PHYSICAL HISTORY OF THE PLATTE RIVER IN NEBRASKA:

FOCUSING UPON FLOW, SEDIMENT TRANSPORT, GEOMORPHOLOGY, AND VEGETATION

SIMONS & ASSOCIATES, INC.

AUGUST 2000

An Independent Report
Prepared for the Platte River EIS Office
U.S. Department of the Interior

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FINAL REPORT

DELIVERY ORDER NO. 114 –

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Focusing Upon Flow, Sediment Transport, Geomorphology, and Vegetation

Prepared for
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Bureau of Reclamation
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Simons & Associates
8/11/2000

1. Introduction

The Platte River system originates on the eastern slope of the Rocky Mountains and flows in a generally eastward direction from the mountains across the plains until it joins with the Missouri River. The Platte River system, including its principal tributaries (the North Platte and the South Platte), has been affected by numerous water resources projects throughout the basin that include water storage reservoirs, diversions, and groundwater pumping. As a result of these water resources projects and other factors, the river has experienced significant changes over approximately the last century. Streamflows are significantly reduced. Channel morphology has been altered. Riparian vegetation has expanded onto formerly active channel areas. These changes have affected habitat for a variety of species of fish and wildlife, including some threatened or endangered species, that are found in or migrate through the Platte River Basin.

One of the principal issues of over-riding concern on the Platte River is the habitat provided by the river to threatened and endangered species as well as other fish and wildlife. The Central Platte River, in what is referred to as the Big Bend Reach (approximately from Lexington to Chapman, Nebraska) has been designated as critical habitat for the whooping crane by the U.S. Fish and Wildlife Service (USFWS). In July 1997, the States of Wyoming, Nebraska, and Colorado signed an agreement with the Department of the Interior to develop a recovery program for four threatened and endangered species which use the Central Platte River.[1] The four target species of primary concern are the whooping crane, least tern, piping plover, and pallid sturgeon. Focusing exclusively on the riverine environment, habitat consists of the river channel including the river bed below water, sand-bars, islands, and riparian vegetation on the floodplain and on islands. The geomorphology of a river system plays a significant role in many key physical and biological relationships that affect vegetation, hydraulics, fisheries habitat, wildlife habitat, and sediment transport. Historic geomorphology regarding the formation of a river system leading to its current configuration and form, as well as trends and potential geomorphic changes, are critical considerations in evaluating the effects of current operations and other possible operating scenarios along with the feasibility of mitigation and enhancement activities. If it is true (or assumed) that there is a relationship between the quantity of habitat and species population supported by the habitat and that any loss of habitat translates into a decrease in species population; then the maintenance (and possible enhancement of habitat) is of great importance.

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[1] Cooperative Agreement for Platte River Research and Other Efforts Relating to Endangered Species Habitats Along the Central Platte River, Nebraska. 1997.

While there has been considerable analysis and discussion about the Platte River, significant disparity of opinion on a technical basis exists regarding the historic changes, factors that caused the changes, the significance of the changes, and potential mitigation strategies to deal with the affected environment. Because of the numerous issues and wide array of parties involved in one way or another in these issues (and nature of involvement), there appear to be significant sources of information that have not been widely available which may be useful in developing an understanding of the Platte River and related issues.

The description of the Platte River is to be developed from a technical perspective. This technically-based description of the river would serve as a basis for a more general description of the affected environment for the Environmental Impact Statement (EIS) being prepared under the three-state agreement. The purpose of the technically-based description of the river is to: compile available technical information pertinent to the affected environment, present in condensed form the technical issues, present an evaluation of the techical issues, and discuss potential approaches to resolve these issues on a technical basis through the EIS process. This work will be guided by the concepts of using the "best available" information and application of the scientific method. The objective will be to produce an unbiased discussion by utilizing such information and by reaching scientifically justifiable conclusions or recommendations.

2.0 Description of the Platte River Basin

The Platte River and its tributaries are formed as runoff from the Rocky Mountains east of the continental divide flow out of the mountains and over the plains towards the Missouri River (see Figure 2.1). The highest elevation in the Platte River Basin exceeds 14,000 feet above mean sea level and, as it joins with the Missouri River, the lowest elevation is just below 1,000 feet.

The climate and hydrology of the Platte River Basin is as diverse as its topography. Precipitation is greatest in the mountains. In the area to the east of the mountains the precipitation is significantly less due to the rain-shadow effect of the mountains since storms generally move from west to east. As one travels farther east towards the Missouri River, precipitation gradually increases but remains less than that experienced in the mountains.

In the mountains, with the generally colder climate at higher elevations, much of the annual precipitation falls as snow. Snowpack builds up over the fall and winter seasons with its release as runoff as the snow melts in spring and early summer. As a result of the interaction of climatic thermal regimes and precipitation patterns, the hydrologic cycle results in a relatively predictable seasonal pattern as indicated in Figure 2.2. Figure 2.2 presents an example of the flow hydrograph typical of the pattern exhibited by streams in the Platte River Basin. Starting in what is referred to as a "water-year," the flow is relatively steady from October through the winter months. As spring approaches there is a general rise in flow culminating in a snowmelt-generated peak flow that typically

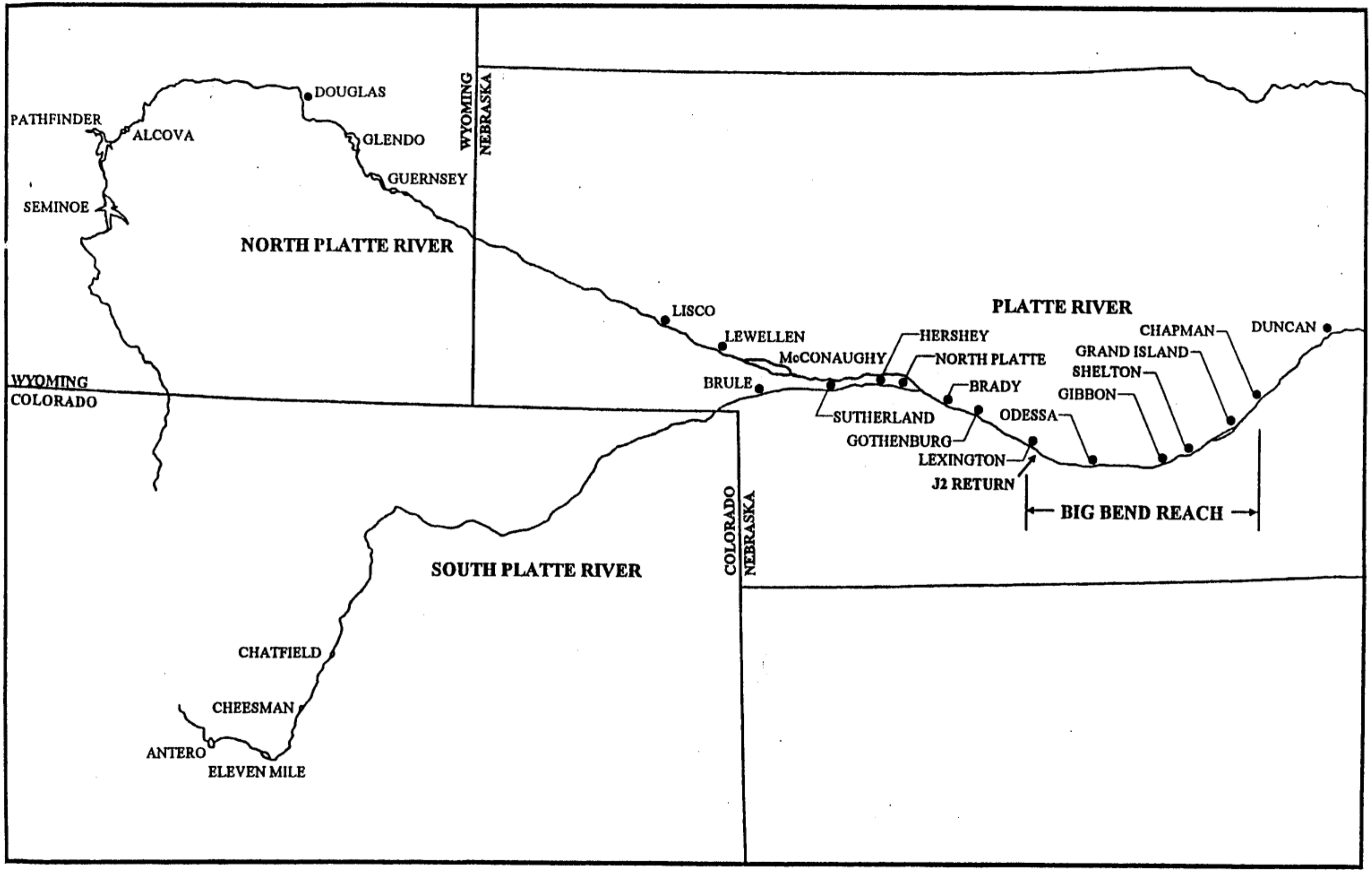

DOUGLAS
PATHFINDER
ALCOVA
GLENDO
GUERNSEY
SEMINOE
WYOMING
NEBRASKA
NORTH PLATTE RIVER
LISCO
LEWELLEN
PLATTE RIVER
CHAPMAN
DUNCAN
GRAND ISLAND
HERSHEY
McCONAUGHY
NORTH PLATTE
SHELTON
BRADY
GIBBON
BRULE
ODESSA
SUTHERLAND
GOTHENBURG
LEXINGTON
J2 RETURN
BIG BEND REACH
WYOMING
COLORADO
COLORADO
NEBRASKA
SOUTH PLATTE RIVER
CHATFIELD
CHEESMAN
ANTERO
ELEVEN MILE

Figure 2.1

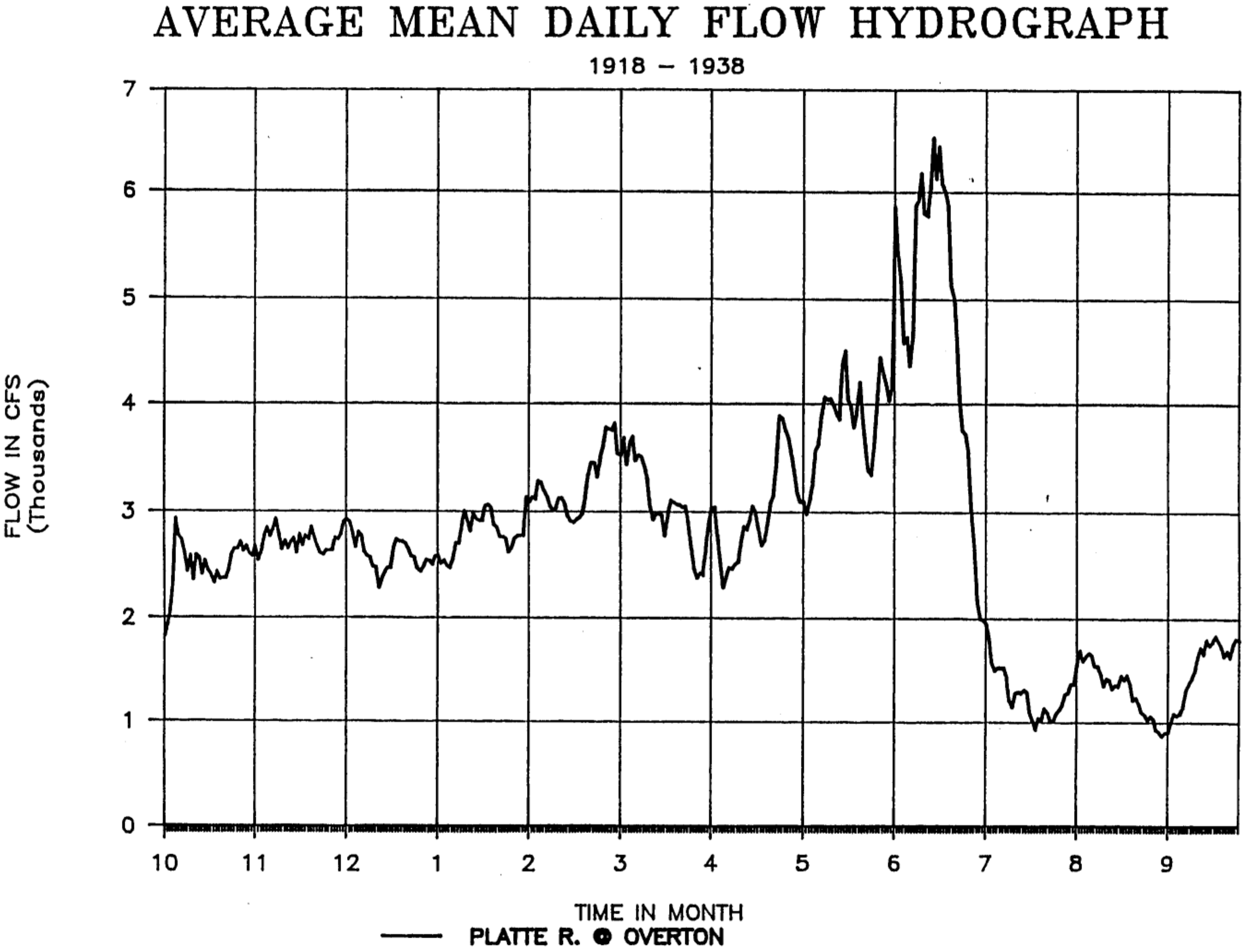

AVERAGE MEAN DAILY FLOW HYDROGRAPH
1918 – 1938
FLOW IN CFS
(Thousands)
0
1
2
3
4
5
6
7
10
11
12
1
2
3
4
5
6
7
8
9
TIME IN MONTH
PLATTE R. @ OVERTON

Figure 2.2

occurs in May or June. After the snowmelt peak, flow rapidly recedes to the lowest levels of the year during the summer. During summer months, the watershed can experience intense thunderstorm activity that can result in significant runoff although such events typically affect only a localized area.

In contrast to the potential for large runoff events associated with snowmelt runoff or significant precipitation events, the Platte River also experiences extreme low flow periods and even periods of no flow. Multi-year droughts, such as the dust bowl era of the 1930's and the 1950's drought, provide an example of a series of dry years that resulted in very low annual and seasonal flows for extended periods of time.

An analysis of water production (Simons & Associates, 1990e) showed that most of the water produced by the watershed comes from the mountains (based on gages located at elevations above 6000 feet). The data show that in the mountain region, annual water production from available gages ranged from 42 to 1704 acre-feet per square mile and averaged 484 acre-feet per square mile. In contrast, annual water production from plains region gages ranged from 6 to 116 acre-feet per square mile and averages 42 acre-feet per square mile. Thus, water production per unit area averages about 10 times more in the mountains than the plains. This distribution of water production coupled with climatic factors provided impetus for the development of the Platte River Basin.

Rivers in the Platte River Basin cover a wide range of geomorphic characteristics as they convey water from the mountains over the alluvial plains. In the mountains, the first order tributaries flow over coarse beds consisting of gravel, cobbles, boulders, and bedrock outcrops. Flow is swift and turbulent but often carries little sediment due to the coarse and relatively stable nature of their river beds. Only on relatively rare occasions is the flow sufficiently strong to disrupt the channel beds and rework the coarse material forming these streams. As the streams flow out of the mountains and onto the plains, the streams do not have sufficient energy due to the decreased slope to transport the coarsest fractions of sediment being eroded and transported in the mountains. This sometimes results in coarse alluvial fans forming at the mouth of canyons or at least transition areas of coarse deposition with more dynamic behavior typical of alluvial streams. An alluvial river is one whose bed is formed of the material that the river itself transports. The river beds of the tributaries transition to considerably finer material consisting of sand and gravel. The bed of the two main tributaries (North Platte and South Platte) in the vicinity of their confluence that forms the Platte River consist primarily of sand. Sand-bed rivers, such as the Platte River in Central Nebraska, are truly alluvial channels that exhibit dynamic behavior responding to relatively frequent events.

Since the EIS focuses primarily on the Platte River in Central Nebraska, most of the discussion will focus on the characteristics of the river in this region. When referring to the Platte River in the remainder of this report, the reference focuses on the Platte River in Central Nebraska unless discussion specifically shifts to another portion of the overall Platte River system.

In order to place the Platte River into perspective, several basic geomorphic techniques are applied. The "idealized fluvial system" (Schumm, 1977) subdivides a river system into three basic components: the sediment supply zone, the transfer zone, and the sediment deposition zone. These three components of the idealized fluvial system are shown in Figure 2.3. While the upper portion of the Platte Basin (i.e., the portion of tributaries that are principally found in the mountains and foothills where steep channels flow with significant turbulence and swiftness) lies in the sediment supply zone, the Central Platte River lies in the transfer zone. Most of the sediment supplied to this zone from the sediment supply zone is transported through the transfer zone to the deposition zone farther downstream, hence the designation as the transfer zone. Thus, the Central Platte River is an alluvial river in the intermediate zone, designated as the transfer zone, flowing over an alluvial plain. Figure 2.4 shows a profile of the Platte River as it extends to the continental divide. The slope of the river in the mountain region is clearly steeper than the river in the plains region. Figure 2.5 focuses on the portion of the river in Nebraska.

Rivers come in many different types including such categories as straight, braided, and meandering. Lane (1957) presented a graphical method of evaluating stream type based on flow and slope. The Platte River, in Lane's diagram, plots as a braided river (Figure 2.6). It should be noted, however, that the point on the diagram representing the Platte (in pre-development conditions) plots close to the line separating braided and transitional or intermediate streams. This implies that even relatively small changes in characteristics governing the geomorphology of the Platte could cause a shift or change in channel type. Descriptions, maps, and historic photographs confirm that the Platte River was a wide, shallow, braided river. Since it is an alluvial river with sandy bed and bank material, and it is subject to relatively large flow events, the river was quite dynamic. In other words, the Platte River was subject to shifting of the river bed and other features such as bars or islands, as the continuously changing flow regime and upstream sediment supply flowed through this reach of the river.

One of the key issues regarding riverine habitat along the Platte River deals with riparian vegetation and changes that have occurred over time with woody vegetation along and within the river. Woody, riparian vegetation (typically cottonwoods, willows, and some other species) that grows to heights greater than about 3 feet obstructs the view of the bird species of concern. The lack of a sufficient distance of clear view, or what may be called unobstructed view, reduces habitat quality since the birds cannot see potential predators. The species of interest prefer areas of habitat with sufficient unobstructed view so that they have sufficient time and space to deal with predators. Since the Platte River channel consists primarily of sand, the river provides suitable substrate for establishment and growth of riparian vegetation. Williams (1978), as well as numerous other researchers, has documented the fact that woody, riparian vegetation has expanded onto formerly active channel areas of the North Platte, South Platte, and Platte Rivers over the past century. The causes for the expansion of woody, riparian vegetation and potential approaches to control vegetation are of significant concern for the maintenance or enhancement of habitat.

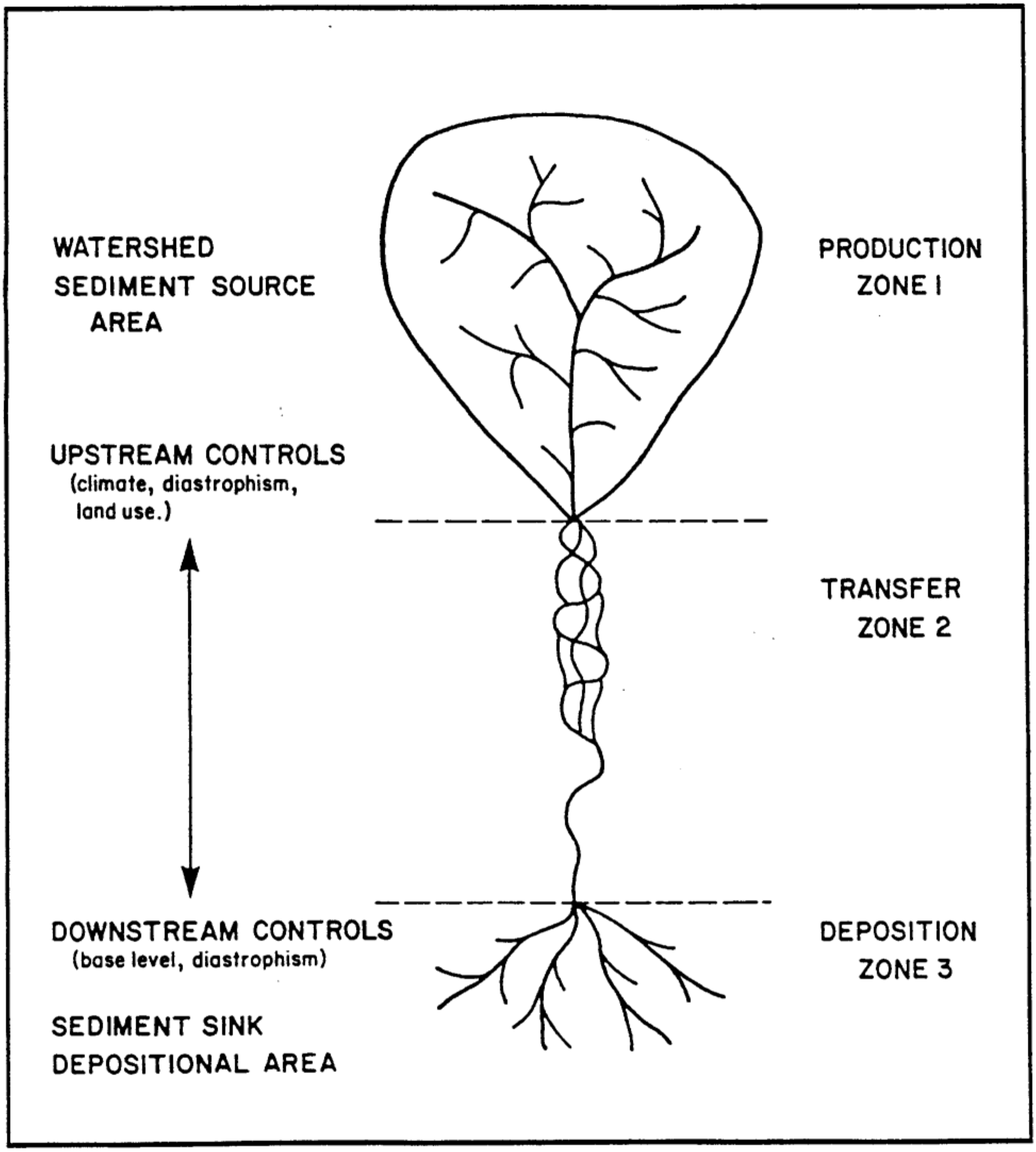


Figure 6-1. Idealized Fluvial System (after Schumm 1977)

Figure 2.3

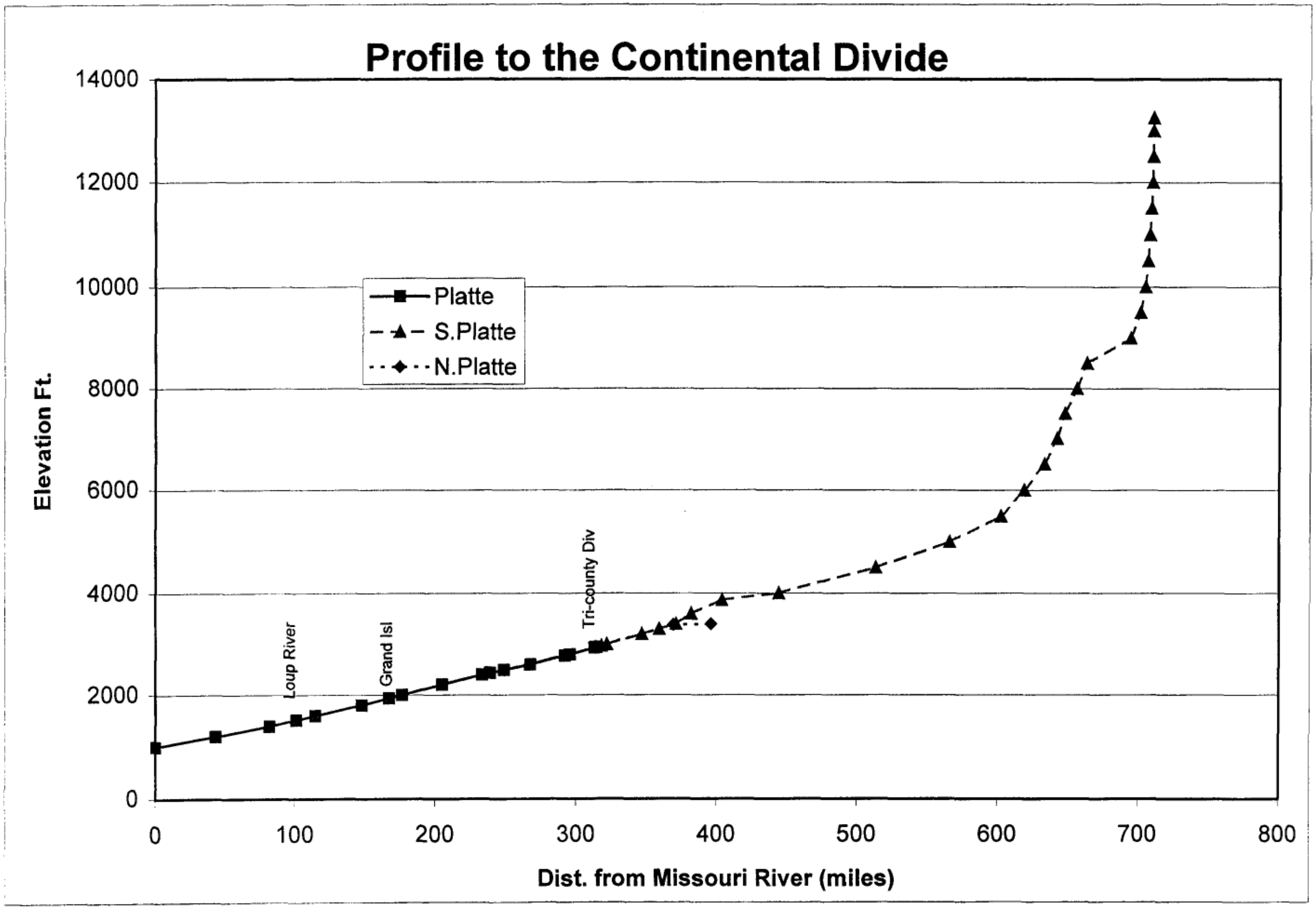

Profile to the Continental Divide
Elevation Ft.
14000
12000
10000
8000
6000
4000
2000
0
0
100
200
300
400
500
600
700
800
Dist. from Missouri River (miles)
Platte
S.Platte
N.Platte
Loup River
Grand Isl
Tri-county Div

Figure 2.4

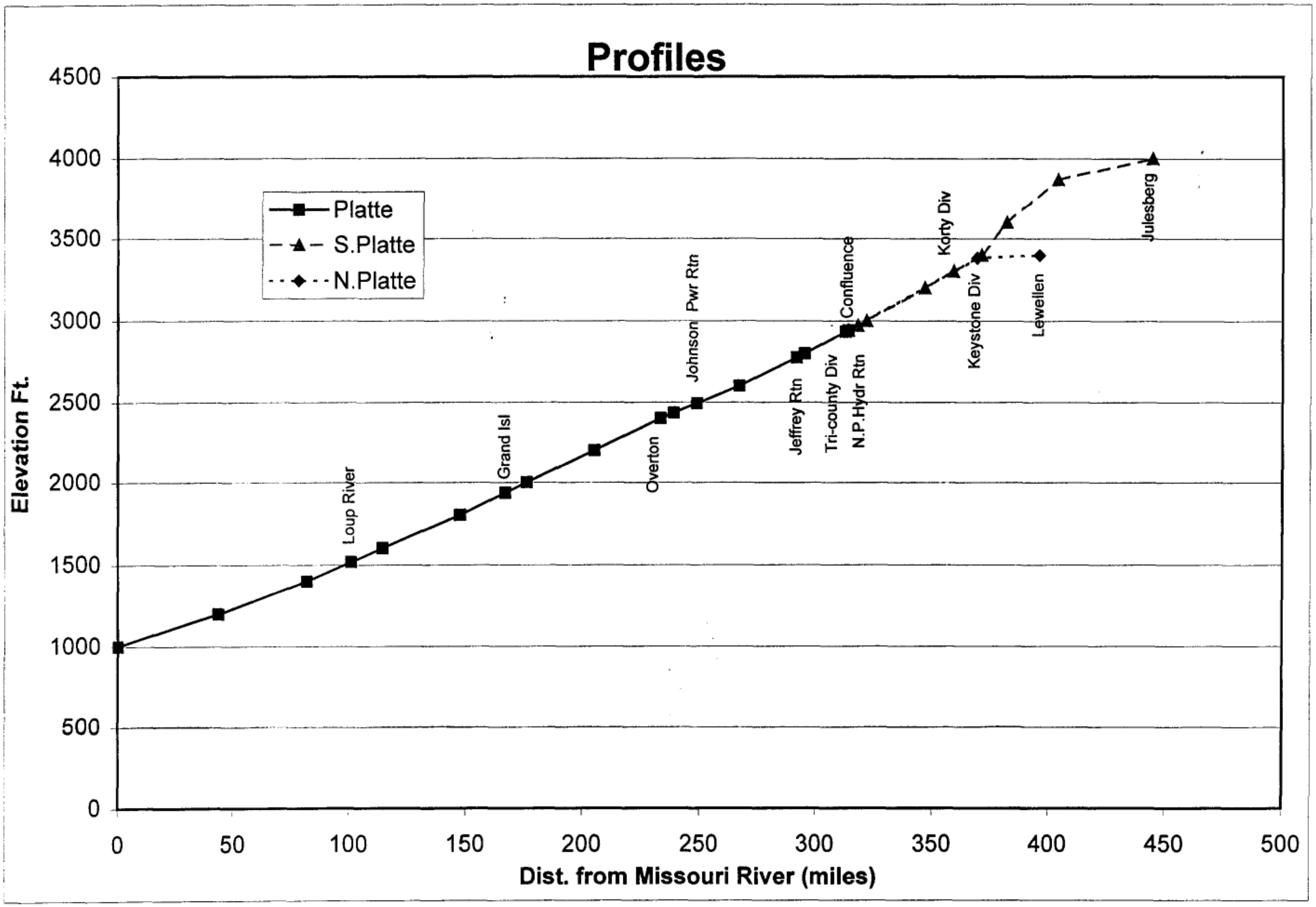
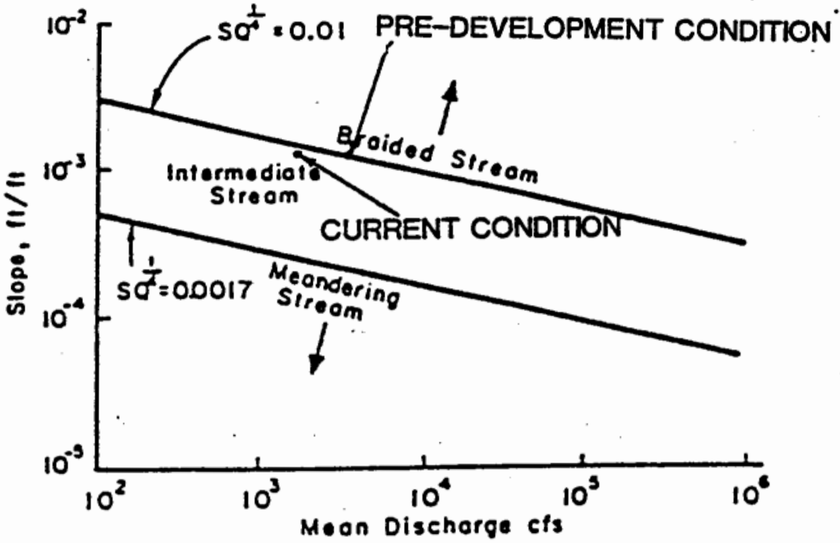

Profiles
Platte
S.Platte
N.Platte
Elevation Ft.
Dist. from Missouri River (miles)
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0
50
100
150
200
250
300
350
400
450
500
Loup River
Grand Isl
Overton
Johnson Pwr Rtn
Jeffrey Rtn
Tri-county Div
N.P.Hydr Rtn
Confluence
Korty Div
Keystone Div
Lewellen
Julesberg

Figure 2.5



Slope-discharge relation for braiding or meandering in sand-bed streams (Lane, 1957).

Figure 2.6

2.1 Water Resources Development History

Precipitation is generally too low for many types of crops in the plains region of the Platte River Basin where temperature and soil conditions are otherwise acceptable for agriculture. Water production from the mountains produces significant runoff that provided the basis for irrigation as a means to develop an agriculturally-based modern economy by using runoff from rivers. As various groups or individuals began to settle the area, water from the tributaries and eventually from the Platte River itself was put to beneficial use beginning in the mid-1800s. Initially, water was diverted from these streams onto the adjacent floodplain during times of moderate to high runoff. Since the need for water extends throughout the summer when agricultural water demand is greatest and natural runoff recedes to very low levels, water storage and management projects were subsequently developed.

Due to the relatively small amount of available water, the semi-arid region west of the Missouri River was once believed to be a desert that could not support human civilization. Eschner et al. (1983) attributes the naming of this portion of the country as "The Great American Desert" to Long in 1820. To grow many types of crops in this area, irrigation was needed to supplement the low precipitation in the plains region of the Platte River basin. Runoff from snowmelt in rivers from the mountains flowing through the plains provides a source for water for irrigation. Diversion of water out of the rivers for irrigation purposes became the initial step in significant water resources development.

2.1.1 Canal Building

Canals were built starting in the 1800's to convey water diverted from rivers and streams to arable land as described below, and subdivided into various segments or sub-basins of the Platte River system.

South Platte River Basin

The earliest irrigation development in the Platte River basin took place in 1838 on the Cache la Poudre River, a tributary of the South Platte River (Eschner et al., 1983). These irrigators dug ditches directly from the river to irrigate lands within the floodplain. With the discovery of gold and early settlement in the region in the 1860's, small irrigation projects were started and larger canals were constructed. Between 1861 and 1870, 376 irrigation canals were constructed in the South Platte River basin (see Table 2.1 taken from Eschner et al., 1983). This was followed by 533 canals between 1871 and 1880, and 364 additional canals between 1881 and 1890.

Table 2.1
History of canal construction in the Platte River Basin, 1851-1930 [1]

River	Number of new canals constructed or existing canals enlarged[2]								Date of earliest canal[3]
	1851-1860	1861-1870	1871-1880	1881-1890	1891-1900	1901-1910	1911-1920	1921-1930	
	South Platte River Basin								
Cache la Poudre River and tributaries.	1	37	85	37	1	46	14	7	1860
Lodgepole Creek and tributaries……..	0	0	31	75	28	26	10	13	1873
Big Thompson River and tributaries…	0	32	29	6	0	8	3	2	1861
Bear Creek and tributaries…………..	2	22	4	3	0	3	7	14	1859
South Platte River and tributaries below mouth of the Cache la Poudre River, except Lodgepole Creek………	0	21	61	104	28	126	55	32	1868
South Platte River and minor tributaries above mouth of the Cache la Poudre……………………………..	25	264	323	139	6	104	52	28	1860
Total, South Platte Basin………..	28	376	533	364	63	313	141	96	
	North Platte River Basin								
Big Laramie River and tributaries……	0	8	98	467	148	263	119	29	1868
Sweetwater River and tributaries…….	0	0	2	43	55	117	46	17	1880
North Platte River, Nebraska ………..	0	0	0	16	36	5	7	1	1888
Tributaries to North Platte River, Nebraska……………………………..	0	0	0	19	51	30	24	13	
North Platte River, Wyoming………..	0	0	2	32	15	47	25	17	1875
Tributaries to North Platte River, Wyoming, except Sweetwater and Big Laramie River ……………………..	0	9	91	740	410	801	436	161	
North Platte River and minor tributaries, Colorado ………………...	0	0	1	310	10	128	75	11	1880
Total, North Platte Basin ………..	0	17	194	1627	725	1391	732	249	
	Platte River Basin (except North and South Platte)								
Platte River tributaries above the Loup River …………………………..	0	0	0	1	3	0	6	53	
Platte River above the Loup River …..	0	0	0	2	7	0	3	16	1882
Total, Platte Basin above the Loup River …………………………..	0	0	0	3	10	0	9	69	

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[1] Data compiled from Biennial Reports of the State Engineer of Colorado, 1883-1926; unpublished data from the files of the State Engineer of Colorado in Denver. Biennial Reports of the Department of Water Resources, Nebraska, 1913-1932; 2nd Annual Report of the Territorial Engineer, Wyoming, 1889; Biennial Reports of the State Engineer of Wyoming, 1893-1930; Tabulation of Adjudicated Water Rights, State of Wyoming, Water Division Number One, 1965.

[2] Numbers are based on appropriations to new canals or additional appropriations to existing canals exceeding 0.3 cubic meters per second.

[3] Based on recorded date of appropriation decree.

By the 1870's, the appropriations granted to these Colorado irrigators exceeded the amount of water available in the river during most summer irrigation seasons (Eschner et al., 1983). This over-appropriation first occurred in the Cache la Poudre basin in 1876. Between 1880 and 1885, the remainder of the South Platte River basin was also over-appropriated. In order to increase irrigation water supplies, many dams were constructed beginning in the early 1880's. 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.

North Platte River Basin

In the North Platte River basin, significant irrigation development began in the 1880's with the construction of the first large canals - the Pioneer Canal on the Laramie River in Wyoming and North Platte Canal in Nebraska (Eschner et al., 1983). By 1884, 22 canal companies were in operation along the North Platte River. By 1889, Wyoming ranked third among all western states in irrigated acreage and canal mileage. By 1894, most of the suitable land in the North Platte River basin was being irrigated. Over-appropriation first occurred in the smaller tributaries in the 1880's, which was followed by over-appropriation of the North Platte River in Nebraska. Tabulation of canal construction in the North Platte Basin is also documented in Table 2.1.

The first irrigation reservoirs in the North Platte River basin were constructed in 1890. By 1906, 27 small reservoirs were in operation in the basin (Eschner et al., 1983). In 1909, the Bureau of Reclamation (USBR) constructed Pathfinder Reservoir, the first major storage dam on the North Platte River, with a storage capacity of 1,045,000 acre-feet. This was followed by a succession of large USBR reservoirs (Guernsey in 1927, Alcova in 1938, Seminoe in 1939, Glendo in 1957). Accompanying the new reservoirs were new canals and additional diversions from existing canals. Between 1901 and 1910, 1391 irrigation canals were constructed. This was followed by 732 new canals between 1911 and 1920, and an additional 249 canals between 1921 and 1930.

Central Nebraska

Irrigation in central Nebraska started in earnest with the construction of the Kearney Canal in 1882. In the late 1920's and early 1930's, central Nebraska farmers suffered great hardships due to a lack of precipitation and a lack of a dependable water supply and upstream over-appropriation in Colorado and Wyoming.

In 1928, the Platte River below North Platte was completely dry for a large portion of the irrigation season. The State of Nebraska ultimately was forced to shut down diversions to irrigators as far upstream as Bridgeport, Nebraska, in an attempt to deliver water to the Kearney Canal, which had a senior water right (G. Hamaker, 1959). According to this report, by mid-July of 1931, the Platte River between North Platte and Columbus was dry for a month. Additional information regarding previous observations of no flow in the Platte River is presented in Section 2.2.3 The lack of a dependable water supply led, in part, to the development of the Central Nebraska Public Power and Irrigation District (CNPP&ID) Project and Nebraska Public Power District (NPPD) Project to store water for irrigation use and reduce the dependency on natural flow during the irrigation season. These projects are also known as Projects Nos. 1417 and 1835 in the Federal Energy Regulatory Commission's (FERC) system.

The construction of Projects 1417 and 1835 was completed in 1941. With a storage capacity of approximately 1,743,000 acre-feet, Lake McConaughy offered dependable storage water supplies to offstream irrigators served by the Central District's Supply Canal, the E-65 and E-67 laterals, and the Phelps County Canal. The Project also provided storage water supplies to non-Project North Platte and Platte River canal companies to supplement their natural flow appropriations and avoid the prospects of future water shortages due to over-appropriation.

Summary of Canal Development

The Platte River system is one of the most highly developed river basins in the world. Within the North Platte and South Platte River basins in Colorado and Wyoming, there currently are thousands of diversions. In Colorado, there are over 4,000 decreed diversion rights held in the South Platte River basin alone. A study in 1970 also reported that 542 South Platte River basin ditches diverted a total of 3,982,658 acre-feet of water, more than four times the total volume of South Platte water that flowed into Nebraska in 1970. As previously noted, a summary of canal construction and enlargement information on the North Platte and South Platte Rivers is set forth in Table 2.1.

2.1.2 Dam and Reservoir Construction

Since snowmelt runoff generally peaks in late spring or early summer and subsequently recedes through the summer season, flow in rivers quickly became insufficient to provide a dependable water supply to irrigate crops through the entire growing season. As a result, in addition to the extensive development of canals and irrigation projects, there are also literally hundreds of upstream storage reservoirs in the North Platte and South Platte River basins. A study by Toups in 1975 found that there are 370 storage reservoirs in the South Platte River basin, each with capacities in excess of 500 acre-feet (Toups, 1975). Toups also reported 1,270 decreed storage rights in the basin and that the 150 largest reservoirs in the Colorado section of the basin have a combined storage capacity of 2,129,742 acre-feet.

In Wyoming, by far the most important storage facilities in the North Platte River basin are the USBR projects. USBR's North Platte Project consists of Pathfinder Dam and Reservoir, Guernsey Dam and Reservoir, Whalen Diversion Dam, Lake Alice, Lake Minatare, two other regulating reservoirs, and over 2,000 miles of canals and laterals. The largest storage facilities of the North Platte Project are Pathfinder Reservoir and Guernsey Reservoir, with current storage capacities of approximately 1,000,000 acre-feet and 45,000 acre-feet, respectively.

The principal facilities of the USBR's Kendrick Project are Seminoe Dam and Reservoir, Alcova Dam and Reservoir, and the Casper Canal and related laterals. The storage capacities of Seminoe Reservoir are approximately 1,017,000 acre-feet. Alcova Reservoir has a storage capacity of approximately 184,000 acre-feet, of which only 30,700 acre-feet are available for irrigation.

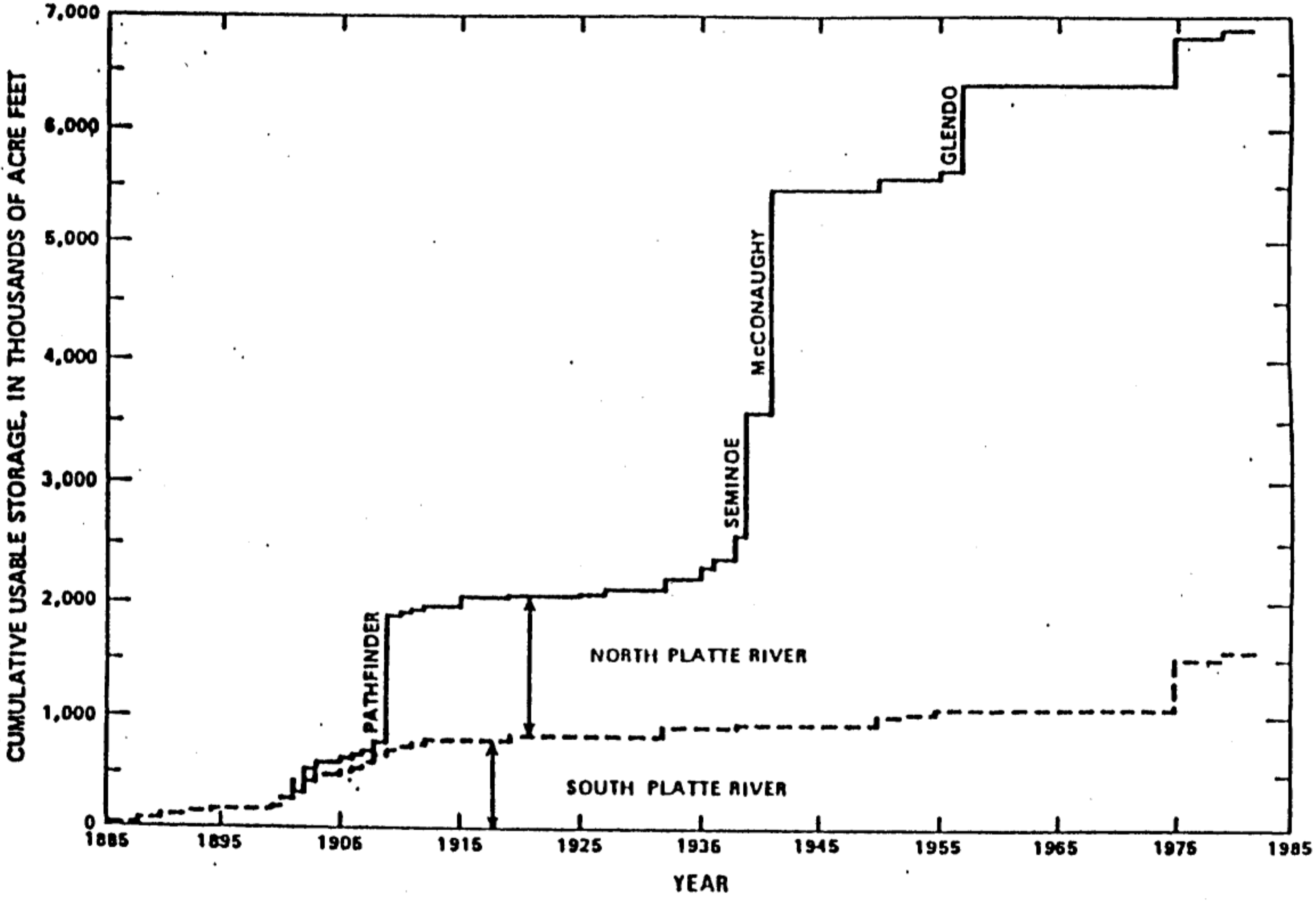
USBR's Glendo Unit consists of Glendo Dam and Reservoir, the Fremont Canyon Power Plant, and Gray Reef Dam and its regulating reservoir. Glendo Reservoir has a total storage capacity of 789,400 acre-feet.

Table 2.2 (USDOI, 1983) lists the storage reservoirs in the Platte River basin with storage capacities exceeding 5,000 acre-feet. The combined storage capacity of these reservoirs is approximately 7,600,000 acre-feet. Of this amount, 47 percent is in Wyoming, 30 percent is in Colorado, and 23 percent is in Nebraska. Figure 2.7, from the same report, shows a graph of the cumulative reservoir storage as it increased over time.

Table 2.2
Storage reservoirs in the study area by sub-area and capacity
(over 5,000 acre-feet)

Name of Development	Functions*	Description, including acre-feet
COLORADO		
Antero Park Reservoir	M	Owned and operated by Denver Water Board, reservoir capacity – 15,878 acre-feet
Eleven Mile Canyon Reservoir	I-M	Owned and operated by Denver Water Board, reservoir capacity – 97,779 acre-feet
Cheesman Lake	M	Owned and operated by Denver Water Board, reservoir capacity – 79,060 acre-feet
Spinney Reservoir	M-I-R	Owned and operated by the city of Aurora, capacity – 48,000 acre-feet
Chatfield Lake	FC-F-R	Corps of Engineers, reservoir capacity – 235,000 acre-feet
Marston Lake	M	An offstream reservoir used by the Denver Water Board for temporary storage of municipal water, capacity – 17,213 acre-feet
Mt. Carbon Dam and Bear Creek Lake	FC-F-R	Built by Corps of Engineers primarily for flood control, – capacity 46,410 acre-feet
Cherry Creek Dam and Reservoir	FC-R	Corps of Engineers, reservoir capacity – 95,000 acre-feet
Ralston Reservoir	M	Stores transmountain diversions which come from Gross Reservoir down Boulder Creek, thence to Ralston by a 9.6-mile long conduit. Water used for Denver's winter municipal supply, capacity – 11,270 acre-feet
Barr Lake	I	Offstream reservoir, capacity – 32,140 acre-feet
Gross Reservoir	M	Provides storage and regulation of Denver's transmountain diversions through Moffat Tunnel, reservoir capacity – 41,811 acre-feet
Standley Lake	I-M	Stores Water from Coal and Woman Creeks and Farmers Highline Canal. Supplies some municipal water to Westminster, Colorado, reservoir capacity – 10,260 acre-feet
Horse Creek Reservoir	I	A USBR offstream reservoir, capacity – 16,970 acre-feet
Prospect	I	Storage – 5,610 acre-feet
Marshall Lake	I	Offstream reservoir, capacity – 10,260 acre-feet
Barkers Meadow Reservoir	P	Reservoir capacity – 11,680 acre-feet, 20,000 kW – operated by Colorado Public Service Co.

Figure 2.7



Cumulative usable storage in reservoirs in the Platte River basin (modified from Bentall, 1975a).

Name of Development	Functions*	Description, including acre-feet
COLORADO (cont.)		
Base Line	I	Storage – 5,380 acre-feet
Pomona Reservoir	I	Storage – 7,000 acre-feet
Six Mile Reservoir	I	Offstream reservoir, 10,850 acre-feet
Colorado-Big Thompson Project	I-P-M-R-F	USBR transmountain diversion – Colorado River – 10 reservoirs, 6 power plants, 183,950 kW, 3 pumping plants, 34 miles tunnels, supplemental irrigation – 994,360 acre-feet
Joe Wright Reservoir	I-M-R	Storage water for city of Ft. Collins; 7,056 acre-feet usable storage.
Long Draw Reservoir	I	Reservoir capacity 11,000 acre-feet.
Boyd Lake	I	Originally constructed for power purpose. Converted to irrigation use in 1927. Offstream reservoir with 44,020 acre-feet capacity.
Home Supply	I	Soil Conservation Service's 38-mile channel rehabilitation, 1 storage reservoir, 5,000 acre-feet
Louden	FC-I	Soil Conservation Service's 1 multi-purpose structure, capacity – 5,000 acre-feet
Lake Loveland	I-M	Offstream reservoir, capacity – 14,240 acre-feet
Union Reservoir	I	Offstream reservoir, capacity – 12,740 acre-feet
Milton Reservoir	I	Offstream reservoir, capacity – 31,130 acre-feet
Lower Latham	I	Storage – 5,760 acre-feet
Chambers Lake	I	Storage – 8,824 acre-feet
Douglas	I	Storage – 6,000 acre-feet
North Poudre No. 15	I	Storage – 5,500 acre-feet
Terry Lake	I	Storage – 9,700 acre-feet
North Poudre No. 6 Reservoir	I	Offstream reservoir, capacity – 15,400 acre-feet
Timnath Lake	I	Storage – 10,000 acre-feet
Fossil Creek Reservoir	I	Reservoir capacity – 11,540 acre-feet
Reservoir No. 8	I	Offstream reservoir, capacity – 15,400 acre-feet

Table 2.2 Continued

Name of Development	Functions*	Description, including acre-feet
COLORADO (cont.)		
Cobb Lake	I	Storage – 9,120 acre-feet
North Platte No. 5	I	Storage – 5,750 acre-feet
Park Creek Reservoir	I	Offstream storage – 7,320 acre-feet
Halligan No. 16	I	Storage – 6,500 acre-feet
Black Hollow	I	Storage – 8,000 acre-feet
Windsor Reservoir	I	Offstream reservoir, capacity – 15,620 acre-feet
Empire Reservoir	I	Offstream reservoir, capacity – 37,700 acre-feet.
Jackson Lake Reservoir	I	Offstream reservoir, capacity – 35,630 acre-feet
Bijou No. 2	I	Storage – 6,000 acre-feet
Prewitt Reservoir	I	Offstream reservoir, capacity – 32,900 acre-feet
Point of Rocks Reservoir (North Sterling Reservoir)	I	Offstream reservoir, capacity – 81,350 acre-feet
Julesberg (Jumbo)	I	Offstream reservoir, capacity – 27,200 acre-feet
MacFarlane	I	6,500 acre-feet
NEBRASKA		
North Platte Project	I-P-F-R	USBR – Pathfinder, Guernsey, Lake Alice, Lake Minatare Dams and Reservoirs – 1,134,300 acre-feet. Guernsey Power Plant 4,800 kW – full water supply 226,737 acres. Rehab – 100 miles canals, laterals, canal lining
Lake McConaughy	I-R-P	Owned and operated by the CNPP&ID. Used primarily to store irrigation water – capacity – 1,644,000 acre-feet
Sutherland Reservoir	I-P	Reservoir capacity 64,720 acre-feet. Supplies cooling water for NPPD
Lake Maloney	P	Reservoir capacity 11,950 acre-feet. Supplies cooling water for power generation
Jeffrey Reservoir	I-P	11,500 acre-feet, 18,000 kW
Johnson Reservoir	I-P	54,000 acre-feet, 2 plants, 36,000 kW

Table 2.2 Continued

Name of Development	Functions*	Description, including acre-feet
WYOMING		
Kendrick Project	I-P-F-R	USBR – Seminoe Dam and Reservoir, 1,011,000 acre-feet; Seminoe Powerplant, 32,400 kW; and Alcova Dam and Reservoir, 189,000 acre-feet; Alcova Powerplant 36,000 kW and distribution and drainage system. Irrigation for 24,265 acres
Glendo Unit, Oregon Trail Division	I-P-FC-F-R	USBR – Glendo Dam and Reservoir, 795,200 acre-feet. Gary Reef Dam and Reservoir – 1,800 acre-feet. Glendo and Freemont Canyon Powerplant – 72,000 kW; supplemental irrigation to 37,758 acres
Lake Hattie	I	Reservoir for irrigation purposes, with capacity of 68,500 acre-feet; priority allows only infrequent diversion for storage
North Platte Project	I-P-F-R	USBR – Pathfinder, Guernsey, Lake Alice, Lake Minatare Dams and Reservoirs – 1,134,300 acre-feet – Guernsey Powerplant 4800 kW – full water supply 226,237 acres; supplemental supply 108,715 acres. Rehab – 100 miles canals, laterals, canal lining
Grayrocks Reservoir	M-I-F-R	Laramie River; 104,110 acre-feet
Wheatland Reservoir No. 1	I	Sybille Creek; 15,360 acre-feet
Wheatland Reservoir No. 2	I	Laramie River; 98,334 acre-feet
Wheatland Reservoir No. 3	I	Laramie River, offstream; 90,872 acre-feet
Granite Springs Reservoir	M	Middle Crow Creek; 7,367 acre-feet
Hawk Springs Reservoir	I	Horse Creek; 16,735 acre-feet
LaPrele Reservoir	I-M	LaPrele Creek; 20,000 acre-feet
Rob Roy Reservoir	M	Douglas Creek; 8,894 acre-feet

* Function symbols:
I – Irrigation
F – Fish and Wildlife
FC – Flood Control and Detention
M – Municipal and Industrial Water
P – Power
R - Recreation

2.1.3 Trans-basin Diversions

The availability of water from the lesser developed portions of neighboring watersheds (primarily the Colorado River Basin) coupled with the increasing demand for water in the Platte River Basin led to the concept of diverting water from one basin to the other, hence the term trans-basin diversion. To obtain more water, trans-basin diversion projects were constructed beginning in the 1890's to deliver water primarily from the Colorado River watershed to South Platte River basin irrigators. Figure 2.8 shows that water began to be transferred into the South Platte River Basin before 1900. The volumes of water transferred rose on a relatively steady trend until about 1950 when the Colorado Big Thompson Project came on line, dramatically increasing trans-basin inflow into the South Platte Basin. This imported water increases the water supply to the Platte River Basin, a portion of which reaches the Platte River after having been used and reused and eventually joining the river as return flow.

2.1.4 Groundwater Development

In addition to the development of surface water, farmers began to look to groundwater for irrigation in a significant way in the early 1900's. The Missouri River Basin Commission (1976) stated that,

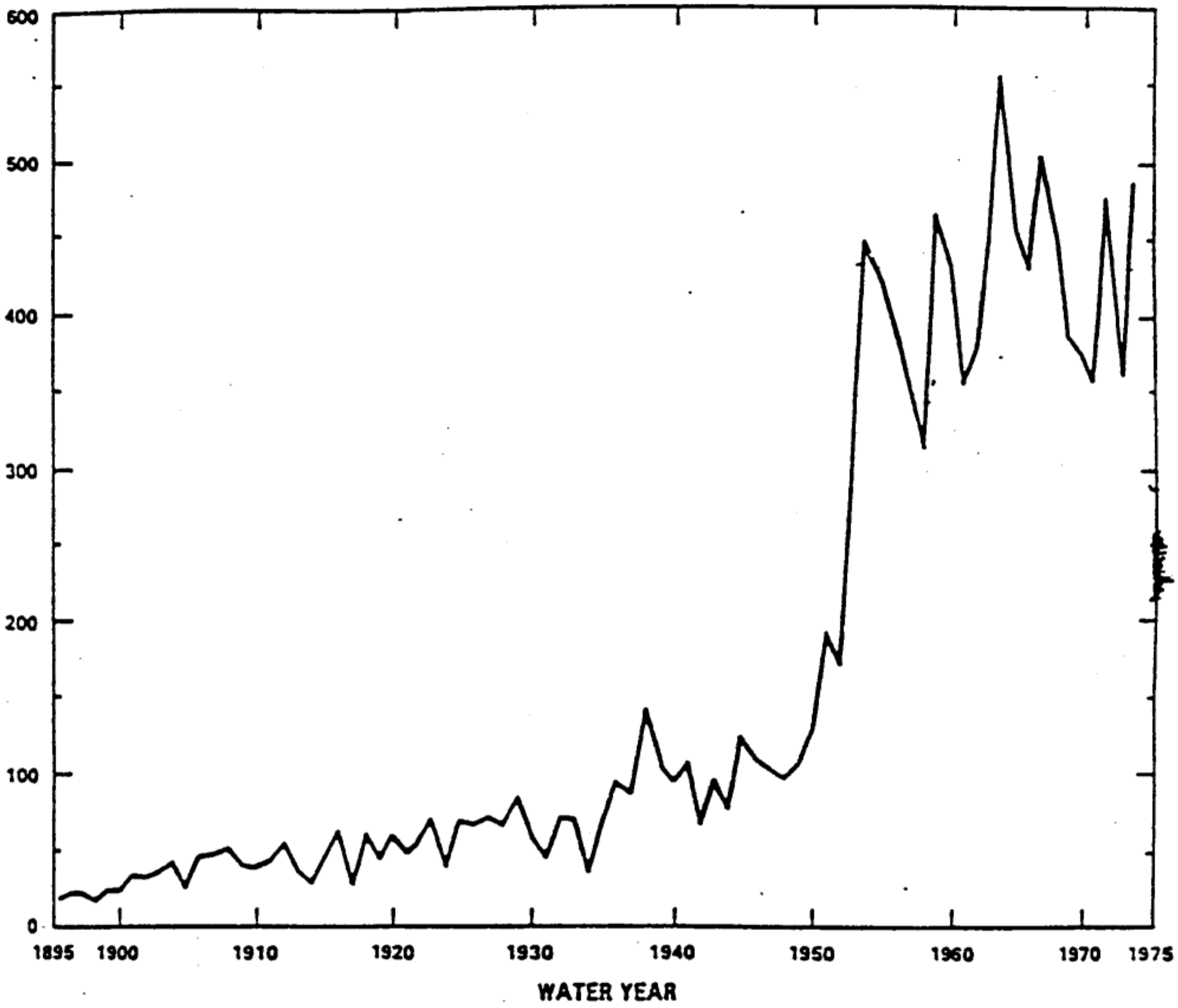
> *Significant use of ground water as a source of irrigation supply began about 1926 and has developed rather rapidly in the last 40 years. Development has been extensive in both valley and upland areas, particularly in the eastern two-thirds of the basin. In 1970 about 60 percent of the total irrigated acreage in the basin was from ground water, accomplished almost entirely by private individuals.*

Figure 2.9 shows the growth of registered irrigation wells from 1930 to 1975, when it was reported by the Missouri River Basin Commission (1976) that there were almost 24,000 wells in 1973.

2.1.5 Summary of Current Water Resources Development Conditions

Water resources development occurred in four basic stages as discussed by Eschner et al. (1983). The first stage was characterized by the construction of small, crude irrigation ditches to provide water to small parcels of land on the floodplain. The second stage expanded construction of larger and more sophisticated canal systems to extend irrigation to benches above the valley floor. During this period, over-appropriation occurred such that canals with later water rights could not always be filled. The third stage reflected this fact by constructing reservoirs to store water during the peak flow period of snowmelt runoff. During this stage, summer flows generally remained over-appropriated since many new canals were constructed. The fourth stage is represented by continued reservoir construction, but at a slower pace. The stored water was used to fulfill existing water rights. Groundwater withdrawals provided water to meet new demands for irrigation.

The Platte River Basin, under current conditions, is one of the most intensively managed river systems in the United States. Because of the great importance of water to those who



—Historical total yearly imports of water to the South Platte River basin since 1895 (modified from Gerlek, 1977).

Figure 2.8

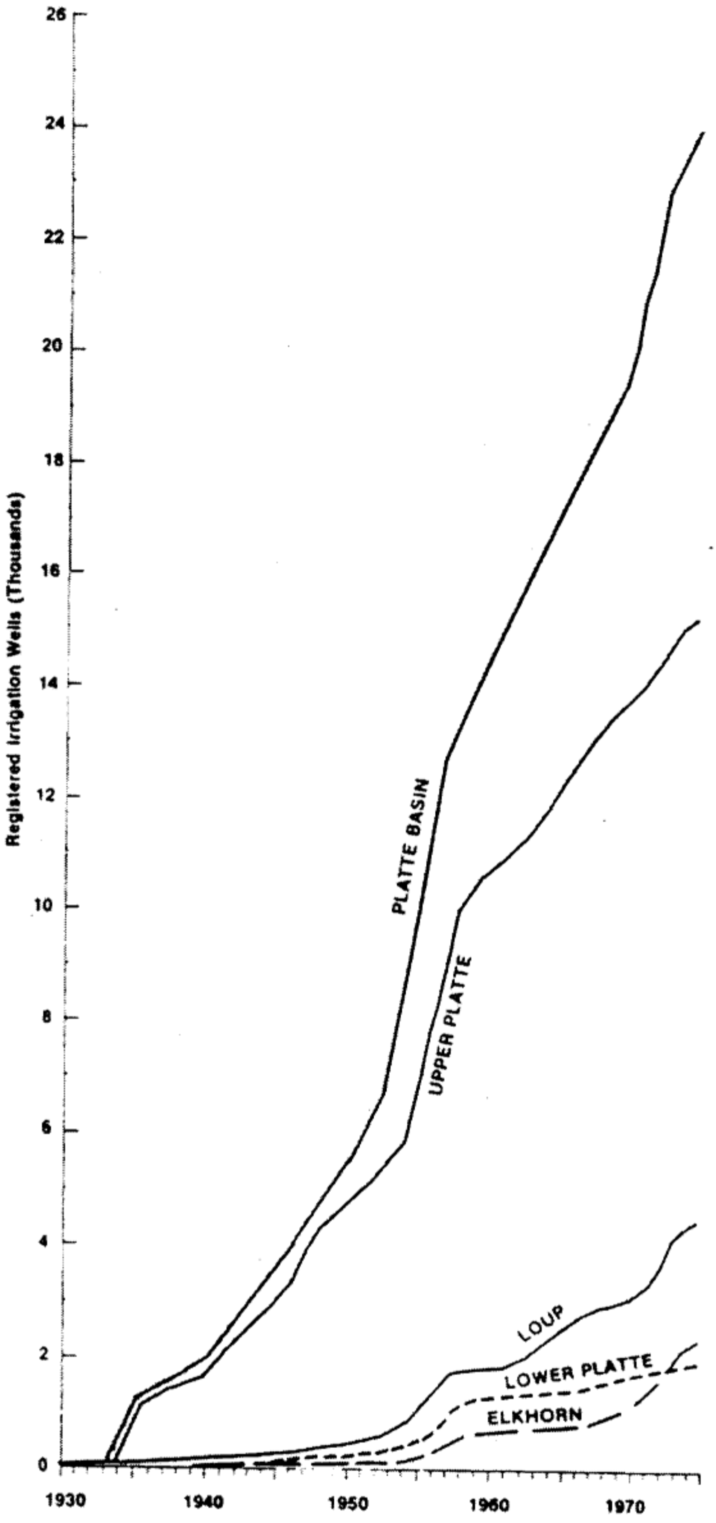


Figure 2.9
Registered Irrigation Wells

live in the basin and the well established legal and structural features of water development that have occurred over the past 100 years and more, these legal and structural features generally remain functional in managing, importing, storing, diverting, and utilizing water resources throughout the basin. Surface and groundwater management and use continue to affect the hydrology, geomorphology, and habitat in the Platte River Basin. The effects of water resources and other development, regarding hydrology and water quality, channel morphology, and habitat, are described in the remainder of this report.

2.2 Flow History

The history of flow as it has occurred over time is reflected in data that have been collected over time at various stream gages in the basin. Since the time frame from about 1895 to 1930 flow data have been collected and are available through the U.S. Geological Survey (USGS). Prior to that time, information on flow can only be based on anecdotal sources. In order to gain an initial understanding of the history and pattern of flow, graphs of flow data are presented. The gages for which graphs have been prepared are: North Platte at North Platte, South Platte at Julesburg, Platte at Overton, and Platte at Grand Island. These stations were selected because they represent a geographic range from upstream of the Big Bend reach, down through most of the Big Bend reach of the Central Platte River. Two of the gages have some of the longest periods of record of any gages in the basin so any long-term trends in flow may be more apparent.

2.2.1 Annual flow

Hydrographs showing the total annual flow in million acre-feet (maf) were prepared for the selected stations (see Figures 2.10-2.13). Starting on the North Platte, for the time period up until about 1930, the total annual flow fluctuated about a value on the order of approximately 2 maf per year. A dramatic decline in flow occurred starting about 1930 with the total flow remaining very low (generally less than a half a maf) until about 1970. This period of low flow can be attributed to a combination of several factors including: the major droughts of the 1930's and the 1950's; as well as water resources development including the construction of several large reservoirs, continued diversions, and groundwater pumping. Thereafter, the flow ranged from as low as less than half a maf to over 1.5 maf. A similar trend is apparent, although the period of record is shorter, at Overton and Grand Island. The same trend is not evident in the Julesburg record. In this case, flows are generally lower in the early 1900's with some higher flows occurring near the end of the record in the more recent years. There are several explanations for the lack of a similar trend despite significant water resources development in the South Platte Basin as described by Simons & Associates (1990e),

> *This lack of change in Julseburg streamflow is explained by several factors. First, the reservoir storage capacity on the South Platte River is substantially smaller than that on the North Platte River. Second, canal construction started earlier in Colorado than in Wyoming and the effects of this early water resources development are not reflected in the data at Julesburg. Third, annual imports of water primarily from the Colorado River Basin increase the available water supply of the South Platte River*

by over approximately 300,000 acre-feet annually. Thus, while the record may not indicate any significant changes due to water resources development, reductions in flow caused by increased consumptive uses in Colorado were at least partially offset by the transbasin import of water primarily from the Colorado River basin.

2.2.2 Peak Flow

The peak flow hydrographs basically follow the same trend as exhibited by the total annual flow hydrographs (see Figures 2.14-2.17). The gage on the North Platte River at North Platte, peak flows in the late 1800's and early 1900's, often exceeded 20,000 cfs and reached almost 30,000 cfs on one occasion. Peak flows dropped to a lower level after the initial construction of mainstem reservoirs on the North Platte River averaging about 10,000 to 15,000 cfs with a maximum of about 24,000 cfs in the time period from about 1908 to 1930. After the completion of several additional reservoirs in the 1930's - 1940's time frame, the peak flow on the North Platte River was dramatically reduced, rarely exceeding 5,000 cfs after 1940. A similar trend is apparent, although the period of record is shorter, at Overton on the Platte River. The same trend is not evident in the Julesburg record on the South Platte River, probably due to the influence of water resources development that occurred prior to the beginning of the historic record and the smaller amount of reservoir storage on the South Platte River compared to the North Platte River.

2.2.3 Seasonal Pattern of Daily Flow

In the mountains, with the generally colder climate at higher elevations, much of the annual precipitation falls as snow. Snowpack builds up over the fall and winter seasons with its release as runoff as the snow melts in spring and early summer. As a result of the interaction of climatic thermal regimes and precipitation patterns, the hydrologic cycle results in a relatively predictable seasonal pattern as indicated in Figure 2.2. Figure 2.2 presents an example of the flow hydrograph typical of the pattern exhibited by streams in the Platte River Basin. Starting in what is referred to as a "water-year," the flow is relatively steady from October through the winter months. As spring approaches there is a general rise in flow culminating in a snowmelt generated peak flow that typically occurs in May or June. After the snowmelt peak, flow rapidly recedes to the lowest levels of the year during the summer. During summer months, the watershed can experience intense thunderstorm activity that can result in significant runoff although such events typically affect only a localized area.

In contrast to the potential for large runoff events associated with snowmelt runoff or significant precipitation events, the Platte River also experiences extreme low flow periods and even periods of no flow. In relatively recent times, multi-year droughts, such as the dust bowl era of the 1930's and the 1950's drought, provide an example of a series of dry years that resulted in very low annual and seasonal flows for extended periods of time.

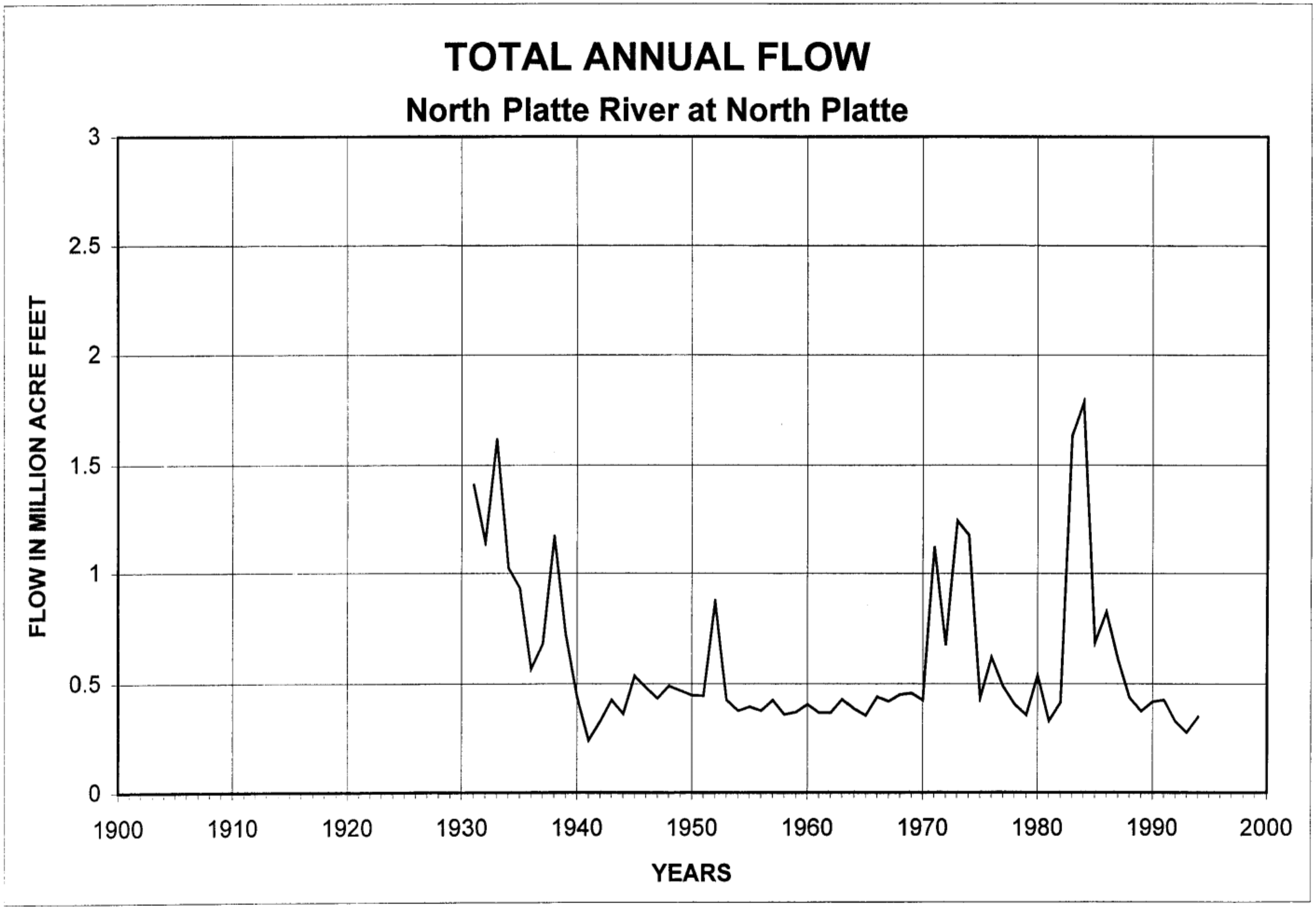

TOTAL ANNUAL FLOW
North Platte River at North Platte
FLOW IN MILLION ACRE FEET
3
2.5
2
1.5
1
0.5
0
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
YEARS

Figure 2.10

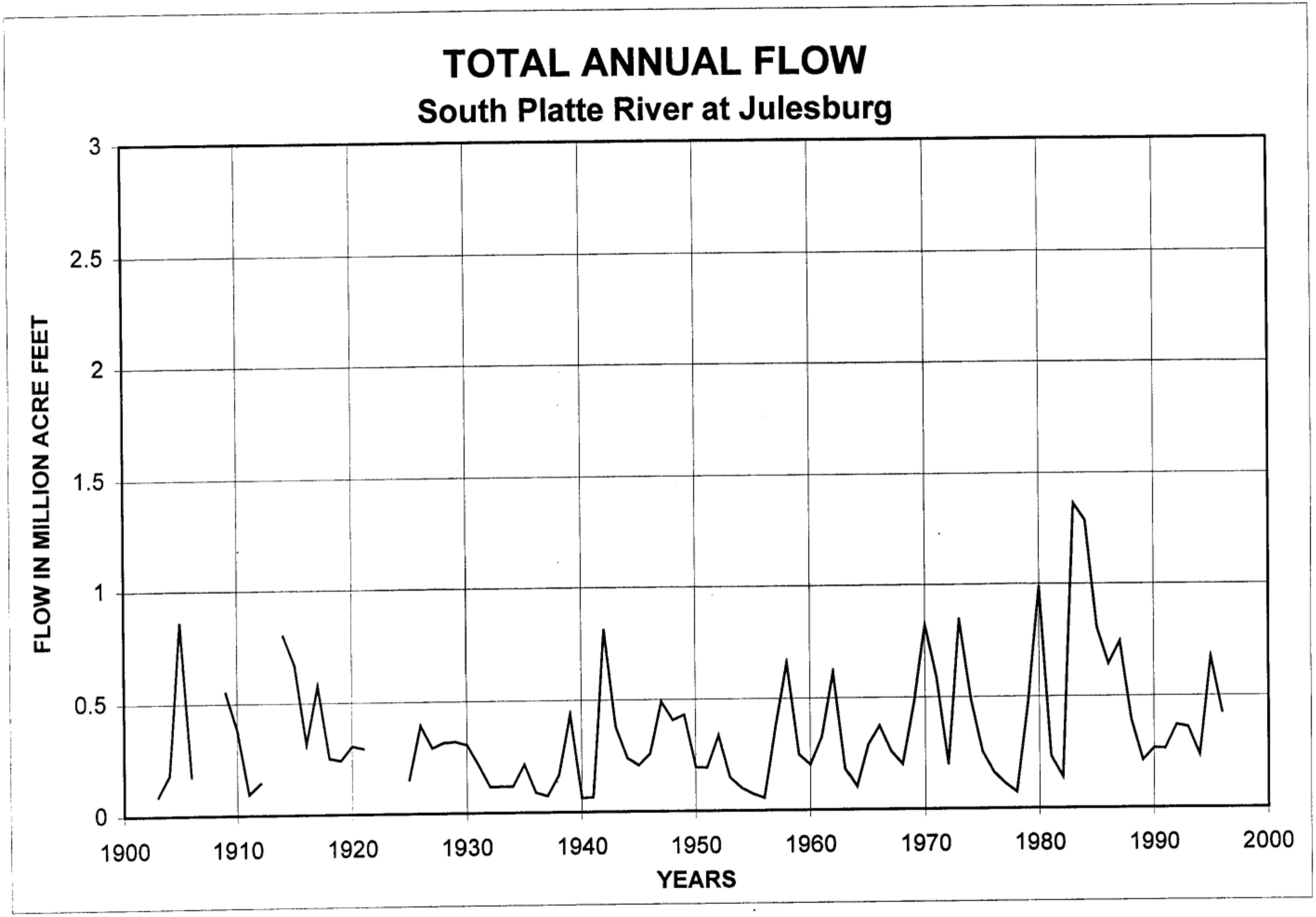

TOTAL ANNUAL FLOW
South Platte River at Julesburg
FLOW IN MILLION ACRE FEET
3
2.5
2
1.5
1
0.5
0
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
YEARS

Figure 2.11

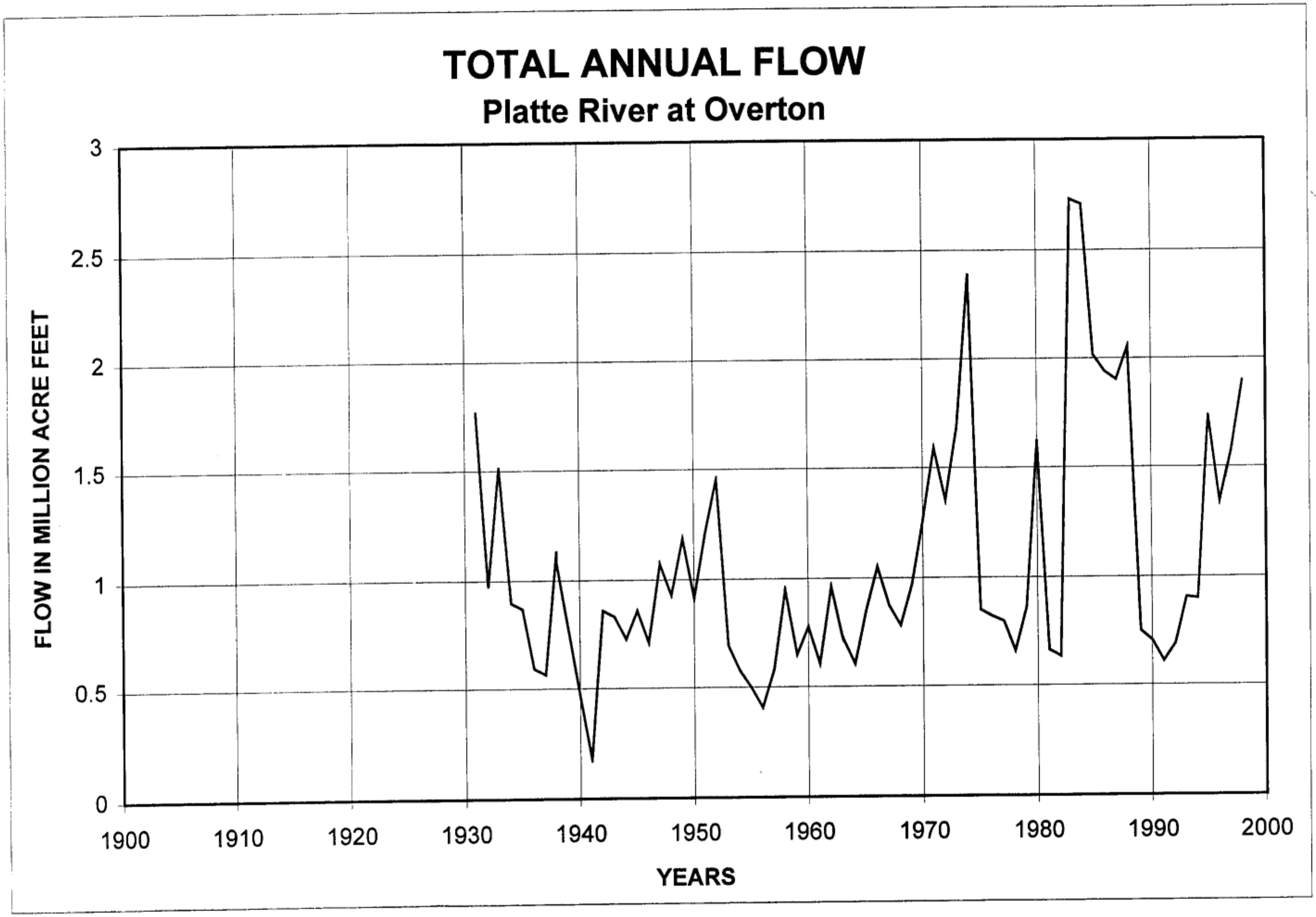

TOTAL ANNUAL FLOW
Platte River at Overton
FLOW IN MILLION ACRE FEET
3
2.5
2
1.5
1
0.5
0
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
YEARS

Figure 2.12

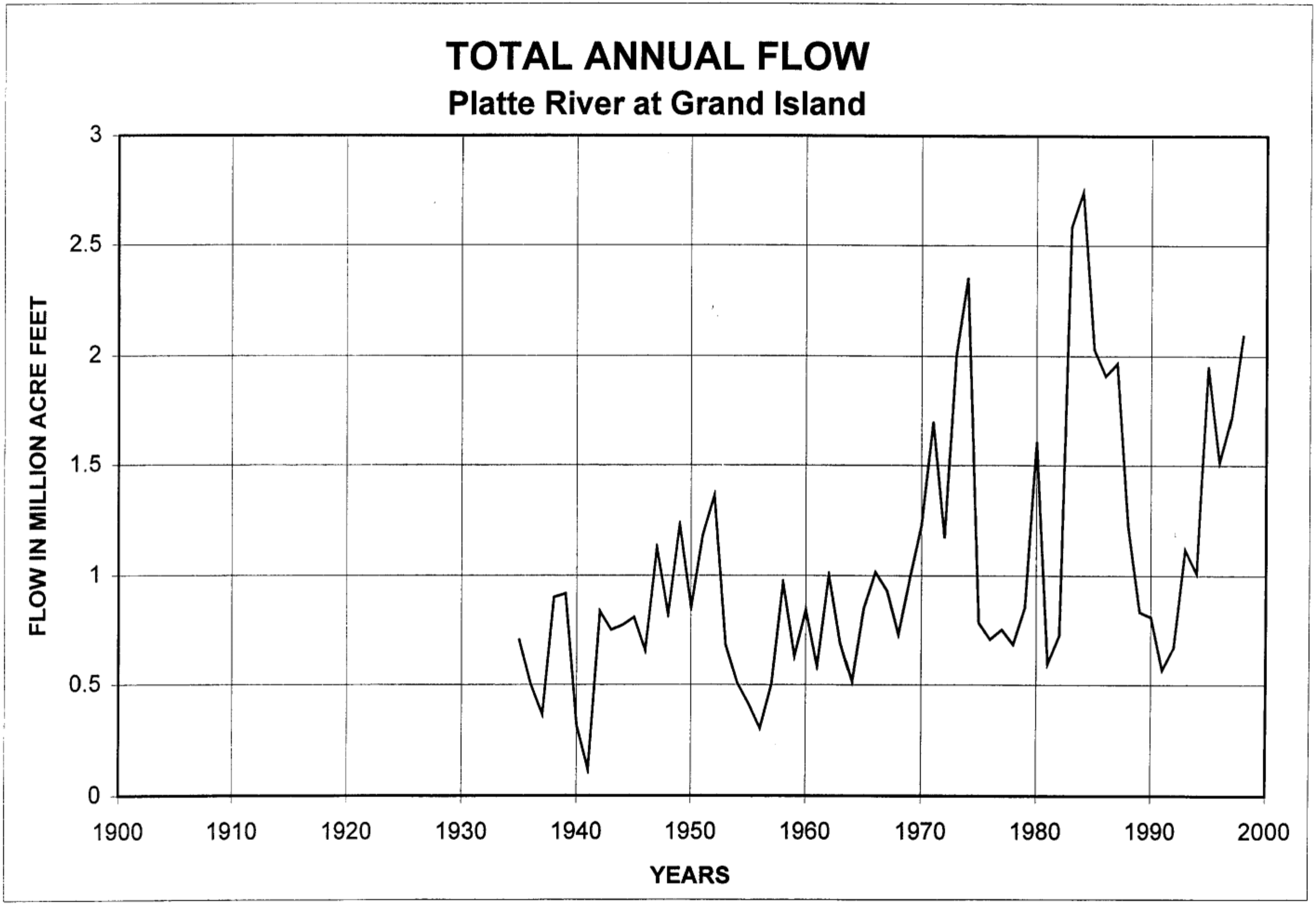

TOTAL ANNUAL FLOW
Platte River at Grand Island
FLOW IN MILLION ACRE FEET
3
2.5
2
1.5
1
0.5
0
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
YEARS

Figure 2.13

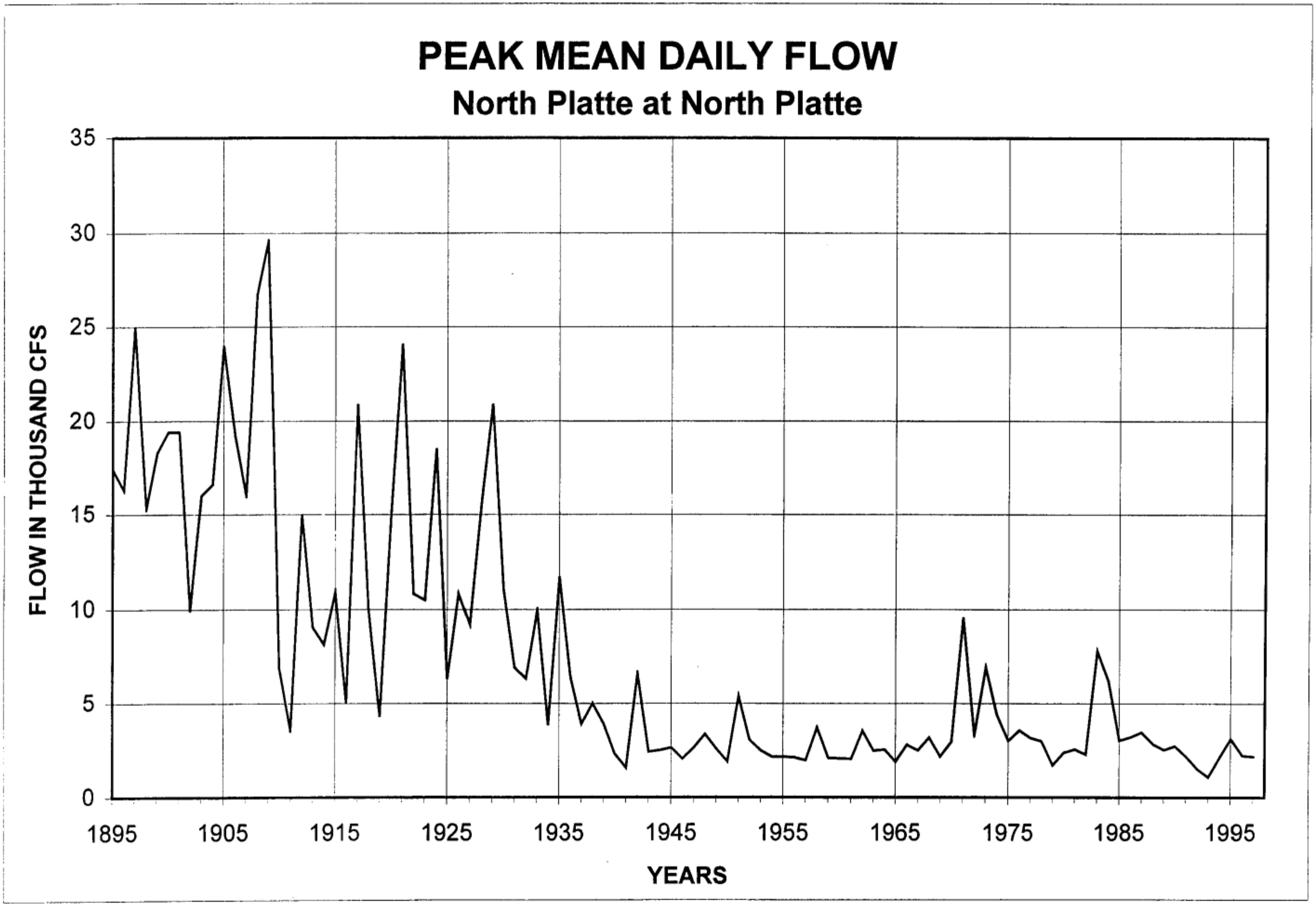

PEAK MEAN DAILY FLOW
North Platte at North Platte
FLOW IN THOUSAND CFS
35
30
25
20
15
10
5
0
1895
1905
1915
1925
1935
1945
1955
1965
1975
1985
1995
YEARS

Figure 2.14

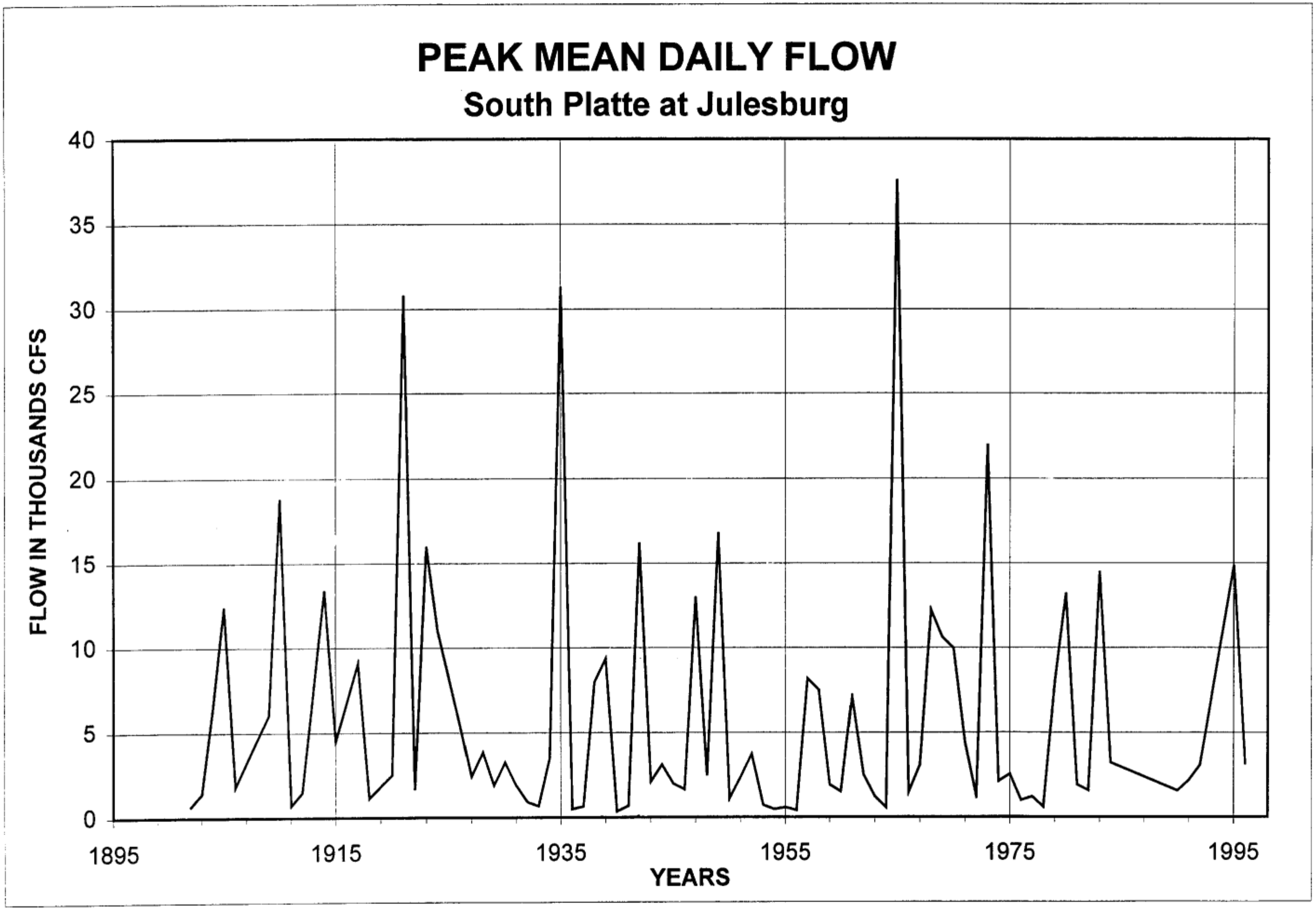

PEAK MEAN DAILY FLOW
South Platte at Julesburg
FLOW IN THOUSANDS CFS
40
35
30
25
20
15
10
5
0
1895
1915
1935
1955
1975
1995
YEARS

Figure 2.15

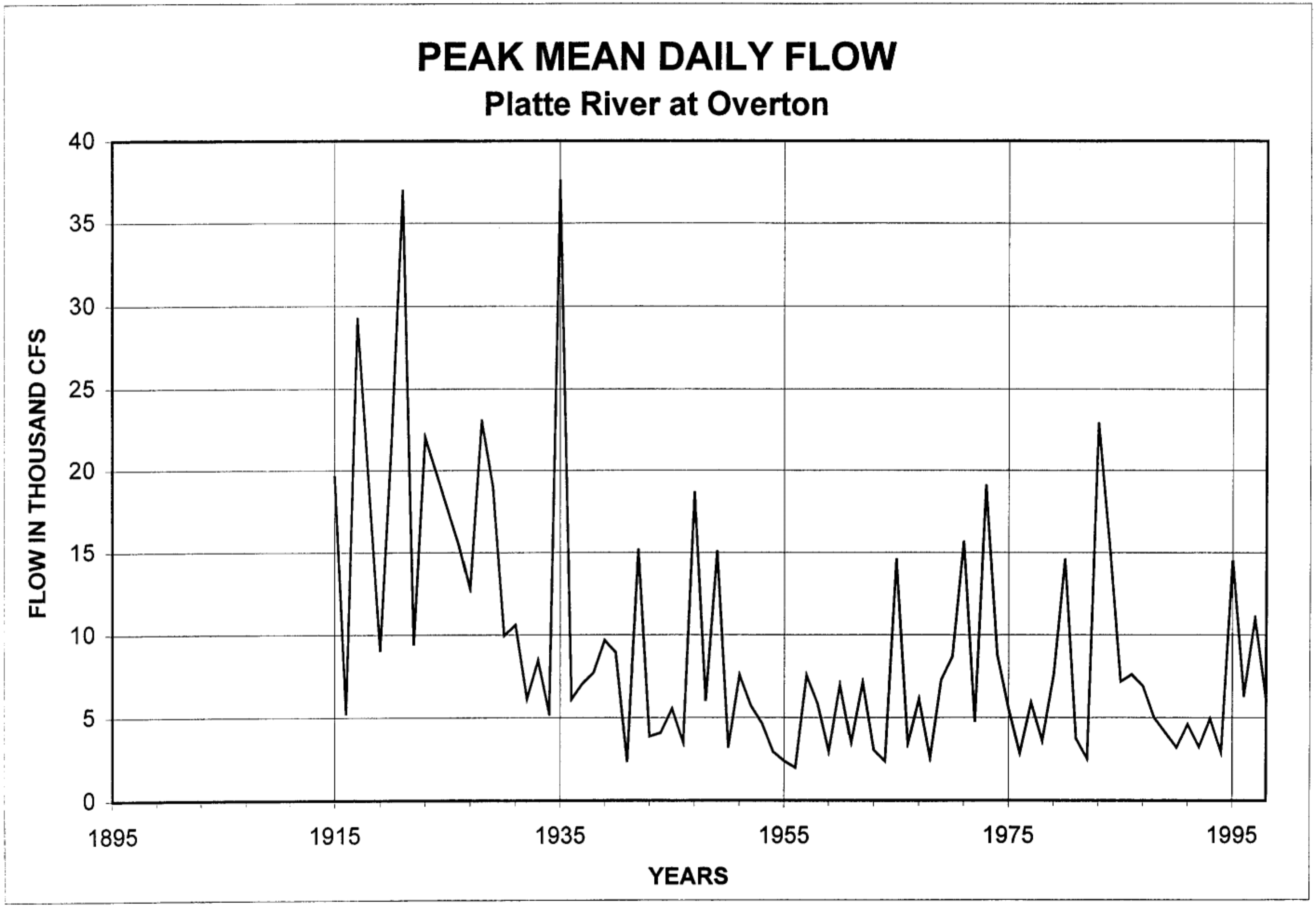

PEAK MEAN DAILY FLOW
Platte River at Overton
FLOW IN THOUSAND CFS
40
35
30
25
20
15
10
5
0
1895
1915
1935
1955
1975
1995
YEARS

Figure 2.16

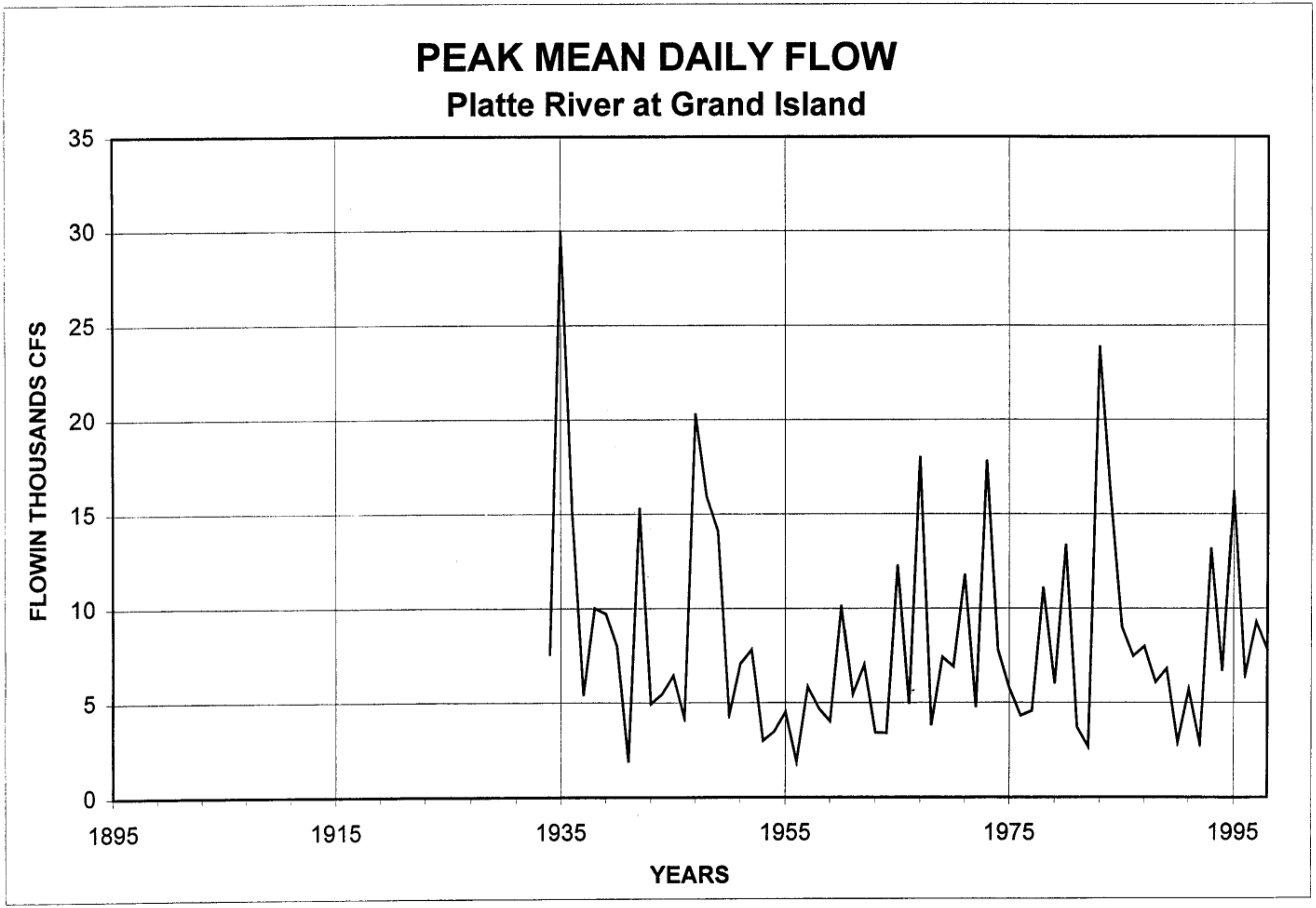

PEAK MEAN DAILY FLOW
Platte River at Grand Island
FLOWIN THOUSANDS CFS
35
30
25
20
15
10
5
0
1895
1915
1935
1955
1975
1995
YEARS

Figure 2.17

Regarding the occurrence of extremely low or no flow on the Platte River, Eschner et al. (1983) report that, *"little is known about the low-flow behavior of the river above the confluence with the Loup prior to irrigation."* They report that Miller (1978)

> *concluded that prior to irrigation the Platte River above the junction of the Loup rarely, if ever, went dry in the summer. This conclusion is based primarily on indirect evidence, such as construction of canals along the Platte to divert water during summer months.*

Miller dismisses the numerous observations (see following paragraphs) of those who traveled and lived along the Platte River of the river going dry by postulating that there may have been water in one of the many braided sub-channels farther away from an observer, or that it may have simply been more convenient or otherwise preferable to dig into the bed to find water rather than to go to where the water might have been flowing. His main logic for the Platte River not going dry is that he finds it difficult to believe anyone would build a diversion or a canal from a river that might have gone dry periodically.

The information on the phenomenon of a periodically dry Platte River is too overwhelming to dismiss. Eschner et al. (1983) provided information showing that the Platte River did in fact go dry. They cite Ware (1911) who described conditions in 1864,

> *From Fort Kearney, for many miles up, there was no water in the river. The water seemed to be in 'the underflow.' We not infrequently rode down to the river, and with shovels dug watering places in the sand of the bed* * * *. *We were told that 75 miles of the river were then dry, and that generally about 125 miles of it were dry in the driest season* * * *.

It is interesting to note that Eschner et al. (1983) characterize 1864 as <u>not</u> unusually dry. They refer to Ware (in Root and Connelley, 1901) writing of the *"unprecedented flood of 1864."* They further discuss that McKinley (1938) reported the river to be unusually high during the spring of 1864.

The occurrence of extreme low-flow conditions on the Platte River is further confirmed by Eschner et al. as they cite Clarke (1902), *"In the summer of 1863, the Platte having so nearly dried up as to make it difficult to secure water for cattle* * * *. *We sank headless barrels in the Platte* * * * *to secure water from an underflow."* They further refer to Fremont, who attempted to navigate the Platte River system. While descending the North Platte on September 3, 1845, Fremont wrote that the river was, *"merely a succession of sandbars, among which the channel was divided into rivulets a few inches deep."* Eschner et al. further state that Fremont and his crew built a bull boat, which, when fully loaded had a draft of 4 inches of water as they attempted to navigate down the Platte River. Fremont (1845) states,

> *On the morning of the 15th [September] we embarked in our hide boat, Mr. Preuss and myself, with two men. We dragged her over the sands for*

> *three or four miles, then left her on a bar and abandoned entirely all further attempts to navigate this river * * *.*

In concluding their discussion of extremely low flows experienced on the Platte River, Eschner et al. (1983) state the following,

> *If the river did not go dry every summer, the flow became relatively insignificant, a "mere trickle of water among sandy shoals (Ghent, 1929 p. 128)." Between the junction of the North Platte and South Platte Rivers and the Loup river, the Platte may have gone dry during years of low precipitation and probably was reduced to a trickle in other years.*

The information presented above indicates, as concluded by Eschner et al. (1983), that indeed flow on the Platte River during the summer after the spring peak was typically very low and, at least on some occasions, went dry over extended lengths of the river. They characterize the Platte River regarding flow as follows, *"Above the confluence with the Loup, the Platte was an intermittent river. It carried little water during the late summer and dried up completely in some years."*

2.3 Groundwater History

A description of the sedimentary deposits underlying the Platte River was provided by Eschner et al. (1983). They stated the following:

> *Unconsolidated deposits of the Platte River valley in the study area consist of Quaternary sediments, which include Holocene alluvium. The Ogallala formation of Tertiary age and Pierre Shale and Niobrara Formation of Cretaceous age underlie the Quaternary sediments in the Platte River Valley . . . Quaternary sediments and, where present, the Ogallala Formation, are the principal aquifers in the Platte River Valley . . . Thickness of saturated alluvium varies from about 6 m to more than 122 m because of an irregular bedrock surface (Bentall, 1975a).*

Thus, there is an aquifer of significant proportion that stores groundwater beneath the valley floor of the Platte River. This significant volume of water has been the source for the large numbers of wells that have been developed as previously discussed (see Section 2.1.4).

Groundwater levels along the Platte River are an area of concern with respect to habitat due to the concept that wetlands affected by groundwater may be a significant source of both habitat and food for wildlife. Groundwater in the vicinity of the Platte River has been shown to be closely tied to the water surface elevation in the river itself as demonstrated by the hydraulic linkage between the river and groundwater levels documented in Eschner et al. (1983). This report states, *"A study near Grand Island indicates that ground-water levels within 0.8 km of the river in that area respond within 24 hours to changes in river stage (Hurr, 1981)."*

Significant changes in groundwater hydrology have occurred along the Central Platte River due to a number of factors. Large numbers of wells have been developed, primarily to irrigate land. The consumptive use of water pumped from wells tends to draw groundwater levels down. The development of irrigation canals and laterals, as well as lakes and reservoirs, fed by surface water diverted from the river generally tends to increase groundwater levels. Changes in water surface elevation along the river due to channel bed elevation changes caused by aggradation or degradation would be expected to affect adjacent groundwater levels. Groundwater data were obtained from a variety of sources (the NNRIS Data Bank of the Nebraska Natural Resources Commission in cooperation with the USGS, USGS Water Supply Papers, CNPP&ID, Twin Platte Natural Resources District, and Conservation and Survey Division of the University of Nebraska) by Simons & Associates (1990b) to evaluate the causes of change in groundwater levels. Adjacent to the river, the water table has remained relatively stable with no significant trends over time as shown in Figure 2.18, typical of well data near the river.

2.4 Sediment Supply and Transport History

Descriptions of the Platte River refer to its muddy or turbid nature. Eschner et al. (1983) present several references regarding this characteristic.

> *The water of the Platte River commonly was referred to as muddy or turbid. The "turbid waters of the Platte" were noted by the Long Expedition (James, 1823). McKinstry (1975), although calling the Platte a river of sand, stated that it was "nearly as muddy" as the Missouri. Taylor (Williams, 1969) wrote that the river was at various points, "swift and muddy," "muddy and turbulent," and "broad, swift and muddy." Kelly (1851) described the river as turbid. Ebey (Baydo, 1971) stated of the Platte: "The water is always muddy and turbid * * *."*

The general consensus of these accounts is that the Platte River, in its pre-development state, transported a significant quantity or concentration of sediment. The history of sediment supply and transport cannot be quantified to the degree that flow can. This is due to the fact that no known sediment transport data were collected until after almost all of the current level of water resources development had been completed.

2.4.1 Suspended Load

The earliest quantification of sediment transport occurred in the form of suspended sediment samples collected in the late 1940's. Appendix A documents the availability of suspended sediment data in the Platte River Basin. These data consisted of suspended sediment samples at a frequency of periodic spot readings (on the order of once a month) to daily readings for a few years at a time.

2.4.2 Bed-material load and grain size distribution

Some bedload transport data were collected, primarily in the 1980's. These data generally consisted of some spot measurements at a variety of locations as documented in Appendix A. Along with the quantity of bedload transport, some samples of the grain size distribution of bedload were collected and analyzed.

2.4.3 Bed-material size gradation and spatial distribution

Eschner et al. (1983) provide some information in the form of pre-development observations of the characteristics of the bed of the Platte River. This information characterizes the bed as predominantly consisting of sand, with some mention on a few occasions of finer particles (mud) as well as coarser particles (gravel). A number of observers characterized the bed of the Platte River as quicksand as typified by the following quotes provided by Eschner.

> *In 1812, Stuart (Rollins, 1935) wrote that the bed of the Platte River, near present day Gosper-Phelps County border, was composed "of such quicksand that it was difficult for our horse to get over, though the water was in no place more than two feet [0.6m] deep." Farther downstream near Fort Kearney, Taylor (Williams, 1969) in 1850 noted, "The bottom is composed of a fine quicksand * * *." Fremont (1845) described the southern channel of the South Platte River near the confluence with the Platte River as being "generally quicksands."*

2.4.4 Bedform size, pattern, and movement

Some early descriptions of the bedforms, patterns, and movement of the bed of the Platte River were presented by Eschner et al. (1983).

> *The account of the Long Expedition (James, 1823) stated of the Platte, "its bed is composed almost exclusively of sand, forming innumerable bars, which are continually changing their positions and moving downward [downstream] * * *." In their travels, members of the Long Expedition observed on the flood plain "extremely numerous natural elevations of earth, of some considerable degree of regularity * * * of a more or less oval outline" with lengths of about 30 m and heights of 0.6 to 1.5 m. These elevations were presumed to have been former sandbars, "Their existence is doubtless due to the action of water."*

Other observations presented by Eschner described the bed of the Platte River near Fort Kearney.

> *In 1849, Pritchard (Mattes, 1969) noted the composition and character of the bed: "The bed of the river is composed of sand, and this is all the time shifting its position and fresh deposits are constantly being made." Evans (Mattes, 1969) wrote in 1849 that the Platte was a wide sheet of water "running over a vast level bed of sand and mica * * * continually changing into short offsets like the shingled roof of a house * * *."*

Karlinger et al. (1983) presented additional information regarding macroforms. They describe Platte River macroforms, referring to Crowley (1981) as, *"large bed forms proportional to the channel dimensions."* They go on to present more detailed information:

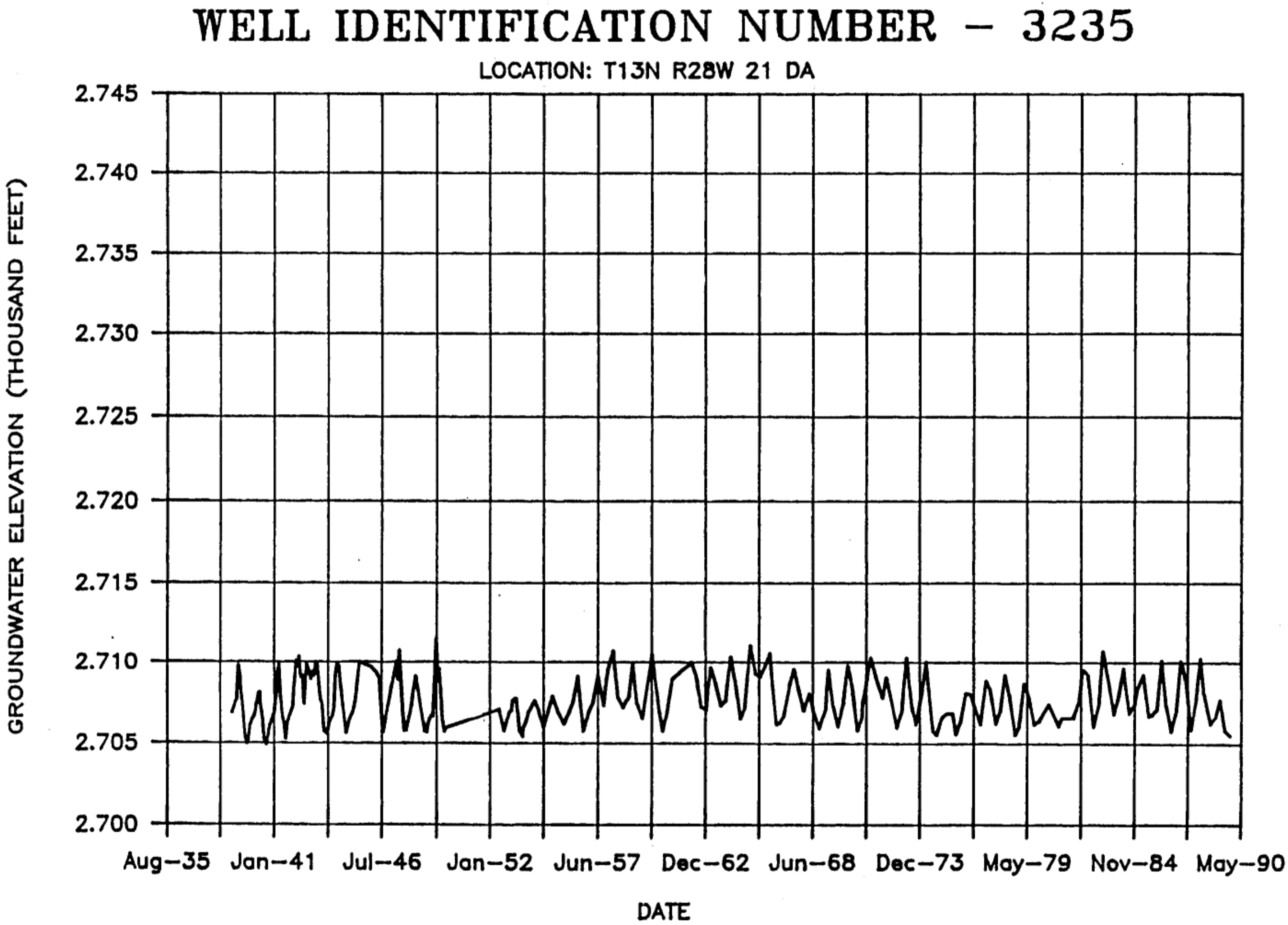

WELL IDENTIFICATION NUMBER – 3235
LOCATION: T13N R28W 21 DA
GROUNDWATER ELEVATION (THOUSAND FEET)
2.745
2.740
2.735
2.730
2.725
2.720
2.715
2.710
2.705
2.700
Aug–35
Jan–41
Jul–46
Jan–52
Jun–57
Dec–62
Jun–68
Dec–73
May–79
Nov–84
May–90
DATE

Figure 2.18

> *In plan view, macroforms are situated obliquely, at about 30°, to the direction of flow (fig. 5). Width of macroforms is about 0.6 times the channel width, and length is about 1.9 times the channel width. The height of macroforms generally does not exceed 2 meters. A steep slipface forms the downstream end of a macroform. Small channels, oriented about perpendicular to the slipface, occur near the downstream end of macroforms. . . Macroforms move only during the highest flows when they are submerged. . . Downstream migration rates of 1.0 to 1.5 m/hr (meters per hour) were measured in the Platte River during 1980 high flows. Long-term rates of migration, computed from measurements on aerial photographs, varied between about 10 and 24 m/yr (meters per year).*

The figure referenced in this citation is reproduced as Figure 2.19 since it provides a good visualization of macroforms on the Platte River.

2.4.5 Sediment Trapping

Information was compiled by Simons & Associates (1990d) documenting the quantity of sediment trapped in various reservoirs in the basin. This information was based on a number of reservoir sedimentation surveys that have been conducted over time. Table 2.3 (after Simons & Associates, 1990d) summarizes the results of these surveys. The table presents the quantity of sediment trapped by each reservoir, for the time periods indicated, both in terms of tons per square mile per year as well as the total tonnage per year. These figures allow comparison of the quantity of sediment production from the upstream or contributing watershed trapped in each of the reservoirs.

Table 2.3 Summary of Reservoir Sedimentation Survey Results

Reservoir	Survey Time Period	Total Sediment Trapped (tons/mi^2/yr)	Total Sediment Trapped (million tons/yr)
Pathfinder (North Platte)	1909-1950	138	0.46
Seminoe (North Platte)	1939-1950	153	1.12
Guernsey (North Platte)	1944-1947 1947-1957	243 107	0.14 0.06
Lake McConaughy (North Platte)	1941-1986	149	1.28
Cheesman (South Platte)	1900-1931	37	0.05

2.4.6 Pre-Development Sediment Transport

An estimate of pre-development sediment transport was made by Simons & Associates (1987a). This estimate is for the quantity of sediment delivered to the Platte River from both the North and South Platte Rivers. It was based on regression equations relating sediment transport to flow using available bedload and suspended load data. The estimate used the regression equation with an estimate of the pre-development annual flow. The result of the estimate was 1.25 million tons for bedload and 2.28 million tons for suspended load on an annual basis. To this number from the regression equations, an estimate of sediment trapped in reservoirs of 4.25 million tons per year was added obtaining a total of 7.8 million tons per year. This estimate is admittedly crude and based on a number of assumptions that may not be valid. Some attempt at verification should be made before relying on this estimate, however, it does provide an initial guess at pre-development sediment transport.

2.5 Channel Geometry

The channel geometry of the Platte River prior to development can be characterized as wide and shallow, and classified as braided in form. Maps of the vicinity of the surveys show a generally wide and open channel or one that had some islands with multiple braided channels (Figures 2.20 and 2.21). The earliest aerial photographs from the late 1930's confirm the generally braided character of the Platte River system (Figure 2.22).

2.5.1 Total Channel Width

One of the most notable features of the Platte River is its width. As discussed by Eschner et al. (1983), *"Most travelers, comparing the Platte River to rivers in the Eastern United States, found the width of the river remarkable; comments on channel width were recorded in most journals."* Two early measurements of width were provided by Eschner et al. (1983). They gave a bank-to-bank width measurement by Captain Bonneville in 1832 (Irving, 1837) of 6600 feet at a location 25 miles downstream of the head of Grand Island. The other measurement was done by Fremont (1845) just downstream of the confluence of the North and South Platte of 5280 feet (one mile). They further summarize other width estimates stating that such estimates during the period 1800-1860 ranged from 3960 feet (three-fourths of a mile) to 15,840 feet (3 miles) with most measurements ranging from 5280 (1 mile) to 10,560 feet (2 miles).

Some channel surveys were conducted in the 1920's associated with the construction of bridges. Channel widths on the Platte River ranged from 1240 feet to 5500 feet (0.23 - 1.04 miles), averaging 0.7 miles. These widths appear to be generally less than those cited above made on the order of 60 to 75 years earlier. This decrease in width could reflect the effect of water resources development that occurred prior to the 1920's, or it could reflect the fact that these were bridge sites which might have been somewhat narrower than the width of the river in general.

2.5.2 Active (unvegetated) Channel Width

The active channel width is defined as the portion of the width of the river channel within its banks that is not vegetated by perennial or woody vegetation. The active channel generally consists of the barren sandy bed above water combined with the portion of the

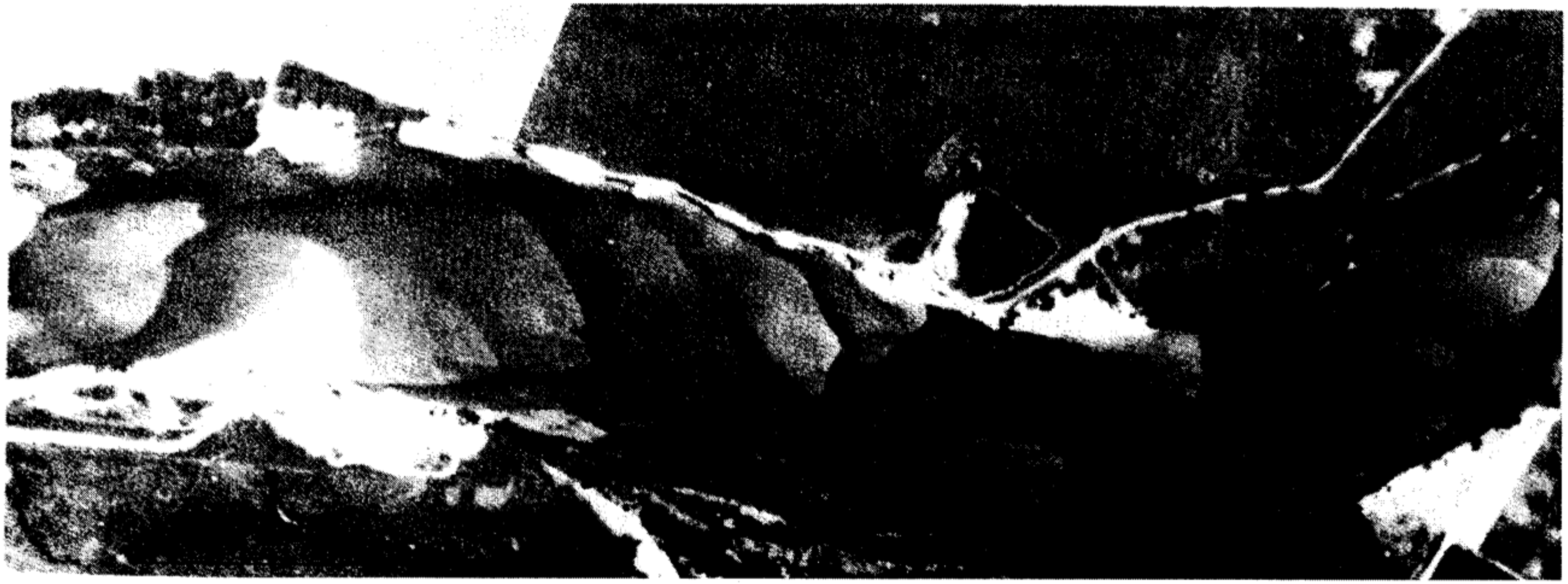
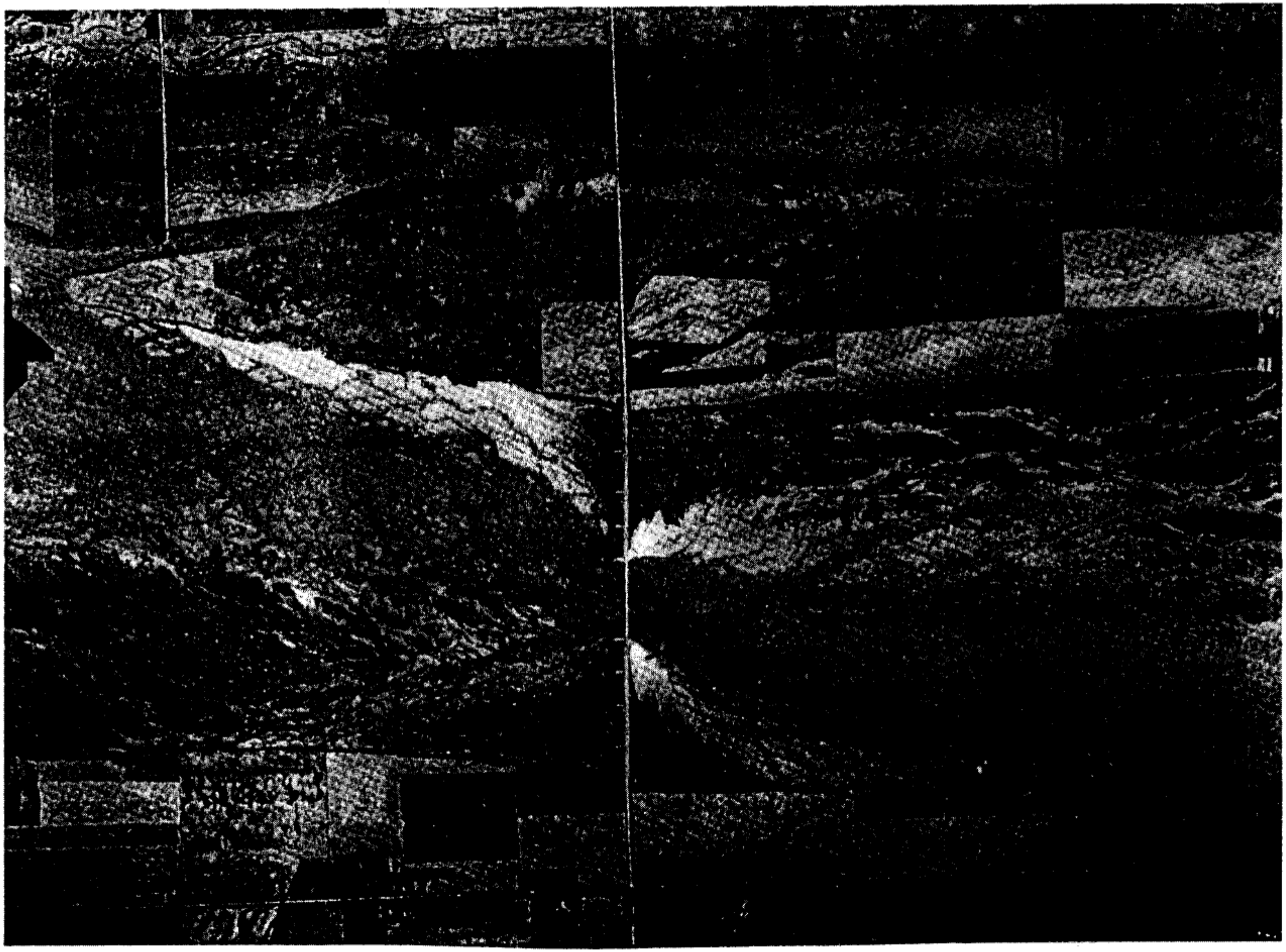


Figure 2.19
Vertical photograph showing external geometry of the Platte River macroforms, Platte River near Grand Island, Nebraska (from Crowley, 1981a).

Figure 2.22



ODESSA BRIDGE 1938

channel inundated by water. An estimate of active channel width can be derived from analysis of General Land Office (GLO) survey maps and notes conducted by Johnson (1989). Based on an evaluation of the extent of islands, Johnson concluded, *"One estimate made in this paper indicates that about 10 percent of the active channel width drawn on plat maps was actually occupied by wooded islands."* Deducting this figure results in about 90 percent of the total channel width being active or unvegetated. Analysis of the change in channel widths over time conducted by Simons & Associates (1990d) showed that based on the 1938 aerial photographs, the active channel width had declined to anywhere from about 10 to 75 percent of the total channel width compared to the 1800's total widths from the GLO surveys.

2.5.3 Wetted Channel Width

Wetted channel widths depend on channel geometry and the magnitude of flow. During peak spring runoff the wetted channel width probably extended from bank to bank, and possibly beyond the banks and onto the floodplain during extreme events. During the late summer, historic accounts show that frequently there was very low or no water in the river. Thus, on a percentage basis, the wetted channel width historically ranged from zero to one-hundred percent.

2.5.4 Channel Depth

The depth of the channel, as described by Eschner et al. (1983), was the *"second most remarkable characteristic of the Platte River."* They state that the river could be forded *"anywhere at almost anytime of the year, except during spring floods."* They cite Long (James, 1823) reporting that the bed of the Platte River, *"is seldom depressed more than six or eight feet below the surface of the bottoms, and in many places even less."* They also report substantiation of this observation by Jessup (James, 1823).

> *The range of the Platte, from extreme low to extreme high water is very inconsiderable, manifestly not exceeding six or eight feet. This is about the usual height of its banks above the surface of the sand which forms its bed * * *.*

Another source cited by Eschner et al. (1983), Warren (1858) reported that, *"when the banks are full, it [Platte] is about six feet deep throughout, having a remarkably level bed."*

Data from the 1920's surveys showed that channel depths on the Platte River ranged from 8 to 12 feet, averaging about 9.4 feet. These depths are on the same order of magnitude as the depths estimated from the 1800's. These depths are slightly greater than those estimated in the 1800's possibly reflecting some scour or possibly due to the generally narrower sections than previously estimated as discussed above.

2.5.5 Islands

A number of islands were found within the banks of the Platte River under pre-development conditions. Eschner et al. (1983) cited Cole (1905) who wrote regarding an observation of the river in 1852:

> *Looking out upon the long stretch of river either way were islands and islands of every size whatever, from three feet in diameter to those which contained miles of area, resting here and there in the most artistic disregard of position and relation to each other, the small and the great alike wearing its own mantel of the sheerest willow green * * *.*

Eschner et al. (1983) divided Platte River islands into two main categories based on size, elevation, and vegetation. Large, forested islands were mapped by Fremont (1845) including: Brady Island, Willow Island, Elm Island, Grand Island, and five other un-named islands. Characteristic of the large islands, Fremont (1845) estimated that Grand Island is, *"sufficiently elevated to be secure from the annual flood of the river."* Innumerable small islands existed in the Platte River in addition to the larger islands. Eschner et al. (1983) stated that,

> *These islands were as small as a few square meters in area; most supported shrubs, young willows, and cottonwoods. A particularly dense concentration of these smaller islands occurred between Fort Kearney and Grand Island: these were named 'Thousand Islands' after the Thousand Islands of the St. Lawrence River (Meline, 1966, p. 21).*

2.6 Woody Vegetation

One of the most significant changes that has occurred along the Platte River system is the significant expansion of woody vegetation onto formerly active channel areas. In other words, vegetation has expanded on portions of the channel that used to be active bed of the river. Woody vegetation, either on islands or along the banks of the river, potentially reduces habitat for threatened and endangered birds due to obstruction of view when such vegetation exceeds one meter in height. As a result, the existence or lack of such vegetation, either on islands or along the riverbanks; plays a significant role in evaluating the quality and quantity of available habitat as it has changed over time. Various researchers have documented the expansion of woody vegetation on the Platte River and its principal tributaries using maps and a series of aerial photographs taken over time. An example of this work (Figure 2.23, R.K. and D.B. Simons - 1994) is presented in a graph that summarizes the percentage of total channel that remains active (i.e., a bed of sand and water without woody vegetation) as it has decreased over time.

Although it is an accepted fact that significant increases in woody vegetation have occurred along the Platte River, primarily in the 1930's through 1960's time period, there is some controversy over the extent of woody vegetation that existed prior to the effects of significant water resources and other development. The extent of vegetation in the pre-development state is important to understanding both the available habitat and also the historic river dynamics that influenced vegetation. Other controversy exists over the

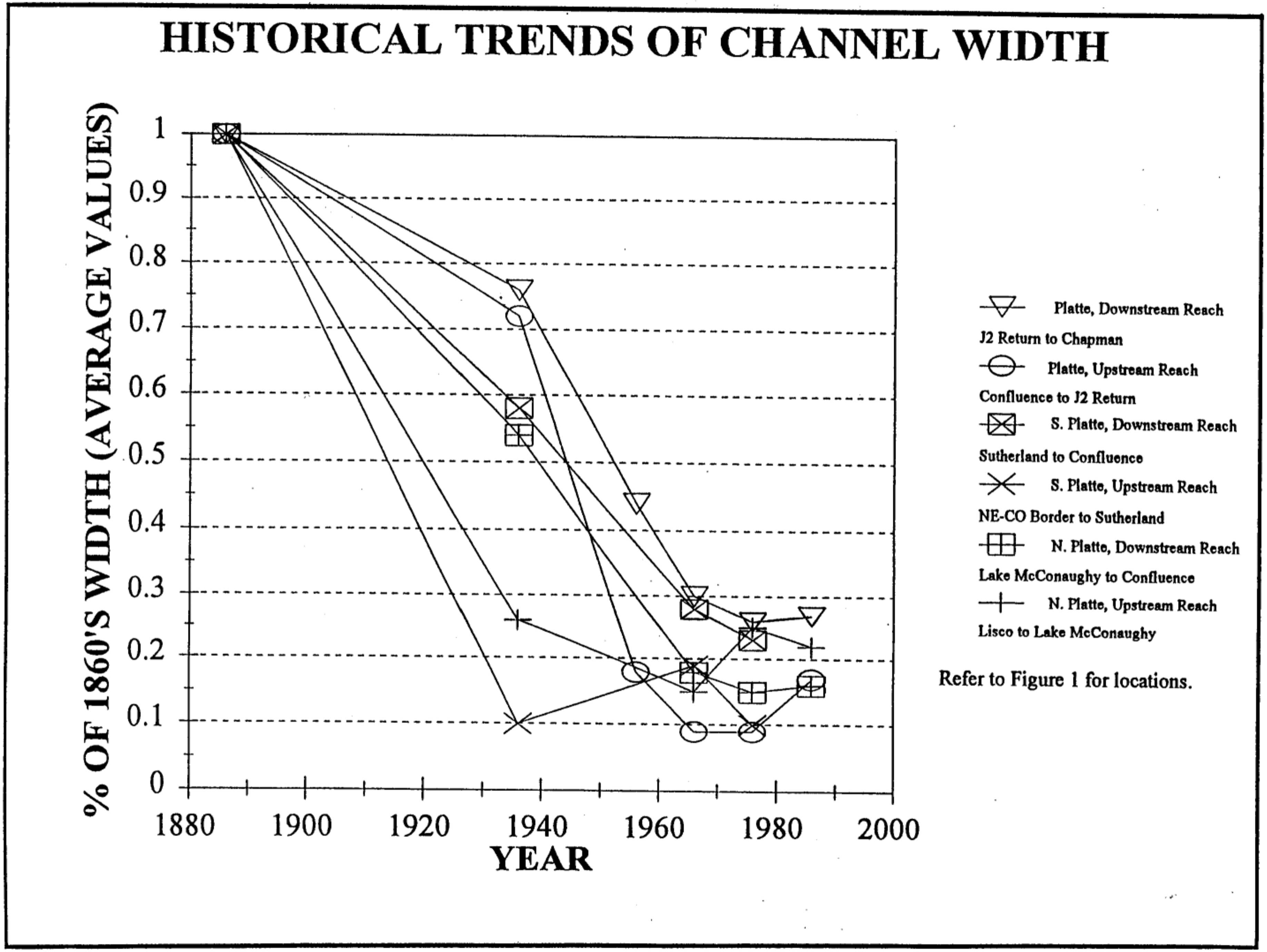
HISTORICAL TRENDS OF CHANNEL WIDTH
% OF 1860'S WIDTH (AVERAGE VALUES)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1880
1900
1920
1940
1960
1980
2000
YEAR
Platte, Downstream Reach
J2 Return to Chapman
Platte, Upstream Reach
Confluence to J2 Return
S. Platte, Downstream Reach
Sutherland to Confluence
S. Platte, Upstream Reach
NE-CO Border to Sutherland
N. Platte, Downstream Reach
Lake McConaughy to Confluence
N. Platte, Upstream Reach
Lisco to Lake McConaughy
Refer to Figure 1 for locations.

Figure 2.23

causes for the changes in riparian vegetation (see section 4.2). The common belief regarding the status of riparian vegetation along the pre-development Platte River is that very little woody vegetation existed. In recent material prepared for the litigation between Nebraska and Wyoming in the Supreme Court, Ellis et al. (1998), citing previous studies conducted on the subject from the 1970's to the mid-1990's, states:

> *Prior to extensive Euro-American settlement, the channels of both the Platte and North Platte rivers were wide, sandy, and with the exception of a few large islands, generally unvegetated west of the confluence of the Loup and Platte Rivers.*

This view is in conflict with the numerous accounts of thousands of wooded islands presented in the previous section. While it is true that the floodplain would be characterized as a prairie with associated dominance of herbaceous vegetation, and the river did not flow through generally forested areas typical of many rivers of the eastern United States; those who observed the river made note of the vegetation that did exist, as previously described on islands of all sizes. In a report by Johnson (1989), he presents results of his analysis of historic accounts, GLO surveys and notes. This analysis demonstrates that there was a significant amount of riparian vegetation along the pre-development Platte River. Johnson demonstrates why the GLO plat maps *"poorly represent the actual mix of islands that occurred in the pre-settlement Platte, North Platte and South Platte Rivers."* This was due to the fact that, *"Surveyors had a general bias against surveying small islands, therefore, they are virtually absent from plat maps, despite frequent written reference to them in general descriptions of the river."* In fact, an example of a surveyor in 1865 made a statement as cited by Johnson and Boettcher (1999) regarding the state of vegetation, *"the greater part of the timber is on the small islands in the Platte River. There are many small islands in the river covered with timber and undergrowth..."* Regarding the more general issue of trees along the Platte River, they go on to say that,

> *The GLO field notes clearly show that numerous trees of several species were able to grow and actually thrive in the Platte River and its tributaries. This does not support the view that peak flows or summer drought in the presettlement river were so severe as to essentially prohibit trees from establishing. Tree seedlings did survive presettlement disturbances in thousands of places in the river to have become trees by the time of the survey.*

Many witness trees used by the surveyors are found on the floodplain adjacent to the river. Thus, the data show that there were a number of trees along the rivers and on islands of the Platte River in its pre-development state with respect to water resources.

It is the contention of Johnson and Boettcher (1999) that the previous studies characterizing the Platte River as being generally unvegetated are distorted because,

> *Prior treatments of the presettlement vegetation of the Platte, however, have overlooked the best single historic source of reliable, quantitative information.... the field notes of the original government land survey. These notes and associated maps from 1859-1866 in central Nebraska depict a surprisingly well-timbered Platte River undergoing deforestation.*

Johnson and Boettcher (1999) cite three major factors that removed significant quantities of trees from the banks of the Platte River.

> *Most of the historic resources (particularly photographs) which support the claim that the natural Platte was sparsely wooded or unwooded were recorded well after westward migration and initial settlement, when any timber, had it existed, would have been depleted or used up. Moreover, such sources postdated three major events which impacted the central Platte's forest resources: the westward passage of thousands of pioneers along the "Great Platte River Road (1847-1866)," the building and maintenance of Ft. Kearney (1848-1871), and the laying of track for the transcontinental railroad in the late 1860's. Considerable exploitation of local timber and fuelwood supplies would have resulted from these activities.*

For example, regarding general timber cutting and use, Johnson and Boettcher (1999) provide the following information supporting the fact that significant cutting of the forest occurred in the mid- to late 1800's. They cite material from the GLO survey notes in the following material.

> *Perhaps the most significant entry regarding wood utilization in the Grand Island area (Township 10, Range 9) was "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 (1866)." Thus, the woodland, although surprisingly extensive compared to recent writings, appears to represent only a portion of that supported naturally by the river environment.*

Regarding the specific effect of railroad construction on timber resources, Johnson and Boettcher (1999) cite W. Stolley's account:

> *With the building of the Union Pacific Railroad, which reached our settlement in the summer of 1866, conditions changed radically... A band of lawless and disorderly people that was let loose by the railroad company, promptly cut down all trees big enough to furnish ties for the railroad... Wherever trees stood, they were taken by these railroad bandits.*

Another factor that adversely affected riparian vegetation along the banks of the Platte River was prairie fires. Fire has been mentioned as a factor that may have limited the extent or quantity of riparian vegetation, Eschner et al. (1983 and citations mentioned in their report of observers in the 1800's). Mattes (1969) states, *"Here was a river without trees on its banks because frequent prairie fires took out the seedlings. But because these fires could not ravage the islands, so timber--mainly willow, cottonwood, and poplar--grew there freely."* It has been suggested that Indians living in the vicinity of the Platte River frequently set prairie fires. Lewis and Clark (de Golia, 1989) noticed many fires across the country set by Indians. Indians used fire as a tool for hunting (to drive bison and to eliminate dry, brown grass thereby re-generating new green grass) and war (to burn out enemy tribes and in controlled burns to prevent themselves from being burned out). While undoubtedly some riparian vegetation has been eliminated by fire, the typical riparian vegetation along the Platte River consisting of cottonwoods and willows does not easily succumb to fire. Rood (1999, personal communication) indicated that current research (in process of publication) shows that such vegetation generally survives prairie fire. Old, nearly dead trees that have dried can certainly burn, but healthy growing trees frequently survive fire. He noted observations of cottonwoods that had experienced fire on three occasions over approximately 100 years were still alive. The research does confirm that young seedlings can be killed by fire, as previously discussed. Based on this information, fire likely removed some old, nearly dead trees and young seedlings but that trees in the broad middle spectrum of age could survive prairie fires. Currier's experience (2000, personal communication) is that burns in 3 out of 10 years can kill large cottonwoods based on observation of the effect of controlled burns. If prairie fires occurred frequently enough and over a broad enough geographic extent, this phenomenon could have potentially prevented a significant portion of the population of seedlings from surviving and growing to maturity. While the effect of fire could be considered significant, it is not possible to quantify the effect of fire on riparian vegetation.

One natural factor other than flow and climate that affected vegetation along the Platte River was buffalo. Buffalo, in great numbers, roamed this area trampling and eating younger riparian vegetation. Based on this type of information, it is thought that buffalo provided some significant controlling effect to riparian vegetation along the banks of the Platte River.

The conclusion reached by evaluation of this wide variety of sources regarding vegetation on the Platte River is that islands of all sizes were densely vegetated as documented by numerous observations referenced in this and the previous section, as well as Johnson and Boettcher's assessment stating, *"Thus, at the time of the survey, the Platte was well-wooded on its numerous small islands, banks, and large island exteriors."* Regarding the condition of vegetation along the banks of the Platte River, the available information indicates that there was a significant but lesser amount of riparian vegetation compared to the islands at the time of most observers. The reduced amount of riverbank vegetation was attributed to several anthropogenic causes (cutting for fuel, construction materials, and the railroad as well as prairie fire - to the extent fires were deliberately set) and damage by buffalo. This again was the conclusion reached by Johnson and Boettcher (1999), *"Fewer trees were recorded on the outermost riverbanks, which were exposed to prairie fires and were nearer trails that provided access to woodcutters."*

In light of the evaluation of historic conditions described above, it is difficult to conclude, as so many have, that the Platte River was largely devoid of woody vegetation prior to significant water resources development. Again, the perception of a river without much riparian vegetation is based on conditions after various anthropogenic factors had already reduced the natural amount of vegetation supported by the river without water resources development and other anthropogenic factors. Based on the GLO survey information pre-dating the destruction of significant quantities of vegetation and the earliest descriptions of the river, one must conclude that there was a substantial amount of riparian woody vegetation along the Platte River under natural conditions with densely vegetated islands of all size and a significant but more limited amount of vegetation along the riverbanks. Part of the perception of the Platte River being poorly vegetated may also come from the fact that there are few braided rivers in a semi-arid climate existing in eastern regions of the country. Thus, those viewing the Platte River for the first time in travelling west had not likely encountered a wide, shallow, braided river with only a limited band of riparian vegetation on a small portion of the floodplain, rather than forested valleys more typical of meandering streams in more humid regions farther east. While it is likely that riparian vegetation along the Platte River was restricted to a relatively narrow zone in a transition area of floodplain between the active channel and upland/grassland that dominated the land surface and the numerous islands within the river banks, nonetheless, the information suggests a substantial riparian woodland existed along the river system under pre-settlement and pre-water resources development conditions considering the braided character of the Platte River. Thus, in developing an understanding of habitat conditions for threatened and endangered birds under pre-development conditions, the effect of woody riparian vegetation on islands of all sizes and along the banks must be factored in to the evaluation. While active channel widths between areas of vegetation on islands and on the banks were considerably greater under pre-development conditions compared to current conditions, such widths were still limited to some degree at the riverbanks and adjacent to islands where woody vegetation existed.

2.7 Summary of Pre-Development Conditions

The following table (Table 2.4) summarizes the pre-development conditions of the Platte River based on the material presented in this chapter.

Table 2.4 Summary of Pre-Development Conditions

Factor	Description of Condition
Annual Flow	~ 2.8 maf [1]
Peak Flow	~15,000 to 45,000 cubic feet per second, averaging ~16,000 cfs [1]
Periods of No Flow	No flow occurred along significant reaches of river on numerous occasions during the summer months
Bed Material	Sand with a median diameter of ~0.41 mm
Bed Forms	Shifting bars, described as continually changing forms with short offsets like shingles on a roof
Sediment Load	Large sediment load with the river described as being muddy and turbid (7.8 million tons per year)[2]
Channel Classification	Braided with sand bars and wooded islands
Total Channel Width	1 to 2 miles (Predominantly, with some areas being narrower as well as wider)
Active Channel Width	Estimated to be ~90% of total channel width
Riparian Vegetation	Densely wooded islands (primarily willow and cottonwood) with a relatively narrow and relatively sparser band of vegetation along the banks. Vegetation estimated to occupy ~10% of total channel width. Vegetation on riverbanks limited, to some degree, by prairie fires and buffalo.[3]

[1] Based on pre-1930 data that include some water resources development. Prior to any water resources development, the actual pre-development condition would be expected to have been somewhat higher.

[2] Based on measured sediment trapping in reservoirs and estimated transport based on current sediment transport/flow regressions and estimated pre-development flow data. The estimate has been characterized by those who made it as "crude."

[3] Note that by the latter portion of the 1800's, a significant portion of the riparian woodlands that had existed under natural conditions had been cut down due to three major factors: 1) the westward migration of thousands of pioneers, 2) construction of Fort Kearney and other buildings, and 3) railroad construction. Note also that prairie fires were often deliberately set by Indians, thereby causing some artificial control of vegetation along the riverbanks.

3.0 Current Baseline Conditions

3.1 Current Level of Water Resources Development

3.1.1 Canals

The previously referenced table (2.1) shows that most canal construction occurred in the late 1800's and early 1900's. To our knowledge, no significant canal construction (if any) has occurred in recent decades. Thus, it appears that the status of canals and associated diversions has remained relatively constant (within the normal bounds of hydrologic variability) for a significant period of time (several decades).

3.1.2 Dams and Reservoirs

Figure 2.7 (previously referenced) showed that most of the dams and reservoirs constructed in the Platte River Basin were constructed in the early to mid-1900's. The most recent reservoirs constructed in the basin were built in the 1970's (Chatfield, Cherry Creek, Bear Creek, and Grayrocks). No dams and reservoirs have been constructed since that time. The total storage capacity of the reservoirs in the Platte River Basin has essentially remained constant for about four decades since the size of those reservoirs built in the 1970's were not large compared to the total volume of storage in existing reservoirs. Thus, for all practical purposes, the reservoir storage capacity has not increased significantly since the late 1950's.

3.2 Flow Characteristics

As discussed above, the system of diversions, canals, and reservoirs has not changed significantly for several decades. Thus, the flow as well as the river has had some time to have adjusted to the significant development which generally preceded these most recent decades. An analysis of flow, groundwater levels, and gains/losses to the river (Simons & Associates, 1988) indicated that the hydrologic system has reached a general status of equilibrium by the end of the 1960's. Since that time, except for some possible continued increase in groundwater use, it appears that the future flow regime is reasonably represented by data starting after about 1970. Thus, assuming no significant change in operation or new project construction in the future, the recent 30 years of data provide the best available representation of current and future hydrologic conditions. Some information is now presented comparing current flow conditions in several categories for the recent time period with previous time periods. These time periods are: pre-1930's, 1930-1970, and post-1970. These time periods basically reflect: a period when most of the diversions were constructed along with approximately the first one-third of the total reservoir storage volume, progressive development to near current conditions including most of the remaining two-thirds of the total reservoir storage combined with major droughts of the 1930's and 1950's, and the state of current water resources development, respectively. The pre-1930's data set extends back to the beginning of the record at each gage. These beginning dates are different at each gage making a direct comparison of gages difficult. A graphical summary of recent flow parameters is presented to show the current flow conditions. The gages selected for such presentation are again the North Platte at North Platte, the South Platte at Julesburg, and the Platte at Overton and Grand

Island. These gages were selected to provide information on the main tributaries as well as the Platte River itself at locations with long periods of record.

3.2.1 Annual Flow

The total annual flow was compared for the various periods described above. Table 3.1 presents this summary averaging total annual flow for these time periods.

Table 3.1 Average Total Annual Flow (acre-feet)

Station	Pre-1930	1930-1970	1970-1998
North Platte at North Platte	2,262,852	590,161	654,866
South Platte at Julesburg	383,607	298,172	495,649
Platte at Overton	2,754,666	927,027	1,366,717
Platte at Grand Island	N/A	733,462	1,376,205

The table shows the significant reduction in total annual flow for the time periods after 1930 compared to the pre-1930 time period (more significant reductions occurred in the historic record on the North Platte and Platte Rivers compared to the South Platte). The average total annual flow 1930-1970 is particularly low due to reservoir construction and filling as well as the two major droughts of the 1930's and 1950's. From 1970-1998 the average total flow is greater due to the relatively wetter periods in the early 1970's and 1980's.

Figures 3.1-3.4 present graphs of the total annual flow for the time period from 1970 to 1998. No discernable trend is evident over this period of almost 30 years. This reflects the fact that no significant new water resources development occurred during this time period. The relatively wetter periods, as described above, are evident on these graphs.

3.2.2 Peak Flow

The peak flow was compared for the various time periods described above. Table 3.2 presents this summary of peaks averaged for these time periods.

Table 3.2 Average Peak Flow (cfs)

Station	Pre-1930	1930-1970	1970-1998
North Platte at North Platte	14,182	3,197	3,411
South Platte at Julesburg	5,677	4,955	5,365
Platte at Overton	16,325	6,362	7,878
Platte at Grand Island	N/A	8,195	8,632

The table shows the significant reduction in average peak flow for the time periods after 1930 compared to the pre-1930 time period (more significant reductions occurred in the historic record on the North Platte and Platte Rivers compared to the South Platte). The average peak flow is somewhat greater in the most recent time period compared to 1930-1970.

Figures 3.5-3.8 show a graph of the peak flow for the time period from 1970 to 1998. No discernable trend is evident over this period of almost 30 years other than the cyclical nature of wet and dry periods.

3.2.3 Seasonal Pattern of Mean Daily Flow

The seasonal pattern of mean daily flow for the recent time period (1969-1998) is presented in Figures 3.9-3.10. Starting in October, the flow remains relatively steady through the fall. During winter, the flow rises and remains relatively high through the spring. Peak flow generally occurs in June, associated with snowmelt runoff. During the summer, the flows decline to their lowest magnitudes of the year before rising again as fall approaches.

3.2.4 Flow-Duration Analysis

Kircher and Karlinger (1983) developed flow-duration curves for a number of stations along the North Platte, South Platte, and Platte Rivers. They subdivided the data into 10-year increments to illustrate the progression of hydrologic change that has occurred in the basin. Their analysis ended in 1979 but shows the effect of water resources development. They noted relatively little change in the South Platte, a general reduction of high flows in the North Platte, and an increase in flows in the low flow range in the Platte River (attributed to irrigation return flows or controlled releases from reservoirs that maintain streamflow during low-flow periods). Figures 3.11 through 3.14 present an extension of this analysis using more recent data (through 1994) for the South Platte at Julesburg, the North Platte at North Platte, the Platte at Overton, and at Grand Island. In general the most recent decades as shown on the graphs (for 80-89 and 90-94) are quite similar to the curves presented by Kircher and Karlinger. Again, on the Platte River gages, the low flow spectrum is significantly different in more recent years compared to the earlier decades with a general increase in low flow.

3.2.5 Flood-Frequency Analysis

Flood-frequency analyses were conducted for several stations in the basin. Figures 3.15 through 3.17 show the associated flood-frequency curves for the respective periods of record at each station. Table 3.3 summarizes the results of the analyses for a typical range of return periods.

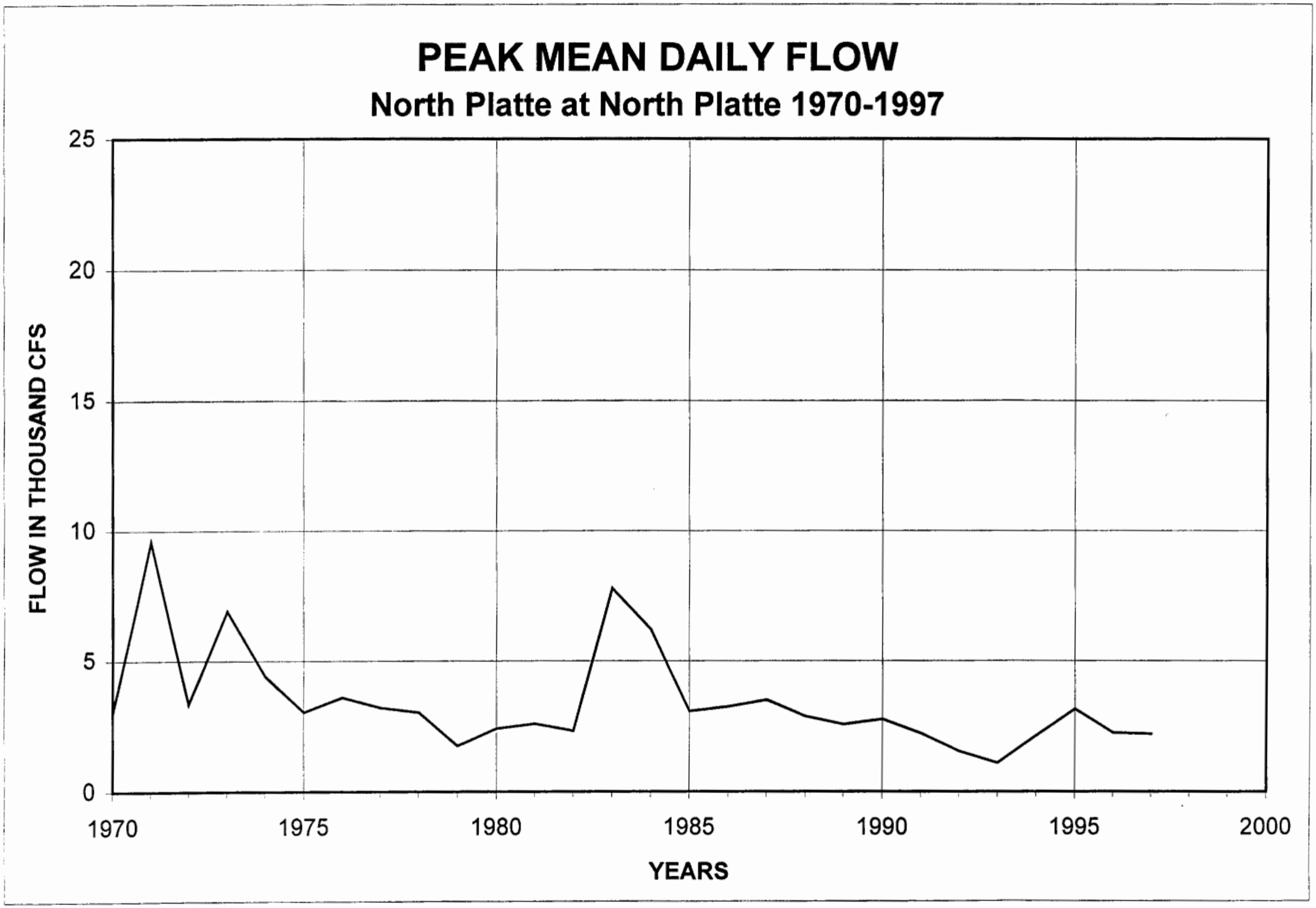

PEAK MEAN DAILY FLOW
North Platte at North Platte 1970-1997
FLOW IN THOUSAND CFS
25
20
15
10
5
0
1970
1975
1980
1985
1990
1995
2000
YEARS

Figure 3.1

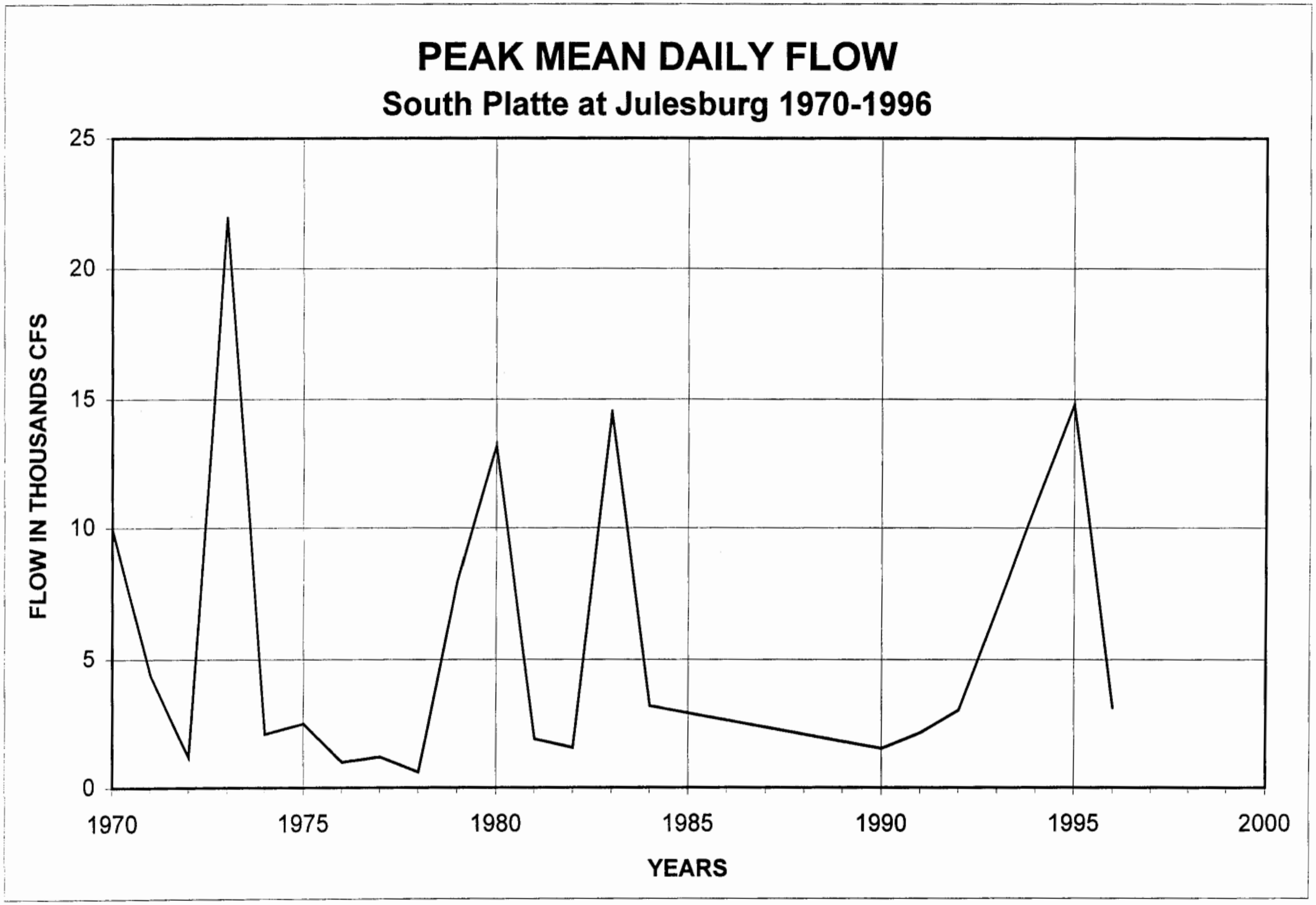

PEAK MEAN DAILY FLOW
South Platte at Julesburg 1970-1996
FLOW IN THOUSANDS CFS
25
20
15
10
5
0
1970
1975
1980
1985
1990
1995
2000
YEARS

Figure 3.2

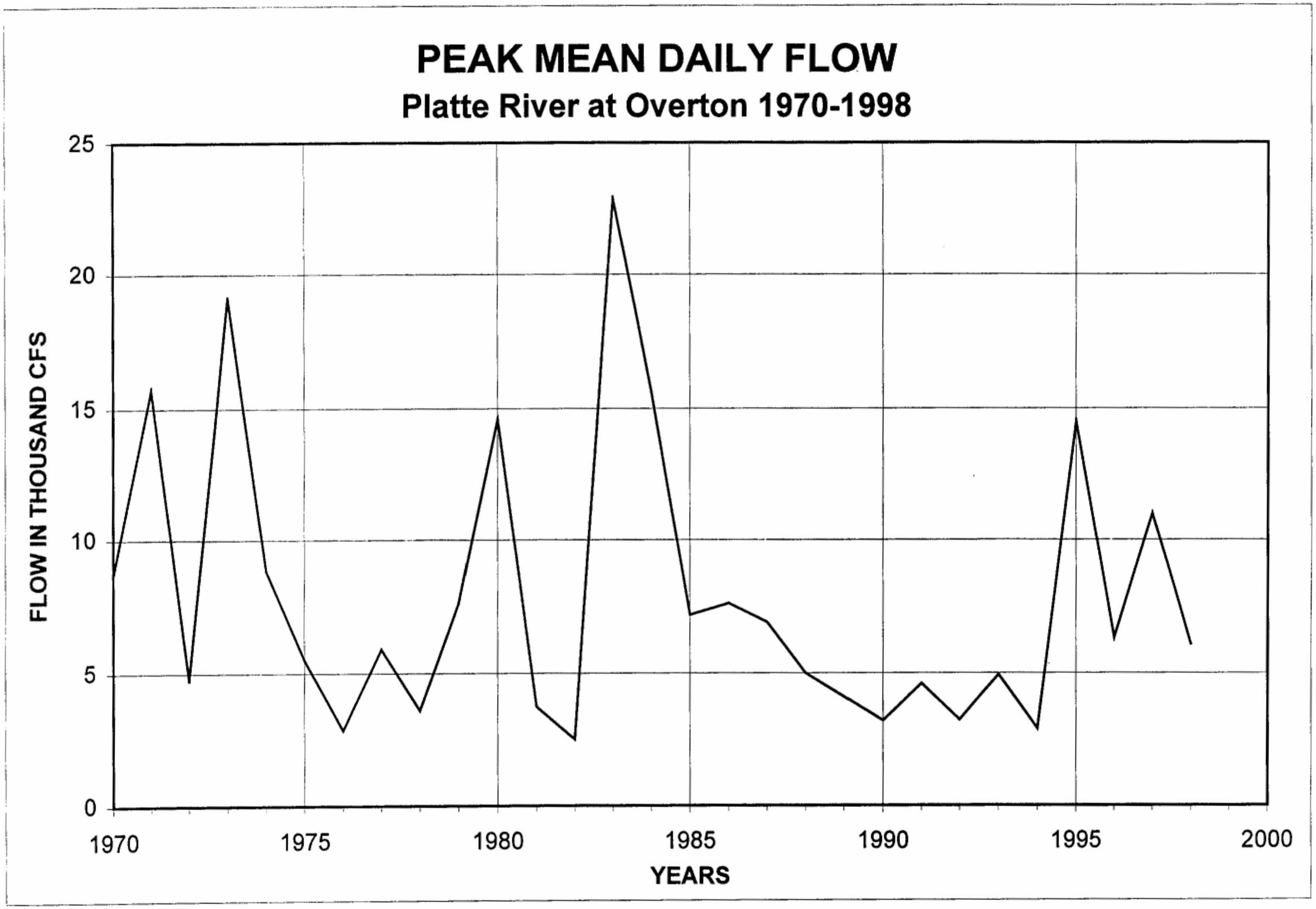

PEAK MEAN DAILY FLOW
Platte River at Overton 1970-1998
FLOW IN THOUSAND CFS
25
20
15
10
5
0
1970
1975
1980
1985
1990
1995
2000
YEARS

Figure 3.3

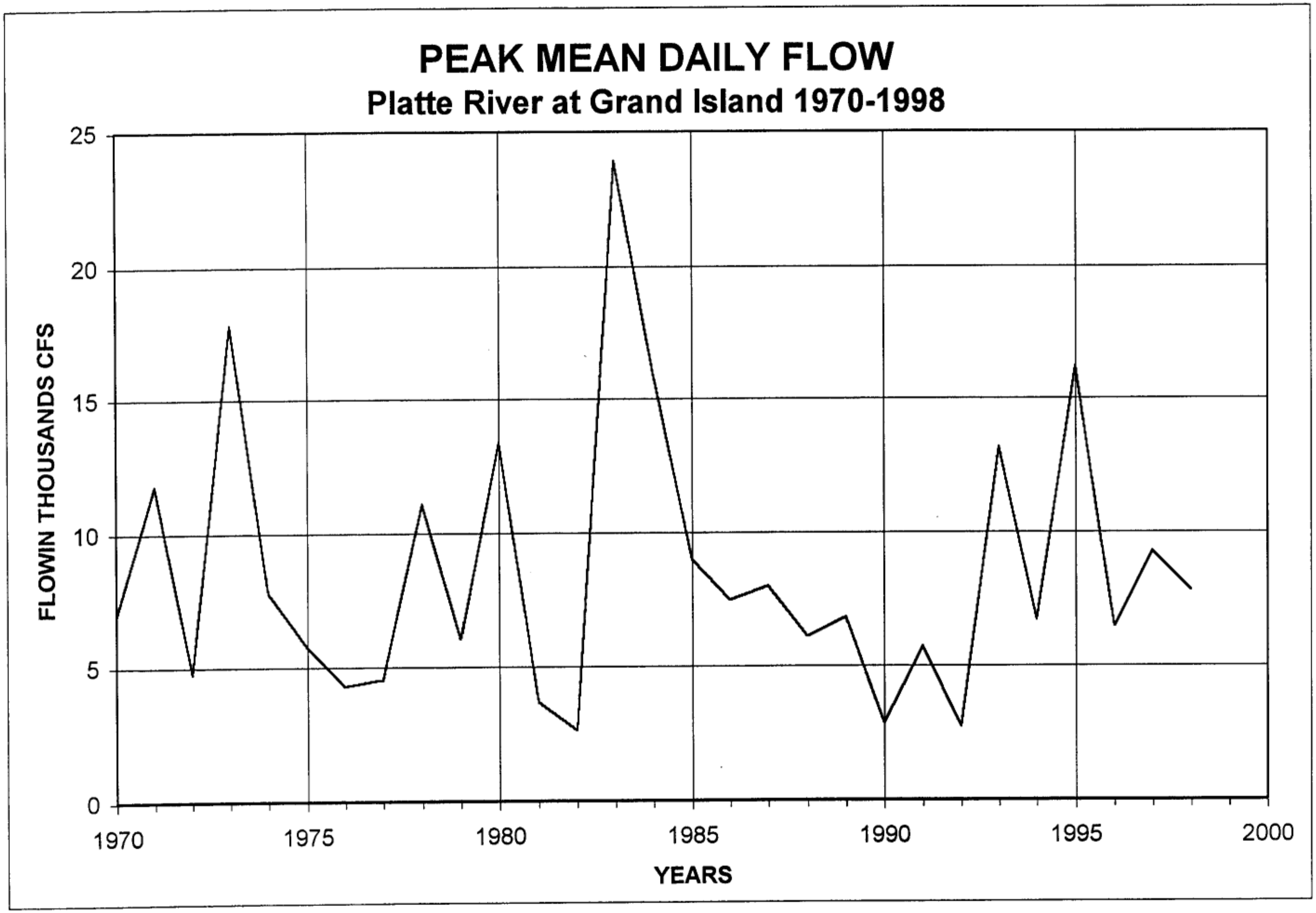

PEAK MEAN DAILY FLOW
Platte River at Grand Island 1970-1998
FLOWIN THOUSANDS CFS
25
20
15
10
5
0
1970
1975
1980
1985
1990
1995
2000
YEARS

Figure 3.4

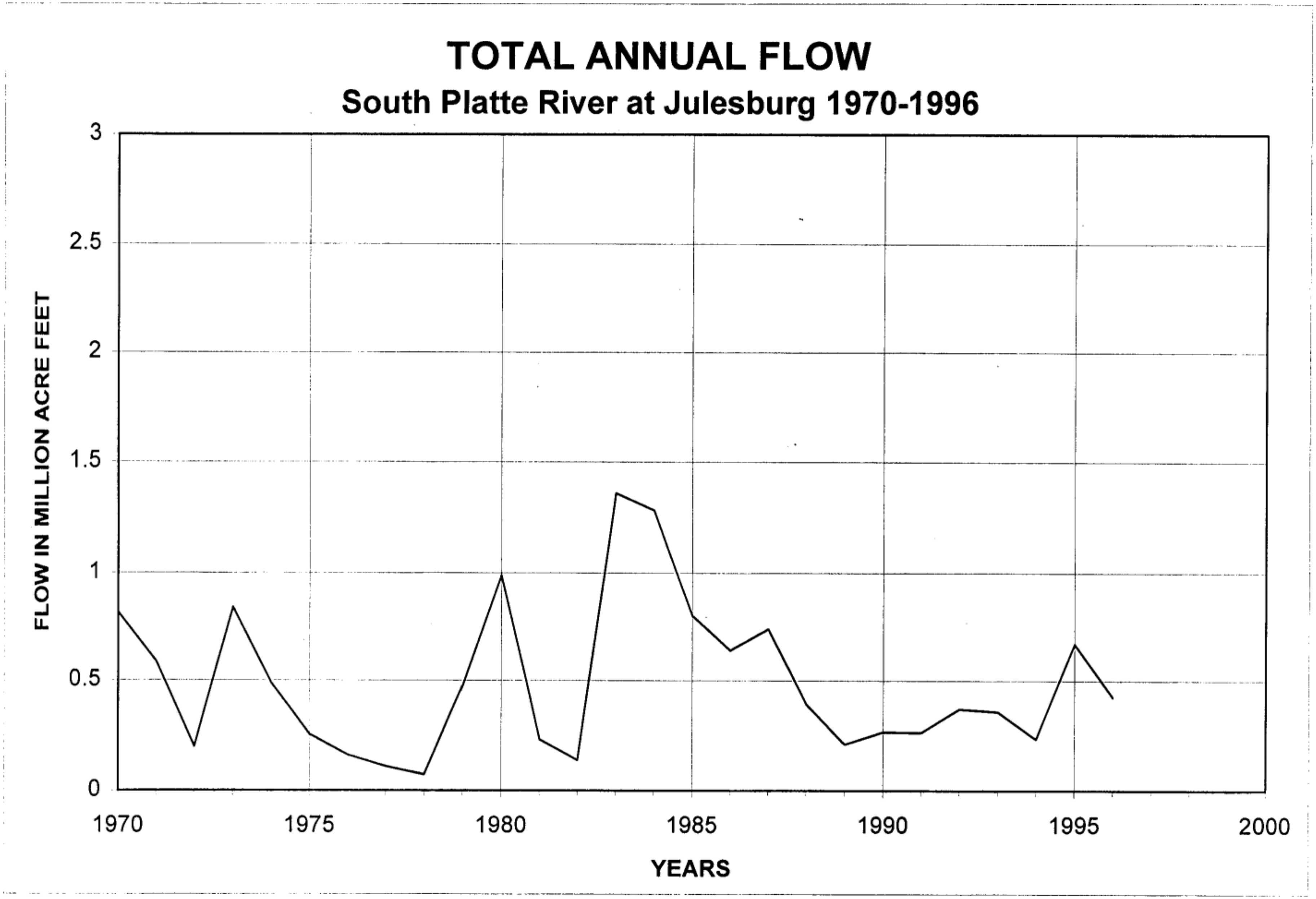
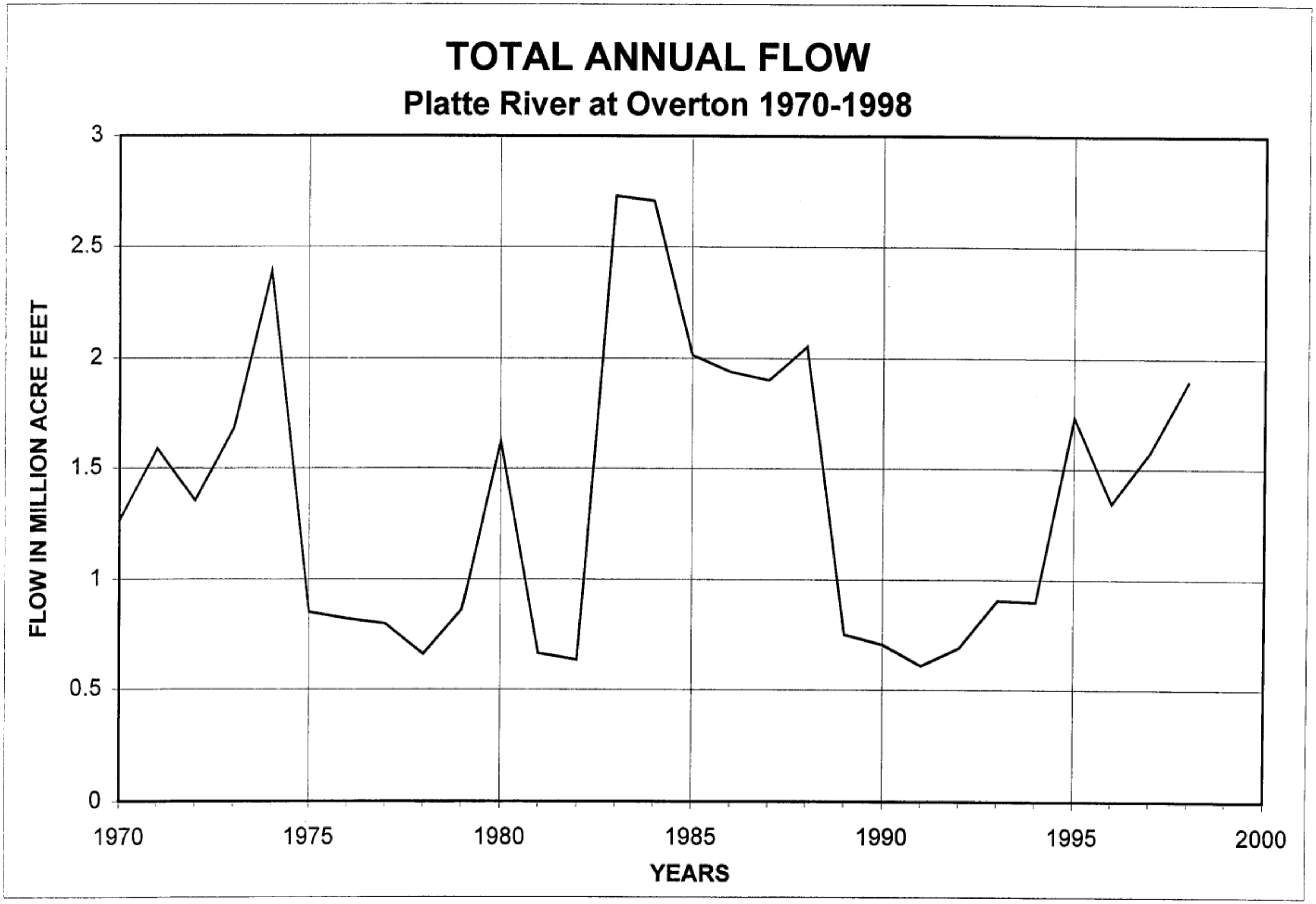

TOTAL ANNUAL FLOW
South Platte River at Julesburg 1970-1996
FLOW IN MILLION ACRE FEET
3
2.5
2
1.5
1
0.5
0
1970
1975
1980
1985
1990
1995
2000
YEARS

Figure 3.6



TOTAL ANNUAL FLOW
Platte River at Overton 1970-1998
FLOW IN MILLION ACRE FEET
YEARS
0
0.5
1
1.5
2
2.5
3
1970
1975
1980
1985
1990
1995
2000

Figure 3.7

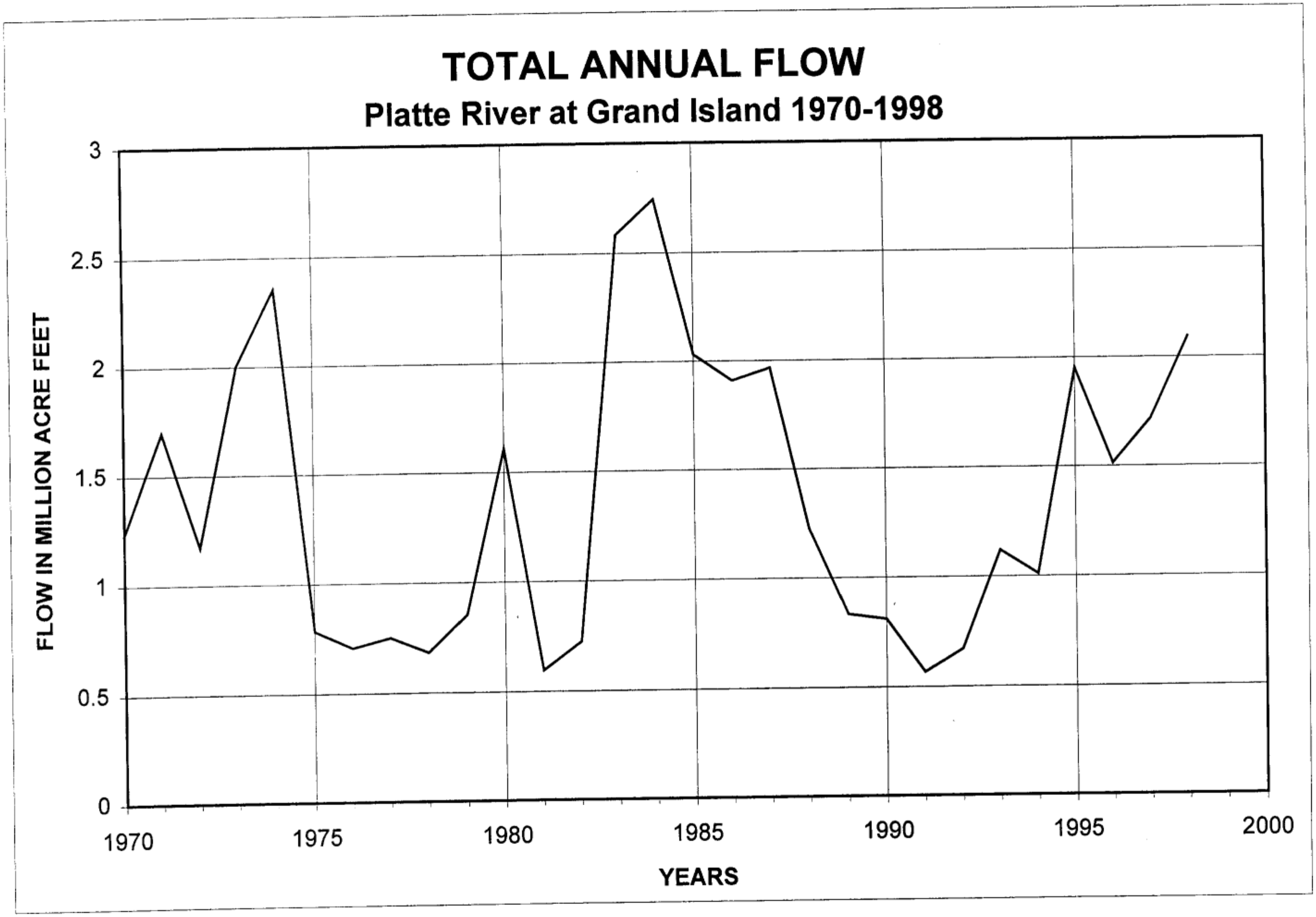

TOTAL ANNUAL FLOW
Platte River at Grand Island 1970-1998
FLOW IN MILLION ACRE FEET
3
2.5
2
1.5
1
0.5
0
1970
1975
1980
1985
1990
1995
2000
YEARS

Figure 3.8

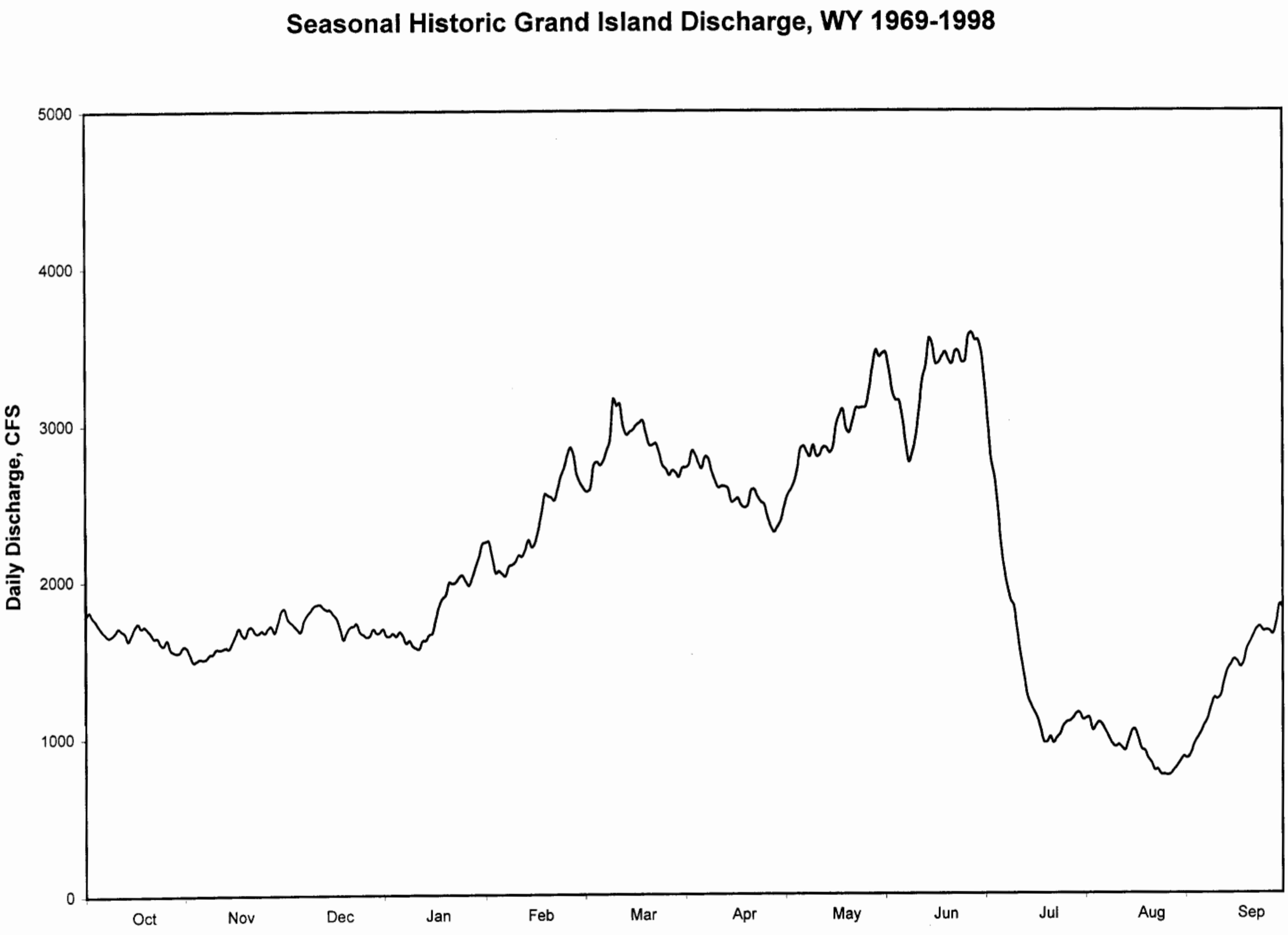

Seasonal Historic Grand Island Discharge, WY 1969-1998
Daily Discharge, CFS
5000
4000
3000
2000
1000
0
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep

Figure 3.9

Seasonal Historic Overton Discharge, WY 1969-1998

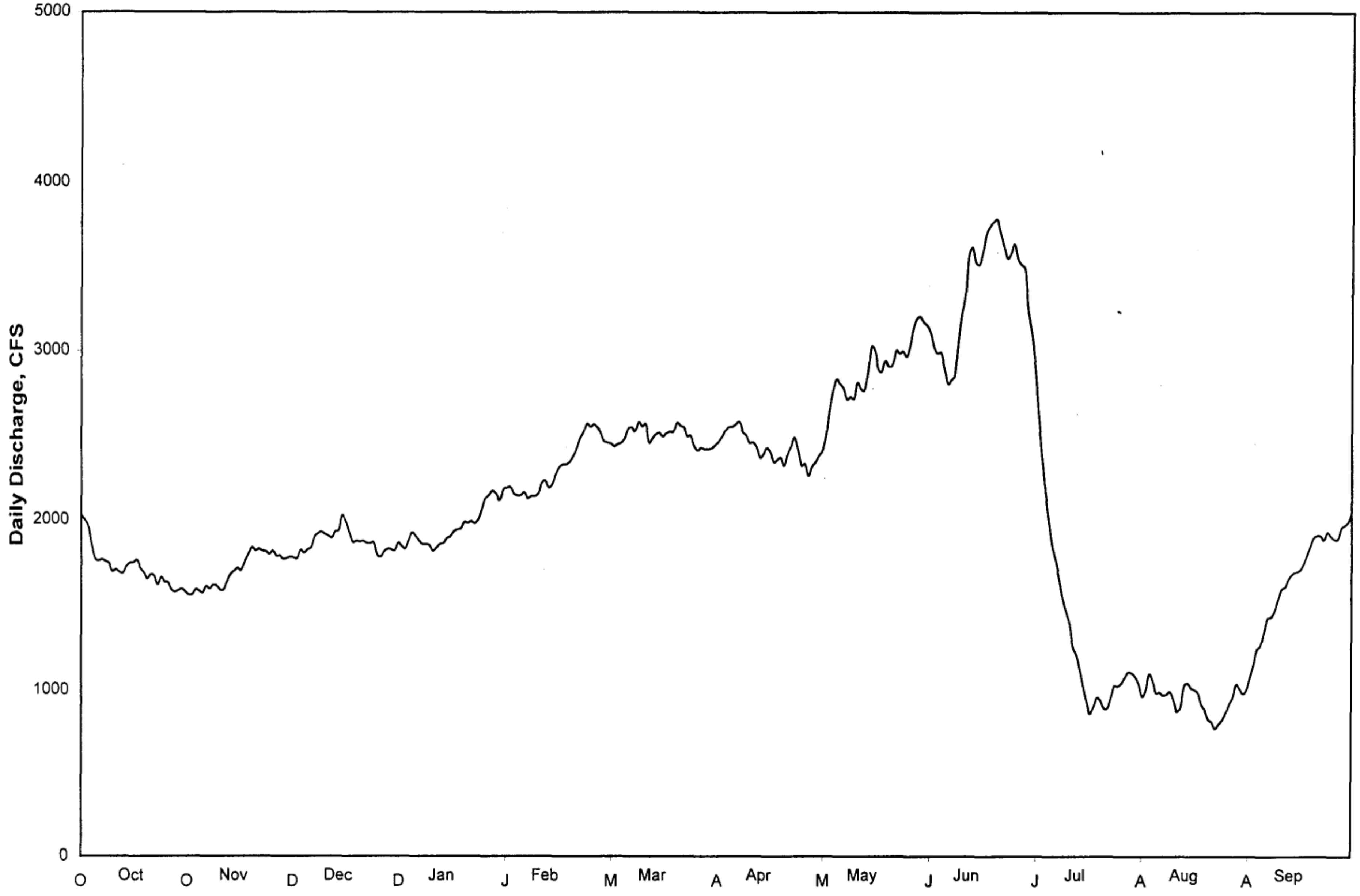


Figure 3.10

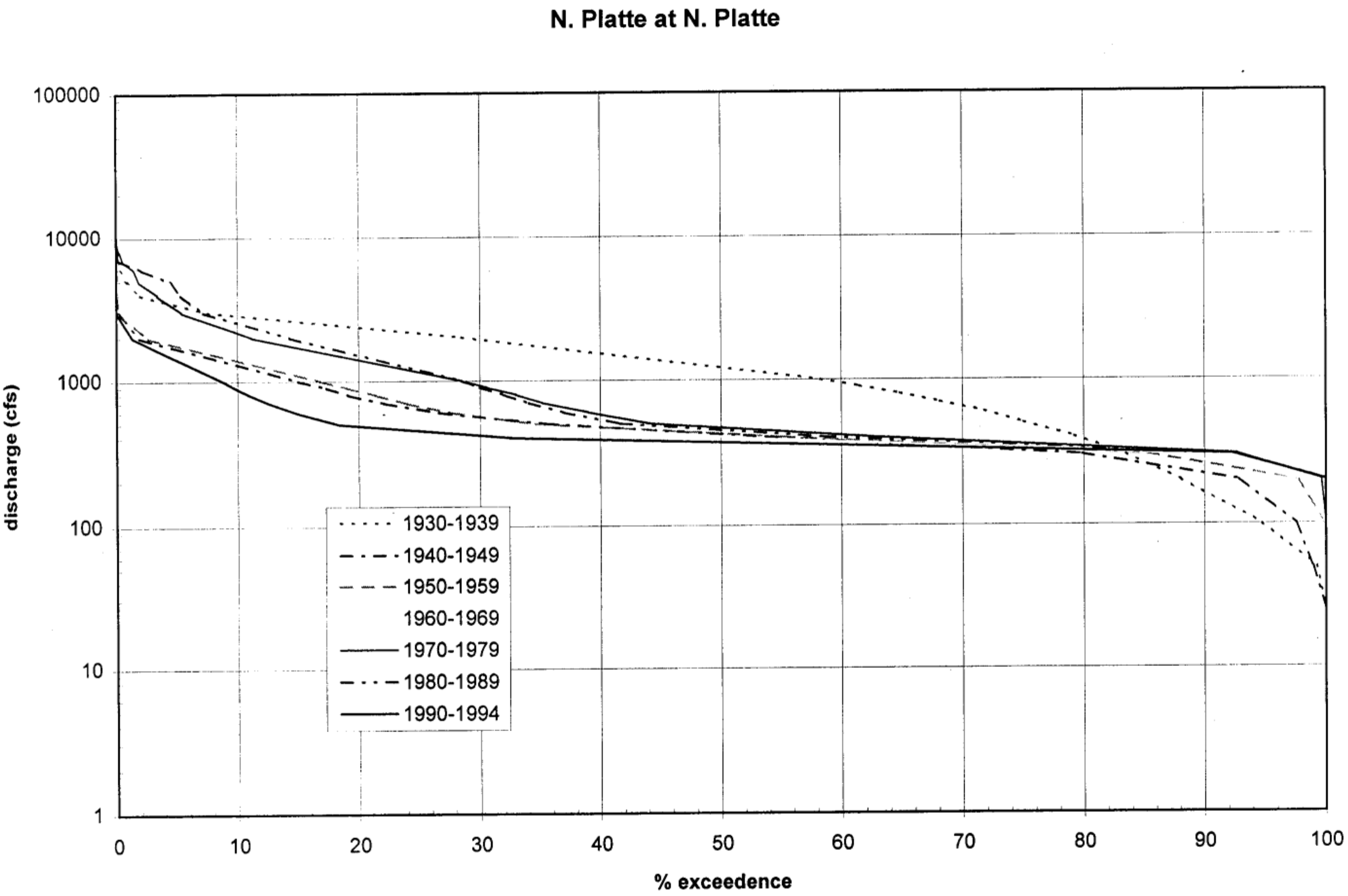

N. Platte at N. Platte
discharge (cfs)
100000
10000
1000
100
10
1
0
10
20
30
40
50
60
70
80
90
100
% exceedence
1930-1939
1940-1949
1950-1959
1960-1969
1970-1979
1980-1989
1990-1994

Figure 3.11

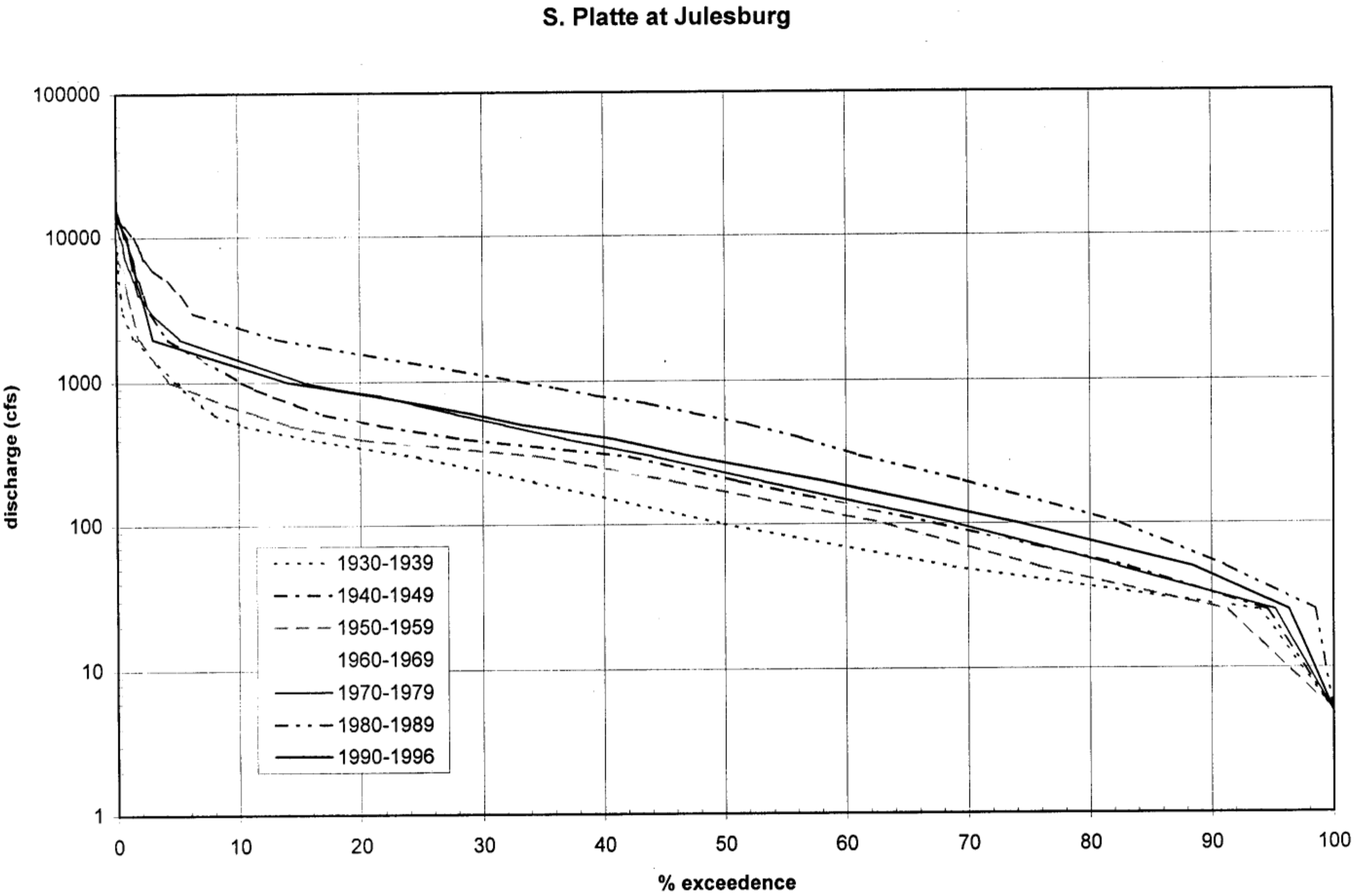

S. Platte at Julesburg
100000
10000
1000
100
10
1
discharge (cfs)
0
10
20
30
40
50
60
70
80
90
100
% exceedence
1930-1939
1940-1949
1950-1959
1960-1969
1970-1979
1980-1989
1990-1996

Figure 3.12

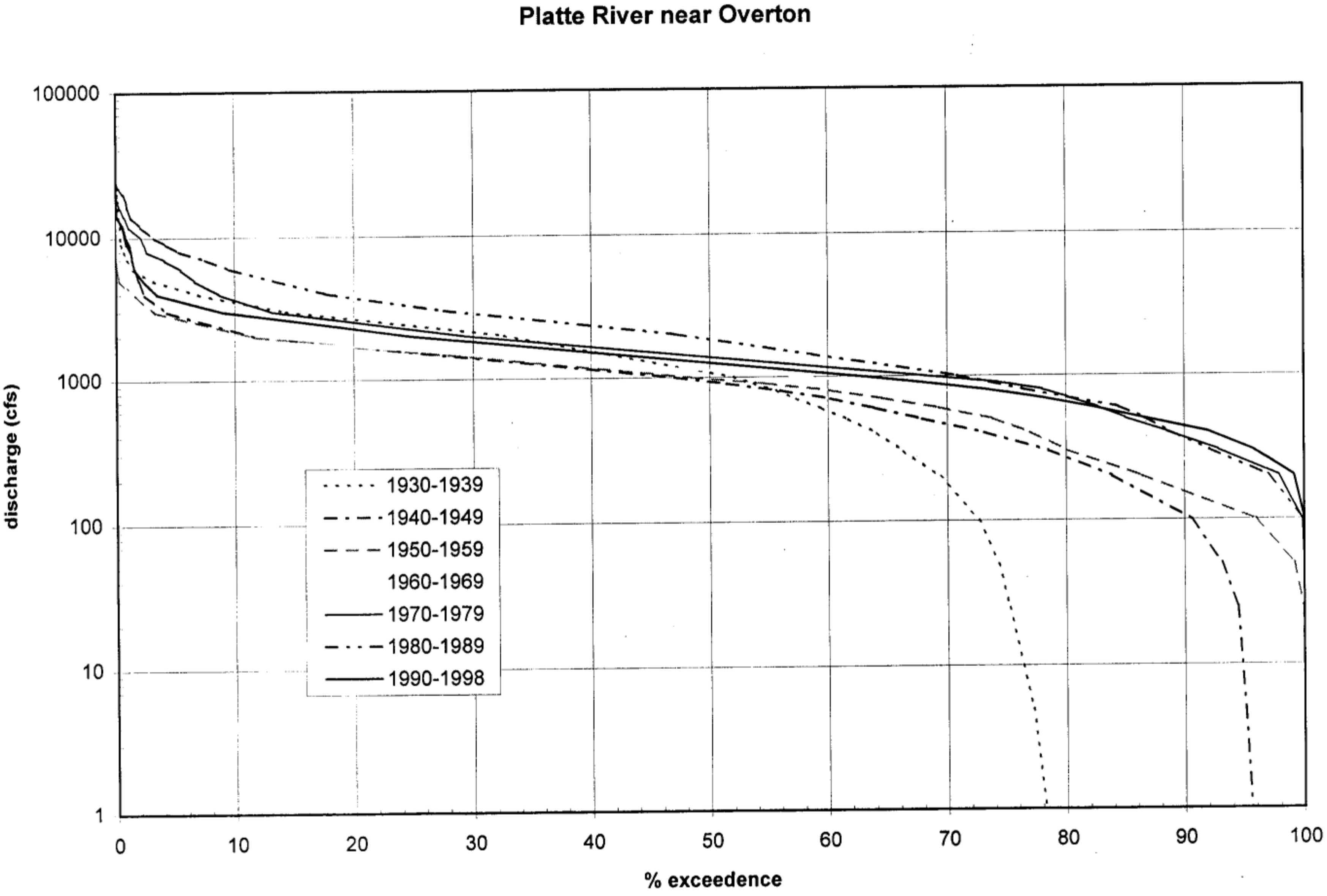

Platte River near Overton
100000
10000
1000
100
10
1
discharge (cfs)
0
10
20
30
40
50
60
70
80
90
100
% exceedence
1930-1939
1940-1949
1950-1959
1960-1969
1970-1979
1980-1989
1990-1998

Figure 3.13

Platte River near Grand Island

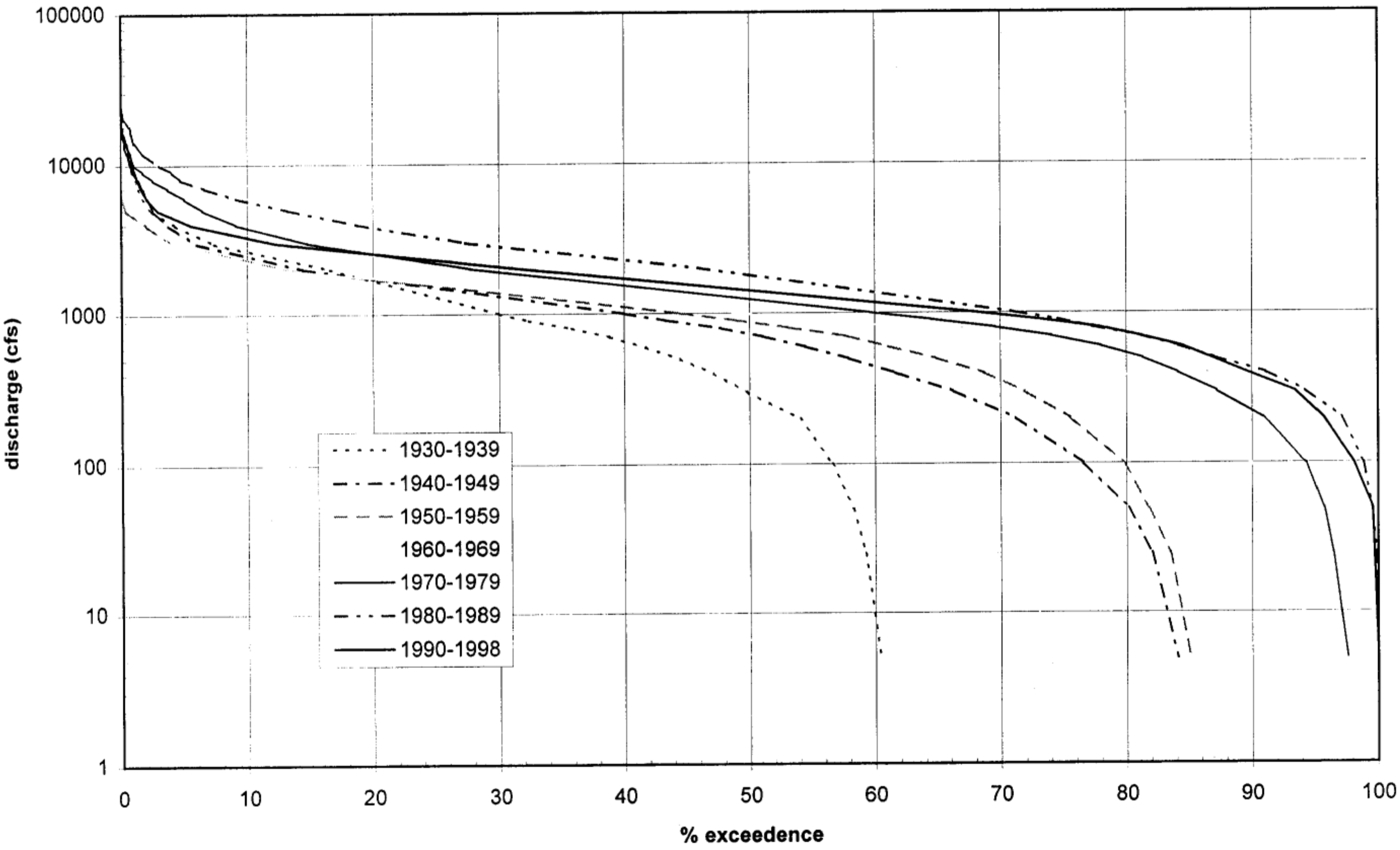
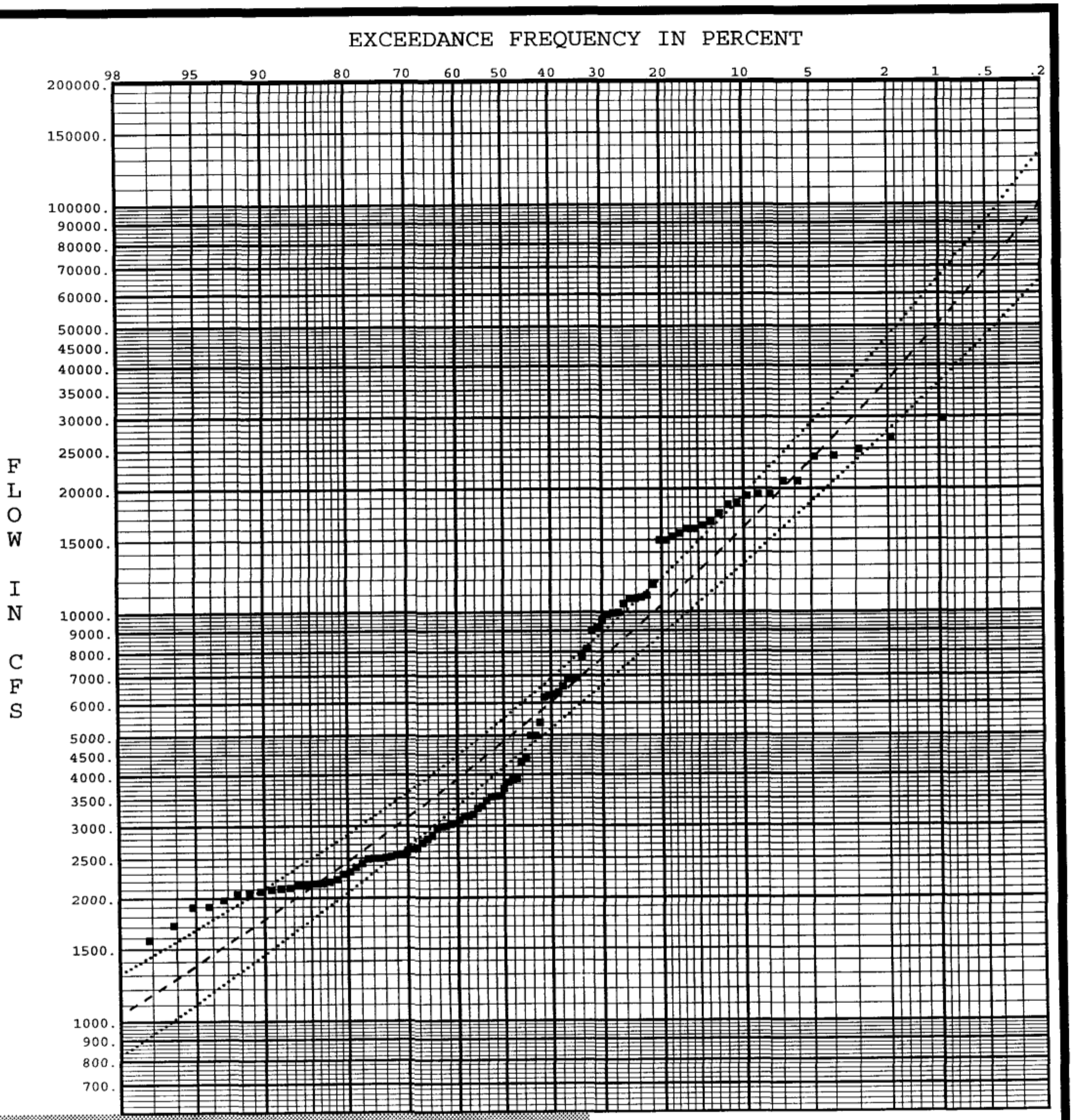


Figure 3.14



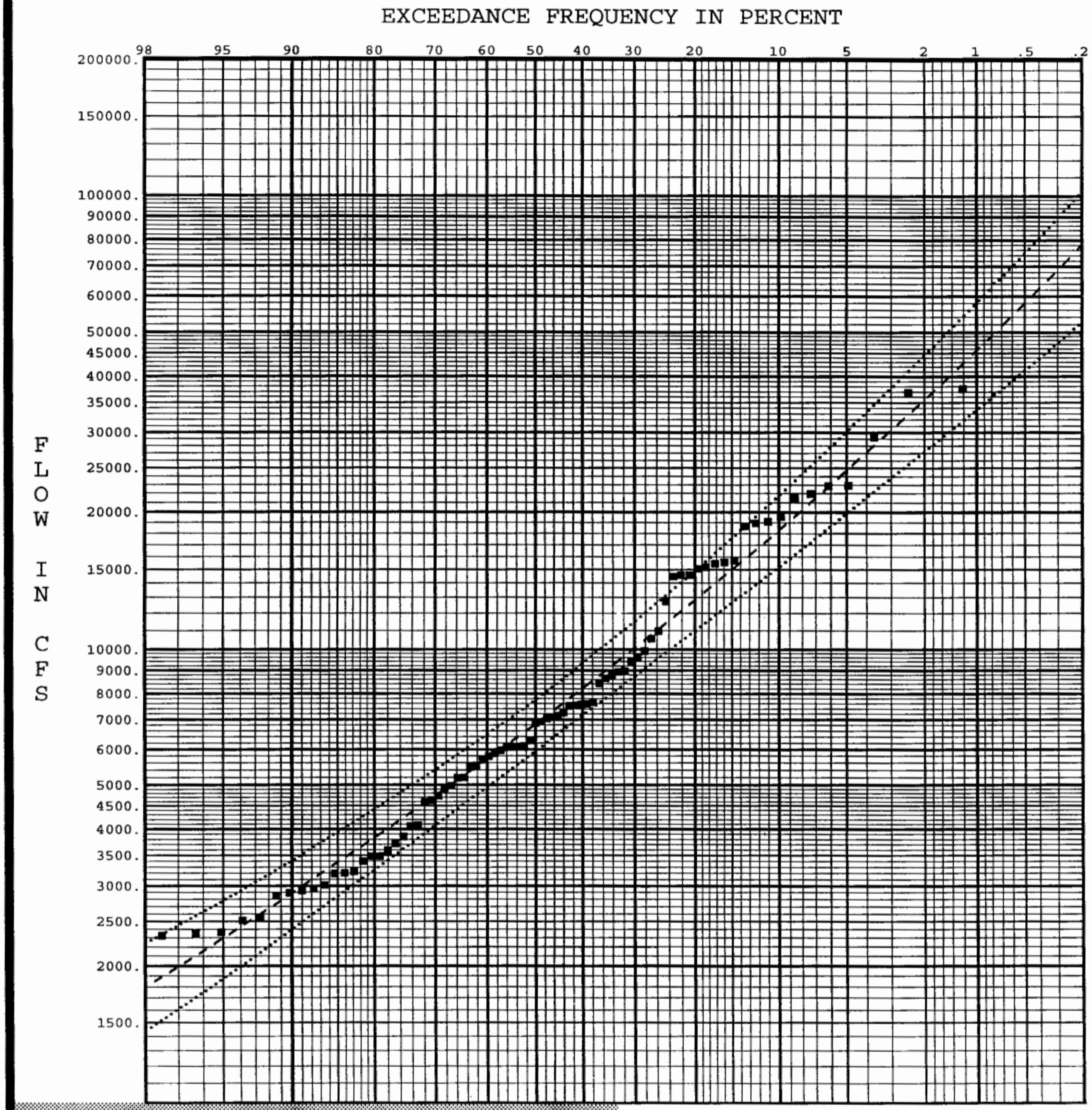
--- FLOW Frequency (with Exp. Prob.)
■ Weibull Plotting Positions
········ 5% and 95% Confidence Limits

FREQUENCY STATISTICS
LOG TRANSFORM OF FLOW, CFS

		NUMBER OF EVENTS	
MEAN	3.7095	HISTORIC EVENTS	0
STANDARD DEV	.3713	HIGH OUTLIERS	0
SKEW	.4573	LOW OUTLIERS	0
REGIONAL SKEW	.0000	ZERO OR MISSING	0
ADOPTED SKEW	.4000	SYSTEMATIC EVENTS	103

NORTH PLATTE AT NORTH PLATTE,
BASIN AREA = 30900 SQ MI
WATER YEARS IN RECORD
1895-1997

Figure 3.15



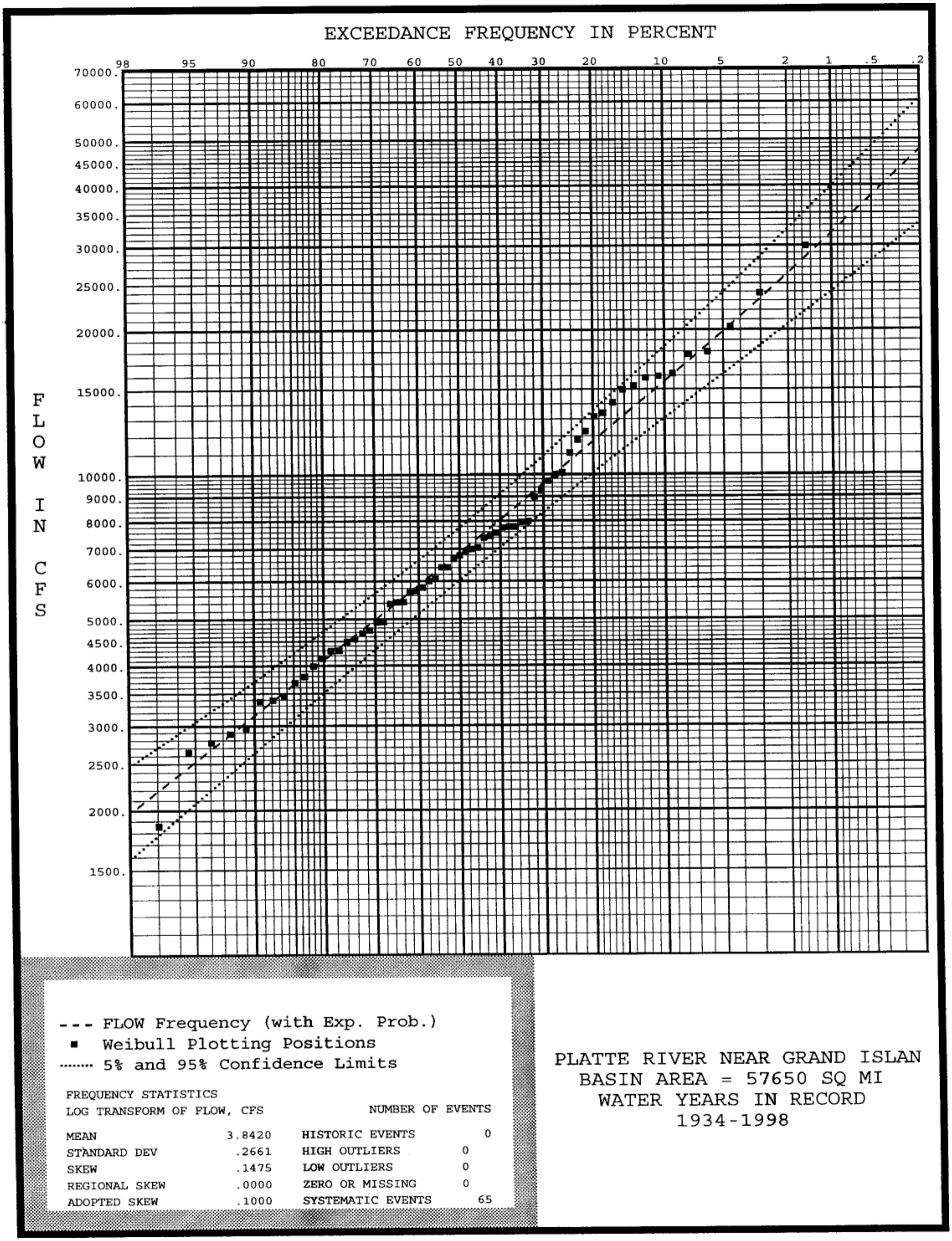
- - - FLOW Frequency (with Exp. Prob.)
▪ Weibull Plotting Positions
······· 5% and 95% Confidence Limits

FREQUENCY STATISTICS

LOG TRANSFORM OF FLOW, CFS		NUMBER OF EVENTS	
MEAN	3.8500	HISTORIC EVENTS	0
STANDARD DEV	.3089	HIGH OUTLIERS	0
SKEW	.3629	LOW OUTLIERS	0
REGIONAL SKEW	.0000	ZERO OR MISSING	0
ADOPTED SKEW	.3000	SYSTEMATIC EVENTS	81

PLATTE RIVER NEAR OVERTON, NE
BASIN AREA = 56300 SQ MI
WATER YEARS IN RECORD
1915-1917,1919-1923,1926-1998

Figure 3.16



FREQUENCY STATISTICS

LOG TRANSFORM OF FLOW, CFS		NUMBER OF EVENTS	
MEAN	3.8420	HISTORIC EVENTS	0
STANDARD DEV	.2661	HIGH OUTLIERS	0
SKEW	.1475	LOW OUTLIERS	0
REGIONAL SKEW	.0000	ZERO OR MISSING	0
ADOPTED SKEW	.1000	SYSTEMATIC EVENTS	65

Figure 3.17

Table 3.3 Flood Frequency Analysis for period of record

Expected Probability	**N. Platte at N. Platte**	**Platte River nr. Overton**	**Platte River nr. Grand Island**
.2 (500 yr)	100000	78400	47700
.5 (200 yr)	68600	58000	38100
1.0 (100 yr)	50700	45700	31800
2.0 (50 yr)	36900	35500	26300
5.0 (20 yr)	23400	24800	19800
10.0 (10 yr)	16000	18200	15600
20.0 (5 yr)	10400	12800	11700
50.0 (2 yr)	4840	6830	6880

The same analyses were conducted for recent data only (1969-1998). These results are also plotted (Figures 3.18-3.20) and summarized in Table 3.4.

Table 3.4 Flood Frequency Analysis (1969-1998)

Expected Probability	**N. Platte at N. Platte**	**Platte River nr. Overton**	**Platte River nr. Grand Island**
.2 (500 yr)	18000	53900	42800
.5 (200 yr)	13900	41000	34700
1.0 (100 yr)	11500	33100	29400
2.0 (50 yr)	9410	26500	24700
5.0 (20 yr)	7140	19400	19100
10.0 (10 yr)	5710	14900	15400
20.0 (5 yr)	4440	11000	11900
50.0 (2 yr)	2880	6420	7360

The previous tables show the general reduction in flow magnitudes for each given return period when comparing the flood frequency analysis conducted with all the available data to the analysis conducted with only the recent data. This reflects the fact that the complete data include the highest peak flows that occurred prior to the current state of water resources development. The most dramatic difference occurs on the North Platte River, where most of the reservoir storage exists.

3.3 Groundwater and Surface Water Interactions

A dynamic interaction occurs between ground and surface water in the Platte River Valley. As reported in Eschner et al. (1983),

> *The Platte River is hydraulically connected with the aquifer in the valley (Lappala, Emery, and Otradovsky, 1979); water can move from the river to the ground water and from the ground water to the river. The river serves as a control on the ground-water system and can influence ground-water levels and reflect changes in those levels. A study near Grand*

> *Island indicates that ground-water levels within 0.8 km of the river in that area respond within 24 hours to changes in river stage (Hurr, 1981).*

Thus, the groundwater level tends to follow changes in the water level in the Platte River in areas in close proximity to the river. As previously discussed (see Section 2.3) the groundwater data near the river show no significant trend over time.

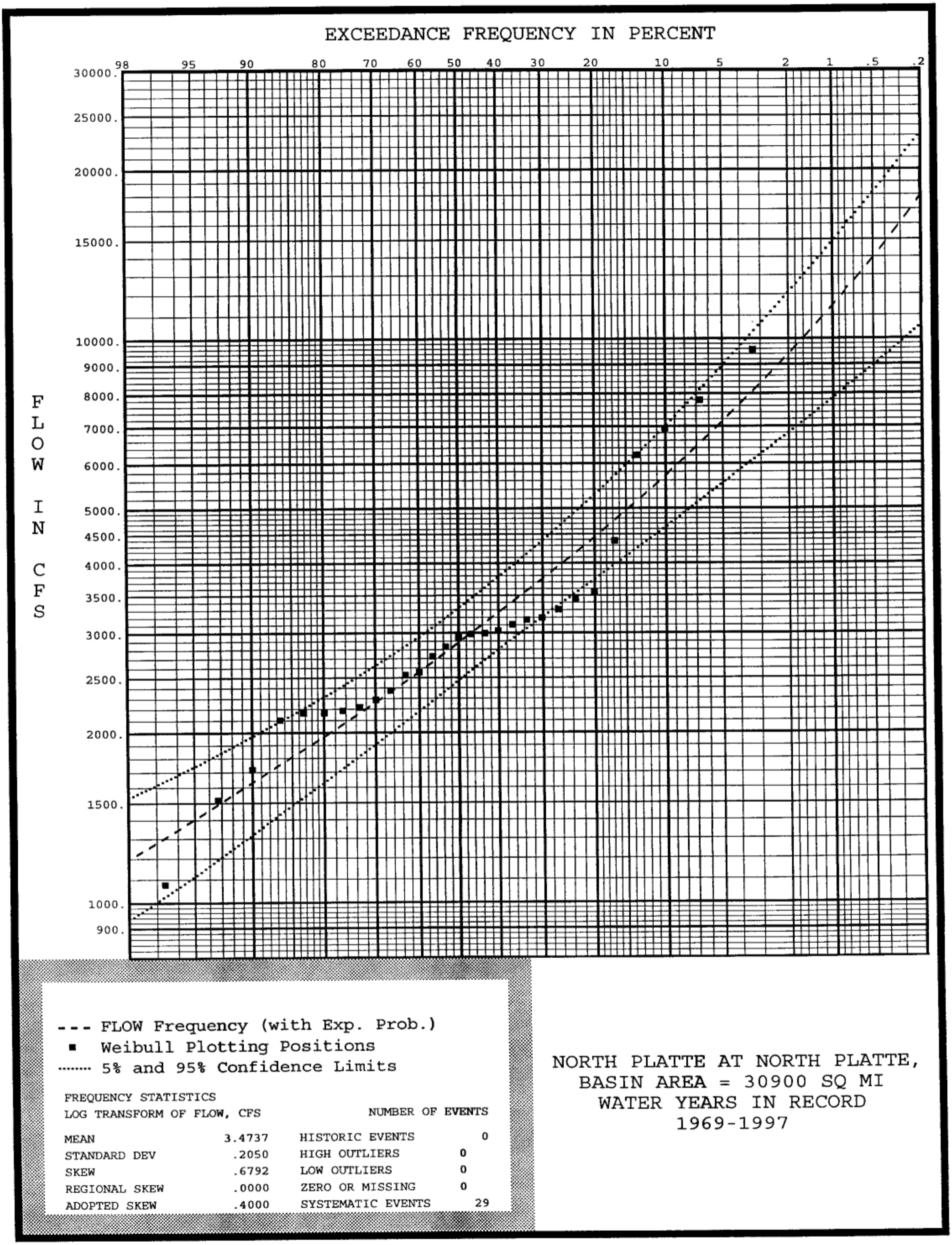
3.4 Sediment Transport and Supply

As discussed in Section 2.4 regarding the history of sediment transport and supply, virtually all of the actual sediment data that exist on the Platte River have been collected during current conditions. Some of the important questions that need to be addressed regarding sediment transport is the effect of changes in sediment transport on the channel.

Geomorphic analysis indicates that the Platte River is located in the transfer zone and downstream of the sediment supply zone. Construction of the numerous dams on the South Platte and North Platte Rivers has resulted in the trapping of virtually all suspended sediment and bedload produced by the watershed upstream of each of these facilities. In addition, a secondary effect of water storage in reservoirs is the reduction in peak flows. Most sediment transport occurs during high flow events. Reservoirs store most water during the runoff season resulting in significant reductions in peak flow. Reduced peak flow causes corresponding reductions in velocity and shear stress exerted on the bed and banks of a river. Reduced velocity and shear stress translates into reduced sediment transport.

As discussed by Leopold et al. (1964), the form of a river is at least partially and possibly significantly controlled by sediment transport through the river. Sediment supplied from the portion of the watershed upstream of the Central Platte River has been significantly reduced. Reductions in sediment supplied to the Central Platte River have been caused primarily by sediment trapping in the numerous reservoirs and diversion of sediment from the river system from the many diversion structures on the river system. In addition, a secondary effect of water storage in reservoirs is the reduction in peak flows. Most sediment transport occurs during high flow events. Reservoirs store most water during the runoff season resulting in significant reductions in peak flow. Reduced peak flow causes corresponding reductions in velocity and shear stress exerted on the bed and banks of a river. Reduced velocity and shear stress translates into reduced sediment transport. Another effect of sediment trapping in upstream reservoirs and reduced sediment supply from the upper portion of the watershed is that the bed of the Central Platte River has been and is becoming coarser through the physical process of hydraulic sorting and armoring.

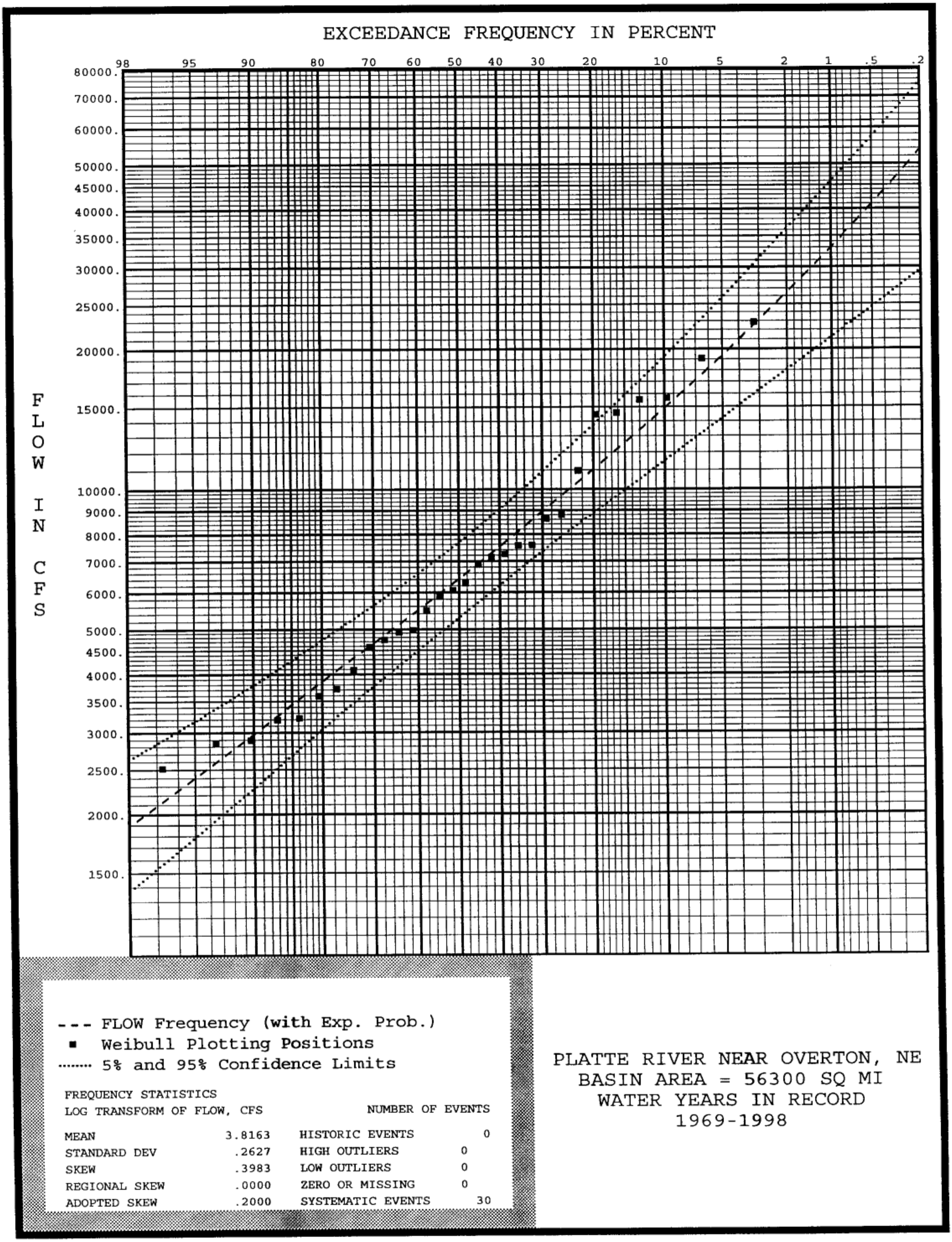
Another effect of sediment trapping in reservoirs is the phenomenon of channel bed degradation downstream of dams. As reservoirs trap a significant portion of the upstream sediment load, particularly the coarse bedload; clear water is released downstream of the dam. Clear water has a propensity for picking up sediment from the river immediately downstream of the dam and hence is sometimes called *"hungry water."* The rate of general river bed degradation tends to be rapid in the beginning of reservoir operation but



FREQUENCY STATISTICS
LOG TRANSFORM OF FLOW, CFS

		NUMBER OF EVENTS	
MEAN	3.4737	HISTORIC EVENTS	0
STANDARD DEV	.2050	HIGH OUTLIERS	0
SKEW	.6792	LOW OUTLIERS	0
REGIONAL SKEW	.0000	ZERO OR MISSING	0
ADOPTED SKEW	.4000	SYSTEMATIC EVENTS	29

Figure 3.18

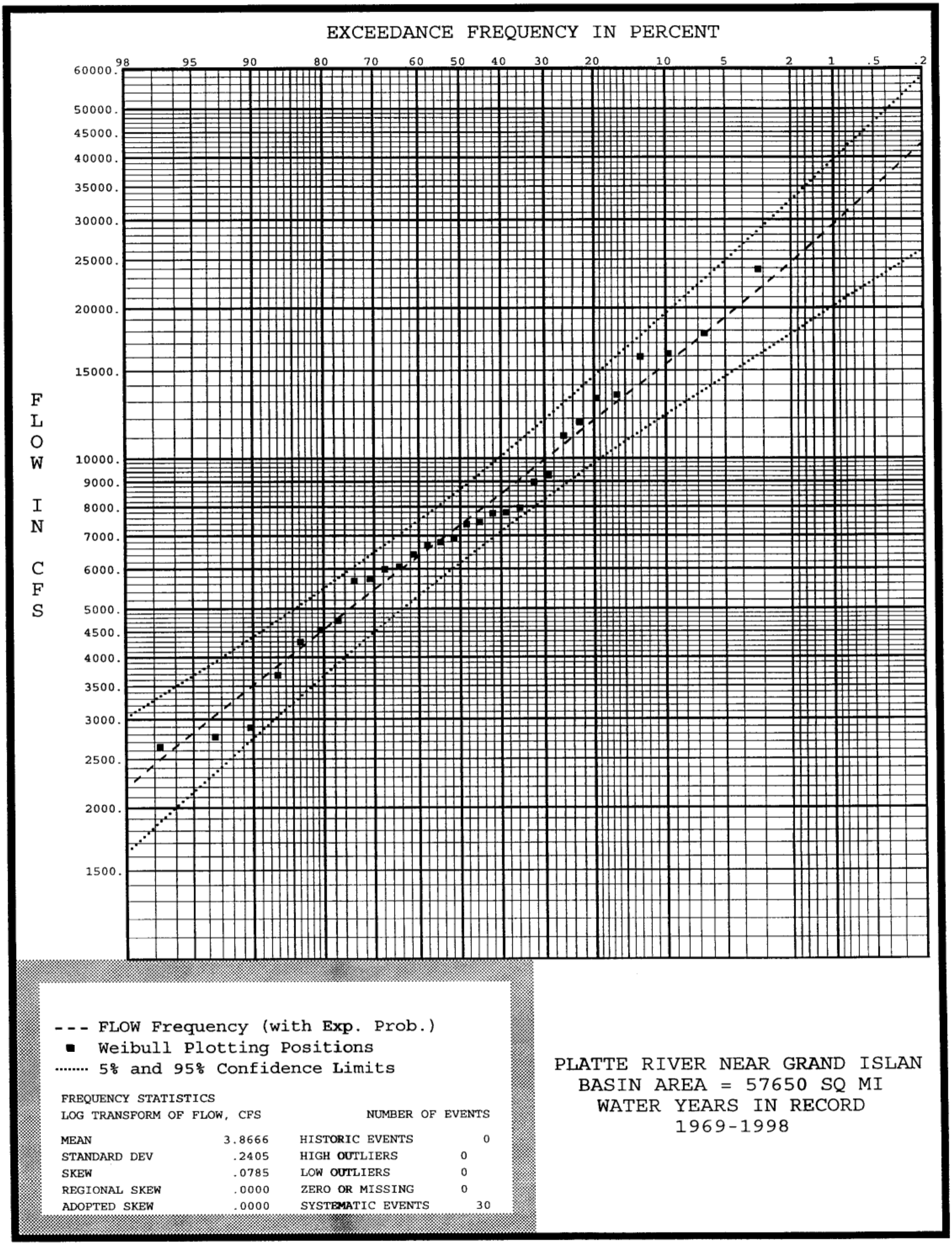


FREQUENCY STATISTICS

LOG TRANSFORM OF FLOW, CFS		NUMBER OF EVENTS	
MEAN	3.8163	HISTORIC EVENTS	0
STANDARD DEV	.2627	HIGH OUTLIERS	0
SKEW	.3983	LOW OUTLIERS	0
REGIONAL SKEW	.0000	ZERO OR MISSING	0
ADOPTED SKEW	.2000	SYSTEMATIC EVENTS	30

PLATTE RIVER NEAR OVERTON, NE
BASIN AREA = 56300 SQ MI
WATER YEARS IN RECORD
1969-1998

Figure 3.19



FREQUENCY STATISTICS
LOG TRANSFORM OF FLOW, CFS

		NUMBER OF EVENTS	
MEAN	3.8666	HISTORIC EVENTS	0
STANDARD DEV	.2405	HIGH OUTLIERS	0
SKEW	.0785	LOW OUTLIERS	0
REGIONAL SKEW	.0000	ZERO OR MISSING	0
ADOPTED SKEW	.0000	SYSTEMATIC EVENTS	30

PLATTE RIVER NEAR GRAND ISLAN
BASIN AREA = 57650 SQ MI
WATER YEARS IN RECORD
1969-1998

Figure 3.20

then decreases over time as the river bed stabilizes and adjusts to the new flow conditions as armoring occurs (given sufficient coarse material in the bed) or as the river bed slope becomes sufficiently flat. Hydraulic sorting and armoring has also been occurring on the Platte River as finer-sized particles that are more easily transported are selectively carried downstream, leaving coarser-sized particles on the surface of the bed in an armor layer in some areas of the river bed. The magnitude of channel bed degradation tends to be greatest immediately downstream of the dam, tapering to little or no effect once a sufficient distance from the dam has been reached. The length of the reach affected by this phenomenon depends on a variety of factors including the change in flows, particularly on the high flow end of the spectrum; bed material size distributions and the existence or lack of geologic or structural controls.

Reduction in the sediment supply, as well as the mobilization of sediment in the river is believed to be a potentially significant factor in the changes that have occurred on the Platte River. As discussed previously, the logic is that prior to significant water resources development the Platte River carried a relatively heavy sediment load that caused the river to be braided and therefore, wide and shallow. With a reduced sediment load as well as a reduced flow, the river no longer had as strong a tendency to be braided, but rather to shift towards a single channel. Without as large a sediment supply, the river would then also have a tendency toward degradation and incision. This would further encourage the shift away from braided and towards a single channel with deeper and narrower geometry. While these tendencies are correct, the question remains regarding the significance sediment transport reductions played in the morphology of the Platte River.

Assuming the Platte River was in a state of equilibrium with respect to sediment transport in its pre-development condition, in other words the sediment transported through the river basically equalled the sediment supplied to the river or the Platte River was somewhat over-supplied with sediment as a condition causing the braided character of the river; the effect of sediment trapping and diversion would tend to cause some relative degree of erosion or channel bed degradation and incision compared to the pre-development state.

Channel Bed Degradation

One of the key questions then is whether or not there has been significant scour of the bed of the river resulting in channel bed degradation, or a lowering of the channel bed. This is an important question as will be discussed later regarding the extent to which erosion or incision of the river had in the changes that have occurred to riparian vegetation and the channel. The opinion held by many in the 1980's was that significant degradation of the channel bed had occurred. To support the alleged general channel bed degradation claim, the Trust, for example, states the following, *"The loss of sediment in the system has contributed greatly to channel narrowing (O'Brien and Currier (1987), Lyons and Randle (1988)). In some areas, the river has incised (scoured 3 to 10 feet (Williams (1978), O'Brien and Currier (1987), Lyons and Randle (1988))."* Specifically, O'Brien and Currier (1987) state:

> *The North Platte River was the major sediment source of the Platte. Little sediment now is derived from the North Platte because most is 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 tributary drainages. The river has responded to this reduction in sediment supply by degrading the channel. From Maxwell to Chapman the Platte has generally degraded 3 to 10 feet between the 1890s and the 1960s (Figure 14). Near Cozad, however, the river has aggraded about 8 feet.*

The amounts of aggradation and degradation reported above were determined by computing the difference in elevation along the river between USGS 30-minute topographic maps prepared in the 1890's, and the 1960's USGS 7.5-minute maps. The problem associated with using these data and results of analysis based on these maps was briefly mentioned in the Appendix V of the Joint Response (Simons & Associates, 1990a). In brief, any conclusion reached after evaluating the map-based aggradation/degradation analysis *"is far too crude to be reliable."* This was explained by applying an understanding of map accuracy standards. National map accuracy standards have been established which are that 90 percent or more of actual elevations should be within +/-50 percent of the contour interval. In other words, using modern maps and a contour interval of 20 feet, if the actual elevation of a given point were surveyed accurately, it should be within +/-10 feet in elevation of what the map indicates. The amount of computed change based on a comparison of maps is on the same order of magnitude of the possible error in the maps (+/- 50 percent of a contour interval or a minimum of 10 feet).

After reflecting on the subject, O'Brien (1995) agreed that the estimated channel bed degradation previously presented by himself and Currier in 1987 was not validated and was an overestimate, *"These changes in bed elevation have not been verified with field data, and most likely overestimate the magnitude of channel bed degradation on the Platte."* While O'Brien recognized that the material he and others relied on overestimated channel bed degradation, he cites Williams (1978) and states that, *"the overall trend in bed elevation has been clearly degradational not aggradational."* Undoubtedly, there is a degradational trend due to sediment trapping and diversion.

Regarding the trend of channel bed degradation, the USFWS has stated:

> *A downward, long-term trend in bed elevations at most U.S. Geological Survey gages throughout the North Platte, upper Platte, and central Platte Rivers is evident from rating curve shifts at these gages. The greatest rates of degradation apparently are occurring at the Sutherland gage (-0.061 ft/yr) on the North Platte River and the Overton gage (-0.096 ft/yr) on the central Platte River. Arresting and reversing these declines is critical to maintaining channel morphology and the hydrology and biological productivity of wet meadows.*

To understand what Williams actually reported in addressing the USFWS and O'Brien's comments, the following material from Williams' report is provided for clarification.

> *The complete records of the 12 U.S. Geological Survey gaging stations within the study reach were examined. Most of these records begin in the mid-1930s, as mentioned above, which means that most stations have records for about the past 40 years. (Several stations actually were established around the turn of the century but not at the present site. Such data were acceptable for the hydrology analysis presented earlier but can't be used for present purposes.) Bed elevations, in meters above mean sea level, were determined as described above. Relative elevation changes with time were then computed for each station to reveal any aggradation or degradation.*
>
> *RESULTS*
>
> *Table 4 lists, and figure 29 shows, the data obtained. The complex history of water regulation and diversion upstream from and within the study reach, together with the shifting and unstable sand bed, complicate the interpretation of the data. Comments will be restricted to pointing out major changes in bed elevation with time at each station.*
>
> *From 1936 to 1976 the streambed at the Minatare station has gradually degraded. The amount of degradation for this period is about 0.7 m.*
>
> *At Bridgeport the bed eroded about 0.5 m from 1931 to 1967 but seems to have filled about 0.2 m around 1967 and has not changed much since.*
>
> *The Lisco station has remained essentially stable since 1933.*
>
> *The Lewellen station is only about eight kilometers upstream from Lake McConaughy. The bed at this station (two channels) has aggraded noticeably since about the mid-1940s. (Lake McConaughy, formed by Kingsley Dam, was created in 1941.) Fill in the north channel at Lewellen has amounted to about 0.6 m and in the south channel to about 0.3 m.*
>
> *The gaging station near Keystone is located just downstream from Kingsley Dam and from the diversion dam of the Sutherland Reservoir supply canal, which began operation in November 1937. The station has been at its present site since mid-1944. During the 10 years from 1944-54, the bed scoured about 0.6-0.8 m. (The channel had also been degrading during the previous several years. According to U.S. Geological Survey notes.) The bed level fluctuated over a range of about 0.2 m from the mid-1950s until the late 1960s. Since the late 1960s, it seems to have gradually aggraded about 0.4 m.*
>
> *The channel of the North Platte near Sutherland has gradually eroded approximately 0.5 m since about 1940.*

> *At North Platte the riverbed elevation seems to have been fairly stable over the past 45 years.*
>
> *The North Platte at Brady today flows mainly in two channels. The bed level in the north channel has undergone periodic fluctuations of several tenths of a meter during the period of record (1939-present). Today (1977) the bed is about 0.5 m lower than it was in 1939-40. The south channel scoured about 0.3 m from 1939-49, then regained 0.1-0.2 m of this over the next 10 years (to 1959) and has remained fairly stable since 1959.*
>
> *Near Cozad the Platte also flows in two channels. Both of these have scoured over the period of record (1940-present). The north channel has degraded about 0.7 m, the south channel about 1.5 m. The latter degradation represents the largest amount of change of the 12 stations studied.*
>
> *The Platte River near Overton was reasonably stable from 1930-49. From 1949-57 it scoured about 0.3 m and has remained at about that same elevation since.*
>
> *Near Odessa the bed of the river has fluctuated about +/-0.2 m since 1938.*
>
> *At Grand Island the river bed has been fairly stable, fluctuating within +/-0.1 m since 1936.*
>
> *The various and inconsistent changes of bed elevation with time mean that the gradient of the river bed has also changed with time in a similarly complex way. The same is true of the channel depth although any changes have not been very large.*

As documented by Williams, channel bed fluctuations have been on the order of a few tenths of a meter or about a foot or two. The largest amount of degradation he notes occurred at Cozad and was 1.5 m or about 5 feet. He mentions fluctuating levels of aggradation, as well as degradation. At most stations, Williams states that the bed has been *"fairly stable," "reasonably stable," "remained about the same," "fluctuated about +/-0.2 m since 1938,"* and *"the river bed has been fairly stable, fluctuating +/-0.1 m since 1936."* Thus Williams supports the fact that some degradation has occurred but of a relatively small magnitude. It is important to note that Williams himself gave some caution regarding the accuracy of the analysis. He stated that the analysis was, *"far from perfect"* and incorporates *"an unmeasurable amount of error,"* and that *"day-to-day shifts in measured elevations are comparable to long-term ones."* In addition, in considering these data, it must be noted that they come from USGS gages that are generally located near bridges. USGS records (Water Resources Data for Nebraska, 1986) show that most of these gages are located within as little as 19 feet to as much as about 1500 feet of bridges. Scour related to bridges is discussed in Simons and Sentürk (1992) and Richardson et al. (1990). In Richardson et al. (1990), the following material discusses scour at bridges.

> *General scour at a bridge can be caused by a decrease width, either naturally or by the bridge, which decreases flow area and increases velocity. This is contraction scour. General scour from a contraction occurs when the flow area of a stream is decreased from the normal either by a natural constriction or by a bridge. With the decrease in flow area there is an increase in average velocity and bed shear stress. Hence, there is an increase in stream power at the contraction and more bed material is transported through the contracted reach than is transported into the reach. The increase in transport of bed material lowers the bed elevation.*

As a result, some of the measured degradation can be attributed to a reduced sediment supply due to sediment trapping in reservoirs and diversion of sediment at diversion structures while the rest of the degradation should be attributed to constriction, abutment, or pier scour due to the bridge itself.

Analysis of cross-section surveys was conducted to evaluate the change in channel bed elevations during the 1980's. Appendix B presents the results of this analysis in graphical and tabular form. Table 3.5 (from Simons & Associates, 1990d) shows that mean bed elevation changes for periods from several months to several years in length at the various Joint Study sites ranged from -0.15 feet to +0.19 feet with an overall mean for all sites arithmetically averaged of -0.003 feet. The average change over this time period in the early to mid-1980's is quite small. It must also be pointed out that during this time, the Platte experienced very large flows that have the capability of significant scour, however, the time period over which these cross-section data were collected is quite short and may not be indicative of longer term trends.

Sediment Budget

Based on the information presented above, there is a tendency for channel bed degradation on the Platte River, but previous estimates of such degradation have been over-estimated. One of the key questions that has been raised regarding sediment transport is whether or not sediment transport, and hence the channel itself, is in equilibrium or if there is a continued trend of aggradation or degradation. Typically, a river would tend to adjust to this new set of conditions based on a reduced sediment load over time with an expectation of reaching some new equilibrium condition. The concept of equilibrium must be tempered by the knowledge that rivers are dynamic. In other words, a river in equilibrium tends to experience some fluctuations in bed elevation or width about some mean value but there are no significant long-term trends of change. This can be described as a condition of dynamic equilibrium. Any discussion of equilibrium in this document refers to a condition of dynamic equilibrium. Whether or not a state of dynamic equilibrium with respect to bed elevation changes has been reached on the Platte River is a matter of balance between the sediment supplied to the reach and the sediment transported through the reach.

A sediment budget, or comparison of sediment transport through the Platte River, has been made by various groups. This has been previously studied by the USBR, the USGS, and Simons & Associates. As reported by Simons & Associates (1987a and 1990d), all known sediment transport data collected up to that point in time were obtained. This included 15 stations on the North Platte, 6 stations on the South Platte, and 7 stations on the Platte River. Appendix A presents the locations of the sediment data collected along with the years for which data were collected, and the frequency of data collection. Where data allowed, Simons & Associates developed regression analyses of suspended sediment transport as well as bedload transport. A summary of the results of this analysis is found in Tables 3.6 and 3.7. In addition to the data obtained from available sources, Simons & Associates collected additional data at sites near Odessa and Shelton on the Platte River in the mid-1980's. These sediment data collection sites were in the vicinity of vegetation demography study sites conducted by Johnson. Data collected at these sites are quite comprehensive, consisting of the following information: water depth and velocity at a number of locations across the channel cross-section (i.e., a flow measurement), bedload transport at a number of locations across the channel (at some of the locations where depth and velocity were measured), bed material (at various locations across the channel), and a composite suspended sediment sample taken at various locations across the channel but composited together for the entire channel.

Relationships between total annual sediment transport and total annual water flow were developed based on the regression equations. Figure 3.21 shows the annual suspended sediment relation with annual flow. The figure shows that, on a per acre-foot basis, the South Platte transports more suspended sediment than the North Platte and Platte Rivers. That is because (1) the few mainstem dams on the South Platte River in which sediment is trapped are not extremely large, and (2) the mainstem dams on the South Platte River do not control the peak runoff for the entire basin. Differences in the amount of suspended sediment transported by the three rivers (as shown in Figure 3.21) can be explained in large measure by the considerable amount of water, and its suspended sediment, that is diverted out of the rivers. This diverted water and sediment reduces the supply of sediment and, therefore, there is less suspended sediment transported downstream of each diversion.

The difference in suspended sediment transported, however, does not have a significant bearing on channel bed elevation change. The sediment transported in suspension consists of quite fine sizes that are not found in appreciable quantities in the channel bed. Even though the rivers have sufficient energy to transport higher quantities of suspended sediment, they do not because the supply is somewhat limited and the river is not picking up much suspended sized (i.e., silt, clay) material from the channel bed to cause a significant change in channel geometry. Thus, while a change or imbalance in bedload (sediment carried near or at the channel bed consisting of bed material or sizes of sediment found in the channel bed) may induce aggradation or degradation, such a change in suspended load has a much less significant or direct effect on the channel. Suspended sediment transport and potential deposition on the flood plain or islands may encourage establishment of vegetation and may enhance survival of vegetation because of a greater capacity to retain moisture in finer sized sediment. Such sediment deposits may have a secondary effect on the channel through their potential effect on vegetation.

Table 3.5

ARITHMETIC AVERAGE OF WEIGHTED MEAN BED ELEVATION CHANGES

Site Number	Average Change (ft)
1	-.07
2	+.02
4A	+.06
4B	-.10
5	-.02
6	+.09
7	+.05
8A	+.19
8A	-.05
8B	+.01
8C	+.01
9B	-.10
9B	-.02
10	+.03
11	+.14
12	-.11
12	-.15
NP	-.03

$\Sigma = -.05$

Mean = -.003

Table 3.6
SUSPENDED SEDIMENT TRANSPORT REGRESSION EQUATIONS

Location	Suspended Sediment Transport Equation T/Day	r squared	# of Data Points	Maximum Q, cfs	Minimum Q, cfs	Source
North Platte at: Douglas	$Qss = 0.00185\ Q^{1.73}$	0.82	1000	8560	85	USGS-WRD
North Platte at: Orin	$Qss = 0.00000272\ Q^{2.57}$	0.73	91	10600	462	USGS-WRD
North Platte at: Cassa	$Qss = 0.000204\ Q^{2.04}$	0.84	1000	8160	150	USGS-WRD
North Platte at: Guernsey	$Qss = 0.00656\ Q^{1.26}$	0.71	631	7800	18	USGS-WRD
North Platte at: Lingle	$Qss = 0.0054\ Q^{1.54}$	0.82	39	4880	130	USGS-WRD
North Platte at: Wyo-Ne Stateline	$Qss = 0.00414\ Q^{1.60}$	0.76	69	8430	177	USGS-WRD
North Platte at: Sutherland and North Platte	$Qss = 3.30\ Q^{0.812}$	0.23	8	2063	572	USGS-1277
South Platte at: Julesburg	$Qss = 0.00780\ Q^{1.77}$	0.91	56	12800	11	USGS-WRD
South Platte at: Kersey, Weldona, Balzak, North Platte	$Qss = 0.0947\ Q^{1.32}$	0.82	21	12397	265	USGS-1277
Platte at: Overton	$Qss = 0.00274\ Q^{1.61}$	0.78	199	18660	2.5	USGS-WRD
Platte at: Overton, Grand Island	$Qss = 0.0472\ Q^{1.28}$	0.93	14	10737	286	USGS-1277

Table 3.7
BEDLOAD TRANSPORT REGRESSION EQUATIONS

Location	Bedload Transport Equation T/Day	r squared	# of Data Points	Maximum Q, cfs	Minimum Q, cfs	Source
North Platte at: Sutherland, North Platte	$Qsb = 1.20\ Q^{0.849}$	0.61	8	2063	618	USGS-1277
South Platte at: Kersey, Weldona, Julesburg, North Platte	$Qsb = 0.0484\ Q^{1.35}$	0.95	15	12397	77	USGS-1277
Platte at: Overton, Grand Island	$Qsb = 0.146\ Q^{1.18}$	0.94	17	10737	231	USGS-1277
Platte at: Odessa, Shelton	$Qsb = 0.475\ Q^{1.12}$	0.96	9	4429	464	S & A
Platte at: Overton, Odessa, Shelton, Grand Island	$Qsb = 0.377\ Q^{1.09}$	0.87	26	10737	231	USGS-1277 and S & A

USBR recognizes this fact in concluding that, while an imbalance of bed-material loads between two locations on a river may indicate aggradation or degradation of the channel bed and hence channel geometry changes, an imbalance of suspended sediment load is not a relative indicator of channel change (Lyons and Randle, 1988). In other words, changes in suspended sediment load in these rivers do not directly translate into significant channel change.

In contrast to suspended sediment, the balance or imbalance of bedload transport is much more critical to channel dynamics. Figure 3.22 shows the relationship between annual bedload sediment discharge and total annual flow. The annual bedload relationship shows the lowest transport on the North Platte River. This is due to the fact that upstream reservoirs trap sediment and control flood peaks. At low flows, the South Platte River has relatively small bedload transport; however, for years with large annual flow, the bedload transport rate increases more rapidly than at other stations and in some cases transport could potentially exceed the amount in the Platte River.

The sum of the bedload transport for the North Platte and South Platte is close to or could exceed the Platte River bedload transport on the basis of per acre-foot of flow. Such conditions—where sediment inflow is roughly equivalent to sediment outflow—indicate that the channel bed should be in a state of dynamic equilibrium. This conclusion is supported by the finding of the USBR report by Lyons and Randle (1988). Their analysis shows that the estimated annual sand load from 1958-1986 at Overton, Odessa, and Grand Island were 698,000, 677,000, and 706,000 tons per year respectively. These values are very close to each other, and from a geomorphic perspective, indicate that the sand load is in equilibrium. This conclusion was expressed as follows in the USBR report by Lyons and Randle: *"The reach of the Platte River from Overton to Grand Island for 1958-86 appears to satisfy the definition of quasi-equilibrium as the mean annual sand load carried into the reach at Overton is approximately equal to the mean annual sand load leaving the reach at Grand Island."* It is important to note that the USBR analysis showed equilibrium in the Big Bend reach, the S&A analysis evaluated bedload transport from a broader perspective including the supply from the South and North Platte Rivers and transport through the Platte River.

Kircher (1983) collected sediment data and conducted analyses and comparisons of mean daily flow and total measured sediment discharge at four locations. Table 3.8 summarizes the results of this analysis.

Table 3.8 Summary of Sediment Data (after Kircher, 1983)

Station	Mean daily flow (m^3/s)	Mean daily total sediment discharge (t/d)
North Platte River at North Platte	23.5	597
South Platte River at North Platte	9.5	307
Platte River Near Overton	39	1,100
Platte River near Grand Island	35.6	1,130

This summary indicates a close balance between Overton and Grand Island indicating equilibrium, supporting the previous comparisons by Lyons and Randle. The sum of sediment transport in the Platte River stations is greater than the sum of the North and South Platte stations that would tend to indicate a potential for degradation since more sediment is leaving than is coming into the reach, however, part of this difference may be due to the loss of suspended sediment primarily, through the diversion process and intervening drainage area that would bring some additional sediment into the reach as indicated by a similar comparison of flows.

Thus, the previous analyses of bedload transport showed that an equilibrium condition is tentatively indicated. In recent discussions regarding the sediment transport issue, some reservations have been expressed regarding the concept of sediment transport equilibrium. Concern was expressed regarding the fact that essentially clear water is released from the J-2 Return and that a substantial percentage of the water that flows down the Platte River below J-2 comes from the J-2 Return. While these facts are true, these conditions dominate the low to middle range of the flow spectrum. Most actual sediment transport, and particularly the bedload component, occurs at high flow. During high flow, the relative effect of the clear water from J-2 is significantly less. Given that the largest canal capacities are on the order of 2,000 cfs, most of the flow and hence most of the sediment during peak flow events (that may be in the 10,000 to 20,000 cfs range) would flow past the diversion structures and down the river. During the high flows of 1983 and 1984 some damage or even breaching of diversion structures is believed to have occurred (Currier, 2000, personal communication). Certainly, during the non-peak flow times the clear water inflow dominates; however, the transport capacity during the low to moderate flow is much less than during large peak flow events. While it is indisputable that sediment trapping is virtually 100 percent behind all the major dams in the watershed, the percentage of sediment trapped or diverted due to diversion structures has not been quantified and is subject to debate (see Simons & Associates, 1990d) regarding alleged diversion of significant quantities of bedload compared to a lack of supporting evidence in terms of significant bedload aggradation in canals and behind diversions assuming the allegations were correct. It should be clear, however, that a significant percentage of bedload in fact continues down the river and is not stopped or diverted. Certainly, some bedload is diverted and trapped by diversion structures but no

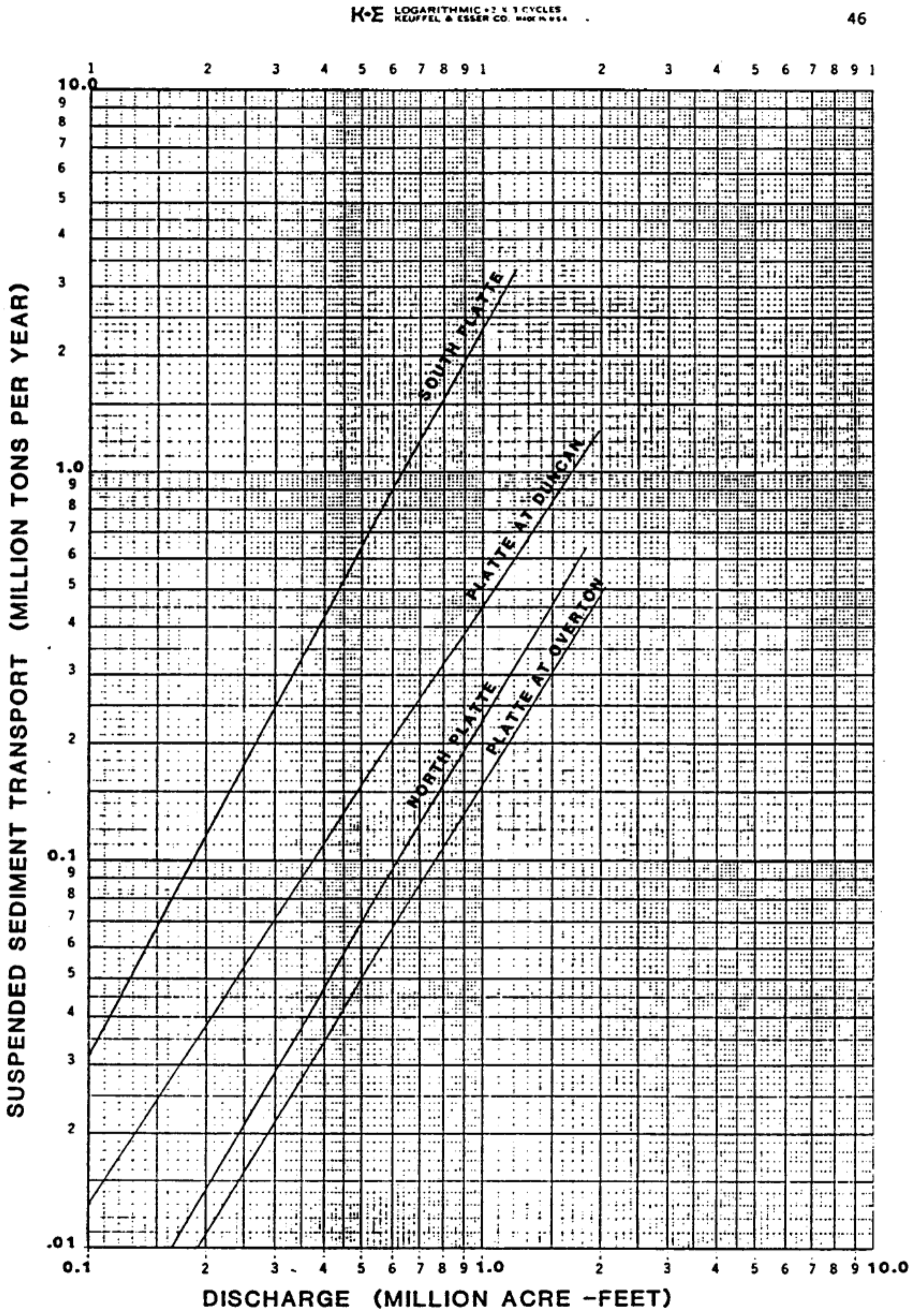


Figure 3.21 ANNUAL SUSPENDED SEDIMENT TRANSPORT

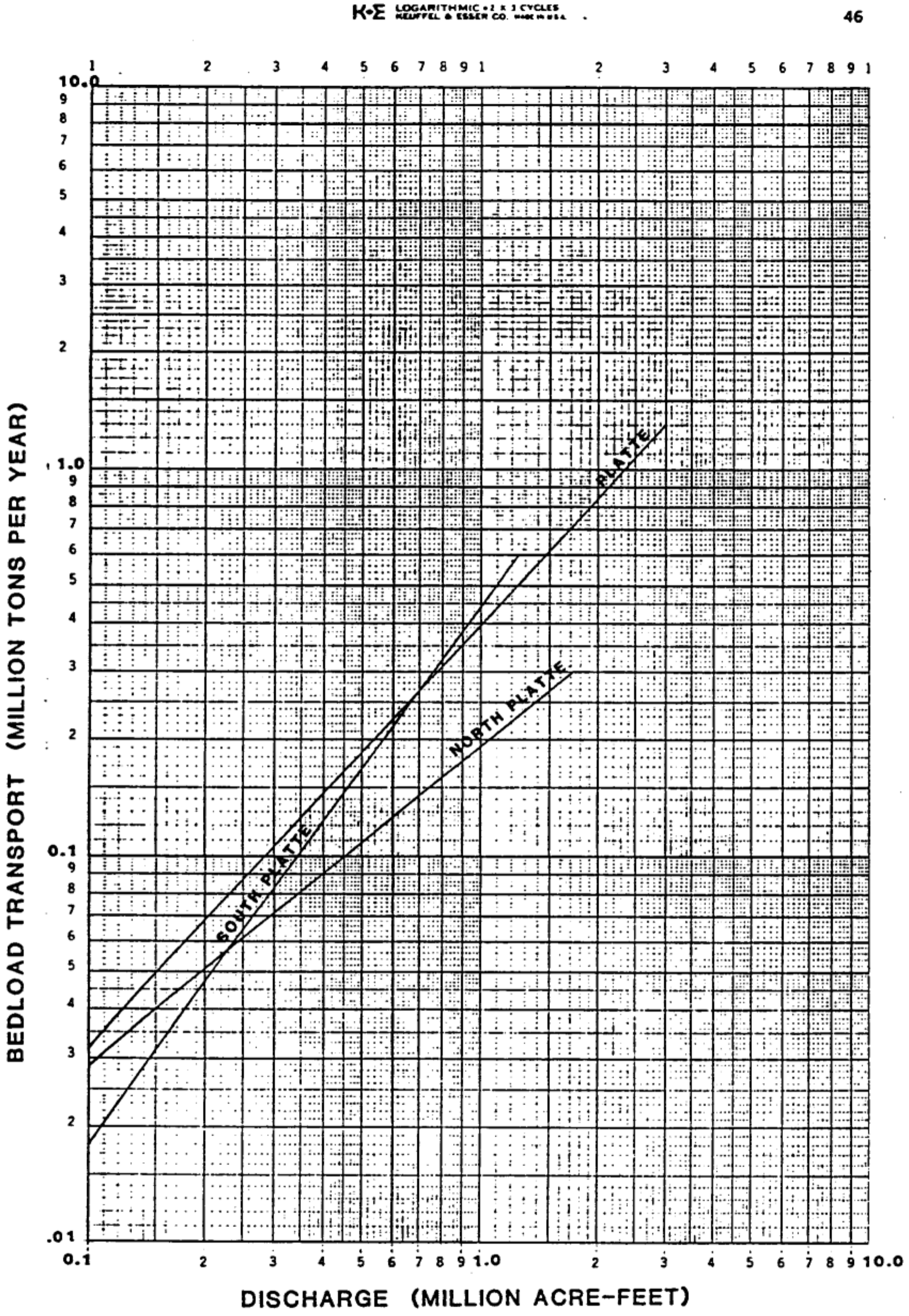


Figure 3.22 ANNUAL BEDLOAD TRANSPORT

quantitative estimates have yet been made of the significance of the effect of diversion of sediment (particularly bedload) from the river.

3.5 Channel Geometry

A number of river cross-sections were surveyed on the North Platte and Platte Rivers by what has been called the Joint Study (a combined effort of the USBR, the USFWS, and the USGS). Some additional cross-section data were collected by Simons & Associates during the 1980's near Shelton and Odessa in support of geomorphic and vegetation studies related to the relicensing of hydropower projects in Nebraska. These were resurveyed after the high flow of 1995. Additional cross-section surveys have recently been conducted by the USBR and USGS at some of the same locations of survey from the Joint Study in 1989 and 1998. These sources of data, particularly from the Joint Study, represent a fairly significant volume of information. While Simons & Associates has conducted some detailed hydraulic analysis of the Joint Study Data (Simons & Associates, 1987b) as well as the data Simons & Associates collected or obtained, no detailed or statistical summary of the data exists. Generally, the data collected in the 1980's and later show that the width of the Platte River generally ranges from about 300 feet to just under 3000 feet, averaging about 1260 feet. Depths at bankfull flow generally range from about 5 to 10 feet. These data demonstrate the relatively wide and shallow nature of the channel geometry of the Platte River, indicated by a large width to depth ratio, continues to exist despite the significant reduction in active channel width compared to the available information regarding channel geometry from observations in the 1800's and early 1900's (see Section 2.5).

3.6 3.6 Woody Vegetation

Woody vegetation, as it currently exists along the Platte River, occupies a significant percentage of what used to be active channel. A number of researchers have documented the expansion of woody vegetation into the channels of Platte River and its principal tributaries. An example of this analysis was presented in Section 2.6 and Figure 2.23. This figure showed the reduction in the percentage of active channel over time as vegetation progressively expanded into the active channel. The complement to the percentage reduction in active channel width is the expansion of vegetation. This analysis shows that for the locations analyzed on the North Platte, South Platte, and Platte Rivers, woody vegetation has expanded onto approximately 72 to 90 percent of the total channel width (leaving only about 10 to 28 percent of the former total channel width as active, non-vegetated width).

3.7 Summary of Current Conditions

The following table (Table 3.9) summarizes the current conditions of the Platte River based on the material presented in this chapter.

Table 3.9 Summary of Current Conditions

Factor	Description of Condition
Annual Flow	~ 1.4 maf (on average, ranging from ~ 0.6 to 2.8 maf)
Peak Flow	~3,000 to 24,000 cubic feet per second, averaging ~8,600 cfs
Periods of No Flow	Relatively infrequent and relatively short occurrences of no flow, generally increased flow during the summer low-flow season
Bed Material	Sand with a median diameter of ~0.86 mm, with some gravel deposits
Bed Forms	Large-scale macroforms, bars and islands
Sediment Load	Significant sand load (but less than pre-development), significantly reduced wash load (due to diversions and return flow). Total sediment load estimated to be ~1 million tons per year.[1]
Channel Classification	Braided/anabranched[2], with significantly greater extent of wooded islands and bars than under pre-development conditions
Total Channel Width	292 to 3311 feet, averaging ~1260 feet based on Joint Study data (1980's)
Active Channel Width	~9 to 28% of pre-development total channel width
Riparian Vegetation	Densely wooded islands with extensive woody riparian vegetation along the riverbanks that covers ~72 to 91% of the pre-development total channel width

[1] Estimate based on a summary of data presented in this report. It represents a sediment transport reduction from pre-development conditions of about 87 percent.

[2] An anabranched river is "A stream whose flow is divided at normal and lower stages by large islands or, more rarely, by large bars; the width of individual islands or bars is greater than about three times of the water width; the channels are more widely and distinctly separated than those of a braided stream." Simons, D. B. and F. Senturk (1992)

3.8 Discussion of Current Trends of Channel Morphology and Vegetation

As a result of the numerous studies that have been conducted on the Platte River in the 1980's and 1990's, the question of the current status of the river in terms of geomorphology, sediment transport, and woody vegetation has been addressed. Regarding sediment transport, the data suggest that the sediment supplied to the Platte River and the sediment transported through the river are roughly in balance. This is supported by bed elevation trends at the USGS stream gages and comparisons of changes in cross-sections. No significant changes in overall geomorphic channel classification have been documented. Studies of vegetation have generally shown that the previous trend of significant woodland expansion has slowed significantly, stopped, and has reversed where erosion has occurred during high flow events. The various analyses suggest that the Platte River has reached a state of equilibrium, or more correctly stated - dynamic equilibrium. Dynamic equilibrium on the Platte River was defined by Simons & Associates (1990d), *"This condition of relatively steady widths with minor fluctuations in narrowing and widening but no significant long-term trend is known as dynamic equilibrium."* The conclusion that the Platte River has reached a state of dynamic equilibrium is supported by Johnson and Boettcher (1999), *"The balance between open channel and woodland area for most reaches has changed little since the 1960's."* Johnson also stated (1996a and 1994a)

> *Aerial photograph analyses of channel area trends indicated that the Platte River has assumed a state of dynamic equilibrium (Johnson 1994a). The field study of tree seedling demography in the modern river has helped us understand why this equilibrium may have been reached. Briefly, the relative channel area stability in recent decades has resulted from (1) reduced tree recruitment caused by a higher proportion of the active channel being covered by water at a given flow as channel area has declined from pre-development levels and (2) increased mortality of seedlings, that have become established in years of low flow, due to greater ice action and effectiveness of summer rainstorm peaks as channel area has declined. Thus, channel area stability has been achieved under stable river management by both reduced recruitment and higher mortality of cottonwoods and willows.*

Also acknowledging the fact that no significant trends in flow exist associated with any significant new water resources development over the past several decades (as shown in Section 3.2) supports the concept of dynamic equilibrium.

The state of dynamic equilibrium appears to hold for most of the Platte River. Currier (1995 and 2000) states that the lower portion of the Platte River from Aldo to Chapman has continued to experience declines in active channel width and may not be in dynamic equilibrium (the Aldo to Chapman reach is about 20 miles long at the downstream end of the critical habitat reach). This is discussed further in section 4.3.3.

4.0 Channel Processes and Causes of Change

4.1 Resource Linkages

Fluvial geomorphology is the study of the interaction between rivers and the surficial topography of the earth including geology, soils, and other sediments. Geomorphic processes continue to occur through erosion and deposition as rivers adjust to hydrologic events and anthropogenic factors. River form as it has developed over geologic or more recent time significantly affects river hydraulics that provide habitat for aquatic life, riparian and other vegetation, and habitat for terrestrial wildlife. The quality and quantity of habitat is a function of hydraulic variables such as velocity and depth, substrate (sediment size distributions), and the relationship between channel/floodplain geometry and flow regarding seasonal patterns of inundation and recession rates of flow hydrographs. All of these important factors are a direct result of the interaction between flow and geomorphology. While other factors may either benefit or adversely affect habitat, the primary factor in the quality and quantity of habitat remains the direct relationship between water and the earth's surface. In some rivers, geomorphic processes are quite dynamic while in others they are relatively static, but punctuated by rare but dramatic events that alter the channel to one degree or another. Despite the relative rate of geomorphic dynamics, the river form created by these processes and the ongoing interaction with flow dictates riverine hydraulics and plays a significant role in habitat and biologic processes.

In discussing geomorphic processes, Leopold et al. (1964) explained that,

> *The shape of the cross-section of a river channel at any location is a function of the flow, the quantity and character of the sediment in movement through the section, and the character and composition of the materials making up the bed and banks of the channel. In nature, the last will usually include vegetation.*

The shape of a river channel and changes that occur in response to controlling factors regarding river pattern and position define the fluvial geomorphology of a river. The shape of a river cross-section plays a significant role in how the river responds to changes in hydrology and other key factors with respect to riparian vegetation and habitat as will be discussed in greater detail in subsequent sections of this chapter.

4.1.1 Natural Resource Inputs

4.1.1.1 Water

Water is the primary factor that directly or indirectly affects the river system. The quantity of flow (hydrology), as it varies over the seasons of the year and from year to year, coupled with the channel geometry (cross-section and slope) and resistance to flow; interact as a hydraulic response that defines the corresponding water surface elevation. Each of the continually varying flows and water surface elevations also include other hydraulic characteristics including the depth and velocity of flow and the extent to which the channel cross-section or flood plain is inundated by the flow. The velocity of flowing water may cause scour and transport of sediment and may cause scour of vegetation. The seasonal patterns of inundation and velocity in the river is controlled by the quantity of flow and the channel geometry. Historic changes in flow, as have been previously presented, have a significant and direct effect on the river, its morphology, and vegetation.

4.1.1.2 Sediment

The watershed contributing flow to a river system also contributes a supply of sediment to the river. As water flows over the bed and banks of the river, it exerts a hydraulic force (shear stress) on the bed and banks of a river that is sometimes large enough to erode and transport the sediment making up the river. If the supply of sediment from upstream sources is greater than the sediment transport capacity of the river, sediment will deposit on the river bed. If the sediment transport capacity of the river is greater than the supply and the flow has sufficient energy to erode the river bed or banks, scour or channel bed degradation and/or bank erosion will occur. As a result, the river pattern and cross-sectional geometry can shift and change as erosion and deposition of sediment occurs.

4.1.1.3 Vegetation

Vegetation generally occurs along river banks, as well as islands and sometimes on exposed (non-inundated) portions of the active channel. Sometimes, emergent vegetation is found generally in inundated areas of the channel where the flow of water is shallow, the velocity of flow is low, and where substrate (bed material) is acceptable for root growth and relatively stable. Vegetation interacts with the channel and flow in a generally stabilizing fashion, although there are limits to the stabilizing influence and intricacies in the relationship between riparian vegetation and the geomorphology of a river. Resistance to flow is increased by vegetation which results in reduced velocity, increased stage, and a tendancy for deposition of sediment due to reduced velocity.

Vegetation is affected by the flow in a number of ways. Riparian vegetation is supported by moisture in the root zone which is controlled by seasonal variations in water level in the river. If flow and water level is too low or recedes beyond the plant's root system to access water, vegetation can be stressed or killed. Recently established or younger plants are particularly sensitive to this phenomenon. If water inundates all or portions of the river bed during the germination season, no new vegetation can become established on the inundated portions of the river. If velocities are sufficient vegetation may be removed by scouring processes including lateral erosion of riverbanks and margins of islands. Ice, as it moves along the river, may also remove vegetation. Thus, there are numerous ways that water, sediment, and vegetation interact; resulting in different channel and vegetation patterns as affected by changes in hydrology.

4.1.2 Human Actions

4.1.2.1 Water Resources Development

Water resources development in the Platte River Basin has occurred as has been documented in previous sections. Development included construction of diversions, canals, reservoirs, and wells. The storage and diversion of water generally decreased peak and average flow in the river. In addition, sediment was trapped behind dams and diverted along with water. Diverted water conveyed in unlined canals increased groundwater levels and created gains to the river, generally increasing low flow. Releases from reservoirs during the drier parts of the year also increased low flow in the river. Development of wells that pump water from the ground tends to decrease groundwater levels. The complex interaction between these various types of water resources development have affected flow in the river.

4.1.2.2 Structures

A variety of structures have been built adjacent to or across the river. Structures that directly affect the river include bridges, bank protection, diversion and outfall structures. Other structures that have some influence on the river include road embankments and possibly buildings. Bridges tend to constrict the flow causing accelerated flow through the opening, backwater upstream of the bridge, and separation zones upstream and downstream of the bridge. This influence extends about one-half mile in both upstream and downstream directions from each bridge. Bridges were estimated to affect approximately 20% of the river (Simons & Associates, 1990d). Bank protection tends to stabilize the river bank so that it is restricted in movement associated with erosion or lateral migration processes. Road embankments tend to confine the flow to the active channel limiting overbank flow. Buildings on the floodplain affect floodplain roughness and may present disturbance factor to habitat (as would other previously mentioned structures). These structures and associated protection measures account for some unknown additional amount of influence on riverbanks.

4.1.2.3 Vegetation cutting or clearing

Vegetation cutting or clearing has occurred for a variety of reasons along the Platte River. Much of this may have occurred in general land development or clearing for agricultural purposes. These activities were more prevalent during the early stages of development as documented by Johnson and Boettcher (1999). Recently, some vegetation cutting or clearing has been conducted on a limited basis for the purpose of enhancing or maintaining habitat. Clearing or cutting of vegetation increases the unobstructed width of the channel and, depending on the degree of clearing, exposes sediment to possible erosion and transport.

4.1.3 Integrating processes

A schematic representation of the integration of resource linkages is presented in Figure 4.1. As water and sediment are produced and flow downstream from the upper portion of the watershed, they have been modified by reservoirs and diversions. In addition, structures such as bridges have been built in the river that further affect the river. As a result of such influences, the river has experienced channel bed degradation to some degree, and has experienced significant expansion of woody vegetation onto formerly active channel areas. These changes have been documented and discussed previously in this report as well as in the numerous references.

Over the years, there have been many attempts to define geomorphic relationships that explain this dynamic behavior of rivers. For example, regime theory and associated stable channel equations were developed by Lacey (1929). These equations define

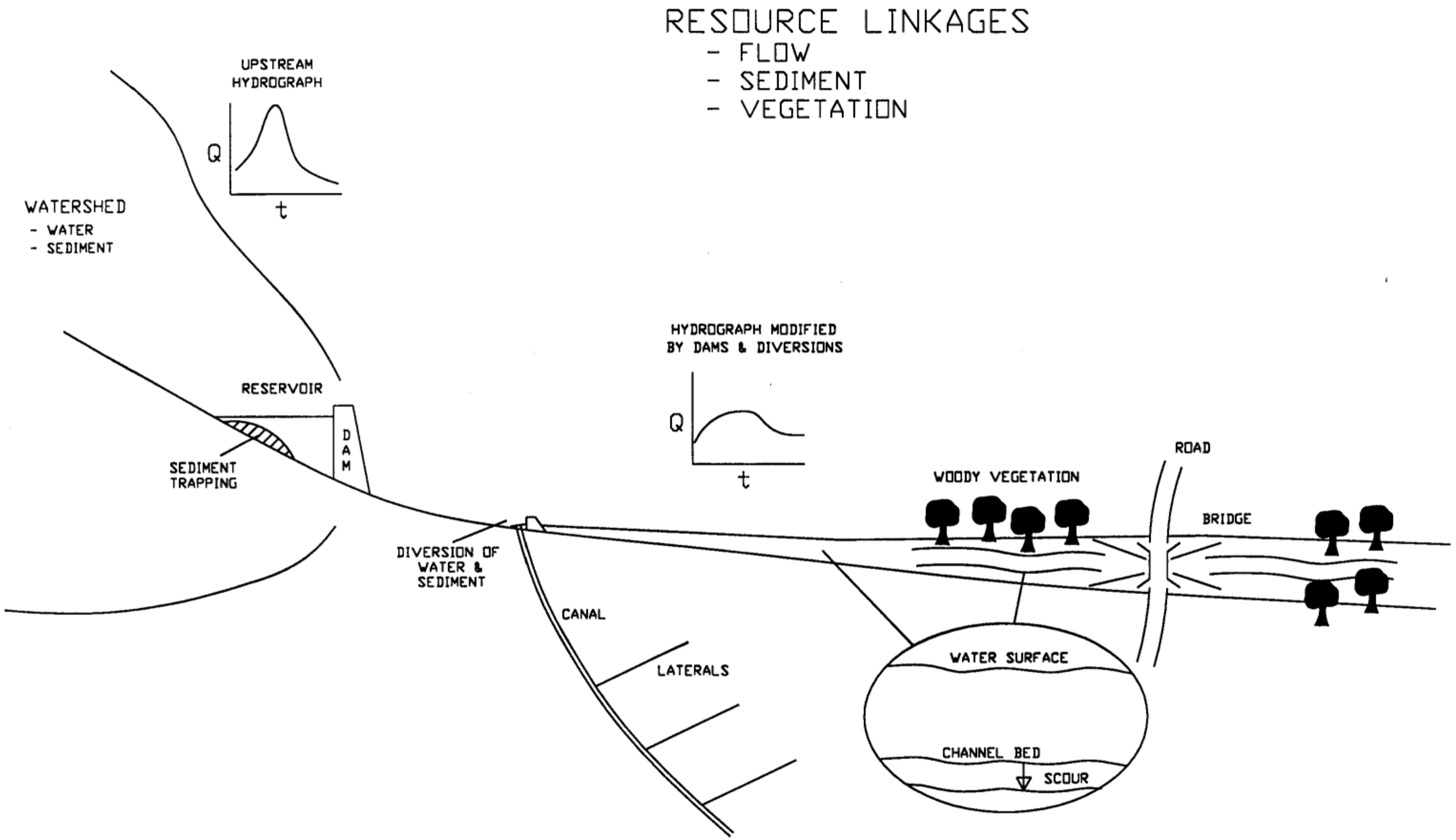

RESOURCE LINKAGES
- FLOW
- SEDIMENT
- VEGETATION
UPSTREAM HYDROGRAPH
Q
t
WATERSHED
- WATER
- SEDIMENT
RESERVOIR
DAM
SEDIMENT TRAPPING
HYDROGRAPH MODIFIED BY DAMS & DIVERSIONS
Q
t
DIVERSION OF WATER & SEDIMENT
CANAL
LATERALS
ROAD
WOODY VEGETATION
BRIDGE
WATER SURFACE
CHANNEL BED
SCOUR

Figure 4.1

relationships between such characteristics of the channel as wetted perimeter, cross-sectional area, and hydraulic radius to sediment characteristics, slope, and resistance to flow. While all of these geomorphic relationships provide useful insight into the geomorphology of the Platte River, they do not fully explain the complex interaction of the flow of water, sediment transport, and riparian vegetation that all have influenced the geomorphology and associated habitat of this river. Theories or hypotheses have been developed to explain the processes affecting the Platte River. These are discussed later in this report.

4.1.4 Resulting Effects on the River Channel

The Platte River has generally become somewhat incised and has tended to shift to some degree away from its braided character towards an island braided or single channel compared to its pre-development state. The slope of the river would have become slightly flatter due to incision, however, the overall gradient cannot be significantly different from pre-development conditions. Significant portions of formerly active channel width have been vegetated. The number and extent of wooded islands have significantly increased. These changes have affected river characteristics including a generally smaller width/depth ratio, smaller water widths, and smaller unobstructed widths across currently active channel areas between areas of woody vegetation. The woody vegetation tends to stabilize areas on where it grows. These areas tend to build up over time as high flows deposit some sediment in the vegetated areas. While significant changes have occurred, there is substantial evidence that the river has reached a state of dynamic equilibrium when minor fluctuations in channel geometry and small changes in extent of vegetation are expected, but no long-term trends of change are in progress.

4.2 Analysis of Factors that May Affect Channel Morphology/Vegetation

At this stage in discussing the changes experienced by the Platte River, it is necessary to develop a sufficient understanding of the factors that may affect the morphology of the Platte River and associated vegetation. Without an understanding of the fundamental factors or causes of change, it is not possible to develop appropriate mitigation measures nor understand their effect.

Before discussing and evaluating these various factors, it is necessary to first understand the basic physical and biological processes that interact in a riverine environment regarding the balance between vegetation and flow. In order for vegetation to exist, seeds must germinate on suitable substrate. Once germinated, in order for a plant to grow, it must survive a variety of events. As flow and corresponding water levels typically recede through the summer growing season soil moisture available to roots is reduced possibly resulting in desiccation. Pulses of high flow associated with thunderstorm events, ice formation and break-up, and the snowmelt peak for the next year may scour vegetation.

Riparian vegetation typically germinates in the late spring and early summer. Considering the dominant species of woody riparian vegetation along the Platte River, the cottonwood, this species of vegetation produces millions or more seeds virtually every season. These seeds are dispersed by wind and water in some cases covering barren substrate with a blanket of cotton. Available substrate on the Platte River consists mostly of sand. Sand is considered a suitable media in which plants can grow and survive. Cottonwood seeds are only viable for a very short period of time ranging from about 1 to 10 days. Seeds are generally produced from about mid-May to mid-July. During the time period of seed production, dispersal and germination, the snowmelt peak often occurs and recedes. When the flow exposes suitable substrate, either because it is low enough that it does not inundate the bed and lower riverbanks or because it recedes after the peak and exposes suitable substrate, seeds are deposited on suitable substrate. Some percentage of the seeds germinate, become established as roots grow into the bed, and begin to grow during the summer season if moisture at or near the surface and in the root zone is sufficient. The timing of seed production is closely associated with the timing of peak flow and the recession limb in a strategy of survival and expansion of the species. Thus, the establishment of vegetation through the process of germination is dictated by the timing of the snowmelt peak and associated recession compared to the timing of seed dispersal and the extent to which suitable substrate is exposed as the flow recedes.

As previously mentioned, a number of factors come into play after germination and establishment that limits survival of seedlings. As the summer season proceeds, some of these plants may not survive if the roots cannot grow fast enough to maintain contact with an adequate moisture supply in the water table below the exposed bed as the flow typically continues to drop to its lowest level of the year. During high flow events that may occur as early as during the summer season associated with intense thunderstorm activity, young vegetation could be eroded. This depends on the magnitude of the flow, associated extent of inundation, and strength of the current as it affects vegetation and scour of sediment into which the vegetation is rooted. During the winter, ice may form in areas where vegetation has been established. Ice can remove vegetation by pulling it out or shearing it off, primarily during ice break-up. As the peak flow occurs the next season, vegetation previously established and growing may be scoured or otherwise removed by peak flow events due either to hydraulic forces or transport of sediment. This cycle repeats year after year and responds to the ever-varying hydrologic input and associated sediment transport and geomorphic conditions.

Riparian vegetation processes have been observed on the Platte River by monitoring the interaction between vegetation and flow. Monitoring was conducted several strategic times each year in order to understand the likely cause of mortality. For example, monitoring was typically conducted each year after the germination season during the summer, in the fall to evaluate survival/mortality during the summer season, after the winter and associated ice, and again in the summer after peak flow season to monitor the effect peak flows on scour of already established vegetation as well as recruitment of new vegetation. These vegetation demography studies (Johnson - 1990a, 1992, 1993, 1994a, and 1996b) consisted of monitoring thousands of seedlings for a number of years through their life history from shortly after germination and establishment through death. For example, near the end of the study period in 1993-1994 about 2,400 seedlings were monitored. In 1994-1995, about 3,000 seedlings were monitored. Monitoring has provided a wealth of detailed information that has been correlated with flow and other data to understand the interaction between flow and riparian vegetation in the Platte River.

Over the years and by a number of analysts, various concepts and factors have been suggested to explain the changes that have occurred along the Platte River. The primary factors that have affected vegetation along the Platte River are summarized below.

1. Total Annual Flow/Mean Annual Flow - Early investigators of Platte River systemic channel changes recognized that stream flow changes probably had a significant role in causing reductions in channel widths through expansion of riparian vegetation. It was suggested that the changes in channel widths may be attributable to reductions in mean annual flow or the total annual volume of streamflow in the river (Williams, 1978).
2. Peak Flow - Peak flow as a key factor in controlling vegetation maintains that peak flows are the agent that eliminates woodland expansion by scouring young vegetation (O'Brien and Currier, 1987). It has been suggested that water resources development, particularly large reservoirs, substantially reduced peak flows and, therefore, eliminated scour of vegetation that previously prevented woodland expansion and associated channel narrowing.
3. Desiccation - It has been suggested that changes in late-summer low/no-flow conditions affecting desiccation were the cause of woodland expansion (Ecological Analysts, 1983). It maintains that trees did not grow in and along the river in the pre-settlement era because it regularly went dry. It is thus suggested that the increase in base flow that occurred as a result of water resources development altered the ecosystem and provided a more hospitable environment for woody vegetation.
4. Flow during the Germination Season - Unlike the desiccation and peak flow concepts that focus on the removal and mortality of already established vegetation, the factor of flow during the germination season maintains that woodland expansion is caused by reductions in flow during the vegetation germination period. These reductions result in increased exposure of substrate thus allowing the germination of vegetation on formerly active portions of the channel bed (Johnson, 1990c and Simons & Associates, 1990d).
5. Sediment Transport - The sediment transport factor relates channel narrowing to reductions in sediment supply caused by the trapping of sediment behind dams coupled with reductions in peak flows (O'Brien and Currier, 1987). The reduction in sediment supply is said to have resulted in channel degradation which, in turn, is said to have caused a narrower and less braided channel. In addition a channel with reduced bed mobility would be more stable allowing vegetation to survive because scour and sediment transport is reduced.
6. Ice Scour - Vegetation may be potentially removed by ice scour. Ice can remove vegetation either by shearing the stem or trunk from the root system, scouring sediment upon which the vegetation is rooted, or by pulling the plant out by the roots as ice moves away from an area with the plant frozen in the ice (Johnson, 1990a).
7. Structures - Structures built out into the river, restricting the width of the river or causing separation zones where sediment tends to deposit, provide ways by which a river may become physically narrower. As a result of physically narrowing and

removing or reducing the influence of flow by bank stabilization, vegetation may become established and grow resulting in expansion of vegetation (Becker, 1986, and Simons & Associates, 1990d).

The following sections present a discussion of the principal factors that have been proposed to explain the changes in channel morphology and vegetation that have occurred on the Platte River system. The discussion of each factor presents background information relevant to each specific factor. Then, the section is sub-divided into two sections discussing Pre-development and Post-development conditions. It is important to understand that one factor may have played a more significant role under pre-development conditions whereas another may have been dominant under current conditions, depending on channel or flow conditions and how each has varied over time. Discussion of this phenomenon is included for consideration in the evaluation of each of the key factors.

4.2.1 The Role of Total Annual/Mean Annual Flow in Channel Morphology/Vegetation

It is a generally accepted fact that reduction in flow such as characterized by total annual or mean annual flow play a role in the expansion of vegetation and channel narrowing that occurred on the Platte River. This concept is illustrated by regime relationships such as those developed by Lacey (1929), when he related the wetted perimeter of a channel to flow ($P = 2.67Q^{1/2}$). As flow decreases, so does the wetted perimeter (which is essentially the same as the channel width). The hydrologic variables of total annual or mean annual flow may be general indicators of other more specific hydrologic changes that affected channel morphology, but they do not by themselves provide a sufficiently detailed explanation of the channel morphology and vegetation changes that have occurred beyond the general relationship that a reduction in width can be related to a reduction in flow. It is recognized, however, that flow in general is the primary driving function behind virtually all of the other factors in one way or another, except regarding structural effects.

Pre-development conditions - Total and mean annual flows were large enough to result in a wide active channel based on the general relationship between flow and active channel. Vegetation was restricted to islands and riverbanks previously estimated to have occupied about 10 percent of the channel width.

Post-development conditions - Water resources development reduced the total and mean annual flows resulting in a reduction in the width of the active channel. The remaining flow-related factors provide more detailed explanation and evaluation of potential causes for change in channel morphology and vegetation so more extensive discussion is presented for these other concepts.

4.2.2 The Role of Peak Flow in Channel Morphology/Vegetation

Peak flow has been suggested as the key variable associated with the potential to remove vegetation by scour or by a combination of scour and the hydraulic forces exerted by the flow on vegetation. Scouring of vegetation by flow depends on the age of the vegetation and the strength of the flow (i.e., velocity and sediment transport). Seedlings on the order of a few months old may be scoured by relatively low flows. Saplings up to a few years old may be scoured but require considerably greater energy and significantly greater magnitudes of flow. Fully mature woody vegetation requires large flood events to be scoured, if it can be scoured at all. Thus, factors including the age of vegetation and the frequency of peaks large enough to scour an available distribution of vegetation combine to determine the pattern of survival and growth of vegetation along a river.

The influence of age of vegetation and frequency of sufficiently large peak flows is demonstrated by recent experience monitoring the effect of flow on vegetation. For example, the only flow event that caused any significant scour of vegetation in the period of time documented by aerial photographs that were studied until 1990 occurred in the extremely high flow period of 1983. Flow during this time period exceeded 20,000 cfs. Johnson (1994b) stated: *"Removal of older seedlings would require considerably higher flows, and established woodland could only be removed on islands and banks by floods of large magnitude, comparable to those of 700 m^3/s [approximately 24,500 cfs] or so that occurred in 1983."* Thus, maintaining the channel by scouring already established vegetation requires large peak flows and may or may not be successful.

Another large peak flow event occurred in 1995 with a peak flow of about 16,000 cfs. This event was important from a scientific perspective, because as Johnson (1996a) indicated,

> *It had special significance to those of us studying Platte River biohydrology, for the following reasons. First, it came 12 years after the last major flood in 1983 (the flood of record at many gages) and 10 years since we began monitoring vegetation in the river in 1985. Thus, it was the first significant flood to occur during our decade-long study of vegetation and streamflow inter-relationships. Our understanding of channel area dynamics had been incomplete without the occurrence of a single large flood of historic magnitude.*

The aspect of the effect of relatively large floods had not been tested in the field until 1995. It is also important to note that flows in the early 1990's were relatively low and had allowed some establishment of new vegetation. The effects of the flood on riparian vegetation were discussed by Johnson (1996a),

> *The flood caused the highest spring mortality of seedlings measured since monitoring began in 1985 and equaled values recorded after the most extreme ice events of the past (98 percent), such as the winter of 1985-1986. The high mortality rates in 1995 were even more significant because the seedling population in the river at the time of the flood was relatively old and well-established. The flood also precluded recruitment of cottonwood and willow trees in 1995 because it occurred in June during the seed germination period.*

Johnson's (1996b) demography study associated with this event revealed that, *"The flood killed virtually all low-growing seedlings, leaving only a few four and five year old seedlings on high sandbars resistant to a flood of this magnitude and duration."* Thus, data exist that support this magnitude of flood being capable of removing all seedlings except those older than four to five years on higher areas of the channel (noting that some of the previously established seedlings had been removed prior to this event by ice scour in earlier years). Older seedlings that are more resistant to scour or those on too high of ground with respect to the flood are not susceptible to the scouring effects of such an event. Currier (1995 and 2000) estimated that only about one-third of the 4- to 5-year old seedlings were removed, leaving about two-thirds remaining. The available information indicates that vegetation can be removed by peak flows but that relatively large flood peaks are, in fact, required to remove established vegetation. In addition, the historic events that actually removed vegetation remained at relatively high levels for a significant period of time through the summer. It is unknown to what extent duration of high flow played in the removal of established vegetation by the flow.

Research has been conducted on the interaction between peak flow and riparian vegetation on a number of river systems including the Platte River. Some of this research focused on the relationship between peak flow and riparian vegetation. While peak flows have been associated with the scour and removal of vegetation, recent research confirmed by a number of scientists indicates that peak flow events are in fact needed for the recruitment of new vegetation. Regarding the dominant woody species along the Platte River, the cottonwood, conditions for cottonwood seedling recruitment have been researched by several biologists as noted in Table 4.1, in a number of river systems from Arizona and New Mexico, through Colorado, Utah, and Montana, on up into Alberta, Canada. As explained by Mahoney and Rood (December 1998)

> *Cottonwood seedling recruitment is episodic and relatively rare even along free-flowing streams. It has been repeatedly concluded that flood events enable cottonwood seedling recruitment both through geomorphic impacts and direct hydrologic patterns (Johnson et al. 1976, Rood and Mahoney 1990, Scott et al. 1996, and citations in Table 1). The flood magnitude required for cottonwood recruitment has been estimated with a dendrochonological approach in which cottonwoods are aged and correlations (or in this case 'core-relations') are investigated between recruitment years and high stream years. . . various researchers have reached relatively similar conclusions regarding the need for moderate flood events for successful cottonwood establishment (Table 1).*

Table 4.1. Estimated flood recurrences associated with cottonwood recruitment based on dendrochronological analyses (chronological listing).

Flood Return Interval (yrs)	*Populus Species*	*River*	*Source*
5	*P. deltoides*	*Milk, AB, MT*	*Bradley and Smith 1986*
3	*P. angustifolia*[1]	*Animas, CO*	*Baker 1990*
10-15	*P. angustifolia*[2]	*Animas, CO*	*Baker 1990*
10	*P. balsamifera*	*Bow, AB*	*Cordes 1991*
3	*P. fremontii*	*Rio Grande, NM*	*Howe and Knopf 1991*
5	*P. deltoides*	*Milk, AB*	*Reid 1991*
7	*P. fremontii*	*Hassayampa, AZ*	*Stromberg et al. 1991*
10	*P. deltoides*	*Red Deer, AB*	*Marken 1994*
10	*P. fremontii*	*Colorado, UT*	*Rood et al. 1997*
9	*P. deltoides*	*Missouri, MT*	*Scott et al. 1997*
10	*P. deltoides*	*Red Deer, AB*	*Cordes et al. 1997*
5-10	*P. balsamifera*	*Bow, AB*	*Rood et al. 1998a*

[1] *Seedlings.*

[2] *Stands.*

> *Studies have consistently suggested that a 1 in 5 to 1 in 10 year flood event is associated with cottonwood recruitment (Table 4.1). These moderate flood events drive the erosional and depositional processes associated with the creation of barren nursery sites on meander lobes, lateral bars, and islands and also provide a pattern of stream flow and stage that is suitable for seedling establishment. Larger floods may cause massive fluvial-geomorphic change that sets the framework for cottonwood recruitment over the next years and even decades (Freidman et al. 1996, Stromberg et al. 1997, Rood et al. 1998).*

This material brings up a number of other factors including germination and sediment related geomorphic issues that are discussed in subsequent sections. Mahoney and Rood discuss further that researchers (as presented in the following literature: Bradley and Smith (1986), Rood and Mahoney (1991), and Scott et al. (1993) agree regarding the effect of the hydrograph on seedling recruitment. The basic concept is that much of the seed release generally occurs after the peak of the hydrograph which is shown to occur most frequently in June. Data (Johnson, 1990a) show that the seed dispersal period for cottonwoods on the Platte River generally extends from mid-May through early to mid-July. For successful germination, seeds deposit (either through the air or by water) on virtually any areas of barren, moist substrate as the water level drops as the hydrograph receeds after the peak flow. An analysis of the timing of peak flow on the Platte River shows that peak flows most frequently occur in May and June (Simons & Associates, 1990a) caused primarily by snowmelt runoff. Thus peak flows, as shown by various researchers, may scour some vegetation; however, they typically occur prior to the end of the seed dispersal period and the scour and sediment redistribution process then provide moist, barren substrate suitable for recruitment of new woody vegetation as the flow recedes and seeds land on exposed substrate.

Pre-development conditions - Prior to significant water resources development, it is thought that peak flows of sufficient magnitude occurred frequently enough to limit the expansion of woody vegetation to islands and a relatively narrow band of riverbank vegetation to be consistent with the earliest observations. Assuming a peak flow occurred every year or two, any vegetation that might have become established in previous years would have been scoured except on islands or riverbanks where frequent flood peaks had insufficient power and depth. The occurrence of frequent peak flows under pre-development conditions would have left a relatively broad expanse of active channel, between the vegetated riverbanks and vegetated islands, that was not vegetated to any permanent degree by woody riparian vegetation. The typical flow hydrograph of the pre-settlement Platte River (as represented by the oldest hydrologic records) would be expected to produce conditions favorable for recruitment of woody riparian vegetation based on the recent scientific literature, however, such vegetation would be limited to the islands and banks where the strength and depth of flow is insufficient to consistently remove vegetation. The combination of the pre-settlement hydrology with current research on conditions favorable for the establishment and regeneration of riparian vegetation are consistent with the description of a relatively well vegetated Platte River (vegetated islands and banklines with broad expanses of unvegetated active channel) before deforestation as summarized by Johnson and Boettcher (1999).

Post-development conditions - Under hydrologic conditions associated with the development of water resources, with significantly reduced peak flows and long duration between peaks due to development as well as periods of drought, the balance between removal of vegetation by peaks and recruitment associated with peaks shifted to favor recruitment over removal. This was previously explained in a qualitative evaluation of the potential for woodland expansion or removal due to flow based on data from 1934 to 1986 (Simons & Associates, 1989). This analysis utilized historic hydrologic data for this time period combined with aerial photographs. One of the results of this analysis was an evaluation matrix of the potential for woodland expansion or removal related to flow during various key periods of the year. This matrix is included below. This evaluation demonstrates that the preponderance of years under which there was a moderate to high potential for woodland expansion contrasted with the low potential for removal of vegetation by the flow particularly during the 1930's through the mid-1960's when the effects of water resources development were strongest during the initial years of a number of large projects. This is the time period when woody vegetation expanded significantly onto formerly active portions of the channel. The combination of increased exposure of the channel bed allowing germination on formerly active areas of the channel and reduced magnitude and frequency of peak flows that reduced removal of vegetation, played a significant role in the expansion of woody vegetation into the Platte River.

EVALUATION MATRIX OF POTENTIAL FOR WOODLAND
EXPANSION OR REMOVAL DUE TO FLOW OF WATER

Year	Winter/Spring Flow	Germination Period Flow (1)	Late Summary Fall Flow	Portions of Channel Exposed to Potential Woodland Expansion	Qualitative Assessment of Potential for Significant Woodland Expansion	Qualitative Assessment of Potential for some Vegetation Removal by Flow
1934	N/A	Extremely Low	Extremely Low	All	High	Low
1935	Moderate	Extremely High to Extremely Low	Low	None to All	High	High
1936	High	Extremely Low	Extremely Low	Virtually All	High	High
1937	Moderate to High	Moderate to Low	Extremely Low	Mid & Upp to All	High	Low to Moderate
1938	High	Moderate to Low	Low to Moderate	Middle & Upper	Moderate	High
1939	Moderate to High	Low	Extremely Low	Middle & Upper	High	Low
1940	Low to High	Moderate to Extremely Low	Extremely Low	Virtually All	High	Moderate
1941	Low to Moderate	Low to Extremely Low	Extremely Low	Virtually All	High	Low
1942	Low to High	High to Moderate	Moderate to High	Upper to None	Low	High
1943	Low to Moderate	Moderate to Low	Low	Upper to Middle	Moderate	Low
1944	Moderate	Low	Low	Middle to Upper	Moderate to High	Low
1945	Low to Moderate	Moderate to Low	Low to Moderate	Middle to Upper	Moderate	Low
1946	Low to Moderate	Low	Low to High	Middle to Upper	Moderate to High	Moderate
1947	Moderate	Low to High	Low	Mid & Upp to None	Low	High
1948	Moderate to High	Low to Moderate	Low to Moderate	Middle to Upper	High	High
1949	Moderate	Moderate to High	Low	Upper to None	Low	High
1950	Low	Moderate to Low	Low	Middle & Upper	High	Low
1951	Low	Moderate	Moderate	Upper	Moderate to Low	Low
1952	Moderate	Low	Low	Middle to Upper	High	Low
1953	Low to Moderate	Low to Extremely Low	Low	Mid & Upp to Vir All	High	Low
1954	Low to Moderate	Low to Extremely Low	Low to Extremely Low	Mid & Upp to Vir All	High	Low
1955	Low to Moderate	Low to Extremely Low	Low to Extremely Low	Mid & Upp to Vir All	High	Low
1956	Low	Extremely Low	Extremely Low to Low	Virtually All	High	Low
1957	Low to Moderate	Moderate to Low	Low	Upper	Moderate	Low
1958	Low to Moderate	Moderate to Low	Moderate to Low	Upper	Moderate	Low
1959	Low to Moderate	Low	Low to Extremely Low	Middle & Upper	High	Low
1960	Moderate to High	Moderate to Low	Low to Extremely Low	Middle & Upper	High	Moderate to High
1961	Low	Moderate to Low	Low	Middle & Upper	High	Low
1962	Low to Moderate	Moderate	Low	Upper	Moderate to Low	Low to Moderate
1963	Low to Moderate	Low	Low	Middle & Upper	High	Low
1964	Low to Moderate	Low	Low	Middle & Upper	High	Low
1965	Low to Moderate	High	Moderate	Virtually None	Low	High
1966	Low to Moderate	Low	Low	Middle & Upper	High	Low
1967	Low	High	Low	Virtually None	Low	High
1968	Low to Moderate	Low to Moderate	Low to Moderate	Middle to Upper	Moderate	Low
1969	Moderate to High	Moderate	Moderate	Upper to None	Low	Moderate

EVALUATION MATRIX OF POTENTIAL FOR WOODLAND
EXPANSION OR REMOVAL DUE TO FLOW OF WATER (CONTINUED)

Year	Winter/Spring Flow	Germination Period Flow (1)	Late Summary Fall Flow	Portions of Channel Exposed to Potential Woodland Expansion	Qualitative Assessment of Potential for Significant Woodland Expansion	Qualitative Assessment of Potential for some Vegetation Removal by Flow
1970	Moderate	Moderate	Moderate	Upper to None	Low	Moderate
1971	Moderate to High	High	Low to Moderate	Virtually None	Low	High
1972	Moderate	Low	Low to Moderate	Middle to Upper	High	Low
1973	Moderate to High	High	High	Virtually None	Low	High
1974	High	Low to Moderate	Low	Middle to Upper	High	Moderate
1975	Low to Moderate	Moderate to Low	Moderate	Middle to Upper	Moderate to Low	Low to Moderate
1976	Low to Moderate	Low	Low	Middle to Upper	High	Low
1977	Low to Moderate	Moderate to Low	Low	Middle to Upper	High	Low
1978	Low to High	Low	Low	Middle & Upper	High	High
1979	Low to Moderate	Moderate	Low	Upper	Low	Low to Moderate
1980	Moderate to High	High to Low	Low	None to Mid & Upp	Low to High	High
1981	Low	Low	Moderate	Middle & Upper	High to Low	Low
1982	Low to Moderate	Low	Low to Moderate	Middle & Upper	High	Low
1983	Moderate to High	Extremely High	High	None	Extremely Low	Extremely High
1984	High	High	Moderate	None	Low	High
1985	Low to Moderate	Moderate to Low	Low to Moderate	Middle & Upper	High	Low
1986	Low to Moderate	Moderate	Moderate	None to Upper	Low	Moderate to Low

(1) Germination period from Mid-May through Mid-July.

Note: Ratings of Low, Moderate & High refer to the flow's ability to remove or prevent vegetation and should not be confused with a statistical analysis of the flow magnitude through these given time periods.

Current research demonstrates that peak flows can scour woody vegetation depending on the age of the vegetation and strength of the flow (peak flows under the current regime range from about 3,000 to 24,000 cfs and average about 8,600 on the Platte River). Once woody vegetation survives and grows to be several years old, it becomes quite resistant to removal by flow, being removed by only relatively large and infrequent flood peaks if removal can occur at all. Such species as cottonwood and willow, however, require periodic flood events to cause some scour and redistribution of sediment in a process of preparing or creating new areas of barren substrate suitable as a seed bed. Then as the high flow recedes, seeds are deposited either through the air or by water on the moistened substrate. Such conditions are favorable for recruitment of new vegetation.

Based on the available information, infrequent peak flows are an agent by which riparian vegetation may be limited by scour but it is also the agent by which vegetation becomes self-sustaining over the long-term by the process of periodic recruitment events. This information is consistent with observations of the process of seedling establishment on the Platte River during the recession limb of peak flow events as seed dispersal and germination generally continue past the time of the typical peak of the annual hydrograph as discussed in a subsequent section. Any scour of vegetation by infrequent peak flows as a means of removing or controlling vegetation is counterbalanced by the recruitment process that induces new vegetation.

4.2.3 The Role of Desiccation in Channel Morphology/Vegetation

Desiccation causes plant mortality when insufficient moisture is available to the roots of the plant. On the Platte River, this can occur as the water level in the river recedes after the typical late spring peak flow and drops to the generally lowest flows of the season during the summer, even as low as zero or no flow. With a sandy substrate, it has been previously shown that the groundwater level some distance away from the river is the same as the water level in the river (see Section 3.3). If the flow and the corresponding stage in the river drops faster than the roots of a young plant can grow and extend into the water table, hot and dry weather can cause young plants to die. As the years go by and a plant has time to develop a sufficient root structure that extends deep enough, then it is significantly less likely to succumb to drought.

Observation of plants on the Platte River under current conditions clearly demonstrates that some plant mortality is caused by desiccation as evidenced by dead cottonwoods, primarily first-year seedlings with dry brown leaves, seen during mid to late summer months of the year. Mortality from drought for first year seedlings ranged from 40 to 77 percent as documented by Johnson (1990a, 1992, 1993, 1994a, and 1996b). After the first year, mortality by desiccation decreases dramatically for older seedlings because as years go by the roots of older plants reach farther down into the water table supported by the river over the long-term, or into the capillary zone immediately above the water table. Observation of mortality by desiccation of older seedlings (2-4 years old) is relatively rare. Death of plants by desiccation was not found to be a dominant factor when compared with other factors based on the vegetation demography studies conducted by Johnson and reported at the conclusion of the various time periods studies as referenced above. Thus, while recent field observations of Platte River vegetation have recorded evidence that severe summer drought conditions can have an effect on young vegetation, the data indicate, however, that desiccation only affects a portion of first year seedlings and that older seedlings are rarely affected by this process because roots have already extended to the water table.

Pre-development conditions - Prior to significant water resources development, a number of observations were made of no flow occurring along significant reaches of the Platte River. Many observations, however, were made of water being available a short distance below the bed of the river. While some mortality of riparian vegetation would be expected under these conditions, given the relatively shallow depth of the Platte River and the available supply of moisture just under the bed, even when the river had gone dry, it is likely that the rate of peak flow recession keeping water below root systems was not sufficient to be the dominant factor that controlled vegetation in the pre-development condition. The fact that a significant extent of vegetation survived pre-development low or no flow periods on higher portions of the channel such as islands and riverbanks is supported by the observations of early travelers and settlers who describe numerous wooded islands and forested riverbanks in and along the Platte River. It should be noted that no data and desiccation mortality observations under pre-development conditions are available to corroborate this position. And, it is likely that mortality by desiccation played a stronger role in pre-development conditions compared to present conditions because of the increase in low flow and decrease in extent of no flow conditions in recent decades. Nevertheless, pre-development mortality by desiccation likely remained a relatively small influence on riparian vegetation.

Post-development conditions - As water resources development occurred, reservoirs stored water during peak flow conditions for release later in the summer when flow in the river was typically quite low or even zero. This has increased low flows. In addition, irrigation returns have also increased the base flow in the river. As the river responded to water resources development, the drop in flow from peak to base was not as large or fast and with the higher base flow the potential for desiccation of vegetation decreased over the years.

An indication of the relative unimportance of desiccation in limiting vegetation is the fact that the driest periods of the 20th century (the major droughts of the 1930's and 1950's) represent the periods of time with the greatest expansion of woody vegetation (refer back to Figure 2.23). While the concept of desiccation is tenable in theory, there is a substantial body of evidence to indicate that late-summer desiccation was not a significant factor limiting woodland expansion. Analyses of 50 years of woodland expansion patterns and trends on the Platte River provide no significant support for desiccation as a dominant factor. The analysis, in fact, shows substantial woodland expansion during the period of the 1950's drought when low flows were a regular occurrence.

Vegetation demography data show that while some desiccation of new seedlings occurs under current conditions, it is not a dominant mortality factor. In addition, desiccation rarely occurs for seedlings 2 years of age and older. Under the current flow regime, with increased flow during the summer due to irrigation return flows, the potential for desiccation has likely been reduced compared to pre-development conditions.

4.2.4 The Role of Flow during the Germination Season on Channel Morphology/Vegetation

The germination period on the Platte River, as previously documented, extends from about mid-May to mid-July (for cottonwoods, which is the dominant woody, riparian species). Typically during the germination season the flow in the Platte River is receding after the snowmelt runoff peak flow of the year. This exposes the sandy riverbed to the seeds whereupon many germinate, become established, and begin to grow. The validity of the concept that flow during the germination season plays a key role in vegetative processes was tested by Johnson and Simons & Associates by two independent methods. These included a statistical correlation between changes in vegetation from aerial photographs and flow, and a hydraulic analysis of the relationship between flow magnitude and the extent of inundation of the channel.

A statistical analysis of the causes of woodland expansion was conducted by Johnson (1990c) using data obtained from a computer digitization analysis of aerial photographs covering a 50-year period from the 1930's to the 1980's. Johnson concluded from the statistical analysis that, while several factors have had a significant effect on woodland expansion, the most important factor was reduction in flow during the vegetation germination period. His explanation is that flow reductions during this period have exposed channel substrate that subsequently became vegetated as seeds germinated and became established on areas not inundated by water. The statistical analysis showed that when average flows during June between sets of aerial photographs were lower than some threshold magnitude, expansion of vegetation occurred. Conversely, when average June flows exceeded the threshold, no significant expansion of vegetation occurred. That threshold is on the order of 2,700 to 3,000 cfs. Johnson (1990a) found further evidence of the importance of this mechanism in his vegetation demography fields study of the Platte River. The demography study showed that when the flow was sufficiently high during the germination period, no significant quantity of seeds germinated resulting in no recruitment of vegetation for that year in which flow during the germination season was high. While this analysis provides useful insight, it does not explain the mechanics of why such flows during the germination season were effective in controlling vegetation.

Independent from Johnson's statistical correlation and in addition to the evaluation presented above, Simons & Associates conducted a hydraulic analysis of channel inundation as a function of flow for Platte River cross-section data surveyed in the 1980's in the vicinity of vegetation demography sites at Odessa and Shelton. This hydraulic analysis computed the percentage of channel inundated by a range of flows. The analysis showed that the active channel was inundated such that no barren substrate was available for colonization by vegetation at flows on the order of less than 3,000 cfs. In other words, at a flow just under about 3,000 cfs, essentially all substrate would be inundated and no germination of seeds would be possible. This hydraulic analysis explains the linkage between flow and the vegetative process. The results match Johnson's analysis that showed no expansion of vegetation occurs when flow during the germination period equals on the order of 2,700 to 3,000 cfs (Johnson, 1995), *"The recommended pulses of 12,000+ cfs are much larger than needed to be effective in eliminating tree reproduction. Averaged over 5-10 year periods, mean daily June flows of approximately 2,700-3,000 cfs historically have been adequate to prohibit woodland expansion in the lower half of the Big Bend Reach."* A magnitude of flow of less than 3,000 cfs then has been quantitatively substantiated to prevent establishment of vegetation by two independent methods. In the pulse flow workshop set up by the USFWS and attended by a number of interested parties (May 17-18, 1994), Currier did not agree with the conclusion that such low flows could maintain the channel. Currier later (1995) presented information that some 4- to 5-year old vegetation survived the peak flows of 1995 (about 16,000 cfs). Subsequently, Currier (personal communication, 2000) indicated that he agrees that flows in the 2,700-3,000 cfs range are effective in removing 1- to 2-year old seedlings. It is important to note that there is a difference between removing vegetation after becoming established by some type of scouring action and preventing vegetation from becoming established. This difference is discussed in more detail in section 4.3.

Based on the analyses presented above, the magnitude of flow that prevents significant germination and the physical process behind it has been established. In another separate hydraulic analysis using historic streamflow data and channel cross-section data from the 1920's - 1930's, the amount of channel narrowing and the timing of such changes on the North Platte, South Platte, and Platte Rivers was also found to be explained to a large degree by the percentage of channel not inundated by water during the vegetation germination period. By explaining the timing of woodland expansion by hydraulic analysis provides support for the germination hypothesis as explained below. In this analysis, 1920's - 1930's channel cross-section data for 7 sites was obtained from the records of the Nebraska Bureau of Public Works, Department of Roads and Bridges. The 7 sites were:

1) Lisco - North Platte River upstream of Lake McConaughy
2) Hershey - North Platte River below Kingsley Dam
3) Brule - South Platte River upstream of the Korty Diversion
4) Hershey - South Platte River below the Korty Diversion
5) Brady - Platte River between the confluence and the J-2 Return
6) Odessa - Platte River downstream of the J-2 Return
7) Gibbon - Platte River downstream of the J-2 Return

Hydraulic analysis of channel cross-sections taken prior to the Projects conducted as part of the analysis conducted by Simons & Associates (1990d) provides some important insight on this issue:

> *This hydraulic analysis, combined with the results of Johnson's statistical analysis and field study observations and the aerial photographic analyses, strongly indicate that exposure of river channel bed to vegetation during the germination period is a dominant fact that has led to woodland expansion and channel narrowing of the Platte River system. It also explains to a significant degree the somewhat different response in channel narrowing to similar,*

> *basin-wide changes in flow. Thus, caution should be used in interpreting results of the aerial photo analysis without applying these concepts of open channel hydraulics and exposure or inundation of the channel bed as a function of flow.*

The phenomena of channel narrowing and woodland expansion has been shown to depend to a significant degree on the flow during the seed germination period and the amount of channel not inundated by the flow during this period. Aerial photo analysis shows that the time periods when most channel narrowing and woodland expansion occurred, such times of greatest change took place during periods of low flow such as the 1950's drought. During periods of low flow, significant portions of the channel bed are above water and exposed to the potential for seed germination. Woody vegetation seeds, such as cottonwood, land on exposed sand bars, islands, or banks via either wind or water and can, if conditions are acceptable, germinate and become established. Obviously the seeds cannot germinate or become established on substrate over which water is flowing or is even just ponded.

Analysis of the percentage of channel inundated by water during the germination period using historic flow data and old cross-section data from the 1920's or 1930's explain, to a significant degree, the amount of channel narrowing and woodland expansion as well as the timing of such changes along the North Platte, South Platte, and Platte Rivers. This is demonstrated in Appendix C. Support for the relationship between inundation during the germination season is provided by evaluation of the timing of the historic changes in woody vegetation at various locations along the Platte River considering the extent of channel bed exposed to vegetation for the different shapes of cross-sections and the timing of flow reductions. This is presented in Appendix D. A computer model utilizing the concept of flow and inundation during the germination season to simulate establishment of vegetation coupled with scour of vegetation during peak flow events was found to provide excellent correlation between measured and computed changes in vegetation. Appendix E presents a discussion of this analysis.

The relative importance of peak flow and flow during the germination season was discussed in Simons & Associates (1989).

> *A comparison is now made of the historic flows on the Platte River near Grand Island and their effect on channel narrowing and woodland expansion for the periods when there was significant change as contrasted with the period of dynamic equilibrium starting in about the 1960's when very little change occurred. Considerable emphasis on peak flows controlling vegetation has been made by various groups. For example, O'Brien and Currier have done some averaging of peak flows as well as other analysis that suggests 8,000 cfs is required to "maintain" the channel. These groups do not mention any other aspect of the flow other than the peaks. During the period when most channel narrowing and woodland expansion occurred (1930's to 1960), the peak daily flow for the*

> *year at Grand Island averaged about 7,300 cfs. From 1960 to 1984 the peak daily flow averaged 8,055 cfs. The relatively small difference in the peak flows for these two periods cannot possibly explain the significant difference in the extent and rates for channel narrowing and expansion that has been documented for these two time periods. Channel size and shape and the relationship between flow and the percentage of the channel inundated by water during the germination season play a key role in the potential for woodland expansion. Peak flow, therefore, cannot be used as a channel maintenance flow criteria. One must look further in the relationship between flow, channel narrowing and the growth of vegetation. There are some major differences in the historic sequences of flow before and after 1960. One of the major and perhaps most significant differences in the flows for these two periods is related to the numbers of years in a row for which the potential for woodland expansion was high. For example, before 1960 there were two main periods where the potential for expansion remained high or moderate. These correspond to the drought periods of the 1930's and 1950's. During these periods the potential remained high or moderate for as long as eight to ten years in a row. Often during these years there were not many significant flow events which could remove vegetation. These long series of years with a high potential for woodland expansion allowed a long enough period for significant amounts of river bed to be exposed which in turn allowed vegetation to germinate and grow. After 1960 there was much less significant channel narrowing and woodland expansion and, although the average peak flow is somewhat higher, the real difference lies in the fact that there were no series of years where the potential for woodland expansion was high longer than three years. The period of 1960 to the present is characterized by a series of high and low flow years without long periods of low flow year after year. Without these long low flow periods, the rate of channel narrowing and woodland expansion reached a state of dynamic equilibrium. Also, because the channel had already narrowed, the same flow after the 1960's inundated a greater percentage of the remaining active channel.*

Recently, Currier (personal communication, 2000) indicated that the previous estimate of about 8,000 cfs was preliminary and may not be adequate to remove some vegetation. This again highlights a difference in approach of removing vegetation or preventing vegetation from becoming established. The possibility that some vegetation may not be removed by a particular magnitude of peak flow does not necessarily mean that factors other than peak flow may remove or prevent vegetation or that some alternative flow regime may be as effective or more effective in meeting the overall objective of maintaining the channel (see section 4.3).

Pre-development conditions - Evaluation of the percentage of the channel inundated during the short time period when germination occurs (primarily mid-May to mid-July) indicates that, during most years, a substantial portion of the channel would be under water under pre-development flow conditions (unlike conditions later in the summer when frequently, the flow was quite low or even zero). This precluded germination on significant portions of the channel and forced vegetative recruitment to occur primarily on numerous islands and along the riverbanks where areas of suitable substrate were exposed. The fact that germination occurred but was restricted to islands and riverbanks is confirmed by observations of those who traveled or lived along the river and noted vegetation in these areas. Of course, whenever suitable substrate was exposed during the germination season, germination would be anticipated to have occurred due to the opportunistic nature of riparian vegetation (primarily cottonwood).

Post-development conditions - As water resources development occurred (along with periods of naturally occurring extended low flow or drought periods), reducing flow during the germination season, greater portions of the active channel were exposed to the seeds. The exposure of portions of the active channel that had typically been inundated under pre-development conditions, but were now exposed to lower flows during the germination season, triggered new areas of vegetative recruitment. The combination of flow reductions as new reservoirs were constructed, filled, and operated (primarily during the early 1900's through about the mid-1950's), as well as the droughts of the 1930's and 1950's, provided an extended period of relatively low flow during the germination season that lasted for several decades. It important to note that the primary water storage season occurs during the snowmelt runoff season which reduces peak flow as well as the flow during the germination season.

Research (Johnson, 1990c and Simons & Associates, 1990d) indicates that germination is precluded by inundation under current channel conditions when the flow during the germination season is on the order of 2,500 to 3,000 cfs. When flow during the germination season is less than this range, germination tends to occur. While the process of germination continues to occur depending on exposure of suitable substrate, it has generally not resulted in a continued trend of woodland expansion due to other factors that remove vegetation. As a result of the relatively smaller flow that inundates the present active channel and the current regime of flow under which little or no new flow reductions have occurred have resulted in a new balance called a state of dynamic equilibrium. A significant component of dynamic equilibrium is the fact that only limited areas of the active channel are exposed during the germination season and that whatever germination that does occur is at a low enough stage to be removed by ice and occasional peak flows.

4.2.5 The Role of Sediment Transport in Channel Morphology/Vegetation

General scour or erosion of the channel bed generally occurs when the sediment transport capacity through a reach of river exceeds the supply of sediment (in the case of no armoring). Whenever erosion occurs to a sufficient extent in the vicinity of vegetation, it may be removed by the flow due to the lack of any supporting soil matrix. The velocity of the flow also causes hydraulic forces on the portion of the vegetation above the bed or bank which can help pull a plant out of the ground. The stem or trunk of a plant can also induce turbulence in the flow that could cause local scour conditions in the immediate vicinity of the plant. Local scour could then lead to erosion and removal of the plant. In addition to direct removal of vegetation by scour, conditions adverse to vegetation may occur as a result of a dynamic, shifting channel such as may be expected under braided conditions. In a braided channel that is frequently shifting and whose bed is generally quite mobile, seeds that germinate and attempt to become established may be precluded from surviving. The concept that a braided river is often caused by an overload of bedload supplied to the river is a generally accepted theory. Schumm (1969) attributed the change in the South Platte from a braided channel to a single channel stream in part to a decrease in bedload movement through the channel as well as a reduction of spring floods. Unfortunately, no definitive analysis has yet been conducted regarding the extent to which sediment mobility and braided conditions played a role in controlling or limiting the extent of vegetation. Also, direct information on actual removal of vegetation due to sediment transport and scour apparently does not exist. Since scour is often greatest under conditions of peak flow and there is some available information associated with removal of vegetation during peak flow conditions, scour of vegetation is often associated with peak flow events as has been previously discussed.

No definitive analysis has been conducted regarding the extent to which the transport of the pre-development sediment supply was a necessary condition in forming a wide, shallow, braided channel. It is clear, however, that sediment transport plays a role in the morphology of a channel and in the vegetation supported by a river system since sediment transport is associated with the phenomenon of scour and potential instability of the bed and banks of the river as well as the general form of the channel.

Pre-development Conditions - Based on descriptions of the pre-development sediment transport and channel characteristics, it can be said that the bed of the Platte River was quite mobile and dynamic due to the braided nature of the river and the continual and significant transport of sediment. As a result, it is likely that vegetation had a difficult time surviving in much of the active channel of the Platte River. While sediment transport and general channel dynamics played a role in controlling the expansion of vegetation there is insufficient information to state that this factor was a dominant or simply a contributing factor.

Post-development Conditions - As water resources development occurred, dams trapped sediment and reservoirs reduced flood peaks while diversions and other water uses generally decreased flow. Sediment trapping and reduced flood peaks reduced sediment supply to the Platte River and sediment transport through the river. As water resources development progressed with associated reduction in flow and trapping of sediment, the channel geometry responded by adjusting to this new regime. The bed has coarsened over time, thereby becoming less mobile. Some limited channel bed degradation has occurred and the river has tended toward a less braided character. These factors have played some role in geomorphic changes and expansion of woody vegetation onto formerly active channel areas of the Platte River.

During the time period of adjustment to the flow and sediment regime, primarily during the 1930's through about 1960, significant expansion of woody vegetation occurred. The extent to which there is a relationship between the adjustment to a regime of reduced sediment transport and expansion of vegetation, however, remains somewhat obscure. This is best illustrated by evaluating the comparative differences in sediment transport reduction in the South Platte compared to the North Platte relative to changes in riparian vegetation on each of these rivers. Considering sediment transport reduction to be a dominant factor maintains that the trapping of sediment and reduced sediment transport to and through the Platte River resulted in substantial reduction in sandload which, in turn, caused the river to narrow and deepen thereby allowing vegetation to expand onto no longer active portions of the river channel. If this concept were true in terms of being the most dominant factor affecting channel morphology and vegetation, one would expect a significant difference in narrowing between the North Platte and South Platte Rivers. On the North Platte River, there are a number of large mainstem reservoirs that trap sediment and reduce sediment transport to a substantial degree. In contrast, on the South Platte, there is not nearly as much trapping of sediment, yet virtually the same amount of woodland expansions has occurred on both rivers. Williams (1978) indicates his apparent relegation of the sediment transport hypothesis to a secondary status behind flow when he stated, *"In the absence of any significant climatic shifts, the various channel changes described above most likely are due to the rather systematic decrease in water discharge (and possibly sediment discharge) that has occurred."* Thus, while it is recognized that changes in sediment transport have played a role in the changes to the channel and associated riparian vegetation, indications are that the reduction in sediment transport played a secondary role in the expansion of woody vegetation compared to the more direct effects of the significant reduction in flow, particularly during the germination season.

Under current conditions, analysis of sediment transport data suggests that the supply of sediment (bed material load) is essentially in balance with sediment transport along and through the Platte River. This suggests a condition of general stability or equilibrium of the channel bed. Some armoring of the bed by gravel sized particles has been observed. During the time period starting in about 1970, there has not been significant additional woodland expansion so that the current existing active channel widths have also experienced a condition described as dynamic equilibrium. Again, the extent to which a state of sediment transport equilibrium contributes to vegetative dynamic equilibrium has not been established as a dominant factor, however, it is certainly at least a contributing factor.

4.2.6 The Role of Ice Scour on Channel Morphology/Vegetation

Ice frequently forms along the Platte River during winter. As previously discussed, ice can remove or damage vegetation as it breaks up and begins to move downstream. Johnson's studies have found that indeed ice does play a significant role in eliminating vegetation under current conditions. In Johnson's report (1994a), he states that, *"seedling mortality is usually highest in winter."* In both the Johnson reports covering 1993-94 and 1994-95, he concludes with essentially the same information, *"seedling mortality is usually highest in the winter associated with ice; ice is an effective mortality factor* *because it can block flow and raise river stage, cause sediment movement, and physically damage living vegetation."* Johnson recorded mortality rates as high as 98 percent due to ice. Furthermore, he states that *"Ice remains the only factor with much potential to kill older seedlings, at least within the flow ranges that we have experienced during the course of this study."* In his evaluation of the 1995 flood, Johnson (1996a) equates the effect of this large event to an ice event in effectiveness of removing vegetation, *"The flood caused the highest spring mortality of seedlings measured since monitoring began in 1985 and equaled values recorded after the most extreme ice events of the past (98 percent), such as the winter of 1985-1986."* Of course, for those relatively rare winters when there is no ice, mortality due to ice obviously goes to zero. These vegetation monitoring studies conducted by Johnson, however, present clear evidence of the significant, if not dominant, impact ice-scour has in controlling vegetation in the Platte River under current conditions.

Pre-development conditions - No data or observations have been noted regarding the role of ice under pre-development conditions. As hypothesized by O'Brien (1995),

> *Historically, winter flows in February and March averaged 3,000 to 4,000 cfs at Grand Island as reported by Simons and Associates (1995), and would have covered only a portion of the active channel area. Furthermore, ice generally only forms in the portion of the active channel that is unvegetated or sparsely vegetated.*

This seems to be a reasonable assessment since the active channel at this time could convey significantly more flow than the lower flow during the winter season. It is likely that some vegetation could have been removed by ice if there had been low peak flows and low flow during the germination season that would have allowed recruitment of vegetation on lower portions of the channel. Then ice could have removed low lying vegetation if winter flows were close to the flow during the peak and germination seasons. Such a case would have been relatively rare and supports the concept that ice did not play a significant role under pre-development conditions.

Post-development conditions - As water resources development occurred, flow during the germination season became closer to flow during the winter. This allowed recruitment of vegetation in lower portions of the channel into areas that were much more frequently affected by ice. The result was documented by the vegetation demography studies by Johnson where ice was found to be the factor that caused the greatest mortality to vegetation compared to other factors. Only the larger and more infrequent peak flows approached the amount of mortality caused by ice on a regular basis. Thus, the role of ice in controlling vegetation has significantly changed from pre- to post-development conditions, going from a minor role to a major role.

4.2.7 The Role of Structures on Channel Morphology/Vegetation

The effect of hydraulic structures, such as bridges, on the morphology and vegetation patterns along the Platte River was explained in Simons & Associates (1990d) as follows:

> *It is well known that the construction of bridges and other hydraulic structures can substantially affect the size and shape of rivers in the vicinity of such structures. In constructing modern bridges, roadway embankments are built out into the river extending some distance into the active channel. Bridge abutments are also constructed at the ends of the embankments built out from each opposite bank to support the bridge. As a result, the shorter center span of the bridge under which water must pass can substantially constrict the flow, causing eddies to form both upstream and downstream of the bridge. The eddies have slower velocities that flow in a circular pattern, causing sediment deposition and the creation of sandbars. In addition, some local channel degradation is likely to occur in the center span where the flow is constricted.*

Analysis of aerial photos over time at bridges (Simons & Associates, 1990d) indicated that "*bridges cause significant channel narrowing and woodland expansion starting approximately 1/2 mile upstream to 1/2 mile downstream--an impact zone of approximately 1 mile for each bridge.*" It is a well-known fact that the constriction of the flow caused by bridges, as well as the obstructions to flow due to bridge abutments and piers, cause general and local scour of the riverbed in the vicinity of bridges.

Preliminary analyses of Platte River system aerial photos clearly indicated patterns of channel constriction and woodland expansion in the vicinity of bridges. Consequently, the following analyses were conducted to examine the effects of bridges on channel narrowing and woodland expansion:

- An aerial photographic analysis and computer digitization analysis using photos from 1938 to 1989.
- An engineering assessment of the structure, design, and location of 12 bridges in the Platte River system using the original bridge and channel drawings.
- An evaluation of sediment deposition and vegetation patterns in and around bridge areas.

The bridge at Odessa is a good example of the local effects of construction and maintenance of bridges on channel morphology. Figure 4.2 shows both a plan view and a cross-section view of the Platte River at the Odessa bridge site in the late 1920's without the proposed bridge. Figure 4.2a shows the same plan and cross-section with the proposed bridge in place. The shaded area represents the roadway embankment that blocked off much of the river so that only a small opening is left near mid-channel where the bridge was built through which the water had to flow.

Table 4.2 shows the percentage of the 1920's channel remaining open after the bridge and its associated roadway embankments were built.

Table 4.2 Percentage of Channel Width Remaining Open after Bridge

Location	Percentage of Channel
North Platte River at Hershey	24
South Platte River at Hershey	29
Platte River at Gibbon	13

Figures 4.3 – 4.9 are aerial photos of the Odessa bridge on the Platte River for the following years: 1938, 1951, 1957, 1963, 1969, 1978, and 1989. These photos document the effects of the Odessa bridge. With the embankments built into the river, the constriction of flow results in separation zones and eddies, which extend several thousand feet upstream and downstream. This causes sediment deposits, which are evident in the 1938 photo of the Odessa bridge (Figure 4.3). These sediment deposits become prime areas for vegetation. This same pattern was repeated for each of the 12 bridges analyzed.

Steele Becker (1986) conducted an analysis of the changes in the Platte River using aerial photographs. He states,

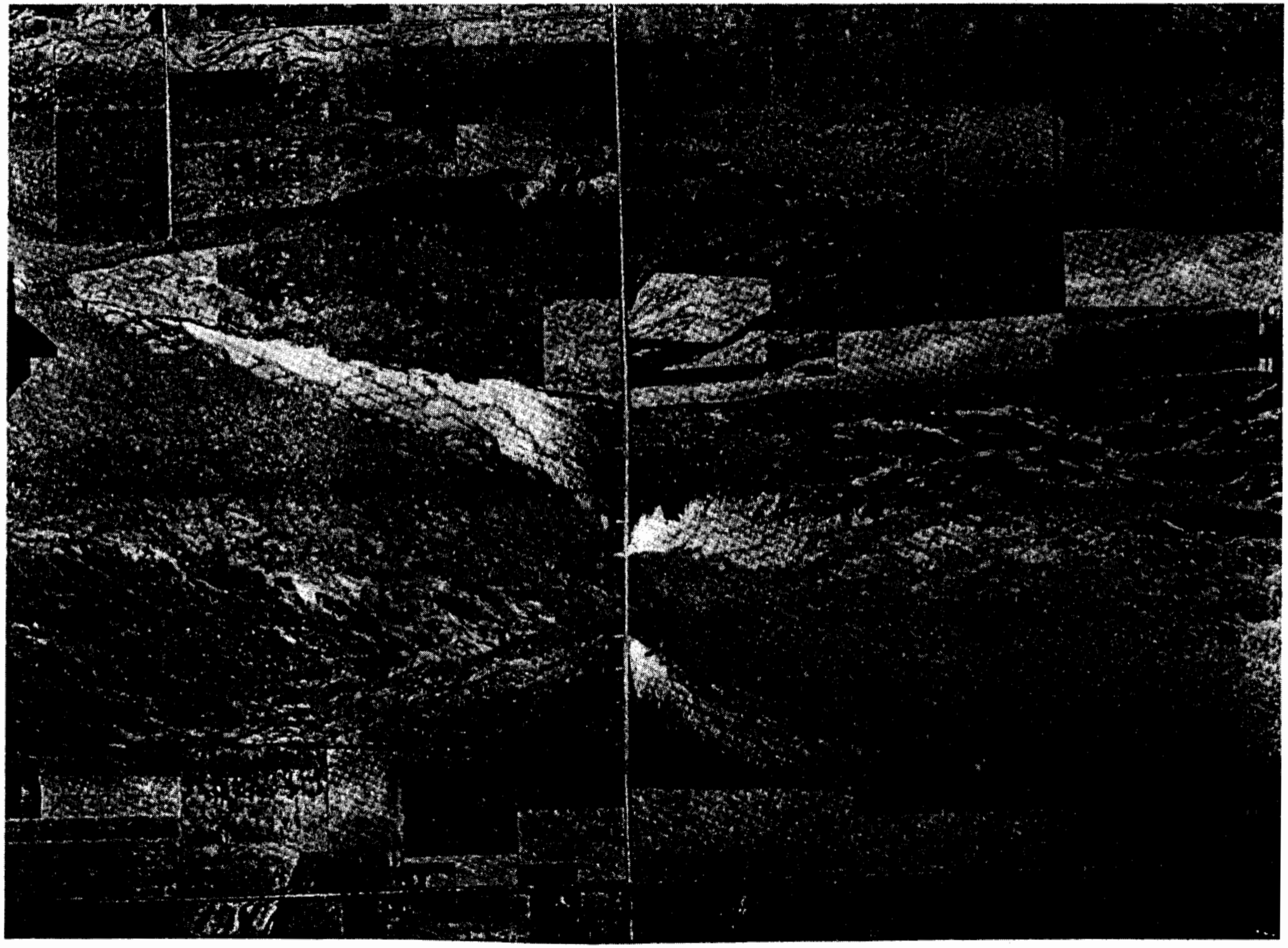
> *There are considerable grounds for questioning the long-standing hypothesis that diversions-withdrawals alone are the primary element in present changes within the channel areas. Rather present changes appear to be more closely tied to river gradient, frequency of bridge occurrence, and man's interference in such areas as bank stabilization and channel blockage. Taken collectively, human factors account for the present pattern, with gradient and bridges more important.*

He goes on to state that, *"The gradual decline in the river over the past 125 years, primarily from decreased flows, has shown the capability of man to forever change the natural pattern of the system."* Thus, Becker opines that the river's present state is influenced to some significant degree by bridges and other structural measures, while acknowledging the primary influence of flow over the long term.

Figure 4.10 is a map showing the locations of bridges on the North Platte, South Platte, and Platte Rivers in Nebraska. Within the State of Nebraska there are about 116 bridges across the North Platte, South Platte, and Platte Rivers from the western state line to Columbus. Within the Big Bend Reach of the Platte River, there are approximately 68 highway bridges. Approximately 20 of these bridges are major Platte River crossings that materially affected the local channel morphology. Based on the aerial photo analysis, bridges cause significant channel narrowing and woodland expansion starting approximately 1/2 mile upstream to 1/2 mile downstream—an impact zone of approximately 1 mile for each bridge. Thus, in the Big Bend Reach, it is estimated that bridges have had a direct effect on approximately 20 miles of the 100-mile reach.

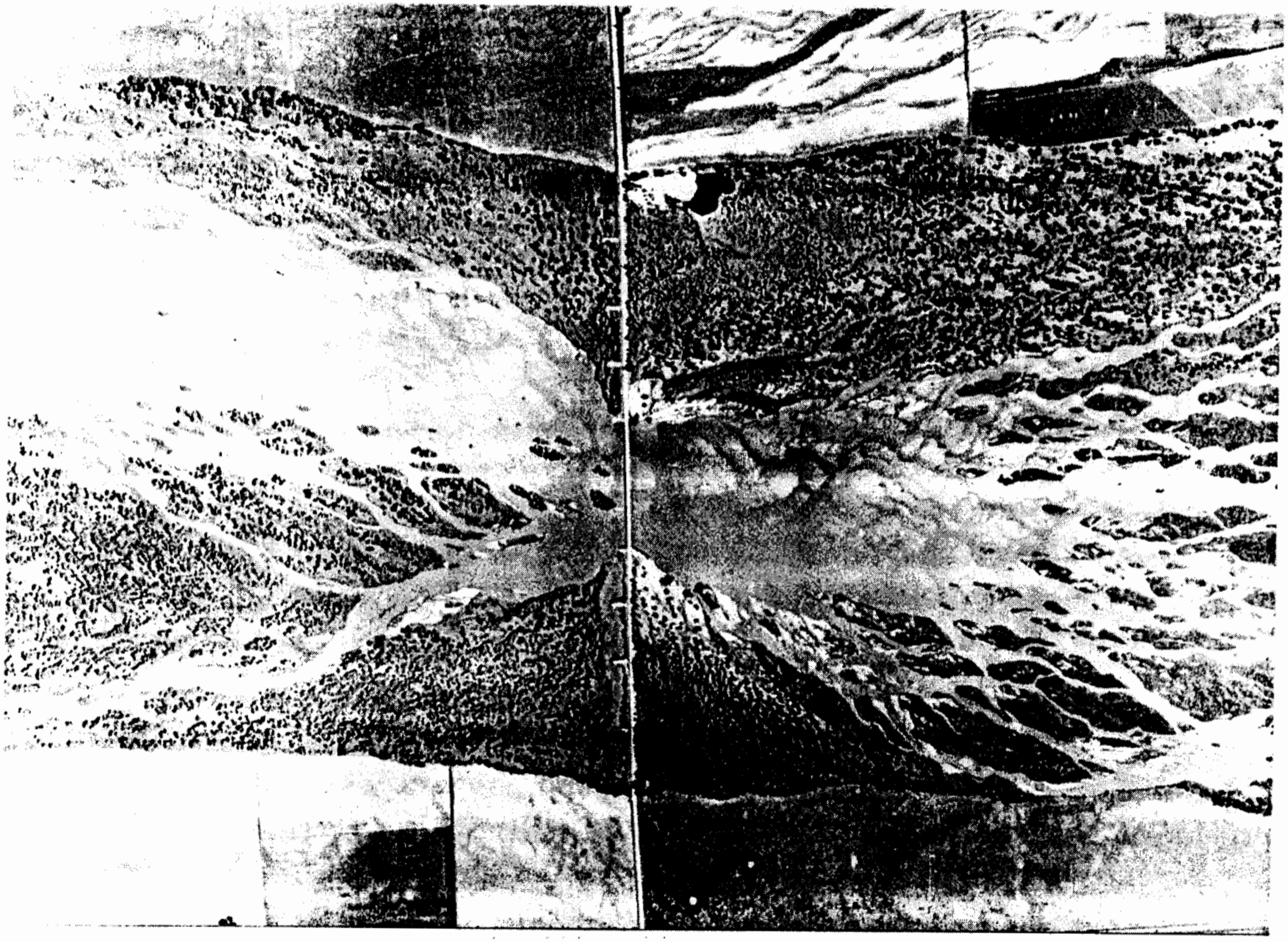
In addition to bridges, there are a large number of other hydraulic structures such as bank stabilization works, which can affect the local morphology of channels, although they probably are not a major factor that have led to channel narrowing and woodland

Figure 4.3

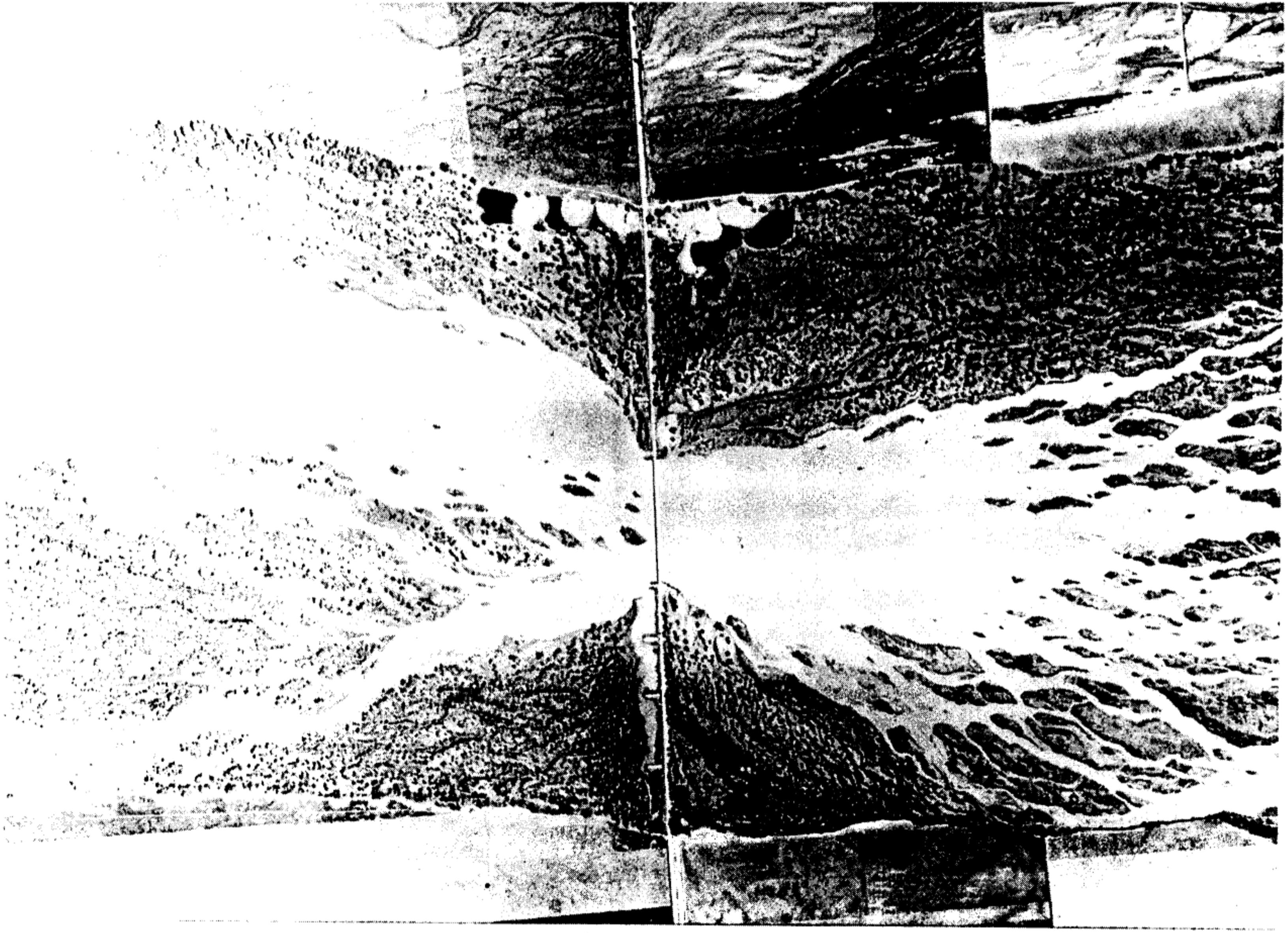


ODESSA BRIDGE 1938

Figure 4.4



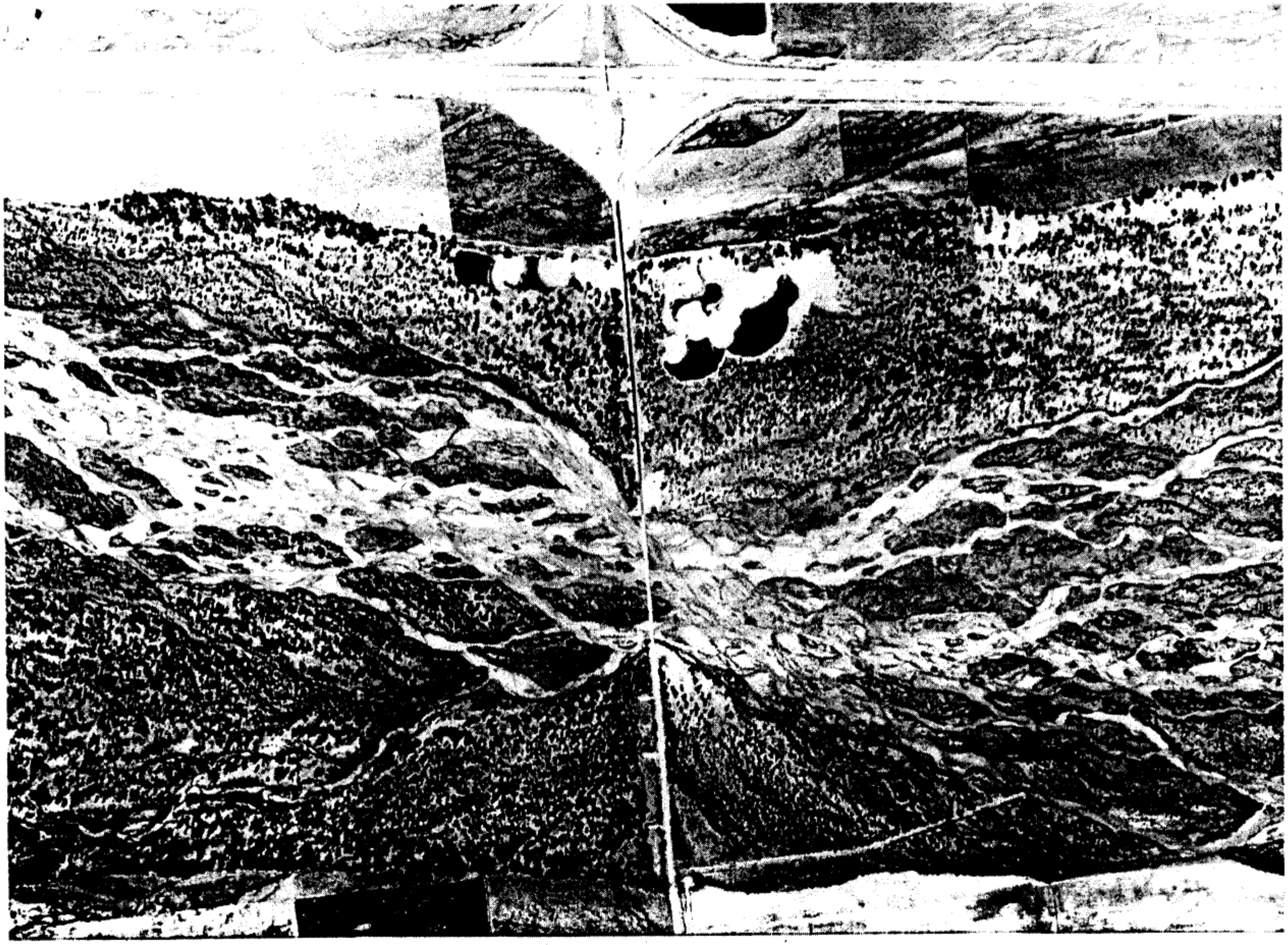
ODESSA BRIDGE 1951



ODESSA BRIDGE 1957

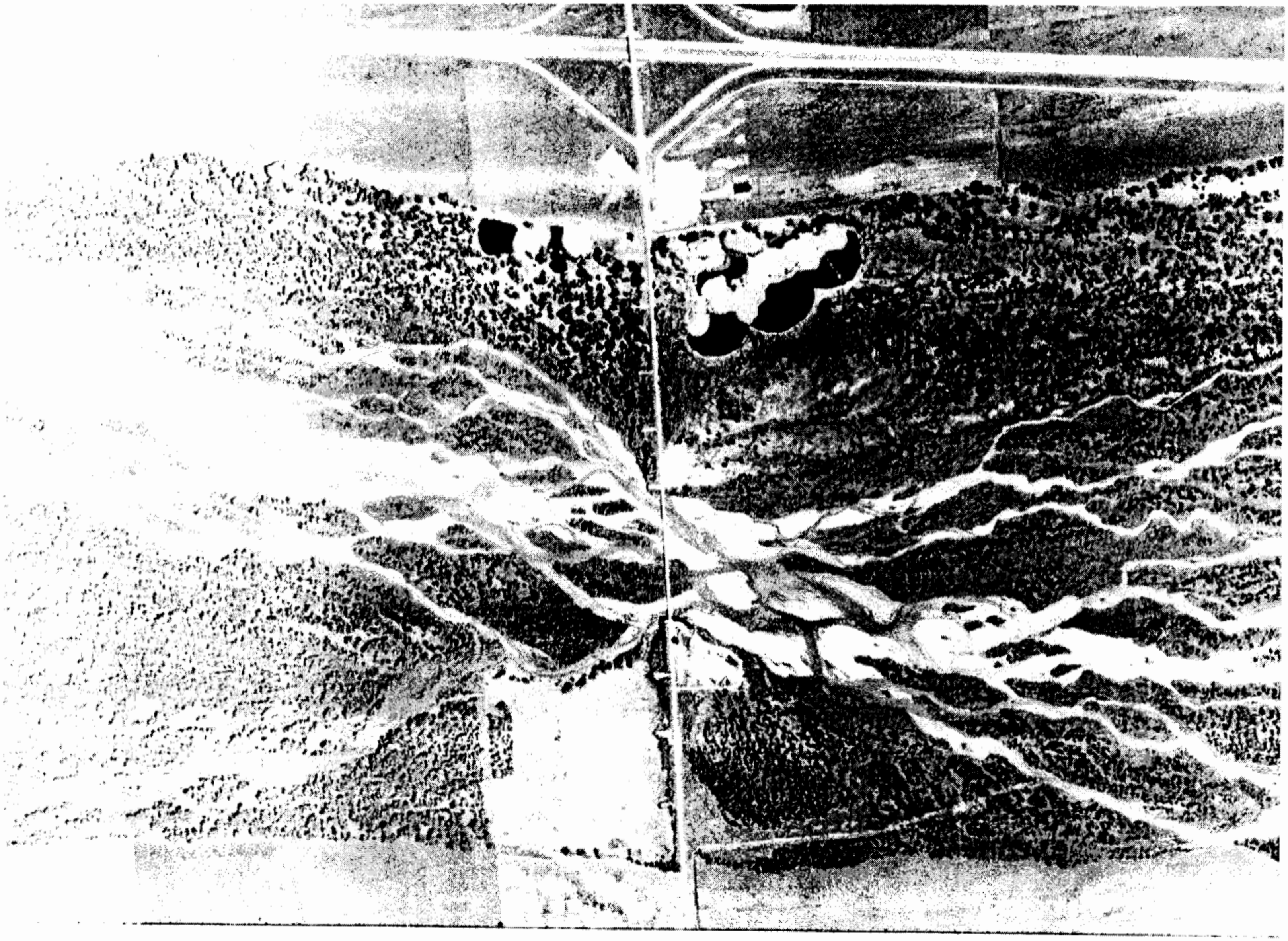
Figure 4.5

Figure 4.6



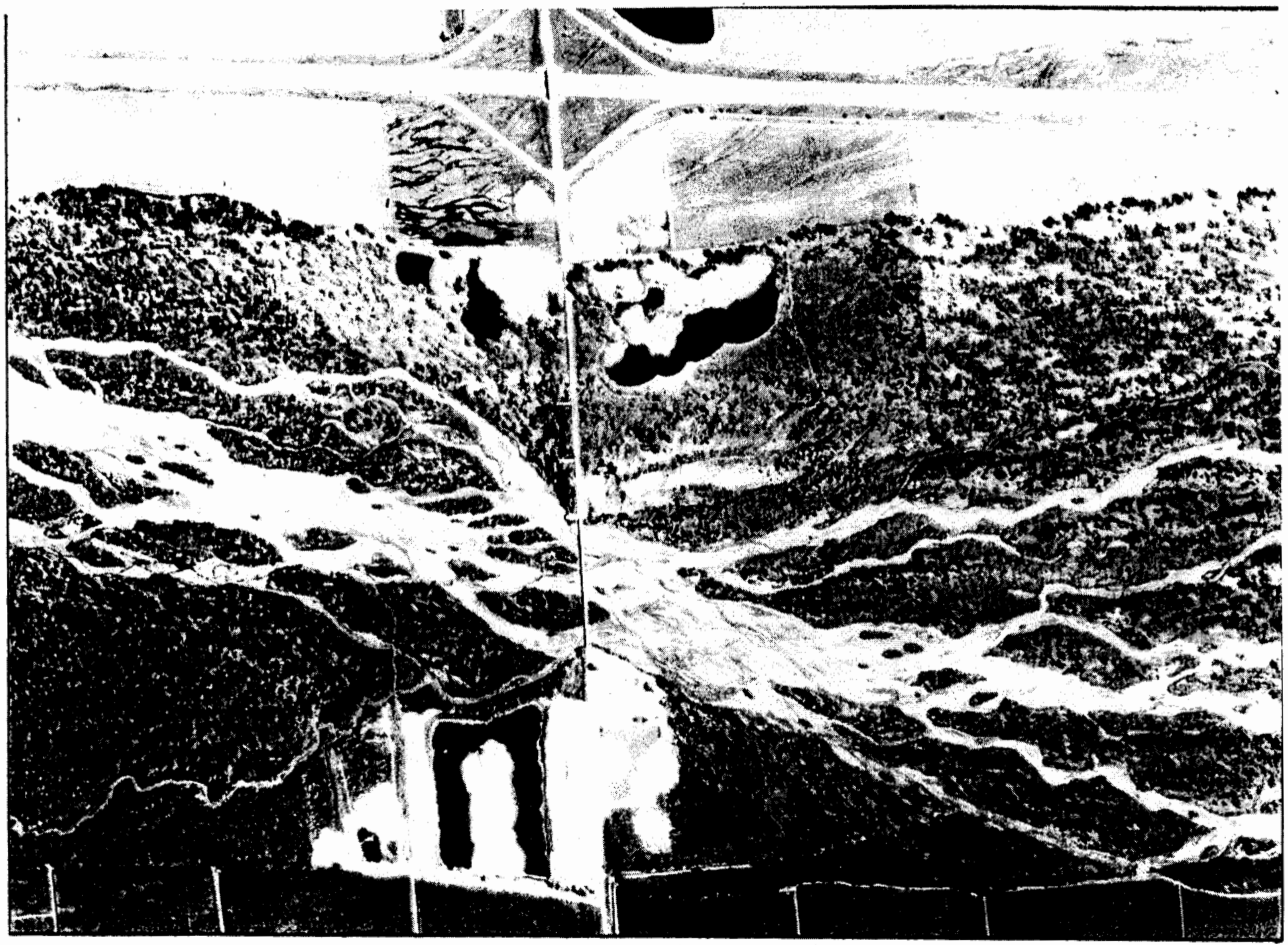
ODESSA BRIDGE 1963

Figure 4.7



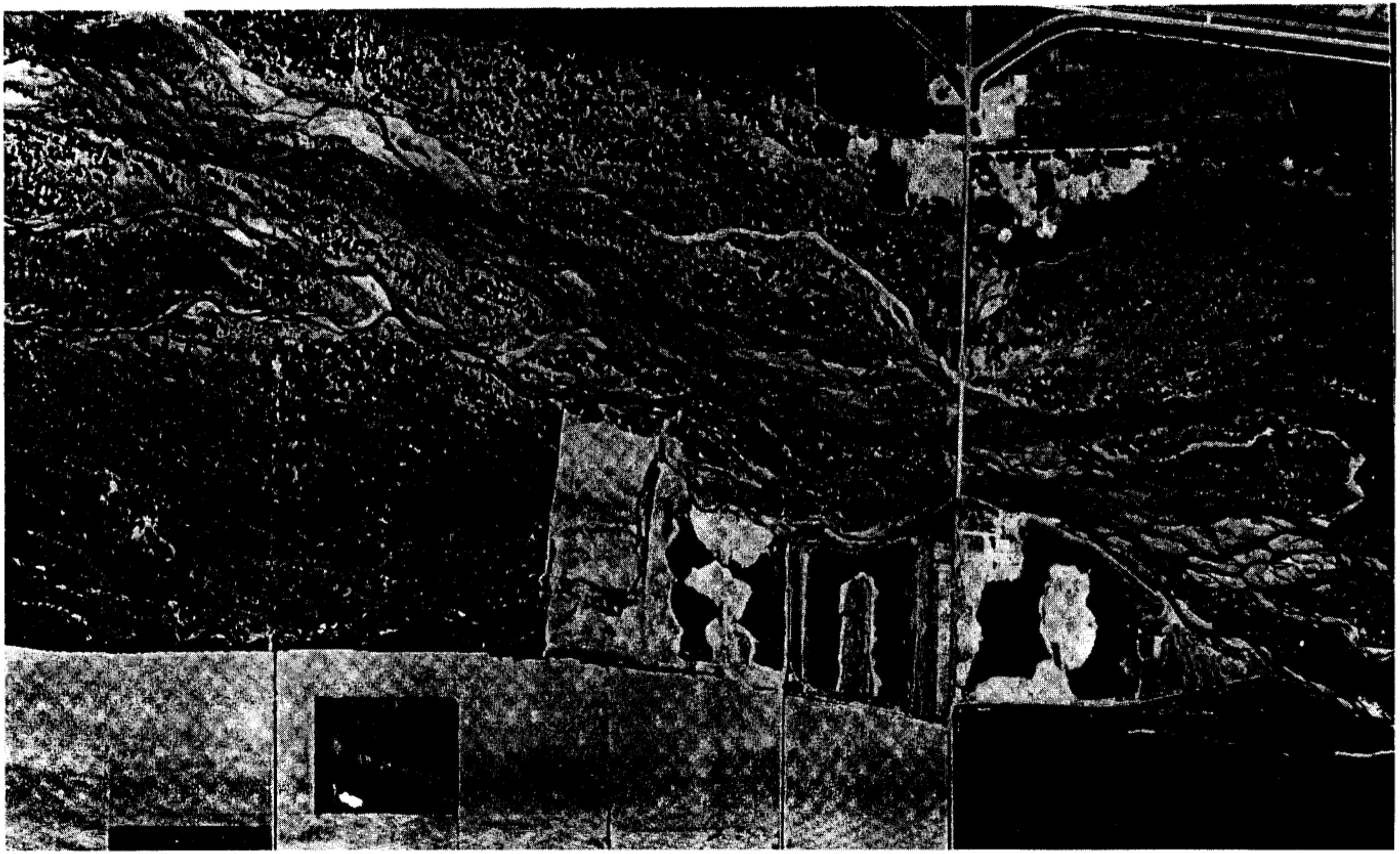
ODESSA BRIDGE 1969

Figure 4.8



ODESSA BRIDGE 1978

Figure 4.9



ODESSA BRIDGE 1989

expansion. These structures do limit the lateral movement of channels and the river's ability to erode its banks. The U.S. Army Corps of Engineers, Omaha District (1989), compiled information on such structures showing the extent of stabilization structures found on these rivers. A summary of this information taken from the report is presented in Appendix F.

Pre-development conditions - The first bridges across the Platte River were constructed of wood. Wood pilings supported a wood deck and spanned the river without significant encroachment from the riverbanks. The open span between pilings was not large but the bridge simply spanned from one set of pilings to the next and so on until the other side of the river had been reached. These types of bridges did not contract the river in any substantive way, allowing the flow to shift and move almost as freely as it would in reaches of the river where there were no bridges.

Post-development conditions - As modern bridge construction techniques developed, including much larger spans using steel and concrete coupled with earth moving equipment, the concept of bridge design changed. The new designs incorporated single or just a few long spans through which the water flowed, with roadways and abutments that extended far from the riverbanks out into the channel to meet the ends of the bridge span. As a result, the river was significantly contracted to a much narrower width. This caused flow separation zones and deposition of sediment on both the upstream and downstream side of the bridge upon which vegetation tended to become established and grow. It has been noted by Currier (personal communication, 2000) that although channels have been narrowed by bridges, the general effect has been to concentrate the flow into a single channel. Away from the bridges, anabranching has occurred resulting in multiple narrower channels with smaller unobstructed widths.

4.2.8 Summary of the Importance of the Factors Affecting Channel Morphology/Vegetation

A summary of the strengths and weaknesses of the various factors affecting channel morphology and riparian vegetation has been developed.

1. Total annual/mean annual flow - The reduction in total or mean annual flow provides the broadest sense of the primary cause of changes in channel morphology and riparian vegetation. It, however, lacks specificity in terms of providing any detailed understanding of the actual processes that govern the relationship between flow and channel morphology and vegetation.
2. Peak flow - Prior to substantial water resources development, peak flows removed vegetation through the process of scour (or prevention of germination as discussed in 4) on nearly an annual basis. Under the current flow regime, removal of mature vegetation occurred rarely, only due to very high flows such as occurred in 1983, with removal of vegetation up to 5 years old in the high flow of 1995. Very high flow is required to remove mature vegetation. Younger vegetation, especially recently germinated vegetation, can be scoured or removed by much smaller magnitudes of flow. While frequent peak flows can maintain a channel with only limited vegetation, peak flows with return periods ranging from about 5 to 10 years and longer have also

been found to be a catalyst for recruitment of new vegetation on both regulated and free-flowing rivers whereby channel morphology is affected resulting in new areas of suitable substrate upon which vegetation germinates and becomes established. Thus, while peak flows can scour already established vegetation, infrequent peak flows are also beneficial in maintaining a healthy and self-sustaining population of woody vegetation by scouring and redistributing sediment thereby developing new, barren substrate upon which seeds can germinate.

3. Desiccation - While some plant mortality is undoubtedly caused by desiccation, data show that under the current flow regime, very little vegetation is removed by this process. In addition, during the significant droughts of the 1930's and 1950's significant expansion of woody vegetation occurred, rather than being controlled by desiccation. Although no data are available to test this factor during pre-development conditions, the relatively shallow cross-sections and the availability of water just below the surface of the channel bed, even when the river was dry, would not likely have been the cause of significant mortality on a percentage basis.
4. Germination - Studies have shown that thousands of plants become established on the bed of the Platte River when flow during the germination season is low, while no plants become established when the flow during the germination season is high enough to inundate the bed. These observations have been confirmed by various analyses including: statistical correlations between flow during the germination season and woodland expansion, hydraulic analysis of the flow required to inundate the channel, physical process computer modeling using the germination flow concept as a basis for establishment of vegetation correlating well with historic data, qualitative analysis of historic flow patterns and vegetation trends, and hydraulic analysis coupled with the timing of woodland expansion at various locations with a range of different relationships between flow and inundation.
5. Sediment transport - Sediment transport either associated with peak flows or ice have been noted to remove some vegetation when scour occurs. Small depths of sediment deposition do not seem to control the expansion of vegetation. Large depths of sediment deposition can cause mortality. Historically, the supply of significant quantities of sediment likely contributed to the wide, shallow, and braided character of the Platte River, which may have helped maintain a continuously shifting river bed upon which vegetation may have found difficult to survive. Contradicting the concept that sediment transport is a dominant factor is that the South Platte, where sediment transport reductions have not been nearly as significant as on the North Platte, has experienced similar degrees of woodland expansion and loss of active channel width indicating that another factor plays a more dominant role.
6. Ice scour - Recent data have shown that ice scour is a major cause of mortality to woody vegetation under current conditions. In pre-development conditions, this may not have been the case because only a relatively small portion of the channel could have been affected by ice since winter flow could have only occupied a relatively small portion of the channel. Under current conditions, however, winter flows as currently managed inundate a significant percentage of the channel when ice magnifies this effect providing a significant control to vegetation.
7. Structures - Structures obviously affect the river and can cause narrowing and separation zones resulting in sediment deposition and establishment of vegetation.

The effect remains fairly local, for example, in the case of bridges the area of effect extends about 1/2 mile upstream and downstream of each location. Estimates show that bridges have affected about 20 percent of the channel length. The effect of such structures on river morphology and habitat does not extend beyond these zones of influence. In other words, changes experienced by the river away from the structures have been caused by other influences such as changes in flow and sediment transport.

4.3 Potential effect of mitigation measures

The Platte River provides riverine habitat for a variety of fish and wildlife species. Maintenance or possibly enhancement of these habitat features are being considered. Several riverine mitigation measures have been suggested. These riverine mitigation measures include: instream-flows (including pulse, flushing, or channel maintenance flows), clearing of vegetation from flood plain or islands, and sediment augmentation. Channel maintenance flows consist of controlled peak flow events with the objective of scouring vegetation, mobilizing, and redistributing sediment to help maintain a wide, shallow river in a braided form if possible and with large unobstructed widths (with little woody vegetation) in order to provide habitat conditions for whooping cranes and other birds. Clearing of vegetation is to reduce the quantity of woody vegetation again to provide large unobstructed widths for whooping cranes and other birds. Sediment augmentation provides additional sediment to help maintain a wide, shallow, braided river; again to benefit whooping cranes and other birds.

To date, no channel maintenance flows have been implemented upon which evaluation of the effects of such a regime could be conducted using actual field conditions, however, some uncontrolled events have occurred that provide a basis for evaluation. No sediment augmentation has occurred. Some clearing of woody vegetation has occurred in a variety of locations and at different times. Some evaluation of clearing programs has taken place. Analysis and evaluation of mitigation measures must rely on available information supplemented with geomorphic and other analytical approaches. Analysis and evaluation of these mitigation measures is now developed based on geomorphic principles, experience with the Platte River, and available information and data. The process of analysis and evaluation addresses the following key issues:

- Is there any analysis supporting the effectiveness of the proposed mitigation measure and provides the specifics of the mitigation?
- Are there potential adverse consequences to the proposed mitigation measure?
- Are there alternative measures that may be more effective in maintaining the channel and at the same time less risky in terms of potential adverse consequences?

Channel maintenance flows – The primary objective of channel maintenance flows is to prevent additional woodland expansion into the exsiting active channel area of the river (along with other potential benefits as explained by Currier - personal communication, 2000; including redistribution of nutrients, flooding of backwater areas, raising of groundwater levels, flooding of wet meadows, and stimulate reproduction of fish and other aquatic organisms). From an enhancement perspective, channel maintenance flows would be viewed as a possible means to remove established vegetation to widen active channel areas thereby expanding active channel area and enhancing the river with respect to unobstructed channel widths. Maintaining the channel can be accomplished by preventing the germination, establishment, and growth of new vegetation. It can also be accomplished by removal of any new vegetation after it becomes established. Enhancement of the channel can only be accomplished by removal of some existing vegetation and then maintaining a wider active channel width as described above. It is important to keep the distinction clear between these two different approaches of maintaining the channel, by either prevention of germination or scour after germination, establishment, and growth.

Sediment Augmentation – The objectives of sediment augmentation are to either maintain the channel form in a braided condition (or to possibly shift back towards a braided condition), to limit or possibly reverse possible channel bed degradation, and possibly to provide a finer, more mobile substrate that may be easier to be kept free of vegetation. The increase in sediment supply by augmentation could accomplish these objectives by providing sufficient sediment to cause or maintain braiding given the linkage between braiding and sediment supply, by providing sufficient sediment so that sediment supply was at least equal to sediment transport capacity thereby preventing general scour, and by providing finer sediment than currently exists on the bed of the river so that it would be more mobile and therefore more difficult for vegetation to colonize and stabilize.

Vegetation Clearing – The primary objective of vegetation clearing is to remove woody vegetation that may affect habitat for various species regarding unobstructed channel widths related to sight distances to predators. Another effect of vegetation clearing is to change cover conditions on the floodplain or islands from a relatively protected or stabilized state with respect to erosion and sediment transport to a condition under which flows may scour and mobilize sediment and keep vegetation from either establishing or removing it after becoming established.

4.3.1 Channel Maintenance Flow Regime - Vegetation

Flow regimes have been developed, primarily related to instream flows to provide enhanced habitat compared to existing flow conditions. With respect to the control of vegetation, a peak flow regime has been prescribed as a means to scour existing vegetation. The recommended peak flow regime for the Central Platte River is a combination of (1) natural flood events (flows greater than channel capacity, approximately 10,000 cfs), and (2) flows less than channel capacity which might be partially created through controlled releases from reservoirs.

The magnitude and frequency of such flows were recommended to range from greater than 12,000 to greater than 16,000 cfs for wet and very wet years at a frequency of once every 2.5 years and once every 5 years, respectively. For normal years, a pulse flow exceeding 3,000 cfs is specified for 3 out of 4 years with a duration of 7 to 30 days followed by a flow rescission at a rate of 800 cfs/day. A flood frequency analysis of data on the Platte River at Overton and Grand Island provide estimates of the magnitude of flow for various return periods. A 2-year flood is about 6,800 to 6,900 cfs, the 5-year flood ranges from about 12,000 to 13,000 cfs, and a 10-year flood ranges from about 16,000 to 18,000 cfs. Thus, the prescribed frequencies of once in 2.5 years for greater than 12,000 cfs and once in 5 years for greater than 16,000 cfs correspond to actual frequencies of about 4.5 years and about 8 years (using the Overton data and analysis). The recommendation specifies that the pulse flow occur in the period from May 1 to June 30. The pattern of the pulse flow was recommended to emulate the historic, natural pattern with the following details: ascend over a period of about 10 days, crest for about 5 days, and descend over a period of about 12 days.

The 16,000 cfs peak flow of 1995 removed virtually all low-growing seedlings and left only a few 4- to 5-year-old seedlings on the higher portions of the channel (Johnson, 1996a) or, according to Currier (1995) only removed about one-third of this age class. As previously discussed, however, available information indicates that vegetation can be removed by peak flows but that relatively large flood peaks are, in fact, required to remove established vegetation. In addition, the historic events that actually removed mature vegetation remained at relatively high levels for a significant period of time through the summer. It is unknown to what extent duration of high flow played in the removal of established vegetation by the flow.

In addition to the removal of significant percentages of existing seedlings, it should be noted that the flow remained above 3,000 cfs past the middle of July. Such a flow would have fully inundated the channel beyond the end of the seed dispersal period. This is the mechanism by which recruitment is completely precluded for a given year, as was the case in 1995, Johnson (1996a). If the peak had occurred earlier and the flood had receded prior to the end of the seed dispersal period, although this flow event would have removed established vegetation as it did, it would have also provided moist, barren substrate for the seeds and a large crop of new vegetation would have been the result consistent with research presented in Table 4.1.

The available data do not allow an evaluation of whether flows less than 16,000 cfs could have removed seedlings as old as 4 to 5 years. It can be concluded that the largest of the proposed scouring flows are capable of significant seedling removal up to an age of 4 to 5 years.

The next question to be addressed deals with whether or not any adverse consequences exist to the proposed mitigation measure. There is a potential for channel bed degradation and narrowing of the river with a regime of artificial peak flow events. O'Brien (1995) stated,

> *. . .there may be a potential for pulse flows to adversely effect (sic) channel geometry over the long term. The possible impacts include channel bed incision, increased conveyance capacity, and further channel narrowing as a result of the limited sediment supply in the system. . .*

In the same document, O'Brien further states that, *"In the absence of a large sediment supply from the North Platte River, high flows in the North Platte can contribute to* *potential channel degradation and narrowing in both the North Platte and Central Platte rivers."* He goes on to state, *"High flow events can result in the formation of high islands where seedlings could be established above the projected water level for the upcoming year."* In other words, sediment deposition tends to occur on islands and the floodplain building up the elevation of these features. As a result, when vegetation becomes established on these features that are now higher in elevation they become less vulnerable to future flow events. Lyons and Randle of the USBR, in a USFWS-sponsored workshop on peak flows, as summarized by Simons & Associates (1995), *"expressed concern over high flow releases down the North Platte due to the tendency toward channel bed degradation and resulting potential channel narrowing."*

There are other concerns related to the maintenance of the river channel and associated habitat. The general pattern of the recommended flow regime is to decrease flow during the winter period in order to increase flow during the summer (for forage fish) and during the spring and fall (for cranes). Observations of the Platte River and associated riparian vegetation indicate that removal of vegetation by ice scour events are important in controlling vegetation as previously described (see Section 4.2.6). Any significant decrease of flow in the winter that would translate into a decrease in extent of ice formation and subsequent ice-related scour of vegetation during ice break-up would result in greater survival of vegetation and additional encroachment of vegetation unless some other compensating means of vegetation control occurs. Any flow regime that causes significant decreases in ice related scour of vegetation would be counterproductive to the concept of channel maintenance, is not recommended, and should be avoided from a channel maintenance perspective.

Regarding the question of whether or not other flow regimes exist to maintain the channel, alternative flow-related strategies to control vegetation basically exist and have been discussed to some degree in the available literature. For example, O'Brien (1995) recommends the following, *"Ideally, as suggested by Simons and Associates (1995 at p. 17) flows should be timed to either eliminate seedling recruitment, or to scour and remove seedlings shortly after they have become established."* This takes advantage of the fact that younger vegetation is easier to remove than older vegetation by, as recommended by Johnson (1996c), *"prescribing appreciably smaller floods to kill more seedlings when they are younger and more vulnerable."* Furthermore, it is recommended to first prevent or minimize germination of vegetation, which can be virtually 100 percent effective, rather than focusing on removal of vegetation when it may be less effective and may cause adverse consequences. Johnson (1996b) states that sufficiently high flows during the germination season, *"will prohibit recruitment and eliminate channel narrowing without the need for large pulse flows."*

Some discussions between Simons & Associates and Johnson over the years have culminated in an alternative flow-related channel maintenance strategy. It includes:

1. Prevention or minimization of recruitment during the germination season by a flow sufficient to inundate the active channel on either a steady or periodic basis (with as low a frequency as one time at the end of seed dispersal) depending on overall

strategic water management objectives considering all pertinent factors (such as potential adverse consequences to tern and plover nesting).

2. Monitoring of flow conditions through the summer to see if any seedlings were established and also to see if any naturally occurring post-germination flow events occurred and were effective in removing any remaining seedlings. If necessary, possibly consider the release of a small post-germination pulse to scour newly established seedlings.
3. Pre-winter monitoring of seedlings to evaluate the need for an ice-scour event. If such an event were warranted, ensure appropriate flow conditions took place during periods sufficiently cold to form ice and other appropriate climatic and flow conditions to move ice during ice break-up.
4. Lack of modification (i.e., no significant change in frequency or magnitude), compared to recent historic conditions (under existing operational conditions), of peak flow events to allow scour and sediment movement associated primarily with events on the South Platte to minimize clear water releases for pulse flow purposes thereby minimizing the potential for channel bed degradation.

Such an alternative provides a multi-tiered approach in preventing/minimizing recruitment of vegetation while taking advantage of naturally occurring scour events (post-germination rainfall, ice, and non-enhanced South Platte events) that will maximize channel maintenance by controlling vegetation while minimizing the adverse consequences of the high pulse regime inducing additional channel bed degradation and narrowing of the channel. Although the peak flow portion of the overall flow regime represents only a relatively small portion of time, the concept of maintaining the river channel through control of vegetation by flow is critical to the overall habitat of the channel for which the remainder of the overall flow regime is intended to benefit.

4.3.2 Sediment Augmentation

Sediment augmentation, in theory, seems conceptually sound but it is unknown to what extent it could be beneficial in maintaining the channel nor has any substantive analysis been conducted regarding the feasibility of such a program. The augmentation of sediment would, to some degree, compensate for the reduction in sediment supply due to sediment trapping and diversion by upstream water development projects. It could possibly prevent or reduce the trend of channel bed degradation that some have argued is a factor in the changes in morphology and vegetation experienced by the Platte River. In addition, it could possibly reverse the trend of bed coarsening and provide a more mobile substrate that may be easier to keep free of vegetation. It could also help maintain a braided channel form. At this point in time, however, there is no available information of which we are currently aware upon which an assessment of the effectiveness of this concept can be conducted. This is a subject that is being addressed by modeling sediment transport and vegetation processes.

Regarding the potential for adverse consequences, there may be some but no documentation or discussion of such consequences is known. It could be argued that sediment augmentation would increase suspended sediment concentrations, which is sometimes considered adverse. If too much sediment were introduced into the system, or if sedimentation occurred in highly uneven distributions, there may be some increase to flooding or certain local features such as water intakes or diversions could be plugged or restricted by sediment deposition. At this point these consequences are nothing more than speculation requiring more detailed assessment. The previous suggestion by Schumm (1969) continues to be valid today. He suggested that it is necessary to better understand the sediment related effects on channel morphology and riparian vegetation,

> *Much remains to be done both in the field and in the laboratory. It is hoped that this review of geomorphic investigations of river channels may provide suggestions for further experimentation in hydraulic laboratories as well as incentive for detailed study of natural river metamorphosis during the recent geologic past.*

There are no known alternative measures to sediment augmentation that are intended to meet the same objectives of such a program.

As a step towards developing an understanding of the inter-relationship between sediment transport induced by sediment augmentation and the response of the channel, an investigation of the effect of sediment and vegetation on the channel is being developed through a combined sediment transport and vegetation model.

4.3.3 Vegetation Clearing

Vegetation clearing has been conducted at several locations over a number of years, primarily at bird sanctuary areas of the river to maintain selected portions of the river for a number of years. Currier (1995) provides an assessment of the overall effect of vegetation clearing,

> *Clearing is a useful tool in managing open channel habitat, but it is not a practical solution for the entire riverbed, and it is not a substitute for flows.*

His assessment indicates that clearing of vegetation, while at least locally successful, is not practical as an overall management tool; probably due to economic and land ownership considerations. Currier goes on to say that through a combination of pulse flows, base flows, and selective clearing and disking he hopes that the open channel habitat can be maintained. Thus, in the view of a proponent of vegetation clearing, it is viewed only as a partial form of mitigation that must be supplemented with flow related mitigation.

In recent analysis of the status of vegetation and width changes, Johnson (1996c) stated that,

> *Only a small portion of the Big Bend reach has experienced recent width reductions--the managed section between Alda and Chapman. No reach upstream of Alda, which includes the large majority of the Big Bend reach, has experienced channel area decreases since the late 1960's. On*

> *the contrary, most reaches have shown increases in channel area. The recent decline in channel area in the Alda-Chapman reach is quite possibly due to local vegetation management activities.*

He attributes the possible or probable cause of these width reductions in these localized areas to *"an oversupply of sediment released by vegetation management activities."* Currier (2000) dismisses the possibility of potential adverse consequences as speculation that is absurd. He stated that recently conducted river surveys conducted by Reclamation/USGS do not indicate a major change in sediment profiles.

Johnson (1997) stated, *"Although upstream vegetation management is a strong candidate for causing localized vegetation expansion and open channel area decline near Grand Island, other causes cannot be ruled out without further investigation."* He goes on to emphasize the importance of determining the cause of channel area declines in this portion of the river,

> *Identifying the cause of the disequilibrium at Grand Island is important because channel area losses in unmanaged reaches may be counterbalancing gains in managed reaches, reducing the overall effectiveness of vegetation management activities in providing wider unobstructed channels for migratory cranes. Moreover, if management turns out to be a causal factor, mangement methods need to be re-evaluated before they are prescribed more widely in the Platte River. Otherwise, vegetation management could initiate channel area declines downstream in unmanged reaches that have been stable or modestly increasing for three decades or more.*

Another potential adverse consequence of clearing should also be considered in conducting an overall evaluation of its continued or expanded application. Johnson (in press) states, *"Although clearing has successfully widened channels, at least temporarily. . . it has counterbalancing side-effects. These include downstream sedimentation and channel narrowing and stimulation of invasive weeds such as purple loosestrife. . ."* The invasion of cleared areas by undesirable plants is then another factor to consider in the evaluation process.

Thus, while advocates of vegetation clearing describe it as a useful tool, others suggest that there are potential adverse consequences to vegetation clearing. Additional and more detailed analysis of this phenomenon should be conducted to better understand the relationship between flow, sediment transport, and vegetation clearing.

While the direct effects of vegetation clearing on such variables as unobstructed channel widths is measurable and can be readily evaluated, the effect vegetation clearing has on the habitat need or its effect on species is not so clear and the secondary effects regarding sediment issues needs to be addressed. A related question is whether or not the current flow regime or alternative flow regimes could maintain cleared land free from woody vegetation without periodic mechanical maintenance.

Regarding the question of whether any alternatives exist to clearing of vegetation to widen the active channel, the available information suggests that peak flows on the order of 16,000 cfs may be required to remove seedlings up to 5 years old (as occurred in 1995) and that small amounts of older vegetation can be removed by flows exceeding 20,000 cfs (as occurred in 1983). Based on this information, it does not appear that flow can be relied on to provide much of a clearing function particularly for mature vegetation. If clearing is required to widen the active channel, it seems that some form of mechanical or chemical clearing would be required.

4.3.4 General Flow Redistribution Considerations

The current philosophy of modifying the current flow regime to one that is perceived to be more beneficial to fish and wildlife is based on providing the highest flow during wet years, somewhat less flow during normal years, and less flow during dry years. Table 4.3 is a recent version of the suggested instream flow targets. Figure 4.11 compares the instream flow targets with current historic averages (1969-1998). Figure 4.12 provides the same comparison without the pulse flows so a more detailed examination of the historic and proposed targets can be made. The modified distribution of flows associated with the instream flow regime is generally lower in the winter months, higher in the summer months, with some other differences occuring other times of the year (such as during the fall) compared to the historic flows. Recommended pulse flows in the spring are equivalent to return periods on the order of 4.5 to 8 years for the 12,000 to 16,000 cfs pulse flows now adjusted through this flow regime to occur more frequently, once every 2.5 to 5 years.

This proposed flow regime raises several issues related to channel maintenance. Under current conditions, significant channel maintenance occurs during the winter when ice scour removes a substantial quantity of relatively young vegetation. Reduced flows during the winter will reduce the effectiveness of ice related scour (Section 4.2.6). According to the scientific literature (Mahoney and Rood, 1998); peak flows, such as the recommended pulse flows with return periods in the 3 or 5 to 10 year frequency range, can result in recruitment of new woody vegetation since these are the types of conditions favorable to establishment of new vegetation rather than conditions that would necessarily result in the removal of vegetation. In addition, as an issue raised in the pulse flow conference, to whatever extent that flow is insufficient from the South Platte requiring additional water to be released from Lake McConaughy, without any accompanying sediment load due to sediment trapping in this and other upstream reservoirs; some potential for channel bed degradation and subsequent potential narrowing of the geometry of the channel would be expected. This may tend to increase the stability of existing vegetation since more of the flow would be contained in a deeper, narrower, and more hydraulically efficient channel. Finally, the general use of water for instream flows may tend to keep upstream water storage at lower levels. This would tend to induce an effect of longer periods of time between flows that may actually control the expansion of vegetation thereby possibly allowing additional woodland expansion as described in the qualitative analysis of flow and vegetation trends (see section 4.2.2). If the above concerns prove to be correct, the combination of these factors tends to indicate

Table 4.3 Pulse flow recommendation for the central Platte River Valley ecosystem during May and June.

	Period	Flow (cfs)	Duration (days)	Frequency (yrs) Exceedence (%)
very wet	May 1 - June 30*	≥ 16,000	5**	1 in 5 (20%)
wet	May 1 - June 30*	≥ 12,000	5**	1 in 2.5 (40%)
normal	May 20 - June 20	≥ 3,000	7-30***	3 in 4 (75%)
dry	May 11 - June 30	none****		all remaining(100%)

* At least 50% of these pulse flows should occur during May 20 to June 20, with May 1 to June 30 as the timeframe for broadest benefit for channel maintenance, and instream and wet meadow habitats. Occurrence between February 1 and June 30 would accomplish the necessary effects for channel maintenance. The 10-year running average for the mean annual pulse flow targets should range from approximately 8,300 cfs to 10,800 cfs.

** The duration of these pulse flows should emulate the historic, natural pattern: (a) ascended over approximately 10 days, (b) cresting for approximately 5 days, and (c) descending over approximately 12 days.

*** The target is for a 10-year running average for the 30-day exceedence flow (i.e., 10-year running average of the annual level exceeded for 30 consecutive days) of at least 3,400 cfs. A flow of 3,000 cfs should be exceeded for 7-30 days in at least 75% of years. Pulse flows should be followed by descending flows approximating a rate of 800 cfs/day.

**** No pulse flows during May and June in driest years; target flows identified in the March 1994 workshop (Bowman 1994), apply under dry year conditions.

Table 4.3 Pulse flow recommendation for the central Platte River Valley ecosystem during February and March.

	Period	Flow (cfs)	Duration (days)	Recurrence(yrs) Exceedence (%)
very wet	Feb 1 - March 31	≥ 16,000*	5**	1 in 5 (20%)
wet	Feb 15 - March 15	≥ 12,000*	5**	1 in 2.5 (40%)
normal	Feb 15 - March 15	3,100-3,600	30	3 in 4 (75%)
dry	Feb 15 - March 15	2,000-2,500	30	all remaining(100%)

* At least 50% of these pulse flows should occur during May 20 to June 20, with May 1 to June 30 as the time frame for broadest benefit for channel maintenance, and instream and wet meadow habitats. Occurrence between February 1 and June 30 would accomplish the necessary effects for channel maintenance. The 10-year running average for the mean annual pulse flow targets should range from approximately 8,300 cfs to 10,800 cfs.

** The duration of these pulse flows should emulate the historic, natural pattern: (a) ascended over approximately 10 days, (b) cresting for approximately 5 days, and (c) descending over approximately 12 days.

Instream Flow Recommendations
and Historic Grand Island Discharge, WY 1969-1998

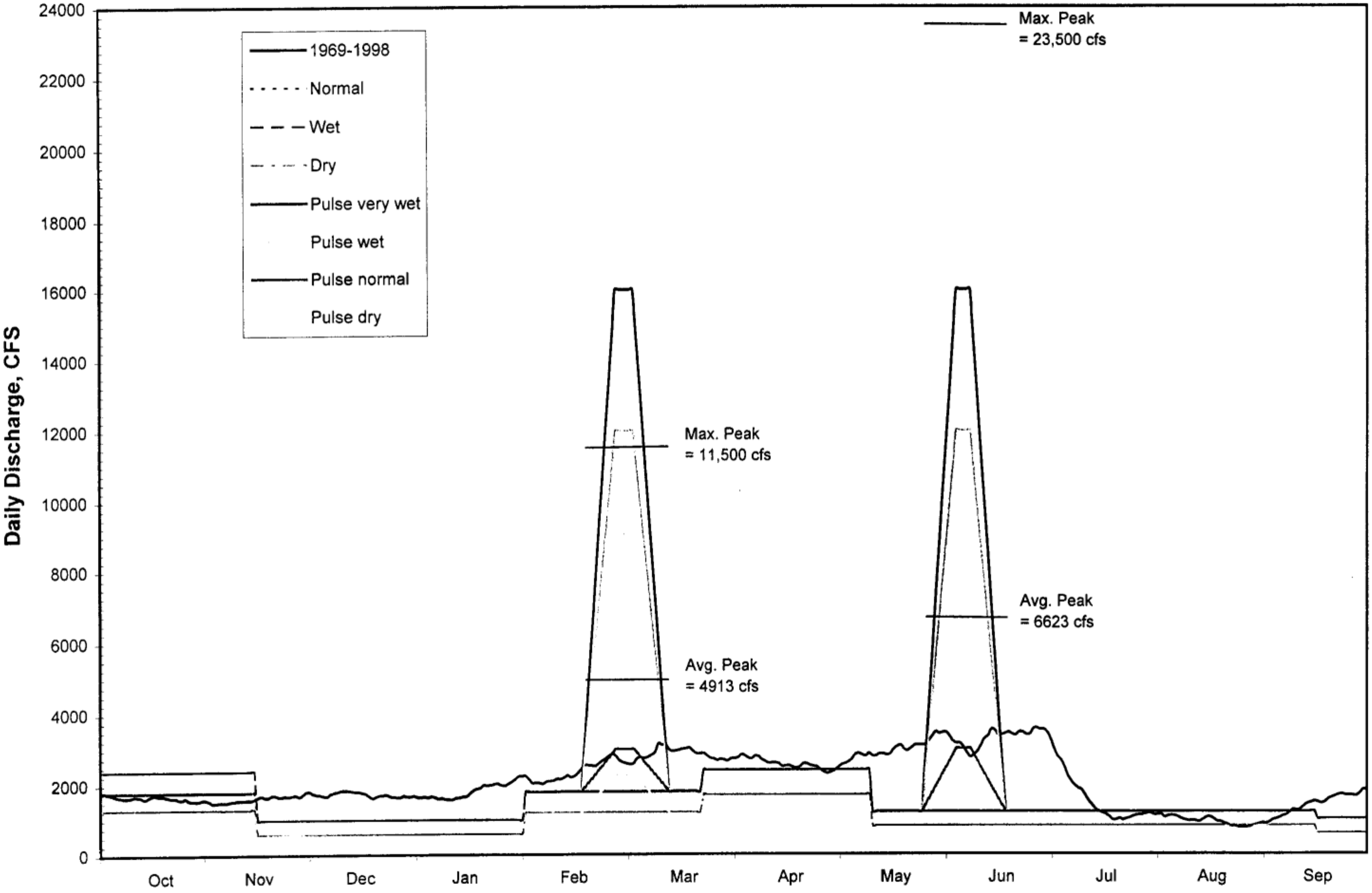


Figure 4.11

Instream Flow Recommendations
and Historic Grand Island Discharge, WY 1969-1998

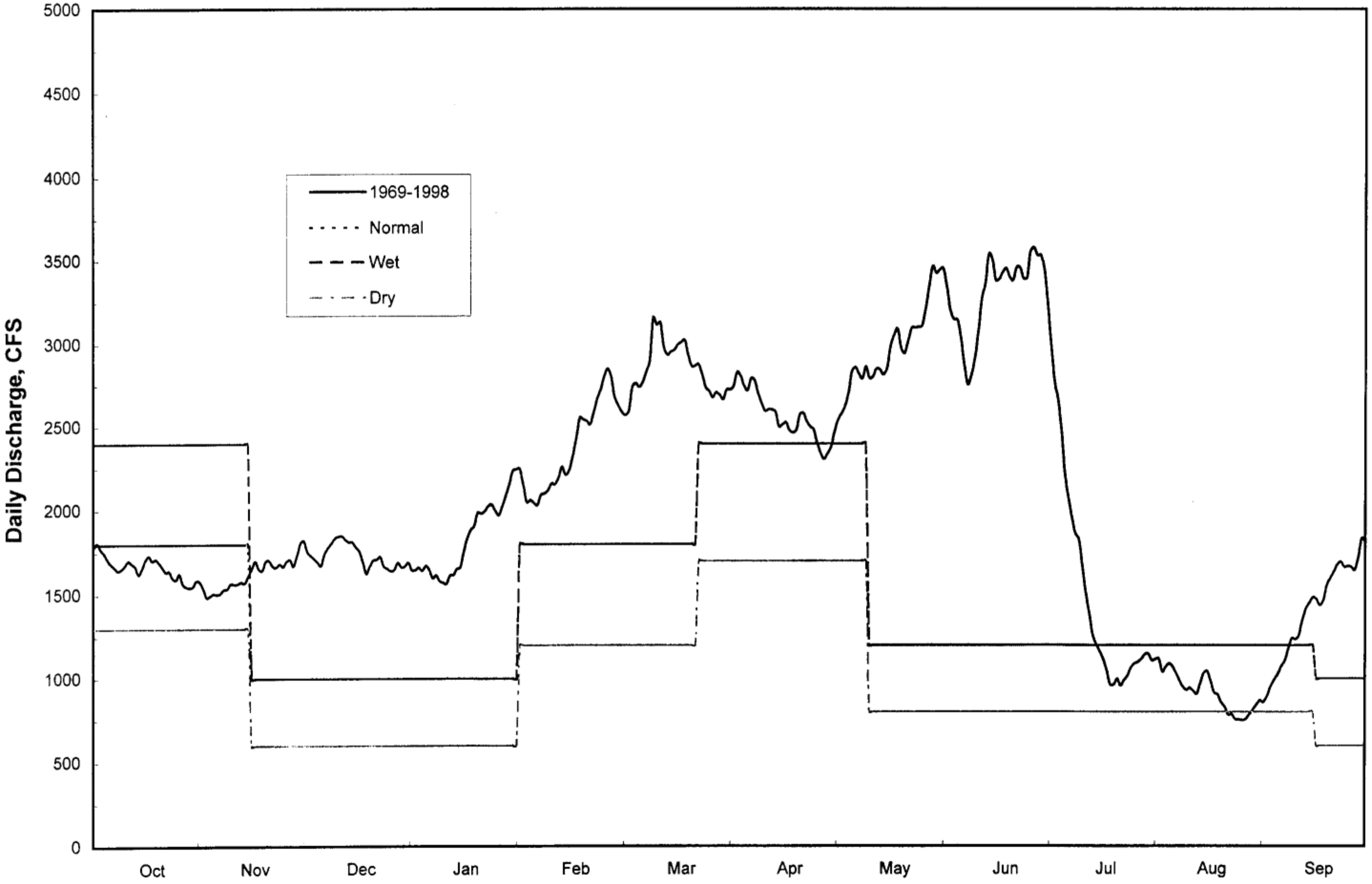


Figure 4.12

an unintended consequence of the instream flow regime may be an increment of additional woodland expansion. Based on these concerns, it is advisable to carefully evaluate the proposed flow regime and consider an alternative to this flow regime that has less potential for adverse consequences associated with the currently proposed regime; that being a tendency for woodland expansion due to a longer period between flows that control vegetation, reduced ice scour, reliance on scouring flows that may induce recruitment of vegetation, lack of direct consideration of prevention of germination, and a potential for channel bed degradation.

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APPENDIX A

Sediment Data

TABLE 2.2

NORTH PLATTE

Station	Years	Frequency of Data
North Platte at Alcova	1976, 81, 82, 83	Spot readings, 1/month
North Platte near Northgate	1972, 73, 74, 75	Spot readings, 1/month
North Platte above Seminoe	1974	"1" Reading
North Platte near Goose Egg	1951, 52, 53, 57, 58, 83	Daily readings
North Platte at Orin	1971, 72, 73, 74, 75, 76, 77, 80, 81	Spot readings, 1/month
North Platte near Douglas	1947, 48, 49, 50, 51, 52	Daily readings
North Platte below Casper	1947, 48, 49, 50, 51, 52, (71-82)	Daily and monthly readings
North Platte near Lingle	1970, 71, 72, 73, 75	Monthly readings
North Platte below Guernsey	1947, 48, 49, 51, 52, 53	Daily readings
North Platte at State Line (Wyoming-Nebraska)	1971, 73, 74, 75, 76, 77, 78, 79, 81, 82	Monthly spot readings
North Platte at Cassa	1947, 48, 49, 51, 52, 53	Daily readings
North Platte at Lisco	1980	Do not have yet
North Platte near Sutherland	1979	Do not have yet
North Platte at North Platte	1979, 80	Do not have yet

TABLE 2.3

SOUTH PLATTE RIVER

Station	Years	Frequency of Data
North Fork South Platte at South Platte	1967	Do not have yet
South Platte at Littleton	1982, 84	6 readings/year
South Platte near Kersey	1952, 55, 79, 80, 62-67	Spot readings, 2/month
South Platte at Fort Morgan	1953	Do not have yet
South Platte near Weldona	1953, 77, 78, 79, 81, 82, 83, 84,	1953, Spot readings, Other years daily
South Platte at Balzac	1979	Do not have yet
South Platte at Julesburg	1949, 52, 70, 75, 76, 81, 82, 83, 84	Spot readings, 4-6/yr.

TABLE 2.4

PLATTE RIVER

Station	Years	Frequency of Data
Platte River at Louisville	1971, 72, 73, 74, 75, 76	Daily readings
Platte River at North Bend	1966, 73, 74, 75	Spot readings, 2-6/yr.
Platte River at Schuyler	1966, 67	Spot readings, 4-6/yr.
Platte River near Duncan	1979, 80	Spot readings, 4-6/yr.
Platte River near Overton	1950, 51, 52, 53, 64, 65, 66, 67, 68, 69, 71, 73	Spot readings, 2-12/yr.
Platte River near Grand Island	1979, 80	Do not have yet
Platte River at Odessa	1952	Do not have yet

Table 2.5

Number and name of sediment-data stations

Station No. in figure 1	U.S. Geological Survey station No.	Station name
1	06691000	North Platte River near Sutherland, Nebraska
2	06693000	North Platte River at North Platte, Nebraska
3	06754000	South Platte River near Kersey, Colorado
4	06758500	South Platte River near Weldona, Colorado
5	06760000	South Platte River at Balzac, Colorado
6	06764000	South Platte River at Julesburg, Colorado
7	06765500	South Platte River at North Platte, Nebraska
8	06766000	Platte River at Brady, Nebraska
9	06766500	Platte River near Cozad, Nebraska
10	06768000	Platte River near Overton, Nebraska
11	06770000	Platte River near Odessa, Nebraska
12	06770500	Platte River near Grand Island, Nebraska
13	06772600	Platte River near Central City, Nebraska
14	06772800	Platte River near Clarks, Nebraska
15	06772850	Platte River near Silver Creek, Nebraska
16	06774000	Platte River near Duncan, Nebraska
17	06794700	Platte River near Schuyler, Nebraska
18	06796000	Platte River near North Bend, Nebraska
19	06796500	Platte River near Fremont, Nebraska
20	06796550	Platte River near Venice, Nebraska
21	06805500	Platte River near Louisville, Nebraska

Table 2.6

TYPES OF DATA COLLECTED

Station No.	Hydraulic Data	Suspended Load Data	Bedload Data	Suspended Size Distribution	Bedload Size Distribution	Bed Material Size Distribution
1	x	x	x	x	x	x
2	x	x	x	x	x	x
3	x	x	x	x	x	x
4	x	x	x	x	x	x
5	x	x	x	x		x
6	x	x	x	x	x	x
7	x	x	x	x	x	x
8	x					x
9	x					x
10	x	x	x	x	x	x
11	x					x
12	x	x	x	x	x	x
13						x
14						x
15						x
16	x					x
17						x
18	x					x
19						x
20						x
21						x

APPENDIX B

Bed Elevation Change

TABLE 3-2

WEIGHTED MEAN BED ELEVATION CHANGE TRENDS (FEET)

Site	Section ID	05/10/85 - 08/01/85
		Weighted Mean Bed Elevation Change (feet)
1	0	-0.33
	594	-0.03
	1285	0.03
	1690	0.01
	2589	-0.03
	SUM:	-0.35
	MEAN:	-0.07

Site	Section ID	10/10/84 - 04/10/85	04/10/85 - 07/22/85	10/10/84 - 07/22/85
		Weighted Mean Bed Elevation Change (feet)	Weighted Mean Bed Elevation Change (feet)	Overall Weighted Mean Bed Elevation Change (feet)
2	0	-0.05	0.42	0.37
	691	0.01	-0.04	-0.03
	1166	0.16	-0.08	0.08
	2341	0.03	0.13	0.16
	2775	-0.08	0.11	0.03
	3635	-0.36	-0.15	-0.51
	4233	0.19	-0.16	0.03
	4777	-0.01	0.04	0.03
	SUM:	-0.11	0.27	0.16
	MEAN:	-0.01	0.03	0.02

TABLE 3-2 (CONTINUED)

Site	Section ID	03/27/85 - 07/8/85 Weighted Mean Bed Elevation Change (feet)
4A	0	0.11
	1268	0.29
	1629	-0.04
	2397	-0.05
	2967	0.14
	3370	-0.07
		SUM: 0.38
		MEAN: 0.06

Site	Section ID	03/27/85 - 07/09/85 Weighted Mean Bed Elevation Change (feet)
4B	0	-0.21
	829	0.11
	1413	-0.41
	2073	0.10
		SUM: -0.41
		AVG: -0.10

TABLE 3-2 (CONTINUED)

Site	Section ID	05/06/85 - 07/85 Weighted Mean Bed Elevation Change (feet)
5	0	0.10
	949	-0.09
	1880	-0.20
	3135	0.13
		SUM: -0.06
		MEAN: -0.02

TABLE 3-2 (CONTINUED)

		10/03/84 - 04/03/84	04/03/84 - 07/17/85	07/17/85 - 06/09/86*(00)	10/03/85 - 06/09/86
Site	Section ID	Weighted Mean Bed Elevation Change (feet)	Weighted Mean Bed Elevation Change (feet)	Weighted Mean Bed Elevation Change (feet)	Overall Weighted Mean Bed Elevation Change (feet)
6	0	0.12	-0.14	0.09	0.07
	563	0.01	-0.10	0.03	-0.06
	1433	0.03	0.17	-0.19	0.01
	2324	0.03	0.00	0.27	0.30
	3021	-0.07	0.18	0.24	-0.35
	3927	-0.03	-0.11	0.28	0.14
	5033	0.24	-0.09	-0.05	0.10
	5623	-0.04	0.08	0.01	0.05
	6872	0.08	0.21	-0.45	-0.16
	SUM:	0.37	0.20	0.23	0.80
	MEAN:	0.04	0.02	0.03	0.09

		10/09/84 - 04/22/85	04/22/85 - 07/15/85	10/09/84 - 07/17/85
Site	Section ID	Weighted Mean Bed Elevation Change (feet)	Weighted Mean Bed Elevation Change (feet)	Overall Weighted Mean Bed Elevation Change (feet)
7	0	1.58	-1.79	-0.21
	538	-0.01	0.18	0.17
	1389	-0.15	0.01	-0.14
	2405	0.14	0.15	0.29
	2844	0.14	-0.01	0.13
	SUM:	1.70	-1.46	0.24
	MEAN:	0.34	-0.29	0.05

TABLE 3-2 (CONTINUED)

Site	Section ID	04/05/85-07/13/85 Weighted Mean Bed Elevation Change (feet)
8A	0	0.08
	336	0.37
	544	0.09
	766	0.23
		SUM: 0.77
		AVG: 0.19

Site	Section ID	04/05/85-07/13/85 Weighted Mean Bed Elevation Change (feet)
8A	0	-0.21
	360	-0.04
	784	0.10
		SUM: -0.15
		AVG: -0.05

TABLE 3-2 (CONTINUED)

Site	Section ID		03/21/85 - 07/12/85 Weighted Mean Bed Elevation Change (feet)		07/13/85 - 05/21/86 Weighted Mean Bed Elevation Change (feet)		03/21/85 - 05/21/86 Overall Weighted Mean Bed Elevation Change (feet)
8B	0		0.04		-0.13		-0.09
	614		0.17		0.15		0.32
	1021		0.13		0.16		0.29
	1815		-0.28		-0.03		-0.31
	2564		0.11		-0.25		-0.14
		SUM:	0.17	SUM:	-0.10	SUM:	0.07
		AVG:	0.03	AVG:	-0.02	AVG:	0.01

Site	Section ID		10/16/84 - 04/18/85 Weighted Mean Bed Elevation Change (feet)		04/18/85-07/19/85 Weighted Mean Bed Elevation Change (feet)		10/06/84-07/19/85 Overall Weighted Mean Bed Elevation Change (feet)
8C	0		0.09		-0.08		0.01
	506		0.02		0.03		0.05
	1050		0.09		-0.12		-0.03
	2262		0.06		-0.06		0.00
		SUM:	0.26	SUM:	-0.23	SUM:	0.03
		AVG:	0.07	AVG:	-0.06	AVG:	0.01

TABLE 3-2 (CONTINUED)

ite	Section ID	03/24/83 - 03/31/83 Weighted Mean Bed Elevation Change (feet)	03/31/83 - 10/18/83 Weighted Mean Bed Elevation Change (feet)	10/18/83 - 04/02/85 Weighted Mean Bed Elevation Change (feet)	04/02/85 - 07/10/85 Weighted Mean Bed Elevation Change (feet)
9B	0	0.06	-0.08	-0.02	-0.03
	257	-0.07	0.08	-0.10	-0.09
	464	0.02	-0.23	0.15	0.04
	698	0.17	-0.37	0.13	0.06
	1025	0.02	-0.19	0.13	-0.02
		SUM: 0.20	SUM: -0.79	SUM: 0.29	SUM: -0.04
		AVG: 0.04	AVG: -0.16	AVG: 0.06	AVG: -0.01

ite	Section ID	07/10/85 - 10/02/85 Weighted Mean Bed Elevation Change (feet)	10/02/85 - 04/03/86 Weighted Mean Bed Elevation Change (feet)	04/03/86 - 06/12/86 Weighted Mean Bed Elevation Change (feet)	03/24/83 - 06/12/86 Overall Weighted Mean Bed Elevation Change (feet)
9B	0	-0.10	0.24	-0.12	-0.05
	257	-0.05	0.13	-0.12	-0.22
	464	-0.02	0.06	-0.01	0.01
	698	-0.05	0.19	-0.22	-0.09
	1025	-0.12	0.11	-0.07	-0.14
		SUM: -0.34	SUM: 0.73	SUM: -0.54	SUM: -0.49
		AVG: -0.07	AVG: 0.15	AVG: -0.11	AVG: -0.10

TABLE 3-2 (CONTINUED)

		04/01/85 - 07/11/85	07/11/85 - 10/03/85	10/03/85 - 06/11/86	04/01/85 - 06/11/86
ite	Section ID	Weighted Mean Bed Elevation Change (feet)	Weighted Mean Bed Elevation Change (feet)	Weighted Mean Bed Elevation Change (feet)	Overall Weighted Mean Bed Elevation Change (feet)
9B	0	-0.04	0.09	-0.12	-0.07
	203	0.03	0.01	0.02	0.06
	388	0.02	0.05	-0.01	0.06
	607	0.00	0.05	0.05	0.10
	812	0.01	0.00	-0.07	-0.06
	1131	-0.03	0.05	-0.06	-0.04
	1526	-0.02	-0.11	-0.09	-0.22
		SUM: -0.03	SUM: 0.14	SUM: -0.28	SUM: -0.17
		AVG: -0.00	AVG: 0.02	AVG: -0.04	AVG: -0.02

TABLE 3-2 (CONTINUED)

Site	Section ID	10/01/84 - 04/05/85 Weighted Mean Bed Elevation Change (feet)	04/05/85 - 07/13/85 Weighted Mean Bed Elevation Change (feet)	10/01/85-07/13/85 Overall Weighted Mean Bed Elevation Change (feet)
10	0	-0.24	——	-0.24
	167	0.04	-0.16	-0.12
	347	0.01	0.07	0.08
	564	-0.04	0.03	-0.01
	766	0.00	0.11	0.11
	1188	0.15	0.11	0.26
	1470	0.01	0.07	0.08
	1885	0.06	——	0.06
		SUM: -0.01	SUM: 0.23	SUM: 0.22
		AVG: -0.00	AVG: 0.04	AVG: 0.03

Site	Section ID	10/04/84 - 04/12/85 Weighted Mean Bed Elevation Change (feet)	04/12/85 - 07/20/85 Weighted Mean Bed Elevation Change (feet)	10/04/84-07/20/85 Overall Weighted Mean Bed Elevation Change (feet)
11	0	0.12	0.08	0.20
	890	0.12	-0.03	0.09
	1424	-0.07	0.07	0.00
	1752	0.17	0.11	0.28
	2031	-0.02	0.16	0.14
		SUM: 0.32	SUM: 0.39	SUM: 0.71
		AVG: 0.06	AVG: 0.08	AVG: 0.14

TABLE 3-2 (CONTINUED)

ite	Section ID		04/16/85 - 07/85 Weighted Mean Bed Elevation Change (feet)
12	0		-0.37
	653		0.04
	2057		-0.16
	2613		0.07
		SUM:	-0.42
		AVG:	-0.11

Site	Section ID		10/12/84 - 04/15/85 Weighted Mean Bed Elevation Change (feet)		04/15/85 - 07/16/85 Weighted Mean Bed Elevation Change (feet)		07/16/85 - 06/13/86 Weighted Mean Bed Elevation Change (feet)		10/12/84 - 06/13/86 Overall Weighted Mean Bed Elevation Change (feet)
12	0		0.01		-0.10		-0.09		-0.18
	813		-0.07		0.17		-0.33		-0.23
	2335		0.30		-0.23		-0.12		-0.05
		SUM:	0.24	SUM:	-0.16	SUM:	-0.54	SUM:	-0.46
		AVG:	0.08	AVG:	-0.05	AVG:	-0.18	AVG:	-0.15

TABLE 3-2 (CONTINUED)

Site	Section ID	04/09/85 - 08/02/85 Weighted Mean Bed Elevation Change (feet)
NP	0	0.01
	212	0.00
	470	-0.04
	651	-0.15
	933	0.01
	1071	-0.04
		SUM: -0.21
		MEAN: -0.03

APPENDIX C

Hydraulic Analysis of Woodland Expansion

Historic flow data along these rivers were obtained from records of the USGS. Old cross-section data from the 1920's or 1930's that described the channel geometry of these rivers were obtained from the Nebraska Bureau of Public Works, Department of Roads and Bridges. The following material explains the analysis of channel width and woodland change from a hydrologic and hydraulic perspective. The analysis of the various locations subdivides the river system into several different reaches relative to local water resource development. Examining the timing of channel changes in the different reaches accounting for differences in channel geometry provides important insight into why the timing of change was different for the various reaches.

North Platte River Upstream of Lake McConaughy

Cross-section data from 1927 were obtained at Lisco on the North Platte which is located upstream of Lake McConaughy. Based on the cross-section data, a hydraulic analysis using Manning's equation was conducted. The hydraulic analysis determines the relationship between flow and the percentage of the channel inundated by water. Figure C.1 presents in graphic form the results of this analysis. To understand what this graph means, the amount of channel covered by water at a few different magnitudes of flow is now discussed. For example, at a flow of 1,000 cfs, the percentage of channel covered by water is only about 8 percent. At 10,000 cfs (1E4 meaning 10 to the fourth power), the amount of channel covered by water rises to about 22 percent. The amount of channel covered by water reaches 100 percent at a flow in excess of 60,000 cfs.

The shape of the curve defining the relationship between the percentage of channel inundated and flow is quite steep in the high flow range. Conversely, it is quite flat in the lower flow range. As the flow increases three orders of magnitude (a factor 1,000 times) from 10 to 10,000 cfs, there is only a very small increase in the percentage of channel inundated by water. On the other hand, as the flow increases above 10,000 cfs, the percentage of channel inundated begins rising rapidly. The shape of this curve influences the extent of channel width and woodland changes and timing of the changes as flows change. A decrease in flows of 10,000 cfs from 30,000 cfs to 20,000 cfs would cause a significant amount of channel bed to become exposed. The same magnitude of decrease in flow from 11,000 cfs to 1,000 cfs would not cause nearly as much of an increase in the amount of channel bed exposed. This relationship, as dictated by the shape of the cross-section, then has implications regarding the effect certain changes in flow can and do have on the channel and on the potential for woodland expansion.

The active river channels were created and maintained largely by flow and other less significant physical processes in a fairly wide condition in the 1800's, as indicated by the GLO survey maps. As significant water resources development in the upstream portion of the watershed, including large mainstem reservoirs and numerous diversions came on line, peak flows decreased starting in about 1930. Drought also played a major role in the low flows of the 1930's. These initial flow reductions caused by early projects and exacerbated by the drought caused much of the channel bed to be exposed to woodland expansion due to the rapid decrease in the percent of the channel inundated by water with flow decreases in the high range. From a hydraulic perspective, there was a significant percentage of the original channel upon which seeds could germinate and woody vegetation could become established and grow with the initial flow reductions. This is confirmed by the aerial photo analysis. Figure C.2 shows that most channel narrowing and woodland expansion that ultimately occurred on the North Platte upstream of Lake McConaughy had already occurred by 1938, the date of the earliest aerial photography. Further reductions in flow due to water development after 1938 could not further reduce the channel widths significantly because the hydraulic analysis shows that as flows continue decreasing in the several thousand cfs range, the percent inundated curve is very flat, indicating that not much more of the channel is exposed to potential woodland expansion. This is also confirmed in Figure C.2 that shows little change in channel width after 1930.

North Platte Downstream of Lake McConaughy

In the reach downstream of Lake McConaughy, cross-section data were obtained for Hershey from 1927. The percent inundated flow curve for this data is considerably different than for the reach upstream of Lake McConaughy (see Figure C.3). Whereas the cross-section at Lisco shows a rapid decrease in the amount of channel covered by water as flow decreases from 30,000 to 10,000 cfs, the decrease in amount of channel inundated at Hershey for the same reduction is much less substantial. At Lisco there is not much reduction in inundated width below 10,000 cfs; but at Hershey, the reduction in width inundated continues steadily as flow decreases. The difference in the shape of the cross-section then causes a different response in the percentage of channel covered by water and hence the extent of potential woodland expansion and timing of narrowing for the same change flow. Thus, at Hershey, the channel shape prior to the Projects dictated that as flows decreased there was the potential for continued narrowing and woodland expansion both before and after 1938. Figure C.4 shows this more gradual narrowing over time that continued into the 1950's, as discussed in the above channel narrowing and woodland expansion analysis from a hydraulic perspective.

South Platte Upstream of Korty Diversion Dam

Cross-section data for this portion of the South Platte is located at Brule (1924). Hydraulic analysis of this cross-section shows that, like the North Platte upstream of the Projects, most exposure of the channel bed occurs when flows are reduced on the high end of the flow range (Figure C.5). This means that significant narrowing would tend to occur with flow reductions during the early time periods as water development first took place in the basin. More recent flow reductions that would further reduce flow, say below 10,000 cfs, would not tend to induce significant additional increments of

Figure 1

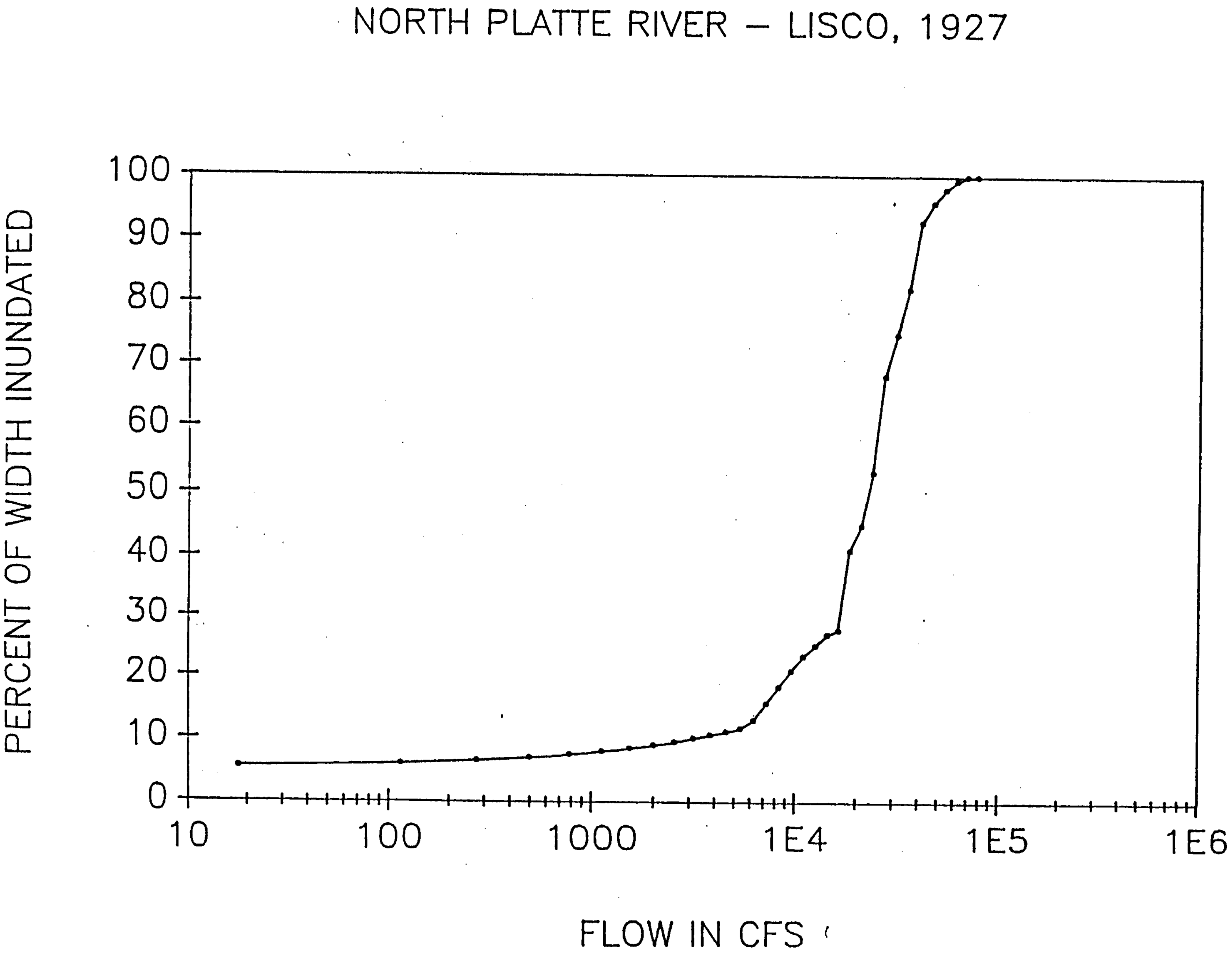

NORTH PLATTE RIVER – LISCO, 1927
PERCENT OF WIDTH INUNDATED
100
90
80
70
60
50
40
30
20
10
0
10
100
1000
1E4
1E5
1E6
FLOW IN CFS

Figure 2

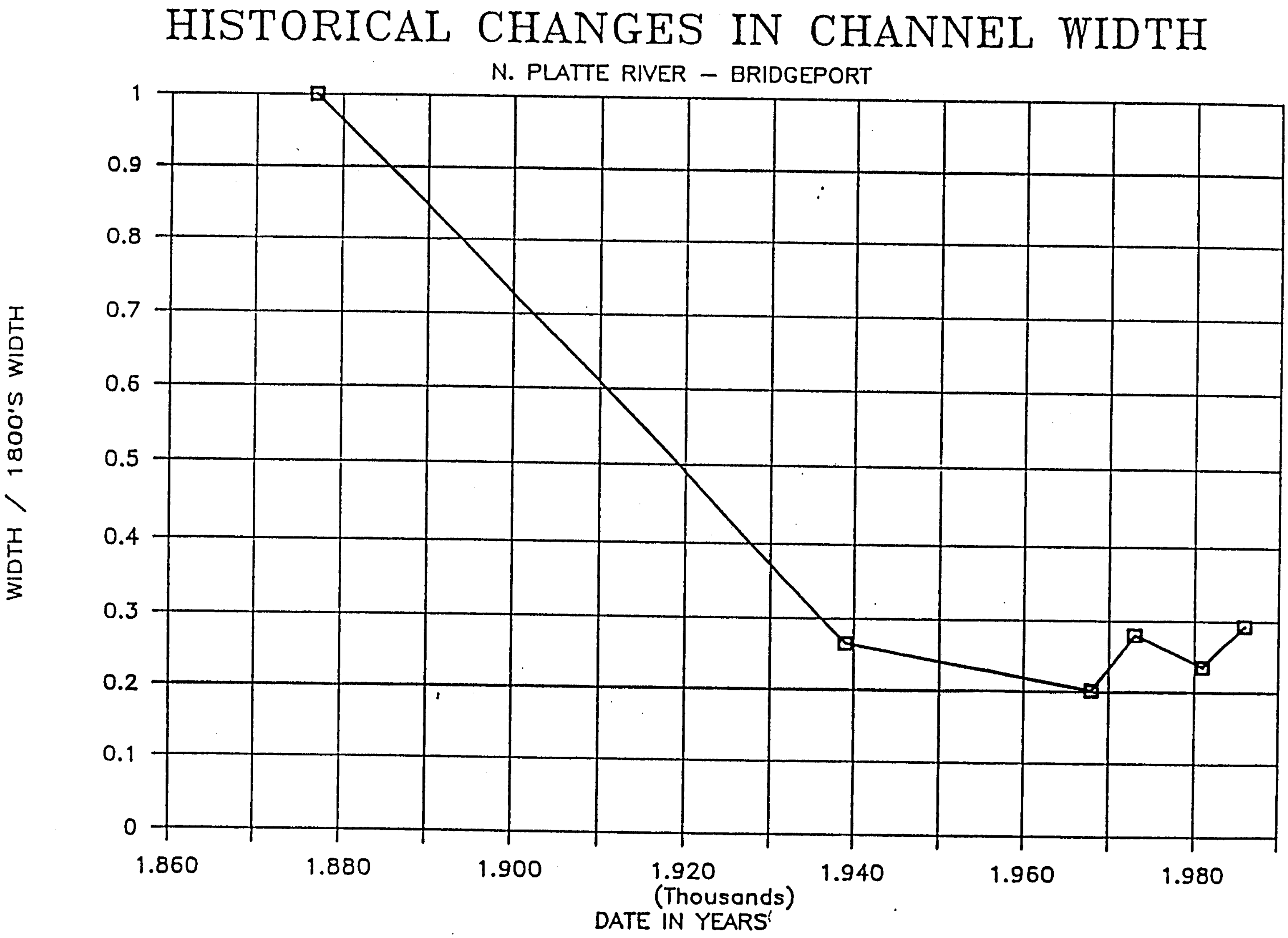

HISTORICAL CHANGES IN CHANNEL WIDTH
N. PLATTE RIVER – BRIDGEPORT
WIDTH / 1800'S WIDTH
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1.860
1.880
1.900
1.920
1.940
1.960
1.980
(Thousands)
DATE IN YEARS

Figure 3

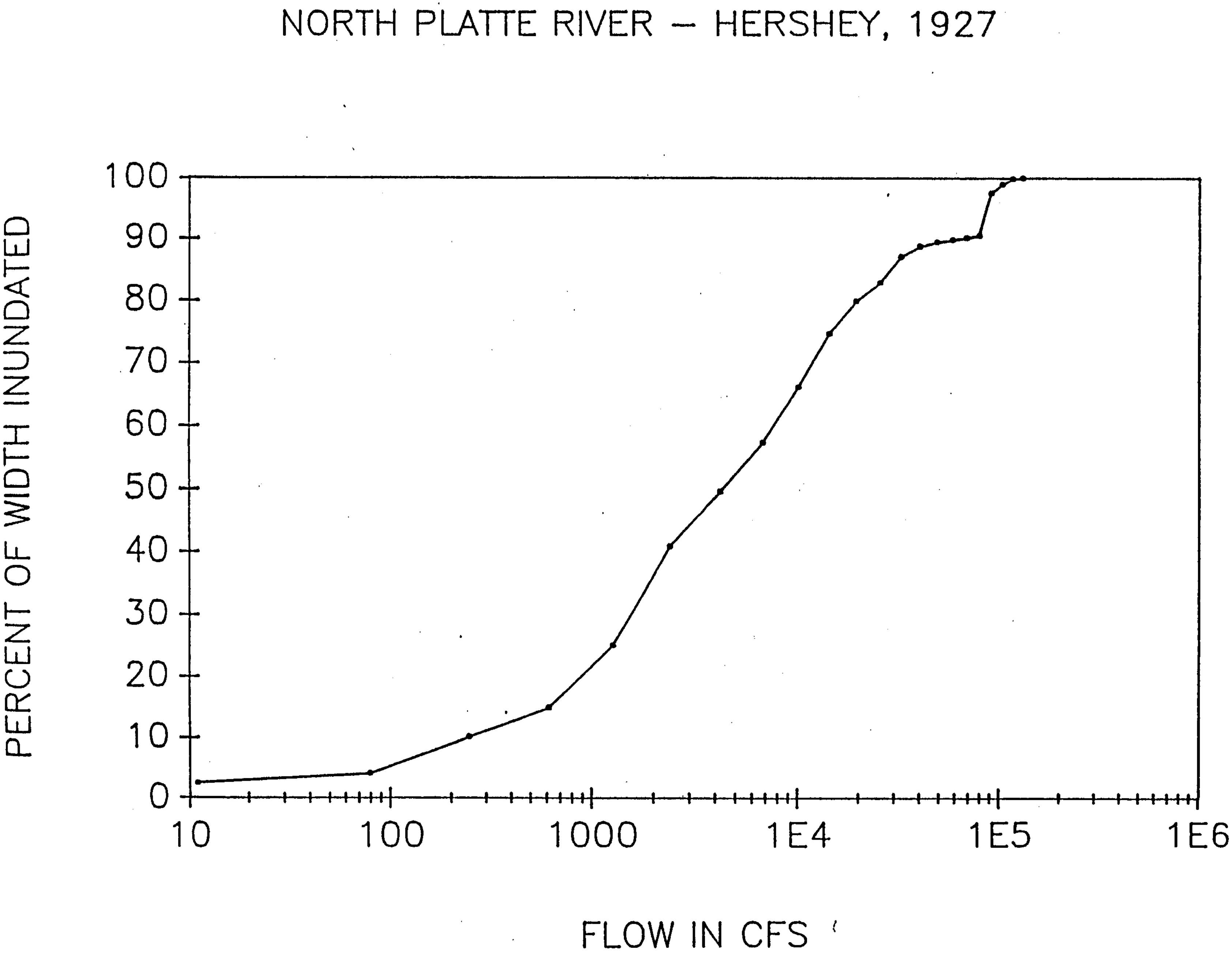

NORTH PLATTE RIVER – HERSHEY, 1927
PERCENT OF WIDTH INUNDATED
100
90
80
70
60
50
40
30
20
10
0
10
100
1000
1E4
1E5
1E6
FLOW IN CFS

Figure 4

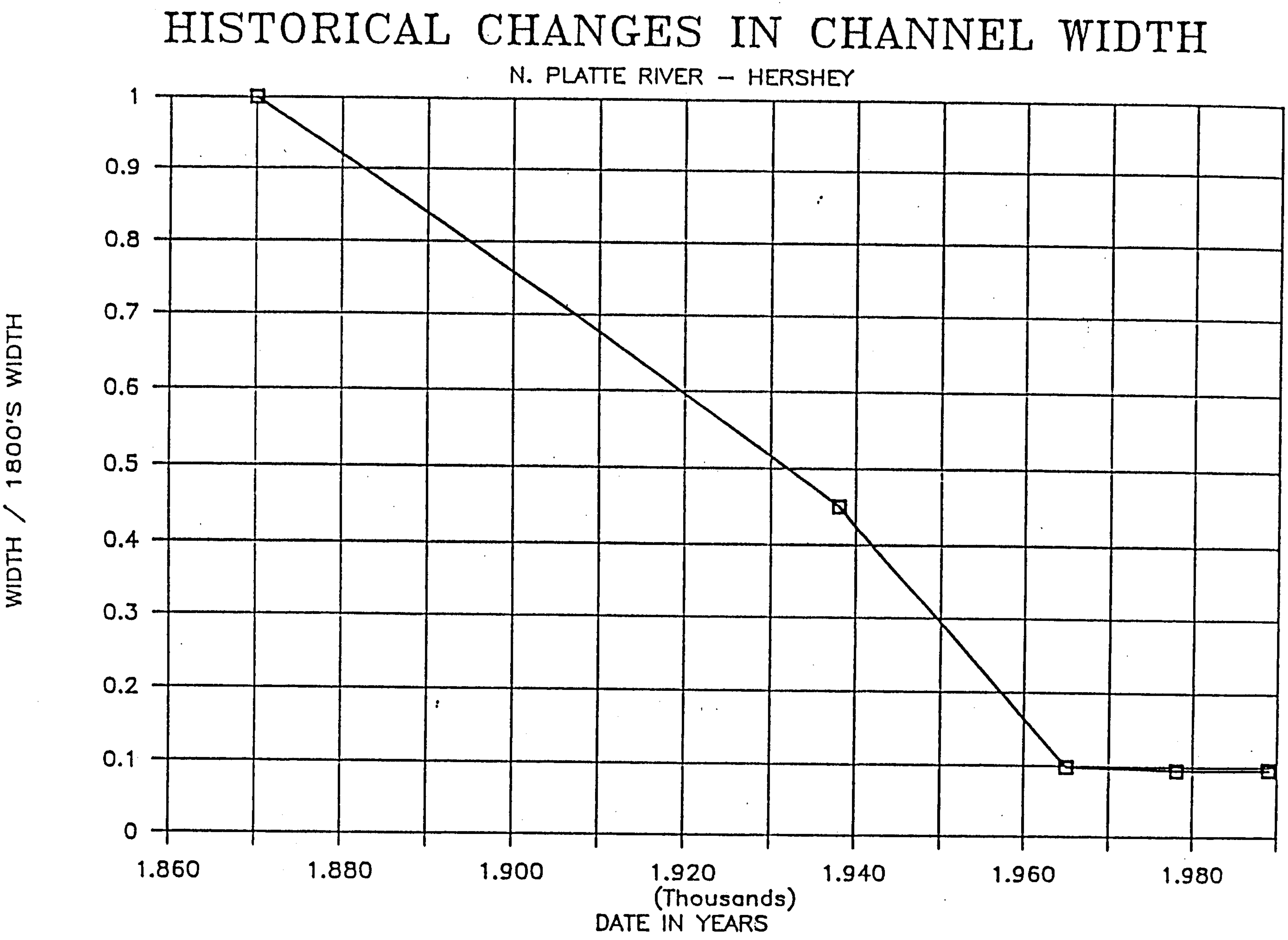
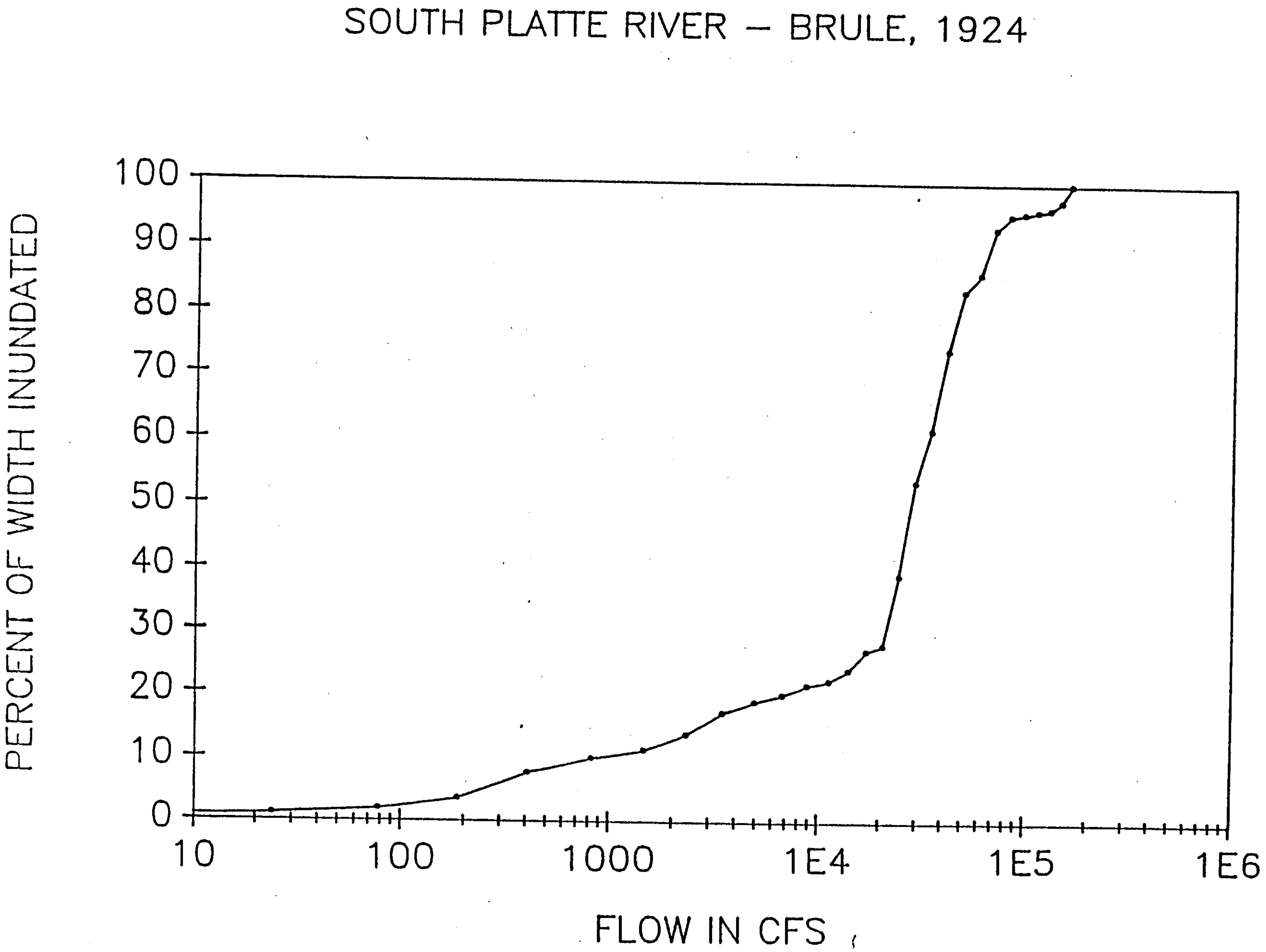

HISTORICAL CHANGES IN CHANNEL WIDTH
N. PLATTE RIVER – HERSHEY
WIDTH / 1800'S WIDTH
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1.860
1.880
1.900
1.920
1.940
1.960
1.980
(Thousands)
DATE IN YEARS

Figure 5


SOUTH PLATTE RIVER – BRULE, 1924
PERCENT OF WIDTH INUNDATED
100
90
80
70
60
50
40
30
20
10
0
10
100
1000
1E4
1E5
1E6
FLOW IN CFS

narrowing. This tendency for significant narrowing early in the development process with little additional narrowing in the more recent time period is again confirmed by aerial photo analysis of the historic channel narrowing and woodland expansion, as shown in Figure C.6.

South Platte Downstream of Korty Diversion Dam

Hydraulic analysis of the cross-section on the South Platte at Hershey shows a different relationship of percent inundated versus flow than the relationship on the South Platte upstream of Korty (see Figure C.7). At Hershey, there is virtually no change in the amount of channel inundated above 10,000 cfs. As flows are reduced below 10,000 cfs, however, significant reductions in the amount of channel bed inundated by water occur. Therefore, no significant potential for channel narrowing and woodland expansion existed with early flow reductions at the beginning of water resources development, but there was a significant potential once flows were reduced to lower levels. As with the North Platte downstream of Lake McConaughy, most change would tend to occur in the more recent past rather than prior to 1938. This is shown in Figure C.8 documenting the historic changes at this site.

Platte River at Brady

The percentage of channel covered by water as a function of flow based on 1926 cross-section data at Brady is shown in Figure C.9. At this location, the amount of reduction in inundated channel bed is fairly steady throughout a wide range of flow. As a result, there would be a potential for incremental narrowing as each incremental decrease in flow occurred as a result of water resources development. Figure C.10 confirms this fact as channel narrowing and woodland expansion continued through to the 1960's as each additional project decreased incrementally the amount of water flowing by this reach of river.

Platte River at Odessa and Gibbon

The reach of river downstream of the Projects is represented by cross-sections at Odessa (1929) and Gibbon (1921). Results of hydraulic analysis using the Odessa data (Figure C.11) show very little potential for change as reductions occurred within the high range of flow during early time periods, but significant potential for change as further flow reductions took place in the more recent time frame. From a hydraulic perspective, then, most narrowing in this reach of channel would tend to occur in the recent past after significant water resources development had already begun. Figure C.12 shows the historic narrowing over time at Odessa showing little narrowing prior to 1938 but more significant and continued narrowing into the 1960's.

The analysis at Gibbon (Figure C.13) shows again that most potential for narrowing of the channel width and woodland expansion would occur when flows are reduced from about 15,000 cfs to a few thousand cfs. Not much change in the channel would occur when initial changes in flow above 15,000 cfs occurred as a result of the initial stages of water resources development. Again this pattern of change, as dictated by the available cross-sectional geometry from the 1920's is shown by the analysis of aerial photo data close to Gibbon, as given in Figure C.14.

Figure 6

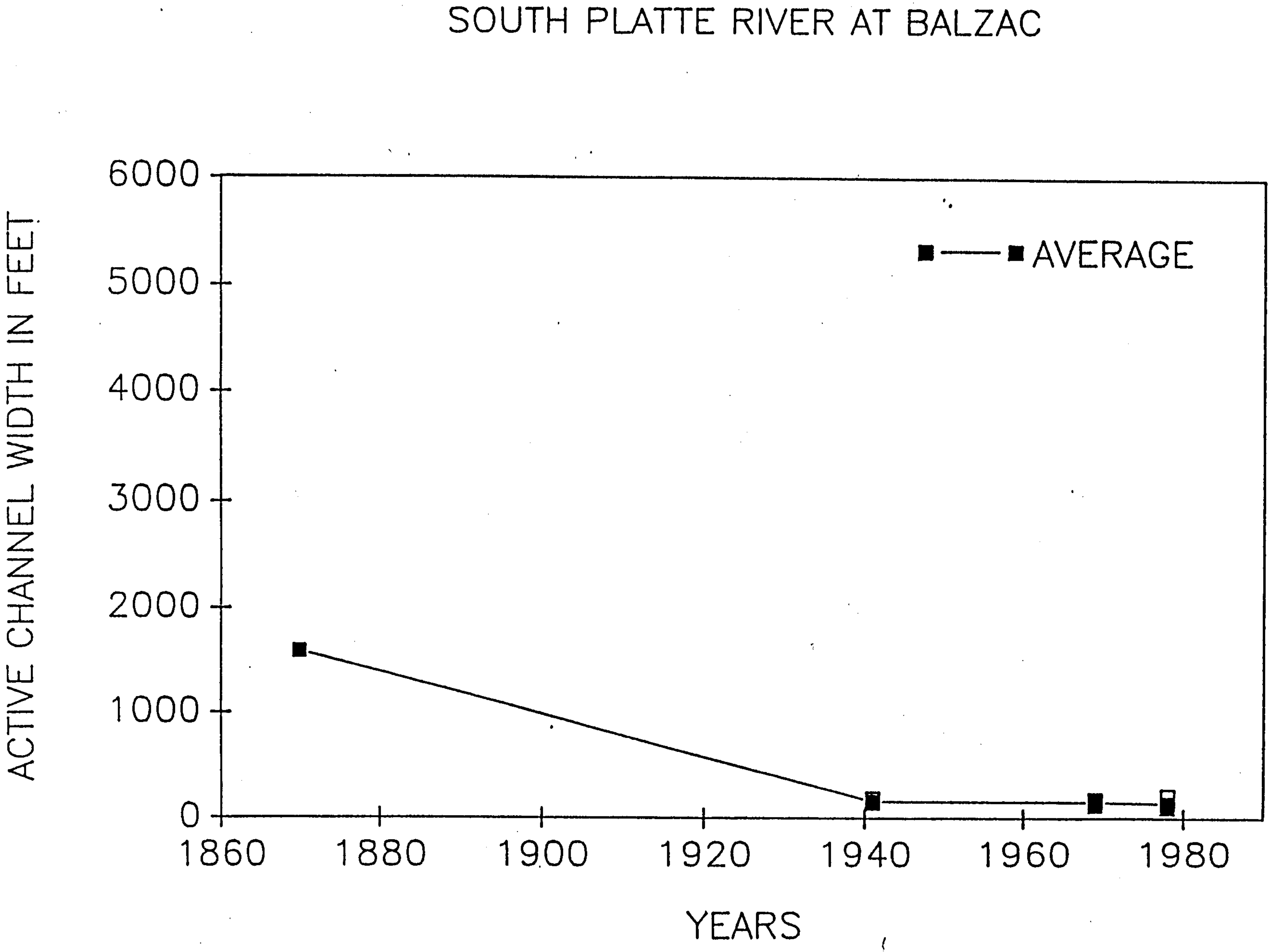

SOUTH PLATTE RIVER AT BALZAC
ACTIVE CHANNEL WIDTH IN FEET
6000
5000
4000
3000
2000
1000
0
1860
1880
1900
1920
1940
1960
1980
YEARS
■——■ AVERAGE

Figure 7

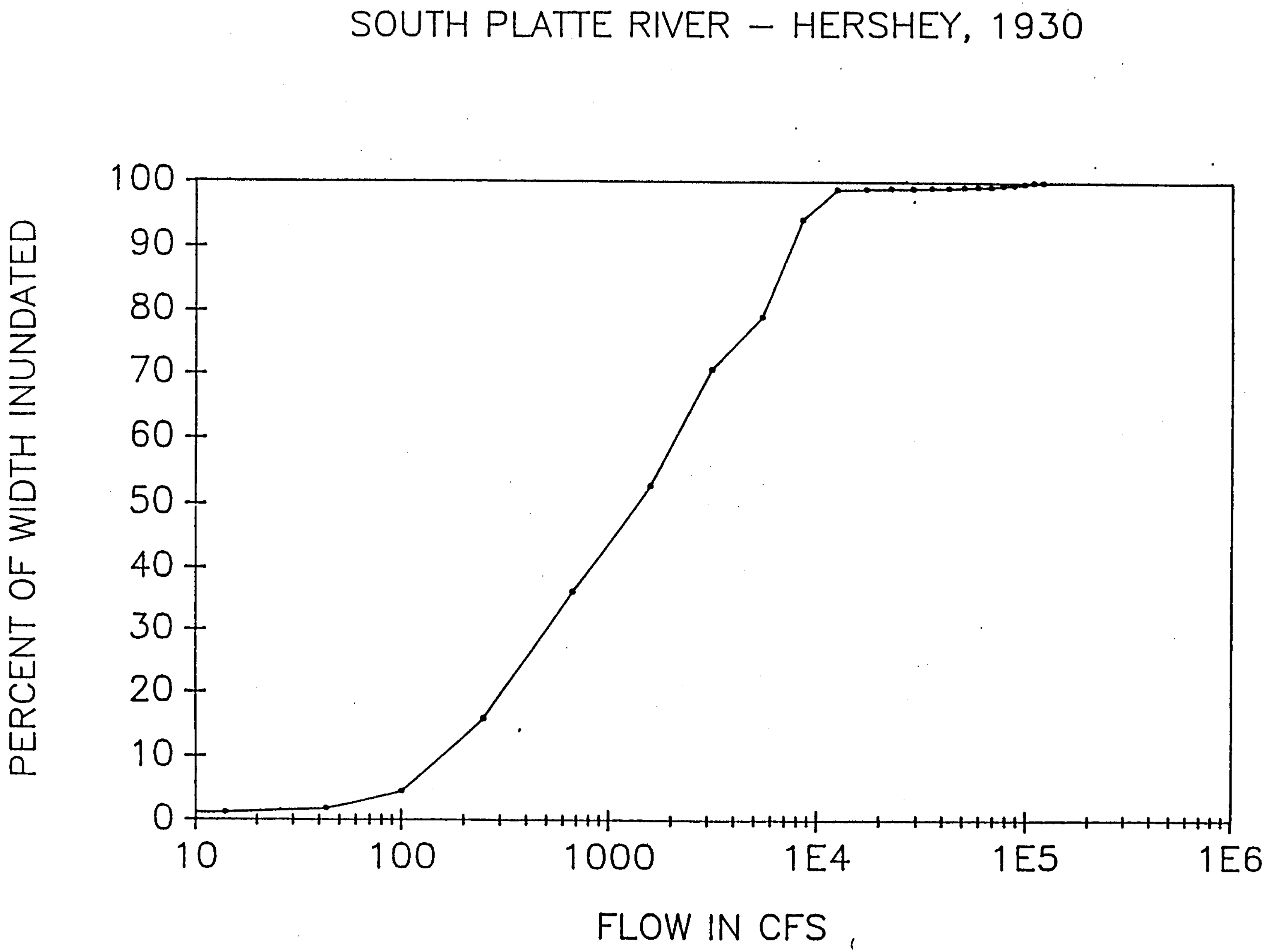

SOUTH PLATTE RIVER – HERSHEY, 1930
PERCENT OF WIDTH INUNDATED
100
90
80
70
60
50
40
30
20
10
0
10
100
1000
1E4
1E5
1E6
FLOW IN CFS

Figure 8

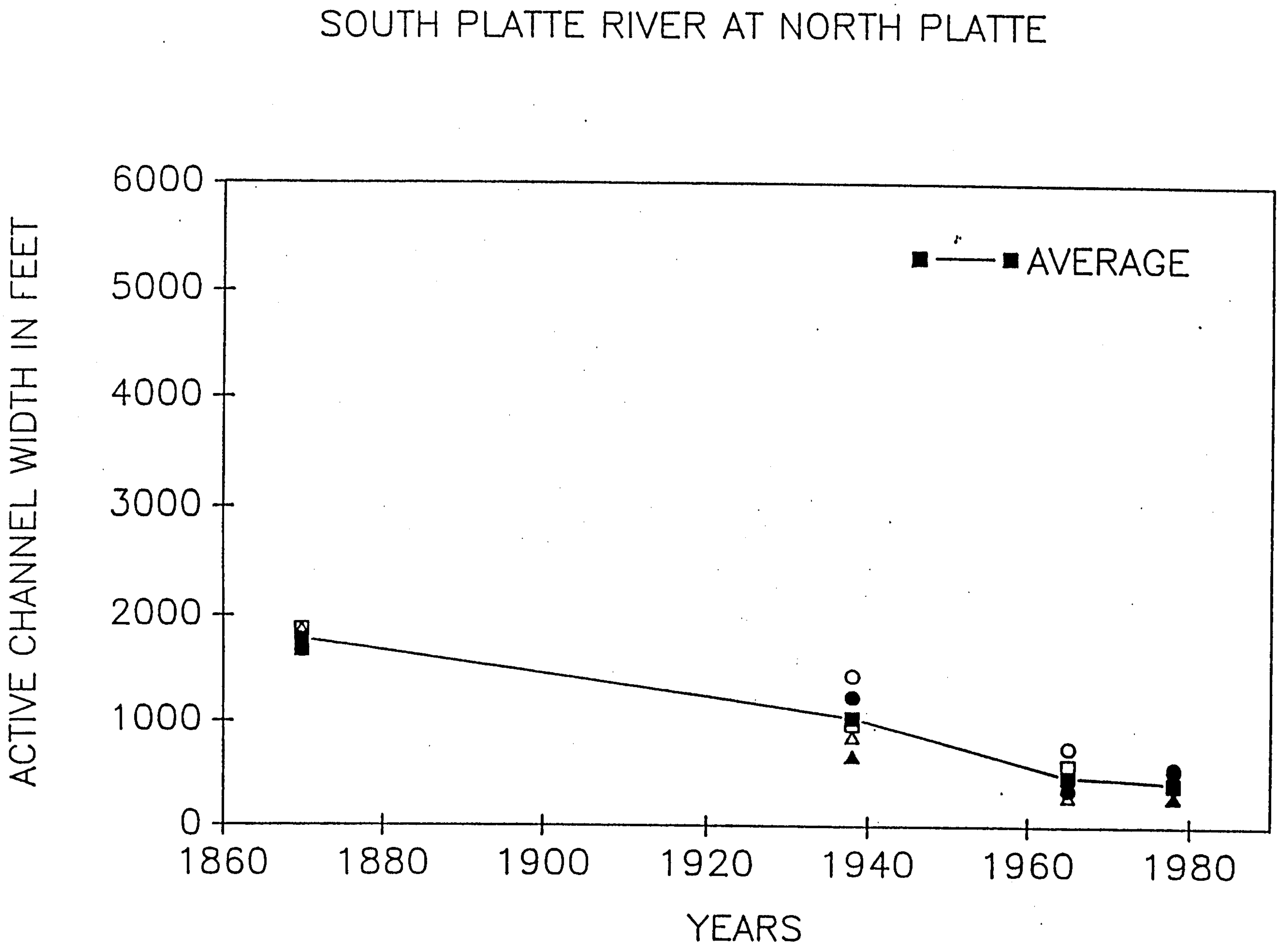

SOUTH PLATTE RIVER AT NORTH PLATTE
■—■ AVERAGE
ACTIVE CHANNEL WIDTH IN FEET
6000
5000
4000
3000
2000
1000
0
1860
1880
1900
1920
1940
1960
1980
YEARS

Figure 9

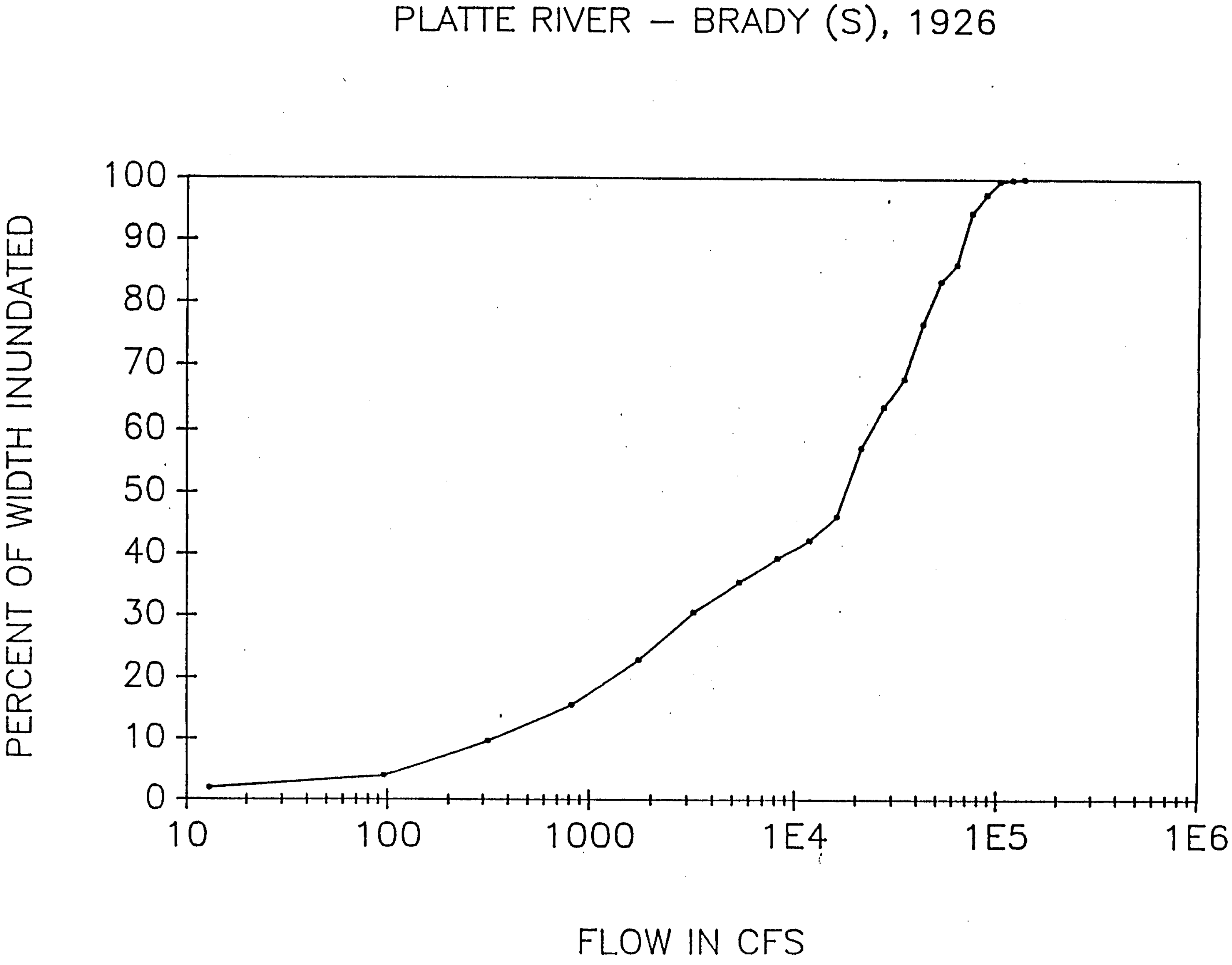

PLATTE RIVER – BRADY (S), 1926
PERCENT OF WIDTH INUNDATED
100
90
80
70
60
50
40
30
20
10
0
10
100
1000
1E4
1E5
1E6
FLOW IN CFS

Figure 10

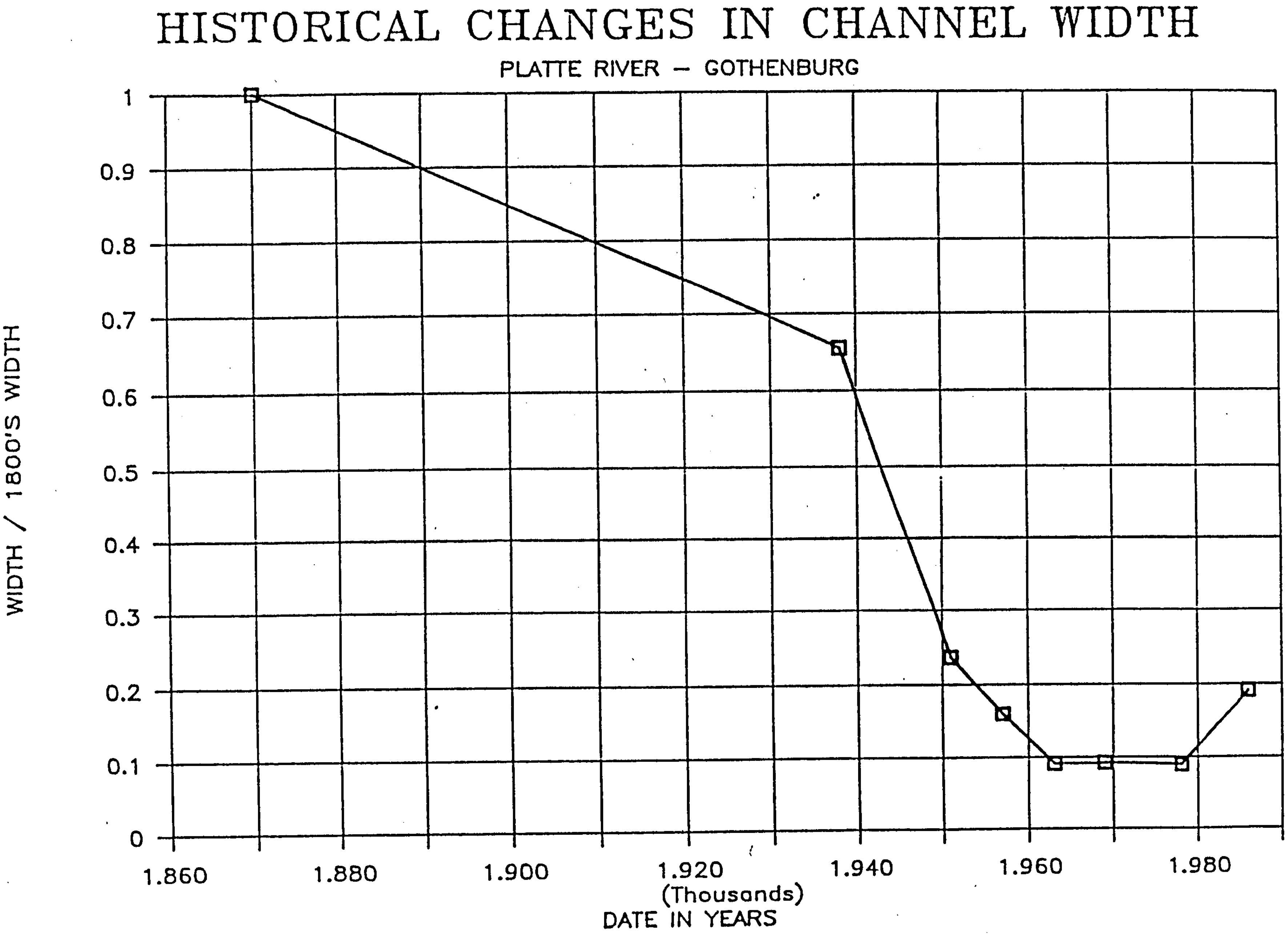

HISTORICAL CHANGES IN CHANNEL WIDTH
PLATTE RIVER – GOTHENBURG
WIDTH / 1800'S WIDTH
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1.860
1.880
1.900
1.920
1.940
1.960
1.980
(Thousands)
DATE IN YEARS

Figure 11

PLATTE RIVER – ODESSA, 1929

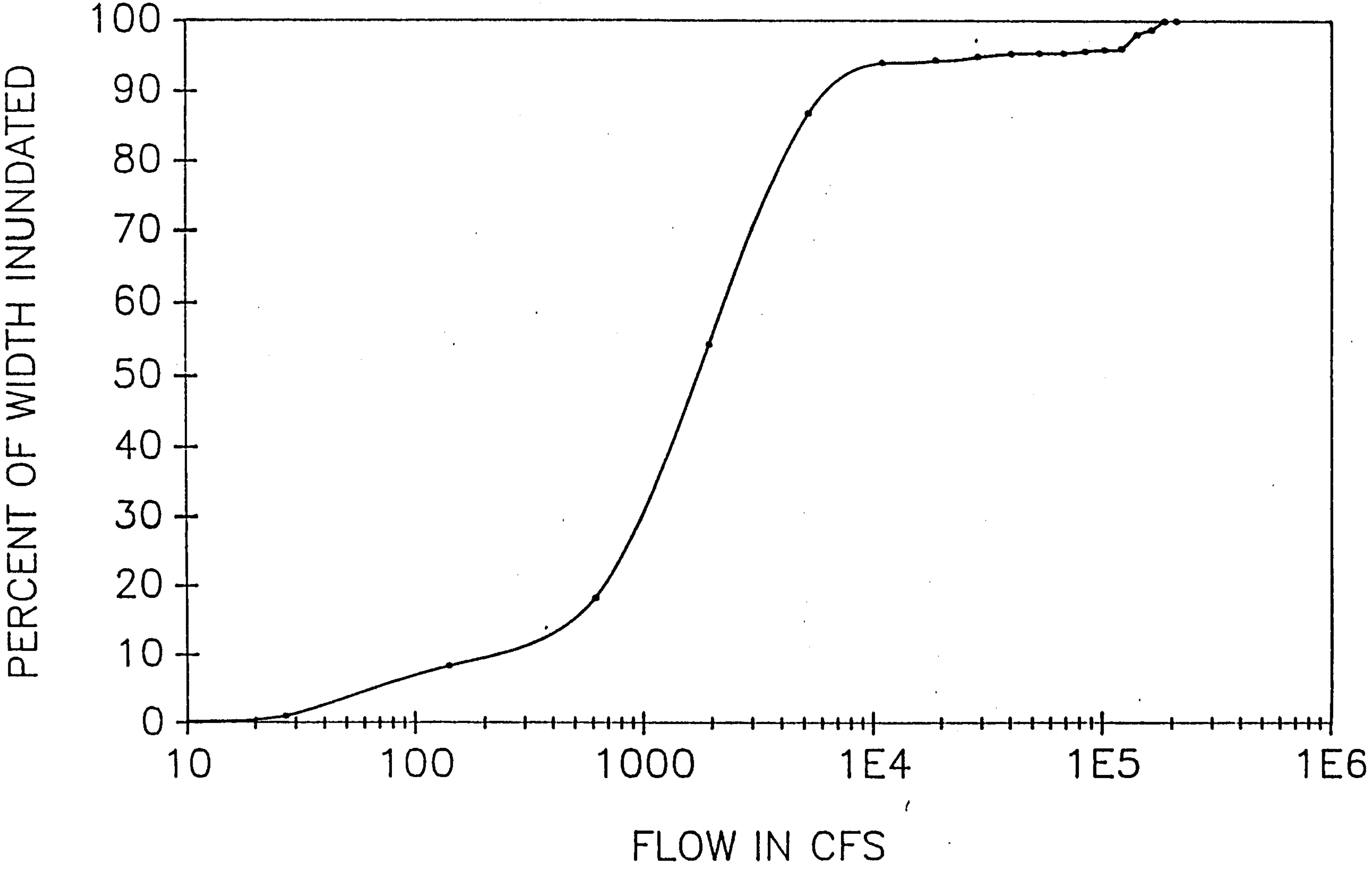


Figure 12

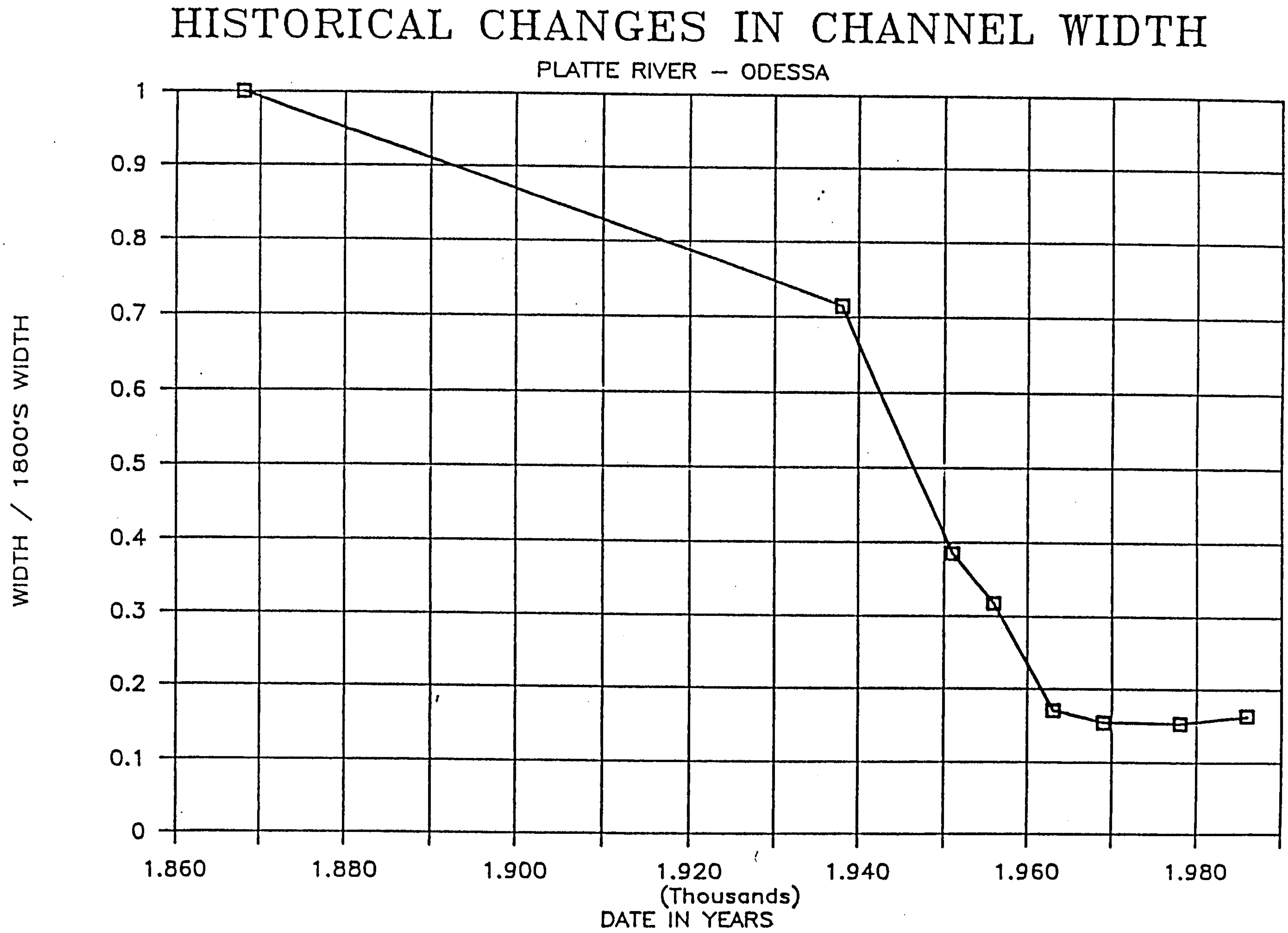

HISTORICAL CHANGES IN CHANNEL WIDTH
PLATTE RIVER – ODESSA
WIDTH / 1800'S WIDTH
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1.860
1.880
1.900
1.920
1.940
1.960
1.980
(Thousands)
DATE IN YEARS

Figure 13

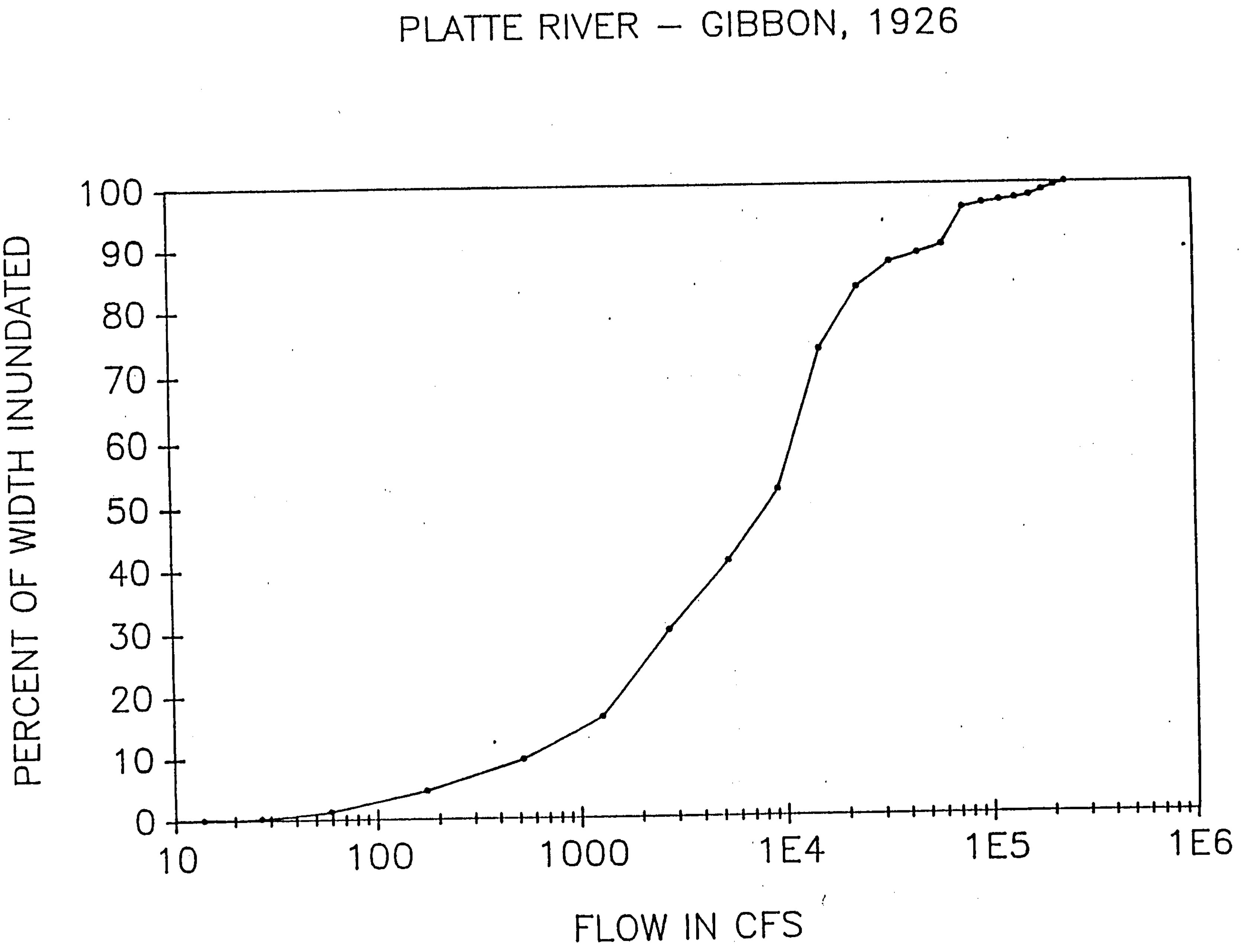
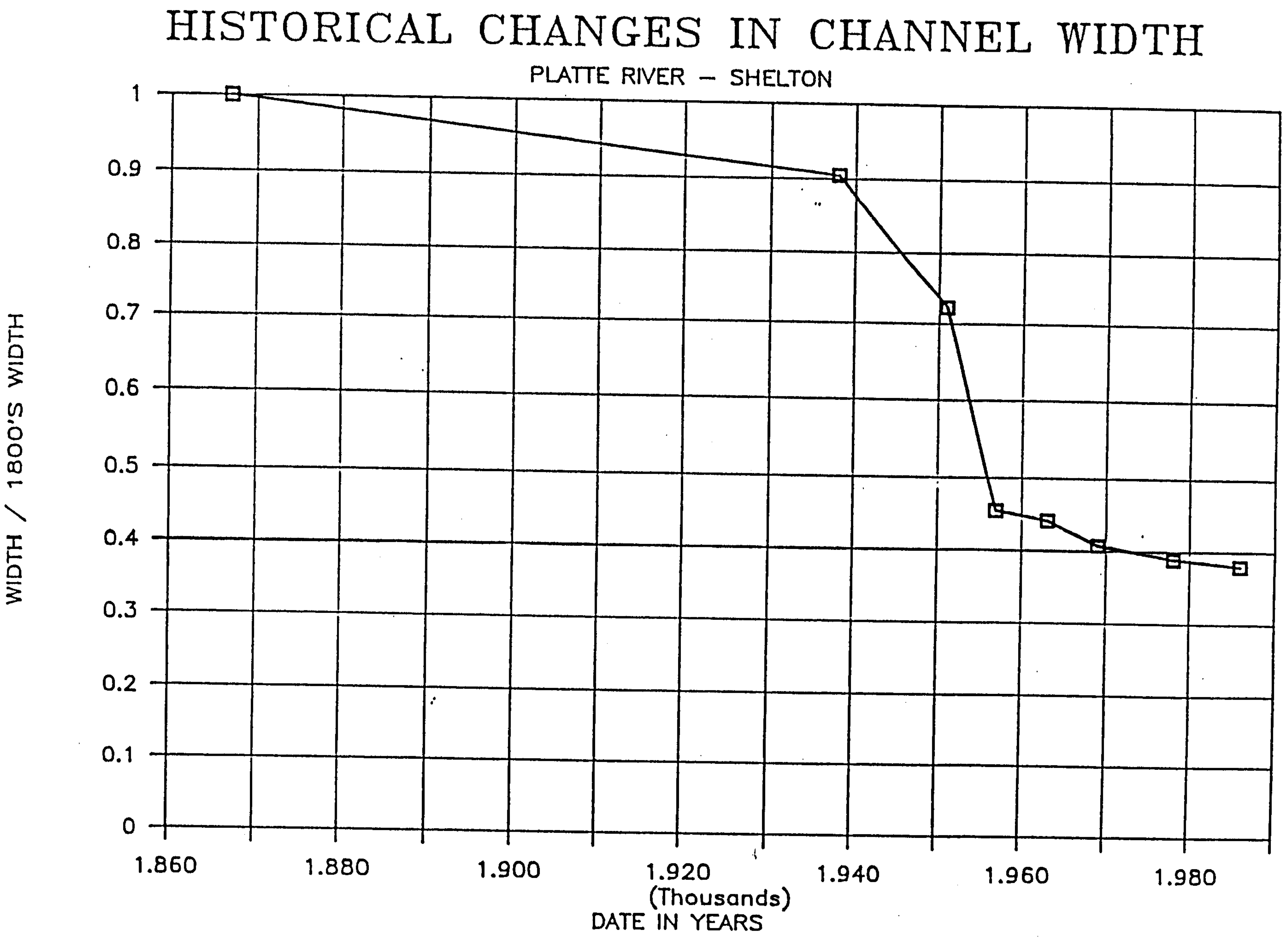

PLATTE RIVER – GIBBON, 1926
PERCENT OF WIDTH INUNDATED
100
90
80
70
60
50
40
30
20
10
0
10
100
1000
1E4
1E5
1E6
FLOW IN CFS

Figure 14


HISTORICAL CHANGES IN CHANNEL WIDTH
PLATTE RIVER – SHELTON
WIDTH / 1800'S WIDTH
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1.860
1.880
1.900
1.920
1.940
1.960
1.980
(Thousands)
DATE IN YEARS

APPENDIX D

Timing of Woodland Expansion

Discussion of the Timing of Woodland Expansion for the Selected Reaches

Woodland expansion onto formerly active channel generally occurred at an earlier time period on the North and South Platte Rivers than it did on the Platte River. This general west to east progression has been hypothesized to be a result of the same general west to east progression of water resources development, i.e., starting earliest in the tributaries farther west and progressing downstream to the east as time went on. This hypothesis basically associates the resulting channel response with localized effects of a project rather than a more general concept of why the change occurred. This rationale could be considered valid if the following conditions were true:

- no reduction in flow (particularly during the germination) occurred after 1938, the date of the first aerial photographs, due to upstream water resources development,
- all channel cross-sections, in both upstream and downstream portions of the basin, had the same shape, i.e., percent inundation versus discharge curves, and thereby would respond the same way to a reduction in flow, and
- no narrowing after 1938 actually occurred anywhere in upstream portions of the basin.

In fact, none of these conditions are met:

- Significant water resources development occurred in the upstream portions of the basin after 1938 as listed below:

North Platte:

Alcova (1938)	184,000 acre feet
Seminoe (1939)	1,026,360
Glendo (1957)	795,000
Grayrock (1975)	104,000

South Platte:

Cherry Creek (1957)	96,000
Chatfield (1975)	235,000
Bear Creek (1979)	46,000
Spinney Mountain (1981)	48,000

The increase in reservoir storage in the upstream portion of the watershed (not including Lake McConaughy in the downstream portion of the watershed) since 1938 was 2,533,360 acre-feet. Thus, a substantial percentage of all reservoir storage in the basin occurred in the upper portion of the basin and occurred after 1938. This increase in reservoir capacity decreased peak flow and flow during the germination season.

As shown in Figures C.1, C.3, C.5, C.7, C.9, C.11, and C.13, the channel cross-sections were significantly different in the various reaches prior to 1938 causing different percent inundation versus flow relationships and hence different amounts and timing of channel narrowing or woodland expansion. Where cross-section shapes allowed, some narrowing did occur in upstream locations in the basin after 1938.

Significant narrowing could have and did occur in most upstream areas prior to 1938, yet could not and did not occur farther downstream simply because the cross-section shapes were different based on the 1920's cross-section data. A further and later reduction in peak flow to a magnitude of around 10,000 cfs could and did cause significant narrowing downstream prior to 1938 simply because of the different channel cross-sectional geometry.

Significant narrowing could not and did not occur (for the most part) in upstream areas after 1938 because further flow reductions, below 10,000 cfs after 1938, did not cause significantly less of the channel to be inundated. Conversely, farther downstream, additional reductions in flow after 1938 could and did cause narrowing. This later narrowing was again dictated largely by the shape of the channel and the response given basin-wide flow reductions from water resources development that occurred in both upstream and downstream portions of the basin.

This analysis shows that there is an explanation for the timing of woodland expansion generally being earlier in the upstream portions of the basin and later in downstream portions of the basin. This explanation again links the channel geometry and associated hydraulics of inundation during the germination season with the basin-wide flow reductions that occurred particularly during this season of the year. It also suggests that the explanation of timing due to timing of development in upstream versus downstream portions of the basin is largely coincidental. The response of the river to changes in flow is quite complex and will be different in different reaches, depending on the pre-existing channel geometry and flow changes related to key biological processes of riparian vegetation. It can therefore be concluded that the same reduction in flow can cause a different amount of channel bed to be exposed during the germination season at different locations resulting in different amounts and timing of vegetation and channel narrowing. Specifically, the channel geometry of the upstream portions of the North Platte and South Platte dictated that most narrowing occurred as a result of early water development because the amount of channel inundated by water was significantly and dramatically reduced, exposing much of the channel bed to vegetation when the flows were reduced below 10,000 cfs. In contrast, the channel geometry of the North Platte, South Platte and Platte Rivers in downstream reaches dictated that little narrowing occurred as a result of early water development, but that narrowing would continue over time as water development continued because the amount of channel inundated by water decreased gradually as the flow was reduced. The analysis presented above is important in developing an appropriate understanding of the effect of flow on changes in vegetation. It lends support to the concept that flow during the germination season plays an important role in vegetation changes in the Platte River and explains to a significant degree the extent and timing of this change.

APPENDIX E

Computer Modeling of Woody Vegetation

Based on two of the key flow-related factors that affect vegetation, flow during the germination season and peak flow, a computer modeling analysis was conducted of woodland changes along the Platte River (see Simons & Associates, 1990c). This modeling analysis is described below.

Physical Processes

As mentioned in the introduction, channel narrowing and woodland expansion are phenomena governed by a few key physical processes. These physical processes are discussed below.

The substrate of the channel bed of the North, South, and Platte Rivers in the area of interest is prone to establishment and growth of vegetation because it consists mainly of sand upon which seeds can readily germinate and grow. Germination and establishment of seeds can readily be observed in the summer on the sandy bed of these rivers. Seeds, however, cannot germinate and become established on the sandy substrate on portions of the channel bed that are covered by water. During the seed dispersal period which roughly extends from mid May to mid July (Johnson, 1990a), seeds can be observed floating on the water surface. Often these seeds land on exposed sand bars and/or along the exposed portions of river banks. It is only on these exposed portions of the channel that lie above water that seeds germinate. No seeds were observed that germinated and rooted on an area inundated by water.

Two of the key factors controlling channel narrowing and woodland expansion are thus the magnitude of the flow of water during the seed dispersal and germination period and the amount of the channel above water which is then exposed to seed germination and establishment of vegetation. These two key factors are hydrologic and hydraulic processes.

Vegetation also can be removed by flowing water, but older established vegetation is less easily scoured than newly established vegetation. Seedlings, especially those that have recently germinated, are easily removed by whatever magnitude of flow passes over them. In contrast, older, more mature vegetation can withstand flows of considerable magnitude and may only be removed by extremely high flows. An example of removal of mature trees occurred as a result of the 1983 floods (which were in excess of 20,000 cfs). Thus, the age of the vegetation dictates, to a substantial degree, the magnitude of flow required to remove it. Similar to the factors controlling the establishment of vegetation, the removal of vegetation also is controlled to a substantial degree by hydrologic and hydraulic processes.

In summary, whether or not vegetation germinates, becomes established, and then grows to maturity mainly depends on (1) the magnitude of flow during the germination period, (2) the corresponding amount of active channel bed not inundated by the flow, (3) the length of time between peak flows which allows established vegetation to either mature undisturbed or not, and (4) the potential for removal of the various ages of vegetation by the flow.

Other factors also have been mentioned as reasons for channel narrowing and woodland expansion or lack thereof. These include bridges or other structural controls, desiccation of vegetation, and ice-related scour. Bridges and other structural controls (e.g., stream bank stabilization projects and dikes) certainly can and do affect channel geometry and have been shown to cause a narrower channel and woodland expansion. The effects of such structures are localized and do not cause general channel change along an entire river unless, of course, such structures occur consistently mile after mile (see Simons & Associates, 1990d). Similarly, desiccation has not been shown to be a major factor in controlling vegetation in the last 50 years (Johnson, 1990a, 1992, 1993, 1994a, 1996b). Ice-scour probably has a significant role in removing vegetation, but is a process that varies from year to year and location to location, depending on air temperature, ice cover, local channel characteristics, and the right mix of flow conditions.

Modeling Approach

Based on the above understanding of the key physical processes that control channel narrowing and woodland expansion, a methodology to analyze these phenomena was developed using a physical process computer model (referred to as "CHANWID") of channel hydraulics and the relationship between flow, woodland expansion, and scour. The first step in this approach was to determine the relationship between the magnitude of flow during the seed germination period and the corresponding amount of channel inundated by water. This was done by open channel hydraulic computations solving Manning's equation, one of the most widely used equations in the field of open channel hydraulics. Given a magnitude of flow, the equation can be used to determine the corresponding depth of flow or water surface elevation. Manning's equation is often written in the following form:

$$Q = [1.49/n]\, A\, R^{2/3}\, S^{1/2}$$

where Q is the flow, n is Manning's resistance to flow parameters, A is the cross-sectional area occupied by water, R is the hydraulic radius of the inundated portion of the channel, and S is the longitudinal slope of the river. Data required for the open channel hydraulics portion of the physical process model include surveyed channel cross-sections, slope of the river, the Manning's resistance to flow parameter, and appropriate flow data. The discharge (Q) variable of the model used one value of flow during the seed germination period and one value of peak flow for each year. Since Johnson has shown a strong correlation between mean June flow and woodland expansion, as previously referenced, and because it is representative of the quantity of water flowing during the germination period, mean June flow was selected as one of the flow variables used as input. The second flow variable selected for the model was the peak mean daily flow of each year.

The open channel hydraulics component of the CHANWID model computes the water surface elevation or, in other words, the depth at which water would flow in the channel for a given magnitude of flow. From the water surface elevation determined using the above hydraulic analysis, the portion of the channel and the individual points on the cross-section that are under water and hence affected by the peak flow are determined. Also, the portion of the channel and the individual points above water exposed to potential germination and vegetation growth for the germination flow are determined. Once these portions of channel and individual cross-section points are determined for both the peak flow and germination flow, the vegetation components of the CHANWID model are applied to simulate woodland expansion and scour year by year.

Tests using simplified channel geometry documented that the model functions properly and responds appropriately to input streamflow variables, the hydraulic calculations of exposed channel area, and both the vegetation and scour parameters. While straightforward in concept, the model is based on the key physical processes that appear to have had a dominant role in causing channel narrowing and woodland expansion. The next step, therefore, was to ensure that the model can be successfully calibrated so that model results reproduce historical narrowing and woodland expansion patterns that have been documented in the Platte River system by analysis of maps and aerial photos.

Model Calibration

The objective of the CHANWID model calibration process was to accurately simulate the historical patterns of channel narrowing and woodland expansion at a number of Platte River system locations over an extended period of time. If the CHANWID model would accurately simulate historical changes over a wide range of flow conditions, it could be used with confidence to evaluate future trends under a different set of flow conditions.

The key step in the calibration process is the determination of the parameters for the vegetation establishment and vegetation scour components of the CHANWID model: the vegetation parameter, the scour parameter, and the two flow level scouring triggers. These parameters were selected based upon analyses of historic data. For example, at several locations, channel widening by scour of established trees appears to have occurred as a result of the 1983 flood. This means that the historic peak flow of 1983 was sufficiently large to exceed the high flow level in the CHANWID model that triggers scour of mature vegetation and that the appropriate high flow level is less than the peak. The next step, therefore, was to examine historic records to identify periods of high flow without associated scour of vegetation. The high flow level that was then used in the CHANWID model would be less than the 1983 flow but greater than the next highest flow that did not scour vegetation.

The scour parameter was determined by analyzing the magnitude of channel width that was vegetated with mature vegetation and then subsequently scoured by the peak flow. If the amount of vegetation scoured, as indicated in the aerial photo analyses, was large, the selected scour parameter was also comparably large. If, on the other hand, the aerial photo analyses showed little widening, the selected scour parameter was set at a low value.

As noted above, the amount of active channel becomes established with woody vegetation as a function of the vegetation parameter. The magnitude of the vegetation parameter was thus determined by examining aerial photographs to assess the percentage of the channel that became established with vegetation. If virtually all of the unexposed channel historically became established with vegetation, the vegetation parameter selected would be very high.

The low flow variable in the model above which scouring of young vegetation is triggered, was used as a refinement in the calibration process. It controls, to a degree, the rate of change that is simulated given the flow data and measured channel narrowing data. If the flow trigger that scours young vegetation is set too low, the CHANWID model will tend to show too slow or not enough narrowing compared with historic records.

Site Selection and Data

The data required to calibrate and run the model include river cross-section and other hydraulic data (i.e., river slope and resistance to flow or Manning's n), streamflow data, and historic channel width data over time. Data on historic changes in channel widths can be obtained at any location along the river system given availability of maps and aerial photos. The availability of streamflow data recorded at USGS stream gages somewhat constrained the selection of study sites because the sites need to be near the stream gages, and the periods of record for some of the USGS gages do not extend far enough back to adequately cover the desired modeling period.

The most limiting data need, however, was the historic cross-section data collected prior to significant channel narrowing. Cross-section data from the 1920's was collected by the Nebraska Bureau of Public Works, Department of Roads and Bridges, prior to modern bridge construction. These data were used to define the “baseline” cross-section geometry. Streamflow data from the USGS gages closest to the available cross-sections were used. River slope data were derived from maps and USGS elevation data. Resistance to flow as defined by Manning's n was determined based on tables from a hydraulics handbook (Chow, 1959) and recent field measurement data. The above information provided all of the necessary input data of the CHANWID model. To calibrate the model, the results of channel narrowing and woodland expansion computed by the model were compared to measurements of narrowing over time based on the GLO map/aerial photo analyses. Of course, the aerial photo analysis used to compare the historic channel narrowing to compute results was located away from the bridges since the construction of bridges locally affects channel narrowing. The five selected study site locations (based upon the availability of historic cross-section data) were the North Platte River at Hershey, the South Platte River at Hershey, and the Platte River at Gothenburg, Odessa, and Gibbon. These locations cover reaches of the North Platte and South Platte Rivers that are within the Projects' area as well as two locations downstream of the Projects.

Model Calibration Results

The results of the CHANWID model calibration process are shown in Figure E.1 for one of the locations modeled. It compares historic channel width changes and the computed model results. Historic channel width data measured from maps and aerial photos are plotted using a plus (+) sign. Each year for which data exist since the time of the cross-section survey has a corresponding computed channel width. The vertical scale on the left-hand side of each figure is the ratio of the active channel width to the total channel width. The total channel-width is the pre-settlement era channel width measured from the GLO maps. As channel narrowing and woodland expansion occurs, the percentage of active channel compared to total channel width decreases. The horizontal scale along the bottom of each figure is the data in years beginning in either 1860 or 1870, depending upon the date of the GLO maps. The observed data always start, then, at earliest data with an active channel width over total channel width of 1.0 (or 100 percent).

Summary of Calibration Results

It is evident that the CHANWID model, based on documented physical processes, can accurately reproduce measured historical channel width changes as woody vegetation expands onto portions of the channel that were formerly active flow paths. The fact that the CHANWID model works well with constant calibration parameters over a long time period, including periods of drought and floods, periods of rapid channel change, and periods of stability (dynamic equilibrium), is significant. It tends to corroborate the original basis for the model - that the physical processes selected control, to a significant degree, the phenomena of channel narrowing and woodland expansion of the Platte River system. It also indicates that the CHANWID model can be used to predict future channel changes under future flow scenarios.

Figure E.1

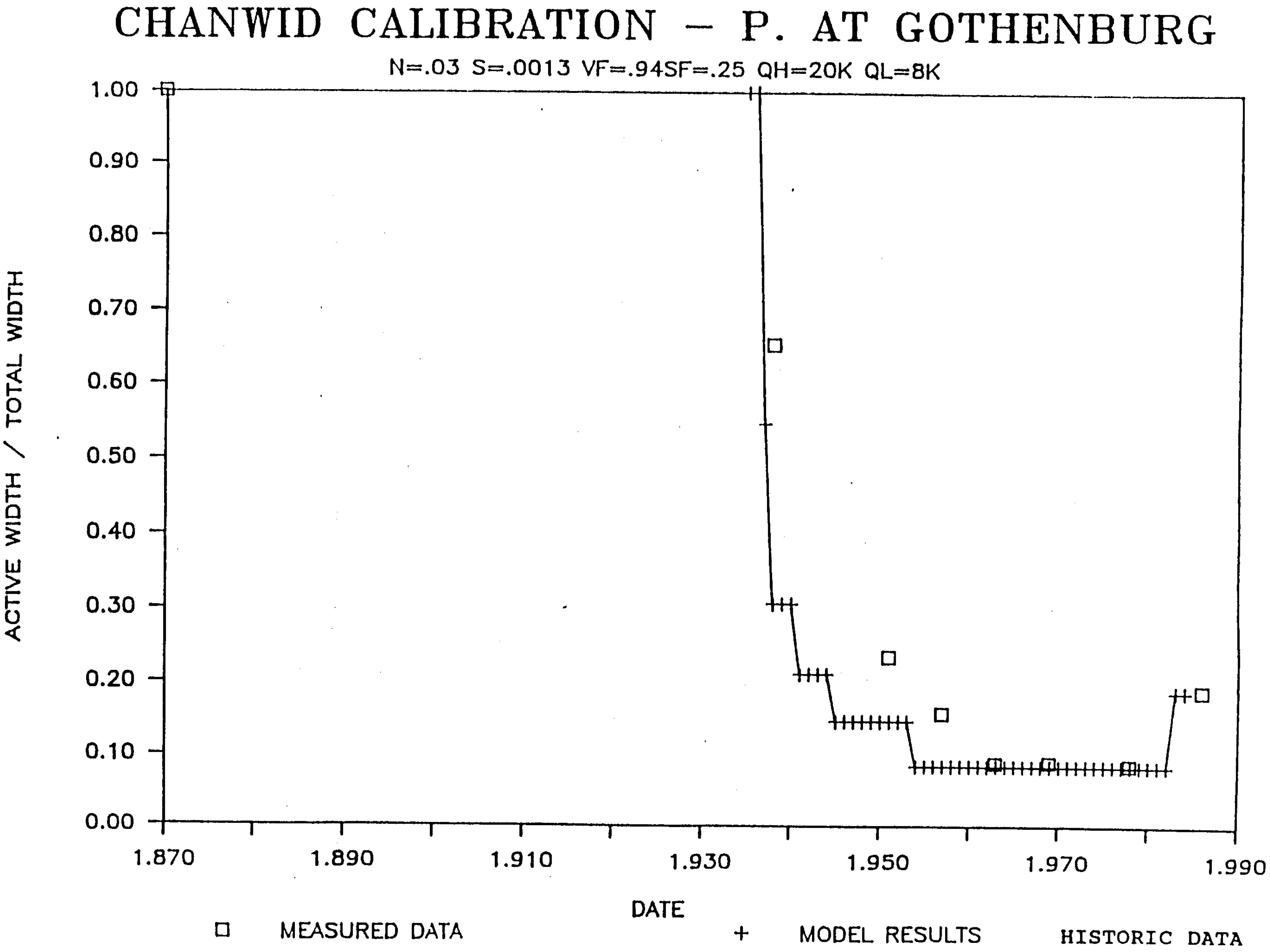


FIGURE 3.1

APPENDIX F

Structures

3.1 South Platte River. Bank protection measures at 32 locations consisting of 43 structures were noted for the 22-mile reach of the South Platte River. Included are three bridges and one dredge-fill area. Structures placed along the eroding bankline parallel to the flow constitute the majority of the structures with a total of 20. The remaining structures deflect current away from eroding banks (jetties, hardpoints, etc.), or are a combination of jetties and revetments. The median length for the 15 jetty structures is 75 feet. The prevalent material type used in the bank protection structures is broken concrete (24 cases), followed by used automobiles (13 cases). Trees, wood, steel, tires and asphalt are the other materials used (12 cases). Asphalt was found in three structures. All but one of the existing structures are located along the outer banks, and there are no chute closures in the reach. More of the structures provide protection to adjacent transportation facilities than for any other single use. Dry or irrigated agricultural land and pasture account for 40 percent of the adjacent land use. Eight farmsteads are protected by structures in this reach.

3.2 North Platte River. Thirteen revetments, three bridges, six hardpoints, three chute closures, and one diversion dam were documented on the lower 11 miles of the North Platte River. These 25 structures are located at 19 sites. Revetments in the reach average nearly 200 feet in length. Hardpoint length averages 50 feet. Except for chute closures, all of the structures are located on the outer banks of the river. Identified adjacent land use includes pasture and transportation (six sites each), four farmsteads, parks (three sites), and irrigation works. Banks sparsely vegetated with grasses are most common in eroding areas, while grassed banks interspersed with hardwoods are the norm throughout the reach. Broken concrete was the most frequently identified material, found in 10 instances. Junkpiles, wood, trees and bridges account for an additional 12 sites. Asphalt was found in two structures. Active erosion at 7 of the 19 sites was noted.

3.3 Platte River Mile 310.5 to 281.0. Sixty-seven structures at 34 sites were observed in the upper 30 miles of the Platte River. Of these, 27 are revetments, 3 are bridges, 3 are chute closures, 2 are diversion dams, and 1 is a levee. There are also 28 hardpoints at 8 sites. Only one of the structures is permitted. Broken concrete is used in 20 sites that account for 30,015 feet of the 45,665 total feet of protection. Junkpiles and car bodies account for another 15 sites. Earth of the material types listed are used in at least one structure in the reach. Asphalt was found at two sites. Identified bankline conditions were evenly distributed among all types (dear, mostly dear with some grass, mostly grass, grass with some woody, mature hardwood, willow/cottonwood, tree and heavy brush, and other). Active erosion is occurring at 17 of the sites. Facilities of one type or another were identified as the adjacent land use in twenty-two cases, while agricultural uses were identified in an equal number of cases.

3.4 Platte River Mile 281.0 to 215.0. At 83 sites in this reach, 114 structures were documented during field investigations. Total structure length in the reach is 84,336 feet.

There are 70 revetments and 19 hardpoint or jetty structures. Ten bridge crossings, six chute closures, and one diversion dam are located within the reach. The remainder of the structures does not fit into a category, or are levees.

Broken concrete is used in 54 structures that account for nearly 80 percent of the total structure length. Used car bodies are the second most common material type, found in 22 structures. On a percentage basis, this reach has the fewest number of structures containing what is normally considered junk or refuse. There are 31 farmsteads in the reach that are protected by structures. Twenty-six structures protect adjacent transportation facilities, and pasture is the adjacent land use at 24 sites. The remaining 29 identified land uses are primarily agricultural in nature. Two bank types, sparse grass and grass with some mature trees, were identified as the bank type in over 60 percent of the cases. Each of the eight bank types is found in at least two instances.