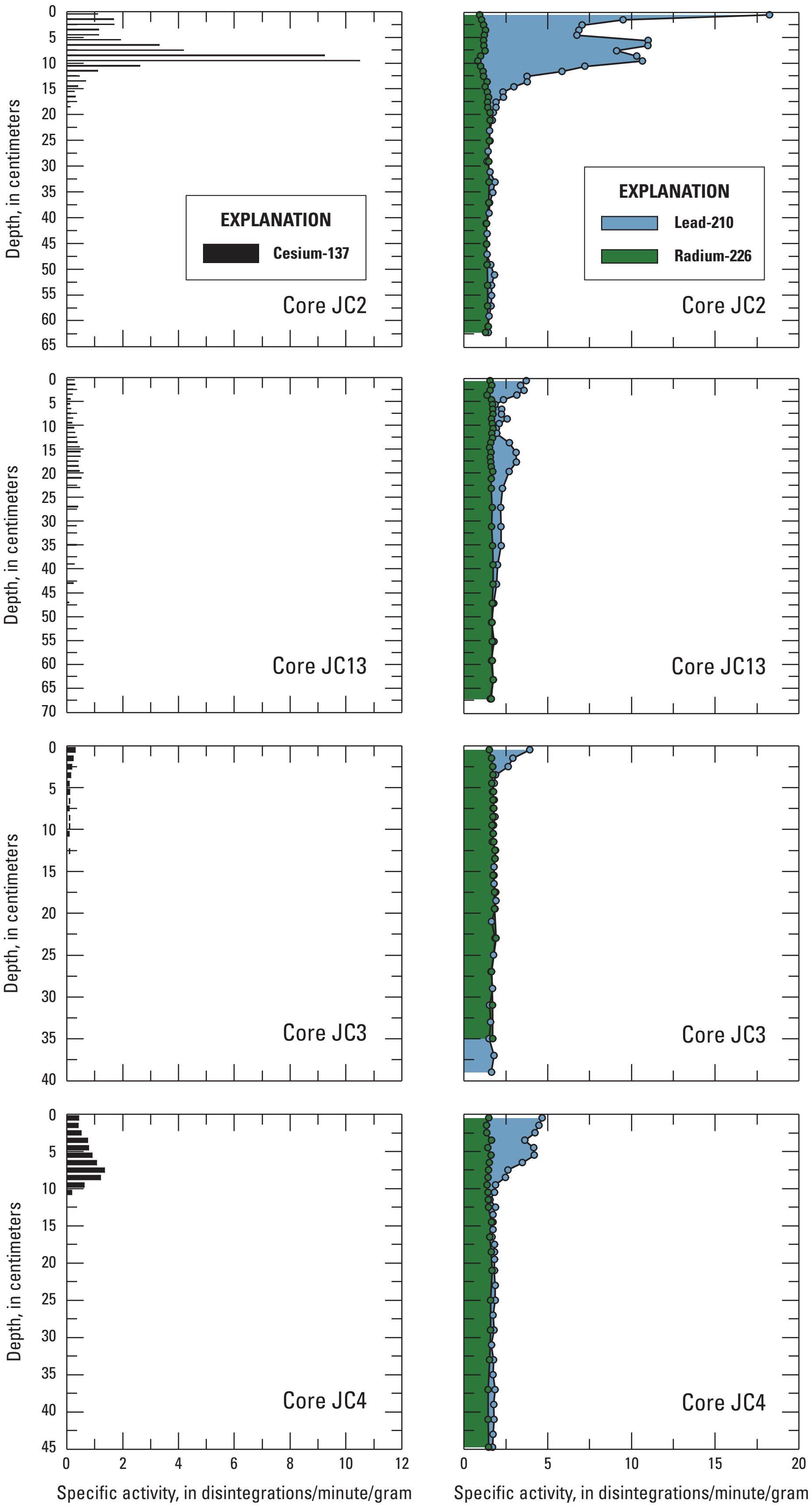


Figure 16. Radioisotope profiles for cores from Pool 320 within J. Clark Salyer National Wildlife Refuge. The difference between total lead-210 (^{210}Pb) and radium-226 approximates unsupported ^{210}Pb.

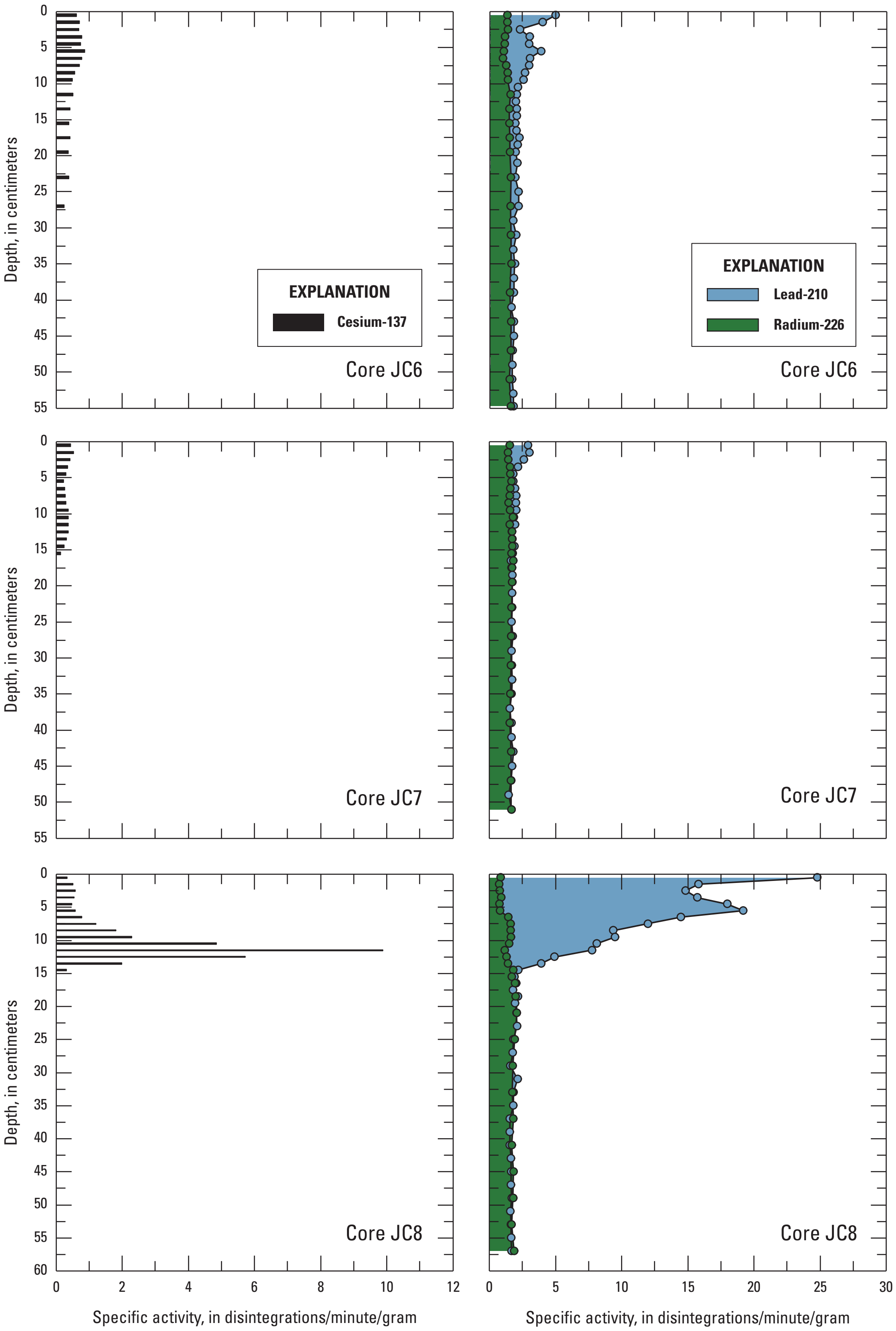


Figure 17. Radioisotope profiles for cores from Pool 326 within J. Clark Salyer National Wildlife Refuge. The difference between total lead-210 (^{210}Pb) and radium-226 approximates unsupported ^{210}Pb.

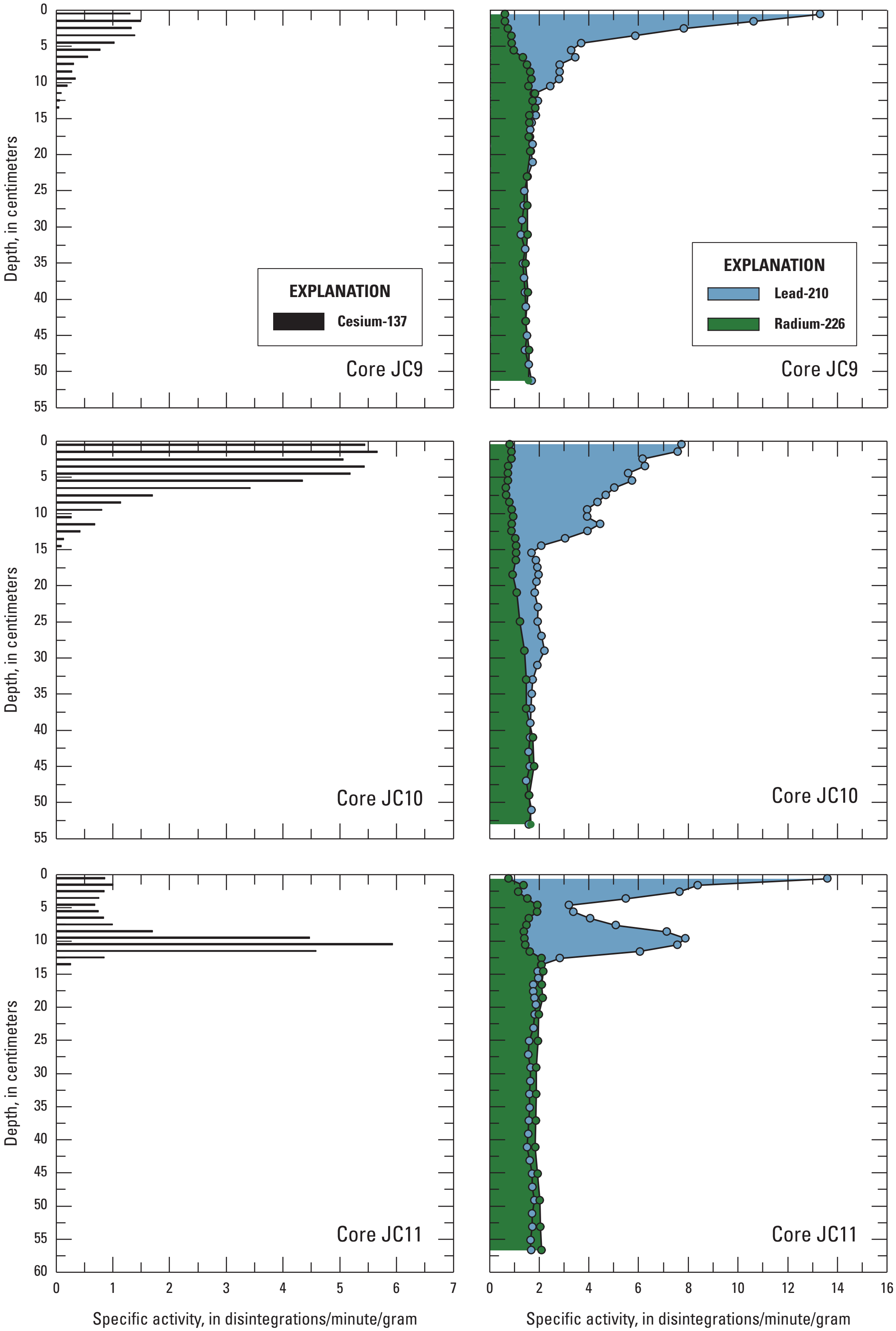


Figure 18. Radioisotope profiles for cores from Pool 332 within J. Clark Salyer National Wildlife Refuge. The difference between total lead-210 (^{210}Pb) and radium-226 approximates unsupported ^{210}Pb.

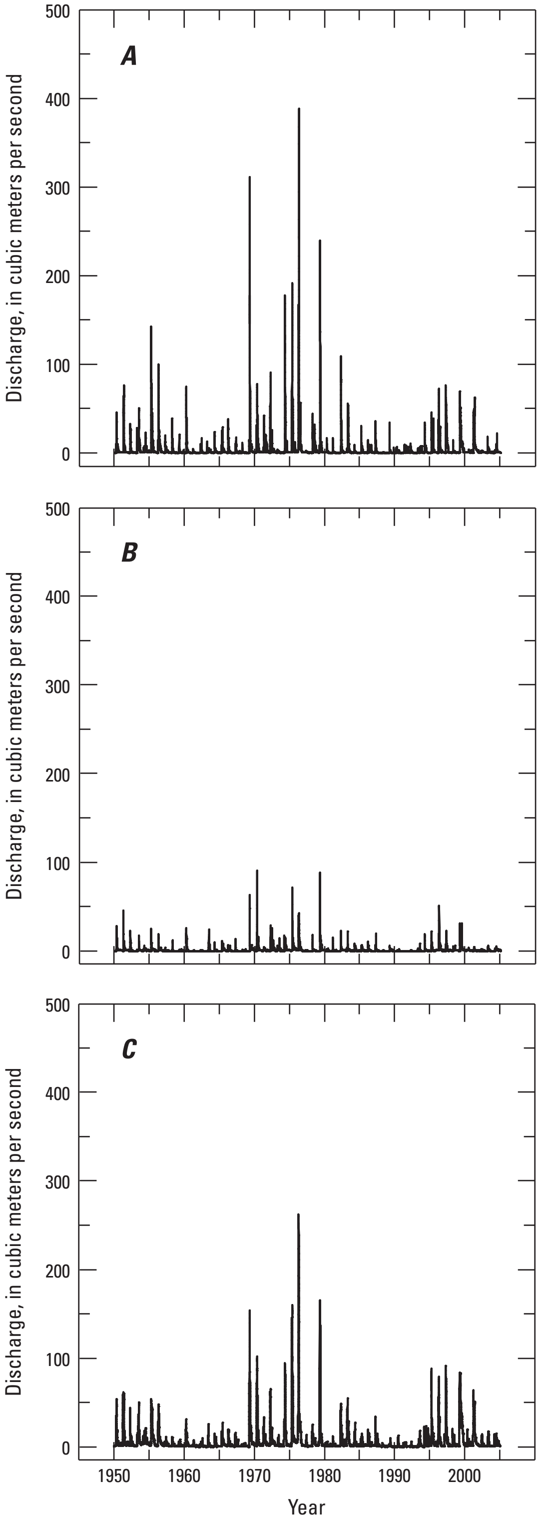


Figure 19. Daily discharge (1950–2005) from U.S. Geological Survey (USGS) streamgages located on *A*, the Souris River upstream of Upper Souris National Wildlife Refuge (NWR) (USGS 05114000 Souris River near Sherwood, N. Dak.); *B*, the Des Lacs River downstream from Des Lacs NWR (USGS 05116500 Des Lacs River at Foxholm, N. Dak.); and *C*, the Souris River upstream from J. Clark Salyer NWR (USGS 05122000 Souris River near Bantry, N. Dak.).

Sediment Accretion Rates

The high variability in soil characteristics that suggest the distribution and volume of sediments at a given location are in a constant state of flux makes it extremely difficult to accurately estimate sediment accretion rates using radioisotopes. Nonetheless, ^{137}Cs and ^{210}Pb activity within each core was examined and attempts were made to estimate accretion rates when feasible. The expected ^{137}Cs inventory at the end of 2004 was estimated at 12.33 disintegrations/minute/square centimeter (fig. 5). All of the cores, except core US2, had detectable levels of ^{137}Cs in some part of the profile (figs. 8–18); however, only 8 of the 29 cores with sufficient data to calculate the total ^{137}Cs inventory had values that exceeded the expected level (fig. 20). Core US3 was approximately 180 percent of the expected value; no other cores exceeded the expected value by more than 17 percent (fig. 20). No obvious patterns in total ^{137}Cs inventory were evident when examined along the upstream to downstream gradients within and among NWRs (fig. 20). Based on the ^{137}Cs inventories, it was evident that sediments transported from the surrounding watershed were not accumulating on a broad scale. Instead, these results suggest that sediments likely are regularly mobilized and deposited elsewhere in the system.

Dating of sediment cores was based on a combination of ^{137}Cs time markers for all cores and ^{210}Pb dates obtained using the CRS model for segments of 17 cores. The first detection of ^{137}Cs was assumed to be 1957 (fig. 5), but the 1963 time marker for peak deposition only was identified in cores US1, JC2, JC8, and JC11 (figs. 12, 16, 17, and 18, respectively). The lack of a well-defined 1963 marker was likely because of mixing or periodic redistribution of sediment, which confounded interpretation of results. Given these constraints, our ability to determine sediment accretion rates based on the 1963 marker was limited to four cores (table 2). Estimated mean accretion rates for all cores were 0.35 cm per year (cm/year) and 0.22 cm/year based on the 1957 (27 cores) and 1963 (4 cores) ^{137}Cs time markers, respectively (table 2). Mean accretion rate from the ^{210}Pb analyses was 0.32 cm/year (table 2). In addition to variation in accretion rates among the three methods of determination, there also were no obvious upstream to downstream patterns within or among refuges (fig. 21). Cores were compacted during collection of most samples (table 1), and this could bias calculations of sediment density and accretion rates. However, for most cores the soft sediments and muds primarily were located in the upper part of the cores (sediment surface), and although the cores were shortened they still represent the complete sediment profile and provide a depiction of the depositional history. Further, accretion rates calculated using depth (for example, ^{137}Cs peak) and time likely are conservative when using compacted cores.

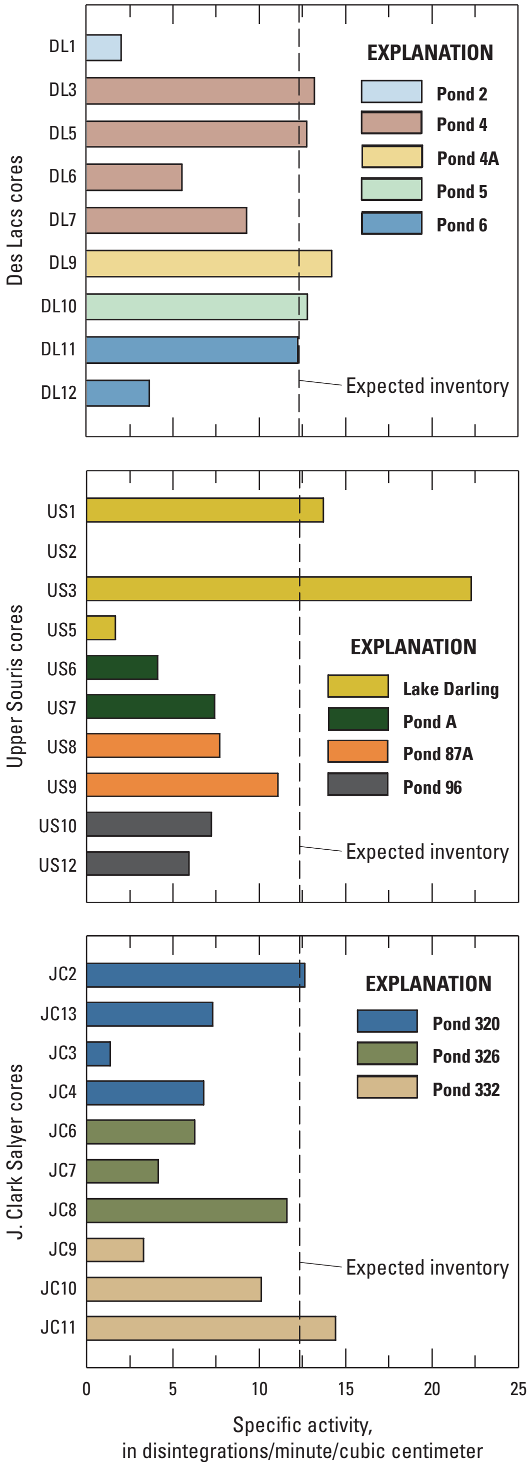


Figure 20. Cesium-137 (^{137}Cs) inventory of sediment cores collected from Des Lacs, Upper Souris, and J. Clark Salyer National Wildlife Refuges. Cores are sorted along the approximate upstream to downstream gradient and color-coded by individual impoundment. The vertical dashed line indicates the expected ^{137}Cs inventory of 12.33 disintegrations/minute/cubic centimeter.

Table 2. Estimated sediment accretion rates based cesium-137 and lead-210 from soil cores collected from impoundments of Des Lacs, Upper Souris, and J. Clark Salyer National Wildlife Refuges in North Dakota.

[NWR, National Wildlife Refuge; ^{137}Cs, cesium-137; cm, centimeter; ^{210}Pb, lead-210; --, no data]

NWR	Core identifier	1957 ^{137}Cs depth, cm	1963 ^{137}Cs depth, cm	^{137}Cs-derived accretion rate, cm/year		^{210}Pb-derived accretion rate, cm/year
				1957–2004 (47 years)	1963–2004 (41 years)	
Des Lacs	DL1	10.5	--	0.22	--	--
	DL3	12.5	--	0.27	--	--
	DL5	19.5	--	0.41	--	0.37
	DL6	11.5	--	0.24	--	0.16
	DL7	15.5	--	0.33	--	0.23
	DL9	11.5	--	0.24	--	--
	DL10	10.5	--	0.22	--	
	DL11	13.5	--	0.29	--	0.17
	DL12	4.5	--	0.10	--	--
Upper Souris	US1	10.5	4.5	0.22	0.11	0.2
	US2	--	--	--	--	--
	US3	19.5	--	0.41	--	--
	US5	--	--	--	--	--
	US6	25.0	--	0.53	--	0.38
	US7	23.0	--	0.49	--	0.34
	US8	5.5	--	0.12	--	--
	US9	31.0	--	0.66	--	0.34
	US10	6.5	--	0.14	--	--
	US12	23.0	--	0.49	--	0.3
J. Clark Salyer	JC2	18.5	9.5	0.39	0.23	0.23
	JC13	47.0	--	1.00	--	0.46
	JC3	12.5	--	0.27	--	--
	JC4	10.5	--	0.22	--	0.43
	JC6	27.0	--	0.57	--	0.62
	JC7	15.5	--	0.33	--	--
	JC8	14.5	11.5	0.31	0.28	0.21
	JC9	13.5	--	0.29	--	0.16
	JC10	14.5	--	0.31	--	0.45
	JC11	13.5	10.5	0.29	0.26	0.34

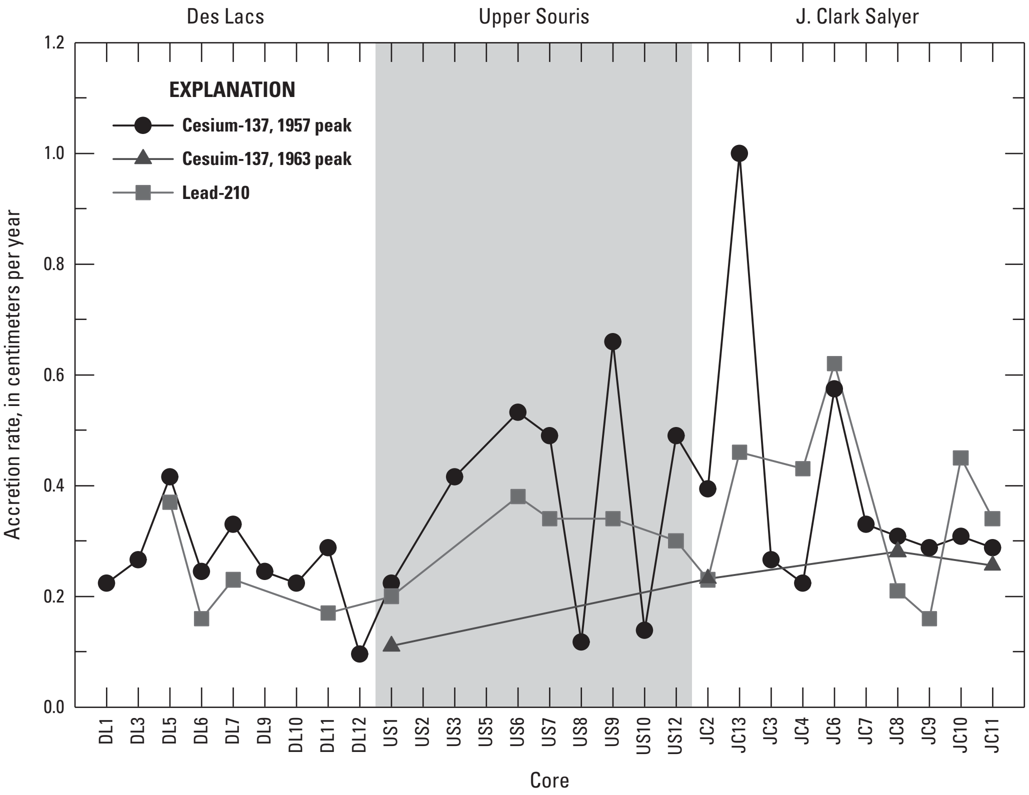


Figure 21. Sediment accretion rates for cores collected from Des Lacs, Upper Souris, and J. Clark Salyer National Wildlife Refuges (NWR). Accretion rates were calculated using the estimated 1957 and 1963 peaks in cesium-137 activity and unsupported lead-210 activity (see table 2). Cores are sorted (left to right) along the approximate upstream to downstream gradient.

Trace Elements and Agrichemicals

Summary statistics for 60 of 62 analyzed elements are presented by NWR in table 3; the remaining two elements, germanium and tantalum, were not detected in any samples. Raw elemental data for each core are presented by depth in *appendix 2*. Based on overall means, elements with the greatest concentrations included iron, calcium, aluminum, magnesium, manganese, and sulfur (table 3). Horowitz and Stephens (2008) determined national baseline values for major and trace elements, nutrients, and carbon from fluvial bed sediments. Twenty-nine of the 60 elements considered for this study were included in the Horowitz and Stephens (2008) study. Based on overall means (table 3), most of the 29 elements fell within the reported baseline ranges, and no elements exceeded the maximum presented values.

Because of limited sample sizes, statistical analyses of elemental and agrichemical concentrations were not carried out. However, qualitative assessments suggested slightly increasing patterns in the concentration of some elements. For example, concentrations of aluminum, boron, and vanadium in sediment cores (figs. 22–24) were lowest in the upstream NWRs (Des Lacs, Upper Souris) and greater in the downstream NWR (J. Clark Salyer). However, these apparent patterns should be interpreted cautiously and further study is warranted before making conclusions as to the accumulation of elements in the downstream part of the Souris River Basin. Concentrations for all 59 agrichemicals were below the analytical detection limits presented in table 4; however, the list of chemicals is extensive and not all of them are presently (2013) used in area. Further, it is not uncommon for studies of aquatic sediments to report nondetects for agrichemicals (for example, Nowell and others, 2000; Tangen and others, 2003; Juracek, 2004; Wax, 2006a; Wax, 2006b; Juracek, 2010). The probability of detection can be dependent on solubility, persistence (half-life), the timing of chemical application in relation to sampling, as well as weather and landscape factors associated with the generation of runoff. Therefore, no strong conclusions should be made based on the absence of detected agrichemicals.

Table 3. Summary statistics for 60 elements detected in sediment cores from Des Lacs, Upper Souris, and J. Clark Salyer National Wildlife Refuges.

[NWR, National Wildlife Refuge; med, median; min, minimum; max, maximum; *n*, number; ppm, parts per million; ppb, parts per billion]

Element	Unit	Detection limit	Des Lacs NWR					Upper Souris NWR					J. Clark Salyer NWR				
			Mean	Med	Min	Max	*n*	Mean	Med	Min	Max	*n*	Mean	Med	Min	Max	*n*
Aluminum	percent	0.010	1.06	1.01	0.43	2.03	75	1.68	1.70	0.94	2.44	115	2.08	2.07	0.72	3.43	75
Antimony	ppm	0.020	0.19	0.17	0.04	0.84	75	0.26	0.26	0.04	0.55	115	0.29	0.28	0.02	0.70	71
Arsenic	ppm	0.100	4.05	3.90	1.20	10.60	75	5.45	5.40	3.00	8.10	115	6.16	5.50	1.00	17.80	73
Barium	ppm	0.500	126.47	145.00	19.80	302.00	75	183.28	186.00	29.80	281.00	115	188.79	225.00	14.50	387.00	75
Beryllium	ppm	0.100	0.53	0.50	0.20	1.00	75	0.80	0.80	0.40	1.00	115	0.89	0.90	0.40	1.20	75
Bismuth	ppm	0.020	0.10	0.05	0.02	0.27	33	0.05	0.04	0.02	0.25	84	0.09	0.08	0.02	0.20	69
Boron	ppm	1.000	18.75	18.00	7.00	31.00	75	25.18	24.00	14.00	64.00	115	38.89	35.00	10.00	78.00	75
Cadmium	ppm	0.010	0.29	0.25	0.12	0.60	74	0.44	0.43	0.29	0.63	115	0.46	0.43	0.29	0.89	75
Calcium	percent	0.010	2.13	2.24	0.52	4.60	75	1.87	1.75	0.70	3.86	115	1.42	1.19	0.65	3.44	75
Cerium	ppm	0.010	27.87	28.00	17.80	40.20	75	34.16	34.20	15.70	42.40	115	32.45	34.00	15.60	44.00	75
Cesium	ppm	0.020	0.81	0.81	0.39	1.39	75	0.84	0.83	0.47	1.30	115	0.82	0.84	0.20	1.88	75
Chromium	ppm	0.500	21.74	21.30	8.30	47.10	75	31.00	31.50	14.60	40.90	115	33.34	34.20	12.70	50.20	75
Cobalt	ppm	0.100	7.30	7.60	4.20	11.70	75	9.71	9.80	5.00	12.20	115	10.01	9.90	6.50	13.10	75
Copper	ppm	0.010	16.88	14.80	5.44	57.20	75	24.89	24.70	18.00	31.80	115	26.48	26.30	9.84	37.30	75
Disprosium	ppm	0.001	1.93	1.93	1.17	2.77	75	2.31	2.32	1.07	2.77	115	2.30	2.41	1.23	2.93	75
Erbium	ppm	0.100	0.95	0.90	0.60	1.40	75	1.15	1.20	0.50	1.30	115	1.15	1.20	0.60	1.50	75
Europium	ppm	0.100	0.57	0.60	0.30	0.90	75	0.74	0.70	0.30	0.90	115	0.70	0.70	0.30	0.90	75
Gadolinium	ppm	0.100	2.58	2.60	1.60	3.80	75	3.18	3.20	1.40	4.00	115	2.98	3.20	1.60	3.80	75
Gallium	ppm	0.020	3.64	3.49	1.54	7.08	75	5.81	5.91	3.20	7.87	115	6.52	6.52	0.89	10.30	75
Gold	ppb	0.500	5.46	3.05	0.60	25.00	8	1.73	1.10	0.70	7.60	18	1.84	1.35	1.00	4.30	10
Hafnium	ppm	0.100	0.13	0.10	0.10	0.20	14	0.12	0.10	0.10	0.20	53	0.20	0.20	0.10	0.40	57
Holmium	ppm	0.100	0.36	0.40	0.20	0.50	75	0.43	0.40	0.20	0.50	115	0.43	0.50	0.20	0.60	75
Indium	ppm	0.020	0.03	0.02	0.02	0.04	35	0.03	0.03	0.03	0.05	114	0.04	0.04	0.02	0.05	75
Iron	percent	0.010	1.56	1.51	0.67	2.73	75	2.50	2.51	1.30	3.12	115	2.63	2.64	0.18	3.73	75
Lanthanum	ppm	0.500	14.88	15.20	8.70	21.20	75	18.36	18.20	8.20	23.30	115	17.20	18.00	8.40	23.00	75
Lead	ppm	0.010	10.05	8.06	3.40	39.80	75	12.77	12.80	8.07	15.80	115	13.97	13.70	7.27	22.50	75
Lithium	ppm	0.100	14.26	14.50	5.60	22.70	75	15.72	15.60	8.40	20.70	115	17.88	17.80	8.40	28.80	75
Lutetium	ppm	0.100	0.10	0.10	0.10	0.10	31	0.10	0.10	0.10	0.10	110	0.11	0.10	0.10	0.20	64
Magnesium	percent	0.010	0.93	1.00	0.47	1.50	75	0.89	0.85	0.57	1.36	115	0.80	0.79	0.37	1.38	75
Manganese	ppm	1.000	405.73	389.00	178.00	911.00	75	611.26	591.00	313.00	1,070.00	115	480.71	397.00	152.00	1,460.00	75

Table 3. Summary statistics for 60 elements detected in sediment cores from Des Lacs, Upper Souris, and J. Clark Salyer National Wildlife Refuges.—Continued

[NWR, National Wildlife Refuge; med, median; min, minimum; max, maximum; *n*, number; ppm, parts per million; ppb, parts per billion]

Element	Unit	Detection limit	Des Lacs NWR					Upper Souris NWR					J. Clark Salyer NWR				
			Mean	Med	Min	Max	*n*	Mean	Med	Min	Max	*n*	Mean	Med	Min	Max	*n*
Molybdenum	ppm	0.010	0.96	0.80	0.31	3.30	75	0.73	0.65	0.11	2.20	115	1.82	1.11	0.05	9.30	74
Neodymium	ppm	0.020	14.21	14.20	8.53	20.20	75	17.63	17.60	7.84	22.50	115	16.43	17.10	7.82	22.00	75
Nickel	ppm	0.100	20.93	21.30	9.50	36.60	75	29.75	29.90	14.20	37.10	115	31.90	31.90	22.30	41.50	75
Niobium	ppm	0.100	0.50	0.50	0.10	0.90	74	0.53	0.50	0.10	0.90	113	0.76	0.80	0.20	1.20	68
Phosphorus	percent	0.001	0.07	0.06	0.05	0.17	75	0.07	0.06	0.05	0.14	115	0.07	0.06	0.00	0.16	74
Potassium	percent	0.010	0.23	0.23	0.10	0.36	75	0.32	0.32	0.21	0.40	115	0.30	0.31	0.14	0.47	75
Praseodymium	ppm	0.100	3.75	3.80	2.30	5.30	75	4.61	4.60	2.00	5.80	115	4.33	4.60	2.10	5.80	75
Rhenium	ppm	0.001	0.01	0.01	0.00	0.04	70	0.01	0.01	0.00	0.02	113	0.01	0.01	0.00	0.02	75
Rubidium	ppm	0.100	15.34	14.90	6.70	26.70	75	21.35	21.30	14.20	29.00	115	22.61	22.60	10.10	37.10	75
Samarium	ppm	0.100	2.96	2.90	1.70	4.20	75	3.73	3.70	1.70	4.60	115	3.43	3.70	1.70	4.40	75
Scandium	ppm	0.100	2.53	2.50	1.00	5.20	75	4.47	4.50	1.40	6.10	115	4.69	4.70	1.00	7.80	75
Selenium	ppm	0.100	0.75	0.70	0.30	1.70	75	0.82	0.80	0.30	1.50	115	1.37	1.15	0.20	3.70	74
Silver	ppm	0.002	0.08	0.03	0.00	0.48	64	0.08	0.08	0.04	0.21	115	0.06	0.06	0.01	0.12	74
Sodium	percent	0.001	0.27	0.24	0.05	0.64	75	0.13	0.12	0.06	0.37	115	0.18	0.17	0.07	0.41	75
Strontium	ppm	0.500	68.07	63.70	27.20	141.00	75	65.96	60.10	37.10	131.00	115	65.01	58.80	35.40	117.00	75
Sulfur	percent	0.001	0.57	0.42	0.11	1.65	75	0.41	0.35	0.06	1.10	115	0.43	0.34	0.02	1.19	75
Tellurium	ppm	0.020	0.04	0.03	0.02	0.07	15	0.04	0.04	0.02	0.12	48	0.04	0.04	0.02	0.07	32
Terbium	ppm	0.100	0.33	0.30	0.20	0.50	75	0.41	0.40	0.20	0.50	115	0.41	0.40	0.20	0.50	75
Thallium	ppm	0.020	0.18	0.18	0.12	0.30	75	0.26	0.26	0.15	0.33	115	0.25	0.26	0.14	0.36	75
Thorium	ppm	0.100	2.29	2.30	0.60	4.60	75	3.68	3.60	1.50	4.90	115	3.00	3.00	0.30	5.70	74
Thulium	ppm	0.100	0.12	0.10	0.10	0.20	69	0.18	0.20	0.10	0.20	114	0.17	0.20	0.10	0.20	72
Tin	ppm	0.050	0.50	0.35	0.06	2.07	74	0.52	0.52	0.20	0.70	115	0.61	0.62	0.07	3.12	69
Titanium	percent	0.010	0.02	0.02	0.01	0.04	75	0.02	0.02	0.01	0.03	114	0.02	0.02	0.01	0.04	57
Tungsten	ppm	0.100	1.67	0.90	0.10	5.20	15	0.50	0.30	0.10	1.10	3	0.38	0.40	0.10	0.80	13
Uranium	ppm	0.100	2.40	2.00	0.80	12.00	75	1.54	1.50	0.90	3.10	115	2.96	2.10	0.50	15.50	75
Vanadium	ppm	1.000	33.17	32.00	14.00	64.00	75	48.04	50.00	27.00	65.00	115	60.42	61.00	29.00	94.00	73
Ytterbium	ppm	0.100	0.68	0.70	0.40	1.00	75	0.90	0.90	0.40	1.10	115	0.87	0.90	0.50	1.10	75
Yttrium	ppm	0.010	9.50	9.40	5.97	13.60	75	12.08	12.10	5.67	14.30	115	11.71	12.40	6.55	14.60	75
Zinc	ppm	0.100	57.90	54.00	20.50	134.00	75	94.61	94.70	75.80	116.00	115	95.71	97.50	64.50	127.00	75
Zirconium	ppm	0.100	3.58	3.20	0.20	10.80	75	5.32	5.30	1.80	9.70	115	7.80	8.00	0.10	15.10	75

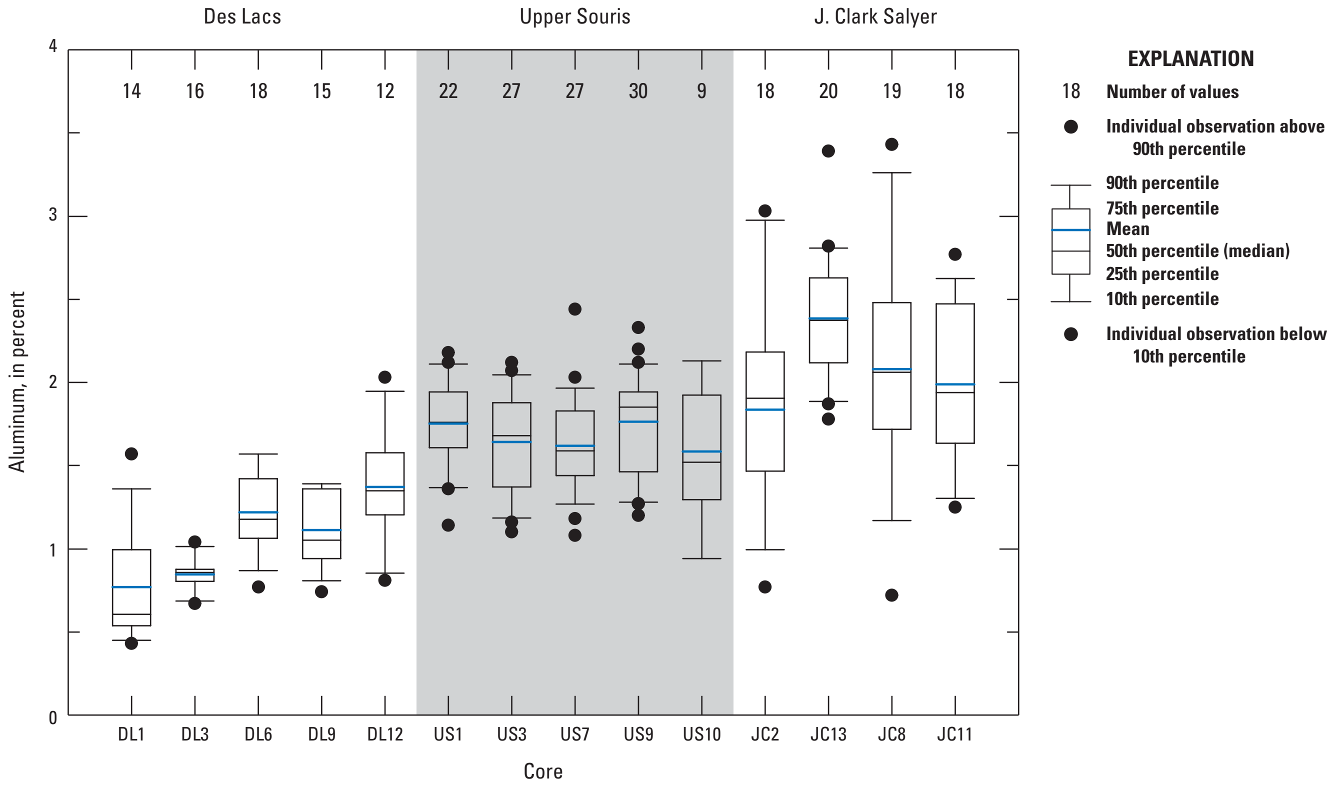


Figure 22. Boxplots of aluminum concentration representing all depth segments for each sediment core. Cores are sorted (left to right) along the approximate upstream to downstream gradient.

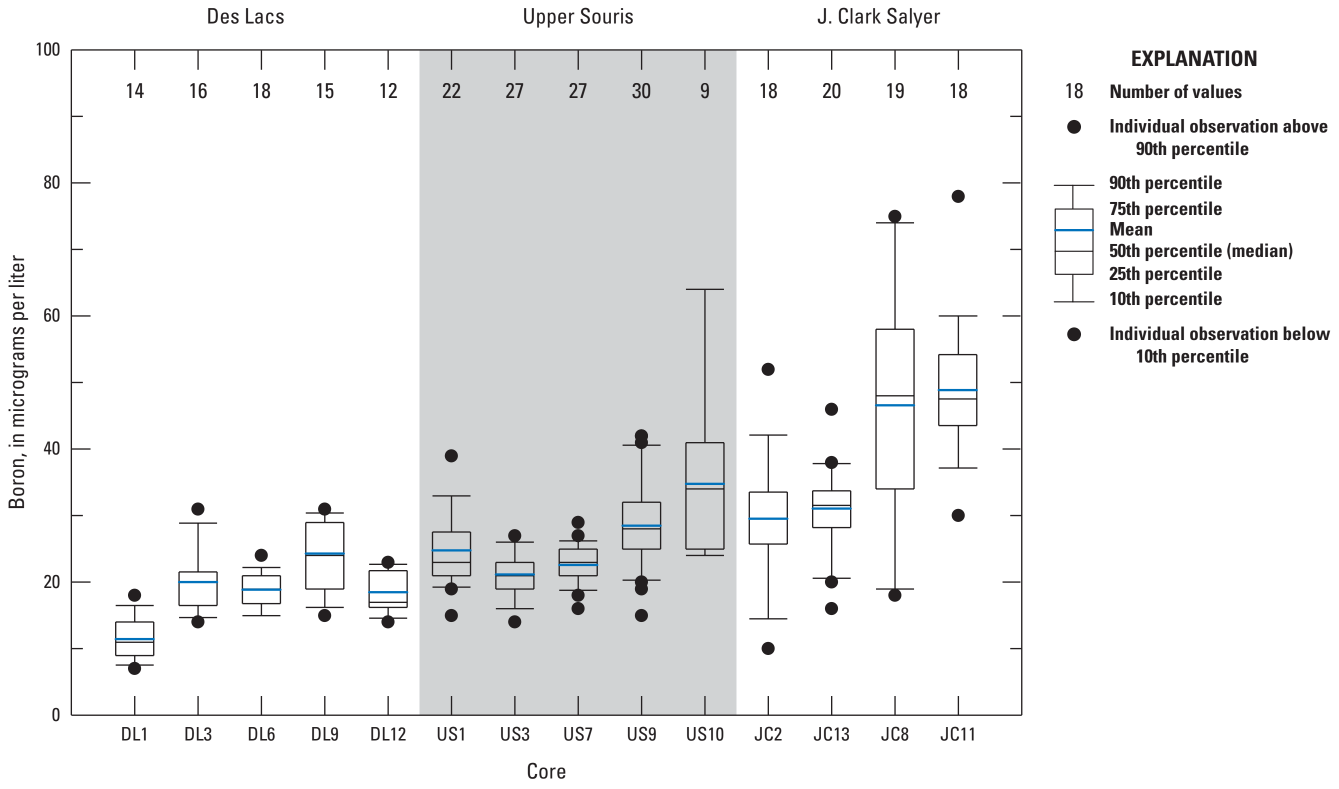


Figure 23. Boxplots of boron concentration representing all depth segments for each sediment core. Cores are sorted (left to right) along the approximate upstream to downstream gradient.

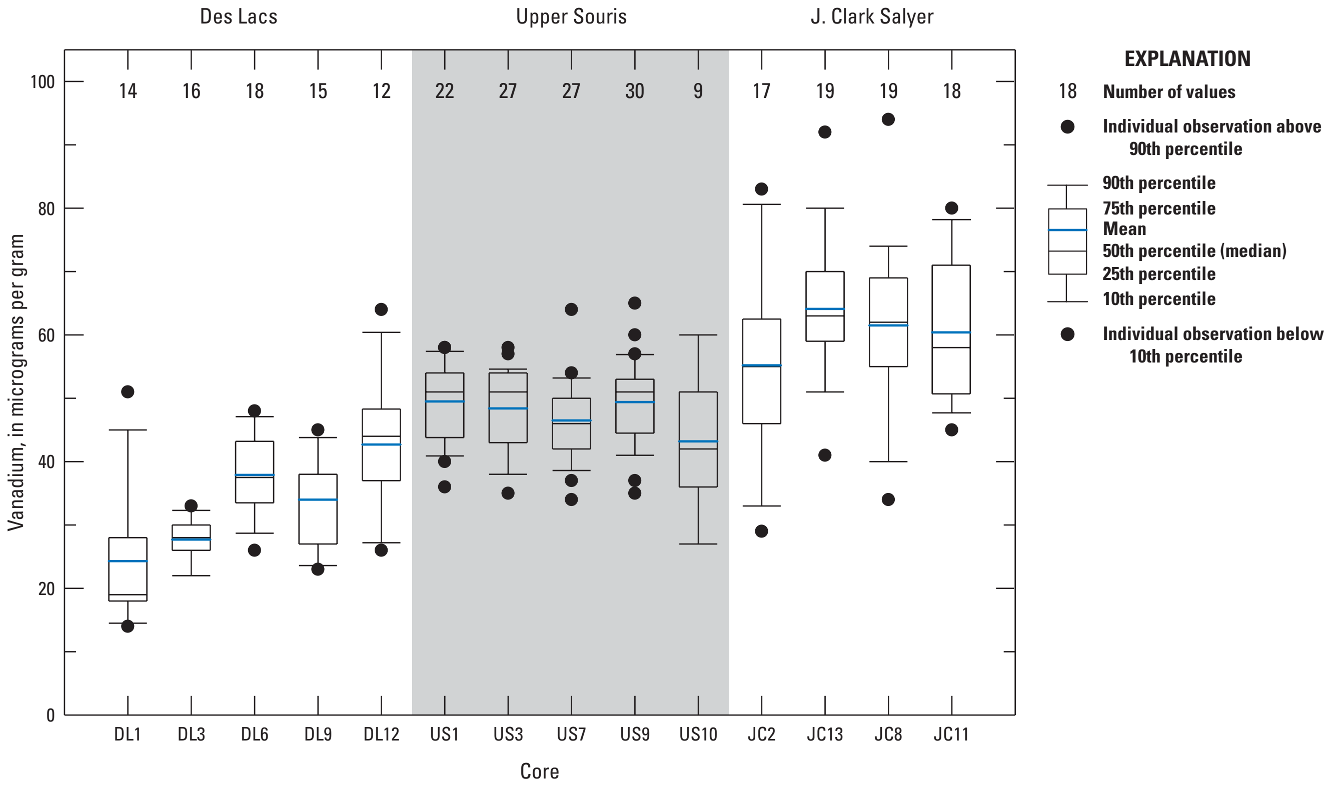


Figure 24. Boxplots of vanadium concentration representing all depth segments for each sediment core. Cores are sorted (left to right) along the approximate upstream to downstream gradient.

Table 4. Analytical detection limits for agrichemicals from surface sediment samples. Some chemicals have two detection limits because the mass of individual samples varied. In most cases, samples with greater mass supported analyses that resulted in lower detection limits.

[µg/g, micrograms per gram; MCPA, 2-(4-chloro-2-methyl-phenoxy) acetic acid; BHC, benzene hexachloride]

Chemical	Detection limit, µg/g	Chemical	Detection limit, µg/g
2,4,5-T	0.015	Dieldrin	0.01, 0.02
2,4,5-TP	0.02	Dinoseb	0.03
2,4-D	0.03	Endosulfan I	0.012, 0.025
3,5 Dichlorobenzoic acid	0.022	Endosulfan II	0.012, 0.025
Acifluorfen	0.03	Endosulfan Sulfate	0.012, 0.025
Alachlor	0.038, 0.075	Endrin	0.012, 0.025
Aldrin	0.038, 0.075	Endrin Aldehyde	0.012, 0.025
Arochlor 1016	0.125, 0.25	Endrin Ketone	0.012, 0.025
Arochlor 1221	0.125, 0.25	Ethalfluralin	0.008, 0.015
Arochlor 1232	0.125, 0.25	Far-Go (Triallate)	0.01, 0.02
Arochlor 1242	0.125, 0.25	Fenvalerate	0.062, 0.125
Arochlor 1248	0.125, 0.25	Heptachlor	0.008, 0.015
Arochlor 1254	0.125, 0.25	Heptachlor Epoxide	0.008, 0.015
Arochlor 1260	0.125, 0.25	Hoelon	0.075
Arochlor 1262	0.125, 0.25	Lindane	0.008, 0.015
Atrazine	0.312, 0.625	Malathion	0.025, 0.05
Bentazon	0.08	MCPA	3.75
BHC (alpha)	0.008, 0.015	Methoxychlor	0.025, 0.05
BHC (beta)	0.008, 0.015	Metolachlor	0.11, 0.22
BHC (delta)	0.008, 0.015	Metrabuzine	0.025, 0.05
Bromoxynil	0.008	Parathion Ethyl	0.025, 0.05
Chlordane (alpha)	0.012, 0.025	Parathion Methyl	0.025, 0.05
Chlordane (gamma)	0.012, 0.025	Pendimethalin	0.012, 0.025
Chlorpyrifos	0.012, 0.025	Pentachlorophenol	0.006
DDD	0.012, 0.025	Picloram	0.015
DDE	0.012, 0.025	Simazine	0.312, 0.625
DDT	0.012, 0.025	Toxaphene	0.25, 0.5
Diazinon	0.012, 0.025	trans-Nonachlor	0.008, 0.015
Dicamba	0.015	Treflan (Trifluralin)	0.008, 0.015
Dichlorprop	0.04		

Summary

Sedimentation of riverine impoundments located on national wildlife refuges is a concern for U.S. Fish and Wildlife Service personnel charged with managing these systems for migratory birds and other wildlife. The addition of sediments can alter aquatic habitats (for example, distribution and composition of vegetation) by reducing maximum pool depths, and water quality can be reduced through addition of sediment-associated chemical constituents (for example, heavy metals, nutrients) and increased turbidity. Although sedimentation of managed impoundments and large reservoirs has been identified as a major problem in the United States, comprehensive information pertaining to sedimentation rates and chemical characteristics are lacking for most national wildlife refuges.

Sedimentation rates were estimated and sediments were characterized across a range of sites within Des Lacs, Upper Souris, and J. Clark Salyer National Wildlife Refuges to support habitat management. It was apparent when examining physical properties and radioisotopic activity profiles of sediment cores along the depth profile that depositional processes associated with sedimentation of refuge impoundments were highly variable with time. For example, the percentage of sands and silts often varied greatly along the depth profile, suggesting episodes of variable river flows and fluvial loads. This conclusion was supported by highly variable streamflows of the Des Lacs and Souris Rivers over a 55-year period. Further, peak levels of ^{137}Cs associated with past deposition often were observed in the near-surface sediments, indicating sediment removal or mixing or both.

^{137}Cs and ^{210}Pb activity from the sediment cores was used to estimate accretion rates for impoundments within the Souris River Basin refuges that ranged from 0.22–0.35 cm/year, depending on method of determination. These estimates are in line with low estimates from similar systems in northeastern South Dakota and northwestern Minnesota, and likely represent comparatively natural rates for these impoundments. Moreover, no patterns in sedimentation rates were identified along the upstream to downstream gradient, either within or among refuges. Based on comparisons between the actual and expected ^{137}Cs inventory there does not appear to be significant sediment accumulation as only 8 of 29 cores exceeded the expected inventory, and only a single core exceeded the expected inventory by more than 17 percent. Further, because approximately 70 percent of cores had less ^{137}Cs activity than expected, there appears to be a high degree of sediment mobilization and transport. Although the average accretion rates among the three methods of determination only differed by 0.13 cm/year, variability did exceed 0.5 cm/year when examined on a core by core basis. This variability demonstrates the difficulty of using radioisotopes to estimate sediment accretion in systems with mixed sediments and low accumulation rates. Nonetheless, radioisotope dating did provide sufficient estimates for assessing overall sedimentation of the impoundments within Souris River Basin refuges.

A subset of sediment cores were analyzed for elements and, based on overall mean concentrations and comparisons to reported values, no elements were reported at levels deemed excessively high. Similarly, surface sediment samples from all sites were analyzed for agrichemicals, with no detectable levels reported. Although concentrations of all elements appeared to be within acceptable ranges, visual inspection of boxplots indicated that concentrations of some elements, such as aluminum, boron, and vanadium, may be greater in the downstream impoundments of J. Clark Salyer National Wildlife Refuge than in the upstream impoundments of Des Lacs and Upper Souris National Wildlife Refuges. However, no conclusions should be drawn based on these apparent patterns without further study.

Data pertaining to sedimentation rates and sediment quality of impoundments of the Souris River Basin refuges were collected in response to an expressed management information need. Based on information presented in this report, sediments and their associated chemical constituents do not appear to be accumulating to a great extent in refuge impoundments. Instead, sediments seem to be regularly mixed, mobilized, or redistributed elsewhere in the system. Further, transport of sediments likely is variable throughout the system because of differences in sediments contributed from the watershed, river flows, and water-control structures. For example, areas above a stop-log structure would likely accumulate sediments, whereas areas associated with a radial gate would likely be characterized by greater sediment transport.

This study was designed to provide an initial assessment of impoundments in the Souris River Basin refuges by characterizing a diversity of locations within each refuge that were anticipated to cover a potential sedimentation gradient from low to high. Future monitoring and research should focus on areas with high potential for sediment accumulation, such as upstream areas adjacent to dams, to identify critical or emerging management issues before habitats are negatively affected. Further, assessments of suspended sediments transported in the Des Lacs and Souris Rivers would augment interpretation of sedimentation data by identifying potential sediment sources and areas with the greatest potential for accumulation.

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