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Platte River Whooping Crane Maintenance Trust

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WOODY VEGETATION EXPANSION AND CONTINUING DECLINES IN OPEN CHANNEL HABITAT ON THE PLATTE RIVER IN NEBRASKA

PAUL J. CURRIER, Platte River Whooping Crane Maintenance Trust, 2550 Diers Ave., Suite H, Grand Island, NE 68803, USA

Abstract: Aerial videography in 1988 and 1994 of the same selected segments of the Big Bend reach of the Platte River in central Nebraska was compared. During this 6-year period, channel area declined 4 to 41% (median 26%). In river segments where the channel had already narrowed significantly and at sites where channel habitat is actively managed declines were less (17-18%). These substantial changes occurred during a time that included a relatively low flow period (1990-92). Flows during the summer germination and establishment period (mid-May through August) for cottonwood (*Populus deltoides*) and willow (*Salix* spp.), the primary woody species, were less than 17 m^3/second 64% of the time during the period and less than 3 m^3/second 25% of the time in 1990 and 1991. Such low flows allowed extensive exposure of the riverbed where germination could occur. Peak scouring and ice flows were also low, remaining below 80 m^3/second throughout 1990-92 except for a few days in May 1991. Because the expanding vegetation recorded in this study had grown to an advanced stage, it most likely became permanently established. Furthermore, high flows in the 340-450 m^3/second range, which occurred in June and July 1995, were effective in removing only a fraction of the newly developed growth.

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Key words: aerial videography, cottonwood, crane roosting, flow management, *Grus americana*, *Grus canadensis*, habitat declines, open channel, Platte River, *Populus deltoides*, *Salix* spp., sandhill crane, whooping crane, willow, woody vegetation.

Each spring, more than 400,000 sandhill cranes (*Grus canadensis*) stage on the Big Bend reach of the Platte River in central Nebraska for a month or more while en route to nesting grounds in Canada, Alaska, and Siberia. At night the cranes roost in shallow, open channels of the river (Sidle et al. 1993). Daytime hours are spent feeding on waste grain in croplands, and resting and foraging in wet meadows near the river channel. Endangered whooping cranes (*G. americana*) also migrate through the central Platte each spring and fall, but they normally stay for only 1 or 2 days. Critical habitat has been designated for the whooping crane along the Platte between Lexington and Shelton (43 Federal Register 94:20938-20942, 1978). Open channel roost habitat for sandhill cranes and whooping cranes on the Platte River has been declining (Currier et al. 1985, Sidle et al. 1989, McDonald and Sidle 1992, Faanes and LeValley 1993) for decades. As peak and mean annual flows have been reduced, the channel has narrowed and become vegetated with woodland and herbaceous islands. Diversions for irrigation and power generation have been primarily responsible for the reduced flows that allowed woodland expansion and island development in the river channel (Williams 1978, Eschner et al. 1981, Currier 1982, Currier et al. 1985, Peake et al. 1985, Johnson 1994). Flow depletions, particularly reductions in peak or pulse flows, have effectively narrowed the streambed and allowed woody vegetation development on former active channels.

Sidle et al. (1989) concluded that 80% or more of the 1860's (pre-development) floodplain channel area had filled with trees along extensive reaches of the Platte and North Platte rivers. Cranes had virtually abandoned some river segments, particularly between North Platte and the J-2 return near Overton (Currier et al. 1985, Faanes and LeValley 1993). Substantial channel narrowing had also occurred in the downstream habitat reaches between Overton and Chapman (Currier et al. 1985, Sidle et al. 1989, Johnson 1994). However, the remaining open-channel areas within this reach (particularly between Kearney and Chapman) continued to provide important migratory habitat for cranes (U.S. Fish and Wildlife Service 1981, Krapu et al. 1982, Krapu et al. 1984, Currier et al. 1985) (Fig. 1). Open channels and mid-river sandbars also provide habitat for other migratory birds, including summer-nesting least terns (*Sterna antillarum*) and piping plovers (*Charadrius melodus*), waterfowl, shorebirds, bald eagles (*Haliaeetus leucocephalus*), and American white pelicans (*Pelecanus erythrorhynchus*) (Currier et al. 1985, Ziewitz et al. 1992).

Faanes and LeValley (1993) documented a significant shift in sandhill crane populations in response to these habitat changes. In 1957, 60% of the crane population was centered in the Lexington to Kearney reach, but by the late 1980's only 5% of the population was using that area. Downstream in the Kearney to Chapman segment, however, crane use increased from 9% to 80% of the population between 1957 and 1989. Shifts in whooping crane use of the river also followed these patterns (Faanes and LeValley 1993). The highest concentrations of sandhill cranes on the river are now between Wood River and Chapman (708 cranes/km on average), where the widest unobstructed channels remain (mean maximum width of 216 m) and there are abundant wet meadows (108 ha/river km). A combination of wet meadow loss and declines in open river channels has led to

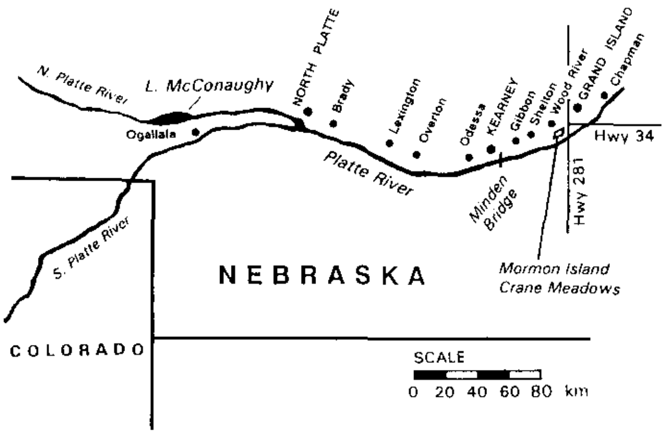

Fig. 1. Big Bend reach of the Platte River in central Nebraska. River segments examined in the study were near Gibbon and Shelton, and in a 24-km reach between Wood River and Chapman.

these shifts in crane distribution, and suitable roosting habitat is currently limited on the river (Faanes and LeValley 1993, Sidle et al. 1993).

Channel Stability and Narrowing

Declines in open channel habitat and shifts in crane populations have long been recognized; however, there has been debate about the specific causes of woodland expansion, and whether such expansion has reached a "steady-state" or "quasi-equilibrium" (Lyons and Randle 1988, CNPPID and NPPD 1990, Currier et al. 1990, Johnson 1994). In such an equilibrium, sediment inputs and outputs in a given river reach would be nearly equal, and overall channel widths would be expected to remain relatively stable in a condition of self-regulation.

Channel narrowing appears to have reached such an equilibrium in the upper stretches of the river between Brady and Overton (Lyons and Randle 1988). In the Big Bend reach between Overton and Grand Island, however, even though sand loads appeared to be in a quasi-equilibrium, width adjustments continued through 1983, and "future adjustments in channel width" were thought possible in the downstream portion of this reach (Lyons and Randle 1988). Additional narrowing was predicted where the widest channels remain. Although CNPPID and NPPD (1990) and Johnson (1994) agreed that extensive channel narrowing occurred as a result of water development, they suggested that the last major episodes of narrowing occurred in the 1960's. In the near term, they predicted that channel and woodland area would remain in a steady state. Currier et al. (1990) provided an alternative view that substantial channel narrowing was continuing in some reaches, noting that CNPPID's and NPPD's own studies (CNPPID and NPPD 1990) indicated considerable woody seedling recruitment and survival had occurred in recent years. Furthermore, the studies by CNPPID and NPPD (1990) and Johnson (1994) excluded a 48-km downstream reach of the river (Wood River to Chapman) which had wide channels and was used extensively by roosting cranes.

Cottonwood and Willow Establishment

Cottonwood and willow trees establish on the Platte and in other riverine systems under a narrow set of environmental conditions (Moss 1938; McVaugh 1947; Kapustka 1972; McLeod and McPherson 1973; Currier 1982, 1986). Weather and flow patterns play a major role in establishment because they affect the length of the growing season, the timing of seed release, the distribution of seeds, and the availability of suitable germination and establishment sites. Along the Platte, the short-lived seeds of cottonwood and willow are released, germinate, and establish seedlings in mid-May through July, mostly on the exposed sandy riverbed as spring flows recede. When seeds land or are washed onto exposed, generally unvegetated sandbars, germination can occur followed by seedling establishment if the site remains moist for 2–3 weeks (Currier 1982, O'Brien and Currier 1987, Johnson 1994).

Cottonwood and willow are pioneering species that are well adapted to the variability of the environment on flood-plains. They produce huge numbers of seeds (up to 650,000 per tree, Kapustka 1972), time their seed dispersal to coincide with the availability of suitable conditions for establishment, have high germinability (80–90%), and grow very rapidly. These species can reproduce vegetatively (particularly after physical damage), and their seedlings are tolerant of flooding, drought, sedimentation, soil saturation, and low soil fertility (Currier 1982, Johnson 1994). During their first year, mid-summer fluctuating flows can bury or scour seedlings from the riverbed, and drought can eliminate seedlings through desiccation. Generally, the earlier in the season the Platte riverbed is exposed, and the longer the riverbed remains at low flows, the greater the potential for extensive seedling germination, survival, and establishment (Currier 1982, Johnson 1994). Earlier riverbed exposure allows seedlings to grow large enough to resist moderate flow fluctuations and droughts. Cooler, wetter growing seasons and limited mid-summer flow fluctuations provide the best conditions for survival. However, subsequent high flow events during winter and late spring can remove substantial numbers of seedlings (Johnson 1994). Beyond the first year, seedlings become more and more resistant to removal by flow events (Currier et al. 1990, Johnson 1994).

During a high water period in the 1970's and mid-1980's, vegetation expansion slowed on the river (Currier et al. 1990, McDonald and Sidle 1992, Johnson 1994). However, widespread woody seedling establishment was noted during a drought in the late 1980's and early 1990's, particularly on the main channel of the river in the Wood River to Chapman reach (Currier et al. 1990). The extent of this open-channel vegetation expansion was examined in this paper for the period 1988-94 in selected segments of the river channel. Hydrologic conditions under which these changes occurred and the potential for scouring flows and mechanical clearing to remove these newly vegetated sites was investigated.

The author appreciates the generous contributions to this study by J. Sidle, who piloted the flights, and the U.S. Fish and Wildlife Service, Grand Island, Nebraska, for providing the camera and computer equipment needed to acquire and print the aerial video images. Thanks also to J. Sidle, G. Lingle, D. Carlson, B. Goldowitz, J. O'Brien, and J. Echeverria for their critical reviews of this manuscript. B. Goldowitz and B. Harvey provided valuable assistance with statistical analyses.

METHODS

Aerial videography taken on 5 July 1988 and 10 June 1994 was used to compare woodland development and island stabilization on the Platte River channel by methodologies described in Sidle and Ziewitz (1990). Depending upon the camera lens in use, videos were flown at 500-800 m above the ground surface. The videos from both years had approximately the same ground coverage. Although river discharge was not identical during the 2 periods, flows were similar enough and low enough that major islands and well established vegetation (cottonwoods and willows at heights of 1.5-3.0 m) were clearly distinguishable during both 1988 and 1994. Flows at Overton were 27 m^3/second and 25 m^3/second in 1988 and 1994, respectively, when the videography was taken, while flows at Grand Island were 49 m^3/second and 38 m^3/second in the 2 years. Videography was taken in both years following relatively high spring flows which precluded the presence of widespread annual vegetation during the sampling periods.

Differences in perennial vegetation and channel area were noted by comparing the percentages of these 2 cover types in the 2 years. Percentage channel area changes were statistically analyzed with a 2-tailed t-test to compare differences in mechanically cleared and uncleared sites and to examine area changes in relation to the extent of channel narrowing that had occurred prior to 1988. River flows during the 1988 to 1994 period were examined to investigate potential causes for vegetation expansion. Changes in channel width were assessed in addition to channel area because cranes generally avoid roosting near islands or banks with vegetation a meter or more in height (U.S. Fish and Wildlife 1981, Krapu et al. 1984). As a measure of changes in view from a crane roost, the width of the widest unobstructed channel was measured on the video images along 20 cross-river transects at each site (i.e., the single, widest channel bounded by banks or vegetated islands >1 m in height was measured on each transect). An index of unobstructed width was constructed by expressing the width of these widest channels as a percentage of the total open channel width present in 1988 (i.e., the sum of all channels on a transect). Percentage widths were averaged for each site and compared between the 2 time periods.

Study Segments

Eleven 0.8-km river segments, located between Kearney and Chapman, were examined. Two sites were selected near Gibbon and Shelton, but the majority were located in a downstream, 24-km reach of the river from west of Highway 281 (south of Grand Island) to the Highway 34 bridge east of Grand Island. Study locations were chosen primarily because of their high use by roosting cranes, a lack of disturbance, and the availability of comparable video images from the 2 time periods. The Trust and other groups have attempted to physically maintain open channel habitat in a number of areas including Audubon's Rowe Sanctuary (Minden to Gibbon bridges) and at Mormon Island Crane Meadows (upstream of the Highway 281 bridge). Sampling was avoided in these river reaches because of the disturbance from clearing, but 2 sites near Mormon Island (river miles 177 and 175) were chosen in order to examine the difference between "natural" vegetation and island development and progression on a managed site. Heavily vegetated river segments were also avoided because they had already extensively narrowed and, in some cases, cranes had abandoned or reduced their use of such areas (Faanes and LeValley 1993). A segment near Shelton (river mile 196) and another near Highway 34 (river mile 169), where substantial channel narrowing had already taken place, were included in the analysis.

RESULTS

Substantial island and woody vegetation expansion occurred on the Platte between 1988 and 1994 (Figs. 2-4). Newly formed islands were generally colonized by trees in the same year; consequently, by 1994 the majority (≥90%) were dominated by even-aged stands of 1.5- to 3.0-m-tall cottonwoods and willows (Fig. 2). Although some woody

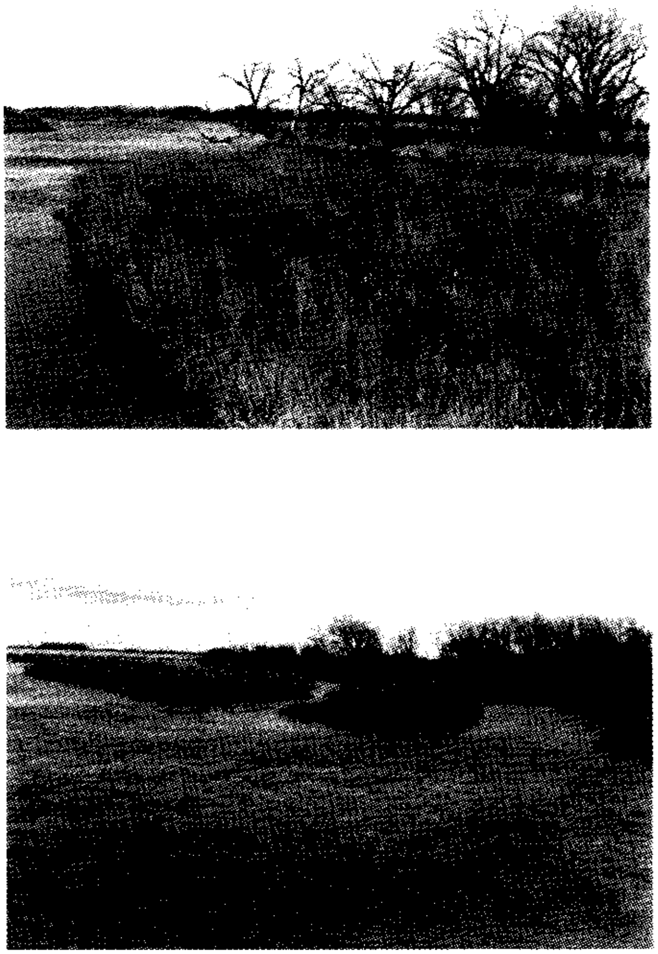

Fig. 2. Recent (1988–94) island development in the Platte River near Grand Island, Nebraska (river miles 173 and 172). Photos (January 1995) are upstream (top) and downstream (bottom) of the South Locust bridge.

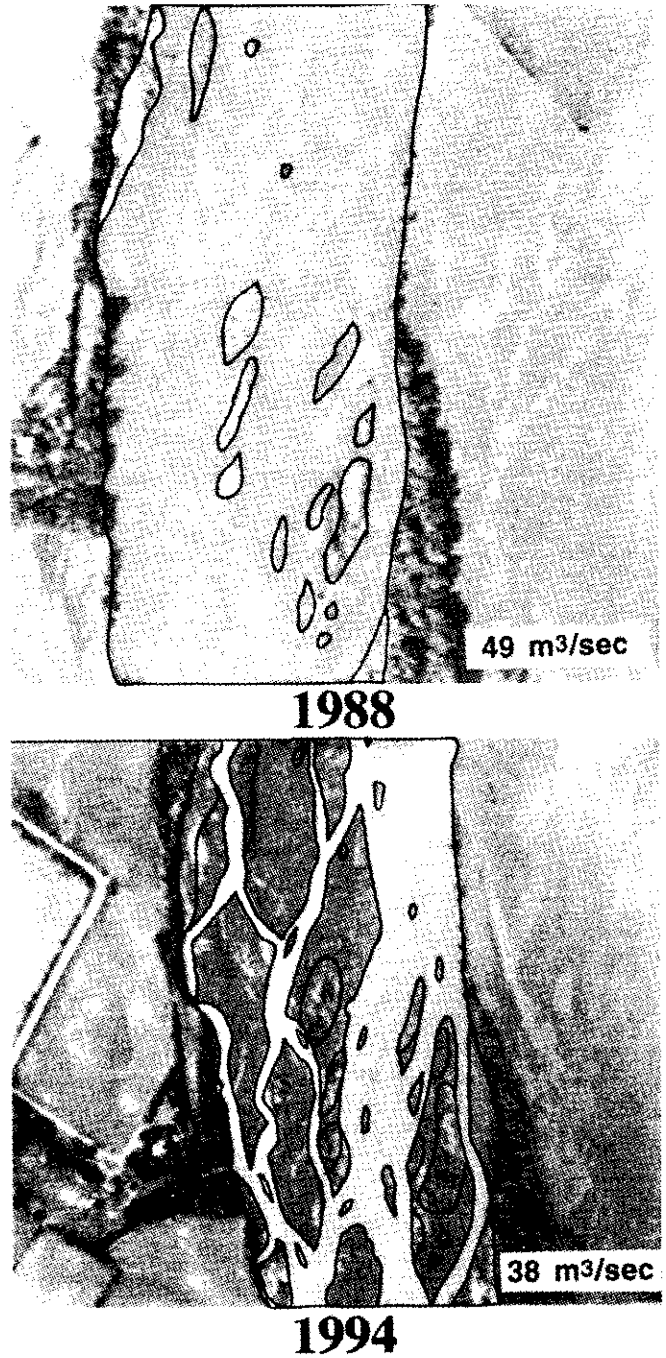

Fig. 3. Aerial videography comparisons of the river channel at river mile 171.5, 1.6 km below I-80 Bridge, near Grand Island, Nebraska. Open channel area declined by 41% in this segment during the 1988–94 period. Island subdivisions marked on the 1994 image represent portions of the channel that were vegetated in 1988. Flows measured at Grand Island.

seedlings most likely developed annually between 1988 and the spring of 1994, many of these seedlings did not survive over the long-term (Johnson 1994). A major episode of successful recruitment, however, was noted during the summer of 1990 (Currier et al. 1990), and to a lesser extent in the summer of 1991 (P. Currier, pers. observ.). These seedlings were able to survive the summer and the following winter, stabilized exposed sandbars, and eventually allowed new islands to develop.

None of the channels examined increased in channel area or width between 1988 and 1994. The percentage cover of open, active channels, and vegetated islands and banks in the 2 sampling periods is summarized in Table 1. In comparison to 1988, open channel declines generally ranged from 16% to 41% in the segments studied, with a median decline of 26%. One exception was the most downstream segment near the Highway 34 Bridge (river mile 168), which showed a

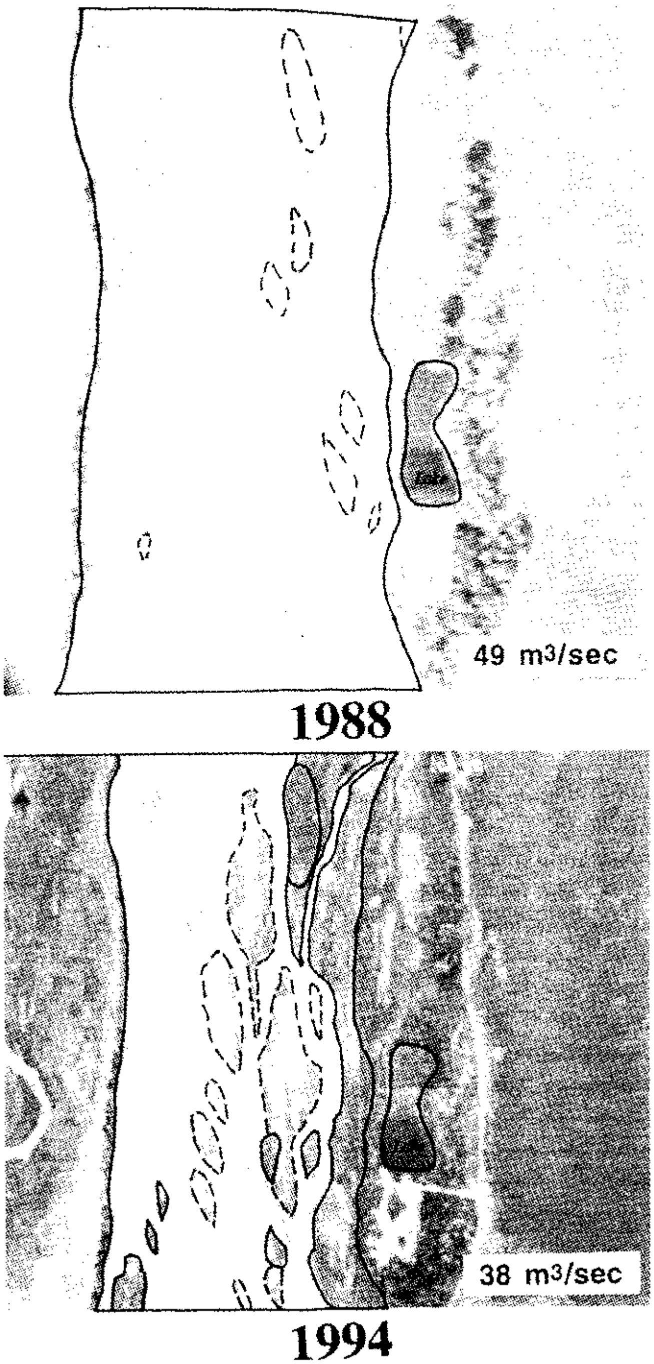

Fig. 4. Aerial videography at Mormon Island Crane Meadows, Nebraska, river mile 177. Dashed lines indicate cleared islands remaining in part of the active channel; solid lines indicate stabilized areas. Channel area declined 17.7% between 1988 and 1994. Flows measured at Grand Island.

relatively small decline of only 4%.

In the segments located 1.6 km above Highway 34 (river mile 169) and near Shelton (river mile 196.7), a substantial portion of the river channel (28% and 30%, respectively) had already narrowed prior to 1988. The 16.8% mean decline in channel area in these segments (river miles 169 and 196.7, $n = 2$) was significantly lower than in the other segments ($\bar{x}$ = 27.6%, $n = 9$) ($t = -2.911$, $P = 0.0195$).

At sites where the channel had been managed by clearing woody growth (river miles 175 and 177), declines in channel area were also lower, but still averaged 19.6% ($n = 2$) and were not statistically different from the remaining unmanaged sites ($\bar{x}$ = 29.0%, $n = 6$) ($t = -1.609$, $P = 0.1588$) (Table 1). Three sites were omitted from the analysis because of the artificial constriction of the channel at mile 168 and substantial prior narrowing in segments 169 and 196.7. At Mormon Island Crane Meadows (river mile 177), the entire width of the channel was cleared and disked on a nearly annual basis between 1982 and 1995. The majority of channel loss at the site was due to island extension along the northern riverbank (Fig. 4). Potential channel losses without clearing were estimated at 34-36%, or about 15% greater than with clearing (Table 1).

Maximum unobstructed channel width (i.e., visibility across the channel) also declined in most segments as vegetation expanded (Table 2). An index of unobstructed width, a measure of the quality of habitat for roosting cranes, was expressed as a percentage of the total channel width in 1988. Except for the Highway 34 Bridge segment (river mile 168), where channel losses were minimal, and the Shelton segment (river mile 196.7), where substantial narrowing had previously occurred, unobstructed width declines were greater than channel area losses. Even though the extent of woody island development was in some cases relatively small, the presence of woody vegetation on islands in the middle of wide-channel areas significantly reduced visibility from the channel. In the Gibbon reach (river mile 201), for example, channel losses were only half (26%) of the 51% decline in unobstructed width. In much narrower reaches, such as Shelton, unobstructed width declines were actually less than overall channel area declines (a loss of 6% compared to 17%).

DISCUSSION

Vegetation Expansion

The channel changes observed between 1988 and 1994 varied depending upon segment location, river management, and the extent of previous channel narrowing. The smallest change, a 4% decline in channel area at the Highway 34 Bridge (river mile 168) occurred in an area where the channel was constricted by concrete rip-rap along the banks. In areas where mechanical clearing was used, channel

Table 1. Percentage of open channel and vegetated island habitat area in selected segments of the Platte River between Kearney and Grand Island, Nebraska, 1988 and 1994. Each segment represents approximately 0.8 km of river channel.

Segment	Open channel 1988	Open channel 1994	Vegetated islands 1988	Vegetated islands 1994	% change in open channel 1988-94
Highway 34 Bridge (mile 168)	80.6	76.5	19.4	23.5	-4.1
1.6 km above Highway 34 (mile 169)	72.5	56.1	27.5	43.9	-16.4[a]
1.6 km below I-80 (mile 171.5)	91.4	50.1	8.6	49.9	-41.3
I-80 (mile 172.6)	95.5	72.1	4.5	27.9	-23.4
South Locust St. (mile 173)	98.7	71.8	1.3	28.2	-26.9
Hannon's Bridge (mile 174.3)	96.4	60.9	3.6	39.1	-35.5
Highway 281 (mile 175.3)	95.8	74.4[b]	4.2	25.6	-21.4[c]
(without clearing)		(59.4)	(40.6)		(-36.4)
Mormon Island (mile 177)	97.0	79.3[b]	3.0	20.7	-17.7[c]
(without clearing)		(63.4)	(36.6)		(-33.6)
1.6 mile above Shelton (mile 196.7)	70.1	52.9	29.9	47.1[d]	-17.2[a]
1.6 km below Gibbon (mile 201)	97.5	71.8	2.5	28.2	-25.7
Kearney Hike/Bike Trail (mile 209.8)	85.9	64.8	14.1	35.2	-21.1

[a] Segments with substantial narrowing prior to 1988.
[b] Includes cleared areas remaining in active channel.
[c] Channel changes adjusted for clearing.
[d] Includes 0.2% loss (erosion) of islands.

narrowing was also less severe and averaged about 15% less than at uncleared sites. Clearing and disking destabilized many of the islands at Mormon Island (river mile 177), but a number of permanent islands still formed at this site during the 1988-94 period (Fig. 4).

At Shelton and 1.6 km above Highway 34, much of the channel had already narrowed prior to 1988. Additional channel losses averaged 17% in these segments and were statistically lower than the declines at the remaining sites (Table 1). Because large areas of the channel had already filled with vegetated islands, fewer areas were available for additional recruitment. Island extension and attachment to neighboring islands (Eschner et al. 1981) were responsible for much of the additional decline. In more open segments, the majority of channel narrowing occurred as new mid-channel islands (Fig. 3).

The growth forms of cottonwood and willow make them particularly adapted to the gradual sedimentation process that occurs when river islands build. With each layer of sediment deposition, these species are able to form adventitious roots and continue to grow, effectively trapping sediment and stabilizing islands. As flows over-top the islands, additional sediment is deposited, aided by the increased surface roughness of the vegetation (Hupp 1992). Without moderate scouring flows to remove young seedlings and islands, the sedimentation process eventually leads to the development of permanent river features.

The expansion of woody vegetation during the 1988-94 period was primarily the result of low summer flows and relatively low pulse flows during the following winters and springs (Fig. 5). Low summer flows exposed extensive areas of the riverbed where successful recruitment could occur, while subsequent winter and spring flows were insufficient to provide the scouring, ice-flows, or riverbed "restructuring" needed to remove the previous summer's seedlings. From 1988 to 1994, flows during the cottonwood and willow seedling germination and establishment period (mid-May through August) were less than 17 m^3/second 64% of the time. In 1990 and 1991, summer flows were even lower, with discharges less than 3 m^3/second occurring 25% of the time.

To illustrate the potential for recruitment in high and low flow periods, I compared flows during the seedling germination period, 1983-87, when little recruitment was observed, and 1988-92, when more than 50% of the active riverbed was covered with new seedlings (Currier et al. 1990, Johnson 1994, P. Currier, unpubl. data). During the germination period, there were more than 3 times as many days in 1988-92 (436 days) when flows were less than 23 m^3/second than in the 1983-87 period (130 days). At flows of 0-11 m^3/second, the difference was even greater, more than 8 times the number of low flow days occurring in the 1988-92 period. Increased exposure of the riverbed in 1988-92 provided ample opportunity for seedling germination and establishment.

The large recruitment of seedlings in 1990 and 1991

Table 2. Index of unobstructed channel width in selected segments of the Platte River, Nebraska, in 1988 and 1994. Numbers represent the maximum unobstructed width of the river as a percentage of total channel width in 1988. Measurements from 20 transects at each river segment were averaged to arrive at the index values.

Segment	Percent $\bar{x}$ max. unobstructed channel width 1988	Percent $\bar{x}$ max. unobstructed channel width 1994	% change in open width (1988-94)
Highway 34 Bridge (mile 168)	65	65	0
1.6 km above Highway 34 (mile 169)	56	39	-17
1.6 km below I-80 (mile 171.5)	77	33	-44
I-80 (mile 172.6)	94	51	-43
South Locust St. (mile 173)	96	59	-37
Hannon's Bridge (mile 174.3)	82	35	-47
Highway 281 (mile 175.3)	91[a]	53	-38
Mormon Island (mile 177)	100[a]	76	-24
1.6 km above Shelton (mile 196.7)	28	22[b]	-6
1.6 km below Gibbon (mile 201)	90	39	-51
Kearney Hike/Bike Trail (mile 209.8)	63	39	-24

[a] Includes cleared areas remaining in active channel.
[b] Includes 0.2% loss (erosion) of islands.

(Currier 1990, pers. observ.), combined with reduced winter and spring mortality, most likely accounted for the majority of the vegetation expansion observed in this study. Throughout the 1990-92 period when widespread seedling recruitment was occurring, winter ice-flows and spring scouring flows remained below 79 m^3/second, except for a short period in May 1991 when flows reached nearly 142 m^3/second. As a result, little removal of seedlings occurred during the winter and spring of these years, a period when seedling mortality is normally relatively high (Johnson 1994).

In contrast, during 1988, 1989, and 1992, much of the riverbed was exposed quite early (April-May), providing an opportunity for widespread recruitment, but mid-summer fluctuating flows most likely eliminated many seedlings (Johnson 1994). In addition, spring flows of 221 to 326 m^3/second in 1993, resulted in an estimated loss of 20-25% of the seedlings and young trees that had developed during the previous 3 years in the Wood River to Chapman reach (P. Currier, pers. observ.). However, 75% or more of the new growth remained. As time has advanced, these remaining woody seedlings have grown, further stabilizing islands, and making it less likely that they will be removed except by exceptionally high flow events (Currier et al. 1990, Johnson 1994).

This interpretation of vegetation expansion is consistent with detailed woody seedling demography studies conducted

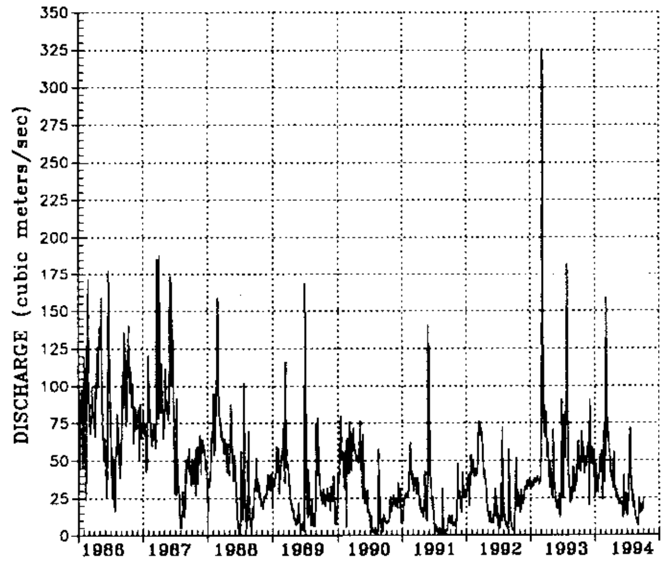

Fig. 5. Hydrograph of the Platte River at Grand Island, Nebraska, 1986-94. Extensive woody seedling recruitment and establishment occurred in mid-summer 1990 and 1991 during low flows. Higher flows in 1993-94 were not sufficient to remove much of the new vegetative growth.

by Johnson (1994) on various segments of the Platte. He observed increased recruitment and survival of tree seedlings during the 1988-92 drought, and concluded that this had led to the establishment of relatively permanent vegetation in areas of the channel that had been unvegetated in 1985-88. Johnson also found an inverse relationship between mean June flow and seedling recruitment, suggesting that extensive seedling development can occur whenever mean June flows are less than 79 m^3/second. Low flows below 79 m^3/second provided ample areas for colonization, and also allowed for rapid seedling growth and potentially higher seedling survival.

High summer flows, on the other hand, covered the unvegetated riverbed, and generally precluded seedling recruitment or were responsible for eroding young germinants (Johnson 1994). Of course, the extent of riverbed exposure is a function of the low flows that are averaged in the June mean. The pattern of June flows (i.e., when peaks occur and how rapidly they decline) is an important determinant of recruitment as well. Johnson (1994) also identified a combination of winter ice cover and relatively high base flows as a seedling removal mechanism. Highest seedling survival occurred when flows were less than 75-85 m^3/second. Likewise, summertime peak flows of 125-225 m^3/second were quite effective in scouring young seedlings, but they were generally ineffective in removing 1-year-old or older trees. Finally, high spring peaks (170-225 m^3/sec) were also found effective in removing the previous year's seedlings, but flows in this range do not occur with great regularity (Johnson 1994).

Table 3 shows the June and July means, and winter-spring peak flows that occurred in 1988-94. Woody tree seedling response in these years was generally consistent with the flow ranges identified by Johnson (1994). Based on Johnson's (1994) criteria, seedling recruitment should have been high in all the years between 1988 and 1993, as June mean flows were less than 79 m^3/second. However, at the end of June in 1989, flows were quite high (128 m^3/sec average during the last 5 days of the month), and undoubtedly most seedling establishment was precluded. In addition, mean July flows may also be an indictor of widespread seedling recruitment and establishment. For instance, during 1990 and 1991, low mean flows in July signaled an extended opportunity for recruitment in 1990 and 1991 (longest extended exposure of the riverbed). Mean July flows in other years were considerably below the 125-225 m^3/second level Johnson (1994) identified for mid-summer removal of young seedlings. These flows, however, were sufficient to substantially inundate the riverbed, limiting opportunities for seedling establishment and survival (e.g., flows of 22-81 m^3/sec, including nearly bank-to-bank inundation in 1993). Winter peak flows in 1988, 1989, 1992, and 1993 also exceeded Johnson's (1994) 75-85 m^3/second criteria associated with higher mortality. The lower winter flows in 1990 and 1991 (62 m^3/sec and 76 m^3/sec, respectively), on the other hand, limited extensive overwinter losses and allowed substantial seedling survival into the next growing season.

Table 3. Mean June, mean July, and following winter flows (maximum pulse or ice flows) at Grand Island, Nebraska, during the 1988-94 period when extensive woody vegetation expansion occurred in downstream reaches of the Platte River channel.

Seedling year	$\bar{x}$ June flow (m^3/sec)	$\bar{x}$ July flow (m^3/sec)	Winter max. flow (m^3/sec) (after Jan-Mar)
1988	15	32	116
1989	27[a]	34	79
1990	19[b]	4.1	62
1991	39[c]	3.7	76
1992	16[d]	22	325
1993	31	81	218

[a] 128 m^3/sec last 5 days.
[b] 14 m^3/sec last 15 days.
[c] 18 m^3/sec last 15 days.
[d] 14 m^3/sec last 15 days.

Long-term Trends in Channel Stability

The 16% to 41% channel reductions identified in this study represent a continuation of long-term trends in vegetation expansion and channel narrowing. The river appears to be continuing its upstream to downstream (west to east) progression from a wide, open-channel braided form towards a series of highly anabranched channels running between stabilized wooded islands (Eschner et al. 1981, O'Brien and Currier 1987, Sidle et al. 1989, Johnson 1994). Although the present analysis was primarily limited to the downstream portion of the Big Bend reach (Wood River to Chapman), it demonstrates that rapid vegetation expansion is continuing in the widest remaining channels of the river. Until recently, these braided segments had maintained 60% to 70% of their 1938 widths (Peake et al. 1985). Even in already highly vegetated and narrowed segments of the river channel, continued narrowing may occur, although most likely at a reduced rate.

The relatively large reductions in active channel between 1988 and 1994 support the view that the river has not yet reached a steady-state equilibrium. This is consistent with Lyons and Randle's (1988) findings that additional channel adjustments were possible in the Odessa to Grand Island reach. Although sediment loads in this reach appear to be in balance, channel morphology has most likely not adjusted completely, particularly in the downstream Wood River to Chapman reach. Furthermore, it is questionable whether upstream and downstream sediment loads are actually in balance. Because Lyons and Randle (1988) used the same discharge rating curves at both the upstream and downstream stations, their "balanced" sediment loads may simply reflect the rating curves, rather than an indication of the true sediment supply.

CNPPID and NPPD's (1990) and Johnson's (1994) conclusions that channel narrowing has essentially ceased and that the river is now in a stable-channel equilibrium are not supported by the channel changes identified in this study. Johnson (1994), as well, recognized additional permanent vegetation development on the river during the 1988-94 drought. Because the CNPPID and NPPD (1990) and Johnson (1994) studies were begun in the mid-1980's, they primarily reflect the limited channel narrowing that occurred during several high flow periods in the 1970's and 1980's. As a result, they concluded that major changes in channel adjustments had ceased. Not until a low flow drought occurred in the late 1980's and early 1990's did another major episode of vegetation expansion occur. Their studies also ignored the area of most rapid channel change (downstream of Wood River) highlighted in this paper.

CNPPID and NPPD (1990) and Johnson (1994) did predict that some additional changes in channel vegetation and narrowing would occur in the steady-state condition.

Under their model, the channel would tend to expand and contract in response to annual fluctuations in flows, but in the long run the prediction was that overall width of the channel would remain relatively steady. This interpretation has some validity in relation to river segments that have already narrowed significantly (e.g., channels in the upstream Brady-Cozad reach that average less than 25% of their historical width). Such channels have adjusted to the increased vegetation by maintaining a more U-shaped or canal-like cross-section. The steady-state theory does not seem to apply, however, to the remaining wide, flat, and braided channels in the river. The extent of recent vegetation expansion in these reaches, the compressed time period over which it occurred (a 2–3 year episode of narrowing), and the advanced stage of growth (some trees >5 years old) suggest that major permanent adjustments in channel width could still occur.

Some of the 1988–94 vegetative growth could eventually be removed by high flows. Flows in the spring of 1993, for example, were high enough (325 m^3/sec) to remove 20–25% of the 2- to 3-year-old seedlings that were present (P. Currier, pers. observ.). High flows on the North Platte River (McDonald and Sidle 1992) and on the Platte (Carlson 1987, Johnson 1994) have reportedly resulted in channel widening. Johnson (1994) noted that highly narrowed channels on the Platte (≤30% of historic width) increased by 4% to 8% as a result of high flows in 1983–84 (565 to 700 m^3/sec), but that widening on broader channels was limited to only 1–2%. A 10–15% increase in channel width was reported by Carlson (1987), however, for the same flow event. Based on these observations during 1983–84 and during a recent high flow in 1995, it seems unlikely that flows will eliminate all of the new 1988–94 vegetative growth. The infrequency of flood events (flows in 1983 were a 40-year high; those in 1995 were the highest in 12 years), and the extent and rapid growth of the newly established vegetation suggest that the long-term trend on the central Platte is still a net loss of open channel habitat.

As Faanes and LeValley (1993) found, many severely narrowed segments have already been abandoned by cranes because they no longer provide suitable roosting habitat. Although cranes prefer wide, shallow, braided channels (Sidle et al. 1993), they are also known to roost in narrower channels. On average, however, a minimum unobstructed channel width of 150 m has been identified for sandhill cranes (U.S. Fish and Wildlife Service 1981; Krapu et al. 1982, 1984; Currier et al. 1985), whereas whooping cranes strongly prefer much wider channels of >300 m (U.S. Bureau of Reclamation 1993). To protect the remaining crane habitat on the Platte, therefore, maintaining channel widths in the 150 to 300 m range is important.

Implications for Instream Flow Management

The data presented here suggest the need for both summer base flows and channel-forming pulse flows in maintaining the channel in the Big Bend reach. Because the Platte has a relatively flat, shallow channel, substrate exposure varies a great deal from high to low flow (Fig. 6). The channel depicted in Figure 6 represents a typical cross-channel profile based on Instream Flow Incremental Methodology (IFIM) data for Mormon Island (river mile 177) (U.S. Fish and Wildlife Service 1990). At high flows (57 m^3/sec to bankfull flows of 340 to 450 m^3/sec), ≥95% of the channel is underwater, leaving virtually no available sites for seedling establishment. But at moderate flows (23–28 m^3/sec), 25% to 34% of the riverbed is exposed, and at low flows (6–11 m^3/sec), 70–80% of the channel is exposed. Maintaining a base flow of 23–28 m^3/second in the channel during the seed germination and establishment period (mid-May through August) would therefore greatly limit opportunities for additional seedling recruitment on the remaining unvegetated riverbed. Summer base flows would also provide important ecological benefits for fish and aquatic organisms.

Some seedling establishment, however, will undoubtedly continue even with improved base flows. Seedlings and saplings that become established can be dislodged and removed through careful management of spring and early summer pulse flows. Bowman and Carlson (1994) identified the need to time such flows to coincide with historic fluctuations in February–March and May–June. At a minimum, these pulses should reach a magnitude of 75 to 225 m^3/second as identified by Johnson (1994). However, Bowman and Carlson (1994) and O'Brien (1995) defended the need for even higher flow events (340–450 m^3/sec) on a periodic basis (return period of 2.5–3 years) for seedling removal, channel maintenance, and a variety of other purposes, including groundwater recharge and nutrient redistribution. Flows in June and July 1995 of 340–450 m^3/second were quite effective in restructuring the bars in unvegetated areas of the channel and where clearing and disking had been done. However, because flows of this magnitude occur infrequently (the last occurred 12 years ago), much of the vegetative growth since 1988 (3- to 5-year-old saplings) was not removed (Fig. 7). Preliminary estimates suggest that 15–25% of the new growth was scoured, but that most of the islands vegetated since 1988 were simply "thinned" by this event.

Implications for Habitat Management

The channel changes noted in this paper will affect the long-term needs of sandhill cranes and whooping cranes that depend on open channel habitat. Such alterations could also

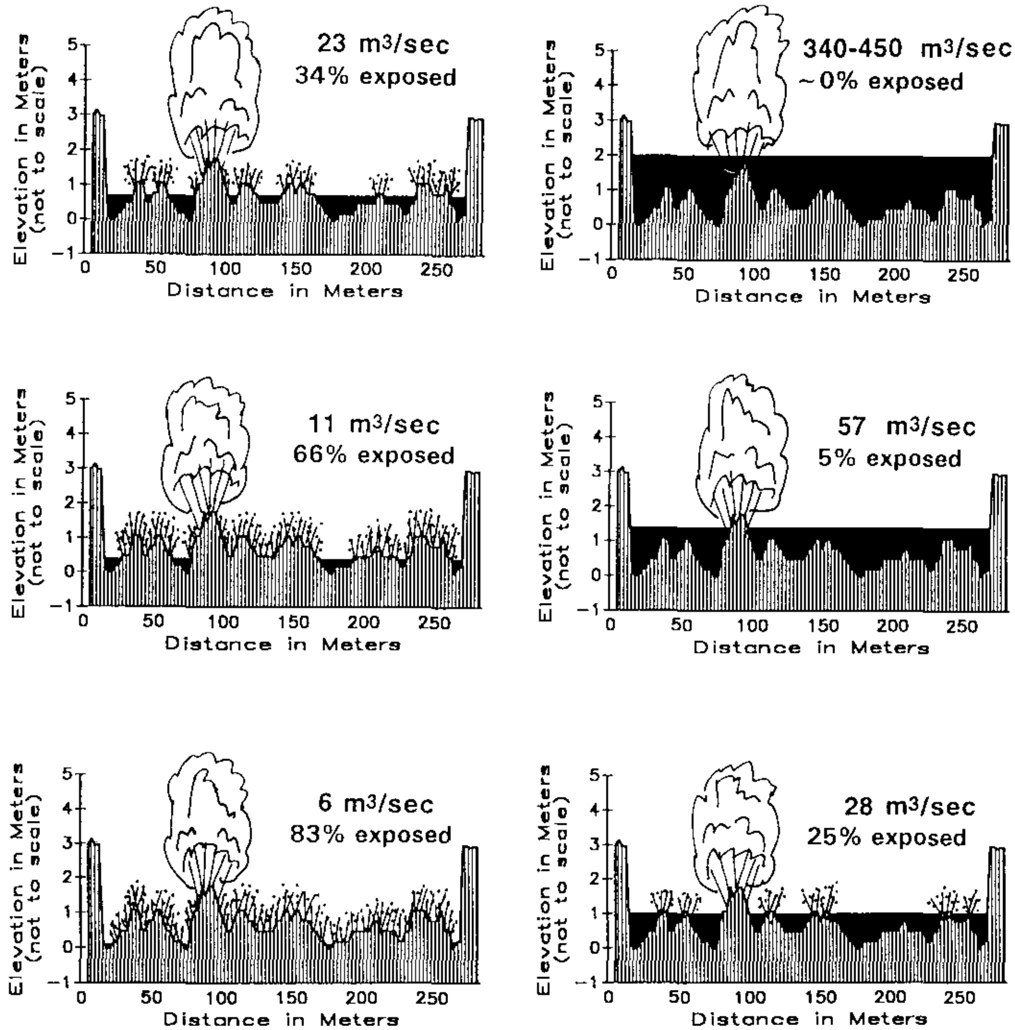

Fig. 6. Proportion of a typical 244-m riverbed cross-section that is exposed at various flows, Platte River, Nebraska. At flows less than 23 m^3/sec, extensive areas are exposed where cottonwood and willow seedling recruitment and establishment can occur.

change the distribution and abundance of waterfowl, shorebirds, least terns and piping plovers, and other species that use the Platte (Currier et al. 1985, Sidle et al. 1990, U.S. Department of Interior 1990). Over the past 10 years, the Platte River Whooping Crane Maintenance Trust, the National Audubon Society, and The Nature Conservancy have actively maintained approximately 27 km of open river channel by mechanical clearing, mowing, and disking on a nearly annual basis (Currier 1984, 1991). These treatments have been an expensive and difficult undertaking, but in conjunction with high pulse flows, they have been at least moderately successful in maintaining wide, open-channel areas on the river (Currier 1991, Currier et al. 1995). Although clearing destabilizes islands and river bars, it is the instream flows that flood and over-top them that are responsible for restructuring the riverbed and maintaining its braided character. Clearing is not a substitute for flows. Through a combination of pulse flows, base flows, and selective clearing, it is hoped that open-channel habitat can be maintained for the thousands of cranes, waterfowl, and other species that use the Platte.

SUMMARY

Analysis of aerial videography documented a trend towards continued narrowing of river channels in some of the remaining major crane roost areas in the Big Bend reach of the Platte. The most rapid expansion of vegetation occurred in a 24-km reach of the river between Wood River and Chapman, but declines in channel area were also observed in

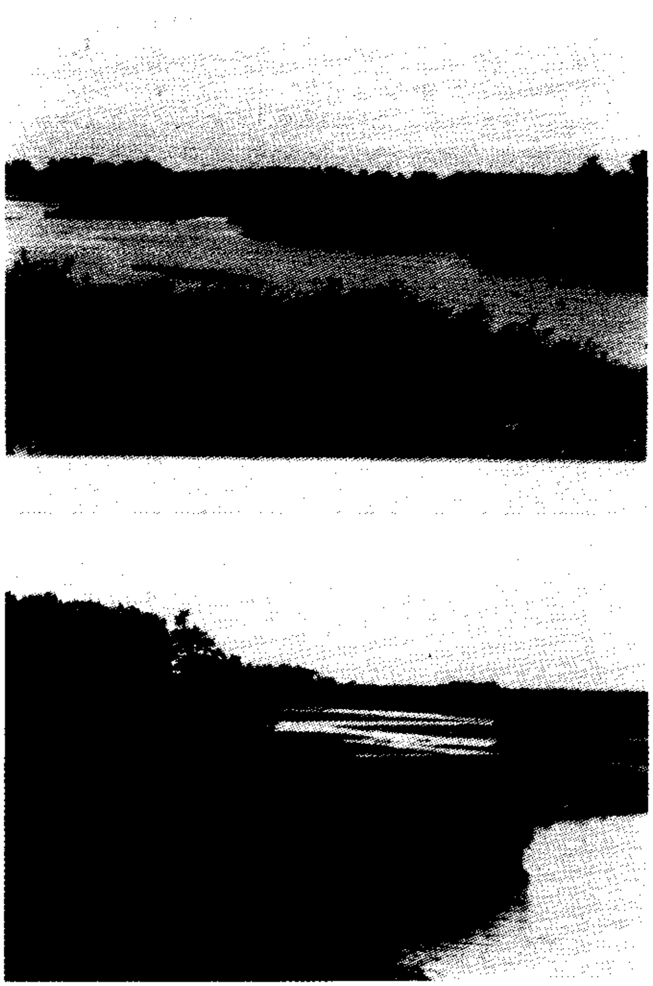

Fig. 7. Woody vegetation development (1988-94) remaining after the 340-450 m^3/sec high water flows in June-July 1995, Platte River, Nebraska. Photos (October 1995) are at river mile 174 near Hannon's Bridge (top) and at river mile 175 near Highway 281 (bottom). In the bottom photo, the channel has been managed and cleared at the right, but uncleared on the left.

open-channel habitat near Minden and Gibbon, and in areas where clearing (Mormon Island Crane Meadows and near Highway 281) and substantial channel narrowing (near Shelton and Highway 34) have occurred. Extensive low flow events in the mid-summer germination and development period for cottonwood and willow, as well as reduced winter and spring peak flows, appear to have allowed vegetation expansion. This interpretation is consistent with the demography studies conducted by Johnson (1994), but the presence of substantial, permanently established vegetation during the 1988-94 period is counter to Johnson's and CNPPID and NPPD's (1990) conclusion that the river has reached a steady-state and that significant additional narrowing will not occur. Instead, the data presented here suggest that the river is not in equilibrium, and that further channel adjustments are possible under the existing water regime. Unless water management is undertaken to maintain fluctuating spring and summer pulse flows (75 to 225 m^3/sec annual minimum; 340 to 450 m^3/sec on a 2.5- to 3-year return period) and mid-summer base flows (23 to 28 m^3/sec range), channel narrowing trends will likely continue. Although physical management of riverbed vegetation and islands can help to sustain open sites for cranes and other species, this type of management alone is not sufficient to maintain the habitat. A combination of land and water management will be required to preserve valuable wildlife resources on the Platte.

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