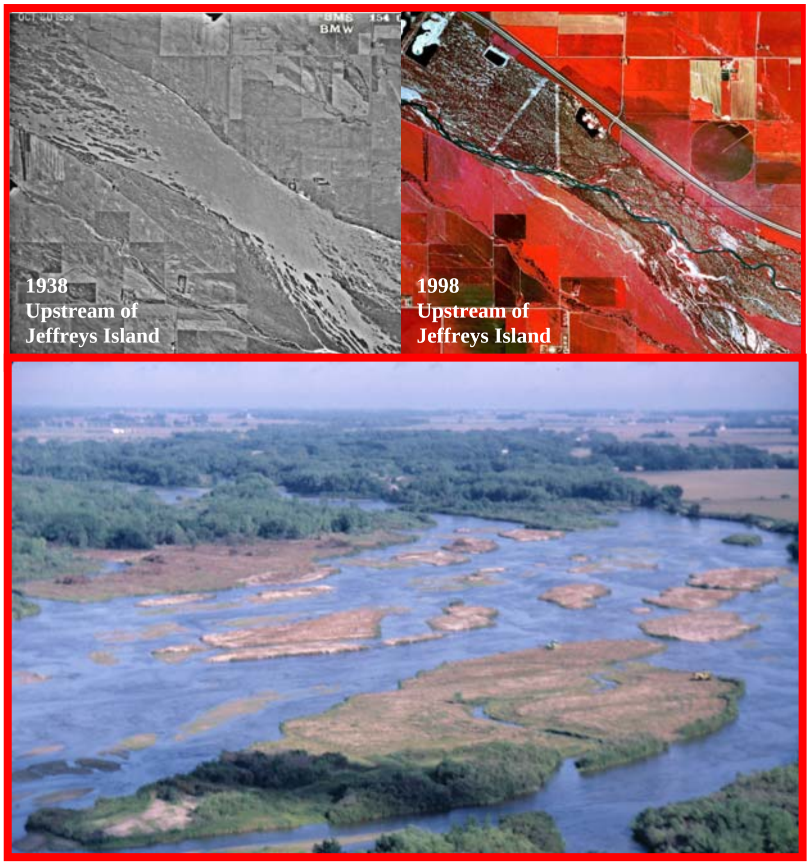
THE PLATTE RIVER CHANNEL: HISTORY AND RESTORATION



U.S. Department of the Interior
Bureau of Reclamation
TECHNICAL SERVICE CENTER
Denver, Colorado
April 2004

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The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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THE PLATTE RIVER CHANNEL: HISTORY AND RESTORATION

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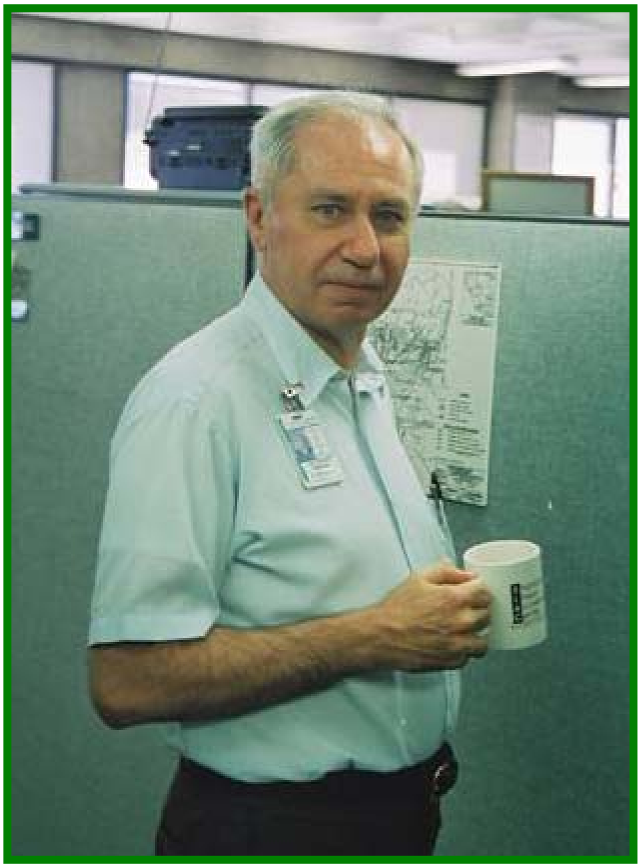
U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center, Denver, Colorado

April 2004

DEDICATION



Peter J. Murphy

July 29, 1939 to October 22, 2002

Dr. Peter J. Murphy wrote the first draft of this report in 2000 and continued to refine it until his demise in 2002. Much of the work presented here is from Dr Murphy's efforts and he remains the first author. Peter has been greatly missed by his colleagues at the U.S. Bureau of Reclamation and we dedicate this report to him.

Dr. Murphy grew up in Brooklyn, New York and began his professional education in 1958 at Manhattan College. After one year of pre-engineering studies, he transferred to the Webb Institute of Naval Architecture with a full scholarship, and while there worked at the United States Lines and the U.S. Navy. Dr. Murphy received a B.S. degree in 1962 and entered the fluid mechanics graduate program at the Johns Hopkins University. He received his Ph.D. degree in 1968, writing a thesis on turbulent vortices.

From 1968 to 1974, Dr. Murphy worked for the Rockefeller Foundation as a Visiting Professor in the Department of Civil Engineering of the Universidad del Valle, Cali, Colombia, as part of the Foundation's University Development Program. In 1974, Dr. Murphy became an Assistant Professor of Civil and Environmental Engineering at Cornel University. He taught undergraduate and graduate level courses and performed research in the areas of sediment transport and lake turbulence. In 1978, Dr. Murphy began teaching as an Assistant Professor of Civil Engineering at the University of Massachusetts, Amherst, and carried out sediment transport research.

In 1984, Dr Murphy began work as an engineering consultant, primarily involved with the estimation of contaminated ground water delivery as part of public health studies. Peter became a hydrologist for the Massachusetts District of the U.S. Geological Survey in 1992. He was involved with flood frequency analysis for the State and was second in charge of managing the Massachusetts Bridge Scour Project.

Dr. Murphy transferred to the U.S. Bureau of Reclamation, Sedimentation and River Hydraulics Group in 1998. During his time with Reclamation, Peter carried out hydraulic analyses for the Dam Safety Program, prepared hydraulic designs for pipeline river crossings, and served on the interagency team preparing the environmental impact statement for the Platte River Recovery Implementation Program (Program) in Nebraska. One of Peter's most significant contributions to the Platte River Program was the development of a new computer model to simulate the linked processes of river flow, hydraulics, sediment transport, the growth and removal of vegetation, and the resulting changes to habitat for endangered birds. The SEDVEG computer model has become important for describing and testing our understanding of Platte River geomorphic processes, and for evaluating the effectiveness of habitat restoration strategies for endangered species.

TABLE OF CONTENTS

DEDICATION.. ii
LIST OF FIGURES ix
LIST OF TABLES xiii
GLOSSARY.. xiv

1.0 INTRODUCTION.. 1

1.1 LOCATION 2
1.2 THE CONCERN.. 2
1.3 OBJECTIVE OF THE PAPER 3
1.4 STUDY APPROACH 4
1.5 FACTORS CONSIDERED 5
1.6 ORGANIZATION OF THE PAPER 5
1.7 PRINCIPAL FINDINGS 6
1.7.1 The Anthropogenic Factor and the Historic River.. 6
1.7.2 Flow 7
1.7.3 Sediment Transport... 7
1.7.4 Basin Structure.. 8
1.7.5 Restoration Strategy.. 8

2.0 HISTORIC SETTING OF THE PLATTE RIVER.......................... 9

2.1 THE PRE-DEVELOPMENT RIVER... 9
2.1.1 The Platte River Alignment 10
2.1.2 The Platte River Profile 12
2.1.3 Distinct Reaches of the Platte River 14
2.1.4 Cycles of Aggradation, Degradation and Stability, and Rates of Change............ 15
2.1.5 The EDS Cycle at the Close of the Pre-Development Period.............................. 16
2.1.6 Conclusions from the Pre-Development Period 16
2.2 THE NINETEENTH CENTURY 17
2.2.1 The Onset of Euro-Settlement 18
2.2.2 Narrative Descriptions of the Platte River 20
2.2.2.1 River Islands and Sandbars.. 20
2.2.2.1 Vegetation on Islands and Outer River Banks.. 21
2.2.2 Watershed Impacts 22
2.2.3.1 Beaver Trapping 35
2.2.3.2 Farming.. 35
2.2.3.3 Mining.. 36
2.2.3.4 Timber Harvest. 37
2.2.3.5 Timing of Human Induced Sediment Impacts 38
2.2.4 Canal Construction 38

TABLE OF CONTENTS (continued)

2.2.5 Climate in the Nineteenth Century 39
2.2.6 Description of the Platte River at the Close of the Nineteenth Century 42
2.2.7 Conclusions for the Nineteenth Century 43
2.3 THE TWENTIETH CENTURY 45
2.3.1 The Growth of Municipal and Irrigation Water Requirements 45
2.3.1.1 Surface Water Use 46
2.3.1.2 Groundwater Impacts 46
2.3.2 Reservoir Construction and Major Flow Diversions 49
2.3.3 Bridges, the Transportation System, and Bank Revetments 51
2.3.4 Climate in the Twentieth Century 52
2.3.5 Conclusions on the Historical Consideration of the central Platte River 53

3.0 CHANGES TO PRIMARY ELEMENTS OF RIVER MORPHOLOGY IN THE TWENTIETH CENTURY 55

3.1 CHANGES TO FLOW 55
3.1.1 North Platte River Flows 57
3.1.2 South Platte River Flows 57
3.1.3 Central Platte River Flows 58
3.1.4 An Estimate of Flow Changes Attributable to Anthropogenic Factors 61
3.1.4.1 Consumptive Use 61
3.1.4.2 Depletions 63
3.1.5 An Estimate of Flow Changes Attributable to Climatic Factors 64
3.1.5.1 Climate Trend Consideration 65
3.1.5.2 Shorter Periods of Climate Fluctuation 65
3.1.5.3 Maximum Percent of Flow Variation Attributable to Climate 67
3.1.6 Summary of Flow Changes 72
3.2 CHANGES TO THE TEMPORAL DISTRIBUTION OF FLOWS 72
3.3 CHANGES TO SEDIMENT TRANSPORT AND SEDIMENT SIZE 76
3.3.1 Sediment Supply and Transport 78
3.3.2 Bankfull Discharge and Effective Discharge 83
3.4 CHANGES TO THE BASIN STRUCTURE 85
3.4.1 Spatial Re-Distribution of Flow and Sediment Inputs 85
3.4.2 Geologic and Man-made Structures 88

4.0 CHANNEL RESPONSE TO CHANGED CONDITIONS 89

4.1 REDUCTIONS IN UNVEGETATED CHANNEL WIDTHS 90
4.2 FLOW REDUCTIONS 92
4.3 VEGETATION AND VEGETATION EXPANSION 95
4.3.1 Riparian Habitat Requirements of Target Species 95

TABLE OF CONTENTS (continued)

4.3.2 Expansion and Ecology of Cottonwoods and Willows on the Platte River.......... 96
4.3.3 Interaction of Vegetation, Channel Flow, and Channel Morphology.................. 99
4.4 REDUCTIONS IN SEDIMENT SUPPLY AND CHANNEL INCISION................ 100
4.4.1 The Occurrence of Incision... 100
4.4.2 The Process of Incision.. 113
4.4.3 Vegetation and Topography Indicators of Incision 115
4.5 COARSENING SEDIMENT AND CHANNEL CHANGES 115
4.5.1 Transition in Sand Source from North Platte to South Platte 115
4.5.2 Process for Transport of Medium Sand Grain Size 119
4.5.3 Process for Transport of Coarser Sand Grain Size 120
4.5.4 Current Condition of Grain Size 120
4.6 CHANGES IN PLAN FORM.. 121
4.7 CHANNNEL CHANGES FROM BRIDGES, DIVERSION DAMS AND BANK PROTECTION.. 126
4.8 TIME SCALES OF CHANNEL PROCESSES IN THE PLATTE RIVER 128
4.8.1 Channel Changes from Flow Reductions 128
4.8.2 Vegetation and Channel Changes 129
4.8.3 Channel Incision Resulting from Reductions in Sediment Supply.................... 129
4.8.4 Channel Changes Resulting from Coarsening Sediment 129
4.8.5 Plan Form Changes 130
4.8.6 Channel Changes from Bridges, Diversion Dams and Bank Protection 130

5.0 OPTIONS FOR RESTORING CHANNEL HABITAT.............. 131

5.1 MECHANICAL WIDENING OF THE CHANNEL AND AUGMENTATION OF ...... MEDIUM SAND 132
5.2 INCREASED ANNUAL HIGH FLOWS.. 133

6.0 SUMMARY AND CONCLUSIONS.. 137

6.1 THE HISTORIC RIVER 137
6.1.1 Geologic Time and the Pre-Development River.. 137
6.1.2 The Nineteenth Century.. 138
6.1.3 The Twentieth Century and Changes to Primary Elements........................... 139
6.2 THE PROCESSES OF HABITAT REDUCTION AND RIVER NARROWING..... 139
6.2.1 Flow and Vegetation Processes and Impacts 140
6.2.2 Sediment Processes and Impacts 141
6.2.2.1 Sediment Coarsening 141
6.2.2.2 Channel Incision 141
6.2.3 Local Impacts from River Structures 142
6.2.4 Impacts to Plan Form 142
6.3 OPTION FOR RESTORING HABITAT 143

TABLE OF CONTENTS (continued)

6.4 FUTURE DIRECTIONS 143

7.0 REFERENCES 145

GEOLOGY APPENDIX 159

A. GEOLOGY OF SOUTH-CENTRAL NEBRASKA 159
B. GEOMORPHIC HISTORY 163

LIST OF FIGURES

Figure 1.1 Endangered species of the central Platte River 1
Figure 1.2 Platte River Basin location map. 2
Figure 1.3 Reductions in unvegetated channel width in the central Platte River. 3
Figure 1.4 Photos of the central Platte River illustrating spatial variations in the narrowing of unvegetated widths and spatial variation in plan form. 4
Figure 1.5 A comparison of the central Platte River flows and basin structure between the Pre-Development period and the twentieth century. 7

Figure 2.1 Evolution of the Platte River alignment. 11
Figure 2.2 Lineaments near the lower Platte River (Kansas Geological Survey, 1982). 12
Figure 2.3 The Platte River in Nebraska. 13
Figure 2.4 Geologic section from Farnam, in southwestern Dawson County, to Arlington, in Washington County, shows shallow location of bedrock under the Platte River at Fremont Nebraska, downstream of Columbus, Nebraska (taken from Lugn & Wenzel, 1938). 14
Figure 2.5 The following photograph of the Platte River, opposite Platte City (near present-day Cozad, NE), was taken by John Carbutt in October 1866. 19
Figure 2.6 Historic USGS Quad Map – North Platte. 23
Figure 2.7 Historic USGS Quad Map – Gothenburg. 25
Figure 2.8 Historic USGS Quad Map – Lexington. 27
Figure 2.9 Historic USGS Quad Map – Kearney. 29
Figure 2.10 Historic USGS Quad Map – Wood River. 31
Figure 2.11 Historic USGS Quad Map – Grand Island. 33
Figure 2.12 Grid points of Palmer drought severity index (PDSI) for Colorado, Wyoming and Nebraska, taken from Cook, et. al, (1999b). 40
Figure 2.13 An average palmer drought severity index (PDSI) for the Platte River Basin based on tree-ring data (Cook, et al., 1996b). 41
Figure 2.14 Longitudinal profile of the Platte River bed in 1901 (Gannetts Slope). 43
Figure 2.15 Nebraska Registered Groundwater Wells, 1994 (Conservation and Survey Division, University of Nebraska-Lincoln, 1994). Source: Nebraska Department of Natural Resources, September 1993. 47
Figure 2.16 Areas of groundwater level change in the High Plains Aquifer, predevelopment to spring 1996 (Conservation and Survey Division, University of Nebraska-Lincoln, 1996b) 48
Figure 2.17 North Platte, South Platte and central Platte Rivers showing location of the Sutherland Canal and the Tri-County Supply Canal. 50
Figure 2.18 Average annual discharge of the principal rivers as indicated by the width of the river (Conservation and Survey Division, University of Nebraska-Lincoln, 1996). 51

Figure 3.1 Platte River mean flows (Randle and Samad, 2003). 55
Figure 3.2 Platte River median flows (Randle and Samad, 2003). 56
Figure 3.3 Platte River 1.5-year flood peak flows (Randle and Samad, 2003). 56
Figure 3.4 North Platte River at North Platte, Nebraska flow-durations curves (Randle and

Samad, 2003). 57

LIST OF FIGURES (continued)

Figure 3.5 South Platte River at North Platte, Nebraska flow-durations curves (Randle and Samad, 2003). The mean flow for the first, second, and fourth time periods are very similar (Table 3.4). 58
Figure 3.6 Platte River near Cozad, Nebraska flow-durations curves (Randle and Samad, 2003). 60
Figure 3.7 Platte River near Overton, Nebraska flow-durations curves (Randle and Samad, 2003). 60
Figure 3.8 Platte River near Grand Island, Nebraska flow-durations curves (Randle and Samad, 2003). 61
Figure 3.9 Mean annual flow data for Middle Boulder Creek, Colorado reconstructed from tree-ring data (Woodhouse, 2001b). 66
Figure 3.10 Mean annual flow data for Clear Creek, Colorado reconstructed from tree-ring data (Woodhouse, 2001b). 66
Figure 3.11 The average Palmer Drought Severity Index (PDSI) for the Platte River Basin based on instrumented data 68
Figure 3.12 North Platte River at North Platte, Nebraska mean annual flow and annual peak flow (Randle and Samad, 2003). 68
Figure 3.13 The comparison of hydrographs for water years 1900 and 1990. 73
Figure 3.14 Platte River Bed Material Grain Size Distributions in 1931 (U.S. Army Corps of Engineers, 1935). 76
Figure 3.15 Median bed-material grain size versus river mile in 1931 and 1980. 77
Figure 3.16 Bed Material Grain Size Distributions of the South Platte River at North Platte, Nebraska in 1979-1980. 77
Figure 3.17 Platte River Sediment-Discharge Rating Curves by Simons and Associates (2000). 78
Figure 3.18 Platte River Sediment-Discharge Rating Curves by Kircher (1983). 79
Figure 3.19 Platte River average annual sediment load based on sediment-discharge equations by Simons and Associates, Inc. (2000). 79
Figure 3.20 Platte River average annual sediment load based on sediment-discharge equations by Kircher (1983). 80
Figure 3.21 Platte River mean annual bed-material load based on the sediment transport model by Murphy et al. (Draft 2003). 80
Figure 3.22 Comparison of bankfull discharge indicators for the Platte River near Cozad, Nebraska. 84
Figure 3.23 Comparison of bankfull discharge indicators for the Platte River near Overton, Nebraska. 84
Figure 3.24 Comparison of bankfull discharge indicators for the Platte River near Grand Island, Nebraska. 85
Figure 3.25 Schematic of Water Resource Infrastructure along the North Platte, South Platte, and Platte Rivers. 87

LIST OF FIGURES (continued)

Figure 4.1 Comparisons of active channel width versus time for various locations along the Platte River. 91
Figure 4.2a Exponential correlation of Platte River Width to the mean flow rate for locations near Cozad, Overton, and Grand Island, Nebraska........ 93
Figure 4.2b Linear correlation of Platte River Width to the 1.5-year flood peak for locations near Cozad, Overton, and Grand Island, Nebraska. 93
Figure 4.3a Looking at the downstream end of the Keystone Bridge pier that was constructed in 1979........ 102
Figure 4.3b Looking upstream toward the Keystone bridge. 102
Figure 4.3c Looking downstream from the left bank, approximately 100 yards downstream of Keystone Bridge.
……..103
Figure 4.3d Looking at the upstream end of the Keystone bridge pier, showing the gap between the base of the pier and the water surface. 103
Figure 4.4a Looking downstream from the Lexington Bridge, just upstream of the Johnson-2 return channel (RM 251.5). 104
Figure 4.4b Looking downstream along the south channel, immediately downstream of J2 return (RM 246.5)........ 104
Figure 4.4c Looking upstream along the south channel, downstream of the J2 return. 105
Figure 4.4d Looking across to the left bank of the south channel, downstream of the J2 return (RM 244.5)........ 105
Figure 4.5 Measurement of channel thalweg incision along the Platte River reach downstream from the Johnson-2 Return channel (river mile 247)........ 106
Figure 4.6a Platte River at mile 246.5, both north and south channels. 107
Figure 4.6b Comparison of 1989 and 2002 Platte River channel cross section surveys for river mile 246.5 south channel. 107
Figure 4.7 Comparison of 1989 and 2002 Platte River channel cross section surveys for river mile 246.0. 108
Figure 4.8 Comparison of 1989 and 2002 Platte River channel cross section surveys for river mile 244.0 south channel. 108
Figure 4.9 Comparison of 1989 and 2002 Platte River channel cross section surveys for river mile 239.9. 109
Figure 4.10 Comparison of 1989, 1998, and 2002 Platte River channel cross section surveys for river mile 239.3. 109
Figure 4.11 Comparison of 1989 and 2002 Platte River channel cross section surveys for river mile 239.0. 110
Figure 4.12 Comparison of 1989, 1998, and 2002 Platte River channel cross section surveys for river mile 237.5. 110
Figure 4.13 Comparison of 1989, 1998, and 2002 Platte River channel cross section surveys for river mile 230.8. 111
Figure 4.14 Comparison of 1989 and 2002 Platte River channel cross section surveys for river mile 228.7. 111
Figure 4.15 Average changes in bed elevation between the years 1984 or 1985 and October

2000 or 2001. 112

LIST OF FIGURES (continued)

Figure 4.16 Estimated downstream progression of clear-water channel incision of the Platte River, based on de Vries as presented by Graf (1998). 114
Figure 4.17 Median bed-material grain size comparisons between 1931, 1980, and 1989....... 116
Figure 4.18 Bed-material grain size distributions in 1931 and 1980 for the North Platte River at North Platte, Nebraska. 117
Figure 4.19 Bed-material grain size distributions in 1979 and 1980 by Kircher (1983) for the North Platte, South Platte, and Platte Rivers. 118
Figure 4.20 Bed-material grain size distributions in 1931 and 1979 for the Platte River near Cozad and Gothenburg, Nebraska. 118
Figure 4.21 Bed-material grain size distributions in 1931 and 1980 for the Platte River near Grand Island, Nebraska.. 119
Figure 4.22 Comparison of 1901 and 1998 Platte River bed profiles. 121
Figure 4.23 Regime channel bed geometry for sand bed rivers, from Chang (1985)................ 123
Figure 4.24 A regime diagram for natural channels based on channel slope and bankfull discharge, taken from Leopold and Wolman (1957). 124
Figure 4.25 Lane's (1957) regime diagram for sandbed streams based on slope and mean discharge, taken from Richardson, et al. (1990). 125

Figure 5.1 Future potential for sustained average channel width with mechanical clearing and leveling of wooded islands and pulse flows. 135

Figure A.1 Nebraska bedrock geology (Conservation and Survey Division, University of Nebraska-Lincoln, 1996a). 159
Figure A.2 Pleistocene glacial deposits in Nebraska (Conservation and Survey Division, University of Nebraska-Lincoln, 1992) 160
Figure A.3 The major rivers of Nebraska exhibiting the southeastern direction of surface water flows, also noted in subsurface flows. 161
Figure A.4 North-south geologic profile from Gibbon to Riverton, Nebraka, taken from Lugn & Wenzel, 1938. 162
Figure A.5 Pleistocene deposits at Lovers Leap, west of Fullerton, and correlation with logs of wells at Grand Island, Aurora, and Holdrege (taken from Lugn & Wenzel, 1938). 162

LIST OF TABLES

Table 2.1 Sequence of late Quaternary events [Holocene] and climate as inferred in the North Platte Valley from Wenzel, Cady and Waite, 1946. 15
Table 2.2 Historical estimates of thousands of acres of crops harvested as reported by the USDA- National Agricultural Statistics Service 36
Table 2.3 Irrigation wells in the Platte Valley (taken from Lugn & Wenzil, 1938). 47
Table 2.4 Compilation of percolation from the Platte Valley between Gothenburg and Chapman (taken from Lugn & Wenzil, 1938). 49

Table 3.1 Irrigated Acres within the Platte River Basin above the Loup River confluence. 62
Table 3.2. Estimated mean annual consumptive use for the Platte River Basin above Loup River confluence. 62
Table 3.3 Mean annual import of water to the Platte River Basin from the Colorado River Basin. 62
Table 3.4 Maximum Percent of Changes in Mean Platte River Flows Presumed Attributable to Climate Fluctuations (Mean flows from Randle and Samad, 2003). 70
Table 3.5 Maximum Percent of Changes in 1.5-Year Flood for Platte River Flows Presumed Attributable to Climate Fluctuations. 71
Table 3.6 Mean Platte River flows (Randle and Samad, 2003). 75
Table 3.7 Median Platte River flows (Randle and Samad, 2003). 75
Table 3.8 Platte River 1.5-year flood (Randle and Samad, 2003). 75
Table 3.9 Platte River average annual sediment loads based on sediment discharge equations by Simons and Associates, Inc. (2000), from Randle and Samad (2003). 81
Table 3.10 Platte River average annual sediment loads based on sediment discharge equations by Kircher (1983), from Randle and Samad (2003). 81
Table 3.11 Platte River average annual sediment loads based on the sediment transport model by Murphy et al. (Draft 2003), from Randle and Samad (2003). 81

Table 4.1 Approximate River Mile of Landmarks along the central Platte River. 89
Table 4.2 Historic un-vegetated or active channel widths of the Platte River as measured from historic maps and aerial photography. 90
Table 4.3 Platte River mean flow, 1.5-year flood peaks, and historic unvegetated or active channel widths measured from historic maps and aerial photography. 92
Table 4.4 Average change in bed elevation for main channel between 1984 or 1985, and 2000 or 2001, based on multiple transects. 112
Table 4.5 Platte River Bridges based on 1998 aerial photographs and U.S. Geological Survey quadrangle maps. 127

Table B.1 Chronolgy of rivers in the central Great Plains, based on geologic formations and radiocarbon dating. 164

GLOSSARY

active channel width – The width of channel over which bedload sediments are transported on a nearly annual basis.

adaptive management program – A method of implementation where management objectives are clearly defined, management actions are proposed to achieve those objectives (based on predictions or hypotheses), the responses of the system to those actions are monitored, and, if necessary, management actions are adjusted to better achieve the management objectives.

aggradation – The cumulative deposition of sediments along the riverbed, which causes the elevations of the river bed, along some reaches, to increase over time.

anthropogenic – Resulting from the effects of human activities.

armoring – A condition of the river-bed material where a surface layer of coarse particles exist that are too large to be transported by previous high flows. This condition occurs during channel degradation or incision when the finest bed-material particles are eroded and only the coarsest particles remain.

basin structure – A geomorphically significant description of the river basin that includes location of flow and sediment inputs and diversions, and features that impact the channel geometry including geologic formations and man-made structures.

bridge segments – Thirteen main road bridges subdivide the habitat study area into river segments averaging seven to eight miles.

central Platte River – The reach of Platte River between North Platte, Nebraska and Chapman, Nebraska.

degradation – The continual erosion of sediments from along the riverbed, which causes the elevations of the river bed, along some reaches, to decrease over time.

EDS cycle – The alternating states of erosion, deposition, and stability along a river channel.

habitat study area – The reach of the central Platte River between Lexington, Nebraska and Chapman, Nebraska.

level one, level two, and level three investigations – Qualitative analysis, quantitative analysis, and numerical or physical modeling or processes represent the three levels of investigation.

over-appropriated – The situation where the annual volume of water, secured by water rights, exceeds the volume of water supplied by the river.

GLOSSARY (continued)

paleo-techniques – Radio carbon dating of material in land surfaces, the description and classifications of soils, the classification and evaluation of the landforms and their stratigraphy are all techniques that help to describe the recent geologic processes acting on a river system.

Palmer Drought Severity Index (PDSI) – A drought model derived by Palmer (1965) from temperature and precipitation data to provide a measure of climatic stress on crops and water supplies. A positive value indicates a wet period and a negative value indicates a dry period.

pedogenesis – The formation of soils on the land surface over time.

plan form – the shape of the river as seen from the air (e.g., meandering, straight, braided, anabranched).

river mile (RM) – Distance along the Platte River, as denoted by river mileage, beginning at Plattesmouth, Nebraska (river mile 0) and increasing in the upstream direction.

stability – A condition of a river channel where there is no net erosion or deposition of sediment along the riverbed or banks.

sustainable – A condition where attributes of the river channel (e.g. width, riverbed elevation) are maintained over the long-term.

thalweg – The thalweg is the deepest point in a channel cross section, and in plan view the thalweg marks the primary, longitudinal flow path.

1.0 INTRODUCTION

The central Platte River is the focus of a proposed, endangered-species-recovery program (Program) that seeks to restore some of the channel habitats of threatened or endangered species. The Program focuses on habitats that have been lost due to narrowing of the unvegetated channel width as a result of vegetation expansion into the formerly active portions of the historic river channel, and lost due to the decreased sand bar building potential of the central Platte River. The term active channel width refers to the width of channel over which bedload sediments are transported on a nearly annual basis and over which permanent vegetation cannot exist (Osterkamp and Hedman, 1977). The basis for this Program is set forth in the *Cooperative Agreement for Platte River Research and Other Efforts Relating to Endangered Species Habitats along the central Platte River, Nebraska*, (Colorado, Nebraska, Wyoming , and the U. S. Department of the Interior 1997), (CA).[1]

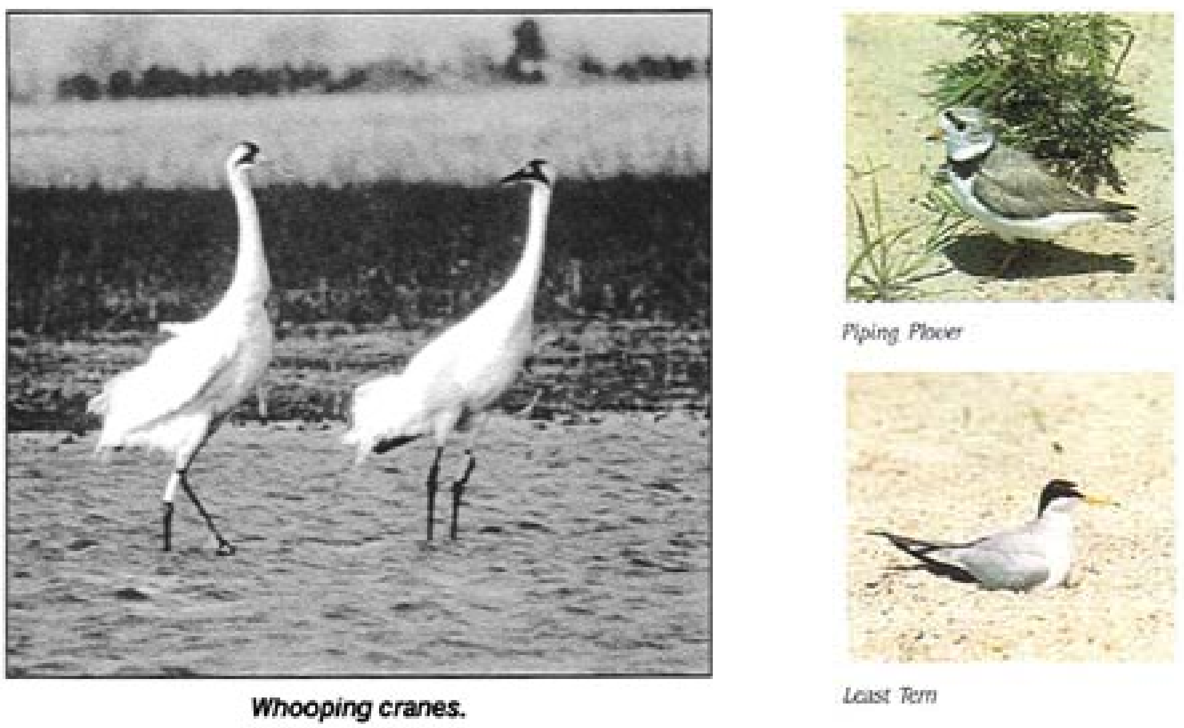


Figure 1.1 Endangered species of the central Platte River.

Three endangered bird species: the Whooping Crane (*Grus americana*), Piping Plover (*Charadrius melodus*) and Interior Least Tern (*Sterna antillarum athalassos*), shown in Figure 1.1, historically used the very wide, sandy, and largely un-vegetated Platte River channel for roosting or nesting (URS Greiner Woodward Clyde Federal Services, 1999). The Recovery Plans (U.S. Fish and Wildlife Service, 1988, 1990, 1994) for the three species include the Platte River among the habitat sites where improvement is needed. Some specifics on the desired

[1] The proposed Program also addresses the pallid sturgeon, which is found in the lower Platte River near the Missouri River. This paper focuses on the central Platte River.

unvegetated channel width and sand bar area are given in the Biological Assessment of the Federal Energy Regulatory Commission (FERC) re-licensing of the Kingsley Dam (FERC 1995). The basic description of the desired habitat is a very wide and shallow river channel with little or low vegetation, water filling the channel during the Crane migration seasons, and dry sand bars surrounded by low water during the summer Tern and Plover nesting season.

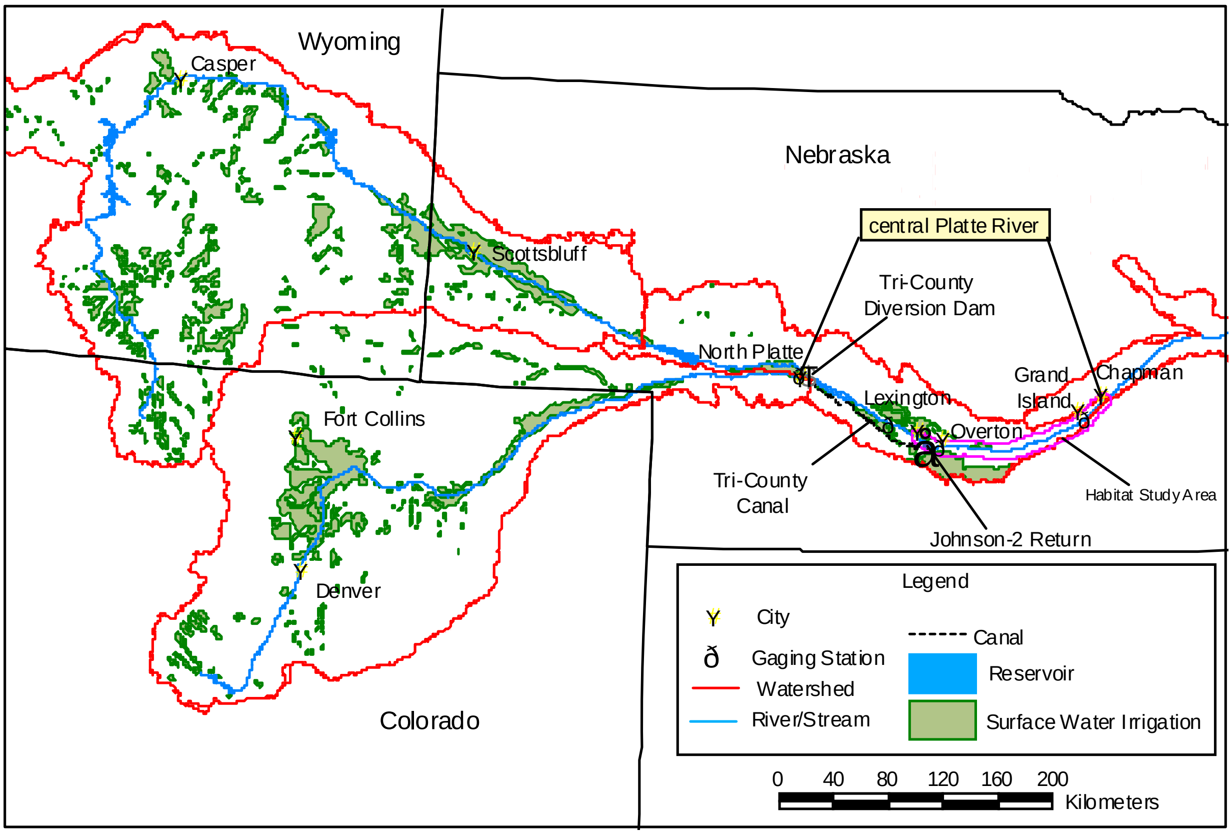


Figure 1.2 Platte River Basin location map.

1.1 LOCATION

The North and South Platte Rivers both originate on the eastern slopes of the Rocky Mountains in Colorado (Figure 1.2). The North Platte River flows north into Wyoming and then southeast across Wyoming and through the northwestern panhandle of Nebraska. The South Platte River flows generally northeast through Colorado and into Nebraska. The North and South Platte Rivers join to form the Platte River at the City of North Platte, Nebraska. From there the Platte River flows generally eastward through Nebraska before joining the Missouri River near Plattsmouth, Nebraska. The central Platte River is used here to specify the reach between North Platte, Nebraska and Chapman, Nebraska, while the habitat study area refers to the lower portion of this reach between Lexington, Nebraska and Chapman, Nebraska.

1.2 THE CONCERN

The historically unvegetated river channel has narrowed substantially in the central Platte River over the last 100 years (Figure 1.3), reducing active channel widths by as much as 80 to 90 percent (Simons & Associates, 2000). Sand bars that are used for nesting by Piping Plovers and Interior Least Terns are now found infrequently, if at all, in the central Platte River. While other reaches have experienced less change, the central Platte River has generally experienced narrowing of the unvegetated channel width throughout its length, with greater percentage reductions in width in the upper reaches and smaller percentage reductions with distance downstream (Figure 1.4).

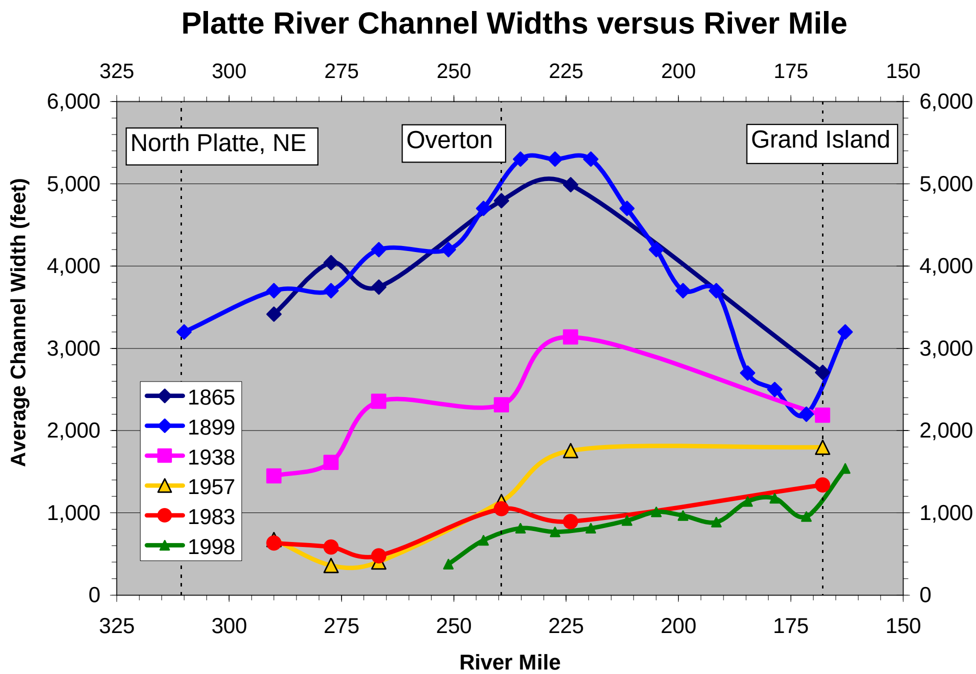


Figure 1.3 Reductions in unvegetated channel width in the central Platte River. Distance along the Platte River is denoted as river mileage beginning at Plattemouth, Nebraska (River Mile 0) and increasing in the upstream direction.

1.3 OBJECTIVE OF THE PAPER

Presented in this paper are past channel habitat trends, their probable causes, and the likely future trends for the river channel, based on a historic review of channel evolution and field data. From this foundation, a strategy for a river restoration program focused on enhancement, or managing causes and mitigating impacts (The Federal Interagency Stream Restoration Working Group, 1998), is considered. Contrary to the general interpretation of the name, the intent is not to "restore" the river structurally and functionally to a historic pre-development condition, but to maximize the unvegetated channel widths and instream habitat that can be maintained, cognizant of natural river functions, and under current and future river management conditions.

Platte River looking east near Gothenburg, Nebraska. RM 284

Platte River looking west near Cozad, Nebraska. RM 267

Platte River looking east near Highway 10 bridge, Buffalo/Kearney Co., Nebraska. RM 208

Figure 1.4 Photos of the central Platte River illustrating spatial variations in the narrowing of unvegetated widths and spatial variation in plan form. RM denotes river mile measured upstream from Plattesmouth, Nebraska (RM 0).

1.4 STUDY APPROACH

This study of the central Platte River, addressing geomorphic, hydraulic, and sediment transport concerns, incorporates a three-level analysis. This approach to analyses of river management options was developed by Simons, Li & Associates (1982), and the ASCE Task Committee on Hydraulics, Bank Mechanics, and Modeling of River Width Adjustment (1998b). The first level by Simon's Li & Associates is a qualitative or theoretical geomorphic analysis. A second, and more detailed level, includes quantitative engineering and geomorphic analysis, while the third most detailed level of analysis includes numerical (computer) modeling. This paper summarizes findings of the first two levels[2], while the third level of analysis using numerical modeling is introduced in Murphy et al. (Draft 2001), and applied in the Platte River Recovery Implementation Program Draft Environmental Impact Statement (U.S. Department of the Interior, 2003).

[2] The authors have pursued the third level of analysis by developing the SEDVEG numerical model (Murphy et al, 2001) that integrates channel hydraulics, sediment transport and vegetation growth and mortality to analyze historic and future trends in channel width for central Platte River habitat.

1.5 FACTORS CONSIDERED

The channel form of the central Platte River, and subsequently, habitat for the endangered species, is dependent on three elements: flow, sediment transport, and basin structure. Basin structure includes the location of flow and sediment inputs for the system, and both geologic structures and structures constructed by man that are impacting the river system. In geologic time, the changes noted to flow, sediment, and basin structure of the central Platte River have been driven solely by climatic factors. In the recent past, however, the presence of major societal developments that impact the Platte River Basin cannot be ignored, and are also considered for an analysis of the observed changes to the river.

1.6 ORGANIZATION OF THE PAPER

Chapter 2 contains a historical review of the Platte River Basin to provide understanding of, and probable causes for, changes to the central Platte River. The historical review begins in geologic time with the Pleistocene, when the central Platte River was formed, and continues to the present. Consideration of events in geologic time not only provides an understanding of the changes that have occurred in the pre-development period, but also provides an understanding of basin structure and features that continue to influence the central Platte River today. The nineteenth century is a transition period that bridges from a river primarily influenced by climate in geologic time, to a river primarily influenced by mans activities (anthropogenic) in the twentieth century. Large societal developments alter basin structure in the twentieth century, and changes to the channel in the twentieth century are the most pronounced.

In Chapter 3, the focus is on analyzing the measured changes to three elements that theoretically and customarily have a significant impact on the form of a river: flow, sediment, and basin structure. Quantitative flow data in the form of instrumented weather and streamflow records in general became available in the Platte River Basin in the late nineteenth century, while quantitative sediment data is not measured until the 1930s. Frequently the flow and sediment data will be subdivided into four time periods for analysis, but there is no intent to select one of the four periods as a target condition. The report “The Platte River Flow and Sediment Transport between North Platte and Grand Island, Nebraska (1895-1999)”, by Randle and Samad (2003) is a foundation reference for Chapter 3 since it presents a detailed description of the flow and sediment reductions in the central Platte River in the twentieth century.

The chronologic presentation in Chapter 2 helps correlate climatic and anthropogenic factors to the changes in basic elements: flow, sediment, and basin structure, presented in Chapter 3. In Chapter 4, the changes to basic elements are tied to the processes, trends, and linkages operating today in the Platte River. And finally in Chapter 5, our understanding of past changes to the river, gained from previous chapters, is applied to propose options for increasing and maximizing unvegetated and active channel widths in the central Platte River in the future. The proposed options are not intended to restore historic channel conditions to the central Platte River, but to maximize channel habitat for target species under the current basin structure and function.

1.7 PRINCIPAL FINDINGS

For approximately 40,000 years, in a period pre-dating human development of the Platte River basin, climate has been the dominant extrinsic factor shaping the Platte River through influences on flows, sediment transport and the geologic nature of basin structure. The river has evolved, under climatic influences on flow and sediment transport, through multiple cycles of aggradation, degradation or relative stability, but rates of aggradation and degradation for this extensive period of time appear to be quite small. And in the 40,000 year history of the river, the Platte River is known to have undergone only one major alignment change, a change in basin structure.

Nearing the end of the pre-development period, there is a cycle change from gradual degradation to aggradation. Under the conditions present at the time of that cycle change, further degradation of the central Platte River appears to have been limited by the lower sand and gravel layer of the Grand Island Formation.

Based on the geology and the morphology of this period, the central Platte River can be divided into three reaches: North Platte to Overton, Overton to Kearney, and Kearney to Grand Island, in Nebraska. Kearney to Grand Island is the youngest reach of river and there may be variations in the channel response of each reach, to changing river conditions.

1.7.1 The Anthropogenic Factor and the Historic River

Climate was the primary influence on the river in the pre-development period, but in the nineteenth century, mans activities began to impact the Platte River in addition to the influences of climate. The anthropogenic impacts for the nineteenth century are not quantified at this time, but are watershed impacts that are estimated to have had less effect on the central Platte River than anthropogenic factors in the twentieth century. The impacts of man include a decrease in average flows in the last decades of the nineteenth century, and a suspected increase in sediment loads beginning in the mid-nineteenth century, however climate remains a significant influence. By the twentieth century, the impacts of human actions in the Platte River Basin resulting from large population increases and the development of large infrastructure systems make climate factors secondary to anthropogenic factors in shaping the Platte River. There is also a cycle change in the twentieth century from aggradation to rapid degradation, with varying rates of degradation along the river.

Average and peak flows, the transport of sediment and median grain size of the channel bed, and the basin structure are all significantly altered by human activities in the twentieth century. As a result of these changes, the central Platte River today can be described as distinctly different from the Platte River in the pre-development period (Figure 1.5), and the rate of this change is relatively abrupt with respect to climate induced change and geologic time.

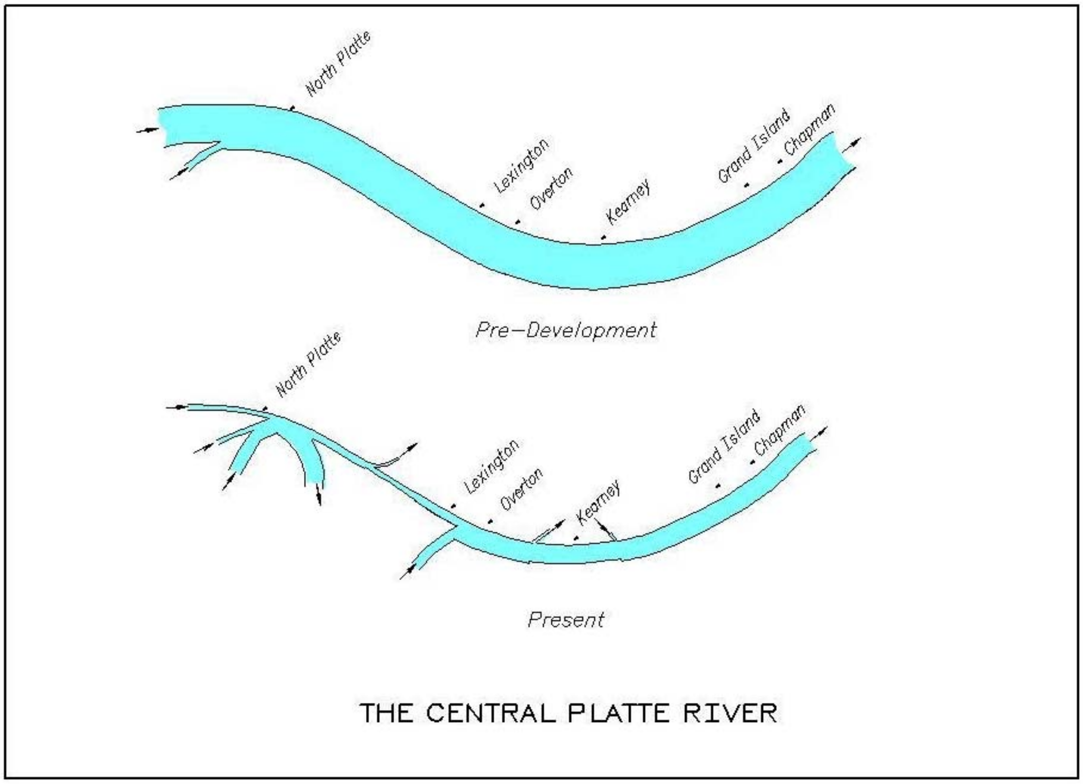


Figure 1.5 A comparison of the central Platte River flows and basin structure between the Pre-Development period and the twentieth century. The river width is scaled to represent average annual flows.

1.7.2 Flow

Based on this study, one of the principal processes associated with the period of rapid narrowing from the early to the mid-twentieth century are substantial reductions in river flow, reductions in flow peaks, and the rapid expansion of vegetation. Flows are limited to the lower-elevation areas of the channel by the reduction in flows. Following reductions in flows and flow peaks, and corresponding to reductions in the active channel width, more areas of formerly sandy banks and
islands could be colonized by vegetation. The encroachment by vegetation into former channel areas reduces the mobilization of sand at higher flows, including the 1973 and 1984 flow events, and prevents the maintenance of formerly wide channels that are desirable habitat for target species.

1.7.3 Sediment Transport

The cause of a more subtle process of reductions in active channel and unvegetated channel width is attributed to a coarsening in sediment grain size. A larger grain size is generally associated with a more deep and narrow channel section; geometry not as supportive of endangered species habitat. More sand is originating from the coarser material in the South

Platte River, and less from the finer-grained supply of the North Platte River, as a result of trans-basin diversions and the construction of Lake McConaughy, resulting in larger median grain sizes to the central Platte River. A coarser grain size also is developing in the central Platte River from channel incision, where the channel bed serves as a main sediment source.

Water diverted to major canals for irrigation and hydropower, returns to the river channel as clear-water causing rapid channel bed erosion at the point of return flow. Channel erosion and incision from clear-water irrigation returns has maximum impact immediately downstream from the source of clear-water, but local bed coarsening causes the erosion process to migrate downstream over time. Narrowing of the active channel width is a geomorphic consequence of incision, and this process reduces habitat available to the target species.

1.7.4 Basin Structure

The twentieth century, when unvegetated channel widths and active channel widths exhibit a pronounced period of narrowing, is also concurrent with a change in the basin structure resulting from the construction of river structures. Basin structure is altered by flow diversion structures that remove flows from long reaches of the river, act as new tributaries when flows are returned at a downstream location, and alter sediment transport and sediment inputs along the river. There has also been a large increase in the number of structures that restrict the horizontal and vertical alignment of the channel including bridges with constricting bridge spans, levees that protect facilities adjacent to the river, rock revetment placed to prevent bank erosion and channel migration, and flow diversion structures that set new grade restrictions. New structures in the basin that reduce flow and sediment, impact habitat for endangered species as described above. New horizontally-constricting structures directly reduce habitat through channel width, and indirectly impact habitat by raising channel velocities.

1.7.5 Restoration Strategy

To interpret the rapid changes noted to the Platte River in the twentieth century, flow, sediment and channel width data beginning near the end of the nineteenth century is combined with historic information on the evolution of the Platte River Basin from the Pleistocene through the present. Knowledge of past channel morphology provides a basis for future restoration strategies aimed at widening short reaches of the river to enhance habitat for the target species. The general strategy includes an annual program with: 1) the progressive clearing and lowering of certain vegetated islands that are located within the river's banks, preferably in the upstream reaches closest to a major irrigation return, and 2) annual releases of high flow within safe channel capacity, of short (1 to 3 days) duration using water from Lake McConaughy and the South Platte River. The clearing and lowering of river islands would immediately increase the area of wide, open channel, key to endangered-species habitat, while at the same time provide more smaller-grained sand from the wooded river islands to the river channel. The annual releases of flow would act to restrict encroachment by vegetation into the areas of cleared and lowered islands, and transport sediment contributing to the development of sand bars that are potential nesting habitat for Least Terns and Piping Plovers.

2.0 HISTORIC SETTING OF THE PLATTE RIVER

Historical information was used to assess the geomorphic changes to the river and the processes and trends associated with these changes. This information was studied with the goal of assisting in the development of effective habitat management programs for the future. This chapter is not a comprehensive historical account but attempts to summarize the factors that may be pertinent to the geomorphology of the central Platte River.

There is no intent with the historical review to select a “target” period on which to model restoration conditions. Rivers are dynamic and evolve to forms reflecting the recent pattern of imposed conditions. A partial restoration of conditions that produced a stable river in a former period, would not guarantee stability or sustainability of the river under future conditions. Instead the approach of this report is to seek means to maximize habitat for endangered species through management actions compatible with current river constraints and demands, and management actions that are based on geomorphic principals as reflected by past channel response.

The evolution of the Platte River is divided into three periods: the pre-development period, the nineteenth century, and the twentieth century. Climate factors are the dominant influence on the shape of the Platte River in the pre-development period. The nineteenth century is a transition period when anthropogenic factors or the impacts from mans’ activities, in addition to climate factors, begin to have an effect on the Platte River. In the twentieth century, anthropogenic impacts overshadow the influence of climate.

2.1 THE PRE-DEVELOPMENT RIVER

The origins and evolution of the pre-development Platte River are traced through the Quaternary period of geologic time, ending at the start of the nineteenth century. Background information for this section, summarizing the geology of the Platte River Basin and estimated cycles of aggradation, degradation and stability over geologic time for the Platte River, can be found in the Geology Appendix.

The central Great Plains where the Platte River is located, is a semi-arid region where evapotranspiration rates approach or exceed precipitation rates, and most rivers are perennial only because of snow melt from the Rocky Mountains. Glacial and periglacial processes are considered to dominate the northern Great Plains, eolian and groundwater processes dominate in the southern Great Plains, but fluvial processes dominate in the central Great Plains region (Hadley and Toy, 1987). In the absence of major impacts from the activities of man, the shape of river channels can be impacted by discharge, vegetation coverage and slope. In the Great Plains region, the shape of river channels is also, at least partially, a function of the sediment load that is transported from the source area (Leopold & Maddock, 1953, Schumm, 1969, Schumm and Meyer, 1979).

Climate factors can directly affect discharge, sediment transport, and vegetation coverage in upland areas. Large deviations from an average condition can affect discharge rates and durations through reduced precipitation and snowpack. Periods of drought can increase vegetation mortality in upland areas, in turn causing increased sediment input to rivers through overland runoff and increased eolian input. Wet periods can increase vegetation in upland areas, decreasing the sediment load to a river.

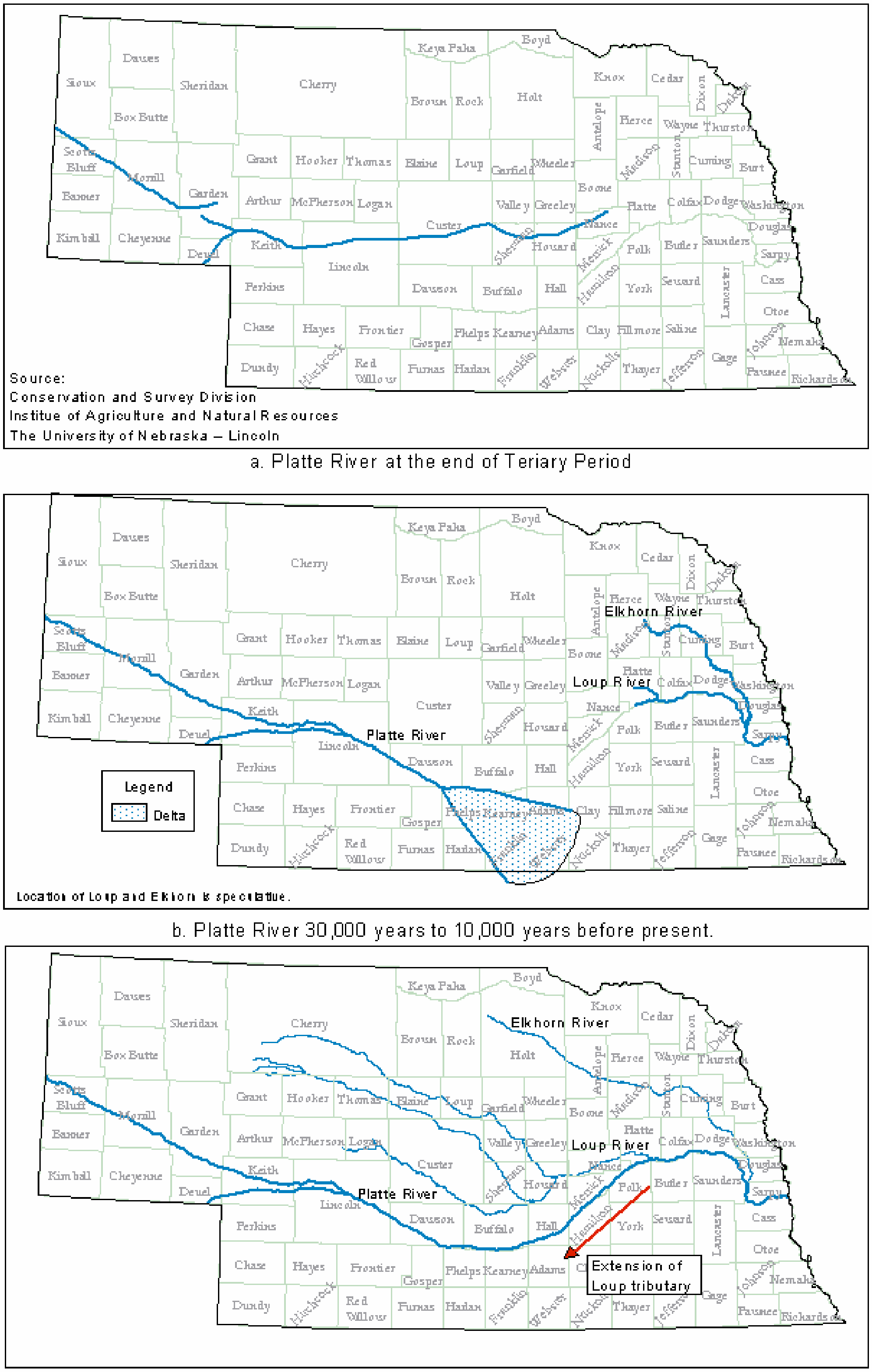
The geomorphic processes sculpting landforms in the Great Plains region is generally described as episodic. Under this hypothesis, when climate is the dominant factor, landforms fluctuate between periods of degradation (erosion), aggradation (deposition) and stability (EDS cycle, Morrison, 1987). During periods of stability, the process of pedogenesis dominates. This pattern is recognized in fluvial systems with periods of degradation, aggradation, and stability, which are recorded in the terrace stratigraphy and floodplains. Episodic river response is believed to be triggered by extrinsic influences such as climate in conjunction with intrinsic influences often referred to as thresholds of fluvial processes. The thresholds for each system are not always obvious or well understood and the same climate patterns may or may not initiate the same response in two similar river systems (Schumm, 1973). Under this scenario of climate dominated morphology, the Platte River system developed.

2.1.1 The Platte River Alignment

The current Platte River alignment appears to have been established in the Pleistocene. Lugn & Wenzel, 1938, estimate the origin of the river at 120,000 years ago, after deposits of the Upland Formation and Loveland Loess, but prior to the deposits of Peorian Loess (Geology Appendix A.). Bentall (1982) uses a slightly later date of 40,000 years ago. With respect to geologic time, either date establishes the Platte River as a relatively young river. Prior to the Pleistocene, and near the end of Tertiary time approximately 2 million years ago (Figure 2.1.a), drainage from the headwaters of the North Platte and South Platte Rivers eroded channels that flowed directly east (Conservation and Survey Division, University of Nebraska – Lincoln, 1980). In the Pleistocene, however, main drainage routes and tributaries flowed to the southeast, due to the retreat and advance of glaciers along the eastern edge of Nebraska (Figure A.2, Geology Appendix).

Topography and geologic formations indicate the Platte River originally followed its present path from the North Platte River southeast to Kearney, Nebraska (Figure 2.1.b.), but then continued to flow southeast beyond Kearney (Lugn and Wenzel, 1938). The flows may have dissipated through seepage in this area (Bentall, 1982), or possibly reached the Missouri River further south. It is postulated that a realignment of the southeast flow route and the formation of the Big Bend between Kearney and Grand Island, Nebraska (Figure 2.1.c.) resulted from the capture of the Platte River by a tributary of the Loup River that was extending southwest (Bentall, 1982).

The present day alignment of the Platte River east of Grand Island (lower Platte River), including the reach that possibly originated as a tributary of the Loup River, corresponds to the location of lineaments (Figure 2.2). These lineaments were noted from Landsat and infrared images (Kansas Geological Survey, 1982) and can indicate bedrock structure or fractures. Bedrock is located closer to the surface on the east side of Nebraska (Geology Appendix, Figure A.1), in contrast



a. Platte River at the end of Teriary Period

b. Platte River 30,000 years to 10,000 years before present.

c. Present day Platte River

Figure 2.1 Evolution of the Platte River alignment.

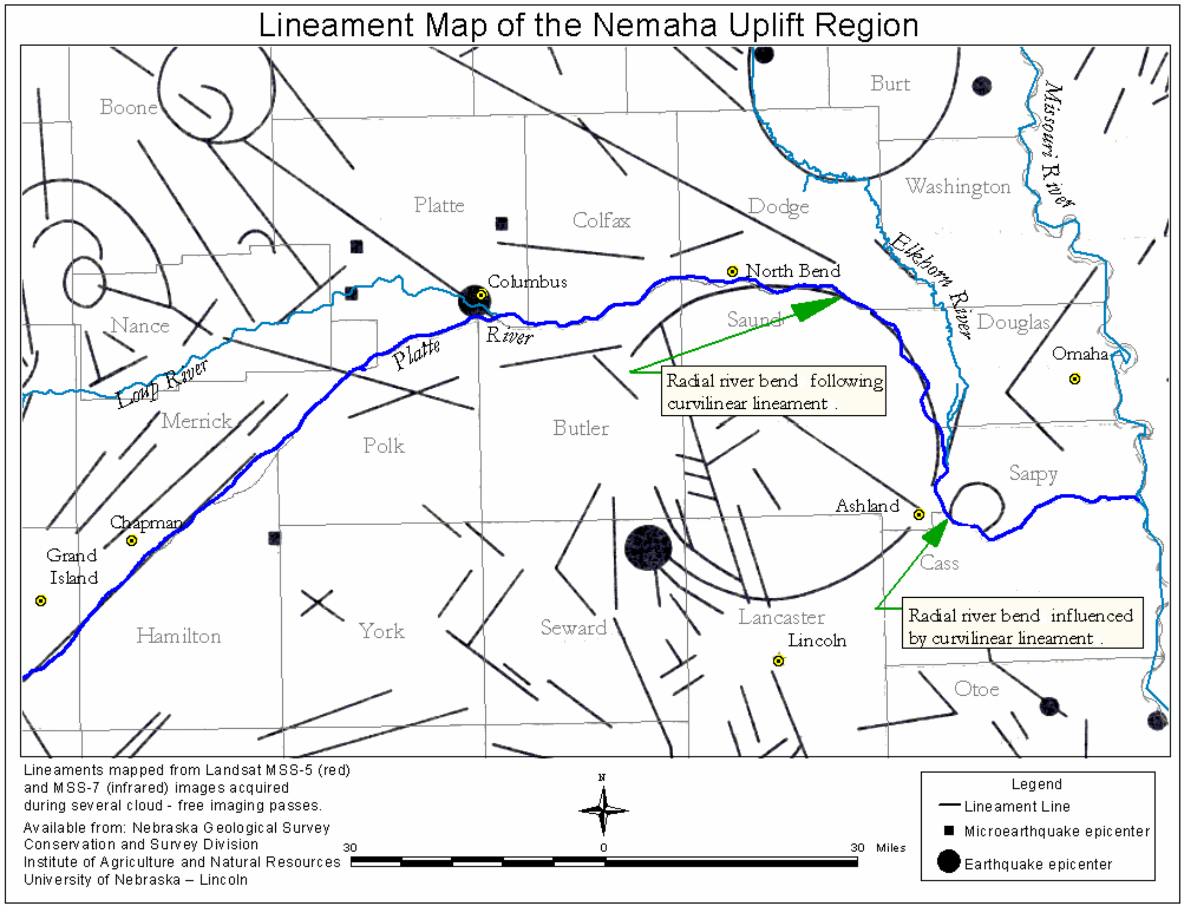


Figure 2.2 Lineaments near the lower Platte River (Kansas Geological Survey, 1982).

to the plains to the west. For this reason, the bedrock features to the east can have more influence on channel alignment in the lower Platte River. From Grand Island, Nebraska to Ashland, Nebraska (Figure 2.2), the Platte River closely follows lineaments, including two curvilinear lineaments, producing two distinct radial bends in the lower river.

Assuming the capture of the Platte River by a Loup River tributary altered the original Platte River alignment, the river channel from Kearney to Grand Island, Nebraska is a much younger reach at 10,000 years or less (Bentall 1982, Lugn and Wenzel, 1938) than other parts of the central Platte River. This reach is characterized by multiple large islands that end at Grand Island, Nebraska, the western limits of lineaments mapped in the Nemaha Uplift Region.

2.1.2 The Platte River Profile

The general channel profile and bed materials also provide further information about the river morphology. From North Platte, Nebraska to Grand Island Nebraska (Figure 2.3), the Platte River generally flows on approximately 100 to 200 feet of alluvial deposits of sand and gravel that overlay bedrock.

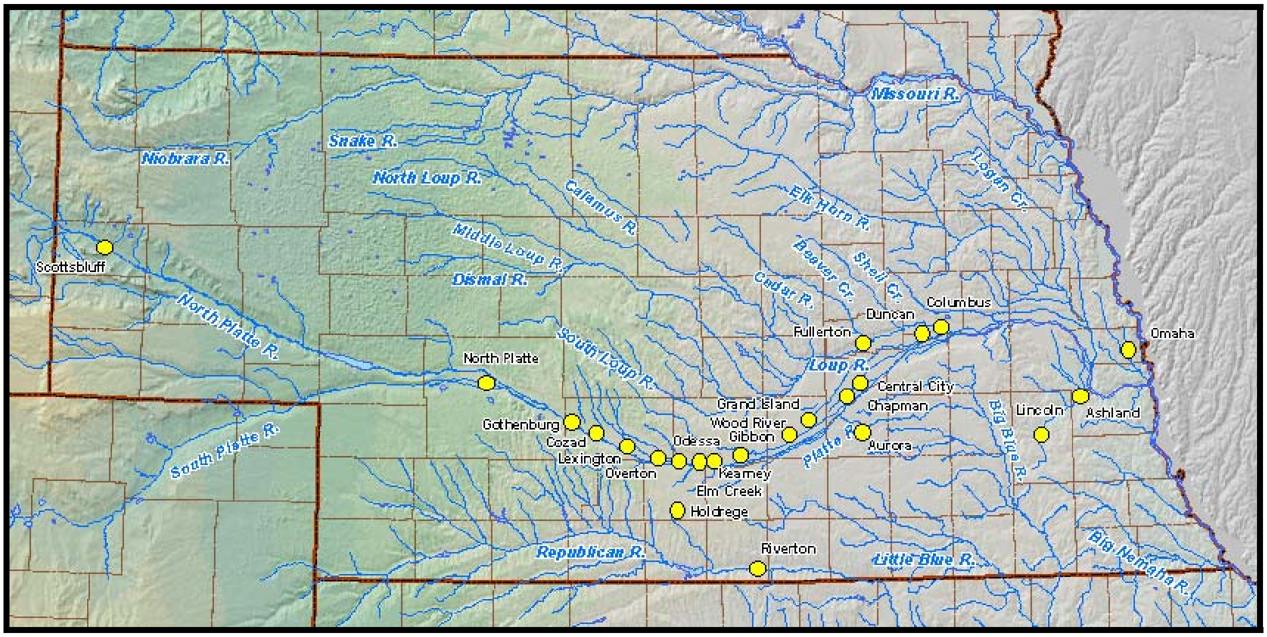


Figure 2.3 The North Platte, South Platte and Platte Rivers in Nebraska.

From Grand Island, Nebraska to the confluence with the Missouri River, the bed of the Platte River flows on 100 ft or less of Quaternary materials that include glacial till before encountering Cretaceous and older bedrock. As previously discussed, the course of the river appears to beinfluenced by fractures in the bedrock. Further downstream near Columbus, Nebraska, the grade may also be influenced by the larger materials of glacial till deposits (Geology Appendix, Figure A.2).

From values reported by Bentall (1991) a distinct break in the river profile can be noted near Columbus, Nebraska, just upstream of the confluence with the Loup River and downstream of Grand Island, Nebraska. From the confluence downstream, the grade of the Platte River is 4.8 ft per mile or less (0.00091). From the confluence upstream, the grade is 6.1 ft per mile to 6.7 ft per mile (0.0012 to 0.0013) persisting on the North Platte tributary, upstream of the confluence of the North Platte and South Platte Rivers. In 1933, the same break in grade was noted in a report transmitted to Congress (Letter from the Secretary of War, 1934). For the Platte River from North Platte, Nebraska to Columbus, Nebraska, a fall of 6.5 feet per mile (0.0012) was noted, while from Columbus, Nebraska to the Missouri River, there was a fall of 4.6 feet per mile (0.00087). An abrupt reduction in grade moving downstream often occurs at confluences where additional flows and sediment loads are introduced. However, this break also corresponds with the limits of glacial activity where 100 ft or less of alluvium and glacial till overlie the Cretaceous bedrock (Figure 2.4). The north-south alignment of the Elkhorn River in northeastern Nebraska shares a similar grade of 4.6 feet per mile in areas of glacial till.

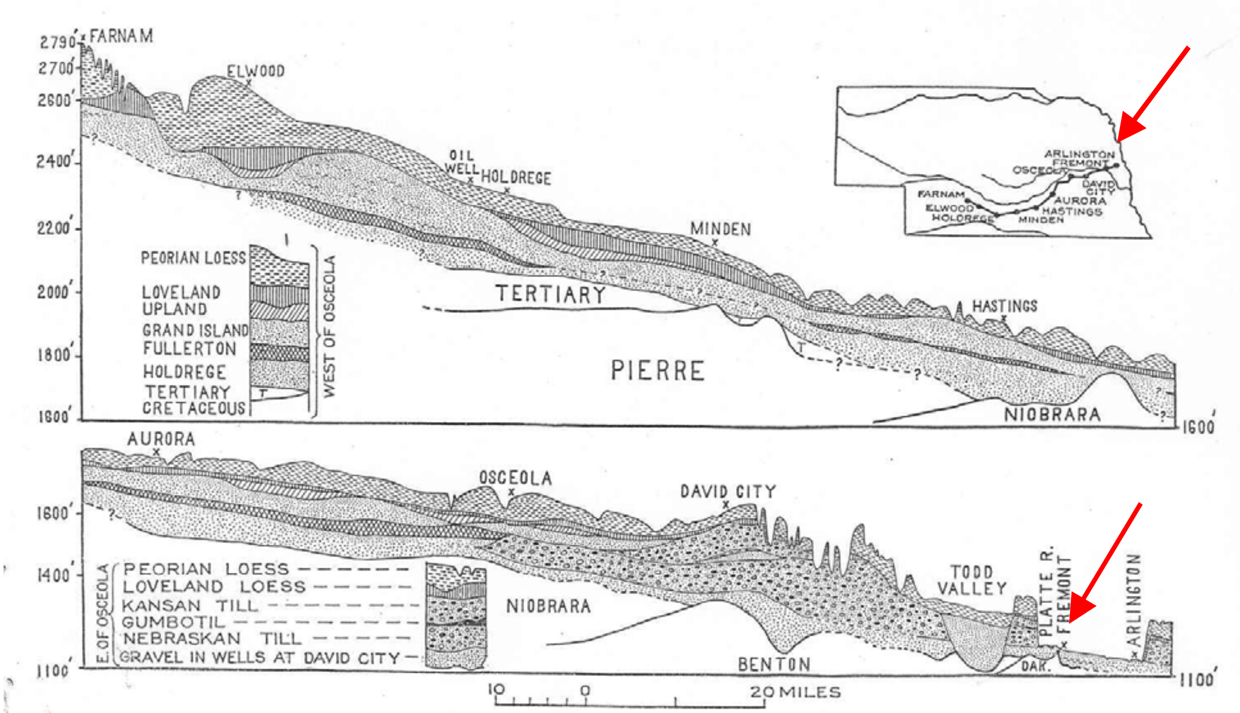


Figure 2.4 Geologic section from Farnam, in southwestern Dawson County, to Arlington, in Washington County, shows shallow location of bedrock under the Platte River at Fremont Nebraska, downstream of Columbus, Nebraska (taken from Lugn & Wenzel, 1938).

2.1.3 Distinct Reaches of the Platte River

The general form of the Platte River can be divided into five distinct reaches based on geologic factors, with the central Platte River being composed of the first three reaches:

- North Platte to Overton, a reach of gaining flow where groundwater contributes to surface water, Tertiary silt, sand and gravel underlying Quaternary alluvium, a southeast flow alignment, and a general grade of 6.5 feet of fall per mile (0.0012);
- Overton to Kearney, a reach of losing flow where surface water is lost to groundwater, Tertiary silt, sand and gravel underlying Quaternary alluvium, an easterly alignment traversing the groundwater flow alignment and the Pleistocene surface flow path, and a general grade of 6.5 feet of fall per mile (0.0012);
- Kearney to Grand Island, a reach of losing flow where surface water is lost to groundwater, Tertiary silt, sand and gravel underlying Quaternary alluvium, a northeasterly alignment following a younger flow path, multiple large islands in the channel, and a general grade of 6.5 feet of fall per mile (0.0012);
- Grand Island to Columbus, Cretaceous chalk, limestone and chalky shale bedrock underlying 100 ft or less of alluvium and glacial till, a northeast alignment following bedrock lineaments, and a general grade of 6.5 feet of fall per mile (0.0012); and
- Columbus to Ashland, Cretaceous shale, limestone, and sandstone bedrock underlying 100 ft or less of alluvium and glacial till, a variable alignment following seismic lineaments, and a general grade of 4.6 to 4.8 ft of fall per mile (0.00087 to 0.00091).

2.1.4 Cycles of Aggradation, Degradation and Stability, and Rates of Change

Rivers in the central Great Plains region, including the Platte River, may have passed through as many as ten cycles of aggradation, degradation and stability (EDS Cycles) in the last 120,000 years (Geology Appendix, Table A.1). This makes the average length of the identified cycles approximately12,000 years, with individual periods of aggradation, degradation, or stability averaging 4,000 years.

The average rate of incision or aggradation in each cycle, due to the long periods of time, becomes relatively small as demonstrated by Wenzel, Cady and Waite (1946) in a study of the geology and ground-water resources of Scotts Bluff County, Nebraska. The authors dated nine terraces of the North Platte River at Scotts Bluff, Nebraska. Seven terraces predate the Holocene, the most recent epoch of geologic time that began approximately 11,000 years ago with the last glacial retreat of the Pleistocene. The erosion-deposition cycle of the youngest two terraces were correlated to climatic changes for the Holocene as estimated from peat bogs in southeastern Canada. Depths of incision shown in Table 2.1 are approximate only, and are based on measurements from a cross section, drawn to scale, in the original paper.

Table 2.1 Sequence of late Quaternary events [Holocene] and climate as inferred in the North Platte Valley from Wenzel, Cady and Waite, 1946.

Erosion and Deposition	Climate inferred-		Age of European climatic changes, in years	Estimated depths of erosion (-) and deposition (+)	Average rates of erosion or deposition, inches per year
	From Terraces	From Canadian peat bogs			
Erosion	Wet (latest glacial advance?)		10,000+	-24 ft	
Deposition of second terrace	Dry	Warm and Dry	10,000 to 7,000	+21 ft	0.084 in/yr
Erosion	Wet	Warm and Moist	7,000 to 5,000	-21 ft	0.126 in/yr
Deposition of first terrace	Dry	Warm and Dry	5,000 to 3,000	+10 ft	0.060 in/yr
Erosion	Wet	Cool and Moist	3,000 to present	-9 ft	0.036 in/yr

Based on the values in Table 2.1, the average degradation rates due to climate are 0.036 inches to 0.126 inches annually, and average aggradation rates were 0.060 inches to 0.084 inches annually. The maximum average rate of incision in Table 2.1 is 0.126 inches annually, or about one foot per century, and occurred during the wet period from 7000 to 5000 years ago. The grade of the river at this site is a fall of 6.3 ft to the mile, similar to the grade of the Platte River as far downstream as Grand Island, Nebraska.

2.1.5 The EDS Cycle at the Close of the Pre-Development Period

Lugn and Wenzel offer some conclusions on the EDS cycle of the central Platte River at the end of the pre-development period. Lugn writes about the Platte River valley from Gothenburg to Chapman, Nebraska (Lugn and Wenzel, 1938). He describes the previous cycle of degradation that appears to be halted by sand and gravel from the lower layer of the Grand Island formation (Geology Appendix A.), before the start of the latest aggradational cycle:

> *The Platte [central Platte River] is now able to transport clay, silt, and fine sand but can only slightly rework the coarser material, which it has now reached in the process of valley cutting. It seems to have been an eroding stream until recently [with respect to geologic time]….*

In Wenzel, Cady and Waite (1946), Wenzel refers to the previous degradation cycle and provides an approximate date for the latest cycle of aggradation in the North Platte River. These comments also apply to the central Platte River due to the similarity in river conditions and Lugn's earlier comments on the central Platte River (Lugn & Wenzel, 1938):

> *[The floodplain of the North Platte River in western Nebraska]… probably has been aggraded several feet since the dissection of the lowest terrace….*
>
> *The North Platte having finished a minor period of downcutting, probably has been in a minor phase of aggrading during the past few centuries.*

Based on Lugn and Wenzel's comments, and without radiocarbon dating specific to the central Platte River, it is assumed that the latest cycle of aggradation for the Platte River began approximately 350 years ago in the seventeenth century.

In the Pre-Development Period, and prior to the nineteenth century, all of the EDS cycles in the central Great Plains (Geology Appendix, B. Geomorphic History) are assumed to be driven by the extrinsic influences of climate. Variations in river response for the region are assumed to be, at least partially, a result of intrinsic factors such as thresholds which vary due to geologic and hydrologic factors.

Woodhouse and Overpeck (1998) used tree-ring data combined with additional paleo-techniques to reconstruct a climate record that extends back 2000 years. They noted that several authors have found a shift in drought regime around 800 or 700 years ago (Laird et al., 1996, Laird et al., 1998, LaMarche, 1974, Dean, 1994, Grissino-Mayer, 1996, Hughes and Graumlich 1996). Droughts prior to this time had greater intensity, duration, and frequency and could last decades, in contrast to droughts since that time which tend to be a decade or less in duration. The extended climate record confirms that climate fluctuations and influences have been relatively typical or consistent since the shift in drought regime approximately 700 to 800 years ago.

2.1.6 Conclusions from the Pre-Development Period

The morphology of the central Great Plains is dominated by climate factors in the Pre-Development period and is primarily a result of fluvial processes. The Platte River is a relatively young river originating in the Pleistocene approximately 40,000 to 120,000 years ago. The river can be divided into five reaches based on geologic conditions, and three of the reaches subdivide the central Platte River. The third reach of the central Platte River is relatively new, having been formed as recently as 10,000 years ago. Due to geologic differences, the three reaches may exhibit some variation in response to changes in channel conditions.

Although the Platte River has exhibited multiple cycles of aggradation, degradation and stability since its origin in the Pleistocene, the average rates of channel incision or aggradation have been relatively small under the influence of climate. The largest average rate of incision at the North Platte site was 0.126 inches per year. In most cases, the evolution of the central Platte River in the Pre-Development period appears relatively slow, with mostly minor changes to basin structure.

At the conclusion of the Pre-Development period, the Platte River is in a cycle of aggradation that is estimated to have begun in the seventeenth century. Under the conditions present at that time, incision of the channel bed may have been arrested by a coarser sand and gravel layer, the lower layer of the Grand Island formation. Climate fluctuations, the dominant influences in this period, have been consistent or typical since the thirteenth or fourteenth centuries, the last 500 to 600 years of the Pre-Development period.

2.2 THE NINETEENTH CENTURY

In general, anthropogenic factors appear to affect rivers only in very recent considerations of geologic time. An example of one of the earliest significant anthropogenic factors impacting rivers is the extensive system of levees constructed to contain the Yellow River in China at least 2600 years ago, and possibly as much as 4000 years ago (Greer, 1979, Simons & Senturck, 1992). Although a relatively small population can impose watershed impacts such as deforestation from fire, there is no evidence that societies inhabiting the Platte River Basin prior to the nineteenth century imposed significant and systematic impacts on the central Platte River.

Beginning with the nineteenth century, many rivers including the tributaries of the Missouri River in eastern Iowa (Bettis & Mandel, 2002) have experienced greater impacts from anthropogenic activities than from climate factors. Osterkamp (1987) points out:

> *All geomorphic features are products of a medley of stresses….The tenure of one set of processes may lead to the primacy of a succeeding set, a premise consistent with Morrison's erosion-deposition- stability model[EDS cycles] but one not totally climate-dependent.*

The one factor recognized as being the dominant influence on the geomorphology of the Platte River Basin since the Pleistocene, and prior to the nineteenth century, is climate. However, beginning in the nineteenth century there was a large increase in population in the Platte River basin. As Schumm (1973) amongst many has noted, "…man's influence [on major landscape changes] is substantial." Therefore both anthropogenic and climate factors need to be considered when analyzing changes to the Platte River since the nineteenth century, and these factors do not have an equal effect. The impacts on vegetation, sediment loads, and flow, from euro-settlement and climate in the nineteenth century, are presented in this section.

Although the Platte River's hydrologic and geomorphic parameters were not extensively measured and recorded prior to the 1900s, the written descriptions provided by hundreds of early travelers in the 1840s to 1860s, photographs beginning in the 1860s, and data collectors from the 1860s forward, help to define the channel from this period as summarized below. Data collection on rivers, including the Platte, improved greatly with the creation of the U. S. Geological Survey (USGS) in 1879.

2.2.1 The Onset of Euro-Settlement

The signing of the Louisiana Purchase by President Jefferson in 1803, caused an increase in travel up the Platte River by bands of explorers and fur trappers. The banks of the Platte River offered a direct and relatively easy route to the west. The Smith-Jackson-Sublette fur partnership in 1830 (Mattes, 1969) is credited with the first wagon train travel along the Platte River. Extensive wagon travel by emigrant parties along the popular Platte River Road continued from the 1840s through the 1860s, and did not greatly diminish until the completion of the trans-continental railroad in 1869. European settlement in the Platte River Basin and headwaters is estimated to have begun even prior to the time of the emigrant wagon trains in the late 1840s.

Based on water appropriations in the Platte River basin, Simons and Associates (2000) have compiled a table of canal construction dates. The onset of significant canal construction occurred along the South Platte River during the period 1851 to 1860; along the North Platte River in the period 1861 to 1870; and along the central Platte River in the period 1881 to 1890. In 1909, the first major reservoir was built in the Platte River basin, and major reservoir construction continued to the mid-1900s.

Prior to major river impacts resulting from european settlement, the main Platte River channel in central Nebraska was generally described by explorers, emigrants, and government land surveyors as wide and shallow. Large, wooded islands along the river were typically named by early explorers and settlers including Grand Island, Indian Island, and Willow Island. These large islands divided the river flow along some reaches of the river among two or more channels, giving those reaches of the river an anabranched or multi-channel character.

Early photographs (Figure 2.5) provide a visual description of the Platte River from 1866 and support written observations. Historic photographs of the Platte River along the Union Pacific Railroad from 1866 can be viewed at the following WEB links:

Figure 2.5 The following photograph of the Platte River, opposite Platte City (near present-day Cozad, NE), was taken by John Carbutt in October 1866. This photograph was obtained from the collection of the Union Pacific Railroad, "Union Pacific Railroad Excursion to the 100th Meridian." http://www.uprr.com/aboutup/photos/carbutt/jc211.shtml

http://www.uprr.com/aboutup/photos/carbutt/jc210.shtml
http://www.uprr.com/aboutup/photos/carbutt/jc212.shtml
http://www.uprr.com/aboutup/photos/carbutt/jc214.shtml
http://www.uprr.com/aboutup/photos/whjackson/187.shtml
http://www.uprr.com/aboutup/photos/steampassengeraction/jes1090.shtml

2.2.2 Narrative Descriptions of the Platte River

A comprehensive book by Mattes (1969), entitled "The Great Platte River Road," contains references to over 700 personal diary and journal accounts of pioneers migrating west along the Platte River from the 1840s through the 1860s. One account from James Evans in 1850 describes his first view of the Platte River (Mattes, 1969, page 162):

> *From the sandhills, it had the appearance of a great inland sea. It looked wider than the Mississippi and showed to much better advantage, there being no timber on the banks to check the scope of the human eye. Grand Island, which lays just opposite in the middle of the river is one hundred miles long, and has some cottonwood trees upon it. There is no tree timber here growing upon the margin of the river, not even a willow switch. There are, however, some timber and brush growing upon the various small islands in the river which can be obtained by wading the rapid sloughs two or three hundred yards across. My first impression on beholding Platte River was, that as it looked so wide and so muddy, and rolled along within three feet of the top of the bank with such majesty that it was unusually swollen and perfectly impassable. Judge my surprise when I learned that it was only three or four feet deep.*

Rufas Sage wrote (Mattes, 1969, page 163) that "*The valley of the Platte is six or seven miles wide, and the river itself between one and two miles from bank to bank.*" In 1866, Julis Birge complained that "*it could not be ferried for lack of water and it could not be bridged for lack of timber*," (Mattes, 1969, page 240). As part of the Utah Expedition from 1857 to 1858, Capt. Gove (Mattes, 1969, page 240) found that the Platte River width varied from 700 yards (2,100 feet) to two miles. When Richard Hickman first saw the Platte River in flood stage in 1852 (Mattes, 1969, page 163), he remarked that it was so large "*it had the appearance of being navigable for the largest size steamboats.*"

<u>2.2.2.1 River Islands and Sandbars</u>

According to travelers' journals, numerous small wooded islands dotted the wide river channels, but the area of those islands is not precisely known (Kellogg 1905, Slichter and Wolff 1906, Currier and Stubbendieck 1985, Johnson and Boettcher 2000). Johnson and Boettcher (2000) estimated that the wooded islands covered 10 percent of the total channel area with significant potential variability in vegetated area depending on seasonal and annual hydrologic variations. Rufas Sage saw the Platte River during low flow in 1841 and wrote that *"Its waters are very shallow, and are scattered over their broad bed in almost innumerable channels, nearly obscured by the naked sand-bars that bechequer[3] its entire course through the grand prairie*" (Mattes, 1969, page 163). In 1849, Charles Kirkpatrick writes that "*The beauty of the Platte consists in the number and variety of the islands.*" Mattes (1969, page 241) cites Perkins, an emigrant on an 1849 wagon train:

[3]Be- used as a prefix is defined as "completely, thoroughly, excessively" or "on, around, over". Chequer is chiefly a British variation of the word checker. The word "bechequer" implies that numerous sandbars were distributed in a checker pattern over the channel bed.

Its appearance was not so much that of the dense, tangled timber belt of today, but more that of little islands, singly and in clusters, in a watery expanse. E. D. Perkins counted "nearly 30" from one vantage point.

2.2.2.2 Vegetation on Islands and Outer River Banks

The extent of pre-development vegetation along the Platte River is the subject of debate (Johnson and Boettcher 2000, page 43):

One view suggests that the Platte River was a relatively featureless prairie river comprised of water, sand, and grassland with few or no trees, while the other describes a river corridor composed of wooded islands and sparsely-wooded banks traversing a prairie landscape. The unwooded prairie river description has been adopted by many recent authors (e.g., Sidle 1989; Gruchow 1989; Sidle et al. 1989; Winckler 1989; Zietwitz et al. 1992; Wilson et al. 1993; Weidensaul 1999). However, the evidence reviewed here suggests that the alternate view is more accurate.

The main part of the debate is the extent of the woodland occurring on islands located between the outer banks of the river. Later USGS maps from the turn of the century (Figure 2.6 through 2.11) demonstrate there were many large islands in the downstream portion of the central Platte River and few large islands in the upstream portion. The presence of large islands in the downstream reach is considered to be due in part to the geologic history of the river. The reach between Kearney, Nebraska and Grand Island, Nebraska is a more recent alignment with an approximate age of less than 10,000 years, in contrast to 10,000 to 30,000 years (Bentall, 1982) for the upstream reach between North Platte, Nebraska and Kearney, Nebraska (Section 2.1.3). Johnson and Boettcher (2000, page 62) estimated the extent of the wooded islands:

Johnson (1994) re-surveyed an upper reach of the Platte River [Range 28 West] and estimated that a minimum of 10% of the river's width on the original plat maps was occupied by wooded islands. This proportion probably increased in the downstream direction, particularly within the approximately 50 mile reach between the cities of Grand Island and Kearney ('Thousand Islands' area) which contained a marked number of islands and trees.

Johnson and Boettcher (2000) provide evidence from historical notes and letters that the pre-settlement Platte River supported a self-sustaining riparian forest near Grand Island and that woodland was extensive along river islands.

It is likely that the riparian forests referred to in the historical notes used by Johnson and Boettcher are on stable vegetated islands, primarily near Grand Island. One quote specifically mentions the margins of the river, and other quotes do not specify that wooded areas are within the active channel. Photos of river locations upstream of Grand Island, such as Figure 2.5, do not appear to support a description of wooded islands and banks.

Historical accounts from pioneer diaries and journals of the 1840 to 1860 period (Mattes, 1969), which are primarily representative of the popular Platte River Road on the south bank of the

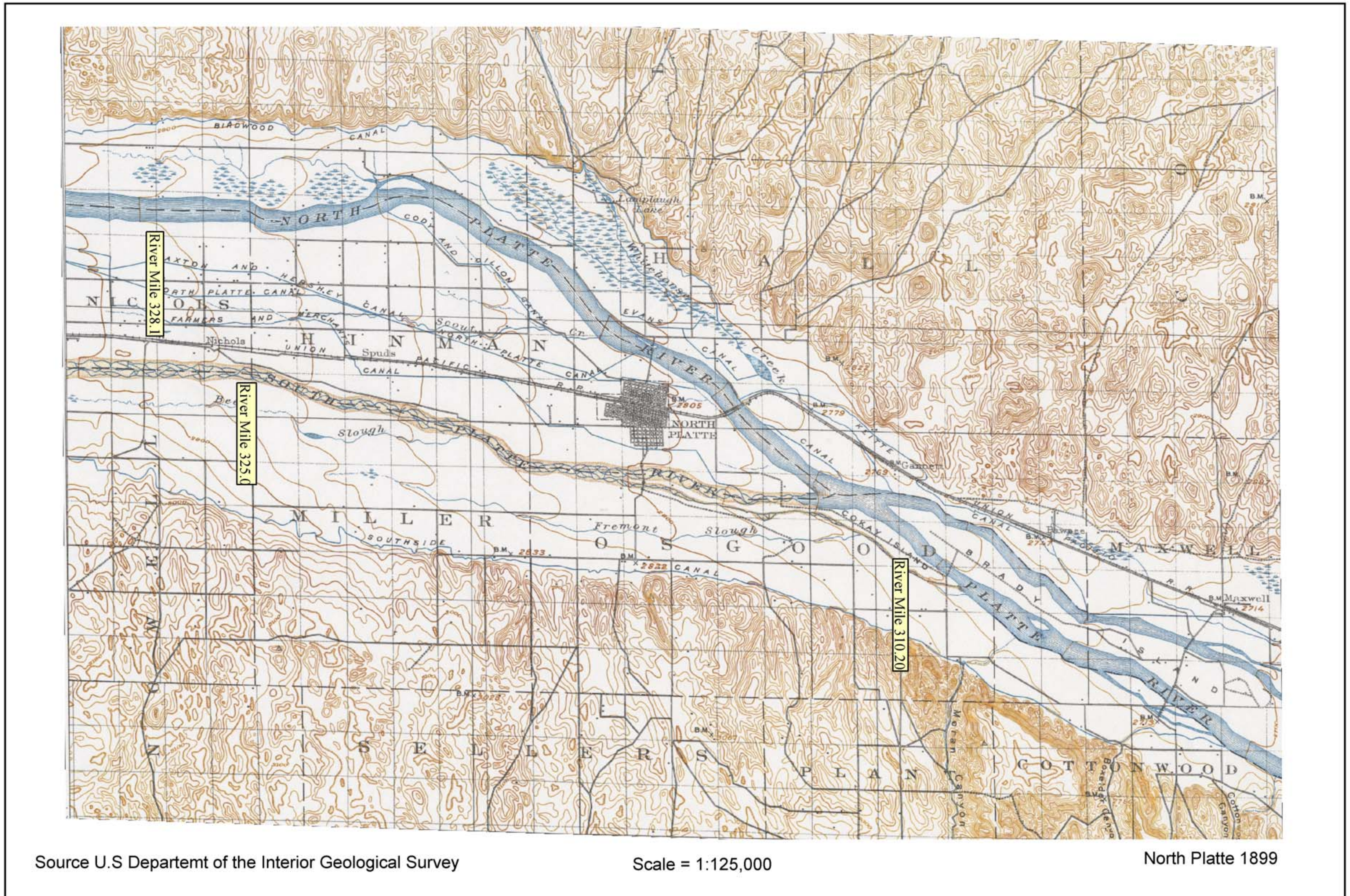
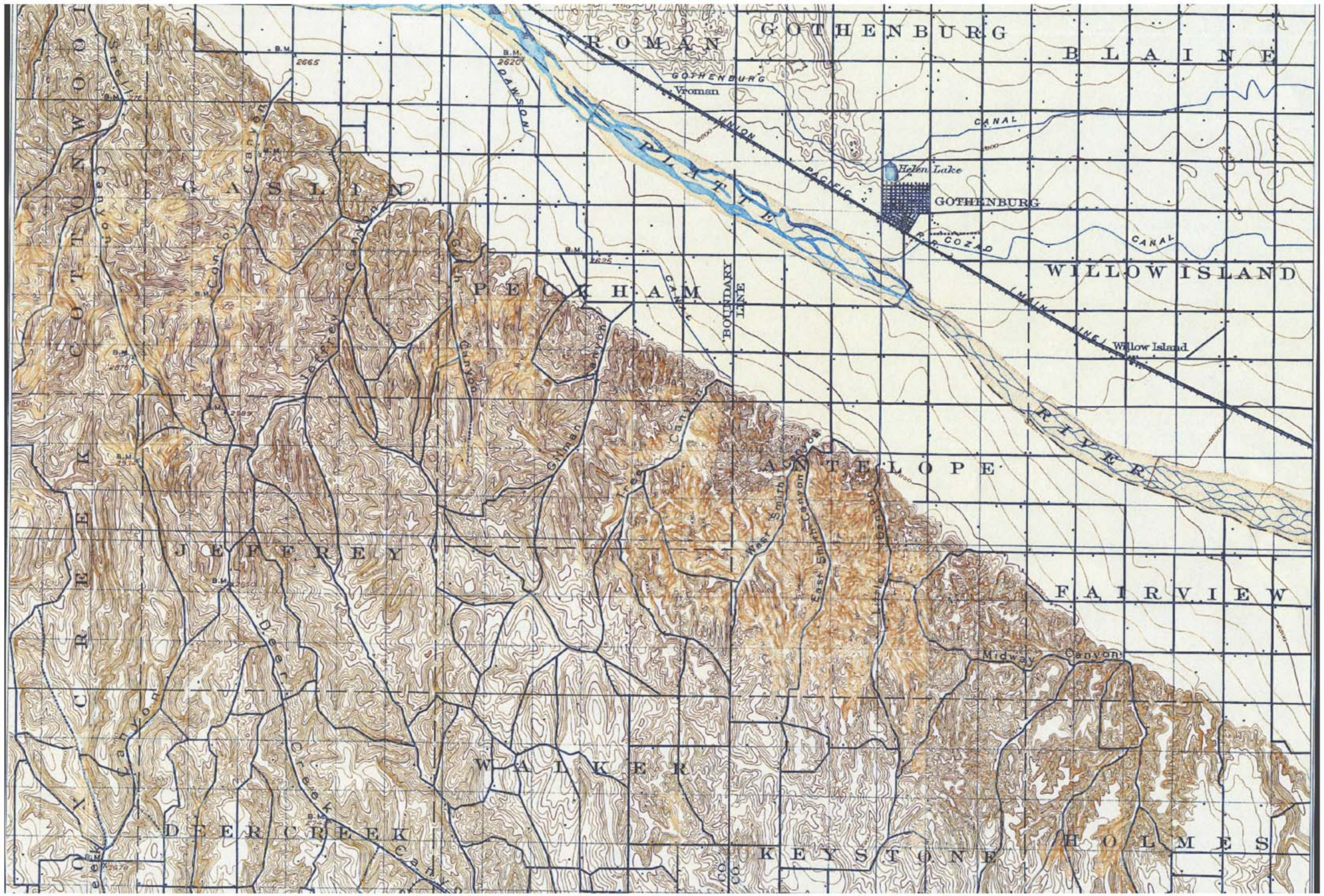


Figure 2.6 Historic USGS Quad Map – North Platte



Source U.S Departemt of the Interior Geological Survey

Scale = 1:125,000

Gothenburg 1902

Figure 2.7 Historic USGS Quad Map – Gothenburg

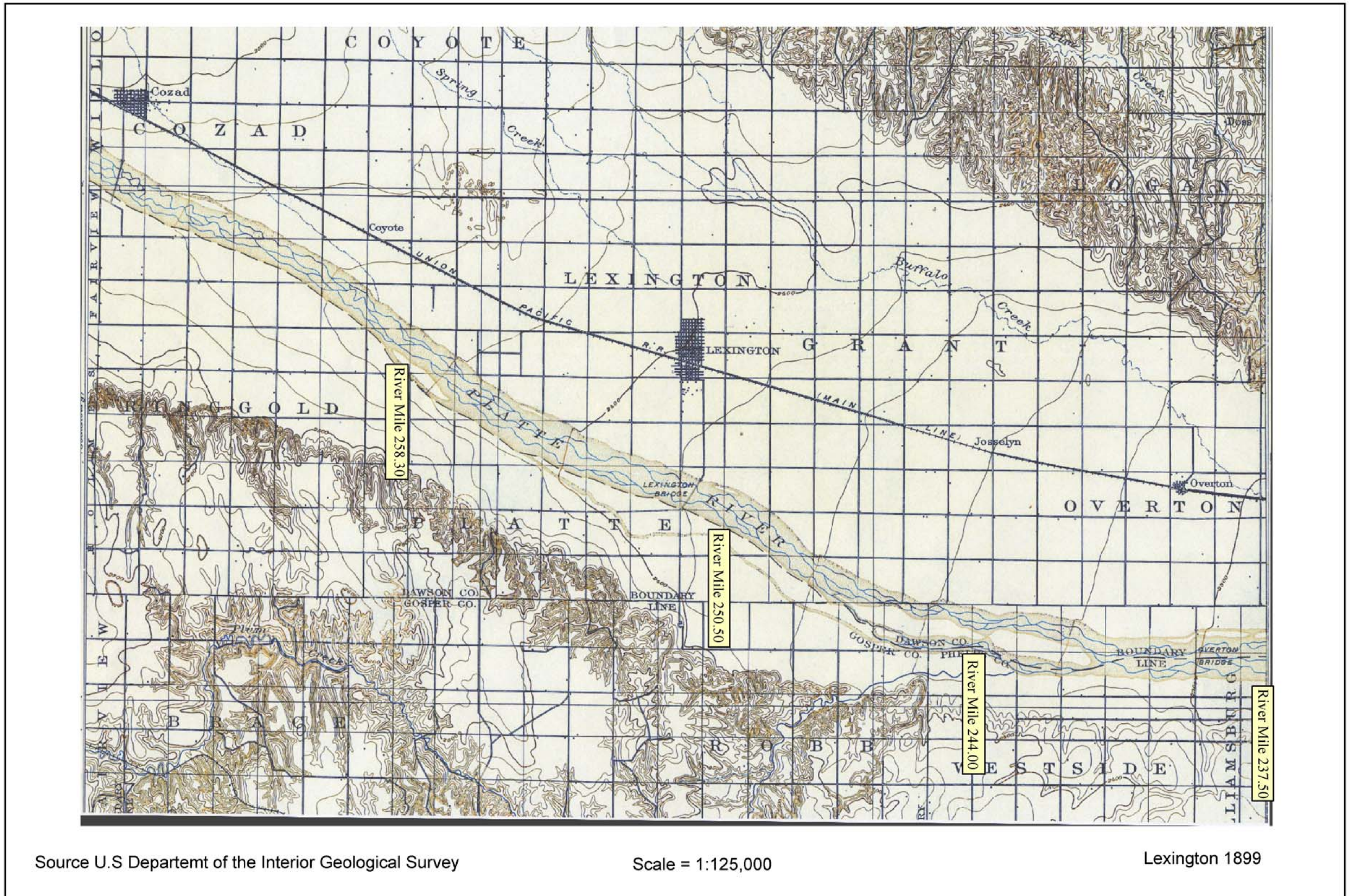


Figure 2.8 Historic USGS Quad Map – Lexington

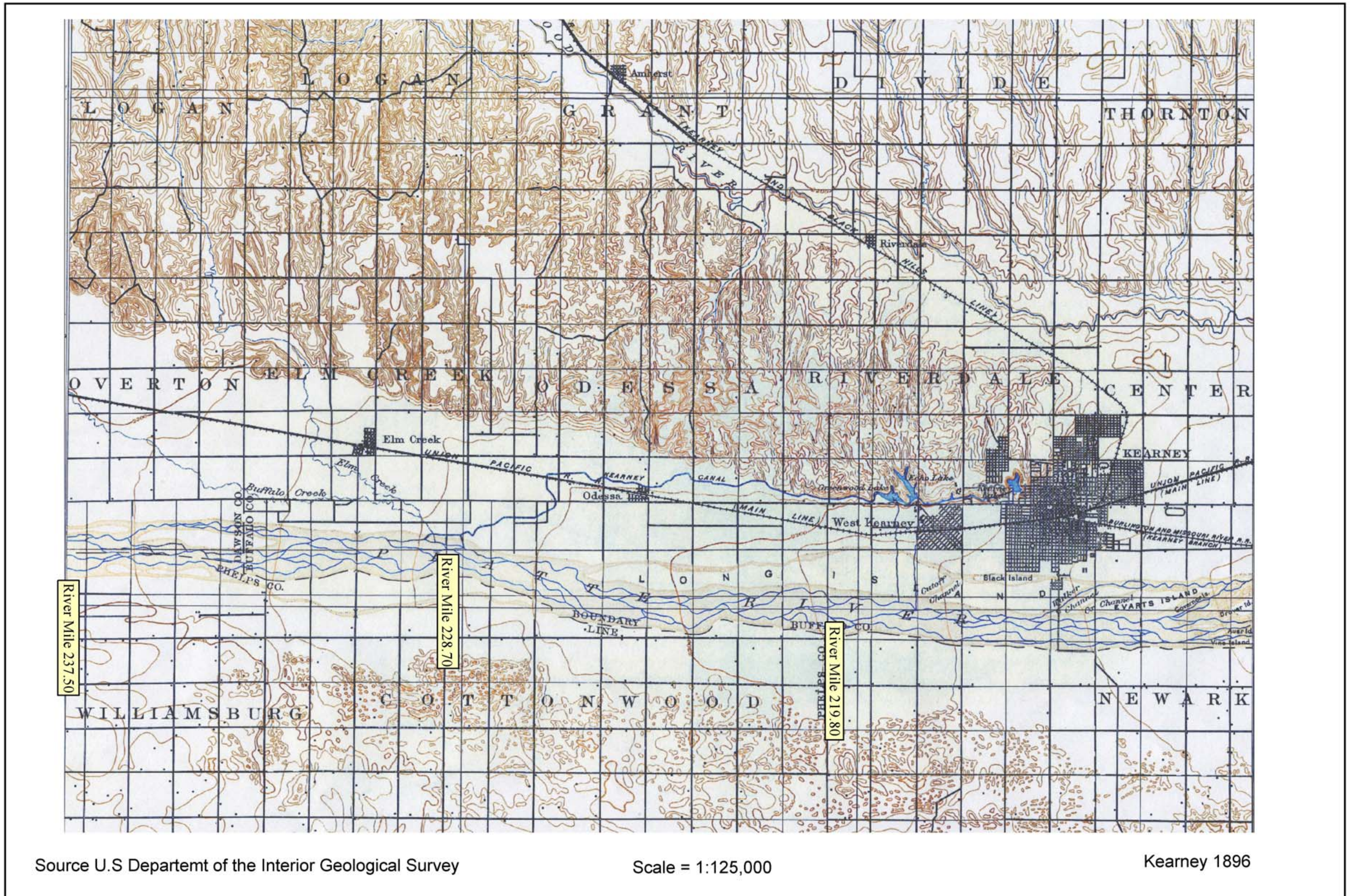
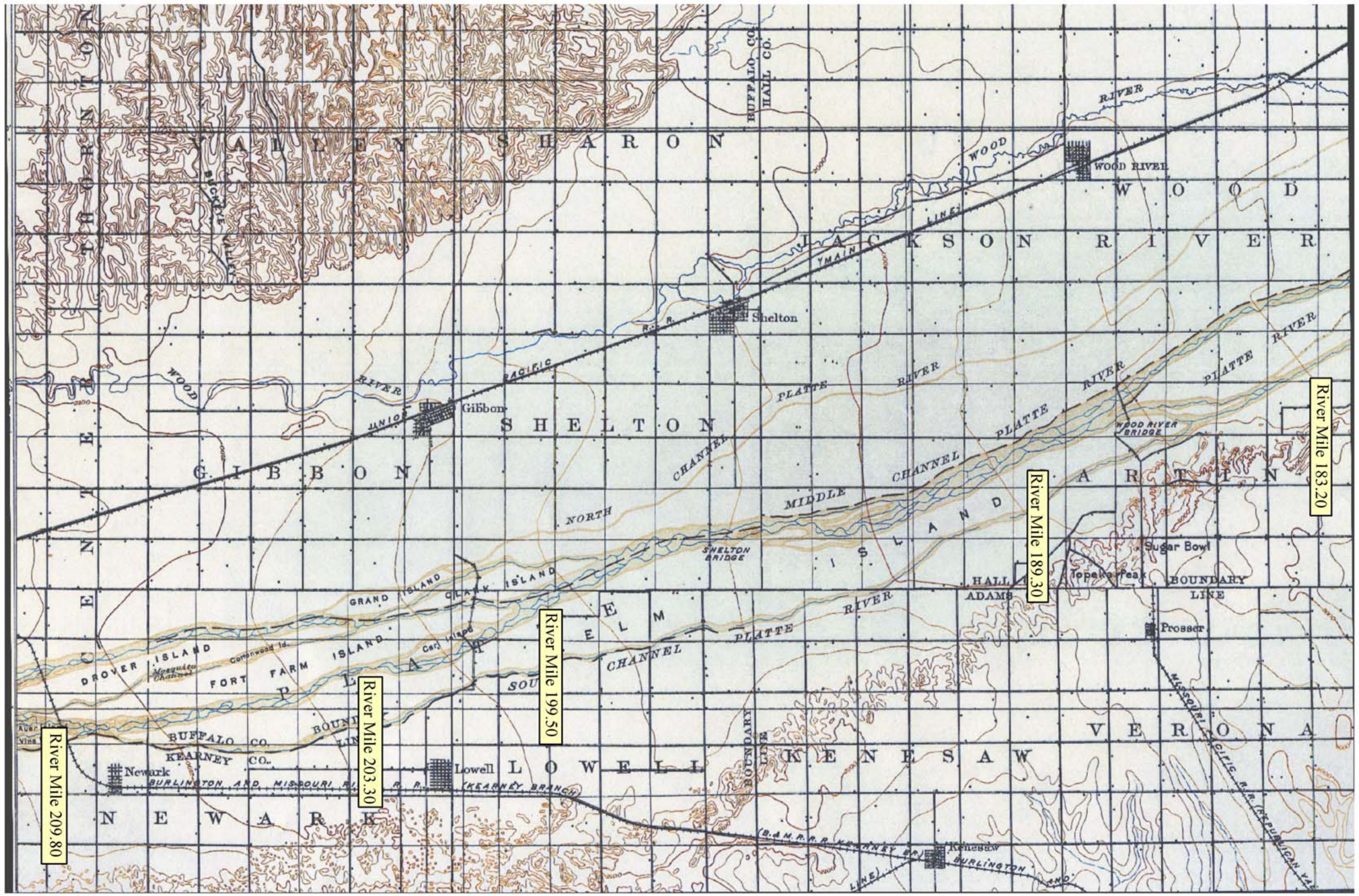


Figure 2.9 Historic USGS Quad Map – Kearney



Source U.S Departemt of the Interior Geological Survey

Scale = 1:125,000

Wood River 1900

Figure 2.10 Historic USGS Quad Map – Wood River

Platte from Kearney west, indicate that trees were scarce along the outer banks of the Platte River, but do acknowledge the presence of wooded islands. The extent of these wooded islands is not precisely known, but the diary and journal accounts from the first pioneers describe a wide, shallow braided river channel with numerous bare sandbars and small wooded islands, singly and in clusters, in an otherwise watery expanse during floods.

The lack of wooded vegetation along the banks has been postulated to be a result of trampling by vast herds of native buffalo (America bison), deforestation by the advance of emigrants and railroads, or the occurrence of prairie fires. Johnson and Boettcher (1999) state that a great degree of deforestation occurred prior to the construction of dams, largely as a result of direct human clearing of the forests. A quote from the General Land Office surveys in 1866 refers to the Grand Island area. "*The margin of the streams or channels of the Platte has been quite well timbered with cottonwood and elm but it has been nearly all cut down and carried away leaving only scattered timber*." Mattes (1969, page 241) wrote:

> "*Here was a river without trees on its banks because of frequent prairie fires took out the seedlings. But these fires could not ravage the islands, so timber — mainly willow, cottonwood, and poplar — grew there freely*."

The relatively recent growth of trees along the Platte River may represent a secondary regrowth of forests that occurs naturally on river islands, and possibly on outer banks, but comparisons of historic maps and aerial photographs indicate that vegetation has notably expanded into areas of formerly active river channel (Section 4.2, Vegetation and Channel Change).

2.2.3 Watershed Impacts

At the start of the nineteenth century, the aggradational trend in sediment transport (Lugn & Wenzel, 1938, Wenzel, et al., 1946) due to climate factors continues from the pre-development period. The assumption is that the river is moving a large volume of sediment through the system due to its high spring flows, relatively steep gradient, and straight alignment. It can be speculated that in the nineteenth century, anthropogenic factors in addition to climate have caused some increase in the sediment load of the Platte River basin.

Watershed activities on the tributaries and mainstem of the Platte River may have had an impact on the central Platte River by increasing the sediment load transported to the mainstem. It is unknown how much material was generated by beaver trapping, farming, mining and timber harvest in the nineteenth century. There is also a question of what portion of sediment from tributaries was transported by flows almost 300 miles to impact the central Platte River, and what portion of material remains stored in the upper watershed. However, the activities of beaver trapping, farming by euro-settlers, mining, and timber harvest, which began in the nineteenth century, mark the start of known anthropogenic impacts on the watershed and tributaries of the Platte River system.

2.2.3.1 Beaver Trapping

Large-scale organized fur-trading began in Colorado in 1815, and William Ashley led a party of trappers through the Platte River Basin in 1824-25. Extensive harvesting of beaver by fur trappers continued until the early or late 1840s when trappers began to leave the South Platte Basin (Wohl, 2001). Wohl comments that later travelers to the region seldom mention beaver in the later half of the nineteenth century. Estimates of the beaver population in western North America, prior to European settlement are 40- 60 million, while the current estimate of the beaver population has come up to 6 to 12 million (Naiman, et al., 1986, Naiman, et al., 1988).

The decimation of the beaver would impact the Platte River Basin stream morphology through the elimination of beaver dams, although the extent of the impact is unknown. Beaver dams serve to reduce stream energy, pond water leading to vegetation diversity and expansion, and at least temporarily trap sediment in the upper watershed. Sediment loads in the tributaries could be expected to increase due to a reduction in the beaver population (Olson and Hubert, 1994, Parker, 1986, Brayton, 1984, Maret, et. al, 1987, Parker, 1991). The magnitude of this increase in sediment is unknown, assumed to be a small increase in tributary streams, and assumed to be an even smaller impact to the central Platte River.

2.2.3.2 Farming

Farming was the primary occupation of many settlers in the nineteenth century. Table 2.2 contains crop harvest statistics for Nebraska, Colorado and Wyoming for the first year they are available, and also for the last year of the nineteenth and twentieth centuries. In Nebraska, 131,000 acres were harvested in the year 1866; and by 1899, 12,123,000 acres of wheat, barley, corn, oats, and rye were harvested (http://www.nass.usda.gov:81/ipedb/).

The drainage area of the Platte River basin in Nebraska, upstream of Grand Island, is approximately 9 percent (http://www.waterdata.usgs.gov/nwis/sw) of the 76,872 square miles in Nebraska (http://www.fedstats.gov/qf/states/31000.html). Using 9 percent of the state total, an estimate for acres of harvested land in the Platte River Basin is one million (9 percent of 12,123,000 acres).

The cultivation of one million acres of land in the Platte River basin can be expected to have some degree of impact on the watershed in the form of increased sediment to the river. The increases in sediment load, however, are not assumed to have been large due to the high permeability of Platte River valley soils, the relatively low terrain slopes in Nebraska, and the narrow width of the basin along the central Platte River. Similarly, farming in Colorado and Wyoming could also be assumed to have raised sediment input to tributaries of the Platte River. However the number of harvested acres in Colorado and Wyoming is lower than in Nebraska, and prior to impacting the central Platte River, sediment would have to move a hundred miles or more downstream prior to the construction of major reservoirs in the twentieth century. Sediment impacts from farming in tributary areas of the Platte, and farming along the central Platte River, are unknown at this time but are not assumed to be large.

Table 2.2 Historical estimates of thousands of acres of crops harvested as reported by the

USDA- National Agricultural Statistics Service, http://www.nass.usda.gov:81/ipedb/											
State	**Nebraska**			**CO**				**WY**			
Year	**1866**	**1899**	**1999**	**1869**	**1879**	**1899**	**1999**	**1889**	**1890**	**1899**	**1999**
Total Acres Harvested (thousands)	**131**	**12123**	**18639**	**11**	**116**	**533**	**6552**	**17**	**23**	**51**	**1775**
Crop											
Wheat	43	2539	1700	11	65	295	2653		5	19	193
Barley		92	3		4	22	86			1	85
Corn,grain	72	7380	8300		23	93	1120	2	2	4	52
Corn,silage			230				100				31
Oats	15	1925	75		23	121	20	15	16	27	27
Proso Millet							240				
Rye	1	179	15		1	2	2				
Sorghum, grain			470				205				
Sorghum,silage			20				10				
Hay			3200				1520				1290
Soy Beans			4250								
Sunflower			97				265				
Flaxseed		8									
Potatoes			26				84				1
Beans, edible			187				145				39
Sugar beets			66				69				57
Vegetables							33				

2.2.3.3 Mining

Mining activities along the tributaries of the Platte River began in the South Platte Basin in 1859, and extended up into the North Platte Basin in Wyoming. To find gold flakes mixed in the sand and gravel at placer mines, individuals used gold pans or rocker boxes, while large, organized groups employed hydraulic mining techniques or, beginning in the twentieth century, floating dredges. Hydraulic mining activities utilized high pressure jets to remove entire reaches of river bed and banks, while dredges with buckets could turn over the river bed, banks, and portions of the flood plain. These techniques could completely rework the beds of streams and introduced large volumes of sediment to Platte River tributaries at the time of the mining operation. After the conclusion of mining, elevated sediment loads could also continue to be transported from these Platte River tributaries, until a new armor layer formed in the disturbed bed of the stream.

Mining activities also indirectly increased sediment loads with the destabilization of slopes through tailings piles, the increase in forest fires sometimes associated with charcoal production for smelting operations, and through timber harvesting for the mining population and mine construction. The denuded slopes around mining settlements in the nineteenth century, and the reworked channel beds with sediment deposits can be seen in old photos.

In addition to increases in sediment loads, stream flows were diverted through constructed ditches to operate hydraulic mining activities and to process the metal ores. The diversions reduced instream flows and disrupted river processes including sediment transport. Mining activities in the South Platte Basin were most widespread from the 1860s to the 1890s, but continued at some locations through the 1930s (Wohl, 2001).

The impact of mining activities on tributary streams of the Platte River in Colorado and Wyoming is still apparent. However the impact of excess sediment generated by these activities, on the central Platte River over one hundred miles downstream, is unknown.

2.2.3.4 Timber Harvest

The railroad construction boom also generated a large demand for timber, in addition to the timber demands for mining settlements and mining activities. By the 1930s, Lugn and Wenzel (1938) reported the central Platte River valley was serviced by the main line of the Union Pacific Railroad along the Platte River, and branch lines extending north; the main line of the Chicago, Burlington & Quincy Railroad from Chicago and Omaha to Denver on the Nebraska plain, and four branch lines; a branch of the Missouri Pacific Railroad; and the St. Joseph & Grand Island Railroad. The Union Pacific railroad was constructed through this region in 1865 to 1869. Johnson and Boettcher (1999) refer to deforestation related to railroad construction in the Grand Island area of the central Platte River.

The headwaters regions of the Platte were far from immune to the railroad boom and timber harvest. Railroads were constructed to service mining operations in the upper South Platte Basin and extensive timber harvesting occurred between 1859 and 1900 (Wohl, 2001). Similar conditions are assumed for the North Platte basin. Timber harvested for railroad ties was skidded then hauled out by ox and mule teams, transported by railroad or floated out on the rivers of the South Platte headwaters. Wohl (2001) provides the following numbers to portray the magnitude of the timber harvests. In support of construction of the Union Pacific railroad line between Cheyenne and Denver, in 1868, contractors delivered 1,200 ties per day. In the following winter more than 200,000 ties were floated down the Poudre River. From 1870 to 1880 millions of ties were cut from the foothills of the Cache la Poudre basin, and harvests also occurred in the Big Thompson, St. Vrain, Boulder, and South Boulder drainages. Wohl (2001) estimates the timber harvests between 1880 and 1900 were even larger than in the first 20 years.

Studies from the Pacific Northwest indicate timber harvests increase erosion of the lumbered hillslopes and increase sediment loads to the streams (Johnson and Beschta, 1980, Megahan and Kidd, 1972, Gray and Megahan, 1981). In these studies a large portion of the sediment transported in runoff originates from the timber access roads or road-related activities. However, due to differences in soils and timber practices, the volume of sediment generated by lumbering activities in the headwater regions of the Platte River Basin in the nineteenth century was likely dissimilar to the results posted by these researchers.

Sediment inputs from timber harvest were also created by the erosive action on stream banks of large numbers of logs floated down relatively small tributaries. Wohl (2001) notes scarring and changes to stream section can still be noted today. Although the timber harvests in the Platte River Basin probably caused increases in sediment to tributary streams at the time of the harvest, the duration of these sediment impacts are estimated on a decadal rather than a century time scale and the volume of increase to the central Platte River is not known.

<u>2.2.3.5 Timing of Human Induced Sediment Impacts</u>
Any or all of these watershed activities: beaver trapping, farming, mining, and timber harvest, may have increased sediment loads to the central Platte River. The potential increase in sediment load in the Platte River headwaters is unknown, and the potential increase in sediment reaching the central Platte River from the headwaters is unknown, but the periods of impact can be approximated. Because sediment-trapping beaver dams in a low flow period can outlast the demise of the beaver population, sediment impacts from the decimation of the beaver population might be expected later in the 1850s as higher flow events return. Extensive mining, farming, and timber harvesting were just beginning in the 1860s but their sediment impacts could be expected by the end of that decade and would logically increase into the 1890s.

As discussed in the Geology Appendix B., the transport of aggraded material in a larger river system may occur in cycles with storage occurring first in the upper watershed, before activated by thresholds to move down to the mainstem river. Whether the excess sediment from anthropogenic activities in the Rocky Mountain headwaters actually reached the central Platte prior to trapping in large constructed reservoirs, or even trapping in the prolific smaller irrigation reservoirs along the Front Range, is unknown and speculative.

2.2.4 Canal Construction

The historical occurrence of water depletions from the Platte due to canal construction for irrigation can be estimated from data compiled by Simon's and Associates (2000) on the Platte River Basin. Although small ditches appeared in 1838 along the Cache la Poudre River in the South Platte Basin of Colorado, the first recorded appropriations occurred in 1859. From 1861 to 1930, an average of 269 canals were constructed or enlarged per decade in the South Platte basin. In 1876, water became over-appropriated for the first time along the Cache la Poudre, and over-appropriations at other areas in the South Platte Basin occurred between 1880 and 1885. Simons and Associates (2000) write about the South Platte Basin:

> *In order to increase irrigation water supplies, many dams were constructed beginning in the early 1880s. These dams did not, however, eliminate the problems of over-appropriation, and thus by 1911-1912 only canals with appropriation rights of 1882 or older received water during typical June flows.*

Water appropriation on the North Platte River did not begin until 1868, but over 1600 new or enlarged canals were constructed in the period from 1881 to 1890. Between 1871 and 1930, new canal construction and enlargement of existing systems averaged 820 systems per decade. The over-appropriation of water in the North Platte River Basin began to occur in the 1880s, on smaller tributaries (Simons and Associates, 2000).

The Kearney Canal, in 1882, became the first major canal construction project on the central Platte River in Nebraska. In Dawson County from 1894 to 1896 nine canals with a total length of 219 miles were constructed to irrigate 157,000 acres of land (Smith, 1897). Lugn and Wenzel

(1938) wrote that settlement in the central Platte River Basin occurred rapidly in the 1880s and drier periods in the early 1890s encouraged Nebraska farmers to construct irrigation canals.

Over-appropriation of water occurred for the first time on the South Platte River in the mid-1870s, while over-appropriation on the North Platte did not occur until the mid-1800s. Prior to the development of trans-basin diversions in the 1900s, the South Platte River is estimated to have contributed only 10 percent of the flows to the central Platte River (Randle and Samad, 2003). Thus, although the development of canals and the over-appropriation of water on the South Platte River occurred approximately a decade earlier than on the North Platte River, the impact on the central Platte River from South Platte flows would be less. By the time over-appropriations in the North Platte River, occurring during the summer irrigation season, are simultaneously combined with the occurrence of South Platte River over-appropriations, only fifteen years remain to the end of the nineteenth century. This allows a relatively short period for the occurrence of geomorphic change resulting from flow depletions by the end of the century.

Decreases in river flow because of irrigation diversion could slow the transport of sediment through the system, however the summer diversions are not estimated to have a large impact on sediment transport. The last decades of the nineteenth century pre-date major reservoir construction (Pathfinder Reservoir, 1909, Section 2.3.2) and high spring flows, in comparison to summer storms, would still transport the bulk of material moved annually through the system.

2.2.5 Climate in the Nineteenth Century

Based on paleo-techniques, primarily tree-ring analysis, a relative comparison of the climate for the nineteenth century and several previous centuries can be made. Tree-ring indices extend the period of instrument records for temperature measurements, the Palmer Drought Severity Index (PDSI), and for some hydrological records of streamflow. The PDSI is a drought model derived by Palmer (1965) computed from temperature and precipitation data to provide a measure of climatic stress on crops and water supplies. PDSI information can be excerpted from a study, Reconstruction of Past Drought across the coterminous United States from a Network of Climatically Sensitive Tree-Ring Data (1999), at web site, http/www.ngdc.noaa.gov/paleo/usclient2.html. The location of data grid points is shown in Figure 2.12 and the circled region in the figure is an example of areal coverage by each point. PDSI data from grid points 47, 48, 57, 58, 59, and 68 are averaged to represent the Platte River Basin in Figure 2.13.

In Figure 2.13, positive PDSI values indicate a wet period and negative values indicate a period of dry, with larger values indicating more extreme conditions. As can be seen from the average PDSI for the Platte River basin in Figure 2.13, the 1800s had more drought periods than either

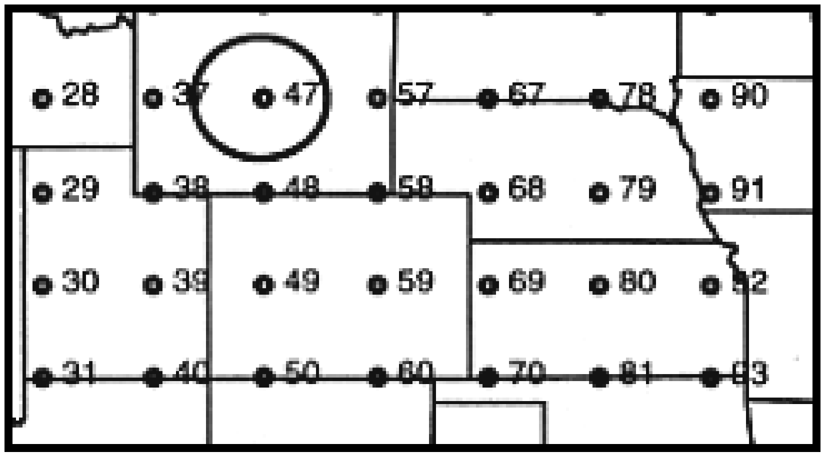


Figure 2.12 Grid points of Palmer drought severity index (PDSI) for Colorado, Wyoming and Nebraska, taken from Cook, et. al, (1999b).

the 1700s or the 1900s. A drier set of years occurred between 1815 and 1825, and the decade of the 1840s. The early 1860s contain a short dry period and the period around the 1870s contains a short but extreme dry period. The decade of the 1840s appears to be the longest and driest period for this 300 year record. Interestingly, the occurrence of this drought decade correlates to a lull in the beaver trapping industry in the South Platte Basin as noted by Wohl (2001).

> *These log or adobe structures were trading centers that took advantage of their proximity to the beaver-rich mountain rivers, as well as their location along the major north-south trading routes….Fort Lupton (1836-46), Fort St. Vrain (1837-46), Fort Vasquez (1837-42), and Fort Jackson (1842-43) were all located within 20 miles (30 km) of one another [Phillips, 1966]. Their proximity indicates the intensty of trapping in the 1830s and early 1840s, and their rapid and fairly synchronous demise signals the exhaustion of the resource. It is understandable that Fremont observed few beaver by the time he traveled through the region in 1843-44.*
>
> *However, the beavers were not completely eradicated and various historical accounts seem to disagree regarding how rapidly the animals began to recover [Wishart, 1979, Peterson, 1982, Watrous, 1972] At least one historian maintains that beaver were again numerous along the [South] Platte River by the late1840s.*
>
> *Fort St. Vrain reopened in 1850 but closed within two years. Yet Kit Carson, who had briefly trapped in North Park beginning in 1832, established several trapping posts on the headwaters of the Poudre River during the winter of 1849-50, about the time that trappers from the Hudson Bay Company were leaving the area because of a dearth of beaver.*

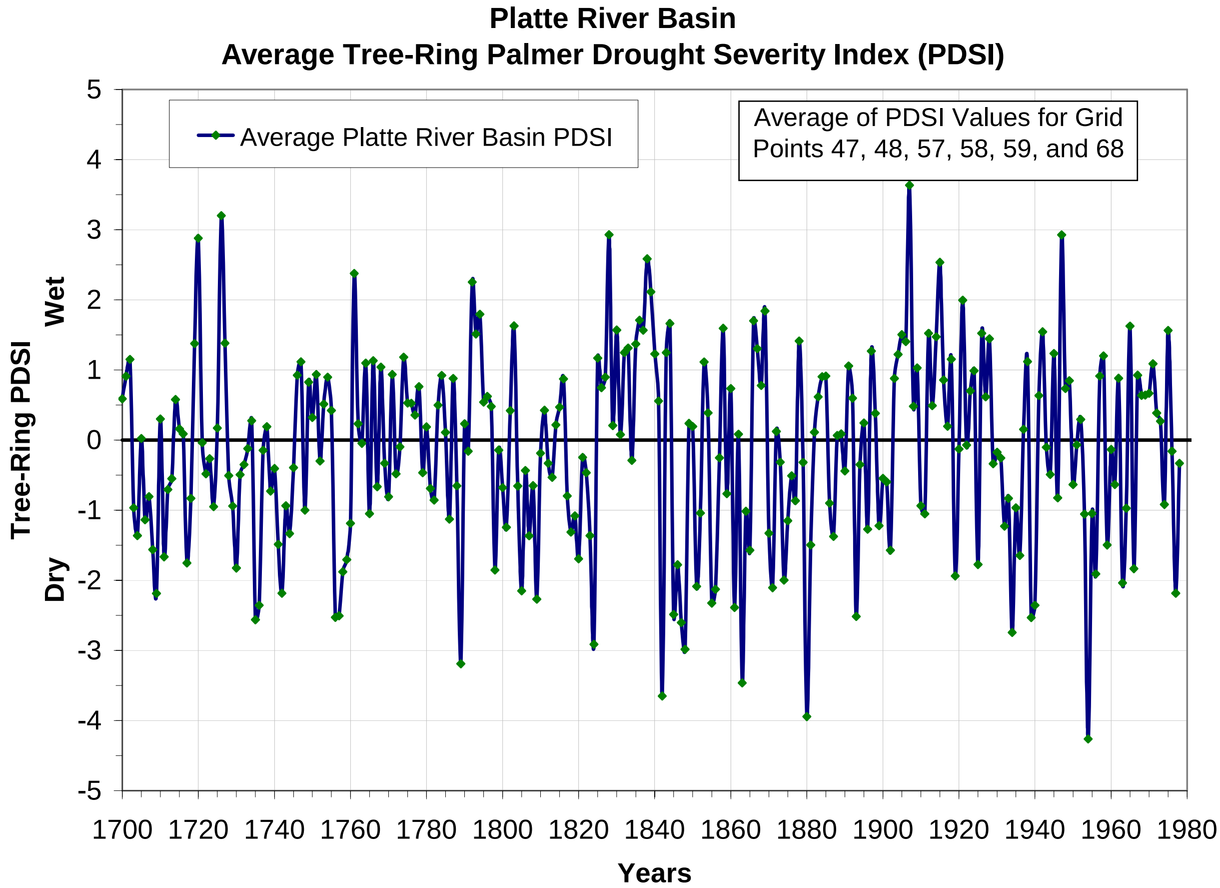


Figure 2.13 An average palmer drought severity index (PDSI) for the Platte River Basin based on tree-ring data (Cook, et al., 1996b). The PDSI value shown is the average for grid points 47, 48, 57, 58, 59 and 68 (Figure 2.12).

Woodhouse (2001b) uses reconstructed streamflows to describe dry periods for the Colorado Front Range. She focuses on tree-ring chronologies sensitive to winter and spring moisture conditions for the South Platte headwaters.

> *The prolonged period of low flow in the 1840s and into the early 1850s is especially notable, along with the two periods of low flow in the 1880s. …The five-year average extreme lowest flows occur almost exclusively in the 19th Century, and are concentrated around 1880, 1887, and the decade of the1840s.*

Mock studied precipitation records from meterorological stations established prior to the US Department of Agriculture in 1891. The records extend from the 1850s to 1890 and are not as reliable as modern weather data, but are studied for trends after careful screening (Mock, 1991). The instrumented data show that a widespread but mild drought occurred in eastern Wyoming, northeastern Colorado and central Nebraska during the early 1870s, in agreement with the PDSI reconstruction and tree-ring data that shows a series of negative PDSI values for this period.

Data from the early meteorological stations also indicate a mild but widespread drought year in 1890 (Mock, 1991).

Implications of the dry periods in the nineteenth century are not only the reduced flows in the Platte River Basin at these times, but there is also the possibility that sediment loads may increase. Increased sediment loads sometimes correlate to extended dry periods when there is more surface erosion due to increased mortality of the upland vegetation. The eroded material can be transported to the river through runoff, and through eolian transport of loess and fine sands which is more active in dry periods (Holliday, 1987). Although an increase in sediment input may occur during severe periods of drought, reduced flows during this period can also limit transport, promoting sediment storage for later high flows.

The drought period in the decade of the 1840s, and the years immediately following is a candidate period for increased sediment loads. Greater sediment could have been generated in runoff from overbank areas where vegetation mortality increased. However, although the headwaters of the North and South Platte Rivers are extensive, the central Platte River watershed is relatively narrow with the high land on the south side of the river draining primarily away from the Platte. The narrow watershed of the central Platte River would decrease the impact of sediment runoff from drought impacts.

In addition to sediment from overland runoff, eolian sources historically have deposited sediment in the central Platte River valley during dry periods. The finer eolian sands may have contributed to suspended sediment transport in the river, in contrast to bedload from overland runoff, during the 1840s. Finally there is the consideration that much of the central Platte River may have been, at least temporarily dry during this drought period, so the transport of overland and eolian sediment could have been delayed until higher flows in the next decade(s). Unfortunately, there is no sediment data from this period to confirm or refute this speculative assessment of increased sediment transport, or the timing of the increases.

2.2.6 Description of the Platte River at the Close of the Nineteenth Century

In 1901, the early Platte River and its two principal tributaries were described by Gannett in some detail in the USGS Water Supply and Irrigation Paper No. 44.

> *Platte River heads in Colorado in two branches, North and South Platte. The former has its source in North Park and the mountains adjacent and has a steep descent within the mountains, dropping to 6 or 7 feet per mile when it enters the plains. The South Platte heads in the mountains at the north end of South Park and enters the plains just above Denver. Within the mountains its slope is extremely steep and irregular, but upon reaching the plains it suddenly diminishes greatly, falling to 8 or 9 feet to the mile. These two branches meet at North Platte, and below their junction the Platte has an average fall of about 6 feet per mile, maintaining that slope with remarkable uniformity. The river is a peculiar one in the fact that it has a relatively steep slope and an extremely straight course, while at the same time it is building up its bed. This peculiarity is due to the fact that it is, taking the year as a whole, an overloaded stream. It is*

subject to great fluctuations in volume. In the springtime, when the mountain snows are melting, it is a river a mile in width, while at other times of the year it is almost or quite dry.

Gannett's 1901 paper includes data tables and a figure describing the profile of these rivers, which are shown in Figure 2.14. The slopes of the Platte River and the lower portion of the North Platte are remarkably constant, as Gannett indicated, and have a slope of 0.00126 between North Platte and Chapman, Nebraska, or 6.65 ft of fall per mile as described in Section 2.1.

Gannett's description implies the central Platte River at the end of the eighteenth century was dynamic, changing from year to year, and was aggrading. There are signs of infilled channels outside the present river boundaries on many aerial photographs and present-day U. S. Geological Survey topographic maps. Wenzel et al. (1946) and Lugn & Wenzel (1938) estimate the aggrading cycle had begun in the seventeenth century.

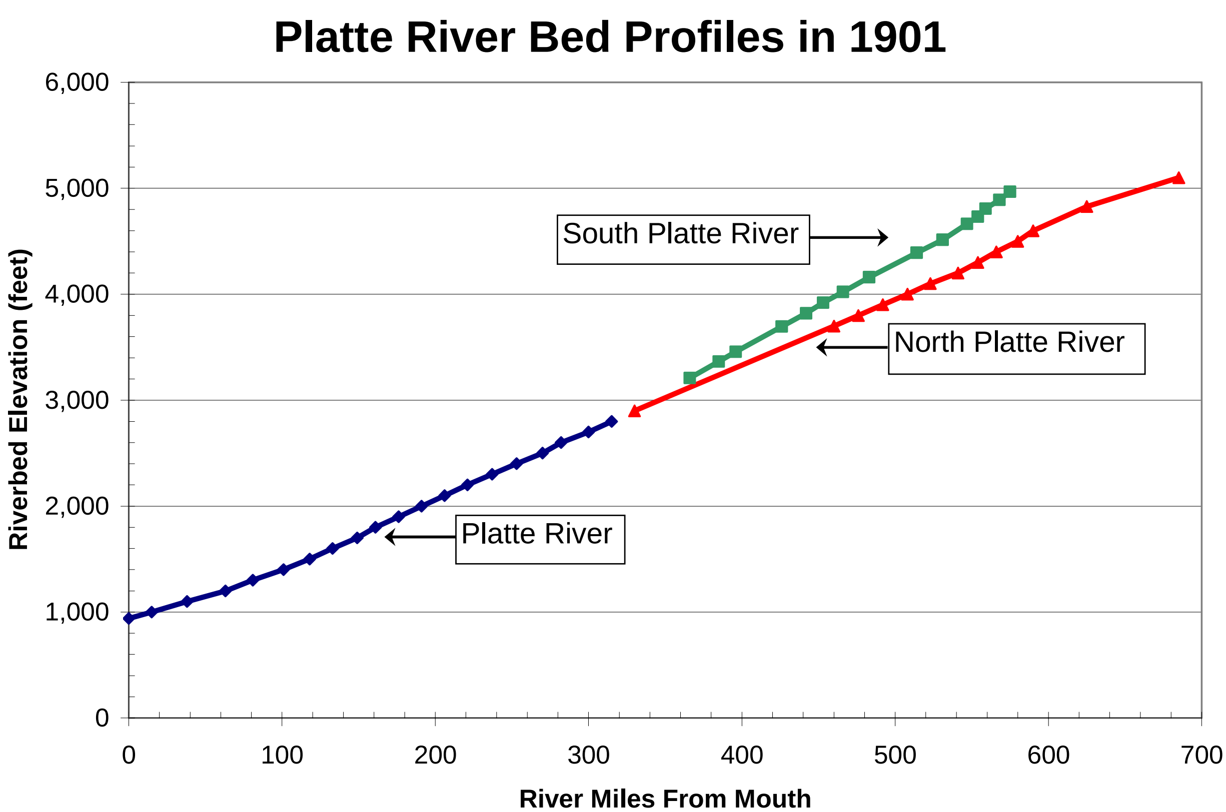


Figure 2.14 Longitudinal profile of the Platte River bed in 1901 (Gannetts Slope).

2.2.7 Conclusions for the Nineteenth Century

In the nineteenth century, climate factors continue, however the increased activities by man within the Platte River Basin are also beginning to have an impact on the river. The extent of woody vegetation on the outer banks, and the extent of woody vegetation on the western end of the central Platte River, is debated. But what can be determined from the narrative is that euro-settlement in the nineteenth century reduced woody vegetation, where it existed along the central Platte River.

It is also not determined here whether the central Platte River at the end of the century, has undergone channel changes from an increase in sediment loads. For the nineteenth century, the primary source of information on sediment load, similar to extent of woody vegetation, is the written narrative of travelers and there does not appear to be a distinction between the description of turbid waters of the 1830s, versus the description of turbid waters in the 1890s. At the start of the nineteenth century, the river was braided and aggrading, with some woody vegetation. At the end of that century, the river is still braided and aggrading, but possibly with an increase in sediment load and a decrease in wooded areas. Increases in sediment load at the end of the century may have resulted from mining and timber harvest primarily in the tributaries, and farming along the central Platte River. Decreases in wooded areas may have occurred along the eastern end of the central Platte River resulting from proximity to the heavily travelled Great Platte River Road, resulting from euro-settlement, and in support of railroad construction activities.

Radiocarbon dating of islands and deposition in the central Platte River basin, geologic field surveys of the entire basin, and the development of sediment budgets for the nineteenth century, could help to define to what extent mans activities and the effects of drought may have increased the sediment load of the central Platte River in the nineteenth century. However at this time, a discussion of changes in sediment load for this century can not be substantiated.

Between the beginning and the end of the nineteenth century, known changes to the Platte River channel can be summarized as narrative description of deforestation at specific areas along the central Platte River; possible increases in sediment load due to beaver trapping, farming, mining, timber harvesting and the 1840s drought; and the summer decreases of flow due to canal construction recorded by each state for water appropriations. References to significant changes to the channel shape or sediment load have not been noted in the narratives. The mid-1800s predate sediment load measurements and the lack of measured channel data, with the exception of the 1865 General Land Office (GLO) survey maps, make it difficult to detect changes to the channel that have occurred by the end of the nineteenth century. However, the close agreement between active channel widths measured from the 1865 GLO maps and the 1896 to 1902 US Geological Survey maps (Figure 2.6 to 2.11) imply that any changes to active channel width between these two dates were not largely apparent. Regardless, at the turn of the century, the USGS topographic maps (USGS 1896-1902) of Nebraska show that much of the central Platte River is a channel nearly a mile wide.

Despite possible changes to the channel in the nineteenth century from both climate factors and mans watershed impacts, data are collected and considered for the end of the nineteenth century simply because land and flow measurements first become available at this time. There is no intent to reference the late nineteenth century as a baseline or target period for current restoration efforts, but this period does provide an example of channel morphology under different conditions from the present. Despite the questions on changes to vegetation coverage and sediment load between the beginning and end of the nineteenth century, channel morphology at the end of the nineteenth century is useful for comparisons to a later period that has greater impacts from human activities. In the next section, which is a historical consideration of the twentieth century, the substantial development of infrastructure for flow regulation, flow bypass systems, transportation, and bank protection, is presented.

2.3 THE TWENTIETH CENTURY

In the twentieth century, the impact of climate factors on the morphology of the central Platte River is largely overshadowed by the impact of anthropogenic factors. The population of the Basin continues to increase rapidly and the comparatively mild anthropogenic impacts of land use in the watershed continue into the nineteenth century, but are exceeded by far more severe impacts of extensive infrastructure in the twentieth century. In the time span of 100 years, anthropogenic activities sizably alter flows and sediment loads in the central Platte River. The anthropogenic impacts of large constructed reservoirs, canals, transportation structures and diversion structures, reroute the river system and alter the characteristics that defined the central Platte River in the previous centuries. Historical development in the twentieth century is described in this section; changes to flow, sediment and basin structure for the twentieth century are described in Chapter 3; and the impacts to the river as a result of flow, sediment, and basin structure changes, primarily in the twentieth century, are described in Chapter 4.

2.3.1 The Growth of Municipal and Irrigation Water Requirements

The surge of population in this semiarid region, which began with the influx of European settlers in the Platte River basin, placed new and large demands on the central Platte River flows. Based on the US census (Gibson & Jung, 2002), in the twentieth century the state of Nebraska grew from 1,066,300 (1900) to 1,578,385 (1990), the state of Wyoming went from 9,118 (1900) to 453,588 (1990), and the state of Colorado grew from 539,700 (1900) to 3,294,394 (1990). The large municipal population of the Front Range of Colorado, located primarily in the South Platte basin, relies heavily on surface waters. The smaller municipal population of Nebraska, in the central Platte River basin, relies primarily on groundwater from the High Plains aquifer. Due to limitations on Platte River flows, and the relatively accessible and abundant High Plains aquifer, the use of groundwater for irrigation in Nebraska increased substantially in the twentieth century. Water requirements associated with the growth of industry in the Platte River Basin is not addressed here, but presented briefly in Section 3.1.4.

2.3.1.1 Surface Water Use

Acres of harvested crops expand in Nebraska from 12.1 million in 1899 to 18.6 million by 1999, and the number of harvested acres for the states of Colorado and Wyoming combined, increase from 0.6 million to 8.3 million (Table 2.2). The Platte River Basin is primarily agrarian, however several larger cities can be found within the South Platte River Basin including Denver, Colorado, Cheyenne, Wyoming and the Front Range cities that lie between the two. Settlement of these cities largely began in the last half of the 1800s, with major growth of both population and associated water supply needs occurring in the 1900s.

In the South Platte basin, water sources for the larger municipalities are surface waters from the South Platte River and its tributaries, and also from trans-basin diversions from the Colorado River Basin. The Denver Water utility serves a population of 1,081,000 (www.water.denver.co.gov) with 129,000 acre-ft/yr of surface water originating primarily in the South Platte basin, and 105,000 acre-ft/yr from trans-basin diversions. This number does not include Denver metropolitan areas such as Arvada, which operate independent water supplies.

The cities of Boulder, Longmont, Loveland, Fort Collins, and Greeley in Colorado, and the city of Cheyenne, Wyoming, are also located in the South Platte basin, and rely on surface water for municipal water needs. The combined population served by the municipal water supplies of these cities is 560,000, as reported by the U.S. Environmental Protection Agency, Local Drinking Water Information (www.epa.gov/safewater/dwinfo.htm). Approximately 85% of this water comes from the South Platte Basin with the remaining 15% supplied by trans-basin diversions. At an average use of 216 gallons per day per person (www.water.denver.co.gov), the current total of South Platte River water for these cities is approximately 115,000 acre-feet per year.

Despite the semiarid climate, land use in the Platte River Basin is primarily agrarian. Irrigation along the central Platte River began to expand in the drier years of the 1890s. By the late 1920s, agriculture in the central Platte River Basin was experiencing the impacts of water shortages, aggravated by the over-appropriation of water occurring upstream on the North Platte and South Platte Rivers (Simons & Associates, 2000). The solution to this problem of water shortages in the early decades of the twentieth century was the construction of large upstream reservoirs, and the construction of large irrigation diversion systems soon followed.

2.3.1.2 Groundwater Impacts

Smaller cities and towns in Nebraska adjacent to the Platte River have also grown in size in the late 1800s and the 1900s. These cities impact groundwater since they rely, with few exceptions, on wells to supply municipal needs. As reported by the U.S. Environmental Protection Agency, Local Drinking Water Information (www.epa.gov/safewater/dwinfo.htm), the cities of North Platte, Gothenburg, Cozad, Lexington, Overton, Elm Creek, Kearney, Gibbon, Shelton, Wood River and Grand Island, all in Nebraska, have a combined population served by their individual municipal water supplies of 88,000. At an average use of 220 gallons per day per person (www.cityofkearney.org/index.asp?SID=510), the estimated use of groundwater is 21,700 acre-feet per year for the small cities proximal to the Platte River and upstream of Grand Island.

Within a couple of decades after the start of canal construction, farmers in the central Platte River valley, noting the limitation on Platte River flows in the early twentieth century, began drilling groundwater wells. The advent of pumping engines spurred this effort and Table 2.3 shows the historical growth in numbers of irrigation wells in the early decades of the twentieth century. In the 1930 U.S. census, approximately 75 percent of all irrigation wells in Nebraska were located in the Platte River Valley between Gothenburg and Chapman.

Table 2.3 Irrigation wells in the Platte Valley (taken from Lugn & Wenzil, 1938)							
Year	Irrigation Wells	Year	Irrigation Wells	Year	Irrigation Wells	Year	Irrigation Wells
1893	1	1916	7	1923	10	1930	140
1910	2	1917	14	1924	18	1931*	65
1911	3	1918	21	1925	26		
1912	24	1919	9	1926	47	**Total**	**772**
1913	17	1920	16	1927	74		
1914	21	1921	14	1928	73	*Incomplete number from year of census.	
1915	14	1922	10	1929	146		

For comparison to Table 2.3, the Nebraska Department of Natural Resources had a registered total of 25,660 groundwater wells for commercial, domestic, irrigation, monitoring and other uses in the central Platte Valley by March 30, 2004 (http://nrcnt3.dnr.state.ne.us/wellssql/Summary.asp?type=nrd). Figure 2.15 illustrates the location of groundwater wells by points, in the state of Nebraska, in the year 1993.

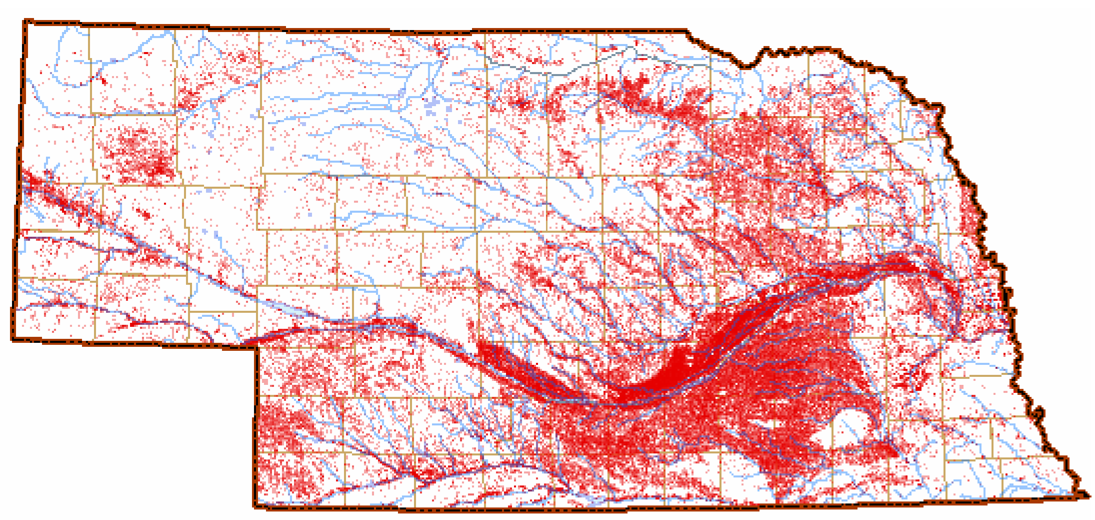


Figure 2.15 Nebraska Registered Groundwater Wells, 1994 (Conservation and Survey Division, University of Nebraska-Lincoln, 1994). Source: Nebraska Department of Natural Resources, September 1993.

The development of wells in the Platte River Basin over the twentieth century does not directly impact flows in the river, but fluctuations in the water table have an indirect result on surface flows (Sanders, 2001). Excessive pumping can lower the general water table elevation, while increased seepage can raise the water table. Changes to the water table in 1995, compared to pre-development water table levels, are shown in Figure 2.16. In the region of the central Platte River, groundwater flow is generally to the southeast. In the region south of the Platte River and west of Kearney, Nebraska, where groundwater seeps in a direction parallel to the Platte River, a rise in the water table can be seen. To the east of Kearney, Nebraska, where seepage from the Platte River moves away from the river to the southeast, there has been a decline in the groundwater table.

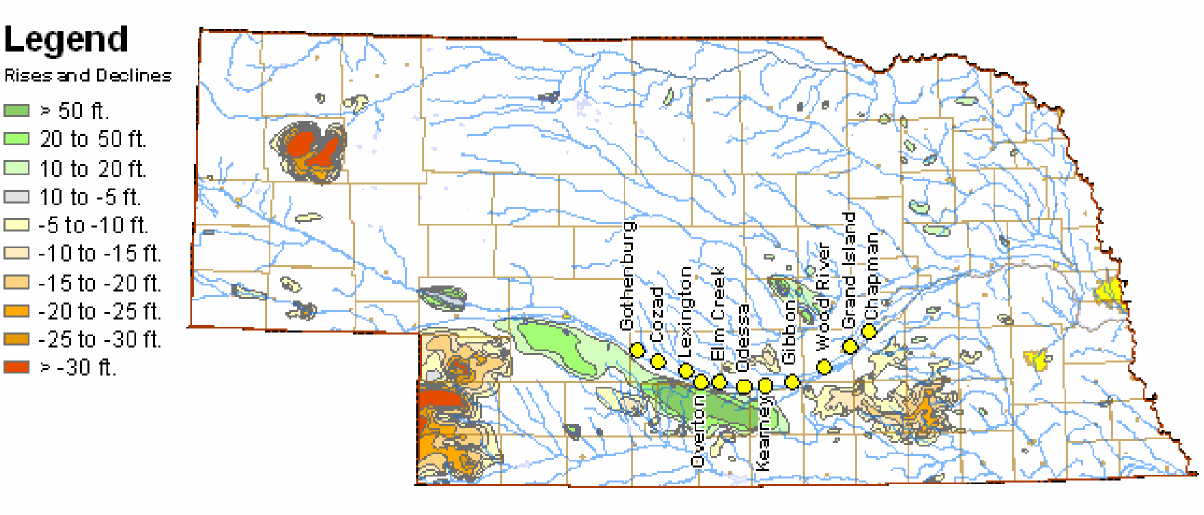


Figure 2.16 Areas of groundwater level change in the High Plains Aquifer, predevelopment to spring 1996 (Conservation and Survey Division, University of Nebraska-Lincoln, 1996b).

In the fall of the drought year 2003, the river bed in the reach from Grand Island, Nebraska to Chapman, Nebraska was dry, while upstream reaches near Kearney, Nebraska still conveyed flow. A high water table can add flow to the channel through groundwater seepage, while a low water table can be receiving flows from the river. Upstream of Cozad, Nebraska, the central Platte River may be gaining flows from groundwater movement out of the Sand Hills, a significant recharge area. In recent years, the reach from Cozad to Kearney, Nebraska, may be gaining flows from the groundwater mound to the south of the river (Figure 2.16), although the general direction of groundwater flow is to the southeast in this region. Further downstream between Kearney and Grand Island, Nebraska, Platte River flows are lost to groundwater through seepage, and the rate of loss may have increased in recent years due to the decreases in groundwater elevations to the southeast (Figure 2.16). The USGS gages on the central Platte River show a reduction in flows from the upstream station at Overton, Nebraska to the downstream station at Grand Island, Nebraska. The differential in mean flow has ranged from 10 cfs (1970 to 1999) to 210 cfs (1910 to 1935) depending on the period of years considered (Randle & Samad, 2003).

Part of the flow differential between Overton and Grand Island, Nebraska may be attributable to irrigation consumption, but not to withdrawals for municipal use at Kearney, Nebraska. For the years 1999 to 2002, the city of Kearney pumped less than an average annual volume of 0.1 cfs from the river, taking more than 99.8% of city water from groundwater wells (http://www.cityofkearney. org/documents/utilities%20Dept/2002%20Annual%20Report.pdf). The Kearney Canal diverts an average annual 189 cfs for irrigation and hydropower, with much of this flow returned to the river upstream of Grand Island, Nebraska.

In 1933, Wenzel made a calculation of the percolation from the Platte Valley between Gothenburg and Chapman, Nebraska based on test holes and the thickness of saturated sand and gravel. The permeability coefficient was interpolated from three Thiem tests. Wenzel's results are shown in Table 2.4. Total seepage for 1933 was estimated at 68.9 cfs and the reach of greatest seepage loss was from Odessa to Wood River (Figure 2.16) although sizeable losses continued to Grand Island, Nebraska.

Table 2.4 Compilation of percolation from the Platte Valley between Gothenburg and Chapman (taken from Lugn & Wenzil, 1938).

Segment of the Valley	Length of Segment (miles)	Ave thickness of sand & gravel (ft)	Interpolated coefficient of permeability	Hydraulic gradient (ft/mile)	Area of cross section* (ft^2)	Discharge through segment	
						(ft^3/sec)	(acre-ft/ year)
Gothenburg to Cozad	10	5	3,875	6.1	132,000	0.9	650
Cozad to Lexington	16.5	15	3,925	6.1	654,000	4.6	3,330
Lexington to Overton	11	31	3,975	6.3	900,000	6.6	4,780
Overton to Elm Creek	9.5	22	4,025	6.5	552,000	5.7	4,120
Elm Creek to Odessa	10	36	4,075	6.5	950,000	7.4	5,350
Odessa to Gibbon	20	50	4,150	6.7	2,640,000	21.5	15,550
Gibbon to Wood River	14.5	45	2,800	6.7	16,160,000	8.9	6,450
Wood River to Grand Island	16	86	1,350	6.7	3,630,000	9.4	6,800
Grand Island to Chapman	10	68	1,000	7.5	1,795,000	3.9	2,820
					TOTAL	**68.9**	**49,850**

*Corrected for direction of hydraulic gradient (assumed at 30 degrees with direction of valley).

2.3.2 Reservoir Construction and Major Flow Diversions

Although small reservoirs were constructed for irrigation in the last half of the 1800s, large reservoir construction that helped to address the problem of over-appropriation of flows, did not begin until the 1900s. Beginning in 1909, large storage reservoirs were constructed on the North Platte River to capture spring flows and provide water for irrigation during the summer. During the period 1909 to 1958, six major dams were constructed across the North Platte River in

Wyoming and Nebraska. Pathfinder (1909), Guernsey (1928), Alcova (1938), Seminoe (1939), Kingsley (1941), and Glendo (1958) reservoirs (Figure 1.2) have a combined storage capacity of nearly 5 million acre-feet (Collier et al., 2000). Large reservoirs also were constructed on the South Platte River, but these were located much higher in the watershed and stored a smaller fraction of the runoff, 1.3 million acre-feet of reservoir storage at present.

Simons and Associates (2000) list the combined reservoir storage capacity of the Platte River basin, for all reservoirs greater than 5,000 acre-feet, at 7.6 million acre-feet. This amount of reservoir storage capacity is equivalent to 5 years of mean annual flow for the central Platte River, as measured at the gage near Overton for the period 1970 to 1999 (Randle and Samad, 2003). The reservoirs store water during periods of high flow and later release the water during periods of low flow. Many of the reservoirs are also utilized for the generation of hydropower. This pattern of reservoir storage significantly reduces annual peak flows, and the application of water to agricultural lands, via thousands of canal diversions throughout a watershed, reduces annual average flows within the river channel.

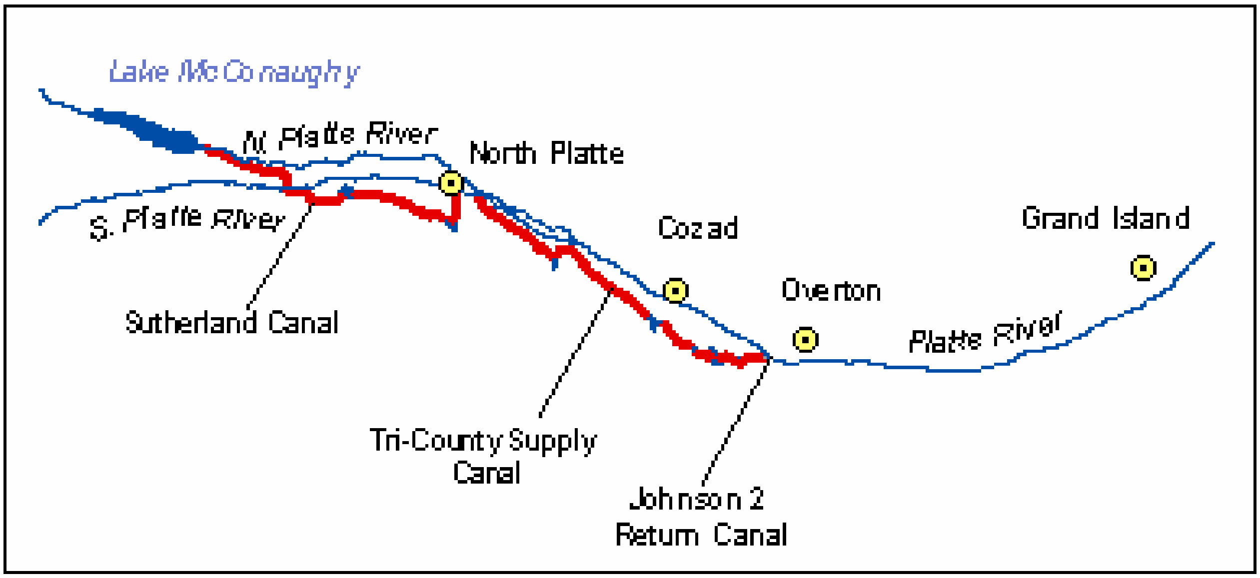


Figure 2.17 North Platte, South Platte and central Platte Rivers showing location of the Sutherland Canal and the Tri-County Supply Canal.

In addition to the storage reservoirs, two structures, the Keystone Diversion Dam and the Tri-County Diversion Dam, were constructed to support large flow diversions for irrigation and hydropower in the central Platte River basin. The Keystone Diversion Dam was completed in 1936, and diverts approximately 69 percent of the average annual North Platte River water from the North Platte River channel (Figure 2.17) for a distance of 58 river miles. The Sutherland Canal returns the flows to the South Platte River at North Platte, Nebraska for a distance of 4.5 miles, before the flows are again diverted by the Tri-County Diversion Dam at the river confluence downstream of North Platte, Nebraska. The Tri-County Diversion Dam began operation in 1941, and diverts approximately 73 percent of the average annual river flow from a 61-mile reach of the Platte River, returning the flows downstream of Lexington, Nebraska where the returns constitute 47 percent of the flows. Figure 2.18 shows the relative volume of flow in the principal rivers by line width. Natural flows tend to increase in the downstream direction, while the discontinuities in flow shown in the figure illustrate the impacts of canal diversions and returns on the North Platte, South Platte and central Platte River. Also shown in Figure 2.18 is the location of the Kearney diversion and return that removes 11 percent of flow from the central Platte River.

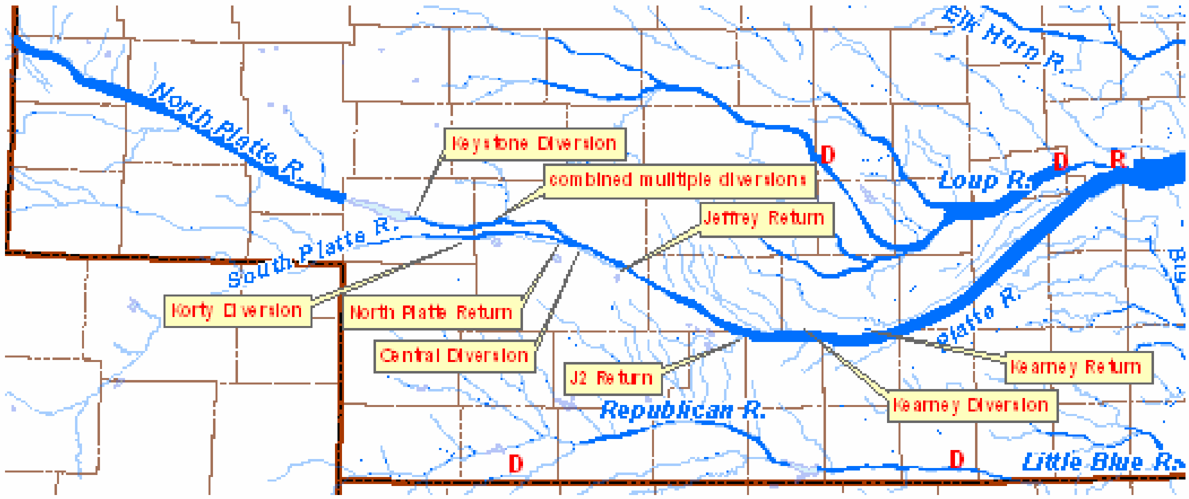


Figure 2.18 Average annual discharge of the principal rivers as indicated by the width of the river. The location of major flow diversions and returns on the North Platte River, South Platte River, and Platte River are labeled. On the Republican River and Loup River, D denotes the location of major flow diversions and R denotes the location of major returns (Conservation and Survey Division, University of Nebraska-Lincoln, 1996).

2.3.3 Bridges, the Transportation System, and Bank Revetments

Due to the physical attributes of level grade, good foundation material, and an east-west orientation, the Platte River Basin has been a major transportation corridor since European settlement began. Several emigrant trails followed this passage in the 1800s and it has been a popular railroad route since the transcontinental line was completed in 1869. Currently, US Interstate 80 is located in the Platte River corridor in addition to State Highways and local roads. The type and number of bridge structures required to support this transportation network can also influence channel form by constricting flows at bridge crossings.

Bridges from the early 1900s were often constructed on wood pilings, referred to here as trestle bridges, and commonly spanned the full width of the channel. Road and railroad departments later replaced these bridges using designs with extended road approaches on earth embankments, and only a few of the trestle bridges crossing the Platte River are still in existence. Between and including Lexington and Grand Island, Nebraska, 13 trestle bridges on piles are shown on the USGS maps of 1896-1902 (figures 2.06 to 2.11) for both road and railroad crossings. For the same reach, the 1998 aerial photographs show a total of 14 embankment bridges and only 3 railroad trestle bridges.

The newer design with earth embankments reduced costs by shortening the length of the bridge span over the river, often the most costly feature of the bridge. The earth embankments locally constricted the multiple river channels and flood plains of the Platte River. Since the bridges often constricted the flood plains and river channel, gravel pits were occasionally excavated adjacent to these bridges following bridge construction. High banks or levees to prevent flooding of the gravel pits also contributed to additional channel constrictions. By the final two decades of the 1900s, the Federal Highway Administration (FHWA) and State Road Departments, were addressing the shortcoming of bridges restricting river flows. The FHWA had established stricter specifications for new bridges that prevent encroachment into the river channel and excessive backwater flooding upstream from the bridge. Therefore, embankment bridges predating the 1980s have the highest propensity for channel form changes through the constriction of flows.

Bank protection systems or revetments, commonly constructed from large rock (riprap) are also used frequently in the twentieth century. The revetments are often intended to protect roads and bridge foundations from bank erosion, or are installed by private landowners to preserve lands. The revetments, like the bridge crossings, create a hardened bank that horizontally confines flows. Hard protection materials, including riprap can also increase flow velocities adjacent to the structure. In 1994, the US Corps of Engineers (Corps, 2001) estimated that 10 percent of the outer riverbank had been protected between North Platte and Columbus, Nebraska. Between 1976 and 2001, the Corps received 157 applications for bank stabilization permits in this reach.

2.3.4 Climate in the Twentieth Century

The last noted climate change for the central High Plains occurred approximately 700 to 800 years ago (Section 2.1.5) and climate for the twentieth century can be typified as average. The 1930s and 1950s droughts are examples of a drought magnitude that occurred with some regularity over the last 400 years. Similar droughts occurred in the central Great Plains in the late 1660s, in the late 1690s (Cleaveland & Duvick, 1992), in the late 1750s, early 1820s, early 1860s and the 1890s (Weakly, 1965, Wedel, 1986, Lawson, 1970, Lawson & Stockton, 1981). In a study of the central United States, Woodhouse and Overpeck (1998) write:

> *The collection of dendroclimatic reconstructions for the Great Plains region suggests that the severe droughts of the twentieth century, although certainly major in terms of their societal and economic impacts, are by no means unprecedented in the past four centuries. Moreover, when all proxy data, including historical accounts of eolian activity, are considered, it is likely that droughts of a magnitude at least equal to those of the 1930s and 1950s have occurred with some regularity over the past 400 years…*

Woodhouse (2001a) uses reconstructed streamflows to describe dry periods for the Colorado Front Range and focused on tree-ring chronologies sensitive to winter and spring moisture conditions for the South Platte headwaters.

This reconstruction suggests that the major low flow periods of the 20th Century, the 1930s, 1950s, and 1960s, have been exceeded in severity several times in the prior two centuries.

From the PDSI index shown in Figure 2.13, it can be seen that the first 25 years of the twentieth century are the wettest period since 1700. The figure ends in 1980, however the end of the century was also wet. In the Front Range region of Colorado, McKee et al. (1999), describe a 26-year wet period from 1905-1931, and a lesser wet period of 17 years in the final two decades of the 20th Century. In summary, the climate of the Platte River Basin in the twentieth century began with a very wet period for the first 26 years. Droughts occurred during the decades of the 1930s, 1950s and 1960s and the last 17 years of the century were wet, although not as wet as the initial decades of the century.

2.3.5 Conclusions on the Historical Consideration of the central Platte River

In the Pre-Development period prior to the nineteenth century, the impacts of climate dominated the morphology of the Platte River. One major realignment occurred approximately 10,000 years ago, however changes to flow, sediment transport and basin structure appear in general, to be gradual under the large extent of time considered. Under climate influences, the river transitioned over long periods through multiple cycles of aggradation, degradation and stability, with the last transition to aggradation estimated at three centuries previous to the present. Under the conditions present at the end of the Pre-Development period, the lower layer of sands and gravels in the Grand Island formation may have been acting as a vertical control on the bed of the central Platte River, preventing further incision. The last detectable climate change, a shift to a less extreme drought regime, occurred 700 to 800 years ago.

The central Platte River can be divided into three reaches based on the geology and morphology of the Pre-Development period. The relevance of these divisions is evident today in some varying responses between channel reaches to current changes in flow, sediment, and channel form.

In the nineteenth century and beginning with euro-settlement, mans activities begin to have an impact on the Platte River Basin. Although the extent of woody vegetation early in the century is debated, coverage declined due to the migration of settlers through and to the area. Beaver trapping, mining, and timber harvest, primarily in the headwater tributaries of the Platte River, are watershed activities that typically increase sediment loads to streams. Water appropriation records indicate that summer flows in the central Platte River decreased due to irrigation in the last decades of the nineteenth century. The nineteenth century had the most extreme occurrence of droughts in the last four centuries, and the 1840s drought, at a minimum, is estimated to have increased sediment loads over a decadal period. Decreases in woody vegetation and potential increases in sediment load have not been quantified due to a lack of data for this century.

Changes in channel form in the nineteenth century resulting from changes in flow and sediment transport may be regarded as relatively small as indicated by a lack of narrative on the topic, and by the correspondence in central Platte River width between GLO mapping from 1865 and USGS mapping from 1898 to 1902. But regardless of potential changes that may have occurred through the nineteenth century, the end of this century marks the start of most quantitative data presented in this study. Although watershed changes probably occurred in the nineteenth century, the end of this century predates most major infrastructure development making it a useful period for comparison to periods with later developments.

In the twentieth century, the impacts of climate upon channel shape and planform are typical of the previous four centuries, but anthropogenic impacts have greatly increased due to population increases and major infrastructure development. There are greater demands on both surface water and groundwater for municipal and irrigation uses, and large infrastructure including reservoirs and extensive canal systems are constructed to supply the increase in water demands, impacting both flow, through timing shift and peak flow reduction, and sediment transport. The infrastructure of the transportation system also expands in the twentieth century, imposing new and multiple restrictions on the horizontal alignment of the central Platte River. The changes to flow, sediment transport and basin structure, as a result of primarily anthropogenic changes throughout the twentieth century, are presented in Chapter 3.

3.0 CHANGES TO PRIMARY ELEMENTS OF RIVER MORPHOLOGY IN THE TWENTIETH CENTURY

As presented in Chapter 2.0, anthropogenic impacts in the twentieth century are substantive, abrupt with respect to geologic time, and have altered three primary elements of channel morphology in the central Platte River: the in-channel flow; the transport of sediment; and the basin structure including location of flow and sediment inputs in the basin and geologic or man-made structures. This chapter focuses on the measured changes of these primary elements to provide a foundation for the processes of change to the channel addressed in Chapter 4.0.

3.1 CHANGES TO FLOW

The mean, median, and 1.5-yr peak flows for the North Platte River, South Platte River and three locations along the central Platte River are shown in Figures 3.1 to 3.3. The information in each figure has been divided into four time periods: 1895 to 1909, 1910 to 1935, 1936 to 1969, and 1970 to 1999. This 105-year historic period was divided into four periods of analysis based on trends in annual flow volume and annual peak flow for the North Platte River gage at North Platte, Nebraska (Randle and Samad, 2003). All three figures exhibit a similar pattern of decreasing flows in the first three periods, with some increase in flow in the fourth period that does not reach levels of the first two periods.

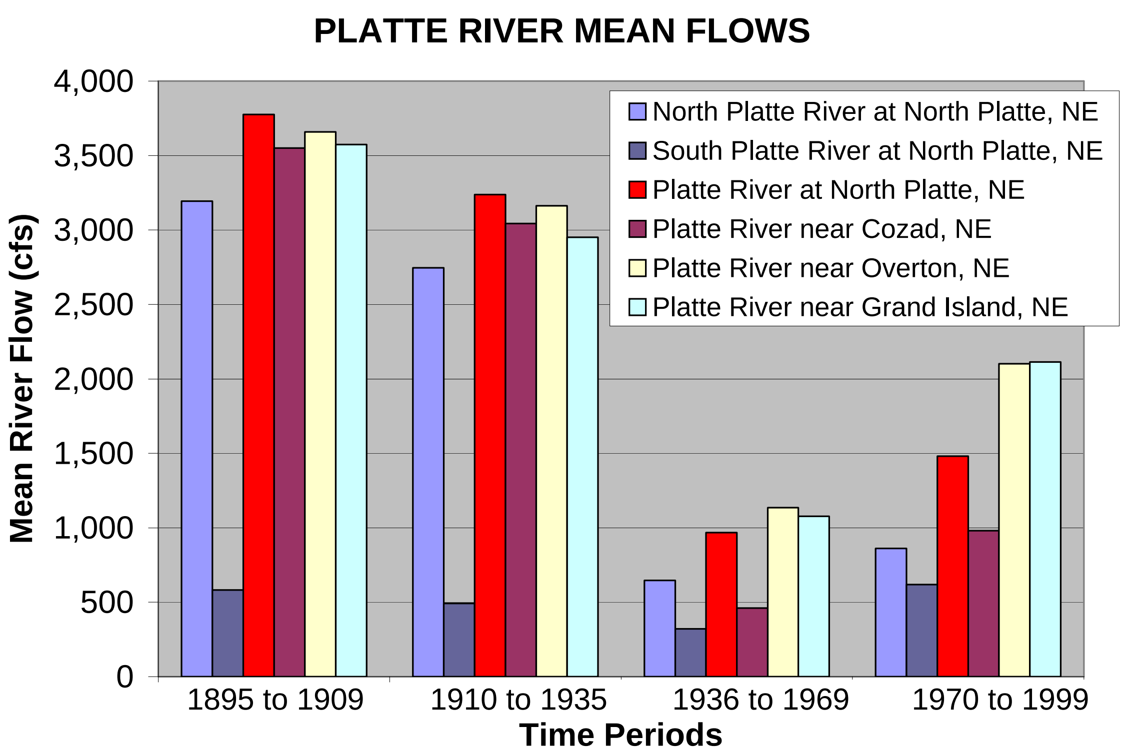


Figure 3.1 Platte River mean flows (Randle and Samad, 2003).

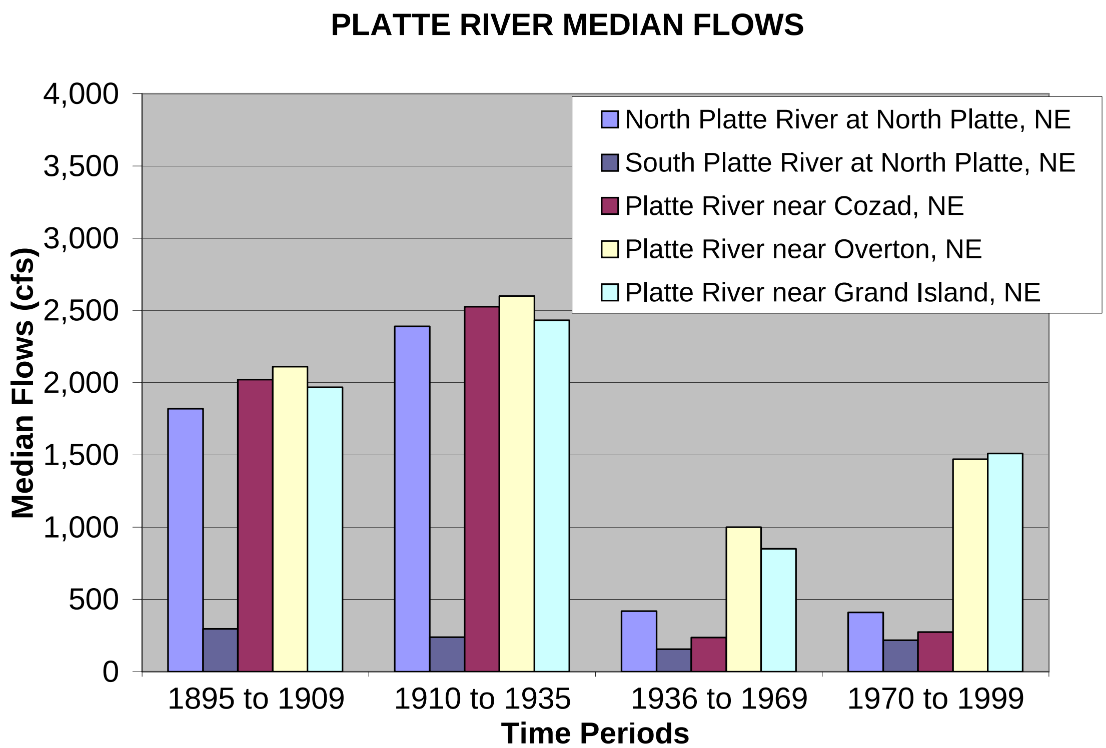


Figure 3.2 Platte River median flows (Randle and Samad, 2003).

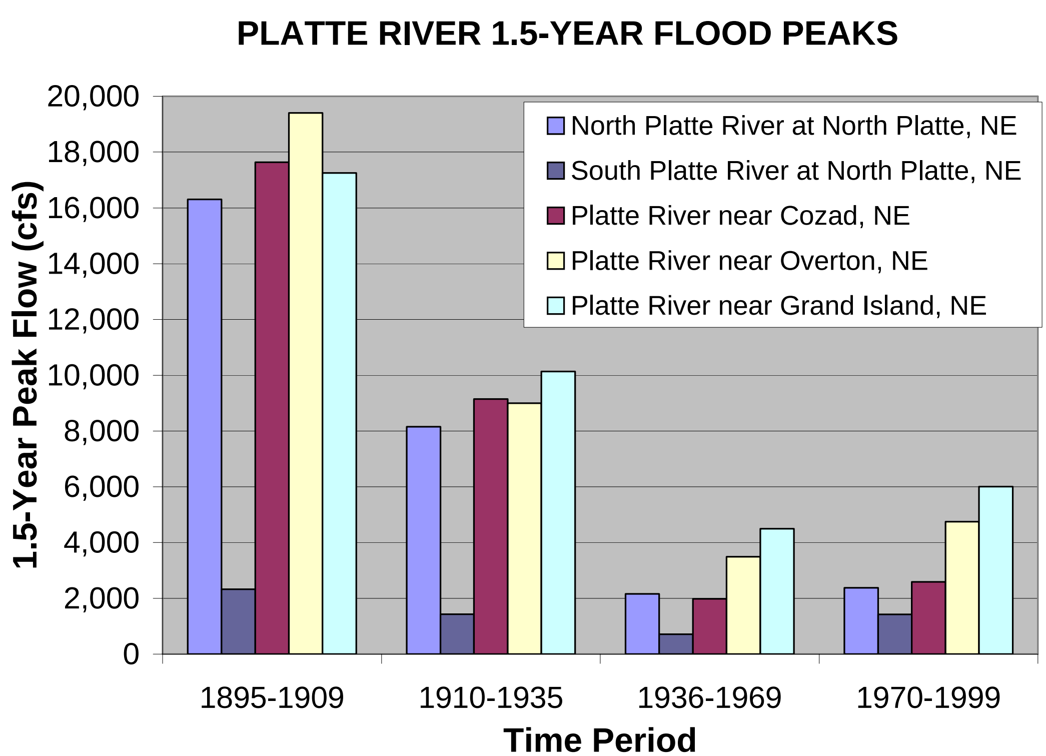


Figure 3.3 Platte River 1.5-year flood peak flows (Randle and Samad, 2003).

Flow-duration curves based on the best available, mean-daily flow data (Stroup et al. 2001) are shown in Figures 3.4 to 3.8 for the four time periods: 1895 to 1909, 1910 to 1935, 1936 to 1969, and 1970 to 1999. A more detailed presentation of Platte River flows can be found in Randle and Samad (2003).

3.1.1 North Platte River Flows

The flow-duration curves for the North Platte River at North Platte, Nebraska, in Figure 3.4 show that the median annual flow rate, the rate exceeded 50 percent of the time, dropped from about 2,400 cfs to 400 cfs in the third period. Major decreases in flow rate on the North Platte River at North Platte coincide with the period of reservoir construction. The Pathfinder Dam in Wyoming began operation in 1909, and was the first of six reservoirs to alter the normal spring flows on the North Platte River.

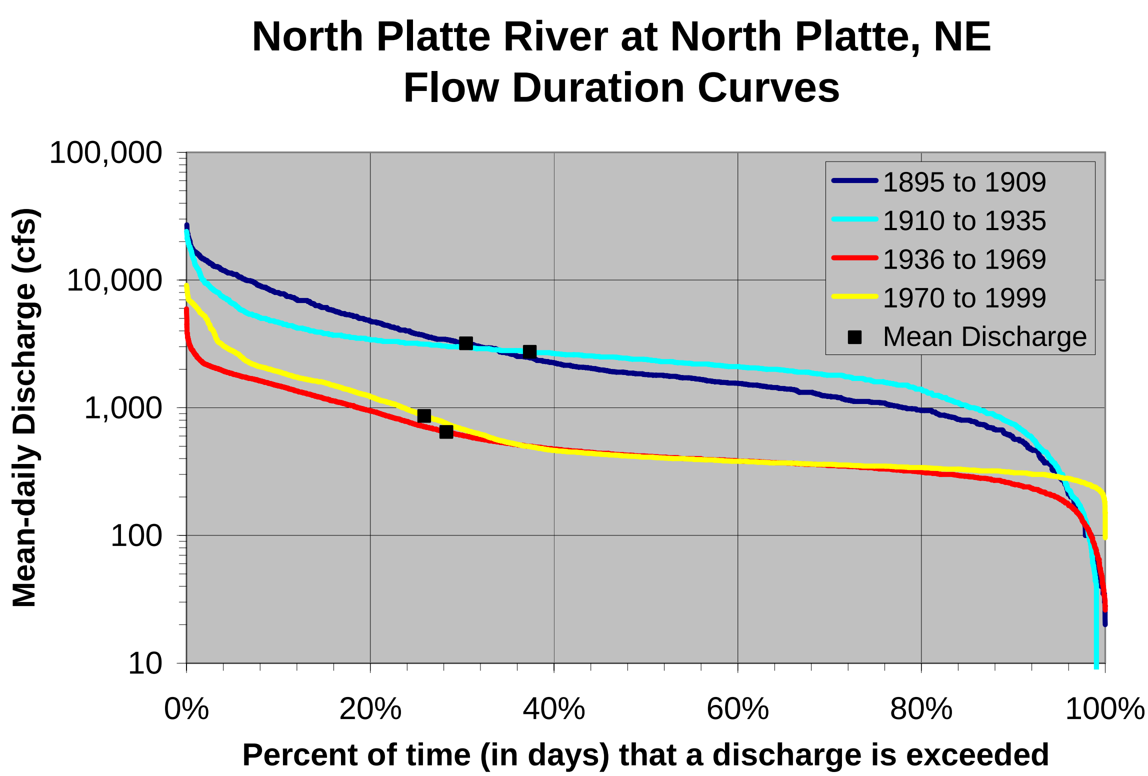


Figure 3.4 North Platte River at North Platte, Nebraska flow-durations curves (Randle and Samad, 2003).

3.1.2 South Platte River Flows

Stream gage data for Denver, Colorado, Duncan, Nebraska, and North Platte, Nebraska (Figure 2.3) were used to estimate the South Platte River flows at North Platte, Nebraska from 1895 until 1902. From 1902 to 1914, the gage on the South Platte River at Julesburg, Colorado was used in the estimating procedure. The USGS gage station on the South Platte River near North Platte, Nebraska began measurements on June 1, 1914. The flow-duration curves in Figure 3.5 show the history of the South Platte River flows at North Platte, Nebraska. Note, that these flows do not include the Sutherland Hydro Return flows, which enter the South Platte River downstream from the USGS gage at North Platte, Nebraska, and are diverted again 4.5 miles further downstream.

The high flows that are exceeded 20 percent of the time for the South Platte River initially decreased over the first three time periods (1895 to 1969) then increased over the fourth time period (1970 to 1999), to a level comparable to the first time period. The mean flow for the fourth time period is actually greater than the mean flow of the first time period (Figures 3.1 and 3.5) because significant water is imported to the South Platte basin, through tunnels under the continental divide, from the Colorado River Basin. The inter-basin transfer projects effectively add another million acre-feet of reservoir storage to the South Platte River and a mean-annual, water-transfer volume of 400,000 acre-feet (Simons & Associates, 2000). Beginning in 1936, the Keystone Diversion Dam diverts water from the North Platte River through the Sutherland Supply Canal to the South Platte River at the Sutherland Hydro Return, but because that flow is diverted a second time in the Tri-County canal system, that water does not appear in the gage record until it reaches Overton, Nebraska, more than 61 river miles downstream.

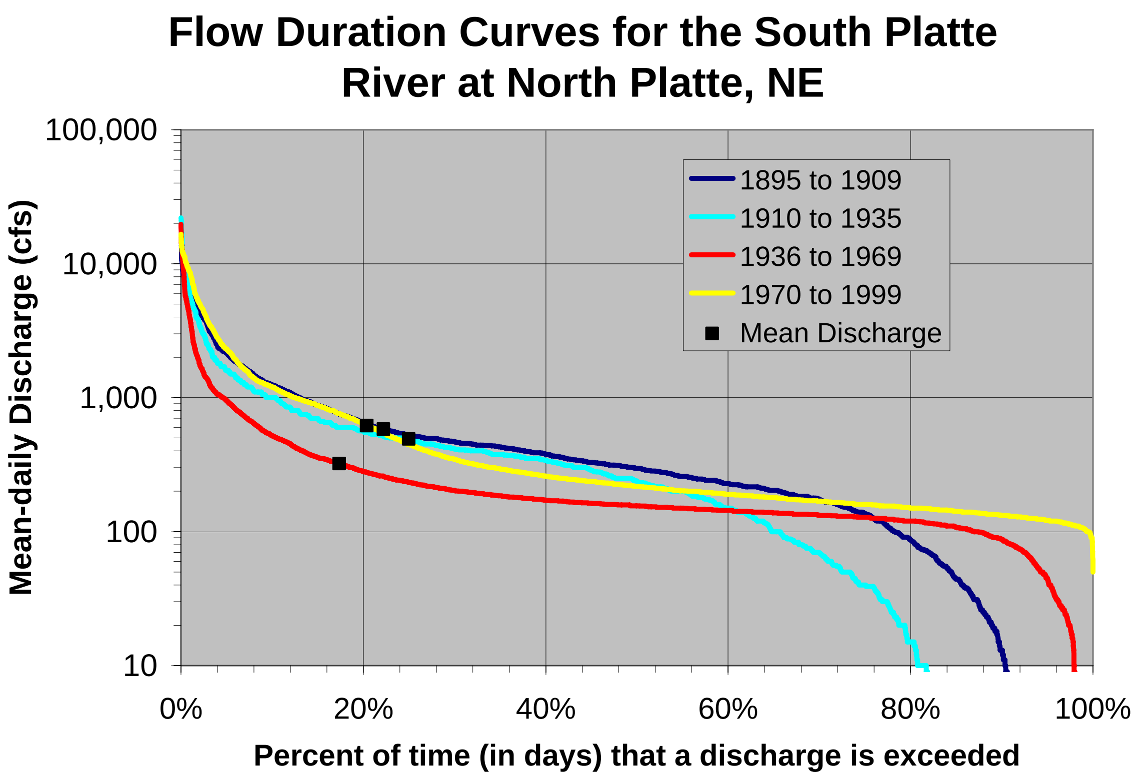


Figure 3.5 South Platte River at North Platte, Nebraska flow-durations curves (Randle and Samad, 2003). The mean flow for the first, second, and fourth time periods are very similar (Table 3.4).

3.1.3 Central Platte River Flows

The flow-duration curves at the three USGS gage stations along the central Platte River, Cozad, Overton, and Grand Island, were very similar between the first and second time periods (1895 to 1909 versus 1919 to 1935) as seen in Figures 3.6, 3.7, and 3.8. The flows along the Platte River became spatially non-uniform between the Cozad, and the Overton and Grand Island gages, once the Tri-County Diversion Dam began diverting water into the Tri-County Canal (1941).

The flow-duration curves for the Cozad gage station (Figure 3.6) indicate a substantial decrease in flows, through a curve shift downwards and left from the second to third time periods (1910 to 1935 versus 1936 to 1969). During low and moderate flow periods, much of the water reaching the Tri-County Diversion Dam is diverted into the canal for purposes of hydropower and irrigation. Most of the diverted water is returned back to the Platte River, 61 miles downstream, through the Johnson-2 return channel (Figures 1.3, 2.17, and 2.18).

Downstream from the Johnson-2 return channel, on the central Platte River, the flow-duration curves for the gages near Overton and Grand Island, Nebraska (Figures 3.7 and 3.8) are very similar. The flow-duration curves for the last two periods, 1935 to 1999, at both Overton and Grand Island gages are noticeably higher than the flow-duration curves for these same periods at the Cozad gage (Figure 3.6), indicating a persisting reduction in flows at Cozad from 1935 to the present. The close agreement between flow duration curves for the gages near Overton and Grand Island, Nebraska (Figures 3.7 and 3.8), show the spatial uniformity of flow downstream from the Johnson-2 return channel. These flow-duration curves of the third and fourth time periods show that both high and low flows occur less frequently than in earlier periods, and that the flows are more uniform over time. A temporal aspect of the more uniform flow is that the ratio of the spring runoff flows to the summer thunderstorm flows has decreased in the latest two periods, due to the storage of high spring runoff flows.

The water diverted into the Tri-County Canal is used for hydropower generation and irrigation deliveries. Return flows through the Johnson- 2 return channel can either be steady throughout the day or fluctuating, depending on the demand for electricity. Return flows can also increase within the short span of a day when irrigation demand suddenly decreases due to significant rainfall negating the need for irrigation deliveries. Hourly flow variations are not well represented by the mean-daily flow data, although they have the potential to wet and dry habitat areas used by endangered birds for roosting or nesting. However, hourly flow fluctuations are beyond the scope of this study.

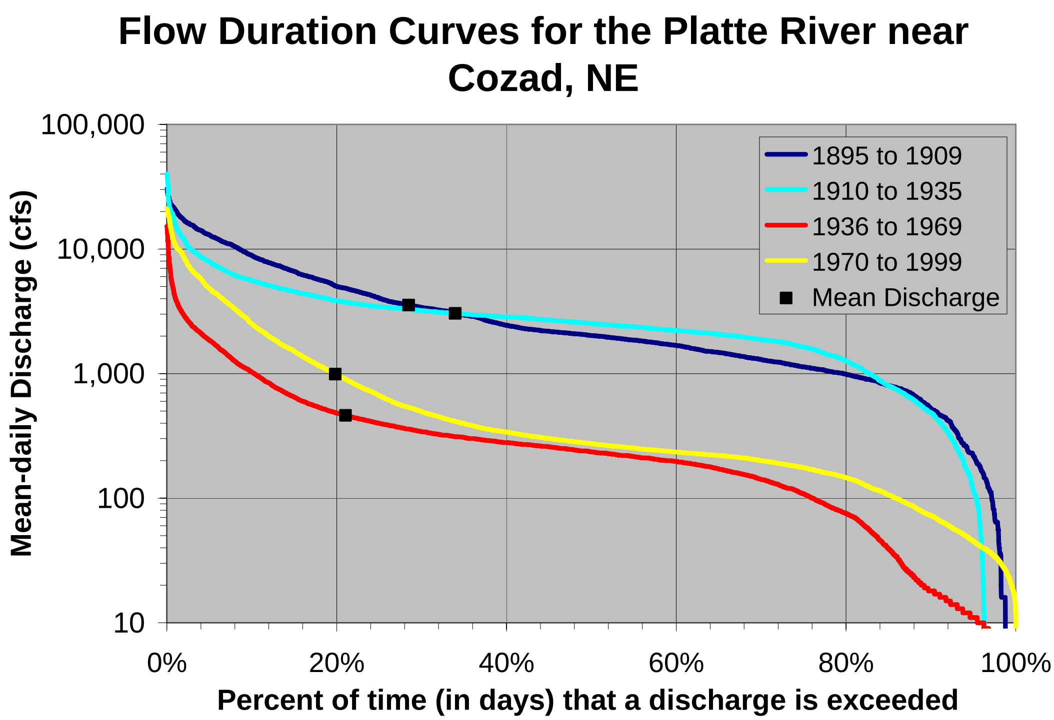


Figure 3.6 Platte River near Cozad, Nebraska flow-durations curves (Randle and Samad, 2003).

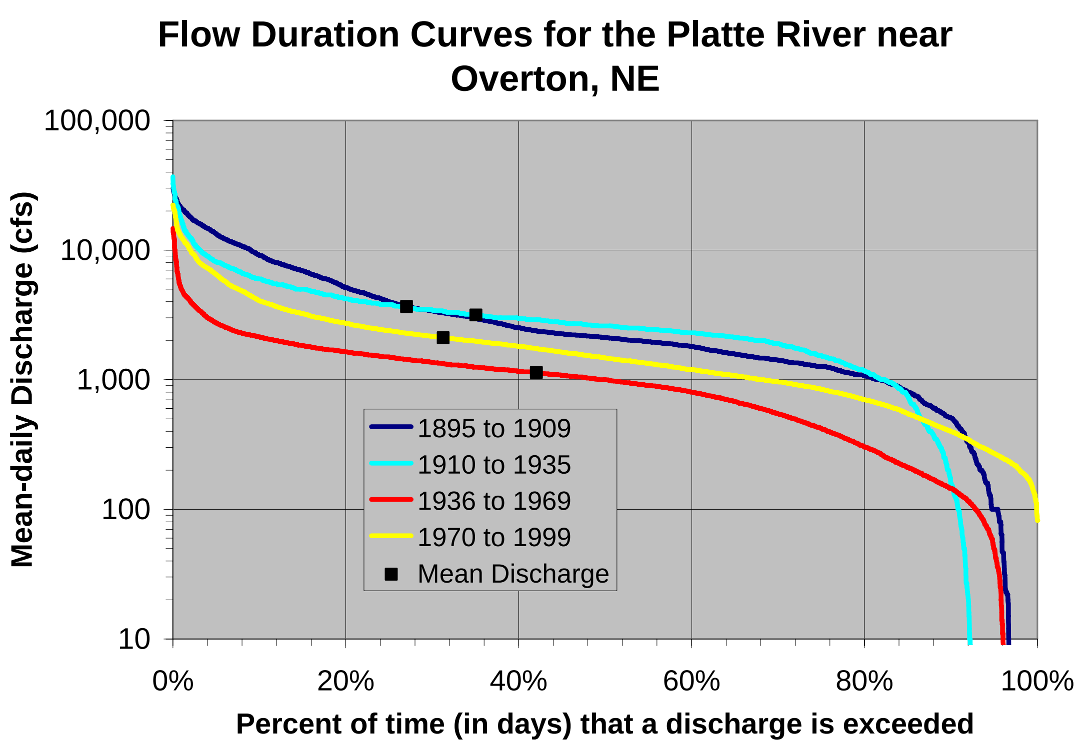


Figure 3.7 Platte River near Overton, Nebraska flow-durations curves (Randle and Samad, 2003).

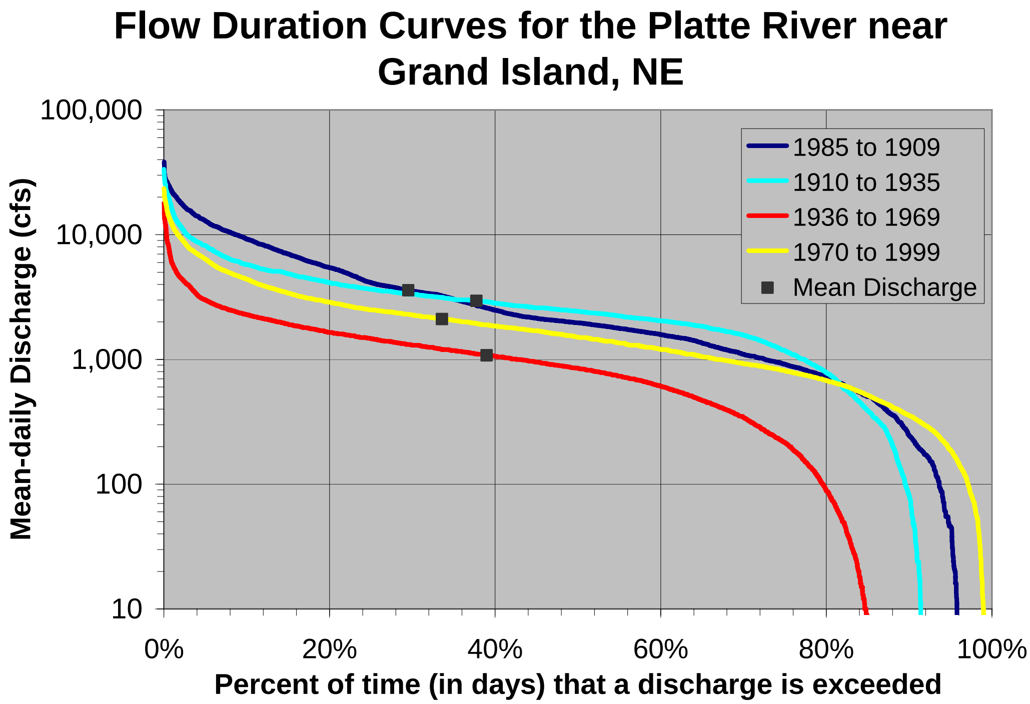


Figure 3.8 Platte River near Grand Island, Nebraska flow-durations curves (Randle and Samad, 2003).

3.1.4 An Estimate of Flow Changes Attributable to Anthropogenic Factors

As discussed above and concluded by Randle and Samad (2003), river flow through the North Platte and Platte Rivers in Nebraska has significantly decreased over the 20th Century. The mean river flows and the 1.5-year flood of the North Platte and Platte Rivers in Nebraska decline during two recent historical time periods, 1936 to 1969 and 1970 to 1999, compared with the river flows from two early historical time periods, 1895 to 1909 and 1910 to 1935. These declines also coincide with the construction of major reservoirs and flow diversion systems.

An estimate for the flow reductions in the central Platte River Basin that could be attributable to irrigation needs, municipal and industrial use, and evaporation from lakes, reservoirs and major canals in the Platte River Basin is developed here. The calculations rely primarily on two sources for estimates of consumptive use of water in the Platte River Basin: the U.S. Geological Survey's 1995 Water-Use Data Files (USGS, 1999) that were developed in coordination with the corresponding state water resource agencies, and the U.S. Bureau of Reclamation estimates of consumptive water use developed for the Platte River Management Joint Study (U.S. Bureau of Reclamation, 1992).

<u>3.1.4.1 Consumptive Use</u>

The U.S. Geological Survey (1999), with some adjustment of their central Platte estimates (Duane Woodward, Central Platte Natural Resource District, personal communication, 2002), indicates the following irrigated areas and population within the Platte River basin, circa 1995 (Table 3.1).

Table 3.1 Irrigated Acres within the Platte River Basin above the Loup River confluence	
Type of irrigation	Irrigated area
Surface-water irrigation	1.9 million acres
Ground-water irrigation	1.6 million acres
TOTAL irrigation	3.5 million acres
Population	3.0 million

Converting these numbers into consumptive use values requires making estimates of per-acre and per-capita consumptive use. Using per-acre estimates for agricultural consumptive use and reservoir evaporation in the basin (U.S. Bureau of Reclamation, 1992), and estimates for municipal and industrial consumptive use in the South Platte Basin from the State of Colorado (1998) yields estimates of mean annual consumptive use shown in Table 3.2.

Table 3.2 Estimated mean annual consumptive use for the Platte River Basin above Loup River confluence	
Type of use	Annual consumptive use (acre-feet per year)
Surface-water irrigation	1,640,000
Ground-water irrigation	1,190,000
Municipal & industrial use	270,000
Lake, reservoir, pond, and major canal evaporation	829,000
Total	3,929,000

The above consumptive uses are partially offset by supplies of non-native water provided through trans-basin imports and "non-tributary" groundwater pumping. The approximate water volumes supplied from trans-basin imports in an average year are as shown in Table 3.3. The term "non-tributary" groundwater pumping refers to the pumping of groundwater within the river basin, but from depths that would not have otherwise contributed to streamflow. The annual volume of non-tributary groundwater pumping within the Platte River Basin is unknown, but is assumed to be tens of thousands of acre-ft per year.

Table 3.3 Mean annual import of water to the Platte River Basin from the Colorado River Basin.	
Basin water imports	Average annual supply estimate (acre-feet per year)
Trans-basin imports into the South Platte basin	350,000
Trans-basin imports into the North Platte basin	16,500

Most of the groundwater withdrawn for agricultural use in the Platte River Basin comes from aquifers tributary to the surface water system, and thus is generally depletive to Platte River flows. However, groundwater mounds where water table levels have been raised due to seepage from irrigation systems, may have increased seepage flow back to the Platte River at specific locations upstream of Kearney, Nebraska (Figure 2.16), offsetting some of the depletion. The depletive and accretion effects may be delayed by many months or years, and not all of the groundwater is tributary. Because of these uncertainties in estimating groundwater volume and movements, a conservative approach to estimate overall river depletions is used here. Depletions and inflow seepage resulting from groundwater use are excluded, as well as accretions associated with non-tributary groundwater supplies, which are relatively small.

In the Platte River Basin above the Loup River confluence, the consumptive use from sources, excluding groundwater, are estimated to be:

Surface-water irrigation consumptive use	1,640,000 acre-feet
<u>Municipal and industrial consumptive use</u>	<u>270,000 acre-feet</u>
Lake, reservoir, pond, and major canal evaporation	829,000 acre-feet
Total water use	*2,739,000 acre-feet*
<u>Minus trans-basin water imports</u>	<u>- 367,000 acre-feet</u>
Net consumptive use	*2,372,000 acre-feet*

Again, this bottom-line figure (approximately 2.4 million acre-feet) is assumed to be a conservative value, as it does not account for the generally consumptive groundwater use in the basin.

<u>3.1.4.2 Depletions</u>
One acre-foot of consumptive use in the Platte River Basin upstream of Overton, Nebraska, equates to something less than one-acre foot of depletion in the central Platte River near Grand Island, Nebraska. A portion of natural river flow in the upper part of the basin never would have reached the central Platte because of natural losses to evaporation, evapotranspiration, and groundwater recharge. A transit loss factor can be applied to convert the consumptive use volume into a depletion volume for the central Platte River.

The State of Colorado (1998) estimated that under present day conditions, flow in the South Platte River experiences weighted-average transit losses ranging from about 3% (December through February) to 73% (July through September) before reaching the Nebraska state line. Transit losses generally decrease as flow distances decrease.

Applying the State of Colorado transit values from the South Platte River, to the central Platte River introduces further uncertainties to this calculation, but is assumed to under estimate the losses. The distances traversed by central Platte River flows are generally greater than the distances addressed in the State of Colorado study, and the North Platte and central Platte Rivers are generally wider than the South Platte River. Both of these factors would presumably lead to greater transit losses for central Platte River calculations. A slightly wetter climate moving east across Nebraska might marginally reduce the rate of transit losses in the central Platte River.

To get a single value for comparing annual volumes of flow, the range of seasonal values for South Platte transit losses (3% to 73%) is averaged to 38%. A value of 38% for annual weighted average transit losses, equates to 62% of the consumptive use in the upper basin of the Platte River depleting flows in the central Platte River.

Therefore, the average annual consumptive use of 2.4 million acre-feet per year, removed primarily in the upper Platte River basin, would equate to a depletion of 1.5 million acre-feet per year in the central Platte River upstream of the Loup confluence. This annual volume of depleted flow is an approximate reduction in mean annual flow of 2,000 cfs. Recognizing all the uncertainties associated with this calculation, a large range should be associated with this 2,000 cfs estimate. However, even at an error range of ± 50%, a reduction in mean annual flow of 1,000 to 3,000 cfs, this estimate demonstrates that flow depletions due to water resource development are substantial.

The mean flow for the Platte River near Grand Island, Nebraska for the period 1895 to 1909 is 3,580 cfs while the mean flow for the period 1970 to 1999 is 2,110 cfs. The reduction between this first and fourth period is 1,470 cfs. This value, 1470 cfs, is easily within the approximate estimate of depletions, 2000 cfs, for these periods even with the addition of flow depletions to the first period not currently included. Based on the above figures and assumptions, and despite the uncertainties associated with this estimate, it appears that consumptive use of water in the Platte River Basin can account for all of the reduction in Platte River flows that have been noted from the period 1895 to 1909 to the latest period, 1970 to 1999.

The climate from 1905 to 1931, corresponding to portions of the first and second time periods (1895 to 1935), was considered to be wet and the climate from 1980 to 1996, corresponding to 16 years of the fourth period, was also considered to have been quite wet (Section 2.3.4). With respect to climatic conditions, both the first and fourth periods appear to be on relatively equal footing for this comparison.

3.1.5 An Estimate of Flow Changes Attributable to Climatic Factors

The discussion above indicates the consumptive use and depletions of water on the Platte River can account for all of the measured flow reductions between the first period, 1895 to 1909, and the fourth period, 1970 to 1999. However, ignoring the information in the previous section, we focus here on estimating the maximum extent that climate influences could be accountable for the flow reductions noted between the first and fourth periods. This consideration of climate impacts is organized to address three questions.

- Has there been a general trend of climate warming that could account for flow reductions from the first to the fourth periods?
- If there is no significant general trend of climate pattern, could fluctuations in the climate patterns be emphasizing flow differences in the four periods selected, and be substantially responsible for the decrease in flows noted from the first to the fourth periods?
- And lastly, if climate fluctuations are a factor, what is the maximum percent of flow reduction that could be attributed to the climate factor?

<u>3.1.5.1 Climate Trend Consideration</u>

A brief summary of information with respect to the temperature record and global warming can be found at the National Oceanic and Atmospheric Administration (NOAA) website (http//www.ngdc.noaa.gov/paleo/globalwarming/paleolast.html). Graphs at this website show temperature data for the northern hemisphere from studies by Briffa et al., 1998, Jones et al., 1998, Mann et al, 1998, and Overpeck et al, 1997. The graphs are consistent in displaying a temperature rise beginning in the 1920s that exceeds temperature increases occurring in the reconstructed record back to the 1400s. Temperatures then begin to level or decline in the 1950s. This occurrence of temperature peak with extreme length of duration, makes the twentieth century the warmest century of record, and gives credence to the discussion of a temperature warming trend.

However, in contrast to the temperature data, both reconstructed stream flow records and the PDSI do not support the theory of a general trend of climate change for the Great Plains. Instead, tree-ring data indicates short periods of wet and dry, with durations of 3 to 10 years, fluctuating around a central norm. No general long term trend of drying is apparent in the twentieth century, although a pattern of bi-decadal drought rhythm has been noted (Cook, et al, 1997, Woodhouse and Overpeck, 1998). PDSI data is shown in Figure 2.13, for the areas of northeastern Colorado and western Nebraska. As discussed in Section 2.3.4, the periods of drought in the twentieth century are no more severe than earlier centuries. The wet period in the first 25 years of the century is the wettest period since the year 1700, with a second wet period occurring at the end of the twentieth century.

The effect of climate on river flows within the South Platte River Basin has been explored by Woodhouse (2001a) using 300 years of tree-ring data for middle Boulder Creek, Colorado (1685 to 1987) and Clear Creek, Colorado (1703 to 1987). The reconstructed river flow data for Middle Boulder Creek and Clear Creek are presented in Figure 3.9 and Figure 3.10.

The reconstructed flow data for both of these creeks indicate that there are numerous wet and dry periods, but no significant long-term trend in mean annual flow. The trend lines indicate a 3 to 4 percent reduction in mean annual flow over the 300-year period for each creek, while the mean flows in these two creeks for the four different time periods from 1895 to 1987 have only changed within ± 5 percent. These are headwater streams that individually constitute less than one percent of the watershed area upstream of Grand Island. However if it is assumed that headwater streams would also reflect climate change, the answer to the first consideration, "*Has there been a general trend of climate warming that could account for flow reductions from the first to the fourth periods?*", appears to be no.

3.1.5.2 Shorter Periods of Climate Fluctuation

The flows on the Platte River, as measured at USGS gage stations, are evaluated using the four periods: 1895 to 1909, 1910 to 1935, 1936 to 1969, and 1970 to 1999. The four periods selected are shown in Figure 3.11 over an average PDSI record constructed from instrument data for grid points 47, 48, 57, 58, 59, and 68 (Figure 2.12) in the upper Platte River Basin. The divisions for periods were not selected based on climate patterns of wet and dry, but were instead selected

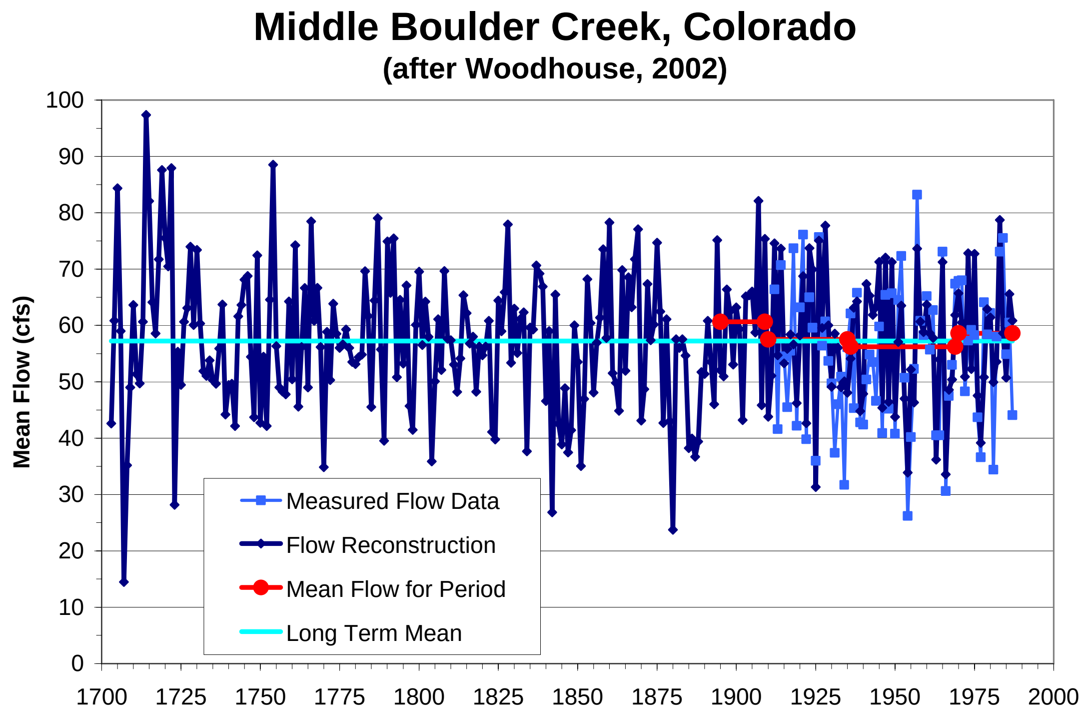


Figure 3.9 Mean annual flow data for Middle Boulder Creek, Colorado reconstructed from tree-ring data (Woodhouse, 2001b).

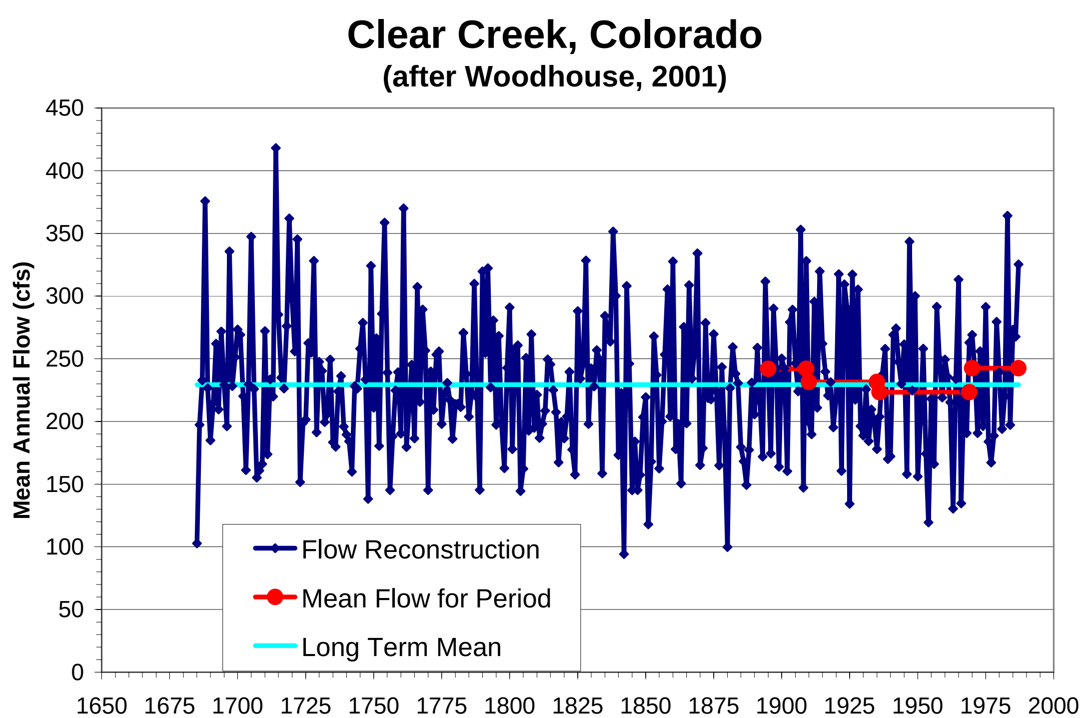


Figure 3.10 Mean annual flow data for Clear Creek, Colorado reconstructed from tree-ring data (Woodhouse, 2001b).

according to breaks in streamflow at the USGS gage at North Platte, Nebraska, as shown in Figure 3.12. Some of the extremes of wet and dry are therefore modulated by the range of the period. The North Platte River gage at North Platte, Nebraska was selected because it has the earliest continuous measured record. The gage at Overton, Nebraska began in 1914, and the gage at Grand Island, Nebraska began in 1933.

As seen in Figure 3.11, the first two periods capture both wet and dry periods, but more wet periods then dry periods. The third period captures more dry periods than wet, and the fourth period is again wetter than dry. The flow patterns of the North Platte River at North Platte, Nebraska (Figure 3.12) reflect the climate patterns (Figure 3.11) in the first three periods, with the first two periods wetter than normal and the third period drier than normal. However there is a discrepancy in the fourth period where climate (Figure 3.11) is wetter than normal but the stream flow record (Figure 3.12) has a drier than normal period. Also, for all four periods, the stream flow values (Figure 3.12) exhibit greater variation from the norm than the average climate PDSI value for the Platte River Basin (Figure 3.11). Therefore the answer to the second question, *"If there is no significant general trend of climate pattern, could fluctuations in the climate patterns be emphasizing flow differences in the four periods selected, and be substantially responsible for the decrease in flows noted from the first to the fourth periods?"*, is no as represented by flows at North Platte, Nebraska. There appears to be some correlation, but the discrepancies in the fourth period indicate climate impacts can only account for a small percentage of the variations.

3.1.5.3 Maximum Percent of Flow Variation Attributable to Climate

To quantify the magnitude of change in stream flow records that could be attributed to wet and dry climate periods, the streamflow data for USGS gages located upstream of reservoirs or irrigation diversions in the headwater branches of the watershed are considered. The percent of variation noted in headwater streams can then be compared against the percent of variation found in the mainstem channel downstream of reservoirs or irrigation diversions.

For headwater streams on the South Platte River, five tributaries with USGS gages were found that had an extensive period of record:

- Clear Creek in Colorado;
- Middle Boulder Creek in Colorado;
- Cache La Poudre River at the canyon mouth in Colorado;
- St. Vrain River at Lyons in Colorado; and
- Big Thompson River at the canyon mouth in Colorado.

For headwaters of the North Platte River basin, extensive flow records were available for two USGS gage stations on the North Platte River upstream from large storage reservoirs:

- North Platte River at Saratoga, Wyoming; and
- North Platte River near Northgate, Colorado.

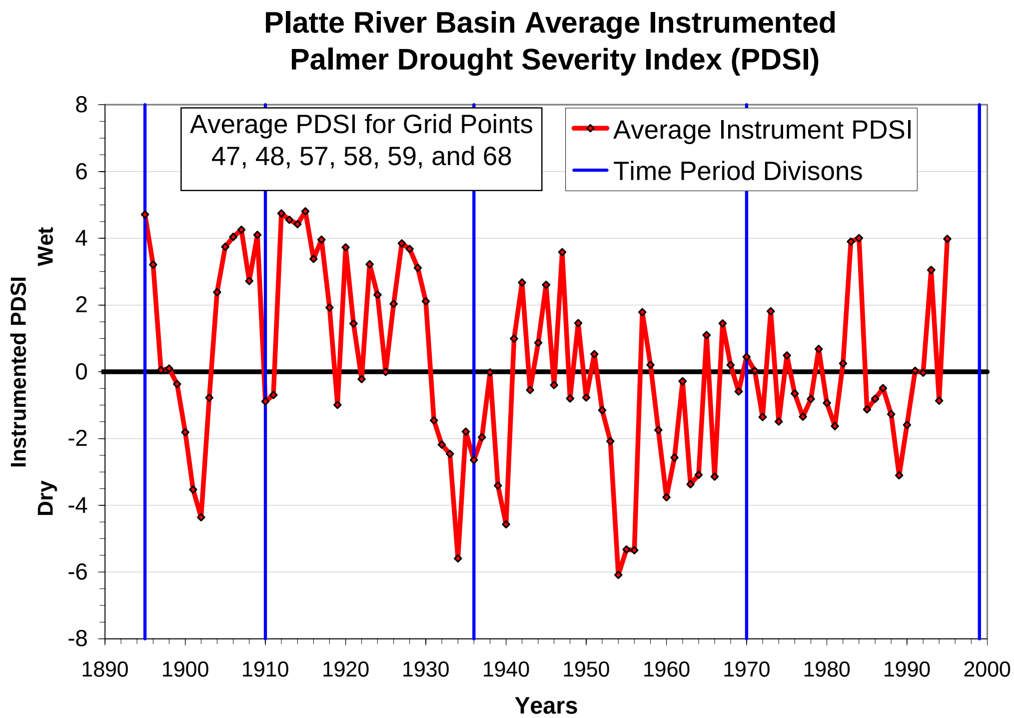


Figure 3.11 The average Palmer Drought Severity Index (PDSI) for the Platte River Basin, computed from PDSI values at grid points 47, 48, 57, 58, 59, and 68 (Figure 2.12), has been divided into four flow periods: 1895 to 1909, 1910 to 1935, 1936 to 1969, and 1970 to 1999. This average PDSI value is based on instrumented data available to year 1995, while the average PDSI value in Figure 2.13 is computed from tree-ring data available to year 1980.

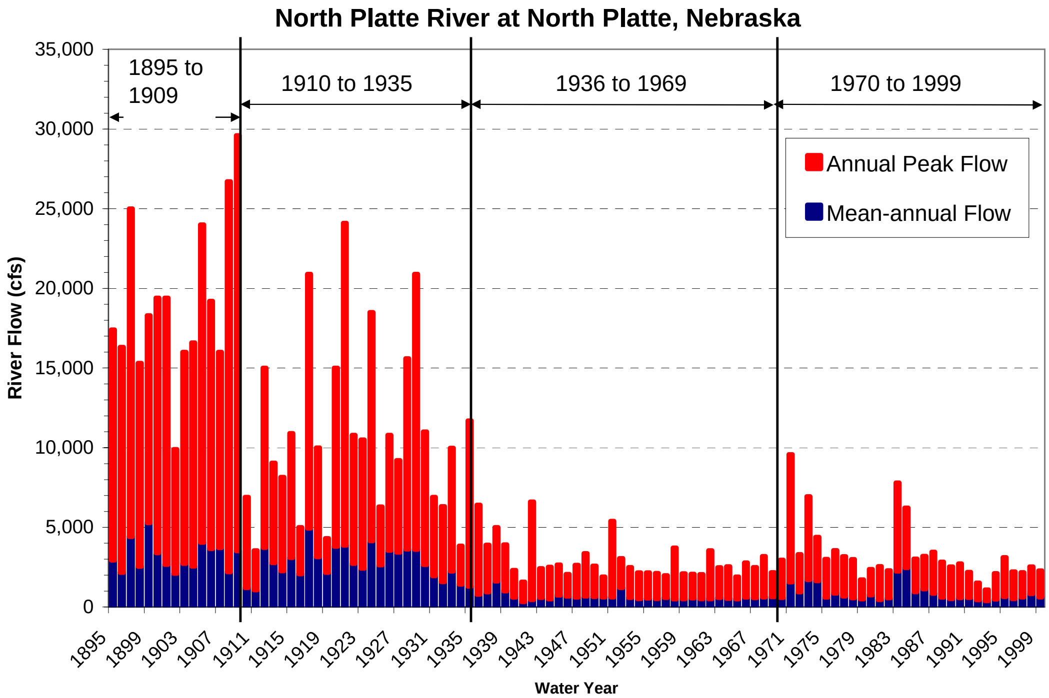


Figure 3.12 North Platte River at North Platte, Nebraska mean annual flow and annual peak flow (Randle and Samad, 2003).

The stream flow of these headwater branches would naturally vary from year to year more than in the main stem river, lower in the basin. Also, there is some farm and ranch land use upstream of the headwater gages, so the inclusion of some depletion effect may be exaggerating climate effects at these locations. Therefore the percent of climate-induced flow variation as measured at headwater gages may be higher than the actual climate-induced flow variation in the downstream mainstem of the North Platte and South Platte Rivers, and most notably in the mainstem of the central Platte River.

Stream flows for the headwater channels are compared to stream flows for mainstem channels, downstream of reservoirs and irrigation diversions, in Table 3.4 for mean annual flow and Table 3.5 for the 1.5-year flood peaks. The flow records have been divided into the four periods first introduced in Section 3.1.5.2. The percentage increase or decrease in flow for each stream, relative to the flow during the period 1910 to 1935, is shown in the last three columns in both tables. The period 1910 to 1935 was chosen as the reference period because stream flow data for this period were available for all gage stations, the time period was prior to construction of most large storage reservoirs, and the mean flows for this period were not the highest of the four periods.

Focusing on the shaded rows of each table that contain headwater streams only, it can be seen that the percent changes are not consistent in percentage, or consistent in being all reductions or increases, when comparing between mean and 1.5-year flood flows, or comparing between the North Platte and South Platte Basins. The individual values indicate no clear pattern of climatic influence on streamflow and can conflict even on reductions versus increases.

In contrast, the magnitude of the changes in mean flow and 1.5-year flood were consistent and greater for mainstem locations downstream of reservoirs including the North Platte River at North Platte, Nebraska, and the gage locations on the Platte River in Nebraska. The 1.5-year flood of the North Platte and Platte Rivers in Nebraska during the period 1895 to 1909, were 71 to 116 percent greater than during the period 1910 to 1935. In comparison, the 1.5-year flood for the North Platte River at Saratoga, Wyoming, during the period 1903 to 1909 were only 19 percent greater than during the period 1910 to 1935. The first period, 1903 to 1909, is prior to the establishment of the one-million-acre-foot Pathfinder Reservoir in 1909

Due to the large variability in individual values for headwater streams, average values of percent change are also considered. An average percent change in flow, compared to the 1910 to 1935 period, is computed for the North Platte headwater stations and the South Platte headwater stations. The next step in Tables 3.4 and 3.5 is to assess the degree that climate can account for the changes in flow noted at downstream mainstem locations. The average headwater value for percent change that is due presumably to climate, is then divided by the downstream mainstem value for percent change that is due presumably to both climate fluctuation and flow changes resulting from reservoir storage and irrigation diversion. The resultant value indicates the percent of flow fluctuation in downstream mainstem rivers that can be attributed to climate.

For the Platte River, the average flow change from the North Platte headwater gages are divided by the average flow change from the mainstem gages on the Platte River. The North Platte and

Table 3.4 — Maximum Percent of Changes in Mean Platte River Flows Presumed Attributable to Climate Fluctuations (Mean flows from Randle and Samad, 2003)							
	Mean Annual River Flows (ft³/s)				Percent Change in Mean Flow relative to the period 1910 – 1935		
Gage Station	1895-1909	1910-1935	1936-1969	1970-1999	1895-1909	1936-1969	1970-1999
North Platte River Basin							
North Platte R. nr. Northgate, CO		502	383	432		-24%	-14%
North Platte R. at Saratoga, WY	1,670	1,310	1,000		+27%	-24%	
A. Average change in N. Platte trib. flows					+27%	-24%	-14%
B. North Platte R. at North Platte, NE	3,190	2,750	646	862	+16%	-77%	-69%
(A./B.) Change in North Platte River flow attributable to climate fluctuation					**100%**[4]	**31%**[5]	**20%**
South Platte River Basin							
Clear Creek, CO	242	231	223	242	+5%	-4%	+5%
Middle Boulder Creek, CO	61	58	56	59	+5%	-2%	+2%
Cache La Poudre R. at canyon mouth, CO	464	409	320	352	+13%	-22%	-14%
St. Vrain River at Lyons, CO	153	131	118	126	+17%	-10%	-3%
Big Thompson R. at canyon mouth, CO	135	127	114	136	+6%	-10%	+7%
A. Average change in S. Platte trib. flows					+9%	-10%	-3%
B. South Platte R. at North Platte, NE	582	492	322	619	+18%	-35%	+26%
(A./B.) Change in South Platte River flow attributable to climate fluctuation					**50%**	**29%**	**0%**
Platte River Stations							
A. Average change in N. Platte trib. flows					+27%	-24%	-14%
Platte River at North Platte, NE	3,780	3,240	968	1,480	+17%	-70%	-54%
Platte River near Cozad, NE	3,550	3,040	461	981	+17%	-85%	-68%
Platte River near Overton, NE	3,660	3,160	1,140	2,100	+16%	-64%	-34%
Platte River near Grand Island, NE	3,580	2,950	1,080	2,110	+21%	-63%	-28%
B. Average change in mainstem flows					+18%	-71%	-46%
(A./B.) Change in central Platte River flow attributable to climate fluctuation, based on the average change for North Platte tributaries					**100%**	**34%**	**30%**

Shaded rows denote stream gages located upstream of large storage reservoirs and major irrigation.

[4] Of the 16% increase in mean annual flow for the North Platte River at North Platte (relative to the period 1910 to 1935), all of the increase is assumed attributable to natural climate variation due to the even greater percent of increase (27%) in mean annual flow in the headwater tributaries.
[5] Of the 77% reduction in mean flow, up to 31% (= -24% / -77%) can be attributed to natural climate variation.

Table 3.5 — Maximum Percent of Changes in 1.5-Year Flood for Platte River Flows Presumed Attributable to Climate Fluctuations (1.5-Year Flood flows from Randle and Samad, 2003)

Gage Station	1.5-Year Flood (ft^3/s)				Percent Change in 1.5-year Flood relative to the period 1910 to 1935		
	1895-1909	1910-1935	1936-1969	1970-1999	1895-1909	1936-1969	1970-1999
North Platte tributaries compared to the North Platte River							
North Platte R. nr. Northgate, CO		2,600	2,220	2,430		-15%	-7%
North Platte R. at Saratoga, WY	9,200	7,720	5,710		+19%	-26%	
A. Average change in 1.5-year flood peak for North Platte tributaries					+19%	-21%	-7%
B. North Platte R. at North Platte, NE	16,300	8,150	2,160	2,380	+100%	-73%	-71%
(A./B.) Change in the 1.5-year flood peak attributable to climate fluctuation					**19%**[6]	**29%**[7]	**10%**
South Platte tributaries compared to the South Platte River							
Cache La Poudre R. at canyon mouth, CO	3,103	2,700	2,492	2,737	+15%	-8%	+1%
St. Vrain River at Lyons, CO	898	744	962	904	+21%	+29%	+21%
A. Average change in 1.5-year flood peak for South Platte tributaries					+18%	+11%	+11%
B. South Platte R. at North Platte, NE	2,330	1,430	712	1,420	63%	-50%	-1%
(A./B.) Change in the 1.5-year flood peak attributable to climate fluctuation					**29%**	**0%**	**0%**
North Platte tributaries compared to the Platte River							
A. Average change in 1.5-year flood peak for North Platte tributaries					+19%	-21%	-7%
Platte River near Cozad, NE	17,600	9,140	1,980	2,590	+93%	-78%	-72%
Platte River near Overton, NE	19,400	9,000	3,490	4,750	+116%	-61%	-47%
Platte River near Grand Island, NE	17,300	10,100	4,500	6,010	+71%	-55%	-40%
B. Average change in 1.5-year flood peak for the Platte River					+93%	-65%	-53%
(A./B.) Change in the 1.5-year flood peak attributable to climate fluctuation, based on the average change for North Platte tributaries					**20%**	**32%**	**13%**

Shaded rows denote stream gages that are located upstream of large storage reservoirs and major irrigation.

[6] Of the 100% increase in 1.5-year flood for the North Platte River at North Platte, Nebraska (relative to the period 1910 to 1935) up to 19% (= +19% / +100%) can be attributed to natural climate variation.
[7] Of the 73% reduction in the 1.5-year flood peak, up to 29% (= -21% / -73%) can be attributed to natural climate variation.

South Platte headwater values were not averaged together for this calculation because the majority of Platte River flow originates from the North Platte River.

Based on average values for mean flows from Table 3.4, climate fluctuations for the first period when compared to the second period, could account for all of the differences in mean flow. However climate differences for the third and fourth periods, when compared to the second period, can only account for, at most, one-third of the differences in mean flow. When considering average values for the 1.5-year flood, climate differences for all periods can only account for, on an average, one-fifth of the differences noted in flow values. Due to attenuation effects and some depletion effects, this estimate of the impact climate influences have on changes in flow in the central Platte River should be regarded as high.

In summary, decreases in stream flow for the Platte River Basin were much greater downstream from storage reservoirs and major irrigation systems than upstream at headwater locations. The magnitude of change noted in mean flow and 1.5-year flood values for the South Platte River, North Platte River and Platte River in Nebraska can only partially be explained by fluctuations in climate. Based on measured headwater flows, the influence of climate fluctuation on South Platte River, North Platte River and Platte River flows can be placed no higher than one-third of the reductions noted in the third period (1936 to 1969), and less than that value in the fourth period (1970 to 1999).

3.1.6 Summary of Flow Changes

The mean, median, and 1.5-yr peak flows (Figures 3.1, 3.2, and 3.3) show a pattern of decreasing flows for the North Platte and central Platte Rivers, until the most recent period of 1970 to 1999. Flows in the most recent period began to significantly increase in the tributary headwater streams, but downstream from the storage reservoirs and diversion dams, stream flows did not approach the flow levels noted in the first two periods. The flow duration curves show high flows, those exceeded 20 percent of the time, for the North Platte River at North Platte, Nebraska (Figure 3.4) and the Platte River near Cozad, Overton, and Grand Island, Nebraska (Figures 3.6, 3.7, and 3.8), decreased substantially since the early 1900s. This decrease in flow frequency coincides with the construction of large storage reservoirs that retain spring flows for summer irrigation and for hydropower generation; and coincides with the construction of diversion systems that move large percentages of the flow through canal systems outside of the main river channel.

The decrease in flow volume is similar in magnitude to estimates of water consumption and depletion resulting from irrigation use, reservoir and canal evaporation, and from municipal use. Although some change in flow is expected as a result of fluctuations in climate, there is no general long-term trend of declining flows due to climate, and the pattern of climate fluctuation can only account for a value less than one-third of the recorded pattern of flow reductions. A one-third estimate of climate impacts based on tributary flows is considered high since no correction has been made for flow attenuation to the central Platte River, or for flow depletions in the tributaries.

3.2 CHANGES TO THE TEMPORAL DISTRIBUTION OF FLOWS

In addition to decreases in the flow volume that have been measured from the end of the nineteenth century to the present, the distribution of flows has also been altered. The construction of reservoirs, irrigation canals and hydropower canals in Nebraska has impacted the temporal distribution of the North Platte, South Platte and Platte River flows in that state.

The cumulative reservoir storage in the Platte River Basin is now 7.6 million acre-feet (Simons and Associates, 2000). This volume of reservoir storage is 2.9 to 9.2 times the mean annual flow rate of the Platte River near Overton, Nebraska, based on the mean flows of the four time periods presented in Table 3.4. This total reservoir storage volume significantly alters the natural flows of the Platte River. Mean river flows downstream would have been substantially reduced during the initial filling of these reservoirs and during subsequent refills. Conversely, downstream mean river flows would increase during periods of reservoir drawdown. However, peak river flows would be expected to significantly decrease downstream from the system of Platte River Basin reservoirs during nearly all years, with the greatest decrease occurring during periods when the reservoirs were drawn down.

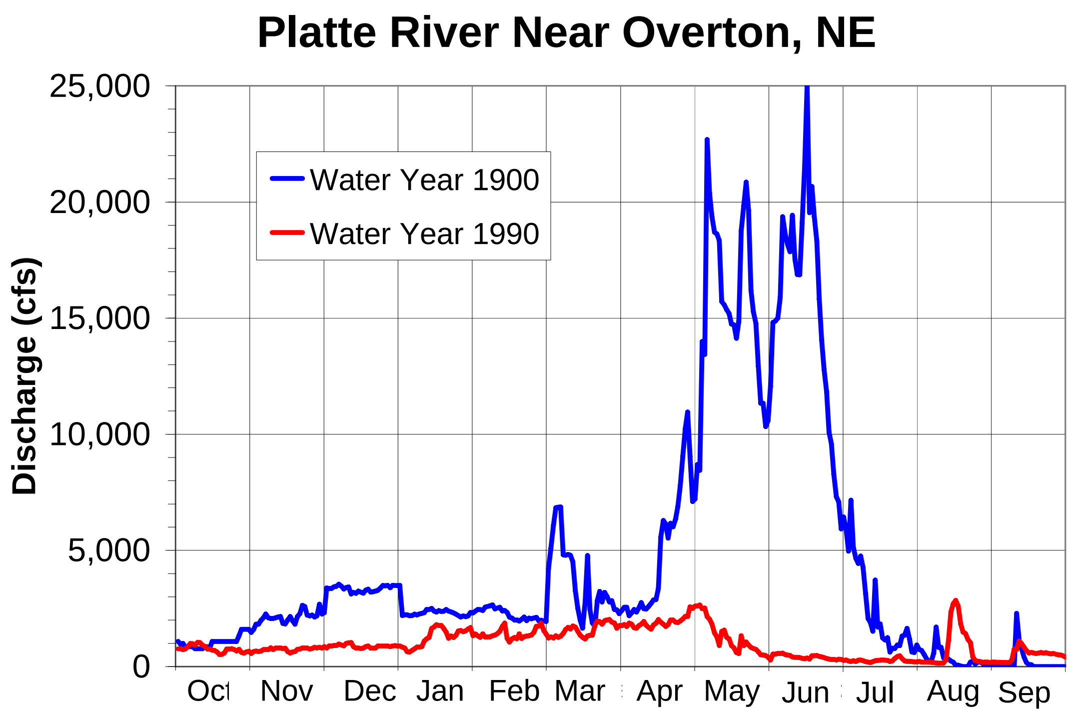


Figure 3.13 The comparison of hydrographs for water years 1900 and 1990 provide an example of how the annual flow volume and annual peak flow have substantially decreased over the twentieth century in response to water resource development in the Platte River Basin.

Before the construction of the first large dam, Pathfinder in 1910 (Figure 1.2), the annual peak river flow usually occurred in late-spring, typically in May or June, due to spring runoff from the Rocky Mountains in Colorado. The hydrographs for water years 1900 and 1990 are presented in Figure 3.13 to compare how the annual peak flow has changed over the 20th century in response to a large decrease in flows associated with the spring runoff. The year 1990 was selected for comparison to year 1900 since it had the most comparable average Palmer Drought Severity Index (PDSI) from the period 1970 to 1995. The average PDSI value based on instrumented data for the Platte River basin (Figure 3.11) is -1.8 in 1900, and -1.6 in 1990, indicating that both years were similarly dry.

Early records from USGS gage stations on the North Platte River at North Platte, Nebraska (USGS Water Supply Papers, 1895-1909), the South Platte River at Denver, Colorado (USGS Water Supply Papers, 1895-1909) and at Julesburg, Colorado (USGS Water Supply Papers, 1902-1909), and the Platte River at Duncan, Nebraska (USGS Water Supply Papers, 1895-1909) contain records indicating large late spring flows on the Platte River. These flows were large enough to carry a large sediment load of medium sand and to maintain wide, shallow, channels of shifting sand.

The annual peak flows and the mean annual flows for the North Platte River at North Platte, Nebraska are presented in Figure 3.1 for the period of record (1895 to 1999). During the period 1902-1909, the average annual Platte River peak flow (average of the annual maximum of mean daily flows) calculated from stream gage data near North Platte, Nebraska was 20,500 ft^3/s and the mean annual flow rate was 2,900 ft^3/s (Stroup et al. 2001). Randle and Samad (2003) calculated the mean and median river flows and the 1.5-year floods for four different time periods from 1895 to 1999 for the North and South Platte Rivers at North Platte, Nebraska and the Platte River near Cozad, Overton, and Grand Island, Nebraska (Tables 3.6, 3.7, and 3.8 and Figures 3.6, 3.7, and 3.8).

The highest elevation sandbars were most likely formed during the large spring floods. The summer flows were generally much smaller than the spring flows, which left dry sand bars surrounded by water for the building of nests by the least tern and piping plovers. Summer thunderstorm flows were small compared to the spring flows, and nests built on the higher portions of sand bars were not as easily washed away. Johnson (1994) reviewed surveyor's notes over the period 1859-1875 and reported that the Platte River commonly had low flows in the summer. During the late 1800s and early 1900s there were numerous summer days with dry river beds along reaches of the channel (Lamb et al. 1911, Schumm 1998). Water then filled portions of the shallow channel during fall, winter, and early spring. The shallow water of the historic channel provided the wide, open view used by whooping cranes for roosting during the fall and spring over a substantial range of flow rates (U.S. Fish and Wildlife Service, 1981). Low summer flows provided dry sand bars surrounded by water, similar to those still found on the lower Platte River, downstream from Duncan, Nebraska.

Table 3.6 — Mean Platte River flows (Randle and Samad, 2003)				
Mean River Flows (ft^3/s) for each time period				
Gage Station	1895 to 1909	1910 to 1935	1936 to 1969	1970 to 1999
North Platte River at Northgate, CO		502	383	432
North Platte River at Saratoga, WY	1,670	1,310	1,000	
North Platte River at North Platte, NE	3,190	2,750	646	862
South Platte River at North Platte, NE	582	492	322	619
Platte River at North Platte, NE	3,780	3,240	968	1,480
Platte River near Cozad, NE	3,550	3,040	461	981
Platte River near Overton, NE	3,660	3,160	1,140	2,100
Platte River near Grand Island, NE	3,580	2,950	1,080	2,110

Table 3.7 — Median Platte River flows (Randle and Samad, 2003)				
Median River Flows (ft^3/s) for each time period				
Gage Station	1895 to 1909	1910 to 1935	1936 to 1969	1970 to 1999
North Platte River at North Platte, NE	1,820	2,390	419	410
South Platte River at North Platte, NE	296	239	156	218
Platte River near Cozad, NE	2,020	2,530	236	274
Platte River near Overton, NE	2,110	2,600	1,000	1,470
Platte River near Grand Island, NE	1,970	2,430	850	1,510

Table 3.8 — Platte River 1.5-year flood (Randle and Samad, 2003)				
1.5-year flood (ft^3/s) for each time period				
Gage Station	1895 to 1909	1910 to 1935	1936 to 1969	1970 to 1999
North Platte River at Northgate, CO		2,600	2,220	2,430
North Platte River at Saratoga, WY	9,200	7,720	5,710	
North Platte River at North Platte, NE	16,300	8,150	2,160	2,380
South Platte River at North Platte, NE	2,330	1,430	712	1,420
Platte River near Cozad, NE	17,600	9,140	1,980	2,590
Platte River near Overton, NE	19,400	9,000	3,490	4,750
Platte River near Grand Island, NE	17,300	10,100	4,500	6,010

3.3 CHANGES TO SEDIMENT TRANSPORT AND SEDIMENT SIZE

During the period 1895 to 1909, prior to the construction of Pathfinder Dam, average annual sediment loads of the Platte River near Cozad, Nebraska were between 4 and 5 time greater than during the most recent time period, 1970 to 1999 (Randle and Samad, 2003). The earliest grain-size data indicates that the median grain size of the river bed in 1930-31 was medium sand (Figure 3.14, U.S. Army Corps of Engineers, 1935). During the period before Pathfinder Dam, open channel widths were on the order of a mile wide and the high flow rates and shifting sand bars of the braided river kept the channel relatively free of vegetation (Lyons and Randle, 1988, Peak, Peterson, and Laustrup 1985).

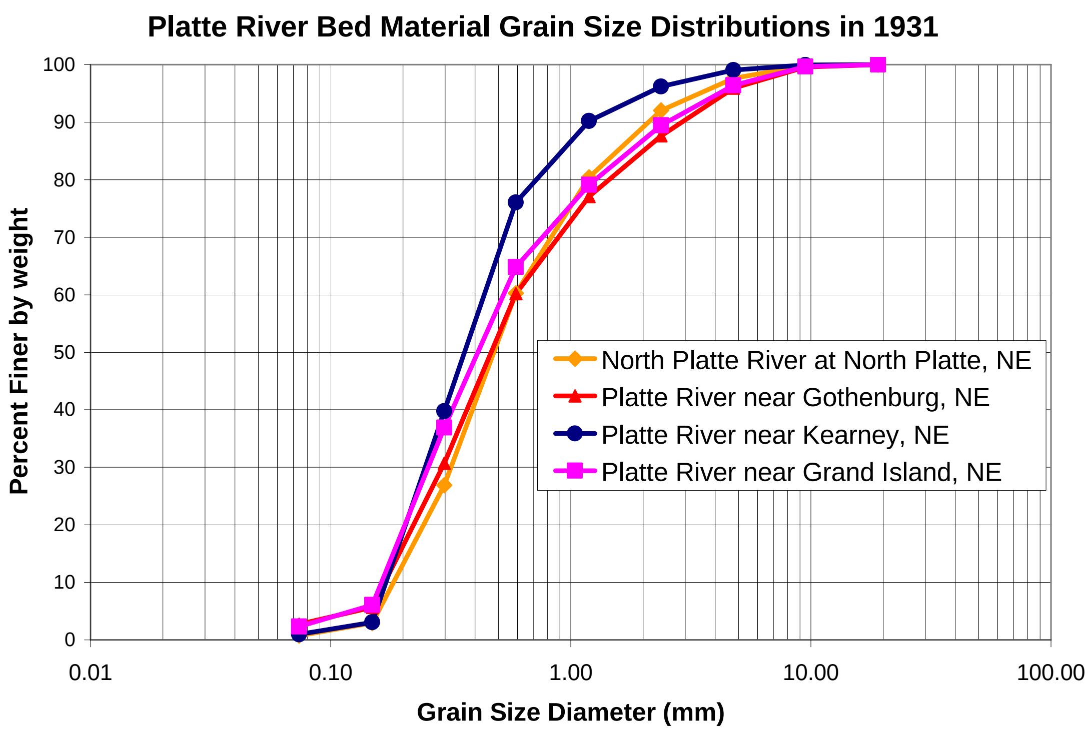


Figure 3.14 Platte River Bed Material Grain Size Distributions in 1931 (U.S. Army Corps of Engineers, 1935).

The North Platte River supplied most of the water and sand to the Platte River, and Figure 3.15 shows the uniformity of the median grain size (d_{50}) of the sand along the North Platte and Platte Rivers. The South Platte River also supplied significant quantities of water and sand, but less than that supplied by the North Platte River (Randle and Samad, 2003 and Simons & Associates, 2000). The South Platte River sand supply was coarser than the supply from the North Platte River (Slichter and Wolff, 1906, Smith, 1970, Kircher 1983). South Platte River grain size distributions are shown in Figure 3.16. The same constant slope and the uniformity of the sand grain size of the North Platte and Platte Rivers indicate that most of the sand (median diameter 0.4 mm) supplied to the central Platte River came from the North Platte River.

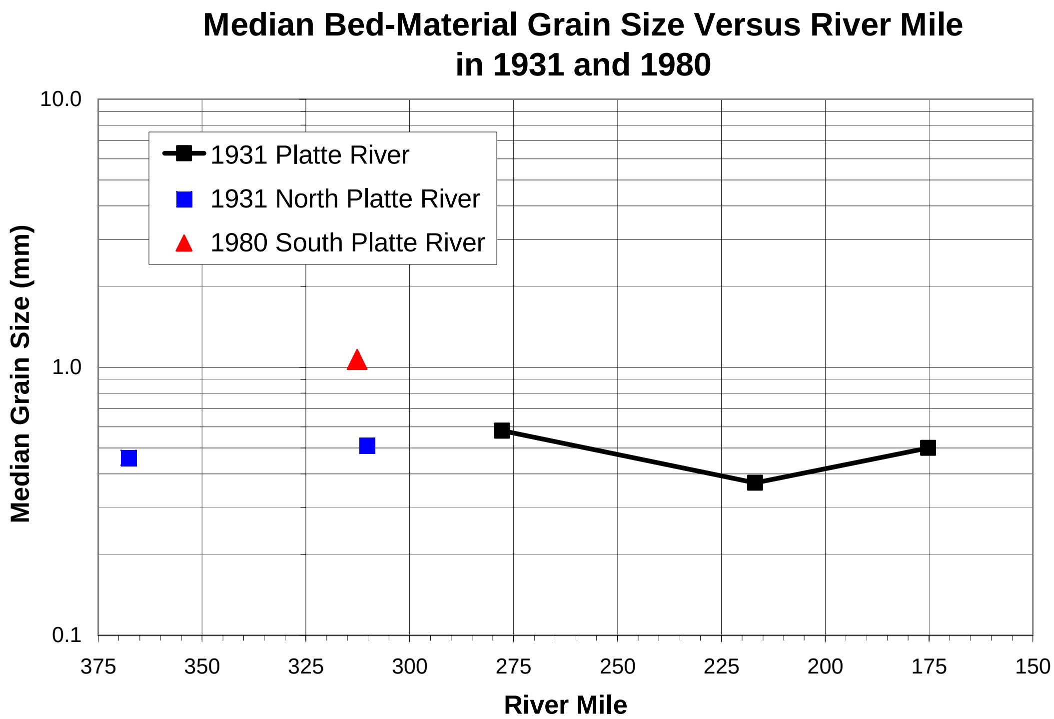


Figure 3.15 Median bed-material grain size versus river mile in 1931 and 1980.

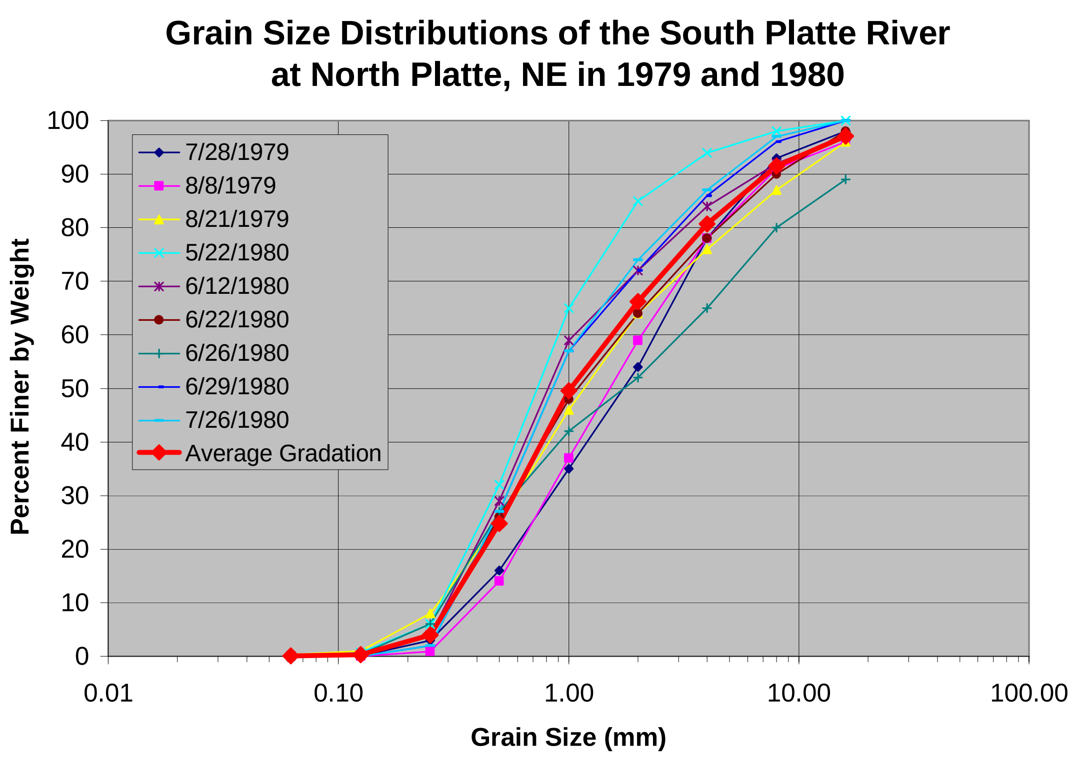


Figure 3.16 Bed Material Grain Size Distributions of the South Platte River at North Platte, Nebraska in 1979-1980.

3.3.1 Sediment Supply and Transport

The large storage reservoirs of the North Platte River trap the sand load and reduce the sand supply to the North Platte River immediately downstream from each reservoir. Most of the sand supply to the South Platte River is downstream from the large reservoirs on that watershed. Therefore, sand loads of the South Platte River, at North Platte, Nebraska, are much less affected by storage reservoirs than the sand loads of the North Platte River at North Platte, Nebraska.

Randle and Samad (2003) applied three different sediment transport functions to the record of mean-daily river flows represented by the flow-duration curves presented in Figures 3.4 to 3.8. The sediment-discharge rating curves presented by Simons & Associates (2000) and the rating curves presented by Kircher (1983) represented two of the sediment transport functions. The third sediment transport function was in the form of a numerical sediment transport model developed by Murphy et al. (Draft 2003). The set of sediment-discharge rating curves presented by Simons & Associates (2000) are presented in Figure 3.17 and the set of curves presented by Kircher (1983) are presented in Figure 3.18. Average annual sediment loads were computed for four time periods and five different gage stations. All three sediment transport functions were applied independently and all three functions produced the same trends in the average annual sediment loads (Figures 3.19, 3.20, and 3.21, and Tables 3.9, 3.10, and 3.11).

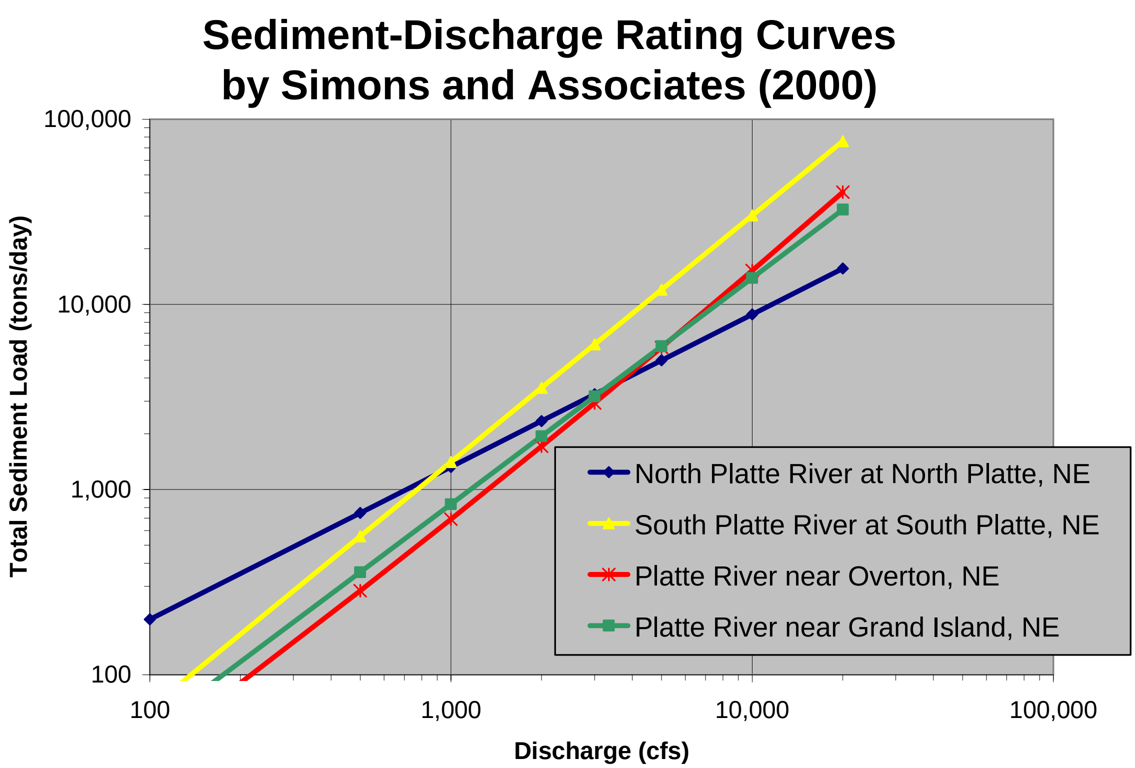


Figure 3.17 Platte River Sediment-Discharge Rating Curves by Simons and Associates (2000).

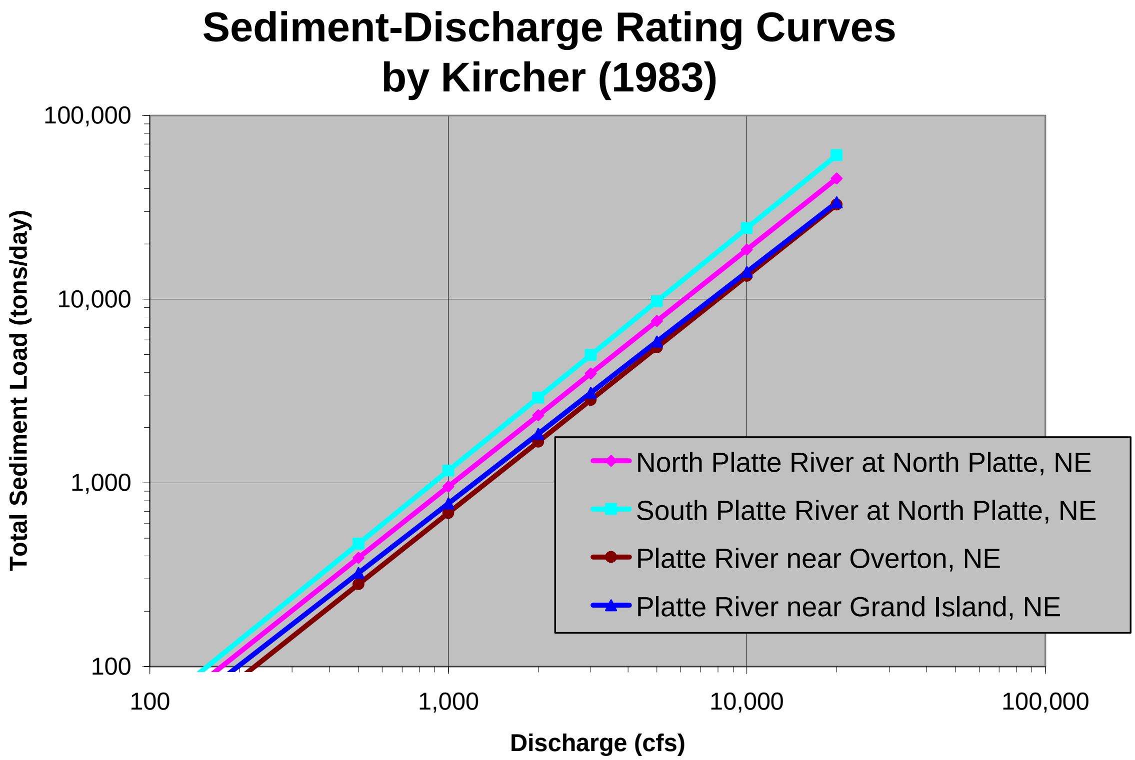


Figure 3.18 Platte River Sediment-Discharge Rating Curves by Kircher (1983).

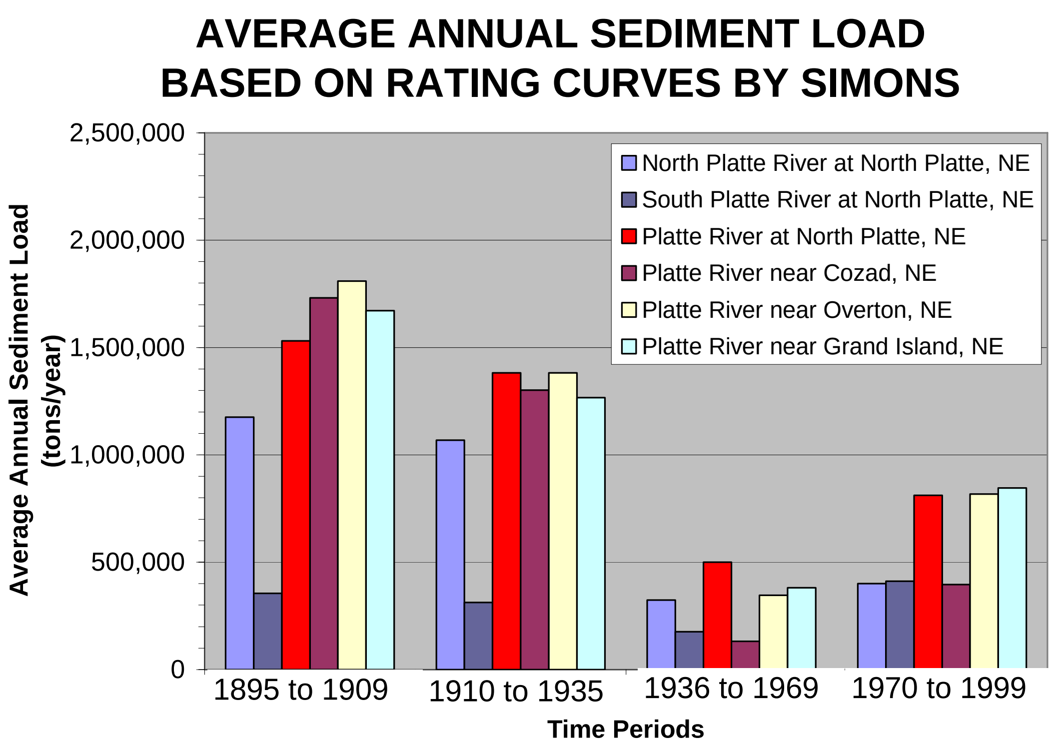


Figure 3.19 Platte River average annual sediment load based on sediment-discharge equations by Simons and Associates, Inc. (2000).

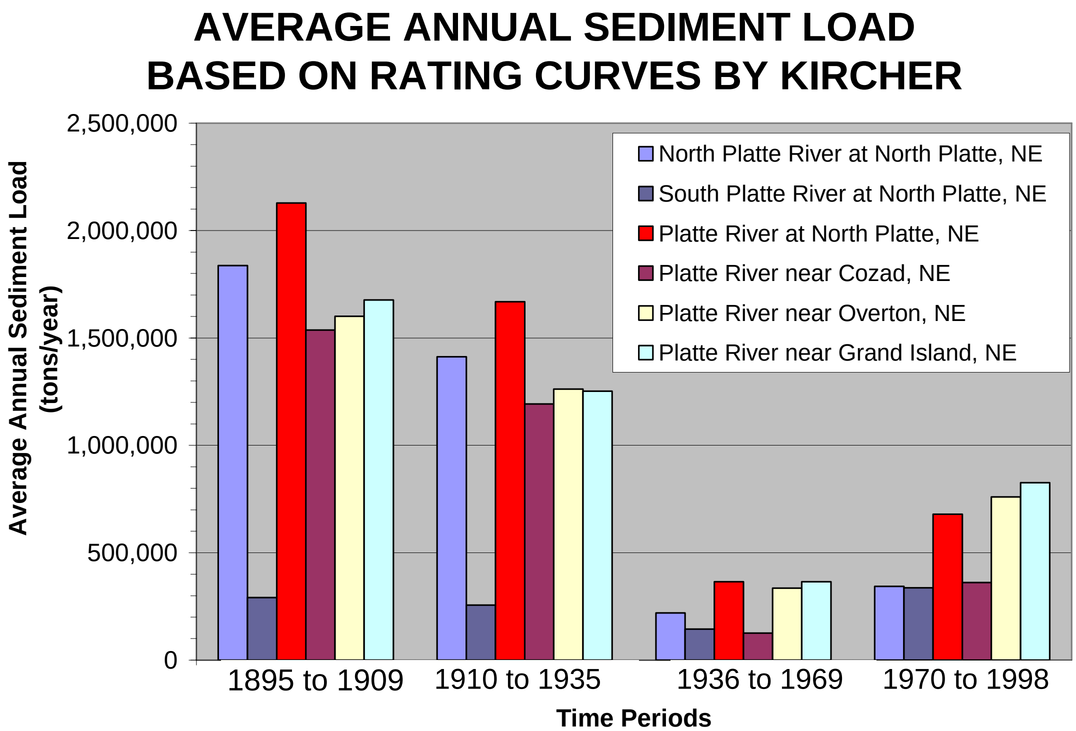


Figure 3.20 Platte River average annual sediment load based on sediment-discharge equations by Kircher (1983).

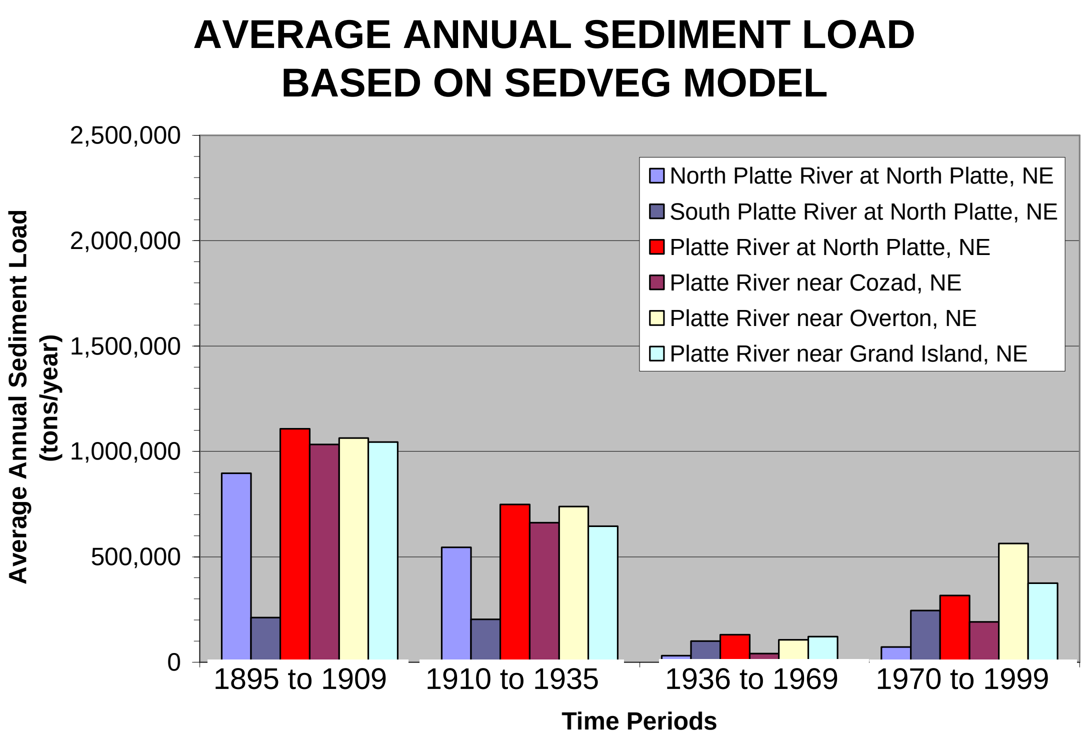


Figure 3.21 Platte River mean annual bed-material load based on the sediment transport model by Murphy et al. (Draft 2003).

Table 3.9 — Platte River average annual sediment loads based on sediment discharge equations by Simons and Associates, Inc. (2000), from Randle and Samad (2003)				
	Average annual sediment load (tons/year) for each time period			
Platte River stream gage location	1895 to 1909	1910 to 1935	1936 to 1969	1970 to 1999
North Platte River at North Platte, NE	1,180,000	1,070,000	324,000	400,000
South Platte River at North Platte, NE	355,000	313,000	176,000	411,000
Platte River at North Platte, NE	1,530,000	1,380,000	500,000	812,000
Platte River near Cozad, NE	1,730,000	1,300,000	132,000	396,000
Platte River near Overton, NE	1,810,000	1,380,000	347,000	817,000
Platte River near Grand Island, NE	1,670,000	1,270,005	381,000	845,000

Table 3.10 — Platte River average annual sediment loads based on sediment discharge equations by Kircher (1983), from Randle and Samad (2003)				
	Average annual sediment load (tons/year) for each time period			
Platte River stream gage location	1895 to 1909	1910 to 1935	1936 to 1969	1970 to 1999
North Platte River at North Platte, NE	1,840,000	1,410,000	220,000	343,000
South Platte River at North Platte, NE	292,000	256,000	145,000	337,000
Platte River at North Platte, NE	2,130,000	1,670,000	365,000	680,000
Platte River near Cozad, NE	1,540,000	1,190,000	126,000	361,000
Platte River near Overton, NE	1,600,000	1,260,000	335,000	760,000
Platte River near Grand Island, NE	1,680,000	1,250,000	365,000	826,000

Table 3.11 — Platte River average annual sediment loads based on the sediment transport model by Murphy et al. (Draft 2003), from Randle and Samad (2003)				
	Average annual sediment load (tons/year) for each time period			
Platte River stream gage location	1895 to 1909	1910 to 1935	1936 to 1969	1970 to 1999
North Platte River at North Platte, NE	896,000	545,000	31,000	71,900
South Platte River at North Platte, NE	212,000	203,000	99,600	245,000
Platte River at North Platte, NE	1,110,000	748,000	131,000	317,000
Platte River near Cozad, NE	1,030,000	662,000	40,900	191,000
Platte River near Overton, NE	1,060,000	739,000	106,000	562,000
Platte River near Grand Island, NE	1,040,000	645,000	121,000	374,000

For the periods 1895 to 1909 and 1910 to 1935, the average annual sediment loads of North Platte River were much greater than the sediment loads of the South Platte River. For these same two time periods, the combined average annual sediment loads of the North and South Platte Rivers were roughly equal to the average annual sediment loads of the Platte River near Cozad, Overton, and Grand Island. In contrast, during the 1970 to1999 period, average annual sediment loads from the South Platte River were as much or more than the average annual sediment loads from the North Platte River. Thus, during the 1970 to 1999 period, the South Platte River became a more significant source of sand to the central Platte River, but with a coarser grain size.

The importance of the different sources of sand, and the locations of deposition and erosion reaches of the Platte River, can be seen from the comparisons of average annual sediment loads at the five different locations during the four different time periods presented in Figures 3.19, 3.20, and 3.21 and Tables 3.9, 3.10, and 3.11. In all three Figures there are common elements of importance (Randle and Samad, 2003):

- During the 1895 to1935 period, the North Platte River supplied much more sand to the Platte River than did the South Platte River.

- During the 1936 to1999 period, the South Platte River supplied as much or more sand to the Platte River than did the North Platte River.

- During the 1895 to1935 period, the Platte River sediment loads were nearly the same along the Platte River from the cities of North Platte to Grand Island, Nebraska.

- During the 1936 to1999 period, the Platte River sediment loads at North Platte, Nebraska were much higher than the sediment loads near Cozad, Nebraska causing deposition in the 70-mile reach between North Platte, Nebraska and the Johnson-2 return channel.

- During the 1936 to 1999 period, the sediment loads in the central Platte River at the gages near Overton and Grand Island, Nebraska were much higher than at the gage near Cozad, Nebraska, reflecting erosion in the reach downstream from the Johnson-2 return channel.

In addition to the average annual sediment loads, computed using the three separate sediment transport functions, the present management of sediment movement at the Tri-County Diversion Dam provides data on the minimum amount of sand moving downstream. Proper operation of the diversion dam means that the diversion of sediment into the canal should be minimized. Therefore, a hydraulic dredge was employed to pump the sand deposited in the pool behind the dam into the downstream channel. Roughly 100,000 tons of sand was dredged each year (Boyd 1995). The minimum flow rate of 100 cfs released to the downstream river channel and the occasional high flows may not be enough to prevent deposition in the downstream channel. Repeat cross section surveys in 1989 and 1998 showed four feet of aggradation at the two cross sections immediately below the diversion dam.

3.3.2 Bankfull Discharge and Effective Discharge

The sediment transport balance of a natural river channel is frequently characterized by the sediment transport caused by one particular flow called the bankfull discharge (Vanoni, 1975 and Leopold, et. al, 1964). This flow is associated with the sediment transport rate that shapes the natural channel, and statistical measures of the flows associated with the duration and intensity of sediment transport, called the "effective discharge", is often considered equal to the bankfull discharge (Wolman and Miller 1960, Andrews 1980). However, Soar and Thorne (2001) found that the effective discharge, computed using equal discharge increments, was less than the bankfull discharge at 86 percent of the 58 sites they investigated.

Effective discharge is defined as the river flow which carries the most sediment over a period of a few decades, and characterizes the flow that forms the time-averaged, morphologic characteristics of the river channel. Randle and Samad (2003) computed four indicators of bankfull discharge for four time periods from 1895 to 1999 for the North and South Platte Rivers at North Platte, Nebraska and the Platte River near Cozad, Overton, and Grand Island, Nebraska. The bankfull discharge indicators were computed for each location and time period using the three different sediment transport functions.

- The 1.5-year flood peaks were computed as indicators of the bankfull discharge. Leopold (1994) stated that most investigations have concluded that the bankfull discharge recurrence intervals range from 1.0 to 2.5 years and is often assumed to have a recurrence interval of 1.5 years. For 58 sand bed rivers in the United States that were thought to have stable channels, 83 percent had a bankfull discharge with a recurrence interval of between 1 and 2 years (Soar and Thorne, 2001).

- The effective discharge values were computed by dividing the flow record into 20 arithmetic or equal discharge increments (Biedenham et al. 2000). The effective discharge computed using this method was then adjusted to the bankfull discharge using the equation presented by Soar and Thorne (2001). This empirical equation is a function of the percentage of long-term sediment load transported by river flows up to the effective discharge.

- The effective discharge values were also computed by dividing the flow record into 19 probability increments (Strand and Pemberton, 1982, Miller, 1951).

- The median sediment transporting discharge values were computed as indicators of the bankfull discharge. The median sediment transporting discharge separates the record of stream flows so that half the sediment load is transported by discharges that are lower while the remaining half is transported by discharges that are greater. The median sediment transporting discharge is determined from a cumulative frequency analysis of discharge and sediment load. This method also yields the discharges that correspond to quartiles of cumulative sediment load (0 to 25 percent, 25 to 50 percent, 50 to 75 percent, and 75 to 100 percent).

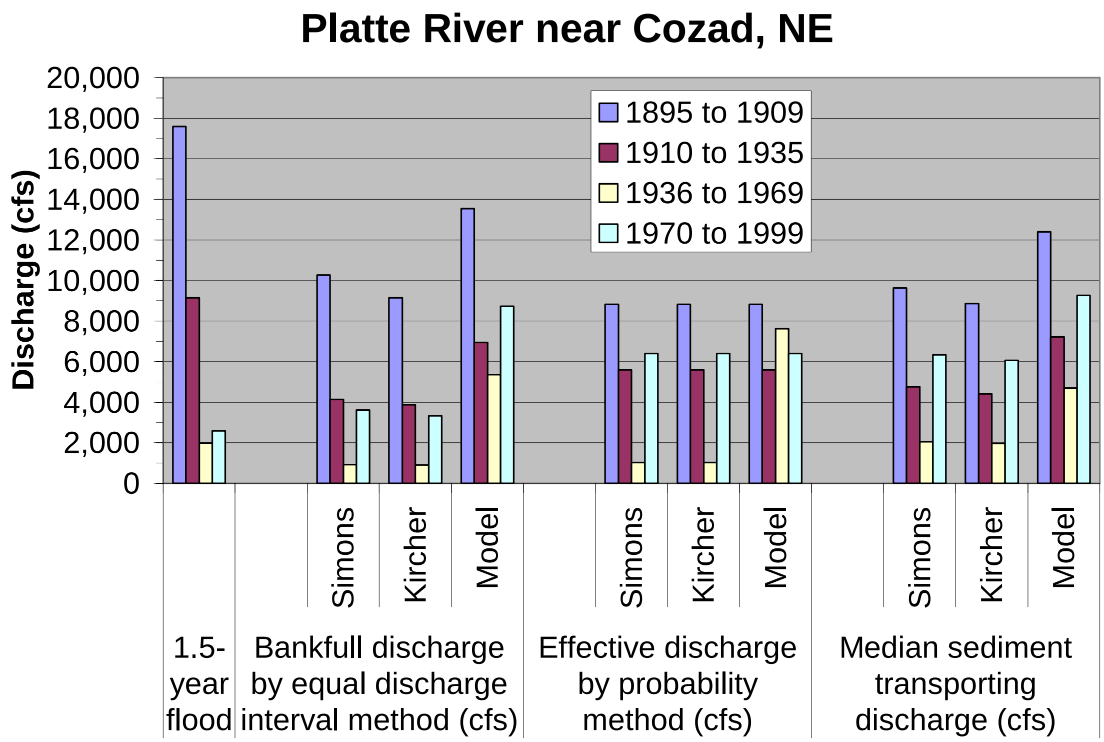


Figure 3.22 Comparison of bankfull discharge indicators for the Platte River near Cozad, Nebraska.

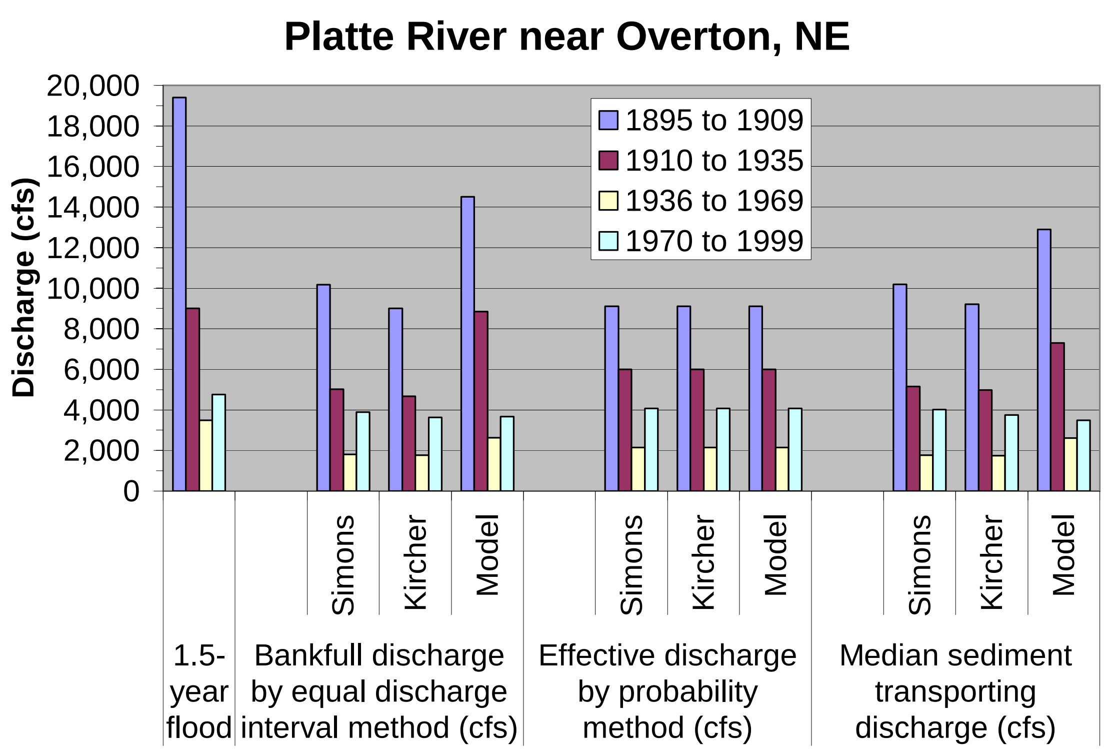


Figure 3.23 Comparison of bankfull discharge indicators for the Platte River near Overton, Nebraska

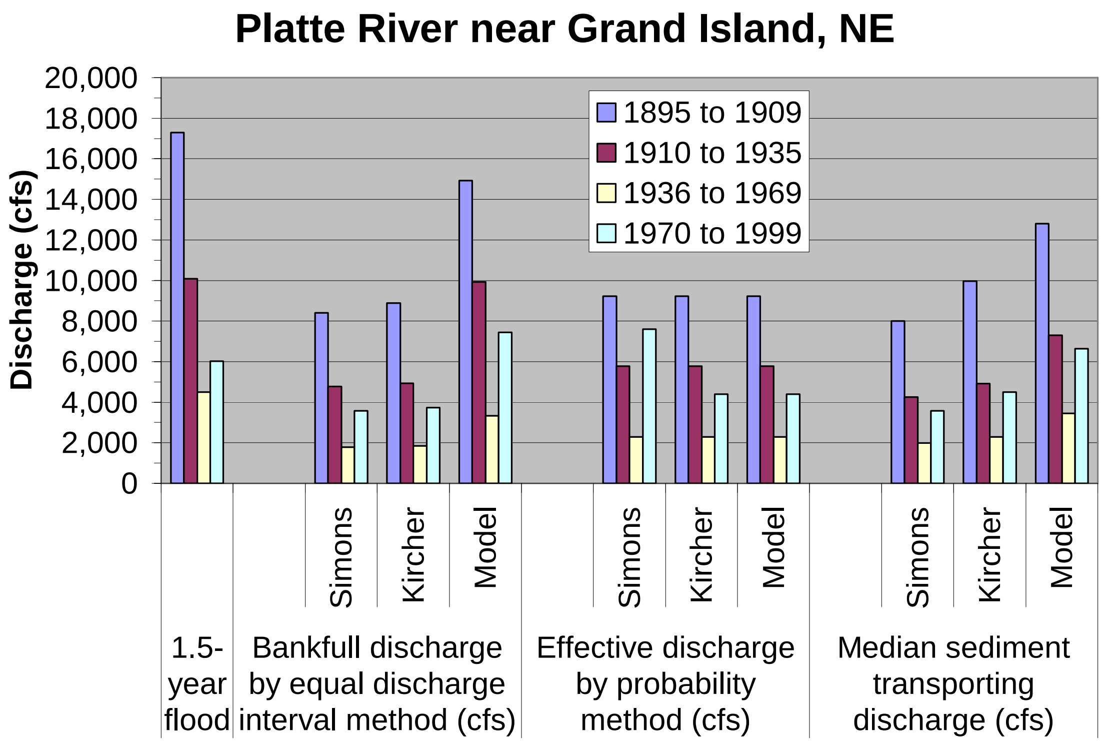


Figure 3.24 Comparison of bankfull discharge indicators for the Platte River near Grand Island, Nebraska.

The comparisons of these four indicators of bankfull discharge for the Platte River near Cozad, Overton, and Grand Island, Nebraska are presented in Figures 3.22, 3.23, and 3.24. The indicators of bankfull discharge were greatest during the first time period (1895 to 1909), were lower during the second time period (1910 to 1935), and decreased again to their lowest values during the third time period (1936 to 1969). The indicators of bankfull discharge increased during the fourth time period (1970 to 1999). During the first two time periods the indicators of bankfull discharge were nearly the same for the Platte River near Cozad and Overton, Nebraska. However, the differences in these indicators are significant between the gage stations near Cozad and Overton, Nebraska the during the third and fourth time periods. This is due to large flow diversions through the Tri-County Canal, which bypass the gage station near Cozad, Nebraska. The indicators of bankfull discharge show a significant decrease over the Twentieth Century (Randle and Samad, 2003).

3.4 CHANGES TO THE BASIN STRUCTURE

The general structure of the Platte River Basin has changed in the twentieth century from the pre-development river that evolved over geologic time. The basin structure, used here to describe the location of flow inputs and sediment sources, has been altered, and the number of structural features imposing vertical or horizontal restraints on the river has increased. Structural features can include geologic formations or features constructed by man.

3.4.1 Spatial Re-Distribution of Flow and Sediment Inputs

The central Platte River in the pre-development period presumably received the majority of flow and sand from the North Platte River. Downstream of the confluence there were small increases in flow from tributaries such as Pawnee Creek, Spring Creek, Buffalo Creek, Plum Creek and Wood River. There were also small flow increases from groundwater seepage between the confluence of the North and South Platte Rivers, and the present day town of Cozad Nebraska, and some flow lost to groundwater seepage between the present day towns of Cozad and Chapman, Nebraska. In general, during the pre-development period there were no significant or abrupt gains or losses in flow, and correspondingly no significant changes to sediment load, in the Platte River between the confluence of the North and South Platte Rivers, and the downstream confluence with the Loup River near present day Columbus, NE.

In contrast, the present-day system of diversion dams, canals, and reservoirs within Nebraska's portion of the Platte River Basin produces distinct discontinuities in the North Platte and Platte River discharge. A schematic of the system is shown in Figure 3.25. The Keystone Diversion Dam diverts 69 percent of the North Platte River average annual flow through the Sutherland Supply Canal for a distance of 58 river miles, and the Korty Diversion Dam diverts 45 percent of average annual flow from the South Platte River to the Sutherland Supply Canal. The water from these diversions is returned to the South Platte and the Platte River for a distance of 4.5 miles near the confluence, where the river approaches natural flows for this short distance. The Central Diversion Dam at North Platte, Nebraska then removes about 73 percent of the Platte River average annual flow, to be conveyed through the Tri-County Canal for a distance of 61 miles, before returning the flow to the Platte River between Lexington and Overton, Nebraska. There are also additional canals including the Western Canal, Gothenburg Canal and Six-Mile Orchard-Alfalfa Canal that divert lesser flows. In comparison to the pre-development system that exhibits no significant change in flows or sediment transport in the downstream direction, the current system has several abrupt and significant decreases and increases in these variables. Figure 3.25 and Figure 2.18 from the previous chapter illustrate the flow irregularities.

The present day changes to the river have altered the pre-development structure of the basin. Essentially the North Platte River becomes a minor tributary at the confluence, and the South Platte River becomes a major tributary only directly upstream of the confluence. The diversion for the Tri-County Canal directly below the confluence becomes a substantial branching or drain of flows, but not of sediment. This configuration not normally found in a natural system where river channels customarily branch in the upstream not downstream direction. Finally, the J-2 return for the Tri-County Canal, 61 miles downstream, functions as a new and major tributary to the Platte River. The North Platte River and South Platte River discharge less sediment due to their reduced discharge, and the two returns that function as tributaries discharge almost no sediment. A diagram comparing flow inputs and volumes, representing some elements of basin structure, for pre-development and present conditions is shown in Figure 1.5.

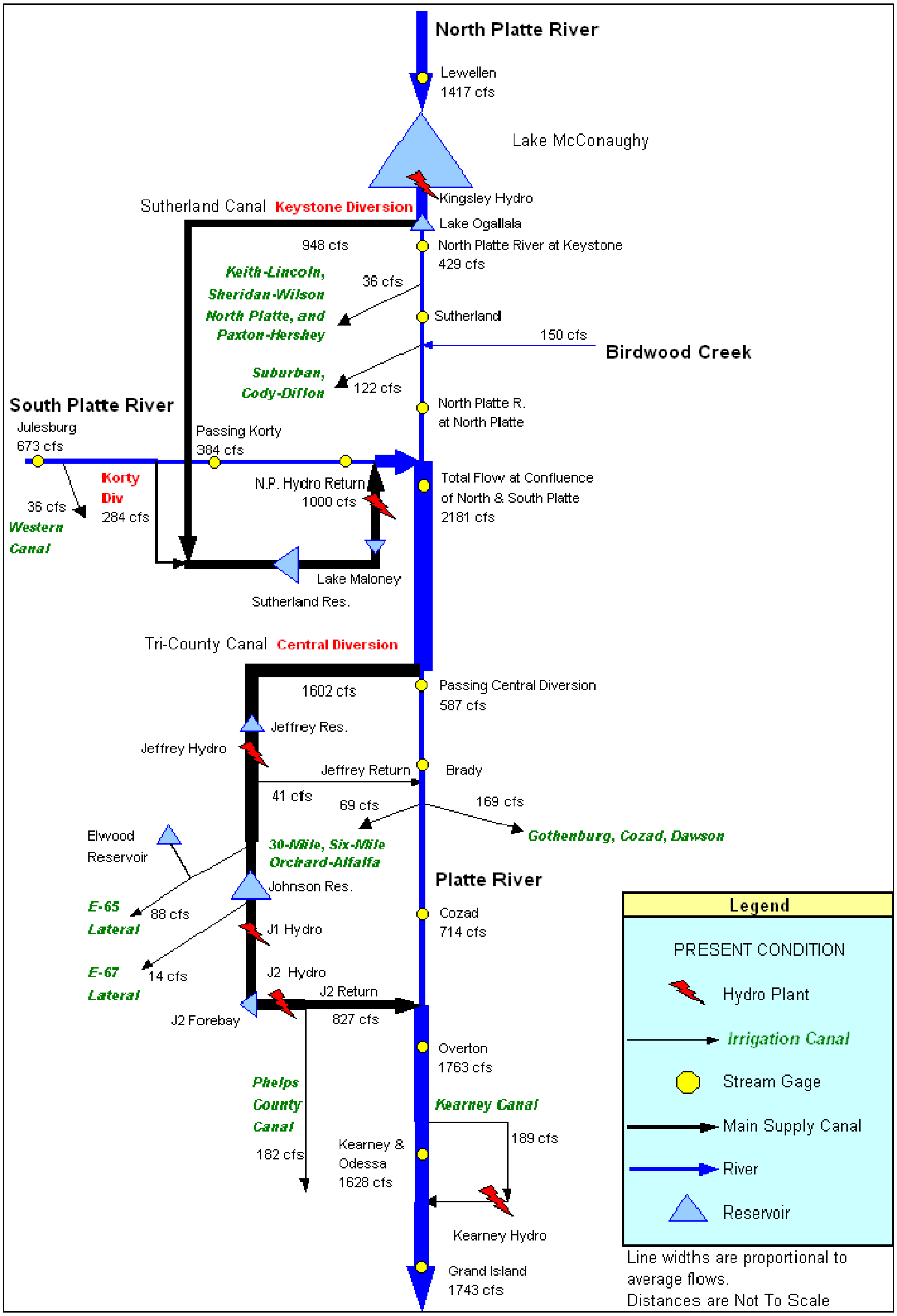


Figure 3.25 Schematic of Water Resource Infrastructure along the North Platte, South Platte, and Platte Rivers. The width of each channel is scaled to the average annual flow rate for the period 1947 to 1994.

3.4.2 Geologic and Man-made Structures

There are relatively few geologic formations that acted as controls on the pre-development central Platte River. Presumably, there was and is a vertical elevation control or base level control in the vicinity of present day Columbus, Nebraska, due to either glacial till or bedrock in this area. Because of the consistent grade beginning near the Loup confluence and extending up the North Platte, it can be assumed that the base level control near Columbus has been fixed for an extensive period.

A second structural control may have been the lower layer of the Grand Island Formation composed of coarser fluvial sands and gravel. By the end of the pre-development period, the erosive energy from a relatively stable regime of pre-development flows and sediment transport, and the erosion resistance of the sediment gradation in the lower layer of the Grand Island formation may have reached a balance. There was no further incision but some aggradation under the general pattern of climate.

In the twentieth century, the geologic base level control near Columbus is presumably still acting. However, the Grand Island formation may no longer be a vertical control under new flow and sediment transport conditions notably at locations of canal return flows. In addition to geologic features, man-made structures can affect the basin structure. For example, the Kearney Diversion Dam across the Platte River, Near Kearney, Nebraska, may be a new vertical control as indicated by plan form, locally influencing the upstream grade of the Platte River. Temporary sand dams and partial diversion dams constructed across portions of the Platte River, upstream of Lexington, Nebraska, may also act as local vertical controls, but this effect is difficult to define since the sand dams, acting as an extension of the diversion dam on side channels, are intended to fail at high flows.

Constructed horizontal controls are provided at the more than 30 locations by railroad and road crossings. Foundation abutments of bridges are normally protected when exposed to erosion, thereby acting as hard points to prevent the lateral migration of the channel. Infrastructure such as roads, railroads and town facilities are sometimes protected with rock revetment to harden the bank and prevent lateral migration of main or side channels.

Figure 1.5 does not show the geomorphically relevant features of added vertical and horizontal controls in the twentieth century, or changes in location or volume of sediment inputs. But on the basis of flow volume changes and locations of major tributaries (flow inputs) and diversions illustrated in Figure 1.5, it can be seen that the central Platte River in the pre-development period is a different river from the central Platte River of today. What is also significant is that the basin structure changes between the pre-development and present river, have been implemented primarily in the twentieth century at a much faster pace than most geologic changes induced by climate factors in the pre-development period.

4.0 CHANNEL RESPONSE TO CHANGED CONDITIONS

Anthropogenic factors acting on the Plate River Basin during the twentieth century have had a dominant impact on the form of the central Platte River channel. The changes to primary elements of the channel: flow, sediment transport, and basin structure, during this century were presented in Chapter 3.0. The focus of Chapter 4.0 is the impact of these changes on habitat for endangered species, and in particular on active or unvegetated channel width. Several geomorphic processes are described including the relation of discharge with vegetation growth and removal, and the relation of sediment transport to channel depth, to analyze the central Platte River channel trends in active or unvegetated channel width. As is common to most occurrences in nature, these processes are inter-related. A broad description of changing channel form is given in the recent book, *Incised River Channels: Processes, Forms, Engineering and Management* (Darby and Simon, 1999).

Discussions in this chapter frequently reference locations by river mile (RM) and Table 4.1 is provided as a reference. The river miles used here were originally assigned by the US Corps of Engineers. The numbering begins at the confluence of the Platte River with the Missouri River in Plattesmouth, Nebraska (RM 0) and the numbering increases in the upstream direction. Distances are based upon the alignment of the main channel of the Platte River in the 1970s.

Table 4.1. Approximate River Mile of Landmarks along the central Platte River.

River Mile	Description
310	Confluence of North Plate River and South Platte River near North Platte, Nebraska, and the location of the Tri-County Diversion Dam
277	Near Gothenburg, Nebraska
266	Near Cozad, Nebraska
255	Start of Habitat Study Area
251	Near Lexington, Nebraska
249	Near Johnson-2 Return Channel
239	Near Overton, Nebraska
231	Near Elm Creek
215	Near Kearney, Nebraska
201	Near Gibbon, Nebraska
185	Near Wood River, Nebraska
166	Near Grand Island, Nebraska
156	Near Chapman, Nebraska
154	End of Habitat Study Area

4.1 REDUCTIONS IN UNVEGETATED CHANNEL WIDTHS

The observed response to reductions in mean and peak river flows in the twentieth century was a narrowing of the active Platte River channel width from North Platte to Grand Island, Nebraska. Measured values are presented in Figure 1.3, and Table 4.2. The earliest channel-width data comes from the first land surveys in the 1860s and pre-dates the first topographic surveys shown in Figures 2.6 to 2.11. The average channel widths for the 1860s period are from the original township, range, and section surveys of the General Land Office (Peake et al., 1985). The channel width from both these surveys likely would include some small wooded islands so the actual un-vegetated width likely would be at least 10 percent less (Johnson and Boettcher, 2000). A set of county property maps, showing the acreage and ownership of land along the Platte River, was prepared between 1905 and 1920. These maps showed all river islands with economic value. Average channel widths from the subsequent years (1938, 1957, 1983, and 1998) were determined from aerial photographs. These average widths from aerial photographs do not include any wooded islands, and the 1983 widths were measured after the occurrence of a peak flow earlier that year.

Table 4.2. Historic un-vegetated or active channel widths of the Platte River as measured from historic maps and aerial photography.

River Mile	Platte River location	1865[P] Average channel width (feet)	1899[EIS] Average channel width (feet)	1938[P] Average channel width (feet)	1957[P] Average channel width (feet)	*1983[P] Average channel width (feet)	1998[EIS] Average channel width (feet)
166	near Grand Island, NE	2,710	2,500	2,190	1,800	1,340	1,250
224	near Odessa, NE	4,990	5,300	3,140	1,760	890	790
239	near Overton, NE	4,800	5,300	2,310	1,140	1,050	740
266	near Cozad, NE	3,750	4,200	2,360	400	480	
277	near Gothenburg, NE	4,040	3,700	1,610	360	580	
290	near Brady, NE	3,420	3,700	1,450	680	630	

* 1983 widths are measured after the occurrence of a major peak flow event earlier that year.
P Channel areas from Peake et al., 1985.
EIS Channel areas from Platte River EIS Office in Lakewood, Colorado.

Based on maps from the 1860s and aerial photographs from 1938, 1957, and 1983, Peake et al. (1985) provided estimates of the channel area, produced on a USGS 7.5-minute quadrangle map base. The reach lengths were measured from USGS 1:24,000 scale topographic maps corresponding to the areas reported in Peake et al (1985). An estimate of average channel width in the vicinity of the gage station was determined by dividing channel area by reach length.

The 1898 and 1998 average channel widths were calculated at the Platte River EIS Office in Lakewood Colorado using the 1898 USGS maps (Figures 2.6 to 2.11) and GIS coverage of 1998 aerial photos (Friesen et al., 2000). Measurements of channel area in 1998 and 1898 were made of entire bridge segment areas (13) in the habitat study area between Lexington and Chapman, Nebraska. Areas were then divided by longitudinal channel length per bridge segment for average channel width. The 1898 values at four upstream areas: North Platte, Brady, Gothenburg and Cozad, are section measurements.

Channel widths along the river, shown in Figure 1.3 and Table 4.2, have reduced by as much as 80 to 90 percent of the former 1860s channel in the upstream reaches, with lesser amounts of decrease in the reaches near Grand Island, Nebraska (Williams, 1978, Lyons and Randle, 1988, Simons & Associates, 2000). The large decrease in channel width occurred in the twentieth century, and Figure 4.1 shows the variation of channel width versus time. The rates of channel narrowing tended to be fastest for the upstream reaches with slower rates of narrowing in the downstream reaches. The greatest reductions in channel width occurred during the 1900 to 1960 period with smaller reductions, or even channel widening in the narrow reach upstream from Overton, during the 1960 to 2000 period.

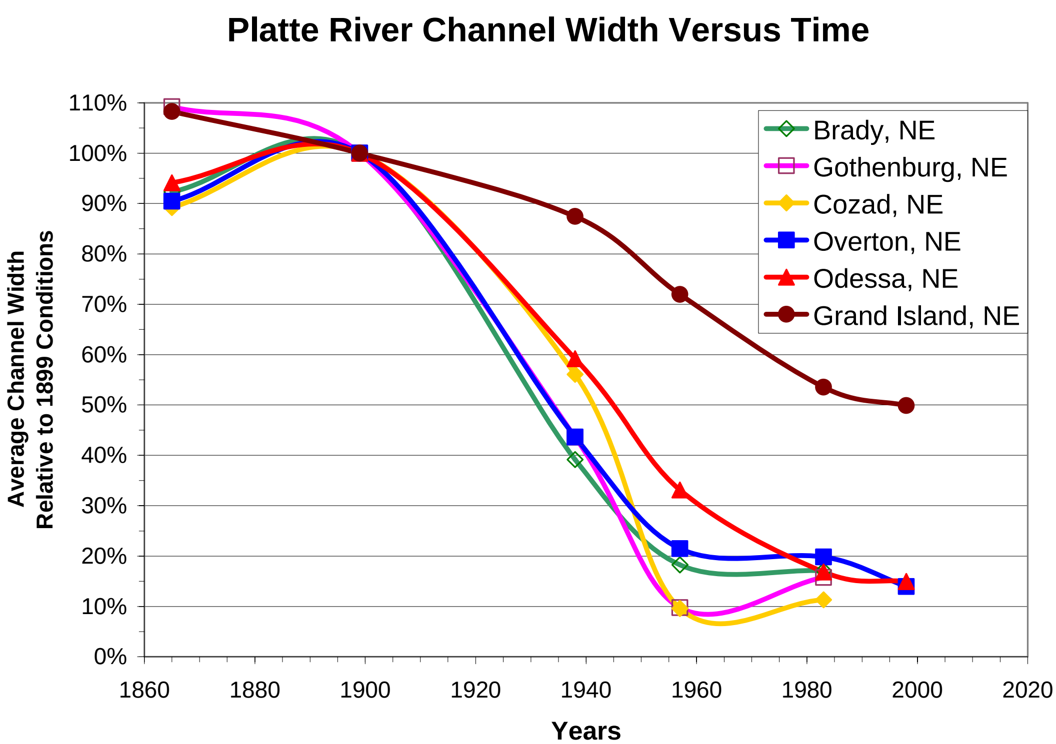


Figure 4.1 Comparisons of active channel width versus time for various locations along the Platte River.

Processes leading to reductions in unvegetated channel widths are presented in succeeding sections and include: flow reductions, vegetation expansion, channel incision from reductions in sediment supply, and coarsening sediment. Regime theory, concerning plan form changes that can result from these processes, is discussed in Section 4.6. Section 4.7 addresses channel width reductions attributable to the construction of river structures, and Section 4.8 considers the time scale of these width reducing processes.

4.2 FLOW REDUCTIONS

The primary process by which channels narrowed involved the reduction in flows (Tables 3.6, 3.7 and 3.8). Reduced flood flows were no longer capable of inundating and mobilizing all of the river bed sands across the historically wide channel.

A simple exponential correlation was found between the active channel widths and the mean river flows, listed in Table 4.3. This simple exponential trend line explained 77 percent of the variance in channel width as a function of mean river flow (Figure 4.2a). A linear correlation was also found between the active channel widths and the 1.5-year flood peaks listed in Table 4.3. This linear trend line explained 84 percent of the variance in channel width as a function of the 1.5-year flood peak (Figure 4.2b).

Table 4.3. Platte River mean flow, 1.5-year flood peaks, and historic unvegetated or active channel widths measured from historic maps and aerial photography.

	near Grand Island, NE				near Overton, NE				near Cozad, NE			
Time periods	1895 to 1909	1910 to 1935	1936 to 1969	1970 to 1999	1895 to 1909	1910 to 1935	1936 to 1969	1970 to 1999	1895 to 1909	1910 to 1935	1936 to 1969	1970 to 1999
Mean flow (cfs)	3,580	2,950	1,080	2,110	3,660	3,160	1,140	2,100	3,550	3,044	461	981
1.5-year peak flow (cfs)	17,300	10,100	4,500	6,010	19,400	9,000	3,490	4,750	17,600	9,140	1,980	2,590
Time Periods	1899	1938	1957	1983	1899	1938	1957	1983	1899	1938	1957	1983
Channel Width (ft)	2,500	2,190	1,800	1,340	5,300	2,310	1,140	1,050	4,200	2,356	403	476

Only the lower elevations of the historic braided channel had enough flow to maintain narrow channels free of vegetation (discussed in *4.3 Vegetation and Channel Change*). As the mean and peak river flow reduced over the period 1910 to 1960, so too did the width of the active river channel (Figures 1.3 and 4.1). Channel narrowing is most pronounced in the reach of the Platte River, between North Platte, Nebraska and the Johnson-2 return channel (river miles 310 to 244). Diversions of river flow through the Tri-County Canal resulted in additional reductions in the mean flow past the Platte River gage station near Cozad, Nebraska.

Regime equations (equation 1) that relate channel width to discharge are well documented in the literature (Leopold and Maddock, 1953, Leopold et al., 1964, Soar and Thorne, 2001).

$$W = a\,Q^{b} \qquad (1)$$

where:

W is the channel width associated with the bankfull discharge,
Q is the bankfull discharge,
a is a coefficient dependent on local conditions, and
b is an exponent, often assigned a value of 0.5.

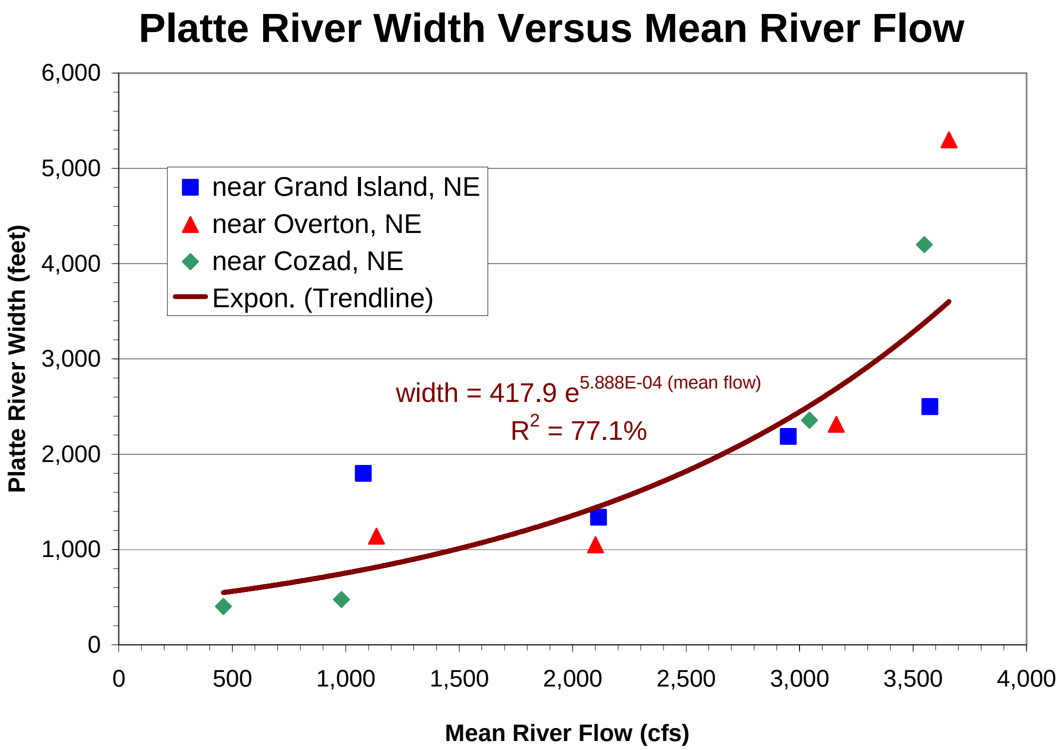


Figure 4.2a Exponential correlation of Platte River Width to the mean flow rate for locations near Cozad, Overton, and Grand Island, Nebraska.

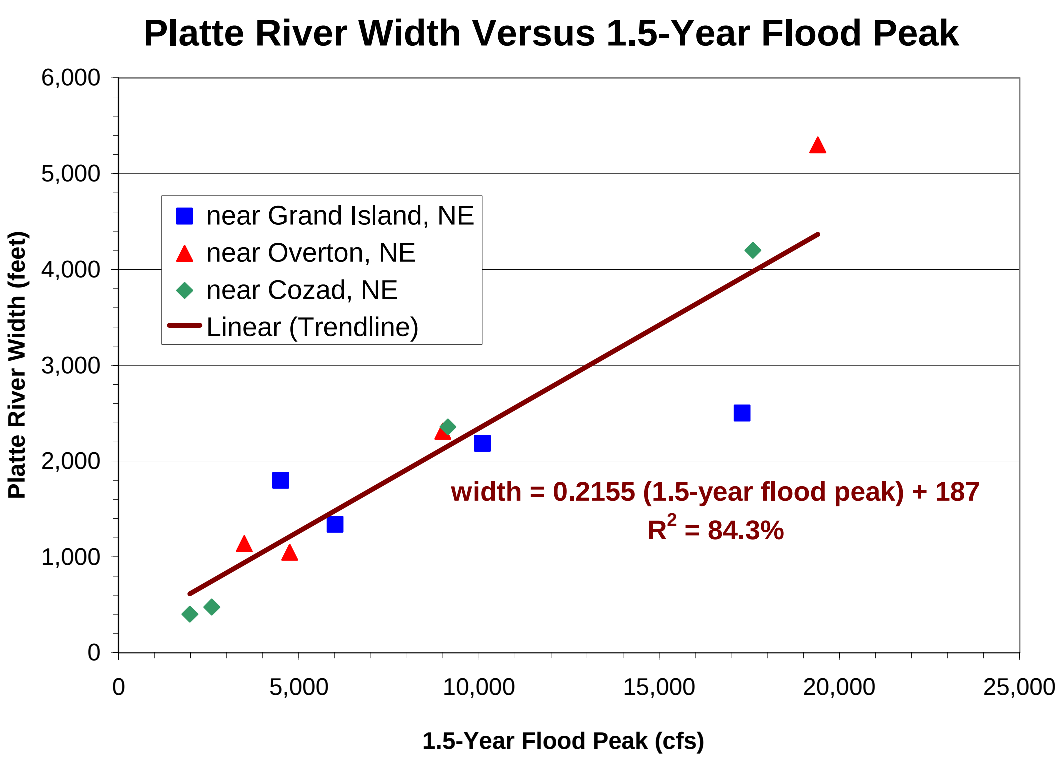


Figure 4.2b Linear correlation of Platte River Width to the 1.5-year flood peak for locations near Cozad, Overton, and Grand Island, Nebraska.

Equation 1 predicts that channel width will decrease following reductions in the bankfull discharge. Lane (1957) developed a qualitative relationship between sediment load and size and river slope and water discharge for conditions of equilibrium where there is no net aggradation or degradation of the riverbed (equation 2).

$$Q_s\, d \propto Q\, S \tag{2}$$

where:

Q_s	is the sediment load (of sizes represented in the riverbed),
d	is the sediment particle diameter of the riverbed,
Q_w	is the water discharge, and
S	is the river channel slope.

According to Lane's relationship, if the water discharge decreases and the river slope remains constant or changes very slowly, then the sediment load and particle diameter will decrease.

Yang (1986 and 1996) theoretically derived a quantitative equation (equation 3) for the prediction of dynamic adjustment of a river channel based on his unit stream power equations (Yang, 1973 and 1979).

$$\frac{Q_s d^{J/2}}{K} = \frac{Q^{J+1} S^J}{W^J D^J} \tag{3}$$

where:

K	is a site-specific coefficient,
J	is a site-specific exponent,
A	is the channel area ($A = WD$),
W	is the channel width, and
D	is the hydraulic depth.

For most natural river channels, the exponent J has a value between 0.8 and 1.5. If an average J value of 1 is used, equation 3 can be simplified to equation 4.

$$\frac{Q_s d^{0.5}}{K} = \frac{Q^2 S}{WD} \tag{4}$$

Yang's equation (equation 4) is similar to Lane's relationship (equation 2), but Yang's equation can be used directly to predict the dynamic adjustments of a river channel due natural and man-caused events once the coefficient K has been determined for the river. The equation demonstrates that channel adjustments are most sensitive to changes in water discharge because water discharge is raised to the second power. This equation predicts that if the water discharge decreases and the river slope remains constant or changes very slowly, then the product of channel width, channel depth, sediment load, and bed-material particle diameter will decrease.

Data for the Platte River follow these equations because water discharge has decreased, channel slope has remained about the same, and channel width and depth and sediment loads have all decreased. Bed-material grain size has increased due to channel incision and because a greater portion of the upstream sand supply is from the South Platte River (Section 4.5).

4.3 VEGETATION AND VEGETATION EXPANSION

Changes in vegetation and channel form are highly dependent and complex. The response of vegetation to changes of flow caused by dams is highly variable and is dependent on pre-existing conditions of flow regime, sediment characteristics, and channel form (Friedman et al., 1998). For instance, reductions of flow in meandering streams and rivers below dams have resulted in a reduction in riparian vegetation establishment and an overall reduction in riparian forest area (Rood and Mahoney, 1990, Friedman et al., 1998, Johnson, 1998). Conversely, reductions in flow in braided streams show the opposite response of riparian vegetation with increases in woody vegetation establishment and an increase in forested area (Friedman et al., 1998, Johnson, 1998). The Platte River was primarily a braided river before historical flows were reduced, and thus riparian vegetation has expanded along the river (Sidle and Faanes, 1997).

The Platte River ecosystem is diverse and wide ranging including grasslands, forest, wetland, agricultural, and urban/sub-urban habitats. The primary concern in this paper is with habitat required for whooping cranes, piping plovers, and least terns that is affected directly by flow in the river. Reductions in flow along the Platte River have most directly affected riparian forest along the river and on channel islands, and wet meadows near the river (Sidle and Faanes, 1997). Wet meadows are affected by groundwater levels that are dependent on river stage near the river. They represent more of an upland type system and are also largely affected by agriculture and residential development.

4.3.1 Riparian Habitat Requirements of Target Species

Least terns and piping plovers select wide channels with large areas of sparsely vegetated dry sand for nesting (Zeiwitz et al., 1992). Required habitat for the least tern and piping plover are very similar. Least terns nest primarily on riverine sandbars with a mixture of small stones, gravel, sand and other material where vegetative cover is usually less than 20 percent (Sidle and Faanes, 1997). Piping Plovers nest primarily upon dry sandbars in the middle of open wide channel beds where vegetative cover is usually less than 25 percent (Faanes, 1983). Presently, more terns and plovers nest on sandpits than along the central Platte River (Sidle and Faanes, 1997), which may be a result of nesting habitat loss along the river. Flows in the river also have effects on the fish species that terns and plovers use as a food source. Any declines in food sources may limit tern and plover populations.

Whooping Cranes do not tolerate human disturbance; the presence of a human can cause Cranes to take flight if they come within one-quarter mile (Sidle and Faanes 1997). They prefer open space and shallow submerged sand and gravel bars to roost. The following roosting site characteristics are preferred by Whooping Cranes (U.S. Department of the Interior, 1983).

- Wide channel, with 90 percent of roost sites being between 510 and 1200 feet wide

- River flow velocities between 1.5 and 6 ft/s (flow velocities may be greater in deeper portions of the main channel)

- Shallow water for roosting along with deeper areas of the channel (all sites evaluated were less than 1 foot deep and 6 of 9 sites were 2 to 6 inches deep)

- Little or no vegetation

- Sandy substrate

- Good horizontal visibility from the roosting area that is unobstructed from riverbank to riverbank by vegetation and for at least a few hundred yards upstream and downstream directions

- Close proximity, usually within 1 mile, to suitable feeding sites

- Isolation of at least 1/4 mile away from roads, houses, and railroad tracks

- Presence of sand bars near the middle of the river with gradual slopes of low relief, no banks over several inches high, and little or no vegetation

4.3.2 Expansion and Ecology of Cottonwoods and Willows on the Platte River

Cottonwoods (*Populus* sp.) and willows (*Salix* sp.) of the family Salicaceae share a similar life history pattern. They are pioneer species (Johnson, 1998) that are relatively fast growing and they require sites relatively free of other vegetation in order to become established. Cottonwoods have small light seeds in "cottony" enclosures that facilitate wind dispersal in late May to early June. Willows have a similar type of seed that is dispersed around the same time period as cottonwoods (Harlow et al., 1979, Johnson, 1994). This corresponds to the natural period of high flow recession so that seeds tend to be deposited on moist sandbars more suitable for germination and the establishment of seedlings (Rood and Mahoney, 1990). Seeds of cottonwoods and willows are viable for only two to four weeks and require continuous moisture (Harlow et al., 1979, Rood and Mahoney, 1990, Johnson 1994). So seedlings tend to be restricted to an elevation range near the river level.

Conditions are probably not ideal for the establishment of seedlings on a yearly basis. Root growth of cottonwoods must maintain contact with the water table as it recedes following flooding (Rood and Mahoney, 1990). If the water table falls too quickly and root growth does not keep up, seedlings will desiccate and die. Once roots are deeply established, after two or three years, cottonwoods become more tolerant to drought by the ability to tap into the water table. However, if the water table was to drop below the reach of roots, and root growth does not keep up, mortality can occur within a few months. On average, cottonwoods live approximately 100 years, but their longevity is influenced by environmental factors, most notably drought stress (Rood and Mahoney, 1990). Willows live from 10 to 30 years (Bellah and Hulbert, 1974).

There are several environmental factors that regulate vegetation growth on sand bars: June flows, summer drought, and winter ice scour (Johnson 1994). When winter flows are high enough and temperatures cold enough, ice scours sand bar vegetation causing high rates of seedling mortality of *Populus* and *Salix*. Seedling survival after ice scour is highly dependent on elevation (Johnson 1994), i.e., whether or not the ice gets high enough to reach the vegetation. High June flows tend to inundate sand bars and mobilize sediment causing seedling mortality, and summer low flows allow for the establishment of seedlings. Annual peak flows of sufficient magnitude that may occur at other times of the year may also be capable of scouring seedlings. If drought conditions exist, summer flows can become low enough that seedlings are unable to get water and die back as a result of desiccation. Severe drought can cause the death of older more established seedlings as well as relatively new growth (Johnson 1994). Johnson (1997) found that seedling mortality was highest in the winter as a result of ice scour (up to 98%), and that during the period of 1985 to 1996 mortality was so high that there was a low probability that a seedling would survive 3 to 4 growing seasons (the amount of time generally needed for it to become highly resistant to erosion). High mortality rates are also seen following flood events. However, once vegetation becomes established in these areas, such as river banks and high sandbars, where there is abundant water just below the surface, the roots of plants stabilize these areas and make them more resistant to erosion. Therefore, the history of the flow in the first years of life of vegetation is important in the establishment of more permanent, mature vegetation.

Under normal rainfall conditions, reduced flows that minimize the effects of high flows and ice scour lead to excellent growing conditions for cottonwood and willow seedlings. The reduction in the annual bankfull discharge of the Platte River as a result of development has allowed vegetation to become established on parts of the channel where the river-bed sands are no longer mobilized by annual floods. Vegetation became established on sand bars and islands exposed during the germination seasons that were formerly part of the active channel (Johnson 1994) because late spring runoff inundated less of the old channel. Flow regulation reduced the likelihood that vegetation would be washed away by flowing water, drowned, buried by sand, or scoured by ice, and so vegetation has been able to persist and become firmly established over the years (Simons and Associates, 2000). Additionally, the increased low flows in the summer helped young plants survive (Schumm, 1998) by keeping the local water table higher. Once vegetation was firmly established, channel roughness increased locally that slowed the flood velocities on the newly vegetated sandy islands and trapped more sand from high flows. This allowed for islands to increase somewhat in elevation so that over time they were less frequently inundated by high flows. The vegetation helped stabilize and define the banks of the narrower channels. The growth of dense riparian vegetation on exposed bare sand, and the reduction in the supply of medium sand relative to the outflow of medium sand at Chapman, Nebraska, have also played a significant role in channel narrowing on the central Platte River. Vegetation grows on exposed bare sand and stops the sand's free movement, forming islands that grow, and promoting channel infilling (Nadler and Schumm, 1981, Johnson 1994). The narrow channels between islands incised, while the new islands aggraded.

Woodland expansion occurred markedly from the 1930s through 1969 with the peak of woodland expansion occurring in the 1950s (Johnson 1994; Johnson and Boettcher, 2000). The period of peak expansion coincides with a major drought in the 1950's. The natural droughts of the 1930s and 1950's, combined with the storage and diversion of river flows, reduced the annual high flows and exposed more sandy islands in the channel than in an average year. Subsequently, more seedlings grew on those sandy islands and the vegetation further encroached on the channels along the Platte River (Johnson, 1998). During these low-flow periods, vegetation was able to survive and further encroach on the active channel despite the possible effects of drought discussed above. This is not unexpected since drought tends to thin seedlings rather than eliminate entire stands (Johnson, 1994). By the time the multi-year droughts were over, persisting new vegetation was well established. The establishment of vegetation during this drought period points to the importance of three environmental factors (high June flows, summer drought, and winter ice scour), in determining seedling establishment. It is possible that a combination of all three factors will increase mortality, while the absence of any one or two could lead to the expansion of vegetation along the Platte River. Exploration of this possibility has implications towards the proper management of the system.

It is likely that the stabilizing effects of vegetation prevented the high flood flows of 1973, 1983, and 1984 from widening the channel by substantial amounts. The vegetation protected islands and banks from erosion and forced any net erosion of the river channel to occur on the streambed rather than on the banks.

The ability of riparian vegetation to resist erosion changes over time. Riparian vegetation is highly vulnerable to river erosion during the first few years of life. It takes a few years for roots to develop enough to resist the scouring effects of flow, and new growth takes time to establish a deep enough root system to reach groundwater and become more resistant to drought. After a few years, the more mature vegetation can be very resistant to erosion and will likely remain resistant until old age.

Riparian areas are naturally very dynamic and highly variable (Rood and Mahoney, 1990). The change in the plant community over time, as determined by the disturbance regime, will affect the long term stability of vegetated bars and banks. Later successional (seral) tree species along the Platte River include green ash (*fraxinus pennsylvanica*), boxelder (*acer negundo*), and american elm (*ulmus americana*) (Johnson, 1994). Where these species are less likely to become established, the *populus-salix* community will age and die back in a relatively short period of time. As this vegetation and the community become old, the resistance to erosion becomes less, especially if the river banks become steep and the root depth is less than the bank height because the channel has incised (Johnson, 1997, ASCE 1998a).

Higher areas that are not frequently affected by flow may progress towards a more stable regional climax community. Boxelder ranges from early to late seral, and it tends not to reproduce in its own shade (Rosario 1988b). Green ash is usually a middle seral species that is established after *populus* and before american elm, however the reduced presence of elm, due to dutch elm disease, has left green ash as a climax species in the Great Plains (Rosario 1988a). American elm is a late seral species that grows best on rich well drained soils and grows poorly on dry sandy soils where the water table is consistently high (Coladonato 1992).

Pioneer species, such as *populus* and *salix*, provide the necessary conditions for the establishment of later successional species along the Platte River by stabilizing islands by trapping sediment and causing a rise in land elevation, increasing organic content of the soil, and increasing surface moisture of the soil (Wilson, 1970). In a study of vegetation succession along the Republican River in Kansas, Bellah and Hulbert (1974) found that green ash, boxelder, and american elm became established within 10 years after the establishment of *populus* and *salix*, and became the dominant species after 30 to 60 years. Wilson (1970) found that the *populus-salix* community dominated for 15-25 years before ash, elm, and boxelder became established along the Missouri River in South Dakota. In each case, the species composition changed from a *populus-salix* dominated stand to a stand dominated by ash, boxelder, and elm.

The same exact trend may not be expected on the Platte River, but similar patterns of succession are expected given the similarity of the climate and plant community of the two systems studied. The shift to later successional species entails a reduced amount of disturbance and long term stability of the soil. Once succession has progressed, the community will likely be stable for a longer period of time, and perhaps self-sustaining, thus adding to the stability of the river system, excepting a large disturbance event.

Under natural flow conditions, the Platte River is a very dynamic ecosystem. Vegetation communities along the active river channel are maintained in an early successional stage due to the high frequency of disturbance by river flow. Succession of the plant community to late seral stages would occur only in areas not subject to the consistent action of flow. Decreases in river flow over the twentieth century have reduced the area subject to flow disturbance, thus allowing for greater long term stability of plant communities.

4.3.3 Interaction of Vegetation, Channel Flow, and Channel Morphology

The stabilized islands and banks have created a feed back mechanism that contributes to channel narrowing and incision (Section 4.4), thus adding to the stability of vegetated islands. In the principal narrowing processes, the effects of reduced annual bank-full flows, reduced and coarsened sand supply, and channel encroachment by vegetation would follow one of two timing patterns, either of which would result in a narrower channel (Friedman et al., 1996).

> *If flows with reduced sand supply (relatively clear water), occurred first (before vegetation could become established on the higher elevations of the channel recently abandoned by the reduction in high flows), erosion would degrade the lower elevations of the wetted channel near the source of the clear water. Then, vegetation would colonize the higher elevations of the former channel, increase the local channel roughness there, lower the velocity of overbank flows, and capture additional sand deposits during subsequent higher flows. The active channel, between vegetated banks, would narrow.*
>
> *If vegetation first established itself during low flow years (droughts, especially during germination seasons) on the higher moist elevations of the abandoned active channel (before any large flows with reduced sand supply*

could degrade the channel), the vegetation would increase the local channel roughness, lower the velocity in vegetated flow zones during subsequent floods, and cause sand deposition in the vegetated areas along the channel. Subsequent high flows of clear water would not erode the areas of the channel protected by deep-rooted vegetation, but would erode the unprotected, lower elevations of the channel. Again, the active channel between vegetated banks would narrow.

If both effects were occurring at the same time, vegetation would colonize the high and moist elevations of the original channel during the germination season, the vegetation would grow, slow the flow, and trap sand during periods of high flow. Erosion caused by clear water would incise the lower elevations of the original channel. Therefore, the vegetated high areas along the channel would aggrade while clear water would degrade the low elevations of the original channel. Further descriptions of the vegetation encroachment and channel narrowing associated with the reductions in annual bank-full discharges, in the central Platte River can be found in Johnson (1994, 1997), O'Brien and Currier (1987), and in Currier (1995, 1996).

Vegetated islands have been mechanically cleared in the last decade by the State of Wyoming, for habitat improvement, but these cleared areas have not been sustained by river flows. Therefore, mechanical clearing has been repeated every few years on lands in order to maintain vegetation-free land near the channel for endangered species habitat.

4.4 REDUCTIONS IN SEDIMENT SUPPLY AND CHANNEL INCISION

The process of channel degradation or incision (erosion of the riverbed that deepens the channel) occurs when river flow has a capacity to transport sediment at a rate that cumulatively exceeds the upstream sediment supply. If there is not enough sediment from upstream, then additional sediment is eroded from the bed and banks of the river. Channel incision can be limited by sand supplied from downstream tributaries, armoring of the riverbed[8] if there is enough coarse material in the bed to stop erosion, and the resultant decrease in river slope. There are few tributaries to the central Platte River, downstream from North Platte, Nebraska and these tributaries do not supply a large source of sediment. Therefore tributary sediment sources are not expected to limit incision on the central Platte River.

4.4.1 The Occurrence of Incision

As discussed in Section 2.2.6, prior to 1900 it appears that the supply of sediment exceeded the transport capacity of the Platte River. The excess sediment was deposited on the bed of the channel, producing laterally shifting channels. In the 1900s, the volume of sediment entering the

[8]Armoring of a riverbed is the process by which fine sediment particles are eroded from the riverbed while coarse sediment particles are not. An armor layer forms when nearly all of the fine particles have been eroded from the surface of the riverbed and a coarse layer of particles exists at the surface that cannot be eroded when riverflows are below a certain threshold.

Platte River was reduced primarily by the construction of reservoirs on the North Platte River. Lake McConaughy, the reservoir formed behind Kingsley Dam, has been in operation since 1941, and is the downstream-most barrier to sediment transport on the North Platte River. Releases from Kingsley Dam and the Keystone Diversion Dam immediately downstream are clear water flows, free of sand.

Flow diversion systems for irrigation and hydropower also reduce available sediment in the central Platte River by causing sediment deposition immediately downstream from the point of diversion and by discharging clear-water (sediment-free) flows back to the Platte River tens of miles downstream. When river flow is diverted, but not the sediment, the capacity of the downstream river flows to keep the sediment moving is decreased and sediment deposition occurs. When clear-water return flows are added back to the river, at a point farther downstream, there is a sudden increase in the sediment transport capacity and sediment is eroded from the riverbed. Discharge from the Johnson-2 Return channel near Overton, NE, more than doubles the average flow in the channel with relatively clear water releases. Currently, the volume of sediment transported in the central Platte River, exceeds the upstream supply of sediment and sediment is eroded from the bed of the channel to counter the sediment imbalance. The average annual sediment load for the central Platte River, calculated by Randle and Samad (2003), is presented in Tables 3.9, 3.10, and 3.11. The sediment transport rates indicate the channel is eroding at a rate of 400,000 tons per year. The amounts of vertical incision measured over a recent 13-year period from 1989 to 2003 are described near the end of this section.

The Keystone Diversion Dam began releasing clear water flows to the North Platte River in 1936. However, after 1941, most of the flows released from Kingsley Dam were diverted into the Sutherland Supply Canal and no longer flowed in the North Platte River downstream of the Keystone Diversion Dam (see the North Platte River in Figures 2.17 and 2.18). Due to the reduced flows in the North Platte River channel, the rate of channel incision downstream from the Keystone Diversion Dam has been relatively slow and is limited to a distance of approximately 15 miles downstream from the diversion dam.

The Keystone Bridge, constructed in 1979, is approximately 2 miles downstream of the Keystone Diversion dam and 4 miles downstream of the Kingsley Dam at Lake McConaughy. In September of 2003, the exposed pile foundation of the bridge was visible during low flow conditions (Figures 4.3a-d). Excluding local scour depths, channel bed degradation measured from the pier form line, was a minimum of 6 ft. In the last 24 years the clear-water flows not diverted into the Sutherland Canal have degraded the channel bed a minimum of 6 ft. The incised banks and terraces indicate greater degradation. Channel incision near the Keystone bridge since 1936, assessed from flood plain terrain, was observed to be about 12 feet. The incision near the Paxton bridge, located 13 miles downstream from the Keystone dam, was observed to be less than 1 foot (Randle and Murphy, personal observation, 2000). There is no

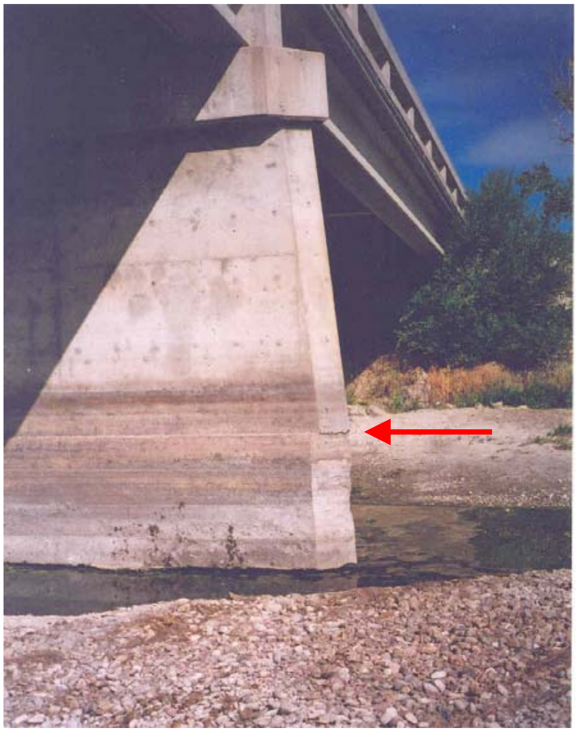


Figure 4.3a. Looking at the downstream end of the Keystone Bridge pier that was constructed in 1979. The form marks on the pier show original channel bed elevation. The base of the pier ends a couple of inches above the water surface. The pier has a pile foundation which is currently exposed (Figure 4.3d) due to channel degradation and local scour.

Figure 4.3b. Looking upstream toward the Keystone bridge. Note the incised geometry of banks and break in bank line consistent with top of form line on piers.

indication of flow constriction at either site and both bridge spans extend the width of the channel, with no long approach embankments. Depth of local scour was excluded from the estimate of depth of channel degradation and the absence of structural constrictions indicates any significant degradation due to a local constriction is doubtful.

Figure 4.3c. Looking downstream from the left bank, approximately 100 yards downstream of Keystone Bridge. Note the incised channel bed and steep banks.

Figure 4.3d. Looking at the upstream end of the Keystone bridge pier, showing the gap between the base of the pier and the water surface. The outline of the exposed foundation pile is discernable in the gap.

Figure 4.4a above. Looking downstream from the Lexington Bridge, just upstream of the Johnson-2 return channel (RM 251.5). The channel has stable, shallow banks.

Figure 4.4b left. Looking downstream along the south channel, immediately downstream of J2 return (RM 246.5). The channel is deeply incised with steep high banks.

The Johnson-2 Return channel, built during the period 1936 to 1941, releases relatively clear water flow into the Platte River channel on the south side of Jeffrey Island at river mile 246.8 (Figure 2.17). After 1941, channel incision was noted along the south channel in a reach extending from the Johnson-2 return channel downstream to the Overton Bridge, a distance of 8 miles (Figures 4.4a-d). This incision would also cause head-cut erosion to progress upstream along the south channel toward its split with the north channel, upstream of Jeffery Island. Because river flow in the north channel around Jeffrey Island would be captured by the south channel, a dike was constructed across the upstream end of the south channel to maintain flows in the north channel and stop the head-cut erosion. After the construction of the dike, the Platte

<table>
<tr><td colspan="2">
Figure 4.4c left. Looking upstream along the south channel, downstream of the J2 return. The high steep bank is actively eroding in this reach of incised channel.</td></tr>
<tr><td></td><td>Figure 4.4d above. Looking across to the left bank of the south channel, downstream of the J2 return (RM 244.5), a high and steep cut bank can be seen.</td></tr>
</table>

River water flowed through the channel on the north side of Jeffery Island and dried up on the south channel between the dike and the return channel. The dike washed away during high flows on several occasions but was rebuilt each time (Jenkins, 1993).

Repeat cross-section surveys of the river channel in the reach downstream from the Johnson-2 Return channel were conducted by Reclamation (Technical Service Center, Denver) and by DJ&A Surveyors (Missoula, Montana) in 1989, 2000, and 2002. Summary results from these surveys are presented in Figure 4.5 and individual sections are shown in Figures 4.6 to 4.14. These figures show the incision process of thalweg erosion and channel narrowing downstream from the Johnson-2 Return channel. A survey of both the north and south channels at river mile 246.5 show that the thalweg of south channel (fed by the Johnson-2 Return channel) is now 13 feet lower than the thalweg of the north channel (Figure 4.6a). Repeat cross section surveys over the 13-year period from 1989 to 2002 show approximately 6 feet of incision immediately downstream from the Johnson-2 Return channel (Figure 4.6b), and 2.5 feet of incision 18 miles downstream (Figure 4.14).

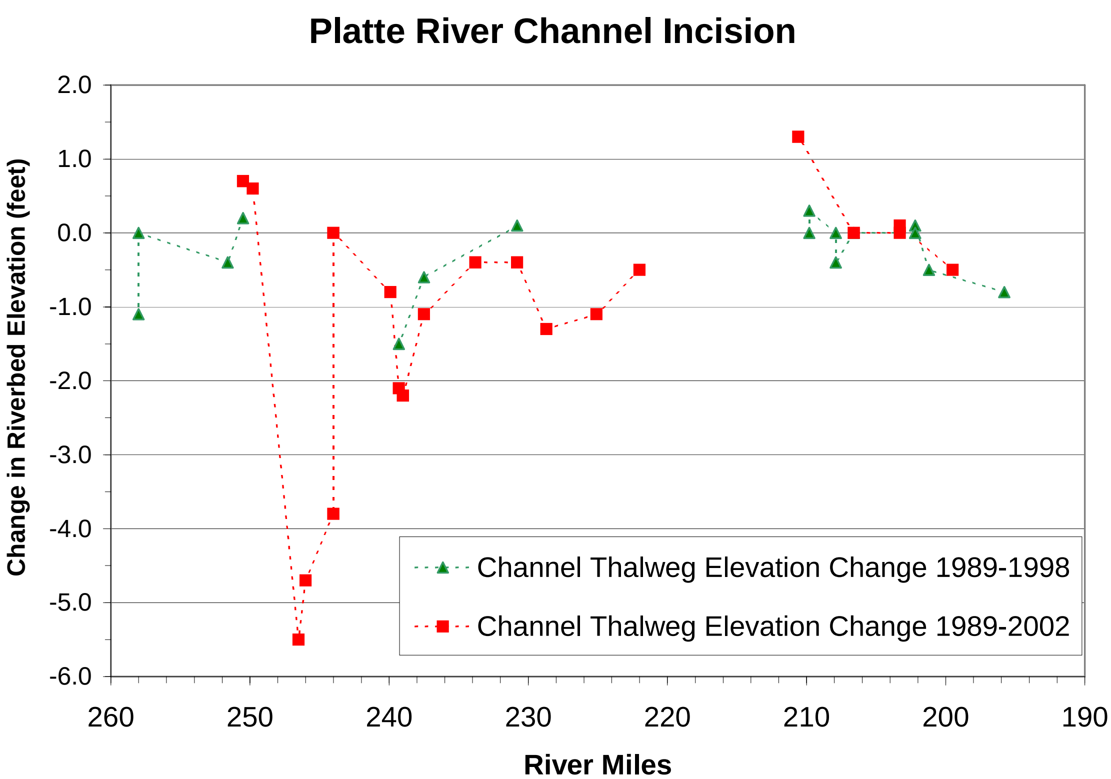


Figure 4.5 Measurement of channel thalweg incision along the Platte River reach downstream from the Johnson-2 Return channel (river mile 247).

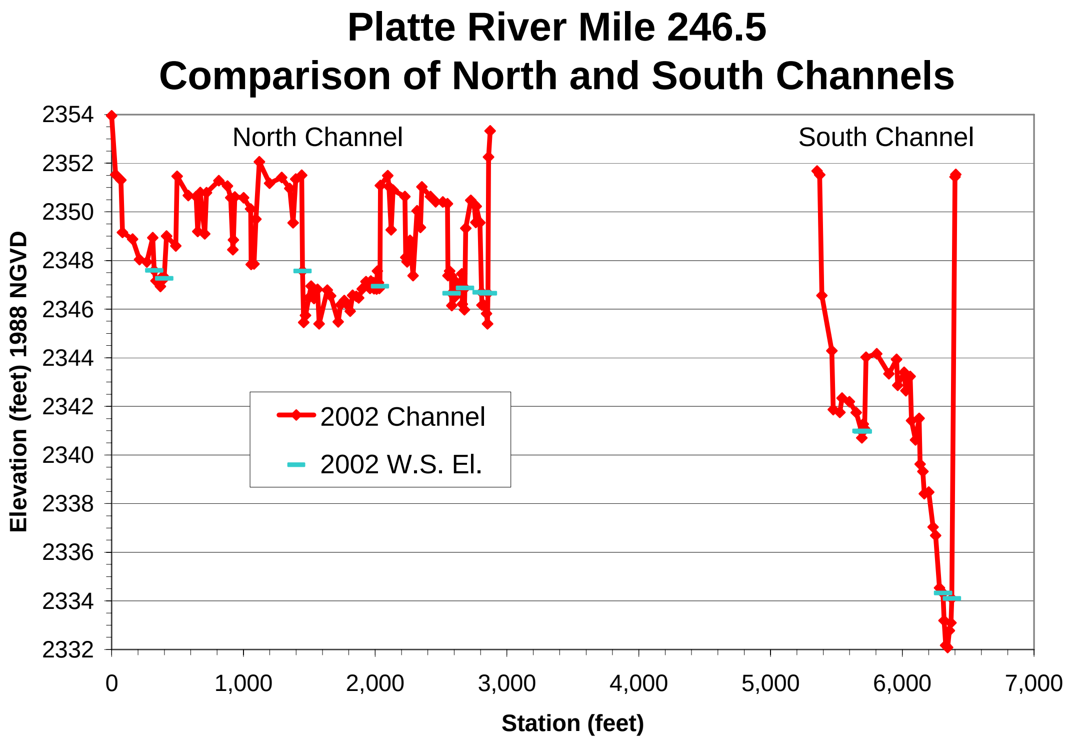


Figure 4.6a Platte River at mile 246.5, both north and south channels. The Johnson-2 Return channel delivers clear water into the south channel, which causes incision. At the time of the 2002 channel survey, the thalweg of the south channel was 13.3 feet lower than the thalweg of the north channel.

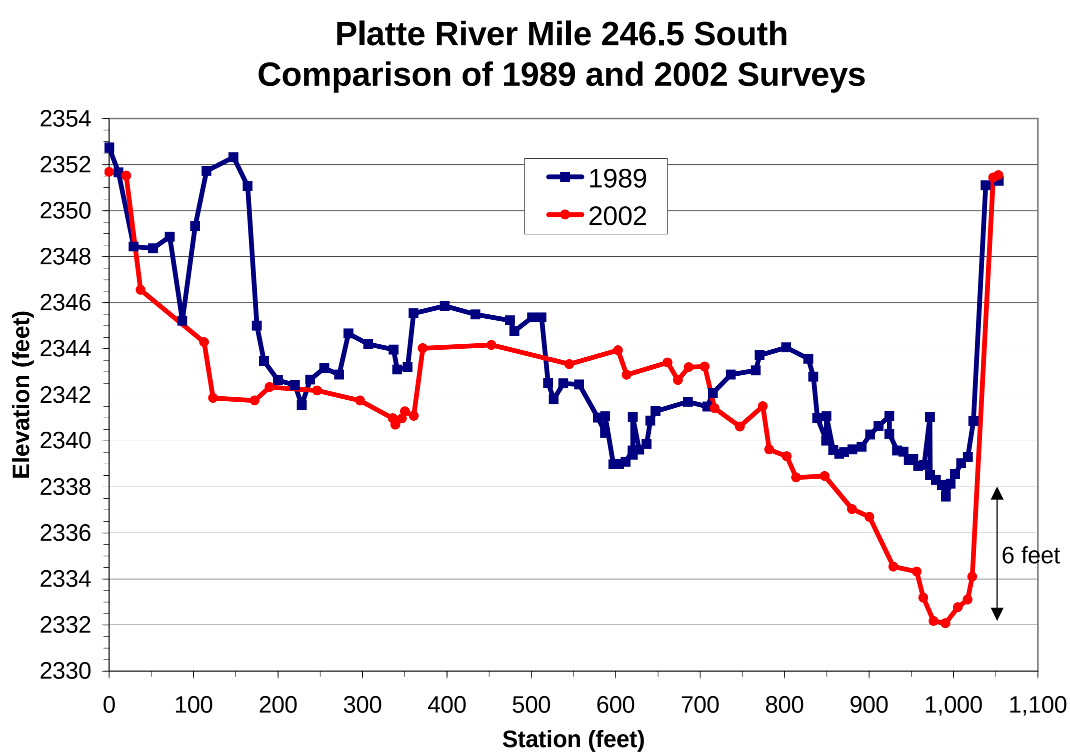


Figure 4.6b Comparison of 1989 and 2002 Platte River channel cross section surveys for river mile 246.5 south channel.

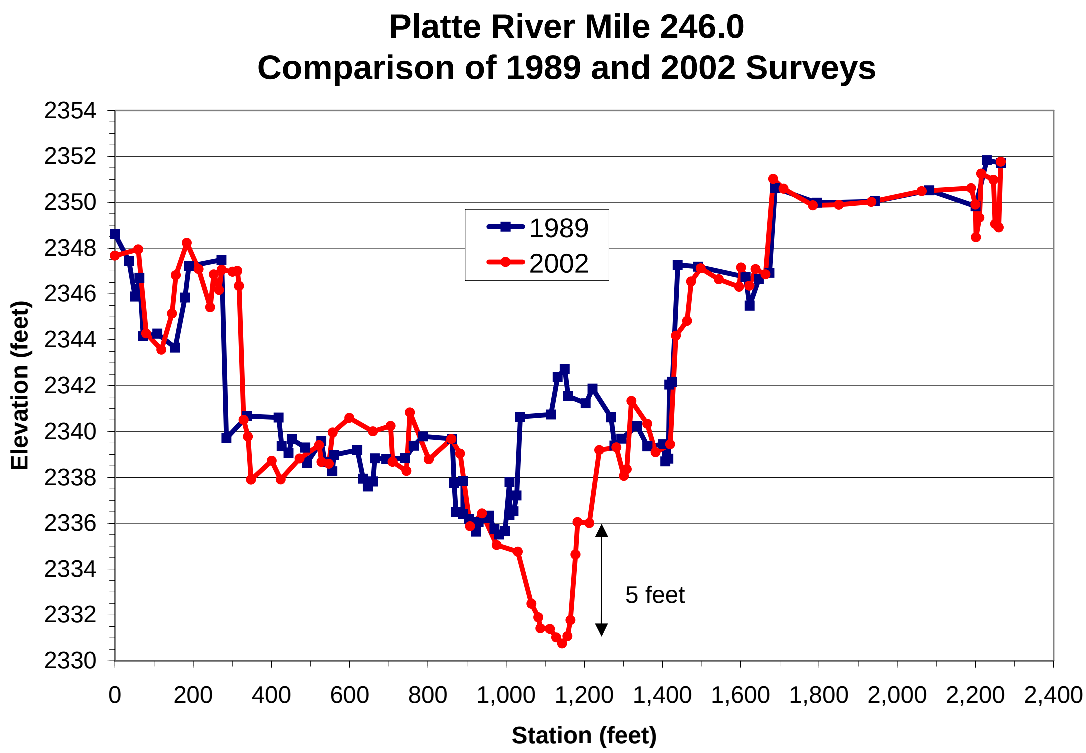


Figure 4.7 Comparison of 1989 and 2002 Platte River channel cross section surveys for river mile 246.0.

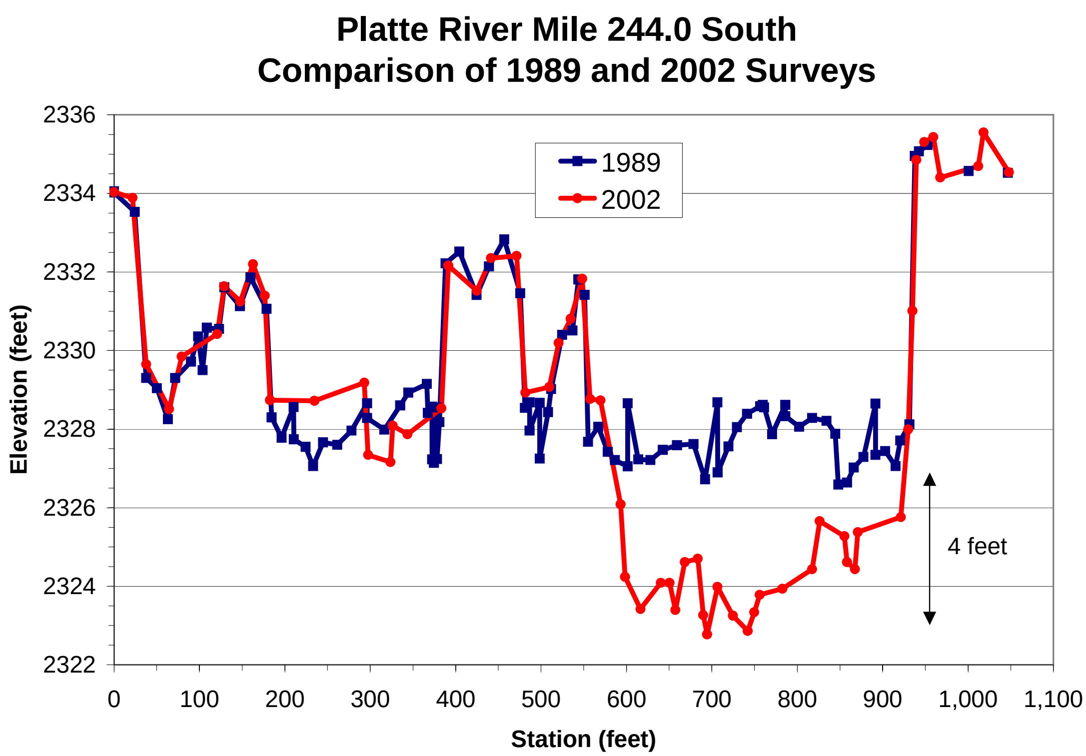


Figure 4.8 Comparison of 1989 and 2002 Platte River channel cross section surveys for river mile 244.0 south channel.

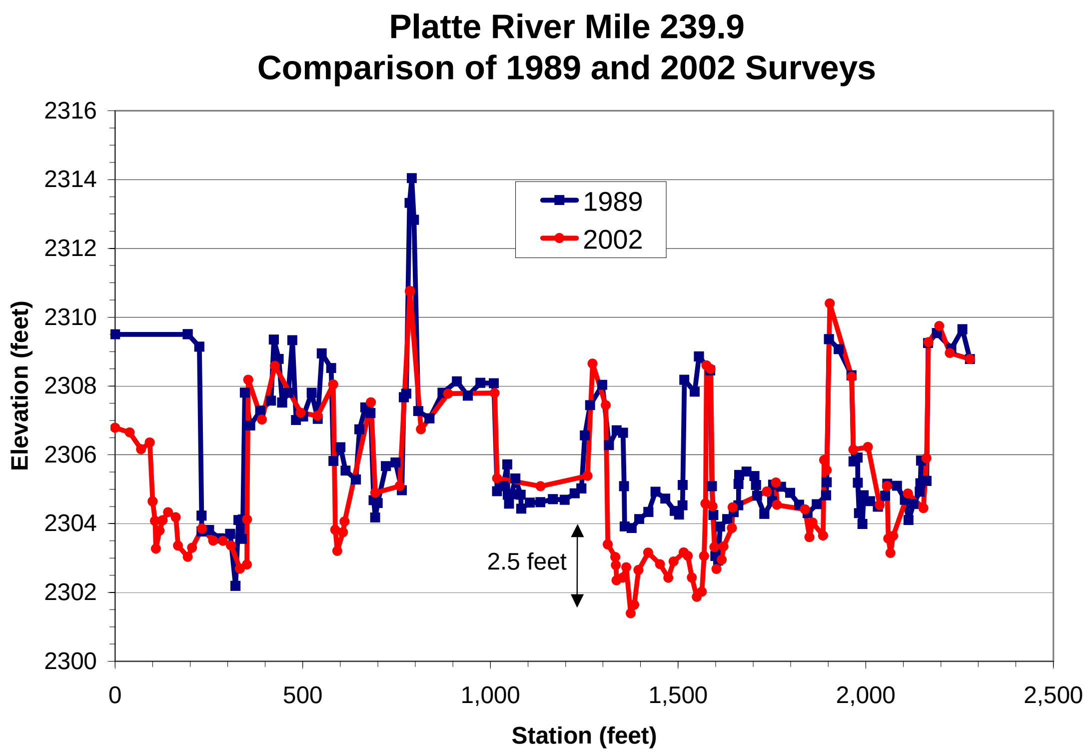


Figure 4.9 Comparison of 1989 and 2002 Platte River channel cross section surveys for river mile 239.9.

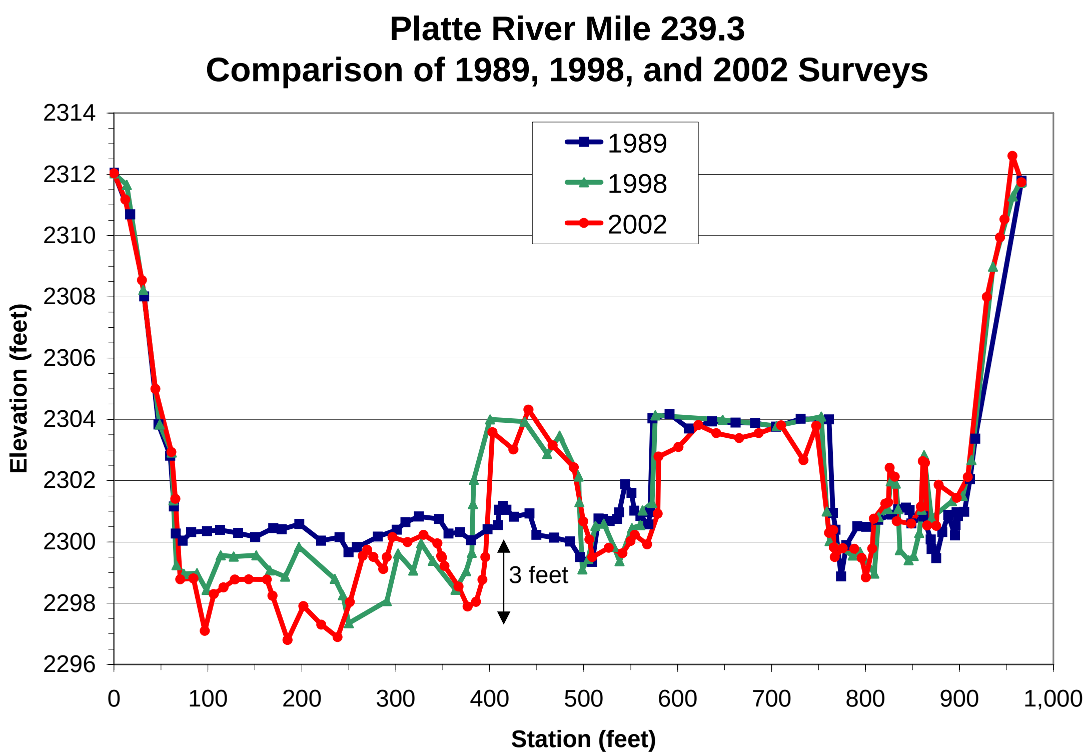


Figure 4.10 Comparison of 1989, 1998, and 2002 Platte River channel cross section surveys for river mile 239.3.

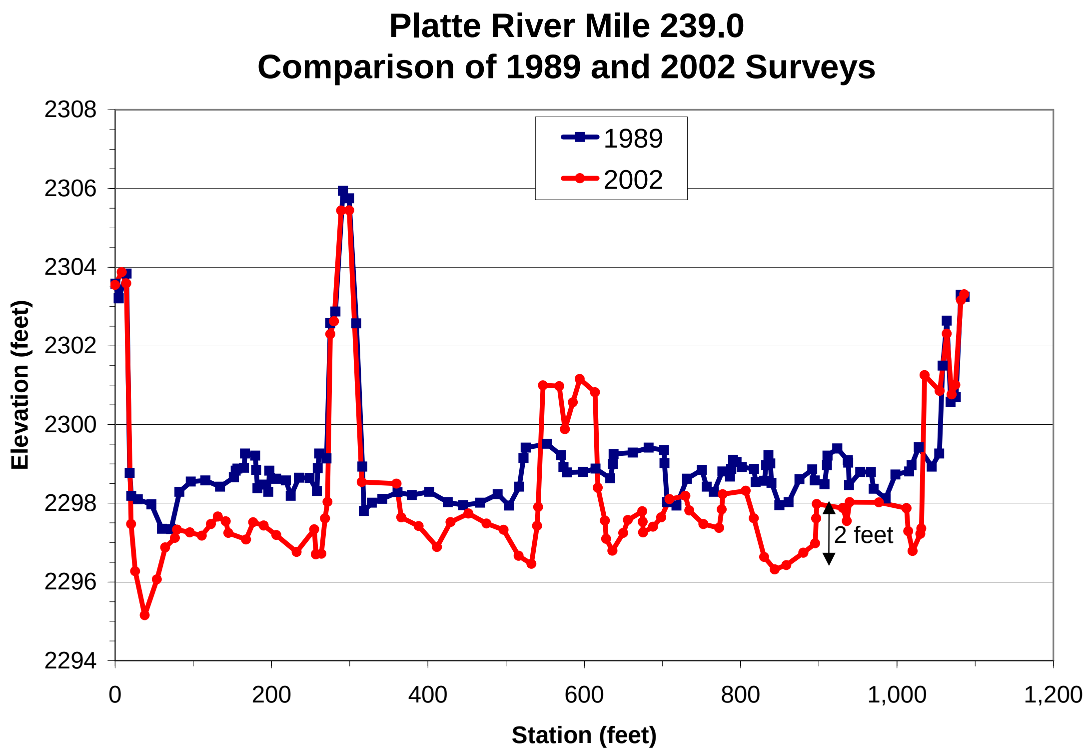


Figure 4.11 Comparison of 1989 and 2002 Platte River channel cross section surveys for river mile 239.0.

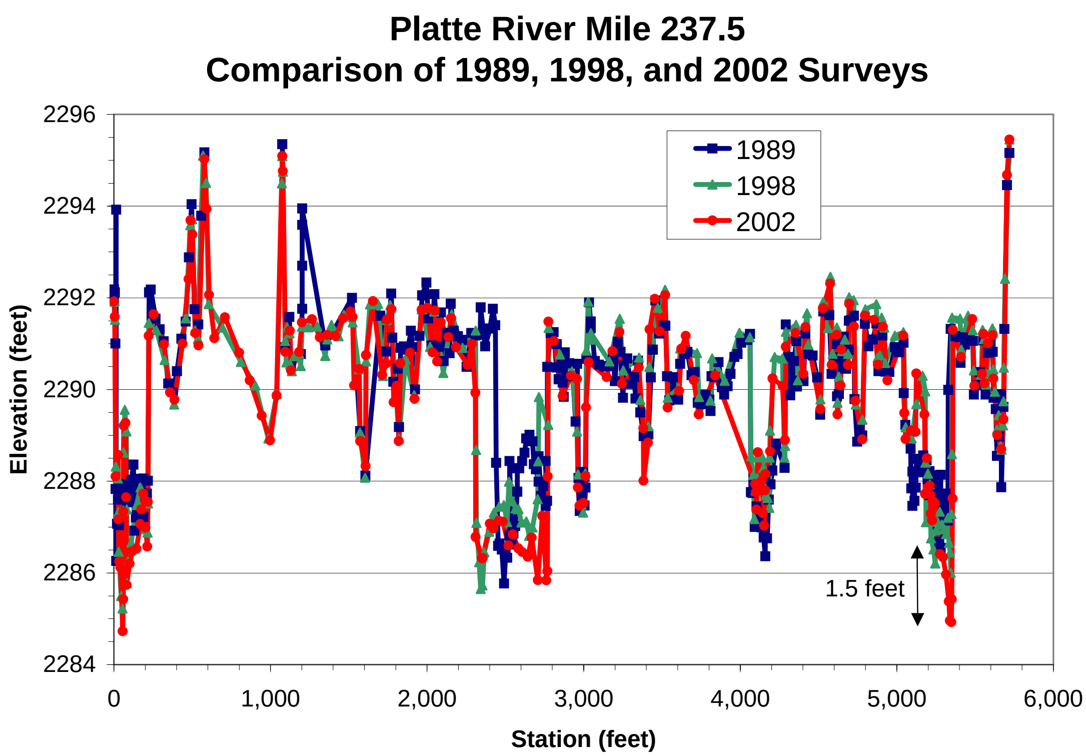


Figure 4.12 Comparison of 1989, 1998, and 2002 Platte River channel cross section surveys for river mile 237.5.

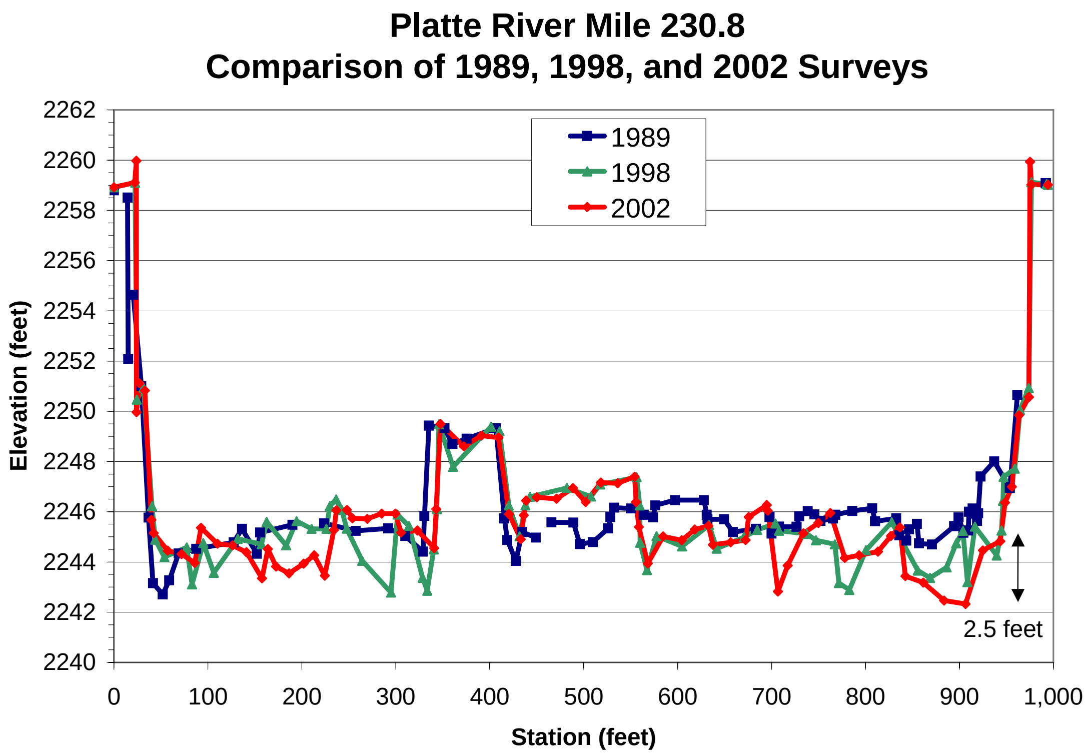


Figure 4.13 Comparison of 1989, 1998, and 2002 Platte River channel cross section surveys for river mile 230.8.

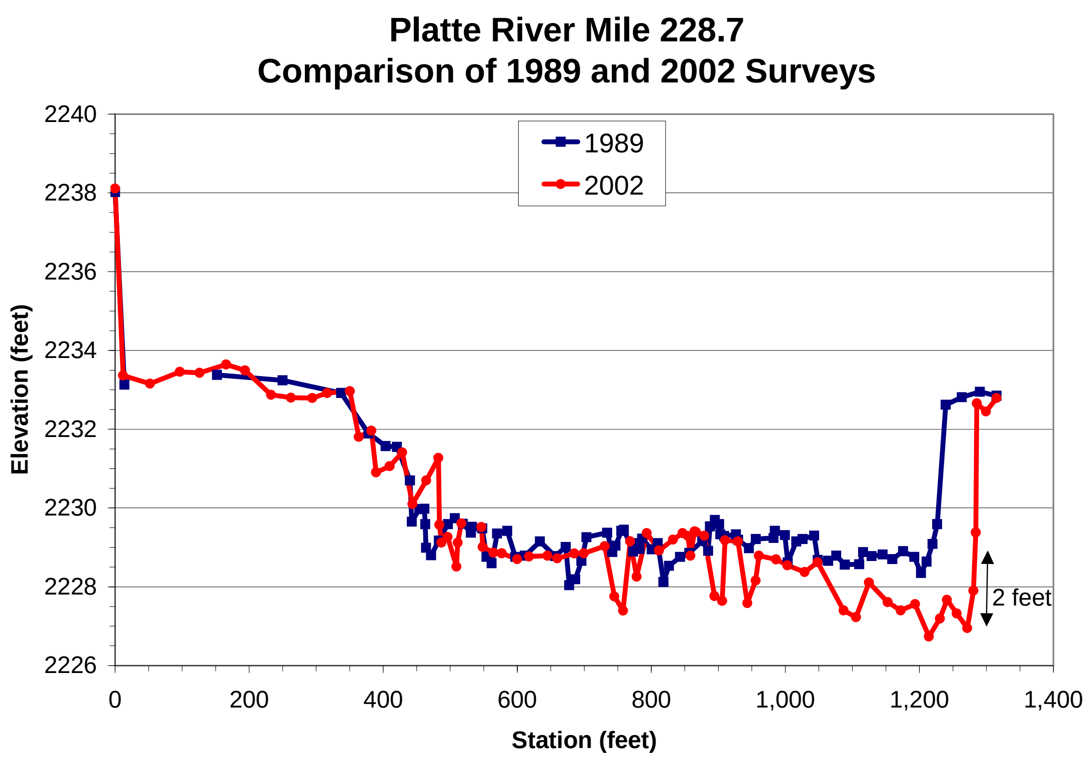


Figure 4.14 Comparison of 1989 and 2002 Platte River channel cross section surveys for river mile 228.7.

Independently, the Reclamation office in Grand Island surveyed the main channel for biologic studies, at river miles shown in Table 4.4. Multiple transects were established in 1984 or 1985 at each site, and repeat measurements were made in the 1980s and in the period from 1998 to 2000. Shown in Figure 4.15 is the average change in bed elevation based on cross-sectional flow area, and the earliest and latest surveyed measurement. Similar to Figure 4.5, the data shows the channel bed has incised over this period downstream of river mile 245, and immediately downstream of the J-2 return. Channel incision often occurs over a narrow portion of the river channel, so the change in bed elevation, averaged over the entire channel width, is often much less than the decrease in thalweg elevation.

Table 4.4 Average change in bed elevation for main channel between 1984 or 1985, and 2000 or 2001, based on multiple transects.

River Mile	Study Site	Number of Transects	Years of Measurement	Average Change in Bed Elevation (ft)	Std. Error of Ave. Bed Elev. Change
244	2	8	1984 & 2000	-1.39	0.20
227	4a	5	1985 & 2001	-0.74	0.06
208	6	9	1984 & 1998	-0.34	0.21
196	8c	4	1984 & 2001	0.15	0.1
191	8b	5	1985 & 2000	0.1	0.13
178	9bw	5	1985 & 2000	0.18	0.06
159	12a	3	1984 & 2000	-0.06	0.03

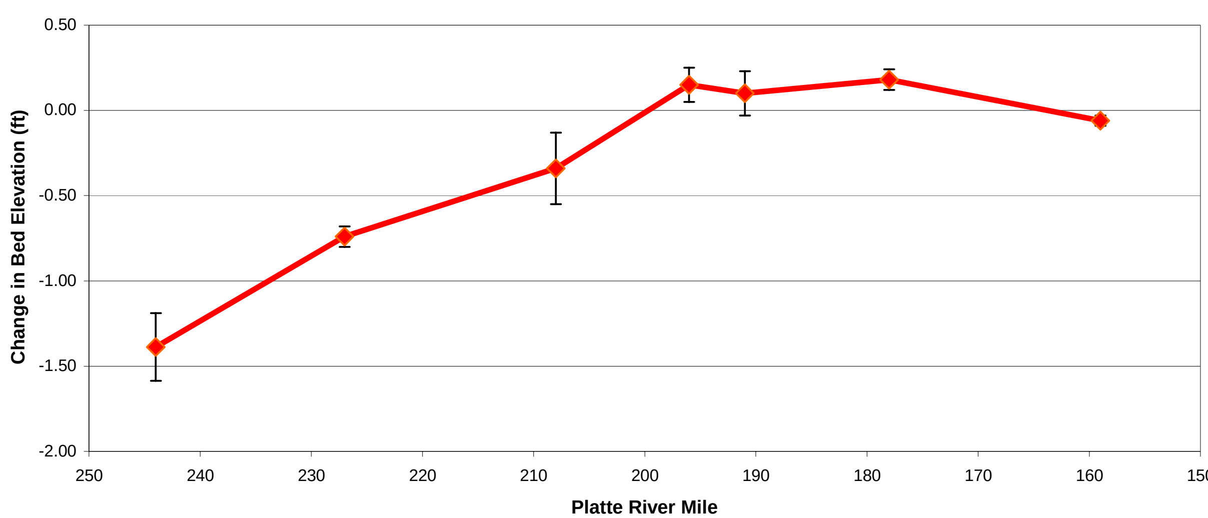


Figure 4.15 Average changes in bed elevation between the years 1984 or 1985 and October 2000 or 2001.

USGS stream gage data indicates smaller increments of incision occurring at downstream locations. The USGS report, *Trends in Channel Gradation in Nebraska Streams, 1913-95* (Chen et al., 1999) includes two gage sites on the Platte River near Odessa, Nebraska and near Grand Island, Nebraska, which are 23 and 79 miles downstream from the Johnson-2 Return channel, respectively. Both sites show statistically significant but small trends toward channel incision: 0.23 feet per decade over 5 decades (1.2 feet from 1938 to 1988) near Odessa, Nebraska and 0.14 feet per decade over 6 decades (0.89 feet from 1933 to 1995) at Grand Island. Just upstream of the habitat reach, the gage station on the Platte River near Cozad, Nebraska shows a statistically-significant, downward elevation trend of 0.41 feet per decade over nearly 5 decades (1.9 feet from 1940 to 1987). The channel degradation at the gage station near Cozad, Nebraska may be caused by headword erosion progressing upstream from the Johnson-2 return channel. Another possible cause of the slow degradation is the reduction of medium size sand supplied from the North Platte River and an increase in the amount of coarse sand supplied from the South Platte River (Section 4.4.2)

All of the measurements discussed here are consistent in indicating a trend of incision in the central Platte River downstream of the J-2 return, which occurs after the Sutherland Canal begins operation in 1941. This is in contrast to the aggrading trend both Gannett (1901) and Lugn & Wenzel (1938) ascribe to the channel in the early decades of the twentieth century.

4.4.2 The Process of Incision

The erosion of fine material from the riverbed causes bed material to become significantly coarser along a reach where channel incision has occurred. Armoring may limit the depth of channel incision if there is enough coarse material in the bed to stop erosion; however an armored riverbed also causes the channel incision to progress further downstream. Armoring and a resultant decrease in local river slope can eventually limit the depth of incision, but incision continues until the cumulative sediment supply from local drainage areas and from the upstream river channel balance the cumulative sediment transport capacity of the river flow. Based on measurements of degradation (Section 4.4.1), the calculated imbalance in the sediment budget (Randle and Samad, 2003, Simons & Associates, 2000), and the time required for the occurrence of this natural process, it is estimated that the incision from clear-water releases at the Johnson-2 Return channel will continue to progress slowly downstream over time. Large floods that convey sediment past the Tri-County Diversion Dam may temporarily halt the process of channel incision.

A reference by Graf (1998) to an analysis method of de Vries and others (1973) has provided a means to predict how quickly channel incision can expand both vertically and downstream from a clear-water source through a channel bed of uniform, single grain size sand. The longitudinal profile of an incision wave is described as a function of the distance along the river channel, the time since the clear-water erosion began, the slope of the river channel, and the sand transport rate. Figure 4.16 shows the percentage of maximum incision depth versus river miles downstream from the clear-water source. The analysis indicates that half of the maximum incision depth would occur at a distance 11 miles downstream after a period of 64 years,

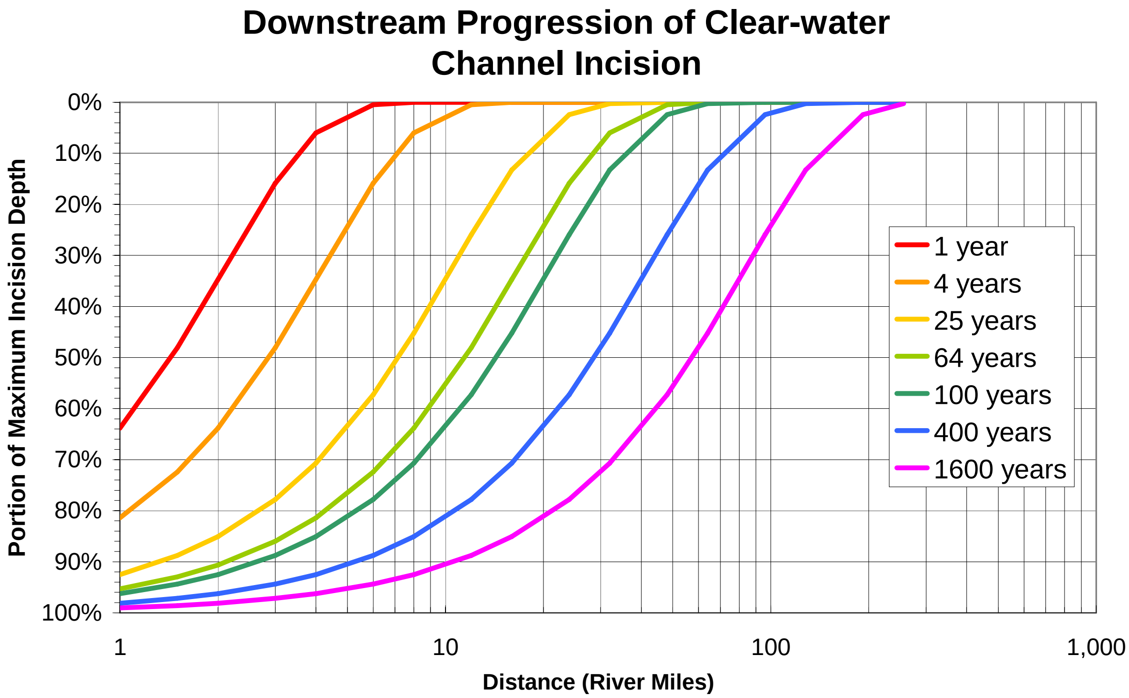


Figure 4.16 Estimated downstream progression of clear-water channel incision of the Platte River, based on de Vries as presented by Graf (1998).

however, it would take more than 400 years for half of the maximum incision depth to occur 30 miles downstream.

Based on the 2002 survey results presented in Figure 4.6b, the south channel has incised 13.3 feet sometime over the 62-year period from 1940 to 2002. This likely represents less than 100 percent of the maximum channel incision at that location because the channel has incised about 6 feet over the 13-year period from 1989 to 2002. The central Platte River is still wide enough that even 2 feet of channel incision could result in significant channel narrowing. If 2 feet of channel incision represents 15 percent of the maximum erosion, then according to the curves in Figure 4.16, 2 feet of channel incision should have occurred about 25 miles downstream since 1940. This appears reasonable since about 2 foot of channel incision was measured 18 miles downstream (RM 228.7) during the 13-year period from 1989 to 2002. Since channel incision often concentrates over a relatively narrow portion of the channel (Figure 4.6a), vegetation has the potential to colonize portions of the channel that are no longer frequently inundated. The curves of Figure 4.16 predict that 2 feet of incision would occur 30 miles downstream after 100 years from 1940 and 60 miles downstream after 400 years.

The slow rate of vertical channel incision can be explained by the large volume of sand generated by a small bed elevation change across a surface area as wide as the Platte, and having a length extending 100 miles in the case of Lexington to Grand Island, Nebraska. Based on de Vries' (1973) analysis, the maximum depth of clear-water incision would take centuries to progress from the Keystone Diversion Dam on the North Platte River, downstream to the town of North Platte, and from the Johnson-2 Return channel at the Platte River, downstream to Grand

Island, Nebraska. This calculation assumes that tributary inputs of sand along the central Platte River are minor and do not offset the deficit, allowing the channel incision to continue downstream.

4.4.3 Vegetation and Topography Indicators of Incision

Less definitive but equally compelling evidence of gradual incision can be gleaned from the topography and vegetation described on historical maps. Areas of the channel that are now wooded islands (U.S. Bureau of Reclamation aerial photographs from 1982 and 1998) were part of the wider unvegetated channel shown on the maps made during the 1860s, 1890s, 1910s (Government Land Office, USGS, and Nebraska Counties) and in aerial photographs of 1938. The presently wooded islands were originally part of the active river channel. Inundation of the active river channel and mobilization of the bed material on nearly an annual basis was required to keep vegetation from becoming established in the active channel (Section 4.8.2 Vegetation and Channel Changes).

Reclamation crews surveyed more than one hundred cross sections of the Platte River channel in 1989 in the reach between Grand Island and North Platte, Nebraska. Hydraulic computations for the river channel in 1989 indicate that, due to current channel depths, the river flow would have to be greater than 10,000 cfs before water would inundate these now wooded islands. The elevation difference between the present bed of the active river channel and the wooded islands of the formerly active river channel can be explained by channel incision, a decrease in the bed elevation. The reduction of mean and peak river flows and the process of slow and gradual channel incision have left portions of the formerly active river channel higher than the present active river channel.

4.5 COARSENING SEDIMENT AND CHANNEL CHANGES

As described in Section 4.4, a general reduction in the volume of sediment can initiate a change in the bed elevation. In this section, the implications for channel depth and width resulting from a change or coarsening in the sand source are described. Two potential causes of coarsening sand in the bed of the river are the channel incision described in Section 4.4, and the change in the proportions of medium sand from the North Platte River and coarse sand from the South Platte River sand. Coarsening grain size is an addition to the processes of decreased bank-full discharge, expanding vegetation, and channel incision, which causes the Platte River channel to narrow.

4.5.1 Transition in Sand Source from North Platte to South Platte

Changes in the sand transport along the Platte River in the twentieth century include a decrease in the input of medium sand from the North Platte and an increase in the input of coarser sand from the South Platte. The change in the relative flow and sand contributions from the North and South Platte Rivers affects the sand balance in the Platte River downstream. Prior to 1909, the North Platte River was the dominant tributary, supplying most of the water and most of the sand. Once the annual mean and bankfull flow rates on the North Platte River were reduced, the sand supply to the Platte River from the North Platte River was also reduced. The reduction in sand load follows the sand-discharge relationships applicable at that time, as estimated by the relationships presented in Chapter 3 in Figures 3.17 and 3.18. Over time, the relative importance of the flow and sand contributions from the South Platte River increased (Figures 3.19, 3.20, and 3.21).

The earliest description found of grain size on the North Platte was a fine quicksand (Lamb et al., 1911), and the earliest measurements were by the U.S. Army Corps of Engineers (USACE, 1935). The USACE measurements of North Platte River sand are a medium grain sand with a diameter of 0.56 mm. The earliest description found on the grain size of the South Platte was a coarse sand (Slichter and Wolff, 1906), and the earliest measurements were made by Smith (1970). The median size of the South Platte River sand in 1970 (Smith, 1970) was about 1 mm, while measurements by Kircher (1983) gave 1.1 mm.

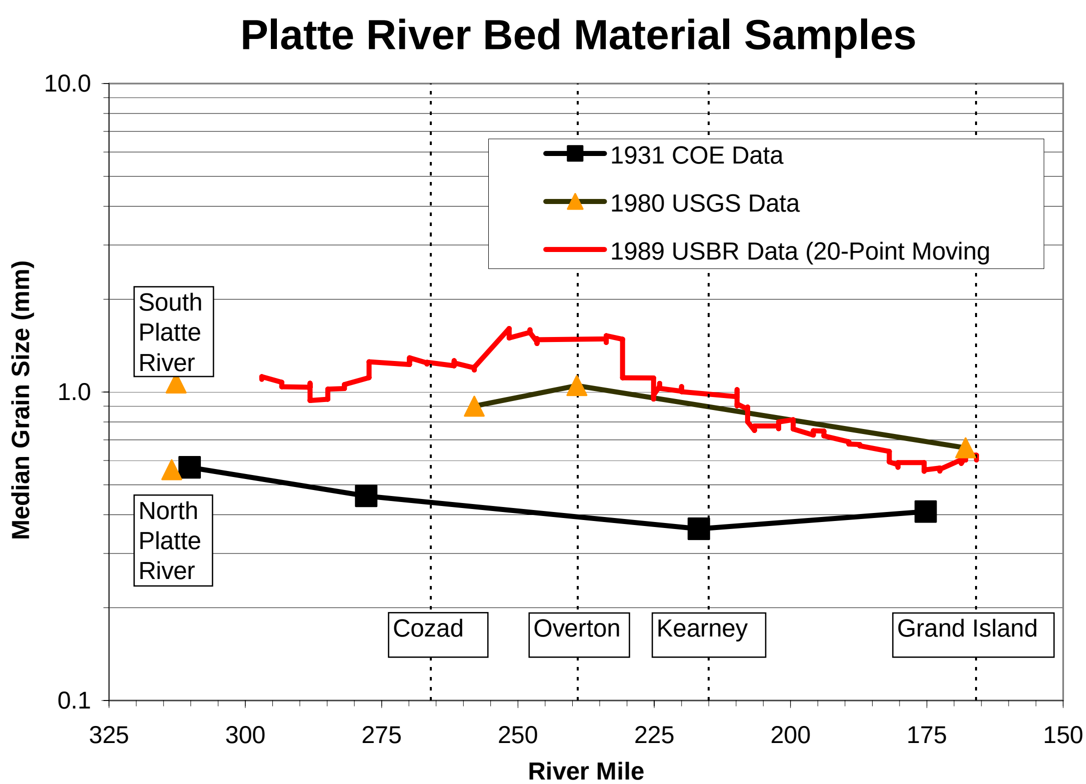


Figure 4.17 Median bed-material grain size comparisons between 1931, 1980, and 1989. Bed material data were collected from the Platte River channel near bridges in 1931 and 1980 and along many points along the river (at bridges and between bridges) in 1989. The river velocity and bed-material grain size both tend to increase at bridge constrictions, but the data in 1989 are as coarse, or coarser, than in 1980.

Figure 4.17, with 1931 data from USACE (1935), 1979-80 data from Kircher (1983), and unpublished Reclamation data from 1989, shows the history of the sand size distribution along the Platte River, including the North and South Platte sand sources. In 1931 (square boxes in Figure 4.17), the sand size profile based on the averages of many samples at bridges along the Platte smoothly connects with the North Platte average source; its grain size distribution history is shown in Figure 4.18. In 1980 (triangles in Figure 4.17), the average sand size profile at bridges connects with the South Platte source. Data measured in 1989 all along the channel show agreement with the 1980 data. The decreases of water and sand from the North Platte River changed the size of the sand source to the Platte River. Although there is still a supply of medium sand in the bed of the 58-mile reach of the North Platte River, downstream from the Keystone Diversion Dam, the amount of river flow available to move it is small.

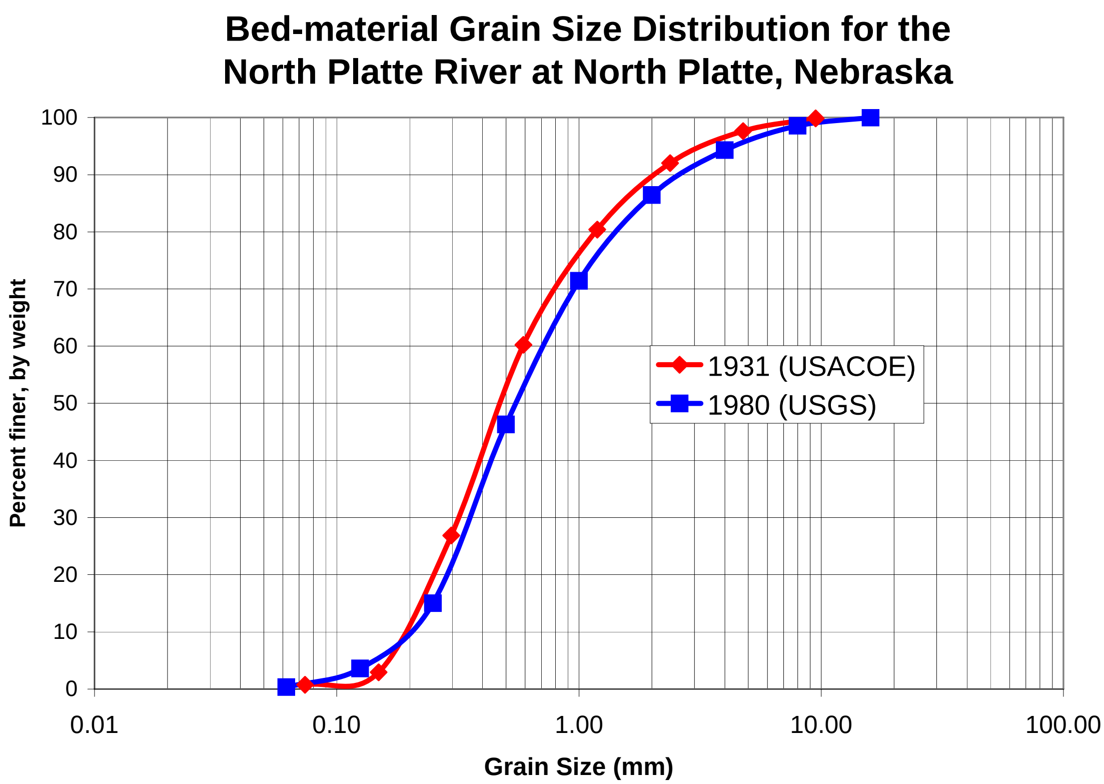


Figure 4.18 Bed-material grain size distributions in 1931 and 1980 for the North Platte River at North Platte, Nebraska.

Coarser sand from the South Platte began to replace the medium sand in the top layer of the river bed in the central Platte River. The bed-material grain size distributions for the North Platte, South Platte, and Platte Rivers are shown in Figure 4.19. The coarsening of the Brady-Cozad reach, from the Tri-County Diversion Dam to the Johnson-2 Return channel, occurs mainly when the flows along that reach are high and, correspondingly, when the sand transport through the Brady-Cozad reach provides sand input to the habitat reach downstream from the Johnson-2 Return channel. This replacement process, shown in Figure 4.17, has roughly reached Kearney at river mile 215, but has not yet reached Grand Island, Nebraska at river mile 166. The median grain size near Gothenburg, Nebraska changed from 0.46 mm in 1931 to 0.9 mm in 1979 (Figure 4.20). During this transition, the median sand size near Grand Island and Chapman, Nebraska has changed from 0.41 mm in 1931 to 0.66 mm in 1980 (Figure 4.21).

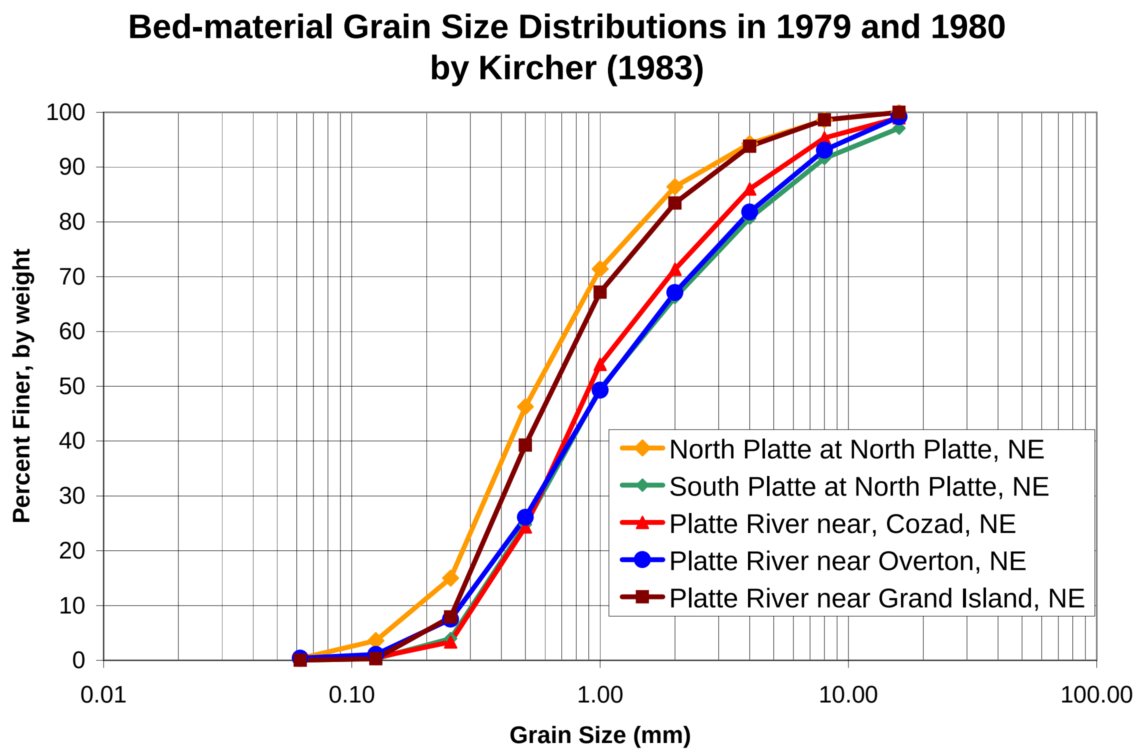


Figure 4.19 Bed-material grain size distributions in 1979 and 1980 by Kircher (1983) for the North Platte, South Platte, and Platte Rivers.

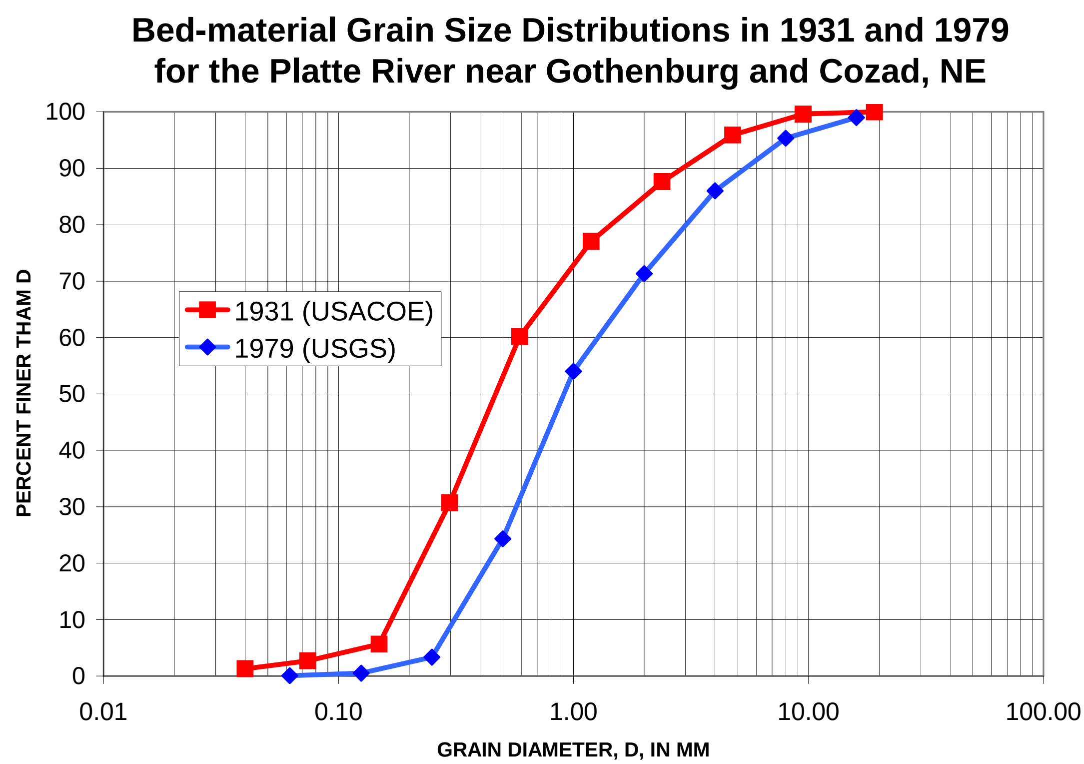


Figure 4.20 Bed-material grain size distributions in 1931 and 1979 for the Platte River near Cozad and Gothenburg, Nebraska.

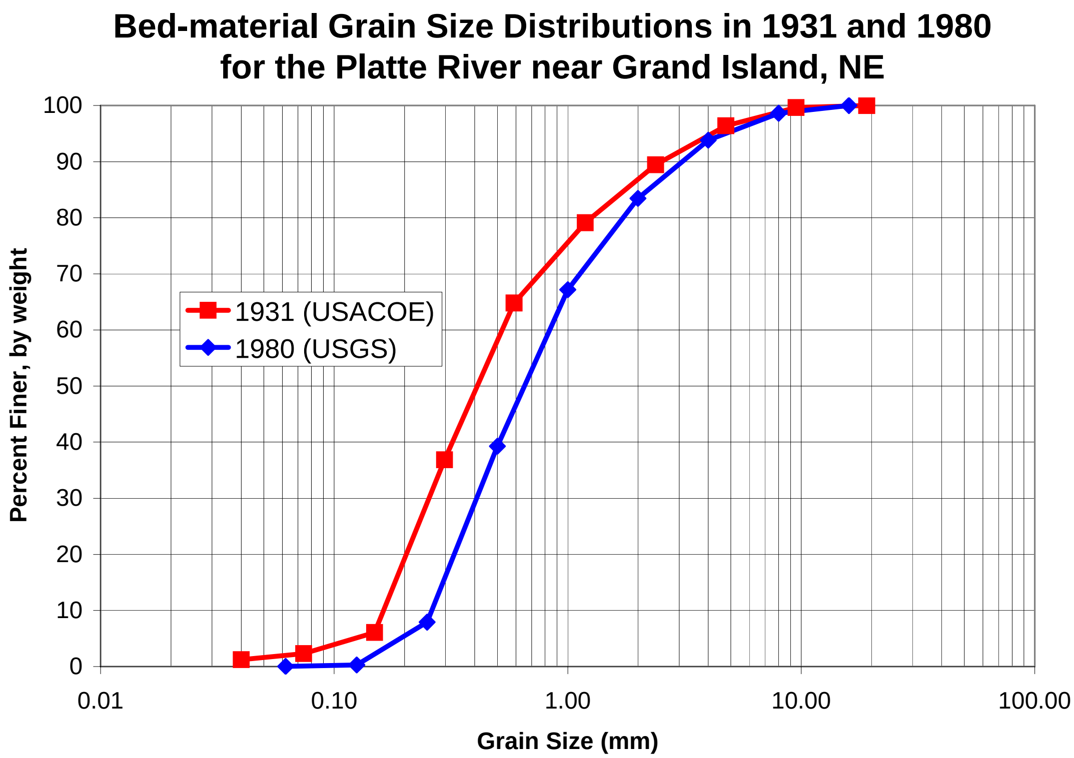


Figure 4.21 Bed-material grain size distributions in 1931 and 1980 for the Platte River near Grand Island, Nebraska.

4.5.2 Process for Transport of Medium Sand Grain Size

The increase in supply of coarser sand and reduction in the supply of medium sand has two effects: (1) it causes net erosion of medium sand from the river bed because the outflow rate of medium sand from the Central Platte is greater than its inflow rate, and (2) it causes a decrease in the mobility of the braided bed because coarser particles require a greater hydraulic capacity to be transported at the same rate as finer particles (Carson, 1984). When the upstream supply of sand becomes coarser, the quantity of sand supplied to the Platte River by a given discharge decreases. However, the medium sand present in the downstream Platte riverbed is still transported at the previous higher rate. Thus, medium sand has the potential to be transported downstream from the central Platte River at a faster rate than the coarser sand that is supplied from upstream.

Considering the reach of the Platte River from North Platte to Chapman, Nebraska, the outflow of medium sand (0.4 mm) at the downstream end of this reach is determined by the flow near Grand Island, roughly equal to the combined flow of the North and South Platte Rivers, and the geometry of a wider channel. The sediment transport at this downstream location is still based mainly on the finer sand that has remained from the time of the earliest measurement. The average annual sediment load for the Platte River near Grand Island, Nebraska indicates a small reduction in the sand outflow from the Chapman end of the reach. However, the inflow of medium sand at the upstream end of this reach is determined by the reduced river flow and sand transport from the North Platte River (Figures 3.19, 3.20, and 3.21) and the small percentage of medium sand (25 percent) from the South Platte River (Figure 4.19). The result is a net erosion of medium sand from the bed of the central Platte River.

4.5.3 Process for Transport of Coarser Sand Grain Size

The sediment transport rates for coarser sand are slower than for medium sand and percentage of coarse sand in the river bed tends to decrease with distance downstream. The outflow of coarser sand at Chapman is low because its percentage in the river bed there is low. The inflow of coarse sand (1.1 mm) from the South Platte River is relatively high because the South Platte has proportionally become a greater source, and coarser sand is the median bed-material size of that river. Still, present day sediment transport is diminished from levels prior to the twentieth century (Lyons & Randle, 1988, Randle & Samad, 2003). Although there is a larger source of coarser sand, the transport of coarser sand through the Brady-Cozad reach is diminished by the reduced flows in this reach. As a result of this, a continual deposition of coarse sand occurs along the Brady-Cozad reach where a large portion of the flow, but not the sand, is diverted from this location.

The regime theory discussed further in Section 4*.6. Changes in Plan Form* shows that coarser sand is associated with natural channels that are more narrow than natural channels composed of fine sand. Because the transport of coarse sand requires higher water velocities than does medium sand, the presence of more coarse sand changes the equilibrium geometry of the channel. Flow rate is the product of mean velocity and area, which is the mean velocity times the width, times the mean depth. For a given discharge, when the velocity is increased, the flow area is decreased. A higher velocity also requires deeper water to maintain the same friction losses. For a constant bank-full discharge, the correspondence of increasing sand grain diameter with increasing velocity and flow depth, causes a channel to narrow as bed material shifts from medium to coarse sand.

Yang (1996) quantified the width dependence on median grain size, indicating that the width is inversely proportional to the square root of the grain size, in a relation similar to the square-root dependence shown in the regime theory. If the bed material grain size increases from 0.5 mm to 0.9 mm, the channel width is reduced by the square-root of 5/9, to 75 percent of its original value.

4.5.4 Current Condition of Grain Size

Grain size measurements of the Platte River indicate a coarsening of sand grain has occurred since 1931 and the coarsened area is presently extending downstream. This coarsening in size of the Platte River bed sands started at North Platte, Nebraska and has been progressing downstream reaching as far as Kearney, Nebraska. Figures 4.17 and 4.20 indicate that the bed of the Platte River has already coarsened throughout the reach between Cozad (river mile 266) and Kearney (river mile 215), Nebraska, where median particle size increased from 0.4 mm to 1 mm.

Coarsening of the river bed leads to channel narrowing; however, the Platte River bed in the reach near Grand Island, Nebraska has so far only been slightly affected. Near Grand Island, the sand bed has presumably begun to coarsen, from 0.41 to 0.66 mm (Figure 4.21). This part of the river has narrowed the least, so that now it is the widest reach along the Central Platte. As medium sand is depleted from the river bed and replaced with coarse sand, the river channel will have a tendency to narrow, as illustrated in Figures 4.17 and 1.3, in the reach from Kearney to Grand Island, Nebraska.

4.6 CHANGES IN PLAN FORM

The association of the quasi-equilibrium channel geometry of natural channels with flow rate, channel slope and sediment properties is called regime theory (ASCE 1998a). The braided pattern typical of the river prior to the 1900s, requires a steeply sloped channel or an over supply of sediment. The average channel slope of the Platte River (0.00126) is considered steep for a sandbed river of this size. The slope has not changed during the 1900s because a large change in river bed elevation is needed to change the average slope over the length of the river, and because the alignment of the river channel is still relatively straight. The recent surveys of the Platte River (U.S. Bureau of Reclamation, 1998) give a profile that is compared to the USGS profile (Gannett, 1901) in Figure 4.22. The recent profile has a nearly identical slope at this scale.

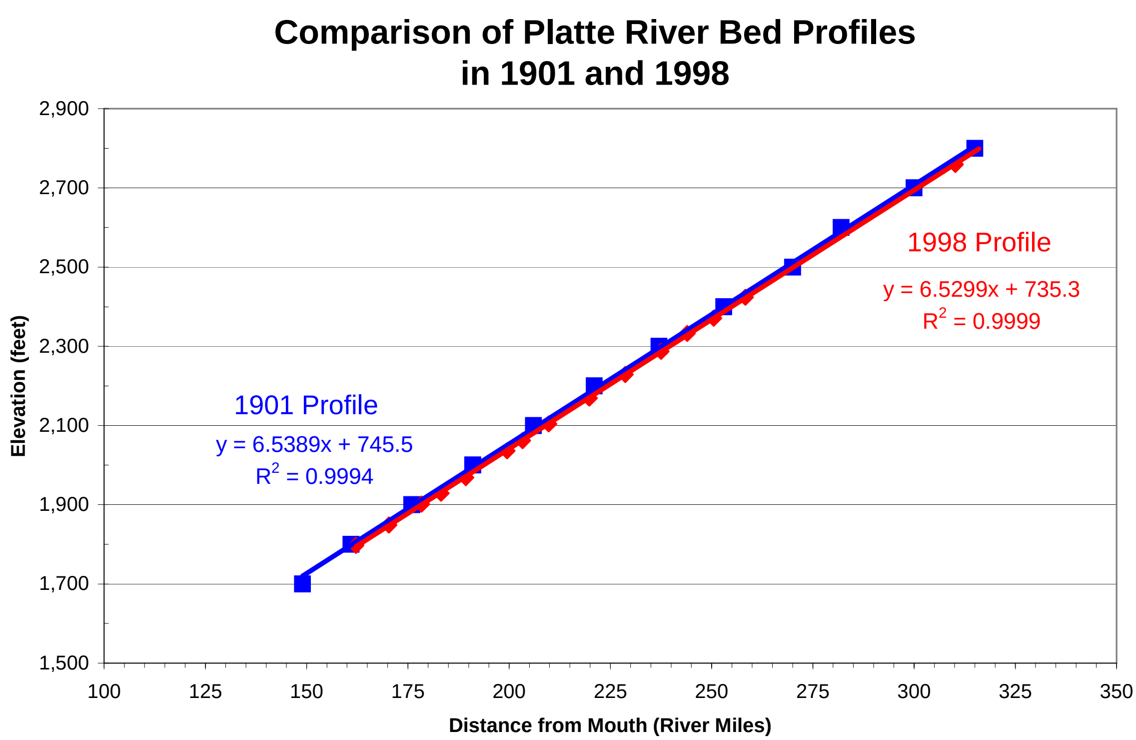


Figure 4.22 Comparison of 1901 and 1998 Platte River bed profiles.

The minimum slope required for a braided channel is a decreasing function of the full bank discharge (Leopold and Wolman 1957, Carson 1984, Chang 1985). However, the threshold slope for a braided pattern is described as also being a function of river-bed grain size (Henderson, 1963 and 1966, Carson 1984, Ferguson 1981, Chang 1985). A coarser river bed requires a higher bank-full discharge to maintain a wide, braided riverbed pattern. Figure 4.23

presents the relation between bank-full discharge, channel slope, median bed grain size, average depth, and channel width developed by Chang (1985). Studies by Lane (1957) and Osterkamp (1978) have used the mean annual flow instead of the 1.5-year flood to describe the slope of braided channels.

As shown in Figure 4.23 and assuming a constant particle size, rivers with lower bank-full discharge require a relatively steep slope in order to maintain a braided channel. A steep channel, with a slope approaching a minimum threshold value for maintenance of a braided form, can change to an anabranched form simply through reductions in bank-full discharge. In contrast, reducing bank-full discharge in a stream with a slope well above the threshold for a braided form would result in a narrower river channel. In the latter case, water would fill only the low sections of the original channel, but the channel would retain a braided form.

The effect of the bed material size is shown in the vertical axis of Figure 4.23. A larger median grain size requires a steeper slope to maintain a braided channel form. A braided channel, with a slope near the threshold value and a constant bank-full discharge, can change from a braided form to an anabranched form with a coarsening of the bed material.

The bank-full discharge of the North Platte and Platte Rivers prior to the 1900s, calculated by Randle and Samad (2003) with different hydrologic and sediment transport methods, was approximately 10,000 cfs. The slope of both rivers was 0.00126 and the median grain size was 0.4 mm. When these values are plotted on Figure 4.23 it can be seen that the Platte River fits Chang's (1985) steep braided river category, however, it is near the threshold slope for a braided channel pattern. The corresponding values of width and depth from Figure 4.23 are approximately 750 feet and 7.5 feet respectively. The average width of the Platte River prior to the 1900s, shown in Table 4.2, ranges from 2,500 feet to 5,300 feet. The qualitative agreement is good, but the width values are not accurate. Two possible explanations for this disparity are that the regime theory does not account for the upstream sediment supply and there may be relatively few data points in the steep, braided-channel category of Figure 4.23, to produce an accurate correlation.

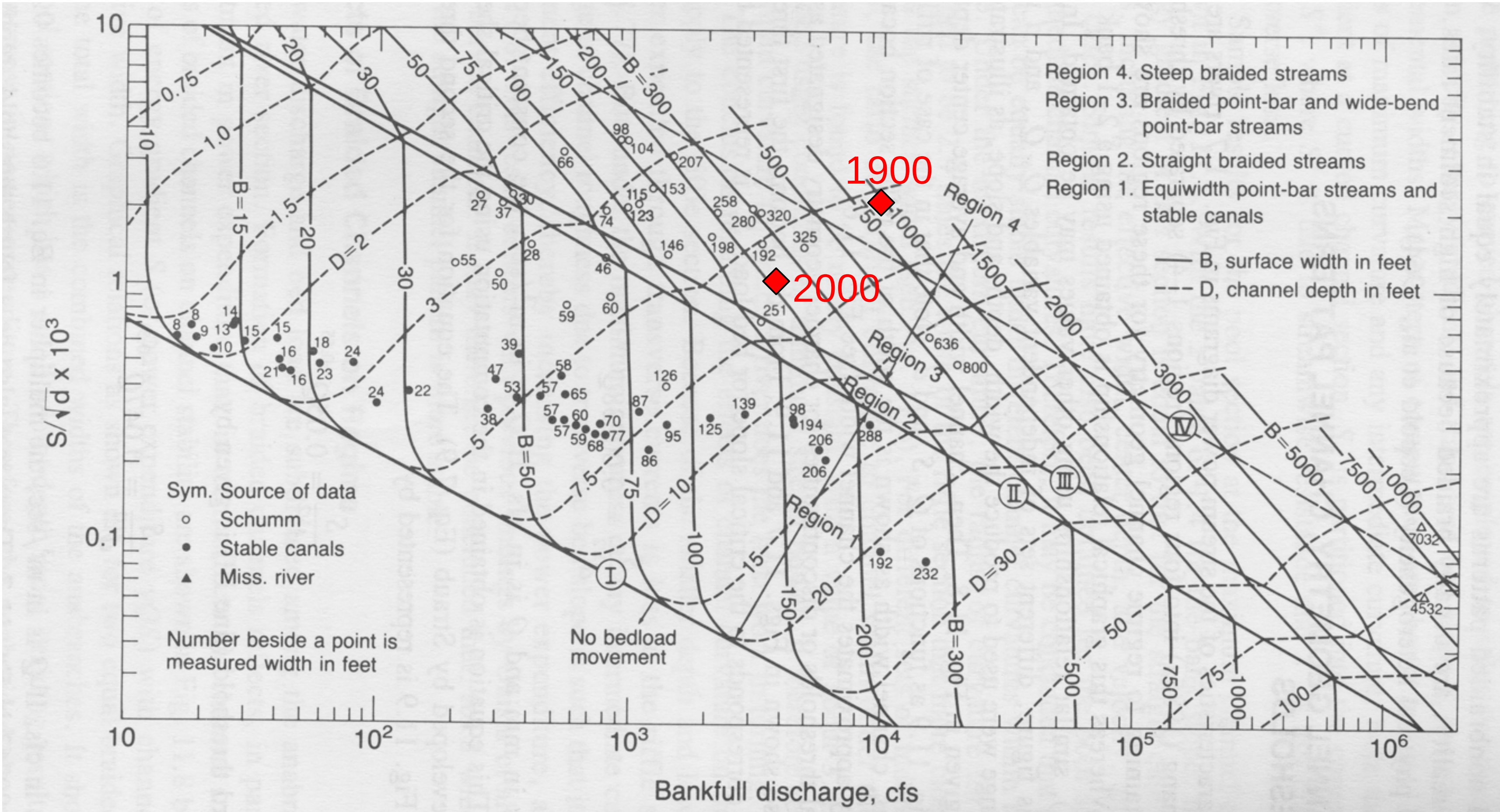


Figure 4.23 Regime channel bed geometry for sand bed rivers, from Chang (1985). For the historic Platte River channel (1900), the bankfull discharge was about 10,000 cfs, the median grain size was about 0.4 mm, and the slope was 0.00126. Therefore, the term $[(S/d^{0.5})1000]$ was equal to 2.0. For the present Platte River channel (2000), the bankfull discharge is about 4,000 cfs, the median grain size near Overton, Nebraska is about 1.5 mm, and the slope is still 0.00126. Therefore, the term $[(S/d^{0.5})1000]$ is now equal to 1.0. Based on the classification by Chang (1985), the Platte River evolved from a steep braided channel (Region 4) to a braided point-bar and wide bend point-bar channel (Region 3).

A second regime diagram by Leopold and Wolman (1957) is shown in Figure 4.24. This diagram does not incorporate grain size but relates plan form, braided or meandering, to bankfull discharge and channel slope. This figure does not use transition areas and gives one simplistic divide ($S=0.06Q^{-.44}$) between a braided and meandering condition. Based on this relation, the 1900 Platte River is braided at 10,000 cfs and a 0.00126 slope, and at the year 2000 shifts to the divide of braided and meandering conditions with a discharge of 4,000 cfs.

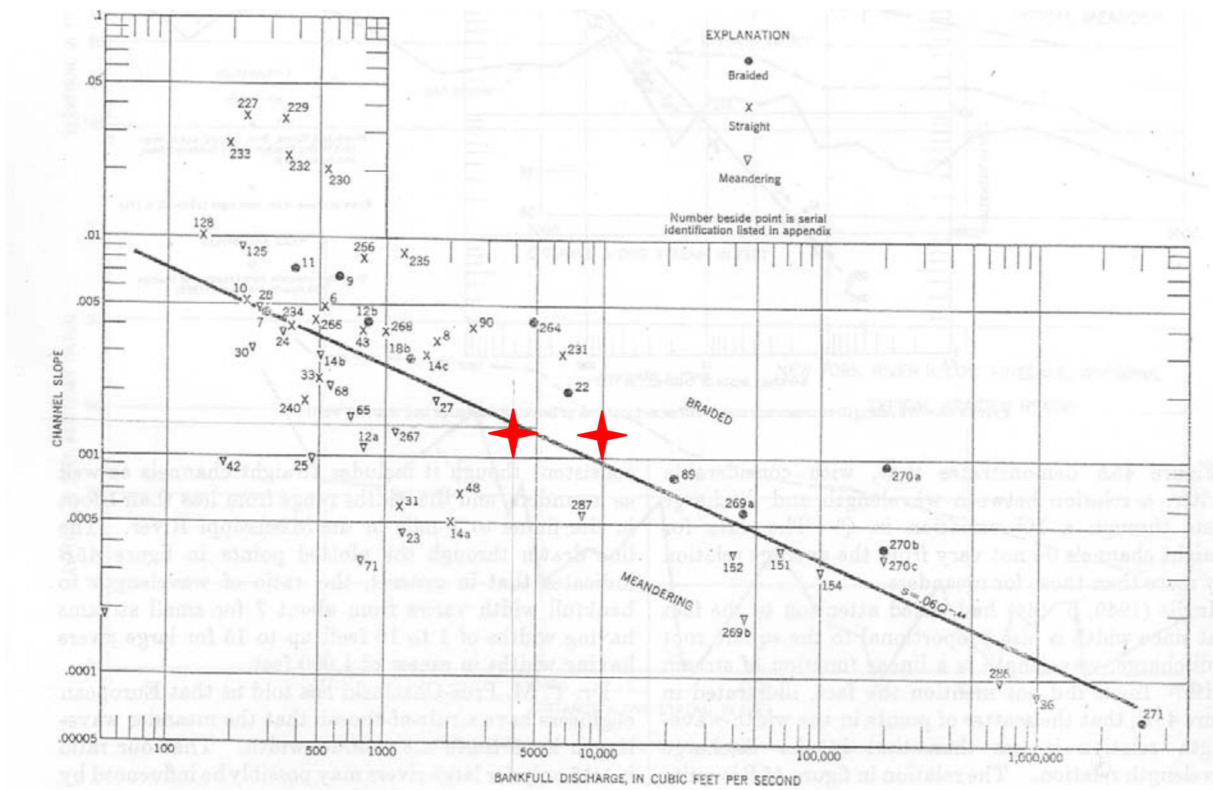


Figure 4.24 A regime diagram for natural channels based on channel slope and bankfull discharge, taken from Leopold and Wolman (1957). Points shown are a slope of 0.00126 and a flow of 10,000 cfs for the Platte River in 1900, and a slope of 0.00126 and a flow of 4,000 cfs for the Platte River in 2000.

A third regime diagram by Lane (1957) is based on channel slope and mean discharge as shown in Figure 4.25. Lane's diagram is not as simplistic as the Leopold and Wolman diagram (Figure 4.24) and recognizes a transition range of conditions between the braided and meandering stream. The Platte River in 1900, with a slope of 0.00126 and a mean discharge of 3,700 cfs, is in the intermediate stream region, near the border of braided condition. At the year 2000, with the same slope but a mean discharge of 2,100 cfs, the Platte River remains in the transition zone, but slightly more distant from a braided condition.

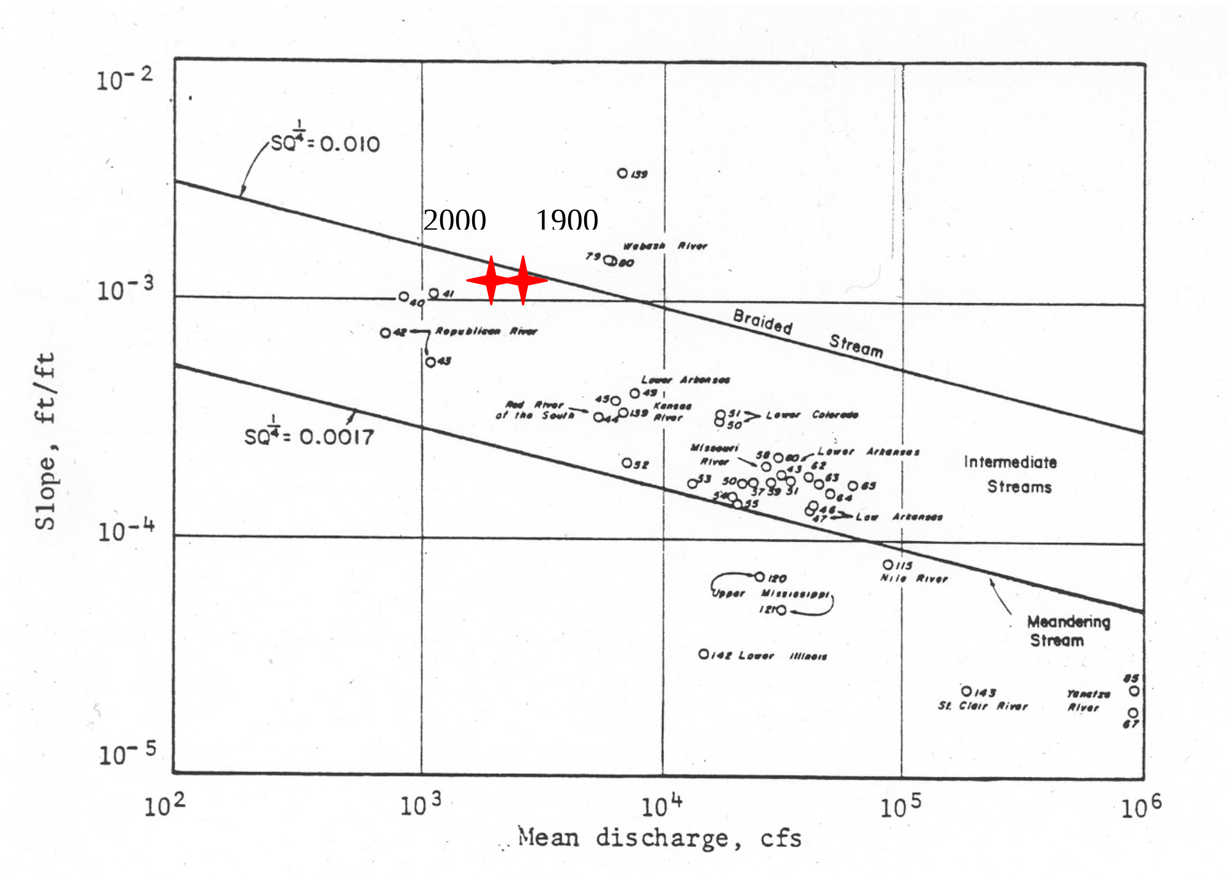


Figure 4.25 Lane's (1957) regime diagram for sandbed streams based on slope and mean discharge, taken from Richardson, et al. (1990). Red points shown are for the central Platte River with a slope of 0.0026 ft/ft and a mean discharge of 3,700 cfs for the year 1900, and a mean discharge of 2,100 cfs for the year 2000.

Regime theory is not quantitatively precise as demonstrated by the variations in stream classifications and zones in Figures 23, 24, and 25. Regime theory does, however, provide a guide to the changes in channel geometry that can be expected with changes in the channel-forming discharge, bed slope, and as in the case of Figure 4.23, bed material grain size. The shifts in the three figures are small and remain near the theoretical divide for braided stream types, yet all three regime diagrams (Figure 4.23, 4.24, and 4.25) illustrate that the reduction of channel-forming discharge in the North Platte and Platte Rivers causes a shift in plan form from a braided condition towards an anabranched or meandering system.

The time series of aerial photographs from the period 1939 to 1998 support the regime theory by showing the evolution of channel form for the Platte River and the encroachment of woody vegetation. In the early photographs, the Platte River still exhibits a steep braided form with a wide channel of shifting sand. Later photographs contain more river reaches with multiple and narrow anabranched channels aligned around vegetated islands.

4.7 CHANNNEL CHANGES FROM BRIDGES, DIVERSION DAMS AND BANK PROTECTION

In contrast to the narrowing processes discussed in previous sections, the reduction in channel width resulting from bridge structures, diversion dams, and bank protection is a localized effect. Becker (1989) and Simons and Associates (1990) have discussed decreases in channel width within approximately ½-mile of a bridge structure. Essentially, the effect of bridge, dam, and bank protection extends only as far as the structure-altered flow pattern. For example, sediment eroded by the faster flows of a constricted bridge segment will often deposit locally once an unrestricted flow pattern is reestablished. The constricting effects of the bridge on channel width, and the scour effects from bridge structure geometry acting on the steam bed, are local conditions that do not migrate downstream or upstream.

Through a large period of the 1900s, there was a trend towards constructing bridges with shorter spans over water, and longer approach embankments. More recent bridge construction often has stricter requirements on allowable bridge backwater that reduces river constriction concerns. Although not all bridge crossings contribute to channel narrowing, it was estimated that bridge structures along the central Platte River may affect as much as 20 percent of the channel length (Simon & Associates, 2000). These effects apply only to segments proximal to the structures.

An estimate of impacts to the river from bridges is further addressed by a 1998 review of bridges over the Platte River. Aerial photographs and quadrangle maps from 1998 show 22 bridges crossing the Platte River between Chapman, Nebraska and the Tri-County Diversion Dam near North Platte, Nebraska (river miles 157.1 to 310.5). That is an average of 7 river miles per bridge crossing (Table 4.5). Of the 22 bridges, 13 were qualitatively assessed based on channel form and bank geometry to significantly constrict one or more river channels for a distance of one-half mile upstream and one-half mile downstream from the bridge. A distance of 13 miles of bridge impacts is 8.5 percent of the 153 river miles between North Platte and Chapman, Nebraska.

Table 4.5 — Platte River Bridges based on 1998 aerial photographs and U.S. Geological Survey quadrangle maps.

River Mile	Bridge Location Description	Significant Channel Constriction	Gravel Pits Locations
157.1	Chapman, NE	Slight	
165.9	RR near Grand Island, NE	Slight	
167.9	HWY 34 Bridge	Yes	
172.7	I-80 and County Bridges near Doniphan, NE	No	
175.3	HWY 281 Bridge	Yes	
181.9	Alda, NE	No	DL
187.3	Wood River, NE	No	
195.7	RR bridge near Denman, NE	No	
195.8	Shelton, NE	Yes	
202.2	Gibbon, NE	No	
207.9	County road across Kilgore Island	Yes	DL, DR
209.8	RR across Kilgore Island	No	
215.0	Kearney, NE	Yes	UL, UR, DL
224.0	Odessa, NE	Yes	UL, UR, DL, DR
230.8	Elm Creek, NE	Yes	UL, DL, DR
239.3	Overton, NE	Yes	UL, UR,DL
251.6	Lexington, NE	Yes	UL, DL, DR
258.0	West of Lexington, NE	Yes	
266.7	Cozad, NE	Yes	UR, DR
277.3	Gothenburg, NE	Yes	UL, DL, DR
288.3	I-80 across Brady Island	Yes	UL, DR
301.0	Maxwell, NE	No	
310.5	Tri-County Diversion Dam	No	

Gravel pit locations:

UL: Upstream of the bridge and left of the river channel (looking downstream).
UR: Upstream of the bridge and right of the river channel.
DL: Downstream of the bridge and left of the river channel.
DR: Downstream of the bridge and right of the river channel.

4.8 TIME SCALES OF CHANNEL PROCESSES IN THE PLATTE RIVER

The central Platte River channel from North Platte, Nebraska, to Kearney, Nebraska, in the last decades of the twentieth century exhibits less change in channel form than noted in earlier decades of the twentieth century (Figure 4.1 and 4.17). This would imply that channel characteristics of grain size, width, depth, and vegetation coverage are approaching a balance with existing conditions including flow, sediment transport, river structures, and climate. In contrast, the trends in grain size, channel width and channel depth discussed in previous sections, indicate channel narrowing may continue downstream of Kearny, Nebraska. This disparity can be attributed to the different time scales, ranging from years to centuries, associated with each process of channel change.

- Width reduction resulting from changes in annual mean and bank-full flow rates is relatively rapid and has already occurred.

- Width reduction resulting from vegetation growth is also relatively rapid and may be complete upstream from Kearney, but could continue in conjunction with other channel narrowing processes downstream.

- Channel incision resulting from a reduction in the supply of sand appears to be ongoing, is a relatively slow process, and may require centuries to complete. This process is on the same time scale as geologic/climatic factors and matches the expected life of reservoirs.

- Grain size changes and coarsening of the river bed, resulting from a change in sediment source, appears to continue downstream from Kearney, and may take decades to reach a stable condition.

- Plan form change resulting from reductions in flow and coarsening of the river bed appears near completion upstream from Kearney.

- Localized width reductions caused by bridges in a sand bed river are relatively rapid and at most locations should be nearly complete within two decades of bridge construction. This estimate is dependent on the hydrologic cycle, and assumes there are no additional causes for change in channel form.

4.8.1 Channel Changes from Flow Reductions

Flow change is a primary process of channel narrowing, and occurs rapidly with each increment of river flow reduction. A large decrease in annual flow rates occurred over the period 1909-1970 (Randle and Samad, 2003), while the flow measurements for the most recent period considered, 1970 to 2002, show no further decreases in mean-annual flows, annual-peak flows and bank-full flows. No further channel narrowing from this process is anticipated, unless additional reductions in annual-average and bank-full flow rates re-initiate this channel narrowing effect.

4.8.2 Vegetation and Channel Changes

Exposed sandy areas of the channel, abandoned in response to decreasing flows over the period 1909-1970, were ripe for the rapid colonization by grass, shrubs, and trees. Within a few decades after each major hydrologic change, the banks of the narrow channels were covered with mature vegetation. The roots of that vegetation stabilized the banks and prevented erosion during occasional high flows. The last major vegetation increase due to low flow occurred during the 1950s drought, and even the large flood peaks of 1973, 1983, and 1984 did not produce large, sustainable width increases. Vegetation effects appear to act more quickly towards encroachment, rather than removal. Additional channel encroachment by vegetation may occur in the future on exposed sand bars, and banks as a result of flow reductions from extended periods of drought, or operation of flow releases.

4.8.3 Channel Incision Resulting from Reductions in Sediment Supply

General reduction in the supply of sediment is most severely felt adjacent to major clear water sources of flow, with impacts diminishing downstream as the sediment deficit is offset by erosion from the bed. The channel incision, or deepening of the channel resulting from a reduction in the upstream sediment supply, continues at the present time to move downstream from the clear-water releases at Kingsley Diversion Dam and the Johnson-2 Return channel. The process of channel deepening causes a corresponding reduction in channel width.

Erosion continues to progress slowly downstream. A study by Chen et al. (1999) indicates that incision is occurring as far downstream as Grand Island. The incision depth can be limited by armoring, and eventually the downstream progression of incision will end when the sediment imbalance is corrected. Sediment sources are material eroded from the channel bed and possibly, sediment inputs from downstream tributaries. Given the slow progression of the maximum depth of clear-water incision (several feet), this process could take centuries to reach an equilibrium condition.

One additional trend to note is the impact of incision processes on wet meadows adjacent to the banks of the Platte. Incision, resulting from decreases in sediment supply or changes in flow, has the potential to alter nearby wet meadows by lowering the water table along the affected reach of the river.

4.8.4 Channel Changes Resulting from Coarsening Sediment

At present, there is an incomplete transition from medium sand to coarse sand, and the effect on channel width due to the change in median particle size, is still progressing in the downstream direction along the central Platte River. Bed material in the medium sand size (0.25 to 0.5 mm) provides a more mobile river bed, and forms a wider equilibrium channel than does a coarse sand bed (0.5 to 1.0 mm).

Because the change during the last 60 years appears nearly complete from North Platte to Kearney and has already begun at Grand Island, several decades is proposed as an estimate of the time needed to complete this transition. The transition in grain size appears to be complete downstream to mile 225, near Kearney (Figure 4.17), and the average width from Overton to Kearney, seen in Figure 4.1, is 800 feet. If the grain size continues to coarsen downstream, and based on currently identified factors, the persisting trend of narrowing implies the total width of all sub-channels from Kearney to Grand Island can also be expected to narrow to near 800 feet.

4.8.5 Plan Form Changes

A comparison of mapping from the early 1900s and the present day show that changes in plan form from a braided to anabranched system have occurred in some reaches upstream of Kearney, Nebraska. Changes in plan form are dependent on the coarsening process, therefore the time scale for future changes in the reach from Kearney to Grand Island, Nebraska is projected over decades.

4.8.6 Channel Changes from Bridges, Diversion Dams and Bank Protection

Localized channel narrowing resulting from channel structures is dependent on the flow history and the age of the structure. In general, the time scale is relatively short with the occurrence of high flow events. As a general estimate, in the vicinity of structures that have been in place more than two decades, channel narrowing is assumed near complete.

5.0 OPTIONS FOR RESTORING CHANNEL HABITAT

The Program seeks to improve channel habitats for Whooping Cranes, Least Terns, and Piping Plovers. In general, these species prefer a wide, shallow, and unvegetated river channel with an abundance of sandbars for roosting and nesting (Section 4.3.1). Restoring a portion of the historic channel requires reversing, in some small but significant amount, the key factors that have led to channel narrowing and other habitat problems, by undertaking the following actions:

- restoring a fraction of the historic bank-full-discharge flows;
- removing vegetation from part of the overgrown historic channel;
- restoring a fraction of the historic supply of medium sand;
- widening the main channel in selected reaches of the river; and
- blocking some of the secondary channels to focus flow in the main channel.

The first two actions have occurred to some degree during recent decades but without coordination. Large peak flows occurred naturally in 1983 and 1984, causing the spillway at Kingsley Dam to release water in 1983. These large flows did not substantially widen the channel on a sustainable basis. Even if the bank-full-discharge flows were increased significantly, it likely would take decades or centuries for higher flows alone to remove the dense riparian vegetation and widen the active channel. Furthermore, the upstream sediment supply would have to be concurrently increased to prevent additional channel incision.

Currently, several agencies and organizations are clearing islands and river bank areas of trees and other vegetation to create roosting and nesting habitat. This produces immediately useful habitat. However, it has not widened the active channel. The clearing of vegetation alone does not provide the wide, shallow channel for roosting or the high, dry sand bars for summertime nesting. Further, because annual high flows are too low to overtop and “activate” most of the cleared areas, vegetation returns to the cleared sites within a few years. Clearing actions are then repeated.

The remaining part of this paper describes a general strategy for creating and sustaining increased amounts of endangered species riverine habitat, following the plan form and regime theory concepts of Figure 4.23. The following restoration actions must be undertaken in a coordinated way and their effects closely monitored. As discussed earlier, the various processes which determine the river’s shape and character are linked. While each action could be tried independently, the results would likely not be as successful as would an integrated program. This general strategy includes: 1) the progressive clearing and lowering of selected vegetated islands that are located within or bordering the river’s main channel and 2) annual high flows of short duration (1 to 3 days) focused within that main channel. The clearing and lowering of river islands would immediately increase the area of open main channel while, at the same time, provide more medium-sized sand to the main river channel. The higher annual flows would scour seedlings on sand bars and avoid the need for regular mechanical clearing of vegetation from the sand bars. The wider channel would also reduce the flow velocities and the erosional process caused by clear-water releases. Implementation of this general strategy would likely occur in a phased and incremental fashion to ensure habitat improvement and to avoid adverse impacts to property along the river channel.

5.1 MECHANICAL WIDENING OF THE CHANNEL AND AUGMENTATION OF MEDIUM SAND

A program of one-time, mechanical, channel widening, through the clearing and lowering of vegetated islands within or bordering the main channel, would be needed to achieve the immediate habitat benefits of a wider active channel. Wooded islands would be mechanically cleared of vegetation and the woody vegetation burned. The islands would be lowered by spreading the river sand that has been deposited on the islands back into the deeper sections of the surrounding river channel to create a wider and shallower channel. Island sand could also be used to block secondary channels. The program of mechanical widening would only need to occur once for each increase in width for a given reach. The increased channel width could then be maintained by an annual program of increased annual high flows. Land bordering the northernmost and southernmost river banks would not be mechanically cleared and lowered.

Island sand is both medium and fine. The addition of island sand to the active channel would locally reduce the median grain size of the river bed, increase the mobility of the bed, and shift the channel towards the wide, braided river channel shown at the top of Figure 4.23. There are enough wooded islands within the Platte River between Overton and Chapman to sustain the supply of river sand for centuries. For example, if sand were added to the channel at the rate of 500 tons per day, the corresponding annual volume would be 100,000 yd^3 per year or 20 acres of island sand cut to a depth of 3 feet (2 mi^2 of island over 50 years). This amount of sand is similar to the amount dredged annually from behind the Tri-County Diversion Dam and pumped into the channel downstream from that dam (Boyd, 1995).

A program of mechanically widening longer reaches by a small amount would better promote channel equilibrium than a program of widening shorter reaches by a large amount. The wider reaches would transport less sand downstream. If a particular reach were widened too much (relative to downstream reaches), then sand deposition would occur in the over-widened reach and erosion would occur in the next downstream reach. Although island clearing has been done for some time, lowering would be more extensive than during the Crane Trust's 1988-92 program (Platte River Whooping Crane Maintenance Trust, 1992), and careful monitoring is recommended.

Some experience with maintaining a wide main channel already exists along the reach just downstream from the Kearney Diversion Dam. That dam and the adjacent sand dikes focus the flow downstream from the Elm Creek bridge into a single channel roughly 800 feet-wide. The diversion of water but not sand into the Kearney Canal increases the sediment concentration in the river and causes a tendency towards local deposition. That reach of the river channel maintains its width until the channel approaches the next downstream bridge.

Additional experience with sediment management and monitoring already exists. Central Nebraska Public Power and Irrigation District regularly employs a dredge to pass about 75,000 cubic yards of sand per year over the Tri-County Diversion Dam (Boyd, 1995). The current dredging practice keeps the sand moving past the dam, but because water is diverted into the Tri-County Canal, there is less water in the river channel downstream from the dam to keep the sand moving. Most of the time there is not enough flow to transport all the sediment downstream, and sand accumulates on the river bed. Annual high flows tend to transport the accumulated sand away from the dam. Monitoring of this practice has revealed no adverse consequences (U.S. Army Corps of Engineers, 1999). Before this current practice was permitted, in 1994, 150,000 cubic yards of sand were stockpiled in a bermed area downstream from the dam. This stockpiled sand eventually re-entered the river channel without adverse consequences during high flow events. These experiences at the Tri-County Diversion Dam have some similarity to the clearing and leveling of river islands, in that river sand would be returned back to the channel for transport during high-flow periods.

5.2 INCREASED ANNUAL HIGH FLOWS

The amount of mechanical widening accomplished will correspond to increases in annual high flows. If the channel were mechanically widened without any program of increased annual high flows, then vegetation would likely grow back, sand deposition would occur, and the channel would again become narrow. Without an increase in annual high flows, wider channel widths could only be maintained through a periodic program of mechanical clearing and leveling.

An increase in the annual high flow, staying below flood stage and within the safe channel capacity, is one practical way to maintain a wider channel, because the higher flow would mobilize the river bed and clear seedlings from that wider channel. Increased spring high flows might not be needed if winter ice or other mechanisms killed the seedlings that germinated the previous season. An annual high flow in late May or early June would have several advantages over high flows in summer or winter:

- The augmented high flow would coincide with the natural spring runoff season. The augmented high flows also would build higher sand bars for nesting terns and plovers and improve the ratio of spring high-water elevations (nest building) compared to the elevations caused by summer thunderstorms (nest destroying).

- There would be time to determine if seed germination, growth, and survival from the previous summer was significant and if high sand bars were available for nesting. Seedlings might be eroded by naturally-occurring summer thunderstorms or winter ice scour and there may already be high bars, so that there may not be a need for an increased annual high flow during the following spring.

- There may be opportunities for canal releases and North Platte River flows to combine with significant flows from the South Platte River, which may yield combined flows higher than flows during the following summer.

Alternatively, an increase in the high flow could also be considered in late August or early September. A high flow during this period would require less flow to erode young seedlings than a high flow the following May when the plants would have experienced a few more months of growth. Also, a high flow during late August or early September would not promote additional vegetation growth because cottonwood seeds would have already dispersed during the pervious June. An even smaller high flow could be considered during winter to help cause ice scour of young plants. It may be desirable to experiment with all three periods through an adaptive management program. In certain types of years, implementation of an annual high flow during one time period may be more effective than implementation during the other periods.

The amount of channel widening that can be maintained by an increase in annual high discharge can be estimated by a theoretical relationship between width and flow rate: width is proportional to flow rate to the 0.41 power (Yang et al, 1981). Figure 5.1 shows the present average active channel widths of the 13 bridge segments between the Johnson-2 Return channel and Chapman, and an estimate of the amount of additional width that could be maintained by increased annual high flows. Presently, annual peak discharges that are equaled or exceeded two years out of three (on average), range from 2,000 ft^3/s (for the reach from North Platte to the Johnson-2 Return channel) to 4,600 ft^3/s (for the reach from the Johnson-2 Return channel flow to Chapman, Nebraska). A program of annual releases of high flow within safe channel capacity could increase the range of annual peak discharges (that are equaled or exceeded 2 years out of 3) to between 6,000 and 8,000 ft^3/s. This increase in annual peak flows could maintain an increase in the present channel widths by the following estimated amounts:

- 20 percent in the Platte River reaches downstream from the Johnson-2 Return channel flow,

- 60 percent for the upstream Platte reaches near Cozad and Brady, Nebraska, and

- 20 percent for the North Platte River channel, in the reach that begins about 20 river miles downstream from the Keystone Diversion Dam, upstream from habitat target reach.

The increase in channel width would be greater in the Cozad-Brady reach because the relative increase in annual peak flow for this reach would be greater than other reaches. Increased high flows would come from an annual short-duration release of high flow within safe channel capacity from Kingsley Dam. The flows near the dam would be clear water that is virtually absent of sand. These clear-water flows tend to cause slow, but long-term erosion of the river bed. However, any increased flow releases from Kingsley Dam that move down the North Platte channel will have picked up a full load of medium sand when they reach North Platte. The extra North Platte water and sand will decrease the dominance of the South Platte on the annual high flows and sand supplies. An increase in annual high flows through the North Platte River channel would accelerate the slow downstream progression of the channel incision below Keystone Dam. However, the annual release of high flow within safe channel capacity would also offset the aggradation that is currently occurring at the North Platte gage at North Platte.

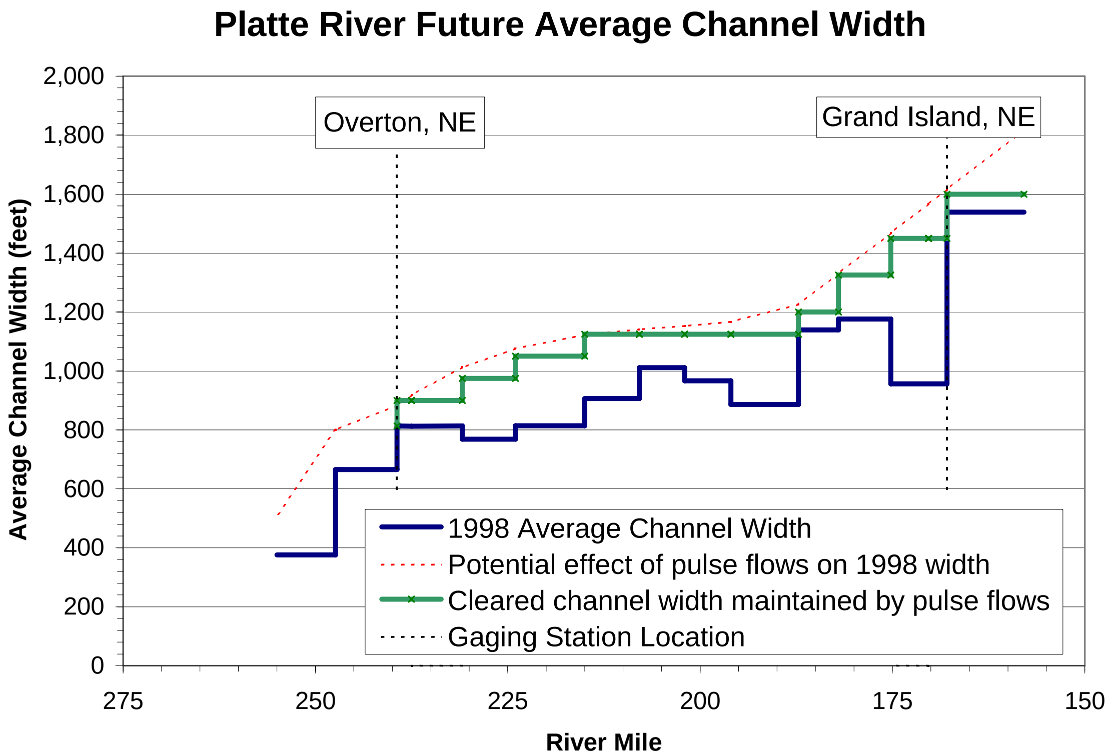


Figure 5.1 Future potential for sustained average channel width with mechanical clearing and leveling of wooded islands and pulse flows.

6.0 SUMMARY AND CONCLUSIONS

The reach of Platte River from Lexington, Nebraska to Chapman, Nebraska is the focus of a proposed endangered-species-recovery program. The Program seeks to restore some habitat for the threatened or endangered Whooping Crane, Piping Plover, and Least Tern that were lost through vegetation expansion and narrowing of the unvegetated and active channel width along the river. The goal for this study is not to determine how to restore the function and structure of the central Platte River to a historic target condition, but rather to determine methods to enhance or maximize the habitat for threatened species through the application of alternatives that are feasible within current constraints and demands on the river.

The emphasis of this study is a historic review and analysis of the geomorphology of the central Platte River, to provide a better understanding of the dominant processes of this system. Understanding the dominant processes can help identify trends in river form, which aid in the selection of management alternatives for restoration that successfully maximize habitat for the target species.

This analysis is based primarily on existing historic field data, historic mapping, aerial photos, written narrative, historic photos, recorded information on Platte River Basin development, and some recent field data collection associated with this study. Historic and recent field data include measurements of river discharge, climate indicators, bed-material size gradations, average unvegetated channel widths or active channel widths, and stage-discharge relationships. An additional and comprehensive data collection program is recommended. Although additional data collection can not fill existing gaps in the historic data, it would help test current hypothesis, strengthen our understanding of geomorphic processes in the central Platte River, aid in trend prediction for future management decisions, and help determine if future management actions are achieving desired results.

6.1 THE HISTORIC RIVER

6.1.1 Geologic Time and the Pre-Development River

The Platte River channel is a relatively young river formed during the Pleistocene and is located in a basin of alluvial materials from glacial times, overlain with loess eolian deposits from the end of this period. Tertiary and Cretaceous bedrock, and glacial till may have some effect on the alignment and profile of the lower Platte River, but the central Platte River is affected more by the alluvial layers deposited during the Pleistocene. The High Plains aquifer, made up of Pleistocene alluvium that underlies all of the central Platte River, has also had some influence on channel flow characteristics.

Over a time scale of tens of thousands of years, the Platte River has cut down fifty to one hundred feet or more through several Pleistocene layers. The River is now resting on the second layer of the Grand Island formation, a coarser layer of alluvial sands and gravels which may have acted as a vertical control in the pre-development period. Originally the Platte River did not complete the big bend, but the alignment continued to the southeast past the area between

Overton and Kearney and into southeast Nebraska. An extending Loup River tributary, developing along a lineament, is suspected of capturing the Platte River flows and creating the youngest reach of the central Platte River from Kearney to Grand Island, Nebraska. This reach has a slightly different plan form with large stable islands.

Over geologic time, climate is believed to have been the primary factor influencing cycles of erosion, deposition, and relative stability (EDS cycles) in rivers in the central High Plains. The influence of climate acts through thresholds specific to each stream. The nature of thresholds and the limited record of climate make it difficult to isolate the climate pattern that triggered each new EDS cycle. In general, the last notable switch in climate pattern for the Great Plains was 700 to 800 years before present. The record of EDS cycles for the central Platte River can be crudely reconstructed from the stratigraphy and topography of the Platte River valley, and from radiocarbon dating of materials at locations on other rivers in the central Great Plains. Although the Platte River has passed through multiple EDS cycles in geologic time, overall the river has incised down to its present elevation. The most recent cycle of the pre-development period is believed to be several centuries of aggradation. The pre-development period for the central Platte River ends in the early nineteenth century.

6.1.2 The Nineteenth Century

European exploration and settlement begins primarily in the 1800s, and marks the beginning of the end of climate dominance over central Platte River geomorphology. The most severe drought for the Platte River Basin since 1700 AD is believed to have occurred during the 1840s, and can be suspected to have caused some increase in sediment from the watershed during this period.

Initial anthropogenic influences on the central Platte River in the 1800s are primarily raised sediment inputs from land use beginning in the 1840s, and flow depletions in the last decades of the century. The beaver trapping industry eradicated almost all beaver in the area by the mid 1800s. The impact of this harvest may have been possibly small increases in sediment load in the Rocky Mountain tributaries, through the gradual elimination of sediment-trapping beaver dams. Extensive gold mining and timber harvesting in the South Platte tributaries and some activity in the North Platte tributaries, may have increased sediment loads to the central Platte River. Timber harvesting for railroad construction and settlement was also noted directly along the central Platte River. The growth of farming and development of cultivated lands was most rapid in Nebraska during the latter half of the nineteenth century. The expansion of tilled land in Nebraska may have introduced some additional sediment directly to the central Platte River, and there may have been some impact from farming practices, to a lesser extent in the Platte River tributaries in Colorado and Wyoming. Although this assessment is qualitative and speculative, these watershed activities are not estimated to have caused substantial increases in sediment load to the central Platte River by the end of the nineteenth century. Rather these activities mark the start of concerted anthropogenic impacts in the Platte River basin.

There are no measurements related to the possible increase in sediment from the 1840s drought, or from anthropogenic impacts throughout the century. Narrative and geologic information support a general description of aggradation and sediment loads for the central Platte River at the start of the century and also at the end of the century, but no differences can be determined from the narrative accounts. The reductions in flows associated with irrigation and canal construction can be estimated from discharge appropriation records but stream measurement records do not begin in the Platte River Basin until close to the end of the nineteenth century.

6.1.3 The Twentieth Century and Changes to Primary Elements

Although climate factors are still present, anthropogenic factors overwhelmingly dominate the geomorphology of the central Platte River in the twentieth century. The large increase in population in the Platte River Basin creates a corresponding increase in water demands and depletions for municipal and irrigation use. The major infrastructure for water development is constructed in this century including reservoirs, irrigation flow diversions, municipal water delivery systems, and groundwater wells. At the same time the transportation system with road crossings over the Platte River greatly expand in the twentieth century, and the presence of river structures such as rock revetments also increase.

The primary geomorphic elements influencing the central Platte River are described here as river flow, sediment transport and basin structure. Flows in the twentieth century show a distinct decrease from 1895 to 1969 then increase slightly in the latest period from 1970 to 1999 although never returning to previous levels. Although climate factors are still present, larger declines in river flow are attributed to the consumption of a large society in the twentieth century than are attributed to periods of drought or any detectable general trend in climate during this latest period.

The transport of sediment over this century exhibits a similar trend of decreasing transport. Flow diversions and reservoir construction also reduce the source of sediment from main upstream tributaries, and increase the importance of the bed of the central Platte River as a sediment source. The average median grain size of the central Platte River has also increased.

The third element, basin structure, is used here to describe the location of flow inputs and sediment sources, and the number of structural features imposing vertical or horizontal restraints on the river. Structural features can include geologic formations or features constructed by man. The location of flow inputs and sediment sources has been notably altered and the number of structural features exerting horizontal or vertical control on the river has increased.

Based on the changes that have occurred to the primary elements of river flow, sediment transport, and basin structure, the central Platte River today can be described as distinctly different from the Platte River of the pre-development period (Figure 1.5). And with respect to geologic time, the changes to these elements in this century can be described as abrupt, and as having overwhelmed the impacts of climate change.

6.2 THE PROCESSES OF HABITAT REDUCTION AND RIVER NARROWING

Reaches of the present channel have an unvegetated or active channel width that is 50 to 90 percent narrower than the channel that existed in the 1860s and in the period 1898 to 1902 (Figure 1.3). The central Platte River has generally experienced what has been called channel narrowing throughout its length with greater reductions in unvegetated or active channel width in the upper reaches, and smaller percentage reductions with distance downstream. The methods or processes by which reductions in unvegetated or active channel width occur on the central Platte River are multiple and complex. These processes are described individually along with their potential rate of progression. The rates of progression ranged from impacts nearly concluded, to impacts that could continue for centuries.

This study found narrowing of the unvegetated or active channel width and changes to channel section and form, to depend directly on: the previous multi-year period of flow rates, the grain size and availability of sediment for transport, and the growth and decline of riparian vegetation. These changes in channel width and form also depend indirectly on: structures acting as vertical and horizontal controls such as geologic features, diversion dams, bridges, levees and rock revetments; and the natural variability of climate.

6.2.1 Flow and Vegetation Processes and Impacts

Narrowing of the unvegetated or active channel widths along the Platte River occurred rapidly during the early to mid twentieth century, and these changes generally appear to have concluded at most locations today. Based on this study, the principal processes associated with this period of rapid narrowing are substantial reductions in river flow, reductions in flow peaks, and the rapid expansion of vegetation. Flows are limited to the lower-elevation areas of the channel by the reduction in flows. Following reductions in flows and flow peaks, and corresponding to reductions in the active channel width, more areas of formerly sandy banks and islands could be colonized by vegetation. The encroachment by vegetation into former channel areas reduces the mobilization of sand at higher flows, including the 1973 and 1984 flow events, and prevents the maintenance of formerly wide channels.

The reduction in peak flows is a normal consequence of the upstream development of storage reservoirs. Large flows during peak flow events are stored in reservoirs for later and gradual release during periods of lower flow. As a consequence, peak flow events in the downstream channel have lesser magnitude and frequency.

Different from peak flows, the reduction of average annual flow in the Platte River may result at different locations from major flow diversions to canals, may result from surface flow depletions for societal uses, or may be a combination of both flow diversions and flow depletions. In all cases Platte River flows continue to be impacted by fluctuations in climate, however the construction of storage reservoirs on the North Platte River and South Platte Rivers has reduced the impacts of climate variations on flows.

Examples of major flow diversions to canals are the Sutherland Canal and Tri-County Canal (Figure 2.17). The Keystone Diversion and Sutherland Canal remove 69 percent of average annual North Platte River flow from river conveyance for a distance of 58 river miles. The flow is returned to the Platte River for 4.5 miles prior to the Central Diversion Dam and Tri-County Canal, which removes 73 percent of average annual Platte River flow and bypasses river conveyance for a distance of 61 miles. Although fluctuations between wet and dry climate periods have some impact on the volume of flow, a calculation of current water depletions indicates that water depletions alone can account for the flow reduction noted between the period 1895 to 1909, and the period 1970 to 1999 at Grand Island, Nebraska. Both periods used for this comparison had generally similar climate with more wet years than dry years.

6.2.2 Sediment Processes and Impacts

Changing sources and sizes of sediment also influence unvegetated and active channel widths, channel sections, and channel form. This impact is not as spatially or temporally uniform as flow and vegetation processes and may be quite pronounced at specific locations while fading to non-detectable levels at downstream locations. Sediment processes include sediment coarsening resulting from changing sediment sources, and channel incision resulting from an abrupt increase in sediment demand.

6.2.2.1 Sediment Coarsening

The cause of a more subtle process of reductions in active channel and unvegetated channel width is attributed to a coarsening in sediment grain size. A larger grain size is generally associated with a more deep and narrow channel section; geometry not as supportive of endangered species habitat. More sand on a percentage basis is being supplied from the coarser supply of the South Platte River, and less from the finer grained supply of the North Platte River, as a result of trans-basin diversions and the construction of Lake McConaughy. This process results in larger grain sizes to the upper Platte River. A coarser grain size also is developing in the central Platte River from channel incision, where the channel bed serves as a main sediment source.

Channel narrowing resulting from coarsening of the grain size occurs at a slower rate than narrowing resulting from changes in flow rate and the growth of vegetation. Based on the rate of unvegetated or active width changes, it is concluded that most of the change resulting from sediment coarsening has already occurred in the reach between North Platte and Kearney, Nebraska. The river bed has coarsened to near or beyond the median size of the South Platte River over much of the channel upstream of Kearney, Nebraska.

Today the median grain size of the sand in the river bed at Grand Island is nearly equal to its size in 1931. However, if the noted coarsening trend continues it is possible that additional erosion of finer grained sand and the resulting channel incision and narrowing effect could continue migrating downstream. The rate for this occurrence would be on the order of several decades.

6.2.2.2 Channel Incision

An abrupt increase in sediment demand and subsequent erosion and incision of portions of the channel are notable downstream of the Kingsley Dam at Lake McConaughy, and downstream of the J-2 Return of the Tri-County Canal, near Lexington, Nebraska. Flow routed through Lake McConaughy drops nearly all of the sediment transported from upstream reaches into the reservoir, and the reservoir outflow is clear water pulling sediment from the channel bed downstream. Water diverted to the Tri-County Canal for irrigation and hydropower is returned to the river channel as clear water, since the low canal velocities are incapable of transporting much sediment, causing channel bed erosion at the point of return flow and downstream.

Channel erosion and incision caused by abrupt increases in sediment demand, has maximum impact immediately downstream from the source of clear water, but local bed coarsening causes the erosion process to progress downstream over time. Narrowing of the active channel width is a geomorphic consequence of incision. With no change to the flow or sediment imbalance, the channel incision and narrowing, which is the slowest of the processes considered here, can continue migrating downstream over a period of decades to centuries.

The downstream migration of this process may be slowed or halted by resultant reductions in bed slope, or by sediment influxes from sources such as tributaries sufficient to offset the sediment deficient. Although this process is distinct only in two short reaches extending tens of miles, less notable impacts appear to be occurring further downstream. Erosion from the sediment imbalance originating at the J-2 Return may possibly extend as far as Grand Island, Nebraska (Chen, et al., 1999).

Due to the complexity of the associated factors for the processes of sediment coarsening and incision, empirical methods are wholly inadequate for estimating: the width impacts from channel incision on the Platte River; the longitudinal extent of the incision impacts; and a time frame for these impacts to occur. A numerical model offers a far advanced method, but still can provide only a general estimate with the level of uncertainty inversely proportional to the availability of current field data.

6.2.3 Local Impacts from River Structures

The twentieth century, when unvegetated channel widths and active channel widths exhibit a pronounced period of narrowing, is also the major period of construction of river structures. The occurrence of bridges having reduced bridge spans, the construction of levees to protect facilities adjacent to the river, and the placement of rock revetment to prevent bank erosion, all largely increased during this century.

In the early twentieth century, pile bridges with long spans began to be replaced by bridges with longer approach embankments and reduced bridge spans that constricted the river channel. The bridges from this era, cause localized narrowing and can account for as much as eight percent of the length of narrowed channel in the project reach. River plan form and cross section are also locally impacted by the construction of levees and rock revetments, which in general confine the channel promoting a deeper and narrower cross section.

Localized channel narrowing effects resulting from bridges, levees, and rock revetment can account for more than eight percent (Section 4.7) of the reductions in channel width. These impacts, however, are found only in segments of the river immediately adjacent to the structures and normally do not migrate or progress downstream or upstream. Although the time scale is very site specific to the structure, a short period of several decades is estimated for the evolution of channel bed and bank impacts resulting from the installation of individual structures.

6.2.4 Impacts to Plan Form

The decrease in river flow and colonization by vegetation of the formerly active river channel; the decrease in sediment to the Platte River, and the coarsening of the bed-material grain size; the construction of river structures; and fluctuations in climate; have all contributed, to some degree, to reductions in unvegetated and active channel width. These processes have also contributed to a general change in the plan form, or shape as seen from the air, of the river, as presented in regime theory and diagrams.

In several reaches the plan form has changed from a wide and shallow braided channel to an anabranched, condition with wooded islands often separating multiple channels that are collectively narrower and deeper than before. The anabranched river does not support broad channel habitat characteristics, with the wide open views and numerous sandbars of the previously braided channel. Additional changes to some downstream reaches could be triggered in the future in conjunction with the coarsening of the channel bed.

6.3 OPTION FOR RESTORING HABITAT

Based on the historic channel narrowing of the Platte River and geomorphic principals that help to identify trends and narrowing processes, a general approach for increasing the amount of endangered-species channel habitat within the reach from Lexington to Chapman is proposed. In general, the goal of the Program is to enhance channel habitat by widening short, sustainable reaches of the river channel. Wider, shallower reaches of river should have water filling the channel during the crane migration seasons, and dry sand bars surrounded by low water during the summer, tern-and-plover-nesting season. Minimal vegetation encroachment within the channel width is critical for the endangered birds. There is no intent to return the entire longitudinal length of the study reach to a historic target width, but rather to restore or maximize habitat at selected reaches of the Platte River between Overton and Grand Island, Nebraska. The Program must be sustainable and feasible at these reaches under the current and future demands on the river.

The general strategy includes an annual program with: 1) the progressive clearing and lowering of certain vegetated islands that are located within the river's banks, preferably in the upstream reaches closest to the J-2 Return, and 2) annual releases of high flow within safe channel capacity, of short (1 to 3 days) duration using water from Lake McConaughy and the South Platte River. The clearing and lowering of river islands would immediately increase the area of wide, open channel, key to endangered-species habitat, while at the same time provide more smaller-grained sand from the wooded river islands to the river channel. While this general strategy seems to be a reasonably plausible approach from a theoretical perspective; site specific evaluation and field testing are required to determine the implementation details and the long-term effectiveness of the approach. Implementation of this general strategy would occur in a phased and incremental approach through an adaptive-management program to ensure habitat improvement and avoidance of adverse impacts.

6.4 FUTURE DIRECTIONS

This report is not comprehensive and does not signal the conclusion of the level one and level two investigation of the Platte River channel form. One area targeted for further investigation is an examination of more localized and reach-based processes. Because changes in sediment and flow have had a dominant effect on the entire study reach, these processes have been the focus of *The Platte River Channel: History and Restoration*. But within the general framework of flow and sediment trends presented, structural and geologic impacts on basin structure, including local variations in profile and plan form, can be causing varying responses of channel morphology at individual reaches.

Basin structure dependent upon the geology and formation of the Platte River channel in geologic time, has implications on current river plan form that has only been introduced and briefly developed in Sections 2.1 and 3.4. Likewise, basin structure resulting from the construction of levees, bridges, small diversion dams, temporary dams, and bank revetment has only been generally introduced and summarized in Sections 2.3.3, 3.4.2, and 4.8.6. Future efforts are planned for a more detailed study of localized variations in the study reach resulting from geologic and structural factors of basin structure, to increase understanding of the Platte River processes and impacts to habitat. This knowledge is sought to select and direct management options that can potentially maximize habitat for target species.

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GEOLOGY APPENDIX

A. GEOLOGY OF SOUTH-CENTRAL NEBRASKA

Rocks of Tertiary age underly much of the central Great Plains with older units from this period exposed in the northwest section of the state. Older Permian, Cretaceous and Tertiary bedrock are exposed on the east side of the state (Figure A.1). Large sediment loads from the Rocky Mountains were transported east and deposited on the plains during the Tertiary Period (To in Figure A.1). Flow paths for the rivers draining the mountains during this period established distinct west to east pattern of flow in the surface of tertiary deposits (Conservation and Survey Division, University of Nebraska-Lincoln, 1996a- report references).

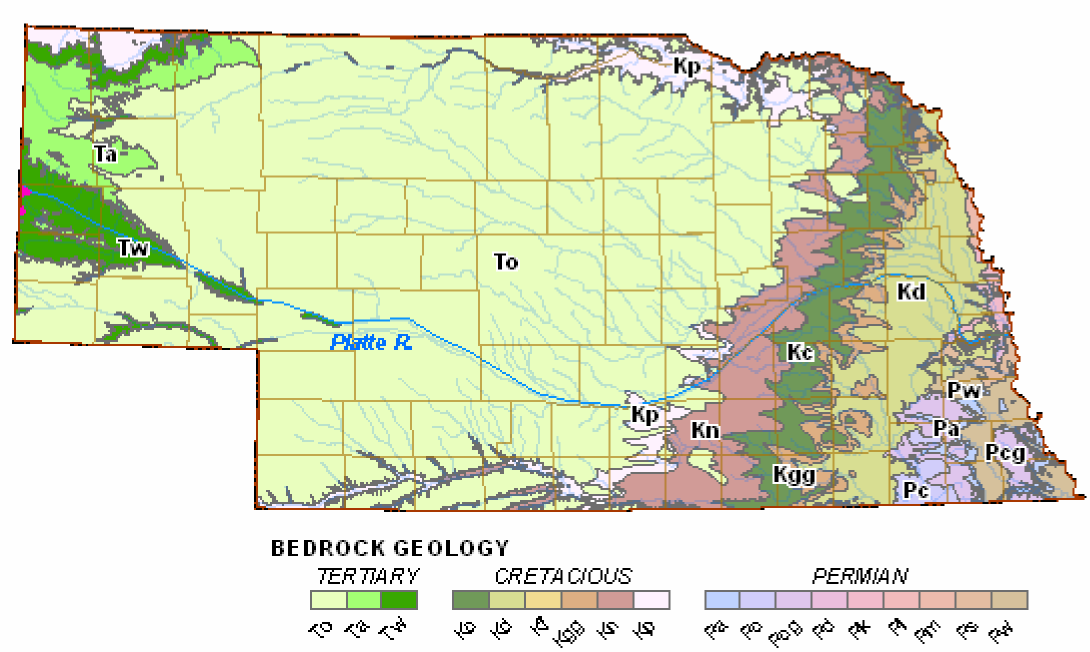

Figure A.1 Nebraska bedrock geology (Conservation and Survey Division, University of Nebraska-Lincoln, 1996a).

Geologic processes throughout time have contributed to the current topography of the central high plains, but events of the Pleistocene Epoch have had a dominant influence on the current alignment and drainage of the central Platte River. During the Pleistocene, repeated advances and retreats by glaciers are delineated by deposits of glacial till. This material can be found along the eastern side of Nebraska, parallel to the Missouri River as shown in Figure A.2 (Conservation and Survey Division, University of Nebraska-Lincoln, 1992).

The presence of glacial moraines to the east, blocked and altered the Tertiary drainage patterns that formerly ran east-west (Figure 2.1a). Gravel and sand transported from the Rocky Mountains in the Pleistocene were then dispersed across the plains with a relatively consistent grade sloping to the southeast. The present day High Plains aquifer, a significant water source for Nebraska, is composed of these Pleistocene deposits, with subsurface flows moving to the

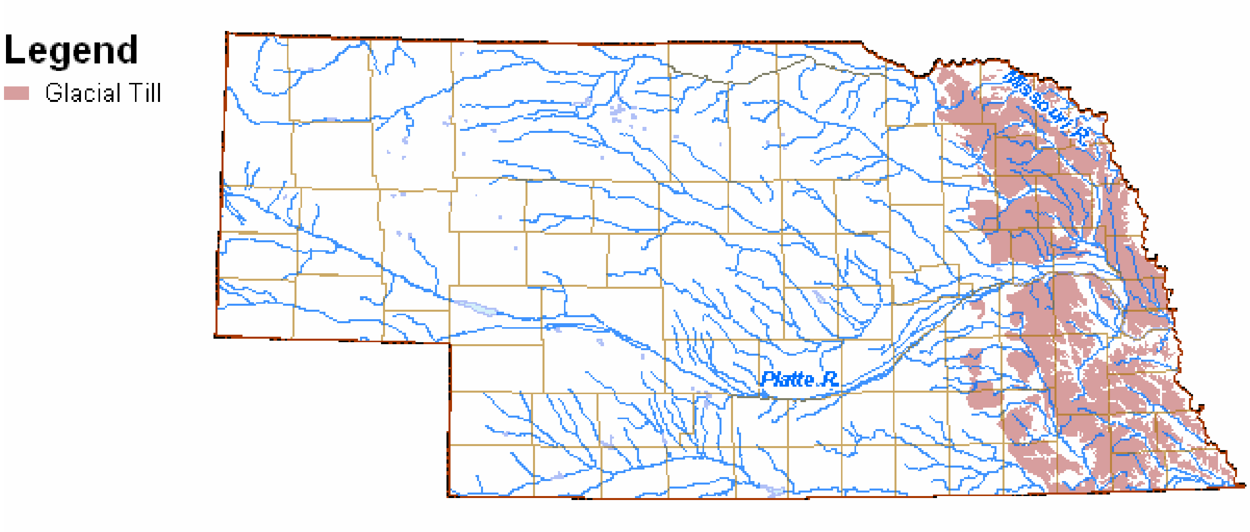

Figure A.2 Pleistocene glacial deposits in Nebraska (Conservation and Survey Division, University of Nebraska-Lincoln, 1992)

southeast (Gutentag & Weeks, 1980). The alignment of surface water tributaries in Nebraska is often to the southeast, reflecting the subsurface direction of flows established by Pleistocene deposits. Examples include the North Platte River in Nebraska from Scottsbluff downstream, and the central Platte River downstream from the confluence of the North and South Platte Rivers to Kearney, Nebraska (Figure A.3).

Nearing the end of the Pleistocene, and continuing into the Holocene (the last 10,000 years), wind borne layers of loess and fine sand were laid over large areas of Nebraska. Mandel (1995) wrote:

> *The dissected Loess Plains dominate central and south-central Nebraska and extend north into northwestern and north-central Nebraska and extend south into north-western and north-central Kansas. The loess sheet is 9 m [30 ft] to 18 m [59 ft] thick throughout much of this region, and exceeds 30 m [98 ft] in some areas between the Platte River and Sand Hills (Swinehart, personal communication, 1992). Broad, flat, undissected Loess Plains cover large areas south of the Platte River in southeastern Nebraska.*

The layers of loess are occasionally punctuated by paleosols that developed during periods of non-deposition. Both the loess and soil layers were easily eroded by the rivers to form the landscape seen today in the central Platte basin.

The sand hill region of dunes to the northwest of the central Platte River and the sandy areas south of the Platte River at Kearney, developed in the Pleistocene and early Holocene and were formed by wind action reworking the silts and fine sand from adjacent rivers (Lugn & Wenzel, 1938). These dunes are now largely stabilized by prairie grasses and other vegetation, but have been destabilized historically during periods of extended drought. The area is an important recharge zone for the High Plains aquifer (Gutentag and Weeks, 1980).

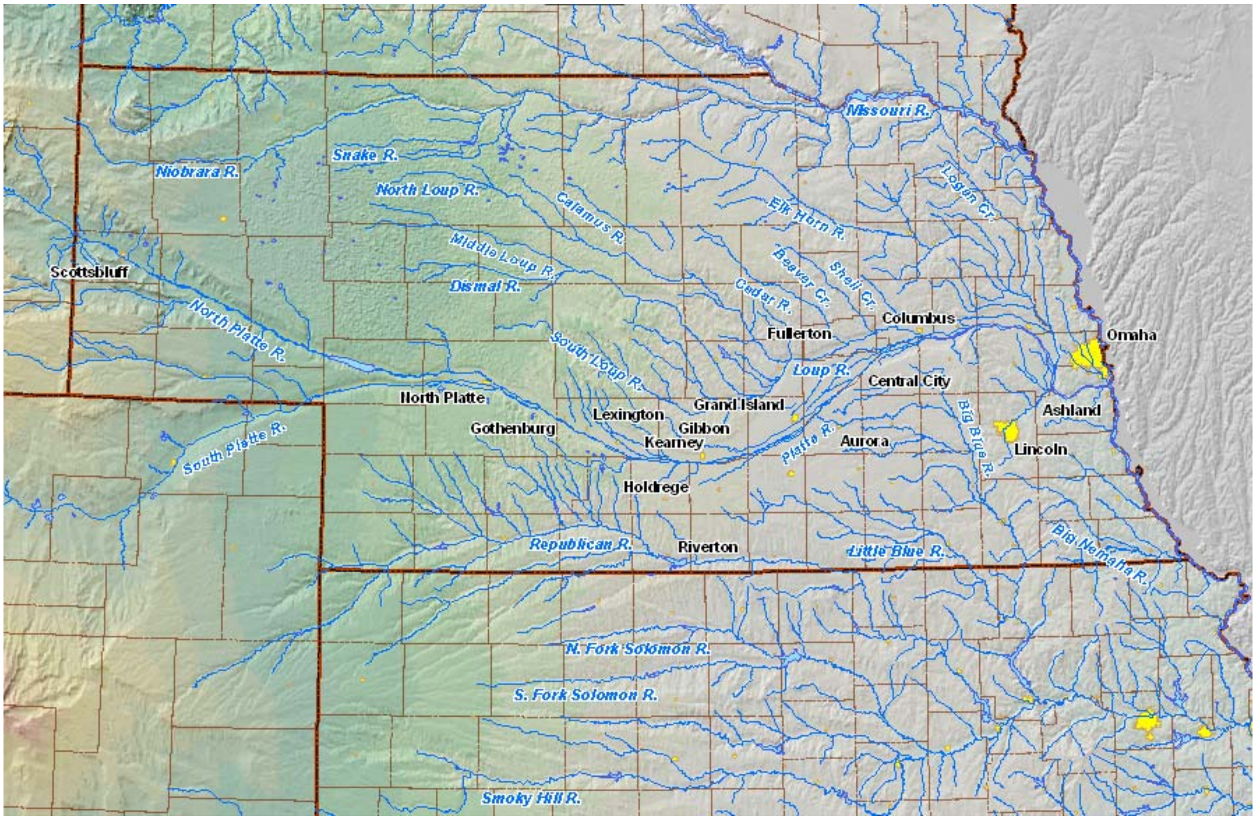

Figure A.3 The major rivers of Nebraska exhibiting the southeastern direction of surface water flows, also noted in subsurface flows.

Subsurface flows from the sand hills move southeast and intercept the Platte River in the reach down stream of North Platte, Nebraska and upstream of Lexington, Nebraska. The downstream reach between Overton and Grand Island is a “losing reach” for river discharge, where seepage from the Platte River drains as ground water to the southeast.

A north-south geologic profile (Figure A.4) shows the Platte River at the Kearney and Buffalo County border. The stratigraphic section includes the Cretaceous Pierre Shale, overlain by the Tertiary Ogallala Formation, then Pleistocene alluvium.

The Pleistocene alluvium (Figure A.5) generally contain two layers of sand and gravel, the Holdredge and Grand Island Formations, a sandy clay layer, the Fullerton Formation that separates the Holdredge and Grand Island Formations, and the clayey Upland Formation that caps the Grand Island Formation (Wenzel, 1940). Pleistocene alluvium can range from 80 to 200 feet in the Platte River Basin (Lugn & Wenzel, 1938). This alluvium is topped by eolian deposits of Loveland Loess and Peorian Loess. The Bignell Loess has also been identified in areas south of the central Platte River (Martin, 1991).

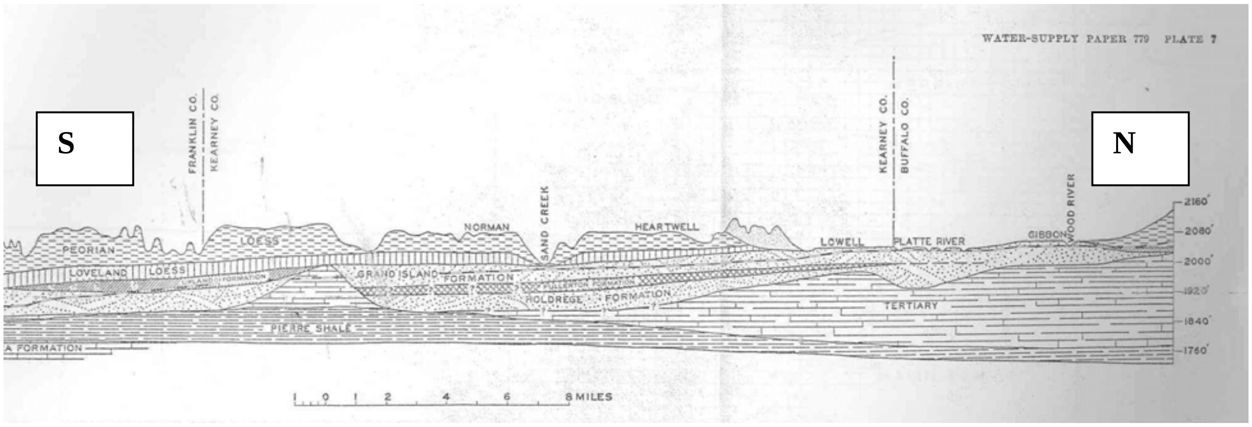

Figure A.4 North-south geologic profile from Gibbon to Riverton, Nebraka, taken from Lugn & Wenzel, 1938.

The Grand Island Formation, the upper layer of alluvial deposits, has an average thickness of 75 feet but can be as much as 150 feet thick, and the "*upper 30 to 50 feet is usually[composed of] fine sand that may have been deposited in part by the wind* (Lugn and Wenzel, 1938)." The central Platte River was described as having cut deeply into the finer materials of the Grand Island Formation, but of late the coarser material of the lower level of Grand Island Formation was retarding further erosion. Lugn observed (Lugn & Wenzel, 1938):

> *The Platte River has cut through the Loveland and Upland formations by being competent to carry such material away. It has also been competent to transport the fine sand that forms the upper part of the Grand Island formation. However, as the river continued to deepen its valley and cut farther down into the Grand Island formation, the material in general became coarser and more difficult to transport.*

In the following section, an approximate reconstruction of channel history for the central Great Plains area is presented, based on geologic indicators reported in published articles.

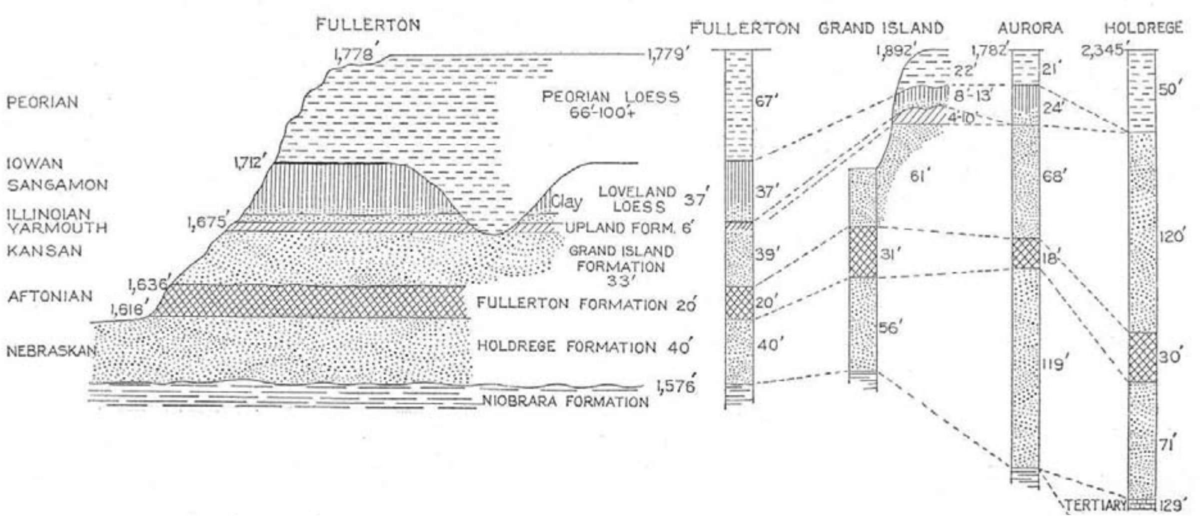

Figure A.5 Pleistocene deposits at Lovers Leap, west of Fullerton, and correlation with logs of wells at Grand Island, Aurora, and Holdrege (taken from Lugn & Wenzel, 1938).

B. GEOMORPHIC HISTORY

Fluvial stratigraphy, the geomorphology of terraces, and paleo-techniques can provide information on fluvial activity and climate patterns, and aid in our understanding of the historical development of the central Platte River. Paleo-techniques include the radiocarbon dating of humous soils, vegetative debris, and archeologic finds.

Table B.1 contains a geologic chronology assembled from Lugn & Wenzel's stratigraphic information for the central Platte River (1938), and radiocarbon dating for rivers in the central Great Plains. Radiocarbon dating information was available from May & Holen (1985, 2003), Bettis & Mandel (2002), Mandel (1995), Martin (1991), and Cornwell (1986). These papers reference radiocarbon dates from Brice (1966), Hall (1990), May & Holen (1985), May (1989), Muhs, et al. (2000), Johnson & Willey (2000), Forman et al. (1995), Forman et al. (1992), Muhs et al. (1996), Olson et al. (1997), and Madole (1994, 1995).

Only data from the central Great Plains Rivers is used in Table B.1, including the Republican River, the South Loup River, and Medicine Creek in Nebraska; the Pawnee River, Smoky Hill River and Arkansas River in Kansas, and the Missouri River in western Iowa. Although several authors collected data from sites on the South Platte River, there is no data from the central Platte River. Therefore, Table B.1 represents the general climate patterns or erosion, degradation and stability (EDS) cycles associated with fluvial activities of the central Great Plains rivers, and is not specific to the central Platte River.

However, since the rivers selected for this chronology are in locations surrounding the central Platte River and share similar climate patterns, the assumption can be made that the general chronology is correlative to the central Platte River. The central Platte River will not match all cycles listed in Table B.1, however one can conclude that the central Platte River has passed through multiple cycles of aggradation, degradation and stability in the last 40,000, or 120,000, years.

Cycles of aggradation, degradation, and periods of relative stability are more detectable in the Holocene since more data is available, due to the younger and better preserved layers. On the Republican River, there are four terrace forming periods of incision:

- 120,000 years ago;
- 40,000 years ago;
- 29,000 years ago; and
- 14,000 to 12,000 years ago.

Loess deposits are noted at four locations at 11,000 years. From 10,500 to 8,000, three layers of Brady soils are reported on several rivers, indicating periods of stability interspersed often with

Table B.1 Chronolgy of rivers in the central Great Plains, based on geologic formations and radiocarbon dating.					
Geologic Period	Age (years)	Formations	Cycle	Features	Refernce
Formation of central Platte River 120,000 to 40,000 years ago.					
PLEISTOCENE					
Iowan	120,000		Incision	T4 terraces	Republic R., NE Cornwell, 1986
Early Wisconsin	70,000	Peoria Loess	Eolian Activity		Republic R., NE Cornwell, 1986
Middle Wisconsin	55,000				
	40,000		Incision	Wet Period T3 terraces	Republic R., NE Cornwell, 1986
	35,000	Peoria Loess	Eolian Activity & Pedogenesis	W soil layer	Republic R., NE Cornwell, 1986
Late Wisconsin	30,000				
	29,000		Incision	T2a terrace	Republic R., NE Cornwell, 1986
	14,000 to 12,000		Incision	Wet period T2b terrace	Republic R., NE Cornwell, 1986
	11,000 to 6,000	Bignell Loess	Eolian activity		Republic R., NE Cornwell, 1986
	11,000		Eolian Activity		Western Kansas Olson et al., 1997 Nebraska & Colorado Muhs, et al., 1996 S. Platte R. Muhs, 2000
	10,500	Brady Soils	Pedogeneses	YY soil layer	Republic R., NE Cornwell, 1986
	10,300		Pedogenesis & Erosion		Southwestern Kansas Bettis & Mandel, 2002
	10,000	Brady Soils	Incision & Pedogenesis		S. Platte R., NE May & Holen, 2003
HOLOCENE	10,000			Landscape similar to today w/ exception of accumulation of Aeolian sand.	May & Holen, 2003
	9,300		Aggradation		Southwestern Kansas Bettis & Mandel, 2002
	8,000	Brady Soils	Pedogenesis & Erosion		Southwestern Kansas Bettis & Mandel, 2002
	7,000		Aggradation		Southwestern Kansas Bettis &Mandel, 2002

Table B.1 *continued*. Chronolgy of rivers in the central Great Plains, based on geologic formations and radiocarbon dating.

Geologic Period	Age (years)	Formations	Cycle	Features	Refernce
	6,100	Bignell Loess	Eolian activity		S. Platte R., NE May & Holen, 2003
	6,000		Eolian Activity		S. Platte R. Forman, 1995
	5500		Eolian Activity (3 periods)		Forman, et al., 1992
	5,000		Pedogenesis & Erosion		Southwestern Kansas Bettis & Mandel 2002
	4500		Incision		Republican R. Martin 1991
	4200 to 3500	Soil	Pedogenesis	Y & other weak layers	Republic R., NE Cornwell, 1986
	4,000		Aggradation		Southwestern Kansas Bettis & Mandel 2002
	4000		Eolian Activity		Western Kansas Olson et al., 1997 Nebraska & Colorado Muhs, et al., 1996
	4000		Incision		S. Loup R. May & Holen, 1985
	3700 to 3000	Soil	Aggradation & Pedogenesis	Middle buried soil layer	Republican R. Martin 1991
	3500 to 3000		Aggradation		S. Loup R. May & Holen, 1985
	3100		Incision	T1 terrace	Republic R., NE Cornwell, 1986
	2800		Pedogenesis & aggradation		Southwestern Kansas Bettis & Mandel 2002
	2700		Aggradation		Republican R. Martin 1991
	2,000		Incision		Southwestern Kansas Bettis & Mandel 2002
	2000	Soil	Pedogenesis	Third and upper soil layer	Republican R. Martin 1991
	2260 to 730	Brady Soil	Pedogenesis		Kansas & S. Nebraska Johnson & Willey, 2000
	1800 to 1100		Aggradation	3 ft of alluvium	Republican R. Martin 1991

Table B.1 *continued*. Chronolgy of rivers in the central Great Plains, based on geologic formations and radiocarbon dating.

Age (years)	Age (years)	Age (years)	Age (years)	Age (years)	Age (years)
	1700 to 900		Pedogenesis & some Aggradation		S. Loup R. May & Holen, 1985
	1500		Pedogenesis & Aggradation		Southwestern Kansas Bettis & Mandel 2002
	1500		Eolian Activity		Nebraska & Colorado Muhs, et al., 1996
	1500		Incision	23 ft of incision	Republican R. Martin 1991
	1050		Pedogenesis	Soil Z	Republic R., NE Cornwell, 1986
	1000		Incision		Medicine Cr., NE Brice, 1966 S. Great Plans Hall, 1990 Southwestern Kansas Bettis & Mandel 2002
	1000		Eolian activity		Madole, 1994 & 1995
	900		Incision	T0 terrace	Republic R., NE Cornwell, 1986 S. Loup R. May, 1989
	800 to 300		Aggradation		S. Loup R. May & Holden, 1985
	500		Aggradation		Southwestern Kansas Bettis & Mandel 2002
	300		Incision		S. Loup R. May & Holen, 1985
(Only anthropo-genic influence; all previous entries assumed to be climate influenced)	200 (~130 for the Platte River)	Alluvium	Aggradation & Incision	Euro-American settlement often causing excess sediment and/or incision resulting from constructed works.	Iowa Bettis & Mandel, 2002
	Present				

periods of incision. From 6100 to 5500, the South Platte River had loess deposits from eolian activity, and four researchers report eolian activity at 4000 years ago.

Frequent cycles of aggradation or pedogenesis are reported from 3700 to 1500 years ago, and Martin (1991), May & Holden (2003) and Bettis & Mandel (2002) make reference to the formation of three soil layers in this window of time. A common period of incision follows from 1000 to 800 years ago. The South Loup River site in Nebraska and Pawnee River site in Kansas experienced an aggradation cycle around 800 years ago, while periods of stability are implied by soils dated between 900 and 600 years ago for the Loup River and several rivers in Kansas. Without the aid of radiocarbon dating, Lugn & Wenzel (1938) and Wenzel et al. (1946) estimate the central Platte began an aggradation cycle approximately 300 to 400 years ago. Finally, a period of incision is noted on the South Loup River around 300 years ago.

These estimates of EDS cycles are not exact and it is difficult to tie EDS cycles directly to the extrinsic influence of climate, possibly due to the great variation in intrinsic thresholds for each river. For example, there can be a sediment transport delay in the upper watershed of a river due to its basin structure, where aggradation was triggered by a climate fluctuation, while degradation from a previous climate cycle continues for a period on the downstream mainstem. An adjacent river may not experience the same delay in cycle change due to a different basin structure.

A transition to wetter climate at 700 to 800 years ago in the Great Plains region (Section 2.1.5), corresponds to periods of aggradation in Table B.1, pertaining to the central Great Plains. Since the transition to a wetter climate 700 to 800 years ago, the pattern of climate fluctuations has been typical or consistent (Woodhouse and Overpeck, 1998). No obvious shifts in climate can be identified in the last 700 or 800 years to explain the shifts in EDS cycles for the central Great Plains Rivers of Table B.1.