GEOMORPHIC AND HYDROLOGIC RESPONSES TO VEGETATION, CLIMATE, AND BASE LEVEL CHANGES, NORTH FISH CREEK, WISCONSIN

by

Faith A. Fitzpatrick

A dissertation submitted in partial fulfillment
of the requirements for the degree of

Doctor of Philosophy
(Geography)

at the

UNIVERSITY OF WISCONSIN-MADISON
1998

Abstract

This study distinguishes between human and natural influences on erosion, sedimentation, and flooding characteristics of streams in the Lake Superior region and quantifies long-term geomorphic and hydrologic responses caused by changes in vegetation, climate, and base-level. North Fish Creek, a Wisconsin tributary to Lake Superior, was chosen for this study because it has a highly-valued natural fishery that has been impacted by erosion and sedimentation problems. Forest clearing, beginning in the 1870s, and agriculture, which peaked in the 1930s and 1940s, were major causes of geomorphic and hydrologic changes resulting in habitat destruction.

Approximately 1 to 2 meters of sediment accumulated in the lower mainstem and floodplain of North Fish Creek and approximately 1 to 3 meters of channel incision occurred in the upper mainstem during the past 125 years resulting in a sedimentation rate near the mouth that is almost 10 times greater than pre-1870 rates. The main sediment source is bluff erosion along the upper mainstem. Furthermore, geomorphic evidence and runoff/sediment load modeling suggest that flood peaks expected once every 1 to 2 years are almost double the pre-1870 flood peaks. Sedimentation in the lower mainstem decreased after the 1940s, corresponding to a decrease in agricultural activity. Modeling results indicate that continuing abandonment of agricultural land and (or) addition of detention basins will further decrease peak flows and related bluff and streambank erosion.

During the past 6,000 years, variations in vegetative cover were minimal compared to variations in climate and base level. Prior to European settlement, the main geomorphic change in North Fish Creek was a change from degradation to progressive aggradation in the upper mainstem at about 4,000 to 3,000 ^{14}C yr B.P. This change may have been caused by a climatic shift to drier conditions. Near the mouth of North Fish Creek and Fish Creek Slough, variations in base level during the Holocene appear to influence geomorphic conditions more than variations in climate. However, presettlement indications of climate-caused degradation in the upper mainstem are observable as pulses of sediment delivered to the mouth.

Acknowledgments

This project could not have been accomplished without the extensive participation of several individuals during all aspects of the project. First of all, Bill Rose and Dave Graczyk (U.S. Geological Survey, Madison, Wis.) made the project possible by suggesting a study of the relations between land use and the geomorphology of North Fish Creek to Bruce Swanson (Fisheries Manager, Wisconsin Department of Natural Resources). The study was funded through a cooperative effort that included the U.S. Geological Survey, the Wisconsin Department of Natural Resources, the University of Wisconsin, and the U.S. Environmental Protection Agency.

Field data collection efforts involved many individuals, including Jim Knox, Dave Mickelson, Tom Cogger, Mike Gardner, William Becker, Diann Kiesel, Ty Sabin, my husband Bill Fitzpatrick, Bruce Rapps, Brian Dalsing, Sam Veda, Steve Gaffield, Keith Ligler, Scott Hulse, Dick Mihalek, Ross Bagwell, Suzanne Femmer, Herb Wright, and last but not least, my son Billy Fitzpatrick.

Digging through historical archives at a variety of state and local agencies also involved many unnamed individuals employed at the Wisconsin Department of Transportation in Superior, Washburn, and Madison, Wis. Three historical societies also were very helpful in tracking down century-old publications and photographs: the Washburn Historical Society, the Ashland Historical Society, and the State Historical Society of Wisconsin.

The multi-disciplinary nature of the project also involved several individuals from various Departments at the University of Wisconsin-Madison, the University of Iowa, and the U.S. Geological Survey, and the Wisconsin Geological and Natural History Survey for assistance in data analyses. Of special note is the time and effort Jim Knox put in to listening to my rambling on the six-hour drive to Ashland, Wis., and the thorough review of my first draft. Ken Potter was extremely helpful in providing guidance for the runoff and sediment transport modeling. Early on, Dave Mickelson assisted in characterization of the glacial stratigraphy in the basin. Chris Kent spent many hours analyzing sediment samples for particle size and organic carbon content. Marge Winkler examined several samples for diatoms. David McJunkin prepared several samples for radiocarbon age determinations. Reid and Robert Bryson helped me with the

macrophysical paleoclimate model for the Ashland Experimental Farm. John Attig made sure my Holocene lake level reconstructions were correct. Dick Baker analyzed selected samples for macrofossils. Todd Stuntebeck provided useful guidance for using HEC-I software. Bob Jarrett provided useful guidance to see me through the U.S. Geological Survey's graduate school program and the runoff modeling. Bill Rose provided comments and guidance on the hydrologic and sediment loading aspects of the study.

Field-based projects are not possible without the acceptance of local land owners, especially where bridges are scarce and the landscape is rugged. David Skulan, the Fiorios, the Mihaleks, the Martinsens, the Johaniks, the Palmers, the Sutariks, Betty Hanson, and Mr. Moore were especially helpful in allowing me access to the stream through their property. Most of these families are descendants from the first European settlers, and their spunk and deep care for their land and North Fish Creek are immediately apparent.

I am deeply grateful to the support I have received from my two Bills. Hopefully, neither has suffered irreversible damage from eating too much frozen or take out food! I know my mom is proud to have her daughter (the perpetual student) finally out of school, maybe this time for good.

Lastly, this dissertation is dedicated to Hilt Johnson, my Master's advisor, who saw me through a very rough transition period after my father's death, and gave me the incentive to even think about getting a Ph.D. Can you get your boots dirty in heaven?

Table of Contents

Abstract i

Acknowledgments ii

Table of Contents iv

List of Figures vii

List of Tables x

List of Appendices xi

Chapter 1. Introduction 1

Research questions 4

Terminology 4

Description of North Fish Creek 5

Surficial geology 5

Soils 8

Climate 9

Vegetation and land use 11

Modern sources of sediment 11

Background on geomorphic response to disturbance mechanisms 14

Forest clearing 14

Climate change 18

Base-level change 18

Chapter 2. Methods 20

Erosion/sedimentation measurements 20

Field methods 20

Laboratory methods 26

Historical documents 30

Flood reconstructions 32

Channel geometry 33

Discharge estimation (HEC-2) 33

Climate reconstructions 35
Historical precipitation records 35
Macrophysical paleoclimate modeling 36
Vegetation reconstructions 37
Rainfall/runoff modeling (HEC-1) 38
Streamflow data collection 39
Model input 39
Sediment-load modeling 49
Suspended-sediment concentration and particle-size analyses 49
Sediment discharge and load calculations 50
Chapter 3. Post-settlement changes in geomorphic and hydrologic conditions (1870-1995) 52
Post-settlement changes in vegetation, climate, and base level 52
Vegetation 52
Climate 60
Base level 60
Flood history 62
Post-settlement sediment budget 64
Field evidence of post-settlement geomorphic and hydrologic change 70
Bluff erosion rates and sediment characteristics 70
Channel width and streambed sediment 76
Upper mainstem channel erosion (reaches 4 and 5) 78
Transition conditions (reach 3) 90
Sedimentation in lower mainstem (reach 2) 97
Sedimentation in Fish Creek Slough (reach 1) 115
Changes in the size of low-magnitude high-frequency floods 123
Model of land-use effects on storm runoff and sediment yield 127
Effects on storm hydrographs and sediment yield 127
Effectiveness of detention basins for reducing erosion 130

Conclusions 132

Chapter 4. Holocene changes in geomorphic conditions 135

Holocene changes in vegetation, climate, and base level 135

Vegetation and climate 135

Base level 141

Holocene alluvial chronology for Midwest streams 144

Holocene history of degradation and aggradation in North Fish Creek 145

Conclusions 154

Chapter 5. Geomorphic and hydrologic responses of North Fish Creek to disturbance factors 157

Chapter 6. Conclusions and suggestions for future work 160

References cited 163

Appendices 174

List of Figures

1. Location of North Fish Creek 6

2. Longitudinal profiles of North Fish Creek and South Fish Creek 7

3. General soils map for the North Fish Creek drainage basin 10

4. Land cover characteristics of the North Fish Creek drainage basin 12

5. Eroding bluff along North Fish Creek near river kilometer 27, sec. 20, T47N, R6W, 1994 and 1996 15

6. Sites where stratigraphic and channel cross-section data were collected along North Fish Creek 21

7. Locations of cores in Fish Creek Slough and Chequamegon Bay and Fish Creek channels in 1906 23

8. Location of subbasins above North Fish Creek gaging station used to model storm hydrographs for different land use conditions 41

9. Photographs of North Fish Creek at railroad crossing, section 3/10, T47N, R5W, Ashland Junction 57

10. Precipitation events greater than 7.6 centimeters (3 inches), Ashland Experimental Farm, Wis., 1990-97 61

11. Diagram of long-term annual sediment budget for North Fish Creek at river kilometer 3 (reach 5), in tonnes per year 68

12. Locations of large eroding bluffs along North Fish Creek, 1990 71

13. Example stratigraphy and particle-size distribution of bluffs along North Fish Creek, reach 5, exposure E-25 74

14.Legend for all figures with stratigraphic diagrams 75

15. Channel cross-section surveys of the modern and relict channels of North Fish Creek in reach 5, Bayfield/Ino site 80

16. Diagrammatic map of cross sections and core locations along North Fish Creek at the Moore site, reach 5 81

17. Cross-section surveys of the modern and relict channels of North Fish Creek in reach 5, Moore site 83

18. Valley cross section along North Fish Creek in reach 5, Moore site 84

19. Cross sections of the modern channel of North Fish Creek in reach 4 85

20. Typical sedimentary sequence of low terraces in reach 4, Bayfield site 86

21. Diagrammatic map of cores and exposures at the Moquah site, reach 4 88

22. Stratigraphic descriptions of cores and exposures at the Moquah site, reach 4 89

23. Particle-size distribution of channel deposits in North Fish Creek 91

24. Particle-size distribution of sand-sized sediment in channel deposits, North Fish Creek 92

25. Cross sections of the modern channel of North Fish Creek in reach 3 93

26. Diagrammatic map of cross sections and core locations along North Fish Creek, Skulan site, reach 3 94

27. Stratigraphic descriptions of cores and exposures along North Fish Creek in reach 3 96

28. Surface elevations and buried cross sections of the pre-1946 relict channel of North Fish Creek in reach 3, Skulan site 98

29. Stratigraphic descriptions of cores along cross section 1-1, pre-1946 channel at the Skulan site, reach 3 99

30. Stratigraphic descriptions of cores along cross section 1-4, pre-1946 channel at the Skulan site, reach 3 100

31. Comparison of cross sections from the modern and pre-1946 channel of North Fish Creek at the Skulan site, reach 3 101

32. Cross sections of the modern channel of North Fish Creek in reach 2 103

33. Diagrammatic map of cross sections and core locations along North Fish Creek, Hanson site, reach 2 104

34. Stratigraphic descriptions of cores along cross sections 7-1, 8-2, 8-3, and 9-1 at the Hanson site, reach 2 105

35. Particle-size distribution of selected samples collected from the floodplain at the Hanson site, reach 2 106

36. Diagrammatic map of core locations along North Fish Creek at the Fiorio site, reach 2 108

37. Stratigraphic descriptions of cores near section line 2/3, T47N, R5W, Fiorio site, reach 2 109

38. Stratigraphic description of core G-6, sec. 2, T47N, R5W, Ashland Junction site, reach 2 112

39. Diagrammatic map of core locations along North Fish Creek, Ashland Junction site, reach 2 113

40. Stratigraphic descriptions of cores along cross section 4-1, sec. 2, T47N, R5W, Ashland Junction site, reach 2 114

41. Stratigraphic description of core G-7, along section line 1/2, T47N, R5W, Martinsen site, reach 1 117

42. Selected core descriptions from Fish Creek Slough and Chequamegon Bay 119

43. Concentration of ^{210}lead, ^{137}cesium, and ^{226}radium in core P-7, Fish Creek Slough backwater, Sept. 1995 121

44. Longitudinal profile, stream width changes, and selected cross sections of the modern and relict channels for North Fish Creek 128

45. Storm hydrographs for North Fish Creek near Moquah, Wis. for a historical storm on September 3, 1991, under different land-use conditions 129

46. Estimated sediment yields for a historical storm on September 3, 1991, under different land-use conditions, North Fish Creek at gaging station 131

47. Comparison of Holocene vegetation and climate reconstructions for sites in Wisconsin, Minnesota, and Michigan 137

48. Comparison of vegetation and climate reconstructions over the past 2,000 years for sites in the northern Midwest and east coast of the U.S. 138

49. Modeled Holocene precipitation and temperature for the Ashland Experimental Farm, Ashland Junction, Wis. based on results from a macrophysical paleoclimate model 139

50. Diagram comparing Holocene alluvial chronology for the Midwest, general Holocene climatic reconstruction for North Fish Creek, and Holocene altitudes of Lake Superior for the Chequamegon Bay area 143

51. Summary of Holocene alluvial chronology in North Fish Creek and Fish Creek Slough 147

52. Estimated Holocene longitudinal profiles for North Fish Creek 148

53. Detailed stratigraphic description of core P-19, Fish Creek Slough backwater 153

List of Tables

1. Land-cover characteristics of the North Fish Creek drainage basin 13

2. Climate stations near North Fish Creek 36

3. Input parameters used for the HEC-1 runoff model of North Fish Creek 42

4. Curve numbers for land use and soil types in the North Fish Creek subbasins 44

5. Characteristics for routing flows through simple channel designs, North Fish Creek 47

6. Characteristics for routing flows through channels with cross-section data, North Fish Creek 48

7. Empirical sediment transport equations for North Fish Creek near Moquah, Wis 51

8. Differences in annual sediment loads for North Fish Creek near Moquah, Wis., between two sets of sediment transport equations 51

9. Logging and fishing history of North Fish Creek, 1870-1890 54

10. Land cover statistics from the 1928 Land Economic Inventory for North Fish Creek 59

11. Long-term and short-term annual sediment budgets for North Fish Creek at river kilometers 3, 17, and 28, in tonnes/year 66

12. Bluff erosion data for North Fish Creek, 1938 and 1990 72

13. Comparison of channel width and streambed-sediment characteristics in 1855 and 1995 77

14. Cross-section characteristics and estimates of bankfull and channel capacity flows for the modern channel and relict channels 124

List of Appendices

Appendix A. Particle-size analyses and organic carbon determinations 174

Particle-size analyses and organic carbon determinations (Walkley-Black method) of floodplain and channel sediment along North Fish Creek Wisconsin, 1995 175

Comparison of sediment texture classification in the field and laboratory 187

Appendix B. Results from radiometric dating 188

Results from radiocarbon age dating of selected samples from North Fish Creek 189

Results from Pb-210, Cs-137, and Ra-226 age dating 191

Appendix C. Results of macrofossil analyses of selected core samples 192

Appendix D. Stratigraphic descriptions of selected cores and streambank exposures 196

Exposure E-7, Bayfield/Ino site 197

Exposure E-25, Bayfield site 203

Exposure E-8, Moquah site 213

Core C-24, Skulan site 215

Core VC-3, Hanson site 217

Core VC-5, Hanson site 219

Core VC-6, Hanson site 221

Core VC-8, Hanson site 224

Core G-1, Hanson site 227

Core G-6, Hanson site 233

Core C-40, WDNR/Ashland Junction site 236

Core C-45, WDNR/Ashland Junction site 238

Core C-54, WDNR/Ashland Junction site 240

Core G-7, Fish Creek Slough 242

Core P-19, Fish Creek Slough 248

Appendix E. Channel cross-section data 250

Cross sections 1-1 through 1-5, Skulan site 251

Cross sections 2-1 through 2-5, Skulan site 252
Cross sections 3-1 through 3-5, Fiorio site 254
Cross section 4-1, WDNR/Ashland Junction site 255
Cross sections 5-1 through 5-5, Moore site 256
Cross sections 6-1 through 6-5, Moore site 258
Cross section 7-1, Hanson site 260
Cross sections 8-1 through 8-5, Hanson site 261
Cross section 9-1, Hanson site 263
Cross sections 10-1 and 10-2, Torkko site 264
Cross sections 11-1 and 11-2, Sutarik site 265
Cross sections 12-1 and 12-2, Mihalek site 266
Cross sections 15-1 and 15-2, Brandis site 268
Cross sections 16-1 and 16-2, Nekoosa site 269
Cross sections 17-1 and 17-2, Nekoosa site 270
Cross sections 18-1 and 18-2, Johanik/DNR site 271
Cross sections 19-1 and 19-2, Johanik/DNR site 272
Cross sections 20-1 and 20-2, Bayfield site 273
Cross sections 21-1 and 21-2, Skulan site 274
Cross sections 22-1 and 22-2, Bayfield/Ino site 275

CHAPTER 1
INTRODUCTION

The purpose of this study was to determine the long-term geomorphic and hydrologic responses and recovery rates for North Fish Creek to human-induced changes in vegetation and natural changes in base level and climate. Human factors, although undoubtedly present to some extent prior to European settlement, were particularly important after European settlement because of widespread clear-cut logging, burning, log driving, and farming.

North Fish Creek, a tributary to Chequamegon Bay in Lake Superior along the Wisconsin shore near Ashland, Wis. (fig. 1), was selected for this study because it contains an important fishery, its aquatic habitat is limited because of erosion and sedimentation problems, and its geomorphic response is not limited by a bedrock control. It also serves as a good example of many streams on clay soils in the northern Midwest that also experienced clear-cut logging, fires, log drives, and agricultural activity following European settlement.

Characteristics of North Fish Creek include eroding bluffs and stream banks along the upper mainstem; sedimentation along the lower mainstem and mouth; and possibly increased frequency and magnitude of floods. In the past, large floods have caused destruction of stream banks and severe erosion in North Fish Creek (Johannes and others, 1970).

Even with its erosion and sedimentation problems, North Fish Creek contains the second largest natural anadromous fish population in the state of Wisconsin and contributes approximately 15 percent of the total anadromous fishery in Wisconsin waters of Lake Superior through its production of steelhead, coho salmon, brown trout, and northern pike (B. Swanson, Wisconsin Department of Natural Resources, written commun., 1994). However, gravel beds are being smothered by large amounts of sand, and pools, important for fish overwintering, are being filled (B. Swanson, Wisconsin Department of Natural Resources, written commun., 1994). Fish managers also are concerned that if the sedimentation problem worsens, it could have a detrimental impact on the recovering salmon and trout populations in Lake Superior (B. Swanson, Wisconsin Department of Natural Resources, written commun., 1994).

North Fish Creek flows into Fish Creek Slough, one of the few remaining fresh-water coastal wetlands in the Great Lakes. The Slough is an important nursery area for nearly every variety of fish found in Lake Superior and is a major spawning area (Pratt, 1981). Several endangered bird species also are found in the Slough and the wetland provides a major nesting area for waterfowl. Sediment derived from the watershed of North Fish Creek may be negatively influencing this rare ecological niche, and may be causing degradation of fish and wildlife habitat (Dickas, 1973).

Wisconsin shorelines and streams are contributing the majority of sediment to Lake Superior (Kemp and others, 1978; Sydor and others, 1979; Bowden, 1975; Stortz and others, 1976; Shuter and others, 1978; Natural Resources Conservation Service and U.S. Forest Service, 1998; Robertson, 1996). Approximately 5.5 million tonnes of fine-grained sediment is deposited annually in Lake Superior (Kemp and others, 1978). Erosion of red clay bluffs in Wisconsin are estimated to produce up to 58 percent of the sediment to lake Superior, whereas, tributaries contribute 30 percent of the sediment load (Kemp and others, 1978). However, there have been no studies that contain detailed information on the amount of sediment contributed by tributaries in Wisconsin over a long period of time. While the sedimentation rate appears to have increased in western Lake Superior historically (Kingston, 1987; Evans and others, 1981), it is not known if this increase is due to greater shoreline erosion, tributary inputs, or a combination of both.

The long-term effects from the interaction of decade-scale climatic events, land use changes, base-level changes, and geomorphic feedback mechanisms on watershed characteristics are not well understood. The sedimentation problem in North Fish Creek and other streams in the Lake Superior region may have been caused by historical logging, subsequent burning, and conversion of the land to agriculture during European settlement of the region in the late 1870's (Dickas, 1973). However, long-term geomorphic disturbance from land use change, which began more than a century ago has not been rigorously examined. Prior to this investigation, no studies of the land-use effects on Wisconsin tributaries to Lake Superior had been done. The nearest study on the geomorphic effects of logging and burning following European settlement was conducted on Indian Creek, a tributary to Lake Michigan in the upper peninsula

of Michigan (Benchley and others, 1993), and no evidence of geomorphic change from logging could be found in that watershed. The only Holocene geomorphic change noted for Indian Creek was downcutting immediately following deglaciation (Benchley and others, 1993).

Fluvial response to climatic events is sometimes difficult to separate from land use changes. For example, a cool, wet climatic episode in the late 1800's (Knox and others, 1976) coincided with the most intense period of logging and burning in the region (Smith and Goc, 1987; Mahaffey, 1977). During the same time period some of the highest levels were recorded in Lake Superior (U.S. Department of Commerce, 1973). Another example is the series of frequent, extreme floods that occurred in the late 1940's and early 1950's in the upper Midwest (Knox and others, 1975). These floods coincided with a period of major agricultural activity in the North Fish Creek watershed.

Other studies in areas where human activity has been more intense have pointed to substantial geomorphic change from human-induced vegetation change (Knox, 1977; Knox 1987; Jacobson and Primm, 1997). For example, in southwest Wisconsin, where pre-settlement vegetation was almost entirely converted to cropland and pasture, low-magnitude high frequency flows on tributaries to the Mississippi River have increased 3 to 5 times and historical sedimentation is as great as 4 meters (m) (Knox, 1977; Knox 1987). In addition, logging and burning of forests and conversion of bottomlands to agriculture (cropland and pasture) of Missouri streams in the Ozark Plateaus over the last 200 years have caused accelerated channel aggradation (Jacobson and Primm, 1997).

Little is known about how stream morphology is influenced by changes in lake levels in the Great Lakes throughout the Holocene. Detailed studies are available on past shorelines and inferred lake levels since deglaciation for the Lake Superior region, yet little is known about how effects of relative base level changes during the Holocene influenced episodes of aggradation or degradation in lower reaches of tributary streams and how these effects were promulgated upstream. North Fish Creek is deeply incised in glacial deposits, and bedrock has not been a limiting factor in its development. Thus, deposits in the floodplains and terraces of

North Fish Creek provide both a better understanding of how lake levels changed during the Holocene, as well as information about how lake level changes influence sediment dynamics in the lower reaches of tributary streams.

Research Questions

Research for this study was driven by the following major questions:

(1) How have the geomorphology and hydrology of North Fish Creek been altered by changes in vegetation or land use, specifically logging, burning, and log drives?

(2) How has the geomorphology of North Fish Creek responded to subsequent changes in land use after European settlement?

(3) Prior to European settlement, what effects have changes in vegetation, climate, and base level had on the geomorphic response and recovery of North Fish Creek?

(4) Will construction of detention basins in the headwaters decrease streambank erosion along the upper mainstem of North Fish Creek?

Terminology

This paragraph briefly describes some of the terminology used in this thesis. "Pre-settlement" refers to the time period prior to European settlement of the drainage basin of North Fish Creek. "Historical" or "post-settlement" refers to the time period from 1870 to the present, or approximately the last 125 years. The year 1870 was selected as the transition year because massive clear-cut logging by European settlers occurred shortly after this year. European explorers and fur traders entered the region a few centuries earlier, but their impacts on vegetation and hydrology were assumed to be more localized due to their small numbers.

"Relict channels" are old channels of North Fish Creek that have been abandoned as the stream shifted to a new location. Most of the shifts in channel location on North Fish Creek occur during large floods. During the largest flood on record, which occurred in 1946, the channel of North Fish Creek changed its location in many places.

Description of North Fish Creek

North Fish Creek drains approximately 195 km^2 of the Bayfield peninsula (Bayfield County) in northern Wisconsin and flows in a northeasterly direction into Fish Creek about 1 km upstream of Chequamegon Bay, Lake Superior at the confluence with South Fish Creek. The mouth of North Fish Creek and Fish Creek Slough are located about 1 km west of Ashland, Wisconsin (fig. 1). Stream length of North Fish Creek is approximately 40 km from its mouth at Lake Superior to its headwaters (fig. 2) and the drainage basin has approximately 180 m of relief. Along this length, the stream can be divided into seven reaches based on similar gradient (figs. 1 and 2). Channel gradients range from approximately 0.00127 m/m in reach 1 to 0.0159 m/m in reach 7.

The entire basin had a 1970 population of about 1,000 people, with an approximate population density of 2.6 people per square kilometer (Dickas, 1973, p. 79). Several small communities are present in the basin: Benoit, Moquah, and Ino. There are no point-source discharges in the drainage basin, although some hay fields are tiled. There are only four road crossings along the mainstem of North Fish Creek (fig. 1). Three road crossings are for U.S. Hwy 2. The other is for old U.S. Hwy 2 near Moquah.

Surficial Geology

The surficial geology of the watershed consists mainly of the Douglas Member of the Miller Creek Formation underlain by the Copper Falls Formation (Clayton, 1984; Clayton and others, 1991; Need and Johnson, 1984; Johnson, 1980). The Douglas Member consists of a reddish-brown clay till with an average composition of 10 percent sand, 26 percent silt, and 64 percent clay (Mickelson and others, 1984). This till is typically called the "red clay" in the region (Mickelson and others, 1984) and is up to 20 m thick (Clayton, 1984). It was deposited during the last glacial re-advance in the Lake Superior region (the Marquette advance) and was deposited between 11,000 and 9,500 ^{14}C yr B.P. (Clayton, 1984; Farrand and Drexler, 1985).

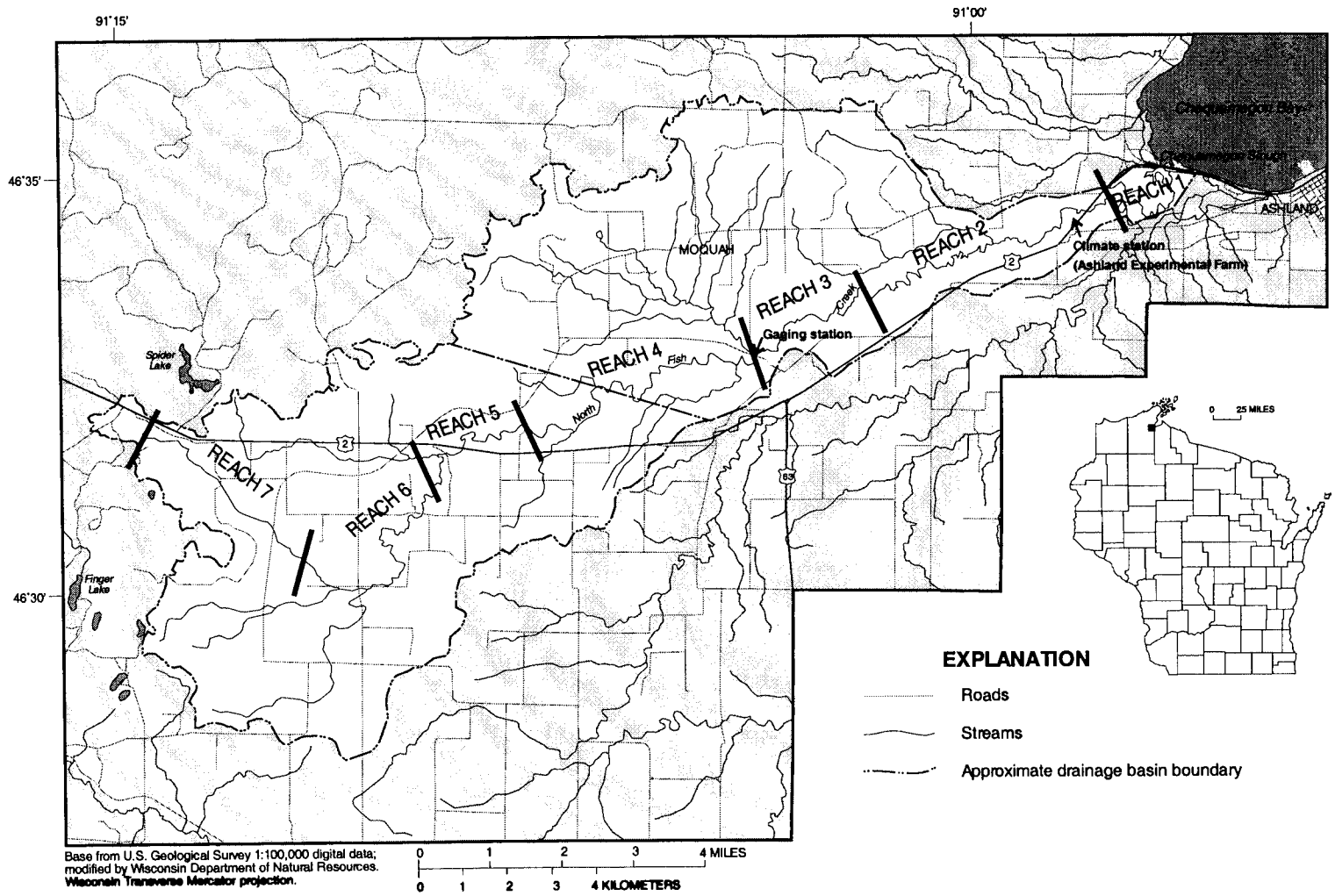


Figure 1. Location of North Fish Creek.

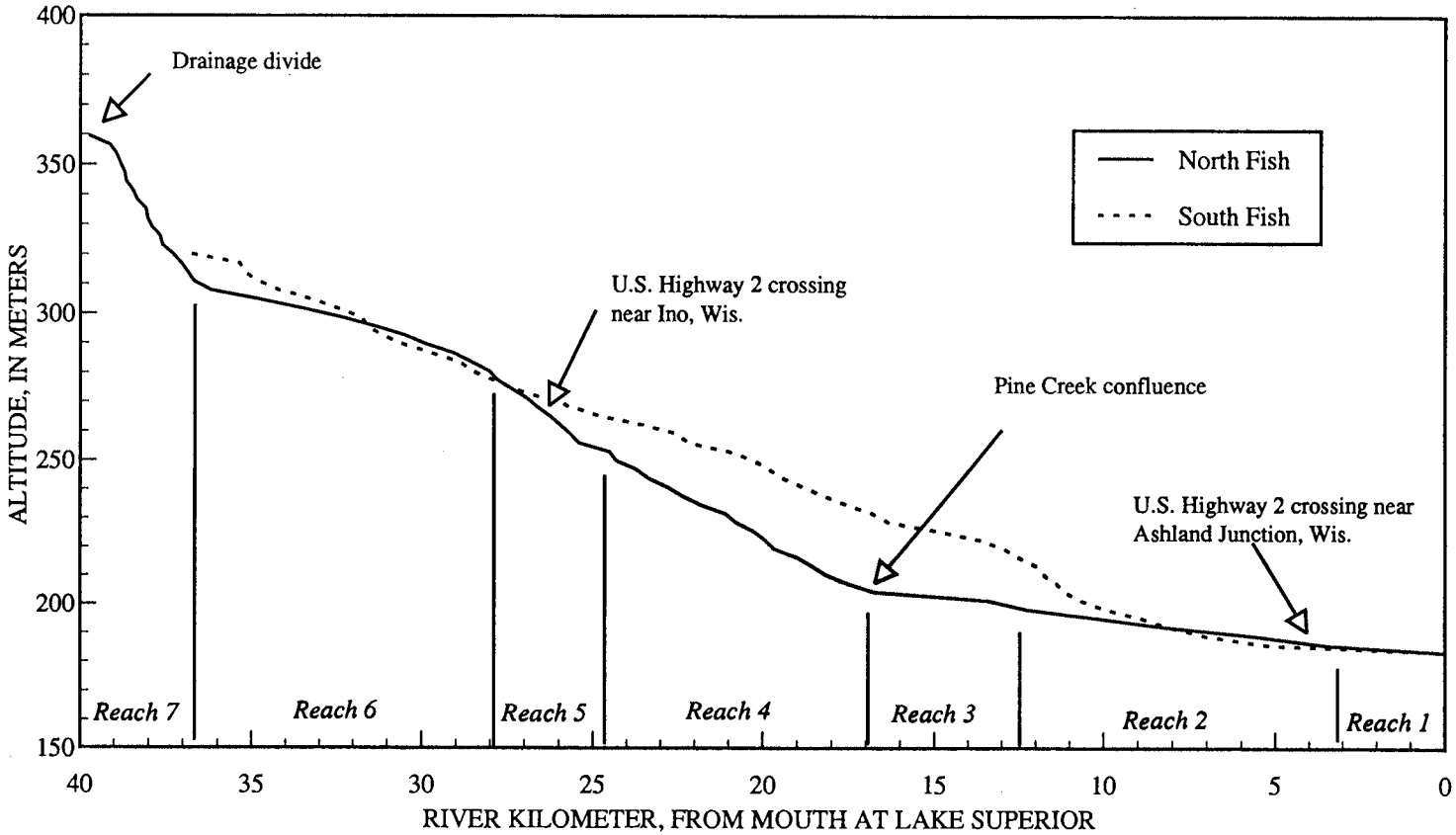


Figure 2. Longitudinal profiles of North Fish Creek and South Fish Creek.

The till surface has been modified by lacustrine activity during higher levels of Lake Superior, with evidence of hummocky collapse topography thought to be caused by deposition of water-logged till or modification of the till by wave erosion (Clayton, 1984).

Along the northern and southwestern edge of the drainage basin, wave erosion during former higher levels of Lake Superior has exposed Copper Falls Formation where the Miller Creek Formation was worn away (Clayton, 1984). Sand deposits, associated with former near-shore environments, also are present (Clayton, 1984). The Copper Falls Formation consists of mostly fluvial sand and gravel in the middle and upper strata, but contains coarse-grained glacial till near the base of the sequence (Clayton, 1984). The Copper Falls Formation was deposited prior to 11,000 ^{14}C yr B.P. (Farrand and Drexler, 1985). The Copper Falls Formation is exposed in many of the 25-m high bluffs along the mainstem of North Fish Creek (Clayton, 1984).

Holocene stream sediment in the North Fish Creek valley was mapped by Clayton (1984) in reaches 1 and 2. Upstream of reach 2, the valley is too narrow to show Holocene stream sediment given the scale of the map in Clayton (19840. Holocene peat or organic sediment occurs in the eastern one third of Fish Creek Slough, and the western two thirds of Fish Creek Slough contains Holocene stream sediment (Clayton, 1984).

Soils

The soils in the watershed mainly consist of silty clay loam and loamy sand (Hole, 1976, p. 109–114). Upland soils mainly belong to two groups: those found in coarse-textured upland and outwash plains, and those found in fine- to coarse-textured lake plains (U.S. Department of Agriculture, Soil Conservation Service, 1961; 1975; 1978). Figure 3 shows the general soil types in North Fish Creek. The coarse-textured upland and outwash soils formed in loamy sand or sandy loam include haplorthods and fragiorthods (Vilas-Omega and Gogebic-Cloquet associations). Fine textured lake or till plain soils formed in silty clay or silty clay loam include haplaquents, eutroboralfs, and haplorthods (Ontonagon-Pickford and Orienta-Superior associations). The Ontonagon-Pickford association contains the most important soils for agricultural

use in Bayfield County. Soils formed in loamy floodplain or terrace sediment include fluvaquents, udifluvents, and udorthents (U.S. Department of Agriculture, Soil Conservation Service, 1975; 1978).

Soil infiltration rates in the North Fish Creek watershed are quite variable, and represent the full range of infiltration rates reported for Wisconsin (Krug and others, 1992; Young and Skinner, 1974). The soils developed in the clay-rich Douglas Member of the Miller Creek Formation (Ontonagon-Pickford Association) along the mainstem and in the southern headwaters have a very low infiltration rate of 0.25 centimeters (cm) per hour. The rate of precipitation and/or snowmelt commonly exceed 0.25 cm per hour; therefore, North Fish Creek is characterized as a flashy stream with frequent, large floods.

Soils developed in the sandy sediments associated with the Copper Falls Formation (Vilas-Omega Association) in the northern headwaters of North Fish Creek have an infiltration rate of 19 cm per hour and thus little surface runoff occurs there. No perennial streams are present in this area of recharge known locally as the "barrens". The recharge from the sand barrens supplies abundant springs that discharge to the middle and lower reaches of North Fish Creek. The flow from these springs causes exceptionally high baseflow in North Fish Creek compared to typical Wisconsin streams with the same size watersheds. These springs are the main factor that make North Fish Creek an outstanding fishery.

Climate

The regional climate of the watershed is dominated by three air masses: the cold, dry polar continental air mass from the arctic and northwestern Canada, the warm, moist maritime tropical air mass from the Gulf of Mexico, and the mild, temperate maritime polar air mass from the Pacific (Eichenlaub, 1979). In addition, the local climate is influenced by the moderating affects of Lake Superior. In general, average annual precipitation is 81 cm and runoff is 36 cm a year (Gebert, 1986). Mean daily July maximum temperature is 25.5° C and mean daily January maximum temperature is -4.5° C. Average annual snowfall is approximately 178 cm (70

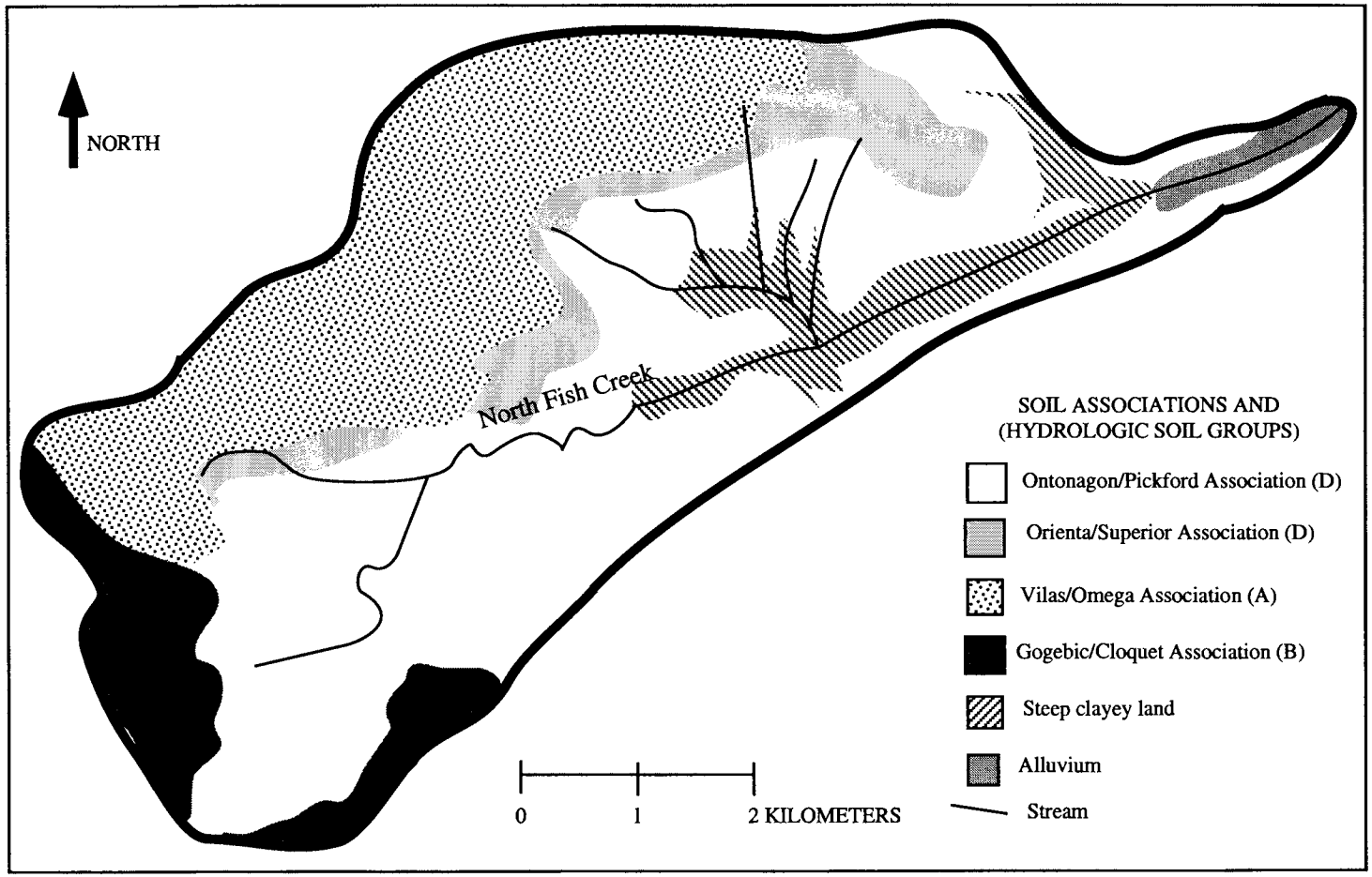


Figure 3. General soils map for the North Fish Creek basin (modified from U.S. Department of Agriculture, 1975).

in.) (Eichenlaub, 1979). There are approximately 120 frost free days annually (Phillips and McCulloch, 1972). Because of the cool temperatures and short growing season, the ratio of precipitation to evapotranspiration is high compared to the southern part of Wisconsin.

Vegetation and Land Use

The drainage basin of North Fish Creek is located in the northern hardwood forest region (Curtis, 1959). Present-day early successional forests in the watershed are typically less than 30 years old and they are mainly composed of deciduous trees (mainly aspen) or a mix of deciduous and coniferous trees (table 3 and fig. 4). Because these forests are harvested every few decades for pulp, very little mature boreal forest currently is present in the watershed. However, based on 1992 satellite data (WISCLAND), forested land accounts for over half of the land cover in the drainage basin (57 percent). Over one third of the drainage basin is classified as grassland (31 percent). The WISCLAND classification system does not distinguish between ungrazed and grazed grassland. In the North Fish Creek basin, land cover classified as grassland is a combination of grazed or abandoned pasture for mainly dairy or beef cattle. Less than 3 percent of the drainage basin is used for forage crops. Land cover in the remainder of the basin consists of coniferous forest (3 percent), different types of wetland (5 percent), barren land (gravel bars in the floodplain of North Fish Creek, 1 percent), and shrubland (1 percent).

Modern Sources of Sediment

Annual total sediment loads in 1990 and 1991were determined for three sites along North Fish Creek by Rose and Graczyk (1996). The average annual total sediment load for 1990 and 1991 from the headwaters of North Fish Creek (upstream of river kilometer 29) was 450 tonnes (Rose and Graczyk, 1996). However, at river kilometer 17, the average 1990-91 sediment load was 13,790 tonnes (Rose and Graczyk, 1996). Thus, the sediment load at river kilometer 17 was 31 times larger than at river kilometer 29, even though the drainage area is only 2 times larger than at river kilometer 29. This strongly suggests that the majority of sediment transported by North Fish Creek is derived from large eroding bluffs, and upland erosion probably is not contributing the majority of sediment to the stream. Photographs of one of the large bluffs

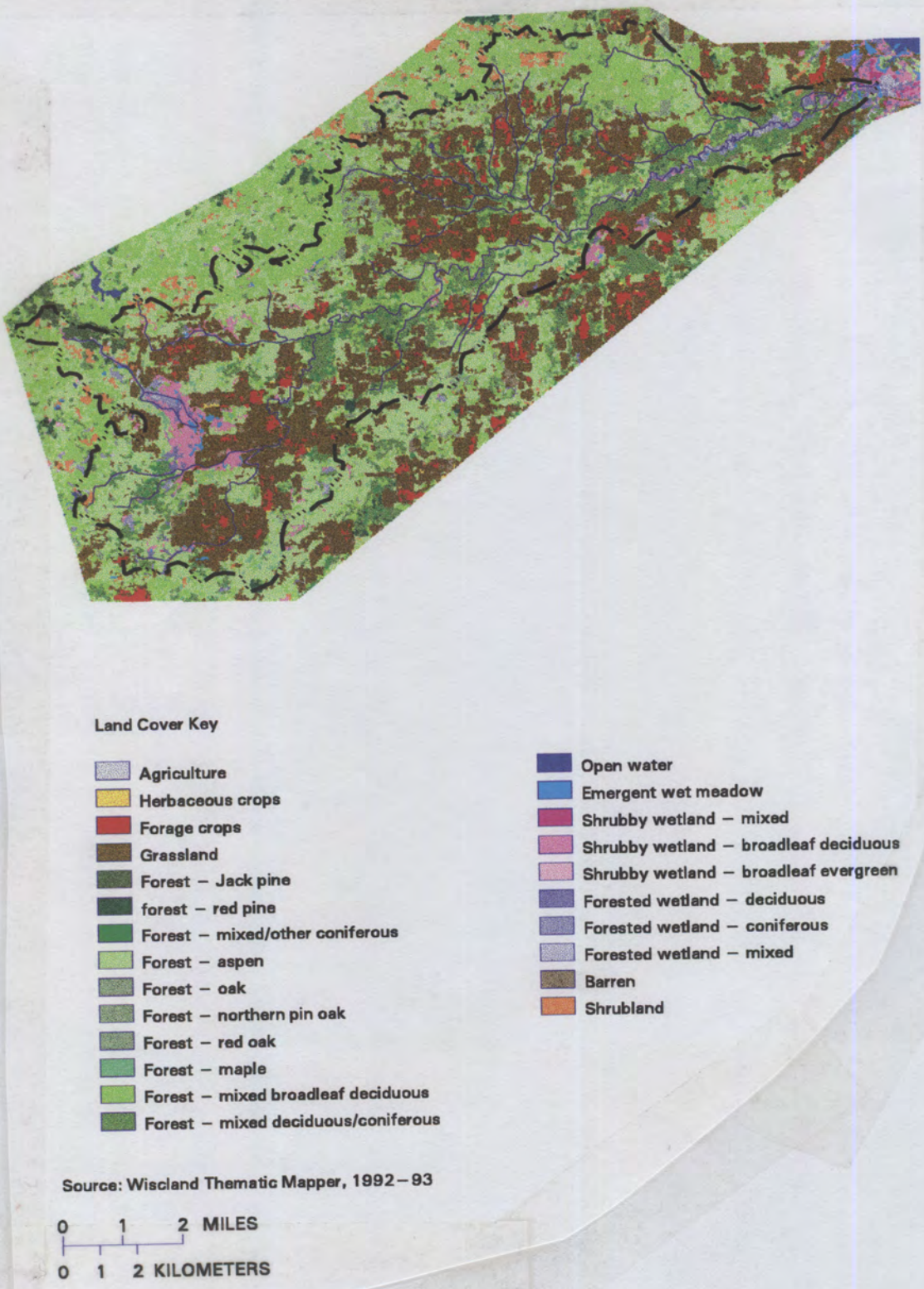


Figure 4. Land cover characteristics of the North Fish Creek drainage basin.

Table 1. Land-cover characteristics of the North Fish Creek drainage basin
[Data are based on 1992 satellite data (WISCLAND).]

Land-cover category	Percent of drainage basin
Agriculture	2.7
Other herbaceous field crops	.1
Forage crops	2.6
Grassland	31.0
Coniferous forest	1.9
Jack pine forest	.6
Red pine forest	.5
Mixed/other coniferous forest	.8
Deciduous forest	43.5
Aspen forest	21.2
Oak forest	1.6
Northern pin oak forest	.1
Red oak forest	.1
Maple forest	.5
Mixed/other broad-leaved deciduous forest	20.0
Mixed deciduous/coniferous forest	12.9
Open water	.1
Emergent wet meadow	.3
Shrub wetland	2.4
Lowland shrub wetland	.1
Broad-leaved-deciduous lowland shrub wetland	2.3
Forested wetland	2.5
Broad-leaved-deciduous forested wetland	1.2
Coniferous forested wetland	.9
Mixed deciduous/coniferous forested wetland	.4
Barren	1.4
Shrubland	1.3

along North Fish Creek in 1994 and again in 1996 (fig. 5) show observable retreat of the bluff and substantial change in channel characteristics in only a 2-year period. A sediment budget from a nearby stream, the Nemadji River, showed that approximately 89 percent of the fine sediment load was contributed by bluff and streambank erosion (Natural Resource Conservation Service and the U.S. Forest Service, 1998).

Background on Geomorphic Response to Disturbance Mechanisms

Three major disturbance mechanisms have influenced the geomorphic characteristics of North Fish Creek. They are changes in vegetation, climate, and base level. The largest disturbance of vegetation resulted from clearing of forests following European settlement, with minor variations during the Holocene. Major climate and base-level changes occurred during the Holocene, with minor climate and base-level changes following European settlement.

Forest Clearing

A change in the amount and type of vegetation in a watershed affects the soil infiltration capacity and thereby affects the pathways by which water enters the stream. Specifically, major factors affecting surface runoff and erosion that are related to vegetation include infiltration, interception, production of organic matter, hydraulic roughness, and infiltration (Dunne and Leopold, 1978; Lowdermilk, 1934).

The removal of forest vegetation has been shown to increase surface runoff and baseflow by the reduction of infiltration, interception, and hydraulic roughness. The increase in surface runoff leads to greater stream power and potential for erosion, gullying, and sediment transport (Leopold and Maddock, 1953).Verry (1986, 1987), in his studies of logging effects on streamflow in northern Minnesota, found that clear-cut logging increased annual snowmelt generated peak flows from 11 to 143 percent. Snowmelt peak flows remained above pre-harvest levels for nine years and also appeared to come several days earlier in the season. Rainfall generated peak flows during the first two years after logging increased by 259 percent and then gradually returned to pre-harvest levels. Storm volumes from surface runoff increased as much as 170 percent.

1994

1996

Figure 5. Eroding bluff along North Fish Creek near river kilometer 27, sec. 20, T47N, R6W, 1994 and 1996.

Other studies also have shown that a decrease in forest cover causes increases in peak flows (Vale, 1982; Hetherington, 1987; Anderson and others, 1976, Reinhart and others, 1963) and annual water yield (Dunne and Leopold, 1978; Hetherington, 1987; Anderson and others, 1976; Verry, 1987; Lynch and others, 1987). Usually these conditions are most noticeable immediately following the clear-cut event and, eventually, streamflow returns to normal if forest cover returns. Recovery is reported to take from only of few years to up to 80 years (Reinhart and others, 1983; Anderson and others, 1976).

Forest evapotranspiration also significantly reduces the amount of water available for runoff and ground-water recharge. In southwestern Wisconsin, results from a soil-water depletion study comparing an uncut forest and a clear-cut forest (Sartz, 1972) indicated that forests can extract water from depths of up to 240 cm and that losses of soil water during the growing season are substantial compared with clear cut land.

If forest cover is not allowed to return after logging, like the watershed of North Fish Creek, and is replaced by immature forest and agriculture, the hydrologic response is more complex than that described above. Although agricultural development was not as intense in the region of North Fish Creek as in southern Wisconsin, some parallel generalizations can be made from studies conducted for the Driftless Area of southwest Wisconsin. In the Driftless Area, hydrologic characteristics of streams were altered after a change in land cover from forest and prairie to agriculture (Knox, 1987). The initial fluvial response to increased floods and sediment loads associated with increased surface runoff included an increase in the frequency of overbank flooding and a subsequent increase in stream bank height (Knox, 1987). The increase in bank height resulted in larger channel capacities. Flood flows that previously spilled out into floodplain remained confined in the channel, which increased the erosive energy of the flow and accelerated channel migration and bank erosion. As the channel migrated, a new floodplain formed below the previous floodplain, and the previous floodplain became a low terrace which was flooded less often (Knox, 1987). Even after improved agricultural techniques, channel capacities are typically 3 times larger than pre-settlement channel capacities (Knox, 1987).

The fluvial response of North Fish Creek may be similar to streams in the Driftless Area in that increased surface runoff initiated by historic logging may have produced a larger channel capacity with greater potential for erosion and sediment delivery. The presence of coarse erosion-resistant cobble and boulder gravels underlying the beds of most Driftless Area channels caused the channels to respond to accelerated historical flooding by lateral bank erosion. However, for North Fish Creek the channel bottom has a high sand component, rendering it vulnerable to scour by the historically accelerated floods, and where channel gradients are steep as in the middle and upper mainstem, significant historical channel entrenchment has occurred and is mainly responsible for the enlarged channel capacity. Downstream in the mainstem of North Fish Creek where longitudinal gradients are flat, the abundance of relict meanders indicate that the stream has migrated significantly. The upper mainstem of North Fish Creek, where the stream gradient is steep, appear to have enlarged channel capacities and are experiencing degradation, while the lower mainstem where the gradient is flat is experiencing aggradation. It is not known exactly how changes in climate, vegetation, and isostatic rebound, and feedback mechanisms associated with channel hydraulics are interacting, but it is probable that they are interacting differently in different parts of the watershed. In addition, there may be an out-of-phase relation among the upper, middle, and lower mainstem.

The effects of clear-cut logging on the baseflow of North Fish Creek are not known; however, other studies have shown that not only does baseflow increase immediately following clear-cut logging and remain greater throughout all months due to decreases in transpiration, but a proportionally larger baseflow may be observed in the growing months (Reinhart and others, 1963). Some evidence also exists for differences in baseflow between pine and hardwood stands (Anderson and others, 1976; Dunne and Leopold, 1978). In general, water yields from pine stands tend to be less than from hardwood stands (Urie, 1966; Swank and Miner, 1968; Swank and Douglass, 1974) mainly because of differences in transpiration rate and growing season between the two groups.

Climate Change

Climatic conditions influence the geomorphic characteristics of streams by affecting the frequency and magnitude of runoff and sediment yield (Knox, 1983). Sediment yields are dependent on the type of vegetation and the seasonality of the precipitation (Walling and Webb, 1983). The response of stream systems to climatic change can be aggradation, degradation, lateral migration, or changes in the geometry of channels and sediment load. Streams in the United States appear to respond somewhat synchronously to major changes in climate during the Holocene (Schumm and Brakenridge, 1987), although the response is regionally different and appears to be related to vegetative type and density (Knox, 1983), physical setting (Knox, 1984), location within the drainage system, type of channel, potential stream power, and geomorphic sensitivity (Schumm and Brakenridge, 1987). Streams respond to hydrologic disturbance by altering their channel dimensions, gradient, meander wavelength, and sinuosity (Schumm, 1968).

In addition to long-term changes in climate, infrequent, large rainfall events also can trigger substantial geomorphic change in arid and humid environments (Patton and Baker, 1977; Baker and Costa, 1987; Osterkamp and Costa, 1987; Fox, 1976; Hack and Goodlett, 1966). These events, although rare, can cause the formation of stream terraces and new floodplains, and transport coarse sediment. High-frequency, low-magnitude flows also are important in rebuilding channel morphology after occurrences of large floods (Wolman and Leopold, 1957; Dury, 1964).

Base-Level Change

Strong base-level influence on hydrogeomorphic activity in many streams results from lake- or sea-level fluctuations, tectonic activity, formation of natural or anthropogenic dams, stream capture, and changes in downstream fluvial activity (for example, a low-order tributary stream entering a much higher order river). For North Fish Creek, base level change is mainly caused by changing levels of Lake Superior. For tributary streams to the Great Lakes, Larsen (1985b) suggested that rising lake levels result in aggradation at tributary mouths, while decreasing levels cause degradation at the tributary mouths.

Studies on small tributaries that drain into reservoirs with potentially large change in water levels indicate that a rapid rise in base level results in less erosion, whereas a rapid fall in base level results in more erosion (Vanderpool, 1980). These rapid changes resulted in localized changes in drainage basin development, but tens of thousand of years are required for base level change to affect upstream reaches in the basin (Vanderpool, 1980).

The development of the drainage systems of Lake Superior tributaries following deglaciation and a drop in lake levels was probably very rapid (Hack, 1965). Lake levels decreased rapidly within a period of about 800 years and dropped from a high of 330 m at 9,800 ^{14}C yr B.P. to a low of about 120 m by 9,000 ^{14}C yr B.P. (Farrand and Drexler, 1985; Clayton, 1984). This drop in base level of 210 m has not been duplicated either in intensity or magnitude since then. Hack (1965) concluded that the characteristics of the modern drainage systems to Lake Superior are determined more by discharge and sediment load than base-level change and that the modern streams are not in equilibrium.

CHAPTER 2
METHODS

The long-term geomorphic history of North Fish Creek was compiled by use of a variety of techniques, including collection and analyses of field data, laboratory analyses, and hydraulic modeling, and review of historical documents. These methods draw upon methods used in several scientific disciplines, including geography, geology, hydrology, hydraulic engineering, pedology, and climatology.

Erosion and Sedimentation Measurements

Characteristics of channel and floodplain sediments and channel geometry are the direct result of streamflow and sediment loads transported by the stream. Pre- and post-settlement geomorphic histories were evaluated through a variety of methods. Sediment cores were collected from floodplain, channel, backwater, and mouth areas of North Fish Creek. Soil geomorphology, age dating of sediment, and landscape position were used to determine chronologies and rates of degradation and aggradation. Aerial photographs, historical field notes, and bridge-construction surveys were used as supplemental evidence to support results from the sediment cores and cutbank exposures.

Field Methods

Data from sediment coring were used to quantify the amount of sedimentation and erosion that has occurred in North Fish Creek prior to European settlement (circa 1870) and during historical (post 1870) variations in land cover and climate since European settlement. Cores from relict channels were used to identify the original size, shape, and sediment characteristics associated with these channels when they were part of the active river system. Some of the relict channels are now partially filled with sediment from overbank vertical accretion.

Approximately 180 hand cores of floodplain and terrace sediment were collected in 1994 and 1995 and described for texture and soil development (fig. 6). These exploratory cores were collected with a 2.5-centimeter (cm) diameter soil probe at depths ranging from less than 1

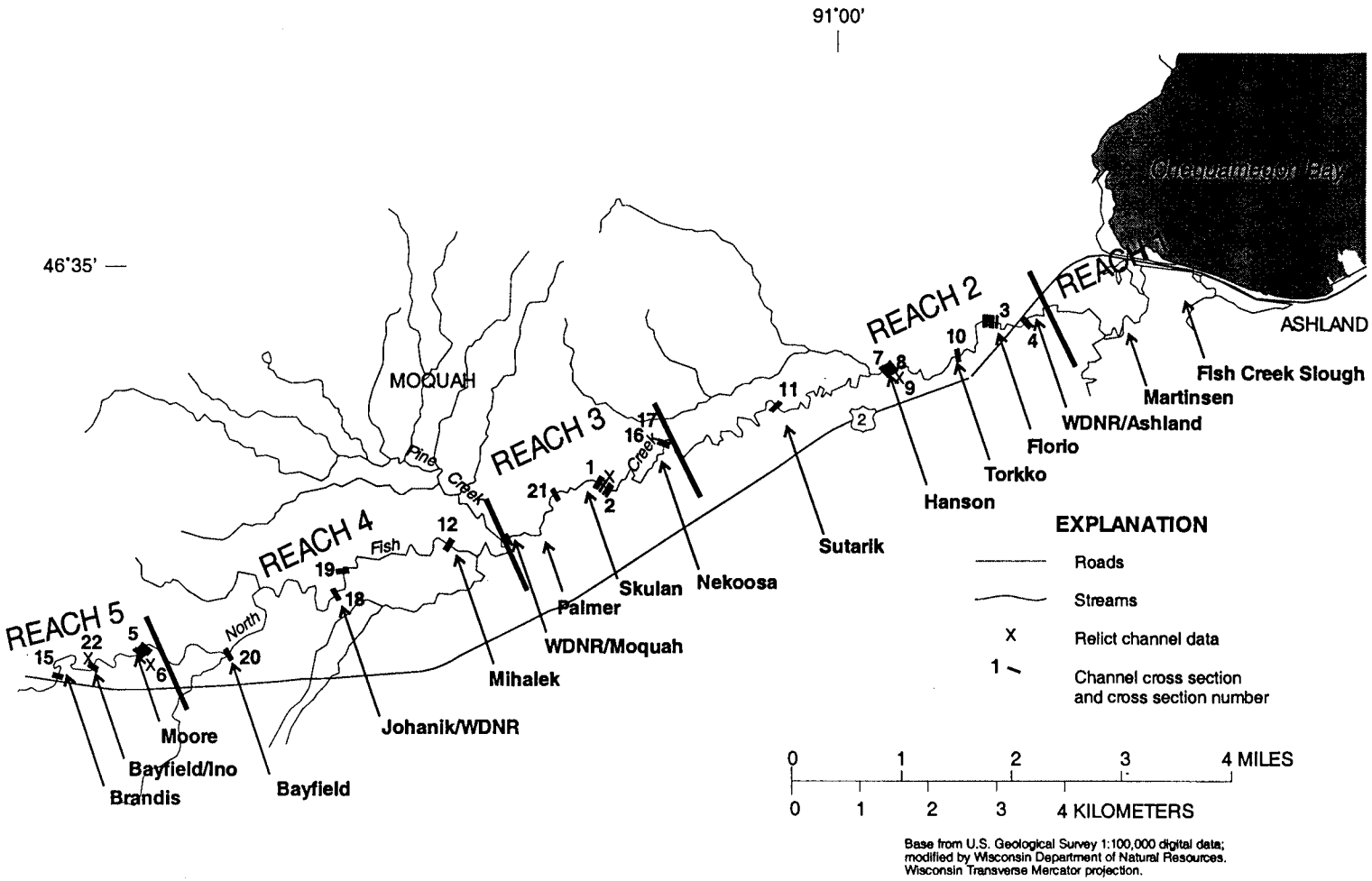


Figure 6. Sites where stratigraphic and channel cross-section data were collected along North Fish Creek.

meter (m) to over 5 m. Hand-coring was the principle method of coring because the remote nature of the stream precluded coring with the traditionally-used truck-mounted soil probe. Most of the cores were collected from river kilometer 27 to the mouth, along the mainstem.

Coring devices capable of collecting larger diameter cores for sample analysis also were employed in 1995. Cores collected with these devices were saved and brought back to the office for further examination and subsampling. The cores were described and sampled for particle size using the U.S. Department of Agriculture textural classification triangle, color (Munsell Color, 1975), radiocarbon dating, and macrofossils. Eight 7.5-cm diameter cores were collected with a vibracorer from floodplain or valley slope sediment at depths ranging from 1 m to over 6 m. A Geoprobe (a tapping type coring device mounted on a four wheel all terrain vehicle) was used to collect nine 5-cm or 2.5-cm cores from depths of up to 16 m from the floodplain. Recovery ratios from cores from both the Geoprobe and vibracore were less than the hand cores; thus, hand core data were collected very near the Geoprobe and vibracore locations and used to adjust depth intervals accordingly. The vibracore was prone to the most compaction and also had a rodding effect (sediment was pushed around the core tube instead of collecting inside of the tube) because of the build-up of friction between the core sample and the tube wall.

Two types of piston corers were used to collect cores from inundated relict channels of North Fish Creek, Fish Creek, Fish Creek Slough, and Chequamegon Bay. Twelve cores (six cores along two transects) were collected from Chequamegon Bay near the mouth of Fish Creek, and 15 cores were collected from Fish Creek Slough (fig. 7). A piston corer designed at the Wisconsin Department of Natural Resources (W.P. Fitzpatrick, Wisconsin Department of Natural Resources, written commun., 1995) worked best in sandy sediment found in relict channels and Chequamegon Bay; however, the WDNR piston corer was limited in depth to less than about 1 m and collected a 7.6-cm diameter core. The modified Livingston piston corer collects 5-cm cores (Wright, 1967; Wright, 1991) and worked best in fine sediment found in the backwater areas of Fish Creek Slough, but clogged when used in sandy sediment found in the main channel of Fish Creek and Chequamegon Bay. The Livingston corer is designed to collect multiple cores at depth; thus, cores were collected from depths up to 3 m.

Figure 7. Locations of cores in Fish Creek Slough and Chequamegon Bay and position of Fish Creek channels in 1906 (based on 1906 Bayfield County plat map). Figure base from 1990 aerial photograph.

Twenty-five stream bank and bluff exposures were examined for two purposes. Stream-bank exposures of fluvial sediment were used to reconstruct both historical and pre-settlement sedimentation rates and help in the interpretation of long-term changes in the evolution of the drainage system. Eroding bluffs are composed of glacial till, outwash, lacustrine, or fluvial deposits. Samples were collected from two large bluffs (over 30 m high) to quantify the texture of sediment resulting from mass-wasting and fluvial toe erosion. The two bluffs sampled are representative of the 10 to 12 bluffs that are in close proximity to the stream and are capable of providing a great amount of sediment to the stream.

The characteristics of paleosols were examined and used as indicators of floodplain stability. There are three general types of paleosols: (1) buried soils that have become buried by younger geologic depositional processes, (2) relict soils that were never buried and that occur on ancient, stable land surfaces, and (3) soils that were once buried but have resurfaced because of erosion (Ruhe, 1965). Soils of the first type, buried soils, were found to be most helpful in reconstructing the sedimentation/erosion history for the valley. Some basic assumptions in using paleosols for measuring surface stability are that buried soils are representative of the same soil forming processes that occur today, and that soils formed in the same environment over a similar time period will look similar. For soils formed in fluvial environments, properties such as color, organic matter content, mineral alteration, and degree of development are useful indicators of climate, vegetation, and moisture conditions under which they were developed, and also the length of time the soil was at the surface before being buried (Holliday, 1990; Birkeland, 1984).

Most commonly there is an unconformity between the top of the paleosol and overlying material. In a fluvial environment, sometimes part of the paleosol will be removed by local scour activity before deposition. In other cases it remains intact. In general, floodplain soils are usually poorly developed because the disturbance rate is great and high water tables inhibit eluviation. Many buried surfaces have limited evidence of incipient A horizons. These surfaces may have less than 1 cm of organic debris accumulation representing the organic litter accumulation on the forested floodplain surface, or a dark zone representing the beginnings of

organic matter accumulation, and possibly traces of rootlets that have grown in place. Paleosols encountered in the floodplain of North Fish Creek generally fall into the very weakly to weakly developed stage of paleosol development (Retallack, 1988).

All occurrence of paleosols in floodplain cores and exposures for North Fish creek were recorded and interpreted to represent brief periods of surface stability on the floodplain. Wood and organic debris from several paleosols were dated using radiocarbon techniques. Organic debris accumulations in channel fill environments were distinguished from incipient paleosols by the surrounding sediment characteristics and inferred depositional setting.

The modern channel geometry of North Fish Creek was surveyed at each section line crossing from the mouth to river kilometer 27 (U.S. Highway 2 bridge near Ino, Wis.) during base-flow conditions (fig. 6). This included at least two transects, or cross sections, of the channel and floodplain (one on the section line and another from a representative cross section) and water-surface slope measurements. A global positioning system and aerial photographs were used to verify the location of each section line where it intersected North Fish Creek. Channel width measurements and streambed sediment were compared with width measurements and streambed sediment recorded in the 1855 Government Land Office (GLO) survey notes. Location of the modern channel at the section line crossings, based on USGS 7.5-minute topographic maps (photo revised in 1975) were checked with channel locations as recorded in the 1855 survey. Based on previous studies that have used GLO surveys, the width measured from the water's edge was used.

The channel geometry and streambed-sediment characteristics of individual relict channels also were surveyed at five localities (fig. 6). Measurements optimally included five cross sections along each relict channel and five cross sections along the modern channel in close proximity to the relict channel. Fewer cross sections were surveyed if the relict channel length was short. Relict channels with cross-section surveys are located at approximately river kilometer 3.5, 7.0, 13.7, 25.0, and 26.0.

Laboratory Methods

Laboratory methods include sediment particle-size and organic carbon content analyses and radiometric dating. Sediment samples from bluff, floodplain, and terrace exposures, and cores were collected for particle-size determinations (Appendix A). Laboratory particle-size analyses included hydrometer and sonic sieve techniques and were conducted at the sediment laboratory at the Geography Department, University of Wisconsin-Madison under the direction of Professor James C. Knox. Air dried samples were sieved to less than 2 mm. A 30-gram (g) subsample was pretreated for humic material with hydrogen peroxide and dispersed with sodium hexametaphosphate. The sample was transferred to a settling tube with distilled water. Hydrometer measurements were made that correspond to five silt fractions (0.062–0.021, 0.031–0.016, 0.016–0.008, 0.008–0.004, and 0.004-0.002 mm) and are based on the equation

$$w=[(p_s-p)g/18u]d^2$$

where w = the settling or fall velocity, ps-p is the density difference between the particle and the fluid, g is the acceleration due to gravity, u is the dynamic viscosity of the fluid, and d is the diameter of the particles (Blatt and others, 1980). The nature of particle movement in a settling medium depends on the balance between accelerating and retarding forces, which are dependent on the size, shape, and density of the particles and the viscosity of the fluid (Guy, 1969). Sonic sifting was used to separate seven sand-sized fractions: greater than 2, 2–1, 1–0.5, 0.5–0.25, 0.25–0.125, 0.125–0.62, and less than 0.62 mm, which correspond to the phi (ϕ) size fractions of less than -1, -1-0, 0-1,1-2,2-3,3-4, and greater than 4, respectively (Wentworth, 1922; Krumbein, 1934).

For quality assurance purposes, comparisons were made for U.S. Department of Agriculture (USDA) textural classifications conducted in the field and laboratory particle size analyses. Results are shown in Appendix A. Most of the textural classifications made in the field were the same as those calculated from laboratory data. Where exceptions occurred, the sample texture was close to the boundary between the two textures on the USDA texture diagram. Thus, in general, field textural classifications are representative of true textural classifications.

Organic carbon content for the same samples was measured using the Walkley-Black method (Janitzky, 1986). Results from this wet-chemical procedure are comparable to dry-combustion methods (Janitzky, 1986).

Wood or organic debris samples for radiocarbon dating were collected from cut bank exposures or cores along North Fish Creek and Fish Creek Slough (Appendix B). Radiocarbon analyses can be useful for dating carbon-rich samples from approximately 200 to 40,000 years old (Bowman, 1990). Radiocarbon (^{14}C) was discovered by Libby (1946) and the conventional radiocarbon dating technique soon followed (Libby and others, 1949). All living organisms acquire the three forms of carbon (^{14}C, ^{13}C, and ^{12}C) through either photosynthesis or eating plants. Theoretically, no new ^{14}C is added after death, and the relative amount of ^{14}C compared to the other stable isotopes of carbon starts to decline (Arnold, 1995). Early on, it was assumed that the $^{14}C/^{12}C$ ratio in the atmosphere, oceans, lakes, and living creatures remained constant over time and across all species. However, ^{14}C concentrations in the atmosphere have changed over time, and isotopic fractionations occurs between plants with different photosynthetic pathways. Fortunately, the amount of isotopic fractionation of ^{14}C can be calculated if the $^{13}C/^{12}C$ ratio is measured (Arnold, 1995). Long-term variability of ^{14}C in the atmosphere has been documented through tree-ring dating back to approximately 13,000 ^{14}C yr B.P. Sometimes freshwater aquatic organisms can appear older because effects from old or hard (carbonate-rich) water that has less ^{14}C than the atmosphere or rainwater (Arnold, 1995). Most laboratories use some type of calibration procedure, such as tree-ring comparisons, to convert the conventional age, usually listed as ^{14}C years before present (^{14}C yr B.P.) to a calibrated calendar years, usually given as AD, BC, or calibrated yr B.P. (cal yr B.P).

All wood or organic debris samples from the vicinity of North Fish Creek are terrestrial, whereas samples from Fish Creek Slough represent a mixture of terrestrial and aquatic plants. All samples were stored in aluminum foil or plastic whirlpack bags and kept on ice for a few days until the samples could be frozen. If samples were collected from cores, care was taken to collect the sample not in contact with the corer. Sometimes a wood sample was trimmed if it was a large enough. Before analyses, the samples were thawed, washed with deionized water, and examined under a macroscopic microscope for signs of contamination from younger root-

lets or younger organic coatings. If the sample contained mostly organic debris it was washed using a stainless steel 63-μm sieve. After washing and examination, the samples were dried at 70°C and subsequently wrapped in aluminum foil and stored at room temperature.

Two types of radiocarbon analyses were performed on 26 wood or organic debris samples (Appendix B). Of the 26 samples, seven were large enough to perform conventional radiocarbon techniques, which use beta particle counting from decaying ^{14}C atoms to estimate the age of a sample. These samples were analyzed by Beta Analytic, Inc. The remaining smaller samples (less than 3 g) were prepared for accelerator mass spectrometry (AMS) analyses at the Radiocarbon Laboratory at the University of Wisconsin-Madison and shipped to Arizona AMS Facility, University of Arizona, Tuscon Arizona, or the Lawrence Livermore National Laboratory, California, for atom counting. One sample sent to Beta Analytic, Inc. was too small for conventional dating, thus AMS analysis was done at their laboratory.

Chemical pretreatment was done at both the University of Wisconsin, Radiocarbon Laboratory and Beta Analytic, Inc. This treatment is performed to remove mechanical contaminants such as associated sediment and rootlets (Beta Analytic, Inc., written commun., 1997). First the samples were leached with dilute hot hydrochloric acid to remove carbonate and calcium. Next the samples were treated with a dilute alkali wash (sodium hydroxide) to remove secondary organic acids. A final rinse with hydrochloric acid is done to remove the insoluble fraction from the alkali treatment and any absorbed carbon dioxide and neutralize the sample (Olsson, 1986).

At the University of Wisconsin, Radiocarbon Laboratory, graphite was synthesized from the sample carbon for AMS dating by Dr. David McJunkin. First, a subsample was selected that would provide approximately 5 mg of elemental carbon. Of the 5 mg, 2 mg were used for AMS dating, 1 mg for $^{13}C/^{12}C$ ratios, and 2 mg for archiving. Chemical pretreatment was performed. The sample was sealed in a quartz tube with cupric oxide under vacuum, and baked at 900°C for 3 hours. The CO_2 was distilled out of the tube under vacuum. Hydrogen gas was added to the tube under 2 atmospheres of pressure. The sample was subsequently graphitized at 580°C onto cobalt. Subsequently, the sealed tubes containing the graphite sample were sent to the Arizona or Livermore AMS facility.

Beta Analytic, Inc. calculated radiocarbon ages through conventional techniques by synthesizing benzene (92 percent C) from the sample carbon and measuring the ^{14}C content in a liquid scintillation spectrometer (Beta Analytic, Inc., written commun., 1995). Two samples required extended counting times. For the sample sent to Beta Analytic, Inc. that required AMS measurements, reduction of the sample carbon to graphite, along with standard and backgrounds was performed by Beta Analytic, Inc. The graphitized sample along with the same standards was sent by Beta to the University of Kiel in Germany for AMS measurement.

Calibration of conventional dating results were done through additional measurements of $^{13}C/^{12}C$ ratios. These ratios allow for calculation of more accurate calendar age correlations, since fractionation of both ^{14}C and ^{13}C are dependent on temperature, pH, and physiological processes (Olsson, 1986). For conventional dating, $^{13}C/^{12}C$ ratios were measured with a mass spectrometer at Beta Analytic. The number of ^{14}C atoms relative to ^{13}C or ^{12}C atoms in a sample are directly measured in the AMS technique (Bowman, 1990). The conventional radiocarbon ages listed in Appendix B is the result after applying $^{13}C/^{12}C$ corrections to the measured age.

Calendar calibrated age ranges, also is listed in Appendix B, reflect additional calibration through 7,200 ^{14}C yr B.P. based on intercepts with a decadal tree-ring curve, plus or minus two times the total standard deviation of the age (Stuiver and Becker, 1993). The CALIB program (Stuiver and Reimer, 1993) was used to calculate calendar ages.

Potential contamination of radiocarbon samples through the presence of younger material, such as rootlets, is negligible because each sample was examined under a low power microscope. However, other effects from sampling old wood (for example if a wood sample came from the center of a very old tree) cannot be eliminated because of the small sample size. In addition, some wood samples may have been deposited by floods, thus, they may yield older age than the surrounding sediment.

Because of a lack of identifiable pre-settlement surface in the backwaters of Fish Creek Slough, five samples from two cores each from Fish Creek Slough were submitted to the U.S. Geological Survey, National Water-Quality Laboratory for ^{210}Pb and ^{137}Cs dating. Core depth ranged from 5.5 to 10 cm and sampled material was relatively homogenous organic-rich clay. Results are listed in Appendix B.

The ^{210}Pb dating technique was originated by Goldberg (1963) and is based on the escape of radon from the Earth, and the subsequent decay of this radioactive gas into ^{210}Pb. This technique is most suitable for dating with the last 150 years because the half-life of ^{210}Pb is approximately 22 years (Olsson, 1986). To account for some of the variability associated with possible fluctuation in the sources of lead or inhomogenous sediment, ^{226}Ra also was analyzed in each of the samples. Optimally, samples from sediment more than 150 years old are collected to measure local concentrations of ^{210}Pb supplied to the sediment from decay of uranium minerals (Olsson, 1986).

Cesium was first detectable in 1945, and in 1954 the first increase occurred in the Northern Hemisphere, corresponding to increased nuclear weapon tests. In 1960 a minimum occurred, followed by a maximum in 1963, and concentrations since then have dropped off substantially (Olsson, 1986). These peaks in concentrations from atmospheric fallout are used to measure sedimentation rates. Bioturbation and erosion/redeposition are common problems with both techniques.

Historical Documents

Information from historical documents, such as the Government Land Office Surveys, aerial photographs, bridge construction records, and newspaper articles, were used to support field and laboratory data. The Government Land Office Surveys were conducted in the 1800's across Wisconsin to map and establish townships, ranges, and sections. In the North Fish Creek watershed, this task was performed in 1855, prior to European settlement. Besides containing detailed descriptions of the vegetation and lay of the land, the surveyors also recorded the location of streams crossing section lines, the width and direction of the stream, and sometimes other characteristics such as streambed sediment (suitability for use as a ford), water clarity,

and velocity. These notes were used to document historical changes in channel width and streambed sediment, and also to compare changes in local floodplain vegetation. This method has been successfully demonstrated in southwestern Wisconsin (Knox, 1987). Copies of the Government Land Office Surveys were acquired from the State of Wisconsin, Department of Justice, Madison, Wis.

Aerial photographs from 1938 and 1990 were obtained from the Wisconsin Department of Transportation, Madison, Wis. Scale of the photos is approximately 1:20,000. The rate of retreat of 17 bluffs located between river kilometer 17 and 27 were measured by comparing aerial photographs from 1938 and 1990. Bluff retreat was measured by measuring the distance from the upper break in slope at the bluff top to a nearby stationary landmark present in both sets of photos. Channel migration also was documented by measuring the distance from the channel to the same stationary landmark. Measurement precision was approximately 10 m. Scale of the photograph at the site of the bluff was calibrated by measuring distances between 5 known points near the bluff to account for slight variations in scale, if present. Distances between the tops of bluffs and the channel and stationary landmarks were verified by use of 7.5-minute topographic maps dated 1964.

Modern bridge designs typically contain data on channel geometry relative to the elevation of the bridge. Historic bridge designs are useful for documenting changes in channel geometry and aggradation/degradation. Bridge designs for current and historical bridge crossings on North Fish Creek were searched for at Wisconsin Department of Transportation Offices in Superior and Madison, Wis. In addition, records at the Bayfield County Transportation Office, Washburn, Wis. were examined. In the past there were more bridge crossings on North Fish Creek than at present. Unfortunately, once a bridge is taken out, records are disposed of. Thus, only one pertinent bridge design was found for the Old Hwy. 2 crossing near Moquah. The first bridge at the site was constructed in 1912, but was replaced with new bridge (at the present location) in 1925. There were no data from the 1912 bridge design on the distance from the channel bed to the bridge structure; however, there is some information on the distance from the top of bridge abutment to the surface of the water.

Several daily newspapers were published in Ashland and the surrounding towns at the turn of the 19th century. After the logging and iron ore eras, many of these papers disappeared, except for the Ashland Daily Press. Historic newspaper articles contained information on changes in recreational fishing, logging, and flooding on North Fish Creek. A data base of logging and fishing activities in North Fish Creek from 1871 to 1890, as recorded in the Ashland Daily Press, has been compiled by Dennis Pratt (Wisconsin Department of Natural Resources, written commun., 1997). The Ashland Daily Press also contained photographs of damage from the 1946 flood; however, only low-quality copies of the photographs from microfiche were obtainable.

Several historical and geological publications were consulted. While Reuben G. Thwaites is known for his historical analyses of the Chequamegon area before the turn of the 19th century (Thwaites, 1895), his son Fredrick T. Thwaites is known for his excellent photographs and notes on sandstone outcrops in the vicinity of the Bayfield Peninsula (Thwaites, 1912).The notes and photographs of F. T. Thwaites are available at the Wisconsin Geological Survey in Madison, Wisconsin. Information from both sources was used as anecdotal evidence for geomorphic change. No photographs by F.T. Thwaites were found for North Fish Creek, only South Fish Creek.

Flood Reconstructions

Estimations of historical low-magnitude high-frequency floods were accomplished through cross-section surveys of relict channels. Bankfull channel capacities were defined for the relict channels and these measurements were then applied to the U.S. Army Corps of Engineers Hydrologic Engineering Center water-surface profile computation model (HEC-2) (U.S. Army Corps of Engineers, 1991) to estimate discharge magnitudes.

Channel Geometry

The size and slope of relict and modern channels were measured in cross section surveys described earlier for assessment of erosion and sedimentation. These data were used in the HEC-2 discharge estimation to quantify how bankfull discharges and channel capacity in older channels compare to modern channels. These data also were used to quantify how channel capacity flows vary along the mainstem, from degradational to aggradational reaches.

Discharge Estimation (HEC-2)

The HEC-2 model requires information on channel and floodplain geometry, distance between cross sections, Manning's roughness coefficients for the channel and floodplain, and energy gradient. HEC-2's water surface profile model uses the standard step method (Bonner, 1974) to compute changes in water surface elevations between cross sections. A version of the model by Boss International, Inc. (1995) was used. Channel cross-section data from two to five transects (two at section line crossings, five at each site comparing relict and modern channel characteristics) were collected according to Benson and Dalrymple (1967). Roughness coefficients were selected based on information in Chow (1959, p.112-113) and photographs in Barnes (1967).

Water surface gradient and distance between cross sections were measured at the time of cross section surveys and used to initially estimate the energy gradient. At sites with five transects, the field indicators of bankfull stage also were used to calculate a bankfull flow gradient. Channel gradient also was estimated from 7.5-minute maps using the distance between contour lines crossing the stream. Where data on the bankfull gradient were not available, the gradient estimated from 7.5-minute maps provided a better fit for bankfull and channel capacity flows than the water surface gradient at baseflow, in part because the map slope probably better represents the slope of the floodplain than the channel. Estimates of differences between water-surface and map gradient estimates have been examined by Magilligan (1988), who

found that topographic maps provide good approximations of the energy grade line for bankfull-stage flows. For the HEC-2 estimations done for this study, the estimates of energy gradient are thought to be the least reliable out of all the input parameters.

It was assumed that estimates of the 2-year flood should approximate the upper limit of what would be expected for bankfull flow, based on the assumption that bankfull flow represents the channel forming discharge that occurs 1 to 2 years for streams in equilibrium (Wolman and Miller, 1960, p.54; Leopold and others, 1964, p. 219). However, because of the evidence for channel degradation at the location of the gaging station, it was not assumed that North Fish Creek is in equilibrium.

In order to improve the reliability of the energy gradient and resulting bankfull flows, a flood-frequency regression equation for a 2-year flood (Q_2) for streams along the southern shore of Lake Superior (Krug and others, 1992) was used to estimate the Q_2 for the gaging station on North Fish Creek near Moquah (river kilometer 17). The regression equation is (in English units):

$$Q_2 = 1.36 * A^{0.857} * S^{0.262} * ST^{-0.291} * SP^{-0.251} * SN^{0.688}$$

where A is drainage area (65.4 mi^2); S is slope of the stream between points that are 10 and 85 percent of the distance along the channel from the point of interest to the basin divide, determined from topographic maps (29.2 feet per mile); ST is the storage from lakes, ponds, and wetlands determined from topographic maps (2 percent); SP is soil permeability (0.41 inches per hour), and SN is mean annual snowfall (60 inches) (Krug and others, 1992). Using the above equation a 2-yr flood at Moquah, Wis., is estimated to have a discharge of 57 cubic meters per second (cms), with a standard error of prediction of 32 percent.

Along certain reaches, bankfull flow, considered to represent floods with a recurrence interval of 1 to 2 years, was different than channel capacity flow. The definition used here for the bank top associated with bankfull discharge is that of Wolman and Leopold (1957) and Knox (1985) and is described as the elevation of the floodplain under construction. Indicators of bankfull stage included breaks in the slope for channel banks, and changes in sediment characteristics. It can also be identified as the top of the coarse-grained sediment associated with the youngest point-bar sequence. Channel capacity flow was identified as the flow at which the

water spilled out onto a flat surface, whether floodplain or terrace. In stream reaches experiencing degradation, the channel capacity was much greater than the capacity required for a 2-year flow event. Slight breaks in the slope of the stream bank represented incipient floodplain surfaces; thus, there was no floodplain along these reaches. In stream reaches experiencing aggradation, the channel capacity was much less than channel capacity required for a 2-year flow event.

Climate Reconstructions

Evidence of past changes in precipitation in the drainage basin were quantified on two temporal scales. Historical precipitation records within or near the drainage basin were available from 1900 to the present. Changes in precipitation during the Holocene also were modeled using a macrophysical paleoclimate model.

Historical Precipitation Records

Daily precipitation data for the available period of record from five climate stations (table 2) were obtained from the State Climatologist's office in Madison, Wis. Thiessen polygons (Dunne and Leopold, 1978) were constructed by connecting nearest neighbor stations and drawing lines perpendicular to them. The entire drainage basin for North Fish Creek is within the Thiessen polygon for the climate station at the Ashland Experimental Farm in Ashland Junction, Wis., located near the mouth of North Fish Creek (fig. 1). This climate station also has the longest record (table 2), beginning in 1900. Prior to 1912, this station was located about 60 m inland from Chequamegon Bay in downtown Ashland. The station was moved 6 km west and 2 km inland to its present location at the Experimental Farm in 1912. The Experimental Farm is approximately 10 m above the altitude of the downtown Ashland location.

Table 2. Climate stations near North Fish Creek

Station name	Latitude	Longitude	Starting year	Approximate distance from center of basin (km)
Ashland Experimental Farm	46° 34'	90° 58'	1900	9
Brule River	46° 32'	91° 35'	1944	36
Superior	46° 42'	92° 01'	1944	33
Port Wing	46° 46'	91° 23'	1947	78
Bayfield 6 N	46° 53'	90° 49'	1944	33
Madeline Island	46° 47'	90° 46'	1945	38

Macrophysical Paleoclimate Modeling

A macrophysical paleoclimate model developed by Bryson and Bryson (1995) was run for two precipitation gages near North Fish Creek: the Ashland Experimental Farm 2.5 km west of Ashland, Wis. and the Brule station near Brule, Wis. The Brule gage is 40 km west of the North Fish Creek basin but was used in the analyses to make sure that the Ashland Experimental Farm site was not experiencing any local lake effects due to its proximity to Chequamegon Bay and Lake Superior.

The macrophysical model is a high-resolution, site specific model that models variations in climate (precipitation and temperature) at the temporal accuracy of about two centuries. The model draws on a set of large-scale climatic boundary conditions. These boundary conditions consist of relations among Rossby long wave equations, thermal wind, or the Z-criterion (Smagorinsky, 1963); a model of global ice volume (Bryson and Goodman, 1986); and a hemispheric temperature model that uses Milankovitch solar variations and volcanic activity Bryson, 1988). The following assumptions are paraphrased from Bryson and Bryson (1995):

(1) The seasonal amount of radiation received and absorbed near the surface by the hemisphere influences the seasonal temperature of the hemisphere (Bryson and Gooodman, 1986).

(2) Volcanic aerosols affect the amount of radiation received by the surface of the hemisphere (Goodman, 1984).

(3) Variations in the areal extent of ice and snow cover cause the largest amount of variation in hemispheric albedo.
(4) Cloud cover is assumed to be equivalently opaque.
(5) In the past, carbon dioxide and water vapor content of the atmosphere have been dependent on temperature (Bryson, 1988)
(6) The Lettau climatonomic method of obtaining mutually consistent set of monthly surface heat budget components is correct.
(7) The latitude of dynamic instability of the westerlies as calculated by Smagorinsky (1963) is valid for estimating the latitude of subtropical anticyclones.
(8) The latitude of the jet streams is closely related to the outer edge of the westerlies as calculated with the Z-criterion (Bryson, 1992).
(9) The variation of the latitude of the intertropical convergence is closely related to the variation of the latitude of the related subtropical pressure system.
(10) The present annual progression of the seasons is a good representation of the past.

The model requires average monthly precipitation values and the location of a precipitation and (or) temperature station. Climate modules used for the Ashland area and provided in the model are the North American latitude of maximum pressure at 120 degrees west (adjusted for the longitude of Ashland, Wis.), the North American jet latitude (usually 500 mb data), and the Eur-Africa and near east latitude of maximum pressure at 0 degrees west. These modules contain monthly averages extending back in time to 39,750 ^{14}C yr B.P. The data in the modules are based on the above assumptions. The Brule record for the Holocene was similar to the Ashland Experimental Farm.

Vegetation Reconstructions

Vegetation reconstructions provided for in the literature were supplemented with limited analyses of fossil plant and animal materials from cores in the North Fish Creek drainage basin. Six macrofossil samples, three each from two cores, were examined by Richard G. Baker, Geology Department, University of Iowa. These samples were chosen to investigate the possibility of major vegetational changes of the slough and lower part of the North Fish Creek valley through the Holocene. One core (P-19) (fig. 7) was located in the backwater area of Fish Creek Slough, and the other core was from overbank sediment from a low terrace at the Hanson site

(VC-8) (fig. 6). At the time of sampling, both cores were thought to represent a good part of the Holocene and had relatively slow sedimentation rates. Macrofossil samples were bracketed by organic samples for radiocarbon dating.

Macrofossil remnants include fruits, seeds, wood remains, stems, leaves, and roots. These remains reflect vegetation in the immediate area surrounding the site (Grosse-Brauckmann, 1986). Every fossil remnant in the sample are counted. Percentages of each species or groups of species are calculated based on the counts.

Two large samples of wood were analyzed by Harry Alden, Center for Wood Anatomy Research, U.S. Forest Products Laboratory, Madison, Wis., 1995. The species of trees can be determined from microscopic analyses of thin slides of wood (Schoch, 1986). Results from these analyses, along with macrofossil analyses, 1855 GLO notes, and other late 19th century publications, were used for documenting pre-settlement vegetation along North Fish Creek.

Rainfall/Runoff Modeling (HEC-1)

One of the possible scenarios suggested for reducing the amount of bluff and bank erosion and subsequent sedimentation is to reduce runoff during snowmelt and rainfall events. This can be done through re-establishment of forest cover in as much as the uplands as possible within the drainage basin or by installing detention basins designed to reduce peak flows. The first approach would take many years, and results would be gradual and in keeping with the pre-settlement vegetation and hydrologic conditions. The second approach involves quicker results that may not adequately represent pre-settlement conditions in all aspects and may result in some side effects that do not benefit aquatic life. Storm hydrographs for three land-use scenarios (complete forest, peak agriculture, and 1992 land use) were modeled. The modeled storm hydrographs were integrated with empirical sediment transport curves derived from gaging station data and sediment samples collected from North Fish Creek. The integration resulted in an estimation of the sediment yield for the modeled storm.

The U.S. Army Corps of Engineers HEC-1 model (U.S. Army Corps of Engineers, 1990) was used to simulate runoff from the North Fish Creek basin at the U.S. Geological Survey gaging station in response to a precipitation event. The HEC-1 model is based on a system of interconnected hydrologic and hydraulic components.

Streamflow Data Collection

Streamflow data were collected over the length of the project, from Oct. 1994 through Sept. 1997. Streamflow data also were collected from Oct. 1989 to Sept. 1991 (Rose and Graczyk, 1996). The gaging station at Old U.S. Hwy 2 was re-established and data were collected at 15-minute intervals over the entire time period according to U.S. Geological Survey methods (Rantz and others, 1982).

Model Input

Start time—A 15-minute increment was used, with a start time of 12:00 AM on September 3, 1991, with 160 time steps. Normal summer baseflow conditions were present prior to the storm event. Observed data are based on 15-minute data from the streamflow gaging station near Moquah, Wis.

Observed hydrograph characteristics—A 15-minute increment was used, with a start time of 12:15 AM on September 3, 1991, with 160 steps. For the observed data, the mean flow was 10.1 cms, peak flow was 47.3 cms, and time of peak was 5.5 hours. Streamflow at the start of the storm was 1.4 cms.

Precipitation characteristics—Total rainfall for the Ashland Experimental Farm was 6.7 cm; for the Brule gage precipitation was 5.7 cm. Ashland Experimental Station hourly rainfall consisted of: 1:00 AM, 0.51; 2:00 AM, 4.3; 3:00 AM, 2.5; 4:00 AM, 0.51; 5:00 AM, 0.25; for a total of 8.1 cm. Estimated 2-year, 24-hour rainfall for the Ashland area is 5.7 cm (Hershfield, 1961; Dunne and Leopold, 1978, p. 62).

The Ashland incremental rainfall was used in the model but first was weighted by total rainfall at the Brule gage (*0.7031), because the Brule rain gage probably better reflects total rainfall for entire basin. The latitude of the Brule gage is similar to the North Fish Creek basin

in line with the direction of most summer storm systems. A 60-minute incremental time step was used for the rainfall data, starting at 1:00 AM on September 3, 1991. The Ashland incremental rainfall was weighted by the Brule total rainfall. Weighted amounts were: 1:00 AM, 0.36; 2:00 AM, 3.0; 3:00 AM, 1.8; 4:00 AM, 0.36; and 5:00 AM, 0.18 cm. All subbasins were assumed to have received the same amount of precipitation.

Subbasin characteristics—The basin above the USGS gaging station near Moquah was divided into ten subbasins (fig. 8). Subbasin delineation was based on location of major tributaries, land use, surficial geology, and possible placement of detention basins. Subbasin areas (table 3) were calculated in a geographic information system using a digital map of the drainage basin boundaries (1:24,000 scale).

Baseflow characteristics—For the baseflow component of HEC-1, initial baseflow for the entire basin (table 3) above the gage was based on observed flow data. Initial baseflow for subbasin 100 was based on USGS miscellaneous baseflow measurements. Initial baseflow for the rest of the subbasins was estimated based on observations of flow conditions while conducting field studies of erosion and sedimentation during storms.

The baseflow recession ratio (table 3) was based on plotting the logarithm of the observed flow at the gage versus time (U.S. Army Corps of Engineers, 1990). The point at which the recession limb fits a straight line defines the start of recession flow and the slope of the line defines the ratio. This was done for the September, 1991 storm and a storm on October 16, 1990. Based on hydrograph recession curves for these two storms, the ratio was slightly adjusted for a better fit of the modeled recession limb to the recession limb of the observed hydrograph. The same baseflow recession ratio was used for each subbasin. The starting recession flow for each subbasin was estimated by weighting the contribution of each subbasin to the starting recession flow for the entire basin.

SCS Curve Numbers—An overall SCS curve number was calculated for the entire drainage basin for three storms that were represented by two summer and one fall events. Scaling was adapted to the 15-minute gaging station data. Curve number equations were used to estimate the curve number (CN) by knowing the amount of runoff (Q) and total precipitation (P).

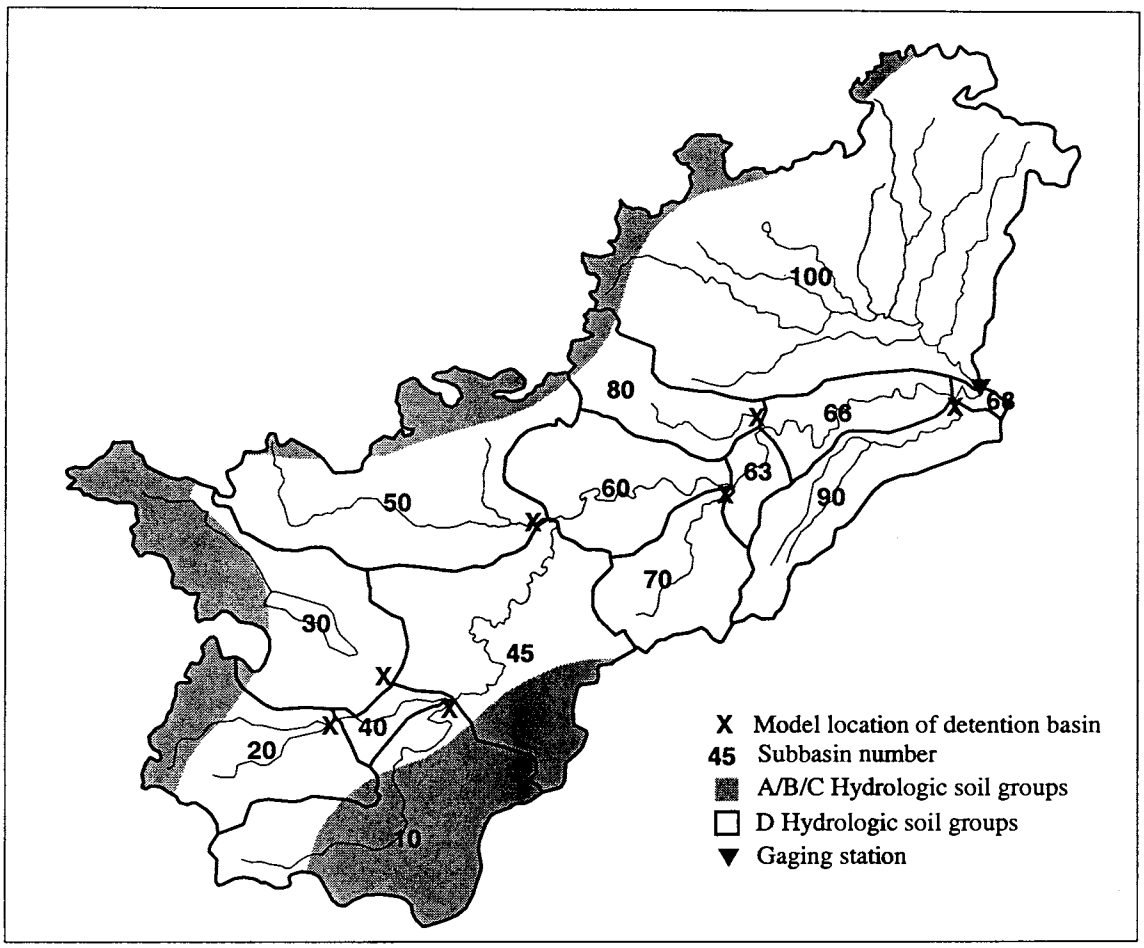


Figure 8. Locations of subbasins above North Fish Creek gaging station used to model storm hydrographs for different land use conditions.

Table 3. Input parameters used for the HEC-1 runoff model of North Fish Creek

[km, kilometers; cms, cubic meters per second]

Subbasin	Basin area (km^2)	Base flow characteristics: Flow at start of storm (cms)	Base flow characteristics: Recession flow for initiating recession rate (cms)	Recession rate ratio	Initial SCS curve number	Updated SCS curve number[a]	Initial time lag (hours)	Updated time lag (hours)
20	6.2	0	0	1.02	66	--	1.02	1.14
30	9.6	0	0	1.02	72	66	1.53	2.56
10	9.8	0	0	1.02	73	-	1.69	2.12
40	1.0	0	0	1.02	80	75	.78	.95
45	10.4	.028	.119	1.02	80	75	1.06	1.32
50	11.4	.028	.119	1.02	71	66	0.92	1.2
60	5.4	.368	1.44	1.02	80	70	0.71	.86
70	4.4	0	0	1.02	78	--	.78	.88
80	3.9	0	0	1.02	70	66	1.46	1.56
63	1.3	.113	.481	1.02	80	75	0.49	.53
90	4.9	.028	.119	1.02	76	--	1.06	1.23
66	3.1	.368	1.44	1.02	80	75	0.63	.81
100	27.7	.566	2.27	1.02	76	70	1.47	1.69
68	.34	.028	.170	1.02	80	70	.26	.30
Entire basin	99.4	1.53	6.14	1.02	75	70	5.62[b]	7.33[2]

a. Curve numbers were updated from U.S Department of Agriculture (1986) to fit specific storm hydrograph and from refined information on hydrologic soil groups.

b. Time lags for the entire basin are based on the sum of time lags from the longest flowpath.

Potential maximum retention after runoff begins (S) was calculated using the equation Q = (P-0.2S)2/(P+0.8S) (U.S. Department of Agriculture, 1986). The value for S was used to calculate CN using the equation CN = 1000/(S+10). CN's for the three storms (July 28, 1991, September 3, 1991, and October 16, 1991) were 68, 70, and 80, respectively. Thus, the summer storms have a CN of about 70 and fall storms have a CN of about 80. The seasonal difference in CN is attributed to differential evapotranspiration rates (more moisture used by vegetation in the summer than in the fall) and potentially different antecedent moisture conditions (less evapotranspiration and typically longer duration/less intense storms in the fall compared to summer).

Initially, SCS curve numbers for each subbasin (table 3) were calculated by overlaying USGS land use data (high altitude photography flown in approximately 1975, 1:250,000-scale) with State Soil Geographic Data Base (STATSGO) (U.S. Department of Agriculture, 1991) refined with Bayfield County soil-survey data (U.S. Department of Agriculture, 1978) traced onto 7.5-minute maps. Land-use categories included cropland and pasture, deciduous forest, mixed forest, evergreen forest, and forested wetland.

Curve numbers for "pasture in poor condition" (table 4) were used as a surrogate to represent averages for both cropland and pasture (U.S. Department of Agriculture, 1986) because they are combined in USGS land-use coverage. Agricultural land in the North Fish Creek basin consists of mainly hay fields and pasture for small herds of dairy cattle based on drive-by observations. At a later date, Wiscland satellite-derived land-cover data (1992) were analyzed for the North Fish Creek basin. It was determined that only 3 percent of the basin was devoted to crops, and 31 percent to grassland (some of which is interpreted to be pasture); thus, the assumption "pasture in poor condition" for agricultural land in the subbasins was found to be acceptable. CN's for the forested land were based on "woods in fair condition." CN's for forested wetland were based on "woods in good condition."

Table 4. Curve numbers for land use and soil types in the North Fish Creek subbasins
[modified from U.S. Department of Agriculture (1986)]

Cover type and hydrologic condition	Curve numbers for hydrologic soil group			
	A	A/B	B	D
Pasture, grassland, or range[a]				
Poor	68	74	79	89
Fair	49	59	69	84
Good	39	50	61	80
Woods[b]				
Poor	45	56	66	83
Fair	36	48	60	79
Good	30	43	55	77

a. Pasture conditions: Poor, < 50% ground cover or heavily grazed with no mulch; Fair, 50 to 75% ground cover and not heavily grazed; Poor, >75% ground cover and lightly or only occasionally grazed.
b. Woods conditions: Poor, forest litter, small trees, and brush are destroyed by heavy grazing or regular burning; Fair, woods are grazed but not burned, and some forest litter covers the soil; Good, woods are protected from grazing, and litter and brush adequately cover the soil.

Soil types in the North Fish Creek basin range from hydrologic soil groups A through D (A being the most permeable and D being the least permeable). In general, A, B, and C soils are interspersed around the edges of the basin and are developed in outwash, ice-contact deposits, and beach deposits. The D soils are in the central and eastern part of the basin and are developed in fine-grained lacustrine-modified glacial till. Initially, a B hydrologic soil group was assigned to the mixture of A/B/C soil types. Upon further investigation and sensitivity testing of HEC-1, it was determined that CN's for the southern subbasins (subbasins 10, 20, 70 and 90) were adequate; however, CN's for northern tributary subbasins and mainstem subbasins were too high. The A/B/C soils grouped into a B hydrologic soil type in these subbasins were responding more similar to an A/B soil types than a B soil type. The D soils in the mainstem subbasins (subbasins 60, 63, and 66) responded more like C/D soils, probably because the clay

layer is thinner near the valley of North Fish Creek where long-term erosion and mass wasting have been significant. In addition, it was assumed that forests along the valley of North Fish Creek were probably in better condition than those in the upland because of they are more remote and have less access points than the upland forests. These refinements in CN's resulted in a better fit of the modeled storm hydrograph to the observed storm hydrograph.

The final CN's for current land use conditions in the North Fish Creek basin ranged from a low of 48 for A/B soils with woods in fair condition to a high of 89 on D soils with pasture in poor condition (table 4). The refinements in curve numbers resulted in an overall CN for the basin of 70 instead of the initial 75. This is the same as the curve number calculated for the modeled storm using the streamflow data at the gage.

The effects of changes in historical land use on the storm hydrograph also were modeled by updating the CN's to reflect pre-settlement conditions (complete forest cover) and at the peak of agriculture (about 1928). For complete forested conditions, CN's were updated using numbers for "woods in good condition" (table 4) (U.S. Department of Agriculture, 1986). This resulted in an overall CN for the North Fish Creek basin of 64.

Land-use data also were estimated from the 1928 land economic inventory (Wisconsin Department of Agriculture and the Geological and Natural History Survey, 1928) and were used to quantify land-use characteristics for the North Fish Creek basin during peak agricultural activity. These data indicated that the amount of agricultural and forested land was similar to present conditions; however, the majority of the land was in row crop instead of pasture and tree diameters were generally less than 3 inches. Thus, curve numbers for "pasture in poor condition" were updated to "row crops in poor condition" and "woods in fair condition" were updated to "woods in poor condition". This resulted in an overall curve number for the entire basin of 76.

SCS Unit Hydrograph Calculations Based On Time Lags—Time lags (table 3) were based calculations of time of concentration and travel time using methods outlined in the Soil Conservation Service TR-55 handbook (U.S. Department of Agriculture, 1986). First travel times for sheet flow, shallow concentrated flow, and channel flow were calculated for each subbasin. Measurements of flow length and slope were derived from 7.5-minute quadrangle maps.

The equation $Tt = (0.007*(n*L)^{0.8})/(P^{0.5}*S^{0.4})$ was used to calculate sheet flow, where Tt is travel time, n is Manning's roughness coefficient, L is flow length, P is 2-yr, 24-hr rainfall, and S is slope (U.S. Department of Agriculture, 1986). Manning's roughness coefficients ranged from 0.17 for crops and residue to 0.4 for light woods. An average length of 91 m was used for sheet flow for all subbasins. The 2-yr, 24-hr rainfall of 5.8 cm was obtained from tables in U.S. Department of Agriculture (1986). Slopes ranged from 0.006 to 0.109 m/m. Travel times ranged from 0.26 hours in subbasin 68 to 1.62 hours in subbasin 100.

The equation $Tt=L/(3600*V)$ was used to calculate shallow concentrated flow, where V is the average velocity estimated from the velocity/slope (unpaved surfaces) relation presented in U.S. Department of Agriculture (1986). Travel time for channel flow was calculated using the same equation used to calculate shallow concentrated flow; however, velocity was calculated using the equation $V = (1.49*r^{(2/3)}*S^{0.5})/n$ where r is the hydraulic radius of a channel. Channel dimensions used to calculated the hydraulic radius were based on regional curves for channel dimensions based on drainage area (Dunne and Leopold, 1978, p. 615) and updated with data from channel cross section surveys of the mainstem. A roughness coefficient of 0.06 was used in all the subbasins except subbasin 30 (accounting for roughness at bankfull flow). Time lags for each subbasin were calculated by multiplying the time of concentration by 0.6. Time lag for the entire basin is 5.62 hours (table 3).

Two other methods were used to calculate time lags: the SCS lag method (McCuen, 1982) and Kirpitch's formula (Kirpitch, 1940). Using the SCS time of concentration formulas resulted in the best fit. Time lags from the SCS lag method were too long, and Kirpitch's equation produced time lags that were too short.

Subsequent HEC-1 runs and comparison to observed data indicated that flow from remote parts of the basin were reaching the gage too soon. Prior to this, the hydraulic implications of the large wetland called Ino Swamp in subbasin 30 were not accounted for. Storage effects of this area were taken into account by raising the Mannings roughness coefficient for this subbasin from 0.06 to 0.1. This increased the time lag for this subbasin from 1.53 to 2.56 hours, and provided a better fit of the modeled hydrograph to the observed hydrograph. Time lags ranged from 0.30 hours at subbasin 68 to 2.56 hours for subbasin 10 (table 3).

For alternative land use scenarios, time lags were adjusted slightly. For complete forest, the travel time for sheet flow was increased slightly by using roughness coefficients for dense woods (n = 0.8) instead of light woods or crops (n = 0.06-0.4). For peak agricultural conditions, the travel time for sheet flow was decreased slightly by using roughness coefficients for crops with less than 20 percent residue (n = 0.06) instead of crops with greater than 20 percent residue (n = 0.17) (U.S. Department of Agriculture, 1986).

Channel routing characteristics—Channel routing was calculated using the Muskingum-Cunge method, which requires data on channel cross-section dimensions, channel length, Manning roughness coefficients for the main channel and overbanks, and hydraulic gradient (table 5). Channel lengths and slopes for each subbasins were measured from 7.5-minute maps. Routing estimates for channel routes 2040 and 4045 were calculated by estimating a simple trapezoidal cross section with a known channel bottom width (table 5). Channel roughness coefficients were assumed to be 0.06 because of abundance of woody debris in the stream during flood conditions.

Table 5. Characteristics for routing flows through simple channel designs, North Fish Creek

Routing	Channel length (meters)	Slope (m/m)	Channel roughness (n)	Channel shape	Channel bottom width (m/m)	Side slope
2040	1950	0.00234	0.06	trap	5.5	1.0
4045	5852	0.00406	0.06	trap	6.1	1.0

For channel routes 4560, 6063, 6366, and 6668, representative channel cross-section surveys were used to provide data for a more detailed 8-point cross-section (table 6). Channel roughness coefficients were assumed to be 0.065, again because of the large amount of debris in the channel, log jams, and beaver dams. Overbank roughness coefficients were assumed to be 0.1 because vegetation in the floodplain and along stream banks is generally composed of trees and shrubs.

Table 6. Characteristics for routing flows through channels with cross section data, North Fish Creek

Route	Left overbank roughness	Channel roughness	Right overbank roughness	Channel length (meters)	Channel slope (m/m)
4560	0.1	0.065	0.1	4389	0.0088
6063	.1	.065	.1	1402	0.0035
6366	.1	.065	.1	4877	0.0061
6668	.1	.065	.1	731	0.0033

Detention basin characteristics—Seven detention basins were added to the subbasins 10, 20, 30, 50, 70, 80, and 90 (fig. 8). The detention basins were located to reduce the peak flow through the reach with severe bluff erosion problems. No detention basin was added to the Pine Creek drainage basin because it entered North Fish Creek below most of the bluffs. Peak outflow from the detention basins was determined to be the peak flow for each subbasin modeled under complete forest. Peak inflow was determined from previous HEC-1 runs for current land-use conditions. Total runoff volume for each subbasin was determined from the observed streamflow data. The amount of storage needed for each detention basin was determined by knowing the peak inflow and outflow rates and total volume needed.

For general purposes, two sizes of rectangular dry detention basins with a rectangular weir were designed: one to contain 67,840 m^3 and the other to contain 37,000 m^3 of runoff. These were adequate to contain the modeled historical storm (more complex and larger designs are needed if detention basins are actually constructed). The smaller detention basins are 213 by168 m and the larger detention basins are 305 by 213 m. Both are 1.5-m deep with 10 to 1 side slopes. The storage/elevation relation for each detention basin was used in HEC-1's storage routing procedure.

Model calibration—Using the parameters described above, the modeled hydrograph of current land-use conditions resulted in the a sum of flows 0.1 percent larger than observed, peak flow 2.0 percent smaller than observed, and time to peak the same as the observed. Thus, this model was deemed adequate at representing runoff from this historical storm.

Sediment-Load Modeling

A relation between streamflow and sediment load was established for the U.S. Geological Survey (USGS) gaging station on North Fish Creek near Moquah, Wis. (USGS station number 040263491) by Rose and Graczyk (1996). Using similar data collection and analysis techniques as Rose and Graczyk (1996, table 5, p. 12), one large runoff event (combination of spring snowmelt and rainfall) was sampled in April, 1996 to extend the relation between streamflow and sediment load to higher flows and to re-evaluate the curve in Rose and Graczyk (1996, fig. 5, p. 11). This additional sampling involved collecting streamflow data and data on sediment characteristics over the storm hydrograph. The spring snowmelt in 1996 resulted in flood flows on North Fish Creek that were larger than those measured during Rose and Graczyk's (1996) study of water years 1990–91.

Suspended Sediment Concentration and Particle Size Analysis

Suspended and streambed sediment were collected during a combined spring snowmelt and rainfall event at the gage on North Fish Creek near Moquah, Wis. Suspended sediment samples were collected by use of the depth-integrating sampler US D-49 and the equal-width-increment (EWI) method (Edwards and Glysson, 1988). Surficial streambed sediment was sampled by use of a rotary-bucket bed-material sampler US BMH-60 (Edwards and Glysson, 1988) at approximately ten verticals (same locations as suspended sediment verticals).

Suspended sediment concentration and streambed sediment particle size analyses were conducted at the USGS laboratory in Iowa City, Iowa, according to methods in Guy (1969). For suspended sediment samples, the filtration method was used for concentration and the

visual accumulation (VA) tube method for particle-size distributions. Particle-size distributions of streambed sediment were determined by the sieve and pipette methods (Guy, 1969). Results from these laboratory analyses are found in Appendix A.

Sediment Discharge and Load Calculations

Total sediment discharge at the gaging station (river kilometer 17) was determined by use of the modified Einstein procedure (Colby and Hembree, 1955). The same method was used by Rose and Graczyk (1996) to keep the new additional data consistent with their data. This procedure is applicable to alluvial channels with streambed sediment less than 16 mm and where a significant part of the measured suspended sediment is similar to the size of the streambed sediment (Stevens, 1985). The streambed at the gaging station is composed of approximately half sand and half larger particles (gravel, and occasional cobbles and boulders). The Einstein procedure was considered to be applicable for this site, although it is recognized that the procedure is most reliable for streams with uniform sand substrates.

Input data needed for the modified Einstein method, in addition to suspended sediment concentration and particle size and streambed sediment particle size, are streamflow, average water depth, effective width of the channel, average depth at the verticals for suspended-sediment, and depth of the unsampled zone (the zone between the nozzle on the suspended sediment sampler and the streambed when it comes in contact with the bottom). These additional characteristics were collected during streamflow measurements. A USGS computer program (Stevens, 1985) of the modified Einstein procedure was used for calculations.

Sediment-transport curves were made using USGS procedures (Glysson, 1987). The equations defining the curves were determined by regression analysis (least squares) of streamflow and total-sediment discharge. Table 7 shows the updates made to the sediment transport curves from Rose and Graczyk (1996) by use of additional data collected during a large storm in April 1996. The main difference between the two sets of equations is that the updated equations are the number of data points, the curves are power functions instead of linear equations, and below a discharge of 1.90 cms, the sediment load remains constant.

Table 7. Empirical sediment transport equations for North Fish Creek near Moquah, Wis.
[Qw, discharge, in cubic feet per second; Qs, sediment load, in tons per day. Sediment transport equations for this study were calculated in pound-foot units for comparison with transport equations from Rose and Graczyk (1996)]

Rose and Graczyk (1996) 1990-91	This study 1990-91, 1995-96
If $Q_w <= 79$, $Q_s = 0.02466 * Q_w$	If $Q_w <= 67$, $Q_s = 1.22857$
If $Q_w > 79$, $Q_s = 2.225 * Q_w - 172.55$	If $67 < Q_w < 181.5$, $Q_s = 1E\text{-}9 * Q_w$^4.9342
	If $Q_w => 181.5$, $Q_s = 0.0116 * Q_w$^1.8065

Table 8. Differences in annual sediment loads for North Fish Creek near Moquah, Wis., between two sets of sediment transport equations

Year	Rose and Graczyk equations with mean daily flow (tonnes)	Rose and Graczyk equations with 15-minute flow (tonnes)	Equations from this study with 15-minute flow (tonnes)
1990	10,850	10,810	8,260
1991	16,720	16,870	13,590
1995		7,960	4,740
1996		18,630	21,990

In addition to updating the sediment transport equations used in Rose and Graczyk (1996), unit values (15-minute) discharge values were used instead of mean daily discharge. There were no apparent differences between the two streamflow data sets for 1990 and 1991 (table 8). However, the updated equations resulted in smaller sediment yields for 1990, 1991, and 1995 and larger sediment yields for 1996. These differences from the original equations are caused by the use of power functions in the new equations instead of linear equations in the old. For mainly small or average events, the original equations will result in a greater sediment yield, and for large events the power functions will produce a greater sediment yield.

CHAPTER 3
POST-SETTLEMENT CHANGES IN GEOMORPHIC AND HYDROLOGIC CONDITIONS (1870-1995)

Post-settlement Changes in Vegetation, Climate, and Base Level

Geomorphic and hydrologic characteristics of North Fish Creek have potentially been affected by three major factors following European settlement: changes in vegetation, climate, and base level. The following sections describe how these factors have varied over the last 125 years, based on a combination of information compiled during this study and from data extracted out of existing literature for the region.

Vegetation

The natural vegetation of the North Fish Creek watershed just prior to European settlement consisted mainly of balsam fir/white spruce boreal forest (Curtis, 1959; Finley, 1976). Other less common vegetation in the watershed consisted of mixed coniferous-deciduous forest of white and red pine, sugar maple, yellow birch, and hemlock (Curtis, 1959).

The main human impacts on vegetation in the North Fish Creek basin occurred during European settlement in the 1870's; however, the land around Chequamegon Bay also was heavily used by Native Americans centuries earlier (Thwaites, 1895; Holzhueter, 1974; Smith and Goc, 1987). In 1659, when Radisson and Groseilliers first came to the area, they described the shores of Chequamegon Bay as uninhabited except for a few Hurons. However, Thwaites (1895, p. 405) noted that by the late 1660's, Father Claude Allouez, of the Jesuit mission, described a village of Hurons and a great village composed of three bands of Ottawas at the bottom of the bay "who plant their fields of Indian corn, and lead a stationary life. They are there, to the number of eight hundred men bearing arms, collected from seven different nations, who dwell in peace with each other." In 1670, the Huron and Ottawa were driven eastward by warring Sioux tribes from the west. Being a large agriculture-based population, it is probable these villages had at least locally significant influences on land cover in the watershed.

For the next 150 years, the shores of the bay were important for fur trading. Evidently, the bay area had problems with sand during the fur trading era for Thwaites (1895) mentions that the original village of La Pointe was moved from the southwest corner of Madeline Island when "the old harbor became shallow, because of the shifting sand, and unfit for the new and larger vessels which came to be used in the fur trade" (p. 419). Other excerpts from Thwaites monograph (1895) pertain to characteristics of Fish Creek and Chequamegon Slough:

> "at the junction of those two creeks [Fish Creek and a creek called Metabikitig-Sibiwishen between Ashland and Ashland Junction] and along their banks, especially on the east bank of Fish Creek, was once a large and populous Indian village of Ottawas, who there raised Indian corn... The soil along Fish Creek is rich, formed by the annual overflowage of its water, leaving behind a deposit of rich sandy loam. There is a young growth of timber along the right bank between the bay and Ashland Junction, and the grass growing underneath the trees shows that it was once a cultivated clearing. It was from this place that the trail left the bay, leading over to the Chippewa River country." (p. 430)

another passage records:

> "Fish Creek has three outlets into the bay, -one on the east shore or near the east side, one central, and one near the western shore; for full two miles up the stream, it is a vast swamp, through which the stream flows in deep, sluggish lagoons. Here, in the early days of American settlement, large brook trout were plenty; and even in my day many fine specimens have been taken from these 'pools'. Originally, there was along these bottoms a heavy elm forest, mixed with cedar and black ash, but it has now mostly disappeared. An old 'second growth,' along the east side, near Prentice Park, was evidently once the site of an Indian settlement, probably of 18th century." (p. 434)

Logging of old growth forests in the Lake Superior Region started soon after the Civil War and greatly expanded with the development of rail lines linking the region to Duluth and to southern cities such as Milwaukee and Chicago (Mahaffey, and Bassuk, 1978). Based on more local data collected from newspaper articles from the Ashland Daily Press (table 9), the

Table 9. Logging and fishing history of North Fish Creek, 1870-1890

[data collected by Dennis Pratt (Wisconsin Department of Natural Resources, 1997, written commun.) from The Ashland Daily Press]

Year	Logs driven (million feet)	Logging Notes	Number of fishing parties	Fishing Notes
1871	0	-	1	-
1872	0	-	3	-
1873	1	Pine harvest noted.	0	-
1874	0	Logs harvested previous year held in boom until Fall.	1	Two promotional features. Three anglers caught 380 brook trout in 3 days. Size of the trout was about 3 fish to a pound.
1875	0	-	4	One angler catches 120 brook trout in a day. Best fishing season ever.
1876	0	-	3	Two anglers catch 110 trout in a day, one weighed 2 pounds. Suggestion that obstructions at the forks should be removed.
1877	0	-	27	Up to several hundred trout could be caught in a day. Large row boats can be taken upstream several miles from the mouth. The creek is navigable 8 miles upstream from mouth by skiffs. Creek shaded.
1878	0	-	20	One angler catches 75 brook trout in a day. Largest trout weighed just over 2 lbs. Four promotional features. Mention that the creek has been fished to death this season.
1879	?	Unknonwn amount harvested and stored in boom until following year.	14	One angler caught 35 brook trout. Size of the trout about 1 pound each. One promotional feature.
1880	0	-	11	One promotional feature. Over the past 10 years 3000-6000 brook trout are taken each year. One angler catches 149 trout in a day. Creek described as having ice cold pools and rapids.
		-		One complaint about the logs stopping up the channel of Fish Creek so as to prevent sportsmen from going upstream in their boats.
1881	?	Bayfield and Fish Creek Booming and Logging Company file to improve Fish Creek.	6	One angler catches 150 trout in a day.
1882	1.5	Bad winter for logging.	4	One angler catchs 200 trout in a day. Fishing reported as good. One promotional feature. One complaint about the Fish Creek Boom Company impeding navigation all summer.
1883	4	About 1 million feet from tributaries. Boom improvements made at the mouth to prevent logs from escaping during a flood.	2	One promotional feature.

Table 9. Logging and fishing history of North Fish Creek, 1870-1890--Continued

Year	Logs driven (million feet)	Logging Notes	Number of fishing parties	Fishing Notes
1884	5.5	All logs from Pine Creek.	1	-
1885	5	Half of logs from Ashland Junction area.	1	-
1886	7	1 million feet from upper Fish Creek, 1-2 million from homesteaders in sections 22 and 28.	3	One angler catches 30 trout.
1887	8.7	Fish Creek turned out more logs than ever before. "The little creek will be filled for a distance of ten miles."	1	One promotional feature, one fishing notice. Fisherman reported as taking fair strings.
1888	7.5	Bad winter for logging.	0	-
1889	5	-	0	-
1890	2	-	0	-

drainage basin of North Fish Creek was logged, burned, cleared and settled starting in the early 1870's (D. Pratt, Wisconsin Department of Natural Resources, written commun., 1996; Pratt, 1997). North Fish Creek also was used to transport logs to Fish Creek Slough and Chequamegon Bay where several sawmills were located. Logs were driven down the stream from remote areas in the basin (fig. 9A) on an annual basis. The photograph in figure 9A was taken about 3 years after the first log drive (Dennis Pratt, Wisconsin Department of Natural Resources, oral commun., 1997). The first lumber mill in Ashland was in operation by 1872 (Burnham, 1929, p. 225). Soon after several lumber mills surrounded the shore of Chequamegon Bay near the mouth of Fish Creek (Burnham, 1929).

Pollen data in cores show drastic changes in the forest composition following logging and burning. For example, pollen data from a short core from Trout Lake, north-central Wisconsin (Webb, 1973) indicate pine pollen decreased by one-half and hemlock also decreased. Simultaneously, birch, oak, alder, ragweed, and pigweed pollen increased.

Mahaffey (1977) states that many unreported fires burned extensive portions of the region in nearly every year through the 1930's. Extensive forest fires that ravaged large areas in northern Wisconsin and northeastern Minnesota include the Peshtigo fire (October 8, 1871), the Hinkley fire (September 1, 1894), and the Cloquet fire (October 12, 1918) (Mahaffey and Bassuk, 1978).

After the decline in logging, major agricultural development in the region occurred from 1895 to 1920 (Mahaffey and Bassuk, 1978). At the turn of the century, the Wisconsin legislature passed a bill authorizing the University of Wisconsin, College of Agriculture to "launch an intensive campaign to promote northern farming" (Davis, 1996, p. 12). Much of the upland areas surrounding the deeply incised valley of North Fish Creek were put into agricultural production, mainly hay and pasture for dairy cattle. Agricultural activity peaked in the mid-1920's to mid-1930's. Since then, the number of farms and land in agricultural production have declined. For example, near the town of Moquah, 35 farms once existed during the peak of agriculture, while today only four farms remain.

A

B

C

Figure 9. Photographs of North Fish Creek at railroad crossing, sec. 2/3, T47N, R5W, Ashland Junction, Wis. (A) circa 1885-88 (J.M. Turner and Co., 1889), reproduction courtesy of State Historical Society of Wisconsin, negative no. WH:(X3)51439; (B) circa 1888-98 (Turner and Turner, 1898); and (C) 1997 (courtesy of D. Pratt, Wisconsin Department of Natural Resources, Superior, Wis.).

Land-use characteristics during the peak of agriculture in the North Fish Creek basin was estimated using the 1928 Land Economic Inventories published by the Wisconsin Department of Agriculture in cooperation with the Geological and Natural History Survey. These inventory maps contain detailed land use information for each township at a scale of 1:63,360. The line-intercept technique was used, which consisted of drawing 16 lines perpendicular to the general valley direction 1 mile apart, and recording the type of land use that intersected a point on the line every 1/8-mile. This resulted in a total of 309 counts on which land-use percentages are based (table 10).

Based on comparisons between the 1928 land-use data (table 10) and 1990 land-use data (table 1), the amount of agricultural land and forest has stayed about the same assuming that the grassland category from the 1990 WISCLAND satellite data is similar to the pasture land from the 1928 Land Economic Inventory. However, the amount of cropland was about 22 percent in 1928 compared to 3 percent in 1990 (table 1).The types of forested land from the two land-use data bases were generally similar; however, in 1928 all trees were recorded as less than 6 inches, and many were recorded as less than 3 inches.

Fish Creek was known as one of the best trout streams in Wisconsin in the late 1800's and early 1900's, in spite of the logging and log driving. The size of the natural fishery in the stream is well-illustrated by the large daily catches of trout throughout the 1870's and 1880's (table 9). As late as 1882, there are indications that large catches (300 trout per day) were still possible (Burnham, 1929). Even into the 1920's Fish Creek was reported to have hundreds of fisherman a day during trout season (Burnham, 1929), showing that even under extremely adverse conditions and degraded habitat the stream continued to be a valued resource.

Table 10. Land cover statistics from the 1928 Land Economic Inventory for North Fish Creek.
[Percentages are based on the line-intercept method (16 lines drawn perpendicular to the valley of North Fish Creek)]

Land-cover category	Percentage of drainage basin
Crop land and open land	22.0
Open land	0.6
Cleared farm crop land	21.4
Pasture	6.5
Permanent pasture	.3
Stump pasture	6.2
Deciduous forest	42.1
Hardwood with some basswood	.3
Popple with some white birch	24.3
Popple with some white birch, scrub oak and some red maple	12.3
Popple with some white birch and pin cherry	1.3
Popple with some white birch, tag alder, willow, and red dogwood	3.9
Coniferous forest	1.6
Spruce (mostly black)	1.3
Tamarack	.3
Mixed deciduous and coniferous forest	22.3
Hardwood with some conifer	.6
Hardwood with some conifer, popple with some birch	4.9
Popple with some white birch and Norway pine	12.0
Popple with some white birch and spruce (mostly black)	1.9
Popple with some white birch, hardwood with some conifer	2.9
Cattail marsh, grass meadow	2.3
Tag alder, willow, and red dogwood	0.3
White cedar (3-15 inches), tag alder, willow, and red dogwood	1.6
Recent burn	1.0
Road	0.3

Climate

The potential for post-settlement climatic change in the vicinity of North Fish Creek was quantified by examination of long-term historical precipitation. For northern Wisconsin, regional droughts occurred in 1910-11, 1929–34, 1948–50, 1955–59, 1962–65, and 1987–88 (U.S. Geological Survey, 1991). Regional flooding occurred in northern Wisconsin in 1922 (snowmelt), 1941 (record rainfall), 1943 (intense thunderstorms), and 1960 (snowmelt combined with rainfall).

To identify local precipitation patterns for the North Fish Creek drainage that may be different from regional patterns, the precipitation record for the Ashland Experimental Farm, Ashland, Wis. was examined. Rainfall events greater than 7.6 cm were identified for the period of record (1900 to 1997). These events resulted in some of the largest floods, as reported on in local newspapers (fig. 10). The 1946 rainfall event contributed by far the most precipitation of any storm on record. Total precipitation over two-day period for this event was greater than 22.9 cm. The second largest storm occurred in 1909 with just over 17.8 cm. Other significantly large storms (greater than 12.7 cm) occurred in 1941, 1961, 1985, and 1992. A 10.2-cm or larger storm occurred at least every 20 years. For comparison, the 100-year, 24-hour rainfall estimated for the Ashland area is 11.4 cm (Hershfield, 1961; Dunne and Leopold, 1978, p. 63).

In general, sometimes 2- to 4-year episodes occurred when rainfall events never exceeded 7.6 cm, whereas in some years 7.6-cm events occurred more than once (fig. 10). The most obvious 5-year episodes without major storms occurred in 1932-37, 1965-70, and 1986-91. Overall, there was a general lack of storms between 1910 and 1940. There also was a noticeable cluster of large storms between 1949 and 1954.

Base Level

The base level of North Fish Creek is controlled by the water level of Lake Superior. Historic levels of Lake Superior have been controlled by isostatic rebound, climate, and human stabilization through lock and dam structures at the mouth. Average levels of Lake Superior at Duluth have been relatively stable since 1860 when historic records began, ranging from an

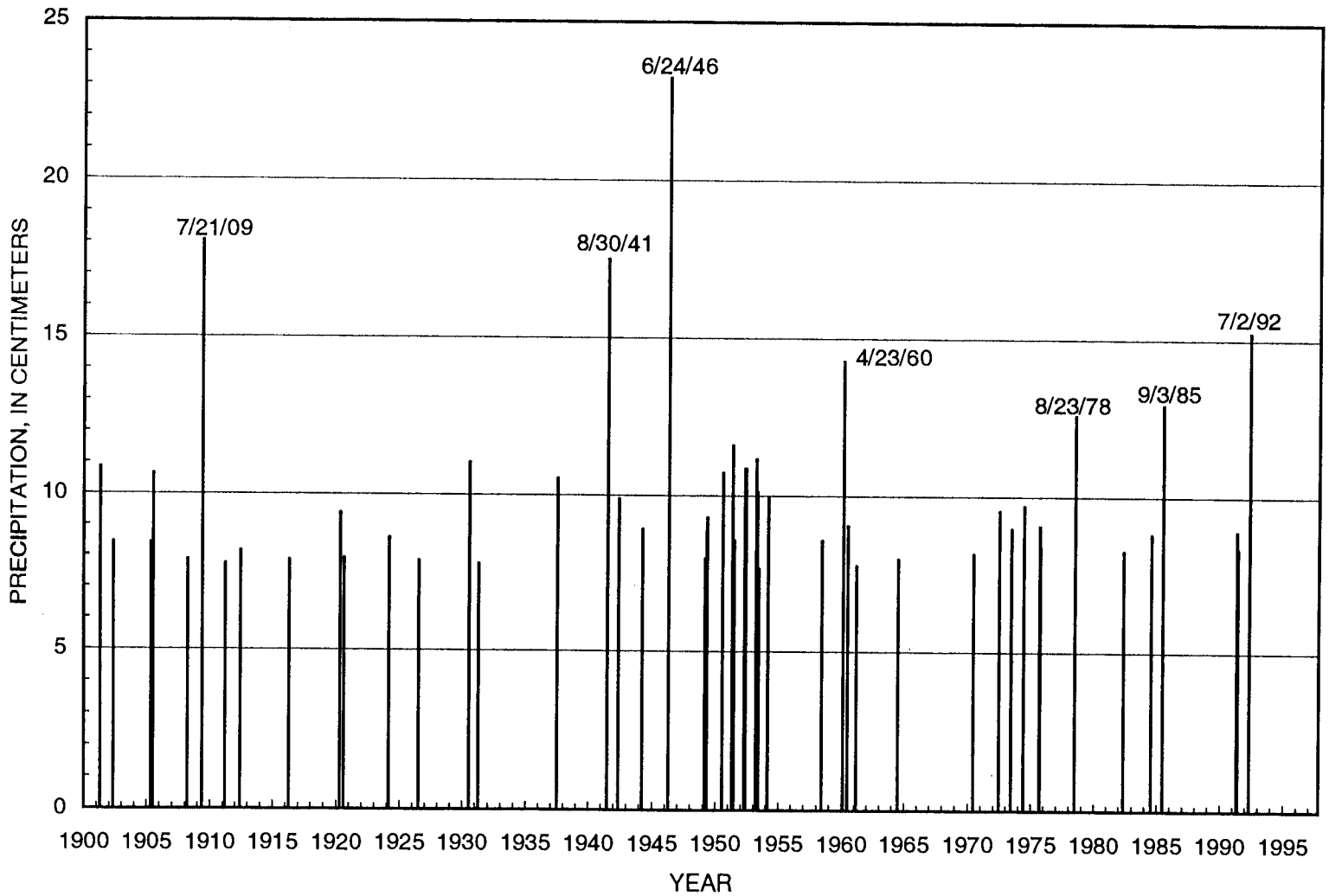


Figure 10. Precipitation events greater than 7.6 cm (3 inches), Ashland Experimental Farm, Wis., 1900-97.

average of about 182. 7 m (599.5 ft) in the late 1800's to a present level of 183.0 m (600.5 ft) with a maximum change in water level of under 2 m during the period of record (International Joint Commission, 1976). In general, low water levels occurred during the 1930's and 1960's and high levels in the 1950's and 1970's (Brinkmann, 1983a). A minimum level of 182.3 m was recorded in 1926, and a maximum of 183.9 m in 1985 (Department of the Army, 1993). Other higher levels of Lake Superior occurred in 1876 and 1950 at 183.5 m. These minor variations in lake level have been thought to be climatically controlled (Knox and others, 1976), and occur during shifts in major atmospheric circulation patterns and may correspond with variations in the position of the summer storm track and cyclone activity (Brinkmann, 1983a, 1983b). However, others have postulated that the increase in the level of Lake Superior during the late 1800's (U.S. Department of Commerce, 1973) was caused by increased runoff of streams draining into Lake Superior because of the reduction in transpiration due to widespread logging and burning in the northern Midwest.

Even though the overall level of Lake Superior has been held relatively constant since the turn of the century because of the St. Mary's Lock and Dam structure near Sault Ste. Marie, there has been an increase of approximately 26 cm of water depth relative to the land over the last 125 years caused by differential isostatic rebound (Larsen, 1994).

Flood History

The gaging station on North Fish Creek near Moquah began operation in 1990; however, a long-term gaging station on the Bois Brule River has streamflow data extending back in time to 1943. Timing and magnitude of streamflow in North Fish Creek responds somewhat similar to the Bois Brule for the overlapping periods of record. A Spearman correlation coefficient (Iman and Conover, 1983) of 0.53 ($p = 0.0001$) was calculated from the correlation analysis of the two records, indicating a weak but significant relation between the two streamflow records. Part of the variability between the two records may be due to the fact that the Bois Brule River has a drainage area three times larger than North Fish Creek gage near Moquah, Wis.

Annual peak flows at the Brule River gage also were examined for trends over the period of record using Kendall's tau, a nonparametric measure of the strength of a trend for data that have skewed or non-normal distributions (Kendall, 1948). Even though there were four exceptionally large annual peak flows clustered within a 10-year period (1944, 1950, 1953 and 1954), there was no overall trend in peak flows (Kendall tau = -0.11, p-value = 0.246). Annual peak flows from three other forested streams in northeastern Wisconsin also did not show a significant trend over a similar time period (Gebert and Krug, 1996).

Results from interviews with local inhabitants along North Fish Creek indicated that major floods on North Fish Creek did not correspond to major floods on the Brule River. Thus, newspaper accounts were examined based on dates from large precipitation events recorded at the Ashland Experimental Farm. All large storms in the Ashland area resulted in flooding problems on North Fish Creek, based on newspaper accounts. For example, the storm on July 21, 1909 (fig. 10) was reported as "the worst rainstorm in the history of Ashland" and a total of 18.3 cm of rain fell over 48 hours (Ashland Daily Press, Wednesday, July 21 and July 23, 1909; Bayfield County Press, July 23, 1909). All railroad traffic was at a standstill from Ashland because of washed-out tracks. The bridge across the main channel of Fish Creek at the head of the bay was washed out. The railroad crossing at Ashland Junction was damaged. Survey notes from the original bridge siting for the U.S. Hwy. 2 crossing near Moquah, Wis., point to a major change in channel conditions. The surveyor writes "the streambed was formerly gravel, but a bad flood in 1909 completely changed its character. The bottom seems to be a shifty sand, with some gravel intermingled." A dam and railroad crossing at Moquah (on a tributary to North Fish Creek or Pine Creek?) was expected to be lost as well.

In 1941, another summer storm occurred in the Ashland area that produced just under 18 cm (fig. 10). Flooding on Fish Creek caused the washout of 30 m of the longer bridge along U.S. Hwy 2 at the mouth of Fish Creek and damage to the shorter bridge near the eastern outlet of Fish Creek Slough at the Bay. The longer bridge was built only four years earlier. This storm was recorded as "surpassing all others in intensity" (Ashland Daily Press, September 2, 1941).

The summer storm in 1946 produced the most rainfall in more than 100 years at about 23.6 cm (fig. 10). Based on newspaper accounts, this storm produced the worst flood in history (The Washburn Times, June 27, July 11, and July 18, 1946; Ashland Daily Press, June 24 and 25, 1946). Several road and rail bridges were washed out along the tributaries and mainstem of North Fish Creek and at the mouth of Fish Creek at the Bay. The long bridge at the mouth of Fish Creek at Chequamegon Bay had to be replaced again. The bridge crossing at old Hwy 13 at Ashland Junction (at the section line between sections 2 and 3, T47N, R5W) also was washed out and never replaced. Water was reported to be "several inches" over the road surface there and water by some cabins near there (on the floodplain?) was reported to be 1.2-m deep (Ashland Daily Press, June 24, 1946). Several buildings were washed away on the terrace just upstream of the bridge at Old Hwy 2 near Moquah, Wis. One building on the terrace, a tavern, was moved 30 m downstream and wedged almost intact against the bridge at Old U.S. Hwy 2. Upstream from this location several cattle were reported to be neck-deep in silt after flood waters receded (The Washburn Times, June 27, 1946).

Some of the smaller storms, such as the storm on September 3, 1905 of about 10.7 cm was reported as the "worst storm in years" that "came with little warning" and caused the sinking of many ships on Lake Superior (Ashland Daily Press, September 5, 1909). However, besides the mention of "tracks at the head of the bay washed out," no other report on flooding was given.

Post-Settlement Sediment Budget

A sediment budget is estimated by adding up the different sources of erosion and subtracting sources of deposition for a given drainage area. Typical types of erosion included in sediment budgets are sheet and rill, gully, channel, floodplain scour, and stream bank (Chesier, 1996). Sheet and rill erosion are typically estimated with the Universal Soil Loss Equation (USLE) described in Wischmeier and Smith (1965,1978), or the Revised USLE (Renard and others, 1993). Gully, channel, and floodplain scour are estimated by use of air photographs, reconnaissance, topographic maps, and interviews. Potential sites of sediment deposition

include uplands, hillslopes, ponds and lakes, stream channels, alluvial fans, and floodplains. The amount of deposition is usually estimated with reconnaissance, bulk density measurements, air photographs, and topographic maps.

Two annual sediment budgets for North Fish Creek (table 11, fig. 11) were estimated to compare general post-settlement erosion and deposition rates based on field data and air photographs to average sediment yield data collected by Rose and Graczyk (1996) for water years 1990 and 1991. Although the time periods are different for the field data and measured sediment loads, the sediment budgets were useful for comparing sources and sinks of sediment among different reaches under different geomorphic conditions and for comparing short-term data (sediment load measurements) to longer-term geomorphic evidence. The long-term and short-term sediment budgets were computed for annual yields. These yields represent averages and do not mean that this exact amount of sediment is eroded and deposited every year. Variations in erosion and deposition occur depending on flood characteristics and antecedent moisture conditions for any given year.

Methods for calculating the sediment budget were expanded from those in Chesier (1996). Textbook dry bulk densities for a mix of sand and fines were used to covert sediment volume to weight. Dry bulk density for loamy sediment is about 1.4415 tonnes per m^3 (90 tons/ft^3) (Brady, 1974, p. 52; Chow, 1964, p. 17-18).

In the following discussion of the sediment budget, several reaches were combined based on the location of sites with sediment load data from Rose and Graczyk (1996). Sediment load data are available at river kilometer 28 (near the boundary between reaches 5 and 6, Hwy 2 crossing near Ino, Wis., drainage area of 50 km^2), at river kilometer 17 (near the boundary of reaches 3 and 4, Old Hwy. 2 crossing near Moquah, Wis., drainage area of 99 km^2), and at river kilometer 3, near the boundary of reaches 1 and 2, Hwy. 2 crossing near Ashland Junction, Wis., drainage area of 123 km^2).

Application of the USLE, which was designed for estimation of sheet and rill erosion at individual hillslope scale, has known problems when applied to the watershed scale. Instead, sediment load data from the upper most site at river kilometer 28 sampled by Rose and Graczyk (site C) was considered a better estimate for upland and minor gully erosion. The average sed-

Table 11. Long-term and short-term annual sediment budgets for North Fish Creek at river kilometers 3, 17, and 28, in tonnes/year

[Yield calculations based on dry bulk density of 1.4415 metric tons/m^3 (90 ton/ft^3) (Brady, 1974; Chow, 1964).]

Component	River kilometer 28	River kilometer 17	Long-term river kilometer 3	Short-term river kilometer 3
Upstream input (+)	0	450	16410	16410
Upland erosion (+)	450	450	200	200
Bluff erosion (+)	0	14140	860	1080
Streambank erosion (+)	0	0	1300	2160
Gully erosion (+)	0	0	910	910
Channel erosion (+)	0	2880	1220	1220
Floodplain deposition (-)	0	-1510	-3430	0
Channel deposition (-)	0	0	-1570	0
Calculated sediment yield	450	16410	15900	21980
Measured sediment yield (1990-91)	450	13790	24400	24400
Difference (Calculated-Measured)	0	2620	-8500	2420

Annual bluff erosion	Long-term reaches 4 and 5	Long-term reach 3
Number of eroded bluffs:	17	2
Height of eroded bluffs (m):	20	20
Total length of eroded bluffs (m):	981	60
Reatreat rate (m/yr)	0.5	0.5
Volume of sediment (m^3)	9810	600
Dry weight of sediment (metric tons)	14140	860

Annual streambank erosion	Long-term reach 3	Short-term reach 2
Number of eroded banks:	15	75
Height of eroded banks (m):	4	2
Avereage length of eroded bank (m):	30	20
Reatreat rate (m/yr)	0.5	0.2
Volume of sediment (m^3)	900	600
Dry weight of sediment (metric tons)	1300	860

Table 11. Long-term and short-term annual sediment budgets for North Fish Creek at river kilometers 3, 17, and 28-Continued

Annual channel erosion	Long-term reaches 4 and 5	Long-term reach 3
Historical erosion (m)	2	2
Erosion rate (m/yr)	0.017	0.013
Channel length (m)	12000	4500
Channel width (m)	10	15
Volume of sediment (m^3)	2000	844
Dry weight of sediment (metric tons)	2880	1220

Annual channel deposition	Long-term reach 2
Historical deposition (m)	1
Depositional rate (m/yr)	0.0083
Channel length (m)	8700
Channel width (m)	15
Volume of sediment (m^3)	1088
Dry weight of sediment (metric tons)	1570

Annual floodplain deposition	Long-term reach 5	Long-term reach 4	Long-term reach 3	Long-term reach 2
Historical deposition (m)	0	1	1	1
Depositional rate (m/yr)	0.0025	0.0042	0.0067	0.0067
Floodplain length (m)	2255	7071	2743	6096
Width of depositional area (m)	12	30	30	45
Volume of sediment (m^3)	68	884	549	1829
Dry weight of sediment (metric tons)	97	1270	790	2640

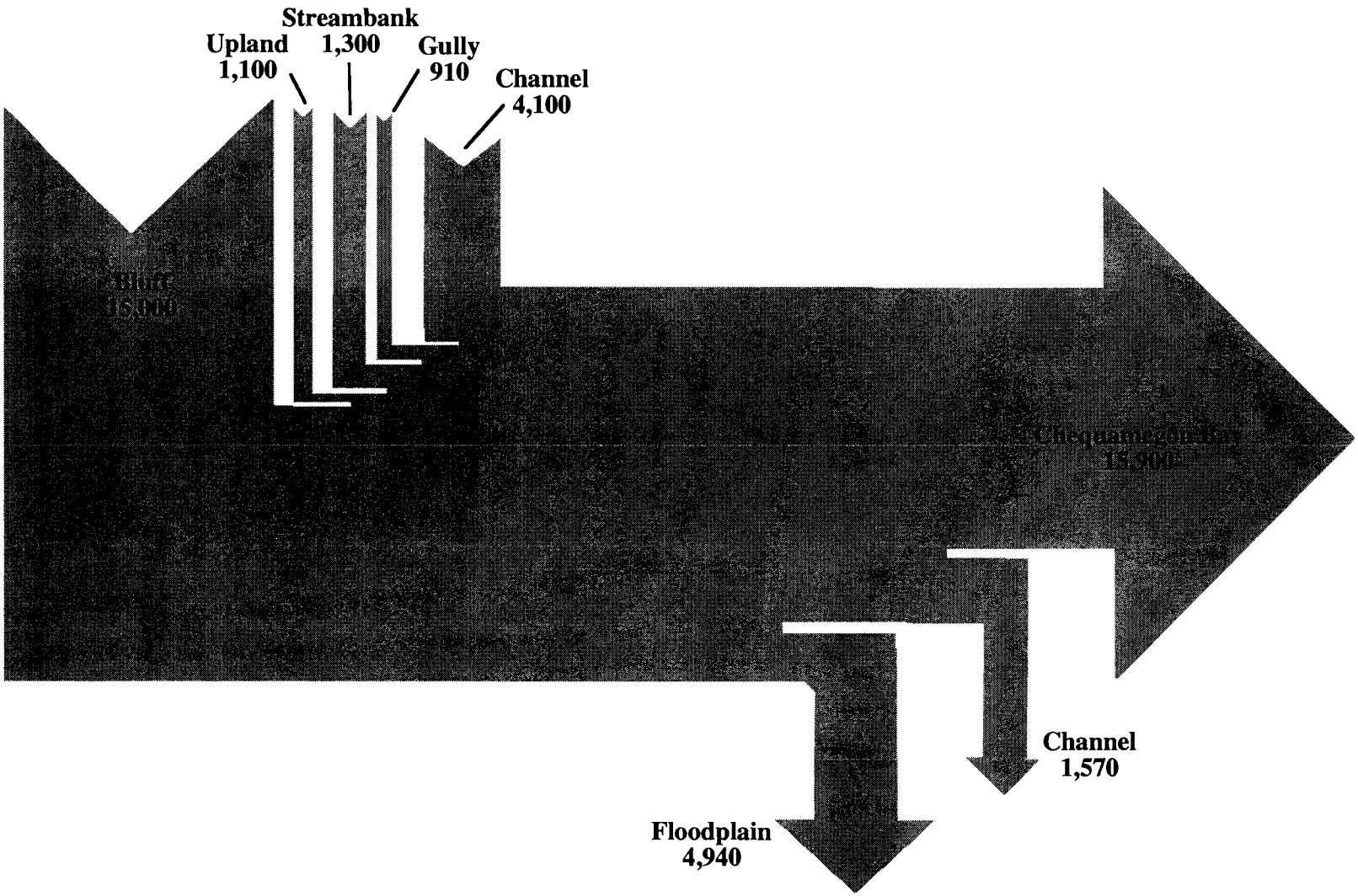


Figure 11. Diagram of the long-term annual sediment budget for North Fish Creek at river kilometer 3 (reach 5), in tonnes per year.

iment yield of 450 tonnes per year from Rose and Graczyk (1996) also was used as an estimate of upland and any tributary erosion and(or) local deposition for the sediment budgets at river kilometer 17 and 3 (table 11).

Bluff erosion rates of 0.5 m per year were used based on air photo information (more details follow in next section). Eroding bluffs historically produced approximately 15,000 tonnes of sediment per year in reaches 3, 4, and 5 (table 11). Stream-bank erosion in reaches 4 and 5 was assumed to be negligible compared to bluff erosion. However, it was estimated that approximately 1,300 tonnes per year have been eroded from streambanks in reach 3 (fig. 11). Average channel erosion over the last 120 years was based on historical degradation rates observed from field surveys. These surveys indicate an average erosion rate of 2,880 tonnes per year from reaches 4 and 5, and 1,220 tonnes per year from reach 3. Gully erosion also was observed along the major tributary feeding into reach 2; thus, a very rough estimate of 900 tonnes per year (based on about 600 m^3 of sediment) were added to the sediment budget to account for this. Evidence from cores and bank exposures indicate that sediment stored historically at tributary mouths and on floodplains is about 4,940 tonnes per year. Channel deposition is estimated to be 1,570 tonnes per year in reach 2.

Inputs of sediment from North Fish Creek to Chequamegon Bay are approximately 16,000 to 22,000 tonnes per year, based on the long- and short-term budgets (table 11, fig. 11). However, some additional floodplain and channel sedimentation occurs within river kilometer 0 (the mouth at Chequamegon Bay) and river kilometer 3.

Long-term inputs from erosion are less than long-term outputs from deposition in reaches 2 and 3, resulting in smaller sediment yields at river kilometer 3 than at river kilometer 17. This result supports the field data that show reach 2 is an aggradational reach. However, the short-term calculated sediment yield and the measured sediment yield at river kilometer 3 is 1.3 to 1.8 times higher than at river kilometer 17. This difference may be caused by temporal variations in sediment yields and lack of large floods during 1990-91 sampling period. The largest flow measured during these two years was less than the 2-year flood, thus, floodplain and prob-

ably channel deposition did not occur. It also is thought that there may be additional bank erosion in reach 2 in the short term, even though over the long term bank erosion is negligible in this reach.

Field Evidence of Post-settlement Geomorphic and Hydrologic Change

Field evidence of post-settlement geomorphic change in North Fish Creek was gathered by measuring bluff erosion rates from air photographs, collecting cores in the floodplain and channel, examining stratigraphy in eroded bluffs and stream banks, surveying modern and relict channels, and gathering geomorphic information from historical maps, photos, newspaper articles, documents, and highway bridge surveys.

Bluff Erosion Rates and Sediment Characteristics

Seventeen large bluffs with potential for erosion and sediment delivery to North Fish Creek were identified between river kilometer 17 to 27 (fig. 12). All 17 bluffs are upstream of the gaging station near Moquah, Wis. Results from the analyses of retreat rates of the bluffs and channel locations from 1938 to 1990 are presented in table 12. Bluff retreat rates were dependent upon whether the channel migrated toward the bluff, was stationary, or migrated away from the bluff. Of the 17 bluffs, 10 represented situations where the channel migrated toward the bluff. The 10 bluffs retreated from 15 to 39 m over the 52 years, with an average retreat of 25 m over 52 years, or about 0.5 m per year.

The volume of sediment lost from these bluffs over the past 52 years was estimated by combining the amount of retreat with the area of exposed bluff sediment. Each bluff is approximately 15 to 25 m high (based on stratigraphic descriptions of two bluffs) and the length of exposed surface ranges from approximately 16 to 156 m. The total length of exposed bluffs from river kilometer 17 to 27 is 981 m. Measurements from bluff 15 were not included (table 12) because sometime in the next decade after 1938 the meander at the bluff was cut off from the main channel, thus prohibiting direct input of sediment to the channel from the bluff. Multiplying the length of all the exposed bluffs by 20 m (the average height of the bluffs) and by

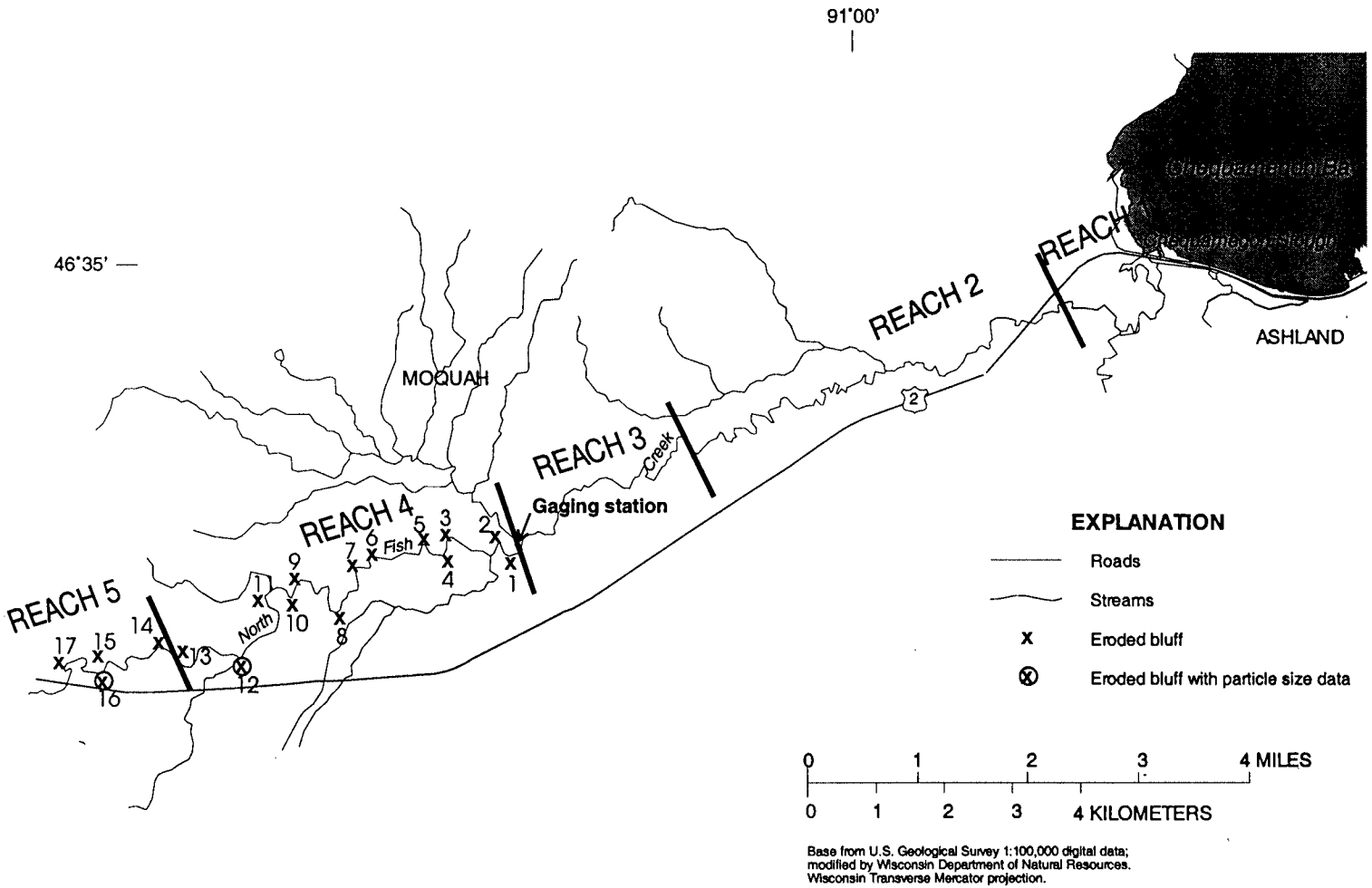


Figure 12. Locations of large eroding bluffs along North Fish Creek, 1990.

Table 12. Bluff erosion data for North Fish Creek, 1938 and 1990

[Distances measured perpendicular to channel direction. Scale conversions for aerial photographs checked against U.S. Geological Survey 1964 7.5-minute topographic maps; --, missing data.]

Bluff number	Location	Reference location	Bluff length (m)	Difference in distance (m) from bluff top to reference location (1990 - 1938)	Difference in distance from channel to reference location (1990 - 1938)	Comments
1	T47N, R6W, sec. 13	Janeck Rd., due south	47	--	-23	Bluff top vegetated
2	T47N, R6W, sec. 13	Old U.S. Hwy. 2, due north	63	-36[a]	-17	Bluff and channel retreat
3	T47N, R6W, sec. 14	Old U.S. Hwy. 2, due north	126	-25[1]	-17	Bluff and channel retreat
4	T47N, R6W, sec. 14	14/23 section line, due south	63	-7	13	Channel migration away from bluff
5	T47N, R6W, sec. 14	Old U.S. Hwy. 2, northeast	95	-39[1]	-11	Bluff and channel retreat
6	T47N, R6W, sec. 14	Old U.S. Hwy. 2, due north	32	-16[1]	-28	Bluff and channel retreat
7	T47N, R6W, sec. 14	Old U.S. Hwy. 2 at 14/15 section line, northwest	63	-33[1]	-36	Bluff and channel retreat
8	T47N, R6W, sec. 22	Tributary crossing at 22/23 section line, southeast	32	-16[1]	-51	Bluff and channel retreat
9	T47N, R6W, sec. 22	Tributary crossing in subdivision of sec. 15, northwest	47	-27[1]	-21	Bluff and channel retreat
10	T47N, R6W, sec. 22	U.S. Hwy. 2, due south	32	-169	7	Stable channel, bluff measurement suspect
11	T47N, R6W, sec. 22	Northwest corner of sec. 22, northwest	16	-15	4	Stable channel and bluff
12	T47N, R6W, sec. 22	U.S. Hwy. 2, southeast	62	5	0	Stable channel and bluff
13	T47N, R6W, sec. 21	Tributary crossing at U.S. Hwy. 2, southeast	156	-19[1]	-31	Bluff and channel retreat
14	T47N, R6W, sec. 21	County Hwy. G, northwest	23	-10[1]	-48	Bluff and channel retreat
15	T47N, R6W, sec. 20	County Hwy. G, due north	--	5	--	Channel migration away from bluff
16	T47N, R6W, sec. 20	U.S. Hwy. 2, due south	62	1	-10	Stable channel and bluff
17	T47N, R6W, sec. 20	County Hwy. G., northwest	62	-28[1]	-18	Bluff and channel retreat

a. Retreat rate used to calculate average retreat rate.

0.5 m (the average retreat per year) indicates that about 9,800 m^3 per year is eroded. This equate to about 14,140 tonnes of sediment potentially delivered to the stream each year, assuming an average bulk density of 1.4415 tonnes per m^3 (Brady, 1974; Chow, 1964, p. 17-18).

Rose and Graczyk (1991) estimated an average total sediment load at the gaging station at river kilometer 17 (fig. 1) of approximately 13,790 tonnes per year in 1990-91, based on suspended and streambed sediment samples collected during floods. Thus, these measurements of bluff erosion rates from aerial photographs support the conclusions of Rose and Graczyk that bluff erosion is the major contributor of sediment transported at the gage.

The particle-size distributions of sediment (Appendix A) in two representative bluffs also were analyzed to compare the textural characteristics of bluff sediment to that transported by the stream at the gage. Results from the analysis of sediment in one bluff are illustrated in figure 13. The particle size distribution for each stratigraphic unit was weighted relative to its thickness in the bluff exposure. The weighted particle sizes were used to calculate an average particle size for the entire bluff. It is assumed that the stratigraphic units erode equally through mass wasting in the upper part of the bluff and by fluvial erosion in the lower part.

The bluffs have the appearance of being completely composed of red clay at first glance, and are typically referred to as "clay banks". The clayey appearance results from the clay-rich Miller Creek formation occurring at the top of bluff sections. Mass wasting from the upper bluff commonly forms a coating over the entire face of the bluff. However, the bluffs contain numerous sandy units (figs. 13 and 14). Much of the sand ranges from fine to medium-sized (fig. 13 and 14). Particle size analyses indicate that two bluff compositions range from 44 to 58 percent silt and clay and from 42 to 56 percent sand when stratigraphically weighted for unit thickness. Thus, eroding bluffs are sources for substantial amounts of sand. Particle-size analyses of suspended sediment collected during Rose and Graczyk's (1996) study indicate that 40 percent of the sediment load at the USGS gaging station is silt and clay and 60 percent is sand.

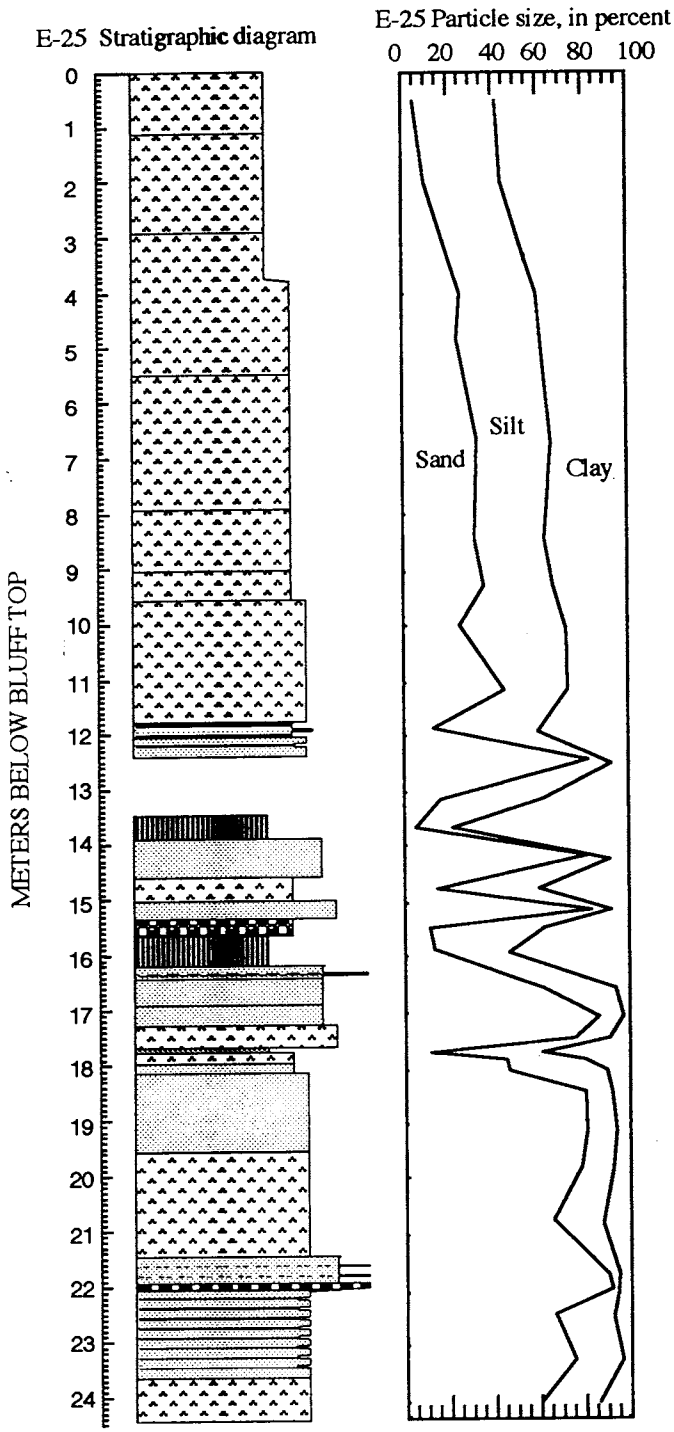


Figure 13. Example stratigraphy and particle-size distribution of bluffs along North Fish Creek, reach 5, exposure E-25 (see fig. 14 for legend).

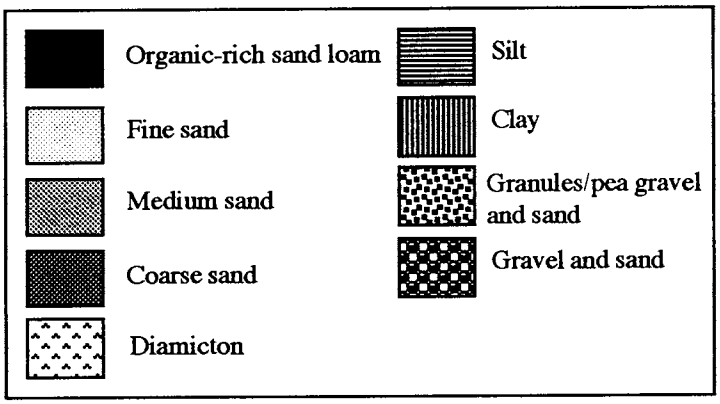


Figure 14. Legend for all figures with stratigraphic diagrams.

Channel Width and Streambed Sediment

Post-settlement changes in the channel width and streambed sediment of the North Fish Creek channel were quantified by comparing descriptions of streamflow width and streambed sediments at section-line crossings of the channel from GLO survey notes with width and streambed sediment of the modern channel at the same section line crossings. The results of the analysis of channel width and streambed sediments are summarized in table 13. Locations of section line crossings are shown on figure 1. Most channel locations on the 7.5-minute topographic maps are within 30 m of the channel locations recorded in the 1855 GLO Survey. A distance of less than 30 m is within the resolution of distances measured on USGS 7.5-minute topographic maps; thus, the location of the channel at most section lines appear to have moved very little. Out of the 13 section line surveys completed, three channel locations appear to be the result of 150-m avulsions that occurred after 1855. They are at T47N, R6W, section lines between sections 20 and 21 and sections 22 and 23; and T47N, R6W/R5W, section line between sections 13 and 18.

The data presented in table 13 indicate that the channel of North Fish Creek has narrowed over the last 140 years (1855-1995) in reaches 4 and 5 and has widened or stayed the same over the last 140 years in reach 2. The narrowing of the channel corresponds with steep gradient (0.00800 m/m), while channel widening corresponds with flat gradient (0.00126 m/m). The channel narrowing of 3.3 m from river kilometer 12 to 15, which does not follow the trend seen from the rest of the measurements, seems to correspond with a short steepening of gradient (0.00263 m/m) at approximately river kilometer 13. The river valley narrows through this reach and the channel is less sinuous. The longitudinal profile of South Fish Creek shows a similar step in gradient at the same river kilometer, although the altitude of the South Fish Creek channel is approximately 20 m above the altitude of the North Fish Creek channel. Field observations of steep, eroding stream banks, lack of floodplain, and observations of the stream flowing on glacial deposits instead of alluvium through this reach suggest that this reach is highly unstable.

Table 13. Comparison of channel width and streambed-sediment characteristics in 1855 and 1995

[--, missing. Changes in channel position based on 1855 Government Land Office Survey notes and 1975 (photo-revised) U.S. Geological Survey 7.5-minute topographic maps. Channel width measured from water's edge during low flow conditions to match most probable width measured in the Government Land Office Surveys, which also were done during low flow conditions.]

Section line	River kilometer above mouth at Lake Superior	Government Land Office Survey, 1855		This study, 1995		Change in channel width, 1855-1995 (meters)	Change in channel position 1855-1975 (meters)
		Channel width (meters)	Streambed sediment	Channel width (meters)	Streambed sediment		
T47N, R6W, sections 20 and 29	26.5	6.0	Gravelly	4.9	Gravel, cobble, boulder	-1.1	24 east
T47N, R6W, sections 20 and 21	24.8	8.1	--	7.9	--	-.2	160 south
T47N, R6W, sections 21 and 22	22.8	10.1	--	9.8	Cobble, boulder, gravel, and sand	-.3	27 south
T47N, R6W, sections 22 and 23	19.6	12.1	--	7.2	Sand and gravel	-4.9	140 south
T47N, R6W, section 14 and 23	19.1	12.1	--	8.7	Boulder, sand, gravel, and cobble	-3.4	26 east
T47N, R6W, sections 13 and 14	17.1	8.1	Gravelly	8.9	--	.8	0
T47N, R6W, section 13 and R5W, section 18	14.6	14.1	--	10.8	Sand, gravel, cobble	-3.3	168 north
T47N, R5W, sections 7 and 18	12.4	13.1	Sandy	9.8	Sand, unstable channel	-3.3	17 west
T47N, R5W, sections 7 and 8	12.1	12.1	Sandy	13.1	Sand with minor gravel	1.0	7 south
T47N, R5W, sections 8 and 9	9.1	12.1	Sandy	12.1	--	0	29 south
T47N, R5W, sections 9 and 10	6.6	10.1	Rocky	12.7	Sand with minor pea gravel	2.6	15 south
T47N, R5W, sections 3 and 10	5.1	14.1	Sandy	14.1	--	0	10 west
T47N, R5W, sections 2 and 3	4.2	12.1	--	14.7	Sand	2.6	21 north

Streambed sediment at section-line crossings (table 7) seems to have changed very little over the last 140 years. Streambed sediment in reaches 4 and 5 is very coarse and mainly consists of gravel, cobble, boulder, and sand. Streambed sediment is mentioned only twice in the GLO records for Township 47 North, Range 6 West, one at each end of the reach in this township. Streambed sediment is described as "gravelly" and is consistent with streambed sediment found in this reach today. The lower reaches were described as "sandy" in the GLO surveys, except for one section line crossing (Township 47 North, Range 5 West, section line between sections 3 and 10) described as "rocky". Current descriptions of the streambed sediment at section line crossings in the lower reach show similar findings, except that the streambed sediment at the section line between sections 3 and 10 contained sand and no rocks. Cores of the channel and floodplain were collected in this reach in an attempt to locate the rocky material referred to in the GLO survey; however, the largest particle size retrieved in cores was very coarse sand and pea gravel. Verification of the channel location at this section line crossing indicates that the modern channel is within 30 m of the channel surveyed in 1855. Thus, no rocky sediment was found in the vicinity of this section-line crossing, and evidence for the rocky material described in the 1855 GLO survey was not found.

Upper Mainstem Channel Erosion (Reach 4 and 5)

From river kilometer 28 to 17 (reaches 4 and 5), the gradient is substantially steeper (0.00775 m/m/) than from river kilometer 17 to the mouth (0.00140 m/m). Data from cores, valley transects, and historical bridge data suggest that the North Fish Creek channel has degraded approximately 1 to 3.5 m along river kilometer 27 to 15 over the last 125 years.

Just downstream of the Highway 2 crossing near Ino, Wis. in reach 5 (fig. 1), several stream-bank exposures were examined. In general, and keeping in mind that data are limited in this reach, the approximate height of the first level surface was 3 m above the channel bottom, and a buried organic zone about 0.10 to 0.15 m thick, presumed to be historic, was identified under 0.8 to 1.5 m of sediment. Abundant charcoal and modern-looking wood was found in the organic zone. This cut is in a terrace, because a new floodplain seems to be forming within the active meander belt. Historical channel entrenchment in this reach further

supports this hypothesis that the early historical floodplain has now become a terrace. Historic sediment on the floodplain or terraces in reach 5 is limited to local areas near tributary mouths or in occasional low-energy overbank areas.

At river kilometer 26, transects from a relict channel abandoned between 1938 and 1950 (based on air photos) and the modern channel were surveyed. This relict channel is located approximately 100 m downstream of bluff E-7 at the Bayfield/Ino site (fig. 6). The most likely time for the avulsion to have occurred is during the 1946 flood. The abandonment of the meander resulted in a loss of approximately 250 m of channel length, causing a steeper gradient in the modern channel and more potential for erosion compared to the pre-1946 channel. Results from the modern and relict channel cross-section surveys indicate that the thalweg of the modern channel in 1995 is 3.5 m below the thalweg of the relict channel (fig. 15), and the water surface in the modern channel was 3.3 m below the water surface in the relict channel. These data suggest that the modern channel at this location has degraded an average rate of 7 cm per year since 1946. This rate is probably greater than the overall degradation rate of the stream channel because of the localized effects of a decrease in channel length through this reach. Bluff E-7 is thought to be one of the most unstable bluffs and has a large potential for erosion; the instability of this bluff probably is accentuated by its proximity to the meander cutoff. The comparison of the relict and modern channel at the Bayfield/Ino site (fig. 15) also indicates that the modern channel is more narrow and has very little floodplain in this reach.

Another relict channel was examined at the Moore Site near the downstream end of reach 5. Data from five cross-sections each of the relict and modern channel were collected (fig. 16). The length of reach measured for the modern channel was 125 m, and the relict channel 120.5 m. Both channels run parallel to each other (fig. 16). Based on air photos, it also was determined that this channel was abandoned sometime between 1938 and 1950, presumably during the 1946 flood.

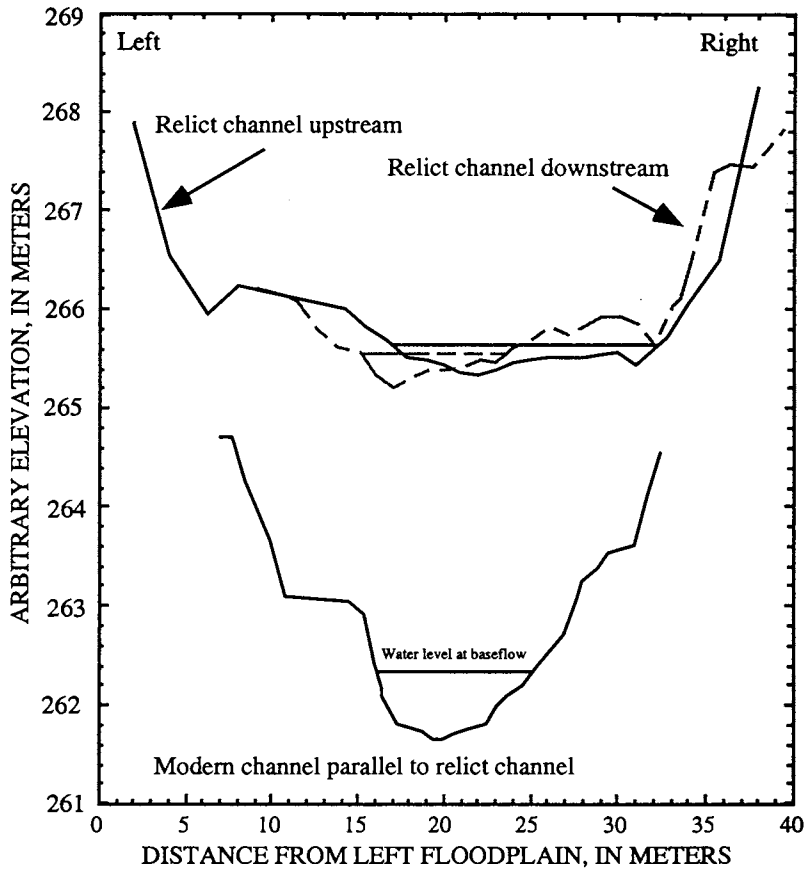


Figure 15. Channel cross-section surveys of the modern and relict channels of North Fish Creek in reach 5, Bayfield/Ino site.

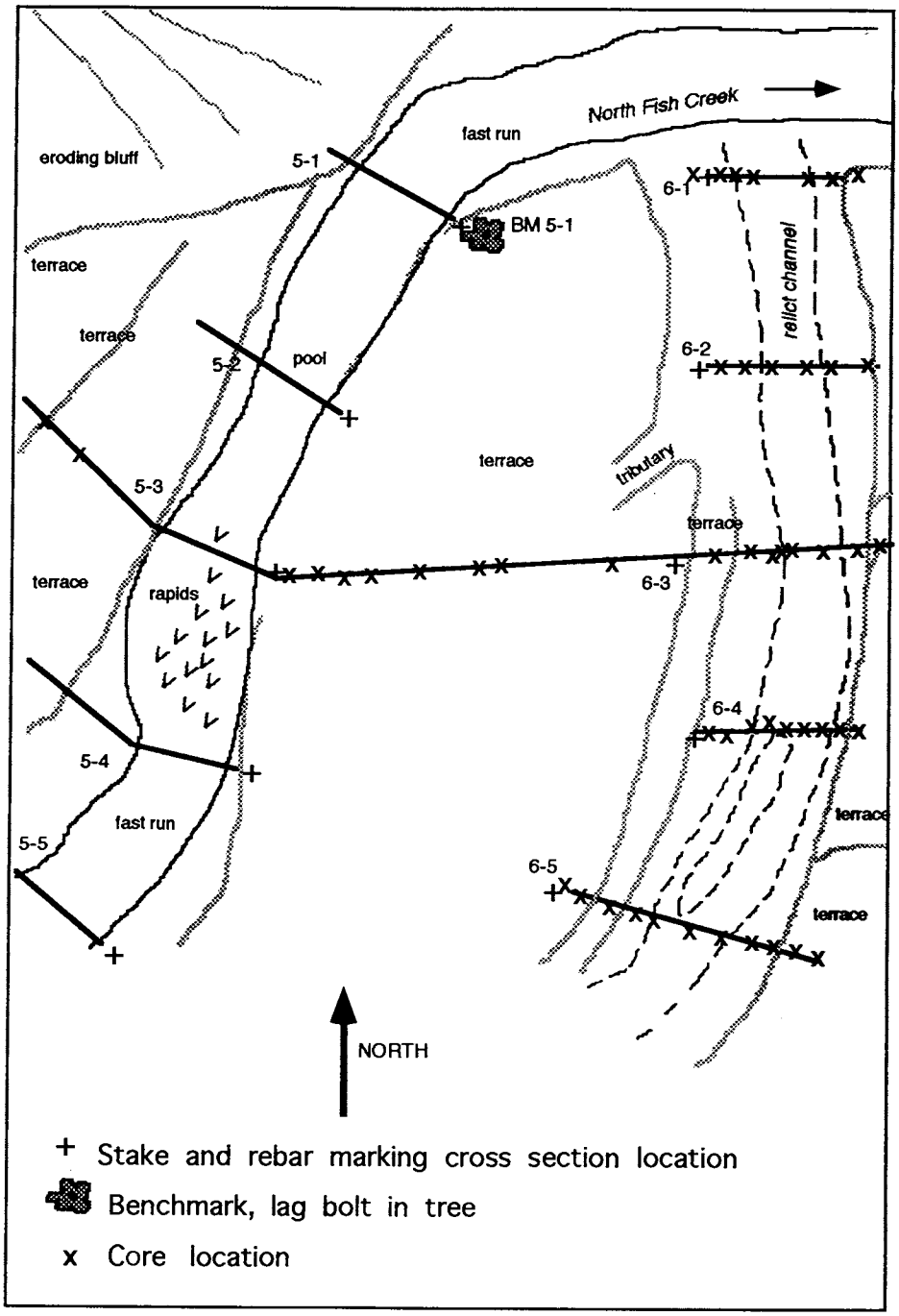


Figure 16. Diagrammatic map of cross sections and core locations along North Fish Creek at the Moore site, reach 5.

A comparison of the cross sections from the modern and relict channel at the Moore Site (fig. 17) indicates that the modern channel upstream of the rapids has not degraded. However, the channel below the rapids appears to have degraded approximately 0.7 m in 49 years, or about 1.4 cm per year. The coarse sediment of the channel bottom in the rapids appears to be prohibiting near upstream channel degradation.

Historic sedimentation is limited to point bars and also some infilling of the relict channel at the Moore site. Most of the terrace surfaces and limited floodplain surface is composed of gravel and cobble.

One of the transects at the Moore Site extends across the North Fish Creek valley and bisects the 1946 relict channel and the modern channel (fig. 18). The valley cross section shows that the capacity of the modern channel is more than double the capacity of the relict channel. Like the modern channel near the top of reach 5 at the Bayfield/Ino Site, the modern channel at the downstream end of reach 5 is very efficient at transporting water and sediment quickly, and energy is not being dissipated like it was in the past when smaller floods could spill out into a more extensive floodplain where some of the stream energy would be dissipated.

In reach 4 at the Bayfield, Johanik/WNDR, and Mihalek sites, modern channel geometry is similar to reach 5 (fig. 19). The channel through this reach is characterized by boulder/cobble rapids and sand and or gravel runs. The cross-sections at T47N, R6W, section 14/23 were located approximately 30 m upstream of a blown-out beaver dam. A channel bar nearby contained a gravel and cobble core topped by 30 cm of medium to coarse sand with multiple buried organic horizons.

Figure 20 shows the typical sedimentary sequence seen in terrace cuts along reach 4. The terraces are composed of sandy diamicton (assumed to be Copper Falls Formation) with gravel/boulder lag deposits from Holocene channel cuts.

Several eroding banks were examined in North Fish Creek and Pine Creek near the downstream end of reach 4 at the confluence of Pine Creek. Cores were collected from a relict channel of Pine Creek (fig. 21). Air photos and interviews with local residents indicate the channel was abandoned during the 1946 flood. Exposure E-13 is in a cutbank on the next

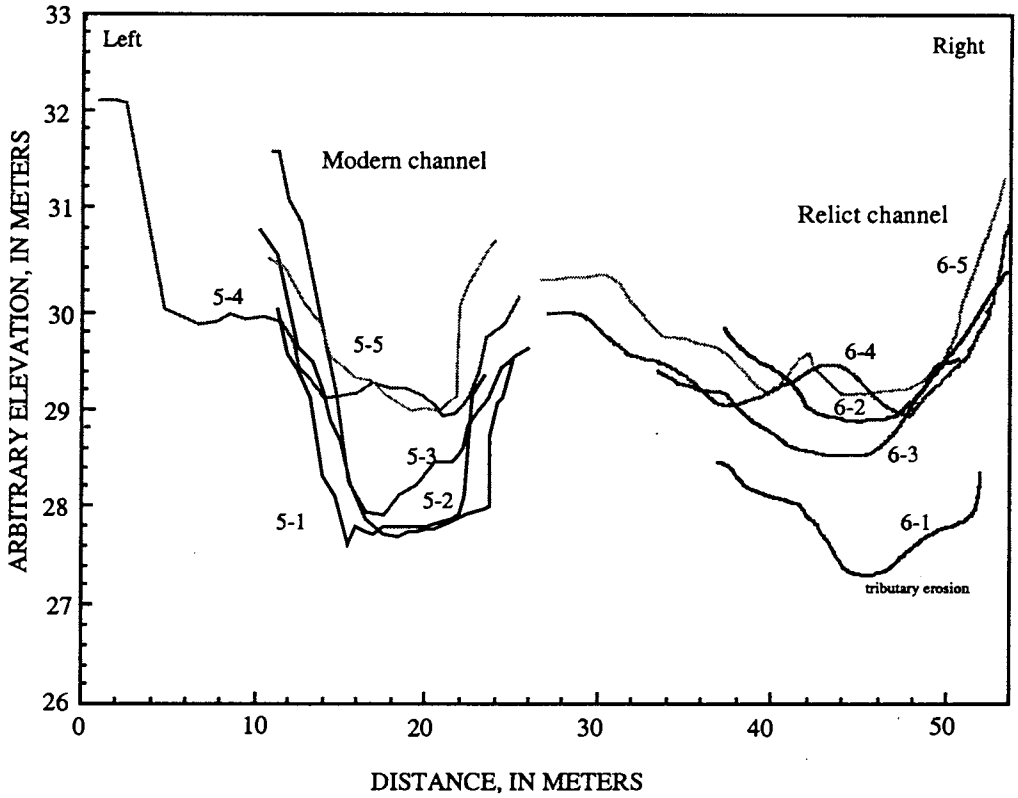


Figure 17. Cross-section surveys of the modern and relict channels of North Fish Creek in reach 5, Moore site.

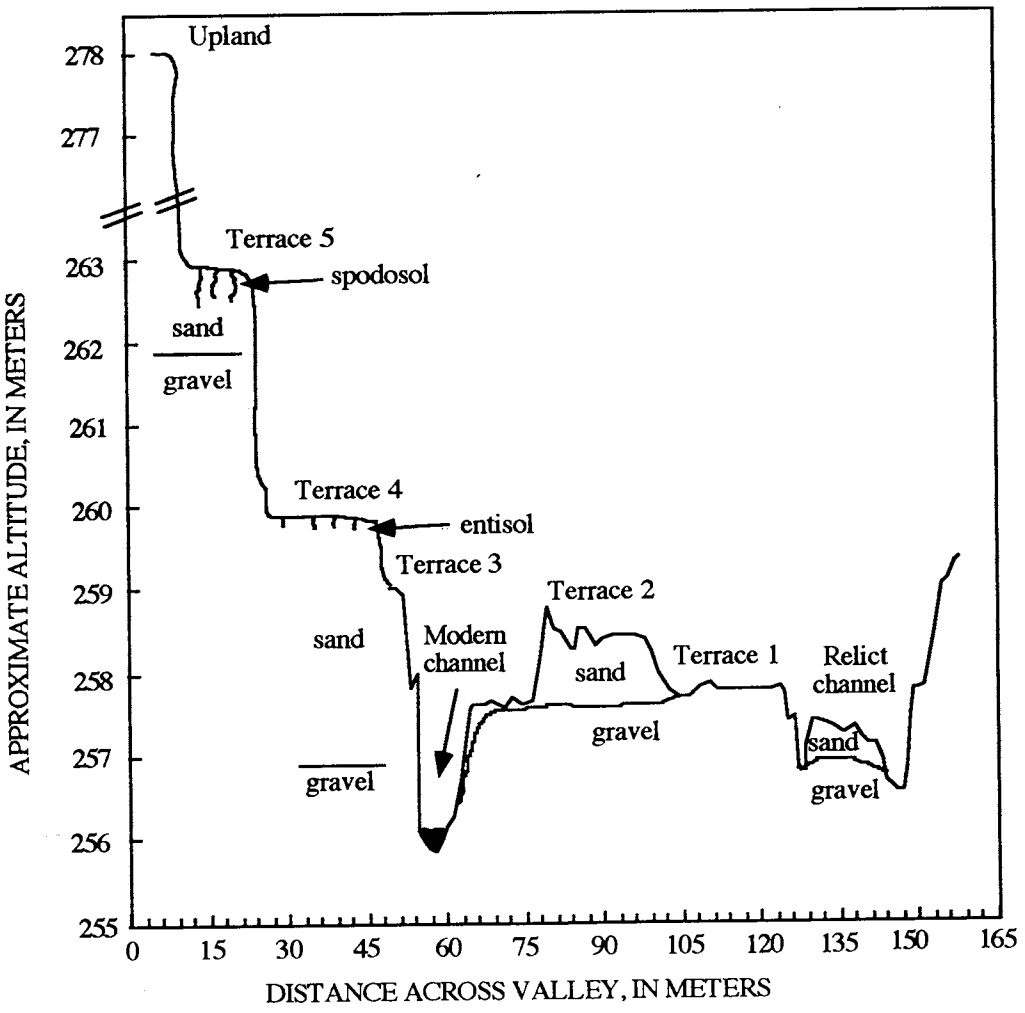


Figure 18. Valley cross section along North Fish Creek in reach 5, Moore site.

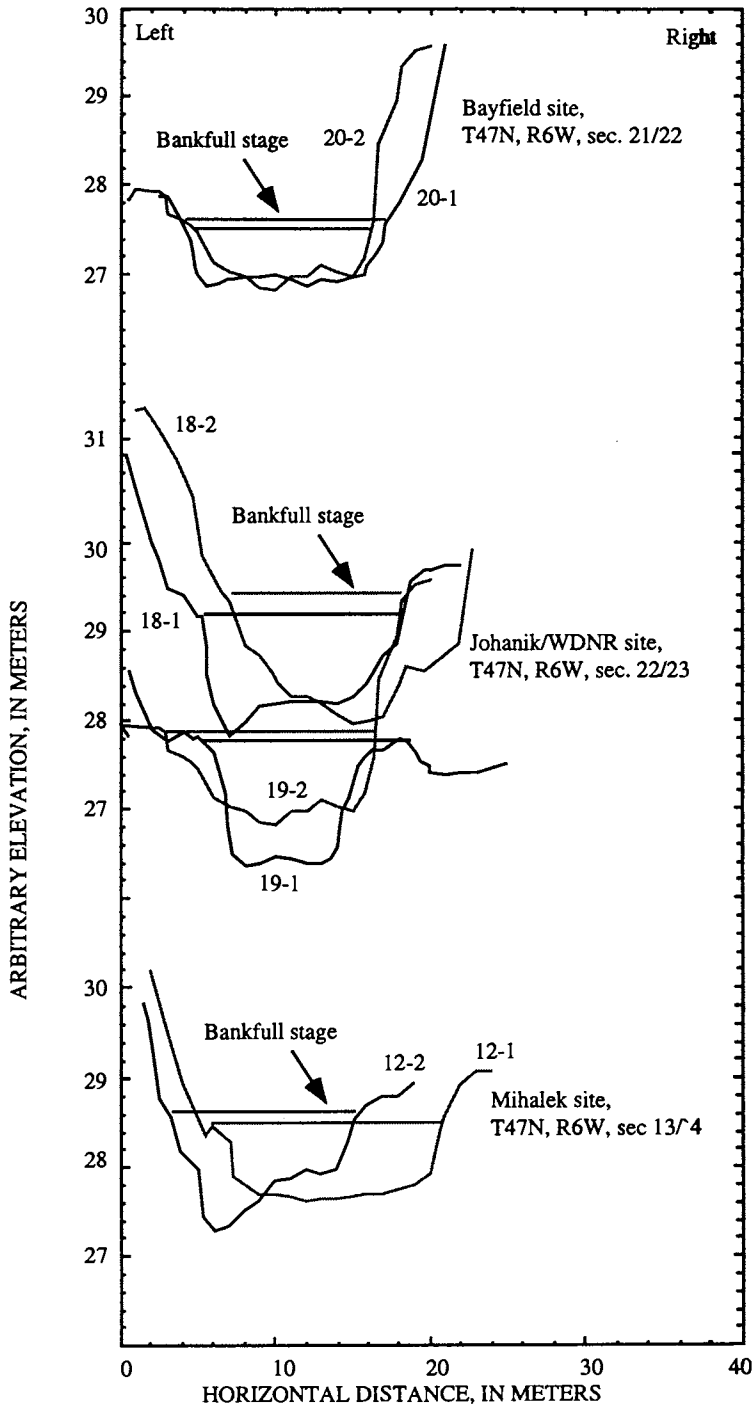


Figure 19. Cross sections of the modern channel of North Fish Creek in reach 4.

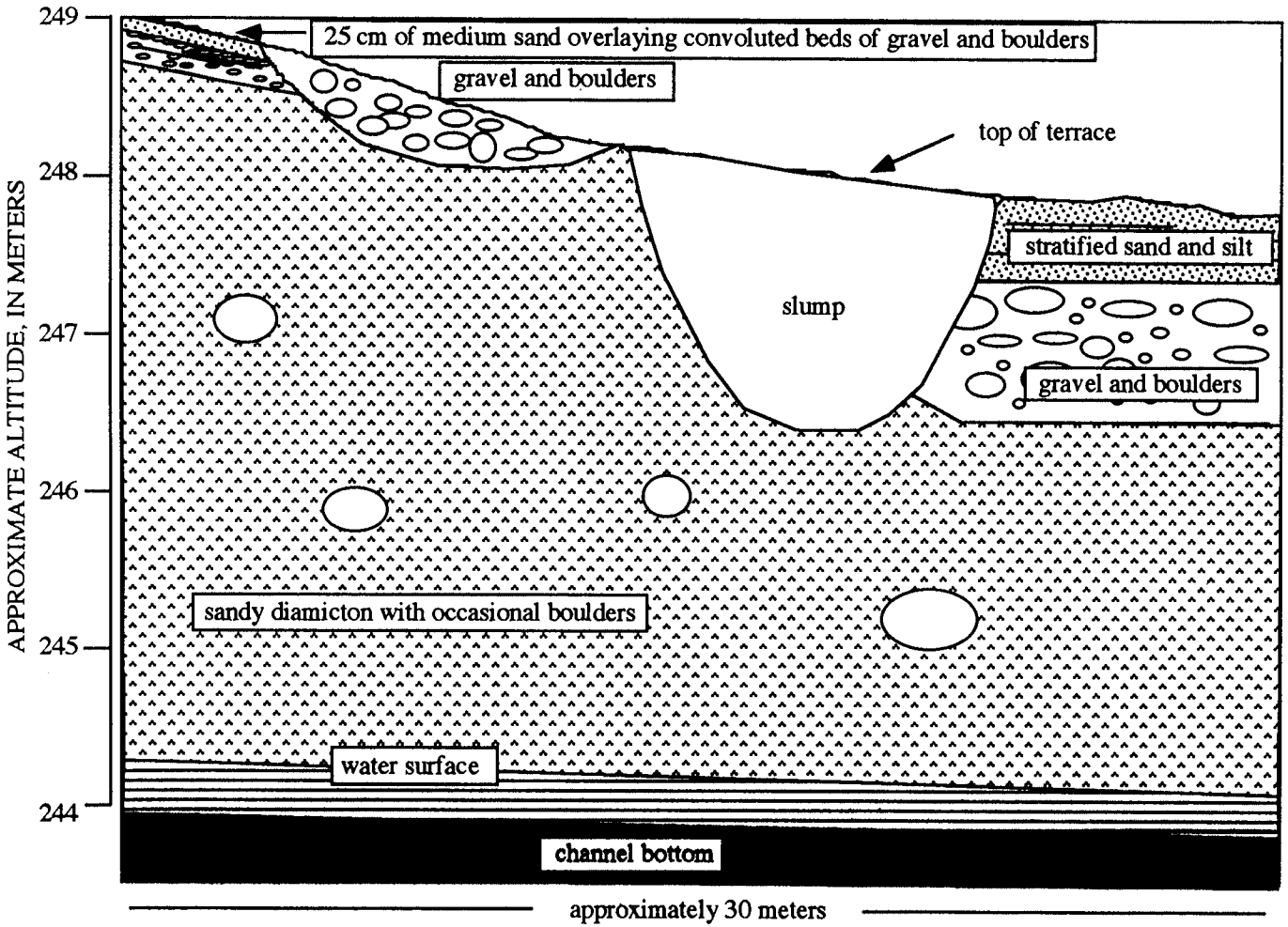


Figure 20. Typical sedimentary sequence of low terraces in reach 4, Bayfield site (30 m upstream of section line 21/22, T47N, R6W).

upstream tributary on North Fish Creek, whereas exposures E-12, E-11, E-10, and E-15 are exposures in low terraces of North Fish Creek, and exposures E-8 and E-9 are exposures in low terraces along Pine Creek (figs. 21 and 22).

The exposure along a tributary of North Fish Creek (fig. 22) indicates that approximately 0.8 m of overbank post-settlement sediment have been deposited. This sediment probably originated from gully erosion. The pre-settlement surface is identified by the occurrence of a relatively thick, dark buried soil and change in texture from fine sand to loam.

Based on degradation rates in reach 4 and the height of modern banks, E-12 and E-11 represent cuts in the pre-settlement floodplain, now a terrace. The sand and gravel at the base of E-12 represents lateral point bar accretion and the finer sediment topping it represents vertical overbank accretion. The position of E-11 is in a much higher energy environment that is prone to flooding, resulting in a series of sand and gravel couplets.

The terrace surfaces at exposures E-10, E-8, and E-9 are occasionally overtopped by large floods. The flood of 1946 overtopped the terraces and was sufficiently powerful to remove most of the buildings located on the land surface between the relict channel of Pine Creek and North Fish Creek. The deposits in the terrace cuts contain approximately 1 m of fine sand, probably deposited as part of or after the 1946 flood. Wood near the base of E-8, located above channel lag gravel had a radiocarbon age of 3690 +/- 70 ^{14}C yr B.P. (BC 2280-1830). Late Holocene deposits above this unit mainly consist of convoluted beds of reddish sand and clay, probably representing overbank floodplain accretion. The gravel deposit in E-8, at about 1.7-m depth, probably represents a late Holocene relict channel of Pine Creek. This relict channel is 2.5 m above the present thalweg of Pine Creek and approximately 0.7 m above the pre-1946 Pine Creek channel.

The cores from the pre-1946 Pine Creek channel and exposure E-15 indicate that 0.9 to 1.2 m of fine to coarse sand have been deposited in the relict channel since it was abandoned 50 years ago. Wood at the base of core C-35, and at the same elevation as the pre-1946 Pine Creek channel, has a radiocarbon age of 140 +/- 40 ^{14}C yr B.P. (AD 1666-1955[1]), supporting a mod-

[1]Influence of bomb ^{14}C since 1955.

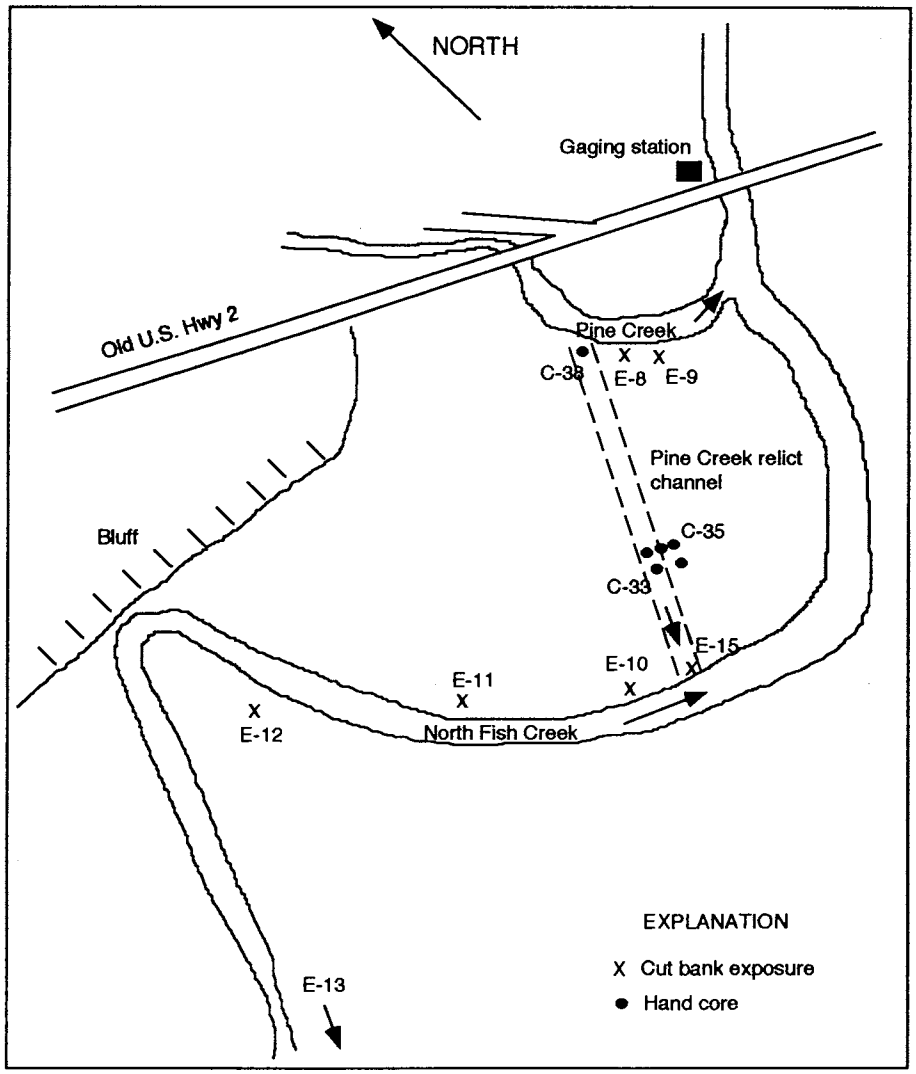


Figure 21. Diagrammatic map of cores and exposures at the Moquah site, reach 4

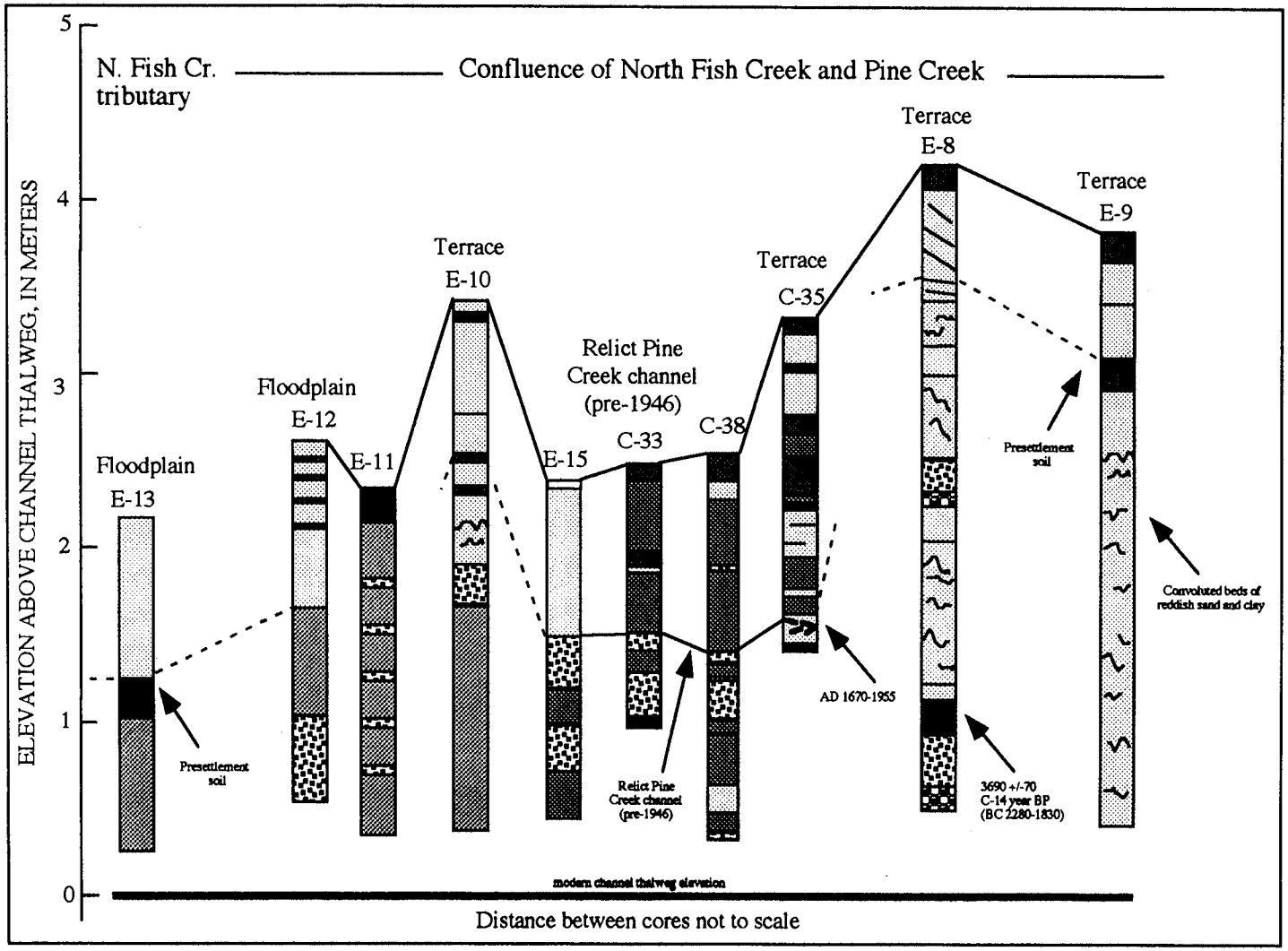


Figure 22. Stratigraphic descriptions of cores and exposures at the Moquah site, reach 4 (see figure 14 for legend).

ern age assignment. This suggests that up to 2 m of sediment may have been deposited in the last 52 years. In addition, the channel of Pine Creek eroded 1.4 m since 1946, or 2.8 cm per year.

Historic bridge design notes for Old U.S. Hwy 2 also support the idea of major post-settlement channel erosion. Bridge abutments of a former Hwy 2 bridge built in 1912 are located 20 m downstream from the present bridge (constructed in 1925). No channel cross-section data were recorded in the 1912 bridge notes; however, the "ordinary water level" was recorded. It was assumed that the ordinary water level of 1912 is equivalent to the modern water level at base flow. Using this assumption, the water level at base flow at this location has dropped approximately 2 m since 1912, or an average of 2.4 cm per year. It can be inferred from these data that the channel has degraded approximately the same amount at this location because the channel bottom is a uniform run (no pools or riffles) in the vicinity of the bridge abutment.

Transition Conditions (Reach 3)

The modern stream channel in reach 3 (river kilometer 16 to 12) (fig. 1) is highly unstable. Cut bank exposures are very common. Mass-wasting of stream banks, that commonly approximate 4 m in height, is typical. Many banks have little vegetation and show evidence of recently toppled trees. Woody debris is very common in the channel. Reach 3 can be distinguished from reach 4 by pronounced flattening of slope (fig. 2), a transition from cobble/boulder and sand channel to a gravel and sand channel, and an increase in overbank sedimentation. Surficial sediment from a typical point bar in reach 3, near the Skulan site (fig. 26), is composed of 0 to 40 percent gravel, less than 5 percent clay, and the rest sand (fig. 23). The sand component is composed mainly of medium sand with lesser amounts of fine and coarse sand (fig. 24).

A comparison of cross sections for modern channels at the Skulan and Nekoosa sites (fig. 25) with cross sections of the modern channel in reach 4 (fig. 20) suggests that although the width of the channel is similar, in general the banks are higher in reach 3 than in reach 4. There also appears to be some widening of the channel for cross sections 16 compared to 17. Cross section 16 is near where the valley widens and the wavelength between meanders decreases. The channel at cross-section 17 appears to be highly unstable and has no observable floodplain.

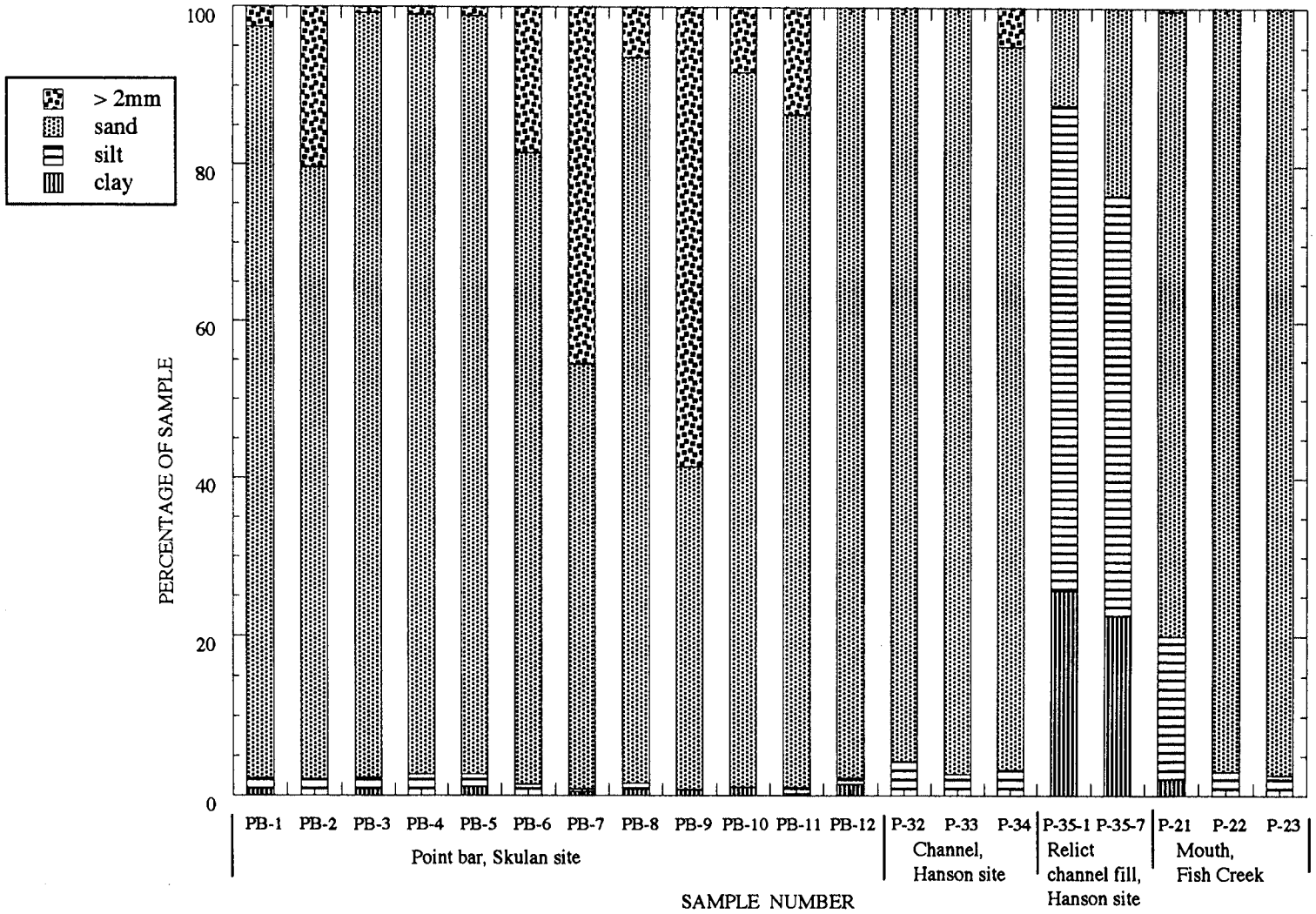


Figure 23. Particle-size distribution of channel deposits in North Fish Creek.

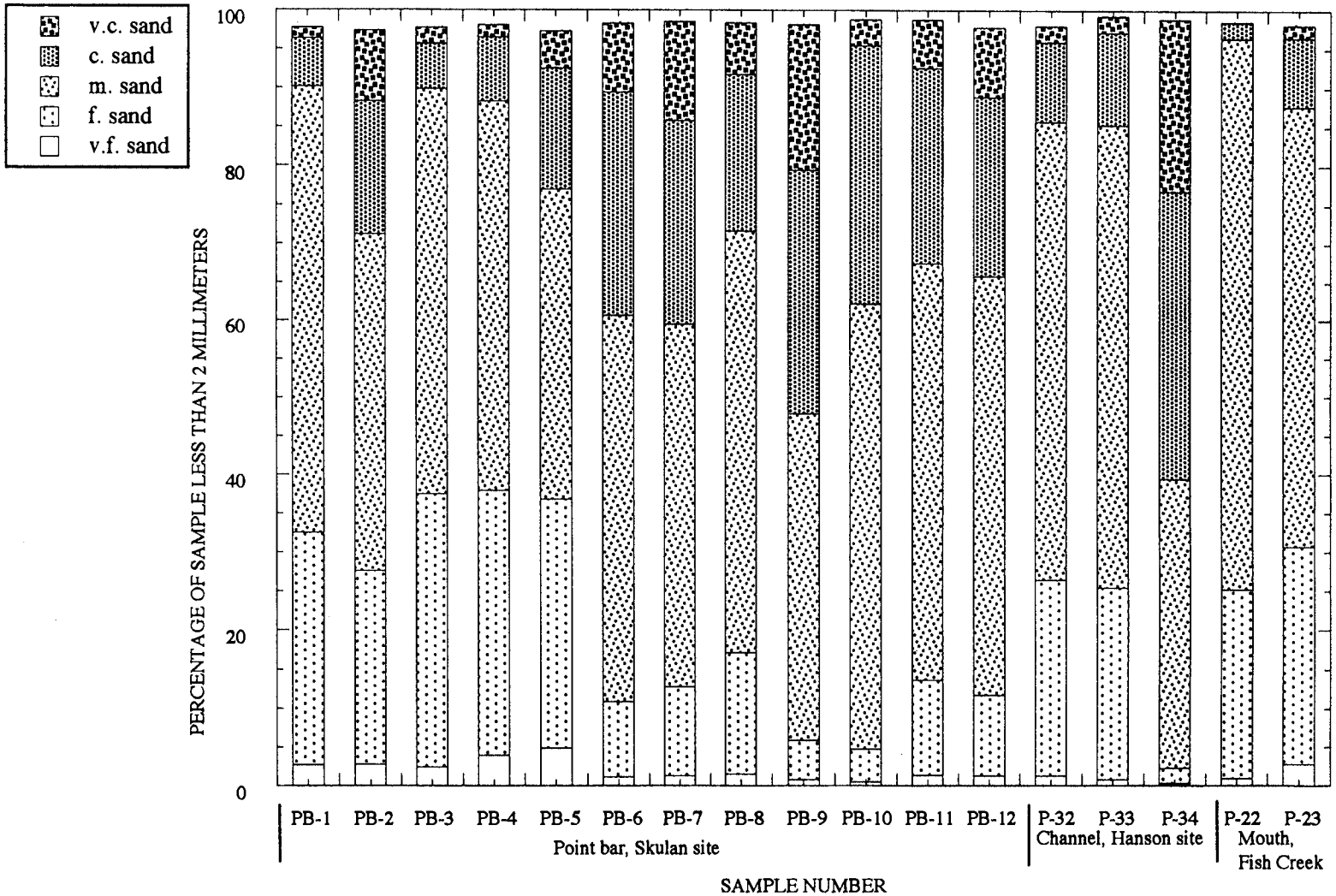


Figure 24. Particle-size distribution of sand-sized sediment in channel deposits, North Fish Creek.

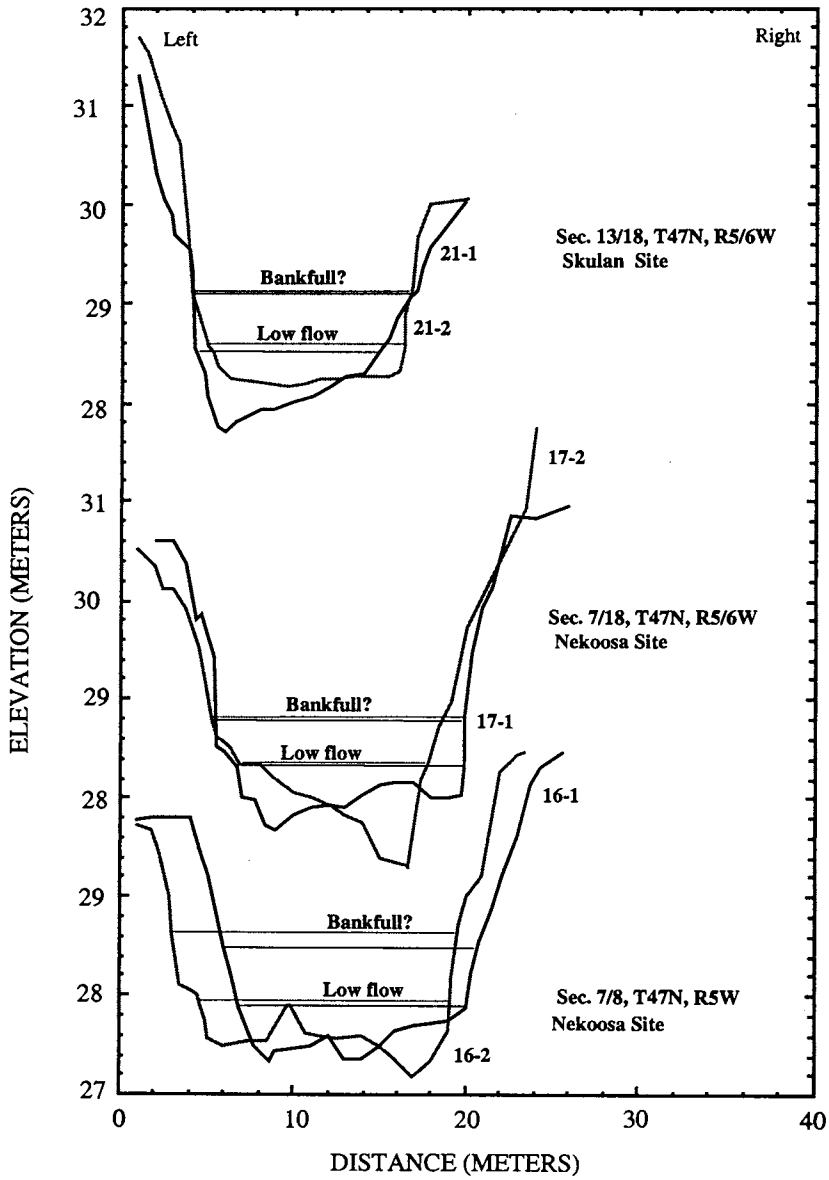


Figure 25. Cross sections of the modern channel of North Fish Creek in reach 3.

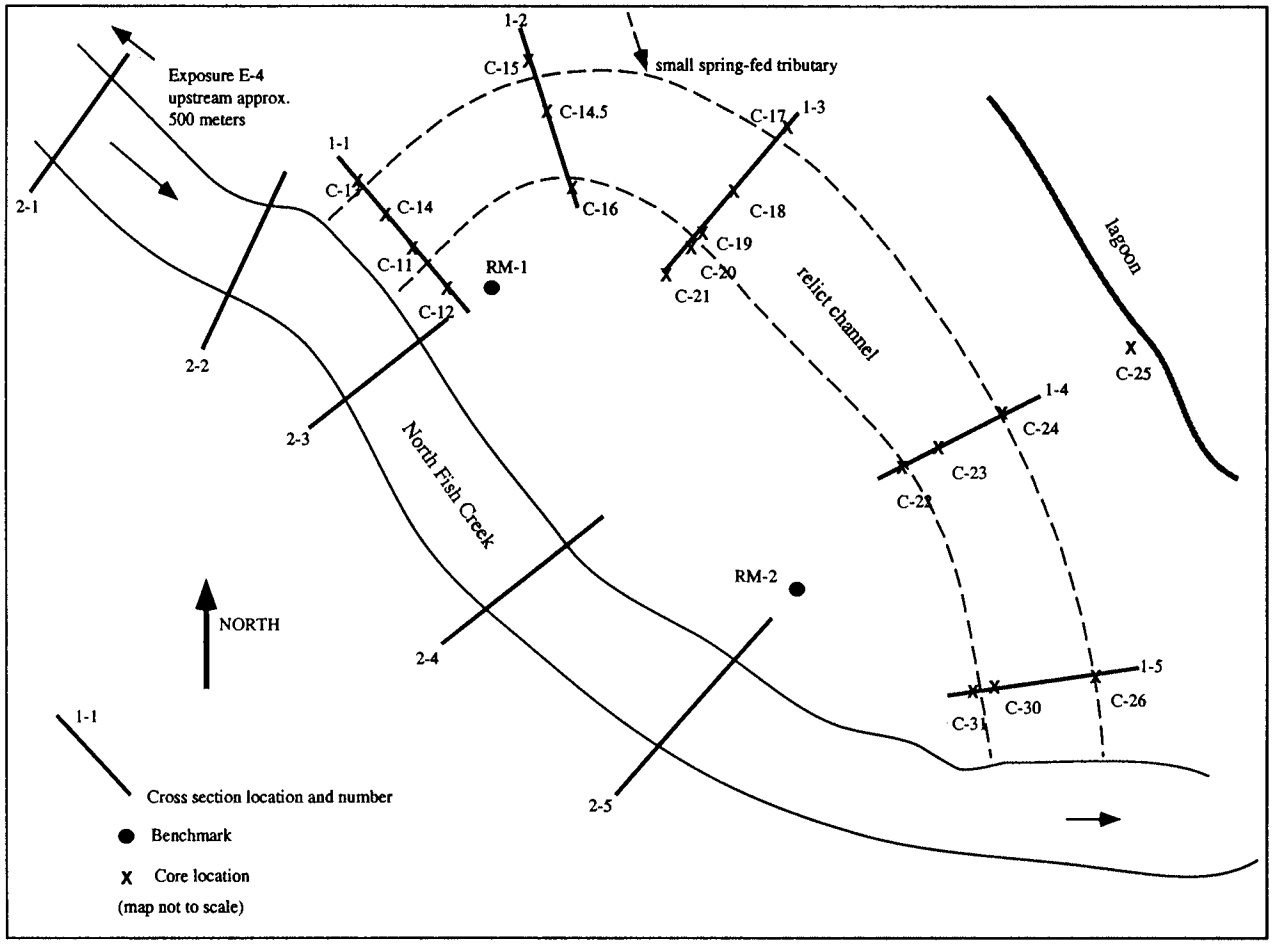


Figure 26. Diagrammatic map of cross sections and core locations along North Fish Creek, Skulan site, reach 3.

Amplitudes of meanders and the width of the valley at this location are much smaller than upstream or downstream. Thus, there appears to be some geologic constriction at this reach that is inhibiting channel migration.

Results from textural analysis and radiocarbon ages of samples from cores and stream bank exposures in floodplain and terrace sediment in reach 3 at the Palmer and Skulan sites indicate that 0.5 to 2 m of historical sediment have vertically accreted on the pre-settlement floodplain surface in reach 3 over the last 125 years (fig. 27). For example, at river kilometer 14, 2 m of overbank vertical accretion sediment has accumulated over the last 125 years at E-4. This sediment is mainly composed of very fine to fine sand (fig. 27). Wood from an organic layer 2 m deep in the exposure has a radiocarbon age of 280+/- 80 ^{14}C yr B.P. (1450-1700, 1720-1820, 1855-1860, or 1920-1950 AD). In comparison, a radiocarbon age of 420 +/- 60 ^{14}C yr B.P. (1410 to 1640 AD) for buried wood below the pre-settlement soil in this same stratigraphic sequence indicates that, at this location, only 0.7 m of sediment accumulated from about 1450 AD to 1870 AD (0.17 cm per year). This suggests that the floodplain sedimentation rate of 1.6 cm per year since 1870 AD is nine times greater than the sedimentation rate of 0.2 cm per year before logging, burning, and agricultural land use were introduced in the drainage basin.

Particle sizes of the overbank deposits commonly change from fine and medium to medium and coarse sand at the top within the top 40 cm of many of the cores and exposures (fig. 27). The presence of multiple buried surfaces within the coarser layer at E-3 and E-4 suggests that the land surface 3 to 4 m above the modern channel appears to be coming more stable over time. The landowner at the Skulan site recalls that the terrace surface 3 m above the channel was last flooded in 1986 or 1987 (probably 1985 based on precipitation records) during a large flood. One exposure near a tributary confluence contained loam diamicton, assumed to be Copper Falls formation, at 1.0 m below the surface. Outcrops of this diamicton along the channel at the Skulan site were not uncommon, indicating that in many places the streambed was flowing on this glacial depositional unit, with little alluvial deposition below the present channel level.

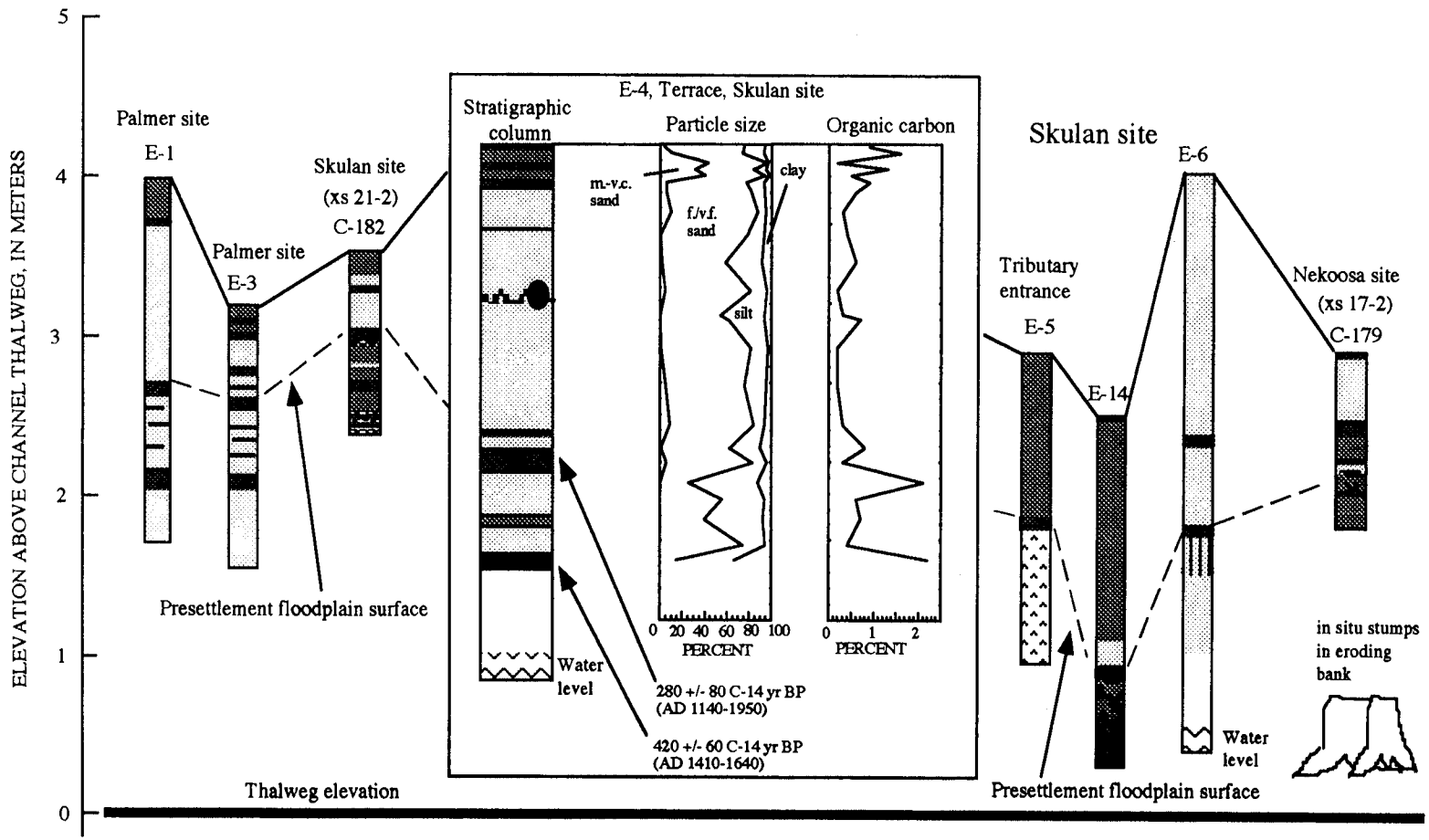


Figure 27. Stratigraphic descriptions of cores and exposures along North Fish Creek in reach 3.

Figures 28 through 31 contain cross section and core information from analyses of a relict channel at the Skulan site abandoned during the 1946 flood. The landowner at the Skulan site reported that his father always talked about how the 1946 flood completely changed the character of the stream. Figure 28 shows the present sediment-filled morphology of the relict channel at five cross sections, superimposed on the original channel geometry interpreted from four or more cores taken at each cross section. For example, figures 29 and 30 show stratigraphic details from cores for cross sections 1-1 and 1-4. Figure 31 compares the five reconstructed cross sections for the relict channel with five cross sections of the modern channel along the same reach. The comparison between the two channels suggests that the channel in reach 3 has degraded approximately 1 m since 1946. An age of 3255 +/- 55 ^{14}C yr B.P. (BC 1690-1670, 1660-1650, or 1640-1410) was established for a basal unit in C-24.This suggests that during the late Holocene the channel was at a similar or slightly lower elevation than the modern channel. The elevation of the pre-1946 relict channel bed 1 m above the dated wood indicates that aggradation occurred sometime between 3000 years ago and 1870. Thus, geomorphic interpretations from these data are similar to those determined at the Moquah site. Channel fill deposits appear in cores C-13 (fig. 29) and C-25 (fig. 30), approximately 2.5 m above the modern channel; however, it is not known whether these deposits are older or younger than 3000 years.

Sedimentation in Lower Mainstem (Reach 2)

Reach 2 (river kilometer 12 to 2) can be distinguished from reach 3 by the disappearance of gravel riffles (fig. 23) and a general decrease in streambank height. The downstream end of reach 2 is located where North Fish Creek enters Fish Creek Slough and the valley widens to the open bay. Stratigraphic reconstructions for this reach are based on data solely gathered from cores because of the lack of exposures in streambanks and bluffs. Several coring devices were used, including a hand corer, a vibracorer, a Geoprobe, and two types of piston corers. Detailed stratigraphic descriptions of selected cores from these sites are found in appendix D.

Cross-section data for the modern channel were collected at five sites in reach 2 (fig. 32). Four of the five sites are located at section line crossings: sec. 8/9, 9/10, 3/10, and 2/3 in T47N,

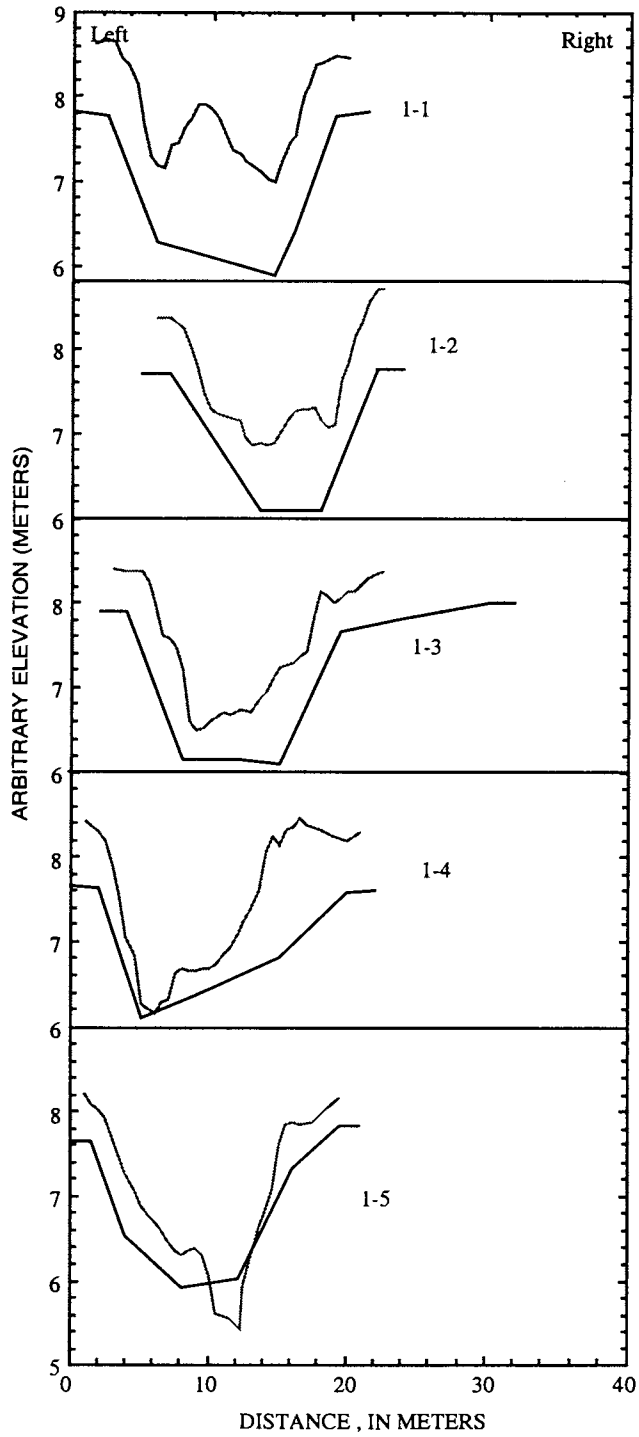


Figure 28. Surface elevations and buried cross sections of the pre-1946 relict channel of North Fish Creek in reach 3, Skulan site.

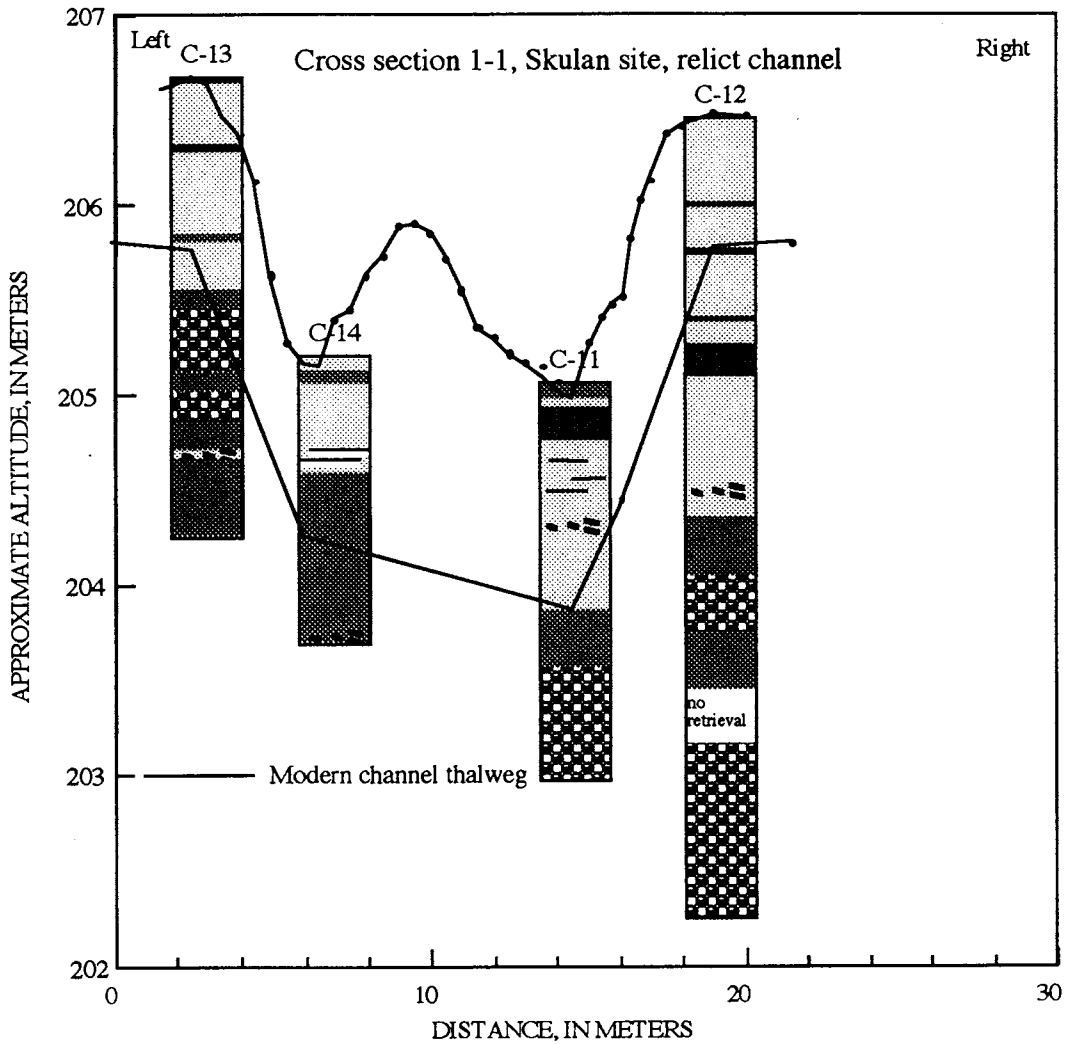


Figure 29. Stratigraphic descriptions of cores along cross section 1-1, pre-1946 channel at the Skulan site, reach 3.

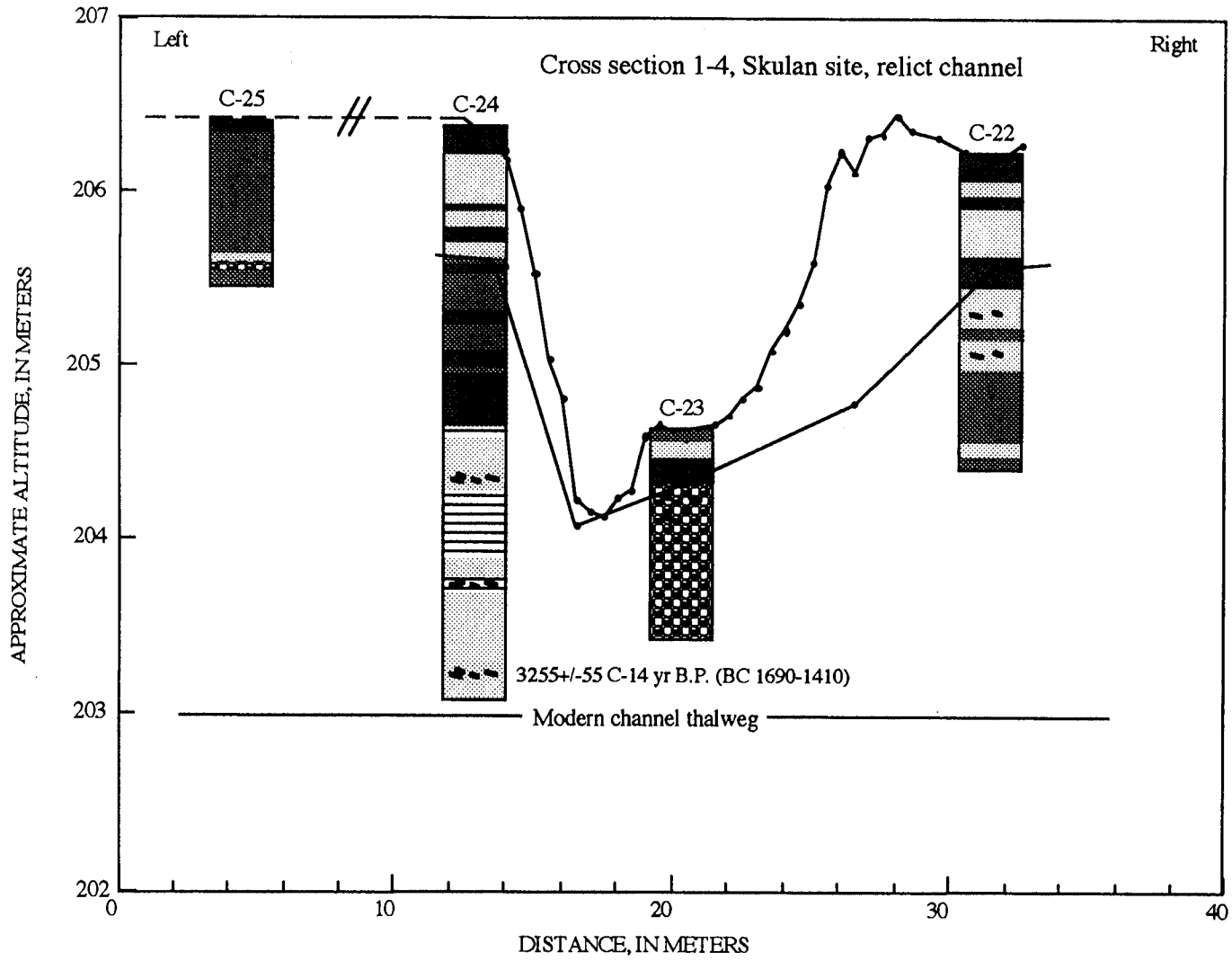


Figure 30. Stratigraphic descriptions of cores along cross section 1-4, pre-1946 channel at the Skulan site, reach 3.

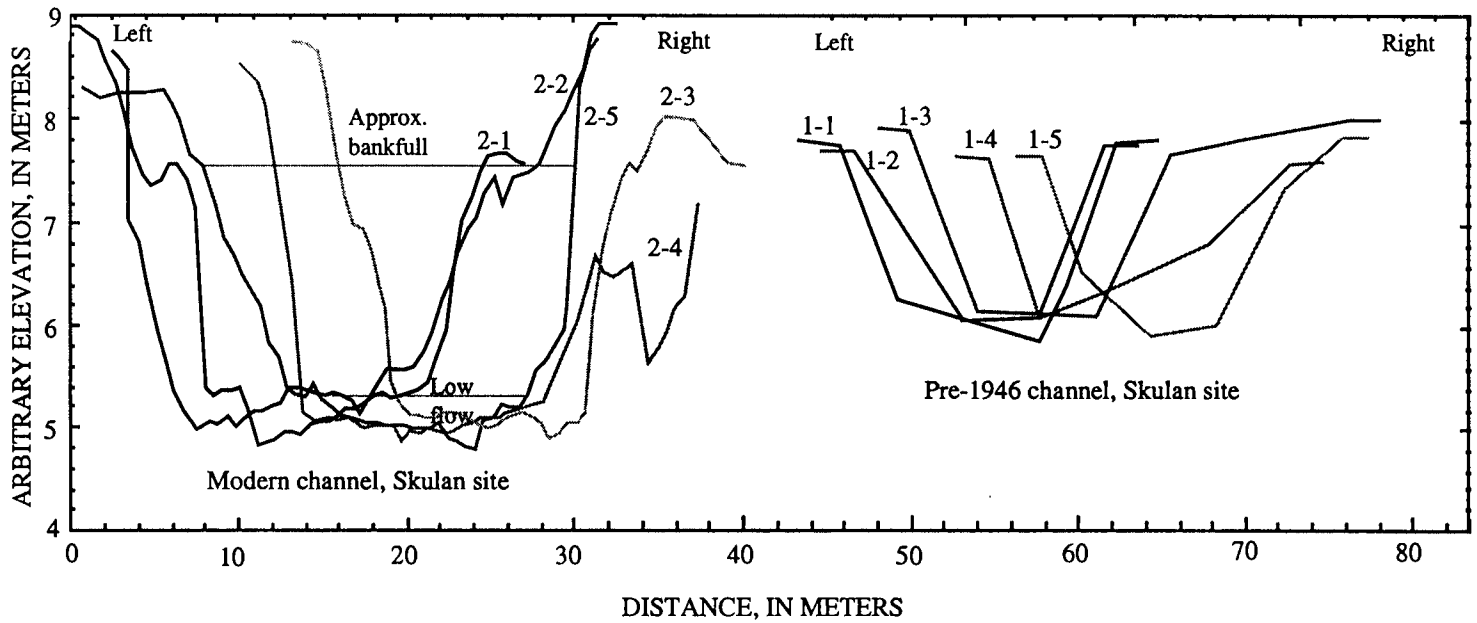


Figure 31. Comparison of cross sections of the modern and pre-1946 channel of North Fish Creek at the Skulan site, reach 3.

R5W. Relict channels also were examined at the Hanson and Ashland Junction sites (figs. 33 and 38, respectively). The cross-sectional profile of the modern channel along reach 2 changes from the upstream to downstream end; banks become noticeable lower and the channel widens.

Cores taken near the Hanson site (fig. 33) are located at the section line between sections 9 and 10, T47N, R5W, where the original 1855 Government Land Office survey recorded a rocky streambed sediment, and a later survey by the WDNR (late 1980's) reported an instream sand depth of about 2 m. Cores were taken along a series of cross sections that incorporate two relict channels (one on either side of the modern channel), the modern channel bottom, and about 150 m of floodplain perpendicular to the general direction of modern flow. The coarsest sediment observed and sampled in the modern channel was pea gravel (Appendix A). Particle-size analyses indicated 1 to 7 percent of the surficial streambed sediment was greater than 2 mm (granules) (fig. 23); the remainder of the sample consisted of mainly medium sand (fig. 24, Appendix A). No evidence of rocky streambed sediment was observed in cores from either the channel or the floodplain. The cores collected at the Hanson site indicate that post-settlement sedimentation is 0.6 or 0.7 m on the floodplain and leveed surface near the channel to 1.2 m in relict channels (fig. 34). No soil development currently exists at the surface near the modern channel, and possibly three buried incipient historical soils exist between the pre-settlement soil and the modern floodplain surface. Within the pre-settlement soil, the overbank sediment is generally composed of very fine-grained sand or smaller-sized particles, whereas post-settlement sediment near the channel is mainly composed of fine and medium sand (fig. 35).The most recently deposited sediment is the coarsest found in the cores (medium-textured sand). Sandy overbank deposits are confined within a zone of about 20 m on either side of the modern channel.

Both relict channels cored at the Hanson site predate the earliest available maps and documents, however, a modern radiocarbon age of 150+/-70 ^{14}C yr B.P. (AD 1650-1955) from the relict channel left of the modern channel was determined for wood pieces in channel fill deposits 1.5 m below the modern floodplain surface that are interpreted to represent the channel bottom when this was the main course of the stream. Thus, it appears that this may have been the channel location at the time of settlement. No radiocarbon ages were obtainable for the

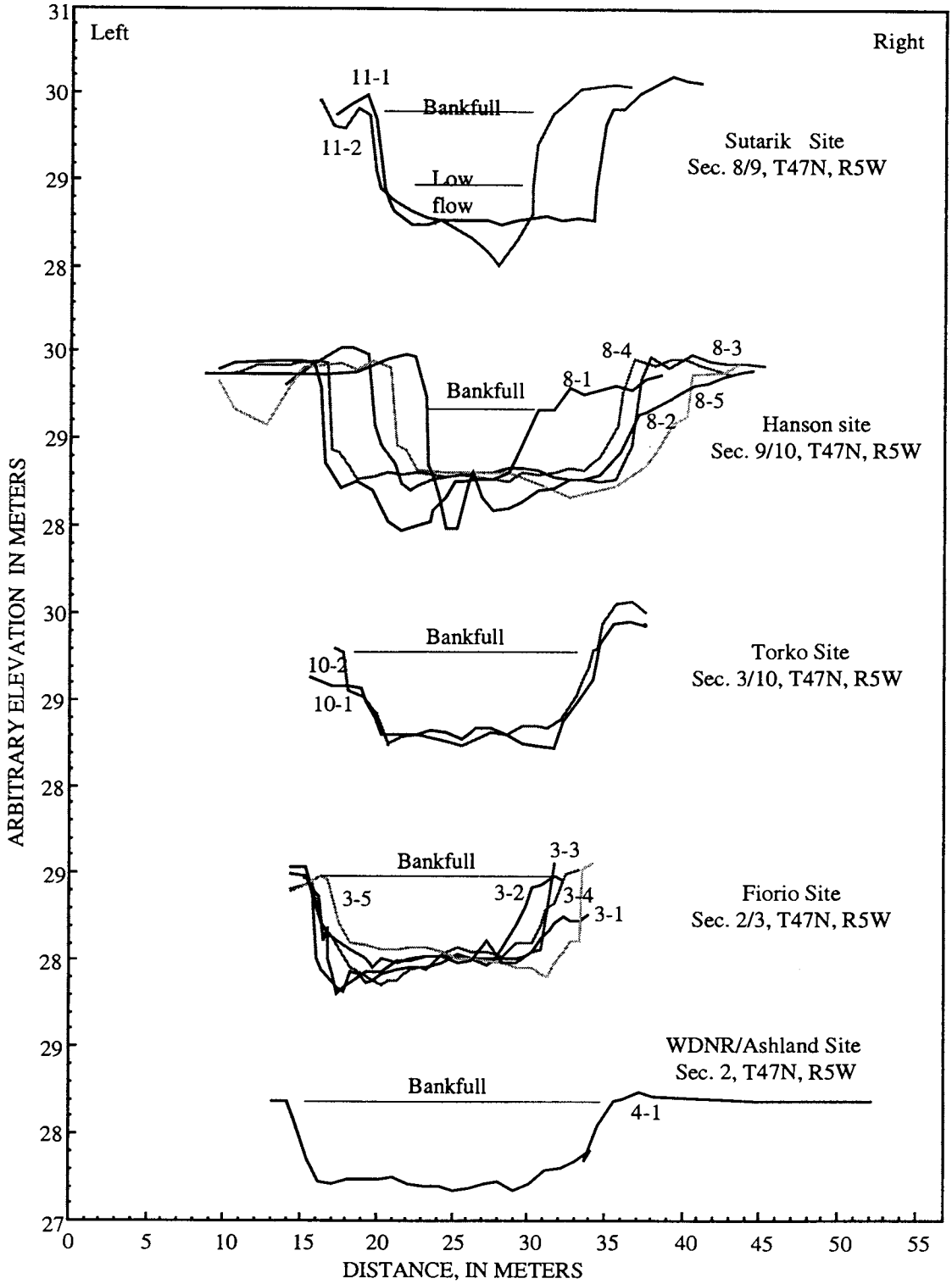


Figure 32. Cross sections of the modern channel of North Fish Creek in reach 2.

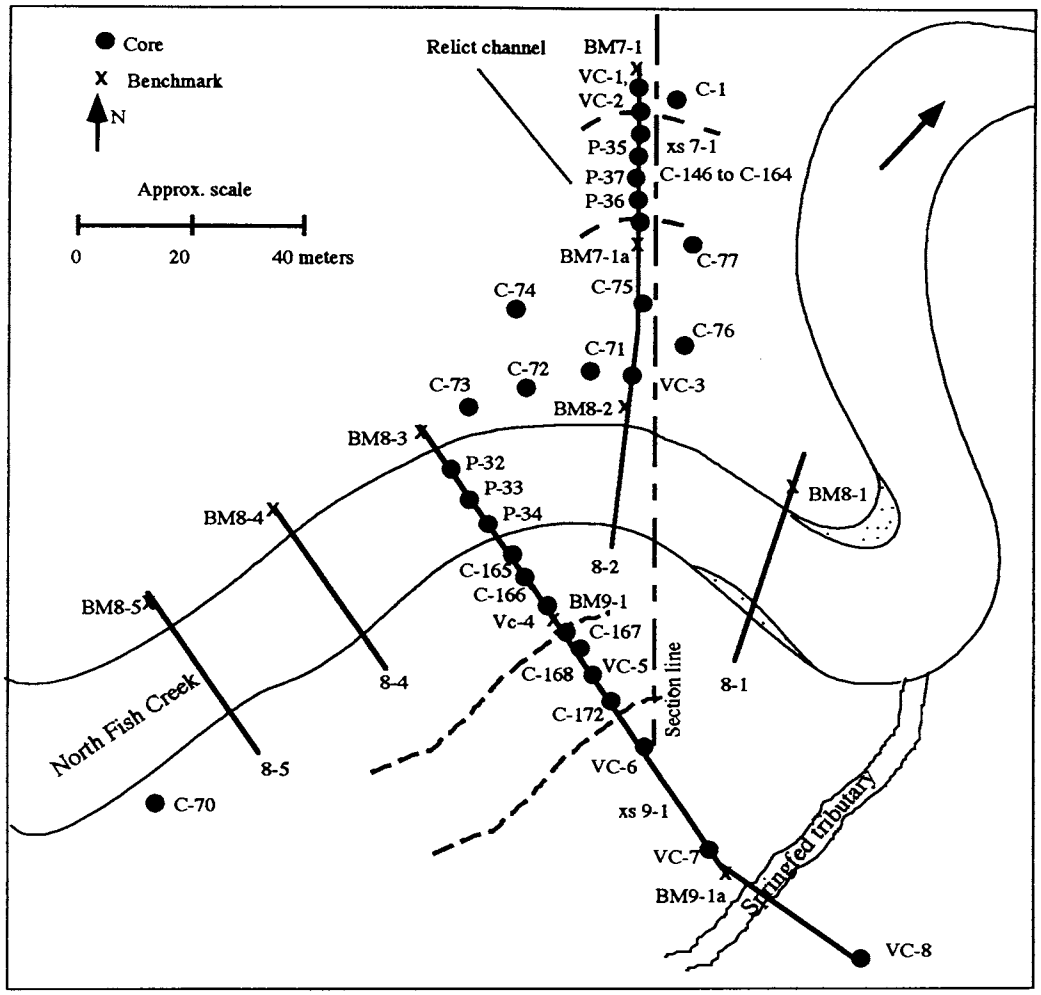


Figure 33. Diagrammatic map of cross sections and core locations along North Fish Creek, Hanson site, reach 2.

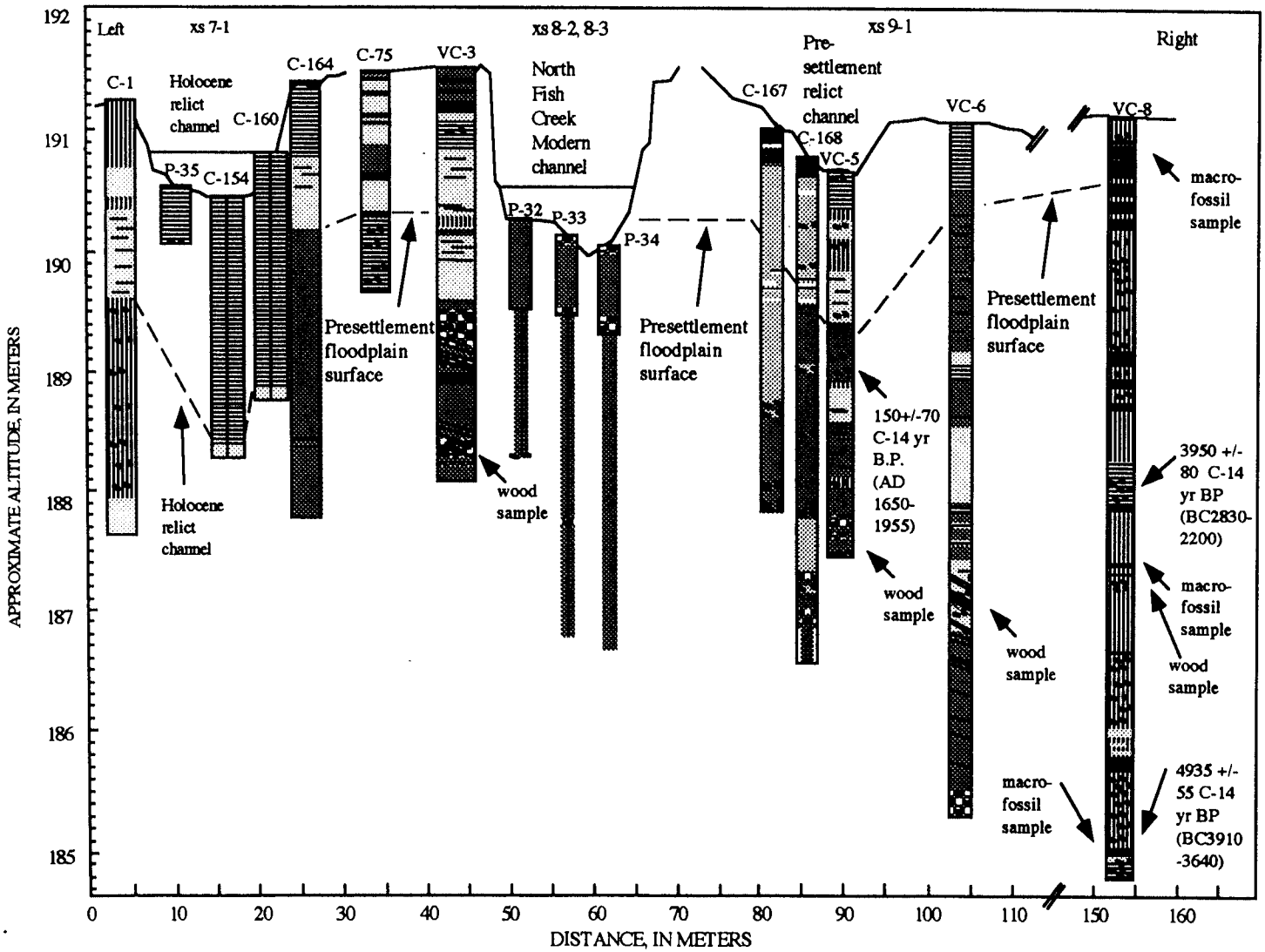


Figure 34. Stratigraphic descriptions of cores along cross sections 7-1, 8-2, 8-3, and 9-1 at the Hanson site, reach 2.

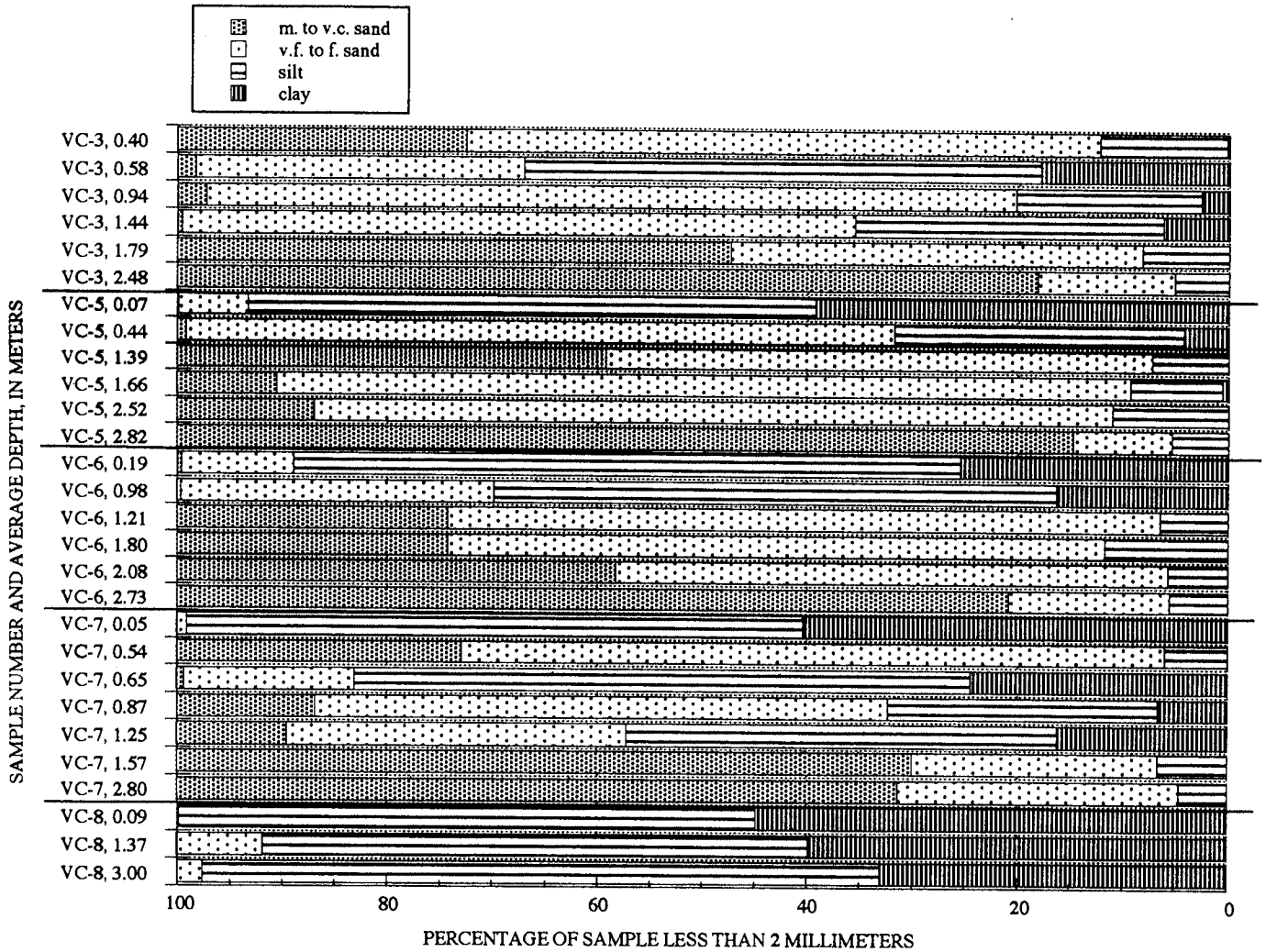


Figure 35. Particle-size distribution of selected samples collected from the floodplain at the Hanson site, reach 2.

relict channel to the right of the modern channel; however, the bottom of the channel is interpreted to be 2 m below the present surface based on a change in sediment texture from silt loam (table A1) to sand. The silt loam filling the channel has a organic carbon content of 1.7 to 2.4 percent.

The fine and medium sand in core VC-6, from about 0.8 to 1.6 m in depth, may represent an overbank deposit when the relict channel was active and near the core site. Later, when the channel migrated to its present location, overbank sedimentation consisted of only clay. The fine-textured nature of sediment in the entire length of core VC-8 (fig. 35) indicates that even though the surface of the floodplain changes very little in elevation, all sediment coarser than silt is dropped out nearer to the channel.

Downstream from the Hanson site, several cores were collected near the Fiorio site on both sides of the modern channel (fig. 36) to identify the stratigraphic position of a buried road surface that followed the section line between sections 2 and 3 (Old U.S. Highway 13). The road was abandoned between approximately 1946 and 1951. No signs of a road are present on the modern land surface, even near the modern channel, except for a pair of cement bridge abutments flanking the stream. The 1906 Bayfield County plat map, the oldest map with roads found during this study, indicates a road and bridge at this location. The bridge corresponding with the cement bridge abutments disappeared sometime between approximately 1946 and 1950 based on Wisconsin Department of Transportation plat maps (1936, 1946, 1951), USGS quadrangle maps (1942), and aerial photographs (1938, 1950). The bridge was not replaced and the location of Highway 13 was moved east.

The cores collected at the Fiorio site indicate that a substantial amount of sedimentation has taken place in the floodplain south of the stream since the road was abandoned approximately 45 years ago (fig. 37). Approximately 20 m due south of the cement bridge abutment the road bed was identified beneath 0.7 m of sediment (fig. 37). The floodplain on the north side of North Fish Creek is about 0.5 m higher than the south side, and the road bed has about 0.2 m of sediment on it. The lack of stratification or layering of the sediment on top of the road bed, coupled with moderate soil development at the surface, suggest that most of the sediment probably was deposited during the 1946 flood.

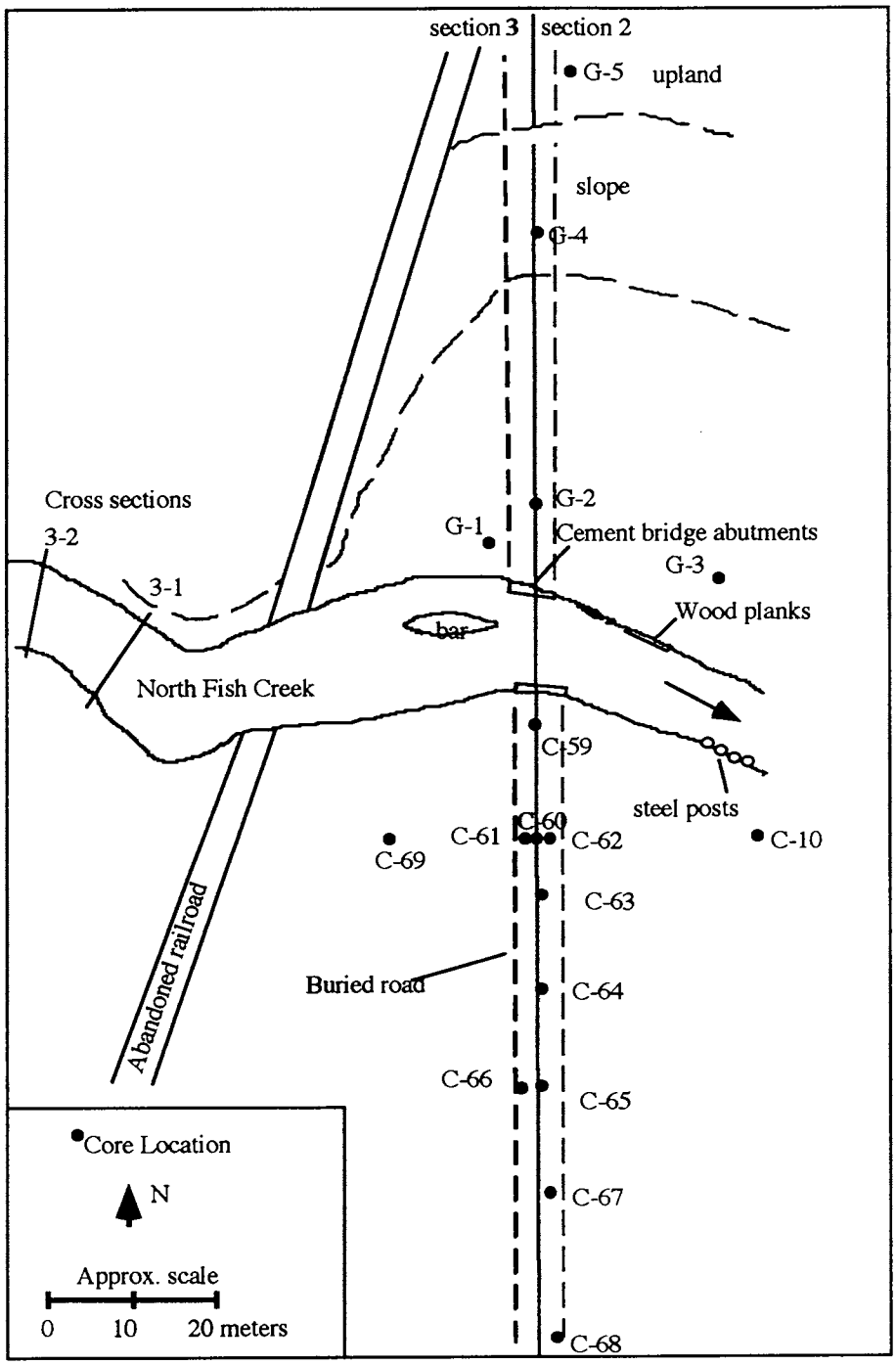


Figure 36. Diagrammatic map of core locations at the Fiorio site, reach 2.

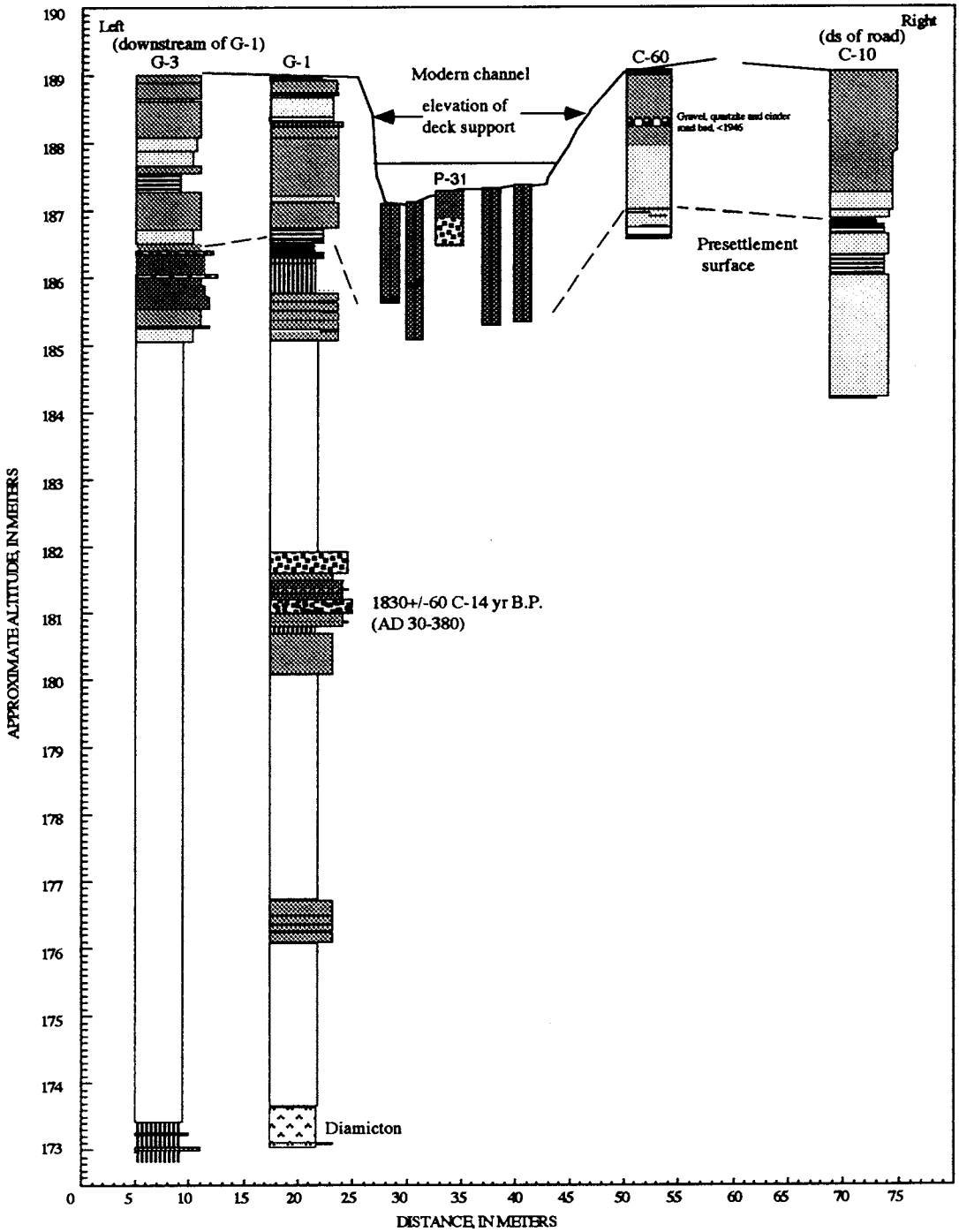


Figure 37. Stratigraphic descriptions of cores near section line 2/3, T47N, R5W, Fiorio site, reach 2.

Approximately 3 m downstream of the bridge abutment, a thick organic zone, presumed to be the pre-settlement floodplain surface, was observed in the left bank approximately 0.5 m above the channel bottom. The pre-settlement soil also was observed at about this same level in many cores, including C-60, C-10 and G-1 (fig. 37). Abundant pieces of wood occur near the top of the pre-settlement soil. Over 75 percent of the wood pieces appears to be from the same species. One such large piece of wood in pre-settlement soil at Fiorio site was identified as fir (*Abies* sp.) by the Forestry Products laboratory in Madison, Wis.

Approximately 1.2 to 1.5 m of sediment were found between the pre-settlement surface and the roadbed. This sediment was deposited after 1870 but before construction of the roadbed (exact date unknown, but probably about 1900). Thus, there has been a floodplain sedimentation rate of approximately 1.4 cm per year since 1946 (0.7 m divided by 49 years) and 4 cm per year between 1870 and 1900. The average sedimentation rate over the last 125 years has been about 1.8 cm per year (2.2 m divided by 125 years).

There also is evidence of an increase in the elevation of the water table at the Fiorio site. The elevation of the top of the abandoned road bed 75 m south of the stream is at about the same elevation as the water level in the wetland adjacent to the abandoned road. These observations were made in the relatively dry summer of 1995 when wetlands could be traversed with dry feet, but knee boots were required in 1993 and 1994. Presumedly the road was originally constructed so as to be a substantial elevation above the water table.

The vegetation in the wetland also has changed. Aerial photographs from 1938 show substantial woody vegetation in the wetland between the old road location and the railroad embankment. Today the wetland vegetation consists mainly of alder and willow. Field observations also indicate that dead spruce and ash stumps and snags are abundant, possibly more evidence that the water table has risen above their tolerance level. Wetlands just upstream of the railroad embankment also show these same trends; thus, the water table change near the Fiorio site is more than just a local effect caused by the railroad embankment.

The floodplain at the Ashland Junction site is considerably wider than at the Fiorio site; the Ashland Junction site is at the end of the North Fish Creek valley proper and at the beginning of Fish Creek Slough. The Ashland Junction site is approximately 3 m above the present

level of Lake Superior. The stream channel gradient is less than 0.70 m/km and channel banks are low and heavily vegetated.

Approximately 100 m upstream from the Hwy 2 bridge crossing at Ashland Junction, a Geoprobe core was collected from the floodplain and about 10 m from the top of the left bank of the modern channel (fig. 38). Post-settlement deposition in the core is approximately 1.7 m, based on a well-developed pre-settlement soil at this depth. The core also shows several historical sedimentary units; all are coarser than pre-settlement sedimentary units.

Several hand cores were collected from a cross-section at the WDNR/Ashland site that extends from the modern channel of North Fish Creek to the upland (fig. 39). The cross section is located approximately 180 m downstream of the Hwy. 2 bridge crossing at Ashland Junction. For about 30 m south and away of the right bank of North Fish Creek (C-39 to C-41), soil development at the surface is minimal to non-existent, and coarse to very-coarse sand dominates the surface (fig. 40). Herbaceous vegetation is minimal, and as much as 30 percent of the surface is bare. Cross section 4-1 bisects the floodplain, which consists of a couple anastomosing channels of North Fish Creek intertwined with several small springfed channels. Near the southern edge of the floodplain, the cross-section intersects two relict channels of North Fish Creek, one of which carries flow derived from North Fish Creek and springflow. The other functions as a lagoon, cut off from the nearby channel by a natural sand levee. Downstream of the cross section along the relict channel several additional cores were taken in the channel and on the terrace surface.

Multiple organic-rich fine-grained zones are located beneath the surface in all cores at the WDNR/Ashland site (fig. 40). In light of modern radiocarbon ages for similar organic zones upstream, the presettlement surface is considered to be the first occurrence with depth of organic-rich, fine-grained sediment. This interpretation is supported by the observation that sediment below the first organic zone tends to be more fine-grained and loamy. Using the preceding criteria, the presettlement surface is identified at 1.1 m or 1.7 m in the core from the natural levee right of the modern channel. Continuing south through the floodplain away from the stream and toward the valley side, soil development increases at the floodplain surface, and surficial sediment becomes less coarse. In addition, a peat-like layer starts to appear below the

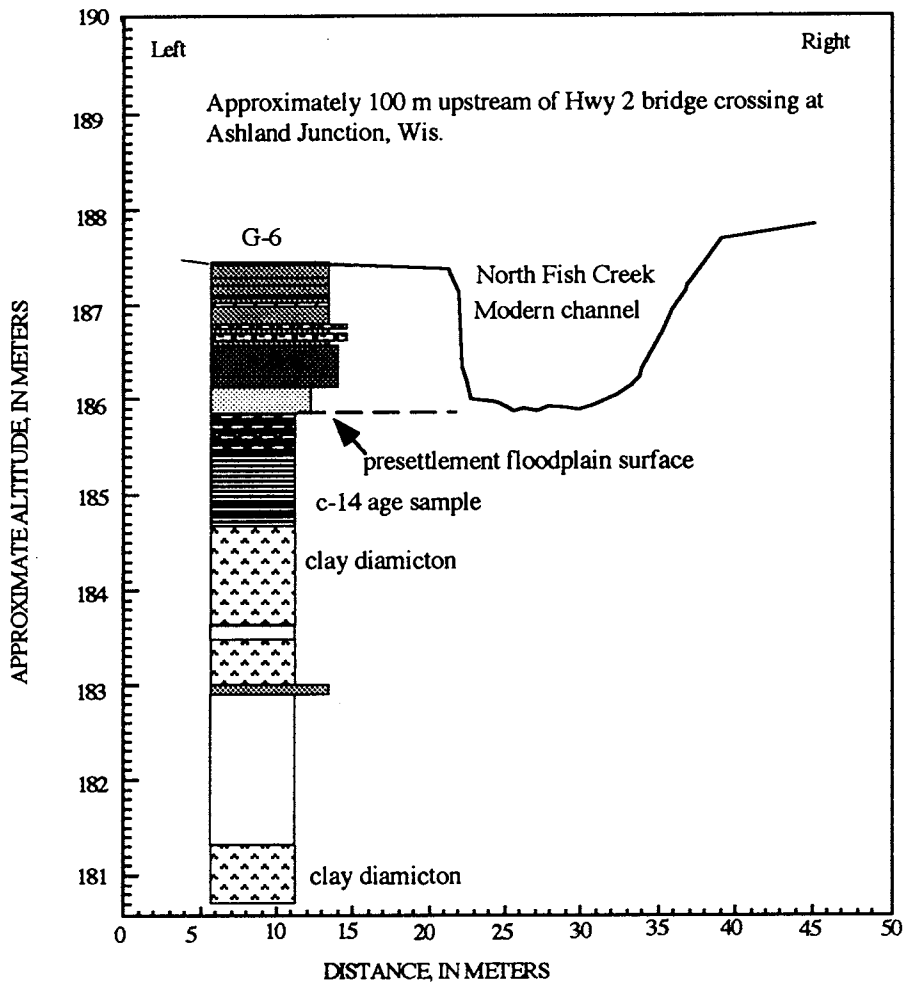


Figure 38. Stratigraphic description of core G-6, sec. 2, T47N, R5W, Ashland Junction site, reach 2.

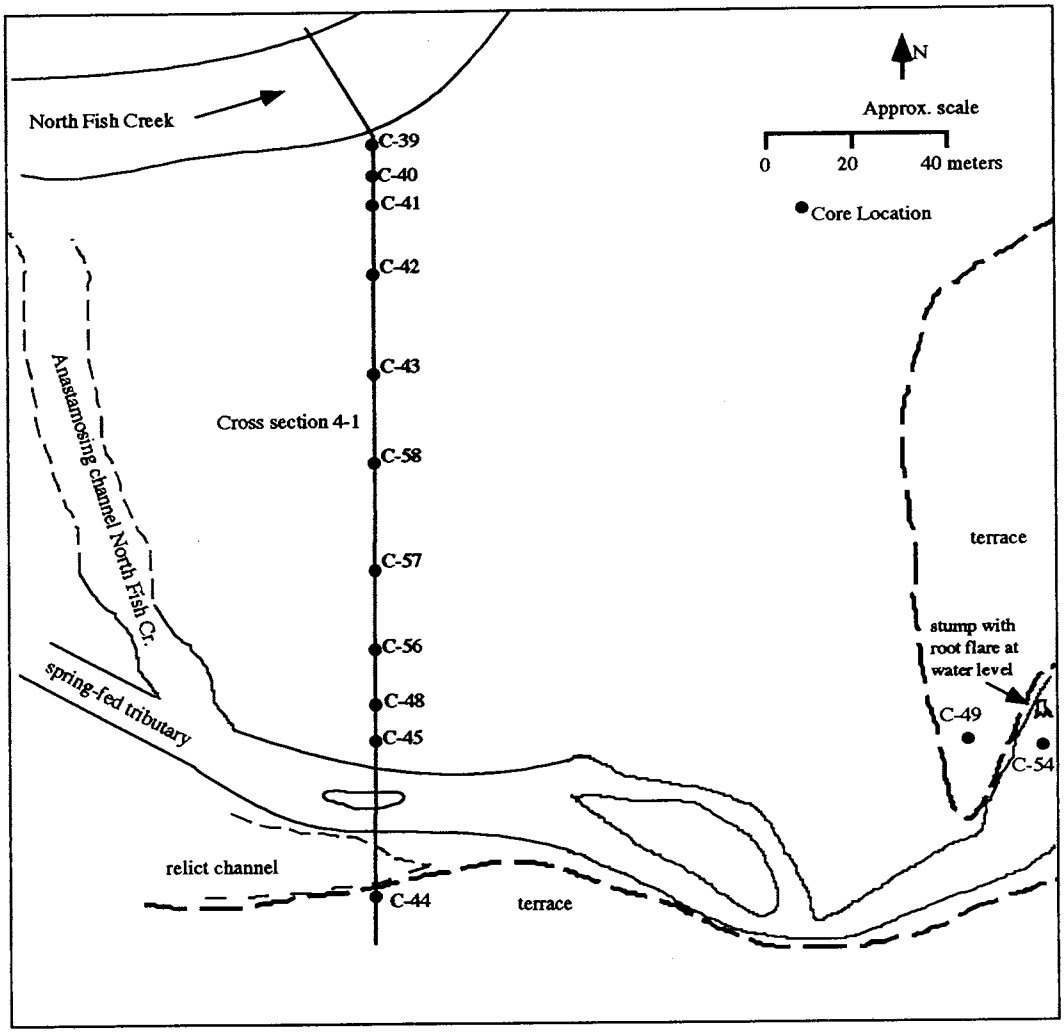


Figure 39. Diagrammatic map of core locations along North Fish Creek, Ashland Junction site, reach 2.

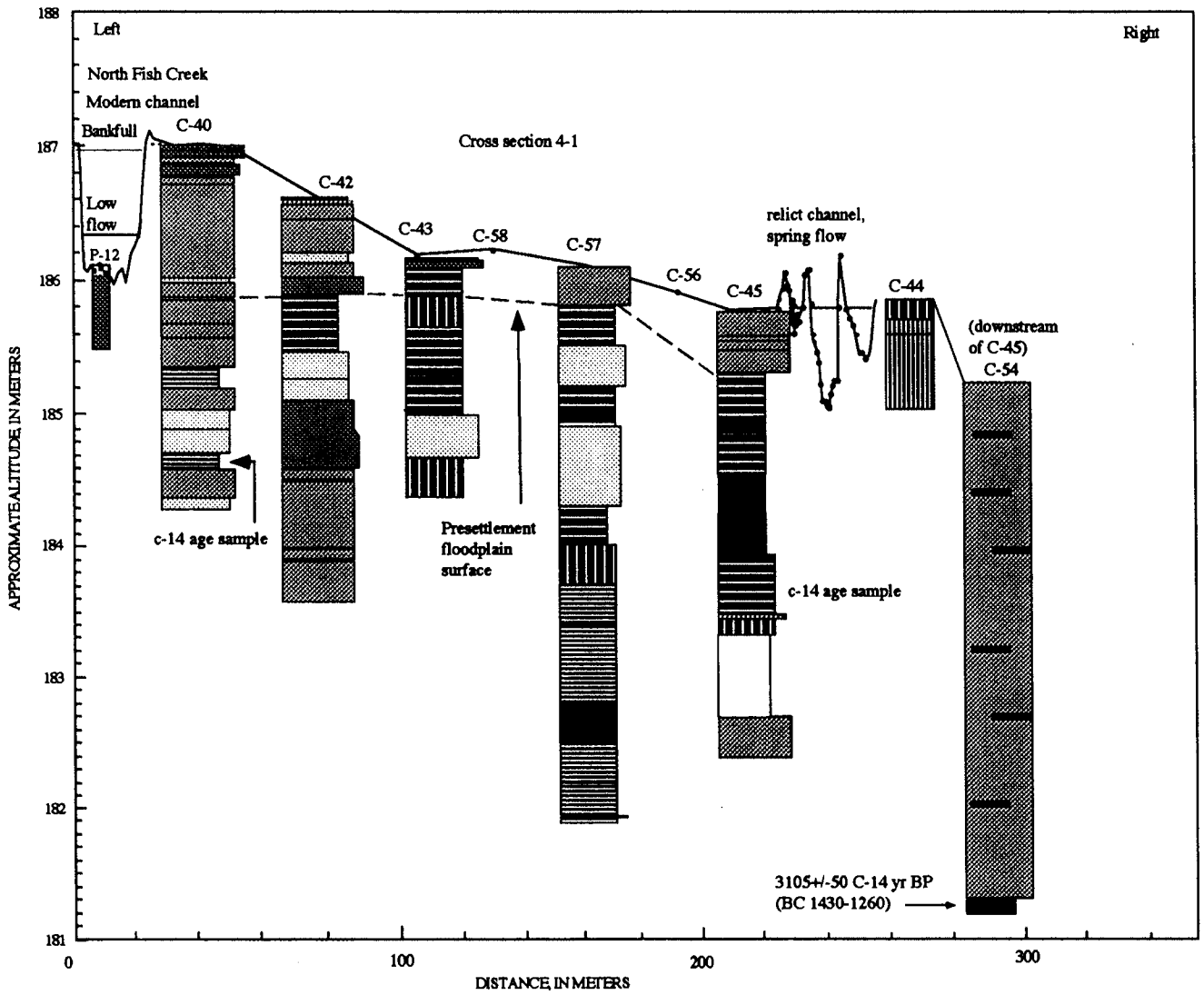


Figure 40. Stratigraphic descriptions of cores along cross section 4-1, sec. 2, T47N, R5W, Ashland Junction site, reach 2.

surface at about 0.7 m at about 50 m away from the modern channel. The thickness of the historical overbank sediment thins to 40 cm at a distance of 100 m away from the modern channel. The anastomosing channels of North Fish Creek provide additional contributions of sediment to the floodplain further south of the main channel, as shown in core C-57. Near the relict channel, approximately 0.5 m of historical sediment has been deposited, presumably originating from the nearby distributary channel of North Fish Creek. The southern edge of the floodplain is marked by a distinct change in lithology from fluvial deposits to dense, red clay diamicton with occasional pebbles and granules (C-44).

The transect data also indicate that the modern channel bottom has aggraded 1 m and the channel has widened over the last 125 years. Water-table data from cores collected along the transect indicate a water-table gradient of approximately 3 cm/m sloping away from the modern channel and toward the relict channels. As the channel continues to aggrade, the water-table gradient between the modern channel and relict or springfed channels continues to steepen. This increases the potential for North Fish Creek to cut over to the older relict channels and other spring flow-derived channels in Fish Creek Slough during high flow.

Indications of a historic increase in the water table relative to the land surface also is apparent at the WDNR/Ashland site. The wetland vegetation here is similar to that at the Fiorio site: abundant living alder and willow, with scattered larger dead trees such as black spruce and ash. About 150 m downstream of the C-45, a large in situ stump was found in the channel (fig. 39). The stump was identified as elm species (*Ulmus*). Scattered evidence of truncated root systems from additional large trees were observed near this stump. The root crown of the stump is located at the current water level in the channel, suggesting that the water table in this reach has risen substantially since the tree was alive. Current vegetation in the floodplain at this location is shrub wetland of alder and willow.

Sedimentation in Fish Creek Slough (Reach 1)

Reach 1 starts at the mouth of Fish Creek at Chequamegon Bay and continues for about 2 km to the confluence of North and South Fish Creek. Several types of cores were collected from the channel, floodplain, and backwater areas in this reach (fig. 7). The gradient in this

reach is similar to reach 2, and stream power is adequate to move a sand bedload at low flow. Seiche effects from Lake Superior are common, especially when strong northeasterly winds are prevalent.

A 16-m core (G-7) was collected with a Geoprobe from the floodplain at the confluence of North and South Fish Creek. The sediment record in the core indicates that 1.8 m of historical overbank sediment has been deposited 20 m distance from the modern channel (fig. 41). The presettlement surface is marked by an abrupt change from mainly silt and very fine to fine sand with little soil development to organic-rich clay and silt (fig. 41). Based on the radiocarbon ages (fig. 41, Appendix B), the post-settlement sedimentation rate at this site is five times higher than during the 500-year period preceding European settlement.

The confluence of North and South Fish Creeks also was the site of "a large and populous Indian village of the Ottawas, who there raised Indian corn" in 1744 AD (Thwaites, 1895, p. 430). The soils in the vicinity of the confluence are now mapped as loamy aquents that are subject to frequent flooding and have poor potential for cultivated crops, hay or pasture, but are good for wetland wildlife habitat (Pratt, 1981). This suggests that conditions are wetter on this surface than 250 years ago.

An additional shallow core was collected 120 m away from the modern channel of Fish Creek. The core contained 1.2 m of silt and clay, with a buried surface possible at 0.8 m depth.

The channel South Fish Creek is much different than that of North Fish Creek. During low flow, there is negligible discharge from South Fish Creek at the confluence, whereas flow in North Fish Creek during low flow is sufficient for transporting the sand bed load. The bottom of the South Fish Creek channel is composed of clay and the water depth is at least twice the depth of North Fish Creek. At low flow North Fish Creek is about 40 cm deep, whereas South Fish Creek is too deep to wade, giving the appearance that North Fish Creek contributes almost all of the sand load to Fish Creek in Fish Creek Slough.

Comparison of aerial photographs of Chequamegon Slough taken in 1938 and 1990 indicate that the area covered by open water in the Chequamegon Slough has increased farther inland. Areas covered by woody vegetation in 1938 now contain herbaceous wetland vegetation. Field observations of abundant remnants of woody vegetation (tree trunks and branches)

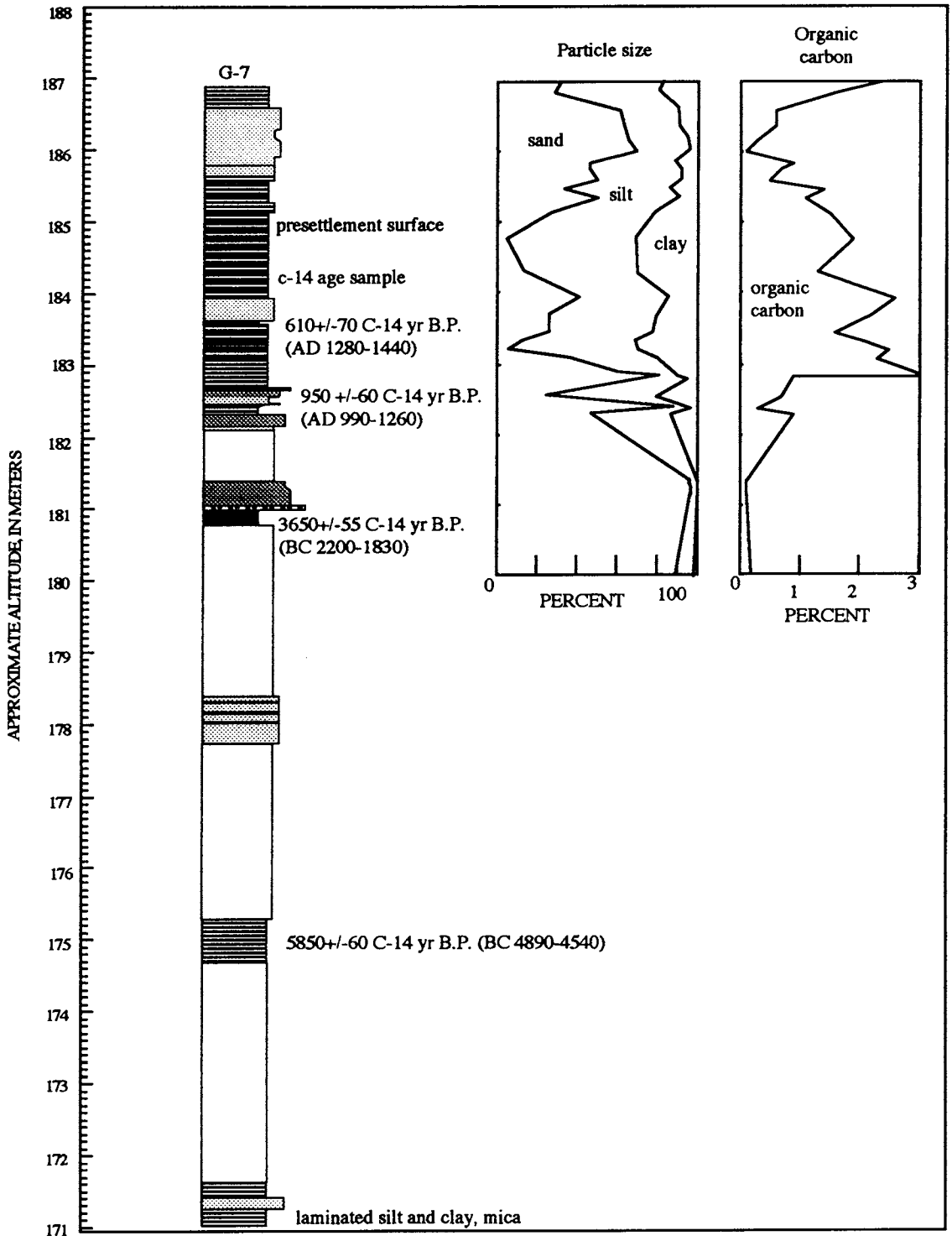


Figure 41. Stratigraphic description of core G-7, along section line 1/2, T47N, R5W, Martinsen site, reach 1.

under approximately 30 cm of water in the backwater areas of Fish Creek Slough now represented by wetland vegetation dominated by rushes or by open water also point to an increase in the level of Lake Superior relative to the land surface. Pratt (1981) also indicates that the amount of open marsh in the slough has increased by possibly 2-fold since the 1855 GLO surveys and also that the mouth of Fish Creek has moved. Thwaites (1895, p. 434) reported that "there was along these bottoms a heavy elm forest, mixed with cedar and black ash, but it has now mostly disappeared. An old 'second growth' along the east side of the slough, near Prentice Park, was evidently the site of an Indian settlement, probably of 18th century."

The 1855 GLO Surveys show the mouth of the Fish Creek to be located approximately 1.5 km east of its present location (fig. 38). This same location for the mouth of Fish Creek appears in 1906 and 1920 Bayfield County Plat Books. The mouth of the creek was at this same eastern outlet on a map at the Madeline Island Museum entitled "A map of that part of the Mineral Lands Adjacent to Lake Superior Ceded to the United States by the Treaty of 1842 with the Chippewa, 1845" compiled by Lieut. Col. George Talcott. Thwaites (1895, p. 434) described three outlets for Fish Creek, "one on the east shore or near the east side, one central, and one near the western shore." He reports that along up to 2 miles of the stream was a "vast swamp, through which the stream flows in deep sluggish lagoons." At the turn of the century a small community called "Nash" also was located at the head of the Bay (Ashland-Bayfield Bicentennial Committee, 1976).

In the western part of Fish Creek Slough, analyses of piston cores indicate that sand is mainly confined to channels that feed from Fish Creek, while the springfed channels and backwater areas are mainly characterized by silt and clay (fig. 42). The eastern half of the slough, near Prentice Park, has an outlet to the bay near the city limits of Ashland, approximately 1 km east of the present outlet of Fish Creek. Based on historical maps, as late as 1920, Fish Creek flowed through the eastern part of the slough and entered the bay slightly east of the present outlet of the eastern slough (fig. 7). Springfed channels flowing into the eastern slough are over 1 meter deep, and sand appears to be limited to the circa 1920 relict channel of Fish Creek (fig. 42). In contrast, water depth in the active channels of Fish Creek in the slough tend to be less than 0.5 m.

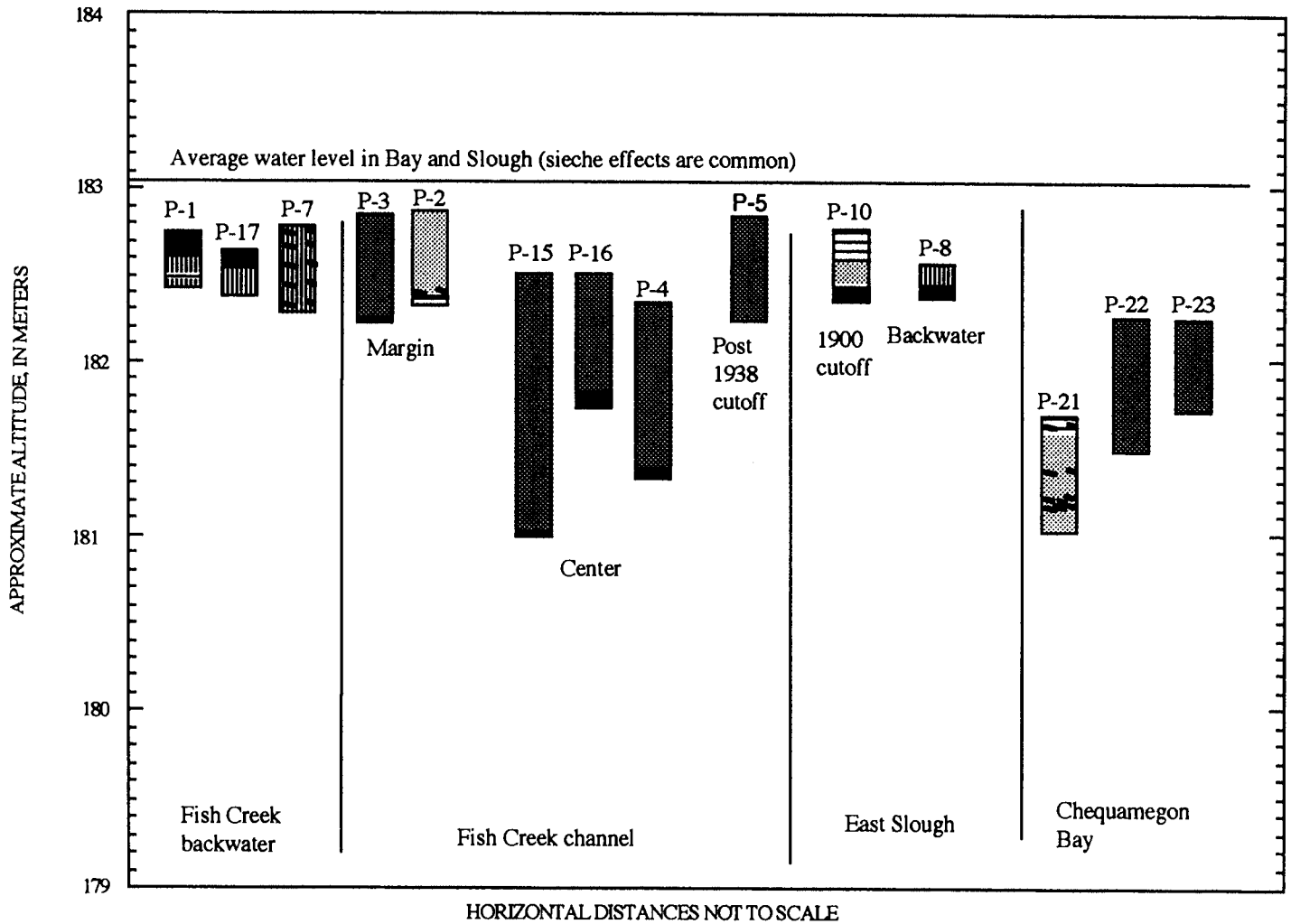


Figure 42. Selected core descriptions from Fish Creek Slough and Chequamegon Bay, reach 1.

Results from analyses of piston cores collected from Fish Creek Slough indicate that approximately 0.5 to 1.5 m of medium to very coarse sand has historically accumulated in the present channel of Fish Creek (fig. 42). The depth of sand at any one point in the channel is highly variable because of the large variability of the original channel bottom contours. Underneath the sand, the channel bottom is composed of dense silt and clay with variable amounts of organic debris. It is assumed that this dense silt and clay represents pre-settlement backwater vertical accretion sediment deposited when the mouth of Fish Creek was 1.5 km east of its present location.

Cores in the backwater areas of Fish Creek Slough (P-1, P-7, P-8, P-9) are composed of red clay, brown silt and clay, and peaty clay with varying amounts of woody debris (fig. 42). From these data it appears that sandy sediment is confined to the channels of Fish Creek and backwater areas are composed of silt and clay. Currently, there is open wetland vegetation in the vicinity of the core locations. Large pieces of abundant wood at depths of approximately 20 cm in cores P-8 and P-9 indicate that the vegetation may have been more similar to lowland forest in the past. A clear break between historical and pre-settlement sediment in the backwater areas is not present in the piston cores. The cores are being subsampled for pollen (presence or absence of ragweed) macrofossils, particle size, and lead/cesium dating to help distinguish the boundary. A core from the center of the abandoned 1855 Fish Creek channel (P-10) contained 33 cm of sand on top of silt. This supports the 1855 GLO survey notes that describe a sandy bottom in the Fish Creek channel near the mouth.

Results from radiometric analyses of the fine grained material in core P-7 from a shallow backwater site (Appendix B), although limited, suggest that little historical sedimentation has taken place on this surface (fig. 43). A maximum concentration of ^{137}Cs within the first 2 cm indicates that little sedimentation has occurred on this surface over the last 30 years. The ^{210}Pb data from P-7 is less clear, and similar variations in corresponding ^{226}Ra concentrations suggest that either the sources of lead changed or the character of the sediment changed over the 10-cm depth sampled, thus, the ^{210}Pb data is inconclusive (fig. 43).

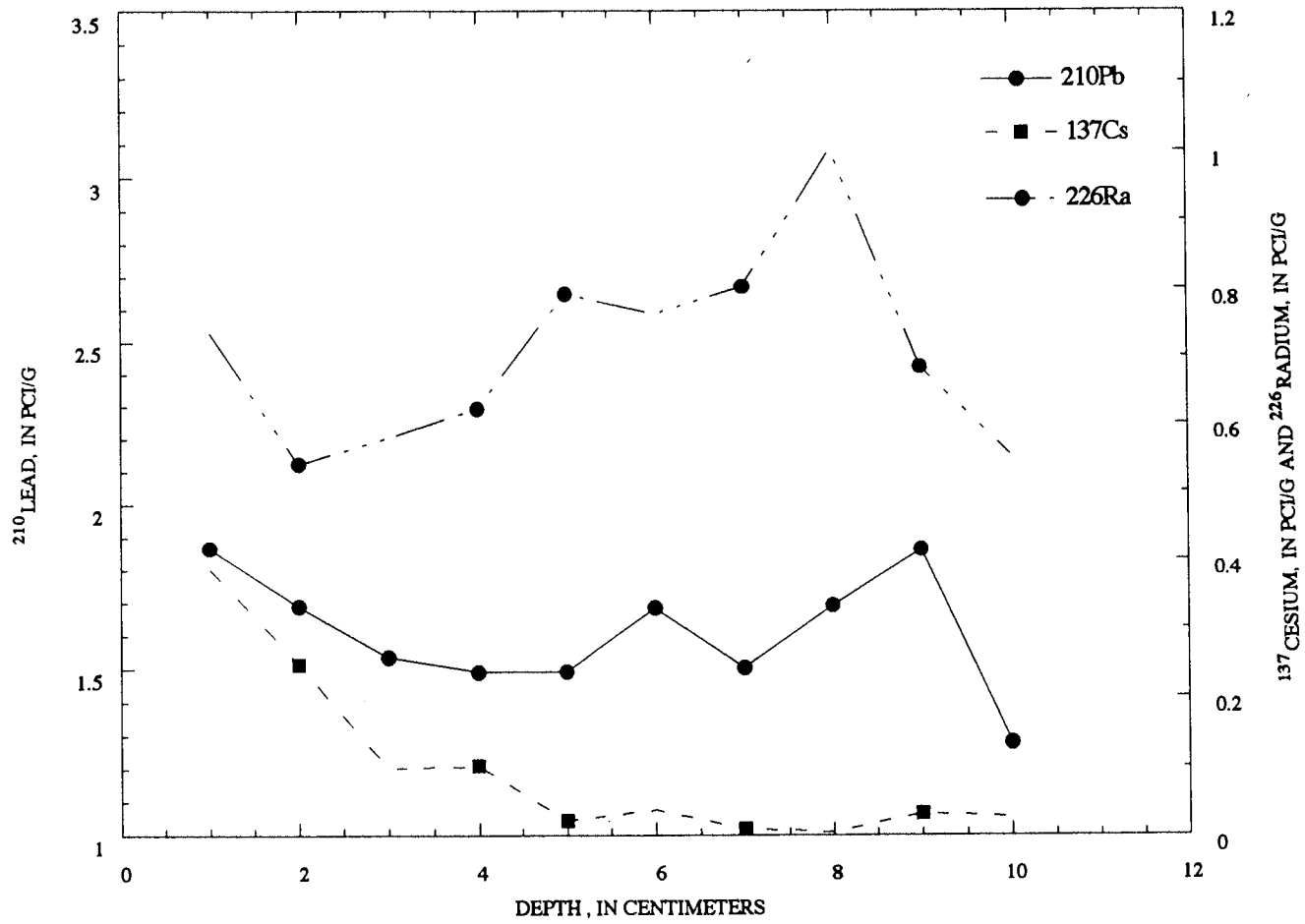


Figure 43. Concentration of ^{210}lead, ^{137}cesium, and ^{226}radium in core P-7, Fish Creek Slough backwater, Sept. 1995.

The deepest piston core, P-19, was collected from the backwater area of the eastern slough (fig. 7). The water depth was 24 cm. The stratigraphy in core P-19 suggests that 0.45 m of historical sediment are present over a buried organic-rich surface that contained macrofossil remains indicative of a fen wetland (Appendix C). Current vegetation consists mainly of rushes, but many fallen dead trees were observed protruding from the water and slightly buried by sediment, indicating a change of vegetation towards wetter conditions occurred at this site. This is consistent with an expected rise of water levels in the slough due to differential isostatic rebound. These findings support Pratt's (1981) conclusion that the amount of open marsh is greater today than it was in 1855.

The entire length of core P-19 was composed of either peat, woody and organic debris, silt or clay indicating that the core location was in a low energy environment for at least the length of time represented by the core. The uppermost radiocarbon age of 450+/- 60 ^{14}C yr B.P. (AD 1140-1340, 1400-1530, 1560-1630) indicates that 1.2 m of sediment accumulated from approximately AD 1440 to 1870 (0.28 cm per year). This sedimentation rate is similar to the floodplain sedimentation rate of 0.27 cm per year estimated for core G-7 from about AD 1350 to 1870.

Most of the cores from the mouth of Fish Creek (P-13 and P-14) and the two transects in Chequamegon Bay (P-20, P-22 to P-30) (fig. 7) are composed almost entirely of sand (fig. 42). It was hoped that these cores would contain sedimentary sequences that reflect the amount of sediment that has accumulated on top of bark and woody debris related to the lumbering activities that began in the 1870's and continued into the early 1900's. Core depths ranged from 0.18 to 1.05 m. All but two cores contained mainly sand with no observable stratification; thus, it is concluded that penetration was not deep enough to obtain evidence of wood and bark presumed to be at greater depths. Surficial samples from these cores are composed almost entirely fine to medium sand (fig. 23, Appendix A) and are similar to other channel samples from reach 2 and 3.

Elsewhere, core P-21 was collected in the bay at the eastern outlet of Fish Creek Slough. Woody debris also was abundant in core P-21 and probably came from the logs stored in the bay in the 1880's for the lumber mills located along the shoreline of the bay. Two cores near

the eastern outlet in Fish Creek Slough (P-21 and P-11) contained some indication of past lumbering activities. Both cores contained a woody debris layer with abundant wood chips from about 0.2 to 0.6 m in depth. These two cores were the only cores out of all cores collected in the Bay that contained wood and bark. The surficial sediment in core P-21 was much different than the other cores from the bay and contained approximately 15 percent silt. Also, the sand fraction was mainly composed of very fine and fine sand (fig. 24). These preliminary data suggest that the large delta at the present mouth of Fish Creek has accumulated over 1 m of sediment after the turn of the century. While most of the sand appears to be coming from Fish Creek, the possible contribution of sediment from lacustrine processes in Chequamegon Bay must also be acknowledged.

Cores from the southern basin of Lake Superior collected by Dell (1972, 1974), including one from Chequamegon Bay, contained as much as 79 cm of sand overlying as much as 3.6 m of brown stratified silt and sand. Dell found that up to 30 m of red nonvarved clay on top of red clay till occurred under brown sediment in the Chequamegon Bay core.

Changes in Size of Low-Magnitude High-Frequency Floods

The size of historical low-magnitude high frequency floods was be indirectly measured by surveying relict channels and using HEC-2 to reconstruct bankfull flows (table 14). In general, the bankfull flows have a recurrence interval of approximately 1 to 2 years (Leopold and Wolman, 1964). However, bankfull flows can range from a recurrence interval of less than 1 to 32 years (Williams, 1978). Channel capacity flows for the modern channel also were calculated (table 14).

The estimated energy gradient used to calculate the bankfull flows was based on the water-surface gradient that best matched with bankfull stage along all of the cross sections. For initial runs, two gradients were tested and compared—the water-surface gradient measured at low flow, and the general channel gradient as measured from stream crossings of contour lines on 7.5-minute topographic maps (table 14). Other studies have shown that both may overpredict the actual energy gradient for large floods (Magilligan, 1988). In many instances, this low-flow water-surface gradient was too flat compared to the inferred gradient for bankfull flow as

Table 14. Cross-section characteristics and estimates of bankfull and channel capacity flows for the modern channel and relict channels

[m, meters; n_{ch}, Manning's roughness coefficient used for the channel; s, seconds; --, data not applicable]

Reach number	Location	Cross-section number	Modern or relict channel (M or R)	Channel gradient from 7.5-minute topographic maps (m/m)	Water surface gradient measured in field (m/m)	Energy gradient used for discharge (m/m)	Bankfull channel area (m^2)	Channel capacity (m^2)	Bankfull flow (m^3/s), n_{ch} = 0.035	Channel capacity flow (m^3/s) n_{ch} = 0.035	Bank-full flow (m^3/s), n_{ch} = .06	Channel capacity flow (m^3/s) n_{ch} = 0.06
5	Brandis site, R6W, sec. 20/29	15	M	.0073	.00065	.0050	7.6-12.3	11.1-17.0	25	40	15	25
5	Bayfield/Ino site	--[1]	M	.010	.0050	.0050	12.4-15.0	23.1-27.9	25	55	15	35
5	Bayfield/Ino site	22	R (<1946)	--	--	.0050	11.1-13.5	--	15	--	10	--
5	Moore site	5	M	.0033	.011	.0070	8.8-13.7	10.0-17.2	25	30-35	15	20
5	Moore site	6	R (<1946)	--	--	.007	4.8-10.2	--	10	--	8	--
4	Bayfield site, R6W, sec 21/22	20	M	.0056	.0030	.0030	10.9-11.1	--	15	15	10	10
4	Johanik site, R6W, sec. 22/23	19	M	.0086	.00068	.0030	7.4-11.6	16.5-21.1	10	25	8	10-15
4	Johanik site, R6W, sec. 14/23	18	M	.012	.00050	.0030	8.5-9.1	19.1-21.3	10	35	8	20
4	Mihalek site R6W, sec. 13/14	12	M	.00450	.00067	.0040	9.6-10.6	16.3-18.5	10-15	35	8	15-20
3	Skulan site, R5/6W, sec. 13/18	21	M	.00091	.00065	.0030	16.6-19.3	22.9-24.6	30-35	45	15	25
3	Skulan site	2	M	.00091	.0030	.0030	22.5-38.4	25.9-44.4	45	55	20	35-40

Table 14. Cross-section characteristics and estimates of bankfull and channel capacity flows for the modern channel and relict channels —Continued

[m, meters; n_{ch}, Manning's roughness coefficient used for the channel; s, seconds; --, data not applicable]

Reach number	Location	Cross-section number	Modern or relict channel (M or R)	Channel gradient from 7.5-minute topographic maps (m/m)	Water surface gradient measured in field (m/m)	Energy gradient used for discharge (m/m)	Bankfull channel area (m^2)	Channel capacity (m^2)	Bankfull flow (m^3/s), n_{ch} = 0.035	Channel capacity flow (m^3/s) n_{ch} = 0.035	Bank-full flow (m^3/s), n_{ch} = .06	Channel capacity flow (m^3/s) n_{ch} = 0.06
3	Skulan site	1	R (<1946)	--	--	.0030	13.7-24.1	--	20-25	--	10-15	--
3	Nekoosa site, R5W, sec. 7/18	17	M	.0026	.0012	.0026	--	35.1-36.0	25	80	15	45
3	Nekoosa site, R5W, sec. 7/8	16	M	.0026	.00067	.0011	15.7-18.3	34.5-38.8	20	45-50	10-15	25
2	Sutarik site, R5W, sec. 8/9	11	M	.0016	.00092	.00092	13.4-16.9	--	15	15	--	--
2	Hanson site, R5W, sec. 9/10	8	M	.0012	.00091	.00091	16.8-21.2	--	15	15	--	--
2	Hanson site	7	R (<1855)	--	--	.00091	17.3-21.8	--	15-20	15-20	--	--
2	Torkko site, R5W, sec. 3/10	10	M	.0014	.00056	.0014	11.9-15.5	--	10-15	10-15	--	--
2	Fiorio site, R5W, sec. 2/3	3	M	.0014	.00044	.0014	11.9-13.3	--	10	10	--	--
2	Ashland Junction site	4	M	.0014	--	.0014	16.5-17.5	--	15	15	--	--
2	Ashland Junction site	9	R (<1909)	--	--	.0014	11.9-12.4	--	10	10	--	--

[1]Cross-section survey done by Michael Kelly, University of Wisconsin-Madison, 1995.

indicated by a mismatch of the modeled bankfull water surface compared to the slight downstream drop in elevation of bankfull stage along the measured cross sections. If possible, cross-section data were collected from a straight reach (run or glide) in between riffles or rapids; thus the measured water-surface gradient may have been less than if the reach extended from riffle to riffle. Except for reach 5, the channel gradient measured from topographic maps was usually steeper than the water-surface gradient at low flow measured in the field. If neither of these fit the cross-section data, intermediate gradients were tested until the best fit with the bankfull stage indicators was achieved.

For reaches 3, 4, and 5, two values of Manning's roughness coefficient (n) were used to bracket possible roughness conditions in these reaches. The channel in reaches 4 and 5 is potentially more rough than reach 2 because the channel bottom material contains abundant boulders and cobbles in these reaches. Reach 3 contains more woody debris and gravel than does reach 2. Two sets of flows are presented in table 9 for cross sections in reaches 3, 4, and 5, are based on a channel roughness coefficients of n = 0.035 and 0.060.

Changes in the bankfull and channel-capacity flows along North Fish Creek relate very closely to energy gradient and aggradational or degradational condition of the channel. In reach 5, bankfull flow was estimated to be about 15 to 25 cms, whereas channel capacity flows range from about 20 to 55 cms. In reach 4, the energy gradient appears to drop slightly and both bankfull and channel capacity flows are less at about 8 to 15 cms for bankfull and 10 to 35 cms for channel capacity. Downstream of the confluence with Pine Creek in reach 3, the gradient lessens slightly; however, both bankfull and channel capacity flows increase to a maximum of 45 and 80 cms, respectively. In reach 2, where aggradation dominates, the bankfull and channel capacity flows become the same and decrease to about 10 to 15 cms. This is an indication that overbank flooding occurs much more commonly in reach 2 compared to reach 3.

Three of the five relict channels surveyed in North Fish Creek originated from the 1946 flood. The time period containing this flood resulted in the most evidence for meander cutoffs. The other two channels were abandoned before 1909, using the 1909 Bayfield County plat map for guidance, which is the earliest reliable source of channel locations in areas other than sec-

tion lines. The location of the stream on maps accompanying the 1855 Government Land Office Survey was only considered reliable if it was at a section line crossing.

Figure 44 show how changes in channel cross-sectional area and bankfull flows change in relation to the longitudinal profile and over the last approximately 100 years. In reach 5 along the degradational reach, bankfull flow has increase up to 2.5 times since 1946. In the transitional reach downstream of the gaging station (reach 3), the bankfull flow has almost doubled. In the aggradational reach (reach 2) the bankfull discharge appears to be about the same as prior to 1909. Thus, where channel gradient is steep, more evidence for change in channel size was observed. In the aggradational reach, the cross-sectional surveys and HEC-2 modeling may not be sensitive enough to detect small changes in channel size and bankfull discharge. The wetland vegetation in the floodplain along the aggradational reach suggests that overbank flooding occurs at least once a year and probably more often.

Model of Land-Use Effects on Storm Runoff and Sediment Yield

Three types of land-use conditions were modeled for North Fish Creek at Moquah, Wis. (river kilometer 17) using the HEC-1 rainfall/runoff model and North Fish Creek sediment-load equations. The land-use conditions modeled are (1) complete forest (representing pre-settlement conditions), (2) peak agriculture in the 1930's through 1940's (as represented by land use statistics calculated from the Bayfield County 1928 Land Economic Inventory), and (3) current land use conditions (1993 satellite imagery). Observed gaging station data was used to successfully calibrate the model.

Effects on Storm Hydrographs and Sediment Yields

HEC-1 model results (fig. 45) suggest that under peak agricultural land use in the basin (about 1928), peak flow for a rainfall event on September 3, 1991 may have been 3 times greater than under forested conditions, and peak flow for current land-use conditions may still be twice as high as compared to results with the basin entirely forested. Using the model parameters described previously for complete forest cover, the modeled hydrograph resulted in runoff that was 70 percent of current conditions, peak flow of 52 percent of current conditions, and a

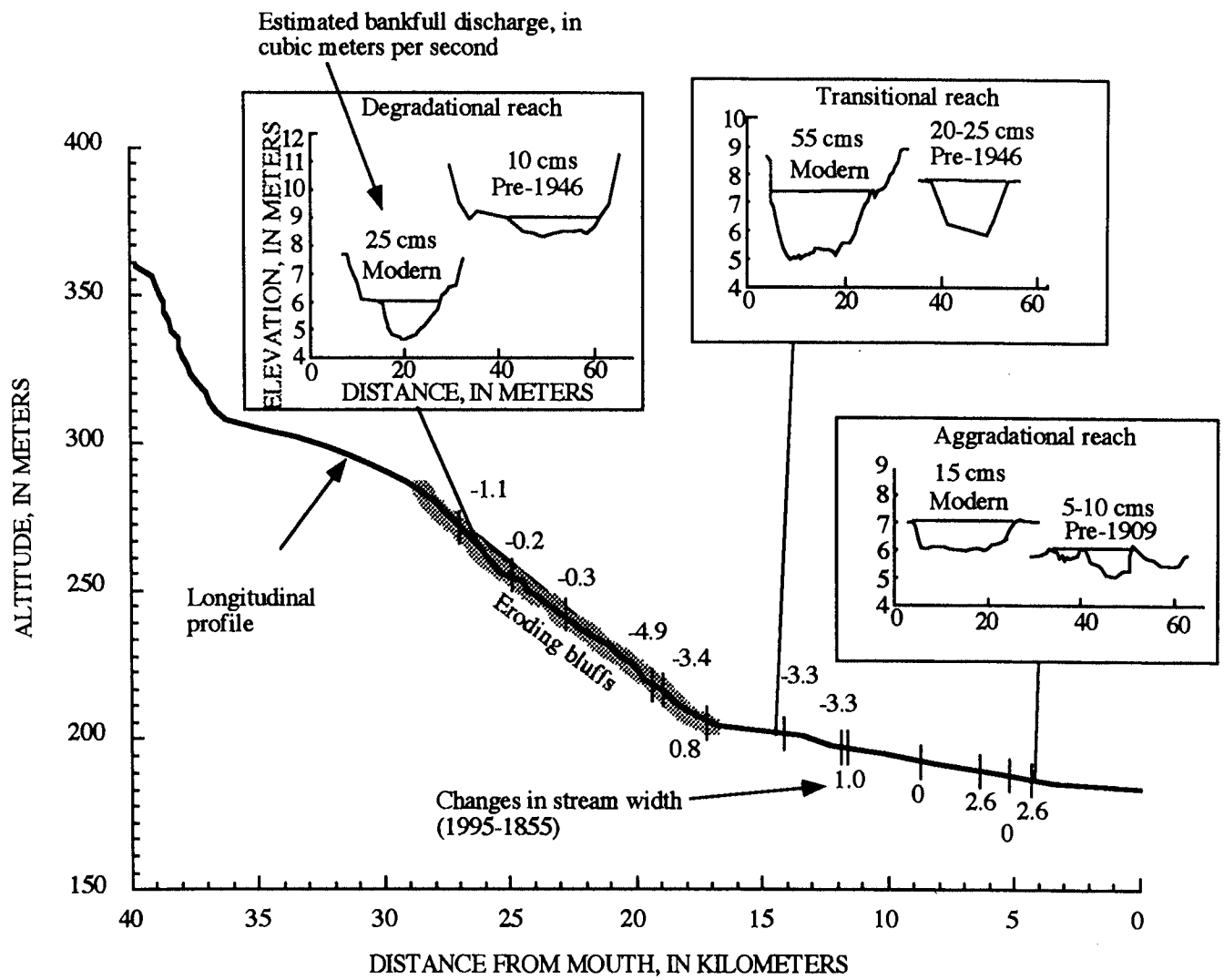


Figure 44. Longitudinal profile, stream width changes, and selected cross sections of the modern and relict channels for North Fish Creek.

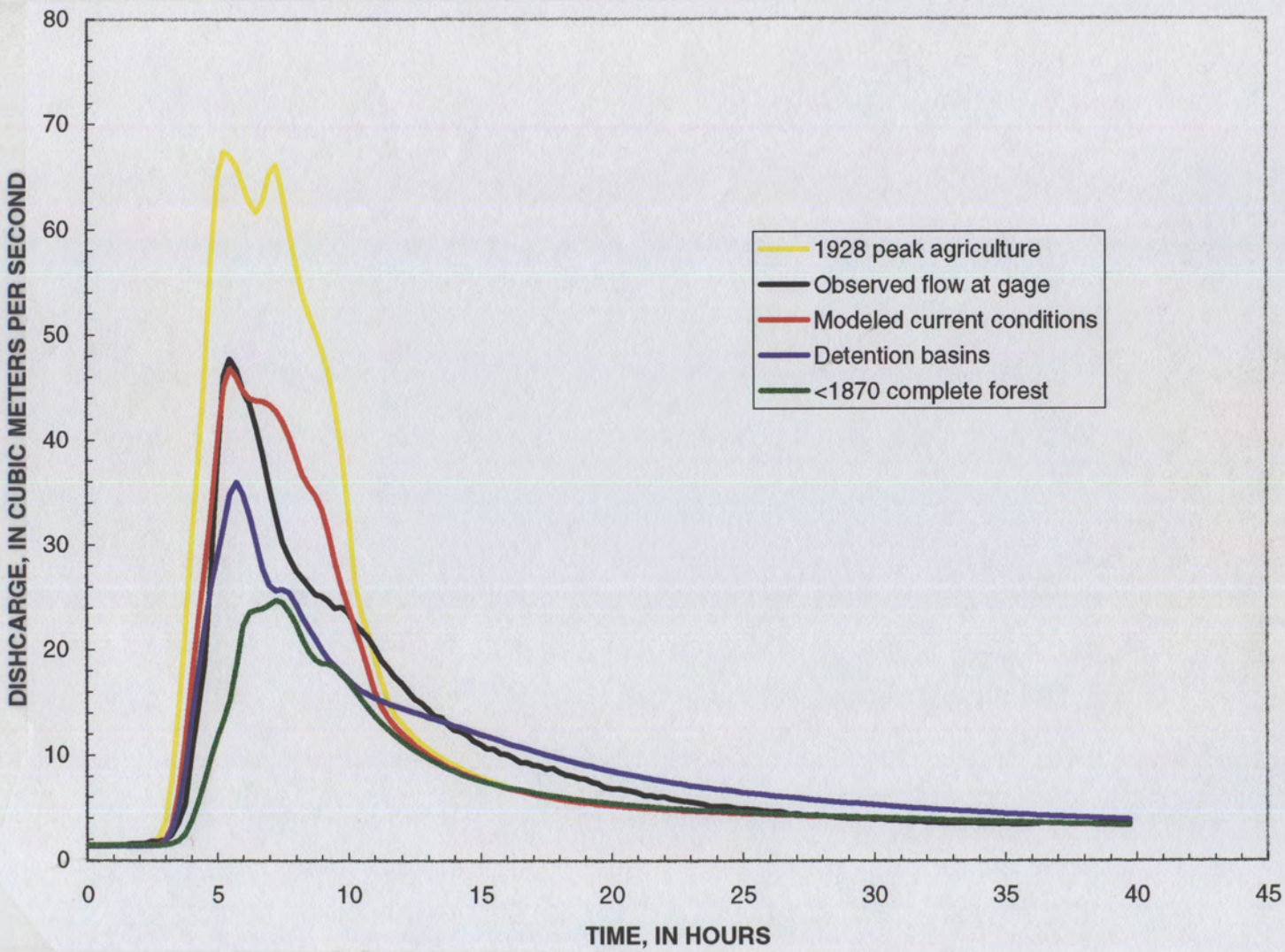


Figure 45. Storm hydrographs for North Fish Creek near Moquah, Wis. for a historical storm on September 3, 1991, under different land-use conditions.

time to peak of 2.1 hours later than current conditions. Sediment yield during peak agriculture may have been at least 5 times greater than if the basin was entirely forested (fig. 46). Current land use resulted in a sediment yield 2.5 times greater than if the basin was entirely forested (fig. 46).

Effectiveness of Detention Basins for Reducing Erosion

The effectiveness of detention basins at reducing bluff erosion was examined by placing seven hypothetical detention basins at the mouths of major tributaries above and along reach 4, where the majority of large bluffs occur. A detention basin was not placed at the mouth of Pine Creek because it enters North Fish Creek below most of the eroding bluffs. The rainfall/ runoff and sediment load model was run for the same historical storm (September 3, 1991) used to examine the effects of different land-use conditions on runoff and sediment loads. The addition of these seven detention basins resulted in 77 percent of the peak flow, and a time to peak of 15 minutes later than simulated storm runoff without the detention basins (fig. 45). The detention basins provided a reduction in sediment yield for the modeled storm of 30 percent (fig. 46). Results also could be further improved by installing one or two detention basins in the Pine Creek subbasin.

Returning the vegetation to its pre-settlement state results in more infiltration and interception than the agricultural land in the basin currently provides, which reduces both the peak runoff and the volume of water that eventually reaches the channel from storm runoff or snowmelt. Even though the installation of several detention basins may reduce erosion, there are other possible side effects of storing runoff over a longer time period than would have occurred under natural conditions. These possibilities presented need to be considered in the management decisions that will follow from the results of the modeling. One of the results of installing detention basins is that the total volume of water entering the channel is not reduced, instead it is spread out over a longer time period. Thus, there may be some warming of downstream flow from the addition of warmer water stored in the detention basins after a flood. In addition, large floods on North Fish Creek result in scour holes that are useful for fish habitat. Historically, these holes have rapidly filled with sand in the months of base flow following a major flood

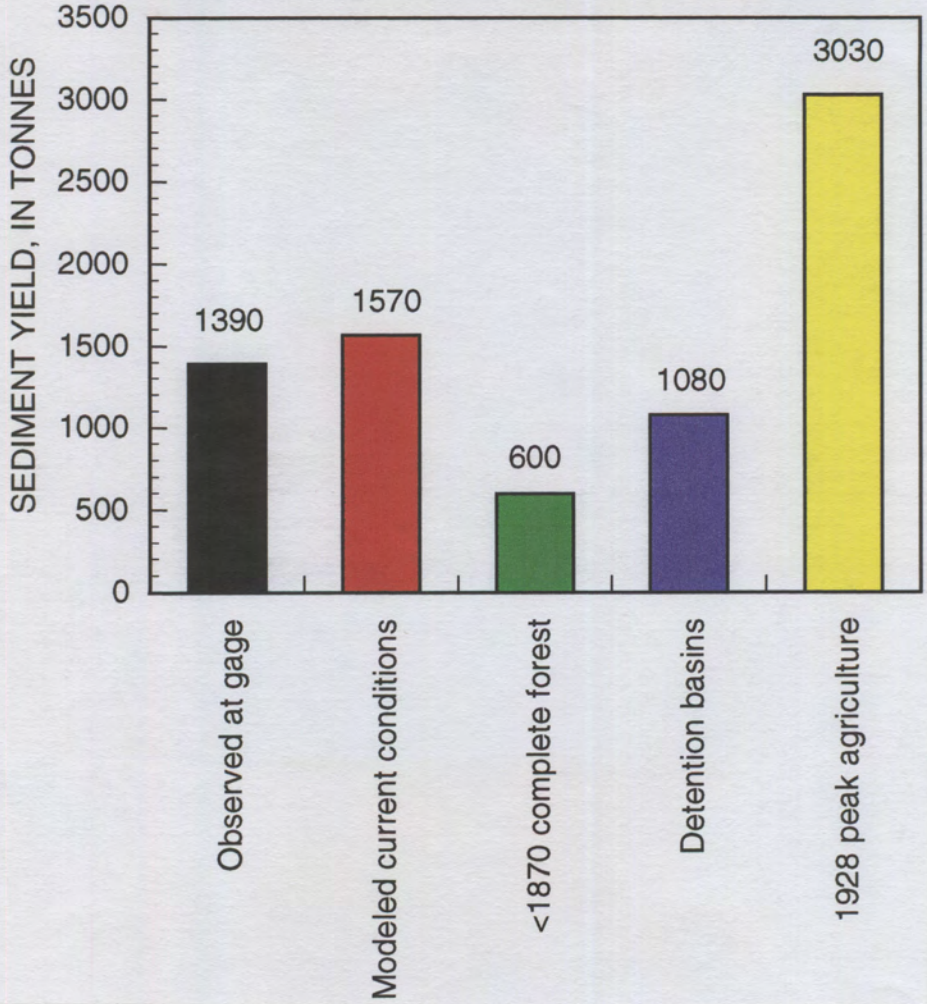


Figure 46. Estimated sediment yields for a historical storm on September 3, 1991, under different land-use conditions, North Fish Creek at gaging station.

event. Moderating the peak flows during floods will result in less scour, and possibly less available pools for overwintering fish. However, it also is possible that the sandy bottom may become more stable over time and pools would not fill in as quickly following a storm.

Conclusions

The geomorphic field evidence and modeling results compliment each other and indicate that removal of forest, followed by agricultural activity significantly altered the geomorphic conditions of North Fish Creek more so than climate or base level fluctuations during the past 125 years. However, high magnitude floods caused by large and infrequent rainfall events appear to be the main factors that enhance the response mechanisms from changes in vegetation and cause the most disturbance in the system. Two large storms in 1941 and 1946, following a period of little storm activity, made the geomorphic response that followed more noticeable in the floodplain stratigraphic sequences and downcutting evidence. In addition, the effects of the clustering of large storms in the early 1950's may also have added to the instability of North Fish Creek.

Post-settlement erosion and sedimentation in North Fish Creek, although mainly influenced by vegetation change, is not constant but is episodic and dependent on the occurrence of large, infrequent floods. Most of the sediment in the stream system is derived from bluff and bank erosion in reaches 4 and 5, with some streambank erosion in reaches 2 and 3, even though the gradient flattens considerably compared to reaches 4 and 5. Sediment contributions from upland areas are minimal; however, accelerated runoff from agricultural land contributes additional runoff that provides the mechanical energy for removal of bluff and bank sediment along the mainstem.

Based on modeling results, peak flows for a 7.6-cm rain storm may be double peak flows under complete forest. During peak agricultural activity in the 1930's, peak flows may have been about three times peak flows under complete forest. Sediment yields for the same rainfall event were about five times higher under peak agricultural activity compared to complete forest. Under current land-use conditions, modeling results suggest sediment yields are just over double presettlement sediment yields.

The channel in reaches 4 and 5 also has historically eroded at an accelerated rate based on accelerated sedimentation rates observed in reaches 1 and 2 and a two-fold increase in bankfull discharge in reaches 4 and 5.

The transitional reach (reach 3) is characterized by a significant change in historical channel size and the ability to transport sediment. Following European settlement, there is evidence of floodplain aggradation. Over at least the last 50 years, channel degradation has occurred.

In the aggradational reach, although evidence is limited for changes in bankfull discharge, the aggradation rate of the floodplain and channel is 4 to 6 times higher than presettlement conditions. Sediment deposited in the last 100 years appear to be becoming more coarse-grained over time in the lower reach of North Fish Creek. In addition, about 1 m of sediment has accumulated in the lower reach on the valley floor and greater amounts have accumulated in the channel since European settlement. The water table also appears to be rising in the aggradational reach of North Fish Creek (reaches 1 and 2), perhaps consistent with elevated local streambed elevations caused by aggradation and a steady rising of Lake Superior due to differential isostatic rebound. It is not known at this time if it can be attributed solely to differential isostatic rebound or whether some other factor is contributing to this phenomenon as well.

Northern Wisconsin streams such as North Fish Creek are typically used as reference sites. These data indicate that even though the effects of human activity is less in North Fish Creek than other more intense agricultural basins to the south, geomorphic change is substantial and ongoing. However, both the geomorphic and modeling data suggest that as agricultural activity decreases and forests mature, there has been a decrease in sedimentation in the last few decades.

Currently, the Wisconsin Department of Natural Resources (WDNR) is in the process of acquiring a large portion of the riparian zone around the mid and lower reaches of North Fish Creek, and, for wildlife benefits, is interested in returning it to a patterned mosaic of mature boreal forest mixed with different aged stands of trees. The modeling results suggest that any change from pasture or crop land to forested land will help reduce runoff, thereby reducing erosion and sedimentation. However, these results are limited to a single storm that represents a

low-magnitude high frequency precipitation event. In addition, the runoff and sediment-load relation may change under different land-use conditions. Most likely, the model used here overestimates the sediment load for forested conditions.

The rainfall/runoff and sediment-load modeling results also indicate that the addition of detention basins (increasing storage) on tributaries to North Fish Creek also may help in limiting bluff and bank erosion. However, other methods may be more effective at reducing bluff erosion or more cost effective. These include large bank stabilizations such as sheet pilings or gabions, or rerouting of the river channel away from bluffs and valley sides.

CHAPTER 4
HOLOCENE CHANGES IN GEOMORPHIC AND HYDRLOGIC CONDITIONS

Post-settlement geomorphic changes can be put in perspective by comparison against natural conditions during the Holocene. Regional Holocene changes in vegetation, climate, and base level are first summarized from available literature and then compared with the stratigraphic record for North Fish Creek. The North Fish Creek data are mainly limited to evidence of channel cut and fill sequences and are not sufficiently detailed to characterize changing rates of lateral channel migration as have been done for studies elsewhere.

Holocene Changes in Vegetation, Climate, and Base Level

Holocene geomorphic and hydrologic changes in North Fish Creek were potentially caused by changes in three factors—vegetation, climate, and base level (Lake Superior water levels). Existing literature was gathered from a variety of sources to reconstruct the local history of these changes through the Holocene. Vegetation and climate data are generally derived from pollen cores collected in nearby lakes and ages are established through the use of varve chronology or radiocarbon dating. A macro-climate model for Holocene precipitation (Bryson and Bryson, 1995) also was utilized in this study and compared to the published field data. As described earlier in the methods section, the macro-climate model is based on a combination of variables for large-scale atmospheric circulation, global ice volume, Milankovitch solar variations, and volcanic activity during the Holocene (Smagorinsky, 1963; Bryson and Goodman, 1986; Bryson, 1988; and Bryson and Bryson, 1995). Base level history was compiled from previous studies of relict Holocene shorelines and differential isostatic rebound rates for the Great Lakes.

Vegetation and Climate

Long-term changes in vegetation are often assumed to be mainly caused by long-term changes in Holocene climatic conditions (Webb and others, 1983). Short-term variations in vegetation, on the other hand, may be related to disturbance frequency, such as fires (Gajewski,

1987; Swain, 1973) or windthrow (Davis, 1987). Fires occurred on an average of about once every 100 years in northern Minnesota (Heinselman, 1973). Catastrophic windstorms in northern Wisconsin have a return probability of about once in 1200 years (Canham and Loucks, 1984). Dispersal mechanisms and environmental limitations also may affect the spatial distribution of some species such as hemlock (*Tsuga*) and beech (*Fagus*) in northern Wisconsin (Davis and others, 1986). Local soils and geologic setting also may affect vegetation and climate relations (Brubaker, 1975; Swain and Winkler, 1983).

There are several reconstructions based on cores from lakes and bogs in northern Wisconsin, Minnesota, and Michigan that span the Holocene (fig. 47). There also are vegetation and climate reconstructions for the past 2,000 years that contain higher resolution information (fig. 48). Climatic reconstructions are mainly based on pollen data and radiocarbon dating (Bartlein and Whitlock, 1993; Winkler, 1996; Winkler and Sanford, 1997; Brubaker, 1975; Swain, 1973; Gajewski, 1987; and Gajewski and others, 1985), but also are supported with data from macrofossil analysis (Swain, 1978), varve counting (Bartlein and Whitlock, 1993), charcoal presence and abundance (Swain, 1973; Gajewski and others, 1985), and climate modeling (Webb and Bryson, 1972). The results from macrophysical paleoclimate modeling of Holocene precipitation and temperature (fig. 49) done as part of this investigation also are included in figure 47. As stated earlier in the methods section, the macrophysical paleoclimate model is based on large scale climatic boundary conditions consisting of relations among Rossby long wave equations, terminal wind, the Z-criterion, global ice volume, Milankovitch solar variations, and volcanic activity (Bryson and Bryson, 1995).

The early Holocene (about 10,000 to 8,500 ^{14}C yr B.P.) is generally characterized as being cool and moist in the northern Midwest (fig. 47). In central Minnesota, the ice sheet influenced climatic conditions to about 9,000 years ago by splitting the jet stream and causing cooling because of its high elevation and reflectivity (Bartlein and Whitlock, 1993). Glacial lacustrine varve formation ended at about 9,000 ^{14}C yr B.P. in cores from western Lake Superior, possibly indicating that the ice sheet had retreated to at least the northern shore of Lake Superior (Maher, 1977). A shift from cool and moist conditions to warm and dry conditions after about 8,500 ^{14}C yr B.P. possibly reflects the response of hemispheric atmospheric circulation to final

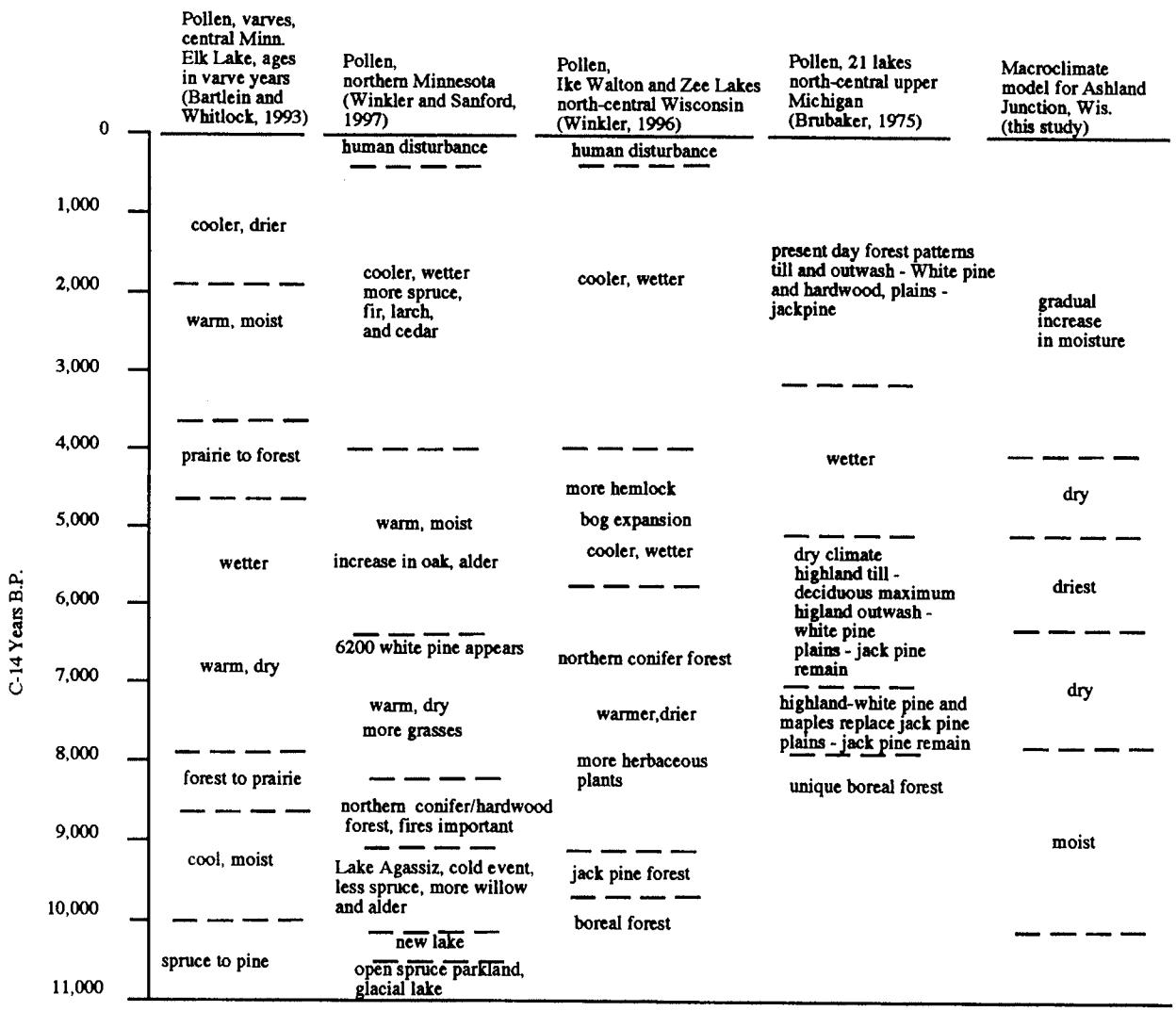


Figure 47. Comparison of Holocene vegetation and climate reconstructions for sites in Wisconsin, Minnesota, and Michigan.

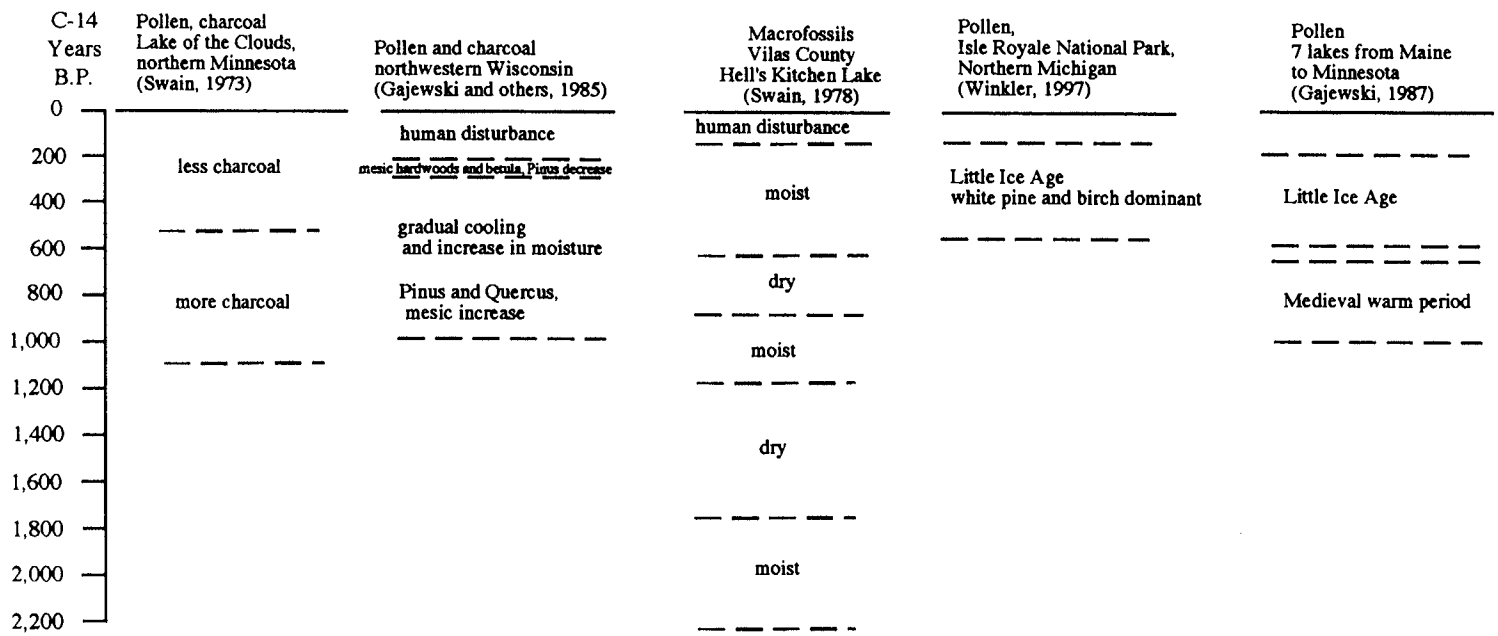


Figure 48. Comparison of vegetation and climate reconstructions over the past 2,000 years for sites in the northern Midwest and east coast of the U.S.

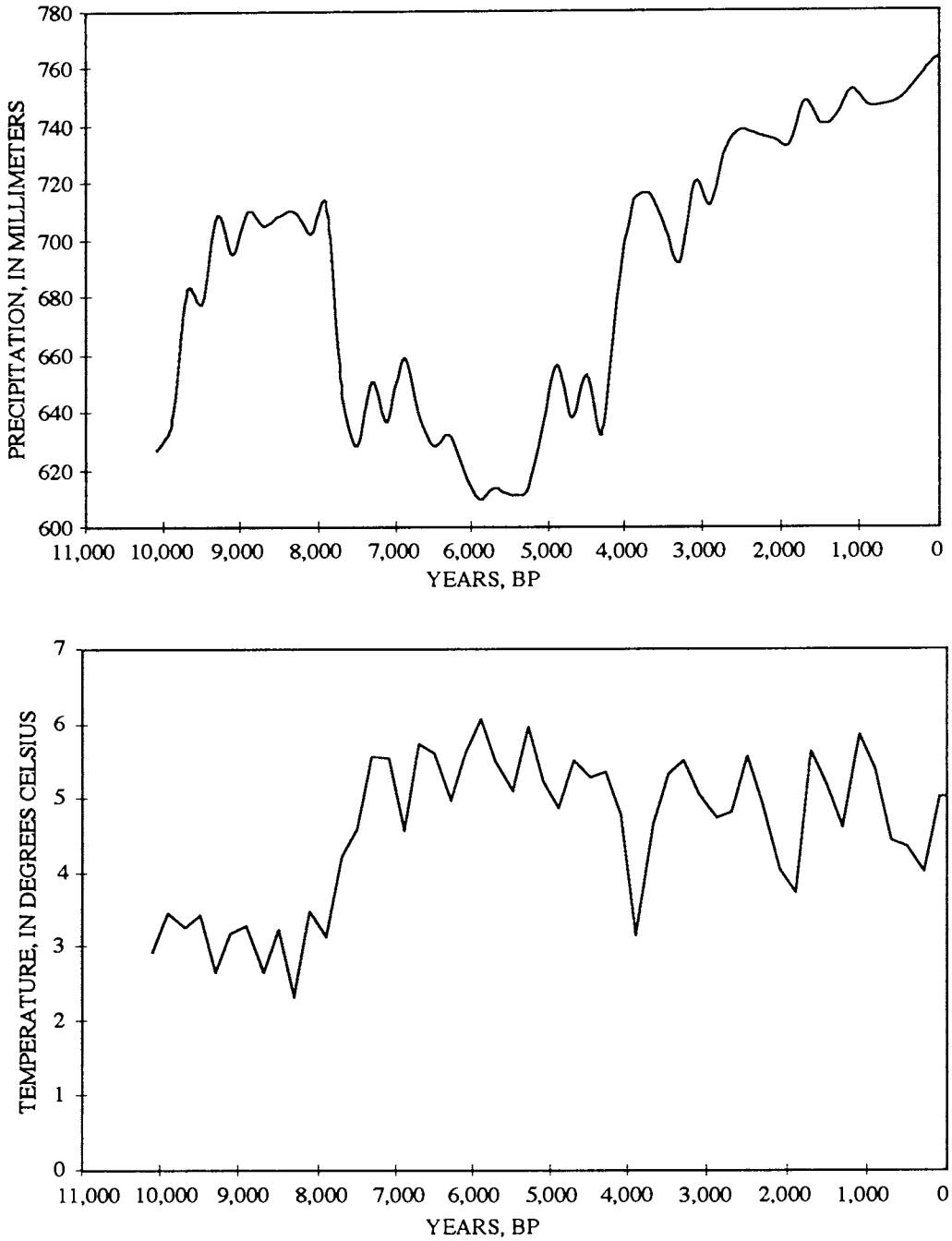


Figure 49. Modeled Holocene precipitation and temperature for the Ashland Experimental Farm, Ashland Junction, Wis. based on results from a macrophysical paleoclimate model (Bryson and Bryson, 1995).

wastage of the Laurentide Ice Sheet and to the strengthening of summer seasonal solar radiation. These changes favored a strengthening of northwesterly air flow over northern Wisconsin and a drying of the climate (Bartlein and Whitlock, 1993; Kutzbach, 1987; Webb and Bryson, 1972; Wright, 1992). The macrophysical paleoclimate model for Ashland Junction, Wis. shows cool, moist conditions from 10,000 to 8,000 ^{14}C yr B.P., followed by warmer and drier conditions between 8,000 and 6,500 ^{14}C yr B.P. (fig. 49). However, the early Holocene may have been slightly drier (about 7 percent less precipitation) than present conditions (fig. 49).

From about 10,000 to 9,000 ^{14}C yr B.P., boreal forest (spruce plentiful) was replaced by jack pine and northern conifer or mixed conifer/deciduous forest (pine plentiful) in northern Wisconsin and central Minnesota (Winkler, 1996; Bartlein and Whitlock, 1993). A maximum of elm pollen was observed in western Lake Superior cores from about 9,000 to 10,000 ^{14}C yr B.P. and an increase of white pine pollen was observed at 8,500 ^{14}C yr B.P. (Maher (1977). Increased deciduous forest development in northern Michigan between 7,000 and 5,000 ^{14}C yr B.P. suggests a drier climate than prior to 7,000 ^{14}C yr B.P. (Brubaker, 1975).

The macrophysical paleoclimate model for Ashland Junction, Wis., simulated warm and dry conditions from approximately 7,900 to 3,900 ^{14}C yr B.P. (fig. 49); however, warm and moist conditions from about 6,000 to 4,000 ^{14}C yr B.P. are inferred from pollen data from northern Wisconsin, Minnesota, and Michigan (fig. 47) (Winkler, 1996, Winkler and Sanford, 1997; Brubaker, 1975; Bartlein and Whitlock, 1993). Warm and moist conditions from about 6,500 to 3,500 ^{14}C yr B.P. were inferred from pollen data from northern Minnesota (Winkler and Sanford, 1997), and wetter conditions from about 5,500 to 4,800 ^{14}C yr B.P. also were inferred from pollen and varve data from a lake in central Minnesota (Bartlein and Whitlock, 1993). Bog expansion and cooler, moister conditions from about 6,000 to 4,000 ^{14}C yr B.P. also were inferred from pollen data from two lakes in north central Wisconsin (Winkler, 1996). Moister conditions after 5,000 ^{14}C yr B.P. were also inferred from pollen data in lakes in north central upper Michigan (Brubaker, 1975).

The late Holocene in northern Wisconsin is characterized by a seasonal distribution of solar radiation that gradually approaches current conditions, thus resulting in climatic conditions cooler than during the middle Holocene (fig. 47) (Bartlein and Whitlock, 1993). Data

from cores from Minnesota and northern Wisconsin show increased dominance of boreal forest in the region during the late Holocene and spruce increased on Stockton Island during the past 2,000 years (fig. 48) (Gajewski, 1987; Swain and Winkler, 1983). These changes in climatic conditions are thought to be local manifestations of a long-term increase in the effects of arctic air masses to produce cooling of the region (Gajewski, 1987; Wright, 1992). Fire frequency also appears to have dropped during the last 1000 years, especially during the last 500 years (Swain, 1973). The late Holocene (3,900 ^{14}C yr B.P. to present) was characterized by the macrophysical paleoclimate model to possibly have a steady increase in precipitation (fig. 49).

Macrofossil data from Hells Kitchen Lake in northern Wisconsin (Swain, 1978) (fig. 48) indicate the presence of two relatively dry periods among three relatively moist periods over the last 2,000 years. The Little Ice Age is represented by a dominance of white pine and birch with cooler and more moist conditions (fig. 48). Human disturbance in the vegetation distribution is noted in most cores as starting at about 150 years ago (fig. 48) and consists of decreases in white Pine and hemlock and increases in ragweed and other herbaceous species (Gajewski and others, 1985; Swain, 1978; and Winkler, 1996; Winkler and Sanford, 1997).

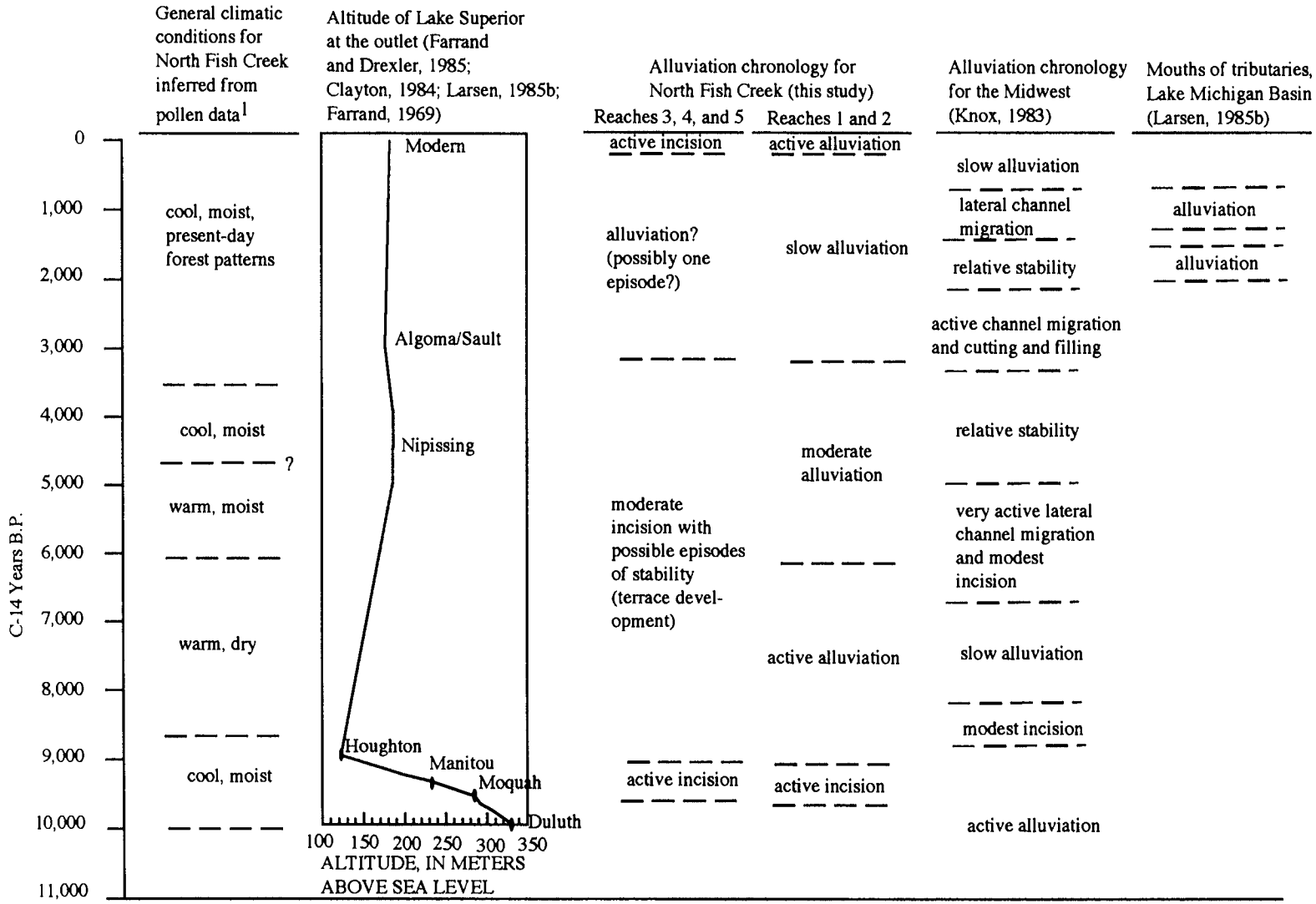
Base Level

The base level of North Fish Creek is controlled by the water level of Lake Superior, which throughout the Holocene has been controlled by a complex interaction among receding glaciers, meltwater inputs, isostatic rebound, and lake outlet erosion. While receding glaciers and meltwater inputs dominated base level fluctuations during the early Holocene, differential isostatic rebound and erosion of lake outlets became more important factors as lake levels stabilized and glaciers retreated out of the Lake Superior basin into northern Canada (Teller, 1985, 1987). Meltwater from Lake Agassiz entered the Lake Superior basin from about 11,300 ^{14}C yr B.P. to 9,900 ^{14}C yr B.P., and after the retreat of the Marquette glacial advance from about 9,800 to 8,500 ^{14}C yr B.P. (Teller, 1987; Colman and others, 1994). Gray silty clay was deposited in Lake Superior during these events. The color contrasts with the red clay derived from more local sources during other time periods (Colman and others, 1994).

Leverett (1929) first identified multiple shorelines along Lake Superior. Since then, Farrand (1969), Farrand and Drexler (1985), Clayton (1984), Teller (1987), Larsen (1985a, 1985b, 1996), and Phillips (1994) refined the lake level history based on radiocarbon ages of shoreline features. The following summarizes their work. Approximate Holocene lake level altitudes at the outlet are shown in figure 50. After the retreat of the Marquette Lobe at about 9,800 ^{14}C yr B.P., levels of Lake Superior quickly decreased from a Duluth level at about 330 m[1] to a sub-Duluth level of 307 m. The levels of Lake Superior continued to decrease as isostatically depressed eastern and southern outlets incised. Several intermediate lake levels formed between about 9,800 and 9,700 ^{14}C yr B.P: (1) the Highbridge at about 291 m, (2) the Moquah at about 285 m, (3) the Washburn at about 260 m, (4) the Manitou at about 233 m, and (5) the Beaver Bay at 198 m. The lake level continued to drop to the extreme low level called Lake Houghton at about 9,000 ^{14}C yr B.P., which was approximately 60 m below the present level of Lake Superior. Between 5,000 and 2,100 years ago, Lake Superior, with Lakes Michigan and Huron, formed one waterbody (Larsen, 1996), which was controlled by the outlet of Lake Huron at Port Huron, Mich. As the outlet rose from isostatic rebound coupled with moister climatic conditions, the lake level rose to the Nipissing high of about 186 to 187 m from about 5,500 to 3,800 ^{14}C yr B.P (Larsen, 1985a). A slight decrease to the Algoma level at about 183 m occurred between about 3,800 ^{14}C yr B.P. and 2,500 ^{14}C yr B.P. as a result of further downcutting of the Port Huron outlet (Farrand, 1969), or from drier climatic conditions (Larsen, 1985a). Farrand's (1969) work also showed a low lake level, the Sault level, at about 2,200 years B.P. The Sault and Algoma levels probably represent the same lake level. After 2,100 ^{14}C yr B.P., Lake Superior functioned independently (Larsen, 1996, 1985b) because of the emergence of a bedrock sill at Sault Ste. Marie due to isostatic rebound (Farrand and Drexler, 1985). The sill continues to separate Lake Superior from Lake Huron.

Since the mid-Holocene, isostatic rebound in the Lake Superior region has occurred at a greater rate in the northeastern sector than the southwestern sector, causing a relative rise of land elevation for the northeastern shore of the lake relative to the southwest (Larsen, 1991,

[1]Altitudes are based on the National Geodetic Vertical Datum of 1929 (NVGD of 1929) and are given in meters above sea level.



[1]Winkler and Sanford (1997), Winkler (1996), Brubaker (1975), Bartlein and Whitlock (1993).

Figure 50. Diagram comparing Holocene alluvial chronology for the Midwest, general Holocene climatic reconstruction for North Fish Creek, and Holocene altitudes of Lake Superior for the Chequamegon Bay area.

1994). Several Holocene shorelines located between the Highbridge and Nipissing levels are beneath the present level of Lake Superior in the western area, while in the east they are above the present level of Lake Superior due to the region's differential rates of isostatic rebound. A relative downward isostatic adjustment rate of 21 cm per century has caused a relative rise for Lake Superior in the Ashland area (Larsen, 1994; Farrand and Drexler, 1985; Coordinating Committee on Great Lake Basic Hydraulic and Hydrologic Data, 1977). This rate appears to have remained nearly constant for the last 4,000 years (Larsen, 1994).

Adjusting elevations based on a lake level rise of 21 cm/century, the Nipissing level occurs about 2.5 m below the present level of Superior in the Chequamegon Bay area (Bona, 1990). The Algoma/Sault level is about 5 m below the present level of Lake Superior (Bona, 1990).

Larsen (1985a, 1985b) suggests that changes in climatic conditions contributed to Nipissing, Algoma, and other late Holocene lake-level fluctuations of the upper Great Lakes, resulting in slightly higher lake levels during cool, moist periods and lower levels during warm, dry periods. These fluctuations varied by as much as 2 m from the present level of Lake Michigan and resulted in aggradation of stream-mouth alluvial fills during high levels and formation of peat deposits in lakeshore marshes during low levels. Although this level of detail is not available of Lake Superior, it is possible that 2-m variations in the level of Lake Superior also occurred during the late Holocene in response to changes in climatic conditions. Stratigraphic evidence of these variations may be superimposed on the gradual relative rise in the Chequamegon Bay area lake level related to differential isostatic rebound.

Holocene Alluvial Chronology for Midwest Streams

Although no data are available for Holocene alluvial changes for tributaries to Lake Superior in northern Wisconsin, data on channel change are available for Midwest streams (Knox, 1983; Larsen, 1985b). Also, Holocene flood frequencies and magnitudes for tributaries of the upper Mississippi River have been documented (Knox, 1985, 1995). Knox (1983) suggests a general correspondence between alluvial episodes and major climatic discontinuities. Because

of differences in large-scale atmospheric circulation patterns, cool and moist conditions during the early Holocene were much different than cool and moist conditions during the late Holocene and the differences contributed to different fluvial responses (Knox, 1983). The early Holocene is characterized in many regions of the U.S. by alluviation with some incision from 7,500 to 8,000 ^{14}C yr B.P. (fig. 50). The mid-Holocene is characterized by large floods in Mississippi River tributaries, and by active lateral channel migration and modest incision on many Midwest streams. The late Holocene is characterized by episodes of active lateral channel migration, stability, and some alluviation; and both large and small floods (Knox, 1983, 1985, 1995).

Western Iowa streams also experienced several episodes of entrenchment and aggradation during the Holocene (Bettis, 1990). Timing and length of the episodes depended on the location of the streams within the drainage network. For example, episodic erosion from 7,000 to 4,000 ^{14}C yr B.P. in second- and third-order streams resulted in aggradation and fan building downstream on larger order streams during the same time period (Bettis, 1990, p. 14). Thus, geomorphic response to changes in climate appear to be related to the stream's size and location within a drainage network.

For tributaries to Lakes Michigan and Huron, alluviation was common from about 1,600 to 1,200 ^{14}C yr B.P., and 950-700 ^{14}C yr B.P. (Larsen, 1985b). More recent stratigraphic data for a Lake Michigan tributary near Sheboygan, Wis., also suggest aggradation occurred at the mouth after 2,000 ^{14}C yr B.P. (Kiesel, 1998).

Holocene History of Degradation and Aggradation in North Fish Creek

The history of channel aggradation and degradation along the mainstem of North Fish Creek and Fish Creek Slough is summarized in figure 51. This figure shows the elevation of the 1995 channel bed in relation to channel bed elevations in the past. Age of the channel is based mainly on radiocarbon dating of wood samples from channel fill or overbank deposits. In reaches 4 and 5, radiocarbon ages were not available for some of the relict channels and their relative age is estimated from stratigraphic position and from development of soil horizons.

Holocene longitudinal profiles for North Fish Creek also were reconstructed from radiocarbon ages of relict channels, terrace and floodplain stratigraphy, and development of soil horizons (fig. 52).

In reaches 4 and 5, the mainstem of North Fish Creek flows on glacial deposits, indicating the present channel has eroded to its maximum extent throughout the Holocene. A valley cross section in reach 5 (fig. 18) indicates the presence of at least five terraces. These have been numbered as 1 at the lowest elevation above the floodplain and 5 at the highest (figs. 19 and 51). Terrace 5 also is the highest terrace mapped on soil surveys (U.S. Department of Agriculture, Soil Conservation Service, 1978), and is about 15 m below the upland surface at this site.

Cores taken on the surface of terraces 4 and 5 at the Moore site indicate that there is potentially a large time difference in the two because terrace 5 is characterized by a well-developed spodosol (Vilas loamy sand), whereas terrace 4 has soil only with A horizon development (most likely a sandy udorthent based on a soil survey report of the Fish Creek basin (U.S. Department of Agriculture, Soil Conservation Service, 1978)). It may take about 3,000 to 4,000 years for a spodosol to develop in the Great Lakes region (Barrett and Schaetzl, 1992, 1993). An impenetrable gravel layer was encountered at 1 m depth in terrace 5 and at 3 m depth in terrace 4. The stratified fining-upward sequences of sand and gravel in these cores are interpreted to be fluvial deposits from North Fish Creek. It cannot be totally ruled out that they alternatively might be meltwater fluvial deposits associated with pre-Holocene glacial activity. If these deposits are indeed derived from Holocene alluvium of North Fish Creek, they indicate that at least one episode of aggradation between downcutting episodes occurred during the early Holocene.

The surfaces of terraces 1, 2, and 3 occur above the channel lag deposit identified in terrace 4. The channel lag deposit in terrace 4 corresponds with the channel elevation in prior to the 1946 flood event (fig. 51). Thus, although exact dates of the episodes cannot be specified, stratigraphic evidence from the Moore sites indicate a cut and fill sequence represented by: an initial cut of about 20 m (early Holocene?), stability (surface of terrace 5 is floodplain), cut of

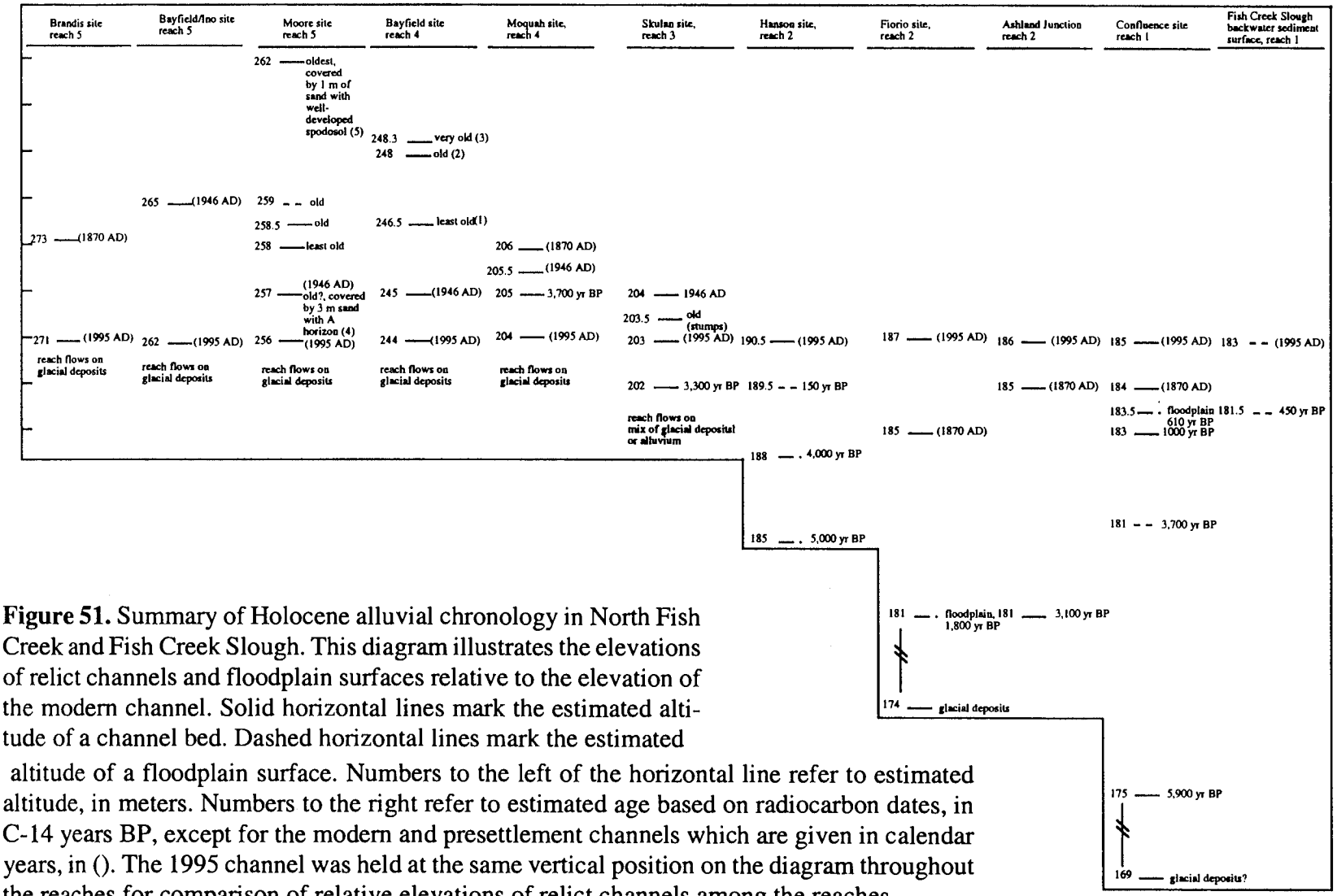


Figure 51. Summary of Holocene alluvial chronology in North Fish Creek and Fish Creek Slough. This diagram illustrates the elevations of relict channels and floodplain surfaces relative to the elevation of the modern channel. Solid horizontal lines mark the estimated altitude of a channel bed. Dashed horizontal lines mark the estimated altitude of a floodplain surface. Numbers to the left of the horizontal line refer to estimated altitude, in meters. Numbers to the right refer to estimated age based on radiocarbon dates, in C-14 years BP, except for the modern and presettlement channels which are given in calendar years, in (). The 1995 channel was held at the same vertical position on the diagram throughout the reaches for comparison of relative elevations of relict channels among the reaches.

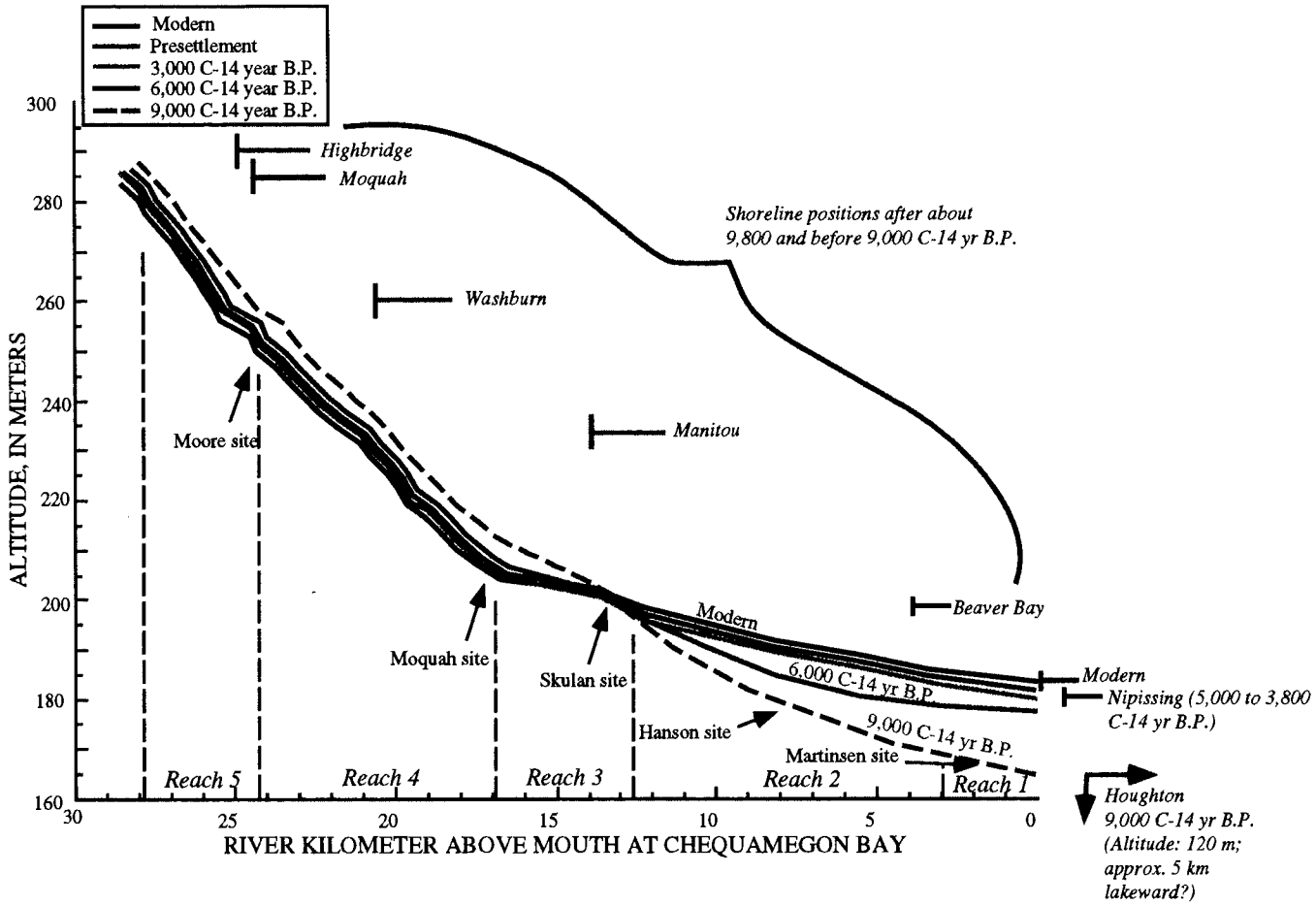


Figure 52. Estimated Holocene longitudinal profiles for North Fish Creek. Holocene levels of Lake Superior are shown in blue

5 m (transition from early/middle Holocene?), fill of about 3 m (terrace 4), cut of 1 m (terrace 3), cut of 0.5 m (terrace 2), cut of 0.5 m (1870 AD?) (terrace 1), cut of 1 m (1946 AD channel), and cut of 1 m (1995 AD channel).

In reach 4, there is evidence for an older channel at the Moquah site (fig. 22). The relict channel is approximately 1 m above the current channel position. The radiocarbon age of the relict channel is about 3,700 ^{14}C yr B.P. (fig. 51) based on the radiocarbon age of wood collected from the wood-rich deposit filling the channel. The elevation of this channel may correspond to the channel elevation underlying terrace 4 at the Moore site since they are both at the same height above the modern channel bed. The age of 3,700 ^{14}C yr B.P. corresponds with the relative post-Nipissing low lake level (fig. 50) if the differential isostatic rebound rate is assumed to be constant after about 4,000 ^{14}C yr B.P. and if absolute lake levels have not varied by more than 2 m. The pre-settlement channel elevation is above this elevation, indicating a fill event occurred between approximately 3,700 ^{14}C yr B.P. and 1870 AD. Based on the macrophysical paleoclimate model (fig. 50) 3,700 ^{14}C yr B.P. also corresponds to a shift from dry to moist conditions, whereas regional pollen data suggest a change from warm and moist to cool and moist conditions (Winkler and Sanford, 1997; Winkler, 1996; and Brubaker, 1975).

Stratigraphic evidence of episodic variations in rates of overbank sand, silt, and clay deposition in reach 4 also were observed in several exposures at the Moquah site (fig. 22). Occasional charcoal also was present in the fluvial deposits prior to European settlement. For example, in exposure E-8, approximately 1.5 m of interbedded sand and clay, with occasional charcoal, is found between a middle/late Holocene channel sequence and an unknown late Holocene channel deposit occurs above it. However, no charcoal was observed in the overbank deposits between the channel deposit and the terrace surface. Although limited, these data support Swain's (1973,1978) findings of alternating drier and moister periods during the late Holocene, with the most moist conditions occurring during the Little Ice Age and coinciding with less fire activity.

In reach 3, data from the Skulan site (figs. 27 and 30) indicate that a relict channel with a radiocarbon age of about 3,300 ^{14}C yr B.P. is located about 2 m below the elevation of the present channel bed. This relict channel may be the same as that dated in reach 4 at 3,700 ^{14}C

yr B.P. These channels indicate a cutting episode occurred when base level at the mouth was lowered and perhaps when climate was shifting from warm and moist to cool and moist (less evapotranspiration and greater runoff). The pre-settlement channel elevation is 2 m above this level, indicating that, similar to reach 5, a fill episode occurred sometime after 3,200 ^{14}C yr B.P.

At the Skulan site, more evidence for episodic flooding and overbank sand deposition was observed from stratigraphic evidence in cut bank exposures. For example two sand units are found between organic debris layers with ages of 280 and 420 ^{14}C yr B.P. (fig. 27). Core C-24 near the Skulan site also shows evidence of episodic overbank deposition and the presence of charcoal deposition between about 3,300 ^{14}C yr B.P. and 1870 AD (fig. 30).

In reach 2, evidence of older channel elevations are found below the present channel bed instead of above it in cores VC-3, C-168, VC-5, and VC-6 at the Hanson site (fig.34). These multiple buried channels occur from about 1 to 4.5 m below the present channel bed. More detailed interpretation of the ages and relations among the channels is awaiting results from radiocarbon analysis.

Although sediment in core VC-8 is limited to silt and clay, pulses of silty clay bounded by material with more organic debris point to episodic events of overbank sedimentation bounded by stable periods which allowed organic debris to accumulate on the floodplain surface. Two wood samples from core VC-8 have radiocarbon ages of about 4,000 ^{14}C yr B.P at about 2 m below the present channel bed, and 5,000 ^{14}C yr B.P at about 5.5 m below the present channel bed. Macrofossil samples from core VC-8 at 0.3, 3.7 and 6.4 m in depth (Appendix C) indicate the presence of a northern wet to wet/mesic floodplain forest at this site throughout the middle and late Holocene. Although data are limited, elm, alder, and balsam fir dominated the macrofossil remains at 5,000 ^{14}C yr B.P. (Appendix C).

At the Fiorio and Ashland Junction sites along reach 2 (figs.37 and 40, respectively), there is limited evidence for minor channel degradation and most evidence indicates progressive aggradation over the last 3,000 years (fig. 51). A relict channel at the Ashland Junction site was has a radiocarbon age of about 3,100 ^{14}C yr B.P., and the channel occurs at a similar elevation to the floodplain level at the Fiorio site at about 1,800 ^{14}C yr B.P (core G-1). This may indicate

that geomorphic conditions were stable from about 2,000 to 3,000 ^{14}C yr B.P., or that a fill and cut sequence occurred during this time period. Other streams in the Midwest were either experiencing cutting and filling during the same time period (Knox, 1983) (fig. 50) and tributary mouths to Lake Michigan may have been degrading (Kiesel, 1998). During this time period, Lakes Michigan and Superior functioned as one waterbody because the bedrock sill at Sault Ste. Marie had not rebounded sufficiently to separate the two lakes (Larsen, 1986). Thus, if differences exist in the alluvial chronology of the tributaries to Lakes Michigan and Superior it may be caused by local differences in climatic conditions of the watersheds rather than base level fluctuations because base level fluctuations should be similar in both lakes.

At the Fiorio site, glacial till occurs 7 m below the elevation of the relict channel in G-1 (fig.37) representing the maximum extent of Holocene stream incision at this site and this deep incision probably corresponds to the very low lake levels immediately following deglaciation. These sites are only 1 km upstream from Chequamegon Bay and the valley could be as deep as 120 m if it were able to erode to base level. Currently, the modern channel is 3 to 4 m above the average level of Lake Superior (183 m asl).

Radiocarbon ages and stratigraphic data from the confluence site (fig. 41) indicate that the channel bed elevation immediately preceding the Nipissing lake level rise was approximately 14 m below the Nipissing lake level (189.5 m) at an elevation of 175 m (fig. 51). By about 3,700 ^{14}C yr B.P., the channel mouth had aggraded to 181 m, which was still about 9 m below the Nipissing level but above the probable 4,000 ^{14}C yr B.P. low lake level of 175 m. The core data were too sparse to provide evidence for an episode of cutting and filling at the mouth that may have occurred because of the fall and subsequent rise in lake level following the Nipissing high.

Evidence of episodic floodplain sedimentation events during the last 1,000 years also can be inferred from core G-7 at the confluence of North and South Fish Creek. For example, between 950 and 600 ^{14}C yr B.P., mainly organic-rich silt and clay dominate the sedimentary sequence. The high organic content indicates the presence of a stable floodplain surface where accumulation of organic debris was able to keep up with overbank mineral sedimentation. The period from 900 to 600 ^{14}C yr B.P. corresponds to a dry period in northern Wisconsin, as evi-

denced by macrofossil data from northern Wisconsin (Swain, 1978). The rate of floodplain sedimentation increased significantly after about 600 ^{14}C yr B.P., suggesting some type of disturbance event occurred in the upstream areas. This disturbance event may have occurred during a minor transition from dry to moist conditions.

Radiocarbon ages of stratigraphic units in Fish Creek Slough reflect the elevation of sediment in backwater areas and not the elevation of the channel bed of Fish Creek. Presently, the channel bed of Fish Creek is about 0.5 m below the active floodplain surface in backwater areas (fig. 42). Core P-19 contains an example of the stratigraphic sequence that occurred in backwater areas of Fish Creek Slough (fig. 53). As mentioned earlier, before the onset of human activity, organic material made up a large percentage of the stratigraphic record from 0.45 to 2.05 m in depth in core P-19. Prior to 1870 AD, presettlement vegetation at the site was most similar to a fen wetland, with larch, willow, and alder and floodplain sedimentation consisted of mainly clay (Appendix D). Below 1.5 m in depth, the texture of sediment in the core is more silty. This occurred prior to about 450 ^{14}C yr B.P. Analyses of organic material at 2 m depth below the floodplain surface indicate sparse macrofossils, although sedge species appear to dominate. Below 2 m in depth, the silty sediment contains less organic debris. Between 2.45 and 2.75 m in depth, the amount of organic debris increases and the sediment is more clayey. Macrofossil analyses indicate that water depths may have been as much as 2 to 3 meters, and vegetation is representative of an aquatic marsh, with abundant *Eleocharis palustris* (Appendix C). The macrofossil and stratigraphic evidence suggests that the sediment between 2.45 and 2.75 m in depth may correlate to the Nipissing lake level high. Between 2.75 and 3.1 m very little organic debris was present in the core. The lack of organic debris suggests more rapid sedimentation rates and may reflect more rapid aggradation coinciding with the Nipissing lake level rise, or possibly a change in climatic conditions from dry to moist preceding the Nipissing high. Additional interpretations will follow after more radiocarbon results are obtained.

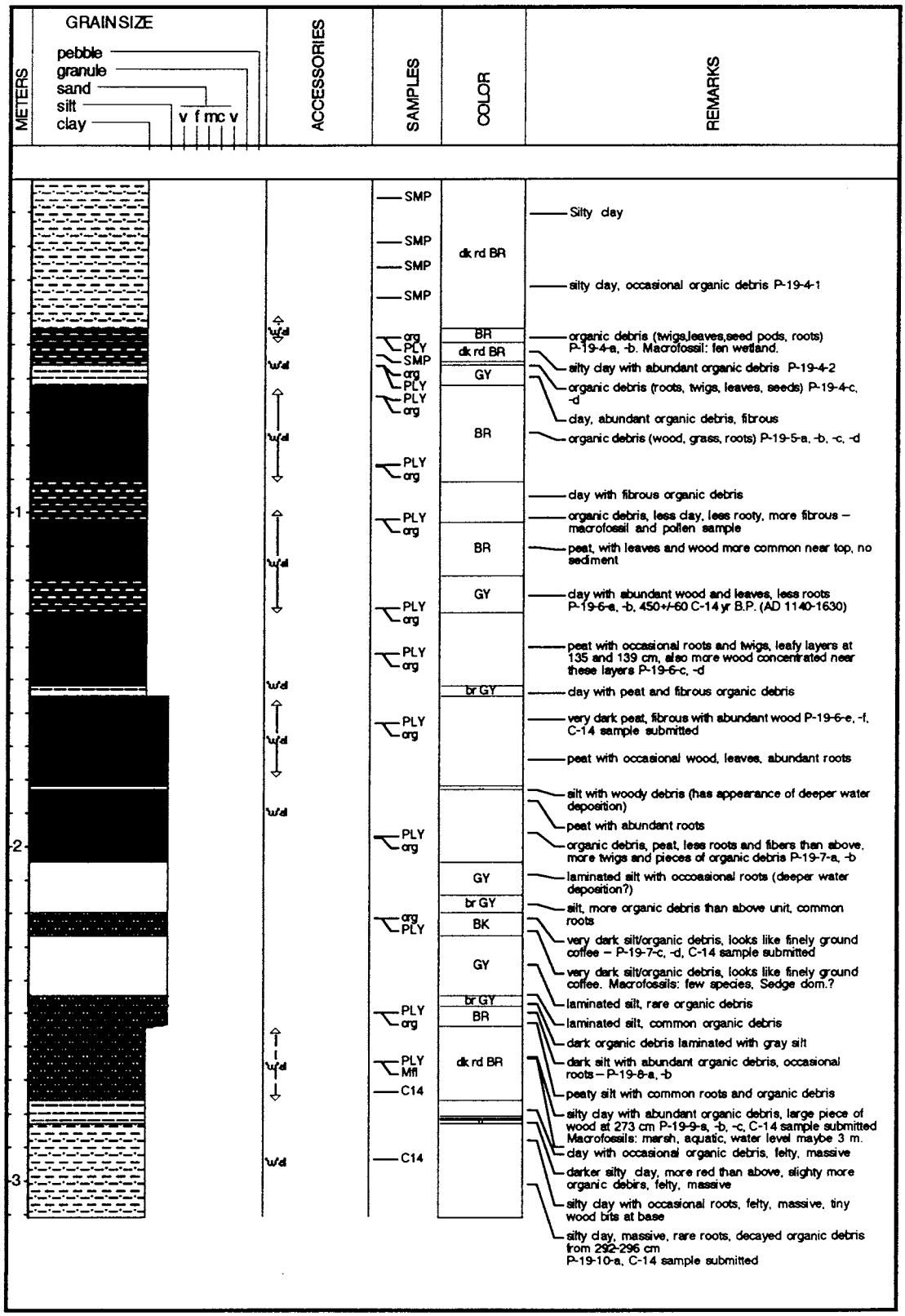


Figure 53. Detailed stratigraphic description of core P-19, Fish Creek Slough backwater.

Conclusions

Radiocarbon ages from floodplain and channel deposits of North Fish Creek suggest that cut and fill episodes in the middle and late Holocene are related to both climate and base-level change. However, whether the response was degradation or aggradation depended on location along mainstem. Differences in temporal patterns of degradation and aggradation along the mainstem throughout the middle to late Holocene can be categorized by the current reach boundaries, which are based on gradient and location within the drainage network. These findings are similar to those found by Bettis (1990) and Schumm and Brakenridge (1987), which emphasize that location in the drainage network is a critical factor when comparing alluvial chronologies among different streams.

Prior to European settlement, the main geomorphic change observed in the floodplain stratigraphic record marks the transition from the middle to late Holocene at about 3,000 to 4,000 years ago. Prior or at about 4,000 ^{14}C yr B.P., the upper mainstem channel (river kilometer 17 to 28) degraded to just above the1995 AD channel position, and just below the 1995 AD channel position from river kilometer 12 to 17. After about 3,000 ^{14}C yr B.P., aggradation dominated the Holocene alluvial record along the upper and middle mainstem (river kilometer 12 to 28) during the rest of the Holocene until 1870 AD when human-induced degradation began. The changes from degradational to aggradational conditions most likely was caused by changes in climatic conditions, although base level also dropped about 3 m during the same time period (Algoma level). In general the climate was cool and moist and approaching present-day conditions from 4,000 to 3,000 years ago, based on previous climatic reconstructions for the region based on pollen data. However, if Larsen (1985a) is correct in his proposal that Nipissing and Algoma lake levels were controlled by climatic conditions, about a 3-meter drop from the Nipissing to Algoma level from about 3,800 to 2,500 ^{14}C yr B.P. suggests that the upper mainstem of North Fish Creek changed from degradational to aggradational conditions at the same time that climatic conditions became drier.

In reaches 1 and 2, aggradation seems to have dominated the stratigraphic record throughout the middle and late Holocene, although minor episodes of cut and fill probably are superimposed on this trend (fig. 52). Sedimentation and organic accumulation rates in the backwater areas of Fish Creek Slough are mainly affected by changes in the level of Lake Superior; however, episodes of increased sedimentation rates during the late Holocene also probably represent responses to upstream degradation following certain changes of climate.

Climate reconstructions based on the pollen record and the macrophysical paleoclimate model for Ashland Junction, Wis., were in agreement for the early and late Holocene, but resulted in different moisture conditions for the middle Holocene. The macrophysical paleoclimate model indicate warm and dry conditions from approximately 7,900 to 3,900 ^{14}C yr B.P. (fig. 49), whereas the pollen data suggest warm and moist conditions from about 6,000 to 4,000 ^{14}C yr B.P. (fig. 47) (Winkler, 1996, Winkler and Sanford, 1997; Brubaker, 1975; Bartlein and Whitlock, 1993). The Nipissing high level of Lake Superior falls within this same time interval, which also suggests that climatic conditions were generally more moist from about 6,000 to 4,000 ^{14}C yr B.P. Thus, the pollen data may be more representative of climatic conditions from about 6,000 to 4,000 ^{14}C yr B.P. than the macrophysical paleoclimate model.

The occurrence of charcoal in fluvial deposits is not limited to post-settlement time, but was commonly found in pre-settlement floodplain and channel deposits. This suggests that fires occurred episodically prior to European settlement. Limited evidence suggests there was more charcoal around 3,000 years ago than prior to European settlement; however, exact dates cannot be distinguished.

Episodes of accelerated transport and deposition of sand in channels and floodplains are not limited to post-settlement conditions, but also occurred during the Holocene along the entire mainstem in all reaches. These data suggest that large destructive floods are commonly a product of unique climatic conditions and have been responsible for episodic overbank sedimentation of sand, silt, and clay. These data support the findings of Patton and Baker (1977) and Hack and Goodlett (1966), that also point to large, infrequent precipitation events as instigators of episodic geomorphic change.

Based on very limited macrofossil data, there is no evidence from this study suggesting that changes in floodplain vegetation occurred along the mainstem during the middle to late Holocene. However, changes in vegetation of Fish Creek Slough from aquatic to wetland and terrestrial species did occur during the late Holocene, and are interpreted to be caused by fluctuations in level of Lake Superior.

CHAPTER 5

GEOMORPHIC AND HYDROLOGIC RESPONSES OF NORTH FISH CREEK TO DISTURBANCE FACTORS

Following European settlement of the North Fish Creek basin, the geomorphic data from North Fish Creek suggest that large floods are needed to produce macroscopic geomorphic change, even though changes in vegetation may have occurred decades earlier. For example, large rain storms clustered in the late 40's and early 1950's resulted in major geomorphic change, even though the land was cleared over 50 years earlier. Based on the photo sequence of North Fish Creek at Ashland Junction in the late 1800's, streambanks appeared to heal quickly from log drives, with banks filling in after log drives ceased.

Geomorphic change was accelerated by human impacts on vegetation in the drainage basin of North Fish Creek; however, a study of the Indian River about 250 km east of North Fish Creek in the upper peninsula of Michigan did not come to the same conclusion (Benchley and others, 1993). The main difference between this stream and North Fish Creek is that the Indian River drains mainly sandy deposits with high infiltration rates. However, no obvious geomorphic changes were observed to be caused by logging or from the construction of several dams along the stream. Nor was there any evidence of geomorphic change during the Holocene, except following deglaciation (Benchley and others, 1993). In addition, another investigation concluded that agricultural activity was not a major cause of sedimentation in streams draining clayey deposits in northern Wisconsin (Red Clay Interagency Committee, 1967). Their conclusion probably reflects the tendency for the amount of sediment contributed to the stream from upland areas to be much less than that contributed by streambank and bluff erosion. However, the Red Clay Interagency Committee fell short of recognizing the increased erosion potential of streambanks caused by the increase in runoff from agricultural areas compared to forested areas. Results of the modeling work in this study show that agricultural land in North Fish Creek significantly contributes more runoff than forested land contributes, resulting in a greater potential for streambank and gully erosion. Thus, agricultural activity is undoubtedly an indirect cause of accelerated streambank erosion and downstream sedimentation in these stream systems.

Proceeding downstream in the drainage network for different age channels (figs. 51 and 52), an interesting feature about gradient becomes apparent. In reach 5, the 1946 channel was 3 m above the current channel, compared to about 1 m in reach 3. Thus, the most degradation due to historical vegetation change appears to have taken place in reach 5. This suggests that in the degradational reaches, the overall mainstem gradient along the degradational reaches of 3, 4, and 5 in 1995 is less steep than in 1946 or prior to European settlement.

The effects of climate on the geomorphic response of North Fish Creek occur at two scales. During the historical period, vegetation changes from human activity resulted in increased runoff; however, degradation in the upper mainstem and aggradation near the mouth was accelerated by high magnitude floods caused by infrequent large summer rain storms. For the Holocene, the scale of climate influence shifts from evidence of episodic precipitation events to regional changes in climatic conditions. This is not to say that large floods were less important, it just becomes more difficult to exactly identify and date the occurrence of such events for climatic conditions farther back in time. Thus, for reaches 3, 4, and 5, a climatic cause is inferred from degradation at the middle to late Holocene transition, although conditions in reach 3 probably were responding to both climate and base level changes.

Changes in climatic conditions as significant influences on the geomorphology and hydrology of North Fish Creek also are indicated by the frequency of charcoal in alluvial sediments. For example, the low frequency of charcoal for sediment with ages between 1,000 and 2,000 ^{14}C yr B.P. is consistent with the idea that cooler and wetter conditions probably suppressed frequencies of fires.

Comparisons between Holocene climate and base level changes for North Fish Creek (fig. 50) indicate the Nipissing high lake level (5,000 to 3,800 ^{14}C yr B.P.) overlaps with the climatic transition from warm and moist to cool and moist (about 4,000 ^{14}C yr B.P.). However, after the Nipissing high, base level was lowest during the middle to late Holocene when the channel in reach 3 and 4 also was at its lowest position, but limited evidence indicates no sign of downcutting at the mouth during this time. There is the possibility, however, that a cut and fill event was missed. With the present data in hand, degradation in reach 3 and 4 during the transition is thought to be caused by mainly climate change and not base-level change. At the

mouth of North Fish Creek, aggradation during the late Holocene appears to relate more to the influence of base level than to climate change, although episodic increases in sedimentation rates may reflect a degradation response to climate change upstream.

The steady increase in the level of Lake Superior relative to land surface from differential isostatic rebound is evidently causing a steady increase in the water table of Fish Creek Slough. These changes are subtle but evident over a 250 year period at least, based on historical accounts of land use by Native Americans in the mid 1700's compared to current vegetative cover (Thwaites, 1895; Pratt, 1981). Stratigraphic investigations from this study support the historical descriptions.

For minor 2-m fluctuations in the level of Lake Superior, either during the late Holocene or after European settlement, no geomorphic response was observable in North Fish Creek near the mouth or farther upstream. The rise in water table at the mouth from a steady increase in water levels of about 21 cm per century due to differential isostatic rebound undoubtedly has augmented sedimentation in lower Fish Creek, but the effects from isostasy could not be separated from the effects of human-induced vegetational changes from clear-cut logging and agriculture.

CHAPTER 6
CONCLUSIONS AND SUGGESTIONS FOR FUTURE WORK

The geomorphology and hydrology of North Fish Creek have been altered by human activity. Accelerated degradation in the upper mainstem and aggradation near the mouth have been mainly caused by increased runoff from agricultural land. The main sediment source is bluff erosion in the upper mainstem (reaches 4 and 5). Unfortunately, the direct effects from logging, burning, and log drives cannot be singled out from the immediately following effects of agricultural activity. In reaches 4 and 5, up to 3 m of channel erosion have occurred over the last 125 years. Channel erosion appears to be somewhat worse in reach 5 than in reach 4. Active channel capacity of the modern channel in reaches 3, 4, and 5 appears to be at least double the active channel capacity prior to 1946 AD. For example, in reach 3, about 1 m of degradation and up to 2 m of overbank sedimentation have resulted in a doubling of channel capacity. This provides a conduit for sediment to be routed more efficiently downstream and further compounds accelerated sedimentation problems observed in reaches 1 and 2.

In reaches 1 and 2, about 1 m of sand has been deposited in the channel and on the floodplain. In the process of degradation in the upper reaches and aggradation near the mouth, there has been an overall decrease in the gradient of the mainstem along its longitudinal profile. Based on GLO survey data, the character of the channel bottom has not changed significantly since the time of European settlement; thus, it is not known if this change in gradient has been large enough to affect streambed-sediment size.

Runoff and sediment yield modeling and geomorphic surveys indicate that land-use conditions in the 1930's caused a three-fold increase in peak flows and five-fold increase in sediment yield compared to peak flows and sediment yield from a completely forested drainage basin. Model results and field observations provide evidence for a decrease in floodplain sedimentation for recent years in reach 2. This reduction appears to coincide with a decrease in agricultural activity in the drainage basin. Analysis of historical daily precipitation data suggests that climatic factors were not responsible for this decline.

Reconstructions of bankfull flows from relict channels suggest that channel capacities increased following the 1946 flood. Available data are inadequate to determine if recent declines in agriculture and maturing of forests are contributing to lessening magnitudes of bankfull flows.

During the past 6,000 years, variations in climate and base level have influenced North Fish Creek more than variations in vegetation. This is because the basin has been mainly forested during its post-glacial history. Destruction of the forest mainly was restricted to fire and windthrow activity during specific Holocene climatic conditions.

Episodic changes in rates of deposition of sand in the floodplain are not limited to post-settlement time, but also occur during natural conditions of the Holocene. The main geomorphic change observed in the floodplain stratigraphic record marks the transition from the middle to late Holocene in reaches 3, 4, and 5. During this time period, the channel degraded to just above (reaches 4 and 5) or below (reach 3) the 1995 AD channel position. Some time after 3,000 ^{14}C yr B.P., aggradation occurred in reach 3, possibly in response to continued degradation in reaches 4 and 5 and continued aggradation in reaches 1 and 2. During the late Holocene changes in base level appear to be the major influences on geomorphic conditions at the mouth of Fish Creek; however, climate-caused degradation in the upper reaches is observable as pulses of sediment delivered to the mouth.

Results from runoff modeling and sediment yields suggest that the addition of seven detention basins on tributaries to North Fish Creek have the potential to decrease annual sediment yields near Moquah, Wisconsin by about 350 to 450 tonnes (about 30 percent). Further refinement of the placement and design may improve their capability of lowering peak flows and reducing bluff and bank erosion. Because the detention basins empty in less than two days, negative impacts from warmer water inputs to North Fish Creek should be negligible.

In this study, a variety of coring devices were experimented with because the rough and forested terrain precluded use of traditional truck-mounted corers. Core samples collected with the Geoprobe were much more useful and easier to collect than vibracore samples. Both types of piston cores worked well in different settings of underwater environments. The modified

Livingston corer worked well only in fine sediment because sandy sediment caused the interior sleeve in the corer to lock up. Even though multiple cores were not possible with the WDNR piston corer, its simplified piston action allowed it to work well in sandy deposits.

As with most studies, interesting paths for additional research far exceeded time and funding confinements. For more details on the Holocene alluvial chronology and its relation to climate and base level fluctuations, deeper cores and more data on relict channel characteristics are needed from the floodplain of North Fish Creek and in backwater areas of Fish Creek Slough. Several additional valley cross sections in upper and lower reaches would have been helpful, too. More relict channels in all reaches should be sampled and dated. These are especially time consuming because many of the older channels are either under water, covered by sediment, or covered by thick vegetation. More effort also could be spent on examining terraces and deposits beneath them.

Geomorphic and hydrologic impacts of logging and log drives could not be separated from agricultural activity because agricultural activity immediately followed logging in the North Fish Creek basin. In order to address this issue, similar methods as those used in this study could be used on a stream that has been completely reforested.

It is possible that the modern organic layer in forested land may be quite a bit thinner than it was during presettlement time. This has implications for determining if hydrologic conditions in modern forests are similar to presettlement forests. For quantifying this hypothesis, upland soils from virgin and cut forests in the same geologic setting could be sampled.

REFERENCES CITED

Anderson, H.W., Hoover, M.D., and Reinhart, K.G., 1976, Forests and water: effects of forest management on floods, sedimentation, and water supply: USDA Forest Service General Technical Report PSW-18, 115 p.

Arnold, L.D., 1995, Conventional radiocarbon dating, *in* Rutter, N.W., and Catto, N.R., eds., Dating Methods for Quaternary Deposits: Geological Association of Canada, GEOtext2, p. 107–116.

Ashland-Bayfield Bicentennial Committee, 1976, Chequamegon—A pictorial history of the Lake Superior region of Ashland and Bayfield Counties: Park Falls, Wis., F.A. Weber and Sons, 48 p.

Baker, V.R., and Costa, J.E., 1987, Flood power, *in* Maher, L., and Nash, D., eds., Catastrophic flooding: Proceedings from the 18th Binghamton Symposium, Boston, Allen and Unwin, p. 1–21.

Banks, G. and Brooks, K., 1992, Erosion-sedimentation and nonpoint pollution in the Nemadji watershed: status of our knowledge, Appendix L, The St. Louis River system remedial action plan, Wisconsin Department of Natural Resources Report, 59 p.

Barnes, Harry H., Jr., 1967, Roughness characteristics of natural channels: U.S. Geological Survey Water-Supply Paper 1849, 213 p.

Barrett, L.R., and Schaetzl, R.J., 1992, An examination of podzolization near Lake Michigan using chronofunctions: Canadian Journal of Soil Science, v. 72, p. 527–541.

Barrett, L.R., and Schaetzl, R.J., 1993, Soil development and spatial variability on geomorphic surfaces of different ages: Physical Geography, v. 14, no. 1, p. 39–55.

Bartlein, P.J., and Whitlock, C., 1993, Paleoclimatic interpretations of the Elk Lake pollen record: *in* Bradbury, J.P., and Dean. W.E., eds., Elk Lake Minnesota: Evidence for rapid climate change in the north-central United States: Boulder, Colo., Geological Society of America Special Paper 276, p. 275–293.

Benchley, E.D., Copes, F.A., Kolb, M.F., Lasca, N.P., Porubcan, P.J., Schabel, M.J., and Whitman, L.G., 1993, Investigation of the influence of late 19th-early 20th century logging on fluvial geomorphology and fisheries habitat on the Indian River: University of Wisconsin-Milwaukee, Archaeological Research Laboratory Report of Investigations 118,

Benson, M.S., and Dalrymple, T., 1967, General field and office procedures for indirect discharge measurements: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 3, Ch. A1, 30 p.

Bettis, E.A., III, 1990, Holocene alluvial stratigraphy of western Iowa, *in* Bettis, E.A., III, ed., Holocene alluvial stratigraphy and selected aspects of the Quaternary history of western Iowa: Midwest Friends of the Pleistocene, 37th Field Conference, Field Guidebook, p. 1–16.

Blatt, H., Middleton, G., and Murray, R., 1980, Origin of sedimentary rocks: 2d Ed., Prentice-Hall, New Jersey, p. 55–66.

Birkeland, P.W., 1984, Soils and geomorphology: New York, Oxford University Press, p. 30-33.

Bona, L.J., 1990, Geomorphology and recent geologic history of Long Island, Apostle Islands National Lakeshore, Wisconsin: Master's Thesis, Geology Dept., University of Wiscon-

sin-Madison, 219 p.

Bonner, V.R., 1974, Water surface profile using the standard step method: U.S. Army Corps of Engineers, Hydrologic Engineering Center, unpublished lecture materials, Reference No. P-16, variable pagination.

Boss International, Inc., 1995, BOSS HEC-2 user's manual: Boss International, Madison, Wis., variable pagination.

Bowden, R.J., 1975, Wisconsin tributary loadings to the upper Great Lakes: U.S. Environmental Protection Agency, EPA-905/4-75-003, 59 p.

Bowman, Sheridan, 1990, Radiocarbon Dating—Interpreting the Past: London, British Museum Publications, Ltd., 64 p.

Brady, N.C., 1974, The nature and properties of soils, 8th ed., Mcmillan Publishing, New York, 639 p.

Brinkmann, W.A.R., 1983a, Association between net basin supplies to Lake Superior and supplies to the lower Great Lakes: Journal of Great Lakes Research, v. 9, no. 1, p. 32–39.

____1983b, Secular variations of surface temperature and precipitation pattern over the Great Lakes region: Journal of Climatology, v. 3, p. 167–177.

Brubaker, L.B., 1975, Postglacial forest patterns associated with till and outwash in northcentral Upper Michigan: Quaternary Research, v. 5, p. 499–527.

Bryson, R.A., 1988, Late Quaternary volcanic modulation of Milankovitch climate forcing: Theoretical and Applied Climatology, v. 39, p. 115–125.

Bryson, R.A. 1992, A macrophysical model of the Holocene intertropical convergence and jet-stream positions and rainfall for the Saharan Region: Meteor. and Atmos. Phys., v. 47, p. 247-258.

Bryson, R.A., and Bryson, R.U., 1995, An archaeoclimatology workbook—High-resolution, site-specific climate modeling for field scientists (version 1.1.4): Center for Climatic Research, University of Wisconsin, Madison, and the Department of Geology and Geophysics, University of Minnesota, variable pagination.

Bryson, R.A., and Goodman, B.M., 1986, Milankovitch and global ice volume simulation: Theoretical and Applied Climatology, v. 37, p. 22–28.

Burnham, G.M., 1929, The Lake Superior country in history and story: Boston, Mass., Chapple Publishing Co., Limited, 464 p.

Canham, C.D., and Loucks, O.L., 1984, Catastrophic windthrow in the presettlement forests of Wisconsin: Ecology, v. 65, p. 803–809.

Chesier, Rob, 1996, Sediment budgets—their preparation and use in watershed planning: Proceedings of the 6th Federal Interagency Sedimentation Conference, v. 2, March 10-14, 1996, Las Vegas, Nevada, p. X-22–X-29.

Chow, V.T., 1959, Open-channel hydraulics, McGraw-Hill, New York, 680 p.

Chow, V.T., 1964, Handbook of applied hydrology, a compendium of water-resources technology: McGraw-Hill, New York, variable pagination.

Clayton, Lee, 1984, Pleistocene geology of the Superior Region, Wisconsin: Wisconsin Geological and Natural History Survey Information Circular 46, 40 p.

Clayton, Lee, Attig, J.W., Mickelson, D.M., and Johnson, M.D., 1991, Glaciation of Wisconsin: Wisconsin Geological and Natural History Survey Educational Series 36, 4 p.

Colby, B.R., and Hembree, C.H., 1955, Computations of total sediment discharge, Niobrara River near Cody, Nebraska, U.S. Geological Survey Water-Supply Paper 1357, 187 p.

Colman, S.M., Keigwin, L.D., Forester, R.M., 1994, Two episodes of meltwater influx from glacial Lake Agassiz into the Lake Michigan basin and their climatic contrasts: Geology, v. 22, p. 547–550.

Coordinating Committee on Great Lake Basic Hydraulic and Hydrologic Data, 1977, Apparent vertical movement over the Great Lakes: Detroit District, United States Corps of Engineers, 70 p.

Curtis, J.T., 1959, The vegetation of Wisconsin: Madison, Wis., The University of Wisconsin Press, 657 p.

Davis, Mark, 1996, "Getting rid of the stumps": Wisconsin's land-clearing program—The experience of the northern lake country, 1900–1925: Transactions of the Wisconsin Academy of Sciences, Arts and Letters, v. 84, p. 11–22.

Davis, M.B., 1987, Invasions of forest communities during the Holocene: beech and hemlock in the Great Lakes Region: *in* Gray, A.J., Crawley, M.J., and Edwards, P.J., eds., Colonization, succession, and stability: 26th Symposium of the British Ecological Society and the Linnean Society of London, Blackwell Scientific Publications, Oxford, p. 373–393.

Davis, M.B., Woods, K.D., Webb, S.L., and Futyma, R.P., 1986, Dispersal versus climate: Expansion of *Fagus* and *Tsuga* into the Upper Great Lakes region: Vegetatio, v. 67, p. 93–103.

Dell, C.I., 1972, The origin and characteristics of Lake Superior sediments: Proceedings from the 15th Conference on Great Lakes Research, p. 361–370.

___, 1974, The stratigraphy of northern Lake Superior late-glacial and post-glacial sediments: Proceedings from the 17th Conference on Great Lakes Research, p. 179–192.

Department of the Army, 1993, Monthly bulletin of lake levels for the Great Lakes: Department of the Army, North Central Division, Detroit District, Corps of Engineers, Sept. 1993, 4 p.

Dickas, A.B., 1973, Wisconsin's Lake Superior Basin Water Quality Study: Center for Lake Superior Environmental Studies 21, variable pagination.

Dunne, T., and Leopold, L.B., 1978, Water in environmental planning: W.H. Freeman and Company, New York, p. 83–255.

Dury, G.H., 1958, Tests of a general theory of misfit streams: Trans. Inst. Brit. Geog., Pub. 25, p. 691–706.

____1964, Principles of underfit streams: U.S. Geological Survey Professional Paper 452-A, 67 p.

Edwards, T.K., and Glysson, G.D., 1988, Field methods for measurement of fluvial sediment: U.S. Geological Survey Open-File Report 86–531, 118 p.

Eichenlaub, V.L., 1979, Weather and climate of the Great Lakes region: Notre Dame, University of Notre Dame Press, 335 p.

Evans, J.E., Johnson, T.C., Alexander, E.C. Jr., Lively, R.S., and Eisenreich, S.J., 1981, Sedimentation rates and depositional processes in Lake Superior from ^{210}Pb geochronology: Journal of Great Lakes Research, International Association for Great Lakes Research v. 7, no. 3, p. 299–310.

Farrand, W.R., 1969, The Quaternary history of Lake Superior: Proceedings of the 12th Con-

ference on Great Lakes Research, p. 181–197.

Farrand, W.R., and Drexler, C.W., 1985, Late Wisconsinan and Holocene history of the Lake Superior basin: *in* Karrow, P.F., and Calkin, P.E., eds. Quaternary Evolution of the Great Lakes: Geological Association of Canada Special Paper 30, p. 17–32.

Finley, R.W., 1976, Original Vegetation of Wisconsin: Wisconsin Geological and Natural History Survey Map, 1:500,000-scale, 1 sheet.

Fox, H.L., 1976, The urbanizing river: a case study in the Maryland Piedmont, *in* Coates, D.R., ed., Geomorphology and Engineering: Stroudsburg, Penn., Dowden, Hutchinson, and Ross, Inc., p. 245–271.

Gebert, W.A., 1986, Wisconsin, surface water resources, *in* Moody, D.W., Chase, E.B., and Aronson, D.A. eds., National water summary 1985; Hydrologic events and surface-water resources: U.S. Geological Survey Water-Supply Paper 2300, p. 485–490.

Gebert, W.A., and Krug, W.R., 1996, Streamflow trends in Wisconsin's Driftless Area: Water Resources Bulletin, v. 32, no. 4, p. 733–744.

Gajewski, K., 1987, Climatic impacts on the vegetation of eastern North America during the past 2000 years: Vegetatio, v. 68, p. 179–190.

Gajewski, K., Winkler, M.G., and Swain, A.M., 1985, Vegetation and fire history from three lakes with varved sediments in northwestern Wisconsin (U.S.A.): Review of Paleobotany and Palynology, v. 44, p. 277--292.

Glysson, G.D., 1987, Sediment-transport curves: U.S. Geological Survey Open-File Report 86–218, 47 p.

Great Lakes Basin Commission, 1975, Erosion and sedimentation, Appendix 18, Great Lakes basin framework study: Great Lakes Basin Commission report, 127 p.

Goldberg, E.D., 1963, Geochronology with Pb^{210}, in Radioactive Dating, Proc. Symp. Athens Nov. 19–23, 1962, IAEA, Vienna, p. 121–131.

Goodman, B.M., 1984, The climatic impact of volcanic activity: Ph.D. Dissertation, Department of Meteorology, University of Wisconsin-Madison.

Grosse-Brauckmann, Gisbert, 1986, Analysis of vegetative plant macrofossils, *in* Berglund, B.E., ed., Handbook of Holocene Palaeoecology and Palaeohydrology: New York, John Wiley and Sons, p. 591–618.

Guy, H.P., 1969, Laboratory theory and methods for sediment analysis: Techniques of Water-Resources Investigations of the United States Geological Survey, Chapter C1, Book 5, 58 p.

Hack, J.T., 1965, Postglacial drainage evolution and stream geometry in the Ontonagon Area, Michigan: U.S. Geological Survey Professional Paper 504-B, 40 p.

Hack, J.T., and Goodlett, J.C., 1966, Geomorphology and forest ecology of a mountain region in the Central Appalachians: U.S. Geological Survey Professional Paper 347, 66 p.

Heinselman, M.L, 1973, Fire in the virgin forests of the Boundary Waters Canoe Area, Minnesota: Quaternary Research, v. 3, p. 329–382.

Hershfield, D.M., 1961, Rainfall frequency atlas of the United States: U.S. Weather Bureau Technical Paper 40.

Hetherington, E.D., 1987, Hydrology and logging in the Carnation Creek Watershed--What have we learned?, *in* Chamberlin, T.E., ed., Applying 15 years of Carnation Creek results: Proceedings of the Workshop held January 13–15, 1987, p. 11–15.

Hole, F.D., 1976, Soils of Wisconsin: Madison, University of Wisconsin Press, 223 p.

Holliday, V.T., 1990, Pedology in archaeology: *in* Lasca, N.P., and Donahue, J., eds., Archaeological geology of North America: Geological Society of America, Centennial Special Volume 4, p. 525–540.

Holzhueter, J.O., 1974, Madeline Island and the Chequamegon region: State Historical Society of Wisconsin, 59 p.

Iman, R.L., and Conover, W.J., 1983, A modern approach to statistics: New York, John Wiley and Sons, 497 p.

International Joint Commission, 1976, Further regulation of the Great Lakes: International Joint Commission Report to the Governments of Canada and the United States, 96 p.

Jacobson, R.B., and Primm, A.T., 1997, Historical land-use changes and potential effects on stream disturbance in the Ozark Plateaus, Missouri: U.S. Geological Survey Water-Supply Paper 2484, 85 p.

Janitsky, P., 1986, Organic carbon (Walkley-Black method), *in* Singer, M.J., and Janitzky, P., eds., Field and laboratory procedures used in a soil chronosequence study: U.S. Geological Survey Bulletin 1648, p. 34–36.

Johannes, S.I., Sather, L.M., and Threisen, C.W., 1970, Surface water resources of Bayfield County: Wisconsin Department of Natural Resources Report, 372 p.

Johnson, M.D., 1980, Origin of the Lake Superior red clay and glacial history of Wisconsin's Lake Superior shoreline west of the Bayfield Peninsula: Master's thesis, University of Wisconsin-Madison,108 p.

Kemp, A.L.W., Dell, C.I., and Harper, N.S., 1978, Sedimentation rates and a sediment budget for Lake Superior: Journal of Great Lakes Research, International Association for Great Lakes Research v. 4, no. 3–4, p. 276–287.

Kendall, M.G., 1948, Rank correlation methods, 4th ed., Charles Griffen, London, United Kingdom.

Kiesel, D.S., 1998, Holocene stratigraphy of the river-mouth sediments of the Pigeon River, Eastern Wisconsin: implications for lake-level fluctuations: Ph.D. dissertation, Department of Geology, University of Wisconsin-Madison, 166 p.

Kingston, J.C., 1987, A paleolimnological record of human disturbance from the St. Louis River estuary, Lake Superior: Abstract, International Association for Great Lakes Research, 30th Conference, p. A–35.

Kirpitch, P.Z., 1940, Time of concentration for small agricultural watersheds: Civil Engineering, v. 10, p. 362.

Knox, J.C., 1977, Human impacts on Wisconsin stream channels: Annals of the Association of American Geographers, v. 67, no. 3, p. 323–342.

____1983, Responses of river systems to Holocene climates, *in* Wright, H.E., Jr., ed. Late Quaternary environments of the United States: v. 2, The Holocene, University of Minnesota Press, Minneapolis, p. 26–41.

____1984, Fluvial responses to small scale climate change: *in* Costa, J.E., and Fleisher, P.J., eds., Developments and applications of geomorphology: Berlin, Springer-Verlag, p. 318–343.

____1985, Responses of floods to Holocene climatic change in the upper Mississippi valley: Quaternary Research, v. 23, p. 287–300.

____1987, Historical valley floor sedimentation in the upper Mississippi valley: Annals of the Association of American Geographers, v. 77, no. 2, p. 224–244.

____1993, Large increases in flood magnitude in response to modest changes in climate: Nature, v. 361, p. 430–432.

____1995, Fluvial systems since 20,000 years B.P., *in* Gregory, K.J., Starkel, L., and Baker, V.R., Global Continental Palaeohydrology: John Wiley and Sons, p. 87–108.

Knox, J.C., Bartlein, P.J., Hirschboeck, K.K., and Muckenhirn, R.J., 1975, The response of floods and sediment yields to climate variation and land use in the upper Mississippi Valley: University of Wisconsin-Madison, Institute for Environmental Studies Report 52, 40 p.

Knox, J.C., Falkner, C., Neuman, P., Rettig, S., Skavroneck, S., and Thomas, D., 1976, An analysis of the International Great Lakes Levels Board Report on regulation of Great Lakes water levels: Hydrology: Rockefeller Foundation Monograph 76–01, Institute for Environmental Studies Working Paper 27, 113 p.

Krug, W.R., Conger, D.H., and Gebert, W.A., 1992, Flood-frequency characteristics of Wisconsin streams: U.S. Geological Survey Water-Resources Investigations Report 91-4128, 185 p.

Krumbein, W.C., 1934, Size frequency distributions of sediments: Jour. Sed. Petrology, v. 4, p. 65–77.

Kutzbach, J.E., 1987, Model simulations of the climatic patterns during the deglaciation of North America, *in* Ruddiman, W.F., and Wright, H.E., Jr., eds., North America and adjacent oceans during the last deglaciation: Boulder, Colo., Geological Society of America, the Geology of North America, v. K-3, p. 425–446.

Larsen, C.E., 1985a, Lake level, uplift, and outlet incision, the Nipissing and Algoma Great Lakes, *in* Karrow, P.F., and Calkin, P.E., eds., Quaternary evolution of the Great Lakes: Geological Association of Canada Special Paper 30, p. 63–77.

___1985b, Geoarchaeological interpretation of Great Lakes coastal environments, in Stein, J.K., and Farrand, W.R., eds., Archaeological sediments in context, peopling of the Americas, v. 1: Center for the Study of Early Man, Institute for Quaternary Studies, University of Maine at Orono, p. 91–110.

___1991, The late archaic-early woodland transition along the U.S. shore of Lake Superior—Site location, isostatic uplift, and lake level: Abstract, National Geological Society of America 1991 Annual Meeting, p. 10.

___1994, Beach ridges as monitors of isostatic uplift in the upper Great Lakes: Journal of Great Lakes Research, v. 20, n. 1, p. 108–134.

___1996, Late Holocene Lake Superior—isostatic and climatic lake level change: Institute of Lake Superior Geology Annual Meeting, Abstracts, p. 29.

Leopold, L.B., and Maddock, T, 1953, The hydraulic geometry of stream channels and some physiographic implications: U.S. Geological Survey Professional Paper 252, 57 p.

Leopold, L.B., Wolman, M.G., and Miller, J.P., 1964, Fluvial processes in geomorphology: W.H. Freeman and Co., San Francisco, 522 p.

Leverett, F., 1929, Moraines and shore lines of the Lake Superior Region: U.S. Geological Survey Professional Paper 154–A, 72 p.

Libby, W.F., 1946, Atmospheric helium three and radiocarbon from cosmic radiation: Physical

Review, v. 69, p. 671-672.

Libby, W.F., Anderson, E.C., and Arnold, J.R., 1949, Age determination by radiocarbon content: Science, v. 109, p. 227–228.

Litherland, A.E., and Beukens, R.P., 1995, Radiocarbon dating by atom counting, *in* Rutter, N.W., and Catto, N.R., eds., Dating Methods for Quaternary Deposits: Geological Association of Canada, GEOtext2, p. 117–124.

Lowdermilk, W.C., 1934, The role of vegetation in erosion control and water conservation: Journal of Forestry, v. 32, no. 5, 529–536.

Lull, H.W., and Sopper, W.E., 1968?, Prediction of average annual and seasonal streamflow of physiographic units in the Northeast: Reprint from the USDA Forest Service Northeastern Forest Experimental Station?, p. 507–522.

Lynch, J.A., Sopper, W.E., and Partridge, D.B., 1972, Changes in streamflow following partial clearcutting on a forested watershed, *in* Csallany, S.C., McLaughlin, T.G., and Striffler, W.D., eds., Watersheds in transitions: American Water Resources Association Proceedings, Fort Collins, Colo., June 19-22, 1972, p. 313–320.

Mahaffey, C.G., 1977, Changing images of the cutover: an historical geography of resource utilization in the Lake Superior region, 1840–1930: Ph.D. dissertation, University of Wisconsin-Madison, v. 1, 244 p.

Mahaffey, C.G., and Bassuk, F.R., 1978, Images of the cutover: a historical geography of the resource utilization in the Lake Superior region, 1845–1930: Institute for Environmental Studies Report 98, 38 p.

Maher, L.J., 1977, Palynological studies in the western arm of Lake Superior: Quaternary Research, v. 7, p. 14–44.

Magilligan, F.J., 1988, Variations in slope components during large magnitude floods, Wisconsin: Annals of the Association of America Geographers, v. 78, no. 3, p. 520–533.

McCuen, R.H., 1982, A guide to hydrologic analysis using SCS methods: Englewood Cliffs, New Jersey, Prentice-Hall, 145 p.

Mickelson, D.M., Clayton, L., Baker, R.W., Mode, W.N., and Schneider, A.F., 1984, Pleistocene stratigraphic units of Wisconsin: Wisconsin Geological and Natural History Survey Miscellaneous Paper 84–1, p. 7–11.

Munsell Color, 1975, Munsell Soil Color Charts, Baltimore, Munsell Color Division of Kollmorgen Corp., variable pagination.

Natural Resources Conservation Service, and U.S. Forest Service, 1998, Executive summary report: Erosion and sedimentation in the Nemadji River Basin, Nemadji River Basin Project, 16 p.

Need, E.A., and Johnson, M.D., 1984, Stratigraphy and history of glacial deposits along Wisconsin's Lake Superior shoreline—Wisconsin Point to Bark Point: Geoscience Wisconsin, v. 9, p. 21–51.

Olsson, I.U., 1986, Radiometric dating, *in* Berglund, B.E., ed., Handbook of Holocene Paleoecology and Paleohydrology: Chichester, John Wiley and Sons, p. 273–312.

Osterkamp, W.R., and Costa, J.E., 1987, Changes accompanying an extraordinary flood on a sand-bed stream, *in* Maher, L., and Nash, D., eds., Catastrophic flooding: Proceedings from the 18th Binghamton Symposium, Boston, Allen and Unwin, p. 201–224.

Patton, P.C., and Baker, V.R., 1977, Geomorphic response of central Texas stream channels to

catastrophic rainfall and runoff, *in* Doehring, D.O., ed., Geomorphology in arid regions: Proceedings Volume of the Eighth Annual Geomorphology Symposium held at the State University of New York, Binghamton, N.Y., p. 189–217.

Phillips, A.M., 1994, The deglaciation, post-glacial shoreline sequence and archaeological potential of the Minnesota-Ontario north shore: American Quaternary Association Combined Field Guide, 13th Biennial Meeting, p. 19E–36E.

Phillips, D.W., and McCulloch, J.A.W., 1972, The climate of the Great Lakes Basin: Environment Canada, Climatological Studies, no. 20, variable pagination.

Pratt, D.M., 1981, Environmental and public use inventory of the Fish Creek Slough Project Area: Wisconsin Department of Resources unpublished report, variable pagination.

Pratt, D.M., 1997, Wisconsin's Lake Superior Coastal Brook Trout Fishery—Historical perspective: 59th Midwest Fish and Wildlife Conference, Milwaukee, Wis. Dec. 7–10, 1997, p. 433.

Rantz and others, 1982, Measurement and computation of streamflow: U.S. Geological Survey Water-Supply Paper 2175, 631 p.

Red Clay Interagency Committee, 1967, Erosion and sedimentation control on the red clay soils of northwestern Wisconsin: Leaflet, Soil Conservation Board, Madison, Wis., 23 p.

Reinhart, K.G., Eschner, A.R., and Trimble, G.R., 1963, Effect on streamflow of four forest practices in the mountains of West Virginia: U.S. Forest Service Research Paper NE–I, 79 p.

Renard, K.G., Foster, G.R., Weesies, G.A., McCool, D.K., and Yoder, D.C., 1993, Predicting soil erosion by water—A guide to conservation planning with the Revised Universal Soil Loss Equation RUSLE: U.S. Department of Agriculture, Publication ARS.

Retallack, G.J., 1988, Field recognition of paleosols, *in* Reinhardt, J. and Sigleo, W.R., eds., Paleosols and Weathering through Geologic Time: principles and Applications: Geological Society of America, Special Paper 216, p. 1–19.

Robertson, D.M., 1996, Use of frequency-volume analyses to estimate regionalized yields and loads of sediment, phosphorus, and polychlorinated biphenyls to Lakes Michigan and Superior: U.S. Geological Survey Water-Resources Investigations Report 96-4092, 47 p.

Robertson, D.M., 1994, Influence of surficial soils, land use, and stream gradient on suspended-sediment and phosphorus loads in streams entering the Great Lakes: Abstracts, American Geophysical Union Fall Meeting, San Francisco, December 5-9, 1994, p. 229.

Rose, W., and Graczyk, D., 1996, Sediment transport, particle size, and loads in North Fish Creek in Bayfield County, Wisconsin, Water years 1990-91: U.S. Geological Survey Water Resources Investigations Report 95–4222, 18 p.

Ruhe, R.V., 1965, Quaternary Paleopedology, *in* Wright, H.E., and Frey, D.G., eds., The Quaternary of the United States: Princeton, New Jersey, Princeton University Press, p. 755–764.

Sartz, R.S., 1972, Soil water depletion by a hardwood forest in southwestern Wisconsin: Soil Science Society of America Proceedings, v. 36, p. 961–964.

Schoch, Werner, 1986, Wood and charcoal analysis, *in* Berglund, B.E., ed., Handbook of Holocene Palaeoecology and Palaeohydrology: New York, John Wiley and Sons, p. 619–626.

Schumm, S.A., 1968, River adjustments to altered hydrologic regimen—Murrumbidgee River

and paleochannels, Australia: U.S. Geological Survey Professional Paper 598, 65 p.

Schumm, S.A., and Brakenridge, G.R., 1987, River responses, *in* Ruddiman, W.F., and Wright, H.E., Jr., eds., North America and adjacent oceans during the last deglaciation: Boulder, Colo. Geological Society of America, The Geology of North America, v. K-3, p. 221–240.

Shuter, V., Stortz, K., Oman, G., and Sydor, M, 1978, Turbidity dispersion in Lake Superior through use of Landsat data: Journal of Great Lakes Research, International Association for Great Lakes Research v. 4, n. 3–4, p. 359–360.

Smagorinsky, J., 1963, General circulation experiments with the primitive equations, I, the basic experiment: Monthly Weather Review, v. 91, p. 99-164.

Smith, J.S., and Goc, M.J., eds., 1987, Looking back, moving forward: Ashland, the garland city of the inland seas: New Past Press, Inc., Friendship, Wis., 168 p.

Stevens, H.H., 1985, Computer program for the computation of total sediment discharge by the modified Einstein procedure: U.S. Geological Survey Water-Resources Investigations Report 85–4027, 14 p.

Stortz, K., Clapper, R. and M. Sydor, 1976, Turbidity sources in Lake Superior: Journal of Great Lakes Research, International Association for Great Lakes Research v. 2, n. 2, p. 393–401.

Stuiver, Minze, and Becker, Bernd, 1993, High-precision decadal calibration of the radiocarbon time scale, AD 1950-6000 BC: Radiocarbon, v. 35, no. 1, p. 35–65.

Stuiver, Minze, and Reimer, P.J., 1993, Extended ^{14}C data base and revised CALIB 3.0 ^{14}C age calibration program: Radiocarbon, v. 35, no. 1, p. 215–230.

Swain, A.M., 1973, A history of fire and vegetation in northeastern Minnesota as recorded in lake sediments: Quaternary Research, v. 3, p. 383–396.

____1978, Environmental changes during the past 2000 years in North-Central Wisconsin: analysis of pollen, charcoal, and seeds from varved lake sediments: Quaternary Research, v. 10, p. 55–68.

Swain, A.M., and Winkler, M.G., 1983, Forest and disturbance history at Apostle Islands National Lakeshore: Park Science, v. 3, no. 4, p. 3–5.

Swank, W.T., and Douglass, J.E., 1974, Streamflow greatly reduced by converting deciduous hardwood stands to pine: Science, v. 185, p. 857–859.

Swank, W.T., and Miner, N.H., 1968, Conversion of hardwood-covered watersheds to white pine reduces water yield: Water Resources Research, v. 4, p. 947–954.

Sydor, M., Clapper, R.T., Oman, G.J., and Stortz, K.R., 1979, Red clay turbidity and its transport in Lake Superior: U.S. Environmental Protection Agency, EPA–905/9–79–004, 130 p.

Teller, J.T., 1985, Glacial Lake Agassiz and its influence on the Great Lakes, in Karrow, P.F., and Calkin, P.E., eds., Quaternary geological evolution of the Great Lakes: Geological Association of Canada Special Paper 30, p. 1–16.

____1987, Proglacial lakes and the southern margin of the Laurentide Ice Sheet: *in* Ruddiman, W.F., and Wright, H.E., Jr., North America and adjacent oceans during the last glaciation: Boulder, Colo., Geological Society of America, The Geology of North America, v. K-3, p. 39–69.

Thwaites, R.G., 1895, The story of Chequamegon Bay: Collections of the State Historical Society of Wisconsin, v. 8, p. 397–440.

Thwaites, F.T., 1912, Sandstones of the Wisconsin coast of Lake Superior: Wisconsin Geological and Natural History Survey Bulletin 25, p. 1–66.

Turner, J.M, and Company, 1889, Lake Superior Region Illustrated, Part 1, J.M. Turner and Company.

Turner, L.J., and Turner, J.M., 1898, Hand book of Wisconsin, its history and geography: Burlington Wisconsin, Lura J. and J.M. Turner.

U.S. Army Corps of Engineers, 1990, HEC-1-Flood hydrograph package-User's manual: U.S. Army Corps of Engineers, Hydrologic Engineering Center, Version 4.0, Sept. 1990, variable pagination.

____1991, HEC-2 water surface profiles user's manual, September, 1990: U.S. Army Corps of Engineers, Hydrologic Engineering Center CPD-2A, variable pagination.

U.S. Department of Agriculture, Soil Conservation Service, 1961, Soil Survey of Bayfield County: U.S. Department of Agriculture Series 1939, no. 30, 77 p.

___1975, General soils map, Fish Creek Basin, Bayfield County, Wisconsin, Western Lake Superior Basin, March 1975, 1 plate.

___1978, Interim Soil Survey Report, Nemadji River Watershed and Fish Creek Watershed, Volume 1, Soil description and interpretation section: U.S. Department of Agriculture, Soil Conservation Service, 280 p.

___1986, Urban hydrology for small watersheds: U.S. Department of Agriculture, Soil Conservation Service, Technical Release 55, variable pagination.

___1991, State soil geographic data base (STATSGO), data user's guide: U.S. Department of Agriculture, Soil Conservation Service Miscellaneous Publication 1492, 88 p., scale 1:250,000.

U.S. Department of Commerce, 1973, Hydrograph of monthly mean levels of the Great Lakes: U.S. Department of Commerce, NOAA-National Ocean Survey, Lake Survey Center, 1 oversized sheet.

U.S. Geological Survey, 1991, National water summary 1988-89—Hydrologic events and floods and droughts: U.S. Geological Survey Water Supply Paper 2375, p. 567–574.

Urie, D.H., 1966, Forest cover in relation to water yields on outwash sand soils: Pap. Mich. Academy of Science Arts, and Letters. 51, p. 3-11.

Vale, T.R., 1982, Plants and people--vegetation change in North America: Association of American Geographers, Washington, D.C., p. 29-34; 51-55.

Vanderpool, N.L., 1982, ERODE—A computer model of drainage basin development under changing baselevel conditions, in Craig, R.G., and Craft, J.L., eds., Applied geomorphology: Proceedings from the Eleventh Annual "Binghamton" Geomorphology Symposium, 214–253.

Verry, E.S., 1986, Forest harvesting and water: the Lake States experience: Water Resources Bulletin, v. 22, no. 6, December, 1986, p. 1039-1047.

-----, 1987, The effect of aspen harvest and growth on water yield in Minnesota: Forest Hydrology and Watershed Management, Proceedings of the Vancouver Symposium, August 1987, p. 553-562.

Walling, D.E., and Webb, B.W., 1983, Patterns of sediment yield, *in* Gregory, K.G., ed., Background to Paleohydrology: New York, Wiley and Sons, p. 69–100.

Webb, Thompson, III., 1973, Pre- and postsettlement pollen from a short core, Trout Lake,

north-central Wisconsin: Wisconsin Academy of Sciences, Arts, and Letters, v. 61, p. 141–148.

Webb, Thompson, III., and Bryson, R.A., 1972, Late- and postglacial climatic change in the northern Midwest, USA: Quantitative estimates derived from fossil pollen spectra by multivariate statistical analysis: Quaternary Research, v. 2, p. 70–115.

Webb, Thompson, III., Cushing, E.J., and Wright, H.E., Jr., 1983, Holocene changes in the vegetation of the Midwest, *in* Wright, H.E., Jr., ed., The Holocene of the United States, Minneapolis, Minn., University of Minnesota Press, p. 142–165.

Wendland, W.M., and Bryson, R.A., 1974, Dating climatic episodes of the Holocene: Quaternary Research, v. 4, p. 9–24.

Wentworth, C.K., 1922, A scale of grade and class terms for clastic sediments: Journal of Geology, v. 30, p. 377–392.

Williams, G.P., 1978, Bankfull discharge of rivers: Water Resources Research, v. 14, no. 6, p. 1141-1154.

Winkler, M.G., 1996, The paleoecology and pH history of Ike Walton Lake and comparison with the recent history of Zee Lake: Final Report to the Lac Du Flambeau Water Resources Program, Center of Climatic Research, University of Wisconsin, Madison, Wis., 22 p.

Winkler, M.G., and Sanford, P.R., 1997, Paleolimnological research at Isle Royale, Apostle Islands and Voyageurs National Parks: Summary Report, Western Great Lakes Biogeographic Area, June, 1997, p. 30–33.

Winkler, M.G., Swain, A.M., Kutzbach, J.E., 1986, Middle Holocene dry period in the northern Midwestern United States: Lake Levels and Pollen Stratigraphy: Quaternary Research, v. 25, p. 235–250.

Wischmeier, W.H., and Smith, D.D., 1965, Predicting rainfall-erosion losses from cropland east of the Rocky Mountains—A guide for selection of practices for soil and water conservations: U.S. Department of Agriculture, Agricultural Handbook 282.

___1978, Predicting rainfall-erosion losses—A guide to conservation planning: U.S. Department of Agriculture, Agricultural Handbook 537.

Wisconsin Department of Agriculture, and Wisconsin Geological and Natural History Survey, 1928, Land economic inventory-Bayfield County, Wis.-Forest form and cover maps, scale 1:63,360.

Wolman, M.G., and Gerson, R., 1978, Relative scales of time and effectiveness of climate in watershed geomorphology: Earth Surface Processes, v. 3, p. 189–208.

Wolman, M.G., and Leopold, L.B., 1957, River flood plains: some observations on their formation: U.S. Geological Survey Professional Paper 282-C, p. 87-109.

Wolman, M.G., and Miller, J.P., 1960, Magnitude and frequency of forces in geomorphic processes: Journal of Geology, v. 68, p. 54-74.

Wright, H.E., 1967, A square-rod piston sampler for lake sediments: Journal of Sedimentary Petrology, September, 1967, p. 975-976.

____1991, Coring tips: Journal of Paleolimnology, v. 6, p. 37-49.

____1992, Patterns of Holocene climate change in the midwestern United States: Quaternary Research, v. 38, p. 129–134.

Young, H.L., and Skinner, E.L., 1974, Water resources of Wisconsin Lake Superior basin: U.S. Geological Survey Hydrologic Investigation Atlas HA–524, 3 sheets, scale 1:1,000,000.

APPENDIX A
Results from Particle-Size Analyses and Organic Carbon Determinations

Appendix A. Particle-size analyses and organic carbon determinations (Walkley-Black method) of floodplain and channel sediment along North Fish Creek, Wisconsin, 1995

[USDA, U.S. Department of Agriculture; v., very; f., fine; s., sand; si., silt; c., coarse; cl, clay; mm, millimeters; >, greater than]

		Size classes (mm)																	
		Percentage in each phi class interval																	
		-1-0	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	>9							
		2-1	1-.5	.5-.25	.25-.125	.125-.0625	.062-.031	.031-.016	.016-.008	.008-.004	.004-.002	<.002	Udden-Wentworth						
Sample number	Depth interval (meters)	v.c. sand	c. sand	m. sand	f. sand	v.f. sand	c. silt	m. silt	f. silt	v.f. silt	c. clay	m. clay	Sand	Silt	Clay	USDA texture	Percent organic carbon	> 2 mm	Remarks
E-4-21	0.00-.04	0.01	0.14	3.68	35.87	35.73	13.11	2.31	1.08	1.65	1.46	4.95	75.4	18.2	6.4	loamy f. sand	0.9	0	
E-4-19	.04-.08	0.02	0.26	10.71	36.15	26.30	13.70	2.85	2.04	0.61	2.42	4.94	73.4	19.2	7.4	loamy f. sand	1.6	0	
E-4-20****	.08-.15	0.03	1.94	41.07	45.90	6.71	0.19	1.13	0.53	-0.83	0.83	2.50	95.7	1.0	3.3	f. sand	0.2	0	
E-4-22	.15-.17	0.13	3.00	27.90	39.81	12.50	7.53	1.96	1.05	1.03	0.98	4.12	83.3	11.6	5.1	loamy sand	1.3	0.13	
E-4-23****	.17-.22	0.00	1.09	38.92	45.94	8.26	2.46	0.83	0.83	-0.83	0.86	1.67	94.2	3.3	2.5	sand	0.5	0	
E-4-24	.22-.27	0.00	0.10	5.77	43.24	28.16	11.27	2.30	0.82	1.20	1.09	6.04	77.3	15.6	7.1	loamy f. sand	0.9	0	
E-4-25	.27-.33	0.00	0.08	5.33	48.60	28.08	8.76	1.95	1.39	0.00	0.83	5.00	82.1	12.1	5.8	loamy f. sand	0.6	0	
E-4-18	.35-.50	0.01	0.31	9.18	51.38	26.34	5.51	1.49	0.25	0.37	1.90	3.27	87.2	7.6	5.2	loamy f. sand	0.3	0	
E-4-17	.50-.65	0.00	0.02	0.19	31.36	46.87	10.48	2.20	0.60	1.17	1.78	5.33	78.4	14.5	7.1	loamy f. sand	0.4	0	
E-4-16	.65-.84	0.01	0.10	1.85	22.35	34.55	21.85	4.19	2.86	3.32	2.51	6.42	58.9	32.2	8.9	f. s. loam	0.6	0	
E-4-15****	.84-1.00	0.12	0.13	4.42	44.76	31.60	7.58	3.90	3.34	0.00	-0.41	4.58	81.0	14.8	4.2	loamy f. sand	0.2	0	
E-4-14	1.11-1.05	0.00	0.05	0.07	7.15	46.75	26.29	8.31	5.55	0.00	0.22	5.62	54.0	40.2	5.8	v. f. s. loam	0.3	0	
E-4-13	1.05-1.17	0.00	0.11	0.25	10.00	50.91	21.27	4.98	5.70	0.08	0.04	6.63	61.3	32.0	6.7	v. f. s. loam	0.7	0	
E-4-12	1.17-1.40	0.00	0.01	0.81	30.60	49.83	13.95	1.24	0.23	0.00	0.83	2.50	81.3	15.4	3.3	loamy v. f. sand	0.2	0	
E-4-11	1.40-1.65	0.00	0.03	5.06	34.67	36.18	16.76	2.31	0.00	0.30	0.53	4.17	75.9	19.4	4.7	loamy f. sand	0.2	0	
E-4-10	1.65-1.90	0.00	0.03	8.48	50.99	24.47	8.71	1.48	0.00	0.00	0.84	5.00	84.0	10.2	5.8	loamy f. sand	0.3	0	
E-4-9	1.90-1.94	0.00	0.01	0.83	23.95	37.74	19.44	4.07	0.93	2.95	2.36	7.71	62.5	27.4	10.1	v. f. s. loam	0.8	0	1 humus treatment but darker than normal, lots of organic debris
E-4-8****	1.94-2.08	0.00	0.04	5.25	48.54	28.94	9.09	1.90	1.25	0.53	-0.29	4.76	82.8	12.8	4.5	loamy f .sand	0.3	0	
E-4-7	2.08-2.18	0.00	0.00	0.24	1.23	23.70	43.90	12.15	3.45	2.91	2.44	9.97	25.2	62.4	12.4	si. loam	2.1	0	Required 2 humus treatments, lots of organic debris
E-4-6	2.18-2.30	0.00	0.02	0.02	2.93	52.38	29.04	6.65	1.73	0.64	1.89	4.70	55.4	38.1	6.6	v. f. s. loam	0.6	0	
E-4-5	2.30-2.44	0.32	0.02	0.05	0.90	38.51	36.39	10.29	3.72	2.00	1.74	6.08	39.8	52.4	7.8	si. loam	0.7	0	
E-4-4	2.46-2.6	0.00	0.03	0.05	21.42	52.49	15.43	2.45	1.72	0.74	1.51	4.15	74.0	20.3	5.7	loamy v. f. sand	0.4	0	
E-4-3	2.60-2.65	0.00	0.01	0.07	3.15	11.24	24.38	8.70	10.59	8.34	7.75	25.78	14.5	52.0	33.5	si. c. loam	2.2	0	Required 2 humus treatments

Appendix A. Particle-size analyses and organic carbon determinations (Walkley-Black method) of floodplain and channel sediment along North Fish Creek, Wisconsin, 1995

[USDA, U.S. Department of Agriculture; v., very; f., fine; s., sand; si., silt; c., coarse; cl, clay; mm, millimeters; >, greater than]

		Size classes (mm)																	
		Percentage in each phi class interval																	
		-1-0	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	>9							
		2-1	1-.5	.5-.25	.25-.125	.125-.0625	.062-.031	.031-.016	.016-.008	.008-.004	.004-.002	<.002	Udden-Wentworth						
Sample number	Depth interval (meters)	v.c. sand	c. sand	m. sand	f. sand	v.f. sand	c. silt	m. silt	f. silt	v.f. silt	c. clay	m. clay	Sand	Silt	Clay	USDA texture	Percent organic carbon	> 2 mm	Remarks
E-7-1	1.00-1.50	0.02	0.27	0.99	0.62	1.80	11.70	0.00	2.29	10.24	30.46	41.65	3.7	24.2	72.1	clay	-	0	
E-7-1	1.00-1.50	0.08	0.13	0.87	1.29	1.03	10.78	0.47	6.09	11.01	10.39	57.87	3.4	28.4	68.3	clay	-	-	Hexametaphosphate doubled
E-7-2****	1.50-1.75	3.25	7.61	26.04	27.84	11.39	11.63	3.69	4.02	1.16	3.87	-0.49	76.1	20.5	3.4	loamy sand	-	8.33	
E-7-2	1.50-1.75	3.19	8.80	26.07	26.46	12.03	7.11	5.06	3.82	2.39	1.93	3.14	76.6	18.4	5.1	loamy sand	-	-	Hexametaphosphate doubled
E-7-3	1.75-2.25	3.91	9.47	24.29	20.16	13.12	11.29	4.66	2.07	4.54	4.31	2.18	71.0	22.6	6.5	s. loam	-	3.95	
E-7-3	1.75-2.25	2.45	7.99	23.07	22.97	12.59	9.42	4.74	3.69	3.77	3.44	5.87	69.1	21.6	9.3	s. loam	-	-	Hexametaphosphate doubled
E-7-4	2.25-2.80	2.47	7.02	22.07	24.20	12.33	15.95	3.63	2.78	3.45	3.25	2.86	68.1	25.8	6.1	s. loam	-	3.4	
E-7-4	2.25-2.80	2.45	8.09	22.70	23.22	12.88	7.69	5.04	5.42	2.81	0.25	9.44	69.3	21.0	9.7	s. loam	-	-	Hexametaphosphate doubled
E-7-5	2.80-3.55	0.39	2.50	7.32	10.82	11.14	21.07	11.74	10.64	7.01	7.73	9.63	32.2	50.5	17.4	loam	-	2.5	
E-7-5	2.80-3.55	0.43	2.05	7.47	10.85	11.22	20.79	8.91	12.81	8.52	2.27	14.69	32.0	51.0	17.0	loam	-	-	Hexametaphosphate doubled
E-7-6****	3.55-4.20	1.90	6.72	28.21	27.51	11.68	12.90	3.03	1.83	2.61	3.96	-0.34	76.0	20.4	3.6	loamy sand	-	2.32	
E-7-6	3.55-4.20	1.81	7.66	30.28	25.92	11.14	8.09	3.87	3.37	2.25	1.45	4.16	76.8	17.6	5.6	loamy sand	-	-	Hexametaphosphate doubled
E-7-7****	4.20-4.85	0.02	0.04	2.40	67.19	22.34	5.82	1.77	-0.29	0.57	1.48	-1.33	92.0	7.9	0.2	f. sand	-	0	
E-7-7****	4.20-4.85	0.00	0.05	2.38	66.72	22.72	4.80	0.31	0.88	0.85	-0.21	1.51	91.9	6.8	1.3	f. sand	-	-	Hexametaphosphate doubled
E-7-8	4.20-4.85	0.08	0.28	2.06	2.27	1.53	15.49	1.63	6.25	1.53	54.27	14.62	6.2	24.9	68.9	clay	-	0	flocculation problems
E-7-8	4.20-4.85	0.11	0.32	1.77	2.07	1.39	14.04	0.82	6.04	7.69	4.73	61.03	5.7	28.6	65.8	clay	-	-	Hexametaphosphate doubled
E-7-9****	4.85-6.10	0.06	0.04	4.46	71.78	18.55	4.20	1.33	0.17	0.07	0.67	-1.33	94.9	5.8	-0.7	f. sand	-	0.1	flocculation problems
E-7-9****	4.85-6.10	0.00	0.06	6.98	71.10	16.50	2.04	1.48	3.00	-0.66	-2.27	1.79	94.6	5.9	-0.5	f. sand	-	-	Hexametaphosphate doubled
E-7-10	4.85-6.10	0.05	0.07	0.30	9.95	51.11	31.29	3.05	0.91	0.66	0.59	2.02	61.5	35.9	2.6	v. f.s. loam	-	0	
E-7-10	4.85-6.10	0.00	0.04	0.26	11.14	52.92	24.65	2.69	1.13	1.98	1.02	4.17	64.4	30.5	5.2	v. f. s. loam	-	-	Hexametaphosphate doubled
E-7-11****	6.10-7.30	0.00	0.11	3.51	73.32	17.84	3.88	2.59	0.84	-1.43	0.67	-1.33	94.8	5.9	-0.7	f. sand	-	0	
E-7-11	6.10-7.30	0.09	0.11	4.38	74.98	16.29	2.50	0.01	0.30	0.40	0.31	0.65	95.9	3.2	1.0	f. sand	-	-	Hexametaphosphate doubled
E-7-12	7.30-7.60	0.14	1.35	13.93	35.56	18.91	21.73	3.29	1.47	1.02	1.26	1.33	69.9	27.5	2.6	f. s. loam	-	0.08	
E-7-12	7.30-7.60	0.15	1.02	13.26	34.23	19.80	20.32	2.51	1.96	2.13	0.48	4.13	68.5	26.9	4.6	f. s. loam	-	-	Hexametaphosphate doubled

Appendix A. Particle-size analyses and organic carbon determinations (Walkley-Black method) of floodplain and channel sediment along North Fish Creek, Wisconsin, 1995

[USDA, U.S. Department of Agriculture; v., very; f., fine; s., sand; si., silt; c., coarse; cl, clay; mm, millimeters; >, greater than]

		Size classes (mm)																	
		Percentage in each phi class interval																	
		-1-0	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	>9							
		2-1	1-.5	.5-.25	.25-.125	.125-.0625	.062-.031	.031-.016	.016-.008	.008-.004	.004-.002	<.002	Udden-Wentworth						
Sample number	Depth interval (meters)	v.c. sand	c. sand	m. sand	f. sand	v.f. sand	c. silt	m. silt	f. silt	v.f. silt	c. clay	m. clay	Sand	Silt	Clay	USDA texture	Percent organic carbon	> 2 mm	Remarks
E-7-13****	7.60-8.25	0.06	0.11	1.38	30.28	36.56	24.32	6.95	1.29	-0.28	0.67	-1.33	68.4	32.3	-0.7	f. s. loam	-	0	
E-7-13****	7.60-8.25	0.01	0.14	1.38	33.06	36.94	21.14	4.87	1.17	0.77	0.54	-0.03	71.5	28.0	0.5	f. s. loam	-	-	Hexametaphosphate doubled
E-7-14****	7.60-8.25	0.03	0.07	0.13	0.39	9.50	58.28	25.04	5.02	1.09	2.46	-2.01	10.1	89.4	0.5	silt	-	0	
E-7-14****	7.60-8.25	0.02	0.03	0.08	0.39	9.88	55.50	24.26	7.66	1.01	-2.29	3.46	10.4	88.4	1.2	silt	-	-	Hexametaphosphate doubled
E-7-15****	8.25-8.65	0.04	0.18	0.94	1.73	11.89	47.60	23.54	9.28	1.49	4.47	-1.17	14.8	81.9	3.3	silt	-	0	
E-7-15****	8.25-8.65	0.02	0.08	0.78	1.74	11.74	43.92	22.42	13.46	2.18	-1.62	5.28	14.4	82.0	3.7	silt	-	-	Hexametaphosphate doubled
E-7-16****	8.65-9.90	0.01	0.06	0.38	21.29	49.54	26.13	2.55	1.14	1.90	-0.99	-2.01	71.3	31.7	-3.0	loamy f. samd	-	0	
E-7-16****	8.65-9.90	0.03	0.02	0.40	24.40	48.27	22.40	3.41	1.44	0.02	-0.23	-0.15	73.1	27.3	-0.4	loamy f. sand	-	-	Hexametaphosphate doubled
E-7-17****	9.90-10.52	0.00	0.02	0.80	17.55	44.77	32.12	4.79	1.41	0.72	-0.17	-2.00	63.1	39.0	-2.2	v. f. s. loam	-	0	
E-7-17****	9.90-10.52	0.00	0.04	0.67	15.93	46.11	28.82	4.55	2.56	-0.35	0.83	0.83	62.8	35.6	1.7	v. f. s. loam	-	-	Hexametaphosphate doubled
E-7-18****	10.52-11.48	0.00	0.02	0.85	45.38	39.66	13.18	2.18	0.19	0.72	-0.15	-2.01	85.9	16.3	-2.2	f. sand	-	0	
E-7-18****	10.52-11.48	0.00	0.02	0.85	42.21	43.51	9.79	1.98	1.94	-0.97	-2.07	2.75	86.6	12.7	0.7	f. sand	-	-	Hexametaphosphate doubled
E-7-19****	11.48-11.93	0.00	0.02	0.17	29.14	48.76	20.58	3.05	0.23	1.06	-0.15	-2.85	78.1	24.9	-3.0	loamy f. sand	-	0	
E-7-19****	11.48-11.93	0.00	0.05	0.16	34.11	46.44	15.38	2.28	0.35	0.18	1.09	-0.03	80.8	18.2	1.1	loamy f. sand	-	-	Hexametaphosphate doubled
E-7-20	11.48-11.93	0.00	0.03	0.11	1.21	9.36	42.53	30.90	12.30	2.35	0.70	0.50	10.7	88.1	1.2	silt	-	0	
E-7-20****	11.48-11.93	0.00	0.07	0.10	1.01	9.87	41.16	29.97	12.42	1.75	-2.45	6.12	11.1	85.3	3.7	silt	-	-	Hexametaphosphate doubled
E-7-21****	11.93-12.43	0.00	0.03	0.25	19.47	39.23	30.00	7.89	3.40	1.08	0.67	-2.00	59.0	42.4	-1.3	v. f. s. loam	-	0	
E-7-21****	11.93-12.43	0.00	0.00	0.17	18.82	40.00	27.96	6.86	3.16	1.78	-2.87	4.13	59.0	39.8	1.3	v. f. s. loam	-	-	Hexametaphosphate doubled
E-7-22****	12.43-12.75	0.00	0.03	0.24	17.26	30.04	32.72	11.87	5.22	2.30	-1.00	1.33	47.6	52.1	0.3	v. f. s. loam	-	0	
E-7-22****	12.43-12.75	0.02	0.02	0.23	17.49	30.55	29.51	11.20	8.21	0.46	-2.26	4.57	48.3	49.4	2.3	v. f. s. loam	-	-	Hexametaphosphate doubled
E-7-23	12.75-12.86	0.00	0.01	0.11	0.77	14.47	38.58	19.93	10.53	3.51	1.57	10.53	15.4	72.6	12.1	silt	-	0	
E-7-23****	12.75-12.86	0.00	0.04	0.09	0.76	15.95	38.36	19.56	12.84	1.28	-2.76	13.88	16.8	72.0	11.1	silt	-	-	Hexametaphosphate doubled
E-7-24	12.86-13.49	0.00	0.06	0.07	0.15	3.73	35.66	26.33	19.04	10.10	2.69	2.17	4.0	91.1	4.9	silt	-	0	
E-7-24****	12.86-13.49	0.00	0.02	0.02	0.08	3.63	37.31	24.35	21.10	6.31	-0.08	7.26	3.8	89.1	7.2	silt	-	-	Hexametaphosphate doubled
E-7-25****	13.49-13.77	0.00	0.00	0.04	1.80	32.51	47.63	14.46	4.16	0.72	0.67	-2.00	34.4	67.0	-1.3	silt	-	0	

Appendix A. Particle-size analyses and organic carbon determinations (Walkley-Black method) of floodplain and channel sediment along North Fish Creek, Wisconsin, 1995

[USDA, U.S. Department of Agriculture; v., very; f., fine; s., sand; si., silt; c., coarse; cl, clay; mm, millimeters; >, greater than]

		Size classes (mm)																	
		Percentage in each phi class interval																	
		-1-0	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	>9							
		2-1	1-.5	.5-.25	.25-.125	.125-.0625	.062-.031	.031-.016	.016-.008	.008-.004	.004-.002	<.002	Udden-Wentworth						
Sample number	Depth interval (meters)	v.c. sand	c. sand	m. sand	f. sand	v.f. sand	c. silt	m. silt	f. silt	v.f. silt	c. clay	m. clay	Sand	Silt	Clay	USDA texture	Percent organic carbon	> 2 mm	Remarks
E-7-25****	13.49-13.77	0.00	0.04	0.03	1.81	33.98	42.61	15.14	2.98	1.73	-1.63	3.30	35.9	62.5	1.7	silt	-	-	Hexametaphosphate doubled
E-7-26****	13.77-13.93	0.00	0.04	0.06	0.81	22.89	49.47	17.58	7.74	1.92	0.68	-1.18	23.8	76.7	-0.5	silt	-	0	
E-7-26****	13.77-13.93	0.00	0.00	0.02	0.61	22.40	45.42	18.20	11.37	-1.16	-2.28	5.42	23.0	73.8	3.1	silt	-	-	Hexametaphosphate doubled
E-7-27****	13.93-14.33	0.00	0.03	0.09	1.33	29.37	48.73	15.20	5.86	0.72	0.67	-2.00	30.8	70.5	-1.3	silt	-	0	
E-7-27****	13.93-14.33	0.00	0.00	0.06	1.29	30.75	42.15	16.34	8.29	-1.19	-3.09	5.41	32.1	65.6	2.3	silt	-	-	Hexametaphosphate doubled
E-7-28****	14.33-15.30	0.00	0.02	0.05	1.18	33.33	45.36	13.57	6.27	1.56	-0.17	-1.17	34.6	66.8	-1.3	silt	-	0	
E-7-28****	14.33-15.30	0.01	0.01	0.00	0.33	46.89	30.85	14.06	4.07	1.27	-1.64	4.14	47.2	50.3	2.5	silt	-	-	Hexametaphosphate doubled
E-7-29****	15.30-15.60	0.00	0.03	0.12	1.31	24.18	44.98	19.85	7.63	2.40	-0.17	-0.33	25.6	74.9	-0.5	silt	-	0	
E-7-29****	15.30-15.60	0.00	0.01	0.03	0.98	23.30	44.12	18.94	8.19	0.41	-2.26	6.25	24.3	71.7	4.0	silt	-	-	Hexametaphosphate doubled
E-7-30	19.31-20.16	2.12	4.41	18.09	22.06	12.00	15.53	4.67	7.37	2.39	3.38	8.00	58.7	30.0	11.4	f. s. looam	-	1.77	
E-7-30	19.31-20.16	1.84	4.71	19.13	21.21	11.98	17.43	3.75	3.07	3.52	1.64	11.73	58.9	27.8	13.4	f. s. loam	-	-	Hexametaphosphate doubled
E-8-1	0.00-.15	0.04	0.11	3.59	21.97	24.68	21.88	7.73	5.55	2.21	3.15	9.09	50.4	37.4	12.2	loam	2.2	0	
E-8-2	.15-.55	0.00	0.16	13.67	51.71	23.34	6.34	0.33	0.93	0.27	0.53	2.72	88.9	7.9	3.3	f. sand	0.2	0	
E-8-3	.55-.80	0.00	0.02	2.07	25.42	43.51	18.07	4.22	1.74	1.02	1.46	2.48	71.0	25.1	3.9	v. f. s. loam	0.1	0	
E-8-4	.80-1.05	0.00	0.04	1.31	12.72	27.15	24.16	5.75	4.12	3.16	3.74	17.85	41.2	37.2	21.6	loam	0.2	0	
E-8-5	1.05-1.22	0.02	0.21	17.39	51.69	17.81	7.94	0.28	2.39	0.28	0.96	1.03	87.1	10.9	2.0	f. sand	0.1	0	
E-8-6	1.22-1.70	0.29	0.61	1.56	4.98	22.26	28.12	9.06	5.29	4.00	4.41	19.43	29.7	46.5	23.8	loam	0.2	0.3	
E-8-7****	1.28-1.38	0.00	0.93	33.98	42.19	13.30	3.53	0.47	1.43	-0.83	0.83	4.17	90.4	4.6	5.0	f. sand	0.1	0	
E-8-8****	1.70-1.80	14.20	24.19	36.00	14.11	4.79	0.89	1.30	1.74	-0.85	0.31	3.33	93.3	3.1	3.6	c. sand	0.2	41	
E-8-9****	1.80-1.90	17.51	27.05	34.93	10.72	3.32	1.47	1.08	0.58	-0.31	0.90	2.74	93.5	2.8	3.6	c. sand	0.2	24.8	
E-8-10****	1.90-1.99	7.10	19.61	43.33	17.54	3.34	0.76	0.65	1.85	-1.13	0.04	6.93	90.9	2.1	7.0	c. sand	0.2	27.2	
E-8-11****	1.99-2.19	0.30	3.30	24.49	34.52	16.83	8.25	1.88	1.86	-1.42	0.56	9.44	79.4	10.6	10.0	f. s. loam	0.2	0.02	
E-8-12	2.19-2.44	0.02	0.19	1.13	8.74	32.20	24.62	4.86	3.35	3.16	3.50	18.21	42.3	36.0	21.7	loam	0.2	0	
E-8-13	2.44-2.70	0.00	0.07	4.55	29.18	28.42	12.10	2.61	3.94	0.11	2.47	16.53	62.2	18.8	19.0	f. s. loam	0.1	0	

Appendix A. Particle-size analyses and organic carbon determinations (Walkley-Black method) of floodplain and channel sediment along North Fish Creek, Wisconsin, 1995

[USDA, U.S. Department of Agriculture; v., very; f., fine; s., sand; si., silt; c., coarse; cl, clay; mm, millimeters; >, greater than]

		Size classes (mm)																	
		Percentage in each phi class interval																	
		-1-0	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	>9							
		2-1	1-.5	.5-.25	.25-.125	.125-.0625	.062-.031	.031-.016	.016-.008	.008-.004	.004-.002	<.002	Udden-Wentworth						
Sample number	Depth interval (meters)	v.c. sand	c. sand	m. sand	f. sand	v.f. sand	c. silt	m. silt	f. silt	v.f. silt	c. clay	m. clay	Sand	Silt	Clay	USDA texture	Percent organic carbon	> 2 mm	Remarks
E-8-14	2.70-3.00	0.01	0.09	2.32	17.95	28.03	19.44	4.13	4.87	0.91	3.57	18.67	48.4	29.4	22.2	loam	0.1	0	
E-8-15	3.00-3.09	0.02	0.15	4.32	22.53	26.34	18.89	3.30	4.64	1.34	3.83	14.64	53.4	28.2	18.5	f. s. loam	0.1	0	
E-8-17	3.09-3.19	0.05	0.16	14.58	39.00	18.72	10.00	0.84	1.07	1.60	2.99	11.00	72.5	13.5	14.0	f. s. loam	1.1	0.04	
E-8-18	2.75-2.85	1.34	3.45	9.65	22.41	24.00	17.03	3.66	3.63	1.40	2.39	11.04	60.9	25.7	13.4	f. s. loam	0.2	1.6	
E-8-19	2.85-3.00	0.30	1.34	7.81	17.85	22.25	21.75	6.01	4.51	2.22	3.26	12.70	49.6	34.5	16.0	loam	0.2	0.74	
E-8-21****	3.40-3.60	5.29	10.99	56.00	20.03	3.26	0.27	0.31	0.53	-0.38	0.54	3.17	95.6	0.7	3.7	sand	0.1	46	
E-25-1	0-1.45	0.12	0.52	1.34	1.54	1.73	15.86	1.44	10.69	10.42	10.88	45.46	5.3	38.4	56.3	clay	-	1.0	
E-25-1	0-1.45	0.33	0.66	1.39	1.56	1.68	15.91	2.45	7.06	11.17	8.32	49.48	5.6	36.6	57.8	clay	-	-	Hexametaphosphate doubled
E-25-2	1.45-3.75	0.19	0.77	2.54	3.99	3.17	17.33	1.12	7.94	13.45	11.75	37.75	10.7	39.8	49.5	clay	-	0.2	
E-25-2	1.45-3.75	0.18	0.54	2.44	3.80	3.10	13.21	1.59	6.33	13.13	13.54	42.15	10.1	34.3	55.7	clay	-	-	Hexametaphosphate doubled
E-25-3	3.75-4.85	0.50	2.21	6.10	7.39	5.60	12.00	3.90	7.46	15.12	10.90	28.80	21.8	38.5	39.7	clay	-	2.4	
E-25-3	3.75-4.85	0.61	1.78	5.41	7.14	5.16	12.41	3.37	7.10	12.01	11.70	33.32	20.1	34.9	45.0	clay	-	-	Hexametaphosphate doubled
E-25-4	4.85-5.40	0.91	2.73	7.62	10.03	6.44	12.71	4.95	8.13	12.51	7.86	26.10	27.7	38.3	34.0	clay	-	2.5	
E-25-4	4.85-5.40	0.69	2.90	7.67	8.75	5.81	13.43	3.39	7.07	10.44	9.39	30.47	25.8	34.3	39.9	clay	-	-	Hexametaphosphate doubled
E-25-5	5.40-7.00	0.33	1.77	5.53	6.98	5.61	11.90	3.80	9.31	15.33	11.47	27.95	20.2	40.3	39.4	clay	-	0.2	
E-25-5	5.40-7.00	0.53	2.04	6.70	8.78	6.32	13.18	3.37	8.20	12.81	10.03	28.04	24.4	37.6	38.1	clay	-	-	Hexametaphosphate doubled
E-25-6	7.00-10.10	1.84	3.94	9.08	11.67	7.22	12.92	5.13	6.52	10.20	7.94	23.53	33.8	34.8	31.5	clay	-	0.9	
E-25-6	7.00-10.10	1.76	4.04	9.64	10.84	7.25	14.15	2.62	6.93	9.31	7.29	26.18	33.5	33.0	33.5	clay	-	-	Hexametaphosphate doubled
E-25-7	10.10-11.50	1.33	3.42	9.33	10.23	7.34	13.88	2.65	6.98	8.75	7.70	28.40	31.7	32.3	36.1	clay	-	0.7	
E-25-7	10.10-11.50	1.67	3.77	9.23	10.48	7.16	14.49	2.59	6.12	7.84	7.89	28.76	32.3	31.0	36.7	clay	-	-	Hexametaphosphate doubled
E-25-8	11.50-12.20	2.16	4.60	10.71	12.70	7.51	10.90	6.02	6.18	9.42	6.38	23.41	37.7	32.5	29.8	clay	-	6.3	
E-25-8	11.50-12.20	1.00	4.16	11.57	11.95	7.52	15.61	1.75	5.48	8.02	7.58	25.36	36.2	30.9	32.9	clay	-	-	Hexametaphosphate doubled
E-25-9	12.20-13.45	0.35	1.42	8.02	9.64	7.60	11.03	8.89	12.65	16.07	9.38	14.96	27.0	48.6	24.3	loam	-	0.5	
E-25-9	12.20-13.45	0.17	1.30	6.83	9.79	7.55	17.76	2.80	12.27	14.33	8.63	18.58	25.6	47.2	27.2	loam	-	-	Hexametaphosphate doubled
E-25-10	13.45-15.00	2.36	5.40	12.71	14.89	8.53	11.80	3.69	7.89	8.47	6.08	18.16	43.9	31.9	24.2	loam	-	4.6	

Appendix A. Particle-size analyses and organic carbon determinations (Walkley-Black method) of floodplain and channel sediment along North Fish Creek, Wisconsin, 1995

[USDA, U.S. Department of Agriculture; v., very; f., fine; s., sand; si., silt; c., coarse; cl, clay; mm, millimeters; >, greater than]

		Size classes (mm)																	
		Percentage in each phi class interval																	
		-1-0	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	>9							
		2-1	1-.5	.5-.25	.25-.125	.125-.0625	.062-.031	.031-.016	.016-.008	.008-.004	.004-.002	<.002	Udden-Wentworth						
Sample number	Depth interval (meters)	v.c. sand	c. sand	m. sand	f. sand	v.f. sand	c. silt	m. silt	f. silt	v.f. silt	c. clay	m. clay	Sand	Silt	Clay	USDA texture	Percent organic carbon	> 2 mm	Remarks
E-25-10	13.45-15.00	1.82	6.07	14.27	14.62	8.38	12.38	3.12	6.72	5.98	5.56	21.08	45.2	28.2	26.6	loam	-	-	Hexametaphosphate doubled
E-25-11	15.00-15.35	0.07	0.59	2.66	4.20	5.95	15.46	6.45	10.63	15.04	12.39	26.57	13.5	47.6	39.0	si. cl. loam	-	0.2	
E-25-11	15.00-15.35	0.04	0.40	2.41	4.48	6.17	19.01	4.25	9.79	13.66	9.36	30.45	13.5	46.7	39.8	si. cl. loam	-	-	Hexametaphosphate doubled
E-25-12****	15.35-16.45	0.18	6.66	32.10	30.56	12.24	5.64	1.46	3.34	2.81	-0.45	5.48	81.7	13.3	5.0	loamy f. sand	-	0.0	
E-25-12	15.35-16.45	0.11	6.72	33.61	28.97	12.83	6.93	0.00	0.33	3.01	0.00	7.50	82.2	10.3	7.5	loamy f. sand	-	-	Hexametaphosphate doubled
E-25-13	15.35-16.45	0.05	0.15	1.19	4.99	8.69	17.12	5.82	9.14	14.10	9.87	28.87	15.1	46.2	38.7	si. cl. loam	-	0.1	Interbedded with E-25-12
E-25-13	15.35-16.45	0.00	0.07	1.24	5.98	9.21	17.52	5.12	8.15	14.66	12.10	25.95	16.5	45.5	38.1	si. cl. loam	-	0.9	Hexametaphosphate doubled
E-25-14	17.15-18.10	0.12	0.29	1.10	1.96	1.75	6.79	0.95	5.32	22.10	54.96	4.63	5.2	35.2	59.6	clay	-	8.7	
E-25-14	17.15-18.10	0.07	0.36	1.19	2.09	1.68	12.12	0.69	3.48	0.00	19.45	58.88	5.4	16.3	78.3	clay	-	-	Hexametaphosphate doubled
E-25-15****	17.7-18.55	0.05	0.22	4.39	40.65	33.87	9.02	2.97	0.16	0.30	-1.22	9.58	79.2	12.5	8.4	f. s. loam	-	0.0	
E-25-15****	17.7-18.55	0.03	0.12	3.86	43.65	34.25	9.16	0.58	-1.31	1.18	2.45	6.02	81.9	9.6	8.5	f. s. loam	-	-	Hexametaphosphate doubled
E-25-16	18.55-19.10	0.02	0.15	1.90	6.48	7.78	19.04	4.95	8.91	16.57	18.50	15.69	16.3	49.5	34.2	si. cl. loam	-	0.0	
E-25-16	18.55-19.10	0.00	0.21	1.70	5.50	7.26	13.61	5.12	13.54	13.12	11.85	28.09	14.7	45.4	39.9	si. cl. loam	-	-	Hexametaphosphate doubled
E-25-17	19.10-19.55	0.07	2.30	38.65	32.63	8.93	9.30	1.68	1.72	1.30	2.92	0.49	82.6	14.0	3.4	sand	-	0.0	
E-25-17	19.10-19.55	0.02	2.27	39.27	33.04	8.68	6.89	0.12	0.14	1.85	2.49	5.24	83.3	9.0	7.7	sand	-	-	Hexametaphosphate doubled
E-25-18	19.55-19.80	0.10	0.31	1.21	4.04	7.22	19.43	6.73	14.82	13.50	23.08	9.56	12.9	54.5	32.6	si. cl. loam	-	1.7	
E-25-18	19.55-19.80	0.04	0.21	1.08	3.45	6.75	14.10	6.91	16.35	13.52	7.97	29.63	11.5	50.9	37.6	si. cl. loam	-	-	Hexametaphosphate doubled
E-25-19	19.87-20.63	0.66	2.01	3.32	1.64	1.41	14.37	1.75	6.69	16.75	17.83	33.58	9.0	39.6	51.4	clay	-	3.5	
E-25-19	19.87-20.63	1.51	3.44	4.92	2.04	1.52	10.58	3.25	5.38	14.21	18.94	34.21	13.4	33.4	53.2	clay	-	-	Hexametaphosphate doubled
E-25-20	20.63-20.93	1.97	8.98	12.19	14.98	26.00	21.67	7.27	1.35	1.82	1.59	2.18	64.1	32.1	3.8	f. s. loam	-	9.5	
E-25-20	20.63-20.93	1.59	7.89	10.98	15.58	26.33	24.08	5.12	0.74	1.53	1.96	4.20	62.4	31.5	6.2	f. s. loam	-	-	Hexametaphosphate doubled
E-25-21****	21.53-21.99	0.00	0.26	12.66	48.81	25.48	8.13	1.94	2.26	-0.90	0.03	1.33	87.2	11.4	1.4	loamy f. sand	-	0.0	
E-25-21	21.53-21.99	0.01	0.18	13.50	49.35	23.68	9.12	0.54	0.64	0.49	0.00	2.50	86.7	10.8	2.5	loamy f. sand	-	-	Hexametaphosphate doubled
E-25-22	21.99-22.50	4.93	11.75	24.43	23.21	11.09	10.03	3.76	2.61	1.57	1.88	4.73	75.4	18.0	6.6	s. loam	-	19.3	
E-25-22	21.99-22.50	4.40	11.87	26.02	22.01	11.38	10.15	1.93	1.06	2.64	2.27	6.27	75.7	15.8	8.5	s. loam	-	-	Hexametaphosphate doubled

Appendix A. Particle-size analyses and organic carbon determinations (Walkley-Black method) of floodplain and channel sediment along North Fish Creek, Wisconsin, 1995

[USDA, U.S. Department of Agriculture; v., very; f., fine; s., sand; si., silt; c., coarse; cl, clay; mm, millimeters; >, greater than]

		Size classes (mm)																	
		Percentage in each phi class interval																	
		-1-0	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	>9							
		2-1	1-.5	.5-.25	.25-.125	.125-.0625	.062-.031	.031-.016	.016-.008	.008-.004	.004-.002	<.002	Udden-Wentworth						
Sample number	Depth interval (meters)	v.c. sand	c. sand	m. sand	f. sand	v.f. sand	c. silt	m. silt	f. silt	v.f. silt	c. clay	m. clay	Sand	Silt	Clay	USDA texture	Percent organic carbon	> 2 mm	Remarks
E-25-23	22.50-22.62	0.29	1.26	4.02	5.10	3.82	12.51	3.01	14.71	13.12	12.43	29.74	14.5	43.4	42.2	si. clay	-	0.1	
E-25-23	22.50-22.62	0.31	0.95	3.25	4.33	2.99	15.48	5.76	10.37	17.99	11.99	26.58	11.8	49.6	38.6	si. clay	-	-	Hexametaphosphate doubled
E-25-24	22.62-22.87	2.83	4.13	13.01	14.75	10.29	16.58	6.14	6.40	5.77	7.74	12.36	45.0	34.9	20.1	loam	-	4.6	
E-25-24	22.62-22.87	1.50	3.88	14.03	15.93	9.91	20.80	4.21	2.86	6.90	6.02	13.95	45.3	34.8	20.0	loam	-	-	Hexametaphosphate doubled
E-25-25	22.87-23.09	2.16	4.77	10.96	14.58	11.87	21.67	11.88	9.56	4.61	3.20	4.73	44.3	47.7	7.9	loam	-	2.8	
E-25-25	22.87-23.09	1.63	5.12	12.91	14.60	12.33	20.90	12.24	6.22	3.99	3.76	6.29	46.6	43.4	10.1	loam	-	-	Hexametaphosphate doubled
E-25-26	23.09-23.89	2.34	7.95	28.06	32.57	10.80	8.57	3.62	0.04	0.11	2.08	3.86	81.7	12.3	5.9	loamy sand	-	2.0	
E-25-26	23.09-23.89	2.09	7.07	29.26	30.96	11.22	8.46	0.80	0.06	2.42	1.81	5.84	80.6	11.7	7.7	loamy sand	-	-	Hexametaphosphate doubled
E-25-27****	23.89-24.89	1.30	5.65	27.86	32.53	13.61	10.30	2.52	3.27	-0.36	2.00	1.33	81.0	15.7	3.3	loamy sand	-	0.6	
E-25-27	23.89-24.89	1.03	5.30	27.23	34.31	13.26	8.19	2.60	0.76	1.42	0.87	5.02	81.1	13.0	5.9	loamy sand	-	-	Hexametaphosphate doubled
E-25-28	24.89-25.59	4.24	12.57	31.88	22.66	8.14	8.01	2.81	2.79	1.16	2.71	3.03	79.5	14.8	5.7	loamy sand	-	4.5	
E-25-28	24.89-25.59	4.21	12.57	32.74	21.19	8.03	8.10	1.89	1.68	2.02	0.84	6.73	78.7	13.7	7.6	loamy sand	-	-	Hexametaphosphate doubled
E-25-29	25.59-27.34	3.24	9.13	24.56	17.69	9.73	12.53	4.93	5.89	2.20	3.67	6.42	64.4	25.6	10.1	s. loam	-	7.5	
E-25-29	25.59-27.34	2.60	8.53	26.00	19.33	9.61	12.45	2.62	3.49	3.42	2.48	9.47	66.1	22.0	12.0	s. loam	-	-	Hexametaphosphate doubled
E-25-30****	27.34-27.94	2.09	13.56	50.95	20.73	3.83	4.18	1.09	0.61	-0.36	2.00	1.33	91.2	5.5	3.3	sand	-	1.7	
E-25-30****	27.34-27.94	2.10	10.47	50.86	22.22	4.73	2.12	0.23	-0.49	2.87	1.55	3.33	90.4	4.7	4.9	sand	-	-	Hexametaphosphate doubled
E-25-31****	27.94-28.09	30.58	25.94	24:50	9.96	2.10	5.59	-0.17	0.21	0.01	0.79	0.49	93.1	5.6	1.3	c. sand	-	47.1	
E-25-31****	27.94-28.09	20.90	23.31	30.97	14.23	2.48	1.44	0.24	-0.24	1.15	1.59	3.93	91.9	2.6	5.5	c. sand	-	-	Hexametaphosphate doubled
E-25-32	28.09-29.09	0.15	0.43	3.53	24.35	37.00	19.62	5.79	3.62	1.34	2.00	2.17	65.5	30.4	4.2	v. f. s. loam	-	0.0	
E-25-32	28.09-29.09	0.12	0.38	4.32	24.56	37.03	15.70	5.75	3.21	1.49	3.36	4.08	66.4	26.2	7.4	v. f. s. loam	-	-	Hexametaphosphate doubled
E-25-33	29.09-30.09	1.61	6.33	20.34	29.25	17.05	14.29	5.53	3.08	1.43	0.61	0.49	74.6	24.3	1.1	loamy sand	-	0.8	
E-25-33	29.09-30.09	1.18	5.52	20.43	31.30	16.94	14.06	2.79	2.97	1.42	0.94	2.44	75.4	21.2	3.4	loamy sand	-	-	Hexametaphosphate doubled
E-25-34	30.09-31.09	0.58	3.62	17.91	24.26	11.73	13.35	3.02	7.32	3.55	5.57	9.09	58.1	27.2	14.7	f. s. loam	-	1.5	
E-25-34	30.09-31.09	0.93	4.02	19.94	23.23	11.93	13.40	2.19	6.26	4.25	4.38	9.46	60.1	26.1	13.8	f. s. loam	-	-	Hexametaphosphate doubled

Appendix A. Particle-size analyses and organic carbon determinations (Walkley-Black method) of floodplain and channel sediment along North Fish Creek, Wisconsin, 1995

[USDA, U.S. Department of Agriculture; v., very; f., fine; s., sand; si., silt; c., coarse; cl, clay; mm, millimeters; >, greater than]

		Size classes (mm)																	
		Percentage in each phi class interval																	
		-1-0	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	>9							
		2-1	1-.5	.5-.25	.25-.125	.125-.0625	.062-.031	.031-.016	.016-.008	.008-.004	.004-.002	<.002	Udden-Wentworth						
Sample number	Depth interval (meters)	v.c. sand	c. sand	m. sand	f. sand	v.f. sand	c. silt	m. silt	f. silt	v.f. silt	c. clay	m. clay	Sand	Silt	Clay	USDA texture	Percent organic carbon	> 2 mm	Remarks
PB-1****	0.0-0.05	1.79	7.31	55.90	27.40	2.14	9.12	-1.36	-0.01	0.67	5.21	-8.17	94.5	8.4	-3.0	sand	-	0.83	> 2mm is average from 2 runs
PB-1 2nd run	0.0-0.05	1.36	6.23	57.58	29.84	2.71	0.98	0.98	0.62	-1.13	-0.45	1.28	97.7	1.5	0.8	sand	-	2.58	Hexametaphosphate doubled
PB-2****	0.0-0.05	16.38	23.78	40.86	14.96	1.45	3.73	-0.13	-0.87	1.13	1.16	-2.46	97.4	3.9	-1.3	c. sand	-	18.54	> 2mm is average from 2 runs, pebbles
PB-2 2nd run	0.0-0.05	9.12	17.10	43.54	24.83	2.79	0.06	0.93	1.62	0.00	-1.28	1.28	97.4	2.6	0.0	c. sand	-	20.29	Hexametaphosphate doubled
PB-3****	0.0-0.05	1.64	6.80	51.74	34.30	2.14	2.47	1.14	-0.88	0.31	1.98	-1.62	96.6	3.0	0.4	sand	-	0.19	> 2mm is average from 2 runs
PB-3 2nd run	0.0-0.05	2.03	5.86	52.31	35.14	2.39	0.26	0.26	0.92	0.00	-1.27	2.11	97.7	1.4	0.8	sand	-	0.77	Hexametaphosphate doubled
PB-4****	0.0-0.05	2.14	9.99	54.20	29.74	2.18	3.09	-0.17	0.21	0.77	0.50	-2.63	98.3	3.9	-2.1	sand	-	1.45	> 2mm is average from 2 runs
PB-4 2nd run	0.0-0.05	1.58	8.20	50.40	33.98	3.94	0.13	1.29	2.15	-0.83	-1.48	0.64	98.1	2.7	-0.8	sand	-	1.84	Hexametaphosphate doubled
PB-5****	0.0-0.05	11.35	24.30	37.26	22.34	2.51	4.24	-0.53	-0.47	0.30	1.33	-2.63	97.8	3.5	-1.3	c. sand	-	3.05	> 2mm is average from 2 runs
PB-5 2nd run	0.0-0.05	4.80	15.59	40.09	32.00	4.83	-0.08	0.89	2.44	-1.68	-0.33	1.47	97.3	1.6	1.1	c. sand	-	1.15	Hexametaphosphate doubled
PB-6****	0.0-0.05	19.29	34.28	38.99	5.91	0.57	2.29	0.23	0.27	1.14	-0.34	-2.63	99.0	3.9	-3.0	c. sand	-	21.72	> 2mm is average from 2 runs
PB-6 2nd run	0.0-0.05	8.83	28.80	49.83	9.70	1.11	0.39	0.39	0.96	0.00	-1.47	1.47	98.3	1.7	0.0	c. sand	-	18.36	Hexametaphosphate doubled
PB-7****	0.0-0.05	20.87	29.67	36.35	8.22	1.28	4.94	0.63	-0.96	1.13	0.35	-2.48	96.4	5.7	-2.1	c. sand	-	28.89	> 2mm is average from 2 runs, pebbles
PB-7 2nd run	0.0-0.05	12.67	26.33	46.68	11.53	1.26	0.66	0.66	-0.08	-0.54	-1.47	2.30	98.5	0.7	0.8	c. sand	-	45.49	Hexametaphosphate doubled
PB-8****	0.0-0.05	13.62	25.98	47.21	10.55	0.99	3.59	-0.69	0.14	0.29	0.18	-1.84	98.4	3.3	-1.7	c. sand	-	10.72	> 2mm is average from 2 runs, rock
PB-8 2nd run	0.0-0.05	6.57	20.13	54.52	15.58	1.52	0.01	0.01	1.37	-0.54	-2.10	2.93	98.3	0.9	0.8	c. sand	-	6.36	Hexametaphosphate doubled
PB-9****	0.0-0.05	24.93	33.92	35.36	4.12	0.52	3.32	0.66	-0.16	0.67	-0.70	-2.63	98.9	4.5	-3.3	c. sand	-	53.22	> 2mm is average from 2 runs; granules/pebbles, revised numbers for part. size same as first run
PB-9 2nd run	0.0-0.05	18.67	31.62	42.01	5.07	0.77	0.08	0.08	0.33	-0.30	-1.46	3.13	98.1	0.2	1.7	c. sand	-	58.6	Hexametaphosphate doubled
PB-10****	0.0-0.05	5.57	35.63	53.58	4.03	0.36	3.82	-0.17	-0.16	0.67	-0.01	-3.32	99.2	4.2	-3.3	c. sand	-	2.71	> 2mm is average from 2 runs, rock
PB-10 2nd r	0.0-0.05	3.38	33.26	57.47	4.25	0.46	0.51	0.51	0.17	-1.14	-1.16	2.30	98.8	0.1	1.1	c. sand	-	8.17	Hexametaphosphate doubled
PB-11****	0.0-0.05	12.32	31.31	43.65	8.40	1.04	5.87	0.63	-0.55	1.14	-1.09	-2.71	96.7	7.1	-3.8	c. sand	-	15.71	> 2mm is average from 2 runs; granules/pebbles
PB-11 2nd r	0.0-0.05	6.18	25.14	53.88	12.22	1.36	0.87	0.87	0.02	-0.86	-1.99	2.30	98.8	0.9	0.3	c. sand	-	13.46	Hexametaphosphate doubled
PB-12****	0.0-0.05	19.21	25.37	43.23	8.26	1.32	3.94	1.15	0.18	0.67	0.14	-3.47	97.4	5.9	-3.3	c. sand	-	74.87	> 2mm is average from 2 runs; granules/pebbles

Appendix A. Particle-size analyses and organic carbon determinations (Walkley-Black method) of floodplain and channel sediment along North Fish Creek, Wisconsin, 1995

[USDA, U.S. Department of Agriculture; v., very; f., fine; s., sand; si., silt; c., coarse; cl, clay; mm, millimeters; >, greater than]

		Size classes (mm)																	
		Percentage in each phi class interval																	
		-1-0	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	>9							
		2-1	1-.5	.5-.25	.25-.125	.125-.0625	.062-.031	.031-.016	.016-.008	.008-.004	.004-.002	<.002	Udden-Wentworth						
Sample number	Depth interval (meters)	v.c. sand	c. sand	m. sand	f. sand	v.f. sand	c. silt	m. silt	f. silt	v.f. silt	c. clay	m. clay	Sand	Silt	Clay	USDA texture	Percent organic carbon	> 2 mm	Remarks
PB-12 2nd n	0.0-0.05	8.91	23.10	54.12	10.38	1.31	0.94	0.94	-0.57	-0.54	-0.79	2.21	97.8	0.8	1.4	c. sand	-	-	Hexametaphosphate doubled
G-1-1-(1&2)	0-.49	0.05	2.20	53.50	37.54	2.27	7.43	-1.14	0.66	0.29	1.64	-4.45	95.6	7.2	-2.8	sand	0.2		trace organic debris
G-1-2-(6&7)	1.33-1.46	0.00	0.03	7.33	54.04	22.75	12.57	0.96	1.50	0.65	2.12	-1.95	84.2	15.7	0.2	loamy f. sand	0.1		
G-1-3-8	2.08-2.23	0.05	0.03	0.92	4.39	5.13	14.33	8.75	14.71	16.52	10.64	24.53	10.5	54.3	35.2	si. c. loam	0.2		
G-1-8-(1&2&	7.62-7.9	30.65	19.54	14.95	21.44	5.58	7.51	0.14	0.86	0.00	1.31	-1.98	92.2	8.5	-0.7	c. sand	0.0	36	
G-1-9-1****	8.23-8.74	0.02	0.07	9.79	76.86	10.95	4.48	-0.74	0.62	0.29	1.29	-3.62	97.7	4.7	-2.3	f. sand	0.4		
G-1-11-(1&2	15.24-15.45	0.12	0.63	2.62	3.36	2.40	9.85	1.45	-1.47	4.84	10.10	66.10	9.1	14.7	76.2	clay	1.4		
G-7-1-a	0-.12	0.00	0.02	1.92	13.87	16.25	23.11	10.11	9.33	8.03	6.56	10.80	32.1	50.6	17.4	loam	2.4		
G-7-1-b	.12-.31	0.00	0.05	1.05	12.20	15.34	23.85	10.63	9.64	7.83	5.20	14.20	28.6	52.0	19.4	si. loam	1.6		
G-7-1-c	.31-.6	0.00	0.03	9.53	32.04	20.00	12.33	7.71	5.20	3.29	2.53	7.34	61.6	28.5	9.9	f. s. loam	0.6		
G-7-1-d	.6-.76	0.00	0.03	5.00	28.57	29.53	13.94	3.91	6.04	3.70	1.97	7.35	63.1	27.6	9.3	f. s. loam	0.6		
G-7-1-e	.76-.97	0.00	0.01	1.26	25.66	38.63	17.63	6.09	0.98	4.30	2.28	3.17	65.6	29.0	5.5	v. f. s. loam	0.3		
G-7-1-f	.97-1.12	0.00	0.00	0.49	23.07	46.01	16.76	3.79	2.33	3.35	1.05	3.16	69.6	26.2	4.2	v. f. s. loam	0.1		
G-7-2-a	1.12-1.26	0.00	0.01	0.36	11.41	34.47	24.65	8.03	6.61	3.00	2.44	9.03	46.3	42.3	11.5	loam	0.9		
G-7-2-b	1.27-1.33	0.00	0.00	0.35	8.96	36.74	30.55	8.02	3.78	3.27	1.80	6.52	46.1	45.6	8.3	loam	0.7		
G-7-2-c	1.34-1.53	0.00	0.01	0.16	10.89	38.82	27.24	7.35	3.88	3.32	1.81	6.52	49.9	41.8	8.3	loam	0.5		
G-7-2-d	1.53-1.62	0.00	0.02	0.17	9.47	23.78	33.46	4.78	8.86	5.58	3.13	10.75	33.4	52.7	13.9	si. loam	1.4		
G-7-2-e	1.62-1.77	0.00	0.01	0.21	12.52	37.61	22.52	10.03	5.20	2.71	1.84	7.35	50.4	40.5	9.2	loam	1.1		
G-7-2-f	1.77-2.03	0.00	0.00	0.10	6.07	20.47	26.18	11.12	7.26	7.79	3.54	17.47	26.6	52.4	21.0	si. loam	1.5		
G-7-3-a	2.03-2.53	0.00	0.00	0.02	0.28	4.71	29.26	13.24	11.56	10.19	6.18	24.56	5.0	64.3	30.7	si. cl. loam	1.9		
G-7-3-d	2.53-2.95	0.00	0.00	0.04	1.15	11.81	24.68	11.85	9.16	11.41	8.09	21.80	13.0	57.1	29.9	si. cl. loam	1.3		
G-7-4-a	2.95-3.26	0.00	0.02	0.27	11.69	29.14	23.59	11.02	5.73	4.16	3.42	10.96	41.1	44.5	14.4	loam	2.6	0.6	all organic debris
G-7-4-c	3.32-3.40	0.00	0.01	0.37	5.75	19.78	24.09	11.19	10.28	7.75	5.75	15.02	25.9	53.3	20.8	si. loam	2.2		trace organic debris

Appendix A. Particle-size analyses and organic carbon determinations (Walkley-Black method) of floodplain and channel sediment along North Fish Creek, Wisconsin, 1995

[USDA, U.S. Department of Agriculture; v., very; f., fine; s., sand; si., silt; c., coarse; cl, clay; mm, millimeters; >, greater than]

		Size classes (mm)																	
		Percentage in each phi class interval																	
		-1-0	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	>9							
		2-1	1-.5	.5-.25	.25-.125	.125-.0625	.062-.031	.031-.016	.016-.008	.008-.004	.004-.002	<002	Udden-Wentworth						
Sample number	Depth interval (meters)	v.c. sand	c. sand	m. sand	f. sand	v.f. sand	c. silt	m. silt	f. silt	v.f. silt	c. clay	m. clay	Sand	Silt	Clay	USDA texture	Percent organic carbon	> 2 mm	Remarks
G-7-4-d	3.40-3.81	0.00	0.04	0.45	6.53	18.92	21.80	12.13	8.57	9.02	5.05	17.5	25.9	51.5	22.5	si. loam	1.6		
G-7-4-f	3.60-3.81	0.00	0.01	0.08	1.78	11.03	25.47	9.24	11.49	9.94	8.27	22.69	12.9	56.1	31.0	si. cl. loam	2.1		
G-7-4-g*	3.81-3.86	0.00	0.02	0.05	0.67	4.92	18.17	11.14	17.18	18.04	6.57	23.24	5.7	64.5	29.8	si. cl. loam	2.5		sample size too small-sand OK, silt and clay off, H2O2 treatment after sieving
G-7-5-a**	3.86-4.07	0.00	0.39	6.39	17.13	12.45	17.82	4.98	12.26	8.49	5.12	14.98	36.4	43.6	20.1	loam	2.3	0.5	organic debris,H2O2 treatment after sieving
G-7-5-d***	4.17-4.20	0.03	2.22	15.40	27.92	15.58	17.55	2.46	4.47	4.43	3.20	6.74	61.2	28.9	9.9	f. s. loam	3.0	1.6	sample size too small-sand OK, silt and clay off, all organic debris
G-7-5-e	4.20-4.24	0.55	7.10	34.50	31.35	7.23	7.91	1.02	3.19	1.95	1.34	3.84	80.7	14.1	5.2	loamy sand	0.9	0.7	.5% sediment, .2 % organic
G-7-5-g	4.44-4.57	0.00	0.11	0.79	3.30	20.38	26.91	11.46	9.69	6.90	4.67	15.79	24.6	55.0	20.5	si. loam	0.7	0.5	all organic debris
G-7-5-h****	4.57-4.73	0.00	1.89	47.92	33.81	4.36	5.52	-0.50	1.57	1.93	1.33	2.17	88.0	8.5	3.5	sand	0.3		
G-7-5-i	4.73-4.78	0.00	1.56	10.27	15.13	20.21	23.00	6.19	4.58	5.54	3.71	9.82	47.2	39.3	13.5	loam	0.9		
G-7-6-b****	5.60-5.75	16.98	23.82	31.38	19.98	3.59	4.43	-1.40	1.24	1.14	0.03	-1.17	95.8	5.4	-1.1	c. sand	0.1	32.5	
G-7-6-c****	5.75-5.89	19.27	23.37	36.36	14.76	2.88	4.35	-1.31	0.46	1.35	0.49	-1.99	96.6	4.9	-1.5	c. sand	0.1	39.4	
G-7-7-a	8.48-8.70	0.02	0.19	4.64	61.14	13.73	10.42	0.78	2.10	2.80	2.01	2.17	79.7	16.1	4.2	loamy f. sand	0.3		
G-7-7-b	8.70-8.85	0.00	0.15	5.14	55.39	11.05	12.91	2.87	2.53	3.28	1.96	4.70	71.7	21.6	6.7	f. s. loam	0.4		
G-7-7-c****	8.85-9.00	0.02	0.56	21.81	61.30	8.57	5.83	0.24	0.68	0.94	-0.44	0.50	92.3	7.7	0.1	f. sand	0.2		
G-7-7-d****	9.00-9.14	0.12	0.62	34.34	53.26	5.22	4.44	-0.58	1.08	0.94	0.73	-0.17	93.6	5.9	0.6	f. sand	0.0		
G-7-8-b	11.58-12.19	0.02	1.19	18.84	29.72	16.20	12.37	6.90	2.75	2.95	0.09	8.96	66.0	25.0	9.1	f. s. loam	0.6	0.4	all organic debris
G-7-9-a	15.24-15.46	0.00	0.01	0.40	2.80	12.25	27.82	11.89	11.13	3.34	3.70	26.66	15.5	54.2	30.4	si. cl. loam	0.4		
G-7-9-b****	15.46-15.62	1.55	17.43	52.84	20.40	2.06	3.05	0.58	1.81	0.65	-1.06	0.69	94.3	6.1	-0.4	sand	0.0	0.2	
G-7-9-c	15.62-15.85	0.00	0.00	0.06	0.63	6.38	18.12	15.58	12.08	4.08	5.38	37.69	7.1	49.9	43.1	si. clay	0.2		
P-21	0-.1	0.03	0.65	16.21	27.87	35.12	13.65	1.58	2.55	0.20	0.64	1.50	79.9	18.0	2.1	loamy f. sand	1.4	0.4	all organic debris, H2O2 treatment after sieving
P-22****	0-.1	0.13	2.00	71.25	24.33	0.89	1.67	0.14	1.42	-0.26	-1.38	-0.19	98.6	3.0	-1.6	sand	0.0		
P-23****	0-.1	1.62	8.86	56.94	27.98	2.76	1.23	0.61	1.84	-1.09	-0.57	-0.17	98.2	2.6	-0.7	sand	0.1	0.6	

Appendix A. Particle-size analyses and organic carbon determinations (Walkley-Black method) of floodplain and channel sediment along North Fish Creek, Wisconsin, 1995

[USDA, U.S. Department of Agriculture; v., very; f., fine; s., sand; si., silt; c., coarse; cl, clay; mm, millimeters; >, greater than]

		Size classes (mm)																	
		Percentage in each phi class interval																	
		-1-0	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	>9							
		2-1	1-.5	.5-.25	.25-.125	.125-.0625	.062-.031	.031-.016	.016-.008	.008-.004	.004-.002	<.002	Udden-Wentworth						
Sample number	Depth interval (meters)	v.c. sand	c. sand	m. sand	f. sand	v.f. sand	c. silt	m. silt	f. silt	v.f. silt	c. clay	m. clay	Sand	Silt	Clay	USDA texture	Percent organic carbon	> 2 mm	Remarks
													0.0	0.0	0.0				
P-32****	0-.1	2.09	10.18	59.25	25.20	1.28	2.67	0.17	0.91	0.59	0.31	-2.64	98.0	4.3	-2.3	sand	0.0	1.7	
P-33****	0-.1	2.12	11.86	59.86	24.68	0.76	1.39	0.25	0.84	0.28	-0.21	-1.84	99.3	2.8	-2.1	sand	0.0	1.1	
P-34	0-.1	22.06	37.37	37.16	2.01	0.26	2.64	-0.17	0.43	0.57	-2.95	0.62	98.9	3.5	-2.3	c. sand	0.0	7	includes trace organic debris
P-35-1	0-.04	0.00	0.04	0.05	2.24	9.89	25.53	12.54	14.20	9.76	9.02	16.75	12.2	62.0	25.8	si. loam	2.4		H2O2 treatment after sieving
P-35-7	.24-.28	0.00	0.01	0.11	6.90	16.68	20.77	10.28	11.35	11.29	7.64	14.96	23.7	53.7	22.6	si. loam	1.7		H2O2 treatment after sieving
VC-3-1-1***	0-.8	0.00	0.19	27.28	47.64	12.52	8.51	0.88	1.96	0.70	0.59	-0.27	87.6	12.1	0.3	f. sand	0.6	0.2	all organic debris
VC-3-2-1	.51-.64	0.00	0.03	1.64	10.68	20.54	24.84	8.40	8.28	7.61	6.27	11.71	32.9	49.1	18.0	loam	0.8		
VC-3-2-3	.85-1.02	0.00	0.01	2.69	45.64	31.32	12.31	2.06	1.81	1.44	1.33	1.39	79.7	17.6	2.7	loamy sand	0.0		
VC-3-2-7	1.34-1.53	0.02	0.02	0.34	20.58	43.38	19.23	5.36	2.34	2.39	2.37	3.97	64.3	29.3	6.3	f. s. loam	0.2		
VC-3-2-9***	1.76-1.82	11.64	12.36	30.13	29.94	9.18	5.57	1.54	0.57	0.60	1.32	-2.85	93.3	8.3	-1.5	sand	0.1	33.3	
VC-3-2-14**	2.41-2.55	17.19	31.05	36.26	11.18	1.84	4.65	0.26	0.61	-0.35	0.95	-3.64	97.5	5.2	-2.7	c. sand	0.1	11	
VC-5-1-1	0-.14	0.00	0.03	0.07	2.57	4.04	16.48	6.11	12.67	18.77	13.39	25.87	6.7	54.0	39.3	si. cl. loam	2.7		
VC-5-1-6	.39-.49	0.00	0.01	0.82	30.18	37.20	15.87	7.20	2.21	2.22	2.87	1.43	68.2	27.5	4.3	v. f. s. loam	0.5		
VC-5-2-7***	1.24-1.54	2.99	8.52	31.56	42.57	9.44	5.38	0.83	0.19	0.88	0.43	-2.84	95.1	7.3	-2.4	sand	0.5	3.05	includes trace organic debris
VC-5-2-10**	1.62-1.7	0.00	0.55	8.92	60.31	20.86	7.76	1.27	0.25	-0.47	2.50	-1.95	90.6	8.8	0.6	f. sand	0.4	0.1	all organic debris
VC-5-2-18**	2.48-2.55	0.04	0.11	13.22	59.68	16.24	8.70	2.11	-0.11	0.37	2.16	-2.54	89.3	11.1	-0.4	f. sand	0.3	1.1	
VC-5-2-24**	2.77-2.86	37.06	36.05	13.54	7.37	2.00	5.31	0.00	0.33	-0.28	0.62	-2.00	96.0	5.4	-1.4	c. sand	0.2	15.8	
VC-6-1-2	.1-.27	0.00	0.04	0.30	2.16	8.46	26.99	12.00	11.37	13.18	7.71	17.79	11.0	63.5	25.5	si. loam	1.8		H2O2 treatment after sieving
VC-6-2-2	.92-1.03	0.00	0.00	0.39	9.58	20.19	23.92	11.79	9.90	7.84	3.96	12.43	30.2	53.5	16.4	si. loam	0.2		
VC-6-2-4***	1.19-1.22	0.96	3.60	21.52	53.88	13.87	5.17	0.02	0.98	0.37	0.78	-1.16	93.8	6.5	-0.4	f. sand	0.1		
VC-6-2-8	1.76-1.84	0.00	0.23	25.88	47.20	15.22	9.25	0.81	0.65	1.13	0.61	-0.98	88.5	11.8	-0.4	sand	0.6		
VC-6-2-13**	2.05-2.11	0.03	1.99	42.61	44.26	8.30	4.78	0.37	0.53	0.02	-0.05	-2.83	97.2	5.7	-2.9	sand	0.1		
VC-6-2-16**	2.68-2.77	17.77	34.73	29.72	13.17	2.14	3.58	0.84	0.92	0.30	-0.33	-2.83	97.5	5.6	-3.2	c. sand	0.0	18.7	

Appendix A. Particle-size analyses and organic carbon determinations (Walkley-Black method) of floodplain and channel sediment along North Fish Creek, Wisconsin, 1995

[USDA, U.S. Department of Agriculture; v., very; f., fine; s., sand; si., silt; c., coarse; cl, clay; mm, millimeters; >, greater than]

		Size classes (mm)																	
		Percentage in each phi class interval																	
		-1-0	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	>9							
		2-1	1-.5	.5-.25	.25-.125	.125-.0625	.062-.031	.031-.016	.016-.008	.008-.004	.004-.002	<.002	Udden-Wentworth						
Sample number	Depth interval (meters)	v.c. sand	c. sand	m. sand	f. sand	v.f. sand	c. silt	m. silt	f. silt	v.f. silt	c. clay	m. clay	Sand	Silt	Clay	USDA texture	Percent organic carbon	> 2 mm	Remarks
VC-7-1-1	0-.1	0.00	0.02	0.04	0.08	0.81	16.43	9.58	15.44	17.22	13.21	27.17	1.0	58.7	40.4	si. clay	3.3		H2O2 treatment after sieving
VC-7-1-7***	.49-.59	1.44	3.23	23.62	54.55	12.35	4.69	-0.02	0.97	0.38	0.63	-1.84	95.2	6.0	-1.2	f. sand	0.1	0.2	
VC-7-1-9	.61-.69	0.00	0.06	0.67	7.20	9.05	24.14	11.51	13.49	9.42	8.69	15.76	17.0	58.6	24.5	si. loam	2.1		H2O2 treatment after sieving
VC-7-2-2	.83-.9	0.47	1.99	10.60	34.06	20.46	14.16	4.51	4.27	2.77	2.71	3.99	67.6	25.7	6.7	f. s. loam	0.7		
VC-7-2-7	1.21-1.29	0.02	0.98	9.42	16.13	16.18	23.51	6.00	6.63	4.87	4.84	11.42	42.7	41.0	16.3	loam	2.0	0.1	all organic debris, H2O2 treatment after sieving
VC-7-2-11**	1.53-1.6	22.48	30.41	19.10	18.72	4.67	4.07	0.82	-0.43	2.21	0.63	-2.67	95.4	6.7	-2.0	c. sand	0.1	0.1	
VC-7-3-2***	2.68-2.92	10.21	21.28	38.37	23.22	3.57	3.19	0.43	1.47	-0.53	1.44	-2.64	96.7	4.6	-1.2	c. sand	0.1	6.7	
VC-8-1-1	.01-.16	0.00	0.04	0.03	0.05	0.06	12.98	6.91	12.28	22.73	15.96	28.95	0.2	54.9	44.9	si. clay	3.9		H2O2 treatment after sieving
VC-8-3-3	1.3-1.43	0.01	0.04	0.03	0.89	7.16	20.25	7.87	9.59	14.27	14.26	25.61	8.1	52.0	39.9	si. cl. loam	1.9		
VC-8-3-19	2.9-3.1	0.00	0.02	0.05	0.27	2.08	21.72	11.51	15.63	15.64	9.82	23.26	2.4	64.5	33.1	si. cl. loam	3.0		H2O2 treatment after sieving

* 2nd run, low sample weight (20.358 grams)

**2nd run, adequate sample weight (30.0 grams)

***low sample weight (17.1 g)

****clay has negative value (percentage of clay in sample is negligible)

Appendix A. Comparison of sediment texture classification in the field and laboratory.

Core or exposure	Comments on field texturing
E-4	Sand classification accurate. Silt loam was classified in the field toward the coarser end as fine sand loam a few times but not always. Sometimes loamy sand was classified in the field as sandy loam and vice versa.
E-7	Good match between field and laboratory textures in general. Sometimes silt loam was classified in the field as a fine sandy loam but not always.
E-8	Sometimes sand loam was classified in the field as sand but not always. Sometimes loam was classified in the field as sandy clay but not always.
E-25	Good match between field and laboratory textures in general. Sometimes clay was classified as silt but not always.
G-1	Good match between field and laboratory textures in general.
G-7	Good match between field and laboratory textures in general. Sometimes silt loam was classified as silty clay but not always.
P-21 to P-25	Sediment texture not described in the field.
VC-1 to VC-8	Good match between field and laboratory textures in general. Sometimes silty clay loam was classified as silty clay but not always. Sometimes fine sand was classified as medium sand but not always.

APPENDIX B
Results from Radiometric Dating

Appendix B. Results from radiocarbon age dating of selected samples from North Fish Creek.

[ams, Accelerator mass spectrometry; UW, University of Wisconsin-Madison; -, sample at laboratory; nd, not determined]

Site name	Sample number	Depth (meters)	Description	Type of material	Type of analysis	Laboratory	Date submitted	Conventional radiocarbon age (1 sigma) C-14 yr B.P.	Calendar calibrated date (2 sigma) (Suiver and Becker, 1993)*	C-13/C-12 relative to PDB-1
Fish Creek slough	P-19-6-a	1.15-1.23	backwater	wood/organics	ams	Beta Analytic	10/12/97	450 +/- 60	AD 1140-1340, 1400 - 1530, 1560-1630 (AD 1440)	-26.9
Fish Creek slough	P-19-6-e	1.42-1.52	backwater	wood	ams	UW, Livermore	10/3/97	-	-	-
Fish Creek slough	P-19-7-c	1.99-2.02	backwater	organics/wood	ams	UW, Livermore	10/3/97	-	-	-
Fish Creek slough	P-19-9-b	2.73	backwater	1 piece lg wood	ams	UW, Livermore	12/10/97	-	-	-
Fish Creek slough	P-19-10-a	2.92-3.11	backwater	wood bits/organics	ams	UW, Livermore	10/3/97	-	-	-
Confluence	G-7-4-b	3.26	overbank	wood	conven., extended counting	Beta Analytic	10/12/97	610 +/- 70	AD 1280 -1440 (AD 1350)	-25.9
Confluence	G-7-5-c	4.07-4.17	overbank	wood	conven., extended counting	Beta Analytic	10/12/97	950 +/- 60	AD 990-1220, 1250-1260 (AD 1120)	-26.0
Confluence	G-7-6-d	5.89	point bar	wood	ams	UW/Arizona	11/1/96	3650 +/- 55	BC 2200-2160, 2140-1880, 1840-1830 (BC 1990)	nd
Confluence	G-7-8-b	11.58-12.19	overbank	wood	ams	UW/Arizona	11/1/96	5850 +/- 60	BC 4890-4880, 4850-4540 (BC 4740)	nd
Ashland Junction	G-6-3-2P	1.98-2.03	buried surface	organic debris	ams	UW/Livermore	10/3/97	-	-	-
Ashland Junction	C-40-1C	2.28-2.38	buried surface	wood	ams	UW/Livermore	10/3/97	-	-	-
Ashland Junction	C-45-3	1.95-2.1	buried surface	wood/organics	ams	UW/Livermore	10/3/97	-	-	-
Ashland Junction	C-54-3	3.8-4.0	channel bottom	1 piece wood	ams	UW/Arizona	11/1/96	3105 +/- 50	BC 1430-1420, 1410-1370,1360-1290, 1280-1260 (BC 1330)	nd
Fiorio	G-1-8-2C	7.68-7.8	point bar	wood	ams	UW/Arizona	11/1/96	1830 +/- 60	AD 30-40, 60-360, 370-380 (AD 190)	nd
Hanson	VC-3-2-1C	2.5	channel	wood	ams	UW/Arizona	11/1/96	-	-	-
Hanson	VC-5-2-10C	1.65	channel	wood	conven	Beta Analytic	10/12/97	150 +/- 70	AD 1650 - 1955* (AD 1809)	-22.3
Hanson	VC-5-2-25P	2.9	channel	wood	ams	UW/Arizona	11/1/96	-	-	-
Hanson	VC-6-2-12P	1.99-2.05	buried surface	peat/organics	ams	UW/Arizona	11/1/96	-	-	-
Hanson	VC-8-3-4C	1.43-1.47	overbank	1 piece lg wood	conven, extended counting	Beta Analytic	10/12/97	3950 +/- 80	BC 2830-2820, 2670-2650, 2630-2610, 2600-2200 (BC 2470)	-25.3
Hanson	VC-8-3-8C	1.77-1.94	overbank	wood bits	ams	UW/Livermore	10/3/97	-	-	-
Hanson	VC-8-3-19C	2.9-3.0	overbank	wood bits	ams	UW/Arizona	11/1/96	4935 +/- 55	BC 3910-3880, 3870-3860, 3840-3830, 3800-3640 (BC 3710)	nd

Appendix B. Results from radiocarbon dating of selected samples from North Fish Creek.

Site name	Sample number	Depth (meters)	Description	Type of material	Type of analysis	Laboratory	Date submitted	Conventional radiocarbon age (1 sigma) C-14 yr B.P.	Calendar calibrated date (2 sigma) (Suiver and Becker, 1993)*	C-13/C-12 relative to PDB-1
Skulan	E-4-27	2.08-2.11	buried surface	wood bits	conven	Beta Analytic	10/12/97	280 +/- 80	AD 1140-1700, 1720-1820, 1840-1860, 1870-1880, 1920-1950 (AD 1650)	-25.4
Skulan	E-4-6C	2.55-2.65	overbank	1 piece wood	conven	Beta Analytic	8/1/94	420 +/- 60	AD 1410 -1640 (AD 1450)	nd
Skulan	C-24-4	2.6-2.7	buried surface	wood	ams	UW/Arizona	11/1/96	3255 +/- 55	BC 1690-1670, 1660-1650, 1640-1430, 1430-1410 (BC 1500)	nd
Moquah	E-8-1	3.3-3.4	channel	1 piece wood	conven	Beta Analytic	8/1/94	3690 +/- 70	BC 2280-2250, 2230-1880, 1840-1830 (BC 2090)	nd
Moquah	C-35	1.88-1.9	channel	wood	ams	UW/Arizona	11/1/96	140 +/- 40	AD 1670-1955* (AD 1810)	nd

* Ages in parentheses () are the average calendar ages used for estimating sedimentation rates

Appendix B. Results from Pb-210, Cs-137, and Ra-226 age dating. Samples collected on September 1, 1995 from a backwater environment in Fish Creek Slough.

[pci/g, picocuries per gram)

Site name	Sample number	Depth (cm)	Type of material	Concentration of ^{210}Pb (pci/g)	Uncertainty (2 sigma)	Concentration of ^{137}Cs (pci/g)	Uncertainty (2 sigma)	Concentration of ^{226}Ra (pci/g)	Uncertainty (2 sigma)
Fish Creek slough	P-7-1	0.0-1.0	organic-rich clay	1.868	0.256	0.385	0.075	0.734	0.188
Fish Creek slough	P-7-2	1.0-2.0	organic-rich clay	1.690	0.270	0.247	0.074	0.540	0.200
Fish Creek slough	P-7-3	2.0-3.0	organic-rich clay	1.536	0.226	0.097	0.040	0.579	0.166
Fish Creek slough	P-7-4	3.0-4.0	organic-rich clay	1.491	0.214	0.101	0.041	0.622	0.155
Fish Creek slough	P-7-5	4.0-5.0	organic-rich clay	1.492	0.242	0.021	0.035	0.792	0.189
Fish Creek slough	P-7-6	5.0-6.0	organic-rich clay	1.686	0.264	0.036	0.041	0.763	0.185
Fish Creek slough	P-7-7	6.0-7.0	organic-rich clay	1.505	0.242	0.009	0.036	0.802	0.179
Fish Creek slough	P-7-8	7.0-8.0	organic-rich clay	1.692	0.137	0.004	0.038	1.001	0.169
Fish Creek slough	P-7-9	8.0-9.0	organic-rich clay	1.865	0.328	0.031	0.043	0.684	0.238
Fish Creek slough	P-7-10	9.0-10.0	organic-rich clay	1.280	0.198	0.026	0.039	0.555	0.167

APPENDIX C
Results of Macrofossil Analyses of Selected Core Samples

Appendix C. Results of macrofossil analyses of selected core samples from Fish Creek Slough and the floodplain of North Fish Creek (reach 2, Hanson site)

		Fish Creek Slough (Core P-19)			North Fish Creek floodplain (Core VC-8)		
Macrofossil	**Sample type**	**Depth 31-34 cm**	**Depth 171 cm**	**Depth 260-270 cm**	**Depth 16-21 cm**	**Depth 175-177 cm**	**Depth 210-313 cm**
		Trees					
Larix laricina	Needles	~299	1	--	--	1	--
Larix laricina	Cones	2	--	--	--	--	--
Larix laricina	Cone scales	2	--	--	--	--	--
Larix laricina	Short shoots	4	--	--	--	--	--
Larix laricina	Seeds	6	--	--	--	--	--
Picea glauca type	Needles	22	--	--	--	--	--
Abies balsamea	Needles	--	--	--	10	2	28
Abies balsamea	Cone scales	--	--	--	2	--	--
Abies balsamea	cf. Twig fragments	--	--	--	--	--	19
Pinus strobus	Needles	--	1	--	--	--	--
Thuja occidentalis	Shoots	--	--	--	1	--	--
cf. Betula papyrifera	Fruit	--	--	--	--	1	--
Populus	Bud scales	4	--	--	--	--	--
Alnus incana spp. rugosa	Fruits	25	--	--	1	--	16
Alnus incana spp. rugosa	Female catkin scales	1	--	--	--	--	3
Alnus incana spp. rugosa	Male catkin scales	10	--	--	--	--	18
Salix sp.	Capsules	11	--	--	--	--	--
Salix sp.	Bud scales	1	--	--	--	--	--
Salix sp.	cf. Stipule	1	--	--	--	--	--
Ulmus americana	Bud scales	--	--	--	--	3	14
Ulmus americana	Buds	--	--	--	--	1	7
Other	Bud scales	3	--	--	--	--	5
Other	Buds	2	--	--	--	--	8

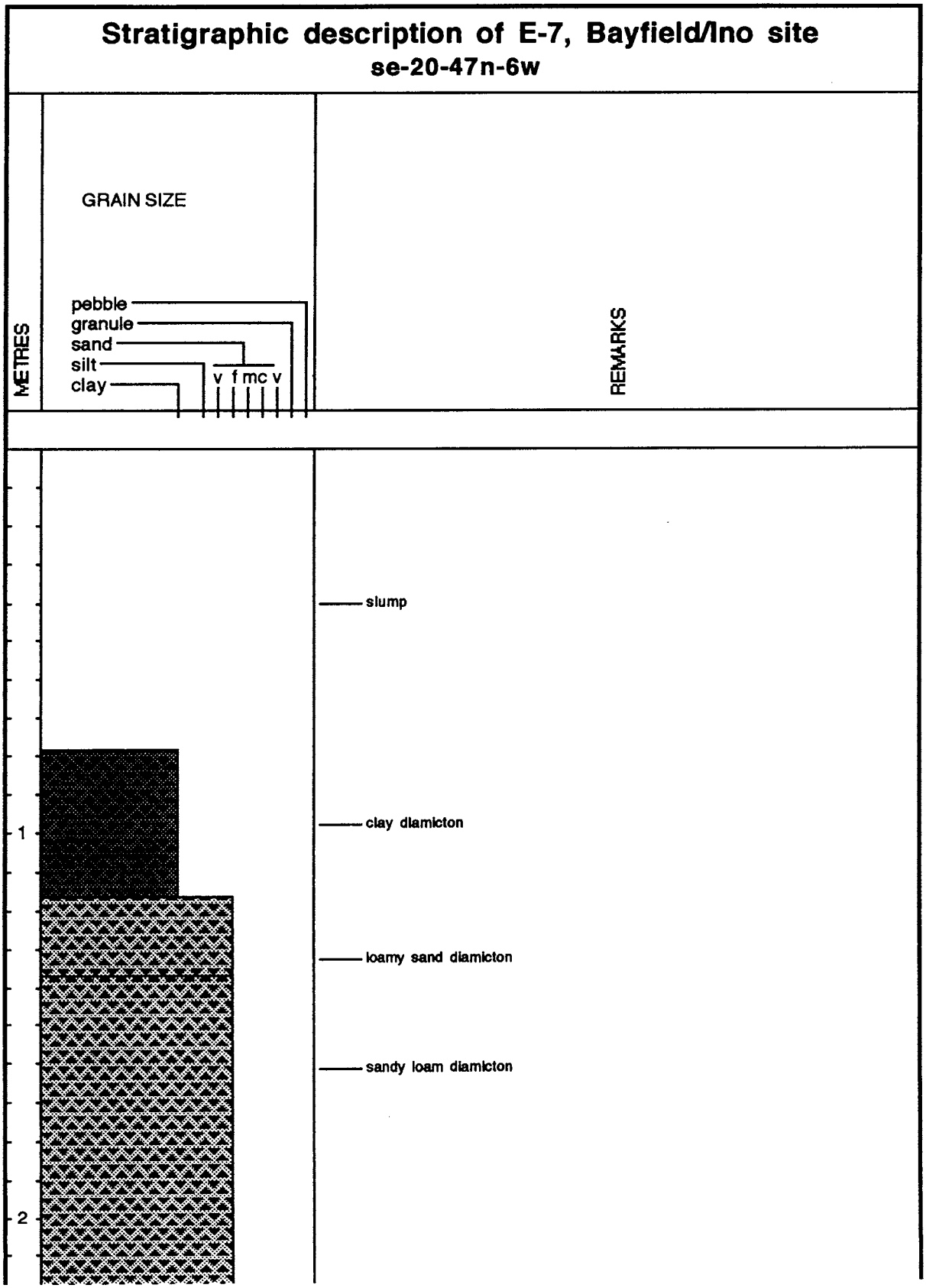
Appendix C. Results of macrofossil analyses of selected core samples from Fish Creek Slough and the floodplain of North Fish Creek (reach 2, Hanson site) (Continued)

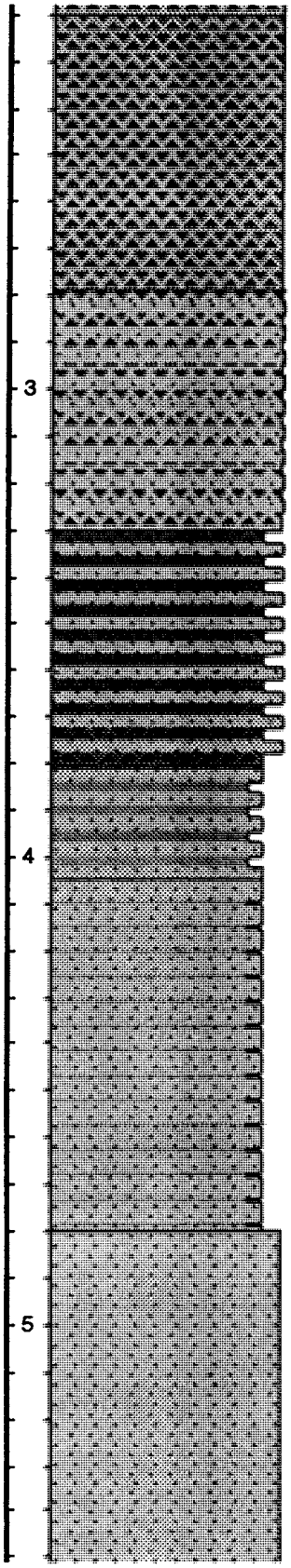
		Fish Creek Slough (Core P-19)			North Fish Creek floodplain (Core VC-8)		
Macrofossil	**Sample type**	**Depth 31-34 cm**	**Depth 171 cm**	**Depth 260-270 cm**	**Depth 16-21 cm**	**Depth 175-177 cm**	**Depth 210-313 cm**
Conifer	Seed wing	--	--	1	--	--	--
		Wetland shrubs					
Caltha palustris	Seeds	1	--	--	--	--	--
Carex disperma	Achenes	2	--	--	--	--	--
Carex cf. lacustris	Perigynia	--	--	1	--	--	--
Carex limosa type	Achenes	5	--	--	--	--	--
Carex stipata		--	--	--	--	--	5
Carex stipata type		--	--	--	--	--	6
Glyceria striata	Caryopsis	--	--	1	--	--	--
Hypericum cf. pyramidatum	Seeds	--	--	1	--	--	--
Lycopus americana	Seeds	--	--	2	--	--	--
Pilea pumila	Fruits	--	--	--	--	--	1
cf. Pilea	Fruits	--	--	--	5	--	--
		Aquatic plants					
Alismataceae	Embryos	--	--	2	--	--	--
Chara	Oospores	--	--	4	--	--	--
Eleocharis palustris type	Fruits	--	--	25	--	--	--
Myriophyllum exalbescens type	Seeds	--	--	4	--	--	--
Naias flexilis	Seeds	--	--	3	--	--	--
Nymphaea sp.	Seeds	--	--	1	--	--	--
Potamogeton (large)	Fruits	--	--	1	--	--	--
Potamogeton (small)	Fruits	--	--	1	--	--	--
Sparganium americanum type	Fruits	--	--	1	--	--	--

Appendix C. Results of macrofossil analyses of selected core samples from Fish Creek Slough and the floodplain of North Fish Creek (reach 2, Hanson site) (Continued)

		Fish Creek Slough (Core P-19)			North Fish Creek floodplain (Core VC-8)		
Macrofossil	**Sample type**	**Depth 31-34 cm**	**Depth 171 cm**	**Depth 260-270 cm**	**Depth 16-21 cm**	**Depth 175-177 cm**	**Depth 210-313 cm**
Typha sp.	Seeds	--	--	2	--	--	--
		Other					
Carex (biconvex)	Fruits	4	6	17	1	2	11
Carex (trigonous)	Fruits	--	2	4	--	--	--
Carex (trigonous)	Perigynia	--	5	--	--	--	--
Viola	Seeds	1	--	--	--	--	1
Other bracts with asymmetrical bases		8	--	--	--	--	6
Other bract-like organs		6	--	--	--	--	--
Catkin fragment		1	--	--	--	--	--
cf. winged umbel	Fruit	1	--	--	--	--	--
cf. Ericaceae	Fruiting head	1	1	--	--	--	--
Polygonum sp.	Fruit	--	--	--	--	--	1
Twigs		9	--	--	--	--	1
Insects		present	present	present	--	--	--
Sphagnum	Leaf	--	1	--	--	--	--
Other mosses		present	none	abundant	--	5	--
Unknowns		22	12	14	1	--	--

APPENDIX D
Stratigraphic Descriptions of Selected Cores and Streambank Exposures


Stratigraphic description of E-7, Bayfield/Ino site
se-20-47n-6w
GRAIN SIZE
pebble
granule
sand
silt
clay
v f mc v
METRES
REMARKS
slump
clay diamicton
loamy sand diamicton
sandy loam diamicton
1
2



loam diamicton, more grey than above units, occasional clay beds, occasional cobbles and boulders

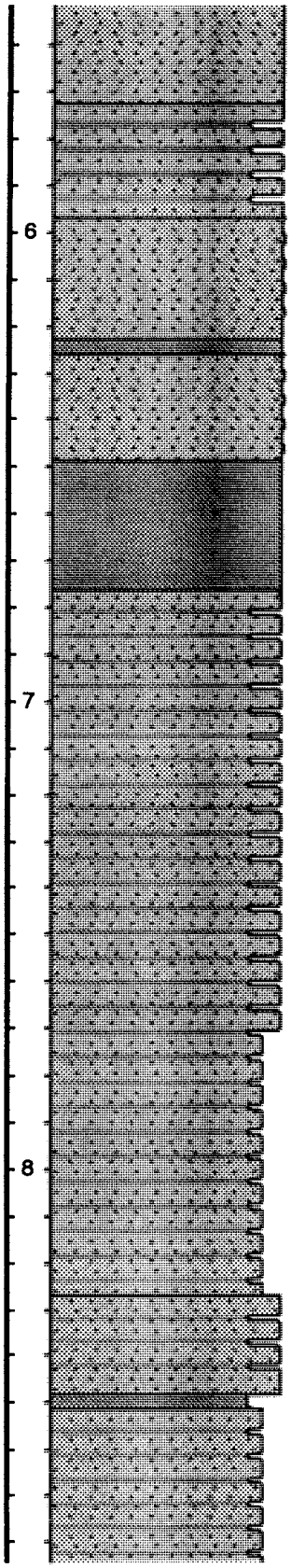
transition zone between clayey diamicton and sand, stratified

interbedded sand and clay diamicton with drop stones, highly contorted bedding, discontinous

sand interbedded with 1/2-cm thick silt beds, heavy minerals marking tops of old dunes or ripples

sand, stratified with heavy minerals and interbedded with silt

fine sand, stratified, reddish color, with heavy minerals marking bedforms



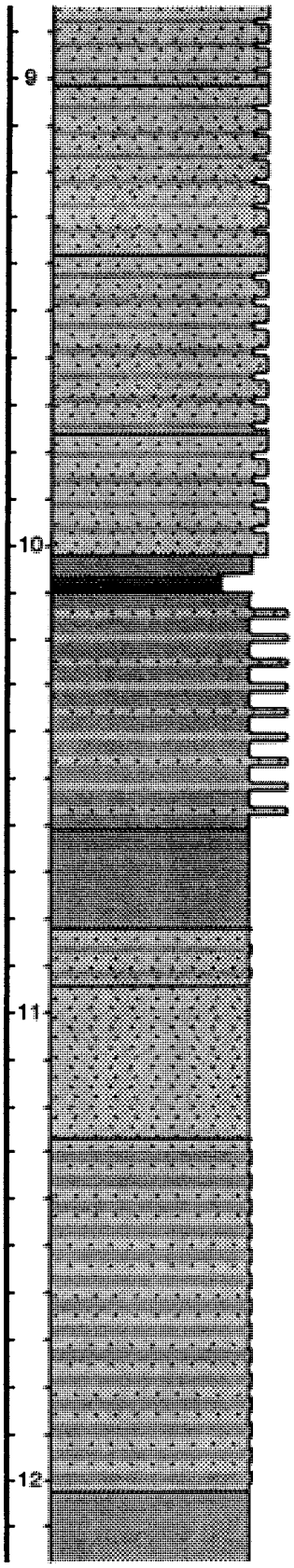
fine sand interbedded with 1 cm thick silt units, reddish brown

fine sand with one 4-cm thick grey silt unit at center, stratified, fining upward

grey silt, fining upwards, stratified

very fine sand, interbedded with occasional silty beds, fining upward

fine sand with 4-cm thick silt bed at center



fine sand, interbedded with <1-cm thick silty units, stratified

fine sand interbedded with 1/4 - 1/2 cm thick silt units, highly convoluted bedding

fine sand interbedded with silt, highly convoluted bedding, some grey silt, some red silt

grey silt, some reddish layers interbedded

reddish brown clay

grey silt, interbedded with fine sand, soft sediment deformation at top of unit, more massive and silty toward base of unit

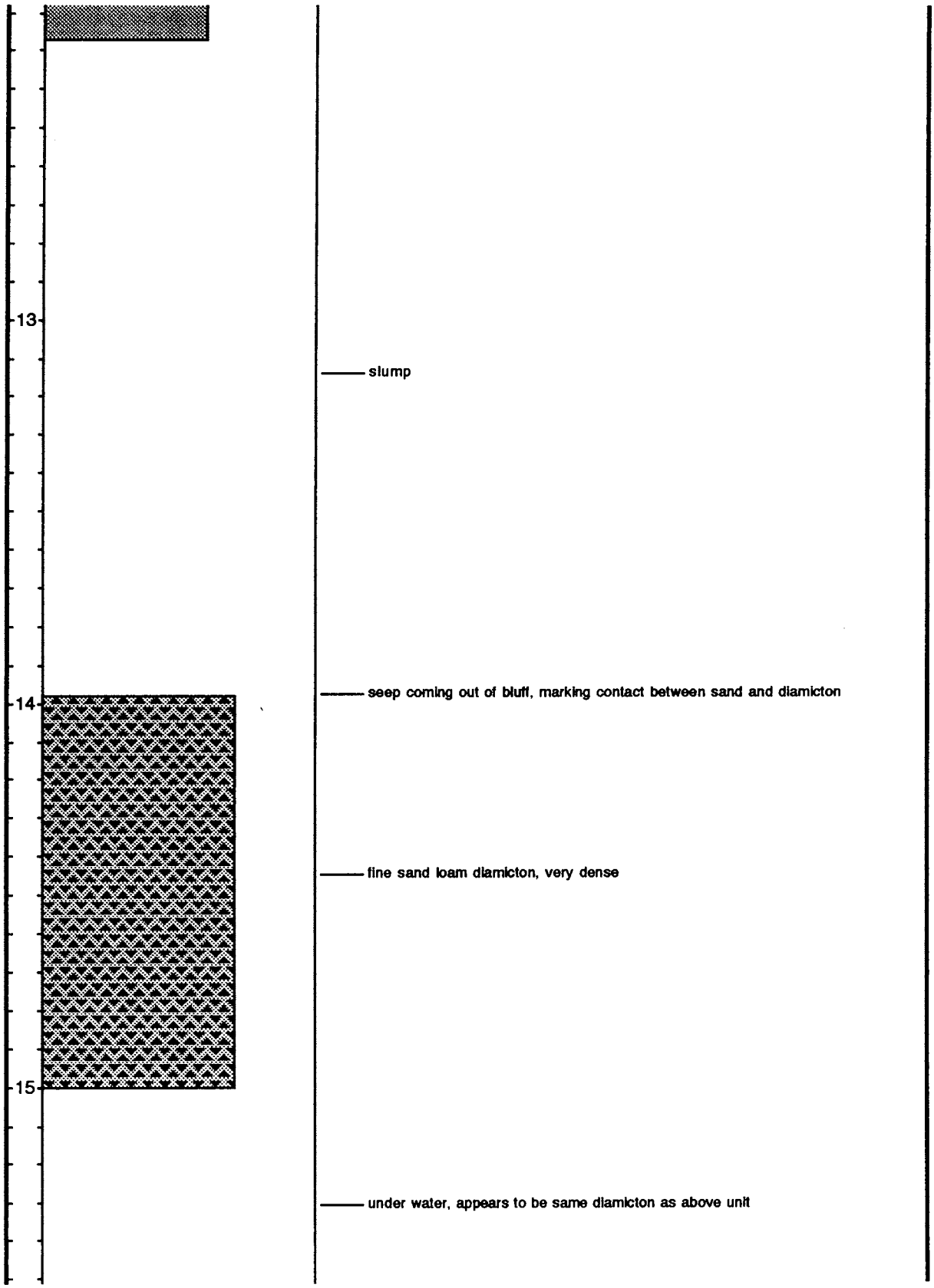
silt loam with fine bedding

fine sand interbedded with silt, fining upwards sequences, couplets average about 5 cm thick

fine sand with faint bedding

fine sand interbedded with silt, number of silt units increase toward base of unit

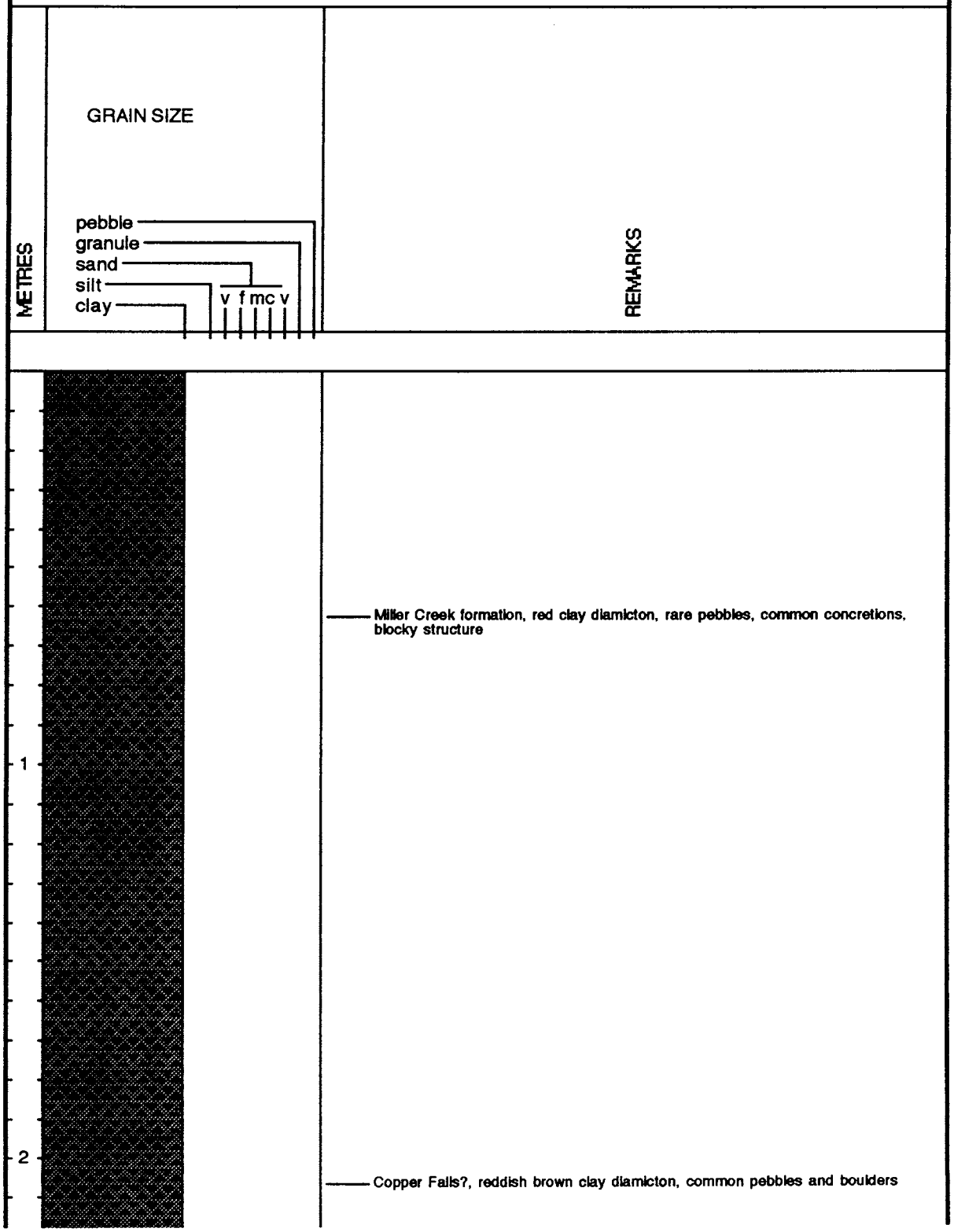
dark grey silt loam with faint bedding

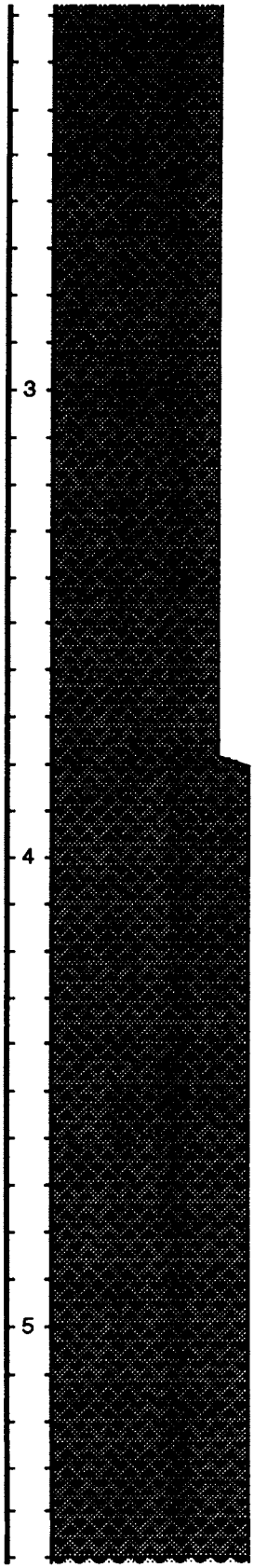

13
14
15
slump
seep coming out of bluff, marking contact between sand and diamicton
fine sand loam diamicton, very dense
under water, appears to be same diamicton as above unit

channel bottom

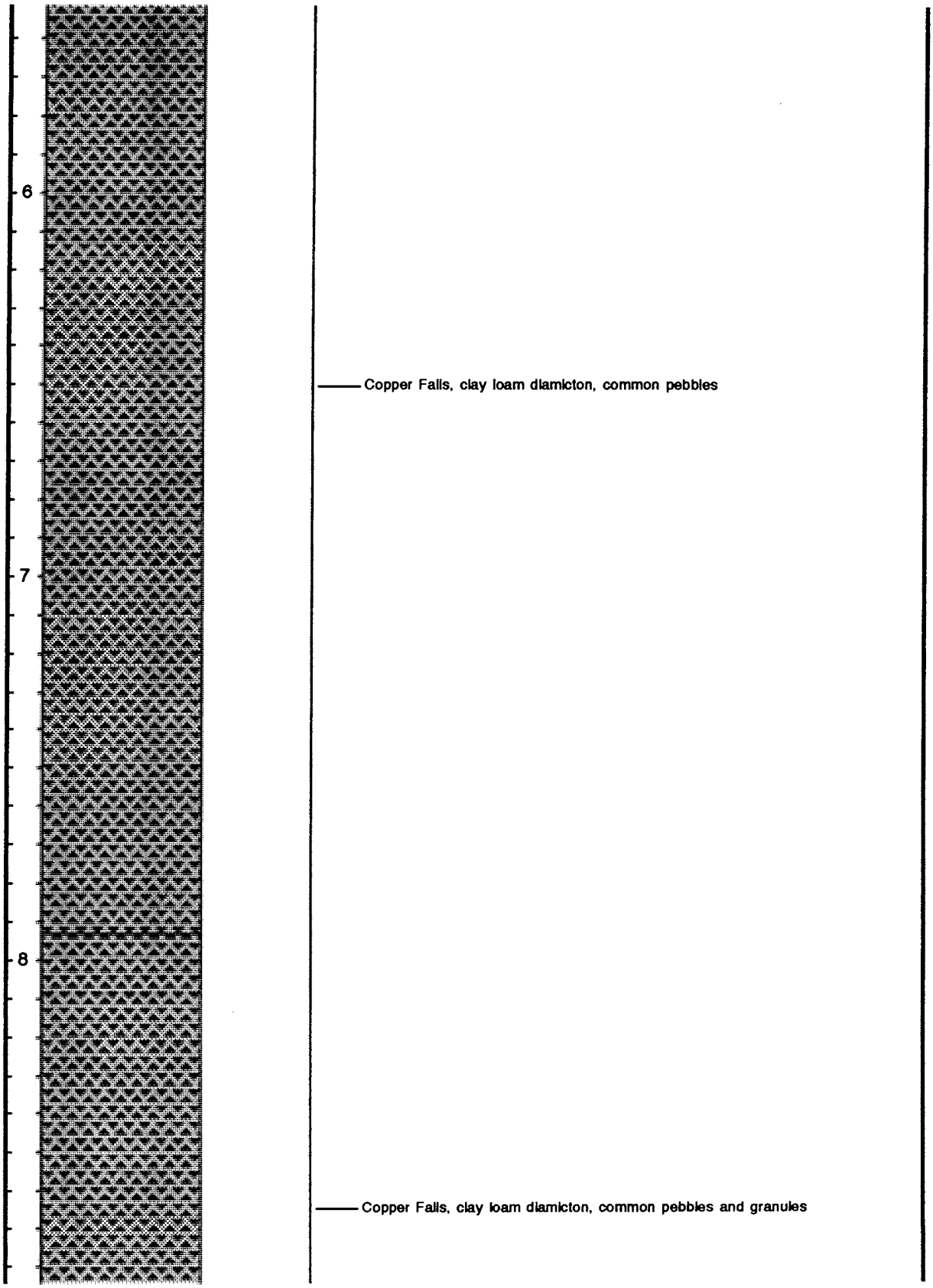
Stratigraphic description of E-25, Bayfield Site

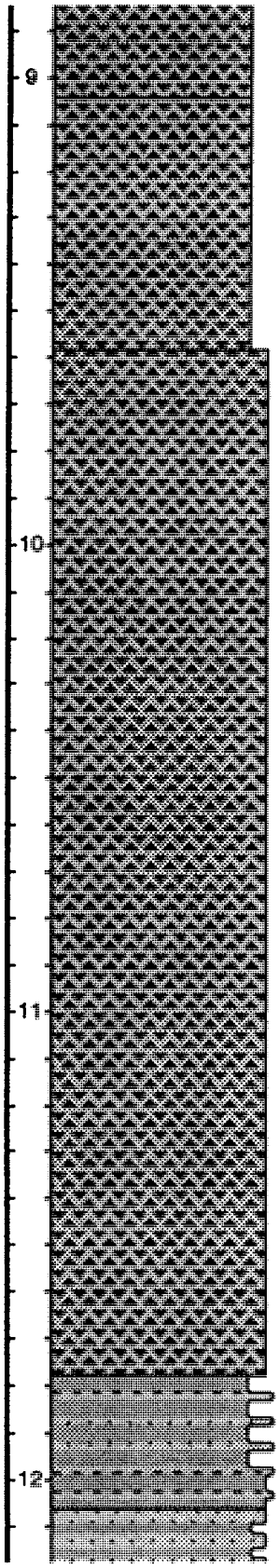
sw-22-47n-6w





Copper Falls?, clay diamicton, occasional boulders, common pebbles


6
7
8
Copper Falls, clay loam diamicton, common pebbles
Copper Falls, clay loam diamicton, common pebbles and granules

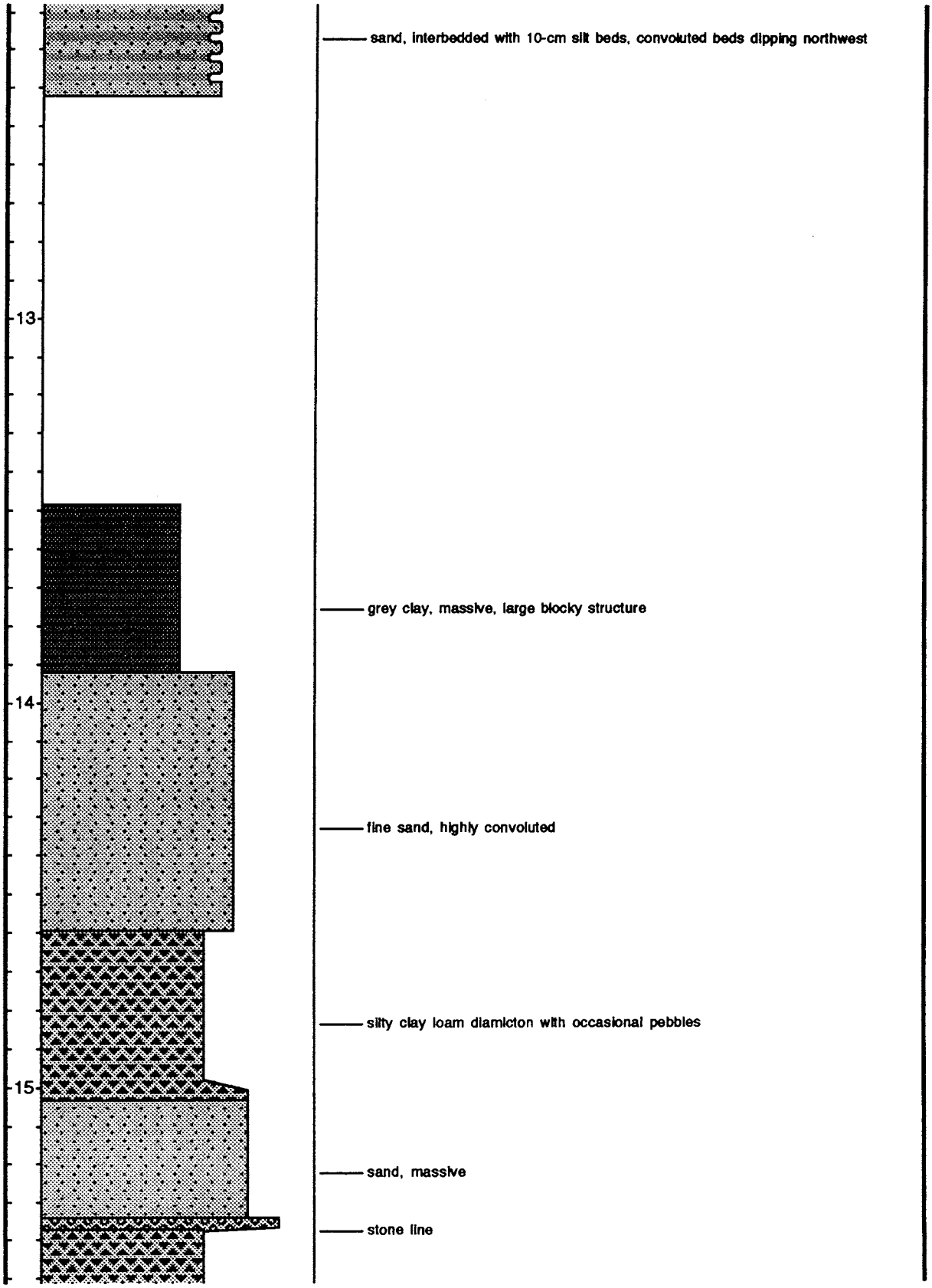


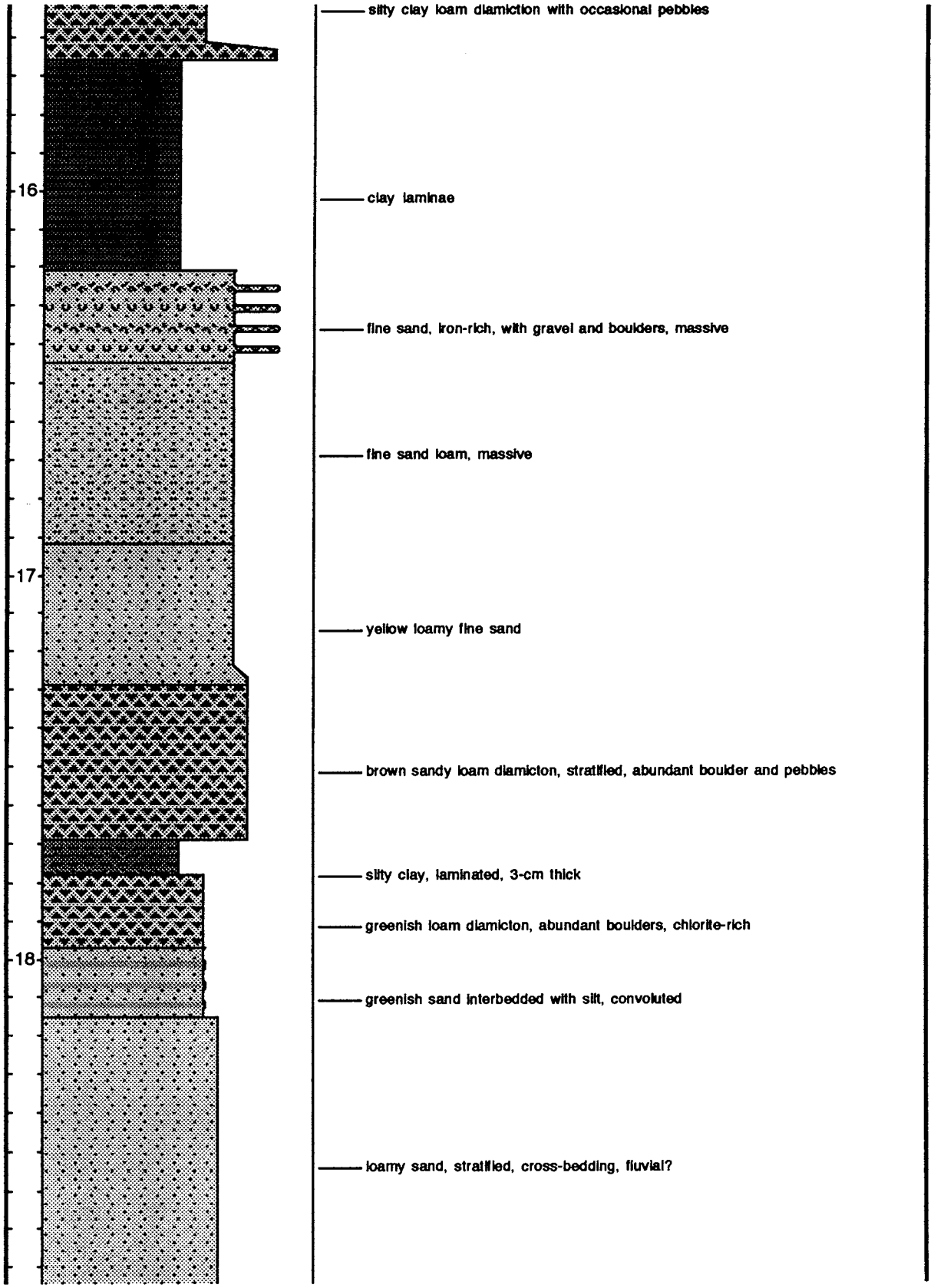
clay loam diamicton, coarser than above, greyish brown, common pebbles and granules, large joints filled with sandy sediment

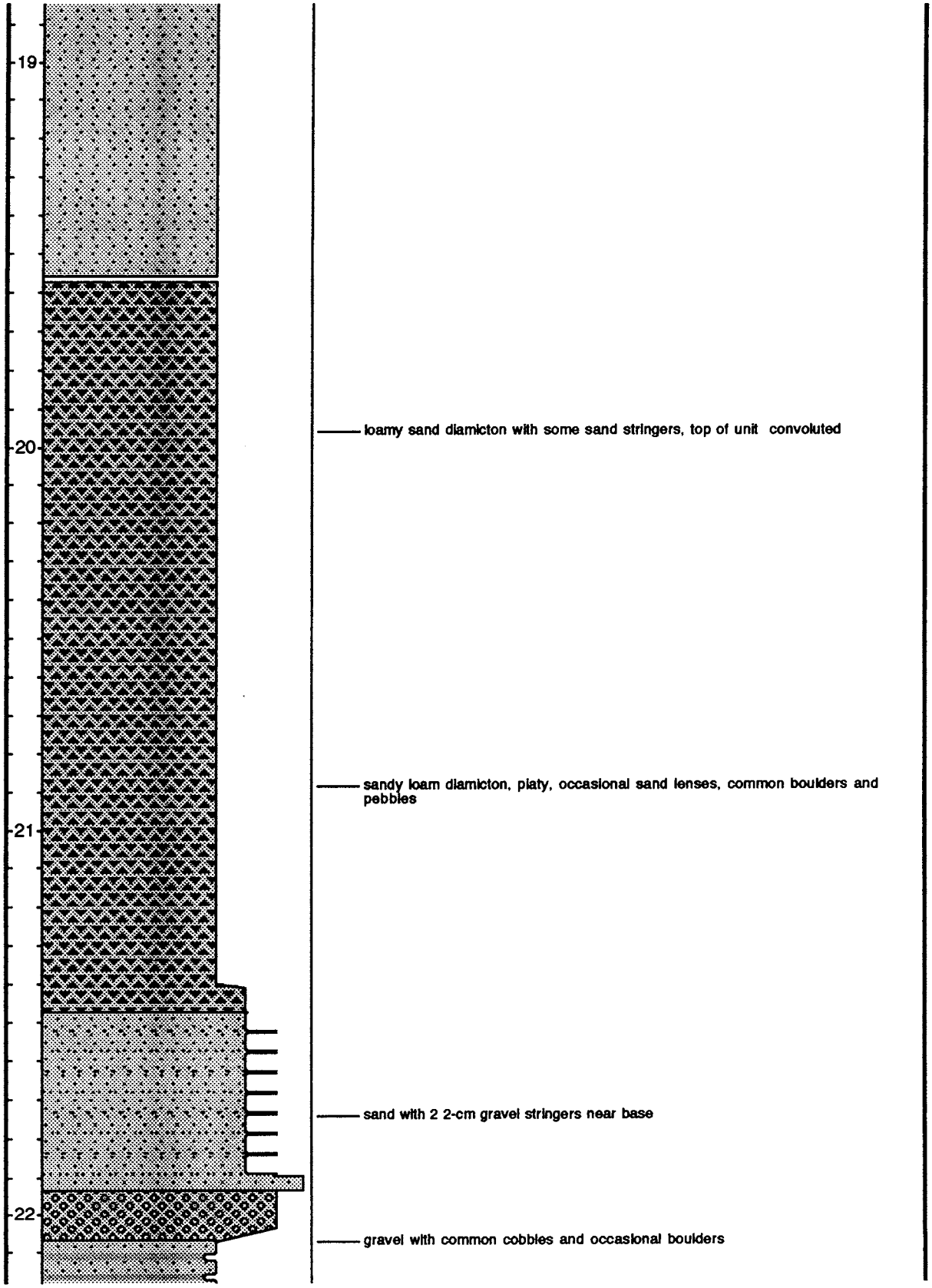
greyish brown loam diamicton, sandier than above, large joints with sand filling

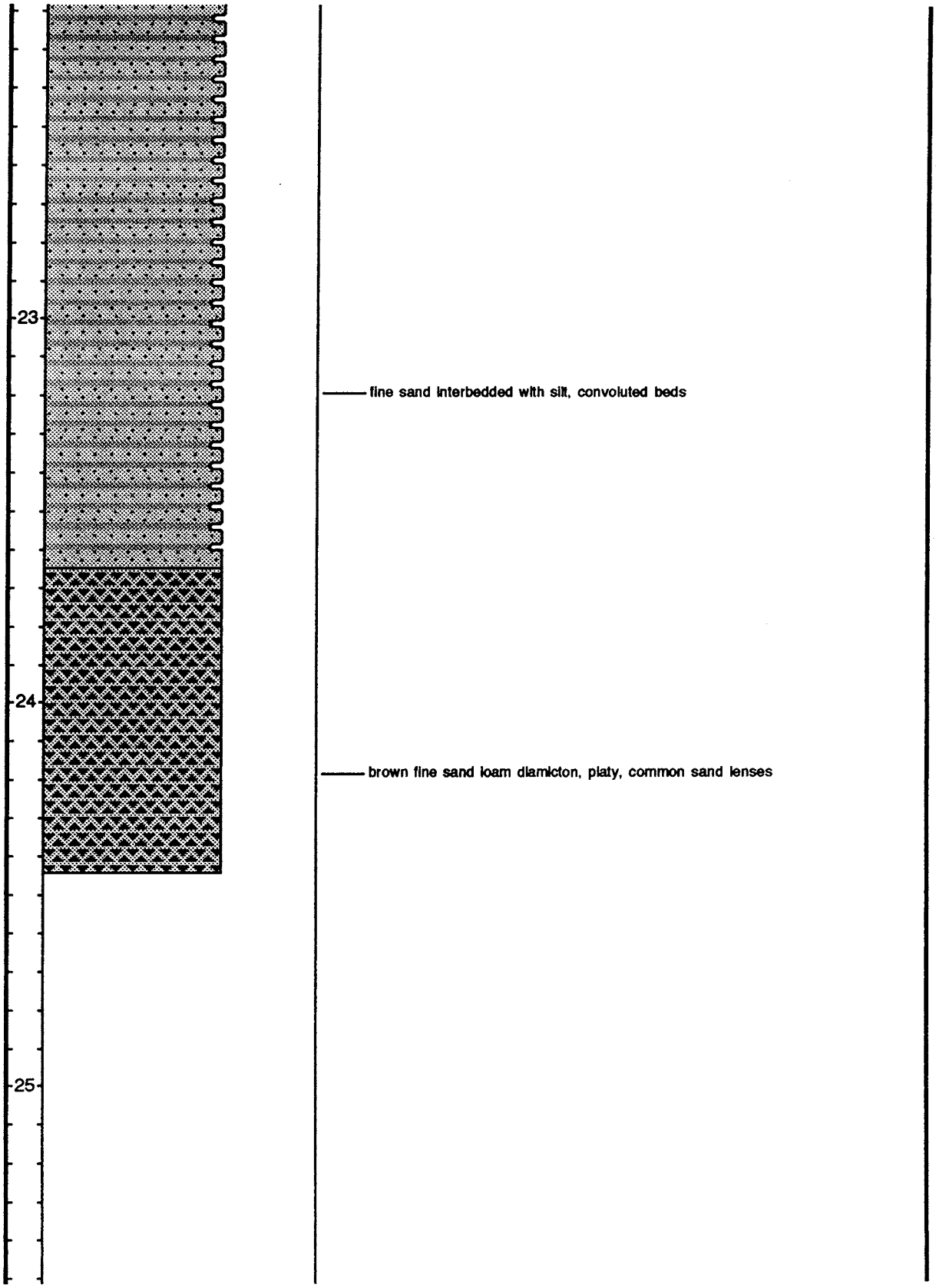
grey loam diamicton, same as above

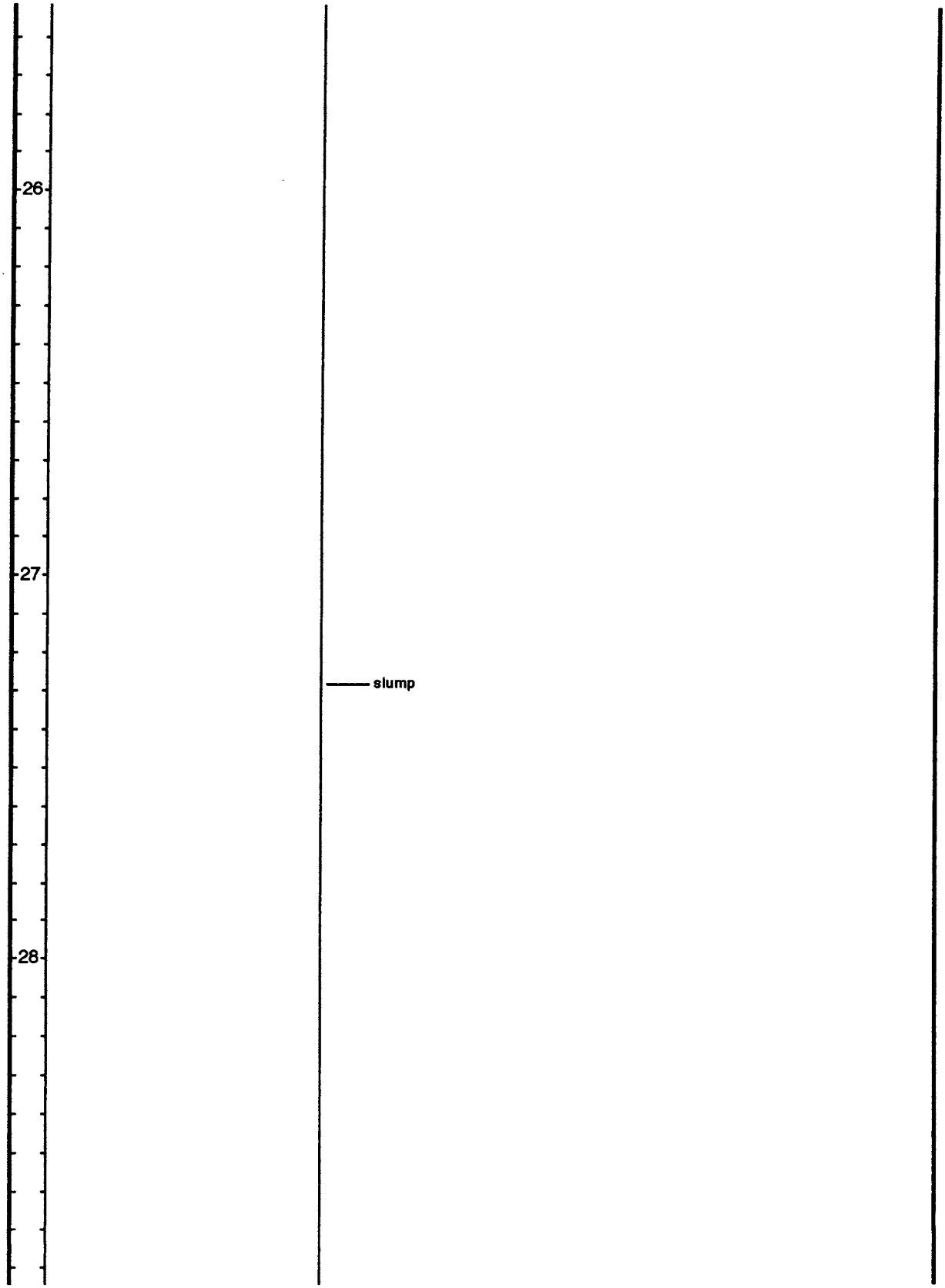
silt interbedded with clay and fine sand, occasional boulders

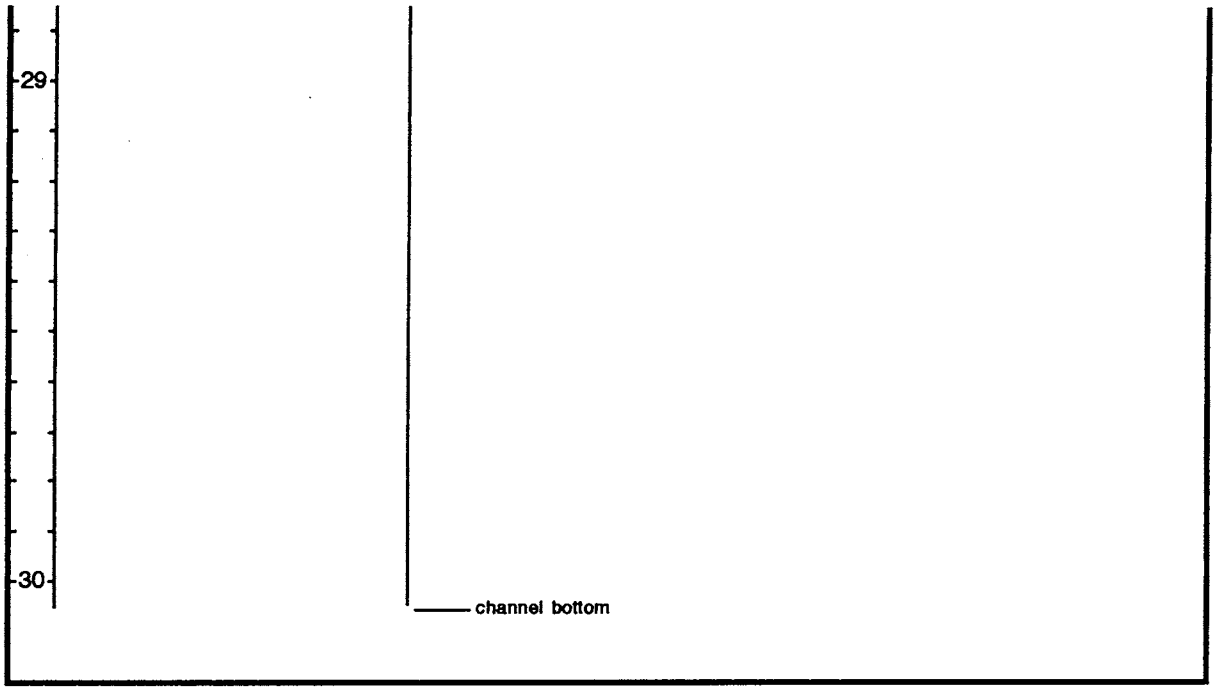

13
14
15
sand, interbedded with 10-cm silt beds, convoluted beds dipping northwest
grey clay, massive, large blocky structure
fine sand, highly convoluted
silty clay loam diamicton with occasional pebbles
sand, massive
stone line


16
17
18
silty clay loam diamicton with occasional pebbles
clay laminae
fine sand, iron-rich, with gravel and boulders, massive
fine sand loam, massive
yellow loamy fine sand
brown sandy loam diamicton, stratified, abundant boulder and pebbles
silty clay, laminated, 3-cm thick
greenish loam diamicton, abundant boulders, chlorite-rich
greenish sand interbedded with silt, convoluted
loamy sand, stratified, cross-bedding, fluvial?


19
20
21
22
loamy sand diamicton with some sand stringers, top of unit convoluted
sandy loam diamicton, platy, occasional sand lenses, common boulders and pebbles
sand with 2 2-cm gravel stringers near base
gravel with common cobbles and occasional boulders

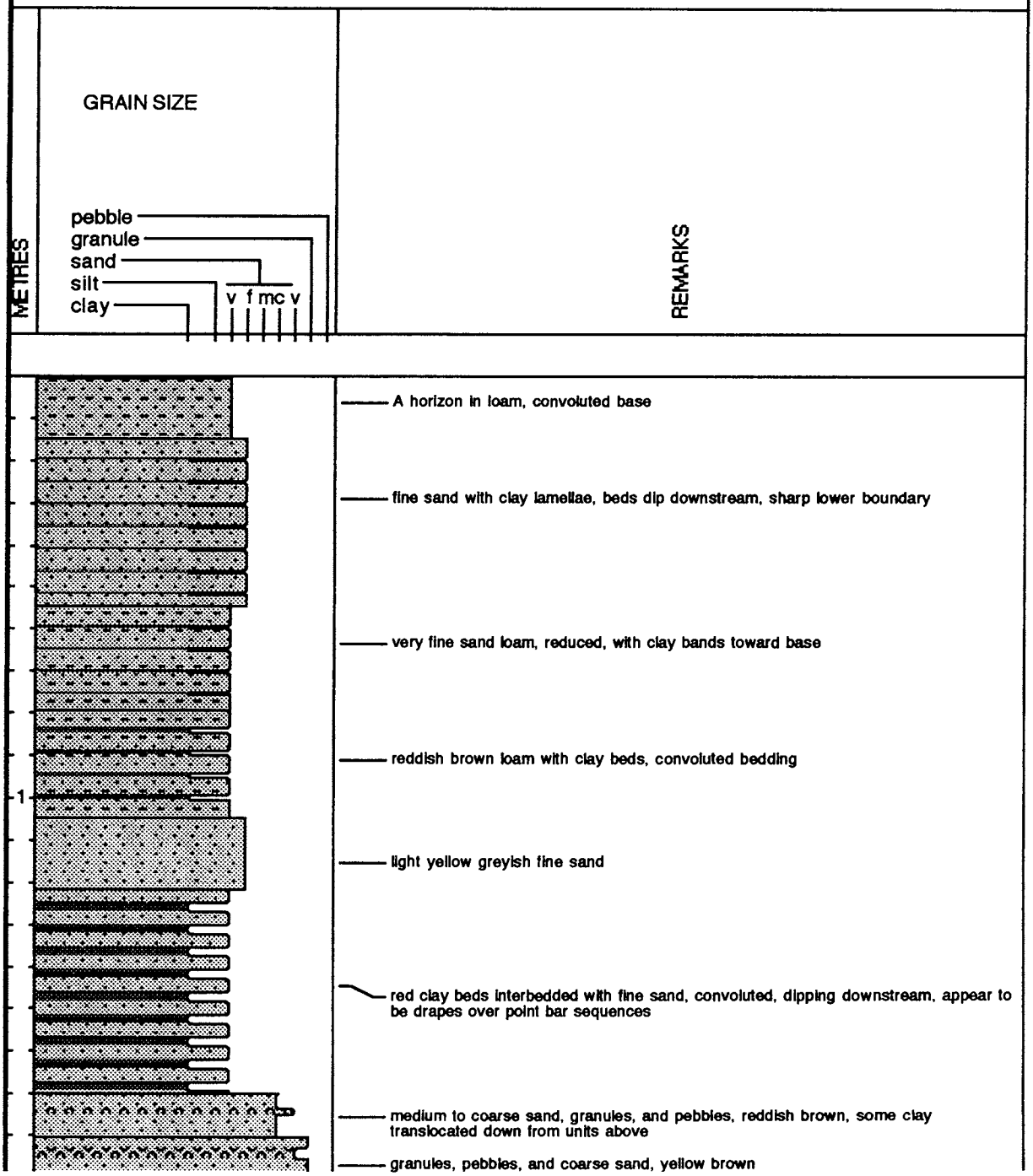

23
24
25
fine sand interbedded with silt, convoluted beds
brown fine sand loam diamicton, platy, common sand lenses

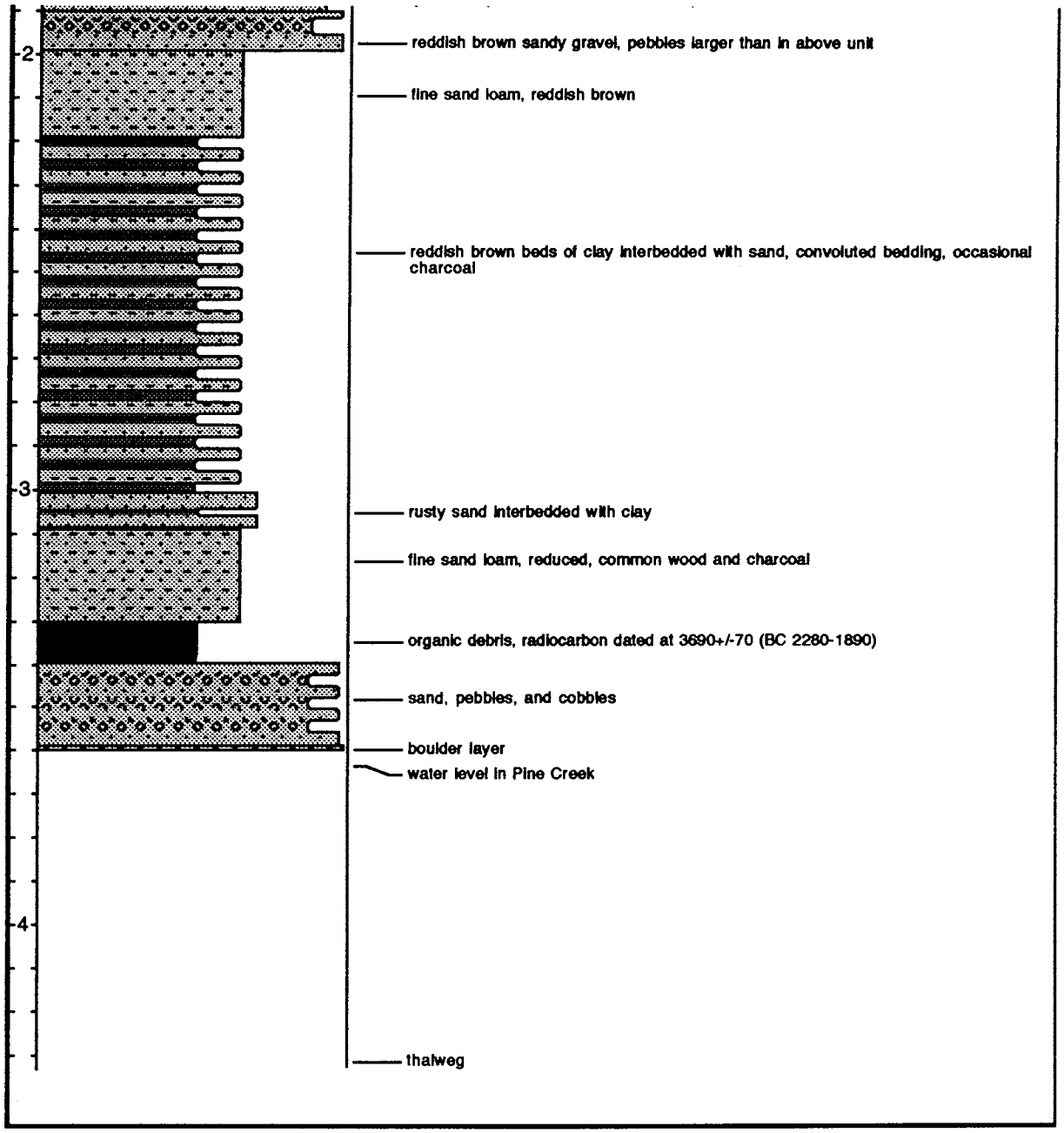

26
27
slump
28


29
30
channel bottom

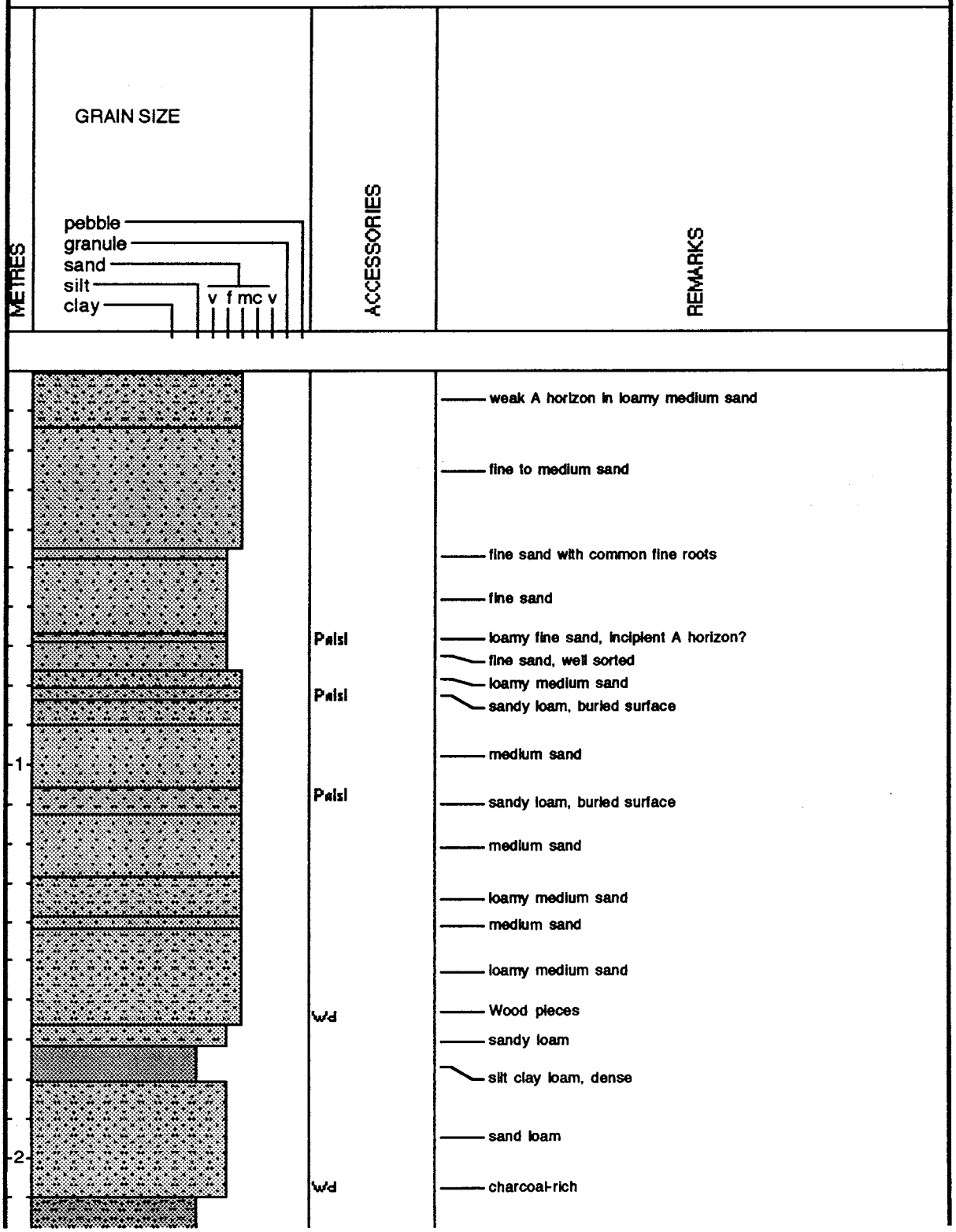
Stratigraphic description of E-8, WDNR/Moquah site
13-47n-6w

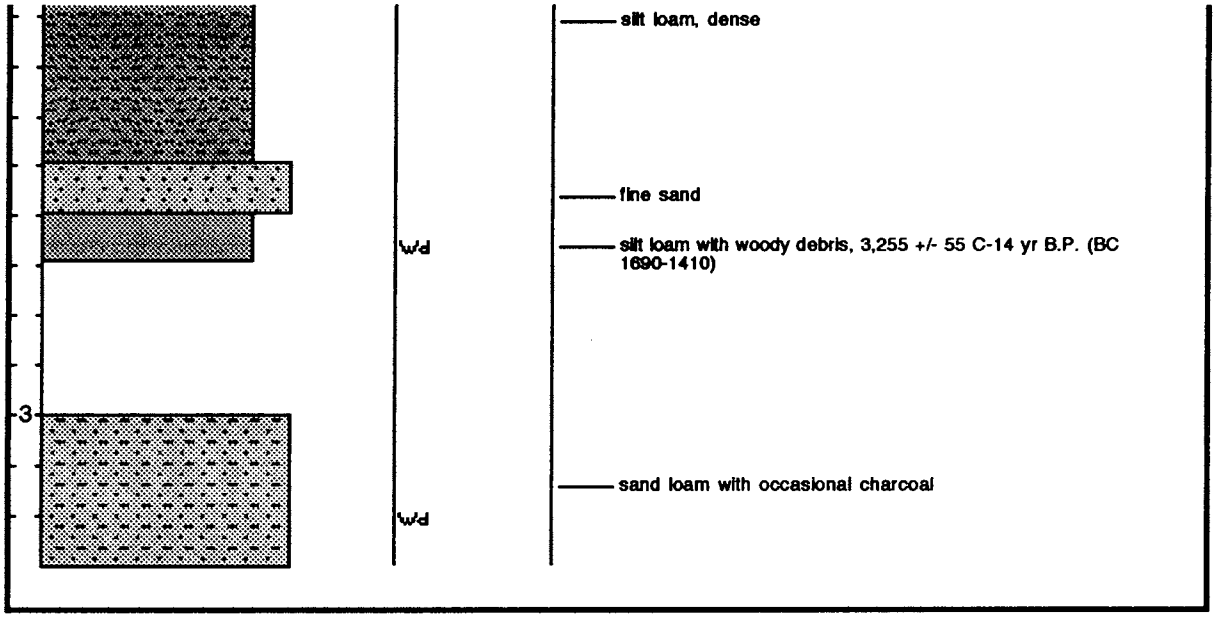
Remarks: Right terrace exposure along Pine Creek about 100 meters upstream of confluence with North Fish Creek.




2
3
4
reddish brown sandy gravel, pebbles larger than in above unit
fine sand loam, reddish brown
reddish brown beds of clay interbedded with sand, convoluted bedding, occasional charcoal
rusty sand interbedded with clay
fine sand loam, reduced, common wood and charcoal
organic debris, radiocarbon dated at 3690+/-70 (BC 2280-1890)
sand, pebbles, and cobbles
boulder layer
water level in Pine Creek
thalweg

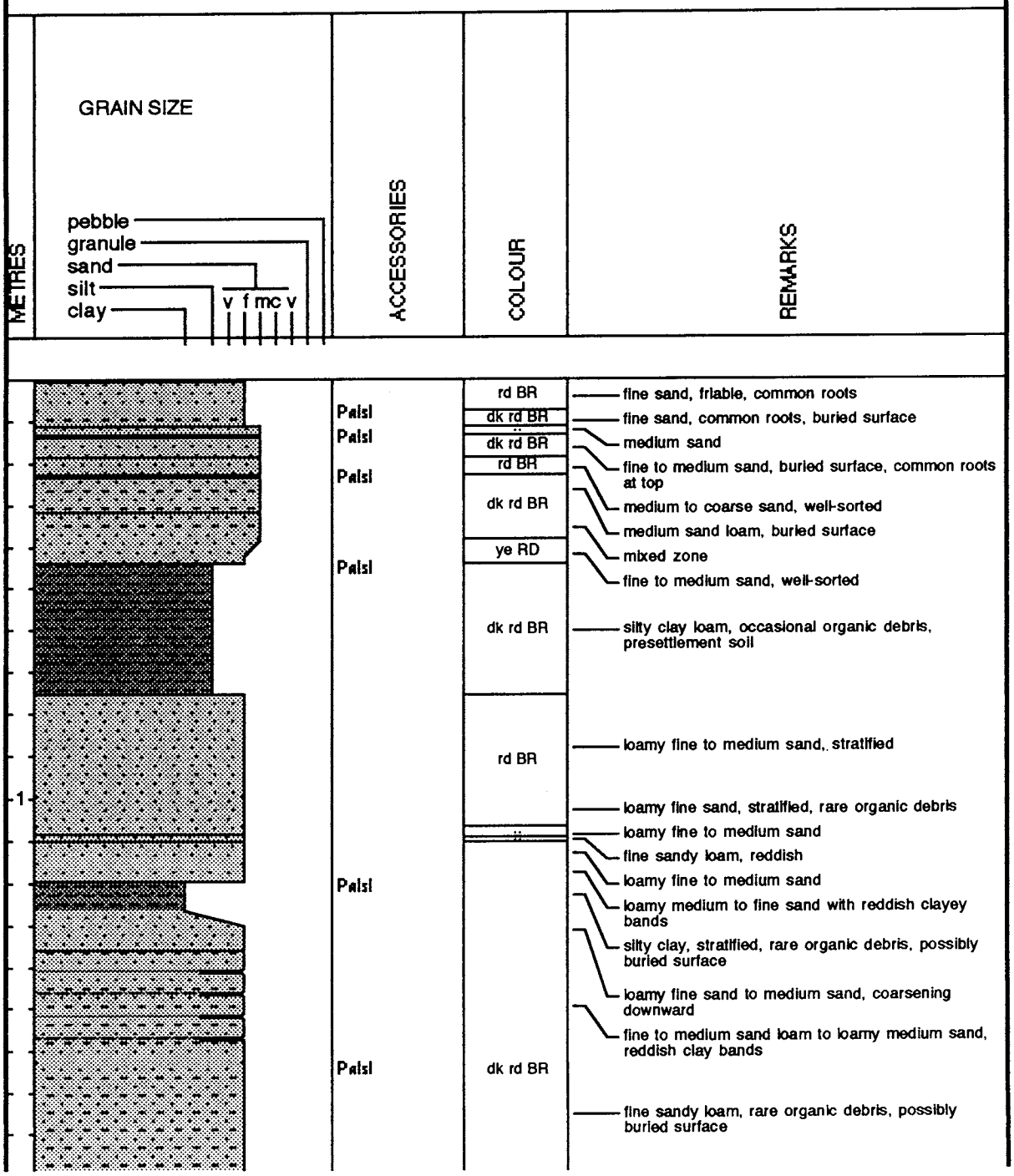
Stratigraphic description of C-24, Skulan site
18-47n-5w

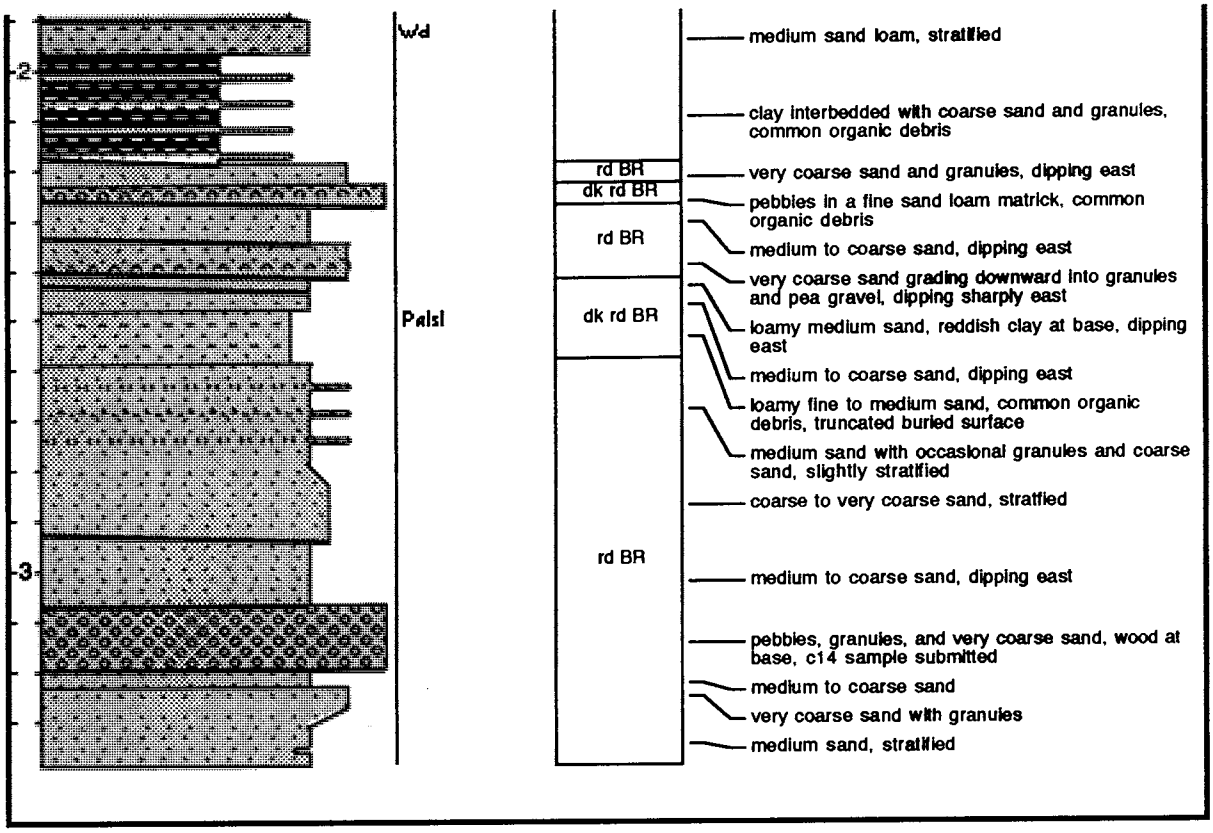



3
w/d
w/d
silt loam, dense
fine sand
silt loam with woody debris, 3,255 +/- 55 C-14 yr B.P. (BC 1690-1410)
sand loam with occasional charcoal

Stratigraphic description of VC-3, Hanson site
10-47N-5W

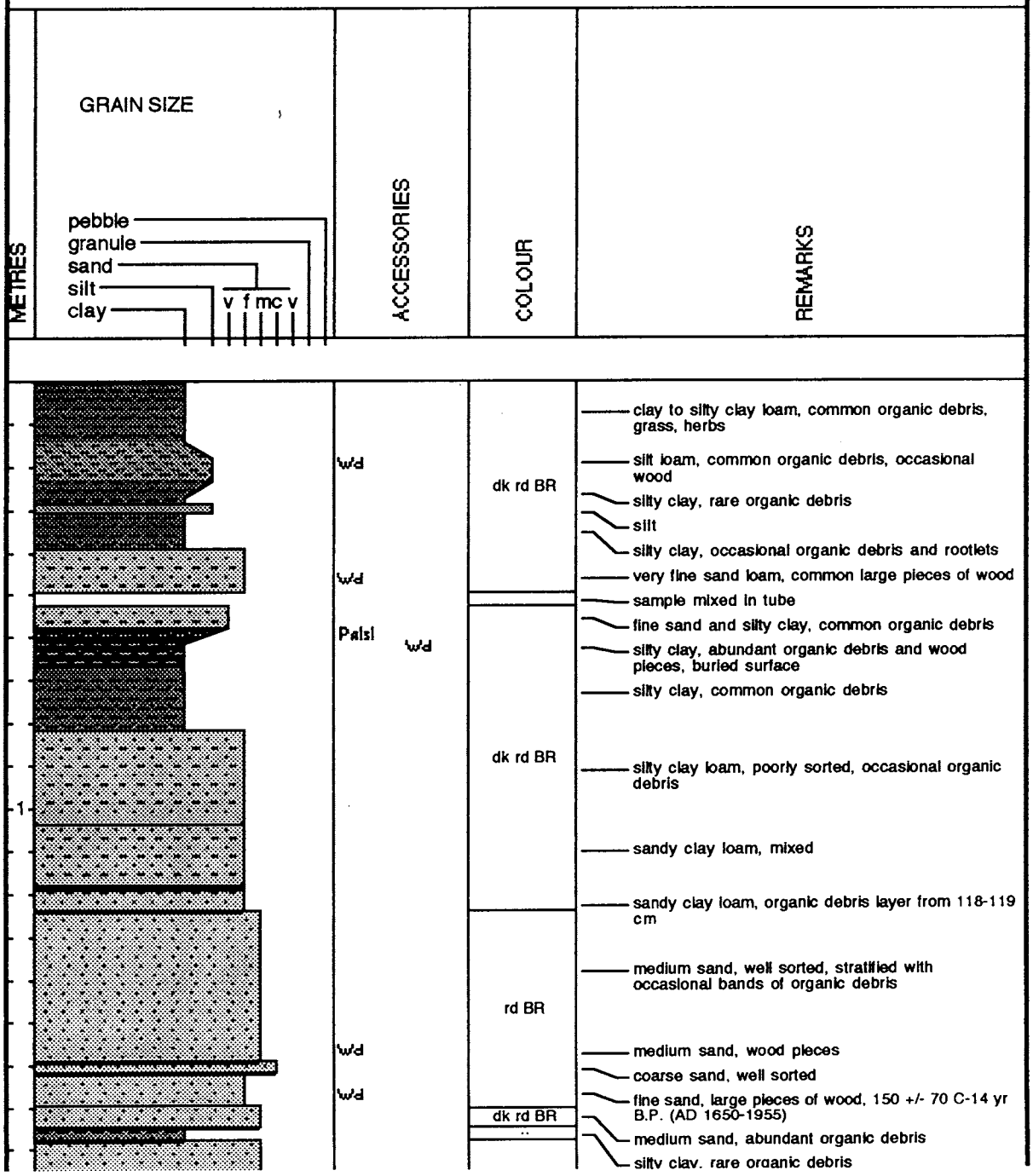
Remarks: Vibracore, assisted by Diann Kiesel and Brian Dalsing, floodplain near North Fish Creek along cross section 8-3.

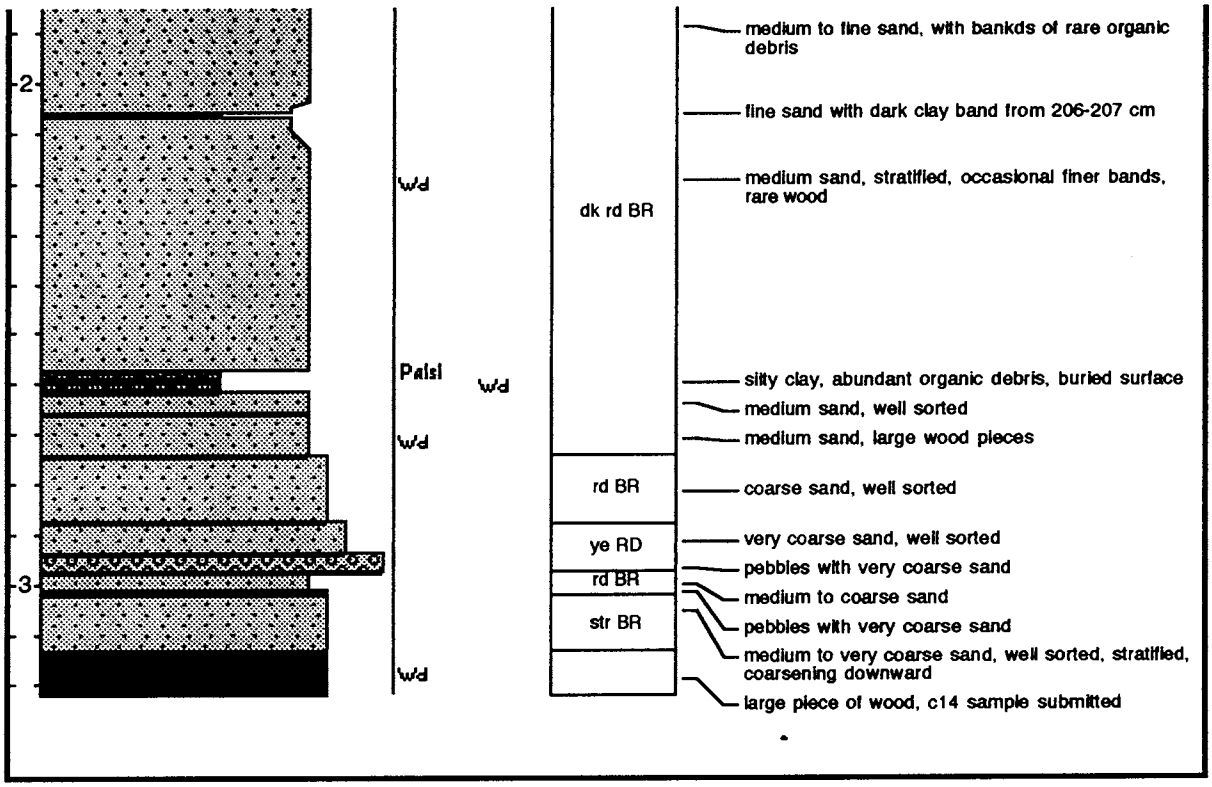



2
3
Wd
Palsl
rd BR
dk rd BR
rd BR
dk rd BR
rd BR
medium sand loam, stratified
clay interbedded with coarse sand and granules, common organic debris
very coarse sand and granules, dipping east
pebbles in a fine sand loam matrick, common organic debris
medium to coarse sand, dipping east
very coarse sand grading downward into granules and pea gravel, dipping sharply east
loamy medium sand, reddish clay at base, dipping east
medium to coarse sand, dipping east
loamy fine to medium sand, common organic debris, truncated buried surface
medium sand with occasional granules and coarse sand, slightly stratified
coarse to very coarse sand, stratified
medium to coarse sand, dipping east
pebbles, granules, and very coarse sand, wood at base, c14 sample submitted
medium to coarse sand
very coarse sand with granules
medium sand, stratified

Stratigraphic description of VC-5, Hanson site
10 -47n-5w

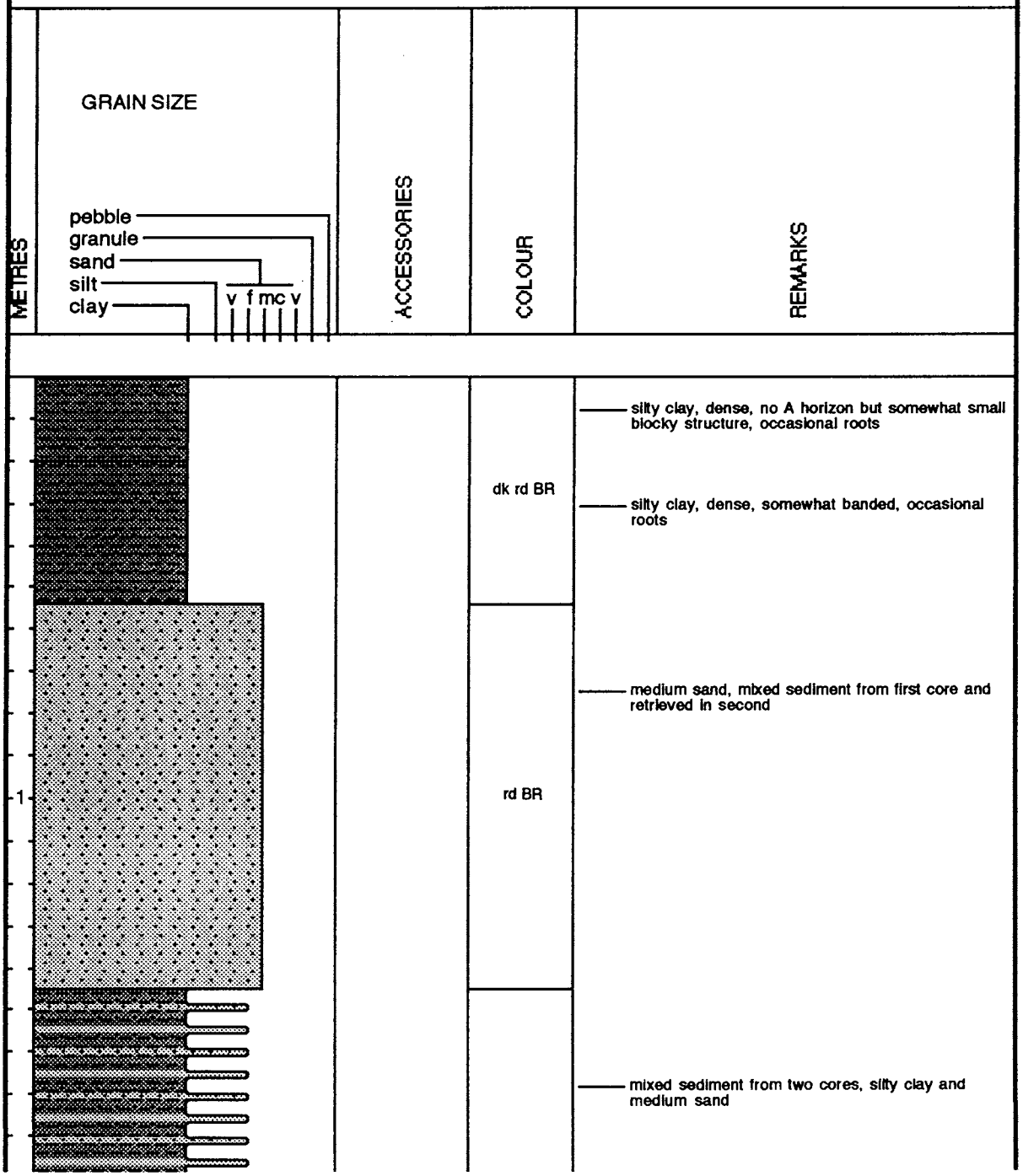
Remarks: Vibracore, assisted by Diane Kiesel, Brian Dalsing, and Bruce Rapps, center of relict channel along south side of North Fish Creek, at cross section 9-1.

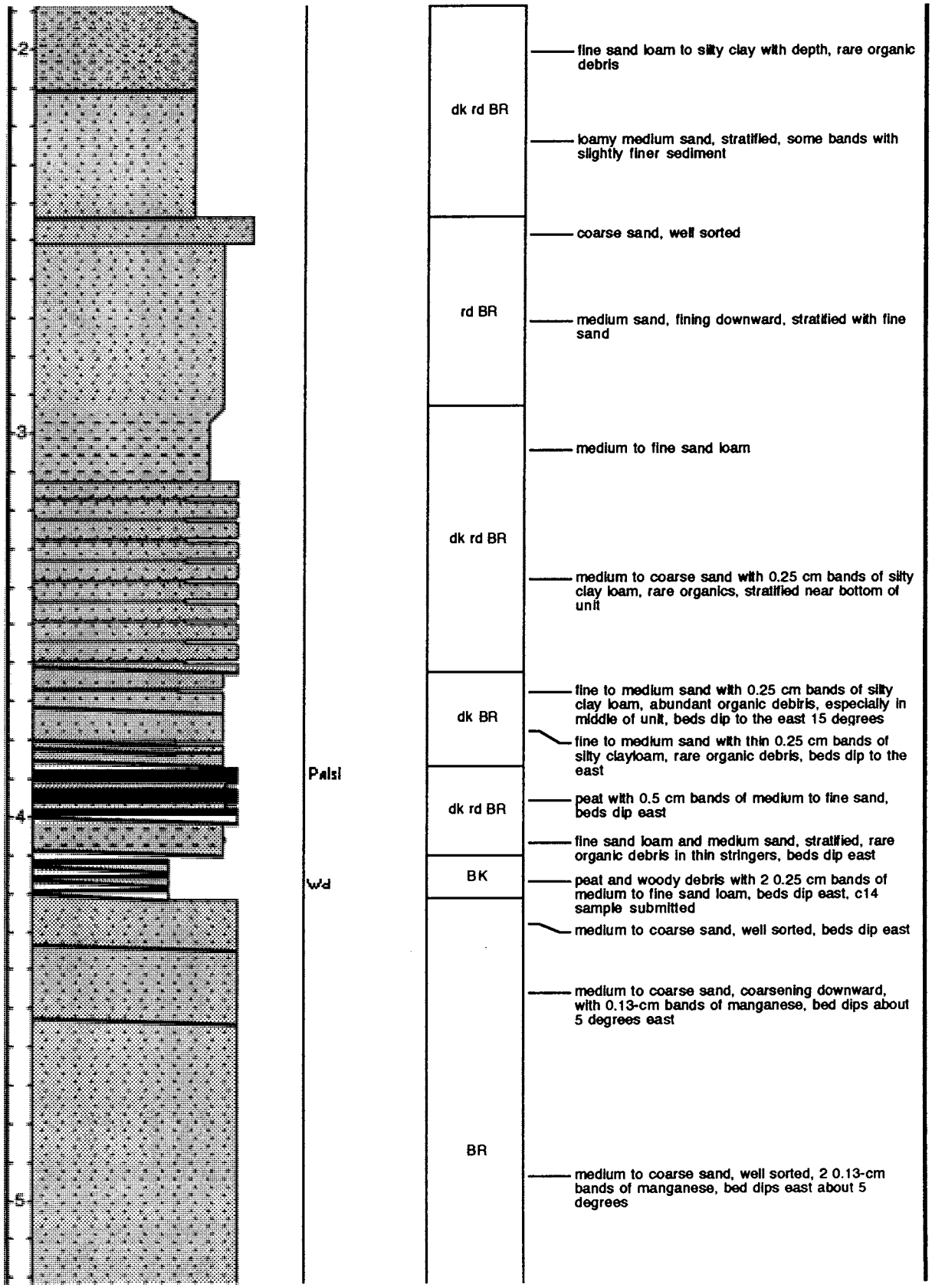


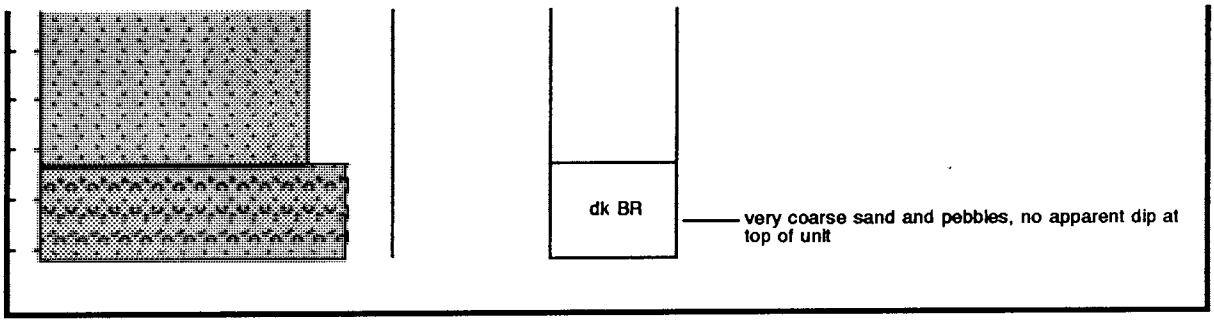

2
3
wd
Palsi
wd
wd
wd
dk rd BR
rd BR
ye RD
rd BR
str BR
medium to fine sand, with bankds of rare organic debris
fine sand with dark clay band from 206-207 cm
medium sand, stratified, occasional finer bands, rare wood
silty clay, abundant organic debris, buried surface
medium sand, well sorted
medium sand, large wood pieces
coarse sand, well sorted
very coarse sand, well sorted
pebbles with very coarse sand
medium to coarse sand
pebbles with very coarse sand
medium to very coarse sand, well sorted, stratified, coarsening downward
large piece of wood, c14 sample submitted

Stratigraphic description of VC-6, Hanson site
10-47n-5w

Remarks: Vibracore, assisted by Diane Kiesel and Brian Dalsing, floodplain along cross section 9-1

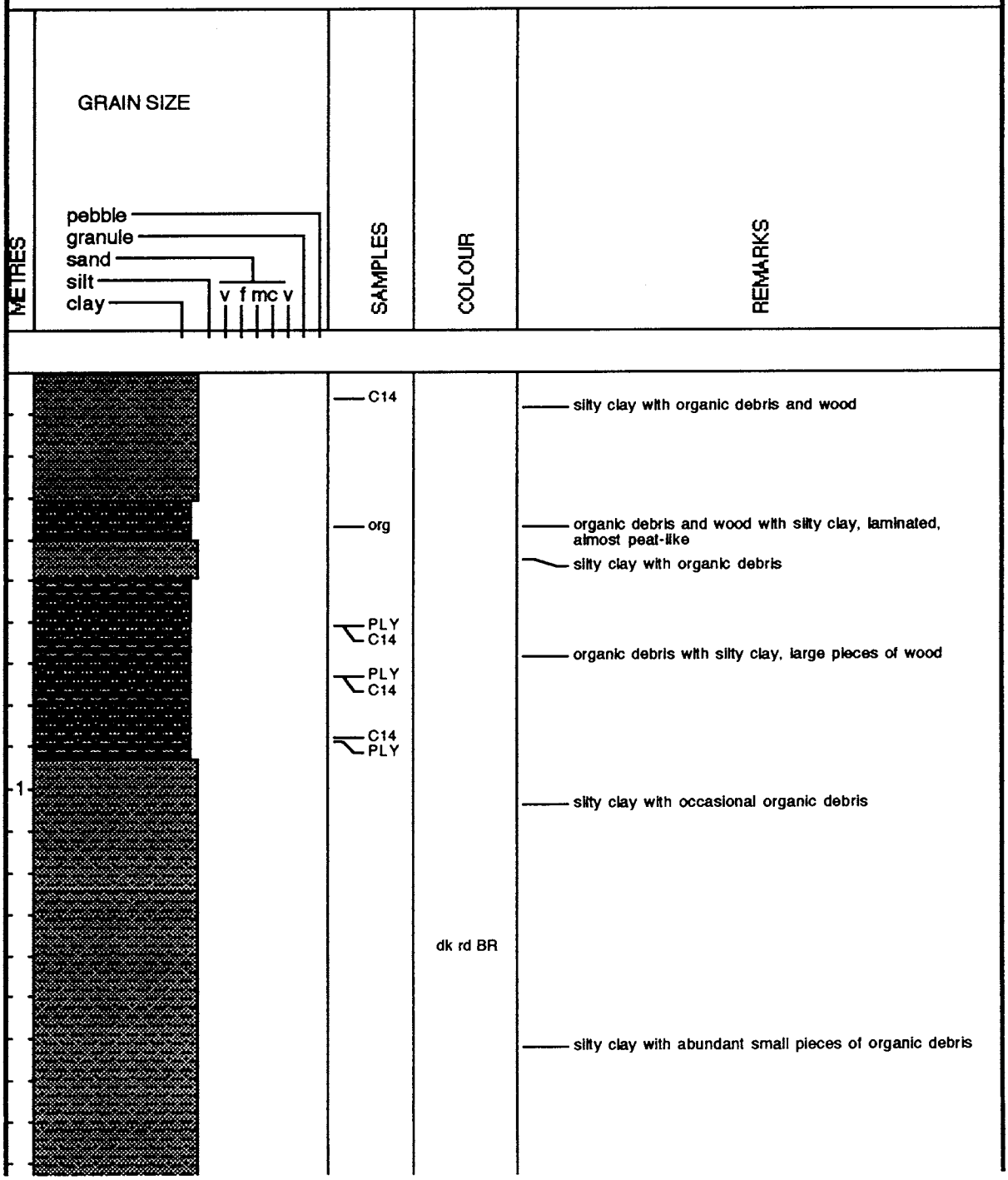


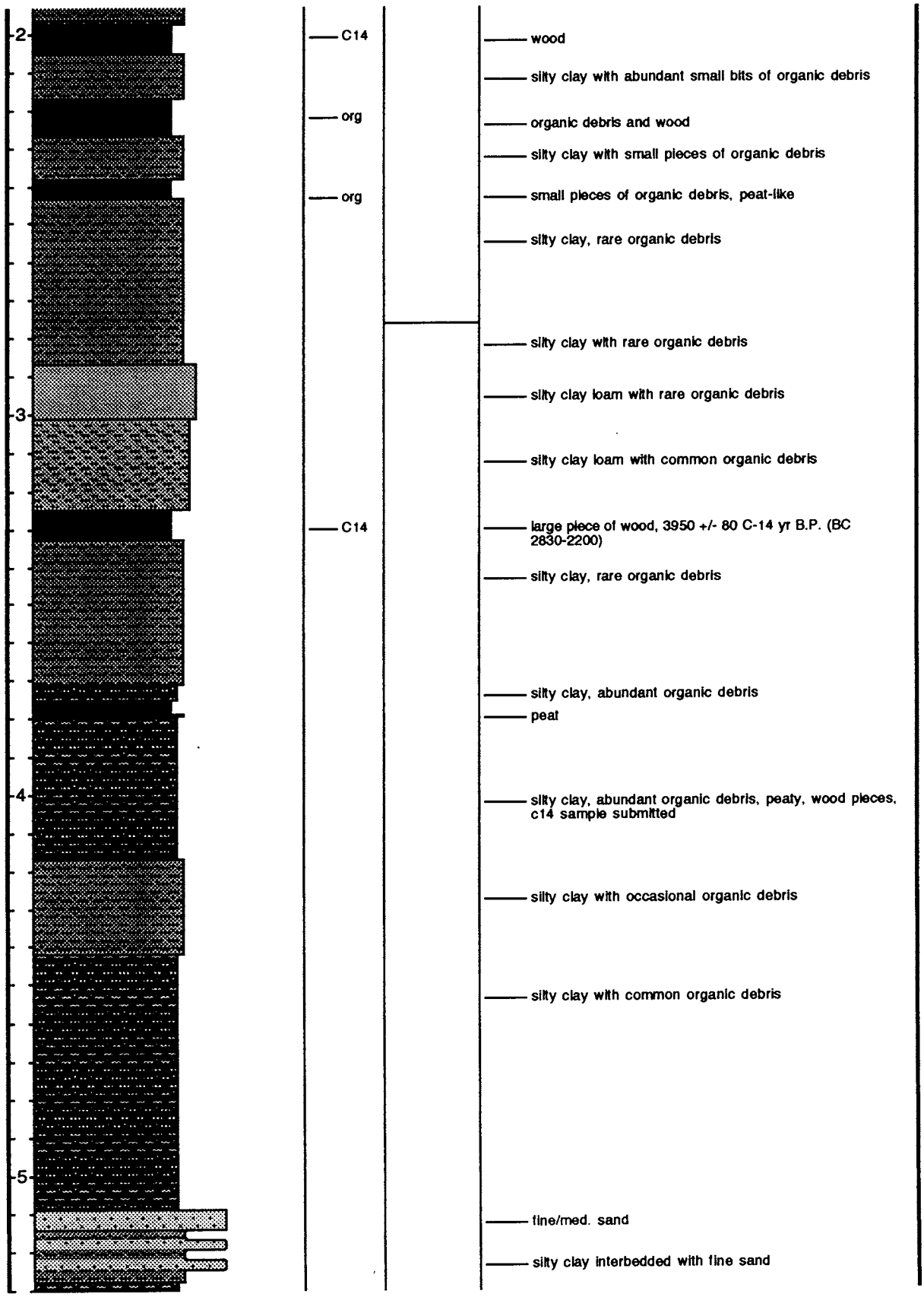

2
3
4
5
Palsl
Wd
dk rd BR
rd BR
dk rd BR
dk BR
dk rd BR
BK
BR
fine sand loam to silty clay with depth, rare organic debris
loamy medium sand, stratified, some bands with slightly finer sediment
coarse sand, well sorted
medium sand, fining downward, stratified with fine sand
medium to fine sand loam
medium to coarse sand with 0.25 cm bands of silty clay loam, rare organics, stratified near bottom of unit
fine to medium sand with 0.25 cm bands of silty clay loam, abundant organic debirls, especially in middle of unit, beds dip to the east 15 degrees
fine to medium sand with thin 0.25 cm bands of silty clayloam, rare organic debris, beds dip to the east
peat with 0.5 cm bands of medium to fine sand, beds dip east
fine sand loam and medium sand, stratified, rare organic debris in thin stringers, beds dip east
peat and woody debris with 2 0.25 cm bands of medium to fine sand loam, beds dip east, c14 sample submitted
medium to coarse sand, well sorted, beds dip east
medium to coarse sand, coarsening downward, with 0.13-cm bands of manganese, bed dips about 5 degrees east
medium to coarse sand, well sorted, 2 0.13-cm bands of manganese, bed dips east about 5 degrees

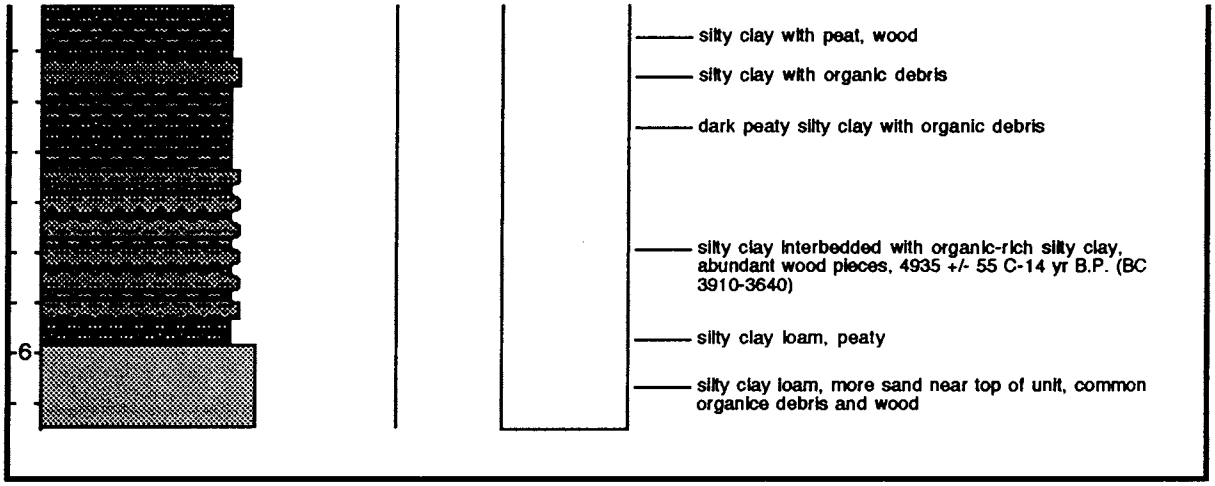

dk BR
very coarse sand and pebbles, no apparent dip at top of unit

Stratigraphic description of VC-8, Hanson site
10-47n-5w

Remarks: Vibracore, low terrace, depths corrected for compaction

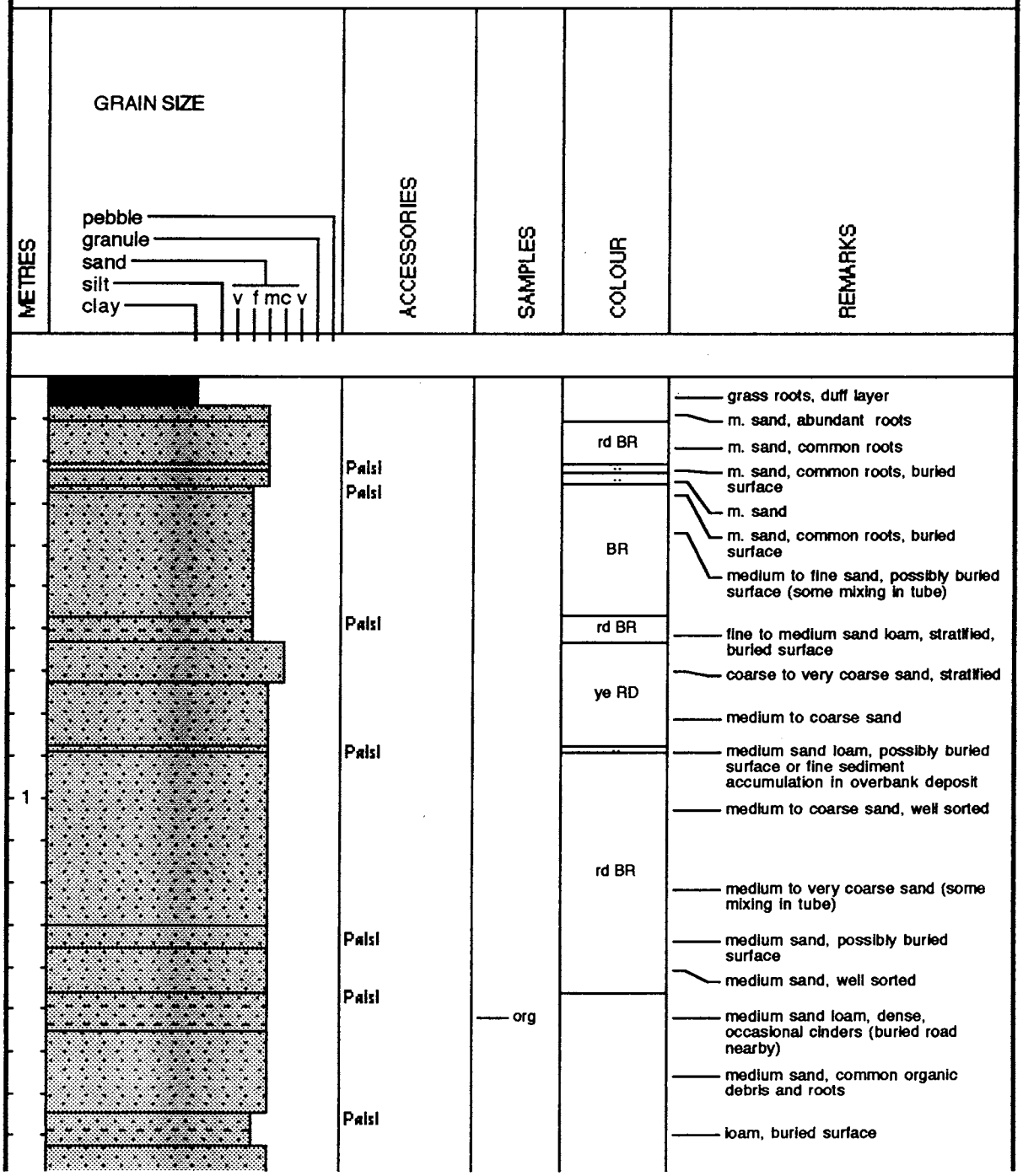


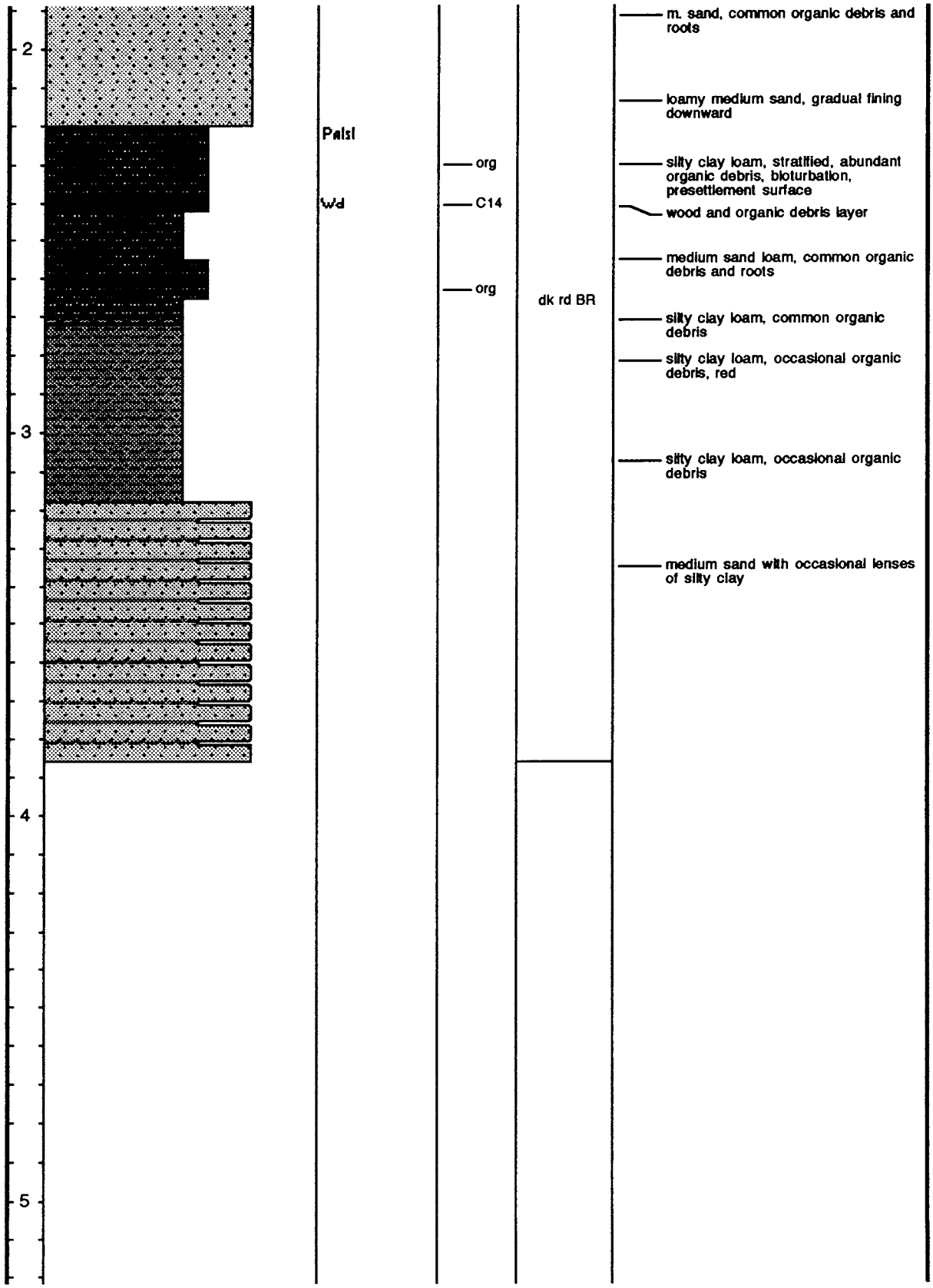

2
3
4
5
C14
org
org
C14
wood
silty clay with abundant small bits of organic debris
organic debris and wood
silty clay with small pieces of organic debris
small pieces of organic debris, peat-like
silty clay, rare organic debris
silty clay with rare organic debris
silty clay loam with rare organic debris
silty clay loam with common organic debris
large piece of wood, 3950 +/- 80 C-14 yr B.P. (BC 2830-2200)
silty clay, rare organic debris
silty clay, abundant organic debris
peat
silty clay, abundant organic debris, peaty, wood pieces, c14 sample submitted
silty clay with occasional organic debris
silty clay with common organic debris
fine/med. sand
silty clay interbedded with fine sand

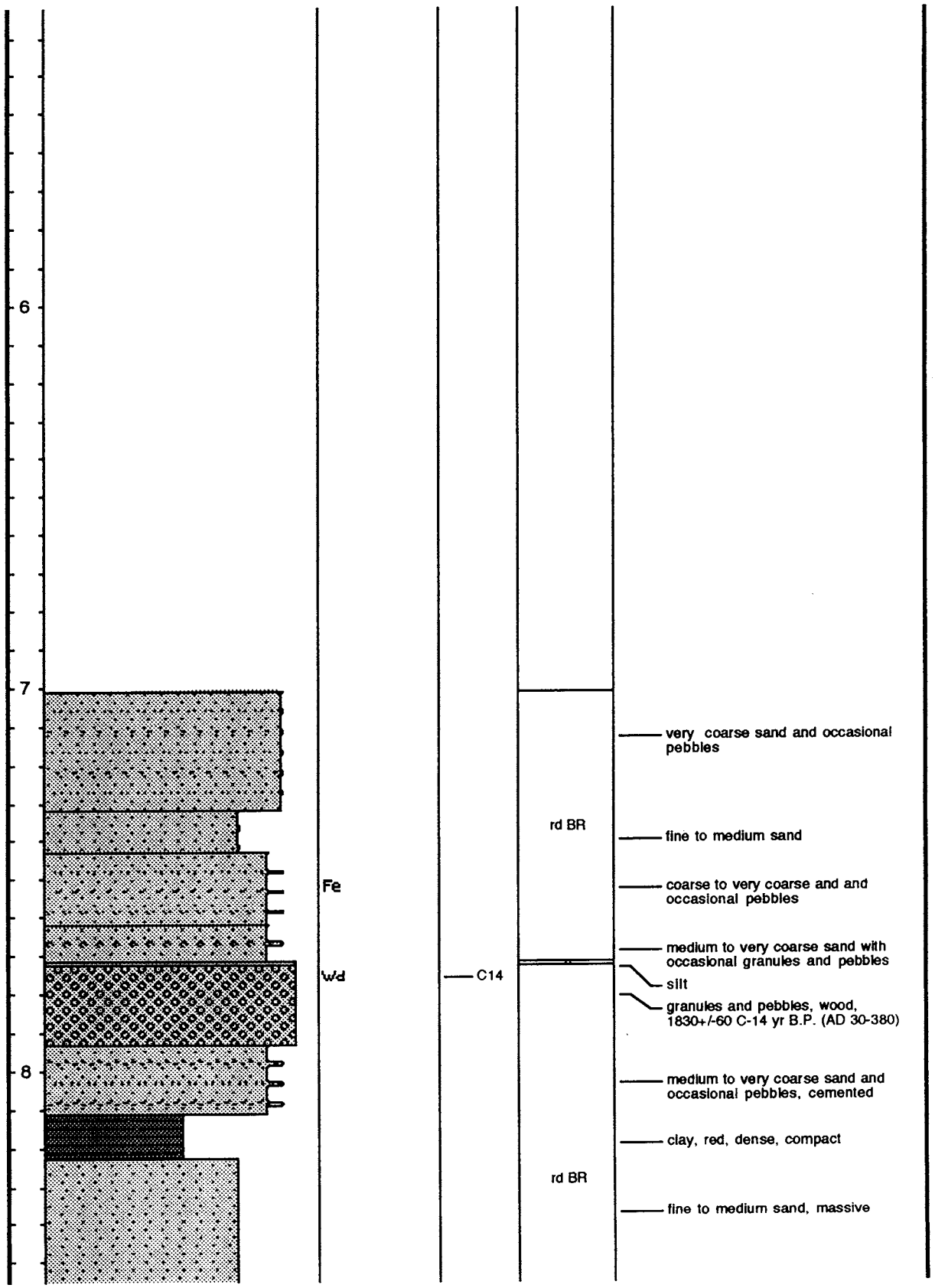

6
silty clay with peat, wood
silty clay with organic debris
dark peaty silty clay with organic debris
silty clay interbedded with organic-rich silty clay, abundant wood pieces, 4935 +/- 55 C-14 yr B.P. (BC 3910-3640)
silty clay loam, peaty
silty clay loam, more sand near top of unit, common organice debris and wood

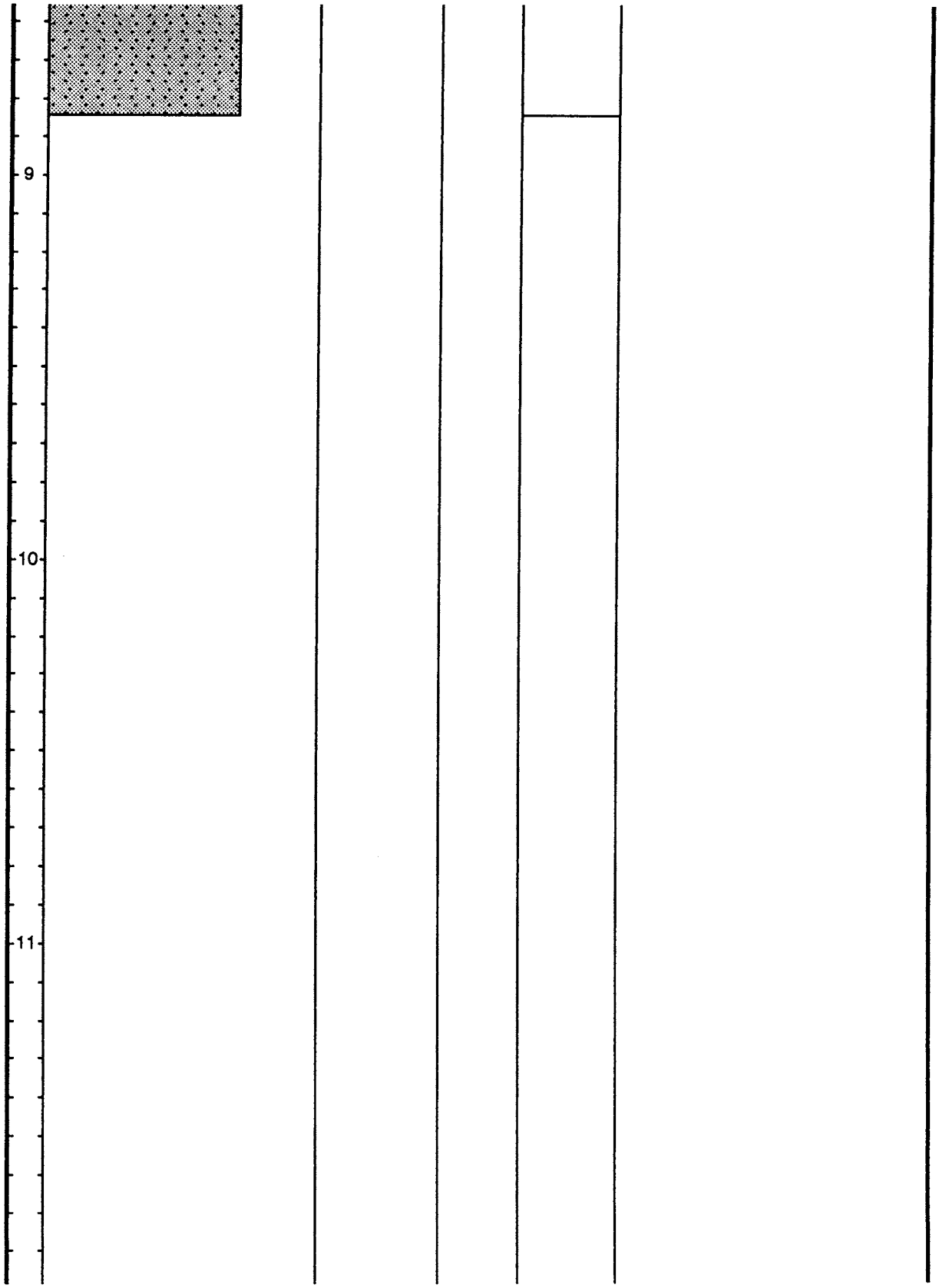
Stratigraphic description of G-1, Fiorio site
2-47N-5W

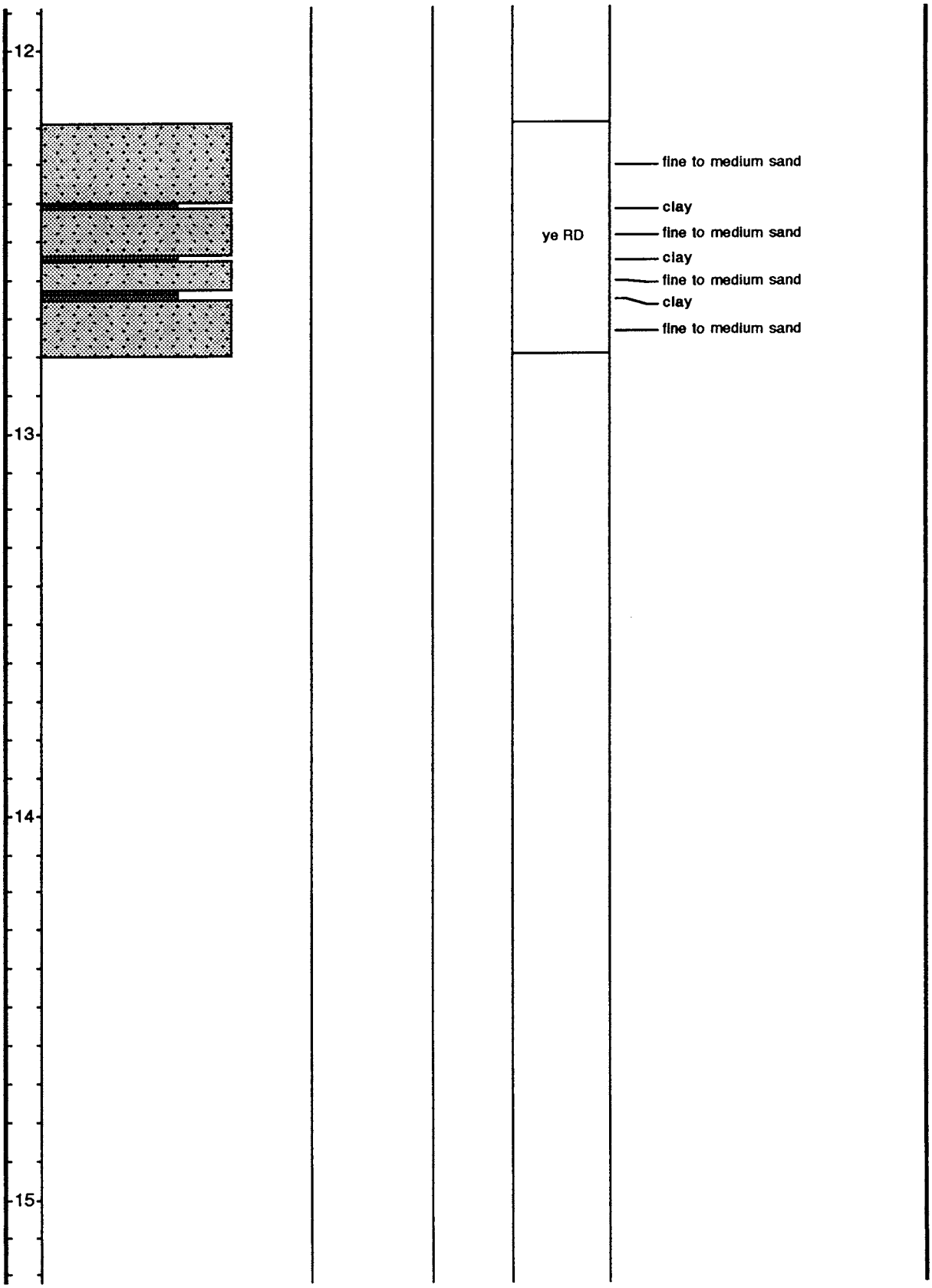
Remarks: Geoprobe core, collected with Ty Sabin and Steve Gaffield, floodplain north of North Fish Creek

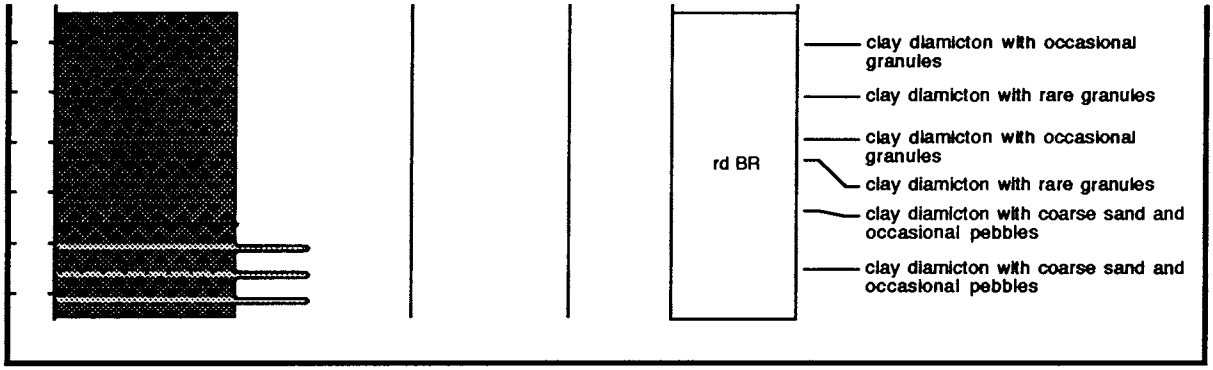



2
3
4
5
Palsl
Wd
org
C14
org
dk rd BR
m. sand, common organic debris and roots
loamy medium sand, gradual fining downward
silty clay loam, stratified, abundant organic debris, bioturbation, presettlement surface
wood and organic debris layer
medium sand loam, common organic debris and roots
silty clay loam, common organic debris
silty clay loam, occasional organic debris, red
silty clay loam, occasional organic debris
medium sand with occasional lenses of silty clay


6
7
8
Fe
Wd
C14
rd BR
rd BR
very coarse sand and occasional pebbles
fine to medium sand
coarse to very coarse and and occasional pebbles
medium to very coarse sand with occasional granules and pebbles
silt
granules and pebbles, wood, 1830+/-60 C-14 yr B.P. (AD 30-380)
medium to very coarse sand and occasional pebbles, cemented
clay, red, dense, compact
fine to medium sand, massive

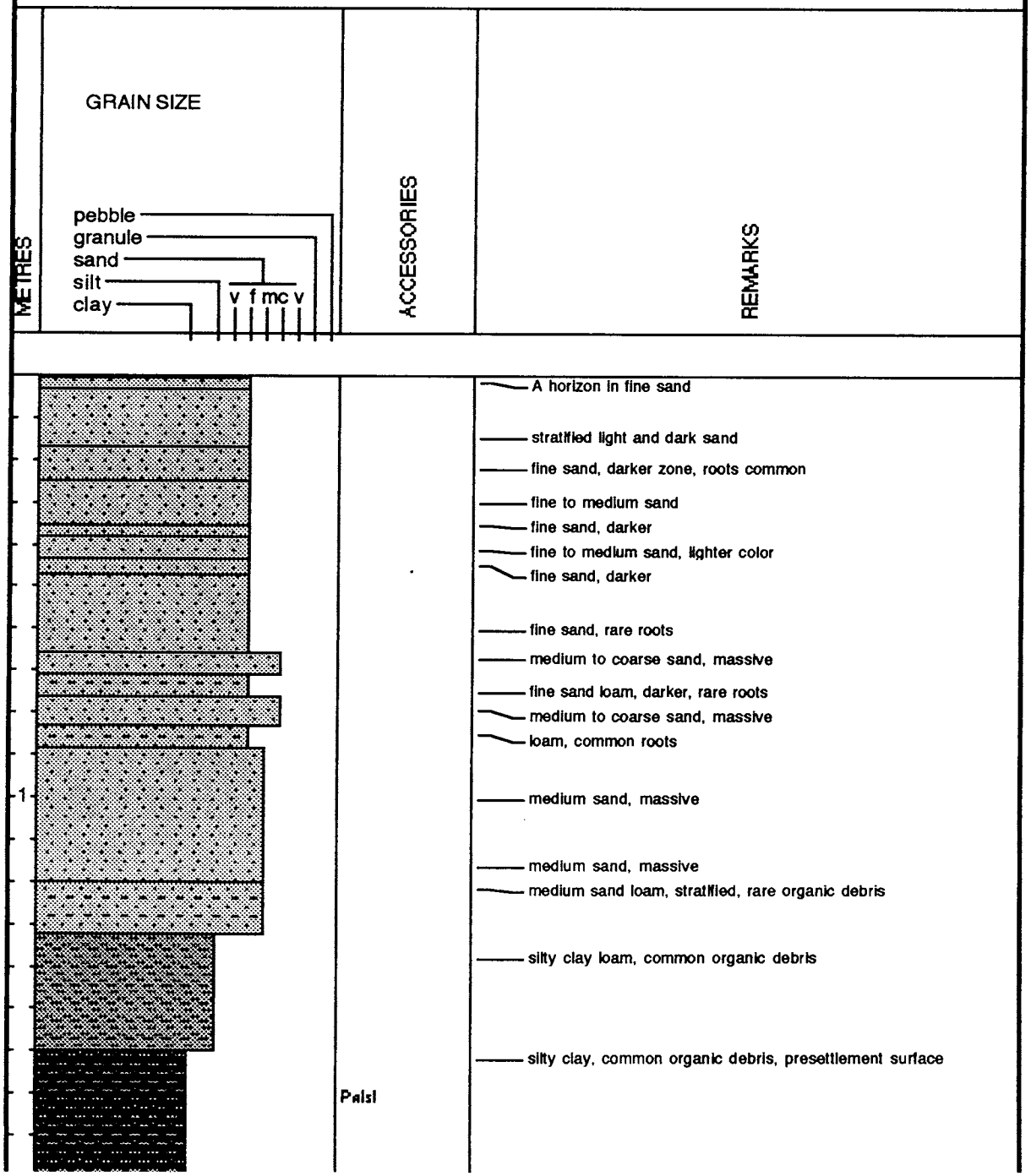

9
10
11

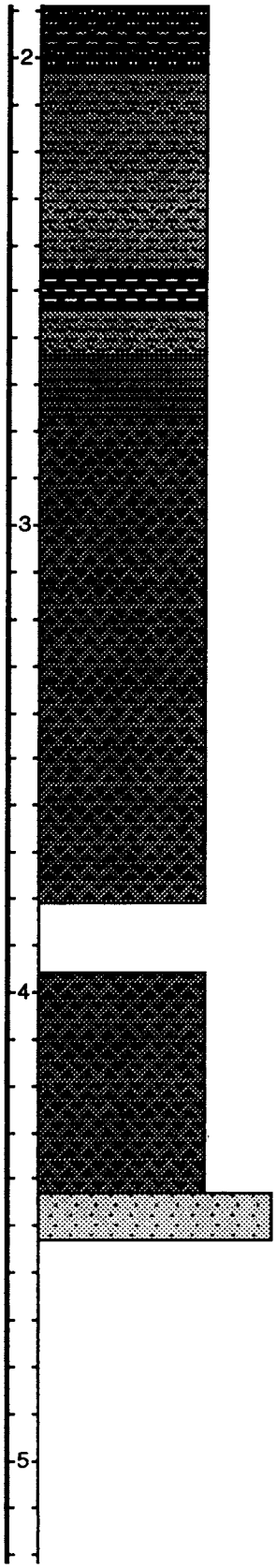

12
13
14
15
ye RD
fine to medium sand
clay
fine to medium sand
clay
fine to medium sand
clay
fine to medium sand


rd BR
clay diamicton with occasional granules
clay diamicton with rare granules
clay diamicton with occasional granules
clay diamicton with rare granules
clay diamicton with coarse sand and occasional pebbles
clay diamicton with coarse sand and occasional pebbles

Stratigraphic description of G-6, WDNR/Ashland Junction site
2-47n-5w

Remarks: Geoprobe, core ollected with Ty Sabin and Steve Gaffield, floodplain, 5 m north of North Fish Creek





silty clay, rare organic debris

clay, common rootlets and organic debris

silty clay to clay, rare organic debris

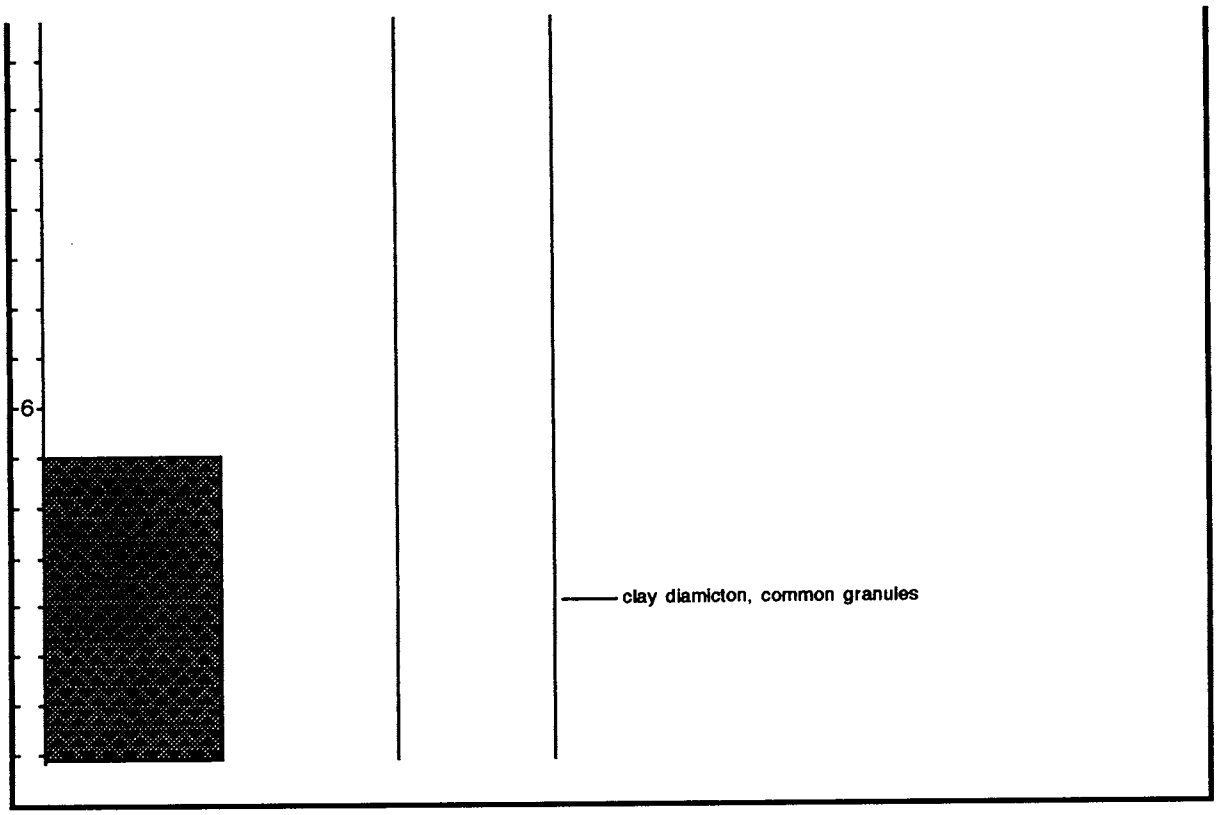
silty clay to clay, rare pebbles

silty clay to clay diamicton, rare granules

clay diamicton, occas. pebbles and granules

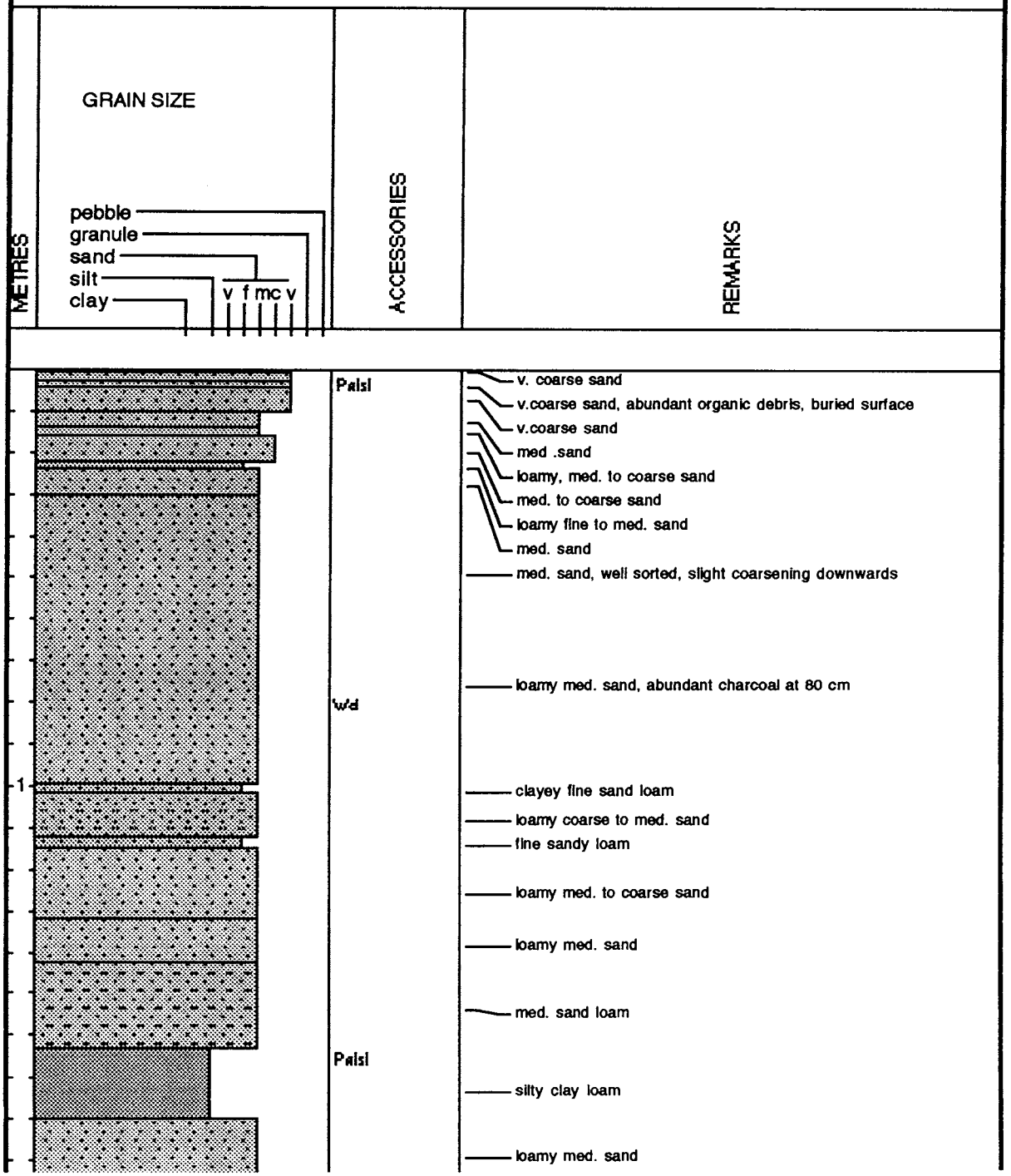
clay diamicton, common granules, occas. pebbles

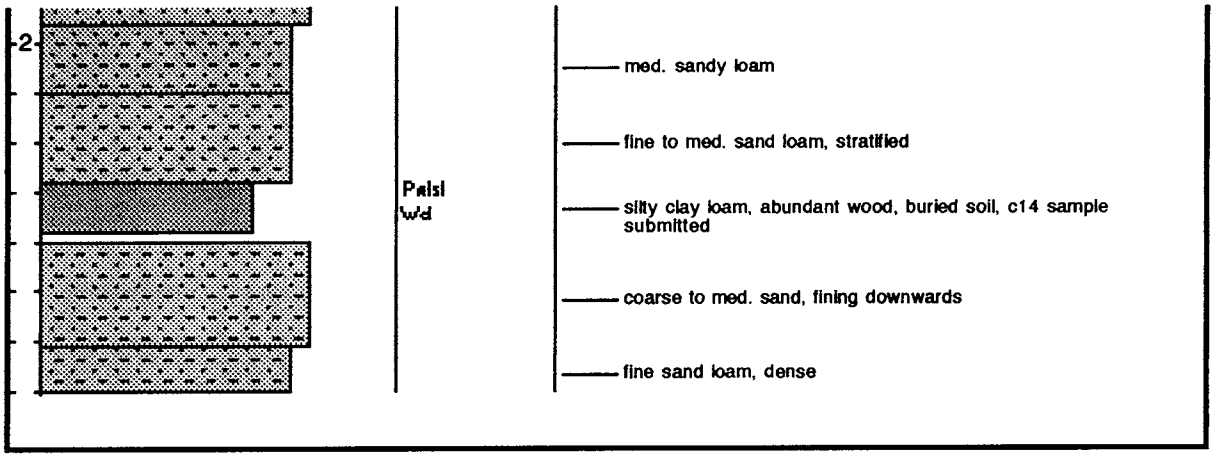
sand possibly (sample was lost)


6
clay diamicton, common granules

Stratigraphic description of C-40, Ashland Junction
2-47n-5w

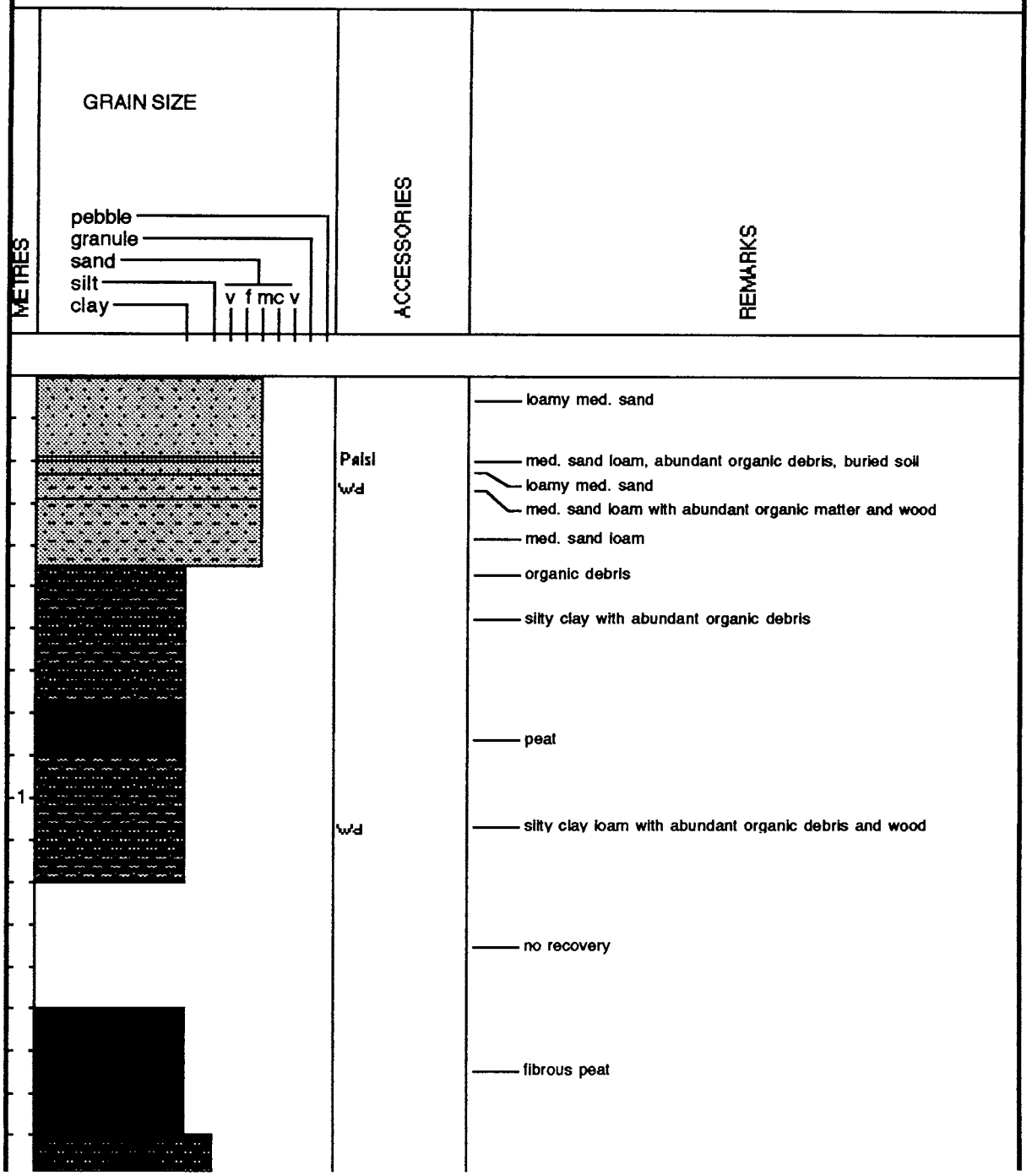
Remarks: Hand core, floodplain south of North Fish Creek.

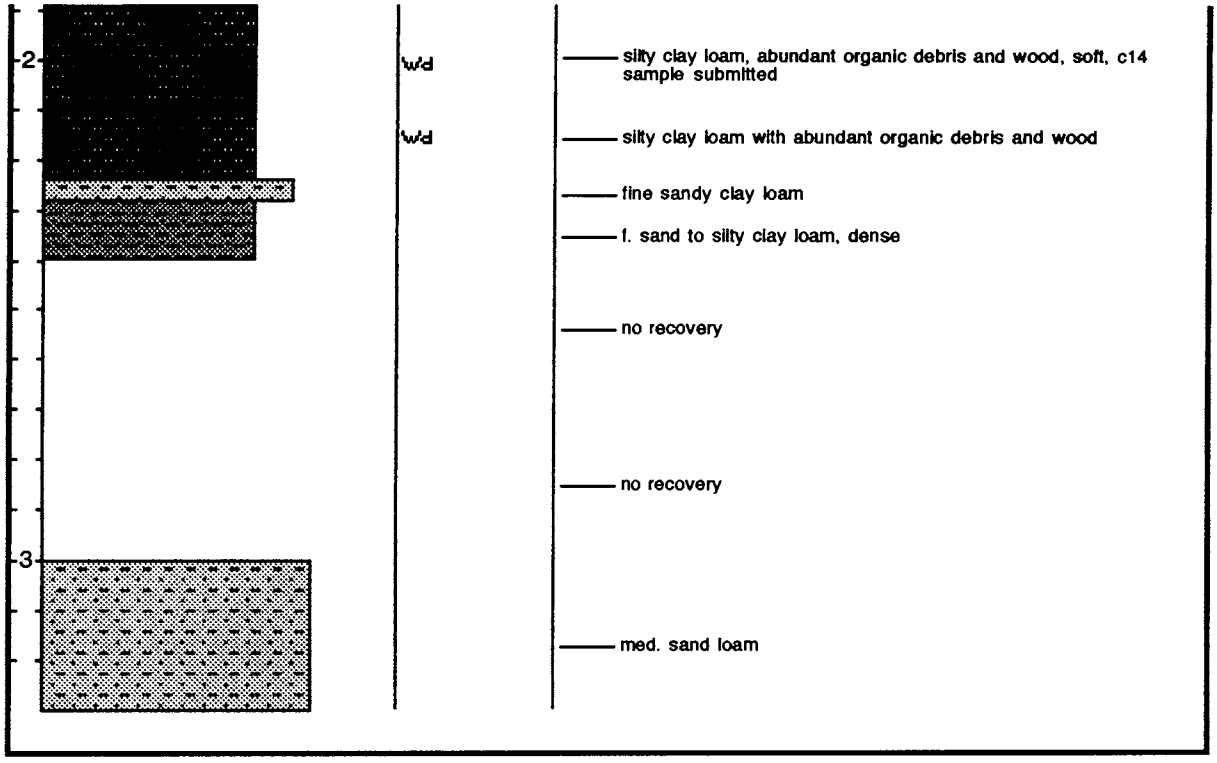



2
Paisl
w/d
med. sandy loam
fine to med. sand loam, stratified
silty clay loam, abundant wood, buried soil, c14 sample submitted
coarse to med. sand, fining downwards
fine sand loam, dense

Stratigraphic description of C-45, WDNR/Ashland Junction site
sw-2-47n-5w

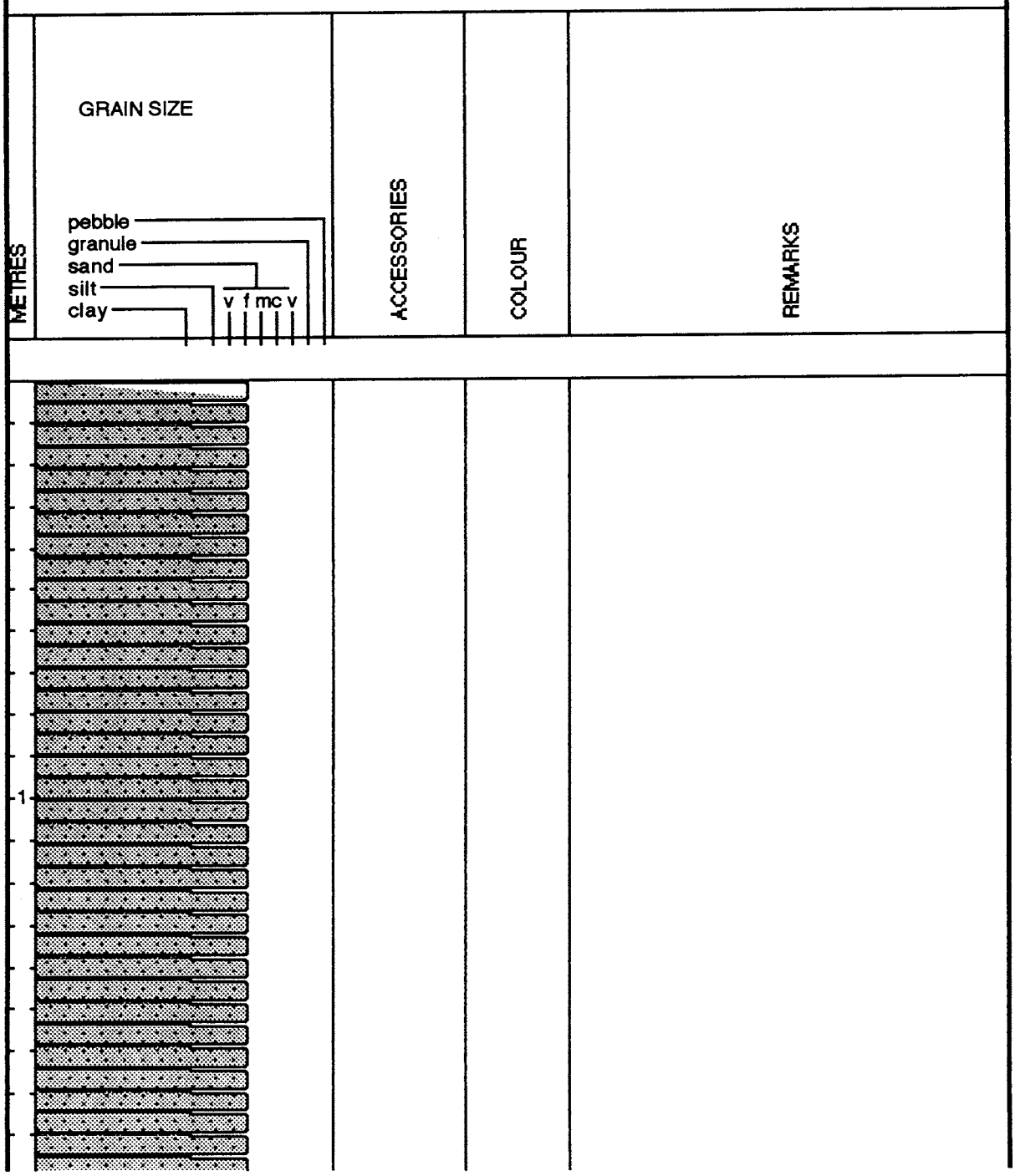
Remarks: Hand core, floodplain south of North Fish Creek

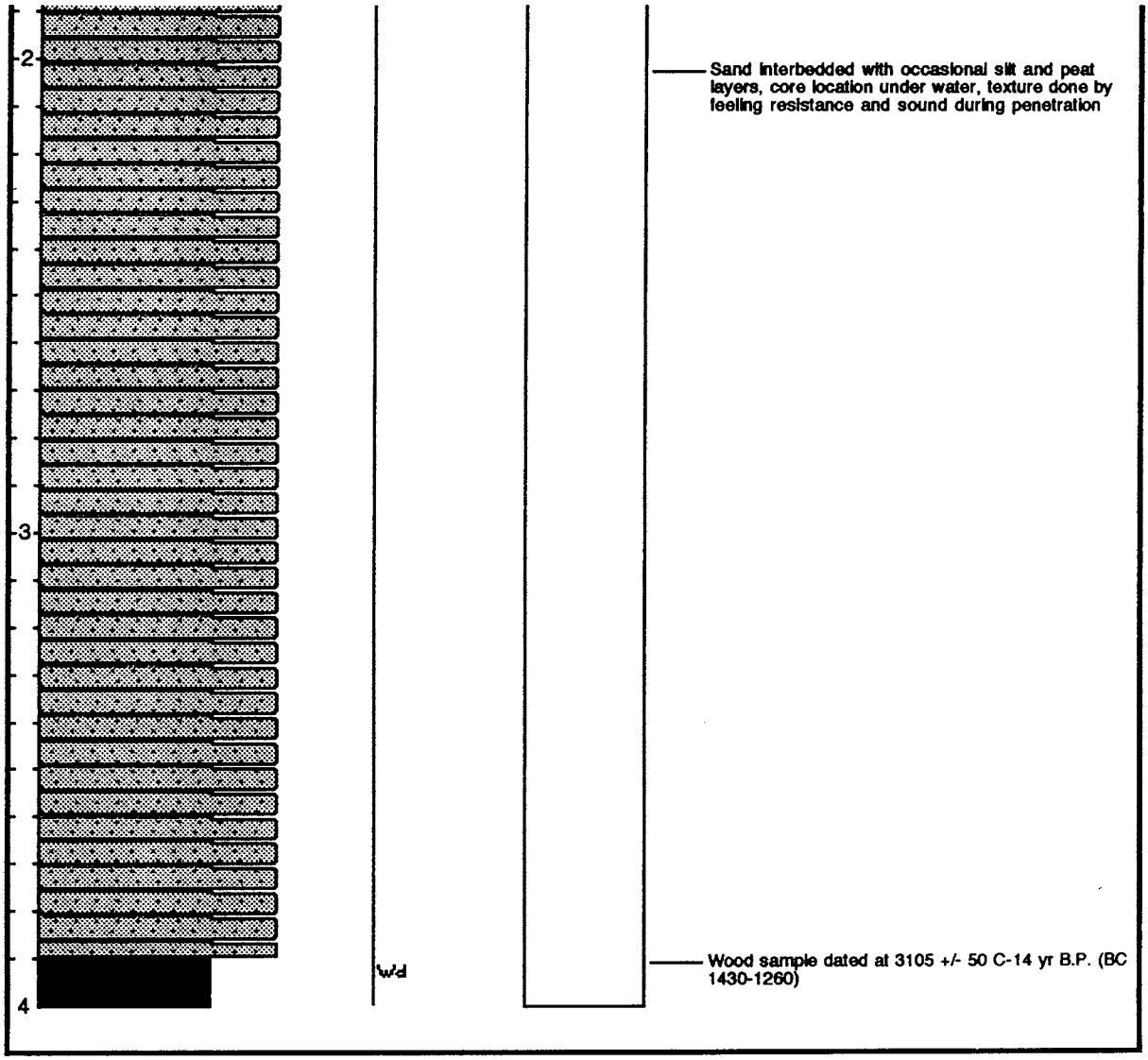



2
3
w/d
w/d
silty clay loam, abundant organic debris and wood, soft, c14 sample submitted
silty clay loam with abundant organic debris and wood
fine sandy clay loam
f. sand to silty clay loam, dense
no recovery
no recovery
med. sand loam

Stratigraphic description of C-54, WDNR/Ashland Junction site
sw-2-47n-5w

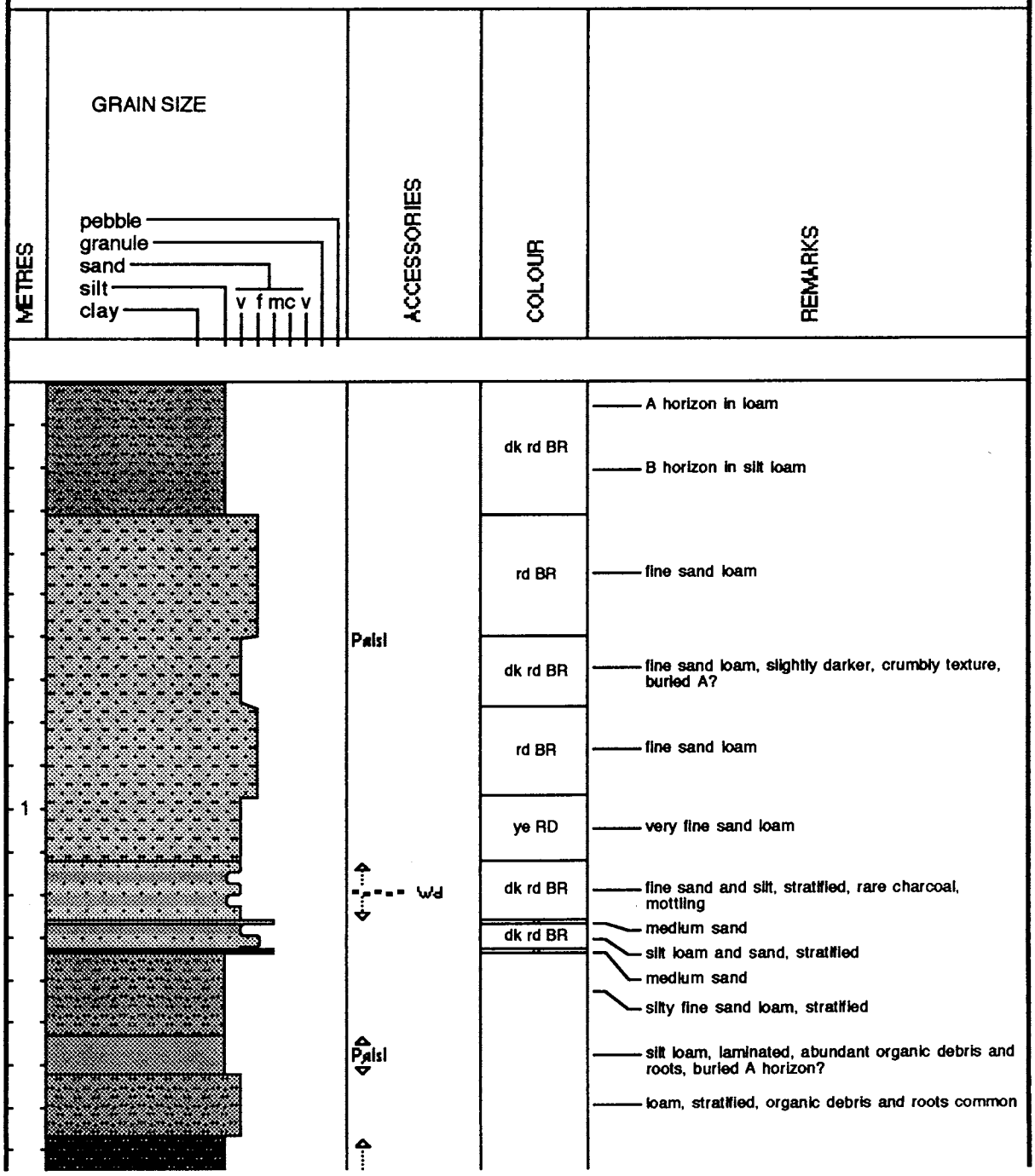
Remarks: hand core, North Fish Creek channel, left side

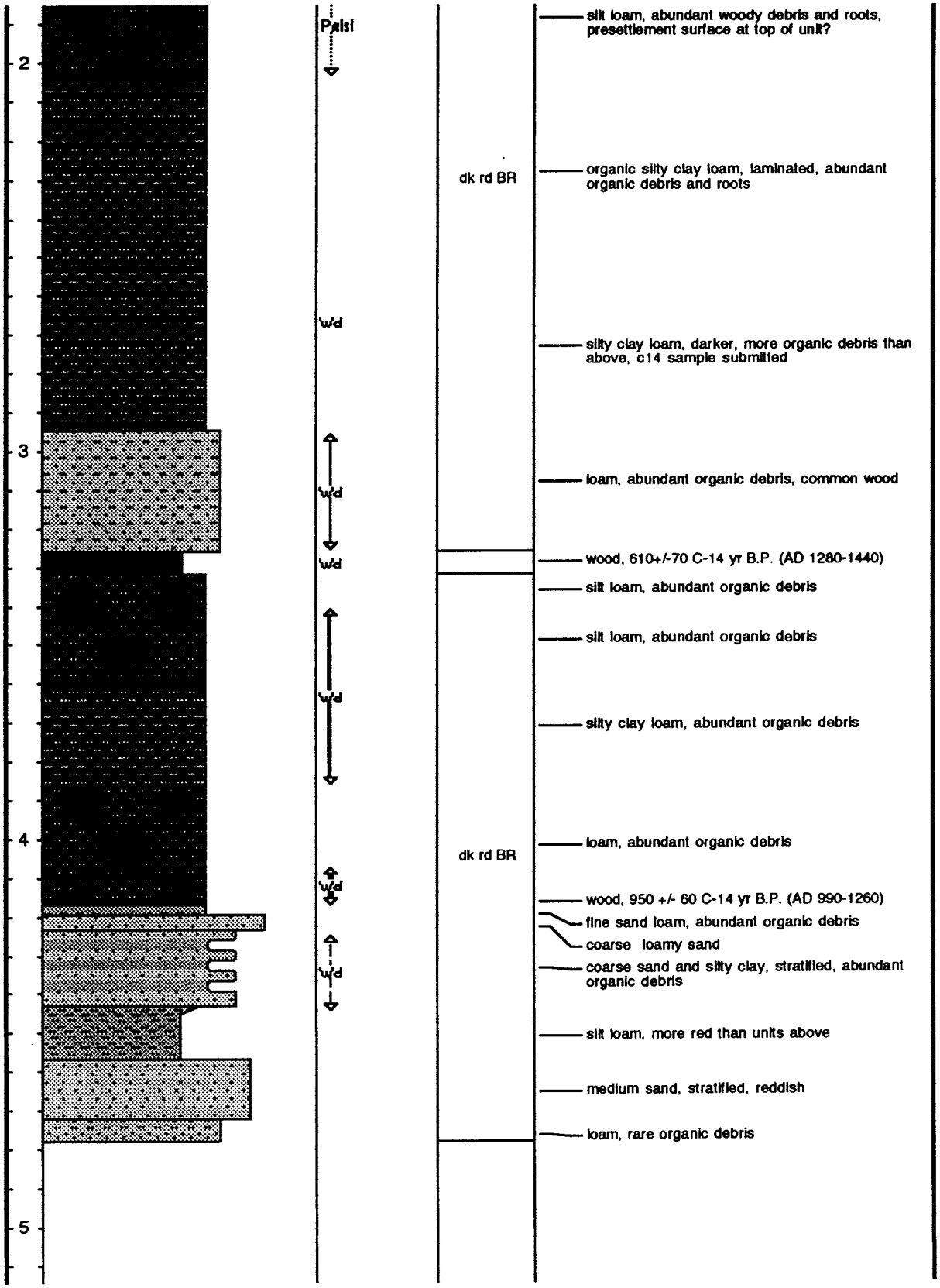


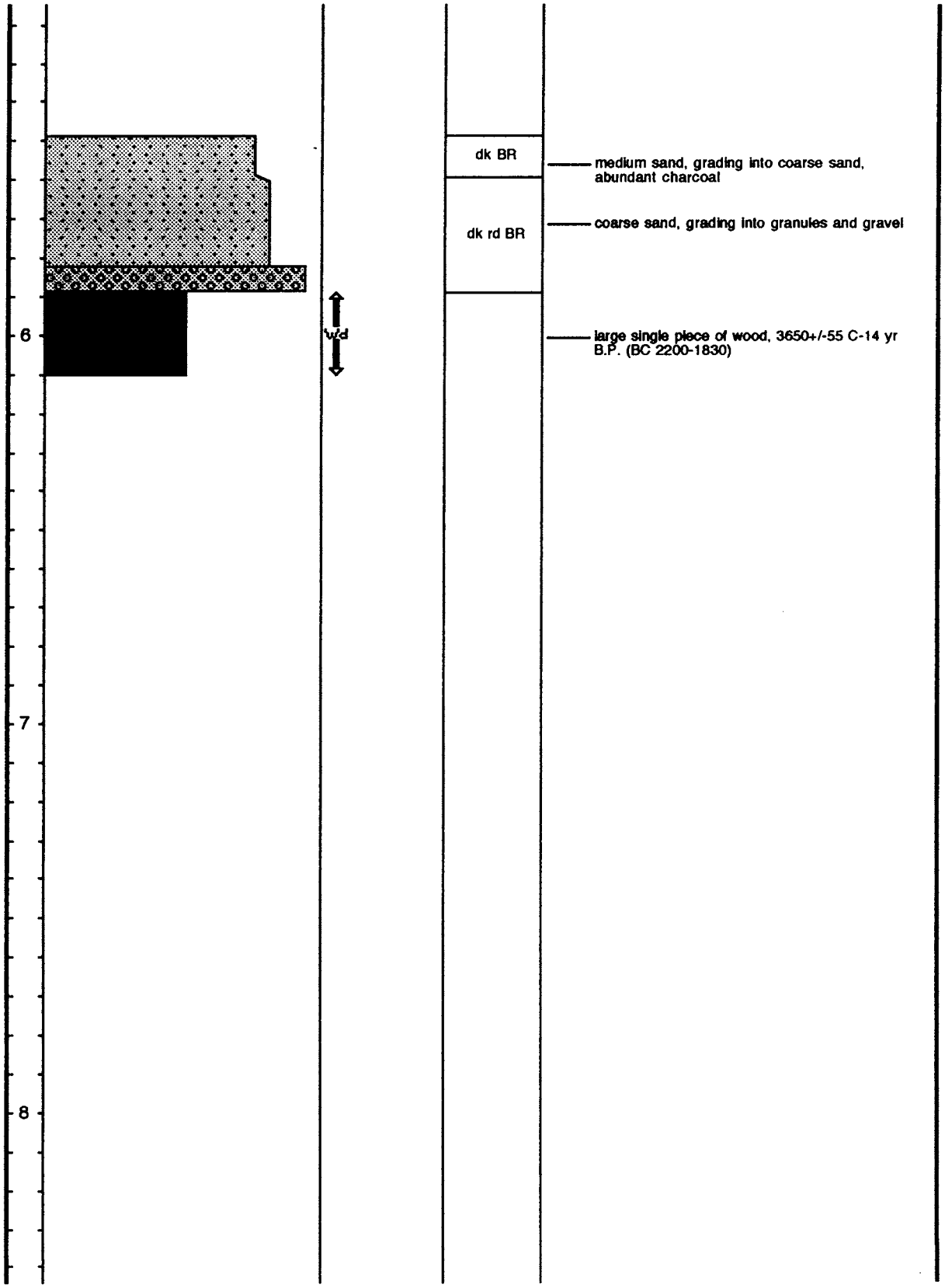

2
3
4
wd
Sand interbedded with occasional silt and peat layers, core location under water, texture done by feeling resistance and sound during penetration
Wood sample dated at 3105 +/- 50 C-14 yr B.P. (BC 1430-1260)

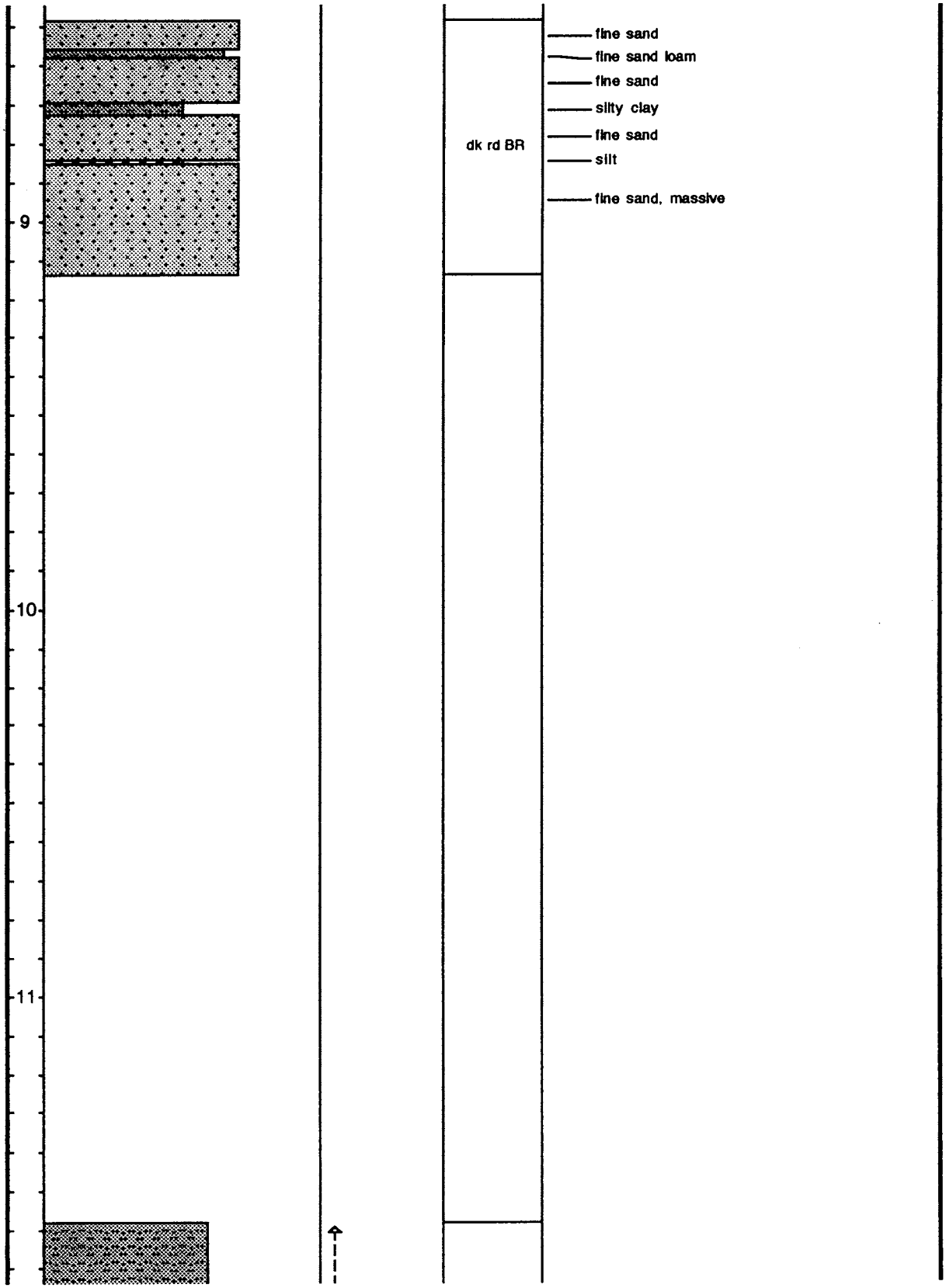
Stratigraphic description of core G-7, Fish Creek Slough
3-47N-5W

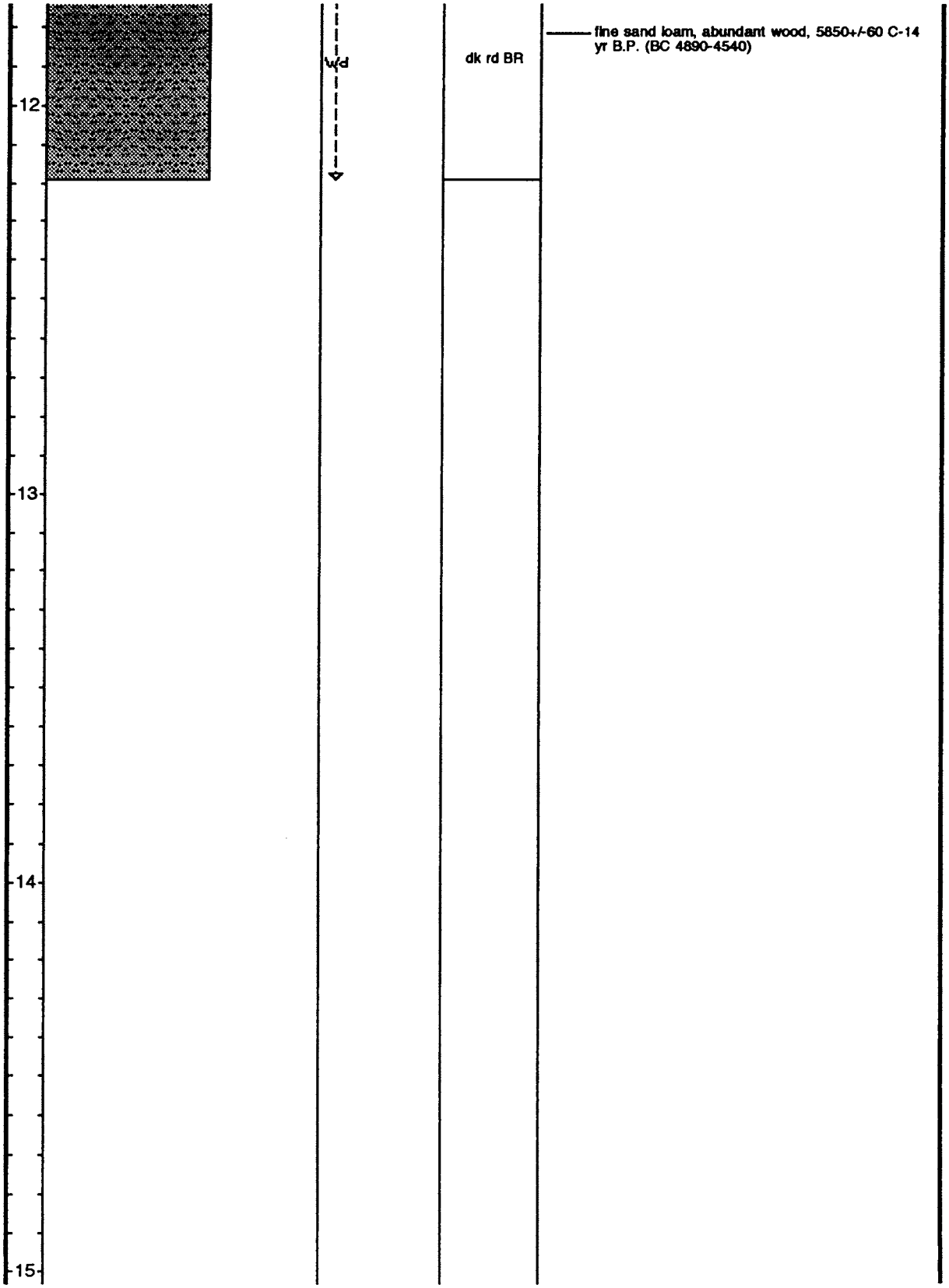
Remarks: Geoprobe core, collected with Ty Sabin and Steve Gaffield, floodplain, 15 m south of Fish Creek.

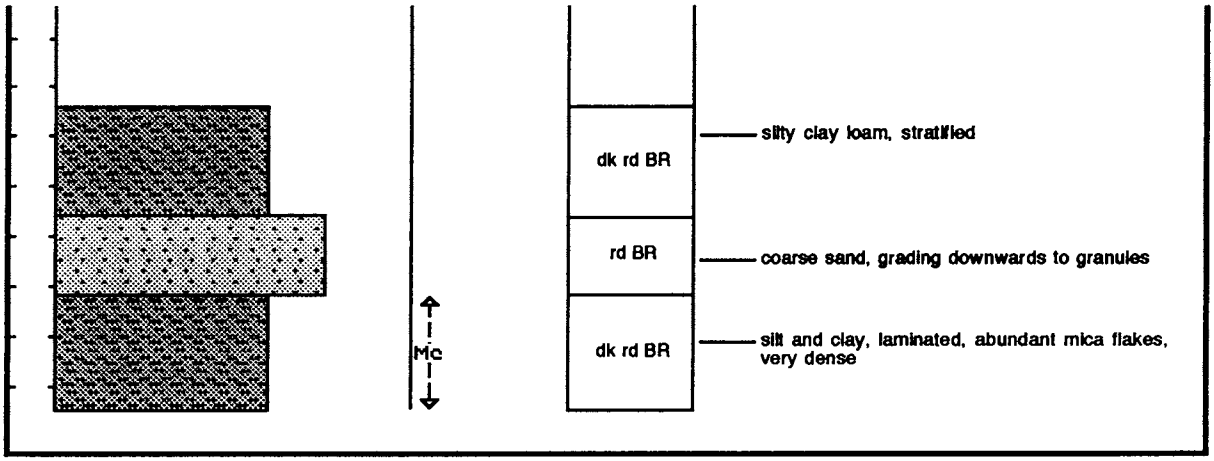



2
3
4
5
Palsi
Wd
Wd
Wd
Wd
Wd
Wd
dk rd BR
dk rd BR
silt loam, abundant woody debris and roots, presettlement surface at top of unit?
organic silty clay loam, laminated, abundant organic debris and roots
silty clay loam, darker, more organic debris than above, c14 sample submitted
loam, abundant organic debris, common wood
wood, 610+/-70 C-14 yr B.P. (AD 1280-1440)
silt loam, abundant organic debris
silt loam, abundant organic debris
silty clay loam, abundant organic debris
loam, abundant organic debris
wood, 950 +/- 60 C-14 yr B.P. (AD 990-1260)
fine sand loam, abundant organic debris
coarse loamy sand
coarse sand and silty clay, stratified, abundant organic debris
silt loam, more red than units above
medium sand, stratified, reddish
loam, rare organic debris


6
7
8
wd
dk BR
dk rd BR
medium sand, grading into coarse sand, abundant charcoal
coarse sand, grading into granules and gravel
large single piece of wood, 3650+/-55 C-14 yr B.P. (BC 2200-1830)

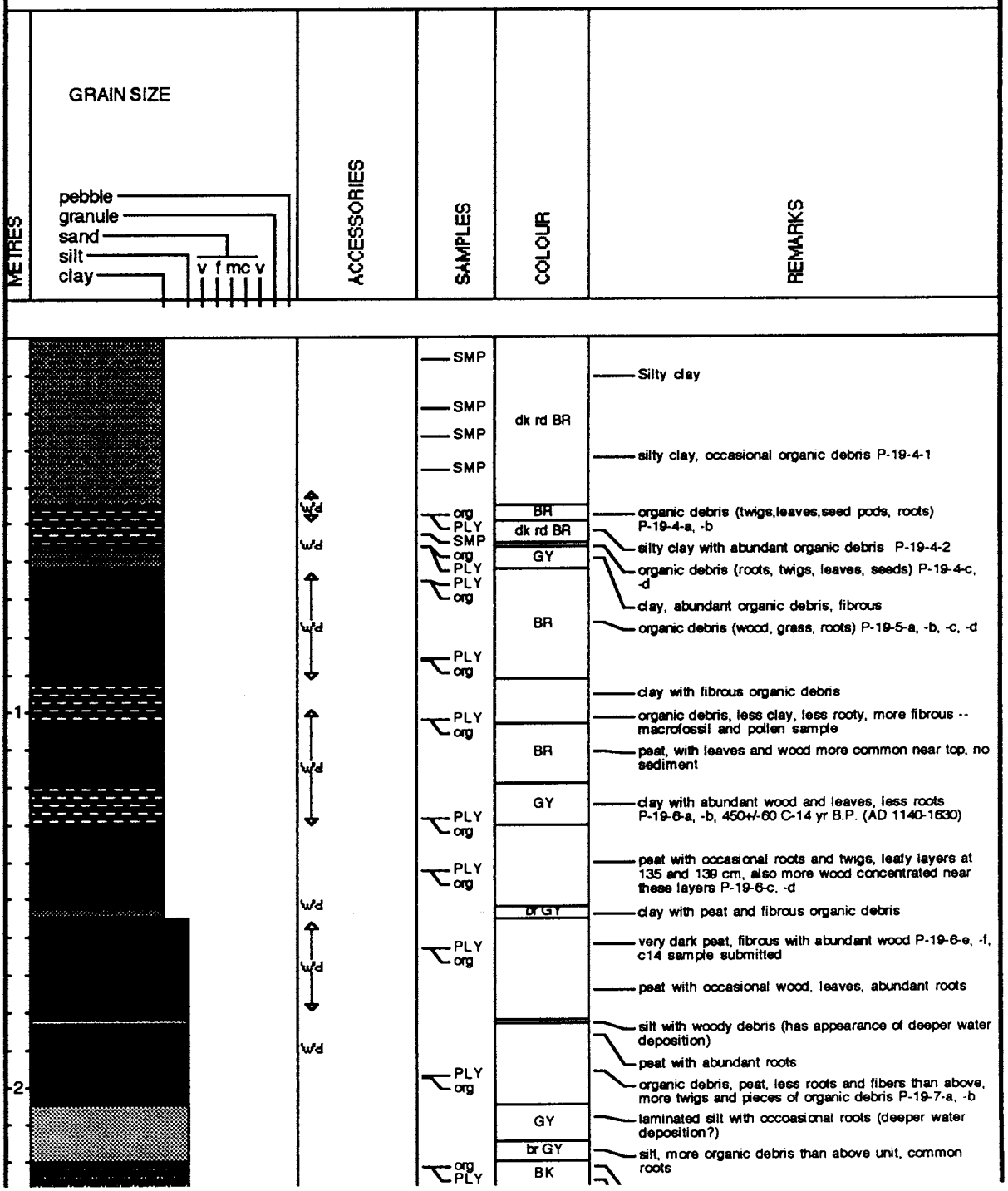

9
10
11
dk rd BR
fine sand
fine sand loam
fine sand
silty clay
fine sand
silt
fine sand, massive

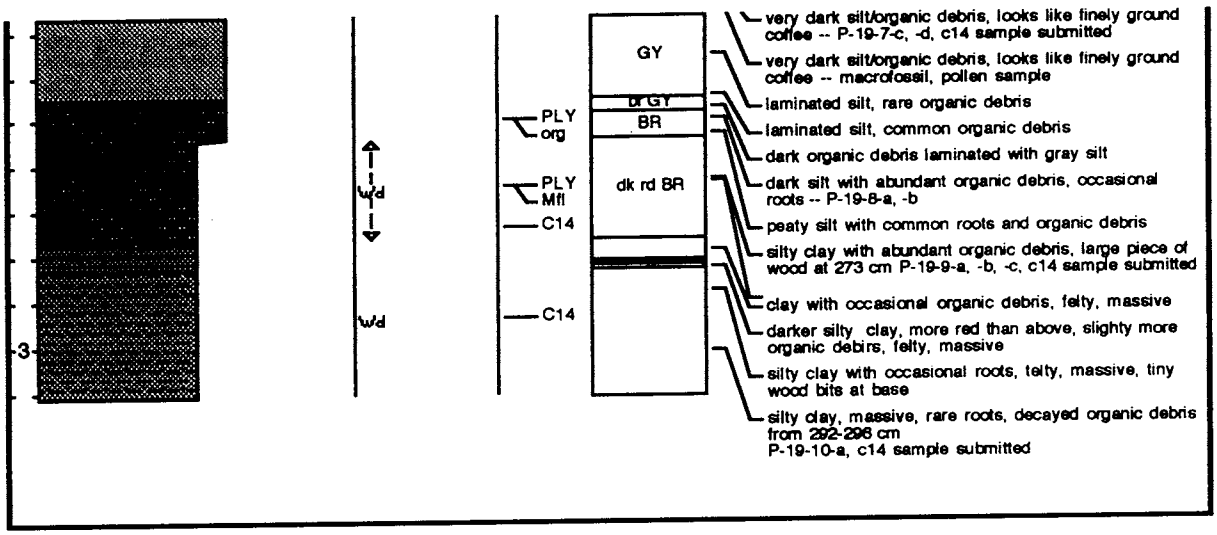

12
13
14
15
d
dk rd BR
fine sand loam, abundant wood, 5850+/-60 C-14 yr B.P. (BC 4890-4540)


dk rd BR
rd BR
dk rd BR
Mc
silty clay loam, stratified
coarse sand, grading downwards to granules
silt and clay, laminated, abundant mica flakes, very dense

Stratigraphic description of P-19, Fish Creek Slough

Remarks: Livingston core from south end of Fish Creek Slough, collected with Herb Wright




-3-
w/d
w/d
PLY
org
PLY
Mfl
C14
C14
GY
Dr GY
BR
dk rd BR
very dark silt/organic debris, looks like finely ground coffee -- P-19-7-c, -d, c14 sample submitted
very dark silt/organic debris, looks like finely ground coffee -- macrofossil, pollen sample
laminated silt, rare organic debris
laminated silt, common organic debris
dark organic debris laminated with gray silt
dark silt with abundant organic debris, occasional roots -- P-19-8-a, -b
peaty silt with common roots and organic debris
silty clay with abundant organic debris, large piece of wood at 273 cm P-19-9-a, -b, -c, c14 sample submitted
clay with occasional organic debris, felty, massive
darker silty clay, more red than above, slighty more organic debirs, felty, massive
silty clay with occasional roots, telty, massive, tiny wood bits at base
silty clay, massive, rare roots, decayed organic debris from 292-296 cm
P-19-10-a, c14 sample submitted

APPENDIX E
Channel Cross-section Data

Appendix E. Channel Cross-Section Data
Cross-section 1-1 through 1-5, relict channel, Skulan site, 1994
T47N, R5W, sec. 18, N 1/2. Horizontal distances are from left floodplain.

1-1 Distance (meters)	1-1 Elevation (meters)	1-2 Distance (meters)	1-2 Elevation (meters)	1-3 Distance (meters)	1-3 Elevation (meters)	1-4 Distance (meters)	1-4 Elevation (meters)	1-5 Distance (meters)	1-5 Elevation (meters)
1.5	8.60	6.0	8.38	3.0	8.39	1.0	8.42	1.0	8.21
2.0	8.62	7.0	8.38	4.0	8.38	2.0	8.29	1.5	8.07
2.5	8.66	8.0	8.25	5.0	8.36	2.5	8.19	2.0	8.01
3.0	8.62	8.5	8.03	5.5	8.24	3.0	7.91	2.5	7.91
3.5	8.46	9.0	7.79	6.0	7.95	3.5	7.54	4.0	7.26
4.0	8.36	9.5	7.48	6.5	7.61	4.0	7.05	4.5	7.06
4.5	8.12	10.0	7.28	7.0	7.57	4.5	6.83	5.0	6.88
5.0	7.63	10.5	7.24	7.5	7.46	5.0	6.25	5.5	6.78
5.5	7.28	11.0	7.21	8.0	7.19	5.5	6.18	6.0	6.70
6.0	7.17	11.5	7.18	8.5	6.58	6.0	6.15	6.5	6.58
6.5	7.16	12.0	7.15	9.0	6.48	6.5	6.26	7.0	6.45
7.0	7.40	12.5	6.95	9.5	6.51	7.0	6.30	7.5	6.34
7.5	7.45	13.0	6.87	10.0	6.59	7.5	6.61	8.0	6.30
8.0	7.63	13.5	6.88	10.5	6.63	8.0	6.68	8.5	6.35
8.5	7.73	14.0	6.86	11.0	6.69	8.5	6.64	9.0	6.37
9.0	7.89	14.5	6.89	11.5	6.68	9.0	6.65	9.5	6.30
9.5	7.90	15.0	7.01	12.0	6.73	9.5	6.66	10.0	6.06
10.0	7.85	15.5	7.14	12.5	6.73	10.0	6.68	10.5	5.62
10.5	7.72	16.0	7.25	13.0	6.70	10.5	6.73	11.0	5.59
11.0	7.55	16.5	7.29	13.5	6.86	11.0	6.83	11.5	5.55
11.5	7.36	17.0	7.29	14.0	6.94	11.5	6.90	12.0	5.45
12.0	7.30	17.5	7.32	14.5	7.09	12.0	7.10	12.3	5.43
12.5	7.22	18.0	7.16	15.0	7.23	12.5	7.22	12.5	5.92
13.0	7.17	18.5	7.07	15.5	7.26	13.0	7.37	13.5	6.61
13.5	7.10	19.0	7.10	16.0	7.27	13.5	7.61	14.0	6.83
14.0	7.02	19.5	7.63	16.5	7.36	14.0	8.05	14.5	7.07
14.5	6.98	20.0	7.83	17.0	7.40	14.5	8.24	15.0	7.59
15.0	7.23	20.5	8.15	17.5	7.82	15.0	8.12	15.5	7.85
15.5	7.41	21.0	8.32	18.0	8.12	15.5	8.32	16.0	7.86
15.8	7.48	21.5	8.56	18.5	8.08	16.0	8.34	16.5	7.85
16.1	7.52	22.0	8.71	19.0	7.99	16.5	8.45	17.5	7.86
16.4	7.82	22.5	8.71	19.5	8.04	17.0	8.36	18.5	8.01
16.7	8.02			20.0	8.13	18.0	8.32	19.5	8.16
17.0	8.12			20.5	8.12	19.0	8.24		
17.5	8.36			21.0	8.22	20.0	8.18		
18.0	8.41			21.5	8.29	21.0	8.28		
19.0	8.47			22.0	8.34				
20.0	8.46			22.5	8.38				

Appendix E. Channel Cross-Section Data
Cross-section 2-1 through 2-5, modern channel, Skulan site, 1994, T47N, R5W, sec. 18, N 1/2. Horizontal distances are from left floodplain.

2-1 Distance (meters)	2-1 Elevation (meters)	2-2 Distance (meters)	2-2 Elevation (meters)	2-3 Distance (meters)	2-3 Elevation (meters)	2-4 Distance (meters)	2-4 Elevation (meters)	2-5 Distance (meters)	2-5 Elevation (meters)
1.5	8.91	1.5	8.65	1.0	8.31	2.0	8.50	1.5	8.72
2.0	8.90	2.0	8.57	2.0	8.21	3.0	8.32	2.5	8.70
2.5	8.94	2.5	8.47	3.0	8.27	3.5	8.10	3.0	8.61
3.0	8.90	2.5	7.02	4.5	8.27	5.0	6.42	3.5	8.26
3.5	8.90	3.0	6.81	5.5	8.29	5.5	5.11	4.0	7.62
4.0	8.82	3.5	6.42	6.0	8.16	6.1	5.04	4.5	7.22
4.5	8.76	4.0	5.95	6.5	8.01	6.5	5.05	5.0	6.97
5.0	8.56	4.5	5.67	7.0	7.66	7.0	5.07	5.5	6.92
5.5	8.35	4.6	5.55	7.7	7.56	7.5	5.04	6.0	6.73
6.0	8.08	5.0	5.36	8.0	7.42	8.0	5.06	6.5	6.35
6.5	7.75	5.5	5.15	8.5	7.18	8.5	5.02	6.8	6.14
7.0	7.50	6.2	4.98	9.0	6.87	9.0	4.98	7.0	5.42
7.5	7.39	7.0	5.05	9.6	6.69	9.5	5.01	7.5	5.23
8.0	7.44	7.5	5.03	10.0	6.51	10.0	5.01	8.0	5.10
8.5	7.59	8.0	5.09	10.5	6.34	10.5	5.00	8.5	5.10
9.0	7.58	8.5	5.01	11.0	6.21	11.0	4.84	9.0	5.08
9.5	7.43	9.0	5.08	11.5	5.83	11.5	4.95	9.5	5.08
10.0	7.17	9.5	5.15	12.0	5.70	12.0	4.93	10.0	5.12
10.5	5.41	10.0	5.14	12.5	5.38	12.5	4.97	10.5	5.11
11.0	5.33	10.5	5.21	13.0	5.32	13.0	4.94	11.0	5.09
11.5	5.37	11.0	5.23	13.5	5.31	13.5	4.92	11.5	5.04
12.0	5.38	11.5	5.38	14.0	5.44	14.0	4.94	12.0	5.00
12.5	5.40	12.0	5.38	14.5	5.28	14.5	4.99	12.5	4.97
13.0	5.21	12.5	5.36	15.0	5.19	15.0	5.03	13.0	5.01
13.5	4.85	13.0	5.34	15.5	5.13	15.5	5.06	13.5	5.08
14.0	4.87	13.5	5.31	16.5	5.08	16.5	5.07	14.0	5.10
14.5	4.90	14.0	5.34	17.0	5.05	17.0	5.11	14.5	5.11
15.0	4.98	14.5	5.30	17.5	5.04	17.5	5.14	15.0	5.06
15.5	4.97	15.0	5.24	18.0	5.02	18.0	5.18	15.5	5.03
16.0	4.95	15.5	5.13	18.5	5.03	18.5	5.19	16.0	4.86
16.5	5.05	16.5	5.42	19.0	5.02	19.0	5.22	16.5	4.93
17.0	5.08	17.0	5.56	19.5	5.00	19.4	5.35	17.0	5.03
17.5	5.08	17.5	5.55	20.0	5.00	20.0	5.66	17.5	5.02
18.0	5.13	18.0	5.57	20.5	5.01	20.5	5.85	18.0	5.12
18.5	5.19	18.5	5.58	21.0	5.04	21.0	6.03	18.5	6.10
19.0	5.21	19.0	5.75	21.5	4.89	21.5	6.39	19.0	6.77
19.5	5.26	19.5	5.93	22.0	4.87	22.0	6.67	19.5	7.07
20.0	5.32	20.0	6.26	22.5	4.81	22.5	6.51	20.0	7.40
20.5	5.35	20.5	6.44	23.0	4.79	23.0	6.46	20.5	7.56
21.0	5.30	21.0	6.72	23.5	5.06	23.5	6.50	21.0	7.50
21.5	5.34	21.5	6.94	24.0	5.09	24.0	6.59	21.5	7.69
22.0	5.36	22.0	7.04	24.5	5.22	24.5	6.09	22.0	7.90
22.5	5.39	22.5	7.28	25.0	5.19	25.0	5.61	22.5	8.00

2-1 Distance (meters)	2-1 Elevation (meters)	2-2 Distance (meters)	2-2 Elevation (meters)	2-3 Distance (meters)	2-3 Elevation (meters)	2-4 Distance (meters)	2-4 Elevation (meters)	2-5 Distance (meters)	2-5 Elevation (meters)
23.0	5.45	23.0	7.43	25.6	5.21	25.5	5.76	23.0	8.00
23.5	5.70	23.5	7.18	26.0	5.32	26.0	5.93	24.0	7.98
24.0	5.97	24.0	7.45	26.5	5.55	26.5	6.16	25.0	7.80
24.5	6.58	24.5	7.47	27.0	5.67	27.0	6.27	26.0	7.57
25.0	7.04	25.0	7.50	28.0	5.96	27.8	7.19	27.0	7.55
25.5	7.28	25.5	7.57	28.2	6.21				
26.0	7.52	26.0	7.75	28.9	8.30				
26.5	7.67	26.5	7.92	29.5	8.67				
27.0	7.69	27.0	8.08	30.0	8.78				
27.5	7.68	27.5	8.26						
28.0	7.61	28.0	8.45						
28.5	7.59	28.5	8.79						
		29.0	8.89						
		29.5	8.90						
		30.0	8.91						

Appendix E. Channel Cross-Section Data
Cross-section 3-1 through 3-5, modern channel, Fiorio site, 1994-5, T47N, R5W, sec. 2/3 line. Horizontal distances are from left floodplain.

3-1 Distance (meters)	3-1 Elevation (meters)	3-2 Distance (meters)	3-2 Elevation (meters)	3-3 Distance (meters)	3-3 Elevation (meters)	3-4 Distance (meters)	3-4 Elevation (meters)	3-5 Distance (meters)	3-5 Elevation (meters)
1.0	29.15	1.0	29.24	1.0	28.98	1.0	28.95	1.9	29.11
2.0	29.13	2.0	29.23	2.0	29.03	2.0	29.03	2.2	29.11
2.5	28.97	2.5	28.96	2.5	29.04	3.0	29.12	3.0	28.60
2.8	28.90	2.7	28.18	3.0	28.60	3.5	29.07	3.5	28.45
3.2	28.38	3.0	28.04	3.4	28.49	4.2	28.58	4.0	28.38
3.4	28.53	4.0	27.85	3.6	28.45	5.0	28.35	5.0	28.28
3.5	28.19	4.5	27.79	4.9	28.07	6.0	28.32	6.0	28.18
3.7	28.01	5.0	28.02	6.0	27.98	7.0	28.28	6.5	28.08
4.0	27.75	5.5	27.99	6.5	27.93	8.0	28.28	7.0	28.18
4.5	27.85	6.0	27.90	7.0	27.88	9.0	28.30	8.0	28.11
5.0	27.89	6.5	27.93	7.5	27.91	10.0	28.31	8.9	28.17
6.0	28.01	7.0	27.99	8.0	27.92	11.0	28.24	10.0	28.20
7.0	28.03	8.0	28.04	8.5	27.99	12.0	28.17	11.0	28.21
8.0	28.15	9.0	28.06	9.0	28.04	13.0	28.18	12.0	28.12
9.0	28.14	10.0	28.08	9.5	28.06	14.0	28.15	13.0	28.14
10.0	28.20	11.0	28.12	10.0	28.05	15.0	28.11	14.0	28.38
11.0	28.21	12.0	28.22	11.0	28.23	16.0	28.06	15.0	28.13
12.0	28.19	13.0	28.18	12.0	28.30	17.0	28.08	16.0	28.11
13.0	28.17	14.0	28.11	13.0	28.25	17.5	27.99	16.9	28.26
14.0	28.18	14.5	28.15	14.0	28.24	18.0	27.96	17.6	28.28
15.0	28.18	15.0	28.30	15.0	28.21	18.5	28.11	18.5	29.29
16.0	28.17	15.9	28.56	16.0	28.35	19.0	28.26		
16.5	28.21	16.5	28.77	17.0	28.35	19.5	28.38		
17.0	28.24	17.0	28.99	17.6	28.56	20.0	28.37		
17.5	28.39	17.5	29.03	17.9	28.73	20.3	29.20		
18.1	28.50	18.5	29.12	18.5	28.81	21.0	29.27		
18.5	28.60	19.0	29.08	19.2	29.16				
19.0	28.67			20.0	29.20				
19.5	28.62								
20.0	28.61								
20.7	28.68								

Appendix E. Channel Cross-Section Data

Cross-section 4-1, modern channel and right floodplain, WDNR/Ashland site, 1995, T47N, R5W, sec. 2, SW 1/4. Horizontal distances are from left floodplain.

4-1 Distance (meters)	4-1 Elevation (meters)	4-1 Remarks
1.0	30.00	lb-modern
2.0	30.00	bank full
2.5	29.79	
3.3	29.33	lew
4.0	29.08	
5.0	29.05	
6.0	29.10	
7.0	29.10	
8.0	29.11	
9.0	29.12	
10.0	29.04	
11.0	29.02	
12.0	29.02	
13.0	28.97	
14.0	28.99	
15.0	29.05	
16.0	29.08	
17.0	28.98	
18.0	29.04	
19.0	29.19	
20.0	29.23	
21.0	29.30	
22.0	29.45	
21.6	29.31	rew
22.5	29.72	
23.5	30.00	bank full
24.0	30.02	
25.1	30.10	
26.0	30.04	
32.5	29.99	C-39
41.5	30.01	C-40
50.8	29.98	C-41
76.8	29.64	C-42
110.5	29.18	C-43
134.8	29.22	C-58
164.3	29.10	C-57
194.3	28.90	C-56
211.3	28.77	C-48
226.3	28.78	C-45
226.8	28.85	:lict channel
227.9	28.93	lb
228.6	29.05	

4-1 Distance (meters)	4-1 Elevation (meters)	4-1 Remarks
229.3	28.96	
229.8	28.92	
230.3	28.69	
230.8	28.84	
231.2	28.80	lew
231.6	28.60	
231.8	28.66	
232.3	28.74	
232.8	28.69	
234.3	28.79	rew
235.0	29.04	island
236.1	29.07	
236.8	28.81	rew
237.3	28.59	
237.8	28.53	
238.8	28.46	pss?
239.3	28.38	
239.8	28.22	
240.3	28.09	
240.8	28.10	
241.3	28.09	
241.8	28.05	
242.3	28.04	
242.8	28.06	
243.2	28.15	
243.8	28.21	
244.3	28.25	
244.8	28.25	
245.3	28.25	
245.6	28.79	:w, main trib
246.3	29.17	bank top
248.3	28.78	lew, relict
249.3	28.71	
250.3	28.66	
251.3	28.59	
252.3	28.45	
253.3	28.45	
254.3	28.41	
255.3	28.44	
256.3	28.52	
257.1	28.78	rew, relict
257.8	28.84	:-44, upland

Appendix E. Channel Cross-Section Data
Cross-section 5-1 through 5-5, modern channel, Moore site, 1995,
T47N, R6W, sec. 21, SW 1/4. Horizontal distances are from left floodplain.

5-1 Distance (meters)	5-1 Elevation (meters)	5-1 Remarks	5-2 Distance (meters)	5-2 Elevation (meters)	5-2 Remarks	5-3 Distance (meters)	5-3 Elevation (meters)	5-3 Remarks
1.9	30.05	lb	0.9	30.86	terrace	1.4	31.64	left terrace
2.5	29.59	toe of slope	1.9	30.58		1.9	31.64	terrace edge
3.0	29.44		3.1	29.67	toe of slope	2.5	31.15	bench
3.8	29.15	break in slope	3.5	29.59	low terrace	3.2	30.92	
4.5	28.37	slope bottom	3.9	29.52	edge of terrace	4.4	29.93	steep slope
5.3	28.15	lew	4.5	29.22	bank full?	5.2	29.21	
6.0	27.66		5.0	28.92		6.0	28.30	lew
6.5	27.83		5.5	28.73	edge of shelf	7.0	27.99	
7.0	27.79		6.1	28.28	lew	8.0	27.98	
7.5	27.76		7.0	27.92		9.0	28.18	
8.0	27.83		8.0	27.76		10.0	28.28	
8.5	27.85		9.0	27.74		11.0	28.51	point bar
9.0	27.83		9.5	27.78	thalweg	12.0	28.50	sand/boulders
9.5	27.83		10.0	27.79		12.6	28.65	shelf
10.0	27.83		10.5	27.81		12.9	28.87	
10.5	27.84		11.0	27.82		13.6	29.03	bank full
11.0	27.86		12.0	27.91		14.1	29.15	
11.5	27.90		13.0	27.98		14.9	29.46	
12.0	27.92		14.0	28.02	break in slope	15.8	29.58	
12.5	27.98		14.3	28.06		16.5	29.67	
12.9	28.16	rew	14.3	28.29	rew			
13.3	29.17	top bank	14.3	28.76				
14.0	29.38	rb	14.7	29.09				
			15.0	29.16	bank full ?			
			15.6	29.55	rb			

5-4 Distance (meters)	5-4 Elevation (meters)	5-4 Remarks	5-5 Distance (meters)	5-5 Elevation (meters)	5-5 Remarks
0.5	32.14	left terrace	1.0	30.56	
1.5	32.12		2.0	30.47	bank full
2.2	32.10	edge of terrace	3.0	30.13	
4.4	30.01	floodplain	4.0	29.90	
6.2	29.86		4.6	29.57	
7.3	29.88		5.1	29.50	lew, point bar
8.1	29.97		6.1	29.36	
9.0	29.93		7.0	29.33	
10.0	29.94		7.9	29.17	
11.0	29.88		8.7	29.09	
11.8	29.69		9.4	29.02	
12.1	29.44		10.1	29.05	
12.6	29.34	lew	11.0	29.03	
13.5	29.11		12.0	29.17	
14.6	29.14		12.0	29.49	rew
15.5	29.17		12.2	30.07	rb
16.4	29.27		12.6	30.29	bank full?
17.4	29.22		13.8	30.65	
18.3	29.23		14.3	30.73	
19.3	29.15				
20.0	29.04				
20.5	28.94				
21.3	28.96				
22.0	29.13				
22.6	29.38	rew			
23.1	29.73				
24.0	29.87				
25.0	30.14				

Appendix E. Channel Cross-Section Data
Cross-section 6-1 through 6-5, relict channel, Moore site, 1995,
T47N, R6W, sec. 21, SW 1/4. Horizontal distances are from left floodplain.

6-1 Distance (meters)	6-1 Elevation (meters)	6-1 Remarks	6-2 Distance (meters)	6-2 Elevation (meters)	6-2 Remarks	6-3 Distance (meters)	6-3 Elevation (meters)	6-3 Remarks
-5.0	28.60	approx	1.0	28.81	lb	4.7	31.03	terrace
1.0	28.60		2.4	28.61	left slope	5.6	31.03	
2.0	28.36		3.2	28.55		8.3	29.82	mid slope
4.0	28.51		4.0	28.49		9.5	29.99	bank full
5.0	28.54	lb top	5.0	28.48		9.9	28.07	channel, base lb
6.0	28.05	slope	6.0	28.34		10.5	27.99	thalweg
7.0	27.38		7.2	27.87	lew	11.3	27.90	thalweg
8.0	27.30		8.0	27.87		13.0	27.83	wd = .44
9.0	27.62	shelf in trib	9.0	27.81	in trib	14.0	28.02	boulder to sand
10.0	27.89	slope	10.0	28.16	rb, bank full	15.0	28.12	wd = .14
11.0	28.43	rb top	11.0	28.42	rb slope	16.1	28.25	rew
12.0	28.36		12.0	28.61		17.8	28.67	rb
13.0	28.22		13.0	28.80	terrace top	18.8	29.23	bank full
14.0	28.38					20.0	29.57	rb
14.5	28.64					20.3	29.61	instrument
15.0	28.99					20.5	29.60	right floodpl.
15.8	29.21	terrace top				22.0	29.62	24 29.66
						26.0	29.59	28 29.69
						30.0	29.61	32 29.66 bas
						47.0	30.42	49 30.45
						51.0	30.42	
						53.0	30.41	= 0.0 1st tape
						54.5	30.23	
						56.0	29.98	
						58.0	29.79	lb channelway
						60.0	29.71	center channel
						62.0	29.71	
						64.0	29.83	
						66.0	29.85	top rt. ch. marg
						67.0	29.77	sandy boulder bar
						69.0	29.76	
						71.0	29.80	
						73.0	29.79	
						75.0	29.76	gravel bar top
						77.0	29.80	79 29.83
						79.7	29.73	rt. egde bar
						80.7	29.40	base lb slope
						81.5	29.44	edge
						82.5	28.85	base active lb

6-3 Distance (meters)	6-3 Elevation (meters)	6-3 Remarks	6-4 Distance (meters)	6-4 Elevation (meters)	6-4 Remarks	6-5 Distance (meters)	6-5 Elevation (meters)	6-5 Remarks
83.3	28.81	trib thalweg	0.0	29.71	chute	-3.5	30.73	sand bar
84.0	28.81	rt. channel	1.8	29.71	base gr terrace	0.0	30.06	gravel bar
84.1	29.07	slope rb	3.0	29.74	side slope	2.0	30.04	
85.2	29.40	top rb	6.0	29.95	gravel bar	4.0	30.11	
86.0	29.39		10.0	29.92		6.0	30.16	
88.0	29.38		11.5	29.69	mid slope	8.0	30.26	
89.0	29.31	gravel terrace	12.5	29.50	bar base	10.0	30.27	
93.2	29.32	instrument	12.8	29.51	sandy high	12.0	30.32	
94.5	29.21	gravel terrace	14.5	29.40	micro channel	13.0	30.22	rt edge bar
95.9	29.12		17.3	29.53	on gravel bar	14.0	29.96	base bar
97.2	29.10		17.7	29.50	top lb trib	15.0	29.89	lt trib terrace
98.3	28.90	mid bank	18.4	29.19	base lb	17.0	29.84	
99.0	28.68	base lb	27.0	29.02	base lb	19.0	29.94	
100.0	28.61	sa/bo channel	28.0	28.91	center relict	19.8	29.71	slope bas
101.1	28.56	mid channel	29.0	28.85	base rb	21.3	29.80	lt trib flood
102.3	28.56	base rb	29.5	29.15	slope rb	22.5	29.78	
103.0	28.83	rb slope	30.5	29.55	top rb	23.5	29.73	instrument
104.0	29.43	upper rb	31.0	29.59	top rb/floodpl	24.0	29.73	left floodplain
104.6	29.76	top rb	32.0	29.56		24.5	29.51	shelf
105.0	29.78	terrace top	33.0	29.72	slope base	25.2	29.64	bar top
106.6	29.81	terrace top	34.0	30.32	slope	26.1	29.27	lew trib
107.0	30.01	slope	35.0	31.20	slope	26.3	29.22	wd = 3 cm
108.2	30.47	mid slope	36.5	32.07		26.9	29.25	rew trib
109.0	30.71	mid slope	37.5	32.17	high terrace	27.3	29.57	top rb
110.0	31.01	terrace slope	38.5	32.23		28.6	29.64	base floodplain
111.0	31.08	terrace slope				29.0	29.81	trib rt. terrace
112.2	31.31	top terrace				31.0	29.96	
112.8	31.34	terrace				32.6	30.02	base rt slope
						41.0	34.68	terrace top
						41.7	34.68	terrace top

Appendix E. Channel Cross-Section Data
Cross-section 7-1, left relict channel, Hanson site, 1995,
T47N, R5W, sec. 9/10 line. Horizontal distances are from left floodplain.

7-1 Distance (meters)	7-1 Elevation (meters)	7-1 Remarks
6.7	29.28	wd = 14 cm
8.0	29.24	wd = 19
9.0	29.15	wd = 28
12.0	29.10	wd = 34
13.0	29.06	wd = 38
14.0	29.06	wd = 37
15.0	29.04	wd = 39
16.0	29.04	wd = 39
17.0	29.05	wd = 38
18.0	29.07	wd = 35
19.0	29.13	wd = 29
20.0	29.20	wd = 23
21.0	29.42	rew
22.0	29.70	slope to rb
22.8	29.99	rb top
24.0	30.03	right floodplain
25.0	29.99	
26.0	30.00	
27.0	30.09	
28.0	30.09	ground BM7-1a
29.0	30.11	end xs7-1

Appendix E. Channel Cross-Section Data
Cross-section 8-1 through 8-5, modern channel, Hanson site, 1995, T47N, R5W, sec. 9/10 line. Horizontal distances are from left floodplain.

8-1 Distance (meters)	8-1 Elevation (meters)	8-1 Remarks	8-2 Distance (meters)	8-2 Elevation (meters)	8-2 Remarks	8-3 Distance (meters)	8-3 Elevation (meters)	8-3 Remarks
1.0	30.16	left fp	0.0	30.02	left floodplain	12.2	30.18	top lb
2.0	30.22		4.0	30.05		12.7	29.29	lb bottom
5.0	30.25		7.0	30.08		13.2	29.24	lew
6.2	30.26	at BM8-1	10.0	30.10		14.0	28.99	wd = 25 cm
7.1	30.22	top of lb	12.0	30.10		16.0	28.97	wd =
7.7	29.95	bank full?	15.0	30.10		18.0	28.97	wd = 25
7.9	29.08		18.0	30.11		20.0	28.96	wd = 25
8.2	29.00	wd = 19 cm	20.0	30.12		22.0	28.83	wd = 42
9.0	28.79	wd = 40	22.0	30.28		24.0	28.70	wd = 54
10.0	28.86	wd = 32	23.3	30.33	ground BM8-2	27.0	28.82	
11.0	28.77	wd = 41	23.9	30.31	lb top	29.0	29.04	
12.0	28.40	wd = 79	24.6	29.84	bank full?	29.7	29.23	rew
13.0	28.30	wd = 90	24.7	29.05	top psa in h2o	30.7	29.55	point bar top
14.9	28.40	wd = 79	25.0	28.95	wd = 28 cm	31.6	29.62	rb bottom
15.0	28.54	wd = 63	25.5	28.69	wd = 53	31.9	30.11	rb top
16.0	28.70	wd = 49	25.9	28.33	wd = 89	34.0	30.13	rt fp
16.5	28.87	wd = 31	26.7	28.34	wd = 88	35.0	30.23	
17.0	28.86	wd = 31	27.4	28.84	wd = 37			
18.0	28.89	wd = 30	27.7	28.97	wd = 25			
19.0	28.90	wd = 29	28.3	28.70	wd = 51			
20.0	28.97	wd = 20	29.0	28.54	wd = 69			
20.6	29.12	rew	30.0	28.57	wd = 65			
22.0	29.69	bank full?	31.0	28.65	wd = 58			
23.00	29.7		32.0	28.76	wd = 48			
24.00	30.0	rt fp	33.0	28.79	wd = 43			
25.00	29.9		34.00	28.88	wd = 35			
26.00	29.9		35.00	28.91	wd = 25			
27.00	29.96		36.00	28.95	wd = 26			
28.0	29.92		37.3	29.21	rew			
29.0	30.04		38.5	29.63	top of pt bar			
30.0	30.11		38.9	29.67	shelf bottom			
			40.6	29.82	shelf top			
			41.1	29.87	rb bottom			
			42.0	29.98	rb top			
			43.0	29.99	rt fp			
			44.0	30.07				
			45.0	30.12				
			46.0	30.16				

8-4 Distance (meters)	8-4 Elevation (meters)	8-4 Remarks	8-5 Distance (meters)	8-5 Elevation (meters)	8-5 Remarks
8.3	29.23	wd = 5 cm	11.7	29.29	lew
8.8	29.21	wd = 5	12.5	29.08	wd = 21
9.5	29.02	wd = 26	13.0	28.85	wd = 45
10.0	28.91	wd = 34	13.5	28.76	wd = 56
11.0	28.92	wd = 36	14.0	28.82	wd = 47
12.0	28.96	wd = 37	15.0	28.91	wd = 39
13.0	28.95	wd = 34	16.0	28.93	wd = 37
14.0	28.96	wd = 31	17.0	28.94	wd = 36
15.0	28.94	wd = 34	18.0	28.96	wd = 34
16.0	28.92	wd = 36	19.0	28.98	wd = 32
17.0	28.94	wd = 35	20.0	29.02	wd = 28
18.0	28.93	wd = 35	21.0	29.02	wd = 28
19.0	28.90	wd = 39	22.0	28.99	wd = 32
20.0	28.87	wd = 41	23.0	28.93	wd = 36
21.0	28.97	wd = 32	24.0	28.89	wd = 40
22.0	28.94	wd = 34	25.0	28.88	wd = 40
23.0	28.96	wd = 32	26.0	28.86	wd = 43
24.0	29.01	wd = 27.5	27.0	28.89	wd = 39
25.0	29.00	wd = 28	28.1	29.27	rew
26.0	29.15	wd = 17	28.6	30.04	rb
26.5	29.28	rew	29.3	30.32	rb top
27.2	29.50	shelf/slope	30.4	30.18	rt fp
27.5	29.89	on slope	31.9	30.33	
28.2	30.27	rb top	33.1	30.26	
29.5	30.21	levee	34.2	30.23	
30.5	30.28	rt fp	35.3	30.22	
31.5	30.27		36.7	30.20	
32.5	30.20				
33.5	30.16				
34.5	30.11				

Appendix E. Channel Cross-Section Data
Cross-section 9-1, right relict channel, Hanson site, 1995,
T47N, R5W, sec. 9/10 line. Horizontal distances are from left floodplain.

9-1 Distance (meters)	9-1 Elevation (meters)
37.8	30.24
41.8	29.98
45.3	29.91
47.3	29.73
48.8	29.71
50.8	29.52
52.8	29.40
54.8	29.41
56.8	29.37
58.6	29.58
60.8	29.80
62.8	29.81
64.8	29.83
66.8	29.80
68.8	29.79
70.8	29.79
72.8	29.79
74.8	29.75
76.8	29.74
78.8	29.65
80.8	29.74
82.8	29.66
84.8	29.61
86.8	29.72
88.8	29.50
90.8	29.59
92.8	29.48

Appendix E. Channel Cross-Section Data
Cross-section 10-1 and 10-2, modern channel, Torko site, 1995, T47N, R5W, sec. 3/10 line. Horizontal distances are from left floodplain.

10-1 Distance (meters)	10-1 Elevation (meters)	10-1 Remarks	10-2 Distance (meters)	10-2 Elevation (meters)	10-2 Remarks
1.0	29.80	lb	2.6	30.13	left floodplain
2.4	29.69	slope	3.2	30.08	lb top
3.5	29.69		3.5	29.64	lb bottom
4.3	29.66	lb top	4.5	29.56	lew
4.6	29.50	lew	5.4	29.37	shelf top
5.3	29.33	shelf lip	6.1	29.01	scour hole
5.7	29.13	base shelf	7.0	29.10	wd = 46 cm
7.0	29.13	channel	8.0	29.12	wd = 46
8.0	29.13	wd = 43 cm	10.0	29.04	wd = 55
9.0	29.17	wd = 40	11.0	29.00	wd = 59
10.0	29.15	wd = 43	13.0	29.14	wd = 44
11.0	29.08	wd = 48	14.0	29.12	wd = 45
11.7	29.16	wd = 41	15.0	29.24	wd = 35
11.9	29.19	wd = 37	16.0	29.24	wd = 34
13.0	29.20	wd = 36	16.7	29.21	wd = 37
14.0	29.12	wd = 45	17.5	29.30	wd = 34
15.0	29.03	wd = 54	18.6	29.58	rew
16.0	29.00	wd = 55	18.8	29.68	shelf top
17.1	28.96	wd = 59	19.0	29.79	shelf 2 top
17.7	29.29	wd = 26	19.4	29.89	slope break
18.7	29.53	rew	19.6	30.09	shelf top
19.6	29.77	rb bottom	19.9	30.14	slope break
20.0	30.18	edge rb	20.3	30.41	rb slope
20.9	30.41	top rb	21.1	30.64	rb
22.0	30.43	rt floodplain	22.2	30.67	rt floodplain
23.0	30.39				

Appendix E. Channel Cross-Section Data
Cross-section 11-1 and 11-2, modern channel, Sutarik site, 1995, T47N, R5W, sec. 8/9 line. Horizontal distances are from left floodplain.

11-1 Distance (meters)	11-1 Elevation (meters)	11-1 Remarks	11-2 Distance (meters)	11-2 Elevation (meters)	11-2 Remarks
1.0	29.71	left floodplain	2.0	29.54	levee
1.8	29.42	scour channel	3.0	29.68	top of levee
2.6	29.38	s edge scour	4.1	29.76	top of lb
3.5	29.62	top lb	4.7	29.49	slope on lb
4.2	29.55	top edge lb	5.2	28.70	lew
4.6	28.91	bottom lb	5.6	28.53	toe edge of shelf
5.0	28.70	lew	5.8	28.43	channel
6.0	28.54	wd = 18 cm	7.0	28.29	wd = .42 m
7.0	28.44	wd = 27	8.0	28.29	wd = .41
8.0	28.36	wd = 35	9.0	28.32	wd = .39
9.0	28.33	wd = 39	10.0	28.33	wd = .39
10.0	28.23	wd = 49	11.0	28.34	wd = .42
11.0	28.11	wd = 61	12.0	28.33	wd = .38
12.0	27.96	wd = 76	13.0	28.29	wd = .42
12.8	27.82	wd = 91	14.0	28.33	wd = .38
14.0	28.09	wd = 62	15.0	28.36	wd = .35
15.0	28.40	wd = 33	16.0	28.38	wd = .33
15.1	28.72	rew	17.0	28.33	wd = .38
15.3	29.21	top rb	18.0	28.36	wd = .35
16.4	29.57	top levee rb	19.0	28.34	wd = .36
17.2	29.69		19.2	28.71	rew
18.1	29.84	rt floodplain	19.8	29.44	rb slope
19.2	29.88		20.3	29.61	rb edge
20.4	29.90		21.0	29.62	rb top
21.4	29.86		22.0	29.80	slope onto flp
			24.0	29.99	top of terrace
			25.0	29.95	
			26.0	29.93	

Appendix E. Channel Cross-Section Data
Cross-section 12-1 and 12-2, modern channel, Mihalek site, 1995, T47N, R6W, sec. 13/14 line. Horizontal distances are from left floodplain.

12-1 Distance (meters)	12-1 Elevation (meters)	12-1 Remarks	12-2 Distance (meters)	12-2 Elevation (meters)	12-2 Remarks
2.0	32.21	left terrace edge	1.5	31.84	left slope
3.0	31.57	slope	1.8	31.67	top cut bank
4.0	30.95		2.1	31.34	slope
5.5	30.37	slope bottom	2.6	30.76	base cut bank
6.0	30.45	floodplain	3.3	30.56	floodplain
7.2	30.29	lb top edge	3.9	30.17	scaour base
7.3	29.88	wd = .08 m	4.8	30.02	
9.0	29.70	wd = .25	5.1	29.97	lew
10.0	29.70	wd = .25	5.4	29.42	wd = .58 m
11.0	29.67	wd = .28	6.1	29.27	wd = .72
12.0	29.62	wd = .33	7.0	29.33	wd = .66
13.0	29.63	wd = .31	8.0	29.50	wd = .48
14.0	29.63	wd = .32	9.0	29.62	wd = .36
15.0	29.67	wd = .34	10.0	29.85	wd = .13
16.0	29.68	wd = .33	11.0	29.86	wd = .12
17.0	29.69	wd = .25	12.0	29.97	wd = .02
18.0	29.75	wd = .2	13.0	29.92	wd = .05
19.0	29.80	wd = .16	14.0	29.97	rew
20.0	29.93	rew	14.7	30.29	shelf edge top
20.6	30.38	top of shelf	15.2	30.53	2nd shelf edge top
20.9	30.57	top of 2nd shelf	16.0	30.69	rt floodplain
22.0	30.93	floodplain edge	17.0	30.79	23 31.08 rt
24.0	31.08				

Appendix E. Channel Cross-Section Data
Cross-section 12-1 and 12-2, modern channel, Mihalek site, 1995, T47N, R6W, sec. 13/14 line. Horizontal distances are from left floodplain.

12-1 Distance (meters)	12-1 Elevation (meters)	12-1 Remarks	12-2 Distance (meters)	12-2 Elevation (meters)	12-2 Remarks
1.5	30.68	terrace	0.5	30.76	terrace top
2.5	30.42	terrace slope	0.9	30.63	at bm15-2
3.5	30.24	left floodplain	1.5	30.59	flooplain top
4.0	30.17		2.0	30.39	lb top
4.5	30.03	lb top	2.4	30.11	break in slope
5.0	29.85	break in slope	3.1	28.99	lew
5.7	29.71		3.5	28.87	wd = .13
6.3	29.35	lb bottom	4.0	28.80	wd = .20
6.4	28.72	wd = .27	5.0	28.73	wd = .26
7.0	28.63	wd = .36	6.0	28.71	wd = .29
8.0	28.68	wd = .3	7.0	28.77	wd = .22
9.0	28.61	wd = .37	7.7	28.84	wd = .16
10.0	28.60	wd = .39	8.0	29.01	rew
11.0	28.60	wd = .39	8.4	29.25	rb slope
12.0	28.64		8.5	29.40	break in slope
13.0	28.70	wd = .29	8.7	29.88	edge rb
13.5	28.98	rew	9.5	30.16	floodplain
13.7	29.26	top shelf	10.0	30.27	base terrace
14.0	29.45	rb slope	10.5	30.41	terrace slope
14.5	29.62		11.0	30.56	
15.2	29.92	rb edge	11.5	30.66	
16.1	30.10	right floodplain	12.0	30.72	
17.0	30.42	edge terrace	13.0	30.79	terrace top
18.6	30.57	bottom terrace	14.0	30.84	
20.0	31.25	top terrace			

Appendix E. Channel Cross-Section Data
Cross-section 15-1 and 15-2, modern channel, Brandis site, 1995, T47N, R6W, sec. 20/29 line. Horizontal distances are from left floodplain.

15-1 Distance (meters)	15-1 Elevation (meters)	15-1 Remarks	15-2 Distance (meters)	15-2 Elevation (meters)	15-2 Remarks
1.5	30.68	terrace	0.5	30.76	terrace top
2.5	30.42	terrace slope	0.9	30.63	at bm15-2
3.5	30.24	left floodplain	1.5	30.59	flooplain top
4.0	30.17		2.0	30.39	lb top
4.5	30.03	lb top	2.4	30.11	break in slope
5.0	29.85	break in slope	3.1	28.99	lew
5.7	29.71		3.5	28.87	wd = .13
6.3	29.35	lb bottom	4.0	28.80	wd = .20
6.4	28.72	wd = .27	5.0	28.73	wd = .26
7.0	28.63	wd = .36	6.0	28.71	wd = .29
8.0	28.68	wd = .3	7.0	28.77	wd = .22
9.0	28.61	wd = .37	7.7	28.84	wd = .16
10.0	28.60	wd = .39	8.0	29.01	rew
11.0	28.60	wd = .39	8.4	29.25	rb slope
12.0	28.64		8.5	29.40	break in slope
13.0	28.70	wd = .29	8.7	29.88	edge rb
13.5	28.98	rew	9.5	30.16	floodplain
13.7	29.26	top shelf	10.0	30.27	base terrace
14.0	29.45	rb slope	10.5	30.41	terrace slope
14.5	29.62		11.0	30.56	
15.2	29.92	rb edge	11.5	30.66	
16.1	30.10	right floodplain	12.0	30.72	
17.0	30.42	edge terrace	13.0	30.79	terrace top
18.6	30.57	bottom terrace	14.0	30.84	
20.0	31.25	top terrace			

Appendix E. Channel Cross-Section Data
Cross-section 16-1 and 15-6, modern channel, Nekoosa site, 1995, T47N, R5W, sec. 7/8 line. Horizontal distances are from left floodplain.

16-1 Distance (meters)	16-1 Elevation (meters)	16-1 Remarks	16-2 Distance (meters)	16-2 Elevation (meters)	16-2 Remarks
1.0	29.77	Left floodplain	1.0	29.71	left floodplain
2.0	29.80		1.9	29.67	@ BM16-2
3.0	29.79	levee top	2.3	29.43	lb edge
4.0	29.78	lb edge	2.8	29.00	break in slope
4.6	29.43	break in slope	3.0	28.61	
5.1	29.19		3.5	28.09	lb bottom edge
6.0	28.48	bankfull?	4.0	28.04	sand bar
6.5	28.20	shelf edge	4.5	28.00	sandbar edge
6.9	27.86	lew	4.7	27.90	lew
7.8	27.49	wd = .37m	4.9	27.73	shelf wd = .17 m
8.6	27.33	wd = .54	5.1	27.55	wd = .35
9.0	27.43		6.0	27.49	wd = .41
10.0	27.45	wd = .44	7.5	27.54	wd = .36
11.0	27.47	wd = .43	8.5	27.54	
12.0	27.58	wd = .52	9.7	27.90	rew bar
13.0	27.36	wd = .53	9.9	27.90	lew bar
14.0	27.36	wd = .52	10.7	27.60	wd = .3
15.0	27.48		11.5	27.59	wd = .32
16.0	27.64	wd = .24	12.5	27.57	
17.0	27.68	wd = .2	14.0	27.58	wd = .35
18.0	27.71	wd = .17	15.0	27.49	wd = .4
19.0	27.74	wd = .15	16.0	27.35	wd = .57
20.0	27.88	rew	17.0	27.17	thal. wd = .74
20.4	28.22	bankfull	18.0	27.32	wd = .59
20.8	28.54	rb slope	19.0	27.63	
21.6	28.86	rb edge	19.1	28.08	rb (undercut)
22.2	29.21	ledge	19.2	28.15	break in slope
23.0	29.60	terrace slope	19.6	28.71	
23.8	30.13		20.0	28.99	rb top edge
24.4	30.32	terrace top edge	21.0	29.19	terrace bot. edge
25.7	30.47		22.0	30.26	terrace top edge
			23.0	30.43	terrace top
			23.5	30.46	

Appendix E. Channel Cross-Section Data
Cross-section 17-1 and 17-2, modern channel, Nekoosa site, 1995, T47N, R5W, sec. 5/6 line. Horizontal distances are from left floodplain.

17-1 Distance (meters)	17-1 Elevation (meters)	17-1 Remarks	17-2 Distance (meters)	17-2 Elevation (meters)	17-2 Remarks
2.0	30.59	terrace	1.0	30.52	terrace
3.0	30.58		2.0	30.34	terrace top edge
3.8	30.37	terrace top edge	2.5	30.11	shelf
4.3	29.80	terr. bot. edge	3.0	30.09	shelf edge
4.6	29.85	@ BM17-1	3.7	29.90	break in slope
5.0	29.65	slump top	4.2	29.66	slope
5.4	29.42	slump edge	4.5	29.52	lb edge
5.6	28.51	slump bot. edge	5.0	29.09	slope
6.0	28.47	shelf	5.3	28.80	bankfull
6.7	28.31	lew	5.6	28.62	point bar
7.0	27.99		6.3	28.52	
7.8	27.97	wd = .38 m	6.9	28.34	shelf
8.4	27.71	wd = .58	7.4	28.34	shelf
9.0	27.67	wd = .64	8.0	28.33	lew
10.0	27.81	wd = .5	8.8	28.21	edge of gravel
11.0	27.89	wd = .48	10.0	28.05	
12.0	27.93	wd = .38	11.0	28.01	wd = .32
13.0	27.89	wd = .41	12.0	27.93	wd = .41
14.0	28.02	wd = .38	13.0	27.82	wd = .52
15.0	28.11	wd = .2	14.0	27.73	wd = .62
16.0	28.14	wd =	15.0	27.38	
17.0	28.15	wd = .155	16.7	27.29	wd = 1.05
18.0	28.00	wd = .32	17.4	28.18	slump top
19.0	28.01	wd = .295	17.8	28.36	rew
19.8	28.03		18.5	28.71	bankfull?
19.9	28.30	rew	19.2	28.96	rb top
19.9	28.78	bankfull	20.0	29.72	terrace
20.4	29.45	rb edge	23.5	30.92	slope
21.0	29.92	terrace slope	24.0	31.75	slope
21.5	30.12				
22.6	30.84	terrace top edge			
24.0	30.81	terrace			
26.0	30.95	terrace			

Appendix E. Channel Cross-Section Data

Cross-section 18-1 and 18-2, modern channel, Johanik/DNR site, 1995, T47N, R6W, sec. 22/23 line. Horizontal distances are from left floodplain.

18-1 Distance (meters)	18-1 Elevation (meters)	18-1 Remarks	18-2 Distance (meters)	18-2 Elevation (meters)	18-2 Remarks
0.4	31.01	steep bank	1.0	31.48	terrace
1.0	30.61		1.5	31.51	
2.0	29.99		2.2	31.36	@ BM18-2
2.5	29.83		2.5	31.28	slope
3.0	29.48	floodplain	3.6	30.92	
4.0	29.42		4.6	30.51	terrace top edge
5.0	29.18		5.2	29.85	terrace bot.edg
5.3	29.17	lb top edge	6.4	29.46	floodpl/bankfull
5.5	28.83	lb slope	7.0	29.32	fldpln. bottomedge
5.6	28.54	lew	8.0	28.85	sand bar
6.0	28.21	wd = .34	9.0	28.74	
7.0	27.83	wd = .70	9.8	28.54	lew
8.0	27.99	wd = .55	10.1	28.44	
9.0	28.18	wd = .35	11.0	28.29	wd = .26
10.0	28.21	wd = .34	12.0	28.28	wd = .27
11.0	28.23	wd = .31	13.0	28.21	wd = .34
12.0	28.22	wd = .32	14.0	28.07	wd = .49
13.0	28.22	wd = .32	15.0	27.96	wd = .6
14.0	28.21	wd = .34	16.0	27.99	wd = .57
15.0	28.29	wd = .26	17.0	28.05	wd = .52
16.0	28.42	wd = .13	18.0	28.40	wd = .18
16.4	28.56	rew	18.5	28.62	rew
17.0	28.74	point bar	19.6	28.57	loopln bottom edge
17.8	28.86	top p.b., bankfull	20.9	28.74	floopln top edge
18.8	29.56	terrace, bot edge	21.8	28.86	terrace
19.7	29.70	@ BM18-1	22.7	29.91	
20.0	29.70	terrace top			
21.0	29.75				
22.0	29.74				

Appendix E. Channel Cross-Section Data
Cross-section 19-1 and 19-2, modern channel, Johanik/DNR site, 1995, T47N, R6W, sec. 14/23 line. Horizontal distances are from left floodplain.

19-1 Distance (meters)	19-1 Elevation (meters)	19-1 Remarks	19-2 Distance (meters)	19-2 Elevation (meters)	19-2 Remarks
0.5	30.56	slope fr. bluff	-0.5	30.52	terrace
1.0	30.30		0.0	30.46	
2.0	29.89	terrace top	0.1	30.11	terrace bot edge
3.0	29.77	terrace slope	0.5	29.95	floodplain
4.0	29.86		1.0	29.89	
4.6	29.80	@ BM19-1	1.4	29.98	@ BM19-2
5.0	29.82		1.5	29.96	levee
5.5	29.73	terrace top edge	1.9	29.92	
6.0	29.64	lb slope	2.2	29.67	bankfull
6.5	29.35	lb slope	2.5	29.51	sand shelf
6.7	29.18	bankfull?	3.2	29.25	lb slope
6.9	28.79	lew	3.7	28.93	break in slope
7.2	28.48	wd = .30 m	4.2	28.81	lew
8.0	28.36	wd = .43	4.6	28.73	wd = .08 m
9.0	28.38	wd = .40	5.0	28.53	wd = .28
10.0	28.46	wd = .40	5.6	28.41	wd = .39
11.0	28.43	wd = .35	6.2	28.32	wd = .48
12.0	28.39	wd = .39	6.7	28.37	wd = .43
13.0	28.37	wd = .405	7.5	28.44	wd = .36
13.5	28.42	wd = .37	8.5	28.56	wd = .24
14.0	28.57	wd = .21	9.5	28.61	wd = .19
14.1	28.79	rew	10.5	28.65	wd = .15
14.3	28.98	rb slope	11.5	28.66	wd = .13
14.7	29.12		12.5	28.66	wd = .13
15.0	29.30	shelf	13.5	28.62	wd = .175
15.3	29.49	rb top edge	14.0	28.60	wd = .2
15.7	29.59	floodplain top	14.5	28.65	wd = .14
16.2	29.67	sand bar	14.9	28.80	rew
17.0	29.66		15.5	28.93	rb slope
18.0	29.80	sand bar top	15.8	29.04	
18.5	29.77		16.4	29.26	bankfull?
19.0	29.64	slope on bar	16.8	29.40	
19.3	29.55		17.7	29.54	bankfull
19.9	29.49	bar/old channel	18.3	29.76	break in slope
19.9	29.41		19.0	29.80	floodplain
21.0	29.39	old channel bott	19.8	29.86	
22.0	29.42		20.4	29.99	terrace slope
23.0	29.41		20.9	30.15	
25.0	29.50	lb tributary	21.8	30.32	terrace top

Appendix E. Channel Cross-Section Data
Cross-section 20-1 and 20-2, modern channel, Bayfield site, 1995, T47N, R6W, sec. 21/22 line. Horizontal distances are from left floodplain.

20-1 Distance (meters)	20-1 Elevation (meters)	20-1 Remarks	20-2 Distance (meters)	20-2 Elevation (meters)	20-2 Remarks
2.4	29.87	@BM20-1	0.5	29.83	flood scour
3.0	29.86	left floodplain	1.0	29.95	terrace
3.8	29.63	floodplain edge	2.0	29.92	floodplain
4.0	29.54	bankfull?	2.5	29.92	@ BM20-2
4.5	29.39	lb edge	2.9	29.88	lb top
4.7	29.25	lb slope	3.1	29.66	bankfull
4.9	29.08	lew	3.7	29.61	point bar
4.9	29.00	wd = .03 m	4.0	29.58	
5.6	28.87	wd = .21	4.5	29.55	
6.3	28.88	wd = .21	5.0	29.46	
6.9	28.94	wd = .16	6.1	29.14	lew
7.2	28.94	wd = .16	7.0	29.03	wd = .15
8.0	28.96	wd = .16	8.0	28.96	wd = .23
9.0	28.97	wd = .14	9.0	28.84	
10.0	28.99	wd = .14	10.0	28.82	wd = .37
11.0	28.95	wd = .17	11.0	28.96	wd = .22
12.0	28.86	wd = .26	12.0	28.96	wd = .23
13.0	28.94	wd = .16	13.0	29.09	wd = .1
14.0	28.92	wd = .17	14.0	29.03	wd = .15
15.0	28.98	wd = .1	15.0	28.97	
15.7	28.99	wd = .07	15.8	29.17	rew
16.0	29.09	rew	16.3	29.59	bankfull
16.5	29.23	slump	16.6	30.46	rb slope
17.0	29.37	bankfull	17.9	30.94	slump
17.1	29.56	slump	18.2	31.33	slump top edge
18.0	29.80		19.0	31.51	terrace slump
19.5	30.27		20.0	31.56	
21.0	31.58				

Appendix E. Channel Cross-Section Data
Cross-section 21-1 and 21-2, modern channel, Skulan site, 1995, T47N, R5/6W, sec. 13/18 line. Horizontal distances are from left floodplain.

21-1 Distance (meters)	21-1 Elevation (meters)	21-1 Remarks	21-2 Distance (meters)	21-2 Elevation (meters)	21-2 Remarks
1.0	31.31	terrace top edge	1.0	31.70	terrace edge
2.0	30.31	break in slope	1.5	31.50	lb slope
2.4	30.05	floodplain slope	2.3	31.08	
2.8	29.89	@ BM21-1	2.9	30.80	@ BM21-2
3.1	29.70	flooplain slope	3.3	30.61	lb edge
3.9	29.53		3.7	29.82	break in slope
4.1	29.32	lb edge	4.1	29.10	lb bottom
4.2	28.54	lew	4.9	28.59	shelf
4.8	28.29	wd = .25 m	5.0	28.55	lew
5.0	28.04	wd = .5	5.2	28.50	wd = .07
5.6	27.75	wd = .8	5.6	28.35	wd = .2
6.0	27.68	wd = .87	6.3	28.23	wd =
6.6	27.80	wd = .74	7.5	28.21	wd = .33
8.0	27.91	wd = .65	8.5	28.18	wd = .36
8.8	27.92	wd = .65	9.5	28.14	wd = .43
10.0	28.01	wd = .52	10.5	28.18	
11.0	28.04	wd = .5	11.5	28.23	wd = .33
12.0	28.16	wd = .38	12.5	28.23	wd = .33
13.0	28.26	wd = .29	13.5	28.26	wd = .3
14.0	28.28	wd = .26	14.5	28.25	wd = .3
15.0	28.53	rew	15.5	28.24	wd = .31
15.5	28.65	rb slope	16.1	28.30	wd = .25
16.0	28.84		16.3	28.54	rew
16.7	29.05	bankfull?	16.4	28.86	rb edge (bankfull)
17.1	29.12		16.8	29.14	break in slope
17.4	29.37	rb slope	17.1	29.68	terrace top edge
17.9	29.56	rb top	17.8	30.00	levee top
18.5	29.69	floodplain slope	19.0	30.03	
19.9	30.02	floodplain	20.0	30.05	

Appendix E. Channel Cross-Section Data
Cross-section 22-1 and 22-2, relict channel, Bayfield/Ino site, 1995, T47N, R5/6W, sec. 20. Horizontal distances are from left floodplain.

22-1 Distance (meters)	22-1 Elevation (meters)	22-1 Remarks	22-2 Distance (meters)	22-2 Elevation (meters)	22-2 Remarks
2.0	31.18	terrace	2.0	32.88	terrace top
2.6	31.15		4.0	31.54	terrace bot slope
3.7	31.10	lb	6.3	30.94	floodplain
4.4	31.04		8.1	31.24	
5.6	30.76		14.3	31.00	
6.8	30.59		15.5	30.81	
8.0	30.54	channel	16.6	30.69	lew
9.0	30.30	wd = .2	17.9	30.51	channel
10.0	30.18	wd = .31	19.0	30.49	wd = .06
11.0	30.29	wd = .2	20.0	30.44	wd = .06
12.0	30.36	wd = .13	21.0	30.36	wd = .13
13.0	30.35	wd = .12	22.0	30.32	wd = .17
14.0	30.38	wd = .09	23.0	30.38	wd = .11
15.0	30.45	wd = .03	24.0	30.47	wd = .03
16.0	30.44	wd = .03	25.0	30.49	vegetation
17.0	30.58	channel	26.0	30.51	
18.0	30.66		27.0	30.50	
19.0	30.78	old rb	28.0	30.52	old rb
20.0	30.71	floodplain	29.0	30.54	floodplain
21.0	30.79		30.0	30.56	
22.0	30.88	@ BM22-1	31.0	30.44	spring, wd = .02
23.0	30.88	floodplain	32.8	30.72	slope base
24.0	30.81		34.0	31.06	@ BM22-2
25.0	30.61	spring, wd = .22	35.8	31.48	terrace slope base
26.0	30.99		38.0	33.26	terrace top
26.5	31.07	break in slope			
27.0	31.43	terrace slope			
28.3	32.36	terrace top			
29.2	32.43	terrace top			
30.5	32.42				
32.3	32.79	higher terrace			