Channel Morphology and Riparian Vegetation Changes in the Big Bend Reach of the Platte River in Nebraska.

J. S. O'Brien, Civil Engineer, Ph.D.
Engineering Research Center, Colorado State University,
Fort Collins, CO

and

P. J. Currier, Plant Ecologist, Ph.D.
The Platte River Whooping Crane Habitat Maintenance Trust,
Grand Island, NE

FINAL DRAFT

February 1987

TABLE OF CONTENTS

PAGE

INTRODUCTION 2

PHYSICAL PROCESSES IN ALLUVIAL RIVERS

River Forms..3
Physical Processes and Sedimentology of Braided Rivers.....4
Alluvial Bar Formation and Growth.........................9
Formative Discharges for Braided Streams..................10
Channel and Valley Slope.................................11
River Form Threshold.....................................11
Channel Roughness..12
Process of Vegetation Establishment......................12

PLATTE RIVER PHYSIOLOGY AND CHANNEL MORPHOLOGY

Geology..13
Climate..17
Vegetation...18
Geomorphology..19
Hydrology..21

PLATTE RIVER CHANNEL MORPHOLOGY CHANGES

Changes in Channel Geometry..............................24
Changes in River Flow Hydrology..........................25
Vegetation Development and Channel Encroachment..........31
Changes in Bed Material Size.............................36

RIVER FORM THRESHOLD - WILL THE PLATTE REMAIN BRAIDED
OR BECOME A MEANDERING STREAM?...............................38

DEFINING A CHANNEL MAINTENANCE FLOW..........................41

CONCLUSIONS..42

REFERENCES...43

INTRODUCTION

Major changes have occurred in the channel morphology and the riparian vegetation of the Platte River in Nebraska since water diversion for irrigation began in the mid 1800's. Dramatic reductions in peak discharge and sediment supply in the Big Bend Reach are responsible for these changes. Prior to 1860, the Platte was a prairie river, a mile or more in width and characterized by a sandy, unvegetated streambed bordered by prairie grasses, marshes, sloughs, and wetland meadows. Very few mature trees grew along the river's course except for those in isolated draws and on the larger river islands.

The Platte was a braided stream, with a straight, steep channel and noncohesive banks. Sandbars were transient features on the streambed. The shallow, wide character of the channel was sustained by a large sediment load and high peak discharges and few sandbars were stabilized by vegetation. Now only a few reaches of the Platte remain as remnants of the original braided stream. Today the river consists mostly of multiple channels threading around permanent, vegetated islands.

Since 1860, peak discharge in the Platte (at Overton) has declined by nearly 70% and as a consequence, the active river channel has narrowed. Transient river bars and islands that were once characteristic of the Platte have now stabilized and become permanent features. Woody vegetation, primarily cottonwood and willow, has established over much of the former floodplain.

Habitat for waterfowl, cranes, and other migratory birds has been threatened by these changes in the morphology and vegetation of the Platte. The decline in channel width has reduced disturbance and predator barriers and resulted in the loss of up to 97% of the nocturnal roosting habitat for sandhill and whooping cranes. In addition, the reduction in the number of active sandbars has eliminated much of the suitable nesting habitat for the interior least tern and piping plover.

To maintain the existing habitat for migratory birds on the Platte, a minimum streamflow hydrograph which incorporates flows that meet the biological needs of the birds and flows that maintain the morphological character of the stream must be delineated. Historical conditions and physical processes leading to morphological changes on the Platte must be thoroughly understood, however, before a channel maintenance flow can be determined. The objectives of this paper are: to familiarize the reader with the general characteristics of alluvial and braided streams, to provide background information concerning sediment transport and the physical processes leading to morphological changes, to present a historical and physiological background of the Platte's hydrology and channel morphology, and to propose a methodology to determine the flow regime required to maintain the existing remnants of braided channel.

PHYSICAL PROCESSES IN ALLUVIAL RIVERS

River Forms

Every river system evolves in a manner that establishes an approximate equilibrium between channel geometry, slope, and the water and sediment it conveys. The stable form of a river is the cumulative result of several physical variables, including the magnitude and frequency of the discharge, the volume and size distribution of the sediment load, the valley slope, and local morphological constraints such as channel boundary materials and geology. The channel form, geometry, and slope are dynamic features which respond to changes in flow conditions and sediment load. For a river to be in equilibrium, such changes will fluctuate about mean values, and the river will appear in a dynamic quasi-equilibrium state (Langbein and Leopold, 1964). Rivers which are not in a dynamic equilibrium require an adjustment of the channel morphology and may be in transition between different river forms and flow regimes. These adjustments may include relocation of areas of scour and deposition, changes in cross section, or increases or decreases in the slope.

There are two major groups of rivers; those whose cross section and shape are bedrock (geologically) controlled and alluvial rivers which are free to adjust channel shape, pattern, and gradient in response to changes in water and sediment discharge. The bed and banks of an alluvial stream are comprised of the sediment that it transports. Hydraulic forces acting on the bed and banks under variable conditions of discharge and sediment load keep the channels of an alluvial stream active.

Alluvial rivers are generally classified as straight, meandering, braided, or a combination thereof. Grouping river reaches into these classifications is not mutually exclusive; a continuum of channel patterns may exist throughout a river's course. For example, braided streams may have reaches that are meandering, or they may have singular branches that meander. The flow regime may also influence river form. During high flows, for instance, a braided river may have a large single channel which transforms into multiple channels at lower flows.

Truly straight river reaches (greater than 10 channel widths) are rare in nature (Langbein and Leopold, 1964) as this form is unstable and will evolve into other forms. Sinuosity, the ratio of channel length to valley length is often used to distinquish between straight and meandering rivers. Although the delineation is not absolute, a sinuosity of 1.5 or greater is generally characteristic of a meandering river form. Meandering streams are typified by an S-curve appearance with alternating bends of deep pools, and shallow crossings. Examples of meandering and braided streams are provided in Figure 1.

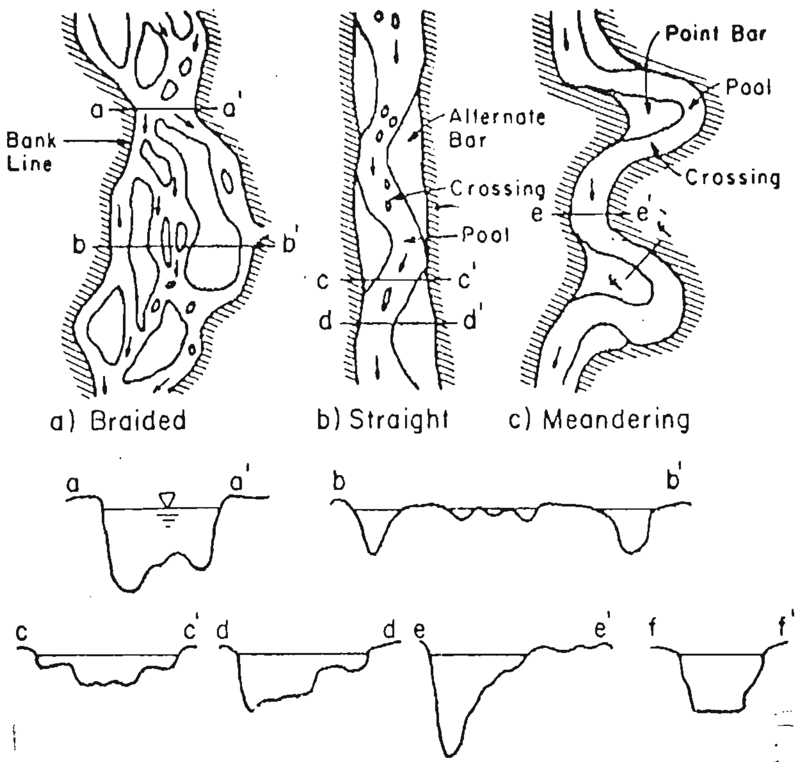


Figure 1. Examples of meandering and braided streams (from Simons, 1976).

Braided rivers have multiple channels running through transient, alluvial bars. These alluvial bars are composed of mounds or waves of sediment which continue to move as long as their sediment particles remain mobile. The characteristics which define a braided stream include a wide, shallow channel, moderate flow velocity, steep slope, and a relatively large sediment load. The exposed bars are reworked frequently to maintain the braided river character. Streams in which exposed bars are stabilized by permanent vegetation (i.e. become islands) lose their braided status. Such streams are known as anabranching streams and are characterized by more stable channels than are found in braided streams.

Physical Processes and Sedimentology of Braided Rivers

Braided rivers readily adjust their cross section to maintain a condition of sediment transport equilibrium. This equilibrium condition represents a balance between the stream discharge, sediment load, bed material size, and slope. Adjustments in cross section do not necessarily indicate disequilibrium in the river system, but can be an effective way for braided rivers to optimize sediment transport and dissipate energy. Braiding is enhanced in high energy, hydrologic systems where the valley slope is steep, discharges are variable, sediment transport is high, and banks and bars are noncohesive and unstable. When a river with a steep slope flows through erodible sediments it dissipates energy by transporting sediment particles and reworking the channel. A braided stream with a wide, shallow floodplain, multiple channels, and numerous mobile bars is the result of the transport of large quantities of sediment. The multiple channels formed in a braided stream have greater combined width but less depth than a single channel stream. In addition, multiple channels are less hydraulically efficient than single channels.

An abundant supply of sediment is a prerequisite for a braided river. The sediment load to braided streams is primarily delivered to the river channel during periods of high discharge, which are normally associated with snowmelt runoff or periodic rainstorms. In arid regions, 40% of the long term sediment supply is carried by short-term runoff events (i.e. events with a return period of less than 10 years; Neff, 1967). Estimates for the Kiowa Creek drainage, a tributary of the South Platte, indicate that greater than 20% of the total annual sediment load is transported by discharges occurring less than 0.1% of the time (Bureau of Reclamation, 1947). Large runoff events can significantly impact river channel geometry because the channel shape will adjust to accommodate the increased quantity of water and sediment. For example, as a consequence of a large flood, the Cimarron River in southwestern Kansas returned to a more braided form by greatly increasing its width, decreasing its sinuosity, and increasing its gradient (Schumm and Lichty, 1963). Such flow events are critical to the maintenance of braided channels (Schumm, 1969). Catastrophic events can also trigger a complex reaction resulting in the storage of sediment in some reaches and the flushing of sediment in others.

Upstream basin controls and landuse practices influence the type and quantity of sediment (sediment yield) transported to a stream. Topography, geology, vegetation, climate, and drainage area also affect the amount of sediment that reaches a stream from its watershed. Climate and precipitation are the dominant hydrologic factors controlling the rate of erosion on the semi-arid plains.

The development of a drainage basin is not continuous, but is punctuated by periods of erosion and denudation. Episodic flushing and storing of sediments in a watershed occurs in response to changes in climate and threshold conditions in the system. As an adjustment to a wetter climate, the drainage system will enlarge. In a drier climatic period, water discharge is reduced and there may be degradation of the river channel, a coarsening of the bed material, and a reduction in active channel width.

Estimates of long term sediment yields for rivers in the Platte River basin range from 20 to 3000 tons per square mile (Table 1). Generally, sediment yields per unit area decline with an increase in the drainage area (i.e., as the basin matures). Annual sediment yields for the mainstem South Platte, for example are conservatively estimated at 80 tons per square mile while two of its major tributaries, Kiowa and Bijou Creeks reportedly contribute 1020 tons per square mile (Missouri River Basin Commission, 1975; U.S. Bureau of Reclamation, 1947). These estimates for Kiowa and Bijou Creeks were empirically derived and are probably low. Sediment yields from the geologic formations in the North Platte River watershed are substantially larger than those from the South Platte, indicating that historically the North Platte was the dominant contributor of sediment to the Platte.

Table 1. Estimates of sediment yields from the Platte River System.

	(AF/Sq. Mi)	(Tons/Sq. Mi)
North Platte River Basin Formations[1]		
Lance	0.50	820
Pierre Shale	1.40	2300
White River	1.80	2940
Fort Union	1.30	2130
South Platte River at Julesburg[2]	0.05	80[4]
Platte River at Overton[2]	0.01	20[4]
Loup River at Columbus[2]	0.29	480
Bijou and Kiowa Creeks[3]	0.62	1,020
Medicine Bow River[5]	0.23	380

[1] Schumm, 1977
[2] Missouri River Basin Commission, 1975
[3] US Bureau of Reclamation, Narrows Report, 1947
[4] Reflects upstream river regulation
[5] Bureau of Reclamation, Glendo Report, 1951

Over the long-term, the area of maximum sediment production moves further up the basin and river profiles and sedimentation patterns in various reaches shift accordingly. On a shorter time scale (decades) a dynamic equilibrium is maintained by changes in sediment load, sediment size, and river gradient. Channel geometry and slope adjust according to the available upstream sediment supply and the ability of the stream to move sediment in a given reach. When the supply exceeds the transport capacity of a reach, sediment will deposit on the stream bed according to size fractions, the largest (coarse) sediments depositing first.

Conversely, when the capacity exceeds the incoming supply, sediment will be scoured from the bed and banks, beginning with the finest sediments. Erosion and/or deposition zones may migrate in order to restore equilibrium. Over the course of the seasonal hydrograph, scour and fill can be on the order of 3 to 6 feet of depth in braided streams (e.g., the Platte at Cozad; Eschner, 1981).

Selective transport of sediment sizes can result in the development of a coarse layer of particles which protects the underlying sediment from hydraulic (scouring) forces. This phenomenon is referred to as "armoring" and may effectively inhibit channel degradation until the discharge and velocity becomes great enough to move the particles in the coarse layer. The degree of armoring is highly variable. An entire reach of river may develop an armor surface or armoring may be limited to a single alluvial bar.

The bed material load of a given reach is a combination of two types of sediment movement, bedload and suspended load. Sediment which moves by the phenomena of rolling or creeping in contact with the streambed is referred to as bedload. The suspended load consists of sediment particles which are suspended or saltated into the main zone of flow. Turbulent mixing, dispersion and gravity results in a continuous interaction of the suspended particles between the bed and the streamflow. Particles are dislodged when the lift and drag forces exceed the resistive forces on the bed. The impact of other particles may also initiate motion. The median size of bedload particles can be an order of magnitude larger than the median size of suspended load particles. Suspended load particles which are not found in appreciable quantities in the bed, are referred to as wash load. The wash load often consists only of silt and clay size fractions. The percentage of silt and clay is small in the bed and banks of braided streams, but is more pronounced in meandering rivers where it is critical for bank stabilization (Schumm 1969).

Bedload is the dominant process of sediment transport in braided streams. Channel shape (width to depth ratio) and sinuosity are governed by the dominant type of sediment load (ratio of the bed load to total load). If the bedload is 11 percent or greater of the total load, a river will be wide and shallow and probably braided (Schumm 1977). Movement of sediment along the bed occurs in a series of microforms which increase in size from ripples to dunes as a function of streampower (Figure 2). Under very high streampowers, which often occur in steep reaches of braided rivers, the bed may plane out or even develop antidunes.

During high discharges sediment moves in large waves, creating macroscale bed forms (Figure 3; Karlinger et al., 1983). These bed forms consist of large transverse bars which develop as small bars and dunes coalesce (Smith 1971). At high discharges large bars tend to be uniformly lobate and repetitive. As the discharge decreases, however, the bars are reworked, and their well defined shape is lost as they disintegrate into random small bars. Smith (1971) observed this transformation on the Platte River during a 5 day period in which he recorded discharge, depth, and the distribution of sediment sizes on a single large bar. As discharge declined, the bar evolved into a series of superimposed and merging smaller bars, exposed bar surfaces, anabranching channels, and shifting fields of small bed forms.

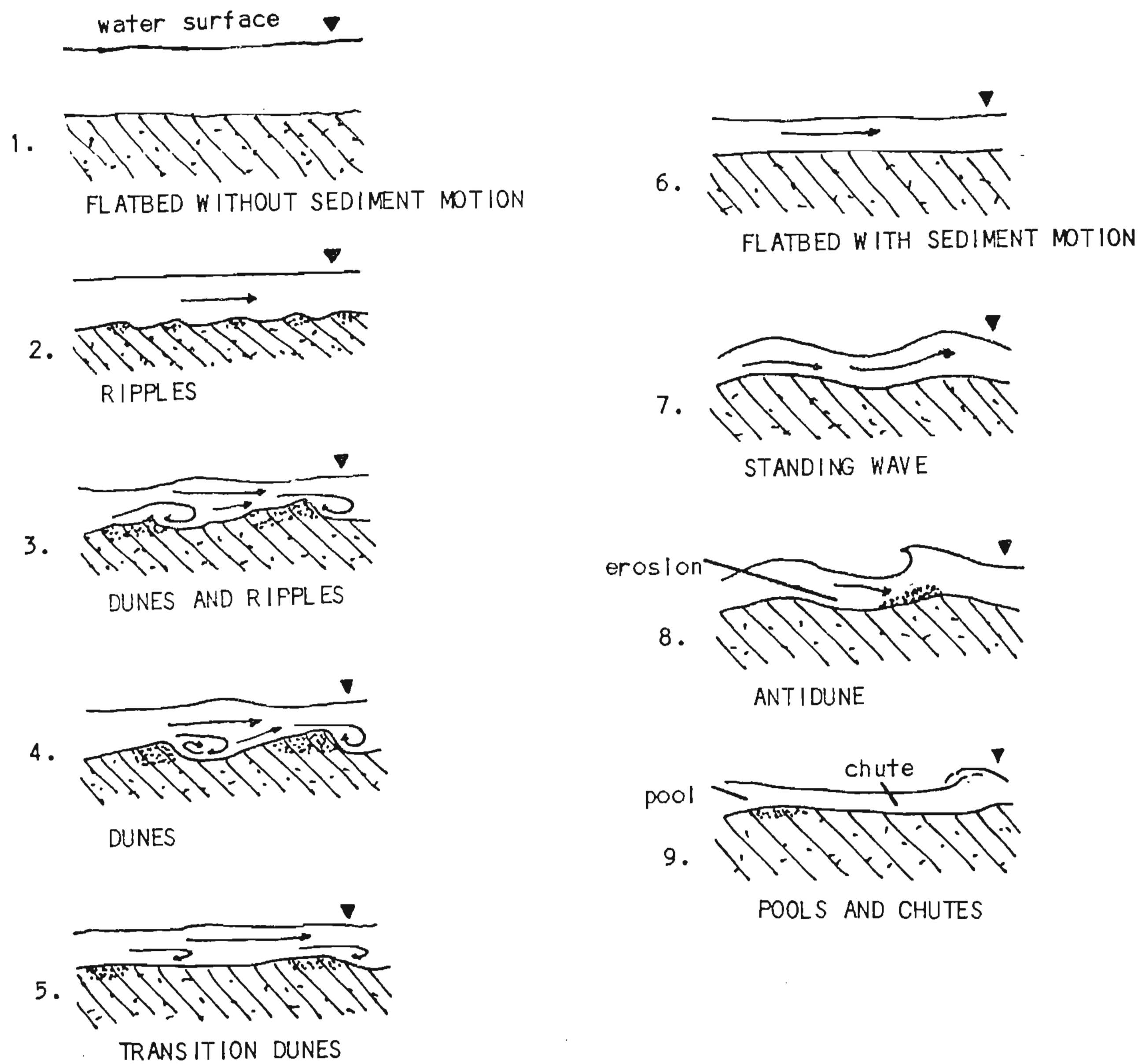


Figure 2. Microforms in alluvial streams in ascending order of increasing water and sediment discharge.

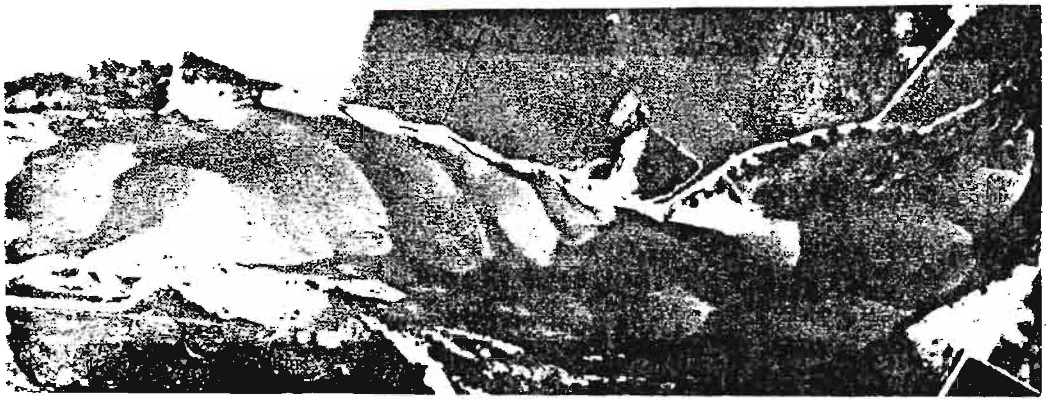


Figure 3. Vertical photograph showing external geometry of Platte River macroforms near Grand Island, Nebraska (from U.S. Geological Survey 1983).

Alluvial Bar Formation and Growth

Initially, a short submerged bar composed of the coarse sediment fraction of the bedload is deposited at high flow. Some sorting of the sediment in the bar occurs as the coarse sediments deposit at the head of the bar and the finer sediments sweep over the bar and are trapped in the interstices of the coarse particles. A tail of fine sediment develops and some lateral accretion takes place with the growth of the bar. Vertical accretion and dropping of the river stage gradually reduces the flow depth over the bar. Particles roll over the bar and are deposited where the flow depth increases and velocity decreases. Bar growth and migration thus occurs in the downstream direction, and scour in the flanking lateral channels helps to lower the water surface eventually exposing the bar. As a bar emerges, it may be stabilized by vegetation. Vegetation age can also suggest a growth pattern of the bar in the downstream direction (Leopold and Wolman 1957). In a complex of islands stabilized by vegetation, further sediment deposition occurs at high stages because of the increased flow roughness and corresponding slower velocities over the island.

Bar size and shape is a function of sediment size and channel slope. Smaller bed material creates smaller bar forms that are more transient because the sediment particles have more mobility. Smaller, more transient bars create braided patterns with no discernible thalweg. Larger, more stable bars are found in conjunction with larger, more definitive and stable channels. A channel thalweg is frequently recognizable. Generally, a stream with smaller bed material will have more bars, a high sediment transport rate, and result in a wider stream. Rivers with larger bars are associated with relatively narrow channels.

The size, shape, and structure of alluvial bars can be an indicator of changes in channel morphology. Alluvial bars may be smaller and more numerous if the streambed is aggrading, or larger and less mobile if the streambed is degrading. Bar shape may also indicate a change in the mode of sediment transport. For example, a degrading stream with less mobile bars, will also have a tendency to move sediment in surges.

Formative Discharges for Braided Streams

Large annual flood events maintain the wide, shallow, relatively straight channels of alluvial rivers. Such flood events are commonly referred to as the channel formative discharge. Generally braided alluvial streams are characterized by large seasonal variation in discharge and thus are "affected by a range of flows rather than a single discharge" (Wolman and Miller, 1960). Nevertheless, the concept of a dominant discharge or channel formative discharge is an important one. Bankfull discharge is usually afforded the status of a dominant discharge, mobilizing most of the bed material sizes, and reworking the bed and banks to form the most efficient cross section for transport of the bed material. For alluvial streams, bankfull discharges usually occur with a return frequency of 1.5-2.0 years (Rosgen, 1982; Leopold and Wolman, 1957). Such a discharge is sufficiently frequent to effectively rework the channel. A frequency of bankfull discharge less than 1.5 years may indicate that large sediment loads are only infrequently being delivered by upstream tributaries (Petts, 1984).

The effective discharge is defined as the flow that transports the most sediment over a long period of time. It is the product of the magnitude of the sediment transported by a given discharge and the frequency of occurrence of that discharge. In a braided stream with high sediment transport rates, the effective discharge can be critical to maintaining the existing channel morphology. In a braided stream there is an unique relationship between the effective discharge, the bankfull or dominant discharge, the mean annual flow, the annual peak flow, and the morphology of the channel. It is therefore inmportant to consider the magnitude and frequency of all these discharges and their impact on channel morphology.

Channel and Valley Slope

A steep slope is an essential ingredient to creating a braided river form. The channel slope is a series of consecutive river reach gradients which reflect short term adjustments to variation of stream discharge and sediment load. Adjustments in channel slope are usually complemented by changes in channel shape. The overall channel profile is known as the valley slope, and is influenced by tributary inflows, geologic controls, localized incision, changes in channel pattern and changes in channel roughness. Depending on the size and quantity of sediment supply and water discharge, braided rivers may achieve equilibrium over a wide range of slopes.

River Form Threshold

The relationship between slope and water discharge has been postulated as a measure to predict whether a stream is braided or meandering (Leopold and Wolman, 1957; Ferguson, 1984). The delineation between a multiple channel, braided stream and a single channel, meandering river is not definitive. Based on the classic work of Leopold and Wolman (1957), it is generally recognized that a river will be braided if its slope exceeds a critical threshold slope.. This concept assumes sufficient sediment supply to permit a river to sustain equilibrium in a braided form. Several investigators, including Leopold and Wolman (1957), Ferguson (1984), Lane (1957), Osterkamp (1978) and Bray (1982), have proposed various empirical thresholds between slope and discharge for braided and meandering streams (some of these are shown in Figure 4). In these relationships, slope S is a function of the discharge Q (cubic meters per second) and the sediment size D_{90} (mm) where D_{90} represents the sediment size that 90% of the sediment is smaller than.

The Leopold and Wolman (1957) relationship for sand bed channels is:

$$S = 0.013\ Q^{-0.44}$$

Ferguson (1984) incorporated sediment size into the threshold relationship to correctly predict channel pattern in 83 out of 89 cases for sand and gravel streams. This relationship is:

$$S = 0.017\ Q^{-0.49}\ D_{90}^{\ 0.27}$$

Both relationships indicate an approximate threshold relationship between slope S and discharge $Q^{-1/2}$.

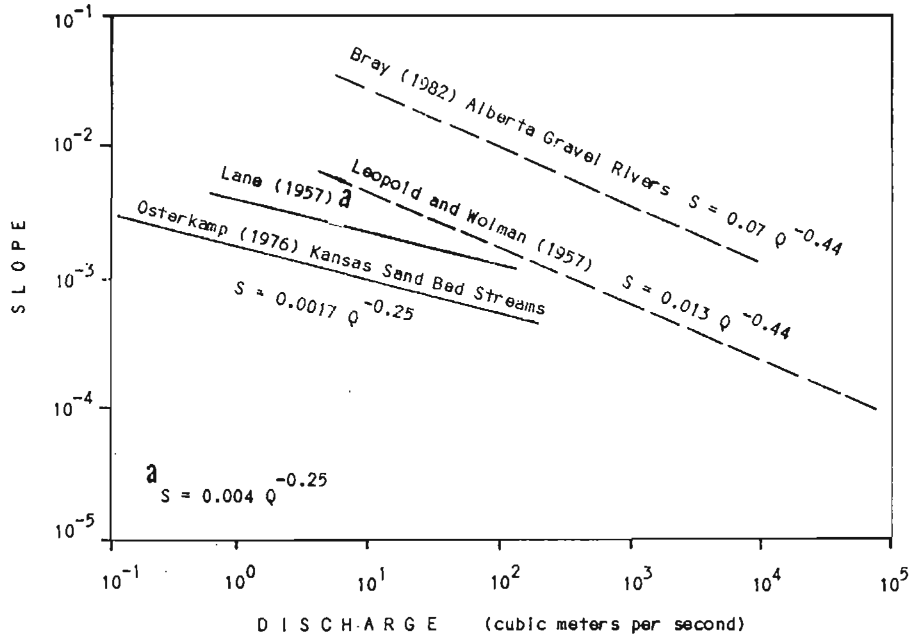


Figure 4. Empirical threshold relationships between discharge and slope (from Ferguson 1984).

Channel Roughness

Analyzing the channel roughness or resistance to flow in a mobile sand bed stream is a very complex problem. Channel roughness is highly variable within a particular river reach. An estimate of overall channel roughness, however, (such as Manning's roughness value) is necessary to predict flow conditions (velocity, depth, and width) and sediment transport in the channel. Very rough channels have less available energy to transport sediment. Bed friction, form drag of the bed (e.g., ripples, dunes, antidunes), river form (e.g., meandering, braided), sinuosity, vegetation, structures (e.g., bridges), and ice cover, are all factors contributing to the overall hydraulic roughness of the channel.

Process of Vegetation Establishment

Cottonwood and willow are the most frequently encountered species developing on the river floodplains in the arid and semi-arid west. Male and female flowers are borne on separate trees. Through wind cross-pollination, the female flowers are fertilized and seed formation occurs. Germination occurs when seeds land on or are deposited on unvegetated, fine-textured, continuously moist, sandy sites (Moss, 1938; Kapustka, 1972; McLeod and McPherson, 1973; Currier, 1982). These sites are often alluvial bars and islands that have been exposed following the spring peak discharge. Seeds are primarily carried in the river channel and deposited as the stage level declines. Germination sites must remain moist for at least two weeks, otherwise the seeds dry-out and do not germinate. Seeds remain viable for only a short two to three week period following release and are apparently not capable of overwintering into the next growing season. Viable seeds are normally present throughout the entire period from mid-May until the end of August because seeds develop and are released at different times.

Following germination, a seedling has several possible fates. It may (1) grow into a healthy seedling two to three feet high during the growing season, (2) it may be scoured from the riverbed and washed downstream by mid-summer fluctuations in flow or by peak flows in the following spring, (3) it may be killed by oxygen stress under conditions of flooding, or sediment burial, or (4) it may dessicate and wither as a result of very low moisture conditions. Most seeds do not become seedlings because they do not land on suitable sites for germination and development. Some seedlings succumb to drought stress during the early stages of development, but cottonwood and willow are very drought tolerant and are capable of rapidly developing root systems to take advantage of subsurface moisture (Currier, 1986). As a result, seedlings are generally able to survive periods of drought except in the most severe years. In braided rivers, nearly all seedlings are removed from the riverbed by peak flows in the following spring. Only seedlings on protected riverbanks and above the stage elevation of the next spring flood are able to survive and develop into mature trees.

PLATTE RIVER PHYSIOLOGY AND CHANNEL MORPHOLOGY

Geology

The Central Platte River in Nebraska begins at the confluence of the North and South Platte rivers near the city of North Platte and eventually flows into the Missouri River near Plattsmouth, Nebraska. The North and South Platte are principally snowmelt streams with headwaters that originate in the Rocky Mountains of Wyoming and Colorado (Figure 5). The North Platte River flows north into Wyoming out of watersheds in Colorado, and then flows east collecting several drainages in Wyoming. Finally the North Platte flows southeast to join the South Platte River in western Nebraska. The South Platte flows northeast out of the central Colorado mountains enjoining several tributaries (Boulder, St. Vrain, Big Thompson, Poudre), and eventually merges with the North Platte River in western Nebraska. The North Platte drains 34,900 square miles and is approximately 665 miles long. The South Platte drainage is about 24,300 square miles and is 450 miles in length. The total Platte drainage upstream from the confluence with the Missouri is 89,000 square miles. The Central Platte River upstream of the Loup, Elkhorn, and Salt river tributaries, drains only a small, narrow watershed of 6000 square miles.

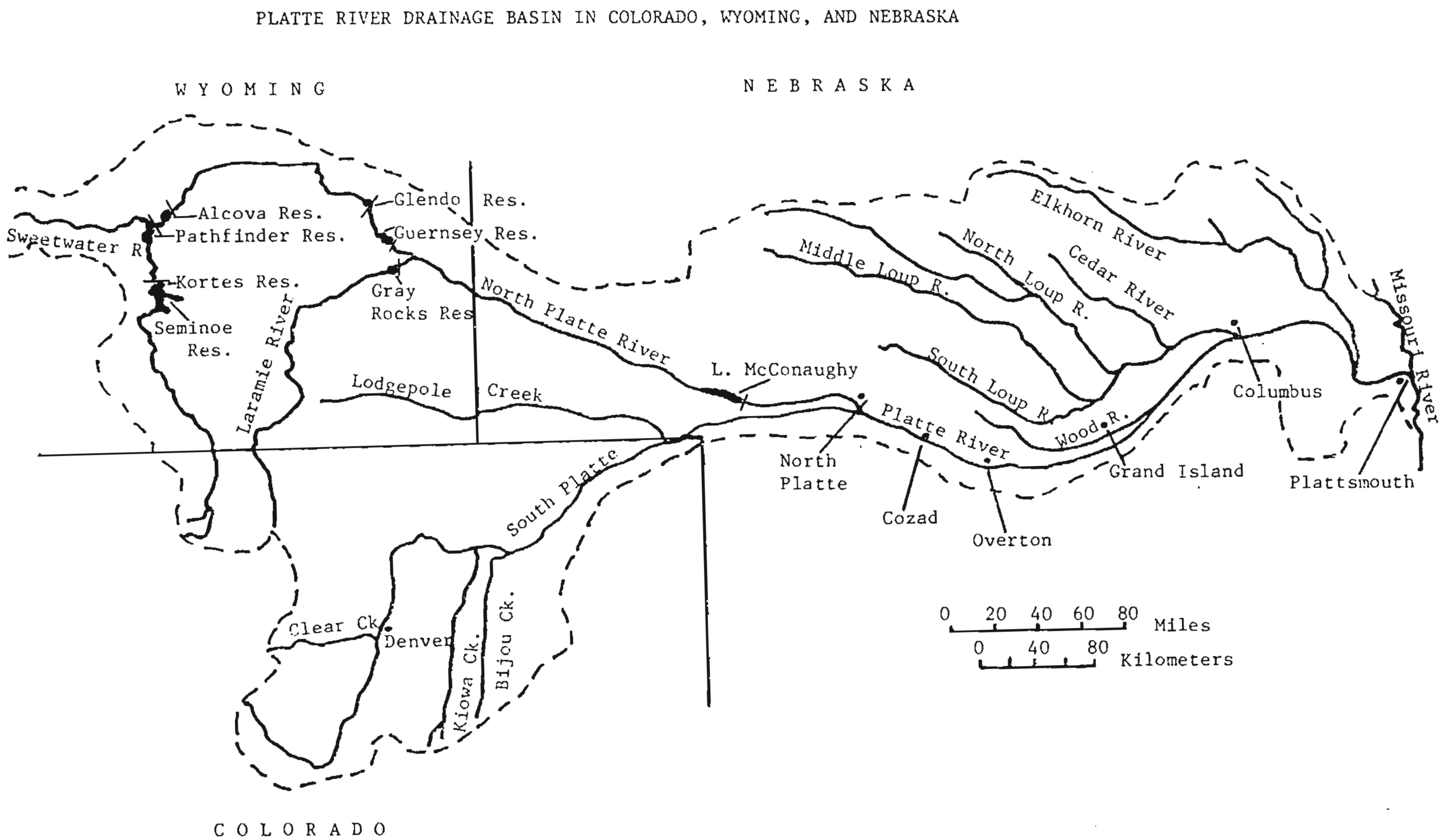


Figure 5. Drainage Basin of the Platte, North Platte, and South Platte rivers (from Bentall 1982).

The tributaries of the North and South Platte Rivers can be categorized into these groups: 1) those that have headwaters in the mountains, 2) those that originate in the foothills or transition zone, and 3) those that drain the eastern high plains of Colorado, Wyoming and western Nebraska. Those tributaries that have headwaters in the mountains and foothills contribute negligible amounts of sediment to the Platte River system. In these areas stream gradients are steep and the bed material is composed of coarse sediments ranging in size up to cobbles and boulders. Slopes range from seventy feet per mile near the headwater sources to ten feet per mile near the mouth of the tributaries.

Tributaries which drain basins of the eastern plains contribute the greatest quantities of sediment to the Platte River system. Most of the sediment load is derived from sheet and gully erosion during rainfall-runoff events. The majority of sand size material in the Platte is contributed through erosion of sedimentary deposits on the eastern plains. The plains zone constitutes the majority of the Platte basin and is part of the Colorado Piedmont and High Plains section of the Great Plains Province. Most of the land surface is underlain by Tertiary and Quartenary sedimentary rocks and Holocene unconsolidated deposits of loess and wind blown sand.

Table 2. Bed material size distribution data for the Platte River system collected in 1979-1980 (US Geological Survey, 1983)

		SEDIMENT SIZE (mm)	
	D_{16}	D_{50}	D_{84}
North Platte River			
Sutherland	0.30	0.70	2.37
North Platte	0.26	0.57	1.80
Average	0.28	0.64	2.09
South Platte River			
Blazac	0.24	0.68	2.64
Julesburg	0.38	1.00	3.42
North Platte	0.42	1.17	5.13
Average	0.35	0.95	3.73
Central Platte River			
Brady	0.40	0.80	2.20
Cozad	0.40	1.03	3.73
Overton	0.40	1.20	4.33
Odessa	0.25	0.75	2.45
Grand Island	0.32	0.65	2.07
Average	0.35	0.89	2.96

The South Platte River is the major erosional agent of the Piedmont section in Northern Colorado. Kiowa and Bijou Creeks, and tributaries draining the Cretaceous and Tertiary beds to the south of the river are the major suppliers of sediment to the South Platte (U.S. Bureau of Reclamation, 1947). Sediments ranging in size from clay to gravel are derived from the sedimentary formations in the South Platte Valley. Historically the South Platte delivered coarser sediments to the Platte than did the North Platte.

Soils of the North Platte River basin are shallow and immature and are closely associated with the geology of the region. In the lower elevations between Casper and Douglas, Tertiary deposits are exposed. Most of these deposits are thick shales (soft shales are found in many of the intermontane valleys) with thin beds of sandstone, limestone and coal. Resistant sandstone forms the ridges and hills. Terrace deposits of sand and gravels laid down by old river floodplains, are found along the North Platte. During the pre-reservoir era (i.e. prior to 1909) fine sediments (silts and clays) were derived from the drainage south of the river between Alcova and Guernsey. The drainage to the north was the primary contributor of the sand-sized sediment in the river (U.S. Bureau of Reclamation, 1951).

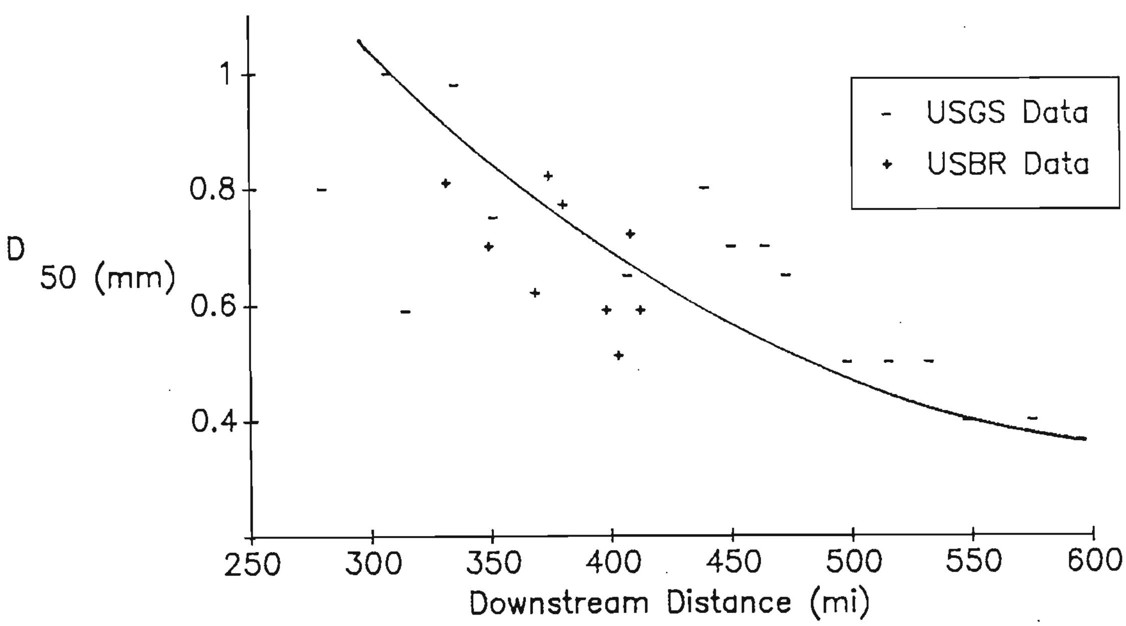


Figure 6. Variation in sediment size in the downstream direction on the Platte River from Brady to Louisville (US Geological Survey 1983).

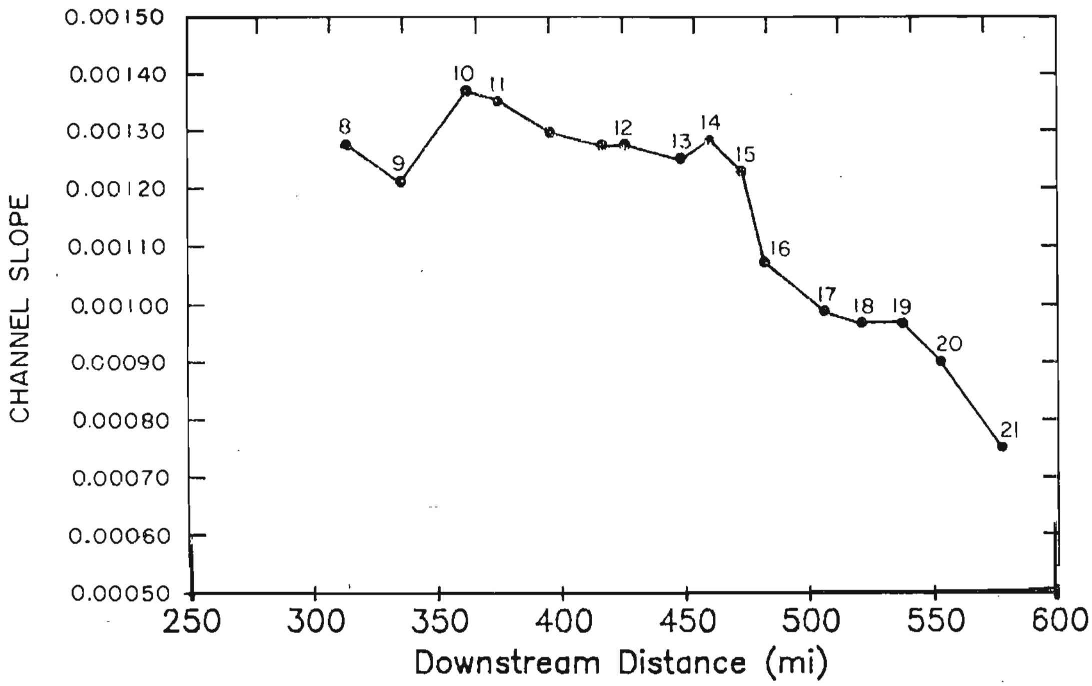


Figure 7. Variation in channel slope with the downstream direction on the Platte River from Brady to Louisville (US Geological Survey 1983).

Historically the North Platte delivered finer sediment to the Central Platte than the South Platte (Table 2). Most of the fine to medium size sand load in the Platte was derived from formations drained by the North Platte River. Since the closure of Kingsley Dam in 1941, however, this sediment source has been essentially curtailed, and the bed material of the Platte has coarsened. Other mainstem reservoirs on the North Platte have also contributed to the storage of sediment upstream of the Platte.

As is the case in most alluvial streams, the bed material size in the Platte is progressively finer in the downstream direction (Figure 6, Table 2). A decrease in channel slope also corresponds with the progressively finer sediments downstream (Figure 7). Additional fine sediments provided by the Loup and Wood Rivers help to maintain the braided nature of the Lower Platte.

Climate

The climate in the Platte River basin is diverse. The upper watershed originates along the Continental Divide in the Rocky Mountains. Much of the annual flow in the Platte is derived from snowmelt in this region where the annual precipitation is 400 to 500 mm. East of the foothills precipitation is quite variable and ranges from 300 to 450 mm, most of which occurs between April and September. Humidity is low in this region and warm summers and cold winters are experienced.

The plains of the North and South Platte River basins are characterized as semiarid with large fluctuations in temperature. The annual precipitation is only 230 to 400 mm. Along the Central Platte in Nebraska, precipitation is higher, and ranges from 450 mm at North Platte to 580 mm at Grand Island (Kircher and Karlinger, 1983).

There is a delicate balance between climate, soils, and vegetation in the arid region between the Rockies and the Central Platte. In general, areas receiving less than 500 mm of annual precipitation experience intense rainfall and runoff events. Areas of low precipitation and sparse vegetation often have highly erosive soils. Under these conditions, flash flooding is common following thunderstorms and large quantities of sediment are eroded from the watershed. Intense summer thunderstorms sweep across the high plains of eastern Colorado and Wyoming and deliver large quantities of water and sediment to the Platte River system through runoff. For instance, Bijou Creek experienced extreme floods following massive thunderstorms in 1935 and in 1965, with reported discharges of 282,900 cfs and 466,000 cfs, respectively (Matthai, 1969).

Vegetation

Prior to pioneer settlement, nearly all of central and western Nebraska was covered by native grasslands (Pound and Clements, 1898; Weaver, 1944). In the Platte River valley, the predominant vegetation consisted of wet meadows and tallgrass prairies in lowlands and on river terraces and mid- to short-grass sandhill prairie on the uplands and bluffs surrounding the valley. Trees were scarce; over long stretches of the Platte, timber growth was either "wholly absent" or consisted of only scattered trees along the shoreline (Kellogg 1905, McKinley 1938). Cottonwood (*Populus deltoides*), Willow (*Salix* spp.), and Red Cedar (*Juniperus virginiana*) were the primary large trees present along the Platte.

Throughout the Prairie Formation the climate is more favorable to grasses than trees, shrubs or indeed any other type of vegetation. On the bluffs and tablelands surrounding the river, sandhill prairie dominated the presettlement vegetation. As rainfall decreases and evaporation increases from east to west, a continuum of prairie associations from central Nebraska to the rocky mountains is present. The "absence of trees, the paucity of shrubs, the dominance of grasses, and a drought-enduring flora" constitute the main features of the prairie (Weaver 1944).

Geomorphology

The development of the Platte drainage is complex and not well understood. It is probable that the general drainage system of the North Platte River was established in Pleistocene times during the glaciation of Nebraska. Extensive gravel sheets covered this region during the period of the Illinois glaciation. The glaciers dammed the rivers and filled the valleys with alluvial deposits. In addition, many episodes of stream piracy or capture occurred.

Stream piracy is the phenomena of one river being captured or diverted by a tributary of another. The river is diverted from its original course and instead flows down the tributary into another river system. This process occurs when a tributary which is lower in elevation intercepts another river while extending its drainage basin. The retreat and advance of the glaciers forced a series of river drainage pattern alterations. Stream captures occurred as the land surface responded from the release of glacial pressures. The causes of stream capture are related to regional uplift, development of the Missouri River during the late Pleistocene era, and climatic change (Buchanan, 1981).

The North Platte is reported to have flowed through both the Niobrara and Republican River drainages before it was diverted or captured by other rivers during uplift and glaciation (Johnsgard, 1984). Since the Niobrara River was not present during the late Tertiary or early Pleistocene period, the Platte River system must be relatively young. It is suspected that the Niobrara was originally part of the North Fork of the Elkhorn River which was captured by a tributary of the Keya Paha River (Buchanan, 1981).

The South Platte River also has a unique geomorphological history. The present South Platte drainage system developed as a series of stream captures which occurred along the eastern front plains of the Rocky Mountains. Piedmont deposition from streams draining the mountains created river systems which were elevated higher than the neighboring drainages. Evolving tributaries captured the higher rivers and diverted them from an eastward to a northeastern direction (Schumm, 1977).

The sequence of geological evolution that resulted in the present location of the Central Platte River is not completely understood, but it is apparent that it also evolved from a series of stream captures. Differences in the elevation of contiguous drainages in Nebraska is probably the result of adjustments to the loading and unloading of sediments from advancing and retreating glaciers. For instance, the Platte River at North Platte is nearly 400 feet higher in elevation than the Niobrara directly to the North and about 250 feet higher than the Republican directly to the South. The Platte River upstream from the confluence of the Loup River appears to have been a tributary of the Loup River which eroded westward, capturing the southeastern flowing Platte (Bentall, 1981). As a result, the Platte from the confluence of the Loup to Odessa may be less than 10,000 years old. The small drainage corridor of the Central Platte is further evidence that this stretch of the river was simply a tributary of the Loup.

Enormous discharges of water and sediment from the retreat of the glaciers and from rare flood events are probably responsible for many of the major islands between North Platte and the confluence of the Loup. Historical floods extended across the valley but were confined by the bluffs adjacent to the river. The major island groups upstream of Grand Island are all located downstream of valley constrictions where slower flow velocities during extreme floods probably resulted in bar formation in the center of the channel. These large islands were noted in the earliest journals and descriptions of the Platte in the 1800's, but they were formed thousands of years earlier (Eschner, 1981).

The North and South Platte rivers join at a point where the valley bluffs are very close. Immediately downstream of the confluence, the bluffs separate and the floodplain expands from 14,000 feet to 24,000 feet in width. Brady Island and McCullough Island are located in this transition zone and most likely are the result of a paleoflood. Similarly, near Gothenburg (approximately river mile 256), the valley bottom narrows to a width of 10,000 feet and then expands to 18,000 feet at the point where Willow Island was formed. Further downstream, in an area where the valley bottom is uniformly very wide a series of long islands were formed as transverse bars. These include Danielson Island, Jeffreys Island, Long Island, and Everts Island. Other paleoflood islands include Kearney, Killgore, Fort Farm, Elm, Shoemaker, Mormon, and Indian Islands. Following the initial deposition and island formation, these islands have grown in the downstream direction as a result of accretion during subsequent floods and through deposition of wind-blown sediments. An examination of the earliest aerial photographs (1938) of the Platte indicates that recent historical flows have flooded many of these paleo-islands including Shoemaker and Mormon. The elevation at the center of these islands is several feet lower than at the island margins, indicating that sediment deposition has occurred at the island margins during overbank flooding (Hurr, 1983). Today, however, these islands rarely flood except at unusually high discharges such as those which occurred in 1983 and 1984 (i.e., in excess of 20,000 cfs).

Unlike the riparian zone today, woody vegetation most likely did not proliferate on these large paleo-islands as they were formed. The physical processes leading to the formation and stabilization of the paleo-islands, however, are essentially the same as those responsible for recent islands on the floodplain. The large paleo-islands were created by very infrequent flood events of large magnitude. Once these islands were formed, they flooded only infrequently, allowing the establishment of a permanent vegetative cover. Trees probably were not widespread because a seed source for cottonwood and willow was not readily available. Further, these islands were high enough above the active river channel that they were relatively dry and not conducive for the growth of trees. Scattered trees may have developed on these large islands initially, but over geologic time most matured and died, allowing grasslands to establish as a permanent cover. At the time of settlement in the mid-1800's these islands were dominated by grasslands (Woodbury, 1847). Once a prairie sod developed, very few additional sites for tree establishment (open, unvegetated, sandy substrate) were available.

The unabated supply of sediment to the Platte and the steep slope of the valley were conducive to the evolution of a braided stream. As a young river with a developing watershed, the Central Platte became an aggrading stream, which continued to build its floodplain as it reworked the valley bottom. Lateral instability is characteristic of such braided streams and even at lower discharges, the wide shallow river migrated back and forth across the valley bottom. It is clear from the earliest topographic maps of the Platte and the historical record (Eschner et al., 1983) that the Central Platte from the confluence of the South Platte and North Platte rivers to Grand Island was a braided stream with thousands of unvegetated bars and islands.

Historical accounts in nineteenth century journals indicate that annual peak flows in the Platte were very large, and that the river was very wide and quite shallow. Accurate measurements of the historical width of the Platte are limited, but two measurements are reported in the literature. Downstream of the confluence of the North and South Platte rivers, Fremont (1845) reported that the channel was 0.99 miles in width (US Department of Interior, 1983). In addition, Captain Bonneville (1832) measured the channel 24.86 miles downstream of Grand Island to be 2200 yards in width (US Department of Interior, 1983). Channel depth was reported to be between 1 and 4 feet, with bankfull depths at 6 to 8 feet (James 1823).

Hydrology

A key to understanding the morphology of the Platte River channels and their changes is to review the hydrology of the river. Pre-development spring runoff produced a hydrograph with a large seasonal variation, peak flows in May and June and low base flow from August to March (Figure 8). Before 1900 pre-development flows exceeded 20,000 cfs almost every year (prior to 1909, flows in the North Platte alone averaged 19,400 cfs). Paleofloods in the Central Platte River were probably in excess of 100,000 cfs. In 1965, the South Platte River flowed 123,000 cfs at Balzac, and 37,600 cfs at Julesburg, Colorado as a result of the same storm that produced 466,000 cfs on Bijou Creek. In the historical record, there are no accounts of overbank flooding. It is clear from the earliest aerial photos (1938), however, that the surrounding wetlands have been subject to overbank flows. The ability of the river channel to modify its cross section to increase conveyance at bankfull flows, probably limited overbank flooding except at very high peak discharges.

Eschner (1982) reports no long-term change in climate over the past 80 years, and speculates that for the eastern plains, climate has been relatively constant for the last 200 years. Although a wet cycle has been postulated for around the turn of the century for the Colorado River system (which probably also affected Platte River flows), it is also apparent that the massive floods of the post-glacier era have not been repeated in recent history. Predictions of the 100 year flood return period have been roughly estimated by the U.S. Geological Survey (Lewis and Caughran, 1958), but these estimates are probably conservative (Table 3).

Table 3. Estimated 100 year flood frequency for the Platte and North Platte Rivers (Lewis and Caughran, 1958).

North Platte River at North Platte (post-McConaughy)	8,900 cfs
South Platte River at North Platte	44,000 cfs
Central Platte from Brady to Grand Island	50,000 cfs

There is some evidence to indicate that the Central Platte River in the Big Bend area occasionally experienced very low flow because of channel infiltration (Eschner et al., 1983). However, "indirect evidence such as construction of canals along the Platte to divert water during the summer months suggests that prior to irrigation the Platte River did not routinely go dry" (Department of Interior, 1983; see Miller, 1978). Unfortunately, inaccurate and inconsistent records kept on stream flow measurements in the late 1800's and early 1900's creates a confusing picture of pre-development low flows. As a result, the occurrence of historic no-flows in the Big Bend Reach prior to irrigation diversion in the mid-1800's can not be documented. No-flow days recorded in the post-1930's, however, were clearly the result of water diversion and storage upstream.

It is unlikely that zero historic flows were anything but a rare occurrence because of the size of the Platte River drainage basin and the perennial flows of the numerous tributaries. Furthermore, groundwater levels in the general area of the river respond very rapidly to changes in river stage (within 24 hours for distances up to 2500 feet from the river), which would insure that there was some water in the river at all times prior to 1860 (Hurr, 1983). Limited gaging records from the pre-development era also suggest perennial flows. For instance, before major reservoir development (pre-1909) the mean annual base flow at Duncan was 970 cfs during August and September. Historic base flows in the Central Platte are shown in Figure 8.

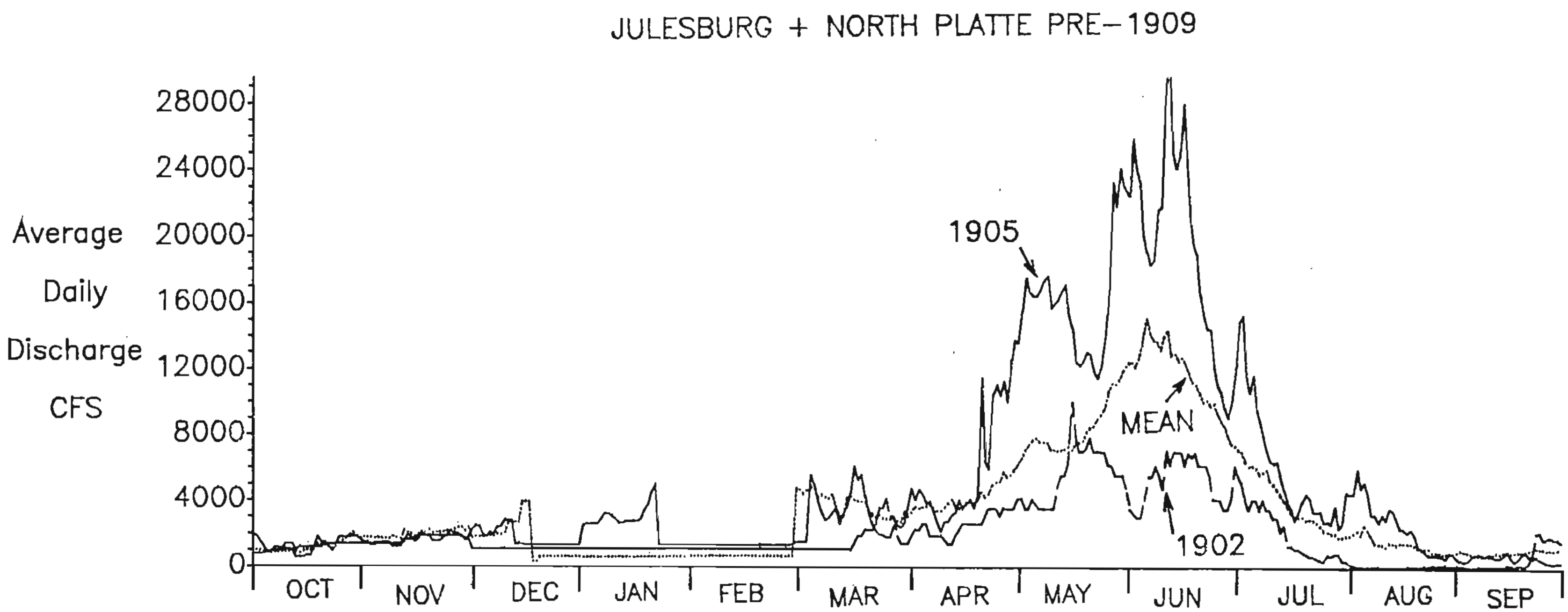


Figure 8. Historic hydrograph of the Platte River using combined data from the North Platte River at North Platte and the South Platte River at Julesburg. These combined data are a representation of Platte River flows prior to 1909. A high water year (1905) and a low water year (1902) are shown in relation to the historic (pre-1909) mean discharge.

It is of interest to note that almost all of the zero discharges reported by Bentall (1982) at Lexington and many of those recorded at Columbus before 1909, were in fact not zero flows. These "no-flows" are the result of erroneous measurements, probably a consequence of the river channel shifting away from the gage, scouring or filling around the gage, or of improper calibration of the gage for lower flow measurements. For example, all eleven days reported by Bentall (1982) at Lexington as "no-flow" days in 1906, actually had gage readings that had been recorded without a corresponding discharge. The low gage values may have produced negative discharge numbers with the improperly calibrated rating curves.

Numerous historical references document the braided form of the Platte (Bradbury, 1819; James, 1823; Kelly, 1952; Evans, 1849). In virtually every account the bed material is described as sand. James (1823) wrote "its bed is composed almost exclusively of sand, forming innumerable bars, which are continually changing their positions, and moving downward ... the alluvial deposits of which the river bottoms are formed, consist of particles of mud and sand, more or less minute." This braided form was maintained by high peak discharges and a large sediment load. Pre-development sediment loads in the Central Platte River can only be estimated. Historically, high peak flows on the North Platte (mean peak flow was 19,270 cfs at North Platte from 1895-1909) undoubtedly delivered substantial quantities of sediment which kept the river wide, shallow and very active.

PLATTE RIVER CHANNEL MORPHOLOGY CHANGES

Changes in Channel Geometry

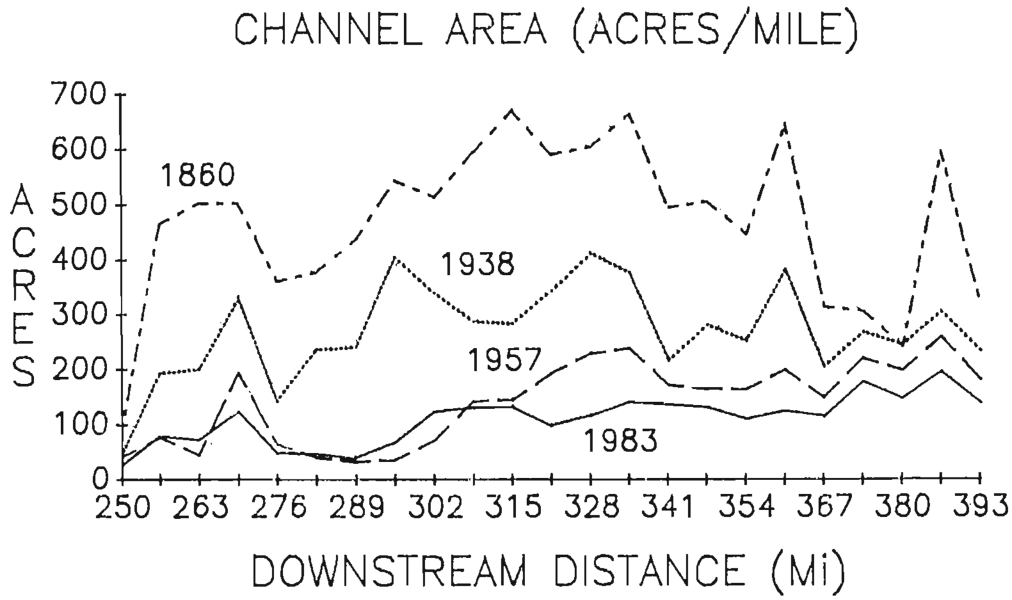
The Central Platte's response to changing flow regimes and reduced sediment load is well documented Williams, (1978), Eschner (1982), Schumm (1969, 1977), Eschner et.al. (1983), Kirchner and Karlinger (1983), Kirchner, (1983), Karlinger, et.al., (1983). From the confluence of the North and South Platte rivers to Grand Island, the river is in transition from being a wide, shallow, braided river to a multiple channel, anatomosing or anabranching stream. Although several channels (principally around major island groups) have maintained a braided pattern at low flows; this entire river reach has experienced more or less a uniform reduction in active channel. Reduction in active channel width has occurred in the last 80 years in response to reduced peak discharges and reduced sediment supply. Banks and islands have been stabilized by permanent woody vegetation following the reduction in active channel. Vegetation encroachment, however, is not the cause of channel narrowing. It only stabilizes inactive cannel areas and protects them from subsequent erosion. This cause and effect relationship may occur in a very short period (several years) and may be permanent. Three to five years of reduced flow appears to be sufficient to permit vegetation to stabilize above the stage where peak flows continue to scour the bed. The changes in morphology and vegetation encroachment on the Platte have been progressive and unabated since the turn of the century. Channels have been reduced 50% to 85% compared with their 1860 width (Currier et al., 1985; Peake et al., 1985; Figure 9). Similar changes have been reported for the South Platte (Schumm, 1969) and the North Platte (Nadler, 1978) Rivers. Schumm (1969) found that the metamorphosis of the North Platte downstream of Lake McConaughy has not yet resulted in a complete transition from a braided to a meandering stream, although the river has become more sinuous.

Changes in River Flow Hydrology

Irrigation development on the North Platte River began in 1847 near Fort Laramie, and continued on a small scale near other military outposts throughout the 1850's and 1860's. The most rapid period of canal construction occurred in the 1880's when cattlemen realized the benefits of irrigation (Table 4). In 1884, 22 canal companies were actively diverting water from the North Platte. Between 1881 and 1890, 1,627 canals were constructed or enlarged on the North Platte River alone. By 1894 most of the land in the basin that could be irrigated by direct diversion was already developed, thereafter canal construction began to taper off. By 1901, summer flows in the North Platte River upstream of Nebraska were overappropriated. Fifteen years later, summer flows within Nebraska were overappropriated. Construction of storage reservoirs on the North Platte began in 1892 and by 1906, 27 small off-river reservoirs were operating in the basin.

In 1909 Pathfinder Reservoir began main stream storage of spring runoff on the North Platte. Subsequently, other mainstream reservoirs followed including Guernsey, 1927; Alcova, 1938; Seminoe, 1939; McConaughy, 1941; and Glendo, 1957 (Table 5). Each reservoir produced a successive decrease in the peak flows in the North Platte River at North Platte (Figure 10). Prior to 1909 (1895-1909) peak discharges averaged 19,270 cfs; from 1910 to 1927 peaks averaged 11,050 cfs; from 1928 to 1941 the mean peak was reduced to 8,710 cfs; and from 1942 to 1980, the average peak was only 3,330 cfs (Figure 11).

South Platte flows have followed a similar decline in peak discharges. Prior to 1927 (11 years) the South Platte averaged (10,000 cfs). From 1928 to 1941 the mean peak was only 4,600 cfs or about 50% of the previous period. It should be noted that this period included one discharge of 37,100 cfs and four years of peaks under 1000 cfs revealing the nature of the drought of the 1930's. The mean peak discharge for 39 years from 1941 to 1980 was 4600 cfs, the same as in the 1928-1941 period.



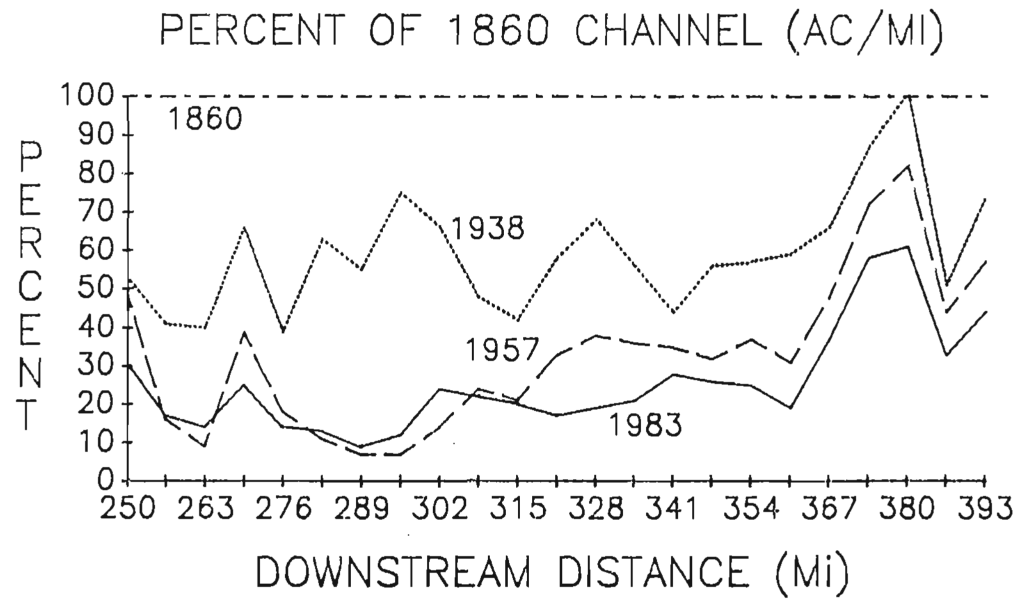


Figure 9. Change in channel area (acres per mile of river) and percent of the 1860 channel remaining in 1860, 1938, 1957, and 1983 on the Platte River between Brady (mile 250) and Chapman (393).

Table 4. History of canal construction and enlargement in the Platte River basin between 1851 and 1930 (from Eschner et al., 1983).

	Number of canals constructed or enlarged		
	South Platte Basin	North Platte Basin	Platte[1] Basin
1851-1860	28	0	0
1861-1870	376	17	0
1871-1880	533	194	0
1881-1890	364	1627	3
1891-1900	63	725	10
1901-1910	313	1391	0
1911-1920	141	732	9
1921-1930	96	249	69

[1] Platte River Basin above the Loup River

No main channel storage has been constructed below Denver on the main stem of the South Platte, but beginning in the 1880's considerable volumes of water were diverted from the South Platte and stored in off-river reservoirs. By 1948 there were 41 reservoirs in the South Platte basin with individual storage capacity in excess of 5,000 Acre-feet. The combined capacity of the reservoirs at that time was greater than 800,000 Acre-feet (Lewis and Caughran, 1958). Reservoir construction for irrigation began in the 1880's and peaked in the period between 1901 and 1910 (Figure 10). The earliest known diversion in the basin occurred between 1838 and 1844 from the Cache la Poudre in Colorado, a tributary of the South Platte River (Eschner et al. 1981). By 1860, 28 appropriations had been granted to allow diversion of water from the South Platte through canals. Canal development grew rapidly after 1860. Three hundred and seventy-six canals were constructed between 1861 and 1870; 533 canals were constructed between 1871 and 1880, and 364 canals were constructed between 1881 and 1890 on the South Platte and its tributaries (Eschner, et al. 1981). Direct diversion had affected the flows in the South Platte so much that summer flows in the river were overappropriated by 1885. Transmountain diversions from the west slope of the Colorado Rocky Mountains to the South Platte basin now supplement natural flows, partially making up this loss during the low flow period from July to October.

Table 5. New usable storage in thousands of acre-feet in the Platte River basin between 1851 and 1980 (from Eschner et al., 1983).

	New Storage in Thousands of Acre-Feet		
	South Platte Basin	North Platte Basin	Platte[1] Basin
1851-1860	0	0	0
1861-1870	0	0	0
1871-1880	7	0	0
1881-1890	115	0	0
1891-1900	136	9	0
1901-1910	434	1141	0
1911-1920	83	79	0
1921-1930	0	64	0
1931-1940	151	1334	44
1941-1950	96	1946	0
1951-1960	62	786	0
1961-1970	0	0	0
1971-1980	437	0	0

[1]Platte River Basin above the Loup River

Discharge records for the Central Platte (1915-present at Overton) commenced considerably after water development began upstream on the South Platte and North Platte rivers. For the period 1915 to 1929, the average annual peak flow was 19,600 cfs. After 1929, discharge at Overton did not exceed 11,000 cfs for 13 years (except for 1935, in which the peak flow was 37,600). Mean peak discharge has been 7100 cfs during the 48 years since 1938. During the 15 year period from 1949 to 1964, the discharge did not exceed 7600 cfs. In four consecutive years (1953-1956) peak flows were less than 5,000 cfs (Figure 11, Table 6).

Irrigation development on the Central Platte River lagged behind that on the North and South Platte for a number of reasons. First, the discovery of gold in Colorado and the large influx of people into the Denver area resulted in an earlier population growth and thus an earlier demand for water than in

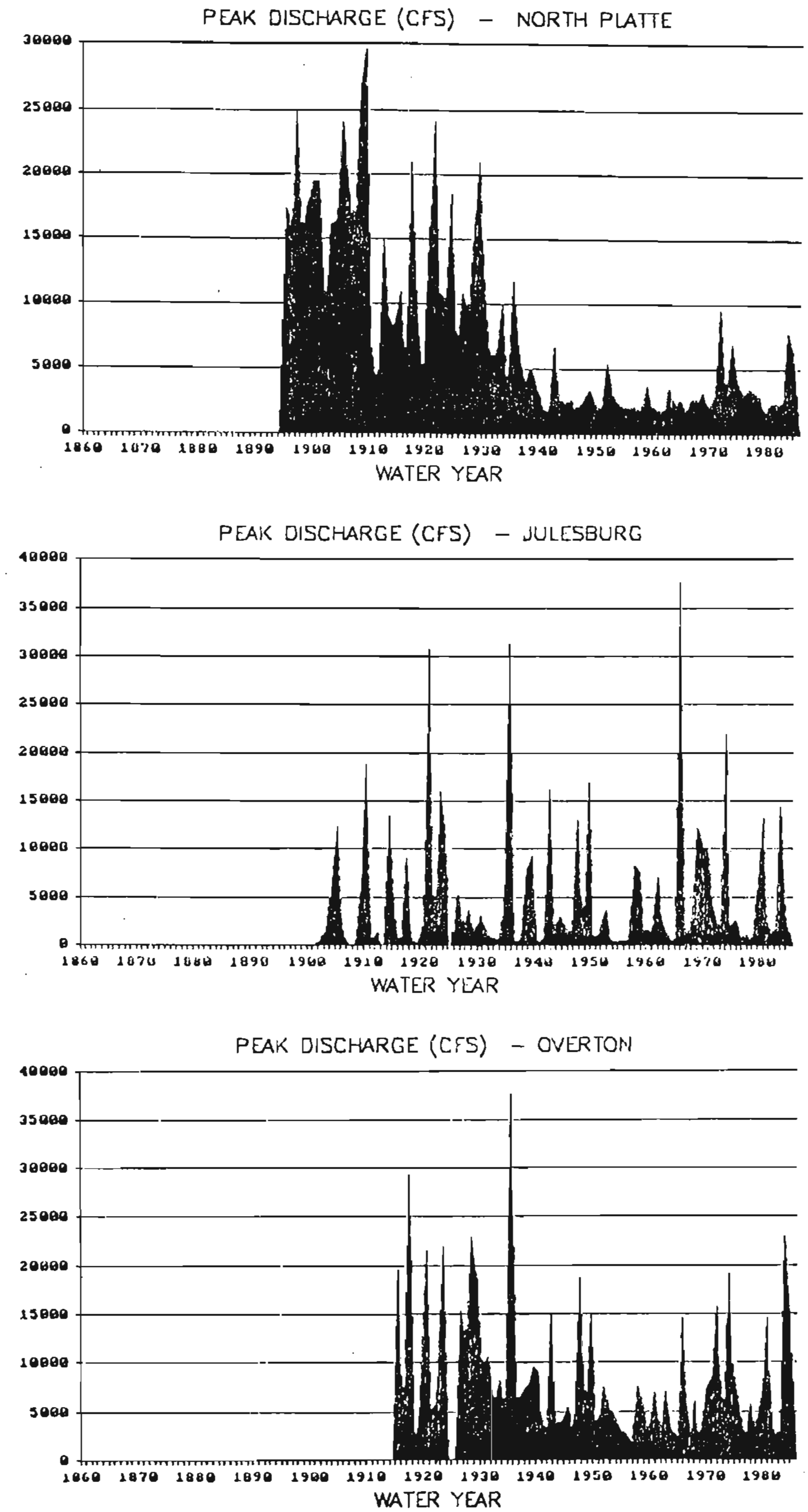


Figure 11. Peak discharge at North Platte on the North Platte River, at Julesburg on the South Platte River, and at Overton on the Platte River for the period of the hydrologic record at each station.

Table 6. Peak discharge in the Platte River at Overton from 1915 to 1984 (source: US Geological Survey)

Water Year	Discharge	Water Year	Discharge	Water Year	Discharge
1915	19600	1939	9660	1962	7100
1916	5200	1940	8940	1963	3020
1917	29300	1941	2330	1964	2360
1918	ND [a]	1942	15200	1965	14600
1919	9000	1943	3860	1966	3410
1920	21500	1944	4070	1967	6100
1921	37000	1945	5530	1968	2550
1922	9400	1946	3490	1969	7260
1923	22000	1947	18700	1970	8660
1924	ND	1948	5990	1971	15700
1925	ND	1949	15100	1972	4750
1926	15500	1950	3210	1973	19100
1927	12800	1951	7550	1974	8810
1928	23000	1952	5710	1975	5500
1929	19000	1953	4640	1976	2860
1930	9940	1954	2930	1977	5890
1931	10600	1955	2370	1978	3600
1932	6120	1956	1970	1979	7580
1933	8440	1957	7530	1980	14600
1934	5210	1958	5800	1981	3730
1935	37600	1959	2960	1982	2520
1936	6100	1960	6950	1983	22900
1937	7050	1961	3490	1984	15600
1938	7680				

[a] ND indicates no data

Vegetation Development and Channel Encroachment

The processes of woody vegetation establishment have been active on the Platte River floodplain since the development of the present drainage system, at least 10,000 years ago. From historic accounts, however, it is clear that woody vegetation was not widespread on the Platte River floodplain at the time of settlement (Eschner, 1981; Currier et al., 1985). Today much of the Platte is heavily encroached with permanent woody vegetation. The key to understanding this change in vegetation is the reduction in peak flows in the Platte. The role of peak flows in controlling woody vegetation has been documented by several authors (Northrup, 1965; Currier, 1982; Potter et al., 1983). Annual peak flows determine the highest elevation at which seeds are placed and can germinate. Seedlings that develop here are the most likely to survive through successive high flow events (Figure 12). The majority of seedlings develop at lower elevations and are scoured away in succeeding years by peak flows (Lewis and Caughran, 1958; Currier, 1982; Currier, 1986)

Peak flows therefore have a dual purpose; they are the principal mechanism by which seeds are deposited in locations where germination and development can take place, and they are the agent that ensures that most of the annual establishment is removed through scouring. The relationship between the elevation at which germination takes place, the magnitude of the peak flow, and the period between successive peaks determines where and how extensive woody vegetation establishment will be.

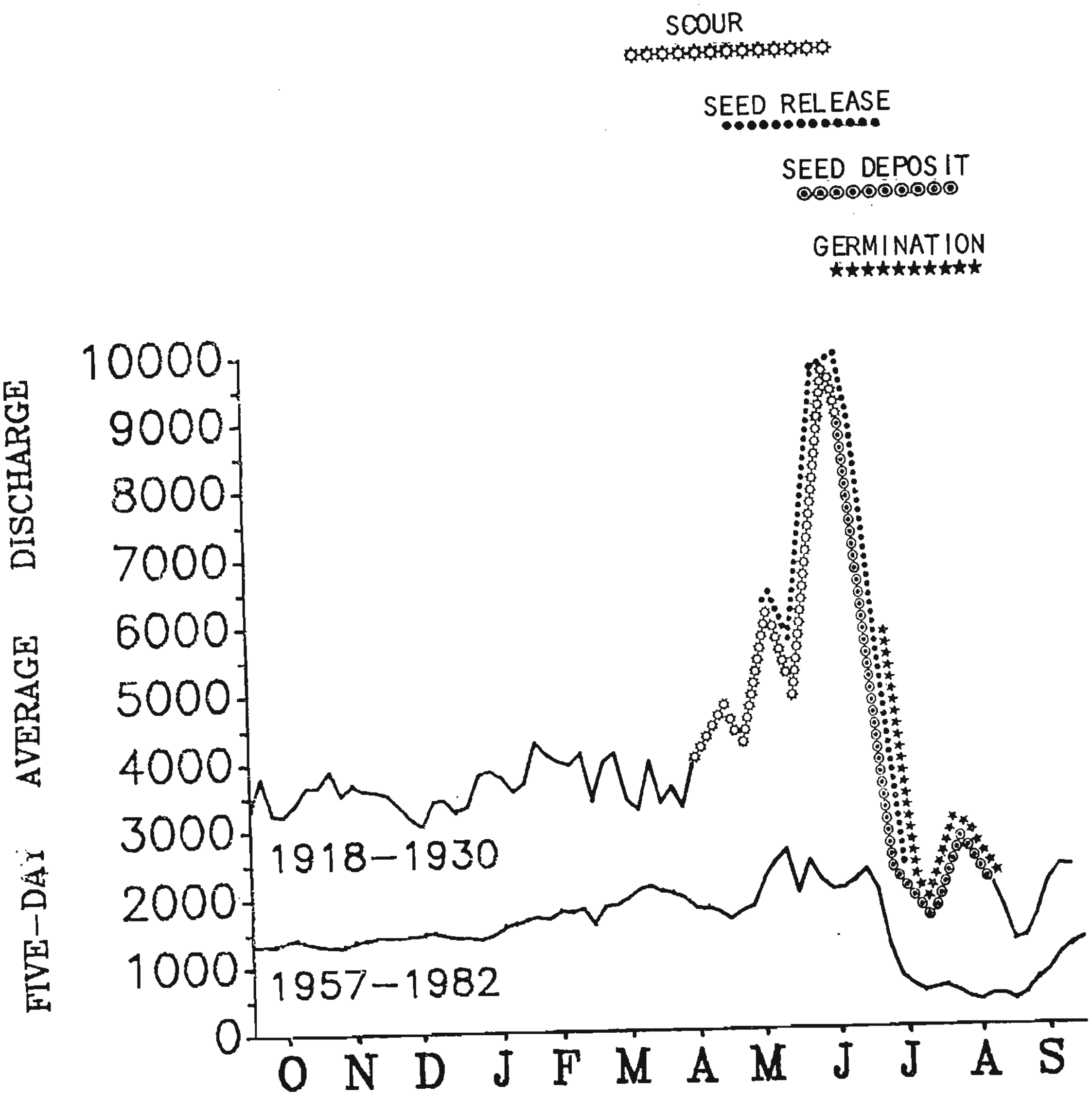


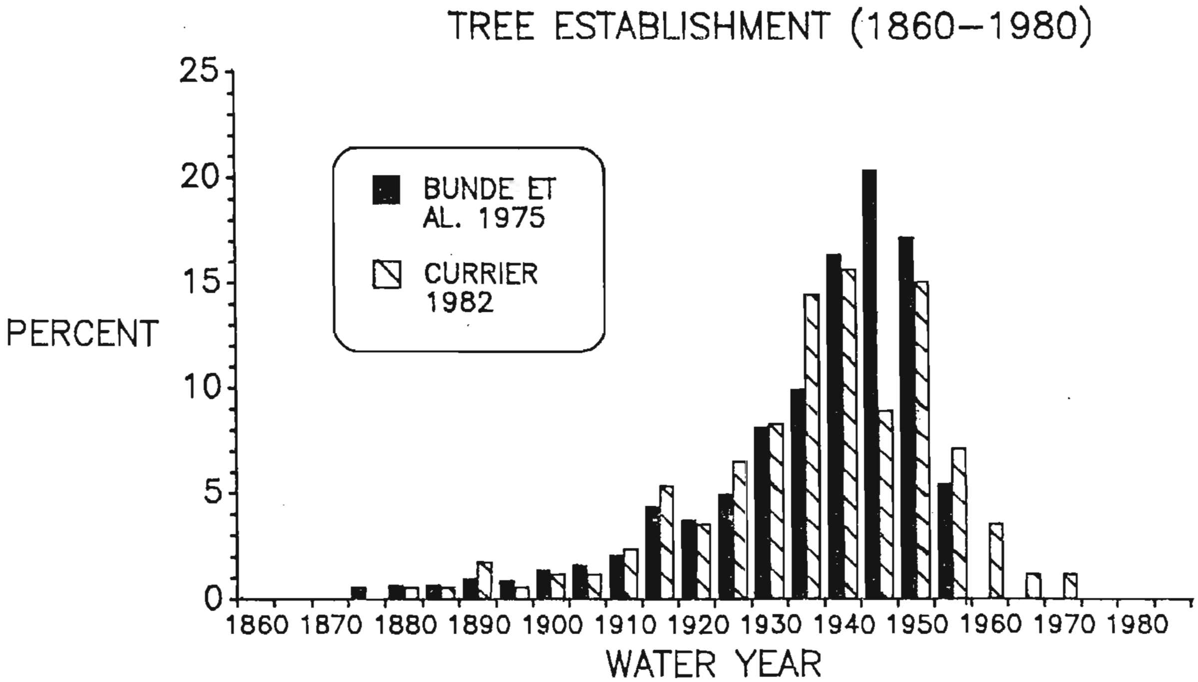
Figure 12. Periods of seed release, seedling germination and development, and seedling scour superimposed on the average annual flow hydrograph for the Platte River at Overton under historic (1918-1930) and post-development (1957-1982) conditions.

An unstable sand substrate is the primary inhibitor of woody plant recruitment. Comparably, vegetation is more easily established in cohesive, fine sediments. When a population of seedlings escapes scouring it begins to stabilize the substrate on a sand bar, allowing further deposition of bed material, and possible island formation. As this process continues, higher peak flows are required to scour away the island because greater flow depth and higher velocity are needed to overcome the increased roughness produced by the vegetative cover. It simply takes more energy to mobilize the sand particles on a vegetated bar.

After three to five years of growth, young cottonwoods are often six to ten feet in height and two to four inches in diameter. At this stage, their removal would require complete island destruction. One to three feet of sediment above the active streambed would need to be scoured to insure island mobilization and removal (Northrup,1965; Currier, 1982). If vegetation becomes established in a reach where unvegetated alluvial bars exist, a more pronounced thalweg will develop when high flows return to the reach in succeeding years. This gradual deepening of the channel makes it more difficult to rework vegetated bars.

Periodic droughts or sustained low flows allow vegetation to establish at elevations below the level of the mean annual peak (Nadler, 1978). Prior to 1929, peak discharge at Overton was not less than 12,000 cfs for two consecutive years. In the 1930's peak flows declined as a result of water regulation and an extended drought. From 1932 to 1934, the peak flow did not exceed 8,500 cfs. Following a rare peak flow of 37,500 cfs in 1935, the Platte at Overton did not exceed 10,000 cfs in 10 of the next 11 years. The 1935 peak was probably sufficient to have removed much of the vegetation on the active channel, but in the years immediately following this high flow event, conditions were nearly ideal for widespread establishment of cottonwood and willow (Figure 13). In the 1950's there were a number of low flow years as well. Seedlings which established near the 15,000 cfs high water mark in 1947 and 1949 were well above the 8,000 cfs level of the subsequent peaks which occurred over the next 15 years. Most of these trees survived. An analysis of tree establishment on the Platte indicates that the majority of trees developed between 1935 and 1960 during a period when high peaks were greatly diminished (Bunde et al., 1975; Currier 1982; Figures 11 and 13). By 1960, the rate of establishment had declined, indicating that most sites above the 8,000 cfs average annual peak (1957-1983) were already occupied by trees and sites for new recruitment were limited.

Aerial photos of the Platte reveal that substantial tree growth had already taken place by 1938. The median age of these trees was estimated at about 20 years in 1938. This age corresponds with the construction of Pathfinder reservoir which began operation in 1909. During the subsequent 20 years the active channel of the Platte was severely altered, allowing substantial vegetation encroachment to take place.



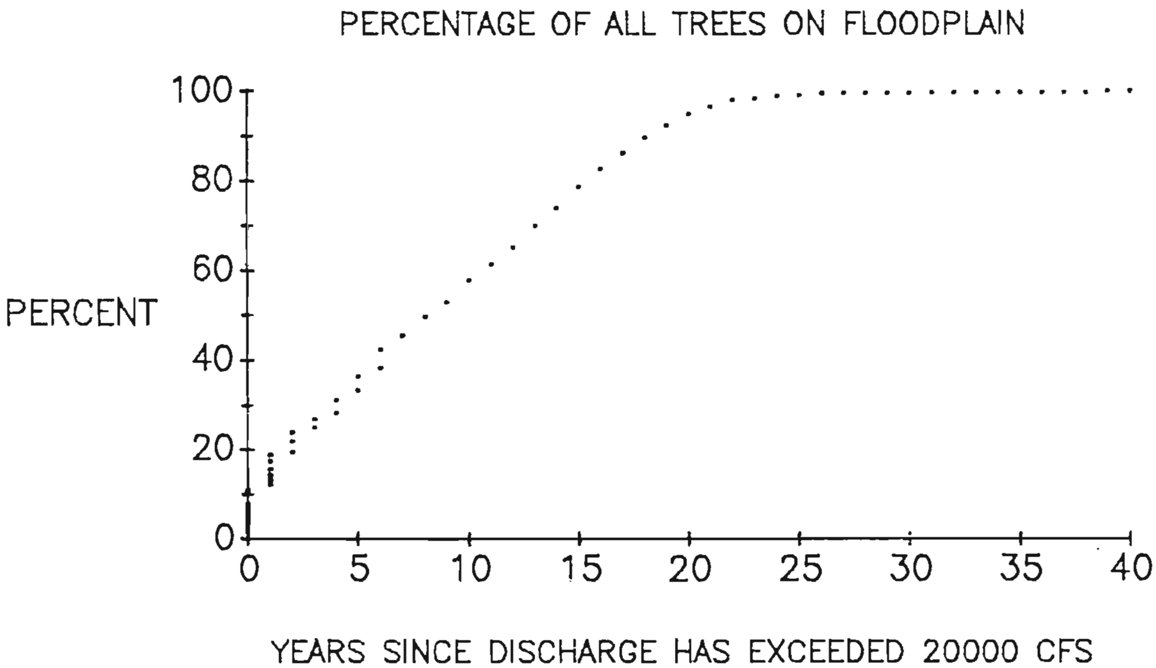


Figure 13. Percentage age distribution of cottonwood trees on the Platte River floodplain within the 1860's high banks. Establishment peaked between 1935 and 1960. The cumulative percentage of all cottonwoods establishing on the floodplain is shown in relation to peak discharge in the lower graph.

No trees or woody vegetation existed in the active channel prior to 1860 except on a few large islands. The concept that plants did not grow on the channel because they died from a lack of moisture (dessication) is inherently wrong. Plant dessication requires a dry riverbed and no precipitation for extended periods during the early life stages of woody plants. Historic low flows in the Platte (pre-1909, prior to reservoir construction) were actually higher then they are today (post-1957, following reservoir development). Pre-reservoir average daily flows for August and September range from 970 cfs to 1210 cfs, while post-reservoir flows are only 680 cfs (Table 7). The Overton gage was not operating before 1918 so the data in Table 7 are a comparison of flows at Overton with the flows at Duncan and the combined North Platte and Julesburg flows. The Overton gage site is located between the upstream gages at North Platte and Julesburg and the downstream gage at Duncan, therefore, the pre-1909 average daily flow should be between 1000 cfs and 1200 cfs at Overton. There has been no increase in the magnitude of the low or base flow during the late summer over the period of record in the Central Platte. Dessication does not explain the lack of woody vegetation prior to reservoir construction because there was more water in the river during the critical low flow months in the pre-1909 period than there is today. Under today's water regime young trees are not dying en mass as a result of dessication.

Table 7. Average daily discharge in August and September.

	Discharge (CFS)
Pre-Reservoir	
Duncan (pre-1909)	970
North Platte + Julesburg (pre-1909)	1210
Post-Reservoir	
Overton (post-1957)	680

Most of the zero flow days that can be documented occurred during the drought of the 1930's, a period when woody vegetation establishment began to accelerate (see Figure 13). Discharge in the Central Platte during the 1930's was already being regulated by Pathfinder and Guernsey reservoirs. During the period of peak vegetation establishment, there were many days within the germination period when zero flows were recorded. For instance, between 1930 and 1940, there were approximately 700 days of no-flow at Overton during the germination period. Zero flows have had little impact on controlling woody vegetation development in the Central Platte. Woody vegetation establishment has been primarily controlled by scouring flows. At the time of settlement there was an abandoned river channel near Grand Island that was filled with wooded islands (Woodbury 1847; Figure 14). The abandoned channel was no longer part of the active streambed and conveyed water infrequently. Abandoned channels in the Central Platte are at higher elevations than the active streambed and thus are often dry. These abandoned channels, however, are forested, while the active stream channel is not. Vegetation developed in these channels because scouring peak flows had been reduced.

The Platte changed from a braided stream with innumerable transient bars to a more sinuous and anabranching stream. Larger, less mobile bars were stabilized by vegetation. Thalwegs developed around some bars and vegetation stabilized islands. Reduced peaks curtailed the river's ability to annually scour woody vegetation from the channel. Over a period of just a few years, diminished flows allowed extensive vegetation encroachment. Subsequent flooding resulted in sediment deposition around the vegetation, and the creation of more permanent islands. In many areas deposition has been on the order of several feet. Eschner (1981) measured an accretion of 0.75 feet in just one season. As vegetation developed over more of the floodplain, the flood-carrying capacity of the Platte declined. Near Kearney, Nebraska, for instance, Lewis and Caughran (1958) reported that there had been no noticeable overbank flooding north of the river for 50 years before 1958. In recent years, peak flows of 20,000 cfs, which are less than the historic peaks in the Platte (Figure 11), have caused flooding on Interstate 80 just north of the river.

Changes in Bed Material Size

Since 1930, the bed material of the Platte has progressively coarsened (Tables 2 and 8). The bed of the North Platte has become more coarse downstream of Kingsley Dam, yet the sediments here are still finer than on the South Platte. On the Central Platte, the rate of coarsening between the confluence and Overton has been more pronounced than in other reaches. Sediment which once moved freely down the Platte is now trapped in reservoirs on the North Platte River. The South Platte restores some of the sand load to the river, but contributes coarser sediments than were historically found in the Platte. Finer sediments have been gradually winnowed from the Platte, creating a coarser bed and allowing larger, less mobile transverse bars to form.

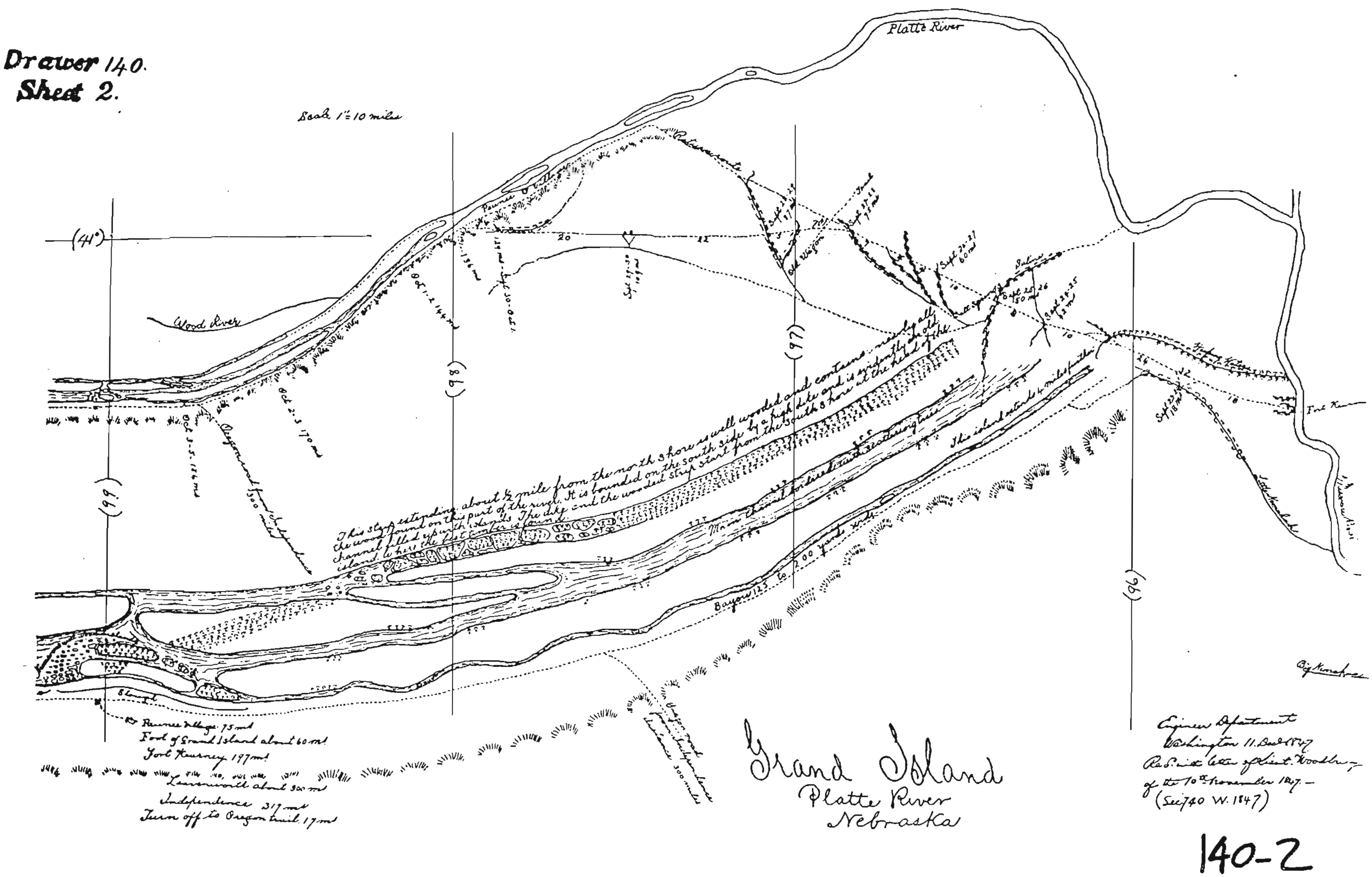


Figure 14. Historical map of the Platte River near Grand Island in 1847 showing woodland vegetation in an abandoned river channel (Woodbury 1847).

Table 8. Distributions of bed size material in the Platte and its tribuitaries.

Location and Dates	No. of Points	Size Distribution (mm) D_{16}	D_{50}	D_{84}
Platte River				
Central Platte (1931)*	159	0.18	0.40	1.08
Overton 1952-77**	75	0.35	0.83	3.03
Central Platte 1982-83***	12	0.33	0.66	2.91
Central Platte 1979-80**	28	0.35	0.89	2.96
North Platte River				
North Platte 1931*	114	0.01	0.56	13.70
North Platte 1975** (at Lingle, WY)	13	0.41	0.82	3.23
North Platte 1979-80	13	0.28	0.64	2.09
South Platte River				
Fort Morgan 1945-7***	16	0.39	1.39	4.26
South Platte 1977** (at North Platte)	1	0.39	0.88	3.50
South Platte 1979-80** (at North Platte)	20	0.35	0.95	3.73
Julesburg 1975**	13	0.47	1.00	2.54
Tributaries				
Bijou Creek 1948***	1	0.23	0.39	0.80
Kiowa Creek 1948***	2	0.24	0.42	0.98
Loup River 1931*	12	0.12	0.33	0.60
Loup River 1975**	41	0.16	0.29	0.48

* Army Corp of Engineers Data. (Along Central Platte)
** USGS Gaging Station Data.
*** Bureau Reclamation Instream Flow Study Data

RIVER FORM THRESHOLDS - WILL THE PLATTE REMAIN BRAIDED OR BECOME A MEANDERING STREAM?

Calculations of the Leopold and Wolman (1957) and Ferguson (1984) river form threshold relationships help to answer this question (Table 9). The critical threshold discharge has been calculated for two sediment sizes representing the historical bed material (D_{90} = 1.00 mm) and the existing bed material (D_{90} = 3.84

mm). The Leopold and Wolman (1957) relation, however, does not include a sediment size component. Assuming an adequate sediment supply, the Leopold and Wolman (1957) relation, specifys a discharge of 8,200 cfs to maintain a braided channel. The existing bed material size is much coarser now than it was when measured in 1931 (Table 8). Using Ferguson's (1984) criteria which incorporates sediment size, the threshold for the historic bed material size of 1.00 mm is 7,800 cfs, while the threshold for the existing bed material size of 3.84 mm is over twice this level or 16,900 cfs. This threshold value indicates that a bankfull discharge of more than 16,900 cfs (with a return period of 1.5 to 2.0 years) needs to be exceeded in order to sustain a braided river form with the existing bed material. Since 1957, following construction of Glendo, the last major reservoir in the Platte River system, the mean peak discharge has been less than 8,000 cfs at Overton. Clearly, the present channel forming discharge is far less than the threshold to maintain a braided stream and the Platte is trending toward a meandering form. Pre-reservoir (prior to 1909) peak discharges exceeded all the threshold criteria on nearly an annual basis.

Table 9. Calculation of threshold discharge based on 2 sediment sizes and the Ferguson (1984) and Leopold and Wolman (1957) equations.

	SEDIMENT SIZE	
	D_{90} = 1.00 mm	D_{90} = 3.84 mm
Ferguson (Discharge Q)	7,800 cfs	16,900 cfs
Leopold & Wolman (Discharge Q)	8,200 cfs	8,200 cfs

The Ferguson (1984) and Leopold and Wolman (1957) threshold relationships assume a continuous supply of sediment is available to maintain a braided stream. There is evidence to indicate that this is not the case on the Platte. The North Platte river was the major sediment source of the Platte. Most of the sediment transported by the North Platte is now trapped in upstream reservoirs, particularly in Lake McConaughy. The sediment supply on the South Platte has also been reduced by numerous small irrigation reservoirs on many of the tributary drainages. The river has responded to this reduction in sediment supply by degrading most of the channel in the Central Platte. From Johnson Lake to Chapman the Platte has generally degraded 3 to 10 feet between the 1890's and the 1960's (Figure 15). At low discharges, flow is now more channelized and drops several feet below the average bed elevation (Lewis and Caughran, 1958).

The Platte River in the Big Bend reach exists in several stages of transformation from active braided channel to a stable single channel stream. Stable anabranching channels comprise the stream

morphology in the transition reaches. The braided form is maintained downstream of the Wood and Loup rivers. These tributaries contribute large quantities of fine sediment to the Platte, enabling the river to maintain a wide, shallow, and active channel. Unlike the channel in the Central Platte, bed material sizes in the Loup have not changed substantially over the past 40 years (1931-1975; Table 8). The Platte may never completely transform into a meandering stream because its bed and banks contain insufficient percentages of silts and clays that are necessary to stabilize the channel and banks.

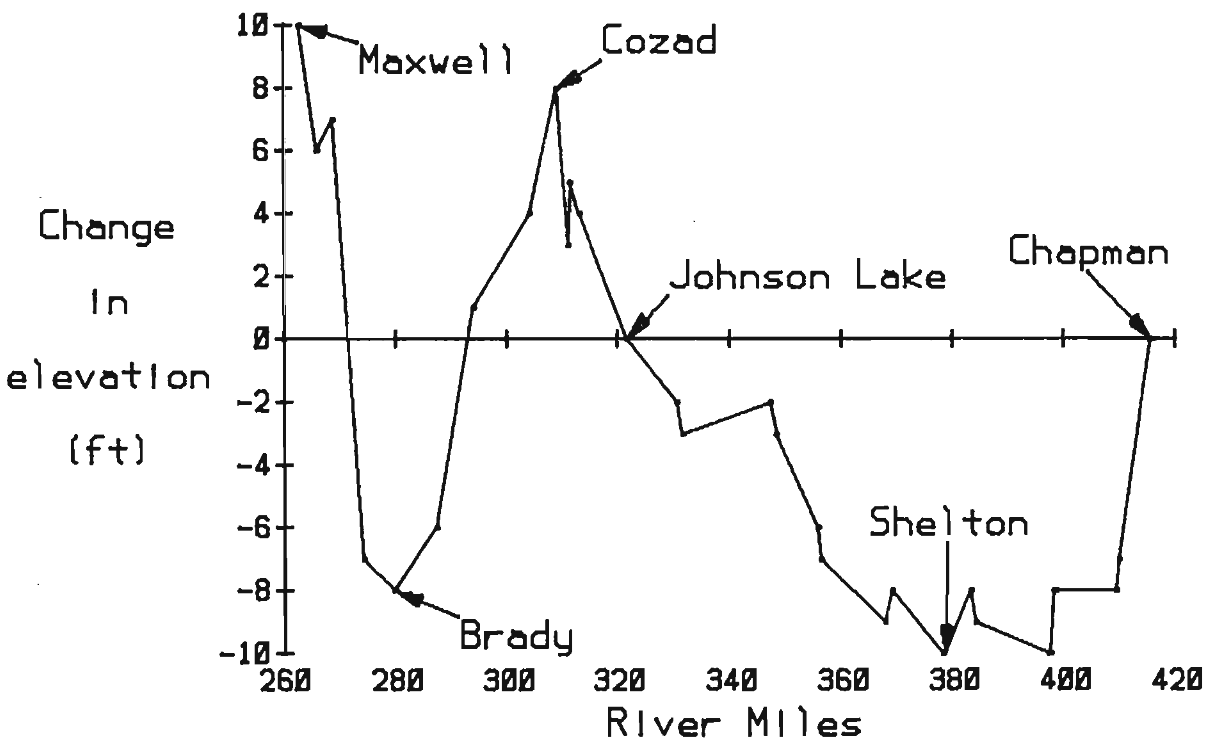


Figure 15. Changes in bed elevation of the Platte River from Maxwell to Chapman from the 1890's to the 1960's, based on US Geological Survey topographic maps. Positive values represent aggradation and negative values represent degradation. (Source: US Bureau of Reclamation, Grand Island, Nebraska, 1986).

DEFINING A CHANNEL MAINTENANCE FLOW

If migratory bird habitat is to be maintained on the Platte, a channel maintenance flow that will sustain the remaining braided reaches of the river must be determined. The physical processes responsible for maintenance of an active, braided, channel geometry must be represented in such a flow regime.

The changes in the physical characteristics of the Platte since the time of development have been outlined. In general the channel has narrowed, the bed has degraded, the bed material size has coarsened, and vegetation has encroached on the active river bed. Additional information is required before a minimum streamflow hydrograph to sustain the remnant braided reaches can be determined.

1) Determine if there is an adequate sediment supply in the Platte River system to sustain a braided river form. This analysis should include both a determination of the sediment yield in the basin and a characterization of the sediment transport potential of the Platte.

2) Synthesize a complete flow record for the Central Platte at Overton that includes the historic pre-development period. This analysis is necessary in order to determine the role of historic flows in the formation and maintenance of braided reaches of the river.

3) Characterize the key physical parameters responsible for the maintenance of specific braided river reaches on the Platte. The braided river reaches would be compared to river reaches that are not being maintained in a braided form, and compared with braided reaches in other sand bed streams. Ultimately, such an analysis would determine the peak channel formative discharge, the incipient motion criteria necessary to mobilize sediment on alluvial bars, the relationship between peak flows and woody vegetation establishment, and the relationship between peak flow timing, duration, and the prospects for long-term channel maintenance.

Once an initial minimum streamflow hydrograph (incorporating channel maintenance flows) is determined, refinements could be made using a predictive mathematical model. The model would have to be sensitive to the characteristics of braided or multiple channel streams, have both water and sediment routing capabilities, and a sediment distribution component that would change the river cross section in response to changes in sediment and water discharge. With appropriate assumptions, such a model could be calibrated to replicate recent historic water and sediment conditions. Then the model could be used to predict changes in channel geometry under hypothetical conditions. In this way, long-term trends in the river system's physical characteristics such as change in sediment size or slope and the impacts of additional water development projects could be analyzed.

CONCLUSIONS

The Platte River system is fairly young in comparison to the age of most large rivers. It's historic braided nature identifies it as such. Reductions in peak discharge and sediment supply have caused changes in river pattern, channel shape, bed material size, and slope. The active channel has narrowed and woody vegetation has formed over much of the former floodplain. The river bed has also degraded, with a corresponding coarsening of the bed material. As the river degrades, it is trending towards a series of stable, more sinuous channels, threading through permanently vegetated islands and banks. The river's ability to maintain its braided river form is weakening.

The key to sustaining the remaining braided characteristics of the Platte is to maintain a sediment equilibrium. The sediment load reduction in the river is the principal reason why the Platte no longer fits the classic definition of a braided stream. The North Platte drained a larger area of more erosive, finer sediments than the South Platte, and contributed most of the historic sediment load of the Platte. This sediment source has been trapped in upstream reservoirs and the South Platte now contributes the majority of the sediment in the Platte. Sediments from the South Platte are coarser than those from the North Platte, enhancing the coarsening of the bed composition of the Central Platte. If future water development curtails the sediment load entering from the South Platte, the additional loss of active channel width may be severe. For this reason, a complete analysis of the historic and potential upstream sediment supply to the Central Platte is recommended.

REFERENCES

Bentall, R., 1982. "Nebraska's Platte River, A Graphic Analysis of Flows", Nebraka Water Survey Paper 53, Institute of Agriculture and Natural Resources, University of Nebraska, Lincoln.

Brady, D.I., 1982. "Regime Equations for Gravel-Bed Rivers", Gravel Bed Rivers., ed. C.D. Hey, J.C. Bathurst, & C.R. Thorne; Wiley, Chichester, England. pp. 517-552.

Buchanan, J.P., 1981. "Channel Morphology and Sedimentology Facies of the Niobrara, North Central Nebraska," Masters Thesis, Department of Geology, Colorado State University, Fort Collins, CO.

Bunde, M., G. Deyle, J. Gray, T. Imel, M. Stines, T. Sweeney, and L. Weiss., 1975. "The Effects of the Selective Removal of Cottonwood Trees Along the Platte River". Student Originated Study - National Science Foundation, Kearney State College. 200 pp.

Bureau of Reclamation, 1947. "Narrows Unit, Feasibility Study," Region 7 Lower Missouri River Basin, Denver, CO.

Bureau of Reclamation, 1951. "Glendo Unit, Hydrologic Data," Appendix II, North Platte River District.

Bureau of Reclamation, 1959. "Report on the South Platte River Basin," No. 97, Region 7, Lower Missouri Region, Denver, CO.

Bureau of Reclamation, 1985. "Final Supplement to the Final Environmental Statement, Narrows Unit, Colorado," Lower Missouri Region, Pick-Sloan Missouri Basin Program.

Currier, P.J., G.R. Lingle, and J.G. VanDerwalker. 1985. "Migratory Bird Habitat on the Platte and North Platte Rivers in Nebraska," Platte River Whooping Crane Trust, 177 pp.

Currier, P.J., 1982. "The Floodplain Vegetation of the Platte River: Phytosociology, Forest Development and Seedling Establishment," Ph.D. Disseration, Iowa State University, Ames, 332 pp.

Currier, P.J., 1986. "Drought Tolerance and Scouring of Riverbed Cottonwood (Populus deltoides Marsh.) Seedlings on the Loup River in Nebraska." (In Preparation).

Department of the Interior, 1983. "Upper Platte River Study," Bureau of Reclamation, Fish and Wildlife Service, Geological Survey.

Eschner, T.R., 1981. "Morphologic and Hydrologic Changes of the Platte River, South-Central Nebraska," Master Thesis, Department of Earth Resources, Colorado State University, Fort Collins, CO.

Eschner, T.R., R.F. Hadley and K.D. Crowley, 1983. "Hydrologic and Morphologic Changes in Channels of the Platte River Basin in Colorado, Wyoming, and Nebraska: A Historical Perspective," U.S. Geological Survey Professional Paper 1277.

Ferguson, R.T., 1984. "The Threshold Between Meandering and Braiding," <u>Channels and Channel Control Structures</u>. Proceedings of the 1st International Conference of Hydraulic Design in Water Resources. Engineering, Ed. K.V.H. Smith, University of Southhampton.

Fischer, N.T., M.S. Toll, A.C. Cully, and L.D. Potter., 1983. "Vegetation Along Green and Yampa Rivers and Response to Fluctuating Water Levels, Dinosaur National Monument". Final Report, National Park Service. Biology Dept., Univ. of New Mexico, Albuquerque. 179 pp.

Fish and Wildlife, 1981. "The Platte River Ecology Study," Northern Prairie Wildlife Research Center, Jamestown, North Dakota.

Hurr, R.T., 1983. "Ground-water Hydrology of the Mormon Island Crane Meadows Wildlife Area near Grand Island, Hall County, Nebraska," U.S. Geological Survey Professional Paper, 1277.

James, E., 1823. Account of an expedition from Pittsburgh to the Rocky Mountains. (A chronicle of the Long Expedition). Univ. Microfilms, Inc., Ann Arbor, MI 945 pp.

Johnsgard, P.A., 1984. "The Platte: Channels in Time," University of Nebraska Press, Lincoln, Nebraska.

Kapustka, L.A., 1972. Germination and establishment of <u>Populus deltoides</u> in eastern Nebraska. Unpubl. M.S. Thesis, Univ. Nebraska, Lincoln. 72 pp.

Karlinger, M.R., T.R. Eschner, R.F. Hadley, and J.E. Kircher, 1983. "Relation of Channel-Width Maintenance to Sediment Transport and River Morphology: Platte River, South-Central Nebraska," U.S. Geological Survey Professional Paper, 1277.

Kellogg, R.S., 1905. "Forest Belts of Western Kansas and Nebraska. USDA Forest Service Bulletin No. 66. 44 pp.

Kircher, J.E., 1983. "Interpretation of Sediment Data for the South Platte River in Colorado and Nebraska, and the North Platte and Platte Rivers in Nebraska," U.S. Geological Survey Professional Paper 1277.

Kircher, J.E. and M.R. Karlinger, 1983. "Effects of Water Development on Surface Water Hydrology, Platte River Basin in Colorado, Wyoming, and Nebraska Upstream from Duncan, Nebraska," U.S. Geological Survey Professional Paper, 1277.

Lane, E.W., 1957. "A Study of the Shape of Channels Formed by Natural Streams Flowing in Erodible Material," U.S. Army Corps of Engineers, Missouri River Division, Omaha, Nebraska, MRD. Sediment Series 9: 106 pp.

Langbein, W.B. and L.B. Leopold., 1964. "Quasi-Equilibrium States in Channel Morphology," America Journal of Science, V. 262, p. 782-94.

Leopold, L.B. and M.G. Wolman, 1957. "River Channel Patterns - Braided, Meandering and Straight," U.S. Geological Survey Professional Paper, 282-B: 39-85.

Lewis, D.D. and G.W. Caughran, 1958. "Platte River in Nebraska," U.S. Geological Survey Lincoln, Nebraska.

Matthai, H.F., 1969. "Floods of June, 1965 in South Platte River Basin, Colorado," USGS Water Supply Paper 1850 B.

McKinley, J.L., 1938. "The influence of the Platte River Upon the History of the Valley." Ph.D. Dissertation, University of Nebraska, Lincoln, Nebraska. 138 pp.

McLeod, K.W., and J.K. McPherson., 1973. "Factors limiting the distribution of _Salix nigra_." Bulletin Torrey Botanical Club. 100:102-110.

Miller, G., 1978. "History of Platte River flows." U.S. Fish and Wildl. Service, Grand Island, NE. Unpublished Manuscript, 18 pp.

Moss, E.H., 1938. "Longevity of seed and establishment of seedlings in species of _Populus_." Botanical Gazette 99:529-542.

Nadler, C.T., Jr., 1978. "River Metamorphosis of the south Platte and Arkansas Rivers, Colorado," Masters Thesis, Department of Earth Resources, Colorado State University, Fort Collins, CO.

Neff, E.L., 1967. "Discharge Frequency Compared to Long-Term Sediment Yields," Symposium on River Morphology, International Union of Geodesy and Geophysics, pp. 236-242.

Northrup, W.L., 1965. "Republican River Channel Deterioration," U.S. Department of Agriculture. Misc. Publication 970, Paper No. 847, Proceedings of the Federal Interagency Sedimentation Conference, pp. 409-424.

Osterkamp, W.R., 1978. "Gradient, Discharge, and Particle-size Relations of Alluvial Channels in Kansas, with Observations on Braiding," American Journal of Science, Vol. 278, pp. 1253-1268.

Peake, J., M. Peterson, and M. Laustrup, 1985. "Interpretation of Vegetation Encroachment and Flow Relationships in The Platte River by Use of Remote Sensing Techniques". Remote Sensing Applications Laboratory, Dept of Geography-Geology Univ. Nebr. Omaha. 182 pp.

Petts, G.E., 1984. Impounded Rivers, John Wiley & Sons, New York.

Potter, L.D., 1983. "Vegetation Along Green and Yampa Rivers and Response to Fluctuating Water Levels, Dinosaur National Monument," Biology Department, University of New Mexico, Albuquerque, N.M.

Pound, R., and F.E. Clements, 1898. "The Phytogeography of Nebraska." Botanical Survey of Nebraska, Lincoln. 422 pp.

Rosgen, D. 1982. "A Procedure and Rationale for Securing Favorable Conditions of Water Flows on National Forest System Lands in Northern Wyoming." U.S. Fish and Wildlife Service, Region 2., pp 88.

Schumm, S.A., 1969. "River Metamorphosis," ASCE, Journal of Hydraulics Division, Vol. 95, pp. 255-273.

Schumm, S.A., 1977. The Fluvial System, John Wiley & Sons, New York.

Schumm, S.A. and Lichty, R.W., 1963. "Channel Widening and Flood-Plain Construction Along the Cinnarron River in Southwestern Kansas," U.S. Geological Survey Professional Paper 352-D.

Simmons, D.B., 1976. "Management of River Systems". In: Instream Flow Needs Proceedings, Vol. 1, J.F. Osborns and C.H. Allman, eds. American Fisheries Society, Bethesda, Maryland. 551 pp.

Smith, N.D., 1971. "Transverse Bars and Braiding in the Lower Platte River, Nebraska." Geological Society of America. Bulletin, Vol. 82, pp. 3407-3420.

Weaver, J.E., 1944. "North American Prairie". American Scholar. 329-339.