PRELIMINARY EVALUATION OF CHANNEL CAPACITY IN THE NORTH PLATTE RIVER AT NORTH PLATTE, NEBRASKA

Prepared for

Central Nebraska Public Power and Irrigation District

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EXECUTIVE SUMMARY

Preliminary Evaluation of Channel Capacity in the North Platte River at North Platte, Nebraska

The Central Nebraska Public Power and Irrigation District (CNPPID) has requested that Parsons perform a field inspection and initial assessment of changes that are alleged to have occurred in the river channel and in the stage-discharge and discharge-flooding relationships in the North Platte River for a reach of the river immediately north of the City of North Platte, Nebraska. In particular, Parsons was asked to evaluate causes of flooding of developed property that has been alleged to be occurring recently along the north bank upstream of the Highway 83 bridge and to suggest possible further investigations or actions that would address the flooding problem. This evaluation has been completed and the results are described in this report.

After receiving reports of flooding, the NWS announced on 9 September 2002 that it was changing the previous 1994 flood stage of 6.0 ft (corresponding to a flow of around 3,800 cfs measured at the USGS gauging station near the Hwy 83 bridge) to 5.7 ft (corresponding to a flow of around 1,980 cfs). The NWS announcement further alleged that "there has been a significant narrowing and filling of the river channel," that "the carrying capacity of the river channel has been reduced," and that with regulation "no extreme flow situations have been allowed [in the past eight years] to…effectively scour out the channel to maintain a high volume capacity."

Because the CNPPID requested an evaluation of "channel capacity," the definition of the term as used in this evaluation should be clarified. In this study, the term is used to describe bankfull conditions, when water is just about to escape over the top of banks of the main unvegetated conveyances in the river. A different term is used to describe the flow rate when water is beginning to restrict access to developed properties in the floodplain. As noted above, the NWS defines this as the "carrying capacity" or flood stage discharge rate. Their origination of this term, and its meaning, were adopted and used in this study and throughout this report. The reader is encouraged to keep this distinction in mind because it is possible to inappropriately use the terms interchangeably.

Parsons' preliminary observations and findings regarding the flooding issues at the subject properties are:

1. The subject properties are located on low ground in a former overflow chute of the river, directly in harm's way of floodplain flow that naturally and historically passed through the undeveloped property without obstruction.

2. The Corps of Engineers determined that the main channel bankfull capacity (not the same as flood stage or carrying capacity) in this reach during the period 1940-1986 was only 1,700 to 2,000 cfs. Any time that the river flow exceeded this main channel capacity, flow could naturally be conveyed toward the subject property. Because flows often exceed the bankfull capacity, it is not surprising that flooding of the overbank area occurs.

3. Observations of flows leaving the main channel of the river in 2002 confirmed that the main channel capacity was still in the range established by the Corps in their 1989 report.

4. The Corps' estimates of main channel capacity of 1,700 to 2,000 cfs match the effective or dominant discharge of 1,700 cfs. In lay terms, this means that the main channel capacity is what geomorphologists would expect it to be. Nothing abnormal is noted in this regard.

5. Flow rates for NWS' definition of flood stage or "carrying capacity' are not the same as channel capacity. Channel capacity should be, and is, less than flood stage. The NWS action in 2002 of setting the flood stage carrying capacity at 1,980 cfs is commensurate in a reach with an effective discharge of 1,700 cfs.

6. Due to the 1,700 to 2,000 cfs capacity of the main channel, presence of shallow flowing water at the subject property would be expected to occur on a regular basis, and because the bankfull channel capacity has not changed, this water has likely been occurring long before the recent report of flooding problems. As noted below and in the report, the depth of this overbank flow is now greater, but not for the reasons alleged by NWS.

7. Even though the capacity of the main channel to carry flow has not changed, once water leaves the main channel, the part flowing over the north floodplain in the study reach now flows deeper than the last time the NWS established the flood stage (1994). This change began to occur around 1991 and was not a gradually-changing phenomenon. Evidences reveal dramatic changes in the overbank area and its hydraulic characteristics in recent years.

8. The floodplain water that naturally flows toward the subject property today now flows deeper and has been inhibited from leaving the property through historical routes by actions of other landowners.

9. The hypothesis that flow rates which reach flood stage are less now than in the past is confirmed, but this change occurred in the 1990's and does not appear to have been gradually decreasing over time.

10. The reasons and evidences that floodplain flows are now deeper are detailed in the report. The primary causes are (1) the recent, rapid, and extensive growth of *Phragmites australis* and Purple loosestrife which increase the overbank resistance to flow; (2) overbank flow chutes on the north floodplain have been blocked by this vegetation, and by numerous beaver dams and rock crossings, forcing the overflow water to rise higher and flow across open ground, (3) drainage chutes and paths immediately downstream of the subject properties have been intentionally and imprudently blocked, inhibiting drainage away from, and raising water levels on, the subject properties; (4) the artificial drain created by the State around 1970 was effective but has ceased to function, and (5) large transient sand bars in the main channel (macroforms) have become larger and have entered or moved to new locations in the reach, contributing to the elevated water levels.

11. Hydraulic properties at the gauge changed abruptly around 1991. These reductions in average flow depth and velocity and increases in flow area and top width did not occur gradually over a long period of time. By examining factors that could have caused these abrupt changes, it was discovered that *Phragmites australis* was reported to have begun its rapid expansion in the area around 1991, the State diversion channel became indistinguishable from floodplain ground around 1994, blockage of natural drains downstream of the subject properties appears to be total around 1995, and the macroforms began to get larger around 1992. Thus, it is hypothesized that these factors produced the adverse changes in the hydraulic properties.

12. The capacity of the main channel to carry flow has not changed, and is not causing the alleged recent flooding problems. Any allegations that the main channel capacity was larger in the past are unfounded, but claims that the flood stage has decreased and that the "carrying capacity" has decreased are confirmed by the evidences gathered in this study.

13. Through interviews with NWS and local property owners, it was discovered that the change in the official flood stage by NWS was based primarily on one landowner's data and observations in 2002,

and that NWS had not independently evaluated the river conditions and had no real scientific basis for making the allegations listed above, and instead based their action on input by the landowner.

14. NWS' claims that the flood stage has decreased and that the "carrying capacity" has decreased are confirmed by the evidences gathered in this study.

Suggestions of additional studies for refining the understanding of the flooding problems are provided in the attached report. A more exhaustive list appears in Appendix E. Further research or evaluation might be beneficial of (1) the topography of the subject properties relative to the conveyances on the floodplain, (2) other changes that occurred in the river setting in the early 1990's that would explain the notable, abrupt changes in hydraulic properties in the 1990's, (3) tests of measures that could be effective in reversing any or all of the five leading causes of the problem listed above, and (4) improved estimates or measurements of the bankfull and carrying capacities.

Suggestions for potential remedies for the flooding problems are also provided in the attached report (see also Appendix F). Because the main channel capacity does not appear to have changed, efforts to alter its capacity as a means of remediating the flooding problem are not advised. Instead, on-site flood protection is recommended, or measures might be implemented to increase carrying capacity of the overbank area by reversing one or more of the five causes listed above.

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REPORT

Preliminary Evaluation of Channel Capacity in the North Platte River at North Platte, Nebraska

I. INTRODUCTION

Property owners along the north bank in the reach immediately upstream of the Hwy 83 bridge have indicated to the National Weather Service (NWS), the County, the City, the Corps of Engineers, and CNPPID that abnormal flooding of their properties has occurred regularly in the past three to five years. The Corps of Engineers visited the site in May, 2002, and prepared a 24 June 2002 assessment of alternatives for alleviating the "nuisance flooding problems." They report that "during the last few years" when flows approach 2,100 cfs, water has been breaking out and flowing along the left bank through approximately 20 houses and outbuildings.

A landowner, Mr. Dallas Shearer, monitored flooding of his property in the summer of 2002 and reported to NWS that river water was at bank full stage on June 29 (Q = 1,460 cfs at a river stage of 5.38 ft), and that access to his property had become restricted on July 1-2. The Department of Natural Resources (DNR) data acquired and provided to NWS by the landowner revealed that the average flow rate and stage during July 1-2 were 1,980 cfs and 5.7 ft, respectively.

Records are not sufficient to know the frequency and magnitude of flows that produced left bank overflows having this depth prior to these recent problems. Several observers report having seen frequent overflows in this area over the past 10 to 20 years. The area is clearly floodplain ground. If the channel capacity (bankfull capacity) is around the 2-yr flood rate, as is often the case for natural channels, frequent exceedences would be expected to occur in any 10 to 20 year period.

Mr. Shearer and Kevin Boyd canoed the river in 2001 when flow was about 2,300 cfs and walked some of the area in 2002 during high flows. Both noted high water on the north overbank. Flows in July 2002 in the range of 2,300 cfs exceeded the main channel capacity in sufficient quantity to result in a few feet of left overbank flow (Kevin Boyd observation). NWS' reduction of FS to 5.7, corresponding to a flow of 1,980 cfs, appears to be justified by this record.

After the September NWS announcement, USBR (2002) independently evaluated stages for annual peak flows between 1600 and 2400 cfs and concluded that the stages have gradually risen from 1940 to 2000. USBR alleges that peak annual flows are most instrumental in channel capacity adjustments.

The terms "channel capacity" and "carrying capacity" are used throughout this report. Because the CNPPID requested an evaluation of "channel capacity," the definition of the term as used in this evaluation is bankfull conditions, when water is just about to escape over the top of banks of the main unvegetated conveyances in the river. A different term is used to describe the flow rate when water is beginning to restrict access to developed properties in the floodplain. The NWS coined this term and defines it as the "carrying capacity" or flood stage discharge rate. Their definition and meaning were adopted and used in this study and throughout this report. The reader is encouraged to keep this distinction in mind because it is possible to inappropriately use the terms interchangeably.

Parsons has completed a reconnaissance-level assessment of all these allegations and has prepared this report of preliminary findings regarding the existence of, causes of, and remedies for any changes that may be occurring in the river valley, main channel capacity, carrying capacity (NWS' definition), and stage-discharge and discharge-flooding relationships in the study reach. The evaluation included (1) a preliminary assessment of NWS' alleged changes in the channel and of the Corps' and NWS' alleged shifts in the stage-discharge relationship at the gage, (2) a preliminary assessment of the leading potential causes of the alleged changes, (3) a preliminary recommendation of additional data that needs to be collected or analyses performed, and (4) a preliminary assessment of potential remediation actions that might be implemented by government or resource agencies. After discussing study limits and tasks completed in Sections II and III, results of each of these four tasks are presented in Sections IV through VII.

II. STUDY LIMITS

In order to stay within the limits of budget and schedule of the CNPPID, several issues were identified regarding the limitations of the scope of this preliminary evaluation. The following describe the key issues and present the assumptions made in finalizing the scope of work:

1. ***Which alleged changes are relevant?*** Based on the work scope and interviews, it is assumed that the goal is to address evidences of, causes of, and remedies for alleged changes in the channel and alleged changes in stage-discharge and/or discharge-flooding relationships during a limited timeframe and in the immediate locale of the subject properties.

2. ***What is the relevant study area?*** It appears that the problem, as understood by NWS and the Corps, is limited to properties in a short reach on the north fringe of the floodplain just upstream of the Hwy 83 temporary road fill and south of Riverside Road, extending west for about 2 to 3 miles. Some evidences of recent high water on the south fringe in the same reach were identified but not explored in the same detail.

3. ***What timeframe of alleged change is relevant to this project?*** Based on the landowner concerns, Corps assessment, and NWS memorandum describing their revision of the 1995 flood stage, it is assumed that the relevant time frame during which changes seem to be more prevalent is about 3 to 8 years. The NDOR significantly shortened the Hwy 83 bridge in the early 1970's, so the evaluation of stream gage data at the North Platte gage was extended back to 1971 but no further due to the effect that this modification could have had on the channel alignments and stage-discharge relationships.

Thus, the study focused on an evaluation of hydraulic properties and alleged channel capacity and flood stage carrying capacity changes over the past 8 years, and on stream gauging and streamflow measurement records over the past 30 years at the North Platte gage at North Platte, and was limited to a river reach extending from about a mile downstream to about six miles upstream of the Hwy 83 bridge where the locations of main channel flow breakouts, reductions in carrying capacity and increased prevalence of overbank flooding have been alleged.

III. TASKS COMPLETED

The scope of work prepared for this study included seven tasks (the scope is available on request). To meet the requirements of the contract, the following seven tasks were completed during the project:

1. Conducted a preliminary search of Internet sites and Parsons' library holdings for data, aerial photos, reports, FEMA studies, etc. related to this locale. Contacted DNR in Bridgeport and acquired streamflow measurement summaries for the stream gage at North Platte from 1971 through 2000. Received and reviewed photos and reports from CNPPID and Twin Platte NRD staff.

2. Acquired and reviewed the following documents:

   a. September 9, 2002 Memorandum by the National Weather Service.

b. July 8, 2002 Memorandum by Corps of Engineers, "North Platte River at North Platte, Nebraska Channel Assessment Study."

c. 6/10/92 FLO (1992) Engineering Report to Twin Platte NRD, "North Platte River Channel Stability Investigation."

d. July 1989 COE "Platte River Cumulative Impacts Analysis Report No. 4."

e. March 2000 Darryl B. Simons Associates' (DBSA) "Analysis of Proposed Union Pacific Railroad Bridge over the North Platte River at Paxton."

f. 9/24/02 USBR report, "Flood Stage on the North Platte River near North Platte."

g. 1981 USGS OFR 81-53, Kircher, "Sediment Transport and Effective Discharge of the North Platte, South Platte, and Platte Rivers in Nebraska."

h. August 2000 Simons and Associates "Physical History of the Platte River in Nebraska."

i. Collection of 24 sets of aerial photos and maps of the study reach dating from 1939 through 2002 (see Table 1).

j. Set of 8 articles on *Phragmites australis* and Purple Loosestrife from textbooks and journals.

3. Prepared for, traveled to and participated in a two-day field tour of the study reach on October 22 and 23, 2002. The field tour included meetings with local landowners and discussion and data collection meetings with resource, government, and transportation agencies or officials.

   a. Prepared questionnaire for data collection.

   b. Prepared pre-trip lists of theories regarding alleged changes and of field/office issues regarding the theories (included in Appendices A and B).

   c. Conducted in-person interviews with Kevin Boyd and Mike Drain (CNPPID), Dallas Shearer (landowner), Les O'Donnell and Roger Klasna (NDOR), Jim Hawks (County), and Jim Goecke (Univ. of Nebraska).

   d. Acquired copies, prints and slides of photographs and maps of the study area from several sources including County, ASCS, Mr. Shearer, and CNPPID.

   e. Placed additional orders for photographs and maps from CNPPID, NDOR, and the City.

   f. Inspected and photographed portions of the north bank and north floodplain of the river from the Hwy 83 bridge to a point about 4 miles west, including developed properties and drainage alterations in this zone.

4. Made telephone, fax, and e-mail contacts to discuss available information and request relevant data, photos, records of construction, study reports, etc. Examined DNR/CSD 1979-80 and 1995 water table maps at UNL campus.

   a. Telephone interviews with Tim Randall (USBR EIS Team), Steve Kemper (NGPC), Mark Peyton (CNPPID), Frank Kwapnioski (NPPD), James Vassos (DNR), Dave Wert (NWS), Walt Vering and Derrick Dickinson (Maxim Technologies), Selma Kessler (KMA), Bob Keller (City of North Platte), and Randall Behm (USACE).

   b. Conducted e-mail correspondence with other agency personnel.

TABLE 1

AERIAL PHOTO AND MAP LIST

Listed in Reverse Chronological Order

DATE	FORMAT	QUALITY	SOURCE	NOTES
????	Blueprint	Fair	Shearer	Unknown date N4PP 920-109A
2/27/02	Electronic	Excellent	City of N.P.	Imagery for their FEMA update
2002	35 mm Slides to CD	Poor	ASCS	Individual sections, some missing
2/2/02?	Xerox Copy	Poor	COE	Poor copy of Plate 1 in COE report
Oct 2002	Print	Good	CNPPID	Oblique from airplane
11/5/01	Contact Prints	Good	NDOR	Copies obtained from NDOR Lincoln
2000	35 mm Slide	Poor	ASCS	Individual sections - Have CD
4/11/99	Xerox Print	Good	CNPPID	Mosaic of 3 overlapping prints
1993	Xerox Print	Good	CNPPID	Shows Kevin Boyd's Inspection Area
9/15/93	Electronic	Good	TerraServer	Downloaded off Internet
1993	Xerox Copies	Poor	ASCS	Four sections on four sheets
1992	35 mm Slide	Poor	ASCS	Individual sections - Have CD
1990	35 mm Slide	Poor	ASCS	Individual sections - Have CD
1986	35 mm Slide	Poor	ASCS	Individual sections - Have CD
1983+	Xerox	Fair	Shearer	Undated, shows Shearer property lines
1983	Color Print	Good	USGS	Photo Revised 1970 USGS Quad Map
1979	Xerox Copies	Fair	FEMA	FEMA FIRM Map
1978	Xerox	Poor	Shearer	Mr. Shearer got this from G&PC
1971	tiff files	Good	CNPPID	Mike Drain, CNPPID (ref no. 21)
1970	Color Print	Good	USGS	USGS Quad Sheet
1965	Xerox Print	Poor	Shearer	Lincoln County Cadastral survey plat
1965	Xerox Print	Fair	Jim Hawks	Copy of copy (Original missing)
5/10/58	Color Xerox	Fair	NDOR	Sec. 28 on 5/11 Good Quality
1957	Xerox Print	Fair	Jim Hawks	
7/19/38	Color Xerox	Good	Jim Hawks	High altitude

5. Received, compiled, and reviewed materials acquired from various agencies and stakeholders and prepared a list of evidences regarding each hypothesis (included in Appendix B – the reader is encouraged to review this in order to understand why several hypotheses are most likely non-operative and others appear to be operative).

6. Participated with a number of sponsors and stakeholders in a conference call on November 27. Discussed progress and preliminary findings on each of the four task items listed in the Introduction.

7. Prepared a written summary of the study findings and recommendations (this report).

IV. EVALUATION OF CHANNEL CHANGES AND STAGE-DISCHARGE RELATIONSHIPS

A. Channel Morphologic and Capacity Changes

The evaluations of changes in the planform of the study reach were conducted from the aerial photographs listed in Table 1. Channel capacity changes were assessed using data from previous investigations, plus data regarding channel capacity, carrying capacity, and flood stage supplied by NWS and Mr. Shearer.

One of the potentially more relevant findings of the assessment of the aerial photographs is that the North Platte River channel formerly flowed in a northeasterly verses easterly direction across the location of the subject properties. The 1938 photo shows this alignment, with a moderate percentage of the braided corridor passing north of River Road at the subject property and Hwy 83 bridge location. More recent photographs reveal the artifacts of this former channel. The construction of River Road, plus development of property north of River Road and north of the subject property have confined and pushed the main channel and its overflow relief area (north floodplain) to the south. North bank overflows that historically passed almost directly through the subject property have been laterally constricted, in an increasing percent with distance downstream, from about two miles upstream of Hwy 83 near the power substation, to a maximum constriction just downstream of the subject property.

The geomorphic relevance of this is that the subject properties were constructed directly in the former path of much of the overbank flow. This creates a two-fold explanation of the incidence of flooding of these properties. The ground along this alignment is probably lower than surrounding ground, and the river would have a natural tendency to continue to direct its overflows directly toward the subject properties. Only artificial means, such as the State diversion channel or the current channel along the west side of the temporary road fill, would re-direct these flows in a transverse fashion across the floodplain and back to the main channel. With the combined effects of the Hwy 83 fill, the temporary fill placed in the early 1970's, and the elimination of the natural drain to and from the Hwy 83 box culvert, depth of water for the same flows would increase and flooding of these particular properties would be expected to be acute. It may also be possible that a check of the dates of construction of the improvements on the subject properties may show that many occurred after the State diversion channel was constructed. If so, it may be that the property had been previously flood prone, and was not considered habitable until the surface was artificially drained by the diversion. This hypothesis that the improvements were constructed in harms way is discussed further in Section V.

It is evident in aerial photographs around the mid-1980s that the three main river channels became much more sinuous and meandering than in the previous decades (see Appendix B). Changes in the drainage downstream of the subject properties also occurred. In addition, the channel sand bars and banks had become more vegetated. In earlier aerial photographs, sand bars and banks were less vegetated. The braided overbank channels were notably more vegetated after 1985, and increased standing water is apparent in the off-channel ponds due to closure of the chutes.

There is little to no data which could prove or disprove that gradual or abrupt aggradation in the bed profile has occurred in this reach. FLO Engineering (1992) reported that there has been 0.5 ft of degradation at N. Platte since 1932.

The USGS (1981) and the COE (1989) both evaluated the effective discharge in this reach and concurred that it is around 1,700 cfs. The studies used data from 1941 to 1979 and 1940 to 1986, respectively. The effective discharge is believed to be representative of the flow which has the greatest influence in shaping the characteristics of a channel and is often considered to be the bankfull flow for a stable river. The COE (1989) confirmed that bankfull discharges in the Sutherland to North Platte reach, using 1940 to 1986 data, were about 1,700 to 2,000 cfs, bracketing the effective discharge, so the bankfull rate was essentially equal at that time to the effective discharge, and overflows above these rates would be expected and were probably occurring in more than the most recent 5 to 10 years. Equating effective discharge with bankfull in this reach appears appropriate because it corroborates Mr. Shearer's and the NWS' observations that the channel capacity (not carrying capacity) is reached or exceeded for flows around 1,500 to 1,700 cfs. It is hypothesized that the main channel capacity does not appear to have declined and nothing appears out of geomorphic balance with regard to the main channel capacity in the study reach. Evidences presented below reveal that the carrying (flood stage) capacity abruptly changed around 1991, which provides explanations of why property flooding has only recently been identified as a problem are given in Section V.

Mr. Shearer alleges that when the flow increases to around 1,980 cfs, access to the subject properties becomes limited. The NWS contends that a flow of 3,804 cfs was needed in 1994 to cause this same problem. Thus, it is hypothesized that the overbank (floodplain) capacity has decreased.

Expecting, or trying to create, a channel capacity greater than this 1,700 cfs rate would be contrary to principles of dynamic equilibrium and therefore ill-advised. The existence of any segments with greater capacity would be serendipitous. The possibility that the North Platte did not flood properties in earlier years until flows reached 3,800 cfs does not necessarily mean that the channel capacity was 3,800 cfs. It is hypothesized that loss of this carrying capacity function is largely due to reductions in overbank capacity rather than channel capacity changes.

Another possible explanation of the reason why the river "safely" carried higher flows in the past is that prior to 1991 the channel size became temporarily enlarged during high flows due to mobilization of bed sediments. When flows dropped back to lower levels, the sediment moving as a layer in the bed ceased moving, and the channel size returned to what existed before the high flow period. This process of temporary deepening of the bed during individual events would not be picked up in standard calculations of channel capacity like those used by the Corps because typical bankfull channel capacity estimates are made from surveys during low flows when the bed sediments are static. The reductions in average velocity and depth observed after 1991 could have resulted in a reduction in the depth and amount of bed material that mobilizes during high flows, possibly explaining the phenomenon described above. Further evidence in support of this explanation is found in FLO (1992). They report that the channel width had stabilized by 1983, and because a significant amount of sediment transport still occurs (reportedly 190,000 to 300,000 tons per year), they conclude that the sediment must be coming from the stream bed. This disregards sediment supplies from the intervening watersheds, which could be substantial.

Finally, at least one of the previous investigations (FLO 1992) noted that the transient sand bars, or macroforms that move as sand waves, appeared to be "much larger" at the end of their study period. Parsons saw some evidence of this in the current study, but the scale of the aerial photography makes it difficult to quantify this phenomenon. Any increases in size or numbers of these structures could cause the kind of hydraulic changes and flooding problems noted here.

B. Changes in Stage-Discharge and Discharge-Flooding Relationships

This section describes the methods and results of an evaluation of whether changes in the stage-discharge relationship have occurred over the study period, particularly in the past 3 to 8 years. Summaries of streamflow measurement data for the period 1971 to 2000 at the North Platte River gauge at North Platte were acquired from the DNR office in Bridgeport. The 1971 start date was selected because the Hwy 83 bridge, where the gauge is located, was shortened by about 1000 ft around 1970.

Data from 101 USGS and DNR streamflow measurements in the range of 2000 cfs were extracted and coded into spreadsheets for graphical and mathematical analysis. These data contain measurements of stream velocity, water surface width, flow area, discharge, and average flow depth. They also contain data regarding the shifts in the rating table made by the hydrographers after each measurement. Due to its length, the data and evaluation methodology are provided in Appendix C. The main findings are reported here.

From 1971 to about 1990, there appears to be about a 9-year cyclic trend in stages for discharges around 2,000 cfs, with swings of 1- to 1.5-ft, but with no apparent gradual increase or decrease in stage. The cycling of the gage heights was moderately sinusoidal with a half period of about nine years prior to 1991. The rise that began about 1990 was at the same rate as earlier rises, but rather than peaking, it continued upward until around 2000 where it appears to have flattened and remained steady until 2002 (this is based on a single measurement in 2002 rather than all measurements between 2000 and 2002, which were not available at the time the data were requested). FLO Engineering (1992) reported that stages at the North Platte gauge have a periodic 0.5 ft rise and fall with no net change. The additional evaluations listed in Section VI include a recommendation that this data be extended throughout the entire period of record to evaluate whether this cycling is evident in the pre-1971 data. Effects of the bridge modification around 1970 will need to be factored in the extended evaluation.

No apparent trend is evident in rating shifts applied to flows in the 1600 cfs to 2400 cfs range from 1971 to 2000 (see Figures C1 and C2). Something around 1991-1993 and thereafter appears to have caused and maintained abrupt changes in these hydraulic parameters. The 101 measurements of flows around 2,000 cfs from 1971 to 2000 show that around 1991 there were moderately abrupt changes in the hydraulics. Water surface top widths and flow areas were stable until around 1991 when both experienced a quantum rise (not gradual) for the same flow rates and remained at the elevated values through 2000. Top widths increased by about 200 ft (70 percent) and flow area increased by about 120 sq ft (20 percent). Similarly, average flow depths and average velocities for flows around 2000 cfs were steady until about the same time (circa 1991), then experienced respective quantum declines of 0.6 ft (30 percent) and 0.5 fps (20 percent). The new levels of these parameters have stayed about the same to the present day - no obvious changes in these parameters were evident during the past 3 to 8 years.

Though somewhat speculative, the average velocities appeared to have begun to decrease a little while before the other changes occurred. Probably more relevant is the fact that the 20 percent decrease in velocities dropped the average velocity from about 3 fps to about 2.4 fps. Though at first blush the 20 percent reduction in velocity may not be considered important, the drop to 2.4 fps is because it is possible that the velocities over part of the channel bottom are now below the threshold for initiation of movement of sands in this reach.

If the 1- to 1.5-ft cycling in stage noted prior to 1991 is a natural phenomenon, it is hypothesized that whatever changes occurred around 1991 also adversely impacted this natural pattern. As noted above, the cycling ceased around this time, and stages for a flow around 2,000 cfs continued to rise another 0.7 ft above the previous peak historical values.

Two significant findings emerged when all 101 measurements of flows around 2,000 cfs from 1971 to 2000 were evaluated. First, a cycling of stages is evident, rather than a continuously rising stage as hypothesized by USBR (2002). The 1971 start date was selected because the Hwy 83 bridge was shortened by about 1000 ft around 1970. This 9-year cycling of stages for flows in the range of 2,000 cfs shows the stages rising from about 3.5 ft in 1971 to 5.0 ft 1980, then they peaked for a year, and then they fell to 4.0 ft around 1989. They then rose again at about the same rate as in 1971 to about 4.8 in 1995, then continued rising at a lower annual rate until reaching 5.7 ft in July, 2002. Second, the individual stage shifts recorded for each measurement were not all negative (contradicting steady aggradation). Instead, they cycled like the stages, but were out of phase, somewhat offsetting the stage shifts. Other parameters besides high flows, such as effective discharge, vegetative encroachment, and natural presence and migration of macroforms are equally suspected in contributing to this cycling.

Other hypotheses of the causes of the quantum changes in the hydraulic parameters, and of the processes by which discharge-flooding and stage-discharge relationships have changed, are described in Section V. The key finding is that the changes are definitely evident, and that they were episodic rather than gradual. Something that happened or began to happen around 1991 caused these changes.

V. EVALUATION OF HYPOTHETICAL CAUSES OF OBSERVED CHANGES

A. Hypotheses Evaluated

Though allegations about changes in the channel and stage-discharge relationship have been made, the discussion in this report is limited to an evaluation of hypotheses that could explain the causes of the *observed* changes described in Section IV.

Because the shift in hydraulic properties could only be documented as having occurred around 1991, and because the shifts in hydraulic parameters and the disruption of the cycling were relatively abrupt, only those hypotheses in Appendix A that could cause these types of changes are evaluated in this report. For the same reasons, only hypotheses regarding short-term rather than gradual long-term changes are evaluated here, as are those related to coincident (or immediately-preceding) causes rather than time-historical causes. The other hypotheses were considered to be unlikely to explain the abrupt changes, but could emerge as highly relevant with additional data and observation.

A delayed effect of some historic change in the river such as the construction of Kingsley dam is a possible explanation, but the absence of gradual changes and the long time-lapse between major development and the current problems tend to discount historical causes. Gradual aggradation of the streambed is also considered to be a possible explanation, but degradation rather than aggradation generally occurs downstream of dams. FLO (1992) studied the degradation in the reach between Kingsley dam and North Platte and reported that there has been about 0.5 ft of degradation at the North Platte gauge. Further, gradual aggradation would not cause the abrupt changes noted here, but an abrupt, coincident rise in sediment influx or bed level could produce these changes. The hypothesis that the changes were the result of recent, coincident changes in the river is considered credible, based on the evidences evaluated.

B. Evaluation of Possible Causes of the Changes in the Channel and Stage-Discharge Relationships

The only noted changes in the river immediately preceding and subsequent to 1991 are (1) rapid and expansive population of the secondary channels and overbank areas by *Phragmites australis* and Purple loosestrife, (2) the continued man-made modifications of the drainage downstream of the subject properties, (3) increased sinuosity and length of the main channels, (4) notable presence of slow-moving macroforms, and (5) the acceleration in the deterioration of the capacity of the NDOR cutoff channel in the 1990's. The first four have been known to cause the kind of hydraulic changes observed. The fifth may explain the allegation that the properties weren't flooding four years ago and earlier, but would not rationally explain the abrupt changes observed in the hydraulic properties.

The continued blocking of floodplain drainage downstream of the subject properties, movement of macroforms into the reach, expansive vegetative encroachment, or the increased sinuosity and channel length would reduce the channel slope through the reach and slow overbank flows, which could account for the 20 percent decrease in average velocity. Reduction of average velocity over a wider width could have resulted in an introduction of, or increase in, a portion of the channel bed experiencing velocities below the critical velocity (that which initiates motion). These changes in hydraulic parameters are in directions that would invoke sediment deposition, higher stages, and more overbank flooding for the same flow rate.

The increased friction and decreased water velocity could also result in decreased energy for transporting sediment through the reach. Consequently, if the channel upstream was not similarly affected, the incoming flow would drop part of its sediment load once it reached the constricted segment upstream of Highway 83. It is also possible that the observed decreases in velocities and depths caused decreases in tractive forces which mobilize the bed sediments. The narrower pre-1991 flow width with higher average depths and velocities would probably mobilize a thicker layer of bed sediment than afterward, resulting in a reduction in channel conveyance. This alone could explain the apparent reduction in bank-full discharges.

C. Leading Potential Causes of the Changes

During and at the end of the data collection phase, evidences regarding each of the hypotheses presented in Appendix A were compiled in outline form. They are presented in Appendix B for a range of issues raised by the various hypotheses. These evidences should be reviewed because they are the basis of the discussion here regarding causes of the observed changes around 1991 in the hydraulic characteristics and carrying capacity.

As noted earlier, the subject properties were constructed in a low-lying area centered in an historical overflow chute. The river has a natural tendency to direct north bank overflows at these properties, and when combined with man-induced reductions in the ability of drains to carry this water past the properties, flooding would be expected. By itself, this doesn't explain why flooding of these properties is alleged to be a recent occurrence or why the flooding appears to be associated with lower total flows than in the past. However, it does explain why the river "prefers" to send water toward these properties. It is hypothesized that this nuisance water has been there all along, but was draining away through the Hwy 83 culvert or across the State cutoff channel up until around the mid-1990's when additional blockage of the natural drainage, plus noticeable presence of larger macroforms in the main channel, plus complete deterioration of the function of the State cutoff channel were noted (see these and other evidences listed in Appendix B).

The leading apparent cause of hydraulic changes that were observed to occur around 1991, and possibly the leading cause of the recent flooding problems being experienced in the reach, is the recent and rapid expansion of the hybridized or exotic strain of *Phragmites australis* in the secondary channels and on the overbanks. This is the most dramatic change documented for this period, and it alone could account for the changes and associated problems. It is hypothesized that the recent, rapid, and extensive growth of *Phragmites australis* and Purple loosestrife has significantly reduced overall capacity of the water and sediment delivery system in this reach.

Before concluding that recent vegetative encroachment caused these changes, it should be noted that the recent flooding of north bank properties could be, about as easily, the result of actions by downstream property owners. It was noted earlier that the COE proved that the channel capacity (bankfull definition) below Sutherland is only 1,700 to 2,000 cfs, and that overflows at around 1,900 cfs are not an unexpected or unusual occurrence. It is possible that more in-depth research of overflow histories would confirm that overflows have been occurring all along, but were only recently a problem due to impacts of drainage modifications downstream of the subject properties or possibly as a result of diminished capacity of the NDOR cutoff channel or effects of macroforms. For example, the 1993 aerial photo reveals that drainage from the subject property that naturally flowed northeast or east appears, finally, to have been completely blocked and diverted to the south along the west side of the temporary road fill. It is also highly likely that a combination of these effects plus the effect of the vegetative encroachment exasperated the problem to the extent that properties are now being affected. The combination of effects is favored over any single cause, but the hypothesis is limited to these causes.

A summary of the properties of, and management options for, *Phragmites australis* is included in Appendix D. Phragmites is a very tall, dense, and durable plant that has colonized the channel banks and floodplain overbanks and chutes throughout the study reach over the past ten years, most notably in the past 8 years. The hybrid Phragmites are much stronger and denser than native Phragmites and other native plants. The genotype grows by rhizome extension and budding, with reeds commonly spaced as close as 12 inches apart. Expansion is rapid, and has been documented at over 10 meters per season on bare sandy deposits. They live long, and are salt and flood tolerant.

Other factors known to have changed around this same point in time are the sizes and locations of macroforms and downstream obstructions and alterations in overbank flow paths, both of which have probably created a slackwater and backwater effect. FLO (1992) reported an increase in size of macroforms, and two large macroforms are currently present upstream and at the Hwy 83 bridge, and if they've been there for the past three years but not before, their presence alone could explain the flooding at the subject properties. Available aerial photos are not of sufficient resolution to resolve this potential cause. These, rather than reductions in peak annual flows or general aggradation are more strongly suspected in contributing to the observed changes.

The most significant man-caused alterations are immediately downstream of the problem area, though not all occurred around 1991. The swale through this area was once quite large, and has been reduced to two 12-inch culverts with flow lines that are probably above the natural flow line. One other factor that could be contributing to the abrupt changes in 1991 is the overgrowth and closure of the State diversion channel (circa 1970), which most likely worked for a time in alleviating flooding but has lost its former function. However, the construction of the diversion, and its eventual demise, are not considered to have caused the quantum shifts in hydraulic parameters.

Effects of these changes are increased sinuosity in the main channel, increased overflows onto the floodplain, raised water levels downstream of and at the subject properties, alterations in conveyance downstream of the subject properties preventing floodplain overflows from efficiently returning to the main channel, local reduction in sediment transport capacity, exasperated backwater and delta effects of the Hwy 83 bridge and temporary road fill, changes in tractive forces which mobilize bed sediments, and local reductions in sediment transport capacity.

The NWS describes 'flood stage (FS) as the water level when flow in the river begins to restrict access by landowners. This carrying capacity should not be confused with channel capacity, because the latter is the flow at which river water begins to break out of its main channels, and is consequently less than flood stage carrying capacity. The reported flood stage (carrying capacity) flow in 1994 was 3,804 cfs, which is contrary to all calculations of effective discharge and bankfull capacity. By NWS' definition, channel capacity is less than flood stage carrying capacity flow. No evidence exists that the channel capacity was anywhere close to 3,804 cfs in 1994 or earlier. On the contrary, the Corps and USGS determined that it was 1,700 cfs around 1985. Flows of 3,800 cfs magnitude may have may have been able to pass by without flooding the subject properties because the overbank portion flowed at lower depths (this is the favored explanation), or as a result of a thicker layer of bed sediments being mobilized before 1991, due to the narrower flow width and higher average depths and velocities that existed before 1991. FLO Engineering (1992) report that they discovered that a layer of bed sediments becomes mobile during high flows in this reach, temporarily increasing the cross-sectional area during the days these flows occur. They also concluded that the upstream channel width had stabilized by 1983, so the large amount of sediment being transported must be bed material. As noted earlier, this disregards sediment supplies from the intervening watersheds, which could be substantial.

A condition of effective discharge being less than dry-channel capacity under equilibrium conditions is conceivable. It is not considered conceivable, however, that a higher capacity channel existed in 1994 as an artifact of pre-Kingsley regime conditions. Both DBSA and the COE report that the channel widths and reaches in this locale stabilized around 1970. Alternatively, it is hypothesized that the capacity has been static from 1940 until around 1991, and overflows for discharges in excess of capacity probably occurred but were not being reported because the water flow was shallow or was able to return effectively to the main channel just upstream of the Hwy 83 bridge.

Because overflows now occur at about the current effective discharge rate, further diminution of capacity is not likely. Further, the FS of 5.7 corresponding to a flow around 2,000 cfs has remained steady since 2000. The current channel is probably in dynamic equilibrium, or there could even be a decline in flood stage if the macroform at the gage migrates downstream.

The possibility exists that these changes are an adjustment of the channel to a conveyance compatible with a change in effective discharge occurring in the 1990's. However, this is discounted because the USGS and COE studies both determined the effective discharge for the years following the closure of Kingsley dam to be 1,700 cfs, which is definitely less than the flood-stage flow rates of 3,804 cfs in 1994 and 1,980 cfs in 2002, and is about equal to the pre- and post-1991 channel capacity. No evidence exists that the effective discharge or bankfull channel capacity experienced a decrease in or around 1991, but this possibility bears further consideration.

There are only anecdotal evidences of general aggradation, and only at the bridge (Dallas Shearer pers. communication). More relevant reports exist of macroforms blocking the main channel, causing local overflows (Kevin Boyd and Dallas Shearer pers. communication). FLO (1992) reported that the transient sand bars (macroforms) appeared to be larger near the end of their study period. A large bar currently exists beneath the Hwy 83 bridge, and these structures are a more plausible explanation than gradual aggradation. If gradual aggradation is discovered to be occurring (see recommended additional investigations in Section VI), some potential causes of the aggradation would be similar to the factors listed above. None of the evidences collected in this study suggest that aggradation has caused these problems, other than the unresolved possibility that one or more macroforms have moved into positions that could be causing the observed changes described here.

USBR's suggestion that reductions in peak annual flows have created this problem is questioned by the fact that moderately high annual peaks occurred in 1971 and 1973 during a period of rising stages, which is contrary to the theory, and somewhat lower "high" flows also occurred in 1983 and 1984 during a period of falling stages. It may be argued that the annual peaks may have caused delayed channel capacity changes or stage-discharge relationship effects, such as causing a delayed change in direction of the cycling, but the ten-year lag and the change directions noted in Figures C3 and C4 are not easily or consistently associated with the presence or absence of high flows. Further evaluation of this possible cause, and correlations of other factors with the cycling, are recommended.

Even stage changes, which are cyclic and not continuously rising as suggested by USBR, appear to have been impacted by the factors that caused the other observed hydraulic changes around 1991. From a low point in about 1986, the stages rose at about the same rate observed from 1971 to 1980, but rather than peaking around nine years later (say, 1995), they continued to rise to the 5.7 ft level in 2002. The hypotheses regarding physical processes operating after 1991 appear to possibly explain this "interruption" in the natural cycling of the stages.

VI. POSSIBLE ADDITIONAL INVESTIGATIONS

The scope of work called for a preliminary evaluation of additional investigations that might aide in either confirming suspected causes of the changes or in confirming that proposed remediation measures will obviate flood problems. Two lists of investigations are outlined in Appendix E. The first includes actions that are possible with relatively small time and expense. The second list includes actions that would be more time and labor intensive.

Neither list is considered exhaustive. The findings are preliminary observations by one person, and it is recommended that other input regarding interpretation of which explanations of the causes of the recent changes are best supported by the evidence. It is proposed that after distribution of this document, other input regarding the evidences and logic of the findings be garnered. Once the validity of the findings is confirmed, a refined list of high-priority, high-potential investigations could be developed and implemented.

Notwithstanding any further review, the following relatively low-cost actions are considered important to refining the evidence list and confirming the causes of the documented changes:

1. Interview other landowners or observers regarding their short and long term recall of flooding conditions along the north floodplain.
2. Research and document the changes in floodplain drainage downstream of the affected properties, including fill dates and quantities, channel maintenance efforts, and other facts.
3. Using the new City topographic survey, carefully examine the topography around the subject properties to determine if they are in a low swale with relatively high accessibility of incoming overflow water but no current drainage routes back to the river.
4. Compile available bed sediment grain size distribution data and compare its critical velocity with 2.4 fps, using sixth-power relationship to examine whether velocities at bed have fallen below critical velocities.
5. Evaluate whether a reduction in average velocity from about 3 fps to about 2.4 fps would cause a reduction in percent of the bed surface that would experience critical (initiation of motion) velocities.
6. Walk the route of the primary overbank channel chute or chutes from the river bank near the location of the macroform noted by Boyd and Shearer in 2001 to the affected properties and document vegetative encroachment, beaver dams and rock barriers used for vehicle crossings. In addition, walk the length of the NDOR diversion channel beginning near the power substation and document lengths and locations of open and encroached segments.
7. Acquire the full set of streamflow measurements for the period of record from DNR and then repeat the analysis described in Appendix C for pre-1971 data.

8. Because changes in hydraulic parameters were only evaluated for discharge around 2,000 cfs, and because the NSW and others believe that the discharges of 3,800 cfs passed without flooding the properties as recently as 1994, the analysis in Appendix C should be repeated for the period of record using flows in the 3,800 cfs range. This is a much smaller subset of data, but some conclusions would likely be possible regarding any shift in hydraulic conditions at this level of flow.

9. Attempt to correlate the changes noted in Appendix C and items 5 and 6 with other possible causes such as mean annual flow, monthly flows, groundwater levels, construction of homes and access routes, drainage modifications, sand and gravel mine development and operations, or other factors.

10. Make detailed observations of channel and overbank flow conditions during the next event having flows of 1,700 to 2,000 cfs. Obvious purposes would be to establish the channel capacity and identify locations of overflow initiation. Drainage routes back to the river should also be observed.

11. Suggest to DNR that bed levels for each future streamflow measurement in the 1,700 to 2,500 cfs range be tied into the datum at the stream gauge. This would allow the bed elevations to be plotted over time.

12. Design and implement a system for observing location and movement of macroforms in the reach from the bridge upstream for about 3 miles.

13. Design and implement a system for testing whether aggradation may be occurring in the study reach. It should be noted that this process is difficult to observe, and could involve five to ten years of detailed data collection. Aggradation would be evident from several indicators, including upward trends in channel bottom surveys over time at equal flow rates, steady upward shifts in the rating curve, growth of transverse bars, instability and increased sinuosity in the main channel, deposition on the floodplains over tree root wad levels, formation of new secondary channels, absence of vegetative succession along the banks, and absence of these indicators in the non-aggrading reaches downstream or upstream of the alleged aggrading reach.

14. Locate and re-survey USBR or other monumented cross-sections and evaluate aggradation hypothesis

15. Research opportunities for some of the remediation options listed below, such as the possibility of FEMA buyouts of the affected properties, flood proofing the affected properties, acquiring permits for restoration and maintenance of the NDOR cutoff channel, removal of fill downstream of the affected properties, and restoration of the drainage way to, through, and downstream of the double box culvert under Hwy 83 north of the bridge.

VII. POTENTIAL REMEDIATION ACTIONS

Remediation options have been proposed by the USBR (Randall) and the COE (2002). The USBR proposals assume that channel capacity needs to be increased, and the COE proposals address needed improvements in the overbank areas to improve carrying capacity. Parsons has identified a number of options depending on the cause of the problem and the goal of remediation, i.e. whether to alleviate the flooding of the subject properties or increase the carrying capacity (not channel capacity0 through the reach. Lists of options identified by each of these investigators are provided in Appendix F.

As with needed investigations, any remediation action plan should undergo review and comment by others regarding the causes of the changes and the viability and efficiency of the action plans, rather than relying on this single-person analysis. It is proposed that the same procedure used for soliciting input by others in identifying needed additional data collection and analysis be conducted for development of high-priority, high-potential actions that could remediate the short and long-term problems.

Parsons believes that the choice of action items depends on first resolving the cause of the problems so that the actions are beneficial and effective in reversing or obviating the cause, and so they can be directed to the appropriate entity for implementation. For example, if the cause is deemed to be blockage of downstream drainage by developers, responsibility for implementing the remedy may fall on those shoulders. If the cause is deemed to be from natural or uncontrollable processes, identification of the appropriate action and action agency may take considerable cooperative effort.

Next, the specific goal of any action plans needs to be identified because actions that are designed to protect the subject properties from high water may be different than actions taken to restore the pre-1991 carrying capacity or create a higher carrying capacity so that the subject properties are no longer flood prone. Other goals may also exist, each with its own set of associated action plans to accomplish the goal. Finally, responsible entities for implementing the actions would need to be assessed, along with environmental, social, economic, financial and physical feasibilities.

The Corps, USBR, and Parsons have identified a number of options that could reverse or obviate the cause or causes of the observed changes. Some would provide flood protection for the subject property while others could possibly restore the pre-1991 carrying capacity. A partial list of available options is included in Appendix F. They range from diverting flow around the reach, initiating actions toward a FEMA buyout of the properties, flood proofing the properties, constructing levees around the properties, restoring the NDOR diversion channel, blocking chutes that bring water toward the subject properties, restoring the drainway through and downstream of the Hwy 83 box culverts to remove water that arrives on the property, applying herbicides to remove Phragmites stands, confining flows in the main channel to a narrower pre-1991 condition, cutting pilot channels through sand bars and macroforms, and others.

Tests by others of spraying *Phragmites australis* with herbicides have been successful (see Appendix E). A test of aerial spraying with a concentrate of Rodeo or Arsenal, mixed with a surfactant, could be conducted. The literature suggests that four to five annual applications, with two required per year are needed to be effective in managing mature stands. Young stands can be killed with one or two annual applications. One report found in the literature describes a study involving a cost of $65 per acre for a total of two applications in the same year, one at 4 pints of concentrate per acre to defoliate the mature stand and one at 2 pints per acre to reach the under story. If these costs are indicative, a substantial size test area could be selected.

If further research determines that the current effective discharge is less than 1,700 cfs (no evidence for this hypothesis was found), efforts to restore the 1,700 cfs effective discharge through sediment or flow management might be considered. Designing a different flow regime that might restore the effective discharge to 1,700 cfs in order to assure a bankfull capacity of 1,700 to 2,000 cfs could be attempted, depending on the availability of reliable sediment rating curves. It is believed that increasing the magnitude and duration of rates around the desired effective flow rate would be more effective than excavating bed material and/or sending pulse flows down the channel. Flow duration curves developed by Simons (2000) show that the 1990-1994 flows have essentially the same durations of discharges in the 1,700 to 2,500 cfs range as the periods 1940-1959 (however, less frequent occurrences were present in 1990-94 than in 1960-1989). Thus, the flow regime to produce an effective discharge of 1,700 cfs may not be significantly different than the current regime.

Until other data or evidences suggest otherwise, dredging of sediment in the main channel is not recommended. Nor is dredging of sediment in the relief chutes recommended, though removal of vegetation along a 500-ft wide corridor of main channel or in channel chutes near or downstream of the subject properties may be beneficial. Previous investigators have established that large quantities of sediment arrive in this reach from upstream, and any dredging of sediment without knowledge of or adjustments in other controlling factors would likely result in a rapid replacement by the river of the dredged sediments. Excavation of pilot channels through macroforms has been suggested as a means of accelerating their movement downstream, but this is not advised if the macroforms are causing the local flooding because they will re-form and may produce the same problems elsewhere.

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APPENDIX A

ALTERNATIVE HYPOTHESES REGARDING THE ALLEGED AND OBSERVED CHANGES IN STAGE-DISCHARGE AND DISCHARGE-FLOODING RELATIONSHIPS

A. GENERAL HYPOTHESES

1. Main channel capacity has decreased, causing overflow onto floodplain at lower Q's:
   a. Main channel has narrowed
   b. Channel bed level has risen (aggraded)
   c. Channel roughness has increased
   d. Vegetative encroachment in main channels has changed n-value
   e. Width has reduced due to declining peak or mean annual flows
   f. Effective discharge of unvegetated portion is less now than in the distant past
   g. Effective discharge of unvegetated portion is less now than in the recent past
   h. Stream bed has armored and no longer mobilizes at moderate flows, reducing bankfull carrying capacity
   i. Average velocity and depth have decreased, resulting in reduced sediment transport capacity
   j. Average velocity and depth at carrying capacity flow rates have decreased, resulting in reduced tractive forces on the bed and less conveyance during high flows
2. Floodplain stages are now higher for same discharge in the past as a result of aggradation:
   a. Floodplains have narrowed
   b. Floodplains have aggraded
   c. Sediment budget is imbalanced, transport in exceeds transport out
      i. Gravel/sand mining impacts caused this
      ii. Bed material from 3' to 10' incision zone near Kingsley has reached N. Platte
      iii. The energy grade line changed from steeper upstream to flatter in this reach
   d. Highway fill(s) have created slackwater zone resulting in deposition in main channel (delta effect)
   e. Tri-county diversion dam has created slackwater zone resulting in deposition upstream
   f. Slow-moving macro-forms have entered the reach creating a temporary elevated stage
   g. Depositional delta in the slackwater zone from Hwy 83 has reached the bridge and gage locations
3. Floodplain stages are now higher for the same discharge in past as result of changes in overbank roughness:

   a. Vegetative encroachment in floodplain chutes has changed n-value

4. Main channel capacity hasn't changed, but flows in excess of main channel capacity now flow in different routes or deeper on the overbanks:
   a. Vegetative encroachment has caused decline of secondary channel functions
   b. Macroforms have shifted, causing a temporary increase in overflow at breakout points near the macroforms – (suggested by Shearer and Boyd)
   c. Groundwater has risen, resulting in less infiltration of overflows or other hydrologic effects
   d. Natural runoff from lands north of Riverside Road has been directed onto subject property
5. Main channel capacity hasn't changed and overflows toward the subject properties have always occurred, but flows in excess of main channel capacity are now deep enough to flood subject property:
   a. Downstream effect of highway fill(s)
   b. Downstream blockage by reduced capacity of drain toward and downstream of the Hwy 83 box culverts
   c. Heavy development on the south overbank is forcing greater portions of the total flow onto the north bank
   d. Chutes on the north floodplain have been altered in some way as to force more water toward the subject property
6. Main channel and overbank chute capacities haven't changed and flows in excess of main channel capacity have always headed toward subject property, but they can no longer escape flooded property and return to main channel due to downstream alterations:
   a. Final, complete blockage of the natural chute toward the Hwy 83 box culverts occurred in the early 1990's
   b. Downstream blockage of the secondary channel that conveys water on the subject properties back to the main channel at bridge
   c. State bypass channel worked for a time, but had limited life and is no longer providing the relief
7. Subject properties are in harm's way, and are being flooded at no fault to actions by others
   a. Subject properties are in a natural low area
   b. Subject properties are in a former chute of the North Platte River
   c. Subject properties were developed only because the State diversion channel gave the appearance that the property was suitable for housing because natural ponding had been artificially, but temporarily, obviated

B. OTHERS' HYPOTHESES OF CAUSES OF CHANGES (FROM INTERVIEWS)

1. Shearer – level of flow fluctuates more than in the past
2. Randall – reduction in mean annual flow to 25 percent of historical

3. Kwapnioski – disagrees that a trend of change in bed elevation is actually occurring; looked at shifts in rating curves and noticed they went up and down over time; suggests it is possible that stage naturally rises and falls with little or no net change at any given location over time
4. Hawks – state diversion channel no longer functioning
5. Goecke – caused by blockage by road fills; alteration of historical drain through box culverts; strong groundwater discharge out of sandhills – water table in hills rose 2'-3' in 1990's; top of Ogallala is very shallow (12') and very hard at this location

APPENDIX B

EVIDENCES REGARDING VARIOUS HYPOTHESES

(Note: This appendix lists questions that would need to be answered to prove or disprove most of the hypotheses listed in Appendix A. Evidences regarding each issue, both pro and con, are provided below each question.)

1. Do evidences support the hypothesis of gradual, adverse changes in the stage-discharge or discharge-flooding relationships at the gage? (Due to its length, the response to this issue is included in Appendix C).
    a. NWS noted this change sometime between 1994 and 2002, not earlier
    b. Hydrographer's recall
        1) Vassos (Pers. Convers. 11/21/02) – "one of the most stable ratings around;" the shape of the rating curve stays about the same and only shifts up or down with the corrections; small shift was applied this fall and made retroactive through the water year
    c. USBR (2002) analysis suggests gradual long-term increases in stages for flows in the 2000 cfs range
    d. Stage/streamflow measurement records support abrupt change around 1991
        1) See Appendix C
    e. Rating curves – shifts recorded on streamflow measurement summaries do not support single-direction trends
        1) See Appendix C
2. Has there been a change in occasions and extent of observed high water on the north overbank?
    a. Lay observations
        1) Kemper (NGPC at Buffalo Bill campground) – definitely something going on (been there 2 seasons)
        2) Shearer – owned property on river 4 to 5 yrs; 1st noticed problem three years ago (2000)
    b. County and NDOR observations
        1) Hawks – has observed water on overbank from River Road over past 13 years
        2) Klasna – has frequently seen water on overbank around substation (23 years exposure – used to hunt north shore)
        3) O'Donnell – only got involved when water approached highways, but aware this area has experienced high water over the years
3. Do aerial photos show whether the main channel in the study reach has experienced recent or long-term changes in planform? This includes width changes, sinuosity changes, alignment changes, vegetative encroachment.

a. 1938 Well-braided channel, floodplain width at bridge roughly 8000 feet, photo shows evidence of historical channel north of east-west River Road passing directly through the location of the subject properties, little vegetation on sand bars

b. 1958 Reduction in braiding, floodplain width at bridge roughly 5000 feet with secondary channel culvert in use north of main channel bridge, northern main channel has been forced south, vegetation expansion occurring

c. 1978 Three major main channels developing, open channel width of main channels decreasing both up and down stream of bridge, sinuosity increasing, floodplain width at bridge roughly 3130 feet, drainage to north culvert has been blocked by temporary road fill, channel flow continuing to shift toward south upstream of bridge, sand bars completely vegetated

d. 2001 Well-developed anabranched/meander belt within channels, overbanks nearly completely vegetated

4. Do the aerial photos show whether there have been changes in the floodplain planform morphology or floodplain relief function at or upstream of the subject properties?

   a. 1958 Development of sandpit in former secondary channel on western edge of subject properties–roughly 2400 feet long

   b. 1971 Development of several other sandpits on western edge and along southern boundary of property, channel to Hwy 83 culvert on northern side is full of water, most likely standing

   c. 1978 Pond size west of subject properties has grown to roughly 5000 feet long, southern boundary ponds have disappeared, culvert under Hwy 83 appears dry

   d. 1983+ Appearance of new ponds on the north side of the highway, drainages to west of large pond on western boundary appear to be blocked, Hwy 83 culvert appears dry

   e. 2000 Ponds and blocked drainages still in existence, ditch to Hwy 83 culvert completely full of water, most likely standing

   f. 2001 Ponds and drainages still in existence, Hwy 83 culvert dry

5. Do the aerial photos show whether there have been changes in the floodplain planform or drainage function downstream of the subject properties?

   a. 1938 No ponds downstream of subject properties, clear that a primary conveyance channel of the river used to pass through the center of the subject properties

   b. 1958 Development of two small ponds on either side of Hwy 83

   c. 1978 Pond on eastern side of Hwy 83 doubled in size, new addition of a large pond on the west side of Hwy 83 downstream of the subject property, water drained from pond via Hwy 83 culvert to eastern side of Hwy 83

   d. 1983+ Addition of other ponds on both sides of Hwy 83, ponds on west side of Hwy 83 downstream of the property still appear to drain via Hwy 83 culvert to eastern side of Hwy 83

   e. 1993 Addition of more ponds on each side of Hwy 83, ponds on east side now appear to be draining to the south, entering the Platte at the bridge rather than paralleling the river

   f. 2001 Drainage from ponds on downstream side of subject property appears further modified

6. What do the aerial photos reveal about changes in the State's 1970 diversion channel?
   a. 1971 Diversion channel in place and 100% functional, drains water from northern channel, appears to be dissected by an easterly floodplain chute
   b. 1978 Diversion channel still functioning 100%, clearly see easterly channel cutting through it
   c. 1983+ Diversion captured by intersecting channel probably changing the dynamics, NDOR channel functioning at 50%
   d. Mid-1990's Diversion channel overgrown with portions and is indistinguishable from floodplain
7. Are macroforms evident throughout the study period, and what influence might they have on the discharge-flooding and stage-discharge relationships?
   a. Boyd/Shearer noted that one was probably causing the overflows two years ago
   b. Macroform at location reported by Boyd/Shearer possibly same one detectable upstream in earlier photo
   c. Unvegetated point bars are evident in most photos, macroform sizes are difficult to scale from photos
   d. FLO (1992) – transient sand bars are much larger, these macro-forms tend to move as waves
8. What are the lay and other evidences regarding general aggradation/degradation at the locale?
   a. Shearer – notably higher sand bar at Hwy 83 bridge; sedimentation at bridge "very obvious," 1st time had to duck under bridge when canoed
   b. FLO (1992) – 0.5 ft of degradation at N. Platte since 1932
   c. FLO (1992) – bed at N. Platte gauge has periodic 0.5 ft rise and fall with no net change
   d. FLO (1992) – notes that bed mobilizes during increased Q, increasing conveyance
9. What are the evidences regarding amount and mode of sediment transport in this reach?
   a. Kircher (1983) – 1941-79, average 660 tons/day; 50-yr average is 240,000 tons/yr
   b. Corps (1989) – 1940-86; 191,000 tons/yr
   c. FLO (1992) – banks in 1983 fairly stable, thus sediment source must be from the bed of the river
   d. FLO (1992) – transient sand bars are much larger, these macro-forms tend to move as waves
   e. Karlinger et al. – ditto FLO (1992) below Hershey
   f. Randall – 12' incision downstream of dam; no signs of incision 10 mi downstream; 1970-1998 average 300,000 tons/yr; sediment source not clear;
10. What are the evidences regarding upstream secondary channel conveyance and vegetation effects?
    a. FLO (1992) – side channels are becoming encroached by vegetation, increases resistance and assists in sediment deposition
    b. FLO (1992) – vegetation notably more prominent after 1977
    c. FLO (1992) – secondary channels have been abandoned, reducing capacity
    d. Shearer – vegetation growth largely in last 5 to 6 years

e. Peyton – *Phragmites australis* was first noticed in area in early 90's, exploded following high water in 1995+, invasion traveling west to east from about Ogallala to Overton, vertical growth rate reportedly as high as 2 ft/day

f. Lauren Brown's Textbook– Phragmites australis (typically 3 m tall) invades ditches, ponds and marshes that have been filled, diked, or otherwise altered – thus, encroachment is often a symptom, not a cause, of capacity disturbance; cutting or burning Phragmites is futile

g. Lewis – notable blockages of secondary channels by beavers and numerous rock-fill crossings around power substation and to the east

h. Shearer – several channels are blocked (a reference to area around the substation)

i. Klasna – majority of *Phragmites australis* growth was in the past 5 years (has 23 years exposure)

11. What are the evidences regarding fill, channel alterations, and vegetation effects downstream of the subject properties?

a. Hawks – Hwy 83 bridge shortened by 1000' in about1970

b. Hawks - In about 1970, the State placed fill to allow bypass for traffic and excavated diversion channel; fill remains

c. Hawks – Hwy 83 bridge deck widened 4 to 5 years ago,

d. Shearer – fill was recently placed in the downstream floodplain by a local judge, and in early 1970's for old bypass road

e. Shearer – north channel downstream of Hwy 83 is silted, doesn't flow

f. Hawks – channel downstream of Hwy 83 badly silted; city drain along railroad track on south bank upstream of bridge reverses flow direction during high water

g. Several – bypass channel excavated by State as part of 1970 Hwy 83 bridge reconstruction is no longer functioning

h. Lewis – capacity of former route under box culverts has been reduced to two 12" pipes which do not flow until after gravel pit fills to elevated flow lines of the two pipes

12. What are the evidences regarding morphology of, and conveyance capacity of, the main channel(s) in this reach?

a. Schumm – transformation not complete but has become more sinuous

b. Corps (1989) – all reaches within study area (12 mi of N. Platte) are relatively stable

c. Lewis – vegetative succession evident at locations examined

13. What are the evidences regarding "bankfull" capacity and capacity at "flood stage?"

a. FLO (1992) – historically, channel capacity was "easily 8,000 cfs,' 1992 was 3,050 at N. Platte, which equates to a 2- to 5-yr flood. (Editors note: This is undoubtedly a reference to carrying capacity, not channel capacity)

b. NWS – flow of 1,980 cfs and FS of 5.7 ft now restricts access to properties (this is not the same as the channel capacity), carrying capacity was 3,804 in 1994 (at FS of 6.0 ft)

c. FLO (1992) – bankfull decreases in downstream direction

d. Behm (COE 2002) – 2,000 cfs

e. Corps (1989) – bankfull is 1,700 to 2,000 cfs (using 1940-1986 data). Effective Q is 1,700 cfs; graph had a secondary peak at 3,700 cfs

f. USGS (1981) – effective discharge at N. Platte is 1,695 cfs (using 1941-1979 data)

14. Annual peak flow history since Hwy 83 bridge was shortened (year/Q cfs)

    a. 1971/ 9,600; 1973/6,900; 1983/7,800; 1984/6,200; 1995/ 3,100

15. Evidences regarding changes in groundwater levels

    a. Goecke reports substantial rises in sandhills north of town in recent years

    b. Conservation and Survey Division has 1979-80 and 1995 water table maps. Lewis and Goecke examined and saw no notable differences in study reach c.

APPENDIX C

EVALUATION OF CHANGES IN STAGE-DISCHARGE RELATIONSHIPS AT NORTH PLATTE GAUGE

(Note: As with Appendix B, the hypothesis regarding whether there have been changes in the hydraulic relationships at the North Platte gauge is broken into several issue categories, followed by descriptions of the findings of this evaluation.)

1. Has there been a consistent upward shift in the rating curves for flows around 2000 cfs?
    a. There has been no trend in rating shifts applied to the flows in the 1600 cfs to 2400 cfs range from 1971 to 2000 (Figure C1). Of the 101 discharge measurements in this range, 44 had a positive shift applied, 50 had a negative shift applied, and 7 had no shift applied. The cumulative shifts applied over this range and period is -0.33 ft. In addition, of the 101 discharge measurements, the conditions and quality of the measurements for 33 are labeled "Excellent", 61 "Good", 4 "Fair", and 0 "Poor".
    b. Likewise, there has been no trend in shifts applied to the narrower range flows in the 1900 cfs to 2100 cfs range from 1971 to 2000 (Figure C2). Of the 23 discharge measurement in this range, 15 had a positive shift applied, 8 had a negative shift applied, and 0 had no shift applied. The cumulative shifts applied over this range and period is 0.79. The shifts are evenly spaced over time. The ratings for the quality of 23 measurements are 7 "Excellent", 16 "Good", 0 "Fair", and 0 "Poor".
2. Have gage heights corresponding to the discharges around 2000 cfs changed in the short or long term?
    a. A plot of all gage heights for 101 flow measurements between 1600 cfs and 2400 cfs shows a cyclical progression, with as much as 1.5 ft of both upward and downward shifts (Figure C3). The peak in corresponding gage heights was in the early 1980s and a minimum in the late 1980s or early 1990s. Though extremely high annual peaks occurred in 1971 and 1973, gage heights for a flow of 2000 cfs were rising and continued upward until about 1981. The gage heights rose about 1.5 ft between 1972 and 1980, then declined about 1.0 ft between 1981 and 1989 when two high flows occurred. This 9-year half cycle was apparently disturbed by some occurrence around the mid-1990s when gages continued to rise. The data suggest that there has been an overall increase in corresponding gage heights, although we may be experiencing another crest and could experience another downturn. For the 10-year period from 1970 to the early 1980s a trend upward was evident. For the next 10-year period, from the early 1980s to 1990, a trend downward was evident. Again, for the last decade of the century from 1990 to 2000 we are again seeing a trend up. It is clear that the shifts are cyclical and not continuously rising as inferred by the USBR.
    b. A plot of all flow measurements between 1900 cfs and 2100 cfs, to hold discharge more constant, shows approximately the same trends in gage heights as the wider range (Figure C4). One difference is that the downward trend for the 1900 cfs to 2100 cfs range may be a couple years shorter. This is hard to detect because of a lack of data for this range in the late 1980s. However, the tighter discharge range has fewer outliers and forms a smoother curve.
3. Has the average depth of flow at the gage changed for the flows around 2000 cfs?

a. A plot of average depth of flow corresponding to the 1600 cfs to 2400 cfs range shows no change or a slight trend downward from 1971 to around 1991 (Figure C5). The trend then appears to step down about 0.6 ft by mid-1994, where it again levels off.

b. A plot of average depth of a narrower range of flows from 1900 cfs to 2100 cfs shows a more uniform trend downward from 1971 to 2000 (Figure C6). The average depth appears to be significantly lower starting in mid-1996 for the range. Of significance is that two measurements in 1982 had gage height difference of 0.7 ft. Due to a lack of data points for the years between mid-1991 to mid-1996, it is not evident whether the trend down was immediate or occurred over a several year period.

4. Has the cross-sectional area at the gage changed for flows around 2000 cfs?

a. A plot of all cross-sectional areas for flow measurements between 1600 cfs and 2400 cfs shows a cycling, but non-trending tendency, from 1971 to 1991 and a definite step upwards from 1991 to 2000 (Figure C7). By mid-1994 a significant quantum step in the cross-sectional areas is shown. A lack of data from mid-1991 to mid-1993 makes it difficult to determine if this was an immediate shift or whether it occurred gradually over the 3-year period.

b. A plot of all cross-sectional areas for a narrower range of flow measurements between 1900 cfs and 2100 cfs, to hold discharge more constant, shows the approximately the same trends as for the wider range (Figure C8). With the fewer flows in this range there is much less scatter and the horizontal trend from 1971 to mid-1991 is less cyclic. From mid-1996 to 2000 there is a 120 sq ft increase. Again, due to a lack of data points for the years between mid-1991 to mid-1996, it is not evident whether the trend up was immediate or occurred uniformly over the 5-year period.

5. Have water surface top widths at the gage changed for flows around 2000 cfs?

a. A plot of all widths corresponding to flows between 1600 cfs and 2400 cfs shows that the points are tightly grouped with a very minor trend towards increasing widths from 1971 to 1991 (Figure C7). In mid-1994 there is a very evident increase in channel widths of about 200 ft and an increase in scatter. A lack of data from mid-1991 to mid-1994 makes it difficult to determine if this was an immediate shift or whether it occurred gradually over the 3-year period.

b. A plot of all water surface top widths for a narrower range of flow measurements between 1900 cfs and 2100 cfs, to hold discharge more constant, shows approximately the same trends as for the wider range (Figure C8). With fewer flows in this range there is much less scatter and the trend from 1971 to mid-1991 is still virtually flat. By mid-1996 there is an evident 180 ft to 200 ft increase in channel top widths. Again, due to a lack of data points for the years between mid-1991 to mid-1996, it is not evident whether the trend up was immediate or occurred gradually over the 5-year period.

6. Have average velocities at the gage changed for flows around 2000 cfs?

a. A plot of average velocities corresponding to flows between 1600 cfs and 2400 cfs shows virtually no trend from 1971 to around 1989 to 1991 (Figure C9). The data points are well grouped with a very minor trend towards decreasing velocities. From 1991 to 1994 a more significant decreasing trend of 0.5 fps (20 percent) in average velocities occurs and then flattens off to 2000. The scatter of the plots appears to increase slightly after mid-1989.

b. A plot of all average velocities for a narrower range of flow measurements between 1900 cfs and 2100 cfs, to hold discharges more constant, shows approximately the same trends as for the wider range (Figure C10). With fewer flows in this range there is much less scatter but the trend from 1971 to 1989-1991 is still virtually flat. Post 1991 there is an evident quantum 20 percent decrease in average velocities. A transitional point in the decreasing velocities is evident in mid-

1991 and the velocities appear to hit a constant but lowered level by 1996 and continue at this level until mid-2000.

Figure C1. Shift Trend Over Time For 1600 cfs to 2400 cfs

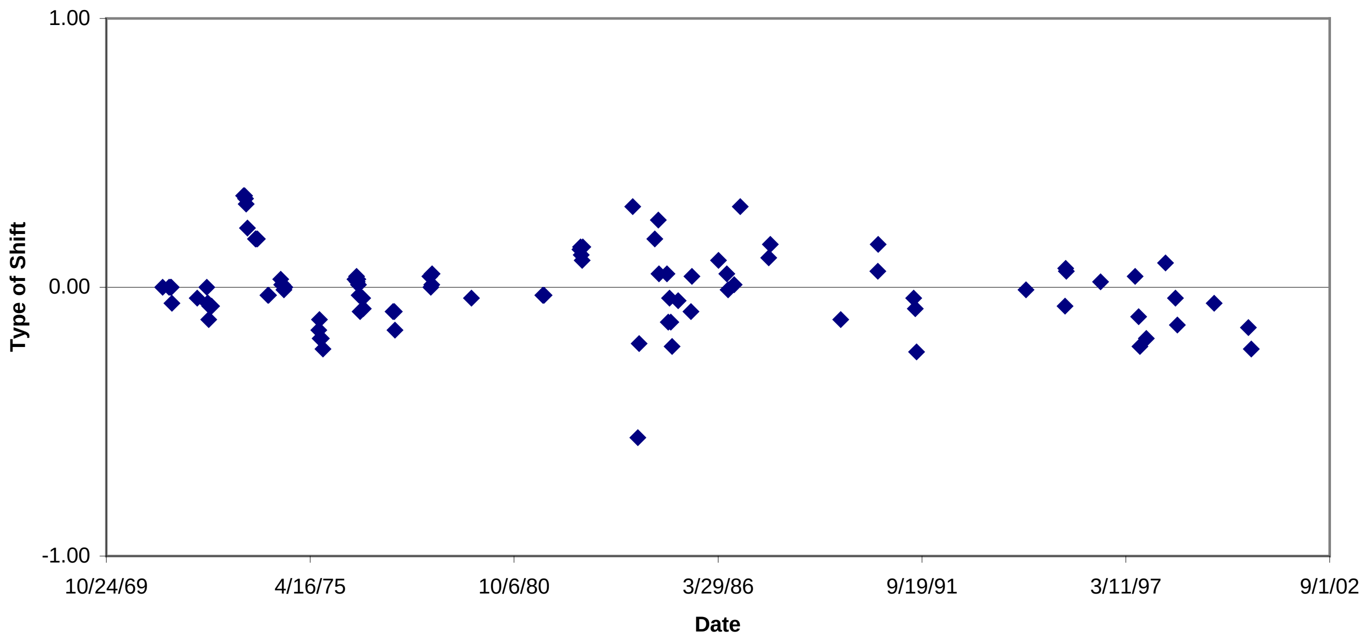


Figure C2. Shift Trend Over Time For 1900 cfs to 2100 cfs

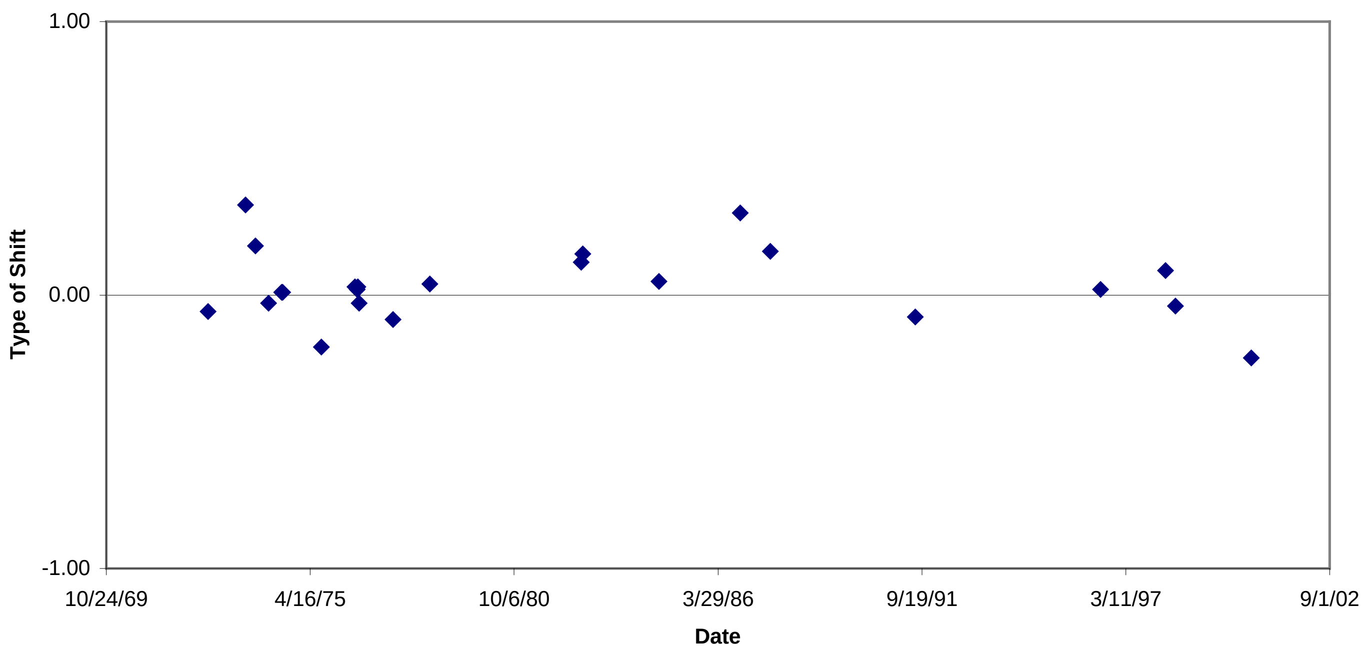


Figure C3. Gage Height Over Time For 1600 cfs to 2400 cfs

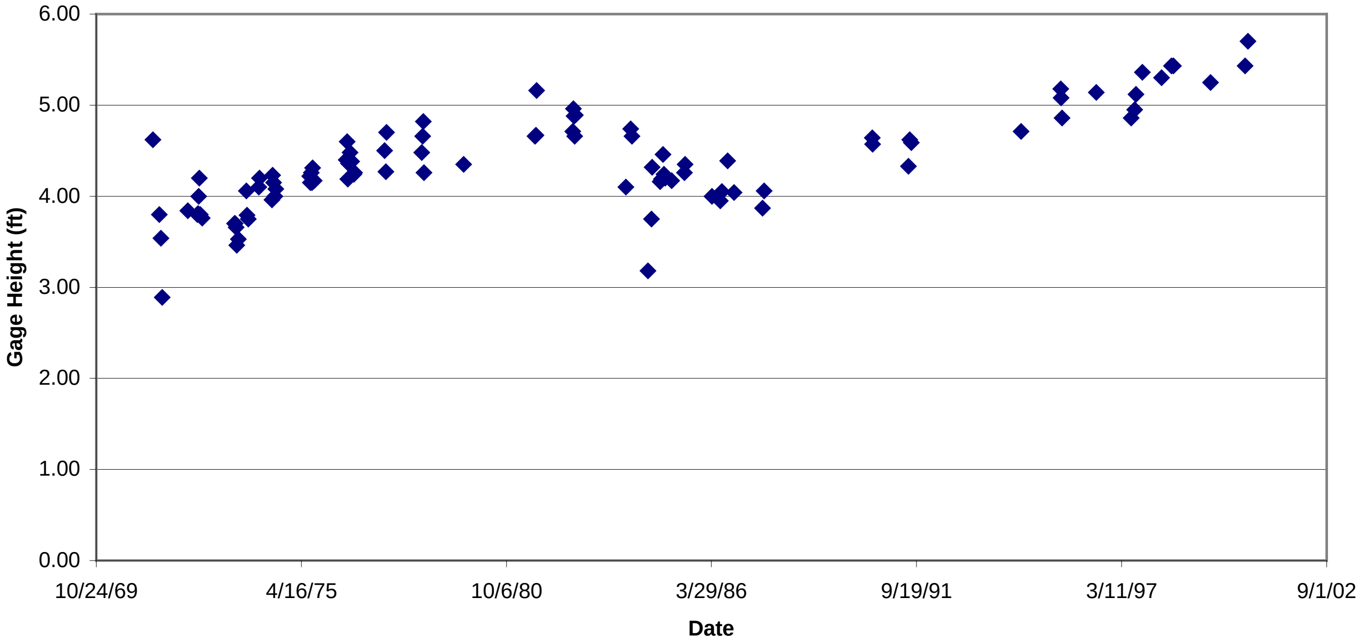


Figure C4. Gage Height Over Time For 1900 cfs to 2100 cfs

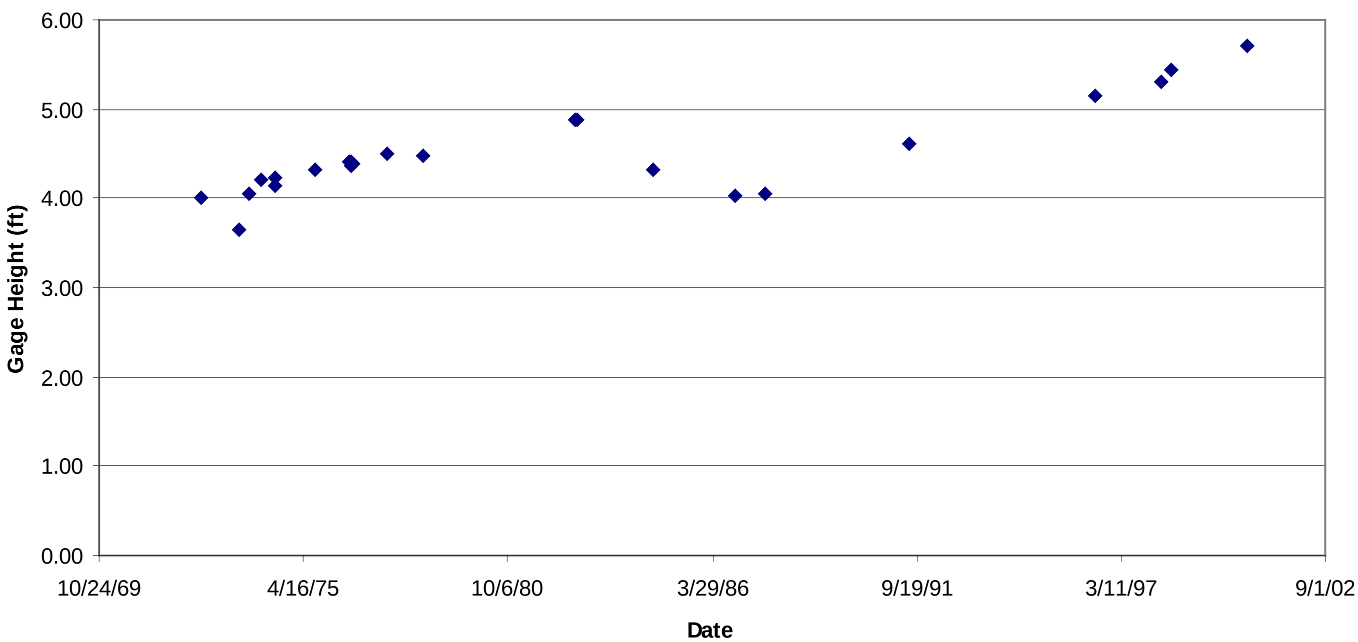


Figure C5. Trend In Average Depth Over Time For 1600 cfs to 2400 cfs

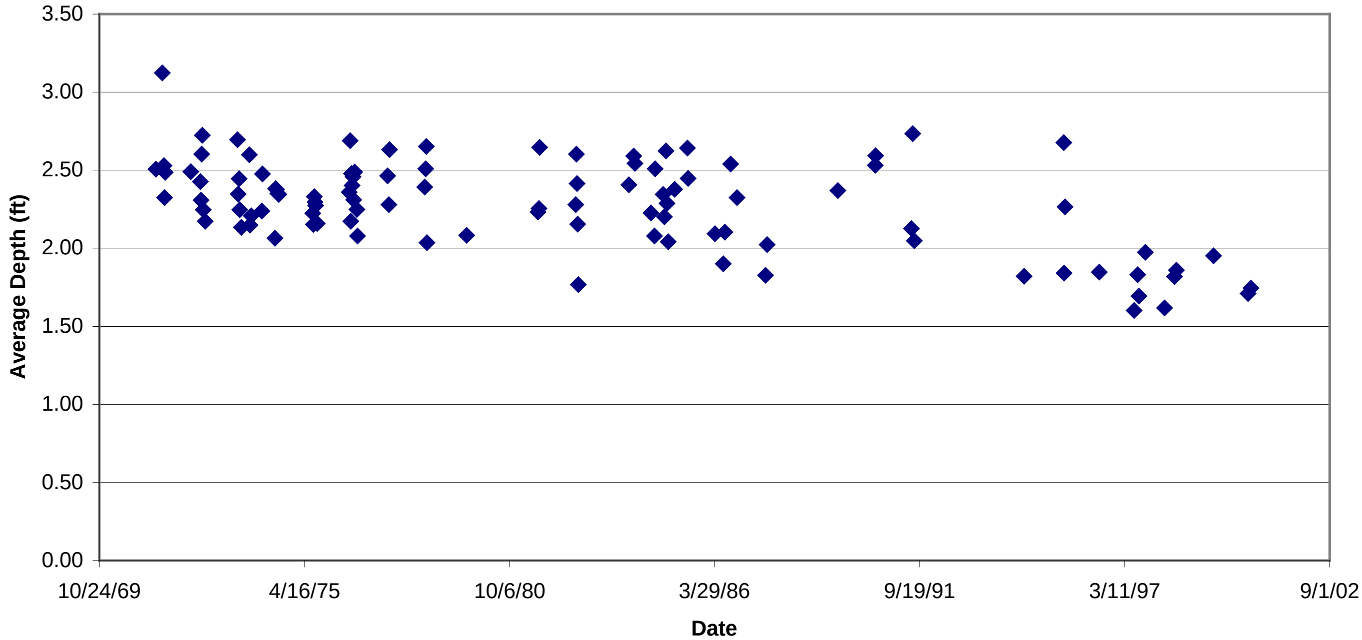


Figure C6. Trend In Average Depth Over Time For 1900 cfs to 2100 cfs

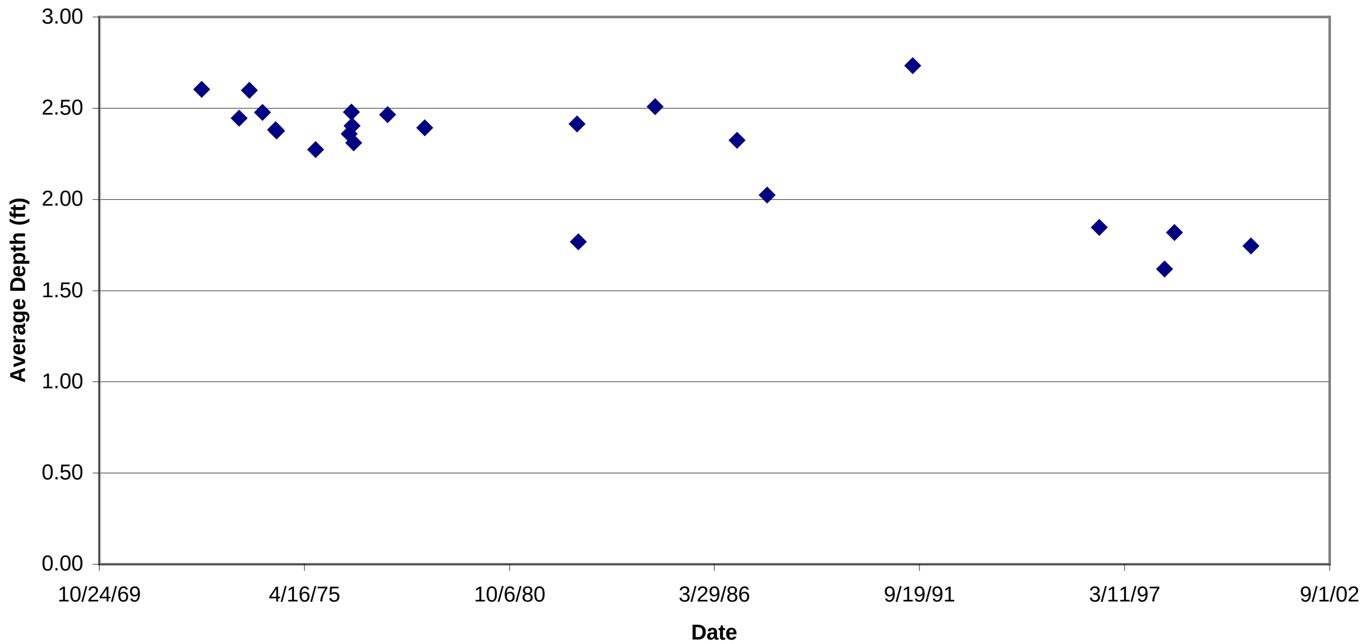


Figure C7. Trend In Cross-sectional Area and Top Width Over Time For 1600 cfs to 2400 cfs

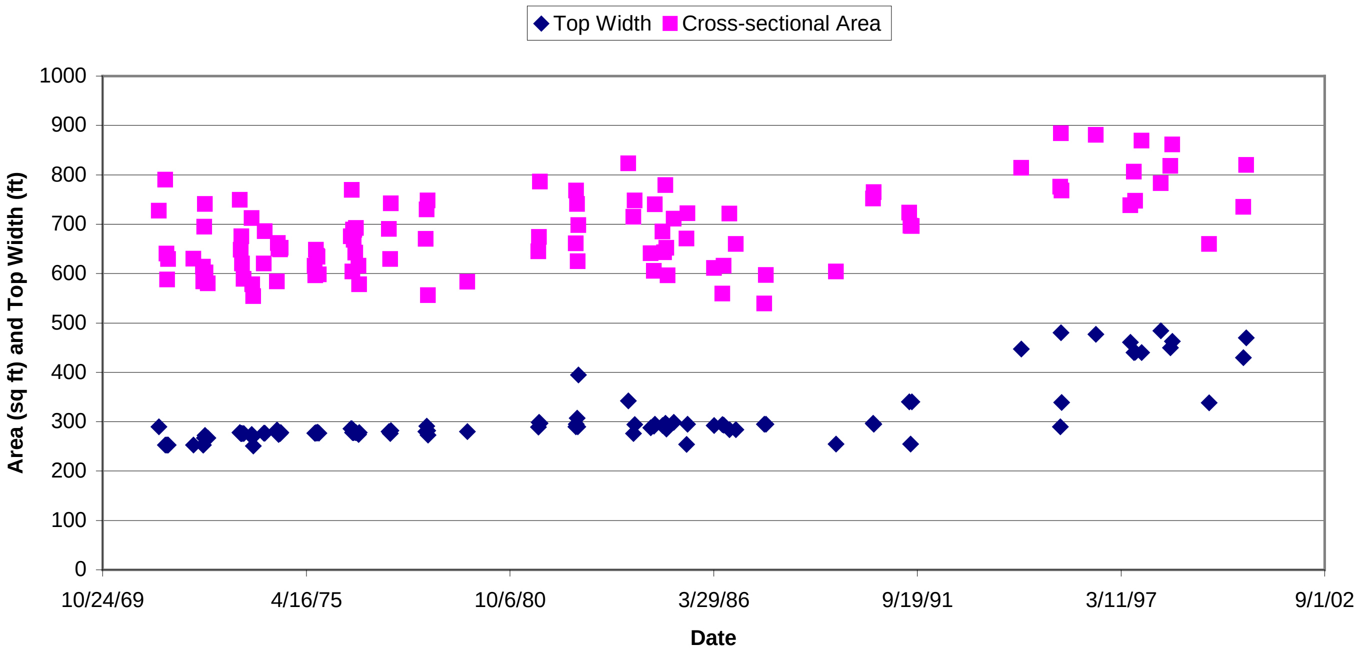


Figure C8. Trend In Cross-sectional Area and Top Width Over Time For 1900 cfs to 2100 cfs

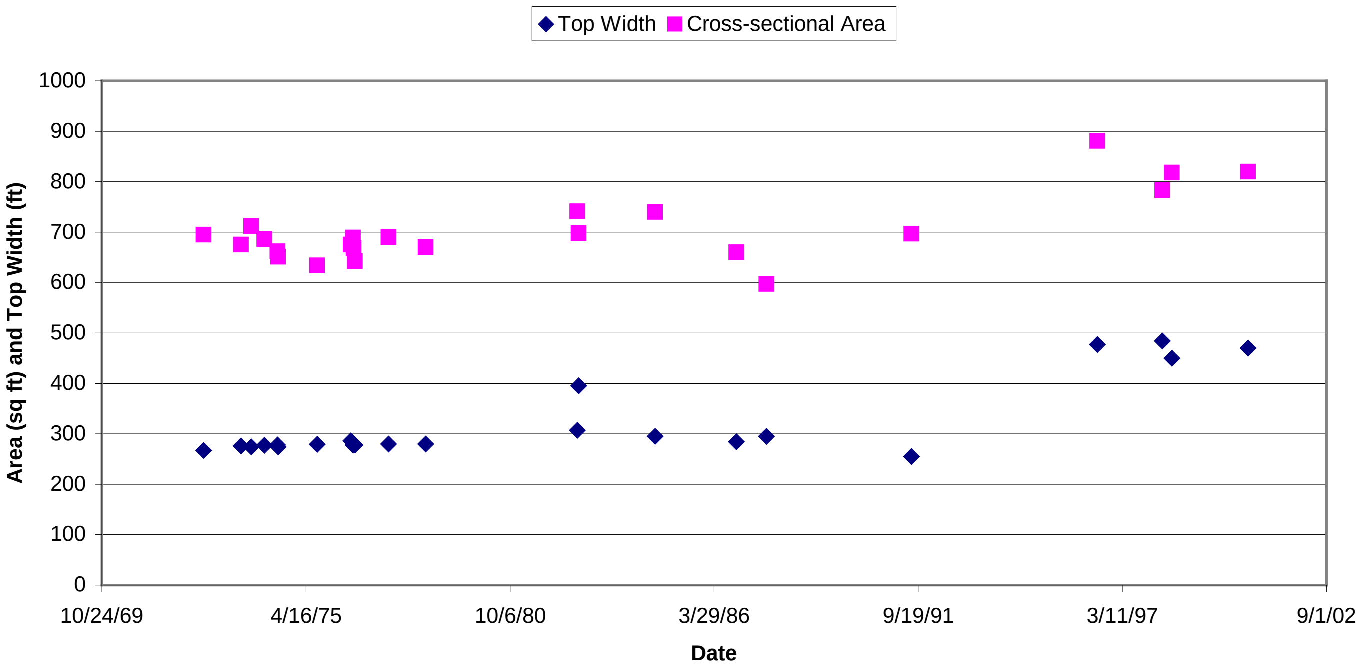


Figure C9. Trend In Average Velocity Over Time For 1600 cfs to 2400 cfs

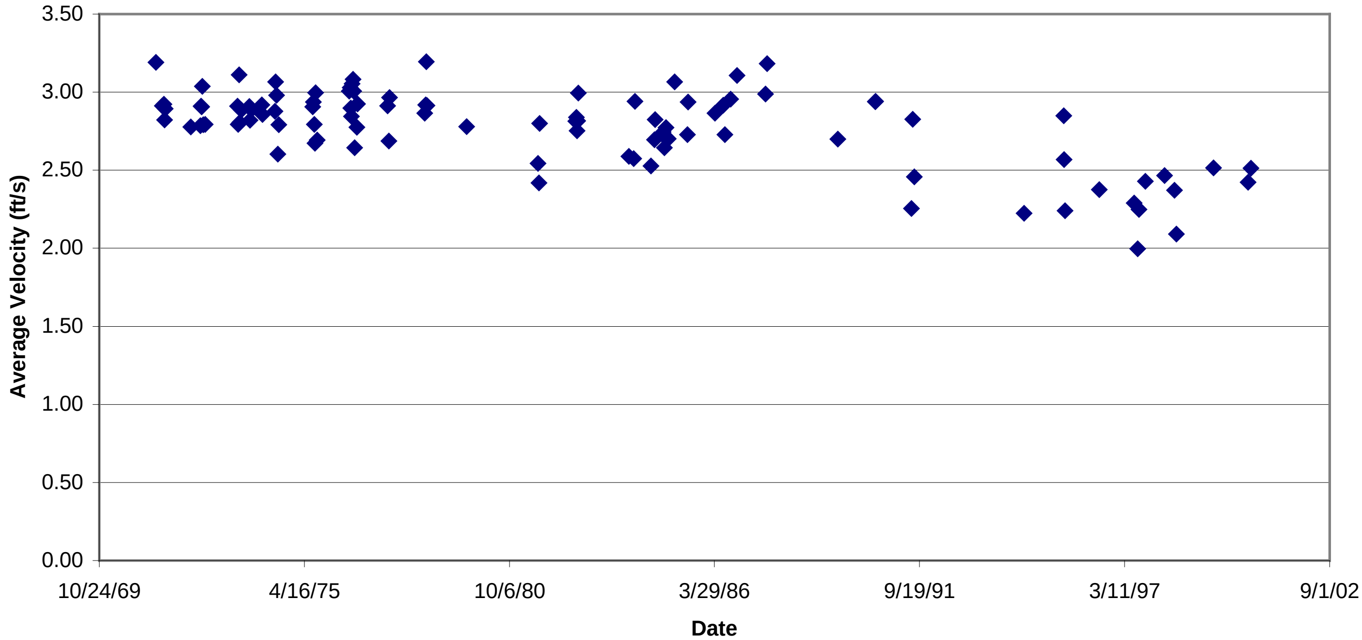
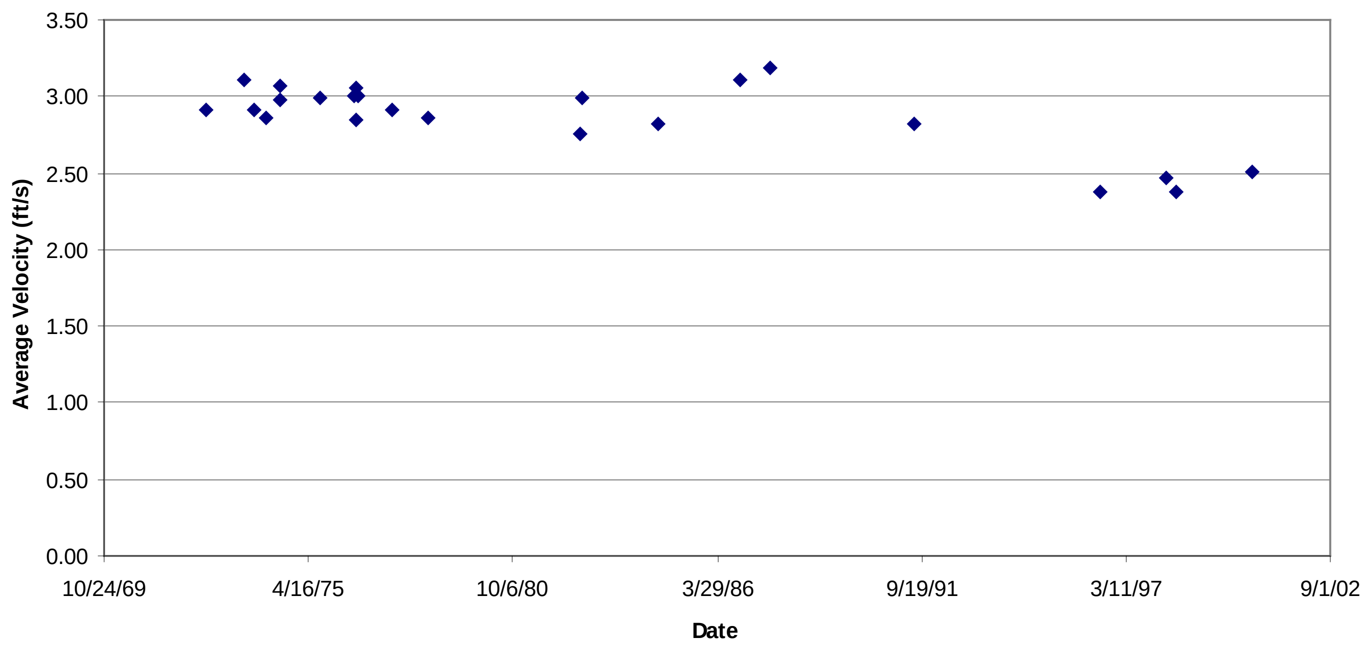


Figure C10. Trend In Average Velocity Over Time For 1900 cfs to 2100 cfs



APPENDIX D

SUMMARY OF PROPERTIES OF PHRAGMITES AND MANAGEMENT OPTIONS

Several inquiries were made regarding the properties of *Phragmites australis* and means of controlling their expansion. The most useful information was provided in the form of telephone conversations and reports supplied by Derek Dickinson and Walt Vering with Maxim Technologies. Their firm is involved in phased construction of wetlands for use by the City of North Platte in mitigation, and they experienced invasion by Phragmites in the first year. Mark Peyton with CNPPID and Amber Brenzikofer with Parsons also provided biological input to this survey. All advised that the plant be understood prior to attempting any management actions.

Based on these interviews and a casual reading of the technical journal articles, the following information was gleaned.

A. Properties of Phragmites

- Scientific name is *Phragmites australis* – named after Australian specimen discovered in 1799
- Same as *Phragmites communis*
- Common names are 'common reed," "giant reed," "giant reed grass"
- Reported to be the most widely distributed flowering plant in the world
- Wetland plant, classifies by Reed's classification system as "facultative wet species, 67% to 99%"
- Perennial, freshwater wetland plant, salt tolerant, also found in saltwater marshes
- Invades ditches, ponds and marshes that have been filled, diked or otherwise altered
- Inhabits open water up to 2 m deep
- Cannot spread in open water greater than 0.5 to 1 m deep
- Sudden changes in water level are deleterious
- Spreads by rhizome extension and budding, very large stands are often clones of a few individuals
- Rate of expansion by rhizome extension has been documented at over 10 m per growing season
- New plants have a much higher rate of expansion than mature plants
- Grows most vigorously about 2-4 years after germination
- Mortality in juveniles is high due to flooding, frost, salt
- Greatest invasions have been in East, Midwest, and Mississippi delta regions
- Invasion in U.S. is relatively recent phenomenon
- Presence has been noted in 1000-yr old clothing and blankets from Anasazi sites in southwest Colorado
- Native genotypes occur in some parts of the western U.S.

- Often find two distinct genotypes in stands; speculation that Old World import is mixing genetically with native genotype giving a hybrid that competes beyond the parent stock
- Accumulation of culms and litter at base results in elevated substrate
- Encourages sediment deposition

B. Theories of Invasion

- Environmental constraints have been minimized
- Nutrient loads have been increased
- Additional resources have been made available (light, space)

C. Management of Phragmites

- Causes of invasion, particularly increased nutrients, are here to stay; one authority states that the invasion cannot be reversed
- Flooding, water drawdown and burning are not effective – plant quickly re-colonizes de-vegetated areas
- Management should target the younger growth because it has the greatest rate of expansion
- Spray applications of Rodeo (glyphosate) have had 100% effect in some areas, with slow recovery
- Wipe on applications of Rodeo have had 38% effect in first year, 100% in 3 years
- Wipe-on applications of Arsenal (Imazapyr) have had 75% effect in first year, 100 % in 3 years
- Rodeo applications are more effective on young plants
- Young plants require one to two annual applications
- Established colonies require four to five annual applications
- Spring or fall burns tend to increase growth
- Summer burns tend to control spread
- Cutting or cutting plus herbicide applications decrease the number of plants per unit area and the percent cover
- Burning during the emergence period results in death of the majority of shoots
- Experts advise that Rodeo TM be mixed with surfactant to stick to plant
- Tests results with Rodeo/surfactant mix:
    - 4 pints/acre of concentrate resulted in 90-98 % kill in studied site
    - Must apply herbicide after tasseling stage (late August)
    - Must repeat later at around 2 pints/ac to get shaded plants
    - Two applications at 4 then 2 pints/ac reported to cost $65/acre
    - Native vegetation normally returns

APPENDIX E

POTENTIAL SHORT- AND LONG-TERM ADDITIONAL INVESTIGATIONS

1. Short-term, simpler investigations:
   a. Interview Marty Craig (Dawson Co.) and Jerry Valeski (UNL) regarding Phragmites and Reed Canary Grass history, longevity, and management options
   b. Walk the route of the primary overbank channel chute or chutes from the river bank near the location of the macroform noted by Boyd and Shearer in 2001 to the affected properties and document vegetative encroachment, beaver dams and rock barriers used for vehicle crossings. In addition, walk the length of the NDOR diversion channel beginning near the power substation and document lengths and locations of open and encroached segments.
   c. Check discharges in NWS report against adjusted rating curve for this water year (Mr. Vassos noted that he adjusted it at the end of the year and backed the adjustment through the year)
   d. Interview more landowners
   e. Check county and city records regarding when the improvements on the subject properties were made
   f. Use correlation methods to compare the cycling in stage height for 2000 cfs with other hydrologic parameters such as peak annual flows, presence and migration of macroforms, daily flows, or moving-averages of flows
   g. Compile available bed sediment grain size distribution data and compare its critical velocity with 2.4 fps, using sixth-power relationship to examine whether velocities at bed have fallen below critical velocities
   h. Sample bed sediments to test whether coarsening or armoring is evident
2. Longer-term, more time-intensive investigations:
   a. Plot the hydraulic parameters from 1940 to 1971 to extend the analysis of trends through the period when the Hwy 83 bridge was 1000 ft longer. Make adjustments using rating table values to normalize flow measurement parameters such as area, depth and stage to a single flow rate rather than a range of flows. This may remove some of the apparent scatter from the various data sets and focus the results and better identify the cause/effect relationships.
   b. Evaluate the relevance and validity of the 1991 abrupt change identified here for Q = 2,000 cfs, using other targeted flow rates, such as the 1994 flood stage discharge of 3,804 cfs. A flow around 3,000 to 3,500 should be selected, because the 3,804 cfs flood stage rate is greater than bankfull
   c. In field or laboratory, determine the threshold depth and velocity for mobilization of bed materials in this reach
   d. Develop new, or use others' sediment rating curves and determine historical and current effective discharges and evaluate 5-yr moving means in effective discharges, especially after 1990. Also evaluate flows contributing to the dual-peaked nature of the COE 1989 histogram.

e. Assess river operations and sediment rating curves to see if there is a regime that could raise the effective discharge to a higher level

f. Design and implement an experiment to test the "thicker bed mobilization layer" hypothesis.

g. Dig around trees for original floodplain level - Look for lateral instabilities or buried tree root levels as indicators of aggradation

h. Locate and re-survey USBR or other monumented cross-sections and evaluate aggradation hypothesis

i. Monitor breakout points and incoming and outgoing flow routes at the subject properties during high flow

APPENDIX F

POTENTIAL SHORT- AND LONG-TERM REMEDIATION ACTIONS

1. Identified by Randall (Pers. Convers. 11/25/02)
   a. Dredge a pilot channel down the main channel (unspecified location) and send pulse flow to enlarge channel
   b. Open gates at Tri-County to sluice upstream sediment
2. Identified by Corps (2002)
   a. Close upstream end of north main channel – dismissed by Corps due to environ/cost/maint measures
   b. Total closure of side chute(s) bringing water to subject properties – dismissed by Corps due to likely environmental impacts
   c. Cleaning the vegetation in the side chute to make it more efficient – dismissed by potential that main channel could shift, making problem worse
   d. Combination of two partial side chute closures (one just downstream of State diversion) and by cutting a pilot channel through large bar at upstream end – considered least intrusive and best long-term performance (Note: this bar was observed in 2001, but was no longer evident in 2002)
3. Parsons Alternatives
   a. The available options depend on which "leading" theory prevails regarding hydraulic changes
      1). If it's concluded that Phragmites caused the problem
         a. Test Rodeo application along any route desired for removal of water on subject properties
         b. Test Rodeo application on large stands along main channels to increase capacity
      2). If it's concluded that stages for flow of 2,000 cfs are cyclic (9 yrs up, 9 yrs down) and could drop 1 to 1.5 ft again
         a. Monitor stages for Q = 2,000 cfs and tie bed levels to datum
         b. Monitor macroform movement
      3). If it's concluded that macroforms caused the changes
         a. Wait until they pass
         b. Encourage their passage
      4). If it's concluded that the "dry-river" bankfull channel capacity is truly 1,700 cfs (the effective discharge) and that the carrying capacity is 1,980 cfs
         a. To the extent possible, regulate peak flows below the carrying capacity level

b. Evaluate possible options to increase the carrying capacity

c. Evaluate bypass options that prevent arrival of flows in excess of flood stage

5). If it's concluded that blockage of the drainage downstream of the subject properties is causing the problem

a. Remove the temporary bypass road fill material

b. Restore the drain way through the Hwy 83 culverts

c. Restore the State diversion channel

d. Improve the current drainage route along the west side of the temporary bypass road fill

3. The available options depend on the goal(s)

1). Is the goal to mitigate cause of flooding of subject properties?

2). Is the goal to provide/restore enough capacity to move 2,500 to 3,000 cfs?

a. If the goal is to mitigate flooding of subject properties

1). Restore natural downstream outlets through Hwy 83 box culverts

2). Restore State diversion channel

3). Regulate flows below FS

4). Flood-proof the properties (ring dikes, flood walls, elevate improvements, etc.)

5). Upstream diversion of arriving overbank flow

6). FEMA buyouts

b. The reach appears to be in dynamic equilibrium, with a channel capacity of around 1,700 cfs and a flood stage at around 1,980 cfs. If the goal is to increase carrying capacity to 2,500 cfs or higher

1). Dredging of sediment from the main channel to increase its capacity is not suggested because it could result in practically immediate replacement of the dredged material by incoming sediment. The channel would likely restore its most recent equilibrium condition, which is the present condition.

2). The COE estimated the effective discharge at North Platte in 1989 to be 1,700 cfs but their histogram showed a secondary peak of 3,700 cfs (using 1940 to 1986 data). An independent study by USGS (1981) resulted in a similar, single value of 1,694 cfs with no mention of multiple peaks.

3). The channel capacity, depending on location may vary in the dual-peak 1,700-to-3,700 cfs range depending on location in the reach, possibly affected by the presence or absence of macroforms. Waiting for the macroforms to leave, or encouraging their departure, might expand the reach lengths having the higher capacity.

4). It may be that providing/restoring a carrying capacity of 2,500 cfs or higher can only be accomplished permanently by increasing restoring the pre-1991 hydraulics or by altering the channel hydraulics to mobilize greater depths of bed sediment during high flows.

5). The carrying capacity might be increased to its pre-1991 value by attempting to contain the discharges at the carrying capacity rate within the width that existed prior to the 200 ft increase in flow width in 1991. Though the effective discharge before 1991 was also 1,700 cfs, high flows may have, under the narrower width and higher velocity conditions, mobilized a thicker layer of bed material, resulting in greater conveyance with no stage increase. Low-level berms along the banks might accomplish this dual goal. The decreased-depth-of-mobilized-bed hypothesis needs further evaluation.

6). If the current effective discharge is less than 1,700 cfs, a flow regime that might restore the effective rate might be designed, depending on the availability of reliable sediment rating curves. It is believed that increasing the magnitude and duration of rates around the desired effective flow rate would be more effective than excavating bed material and/or sending pulse flows down the channel.

7). Flow duration curves developed by Simons (2000) show that the 1990-1994 flows have essentially the same durations of discharges in the 1,700 to 2,500 cfs range as the periods 1940-1959, but less frequent occurrences than those experienced in 1960-1989. Thus, the flow regime to restore any loss of effective discharge may not be significantly different than the current regime.