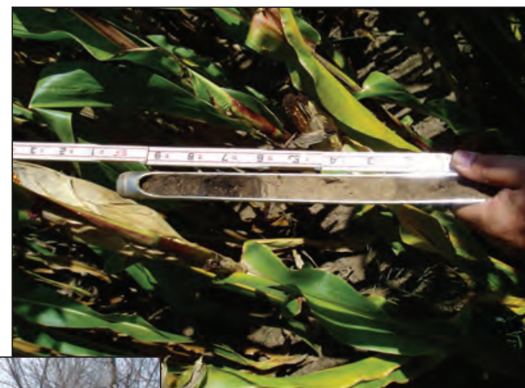
In cooperation with the U.S. Environmental Protection Agency

Sedimentation History of Halfway Creek Marsh, Upper Mississippi River National Wildlife and Fish Refuge, Wisconsin, 1846–2006



Scientific Investigations Report 2007–5029

U.S. Department of the Interior
U.S. Geological Survey

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Cover photos (clockwise from top left):
View of Lower Halfway Creek Marsh looking southwest, August 4, 2005 (photo taken by James C. Knox);
Core PD-2, showing boundary between historical overbank sedimentation and presettlement soil at 5.6 ft depth, September 6, 2005 (photo taken by Faith A. Fitzpatrick); Halfway Creek through the upper part of Halfway Creek Marsh, February 28, 2006 (photo taken by Faith A. Fitzpatrick).

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Conversion Factors, Abbreviations, and Vertical Datum

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
yard (yd)	0.9144	meter (m)
	Area	
acre	4,047	square meter (m^2)
	Volume	
cubic yard (yd^3)	0.7646	cubic meter (m^3)
cubic yard per year (yd^3/yr)	0.7646	cubic meter per year (m^3/yr)
	Mass	
ton, short (2,000 lb)	0.9072	megagram (Mg)
ton per acre per year (ton/acre/yr)	2.242	megagram per hectare per year (Mg/ha/yr)

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29).

Altitude, as used in this report, refers to distance above the vertical datum.

Sedimentation History of Halfway Creek Marsh, Upper Mississippi River National Wildlife and Fish Refuge, Wisconsin, 1846–2006

By Faith A. Fitzpatrick, James C. Knox[1], and Joseph P. Schubauer-Berigan[2]

Abstract

The history of overbank sedimentation in the vicinity of Halfway Creek Marsh near La Crosse, Wis., was examined during 2005–06 by the U.S. Geological Survey and University of Wisconsin–Madison as part of a broader study of sediment and nutrient loadings to the Upper Mississippi River bottomlands by the U.S. Environmental Protection Agency, U.S. Fish and Wildlife Service, and U.S. Geological Survey. Historical sedimentation patterns and rates were interpreted from field-scale topographic surveys and sediment cores collected from the marsh and upstream flood plains. Historical maps and aerial photographs were used to establish the timing of disturbances and to document changes in channel patterns after Euro-American settlement (post 1846). Episodic overbank sedimentation patterns and rates were linked to watershed agricultural activity, large floods, artificial levee construction, channel alterations, and dam failures over the past 160 years. These forces affected sedimentation on and between levees, the development of alluvial fans and flood-plain splays, and the general pattern of flood-plain sedimentation through the upper and lower marsh. Historical overbank deposits, episodically deposited after about 1860, are as much as 6 feet thick in the upper marsh and as much as 4 feet thick in the lower marsh, representing a total volume of approximately 1.8 million cubic yards.

These stratified deposits consist of multiple layers of silt and clay, very fine to fine sand, and some medium to very coarse sand. Coarse-grained deposits are associated with flood-plain splays caused by breaches in artificial levees during large floods. Estimated sedimentation rates were highest from 1919 to 1936 [26,890 cubic yards per year (yd^3/yr)] and exceeded by about 30 times the 1846–85 rate of 920 yd^3/yr and exceeded by 7 times the 1994–2006 rate of 3,740 yd^3/yr. The 1994–2006 sedimentation rate was the lowest since Euro-American settlement, but natural levees along the 1994–2006 channel of Halfway Creek through the lower marsh continued to form and are currently (2006) about 1 foot higher than the surrounding marsh. Natural levee building in the lower marsh from 1994–2006 was accentuated by the lack of overbank sediment storage in the upper marsh. The historical storage of sediment in the upper and lower marsh affects modern streamflow and sediment transport processes of Halfway Creek and Sand Lake Coulee through the marsh, and it also affects marsh vegetation and wildlife habitat. Results from this investigation will help improve the understanding of how past overbank sedimentation patterns continue to influence modern and future water quality, sediment transport, nutrient loads, and water-related resources in riparian habitats common to the Upper Mississippi River National Wildlife and Fish Refuge.

Introduction

Halfway Creek Marsh is in the lower reach of Halfway Creek and Sand Lake Coulee and in the bottomlands of the Mississippi River north of Onalaska, Wis. (fig. 1A). The marsh is part of the U.S. Fish and Wildlife Service (USFWS) Upper Mississippi River National Wildlife and Fish Refuge and has upper and lower sections separated by County Highway ZN near Midway (fig. 1B). The upper marsh historically was more extensively drained than the lower marsh primarily because of its use for agriculture. The lower marsh is wetter than the upper marsh and

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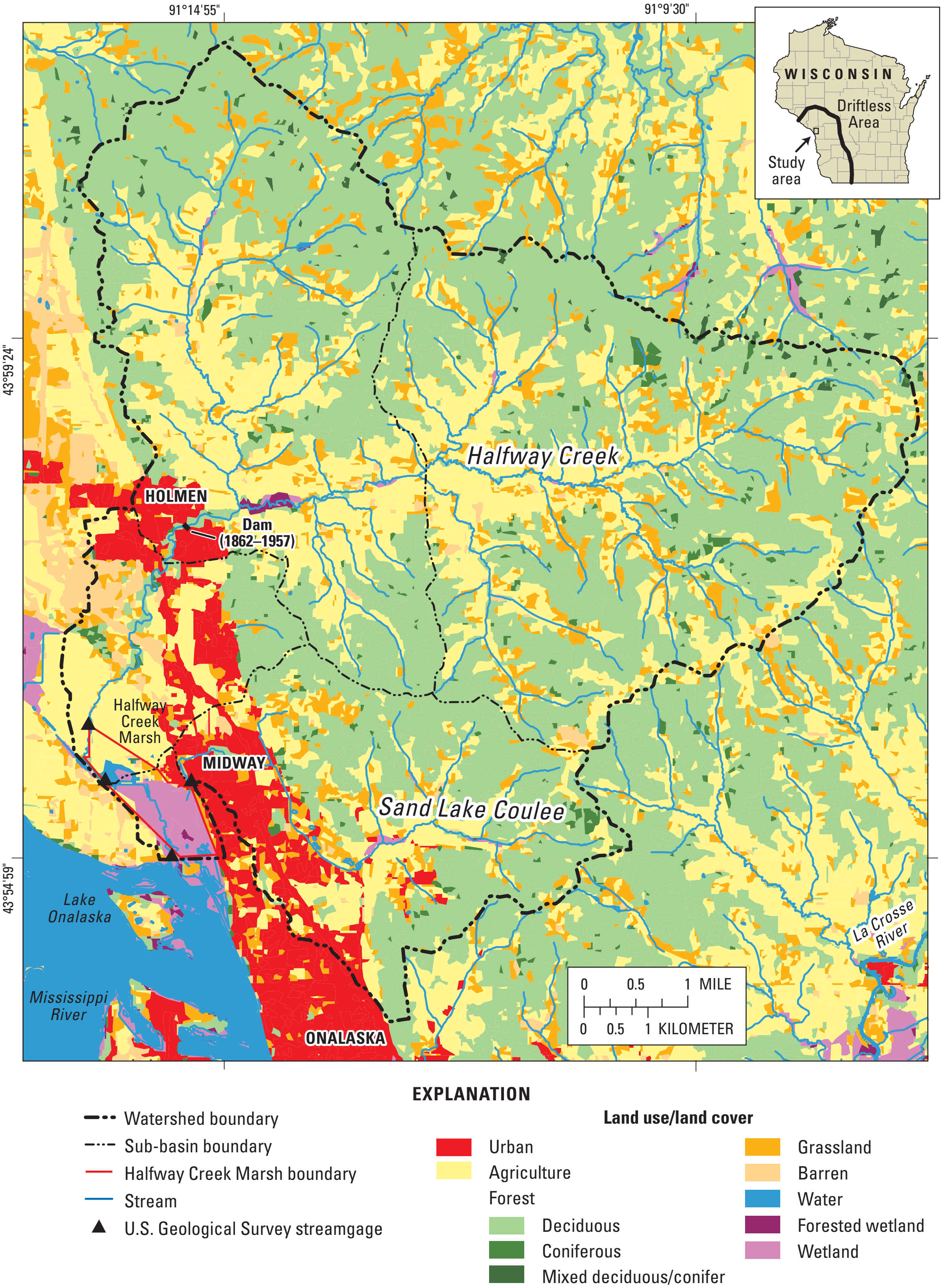
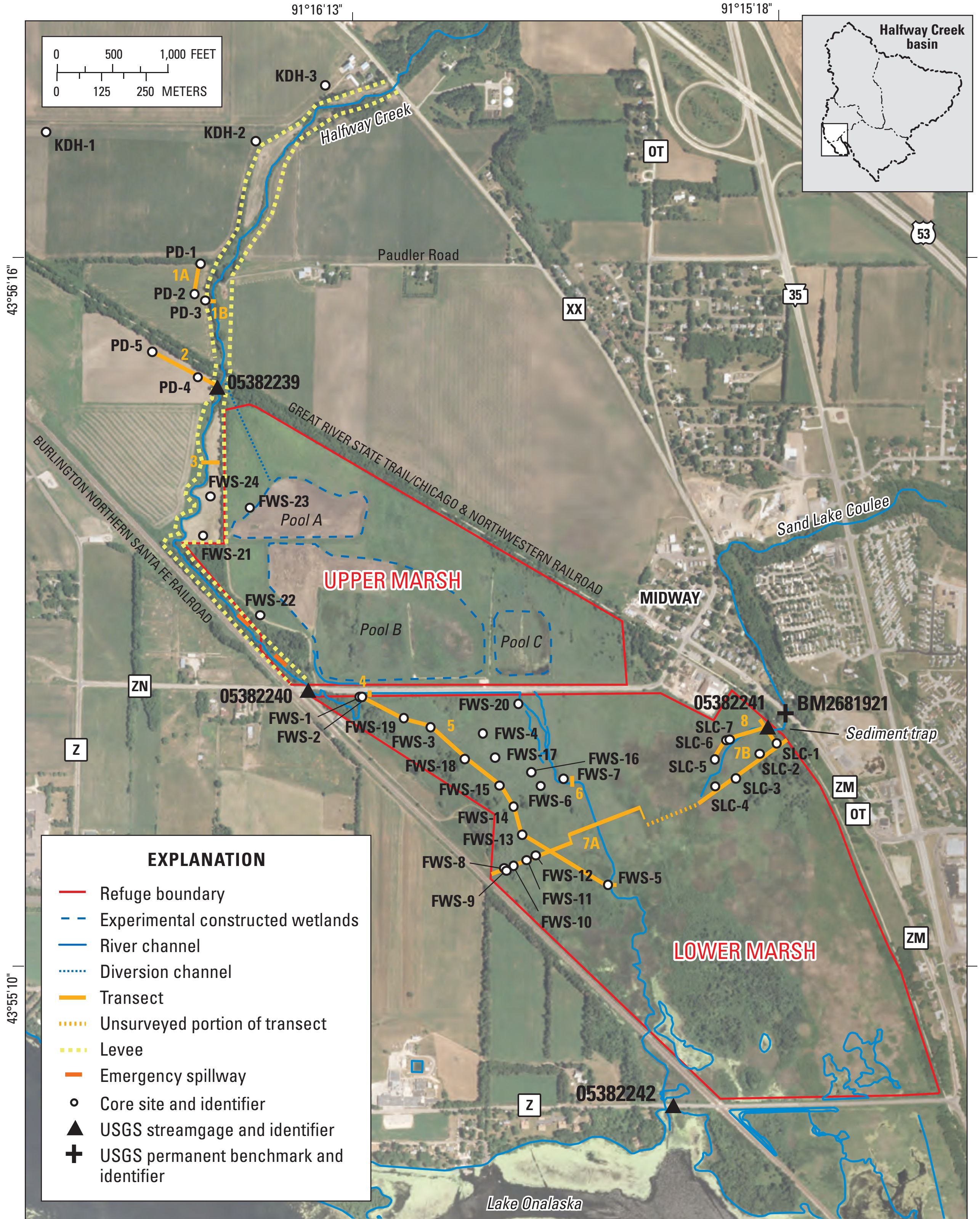


Figure 1A. Location, land cover, and watershed boundaries for Halfway Creek Marsh, Wis. (Reese and others, 2002).



Base from U.S. Department of Agriculture, 2005.

Figure 1B. Core site locations and U.S. Geological Survey (USGS) streamgages near the Upper Mississippi River National Wildlife and Fish Refuge, Halfway Creek Marsh, Wis.

historically had less agricultural disturbance. Halfway Creek and Sand Lake Coulee have channelized reaches and drainage modifications in the upper and lower marsh. Halfway Creek has levees through the upper marsh as part of a historical flood-control project.

Flooding, sedimentation, and nutrient enrichment problems have been extensive along Halfway Creek and Sand Lake Coulee and in the marsh since the beginning of Euro-American agriculture in the watershed. Further flooding and sedimentation problems were caused by dam construction and subsequent dam failure in Holmen, construction of artificial levees between County Highways XX and ZN, and the constructed extension of drainage from Sand Lake Coulee into the marsh (figs. 1A–B). Since the late 1800s, channels of Halfway Creek and Sand Lake Coulee have been modified and dredged in and near the marsh to alleviate flooding and sedimentation problems. Sedimentation in the channels where they enter the marsh has caused floodwaters to exceed channel capacities and flood residential areas in and near Midway. Increased expansion of residential areas in the two watersheds started in the 1990s and may contribute to additional flooding and sedimentation problems in the marsh.

Reduction of runoff-related nutrients into the marsh and Lake Onalaska is the focus of a cooperative research study among the U.S. Environmental Protection Agency (USEPA), USFWS, the U.S. Geological Survey (USGS), Ducks Unlimited, and other partners (U.S. Fish and Wildlife Service, 2000). Three experimental constructed wetlands (shown as Pools A–C on fig. 1B), including an inlet structure and a diversion channel, were constructed in 1999–2000 in the upper marsh to capture runoff, sediment, and nutrients before they enter the lower marsh and to restore, enhance, and preserve wetland and upland habitat, especially for migratory birds (fig. 1B). Suspended sediment concentrations currently (2006) are monitored at three USGS streamgages (fig. 1B). Scientists from the USGS office in La Crosse, Wis., are monitoring sedimentation rates and nutrient loadings into the three detention-sedimentation basins in the upper marsh.

The USEPA and USFWS are interested in the extent of historical sedimentation in the marsh and the relative inputs of sediment from the Halfway Creek and Sand Lake Coulee. Specific questions asked by the USEPA and USFWS include:

1. What is the extent and character of historical sand deposition in the marsh and can the sand be removed and used for landscaping/fill?
2. Will the channel of Halfway Creek stabilize through the lower marsh?
3. Are more sediment traps needed along Halfway Creek in the upper marsh?
4. Given the rate of sediment deposition, is it worthwhile to improve wetland habitat in the lower marsh?
5. Will sediment deposition rates remain relatively constant in the marsh over the next 50 years?

The general objectives of the present study were to describe sedimentation patterns and character, to estimate rates of historical sediment deposition, and to document how sediment deposition on the flood plain and marsh in recent years (2004–06) compares to that in past times (historical compared to natural and recent compared to long-term historical). This study was initiated in 2005 and was done in cooperation with USEPA. The results will be used to place the last few years of suspended-sediment-load data collected as part of related studies into an historical context. The information will be used by resource managers for future management, protection, rehabilitation, and monitoring decisions for Halfway Creek Marsh.

Purpose and Scope

The principal purpose of this report is to describe the sedimentation history of Halfway Creek Marsh in and near the Upper Mississippi River National Wildlife and Fish Refuge. The report contains a compilation of historical human activities and floods that affected channel morphology and sediment movement and character from about 1846 (beginning of Euro-American agricultural settlement) through 2006 (time of USGS coring and surveying). Historical sedimentation patterns and rates were reconstructed from cores and topographic surveys of Halfway Creek and surrounding flood plains, wetlands, and levees. The potential causes for temporal and spatial variations in sedimentation are described in terms of documented human disturbances primarily during 1846–2006.

Description of Study Area

Halfway Creek Marsh is in a tributary bottomland of the Mississippi River west and south of Midway, Wis., and is fed mainly by Halfway Creek (watershed of 36 mi^2) from the north and east and secondarily by Sand Lake Coulee from the east (watershed of 8 mi^2) (fig. 1A). The watersheds drain lands including the communities of Midway, Holmen, and parts of Onalaska. The marsh is located along the western edge of the Driftless Area, a region in southwest Wisconsin that was not glaciated.

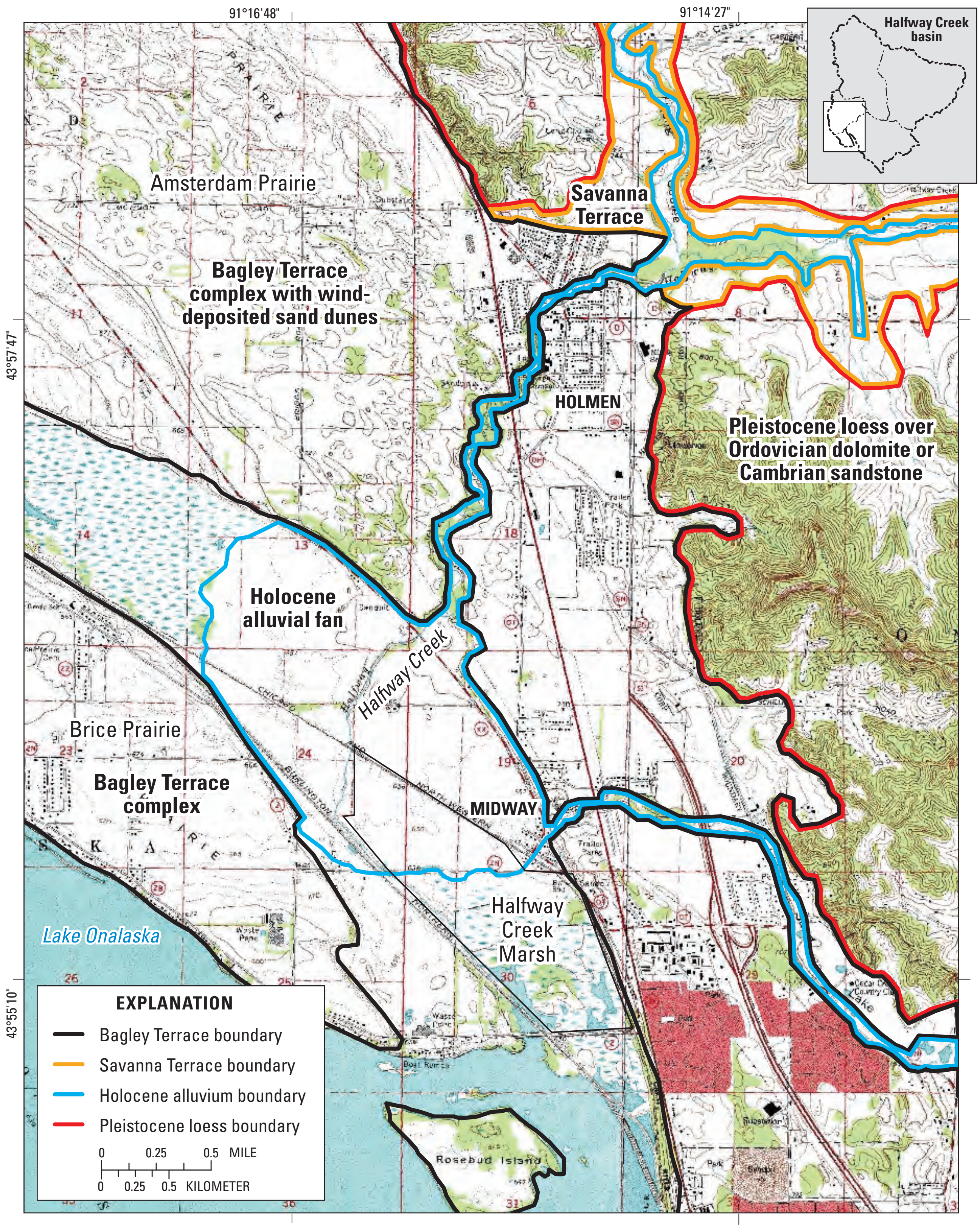
The watersheds of Halfway Creek and Sand Lake Coulee are characterized by moderate to steep, forested slopes separated by relatively flat, narrow, agricultural uplands (fig. 1A). Land cover in the combined watersheds is 49 percent forest, 32 percent agriculture (mostly row crops with some hay crops), 10 percent grassland/pasture, 6 percent urban, 2 percent barren, and 1 percent wetland (Reese and others, 2002). Developed areas are mainly near Midway and Holmen, but residential areas extend along highways that connect Midway to Onalaska to the south of Sand Lake Coulee (fig. 1A). In 1995, Halfway Creek watershed was 5 percent urban land and Sand Lake Coulee watershed was 22 percent urban land (Vierbicher Associates, Inc., 1995). Vierbicher Associates, Inc., (1995) projected a growth of urban land to over 20 percent in Halfway Creek and over 40 percent in Sand Lake Coulee watersheds by 2015. Biotic integrity has been shown to decrease in Wisconsin streams with greater than 10–20 percent watershed urban land (Wang and others, 1997), suggesting Sand Lake Coulee and eventually Halfway Creek may have aquatic communities affected by urbanization. For the Onalaska area, Vierbicher Associates, Inc., (1995) predicted an increase in channel cross-section area from 2 to 4 times to accommodate runoff from added impervious areas.

Annual sediment loads in 1995 were estimated by use of a sediment transport model, which projected an annual yield of 39,100 yd^3 (50,200 tons, assuming 1 yd^3 equals approximately 1.33 tons) for Halfway Creek and 3,400 yd^3 (4,500 tons) for Sand Lake Coulee (Vierbicher Associates, Inc., 1995). These estimates indicate that sediment yields per acre from Halfway Creek were more than 2 times those from Sand Lake Coulee (2.20 and 0.87 ton/acre/yr, respectively). Cultivated subwatersheds in steep bluff tributaries in the western part of the Halfway Creek watershed and near the lower main stem of Halfway Creek (near Holmen and downstream) were estimated to contribute the most sediment per unit area (between 2 to 5 ton/acre/yr).

The longitudinal profile of Halfway Creek from its headwaters to its mouth has a concave-up profile, typical of most natural river systems, and most of its lower course is developed on deep alluvial fill (fig. 1C and fig. 2). There is a slight steepening of the profile in Holmen as the stream leaves the headwater reach confined by the valley bluffs and enters a reach that is incised into a terrace underlain by late Pleistocene sand and sandy gravels. The profile flattens again as Halfway Creek exits the western edge of the terrace and passes across a Holocene (postglacial) alluvial fan developed on a lower surface that is adjusted to the Upper Mississippi River flood plain (fig. 2). Another slight steepening of slope near the stream crossing with County Highway ZN continues into the lower marsh. This steepening is likely a result of human activities involving channel straightening and relocation. Based on 7.5-minute topographic map contours, the average slope of Halfway Creek downstream from the Holmen Dam to County Highway ZN is 0.14 percent and is slightly steeper (0.34 percent) downstream from County Highway ZN to its mouth.

Surficial deposits in the watersheds of Halfway Creek and Sand Lake Coulee are a reflection of bedrock geology and Pleistocene loess (wind-blown silt) (Knox, 1985) (fig. 1C). Bedrock is mainly Ordovician dolomite on upland drainage divides and Cambrian sandstone along hillslopes (Evans, 2003). The physical characteristics of Halfway Creek Marsh and the immediate surrounding area show the effects of transport of water and sediment by the Mississippi River and its major aggradation with sand and gravel during the last continental glacial advance into northern Wisconsin and Minnesota. Side-valley tributaries, such as Halfway Creek and Sand Lake Coulee, also aggraded their lower reaches when the aggrading Mississippi River raised the base level at mouths of tributaries, which resulted in deposition of fine sediments, including major amounts of silt and clay (Knox, 1985). The fine-grained sediments reflect sediment deposition in relatively low-energy slackwater ponds that formed at and near tributary valley mouth locations when the Mississippi River was aggrading, and they also include silt and clay derived from erosion of loess from the surrounding uplands. Loess, which locally consists of 65–75 percent silt, 15–25 percent clay, and minor amounts of sand, was initially transported by strong glacial-age winds blowing across exposed river bars and onto the uplands. A relatively treeless tundra environment prevailed in southwestern Wisconsin during the last glacial maximum, and this condition favored intensive downslope movement of sediments, including recently deposited loess (Mason and Knox, 1997). Much of this gravity-transported sediment accumulated on lower hillslopes, but significant amounts also were transported downvalley and were redeposited in low-energy slackwater environments.

The level of Mississippi River aggradation by the end of the last glacial period reached an altitude of approximately 750 ft in the Halfway Creek Marsh area, whereas the modern low-water stage of the Mississippi River is



Base compiled from U.S. Geological Survey 7.5-minute topographic maps, 1990, Holmen and Onalaska quadrangles.

Figure 1C. Generalized geologic map of Halfway Creek Marsh, Wis. and surrounding area (modified from Evans, 2003).

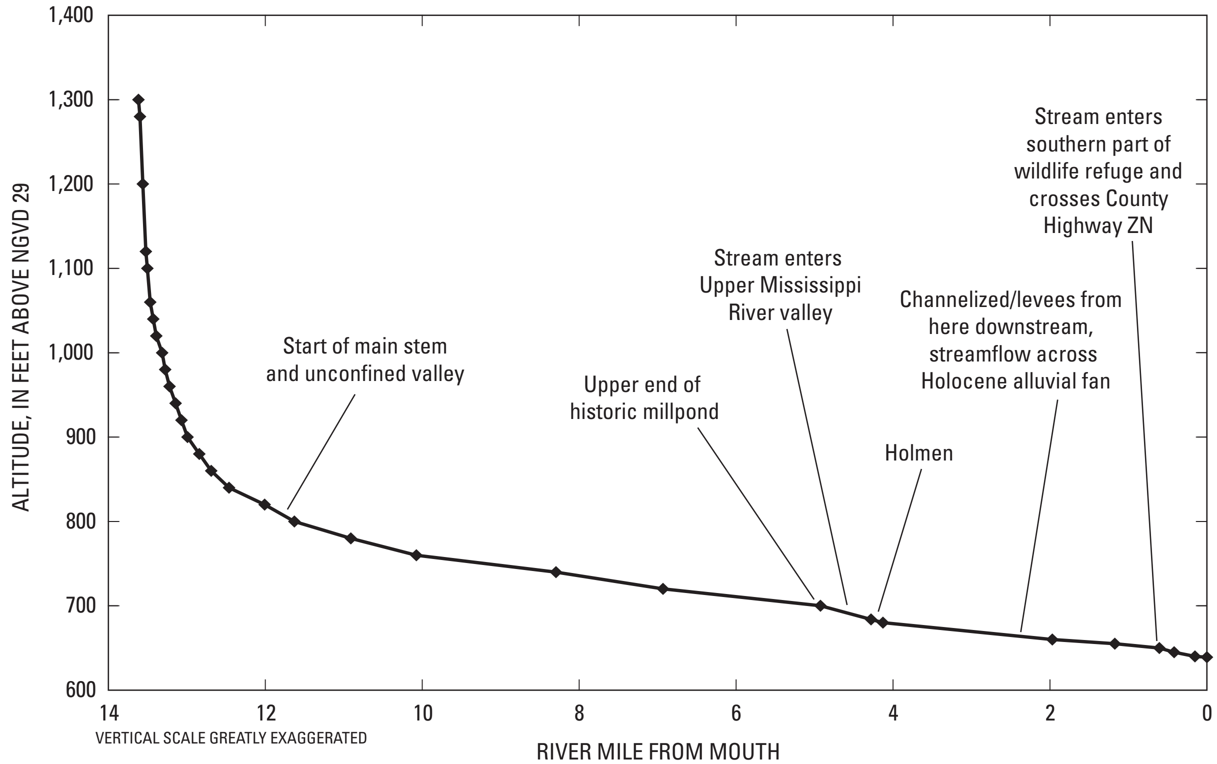


Figure 2. Longitudinal profile of Halfway Creek, Wis., from its headwaters to mouth.

about 640 ft in the same area. Following glacial ice retreat in northern Wisconsin and Minnesota about 16,000 years ago, Mississippi River flows with lower sediment loads—sometimes associated with extreme floods resulting from outlet failures of lakes that had formed along the retreating ice margin—led to relatively abrupt incision of the sand and gravel valley fill (Knox, 1999). The deep incision produced a sequence of terraces (fig. 1C). The Savanna Terrace represents remnants of the former maximum level of aggradation, but erosion removed most of this surface except in protected side valleys such as Halfway Creek, east of Holmen. Two prominent cut-terraces, known as the Bagley Terrace complex, are at altitudes of about 720 ft and 665 in the Holmen-Halfway Creek area. The upper terrace contains wind-deposited sand dunes that range between about 5 and 20 ft in thickness. The Bagley Terrace is underlain by thick deposits of sand and gravel into which Halfway Creek has incised its course between Holmen and County Highway XX. A well near the northwest edge of Holmen (NW1/4 sec. 7, T. 17 N., R. 7 W.) penetrated 150 ft of sand and gravel without reaching bedrock. This implies that the bedrock floor of the Mississippi River valley is below an altitude of 570 ft at this location. A well less than a mile west of the lower marsh (SW1/4, sec. 30, T. 17 N., R. 17 N.) penetrated the bedrock valley floor at 510 ft. Drill cores collected for the U.S. Army Corps of Engineers during construction of Lock and Dam No. 7 (located on the Mississippi River at Onalaska) indicate that incision of the alluvial fill at the late-glacial to postglacial transition probably extended to a depth of 170 ft below the Savanna Terrace top of maximum late-glacial alluviation (Brown, 1931). This depth equates to an altitude of about 580 ft, which is about 70 ft above the bedrock surface of the valley floor. The sand and gravel sediments underlying the Bagley Terrace complex are a potential source of coarse-grained substrate and bedload for Halfway Creek through the marsh. In addition, easily eroded loess (mainly silt), a principal soil parent material of agricultural fields, is a potential major source of suspended load.

Halfway Creek flows across a Holocene-age alluvial fan that is particularly prominent along the reach of channel from County Highway XX at the edge of the Bagley Terrace scarp to County Highway ZN at the entrance to the lower marsh (fig. 1C). The alluvial fan began to develop immediately after an extreme late-glacial-age Mississippi River flood caused by outlet failure of an ice-marginal lake incised the low linear depression between Brice Prairie and the Bagley Terrace (Knox, 1999) (fig. 1C). Subsequently, water and sediment confined by the deep, narrow valley containing Halfway Creek on its course across the Bagley Terrace downstream from Holmen were able to fan out on entry into the lowland beginning in the County Highway XX location, just as water and sediment did during the historical period of Euro-American agriculture until confined by artificial levees along the channel on the fan. A basal radiocarbon age of about 16,000 years ago in conjunction with sequential layers of overlying alluvial sediments indicate that that the fan accumulated progressively throughout the past 16,000 years (Knox, 1999).

Methods

Mapping Historical Channel Locations

The location and proximity of historical stream channels through the upper and lower marsh were important to document to adequately describe overbank sedimentation patterns, rates, and processes. Six historical maps and one set of aerial photographs, all available digitally, were used to reconstruct historical channel changes of Halfway Creek and Sand Lake Coulee in the vicinity of the marsh. The digital maps were georeferenced with a geographic information system by use of a second-order polynomial transformation, with as many section intersections matched for control points as were present on the original maps. When possible, a minimum of 8–12 control points was used to minimize error in georeferencing (Hughes and others, 2006). Low root-mean-square errors and visual checks indicated that the maps were aligned reasonably (M.C. Peppler, U.S. Geological Survey, written commun., 2006).

Three maps were used for interpretation of channel locations around the time of Euro-American settlement: field notes and maps from the 1846 public land survey records (Wisconsin Board of Commissioners of Public Lands, 1846), an 1866 map from the G.K. Warren surveys of the Mississippi River (Warren, 1867), and an 1878 plat map (Snyder, Van Vechten & Co., 1878). Accuracy of the georeferencing for the 1866 map was limited because only five control points were available on the map. In addition, the 1878 plat map was of low resolution, and georeferencing was not as accurate as the other maps; therefore, the channel location was more coarsely defined.

Twentieth century channel locations were described by a 1906 plat map (Ogle, 1906), land economic inventory maps (Bordner Surveys) for La Crosse County from 1937–38 (Wisconsin Department of Agriculture and Wisconsin Geological and Natural History Survey, 1938), 1973 USGS 7.5-minute topographic quadrangle maps, and 2005 aerial photographs (U.S. Department of Agriculture, 2005). The resolution of channel locations improved over time as mapping resolution improved. In addition, U.S. Department of Agriculture aerial photographs from 1938–40, 1956, 1997, and 2002 were used to supplement the main maps and aerial photographs to compare historical and current channel and riparian conditions.

Transect Surveys and Sediment Coring

Data collected from transect surveys and sediment coring of the upper and lower marsh were used to estimate historical sedimentation patterns and rates, using techniques described by Happ and others (1940), Knox (1987), Fitzpatrick and others (1999), Fitzpatrick (2005), Vanoni (2006), and Knox (2006). Historical overbank deposits since the beginning of Euro-American settlement in the Driftless Area tend to be more sandy, lighter in color, and less compacted compared to presettlement deposits. Also, they have more prominent stratified bedding and are lacking soil development compared to presettlement deposits (Knox, 1987). Coring and surveying were done from September 2005 to March 2006, except that cores KDH-1 through KDH-3 were previously collected by James Knox in 1996 (fig. 1B). Transects were surveyed across modern and historic channels, alluvial fans, flood plains, and levee splays. Land-surface and core altitudes were surveyed by use of an electronic theodolite and tied into a Department of Transportation benchmark BM2681921 at Sand Lake Coulee bridge crossing on County Highway O (fig. 1B).

The thickness and texture of historical sediment were examined by collecting cores near transect lines with two devices, a 1-in.-diameter handheld soil probe and a geoprobe (fig. 1B; table 1). The hand-held soil probe was useful for quick exploratory coring and field-based descriptions. The geoprobe (2-in. diameter) is a hydraulic tapping-type coring device mounted on a four-wheel all-terrain vehicle and was used to collect cores for more detailed descriptions of alluvial deposits, for archiving, and for subsampling. Cores were to be collected in the lower marsh near County Highway Z during winter; however, the ground surface of the lower marsh did not adequately freeze during the unusually warm winter in 2005–06, precluding collection of cores there. A global positioning system was used to verify the location of each transect and core.

Table 1. Summary of locations, depths, types, and sample analyses of cores collected near Halfway Creek Marsh, Wis.

[--, not applicable; mm/dd/yyyy, month/day/year; altitude, in feet above NGVD 29; core depth is from land surface]

Core	Date collected (mm/dd/yyyy)	Location		Type of core	Description	Land surface altitude (feet)	Core depth (feet)	Depth to dark, organic-rich soil (feet)
		Latitude	Longitude					
PD-1	09/06/2005	43°56'15"	91°16'33.9"	Hand core	Halfway Creek, field west of levee	660.4	11	5.8
PD-2	09/06/2005	43°56'12.2"	91°16'34.6"	Hand core	Halfway Creek, field west of levee	659.9	11.3	5.6
PD-3	09/06/2005	43°56'11.6"	91°16'33.2"	Hand core	Halfway Creek, field west of levee	658.8	8	5.6
PD-4	09/06/2005	43°56'4.5"	91°16'34.6"	Hand core	Halfway Creek, field west of levee	653.9	8.8	3.5
PD-5	09/06/2005	43°56'6.8"	91°16'39.9"	Hand core	Halfway Creek, field west of levee	650.9	8	3.7
SLC-1	09/14/2006	43°55'31.5"	91°15'19.3"	Hand core	Sand Lake Coulee, alluvial fan	647.9	10.5	8.5
SLC-2	09/14/2005	43°55'30.5"	91°15'21.5"	Hand core	Sand Lake Coulee, alluvial fan	645.3	10.5	6.4
SLC-3	09/14/2005	43°55'28.2"	91°15'24.5"	Hand core	Sand Lake Coulee, alluvial fan	643.3	8	2.0
SLC-4	09/14/2005	43°55'27.4"	91°15'27.1"	Hand core	Sand Lake Coulee, edge of alluvial fan	642.2	8	1.0
SLC-5	09/14/2005	43°55'29.9"	91°15'27.2"	Hand core	Sand Lake Coulee, old channel	643.2	6	1.5
SLC-6	09/14/2005	43°55'31.7"	91°15'25.8"	Hand core	Sand Lake Coulee, old channel	644.0	6	1.0
SLC-7	09/14/2005	43°55'31.7"	91°15'25.8"	Hand core	Sand Lake Coulee, 20 feet south of SLC-6	644.2	3.5	3.0
FWS-1	10/11/2005	43°55'35.2"	91°16'12.7"	Hand core	Halfway Creek, south of Cty Rd ZN	649.0	2.5	2.5
FWS-2	10/11/2005	43°55'35.2"	91°16'12.4"	Hand core	Halfway Creek, south of Cty Rd ZN	648.5	13.3	6.7
FWS-3	10/11/2005	43°55'32.5"	91°16'3.6"	Hand core	Halfway Creek, south of Cty Rd ZN	645.1	8	4.5
FWS-4	10/11/2005	43°55'32"	91°15'56.9"	Hand core	Halfway Creek, south of Cty Rd ZN	645.4	6	2.6
FWS-5	11/29/2005	43°55'18.2"	91°15'40.6"	Hand core	Halfway Creek, lower wetland	641.5	8	2.8
FWS-6	11/29/2005	43°55'27.2"	91°15'49.4"	Hand core	Halfway Creek, refuge	642.7	6	2.0
FWS-7	11/29/2005	43°55'27.9"	91°15'46.5"	Hand core	Halfway Creek, refuge	642.9	9	1.0
FWS-8	11/29/2005	43°55'19.4"	91°15'53.7"	Hand core	Halfway Creek, refuge	642.5	15.5	1.9
FWS-9	02/27/2006	43°55'19.3"	91°15'53.6"	Geoprobe	Halfway Creek, wetland east of railroad	642.5	24	1.5
FWS-10	02/27/2006	43°55'19.8"	91°15'52.7"	Geoprobe	Halfway Creek, wetland east of railroad	642.9	16	--
FWS-11	02/27/2006	43°55'20.3"	91°15'51.1"	Geoprobe	Halfway Creek, wetland east of railroad	642.7	20	2.1
FWS-12	02/27/2006	43°55'20.8"	91°15'49.9"	Geoprobe	Halfway Creek, wetland east of railroad	642.5	12	1.7
FWS-13	02/27/2006	43°55'22.7"	91°15'51.7"	Geoprobe	Halfway Creek, old distributary channel	642.9	12	2.4
FWS-14	02/27/2006	43°55'25.3"	91°15'52.8"	Geoprobe	Halfway Creek, old distributary channel	644.1	16	4.0
FWS-15	02/28/2006	43°55'27.2"	91°15'54.7"	Geoprobe	Halfway Creek, old distributary channel	644.4	16	4.0

Table 1. Summary of locations, depths, types, and sample analyses of cores collected near Halfway Creek Marsh, Wis.—Continued.

[--, not applicable; mm/dd/yyyy, month/day/year]

Core	Date collected (mm/dd/yyyy)	Location		Type of core	Description	Land surface altitude (feet)	Core depth (feet)	Depth to dark, organic-rich soil (feet)
		Latitude	Longitude					
FWS-16	2/28/2006	43°55'28.5"	91°15'50.6"	Geoprobe	West side of creek and fence line	643.0	12	1.9
FWS-16a	2/28/2006	43°55'28.5"	91°15'50.6"	Geoprobe	Duplicate of FWS-16	643.0	12	1.7
FWS-17	2/28/2006	43°55'29.8"	91°15'55.3"	Geoprobe	Halfway Creek, lower marsh	644.2	12	1.1
FWS-18	2/28/2006	43°55'29.6"	91°15'59.2"	Geoprobe	Halfway Creek, lower marsh	645.8	12	4.4
FWS-19	2/28/2006	43°55'33.3"	91°16'7"	Geoprobe	Halfway Creek, south of Cty Rd ZN	646.0	12	5.4
FWS-20	2/28/2006	43°55'34.8"	91°15'52.4"	Geoprobe	West side of Halfway Creek, 50 feet south of Cty Rd ZN	646.1	16	2.8
FWS-21	2/28/2006	43°55'49.9"	91°16'33.2"	Geoprobe	Halfway Creek, upper marsh, inside levee	652.6	16	5.8
FWS-22	2/28/2006	43°55'51.8"	91°16'27.7"	Geoprobe	Halfway Creek, upper marsh, outside levee	648.3	16	2.9
FWS-23	2/28/2006	43°55'52.5"	91°16'27.1"	Geoprobe	Halfway Creek, upper marsh, outside levee	648.9	16	3.6
FWS-24	2/28/2006	43°55'53.5"	91°16'32.2"	Geoprobe	Halfway Creek, upper marsh, inside levee	653.3	16	4.0
KDH-1	8/27/1996	43°56'26.9"	91°16'53.9"	Giddings	Halfway Creek, field west of levee	650.5	22	.0
KDH-2	8/27/1996	43°56'26.4"	91°16'27.4"	Giddings	Halfway Creek, field west of levee	660.0	38	1.5
KDH-3	8/28/1996	43°56'31.6"	91°16'18.7"	Giddings	Halfway Creek, field west of levee	665.0	80	.0

All cores were described for texture, color, compaction, structure, and soil development in the field or laboratory using standard terminology of the U.S. Department of Agriculture (Munsell Color, 1975; Soil Survey Staff, 1951). Field grading of texture was done by rubbing soil between the fingers (Milfred and others, 1967). Recovery ratios (length of extracted core compared to penetration depth) were recorded for all coring devices. Sediment samples from a subset of cores (FWS-15, FWS-18, and FWS-21) were analyzed for particle size and radiometric dating.

Buried soils are commonly found in flood-plain deposits and can be good indicators of flood-plain surface stability. Buried soils in this context represent older flood-plain surfaces (Happ and others, 1940; Birkland, 1984; Retallick, 1985). In general, modern flood-plain soils are usually poorly developed because of the possibility for a fast rate of burial, high water table, and anthropogenic disturbance. Many buried flood-plain surfaces show incipient A-horizon development or only a thin layer of organic matter and remnants of vegetation. The A horizon is a dark zone at the surface of the soil caused by accumulation of decomposing organic matter. The buried flood-plain surfaces can be recognized by one or more of the following characteristics: presence of an A horizon; organic matter accumulation from flood-plain or wetland vegetation; lateral extent of a buried surface that is parallel to the land surface and that may truncate geologic bedding; root traces; and soil structure (Birkland, 1984; Retallick, 1985). Sometimes, part of a buried soil may be removed by scour activity associated with flooding, channel migration, or channel avulsion.

Laboratory Analysis for Cesium-137 and Particle Size

Three cores from the upper and lower marsh were selected for further quantification of particle size and historical deposition rates through radiometric dating. Subsamples from cores FWS-18 and FWS-21 were submitted to the Wisconsin State Laboratory of Hygiene, Madison, Wis. for cesium-137 (^{137}Cs) analysis. Concentrations of ^{137}Cs were determined from direct gamma counting by use of an ultralow-background intrinsic germanium semiplanar detector coupled to a multichannel analyzer (Schelske and others, 1994). Detector efficiency was determined as a function of both sample geometry and sample weight. Cesium-137 was first detected in 1945, and in 1952 the first increase in atmospheric fallout happened in the Northern Hemisphere, corresponding to increased nuclear weapons testing (Krishnaswami and Lal, 1978; Anderson and others, 1987). In 1960, there was a minimum, followed by a maximum in 1963. With the signing of the Nuclear Test Ban treaty in 1963, atmospheric contributions dropped substantially. A date of 1963 was assigned to the sample with the highest ^{137}Cs activity, and average sedimentation rates were determined for the years 1963 through 2006 (time of core collection). Linear sedimentation rates were calculated for the time periods 1860–1963 and 1963–2006, assuming the year 1860 represented the pre-Euro-American settlement marsh or flood-plain surface.

Subsamples of cores FWS-15 and FWS-21 were analyzed for particle size (sand and silt-clay composition) at the USGS Kentucky Water Science Center Sediment Laboratory in Louisville, Ky. There was not enough material left in core FWS-18 for particle-size analysis after subsampling for ^{137}Cs, so a nearby core, FWS-15, with similar deposition history was subsampled as a surrogate for FWS-18.

Historical Sedimentation Loads and Rates

Data on the degree of soil development and texture variations determined from sediment cores from the upper and lower marsh, in combination with radiometric results, reconstruction of historical channel locations, and known dates for human activities (such as artificial levee construction), were used to develop overbank sedimentation patterns and thickness for six historical time periods. Volume of overbank sediment (area × depth) was converted to tons by a conversion factor of 1 yd^3 = 1.33 tons, which is equivalent to the conversion factor used by Vierbicher Associates, Inc., (1995) for ease of comparison. Overbank sediment thickness from individual cores was averaged for cores within similar geomorphic settings and history of human disturbance. Relative comparisons were made for order-of-magnitude differences in overbank sedimentation volumes, rates, and loads.

Human Activities near Halfway Creek Marsh (1846–2006)

Human activities have affected Halfway Creek Marsh beginning with Euro-American settlement of the area in the 1850s and continuing into the 21st century. Activities that affected watershed runoff and sediment inputs are described as well as local activities such as dam building, stream crossings, and levee building. The time periods for the activities help to describe the timing and causes for changes in channel locations and overbank sedimentation patterns and rates.

1846–1866 (Settlement and Holmen Dam Construction)

Major settlement began in the Halfway Creek area in the early 1850s (Olson, 1962). By 1870, 96 percent of La Crosse County was settled (Wingate, 1975). The first land sales in La Crosse County were in 1848, but settlement was not permanent until 1851 in the Town of Onalaska (Renggly and others, 1881, p. 374, 715).

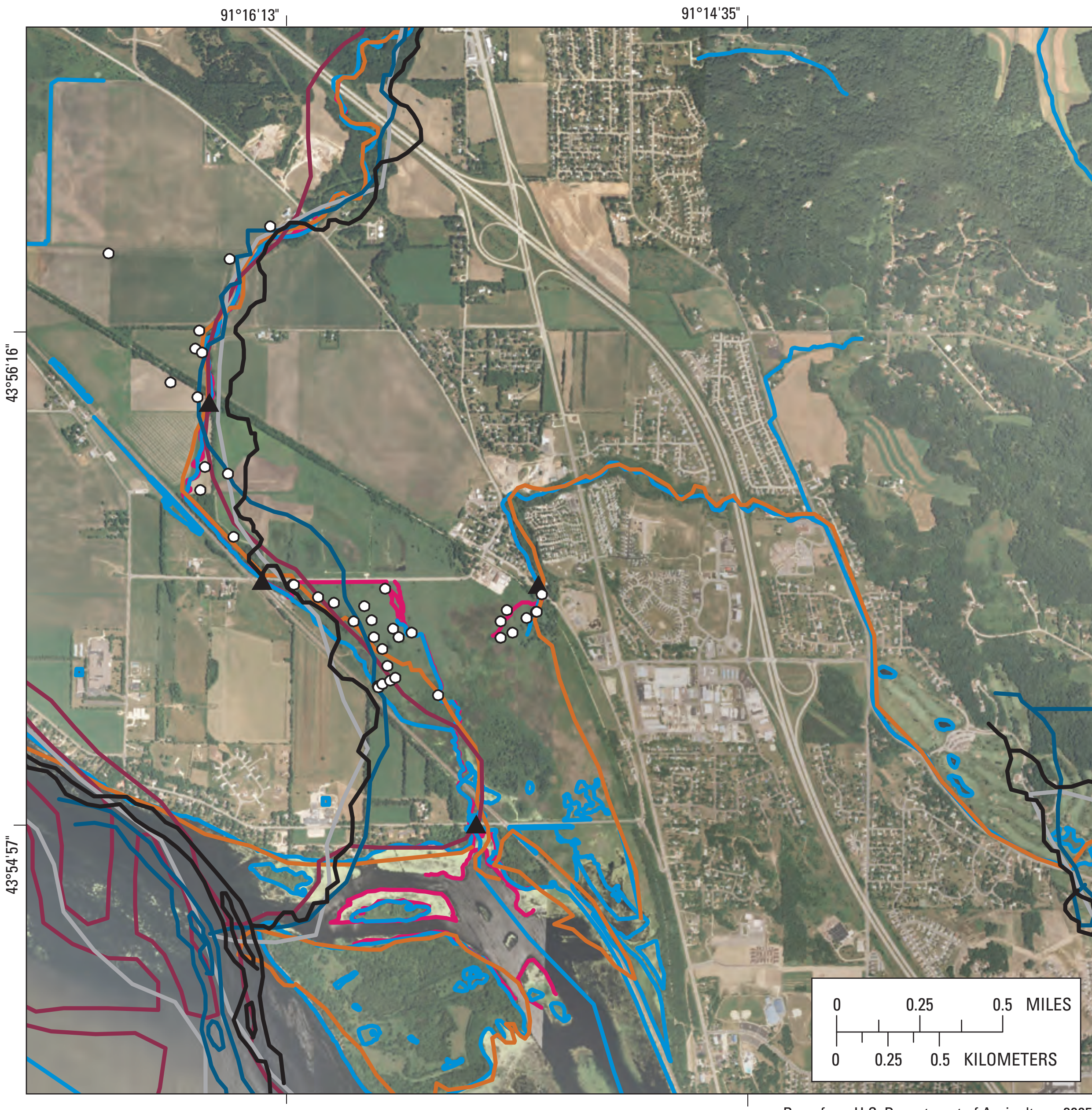
The 1846, 1866, and 1878 maps show the Halfway Creek location before and during Euro-American settlement and railroad building (fig. 3). Halfway Creek's most noticeable difference between the early maps and modern maps is the shift in location of the mouth of Halfway Creek. Before the installation of the Burlington and Northern Railroad (now known as the Burlington Northern Santa Fe Railroad) grade about 1886, the mouth of Halfway Creek was 0.35 mi west of its 2006 position (figs. 1B and 3). Halfway Creek flowed along the southern tip of Brice Prairie to join the Black River, which then flowed southerly along the west side of Brice Prairie (and currently enters the Mississippi River on the north side of Brice Prairie, about 5 miles upstream of the mouth of Halfway Creek). In Holmen, a dam and millpond were constructed on Halfway Creek in 1862 (Olson, 1962) (fig. 1A). This dam was known originally as Casberg's Dam but was later called Holmen Dam (fig. 4). Records of floods are scarce for this period, but a large flood on the Black River and its tributaries in the late 1840s (possibly 1849) caused damage to nearby areas that lasted for months afterward (Renggly and others, 1881, p. 372).

1867–1890 (Railroad Building and Channel Alterations)

The Chicago & Northwestern Railroad was built across Halfway Creek Marsh in 1867 to connect Onalaska, Wis., with Winona, Minn. (Renggly and others, 1881, p. 586–590). The Chicago, Burlington and Quincy Railroad Company constructed the rail line along the west side of Halfway Creek Marsh in 1886 (Railway and Locomotive Historical Society, Inc., 1937). The railroad was expanded to its present two-track configuration during 1900–37. The planform of Halfway Creek and the location of its mouth were likely changed during the construction of the Chicago, Burlington and Quincy Railroad in 1886 (fig. 3). The highway road network was more extensive than present during this time period as well. For example, Paudler Road extended across Halfway Creek in 1878, but by 1937 the bridge crossing and the road west of Halfway Creek were gone. Elsewhere, the 1878 plat map shows a road west of and adjacent to the Chicago & Northwestern Railroad grade from Midway south along the eastern margin of the lower marsh. This road was the precursor to modern County Highway ZM, which is now along the eastern side of the railroad grade. The same 1878 plat map shows that the channel draining Sand Lake Coulee terminated 1.5 mi upstream and southeast of Midway in sandy sediments that underlie the terrace on which Holmen is built. The Sand Lake Coulee channel was subsequently dredged to extend from its former terminus on the terrace to drain directly into Halfway Creek Marsh at Midway.

As agriculture and settlement expanded in the area, changes were made to Holmen Dam. Between 1871 and 1875 (the date is marked as 1871 on a photo and 1875 in the associated text), the first grain mill was constructed and a dam built at Holmen Pond (Olson, 1962). In 1876 the mill dam "went out" and was rebuilt (Olson, 1862). Notes from an 1876 dam inspection (Wisconsin Department of Natural Resources Dam Field File #32.02) indicate that the mill pond covered 22 acres. The 1878 plat map also shows a second mill on Halfway Creek on the northwest side of County Highway XX. No additional information was recovered about the duration and hydrologic significance of the second mill.

By 1875, the population of Holland Township was 863, and the population of Onalaska Township was 1,378. Wheat was the principal crop, and minor amounts of corn and oats also were produced (Butterfield, 1881, p. 253, 261). Farming practices associated with grain production made the soils especially prone to degradation and erosion (Johnson, 1991).



EXPLANATION

Historical channels

- 1846 (Wisconsin Board of Commissioners of Public Lands, 1846)
- 1866 (Warren, 1866)
- 1878 (Snyder, Van Vechten & Co., 1878)
- 1906 (Ogle, 1906)
- 1937–38 (Wisconsin Land Economic Inventory, 1938)
- 1973 (U.S. Geological Survey, 1978)
- 2005 (U.S. Department of Agriculture, 2005)

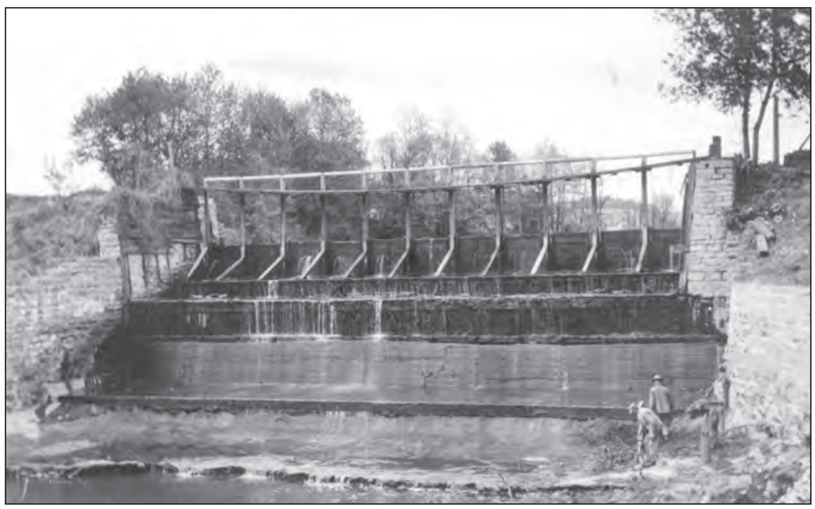
▲ U.S. Geological Survey streamgage

○ Core site location

Figure 3. Historical changes in Halfway Creek and Sand Lake Coulee channel locations, Halfway Creek Marsh, Wis.

Around 1890

1919



1937

Figure 4. Holmen Dam around 1890 (Olson, 1962), 1919, and 1937 (Wisconsin Department of Natural Resources Dam Field File #32.02).

1891–1929 (Floods, Dam Failure, Artificial Levees, and Establishment of the National Wildlife and Fish Refuge)

Gullying and soil erosion, caused by a combination of agriculture and floods, were common problems in the late 1800s and early 1900s (Knox, 2001). Heavy spring rains in 1892 and 1902, early in the growing season, may have contributed to expansion of gullies in tributaries to the Upper Mississippi River drainage in southwest Wisconsin (Knox, 2001). In June 1899, a large flood on Halfway Creek destroyed the Holmen Dam and a bridge and five barns near Holmen (Olson, 1962). The La Crosse weather station recorded 6.5 in. of rain during a 4-day period in June 1899, with more than 11.5 in. of rain for the month. Olson (1962) reported that the flood "washed away a large amount of ground and when the dam was built up again a large mill pond was in evidence." A photo looking east from the downtown shows the extent of erosion through the impoundment upstream of the dam caused by the flood (fig. 5). Dam-inspection notes indicate the dam was rebuilt in 1898 with a combination of concrete, timber, and earth. It is likely that the dam was rebuilt after it was washed out in the 1899 flood; it is not known if the date for the rebuilt dam should be 1899 or whether the dam was rebuilt two years in a row.

Although not documented, another large flood likely happened on Halfway Creek on October 28, 1900, when the nearby La Crosse weather station recorded a total of 7.23 in. of rain in a period of 22 hours, 18 minutes. This rainfall as of 2006 was the greatest amount of precipitation in a 24-hour period since weather records began in 1872 in La Crosse (E.J. Hopkins, Assistant State Climatologist for Wisconsin, oral commun., 2006). All of west-central Wisconsin was anomalously wet in October 1900. The total precipitation for the month of October 1900 in La Crosse was 12.09 in., whereas the annual precipitation normally ranges from 30 to 33 in. Furthermore, separate

Figure 5. Halfway Creek near Holmen, Wis., after the 1899 flood (Olson, 1962).

rainfalls of more than 5 in. in April 1896 and April 1909, plus more than 4 in. on May 7, 1902, and March 1913—all before land conservation methods were practiced in the watershed—undoubtedly contributed to the delivery of large amounts of sediment to Halfway Creek Marsh.

It seems most likely that the displacement of the lowermost reach of Halfway Creek from its more westerly position indicated on the GLO survey of 1846 and the U.S. Army Corps of Engineers G.K. Warren Survey of 1866 was related to the construction of the Chicago, Burlington and Quincy Railroad in 1886. By 1906, Halfway Creek was flowing in a relatively straight channel adjacent to the eastern side of the Chicago, Burlington and Quincy Railroad, and its exit from the marsh was near its modern position (fig. 3).

As noted above, the 1906 mouth of Sand Lake Coulee was not connected to Halfway Creek Marsh but ended near the valley bluff line of the Mississippi River (fig. 3), and County Highway ZM ran along the east side of the Chicago & Northwestern railroad, similar to its location in 2006. At some point in time between 1906 and 1937–38 (based on the Bordner Survey, 1937–38), the Sand Lake Coulee channel was extended into Halfway Creek Marsh (fig. 3). A straight channel was dug through Midway and then southward along the west side of the Chicago & Northwestern Railroad. This added 3.1 mi to the length of Sand Lake Coulee from the bluff line to its 2006 mouth location.

Dam inspection notes from 1919 (Wisconsin Department of Natural Resources Dam Field File #32.02) indicate the Holmen Dam was 69 ft wide and 13 ft high, and made out of concrete and timber (fig. 4). The mill pond covered 40 acres and had a maximum depth of 10 ft and 0.5 mi of backwater effects. The stream bottom was described as “blue clay.”

In the 1920s, large floods and controversial management of the Holmen Dam gates resulted in a lawsuit dispute that continued into the 1930s (Wisconsin Department of Natural Resources Dam Field File #32.02). A complaint filed in 1924 by the Onalaska Pickling Company (located about 2 mi downstream from the dam on County Highway XX) charged that damage to downstream farmlands resulted from mismanagement of the gates and dam by the mill operators. Notes from a 1929 dam inspection indicated that “the creek is very narrow and winding and flows by several high gravel banks.” The report further noted that “flood waters pick up sand and gravel and carry it down to the pickle farm and deposited this material on the flat lands.” The pickle company had previously constructed levees along both sides of Halfway Creek for about a mile along their properties in about 1919 (fig. 1B). The levees were overtopped and washed out during floods in 1925 and 1927. These are possibly representative of only one flood because the dates of the floods may have been misreported in the literature. The pickle-farm representative claimed that the gates of the dam were opened during the peak of the 1927 flood, thus artificially raising the flood peak downstream and causing the levee to fail. The mill operators claimed they opened the gates before the flood peaked and that it was just a really large flood. Another flood in 1929 washed out the dam’s gates. A subsequent dam inspection reported that the mill pond was filled with sediment and as a result had an average water depth of only 2 ft over 20–30 acres at normal stage. The case’s legal deposition indicated that there were several floods (some with ice damage) between the large 1899 flood and a 1931 hearing. The legal deposition notes from the 1924 complaint and 1931 hearing also report that farmers downstream from the dam were having problems with flooding and erosion prior to 1919.

The southern two-thirds of the lower marsh became part of the Upper Mississippi River National Wildlife and Fish Refuge which was established by an act of Congress in 1924. The refuge was established mainly from the efforts of the Izaak Walton League to preserve habitat for fish, migratory birds, plants, and other wildlife along a 261-mile corridor of the Upper Mississippi River from Rock Island, Illinois to Wabasha, Minnesota.

1930–1957 (Dam Failure and Construction of Lock and Dam Number 7)

Further changes to the Holmen Dam were made between 1931 and 1937. A 10-ft-wide taintor gate was added to the center of the Holmen Dam in 1935 (fig. 4). The water levels in the millpond increased by about 2 ft between 1931 and 1937. In 1937, the mill pond at Holmen was about 0.75 mi long and 150 ft wide, covering about 13.5 acres (Wisconsin Department of Agriculture and Wisconsin Geological and Natural Survey, 1938). The Holmen Dam washed out in 1957 (based on dam inspection notes) and was not replaced because by 1957 the mill was electric powered. In 2005, the authors found some remnant pieces of concrete and steel along Halfway Creek at the original site of the Holmen Dam.

During this period, wetland extended upstream of the Holmen millpond for at least 1 mi along the riparian corridor of Halfway Creek (Wisconsin Department of Agriculture and Wisconsin Geological and Natural Survey, 1938). From Holmen downstream to County Highway XX, the flood plain consisted of “swamp hardwoods.” Southwest of County Highway XX (as Halfway Creek flows out of its valley and onto its Holocene alluvial fan on the incised terrace of the Mississippi River), there was a narrow riparian zone of marsh that continued along Halfway Creek until its intersection with the Burlington Northern Santa Fe Railroad. The marsh widened downstream until near the present location of the constructed wetlands.

The Mississippi River Lock and Dam No. 7, located downstream from Halfway Creek near Onalaska, Wis. and La Crescent, Minn., was authorized in 1930 and completed in 1937. The normal low-water stage of the Mississippi River was raised about 6–7 ft following completion of Lock and Dam 7, and this led to an equal subsequent raising of the base level at the mouth of Halfway Creek Marsh (fig. 3). The U.S. Army Corps of Engineers purchased land along both sides of County Highway Z as part of the authorization in 1930. A rise of base level of this magnitude significantly reduced the stream energy gradient of the lowermost segment of Halfway Creek and favored increased sedimentation.

Sand Lake Coulee was connected to the lower marsh by 1938 as indicated by available mapping and photos (fig. 3). This connection was probably associated with flood-control activities and levee construction on Halfway Creek in 1919 and following years. A channel was dredged along the east side of the marsh to convey water from Sand Lake Coulee to its new outlet in Lake Onalaska. Based on the 1938 photos, the dredged channel subsequently filled with sediment and caused a new outlet to form along the northeast corner of the lower marsh.

1958–1993 (Wetland Ditching and Dredging)

After the flood of record in 1965 on the Mississippi River, the Halfway Creek bridge crossings along County Highway ZN were replaced with an earthen berm (James Nissen, U.S. Fish and Wildlife Service, oral commun., 2005). In the lower marsh south of County Highway ZN, sporadic ditching in the channels of Halfway Creek and Sand Lake Coulee was done in the 1970s–80s by a local landowner (fig. 3). No records were found to document the extent of the ditching or the amount of material removed from the channels. Ditches north of County Highway ZN were dug in 1975 to improve drainage in agricultural fields, and the last maintenance was done on these ditches in the 1980s (U.S. Fish and Wildlife Service, 2000). Parts of the drained marsh north of County Highway ZN were farmed as late as the 1990s (U.S. Fish and Wildlife Service, 2000). The USFWS purchased additional land for the refuge south of County Highway ZN in 1991.

In the early 1990s, Halfway Creek flowed along the north side of County Highway ZN (James Nissen, U.S. Fish and Wildlife Service, oral commun., 2005). In May 1993, the channel along the north side of County Highway ZN filled with sand, and the channel was moved to the south side of County Highway ZN. Flooding during June and July of 1993 caused high-water problems in the wetland area around the mouth of Halfway Creek, including Midway (Vierbicher Associates, Inc., 1995). During the 1993 flood, near the head of the marsh and along County Highway ZN, Halfway Creek had sand sedimentation problems (James Nissen, U.S. Fish and Wildlife Service, oral commun., 2005).

1994–2006 (Sand Traps and Constructed Wetlands)

After the 1993 flooding, drainage from Halfway Creek was enhanced; also, a sediment trap was constructed in Halfway Creek along the south side of County Highway ZN in January 1994 (fig. 3) (James Nissen, U.S. Fish and Wildlife Service, written commun., 2007). In 1994, sand was removed from the sediment trap three times (flooding on April 24–26 caused the need for more sand removal). From 1995–2004, sand was removed from the sediment trap approximately annually in the late fall/winter. Material was used as fill at various local construction sites. Other modifications in the mid-1990s included raising the roadbed elevation of County Highway ZN in response to numerous flooding and ice problems and construction of a pond between the Burlington Northern Railroad and the west boundary of the lower marsh. The USFWS purchased land north of County Highway ZN for the refuge in 1994–96.

A sand trap was constructed near the mouth of Sand Lake Coulee between County Highway OT and the Great River State Trail in 1992 (fig. 1B). This trap also was dredged approximately annually from 1994 to 2006 except in 1994, when it was dredged four times, and 1998 when it was dredged two times (James Nissen, U.S. Fish and Wildlife Service, written commun., 2007).

In 1999–2000, the USFWS constructed a 36-in.-diameter inlet structure, a diversion channel, and three experimental wetlands in the upper marsh to help keep the main burden of sediment and nutrients from reaching the lower marsh, and to enhance wildlife habitat, especially for migrating waterfowl and shorebirds (fig. 1B). Since 2004 through the time of the present investigation (2006), the USEPA and USGS have monitored sedimentation rates in the traps and suspended-sediment loads in Halfway Creek upstream and downstream from the diversion. Dikes were constructed around the traps, and additional water-control structures were installed at the southern ends of traps (U.S. Fish and Wildlife Service, 2000).

Sedimentation History (1846–2006)

Sedimentation history for Halfway Creek Marsh is described in terms of overbank sedimentation patterns and rates. In turn, discussion of subsequent adaptations of channel morphology management to sedimentation issues follows. Sedimentation patterns and rates are characterized for six periods: 1846–85, 1886–1918, 1919–36, 1937–69, 1970–93, and 1994–2006. Period breaks correspond to major changes in the rate and spatial extent of overbank sedimentation constrained by dates for available maps or aerial photographs that document channel location changes. The construction of the Chicago & Northwestern railroad across Halfway Creek Marsh in 1867 did not alter the location of Halfway Creek channel, but it did constrict the discharge of high-magnitude floods. However, construction of the Burlington and Northern Railroad in 1886 not only further constricted flood-plain connectivity along the upper marsh, but also involved shifting the location of lower Halfway Creek. In addition, introduction of artificial levees along Halfway Creek in the early 20th century, plus the construction of a channel in approximately 1919 that directly connected Sand Lake Coulee channel to the lower marsh, added further major hydrologic alterations. Lock and Dam No. 7 on the Mississippi River began operation in April 1937, resulting in flooding of the mouth of Halfway Creek by the impoundment. In turn, there was accelerated sedimentation in the lower reaches of Halfway Creek in response to an average base-level rise of about 5–6 ft at the mouth of the watershed caused by the impoundment of Pool 7. Halfway Creek's distributary channel system in the northwest corner of the lower marsh moved progressively eastward and southward as the existing channels and overbank areas accumulated sediment. There was additional channel relocation in 1993–94 when Halfway Creek's channel was moved to the lower marsh along the south side of County Highway ZN and a sediment trap was constructed to facilitate drainage and sand removal. A program of periodic sand removal also was instituted at about the same time for the Sand Lake Coulee channel where it enters the lower marsh.

Overbank Sedimentation Patterns and Estimated Rates

Descriptive information pertaining to sediment coring locations and types of coring are presented in figure 1B and table 1. These cores were the principal source of information for mapping the spatial extent, thickness, volume, and loads of historical overbank sedimentation for the six periods (listed in table 2) representing subareas along a reach of Halfway Creek from County Highway XX to its mouth and along Sand Lake Coulee in the lower marsh. Areas with overbank sedimentation for the six historical periods are shown in figures 6A–6E. The first two digits of the subarea identifier codes shown on figures 6A–6E and in table 2 identify the watershed (H for Halfway, S for Sand Lake Coulee) and the time period (1–6). For example, for period 1 (1846–1885), sedimentation rates were estimated for one large area (H1) that stretched along the length of Halfway Creek (fig. 6A). Sand Lake Coulee was not yet connected to the marsh. Geologic descriptions and transect-survey data representing the coring sites were used in conjunction with ^{137}Cs age controls for cores FWS-18 and FWS-21 to estimate sediment thickness and volumes for each period and subarea.

From 1846 to 1885, overbank sedimentation along Halfway Creek was not substantially constricted by railroads and artificial levees, and the mouth of the creek was at the far western side of the lower marsh, possibly about 0.3 mi west of its current location (fig. 6A). It was not until 1867 that the first railroad line was built across Halfway Creek. This railroad probably had its greatest effect during large floods, when modest backwater effects may have happened upstream from its crossing. Such backwaters may have modestly accelerated overbank flood-plain sedimentation immediately upstream from the constriction, but such effects were not detected in the sediment cores. Overbank sedimentation between 1846 and 1886 appears to have been minimal and is estimated to be only about 0.1 ft (table 2). Land-cover disturbance substantial enough to alter runoff and sediment yields from the watershed mainly happened after 1860 when agricultural development first became established. About 79 percent of La Crosse County was settled by 1860 (Wingate, 1975). Overbank sedimentation volume and rates are estimated to be about 36,000 yd^3 or 900 yd^3/yr for 1846–86. Sand Lake Coulee was not connected to the lower marsh at this time.

The year 1886 represents a benchmark for the beginning of the second sedimentation period. It was during this year that the Burlington and Northern Railroad reorganized the location of lowermost Halfway Creek during

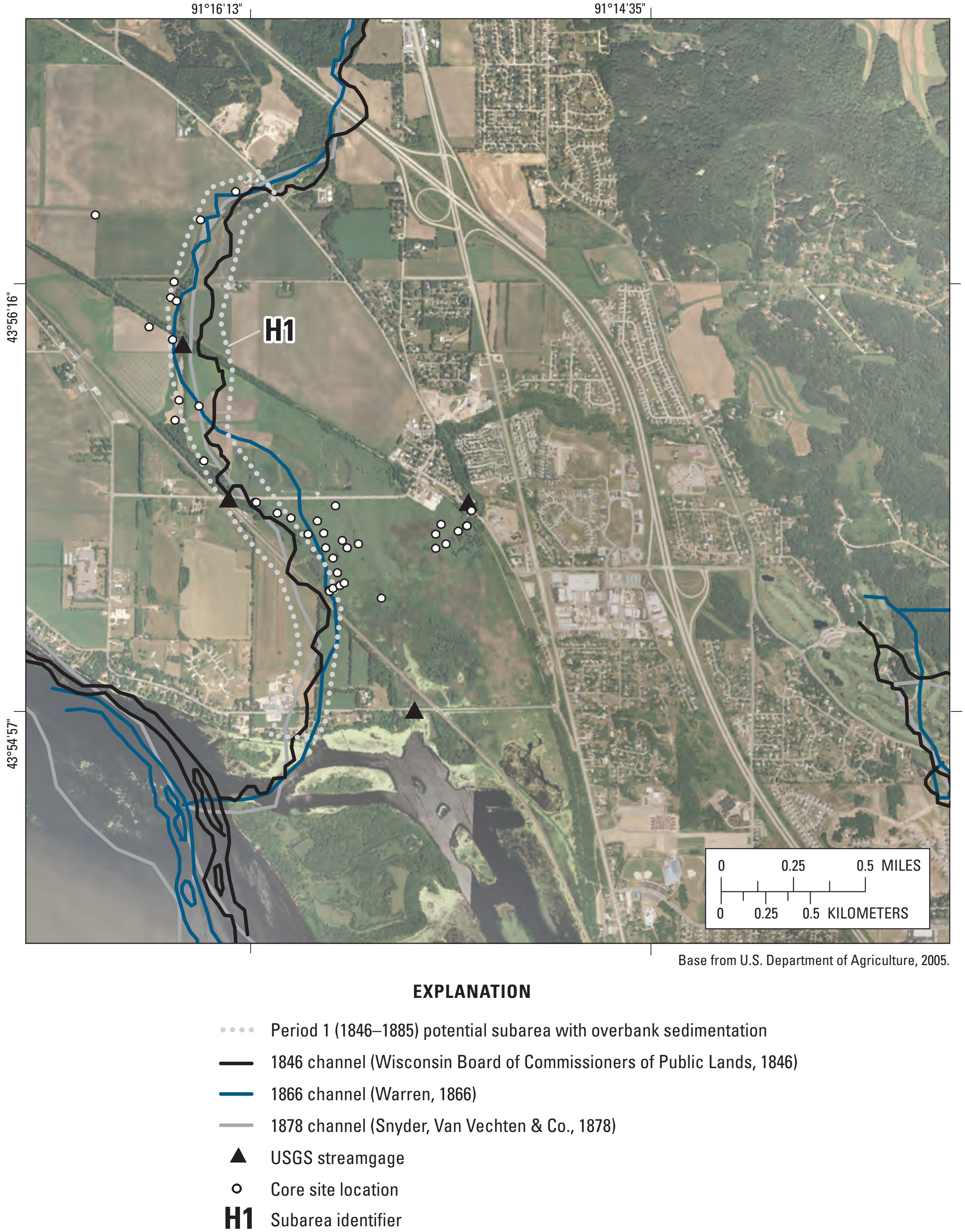


Figure 6A. Historical changes in channel locations and potential subareas with overbank sedimentation along Halfway Creek Marsh, Wis., for period 1 (1846–1885). Overbank sedimentation volumes for labeled potential subareas are listed in table 2.

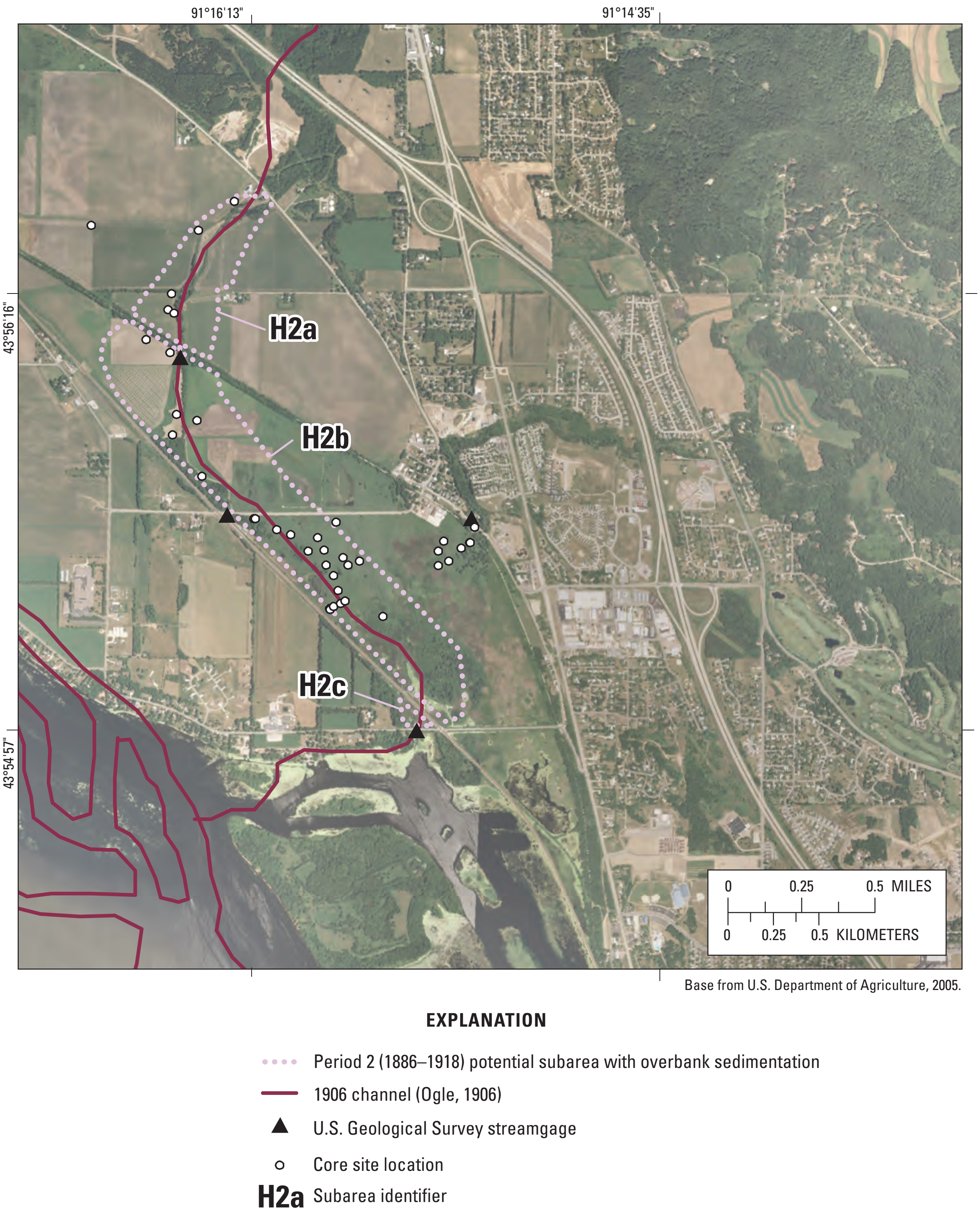


Figure 6B. Historical changes in channel locations and potential subareas with overbank sedimentation along Halfway Creek Marsh, Wis., for period 2 (1886–1918). Overbank sedimentation volumes for labeled potential subareas are listed in table 2.

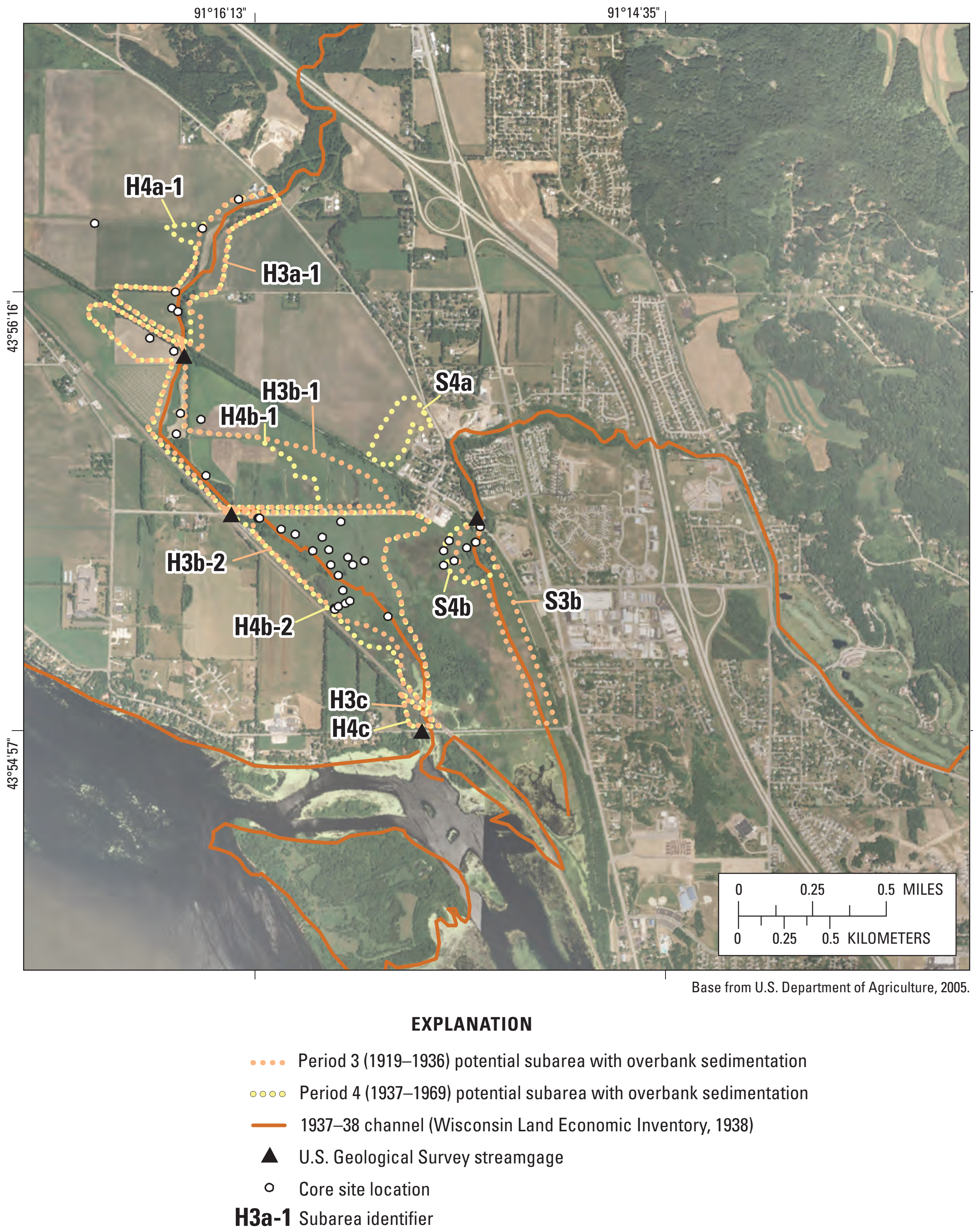


Figure 6C. Historical changes in channel locations and potential subareas with overbank sedimentation along Halfway Creek Marsh, Wis., for period 3 (1919–1936) and period 4 (1937–1969). Overbank sedimentation volumes for labeled potential subareas are listed in table 2.

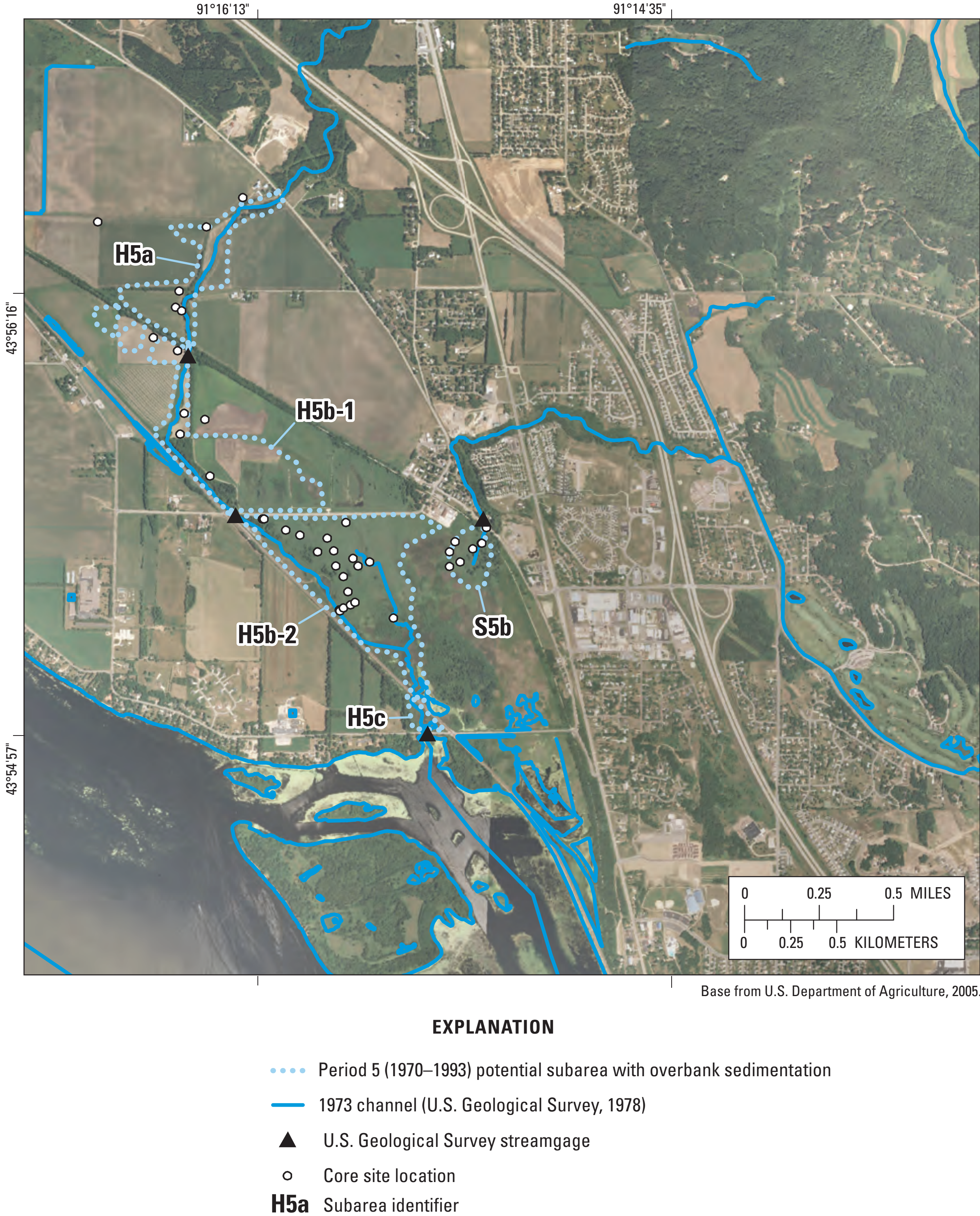


Figure 6D. Historical changes in channel locations and potential subareas with overbank sedimentation along Halfway Creek Marsh, Wis., for period 5 (1970–1993). Overbank sedimentation volumes for labeled potential subareas are listed in table 2.

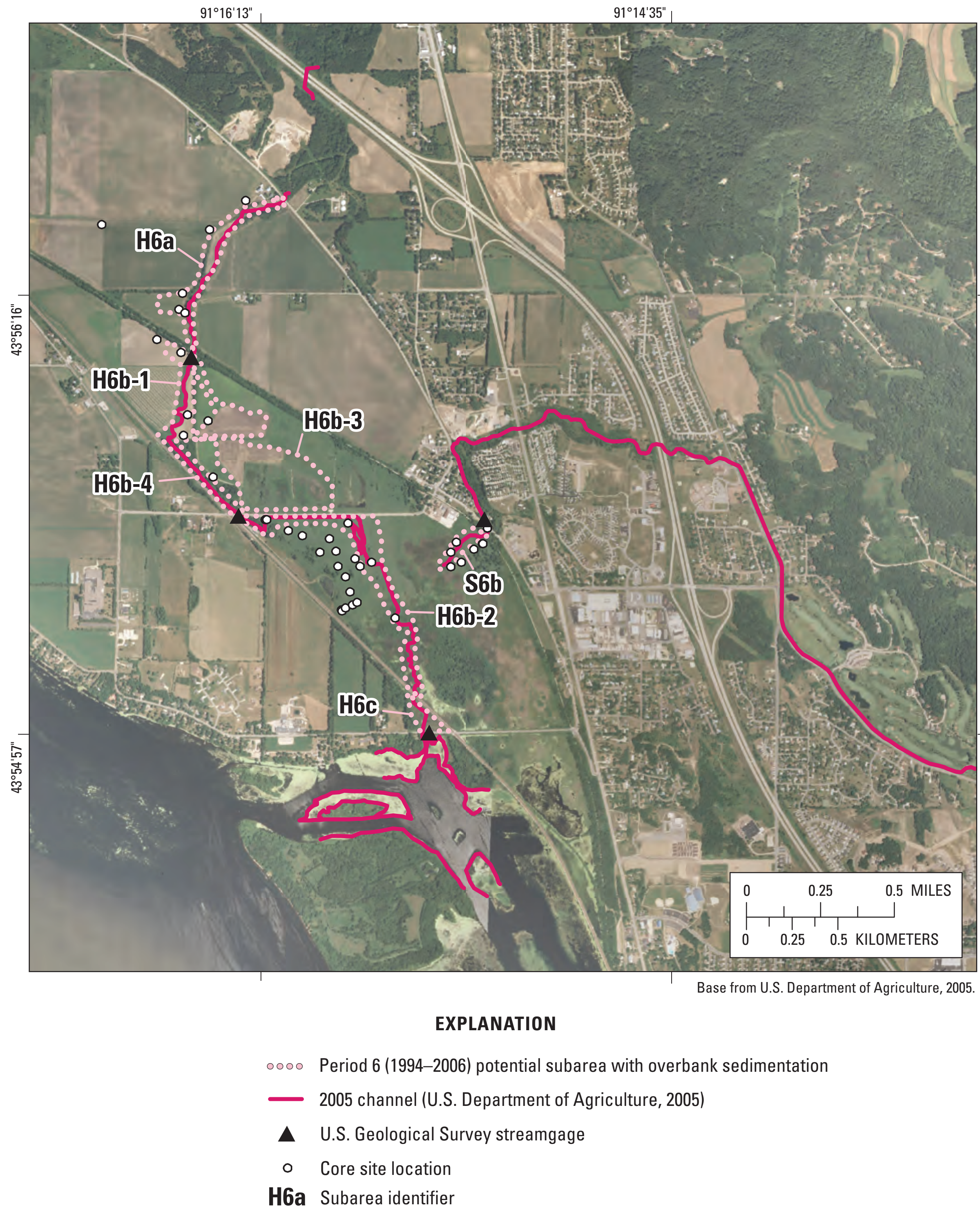


Figure 6E. Historical changes in channel locations and potential subareas with overbank sedimentation along Halfway Creek Marsh, Wis., for period 6 (1994–2006). Overbank sedimentation volumes for labeled potential subareas are listed in table 2.

their building of the railroad bed across Halfway Creek Marsh. Furthermore, the building of the Burlington and Northern line restricted lower Halfway Creek flow during large floods. This second sedimentation episode therefore extended from 1886 until 1918, before levees were built along Halfway Creek and before Sand Lake Coulee was connected to the lower marsh. For convenience of discussion, sedimentation along Halfway Creek during the second episode is proportioned into three subareas (table 2; fig. 6B).

Overbank sedimentation on the lower Halfway Creek flood plain during the second episode (1886–1918) increased an order of magnitude above that of the first episode (1846–85) (table 2). The large increase likely reflected the rapid expansion of wheat farming in the watershed, combined with several large floods and related dam failures. Estimated average depths of flood-plain sedimentation for the riparian zone along Halfway Creek upstream of the Great River Trail (former Chicago & Northwestern Railroad line) and for the upper marsh are 1.25 ft and 0.5 ft, respectively (table 2). Estimates of sediment thickness for this period were calibrated from stratigraphic thicknesses observed at core sites KDH-2 and FWS-22, both representing areas that were cut off from Halfway Creek overbank sedimentation after the construction of artificial levees in 1919 (figs. 7–8). A 1938 aerial photograph does not show any evidence of levee breaches along the west side of Halfway Creek near KDH-2 (fig. 9). The presettlement soil is buried by 1.75 ft of silty fine- to medium-grained sand in KDH-2. The sand units beneath the presettlement soil in KDH-2 down to a depth of about 20 ft are associated with postglacial alluvial fan building by Halfway Creek, whereas deeper deposits represent sedimentation of late-glacial flood-plain outwash associated with the Mississippi River. In core FWS-22, the presettlement soil (peat) is buried by about 0.7 ft of laminated silt thought to be deposited from 1886–1918 (fig. 8). The presettlement soil or peat deposits are underlain by stratified medium- to coarse-grained sand associated with late-glacial Mississippi River outwash. Total overbank sedimentation volume and rate for Halfway Creek for 1886–1918 are estimated to be about 348,400 yd^3 and 10,900 yd^3/yr, respectively (table 2).

The third sedimentation period began in 1919 when construction of artificial levees reduced the potential flood-plain area for overbank sedimentation along Halfway Creek from 324 acres in 1886–1919 to 270 acres in 1919–36 (figs. 6B–6C). This episode ended in 1936, when the first high-quality aerial photography became available for defining channel location. The 1937–38 photography

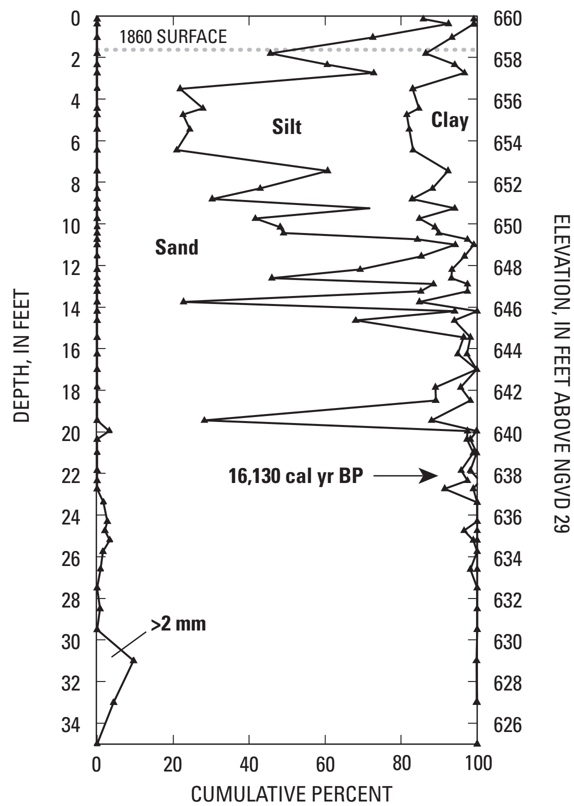


Figure 7. Particle-size data from core KDH-2, near Halfway Creek, Wis., 1996. Location of core site shown on figure 1B. [cal yr BP, calendar years before present]

shows the formation of large episodic flood-plain splays (localized alluvial fans) near breaches or low spots in the artificial levees (fig. 9). Sedimentary units in cores PD-1 through PD-5 (figs. 10 and 11) indicate light-colored, stratified fine- to very coarse-grained sand associated with the multiple flood-plain splays overlying very fine- to fine-grained sand. The latter fine-textured sand most likely was deposited during 1886–1918. The stratified fine- to very coarse-grained sand contrasted sharply with the underlying pre-1860 organic-rich, black silty soil associated with a riparian corridor of sedge marsh. Remnants of the sedge marsh were recorded on the 1937–38 Wisconsin Land Economic Inventory maps. The splay north of the Great River Trail (Chicago & Northwestern Railroad) bisected by transect 1 (fig. 10) is thicker than the splay south of the trail bisected by transect 2 (fig. 11). In general, the splays are thick near the breach in the levees and thin to the west. Total overbank sedimentation volume and rate for Halfway Creek Marsh for 1937–69 are estimated to be about 457,200 yd^3 and 26,900 yd^3/yr, respectively (table 2).

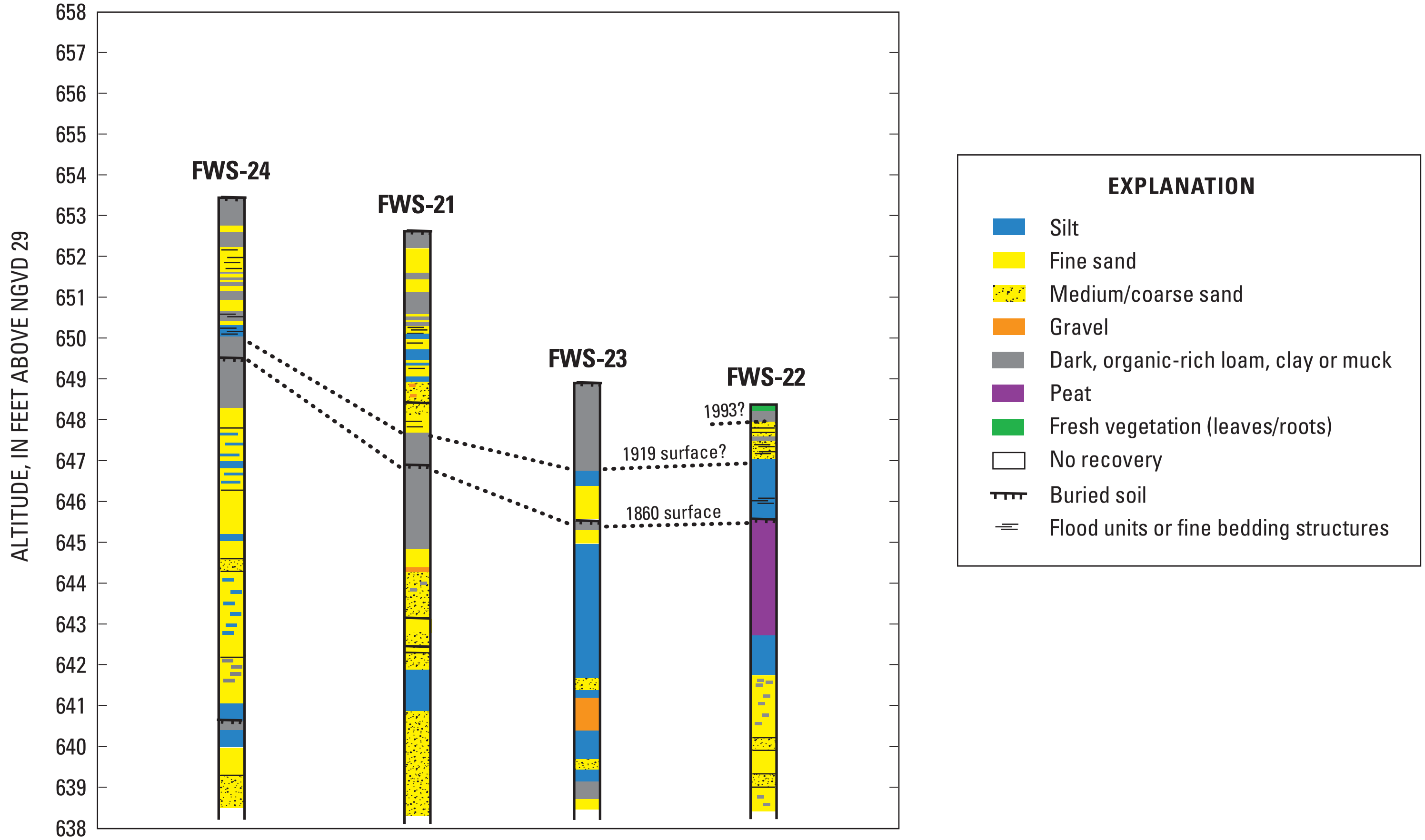


Figure 8. Geologic descriptions for cores FWS-21, -22, -23, and -24, upper Halfway Creek Marsh, Wis., 2006. Locations of core sites shown on figure 1B.

Table 2. Overbank sedimentation areas and volumes and sediment loads for Halfway Creek and Sand Lake Coulee contributions to Halfway Creek Marsh, 1846–2006. Refer to figure 3 for subarea locations.

[ft, foot; yd^3, cubic yard; yd^3/yr, cubic yard per year; ton/yr, ton per year; <, less than; assumption that 1 cubic yard = 1.33 tons, equivalent to Vierbicher and Associates (1995) conversion]

Subarea	Overbank sediment thickness (ft)	Overbank sedimentation area (acres)	Overbank sediment volume (yd^3)	Overbank sediment rate (yd^3/yr)	Overbank sediment load (ton/yr)
	Period 1, 1846–1885				
Halfway Creek total (along channel, H1)	**0.1**	**200**	**36,000**	**900**	**1,200**
Sand Lake Coulee total		**0**	**0**	**0**	**0**
Halfway Creek and Sand Lake Coulee total		**200**	**36,000**	**900**	**1,200**
	Period 2, 1886–1918				
Halfway Creek upstream of Great River Trail (H2a)	1.3	74	148,400	4,600	6,200
Halfway Creek between Great River Trail and Burlington RR (H2b)	.5	247	199,500	6,200	8,300
Halfway Creek downstream of Burlington RR (H2c)	.1	3	400	<100	<100
Halfway Creek total		**324**	**348,400**	**10,900**	**14,500**
Sand Lake Coulee total		**0**	**0**	**0**	**0**
Halfway Creek and Sand Lake Coulee total		**324**	**348,400**	**10,900**	**14,500**
	Period 3, 1919–1936				
Halfway Creek upstream of Great River Trail (H3a)	1.6	48	125,000	7,400	9,800
Halfway Creek between Great River Trail and Cty ZN (H3b-1)	1.1	116	196,400	11,600	15,400
Halfway Creek between Cty ZN and Burlington RR (H3b-2)	.3	103	49,900	2,900	3,900
Halfway Creek downstream of Burlington RR (H3c)	.1	3	500	<100	<100
Halfway Creek total		**270**	**371,800**	**21,900**	**29,100**
Sand Lake Coulee total (through east side of lower marsh, S3b)	**1.6**	**33**	**85,400**	**5,000**	**6,700**
Halfway Creek and Sand Lake Coulee total		**303**	**457,200**	**26,900**	**35,800**
	Period 4, 1937–1969				
Halfway Creek upstream of Great River Trail (H4a)	1.6	50	130,600	4,100	5,400
Halfway Creek between Great River Trail and Cty ZN (H4b-1)	1.0	91	147,000	4,600	6,100
Halfway Creek between Cty ZN and Burlington RR (H4b-2)	1.5	112	269,900	8,400	11,200
Halfway Creek downstream of Burlington RR (H4c)	.2	4	1,200	<100	<100
Halfway Creek total		**256**	**549,000**	**17,000**	**22,700**

Table 2. Overbank sedimentation areas and volumes and sediment loads for Halfway Creek and Sand Lake Coulee contributions to Halfway Creek Marsh, 1846–2006—Continued. Refer to figure 3 for subarea locations.

[ft, foot; yd^3, cubic yard; yd^3/yr, cubic yard per year; ton/yr, ton per year; <, less than; assumption that 1 cubic yard = 1.33 tons, equivalent to Vierbicher and Associates (1995) conversion]

Subarea	Overbank sediment thickness (ft)	Overbank sedimentation area (acres)	Overbank sediment volume (yd^3)	Overbank sediment rate (yd^3/yr)	Overbank sediment load (ton/yr)
Period 4, 1937–1969 (continued)					
Sand Lake Coulee upper marsh fan near Midway (S4a)	.5	15	12,300	400	500
Sand Lake Coulee lower marsh fan (S4b)	1.0	16	25,800	800	1,000
Sand Lake Coulee total		**31**	**38,100**	**1,200**	**1,500**
Halfway Creek and Sand Lake Coulee total		**287**	**586,800**	**18,300**	**24,400**
Period 5, 1970–1993					
Halfway Creek upstream of Great River Trail (H5a)	0.3	54	22,000	1,000	1,300
Halfway Creek between Great River Trail and Cty ZN (H5b-1)	.5	74	53,500	2,300	3,100
Halfway Creek between Cty ZN and Burlington RR (H5b-2)	1.1	116	205,100	8,900	11,900
Halfway Creek downstream of RR (H5c)	.1	4	700	<100	<100
Halfway Creek total		**248**	**281,300**	**12,200**	**16,300**
Sand Lake Coulee total (lower marsh fan, S5b)	**1.0**	**14**	**23,000**	**1,000**	**1,300**
Halfway Creek and Sand Lake Coulee total		**262**	**304,200**	**13,200**	**17,600**
Period 6, 1994–2006					
Halfway Creek upstream of Great River Trail (H6a)	.2	20	4,700	400	500
Halfway Creek between Great River Trail and Cty ZN (H6b-1)	.1	35	5,700	500	600
Upper marsh lane area between artificial levees (H6b-4)	.1	11	1,700	100	200
Halfway Creek lower marsh between Cty ZN and Burlington RR (H6b-2)	.4	33	21,400	1,800	2,400
Halfway Creek downstream of RR (H6c)	.2	4	1,400	100	200
Halfway Creek total		**146**	**34,900**	**2,900**	**3,900**
Sand Lake Coulee total (lower marsh fan, S6b)	**1.5**	**6**	**13,500**	**1,100**	**1,500**
Halfway Creek and Sand Lake Coulee total			**48,600**	**3,700**	**5,000**
TOTAL VOLUME FOR ALL PERIODS (cubic yards)			**1,781,200**		
TOTAL TONS FOR ALL PERIODS			**2,369,000**		

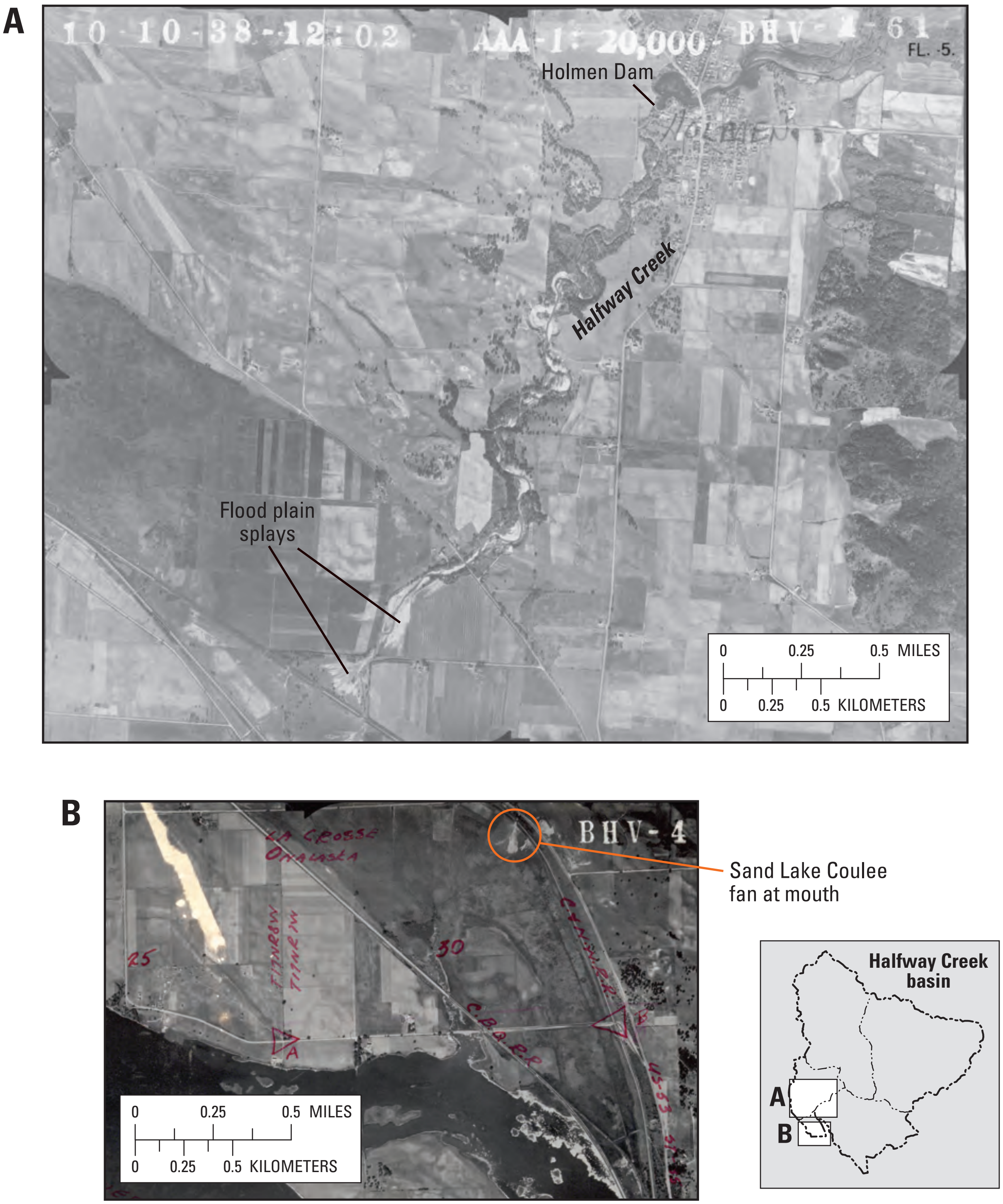


Figure 9. Aerial photographs of Halfway Creek (1938) showing flood-plain splays following dam failure and levee breaks associated with a recent flood. Photographs obtained from the Arthur H. Robinson Map Library at the University of Wisconsin–Madison (source unknown).

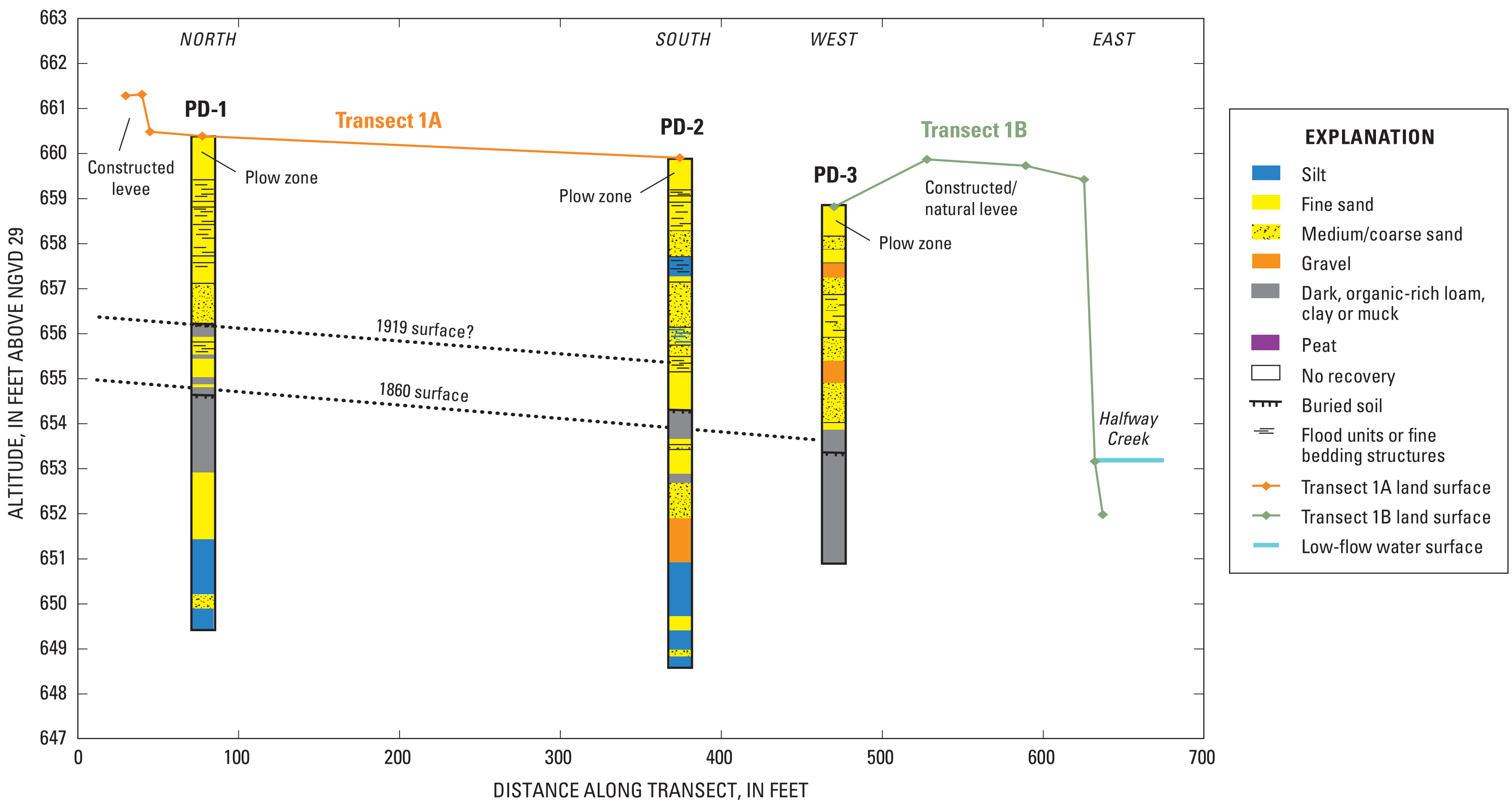


Figure 10. Cross section and geologic descriptions for cores PD-1, PD-2, and PD-3 through a levee breach and flood-plain splay near Halfway Creek, Wis., 2006. Transect and core site locations shown on figure 1B.

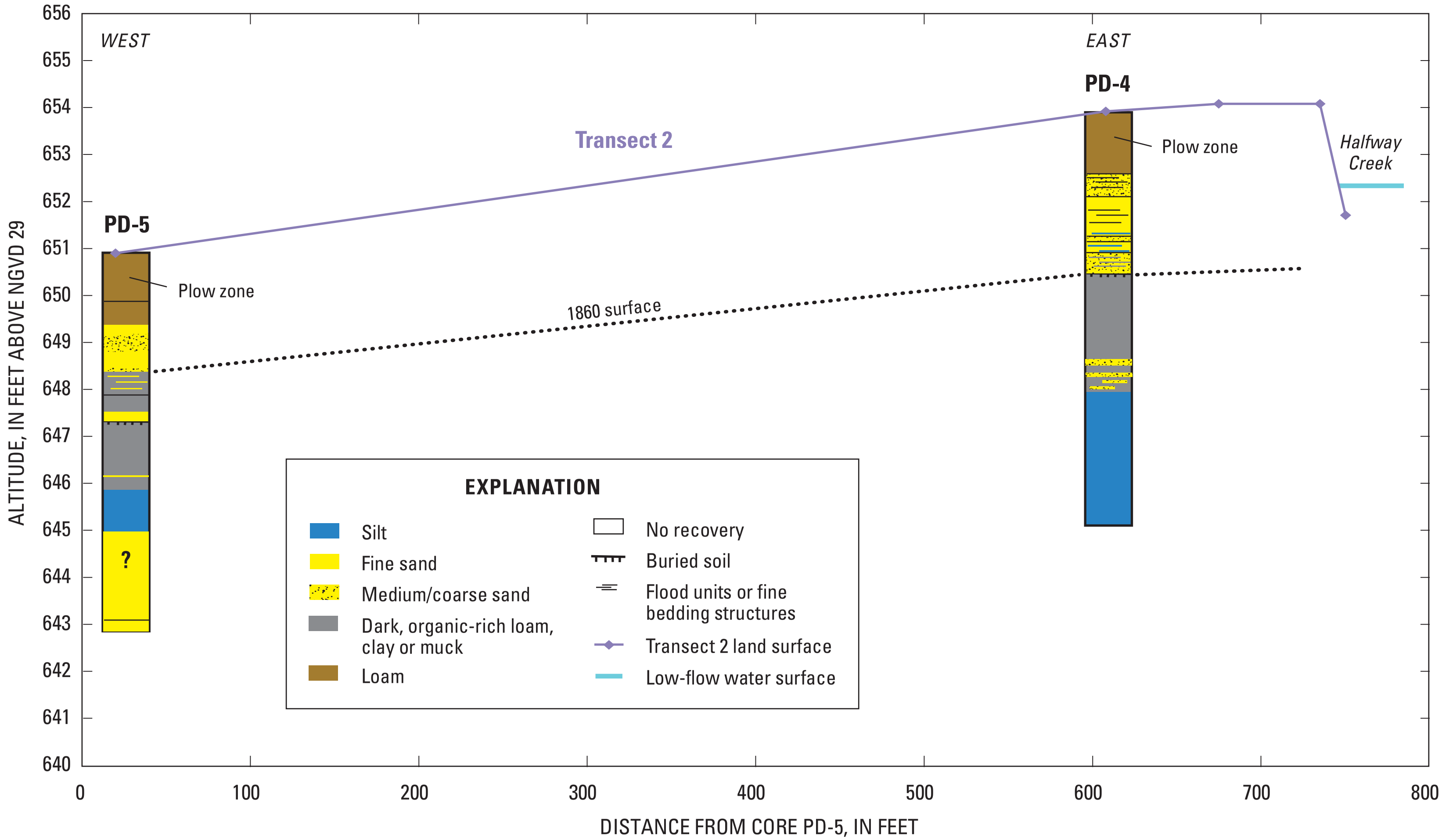


Figure 11. Cross section and geologic descriptions for cores PD-4 and PD-5 through levee breach and flood-plain splay near Halfway Creek, Wis., 2006. Transect and core site locations shown on figure 1B.

These estimates include sediment delivered to the marsh from Sand Lake Coulee (85,400 yd^3), which was first connected to the marsh during this time period. Halfway Creek's contributions to the marsh during this time period were double those from 1886–1918.

The fourth sedimentation period, 1937–69, was a period of continued drainage modifications and of land-cover change in the upper Halfway Creek watershed that reduced peak flows. Sedimentation patterns from 1919 to 1936 and 1937 to 1969 overall were similar (fig. 6C), but sedimentation rates for the two periods slightly differed (table 2). Rates of overbank sedimentation along Halfway Creek were higher during 1919–36 than during 1937–69 mainly because of large floods, dam failure, and remobilization of impounded sediment downstream into the upper and lower marsh during the earlier episode. Estimated rates were 21,900 yd^3/yr for 1919–36 compared to 17,100 yd^3/yr for 1937–69. Given the changes in upland land cover between 1937 and 1969 and expected parallel reductions in surface runoff and soil erosion, lower sedimentation rates in the lower marsh might have been anticipated than what was estimated during this investigation. The continued anomalous high sedimentation rate in the lower marsh (subarea H4b-2) was likely from the construction of artificial levees upstream from County Highway ZN. The levees disconnected Halfway Creek from former flood-plain surfaces that had been available previously for water and sediment storage. The artificial levees on both sides of Halfway Creek between County Highway XX and County Highway ZN essentially created a flume-like channel that very effectively conveyed large floods and their high sediment loads downstream into the lower marsh area, a result of the very limited area for sediment storage within the leveed reach of Halfway Creek. Deposition of sandy alluvial fans around the historical Halfway Creek channel through the lower marsh illustrate this process (fig. 12). The ^{137}Cs profiles from a core in the upper marsh (FWS-21) and the lower marsh (FWS-18) confirm that upper marsh sedimentation rates decreased and lower marsh sedimentation rates increased during 1937–69, most likely in response to the levee effects explained previously (fig. 13). The reach between the Great River Trail (Chicago & Northwestern Railroad) and County Highway ZN (subarea H3b-1) had an estimated overbank sedimentation rate of 11,600 yd^3/yr from 1919 to 1936 compared to an estimated 4,600 yd^3/yr from 1937 to 1969 (table 2). In contrast, the reach in the lower marsh (H3b-2) had an estimated overbank sedimentation rate of 2,900 yd^3/yr in 1919–36 compared to an estimated 8,400 yd^3/yr in 1937–69.

After 1919, the connection of Sand Lake Coulee drainage from the bluffs through Midway and into the lower marsh resulted in additional sediment coming into the lower marsh from the east (fig. 6C). The plugging of the southeastward course of the Sand Lake Coulee channel soon after its construction (exact year unknown) resulted in the building of an alluvial fan into the lower marsh immediately south of Midway, with the mouth forming distributary channels into the lower marsh. These channels migrated north closer to Midway as the fan built outward and upward (fig. 14). The 1938 aerial photograph shows newly flood-deposited, light-colored sediment in the vicinity of the main alluvial fan, as well as a secondary fan formed north of Midway (fig. 9). This secondary fan deposition probably was fed by floodwaters that exited the Sand Lake Coulee channel at the tight bend near the base of the late-glacial (Bagley) terrace in Midway and flooded the field north of the Great River Trail (Chicago & Northwestern Railroad line). Cores SLC-1, -2, -3, and -4 descend the axis of the Sand Lake Coulee alluvial fan (transect 7A, fig. 14). The alluvial fan most likely formed from about 1919 through the 1970s. Core SLC-7 is along transect 7B, which follows the approximate path of the 2005 channel into the marsh. Estimated Sand Lake Coulee contributions of sediment to the lower marsh were higher in 1919–36 (5,000 yd^3/yr) than in 1937–69 (1,200 yd^3/yr). This difference is consistent with changes in land cover over time between these two periods, as discussed previously. The differences also may result from downcutting and channel bank erosion that probably were active during 1919–36 in response to adjustments in the Sand Lake Coulee channel after its constructed extension from the terrace surface into the lower marsh.

A fifth period of sedimentation history for Halfway Creek Marsh is recognized for 1970–93. During this interval, the channel of Halfway Creek was mainly west of its 1937–38 location through the lower marsh, with the possibility of a secondary channel to the east (figs. 6C–6D). The magnitude and distribution of ditching during this period in the upper and lower marsh is not well documented, and it is not known how much sediment might have been removed during these activities. The Sand Lake Coulee fan continued to build outward into the lower marsh from the east, just south of Midway. The estimated sedimentation rate for Halfway Creek (12,200 yd^3/yr) was lower during this period compared to 1919–69 and similar to 1886–1918, most likely because of widespread implementation of agricultural best-management practices in the watershed. In addition, the Holmen Dam was not in place during this period, eliminating sudden bursts of flood-

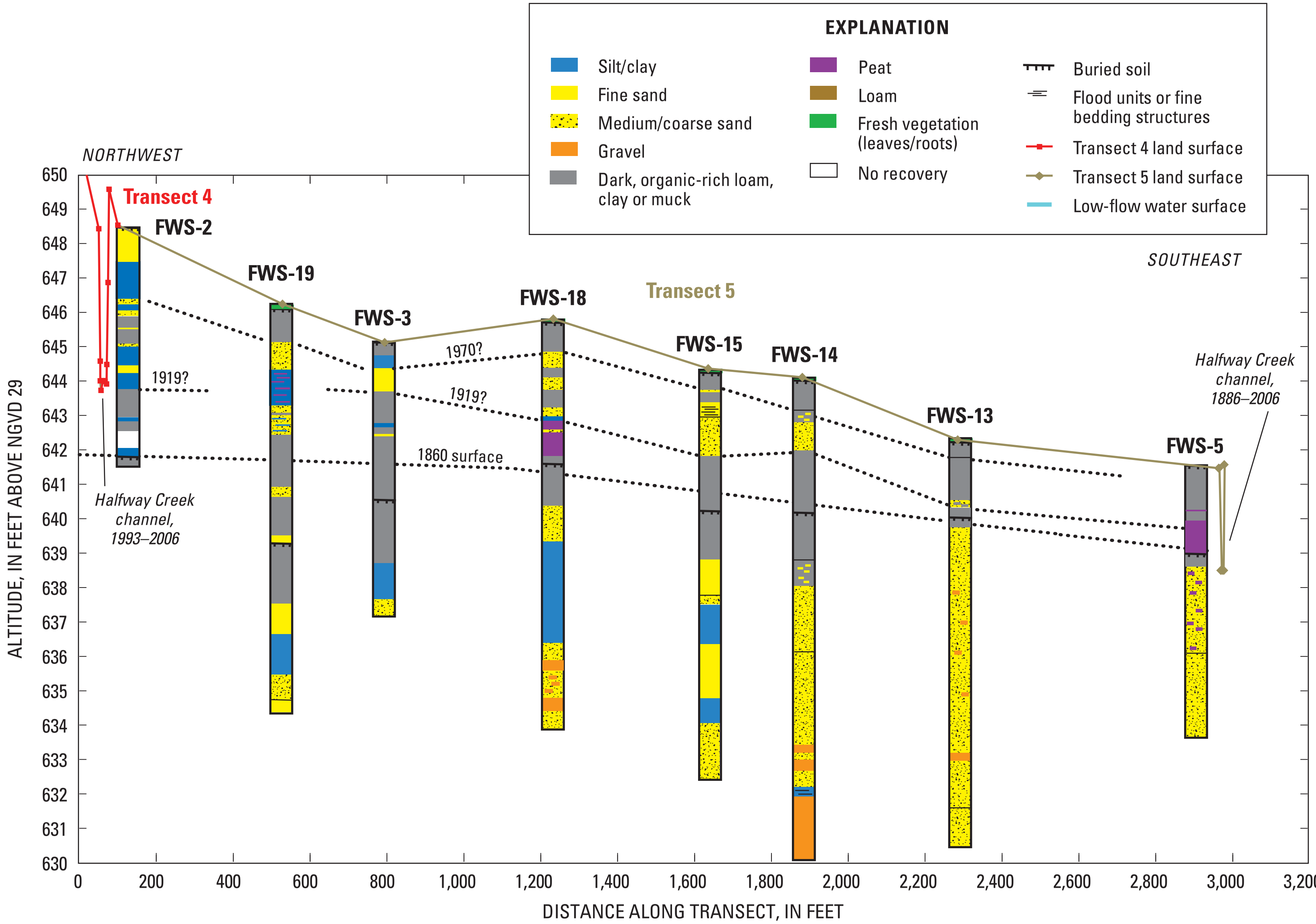


Figure 12. Cross section and geologic descriptions for cores FWS-2, -19, -3, -18, -15, -14, -13, and -5, lower Halfway Creek Marsh, Wis., 2006. Transect and core site locations shown on figure 1B.

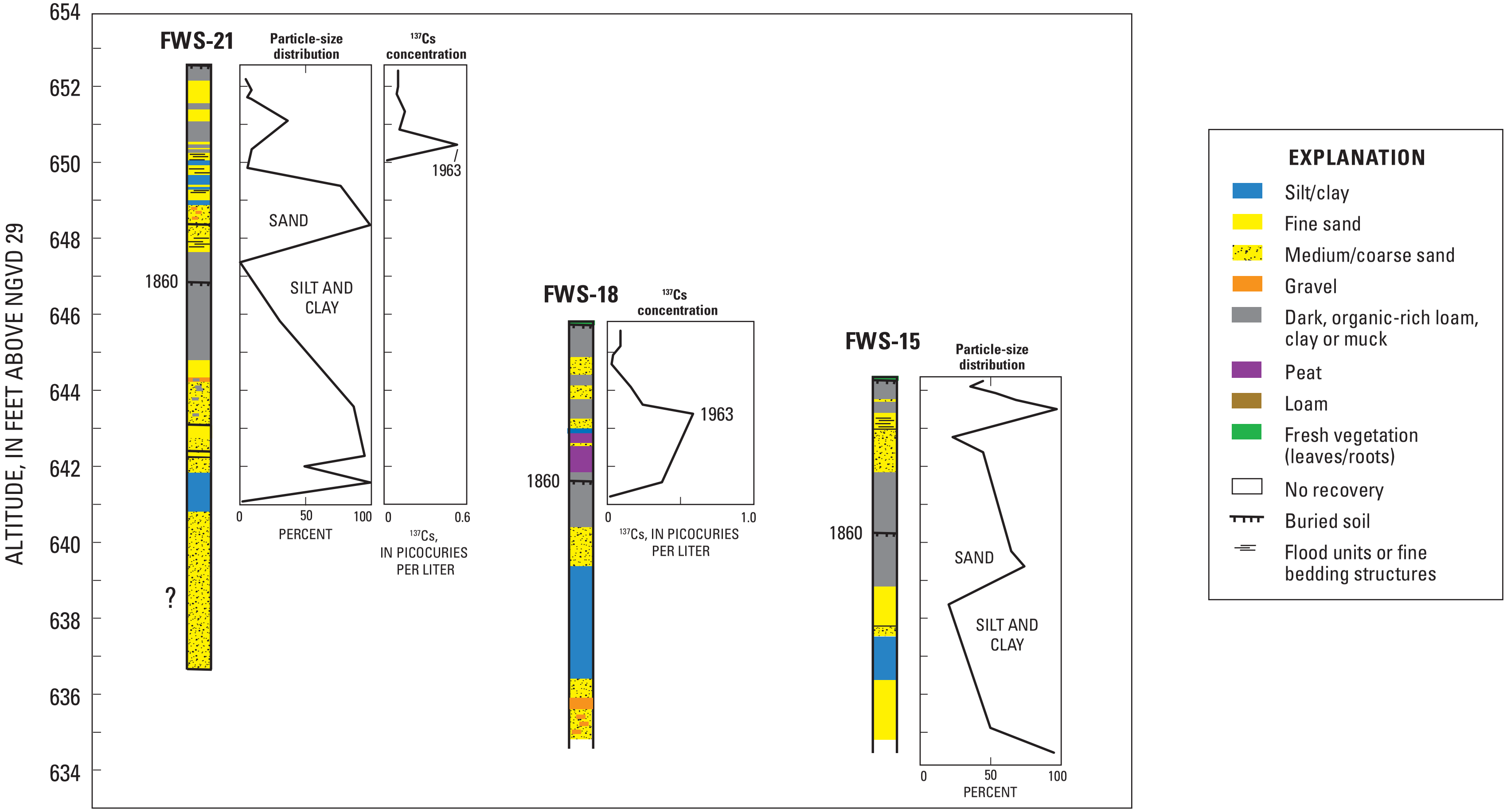


Figure 13. Graphs of particle size and cesium-137 (^{137}Cs) concentrations from cores FWS-15, FWS-18, and FWS-21, with overlays of geologic descriptions and estimated dates, upper and lower Halfway Creek Marsh, Wis., 2006. Locations of core sites shown on figure 1B.

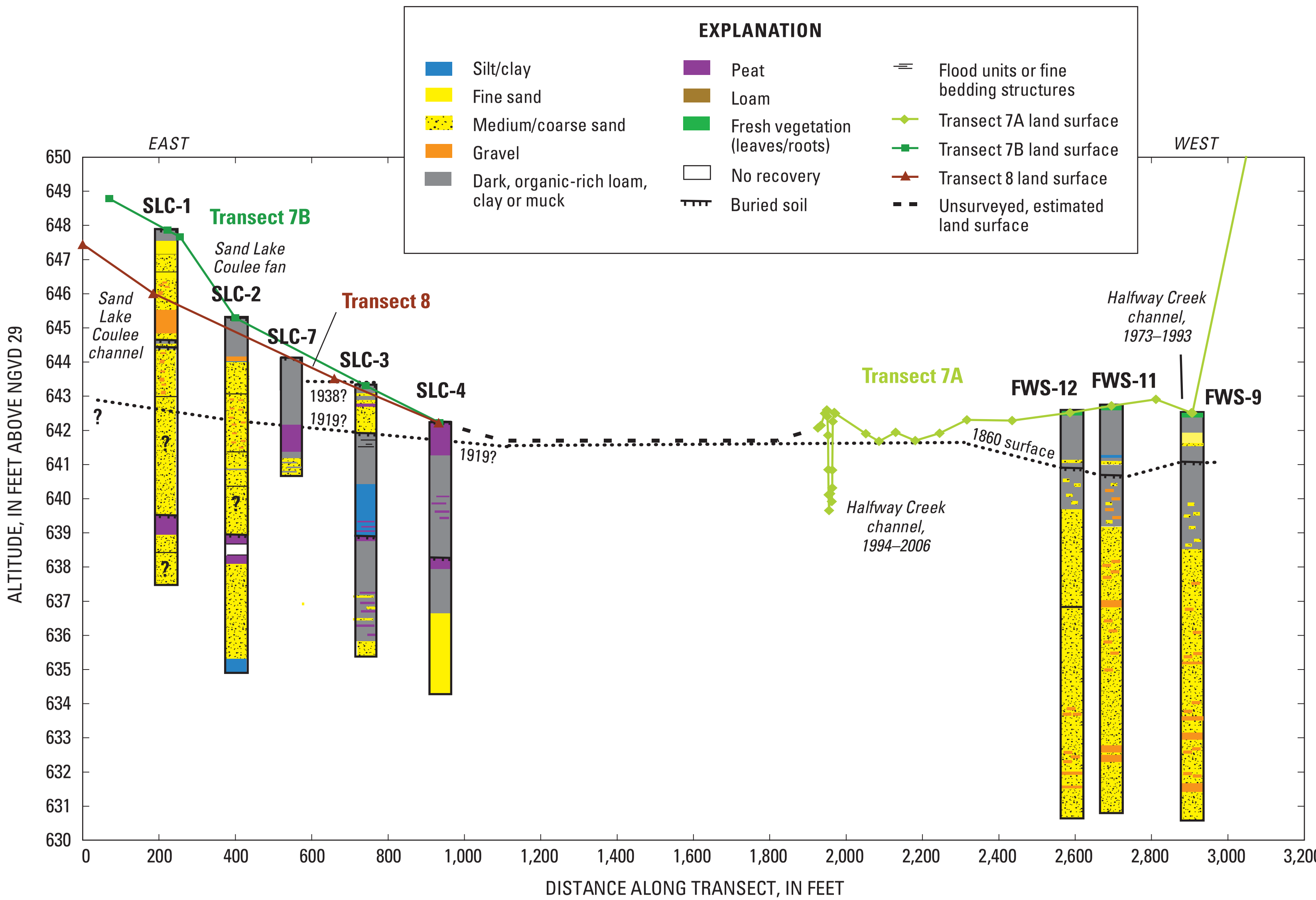


Figure 14. Cross section and geologic descriptions for cores SLC-1, -2, -3, -4, and -7, and FWS-9, -11, and -12, lower Halfway Creek Marsh, Wis., 2006. Transect and core site locations shown on figure 1B.

flow and stored sediment during dam failures. However, sedimentation rates for the Halfway Creek fan in the lower marsh may have peaked during this period because of the lack of available flood-plain storage for sediment in the upper marsh, a result of artificial levees. The lower marsh accumulated an estimated volume of about 205,100 yd^3 of sediment over its northwestern half, and this volume represented about 70 percent of the total volume of sediment deposited along lower Halfway Creek between 1970 and 1993 (fig. 6D, table 2). The estimated sedimentation volume during the period 1970–93 for the Sand Lake Coulee fan was 23,000 yd^3, which is about 60 percent of the volume deposited between 1937 and 1969, whereas the estimated sedimentation rate of 1,000 yd^3/yr for the period 1970–93 is about 80 percent of the rate from 1937 to 1969.

During the sixth period of sedimentation in the Halfway Creek Marsh (1994–2006), the Halfway Creek channel was at its most eastern and central location through the northern part of the lower marsh. During 1994–2006, natural levees either continued to form or formed along Halfway Creek in the lower marsh (fig. 14). These levees are about 1 ft higher than the surrounding marsh. Thus, in the middle of the lower marsh, there is an approximately 1,200-ft wide swath that generally is minimally affected by historical sedimentation except for near-channel areas (fig. 14).

The Halfway Creek estimated sedimentation rate for the sixth period, 1994–2006, is 2,900 yd^3/yr (table 2), which is about 3 times the estimated overbank sedimentation rate during the first period, 1846–86, but only about 22 percent of the 12,200-yd^3/yr rate for the preceding period, 1970–93. Improvements in agricultural practices (and possibly an increase in the amount of forest cover in the watershed) may have reduced the sedimentation rate, combined with removal of 15,900 yd^3 from the Halfway Creek channel along the south side of County Highway ZN from 1994 to 2003. Additional sediment was removed from the diversion channel and from the experimental constructed wetlands in the upper marsh. It is not known how much urban development occurred during this time or what its effect on sedimentation in the marsh would have been.

The 1994–2006 estimated sedimentation rate for the lower marsh area represented by the Sand Lake Coulee alluvial fan is about 1,100 yd^3/yr, which is nearly identical to the 1,000 yd^3 per year estimated for the same area in the preceding period from 1970–93. However, 3,100 yd^3 was removed from a sand trap at County Highway OT/ZM from 1994 to 2006, over the same time period that 13,500 yd^3 of overbank sediment was deposited on the alluvial fan (table 2).

Overbank sedimentation rates for 1994–2006 for the lower marsh can roughly be compared to annual suspended-sediment loads measured during 2004–06 from USGS streamgages on Halfway Creek at County Highway ZN, the diversion channel, and Sand Lake Coulee. Annual suspended-sediment loads entering the lower marsh during 2004–06 have varied: 11,610 tons in 2004, 2,670 tons in 2005, and 840 tons in 2006 (Peter Hughes, U.S. Geological Survey, written commun., 2007). There were fewer floods in 2005 and 2006 compared to 2004. Annual suspended-sediment loads coming out of the marsh from Halfway Creek at County Highway Z were 910 tons in 2005 and 340 tons in 2006; therefore, 60–66 percent of the suspended-sediment load, or 1,760 to 7,650 ton/yr, is stored in the lower marsh. In comparison, based on the core descriptions, the overbank sedimentation load for the marsh for 1994–2006 was 5,000 tons/yr. The loads estimated from overbank sediment thickness are representative of long-term loads that span wet and dry years.

In summary, approximately 1,800,000 yd^3 (or about 2,400,000 tons) of sandy overbank deposits are stored along the margins of Halfway Creek through the upper and lower marsh and in alluvial fan deposits where Sand Lake Coulee previously entered or currently enters the lower marsh. This study connects historical sedimentation rates and patterns in riparian marshes along the Upper Mississippi River system back to tributary watershed conditions and disturbances. However, the history of human activities, magnitude of overbank sediment loading, and continued fluvial adjustments to the loading in Halfway Creek Marsh are likely typical for numerous other small tributaries that flow into critical backwater marsh habitats along the Upper Mississippi River National Wildlife and Fish Refuge and the entire Upper Mississippi River System.

Effects on Channel Morphology

The variable channel morphologies of Halfway Creek and Sand Lake Coulee through the upper and lower marsh are reflections of historical overbank sedimentation patterns and human activities (fig. 15). The channel and flood plain at transect 3 are confined by artificial levees on both sides of the stream, causing accelerated overbank sedimentation within the narrow, confined zone between the levees since about 1919. Based on nearby core data from FWS-21 and FWS-24, there has been approximately 5 ft of historical sedimentation in the field on the east side of the stream,

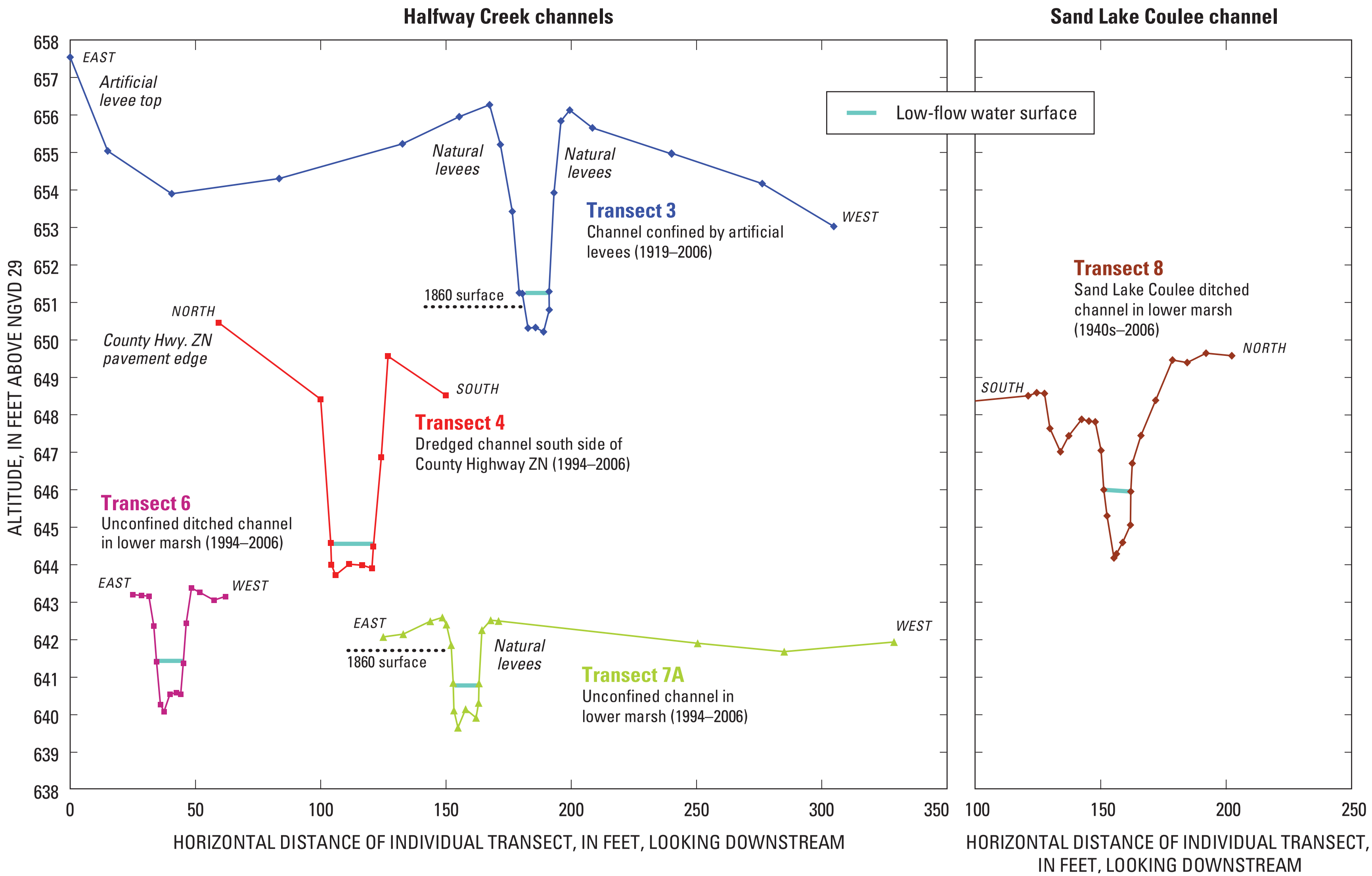


Figure 15. Channel cross sections of Halfway Creek and Sand Lake Coulee, Wis., 2006. Transects are not horizontally related. Locations of transects are shown on figure 1B.

and the top of the natural levee immediately adjacent to the channel is only 1.2 ft lower than the top of the artificial levee to the east. Although morphologic appearance gives an impression that the channel is actively entrenching, this is not the case. The deep channel is due almost entirely to the massive historical flood-plain sedimentation that has extended the heights of the banks above the bed. In turn, confined deep flows generate sufficient shear stresses on the channel bed to move sand and gravel bedload and prevent extensive channel-bed aggradation. The channel bed may have aggraded by 1 ft or more since settlement. Most of the aggradation was likely after 1937 when the lock and dam system was constructed on the Mississippi River and base level was raised by about 6 ft at the mouth of Halfway Creek. The entrenched look of Halfway Creek along the south side of County ZN (transect 4) is the result of channel construction and periodic dredging from 1994 forward. The cross-section capacity of the Halfway Creek channel in the lower marsh (transects 6 and 7A) is less than half that of the channel through the upper marsh, reflecting the absence of artificial levees, lower overbank sedimentation volumes, and young age (1994). Natural levees, about 0.3 to 1 ft high, were present along the lower marsh channel.

The Sand Lake Coulee channel at transect 8 was either constructed or naturally created after 1938 after the former dredged, southeastward-flowing channel filled with sediment (fig. 15). The bed of the channel, where it enters the lower marsh, is at a similar altitude as the dredged channel bed of Halfway Creek along County Highway ZN (transect 4). The altitudes of natural levees and spoil material along the banks of the Sand Lake Coulee channel are higher than the adjacent alluvial-fan surface associated with the 1973 location of the channel (fig. 6D), indicating that Sand Lake Coulee is a major sediment source to the lower marsh.

Summary and Conclusions

The sedimentation history from 1846 to 2006 of Halfway Creek Marsh, Wis., was studied by the USGS, the University of Wisconsin–Madison, the USEPA, and the USFWS. The study was conducted to characterize historical patterns and rates of sediment deposition and to compare sediment deposition on the flood plain and marsh in recent years to the past within the context of human activities, changes in channel locations, and flood history. The sedimentation history was divided into six time periods based on human activities and datable benchmarks in the sediment record. Sediment cores were collected from 2005 to 2006 in the upper and lower marsh. Transects were surveyed across channels, flood plains, alluvial fans, and flood-plain splays associated with historical overbank sedimentation. Sediment texture, color, compaction, stratification, and soil development were used to interpret the historical record of sedimentation in the Halfway Creek Marsh. This study relates estimated historical sedimentation rates and patterns in riparian marshes along the Upper Mississippi River system with tributary watershed conditions and disturbances. The history of human activities, magnitude of overbank sediment loading, and continued fluvial adjustments to the loading in Halfway Creek Marsh broadly approximate those of numerous other small tributaries that flow into critical backwater marsh habitats along the Upper Mississippi River National Wildlife and Fish Refuge and the Upper Mississippi River System.

This study provides scientific information necessary for resource managers in the USFWS and the USEPA to address the five management-related questions posed at the beginning of this study:

1. What is the extent and character of historical sand deposition in the marsh and can the sand be removed and used for landscaping/fill?
2. Will the channel of Halfway Creek stabilize through the lower marsh?
3. Are more sediment traps needed along Halfway Creek in the upper marsh?
4. Given the rate of sediment deposition, is it worthwhile to improve wetland habitat in the lower marsh?
5. Will sediment deposition rates remain relatively constant in the marsh over the next 50 years?

The extent and character of historical sand deposition in the marsh are mainly dependent on proximity of the deposits to historical channels, alluvial fans, and artificial levees. The historical (post-1860) overbank deposits follow along the modern and historical Halfway Creek channels downstream of County Highway XX, through the upper and lower marsh, and in the mouth of Sand Lake Coulee in the lower marsh. The historical overbank deposits are up to 6 ft thick along the banks of Halfway Creek through the upper marsh where the flood plain is confined by artificial levees and in flood-plain splays formed by breaches in the artificial levees during large floods. In the lower marsh, overbank sedimentation patterns follow historical channels and alluvial fans. The northwest and northeast corners of the lower marsh, where Halfway Creek and Sand

Lake Coulee enter, respectively, have 5 to 6 ft of fine- to medium-textured sand layered with dark organic-rich loam or silt-clay units associated with fan deposits. The texture tends to become more fine-grained and organic-rich in the downstream direction through the lower marsh. The historical deposits tend to be lighter in color, less compacted, more stratified and bedded, and have less soil development and organic content than presettlement deposits.

The most recent aggregate estimated overbank sedimentation rate of 3,700 yd^3/yr for 1994 to 2006 for the entire marsh is about 4 times the early settlement (1846–85) rate (900 yd^3/yr). However, the aggregate historical overbank sedimentation rate for the period between 1919 and 1936 was estimated to be 26,900 yd^3 per year, a magnitude that was nearly 30 times the 1846–86 rate and more than 7 times that for 1993–2006. The very high rate of overbank sedimentation between 1919 and 1936 was caused by watershed agricultural practices that promoted surface runoff and soil erosion, several large floods, failures of the Holmen Dam accompanied by sediment flushing of mill-pond sediment and downstream-channel bank erosion, and channelization that directly connected the drainage of the Sand Lake Coulee to the lower marsh. Overbank sedimentation rates for the lower marsh remained anomalously high between 1937 and 1993, especially because levees constructed earlier along the channel of Halfway Creek allowed the remaining small flood plain and channel system to function as an efficient flume for transporting water and sediment into the lower marsh. Although upland land conservation may have reduced sediment inputs from the upstream watershed in recent years, the flume-like behavior of Halfway Creek through the upper marsh makes it a very effective transporter of water and sediment, allowing minimal storage along the way before flow reaches the lower marsh.

Channel changes and sedimentation rates in the lower marsh currently are less severe than a few decades ago; nevertheless, the channel in the lower marsh is adjusting to excess sediment from upstream and the continued building of alluvial fans by Halfway Creek and Sand Lake Coulee. The Halfway Creek channel has shifted eastward toward the center of the lower marsh through natural alluvial fan building and ditching/channelization. Additional upstream flood-plain storage for water and sediment during floods would reduce overbank sedimentation rates in the lower marsh.

In conclusion, approximately 1,800,000 yd^3 (or about 2,400,000 tons) of sandy overbank deposits are stored along the margins of Halfway Creek through the upper and lower marsh and in alluvial fan deposits where Sand Lake Coulee previously entered or currently enters the lower marsh. The historical overbank deposits affect the modern fluvial processes of Halfway Creek and marsh/wetland fluvial dynamics. The fluvial system through the marsh accepts the additional sediment and adjusts within the physical laws that constrain it. System-wide adjustments to historical sediment loading of this magnitude will probably continue for decades and centuries, manifested during extreme floods and moderate flows, continually flushing legacy sediment from channel margins downstream into the lower marsh and eventually to Lake Onalaska and to the Mississippi River. The history of human activities, magnitude of overbank sediment loading, and continued fluvial adjustments to the loading in Halfway Creek Marsh are typical for the numerous small tributaries that flow into critical backwater marsh habitats along the Upper Mississippi River National Wildlife and Fish Refuge and along the Upper Mississippi River System. Due to the high probability of remobilization of stored historical sediment and associated nutrients, and their long-term effects on lowland vegetation and fish and wildlife habitat, it is important to improve understanding of how human activities have influenced patterns and rates of sedimentation in riparian environments. In addition, the legacy of past erosion and sedimentation will continue to influence current and future water quality, sediment loads, nutrient loads, and water-related resources.

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