APPENDIX A

SEDIMENTATION STUDY REPORT

LOUP RIVER HYDROELECTRIC PROJECT
FERC PROJECT NO. 1256

SEDIMENTATION

Loup Power District
Hydro Project

AUGUST 26, 2010

STUDY 1.0 - SEDIMENTATION

Serving You Electrically
LOUP POWER DISTRICT

Loup Power District
Hydro Project

Loup River Hydroelectric Project
FERC Project No. 1256

Study 1.0
Sedimentation

August 26, 2010

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STUDY 1.0 SEDIMENTATION

1. INTRODUCTION

The Loup River Hydroelectric Project (Project) is located in Nance and Platte counties, Nebraska, where water is diverted from the Loup River and routed through the 35-mile-long Loup Power Canal, which empties into the Platte River near Columbus. The Project includes various hydraulic structures, two powerhouses, and two regulating reservoirs. The portion of the Loup River from the Diversion Weir to the confluence with the Platte River is referred to as the Loup River bypass reach.

The Loup and Platte rivers both carry a large sediment load. When water is diverted from the Loup River, it enters the 2-mile-long Settling Basin. The Settling Basin is designed for low velocity to allow heavier sediment materials to settle out of the water before it enters the Upper Power Canal. A Sluice Gate Structure adjacent to the Diversion Weir is operated periodically to mobilize and remove accumulated sediment from in front of the Intake Gate Structure. This process conveys sediment into the Loup River bypass reach. As documented in the Pre-Application Document (PAD), a Hydraulic Dredge removes approximately 2 million tons of sediment from the Settling Basin annually (Loup Power District, October 16, 2008).

The U.S. Fish and Wildlife Service (USFWS) has asserted that Project operations, such as the removal of sediment through Project dredging at the Settling Basin, may affect the morphology of both rivers, which may affect sandbar development and, by extension, may affect interior least tern (*Sternula antillarum athalassos*), piping plover (*Charadrius melodus*), and pallid sturgeon (*Scaphirhynchus albus*) habitat. On the other hand, the District has contended that the morphology of both rivers is in a state of dynamic equilibrium and that any speculated effects on the diverse biological resources of either river are not a result of Project operations. To address this issue, the District conducted this sedimentation study. This study focused on four principal questions:

- How do Project operations affect sediment transport in the Loup River bypass reach and the lower Platte River, defined as the reach between the confluence of the Loup and Platte rivers and the confluence of the Platte and Missouri rivers?
- What is the stream morphology of the Loup River bypass reach and the lower Platte River, and how does that morphology vary over time?
- Is there a discernible relationship between any of the sediment transport parameters and nest counts of the interior least tern and piping plover?
- Is sediment transport a limiting factor for pallid sturgeon habitat in the lower Platte River?

These questions were used to form the goals and objectives of this study, which are described in Section 2. These goals and objectives and the proposed methodology were reviewed and approved by FERC in its Study Plan Determination on August 26, 2009.

2. GOALS AND OBJECTIVES OF STUDY

The goal of the sedimentation study is to determine the effect, if any, that Project operations have on stream morphology and sediment transport in the Loup River bypass reach and in the lower Platte River because stream morphology relates directly to habitat, and habitat may determine species abundance and success. In addition, the study will compare the availability of sandbar nesting habitat for interior least terns and piping plovers to their respective populations and will compare the general habitat characteristics of the pallid sturgeon in multiple locations.

The objectives of the sedimentation study are as follows:

1. To characterize sediment transport in the Loup River bypass reach and in the lower Platte River through effective discharge and other sediment transport calculations.
2. To characterize stream morphology in the Loup River bypass reach and in the lower Platte River by reviewing existing data and literature on channel aggradation/degradation and cross sectional changes over time.
3. To determine if a relationship can be detected between sediment transport parameters and interior least tern and piping plover nest counts (as provided by the Nebraska Game and Parks Commission [NGPC]) and productivity measures.[1]
4. To determine if sediment transport is a limiting factor for pallid sturgeon habitat in the lower Platte River below the Elkhorn River.

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[1] It was determined at the May 27-28, 2009, Study Plan Meeting that productivity measures (fledge ratios) are also an important indicator of the reproductive success of interior least terns and piping plovers. These data were provided to the District by NGPC for use in this study; however, limited data exist for interior least terns and piping plovers on the Loup and lower Platte rivers. Fledge ratios only exist for a few select sandpit sites adjacent to the Loup and Platte rivers between 2000 and 2008. 2005 is the only year of productivity data provided for sandbars in the Loup River. 2008 is the only year of productivity data provided for sandbars in the lower Platte River.

3. STUDY AREA

The study area includes the Loup River from approximately 5 miles upstream of the Diversion Weir, the Loup River bypass reach, and the lower Platte River. Specific study sites were selected based on the availability of gaged flow data from the U.S. Geological Survey (USGS) and Nebraska Department of Natural Resources (NDNR) and are listed in Table 3-1. The records at each gage station include daily and subdaily flow data as well as the associated rating curves and velocity and cross sectional data used to create the rating curves.

In addition to these study sites, the following three "ungaged" sites will also be evaluated:

- Loup River upstream of the Diversion Weir
- Lower Platte River downstream of the Loup River confluence and upstream of the Tailrace Return confluence
- Lower Platte River within 5 miles downstream of the Tailrace Return confluence

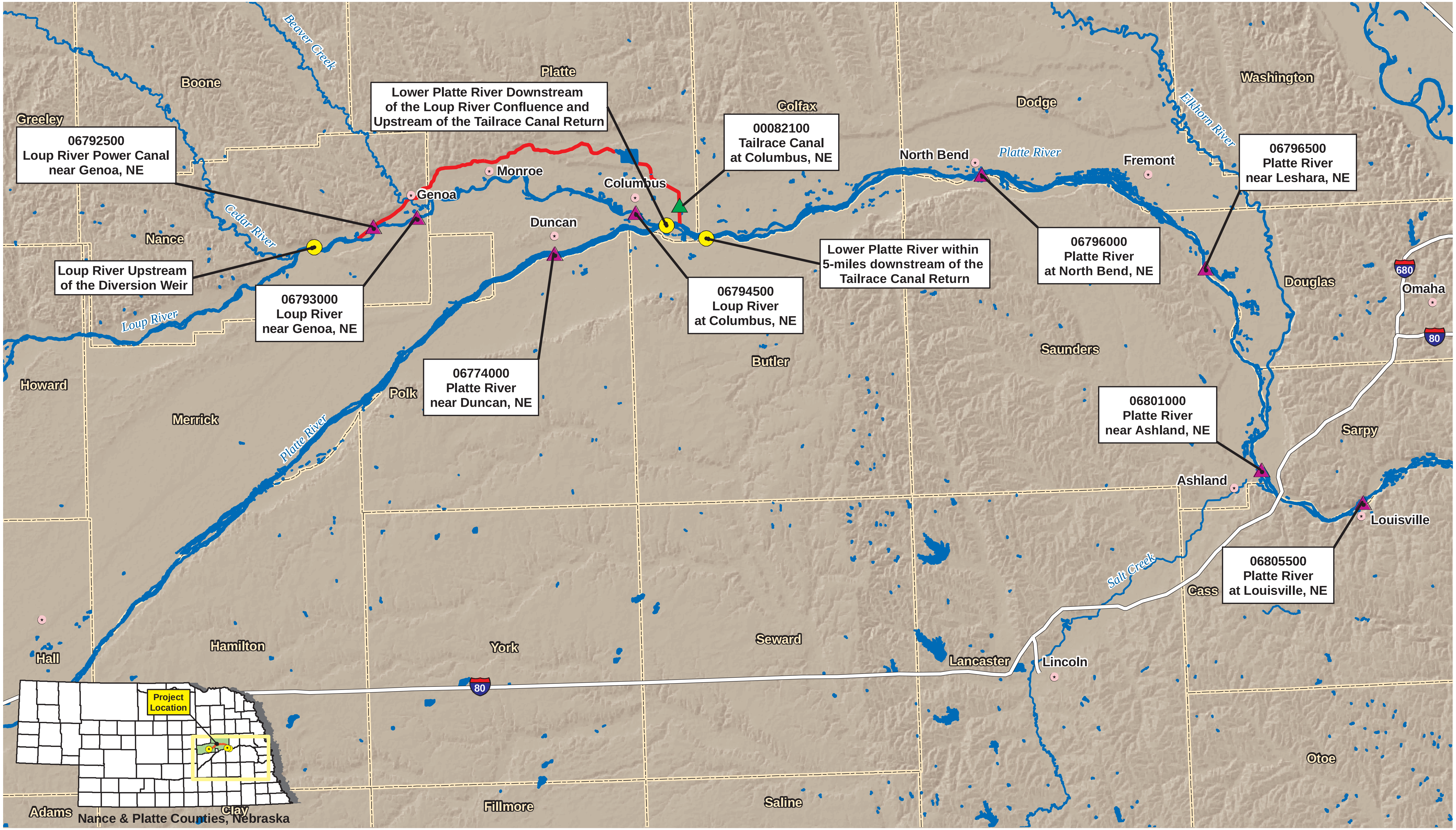
The Loup River site was identified in the Revised Study Plan, and the lower Platte River sites were added by FERC in its Study Plan Determination dated August 26, 2009. Figure 3-1 shows the extent of the study area and the study sites, including the three ungaged sites identified above. Two gage locations on the Loup Power Canal are also shown.

Table 3-1. Study Sites

USGS Gage Number	Gage Name and Location	Drainage Area (sq. mi.)	Mean Daily Discharge (cfs)	Period of Record	Comments
06793000	Loup River near Genoa, NE	14,320	989	1929 - Present	Available discharge and gage height data from April 1, 1929, to present includes daily and subdaily data.
06794500	Loup River at Columbus, NE	15,200	1,197	1934 - 1978	Available daily discharge and gage height data from April 1, 1934, to October 10, 1978. This gage was restarted by NDNR on September 23, 2008.
06774000	Platte River near Duncan, NE	59,300	2,078	1929 - Present	Available discharge and gage height data from May 3, 1895, to present includes daily and subdaily data. Data between 1895 and 1928 are incomplete. The period of record for continuous approved data is 1929 to present.
06796000	Platte River at North Bend, NE	70,400	4,938	1949 - Present	Available discharge and gage height data from April 1, 1949, to present includes daily and subdaily data.
06796500	Platte River at Leshara, NE	NA	4,834	1994 - Present	Available discharge and gage height data from June 29, 1994, to present includes daily and subdaily data.
06801000	Platte River near Ashland, NE	84,200	6,543	1928 - Present	Available discharge and gage height data from September 1, 1928, to present includes daily and subdaily data.
06805500	Platte River at Louisville, NE	85,370	8,273	1953 - Present	Available discharge and gage height data from June 1, 1953, to present includes daily and subdaily data.

Note:

NA = Not available.



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Miles

Source: Stream Gage, Nebraska Department of Natural Resources; Streams/Waterbodies, 2000 Tiger Files

Legend

- ⊙ City
- ▲ NDNR Gaging Station
- ▲ USGS Gaging Station and Study Site
- ● Ungaged Study Sites
- ═ Interstate
- — Stream/River
- — Loup Power Canal
- ■ Waterbody
- ☐ County

Loup Power District Hydro Project

Sedimentation Study Sites

Loup River Hydroelectric Project
FERC Project No. 1256
Study 1.0 - Sedimentation

DATE
August 2010

FIGURE
3 -1

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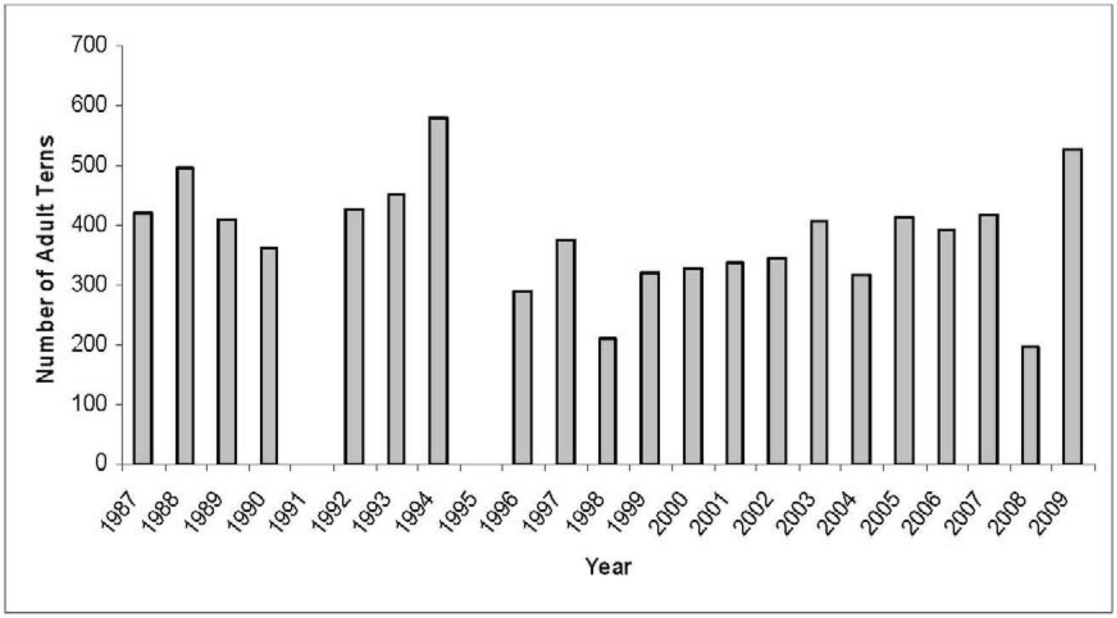
Within the study area, interior least terns and piping plovers use mainly the lower Platte River for nesting, breeding, and feeding. Interior least terns arrive in late April to mid-June and nest in colonies on open sandbars, gravel beaches, or exposed flats. Their nests are shallow depressions with small stones, twigs, or other debris nearby. Egg laying begins in late May with an incubation period of 17 to 28 days (USFWS, September 1990; Thompson et al., 1997). Fledging occurs 3 weeks after hatching, and departure from the colonies is usually complete by early September. Home range during breeding is limited to a reach of the river near the nest; however, this species has been known to fly up to 3.2 kilometers (Smith and Renken, 1990) and possibly farther (USGS, February 23, 2009) from the nest site to forage. Interior least terns are routinely seen in the lower Platte River. A significant colony of interior least terns have become established at the Project's North Sand Management Area (SMA), which has been included in the NGPC Nongame Bird Program's survey of interior least terns since 2007[2] (NGPC, November 30, 2007; Tern and Plover Conservation Partnership, July 30, 2008). A review of survey information from 1987 to 2009 indicates that interior least tern numbers have remained relatively stable in Nebraska during this period, as shown in Figure 3-2 (Brown and Jorgensen, 2009).



Note: No data are included for 1991 and 1995 because those surveys were not conducted during the standardized June summer survey window.

Figure 3-2. Total Number of Interior Least Terns Recorded on the Lower Platte River System, 1987 – 2009

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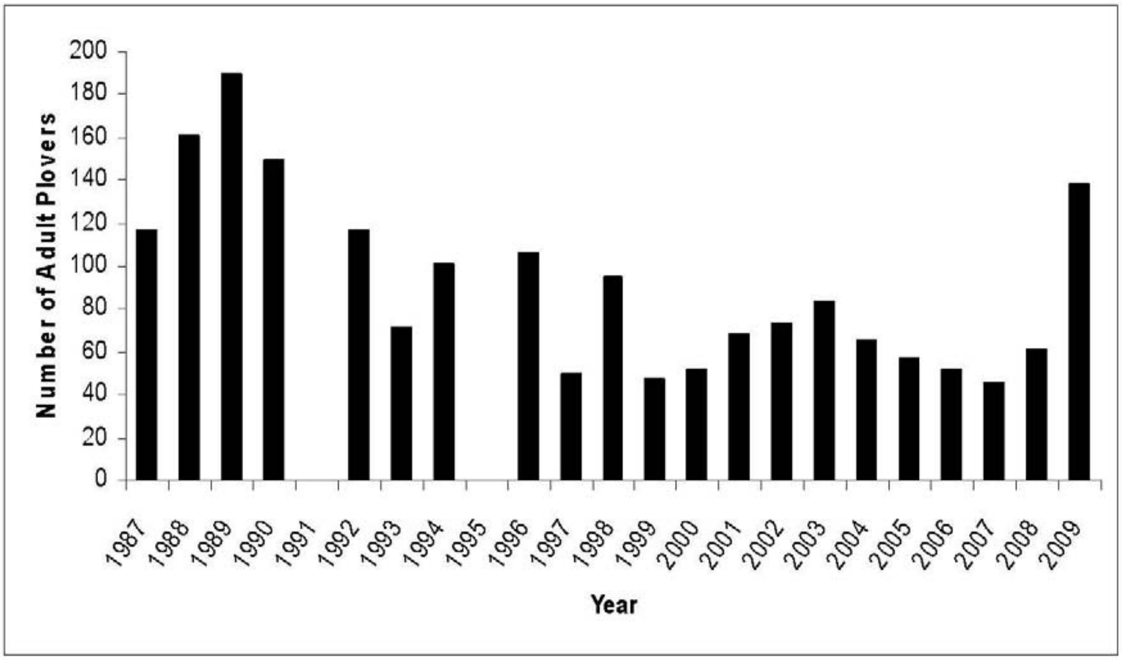
[2] Although the North SMA has been included in the NGPC survey only since 2007, interior least terns have been known to nest at the North SMA since the 1980s.

Piping plovers arrive in mid-April and breed in open, sparsely vegetated habitats, on sandbars in large open rivers, along sand and gravel shores of rivers and lakes, and in alkaline wetlands and sand flats. These migratory birds spend approximately 3 to 4 months on their breeding sites, with nesting and egg-laying commencing in mid-May. Hatching occurs in late May to mid-June (USFWS, 1988; Haig, 1992; USFWS, November 30, 2000). During this time, home range of the piping plover is limited to the wetland, lakeshore, or section of beach on which its nest is located. The shallow nests, frequently lined with small pebbles or shell fragments, are located on dry salt flats, barren sandbars, or gravel beaches with less than 5 to 20 percent vegetation (National Research Council, 2005). Piping plovers frequently nest in interior least tern colonies. Piping plovers are routinely seen in the lower Platte River and are also known to nest at the Project's North SMA, which has been included in the NGPC Nongame Bird Program's survey of piping plovers since 2007[3] (NGPC, November 30, 2007; Tern and Plover Conservation Partnership, July 30, 2008). A review of survey information from 1987 to 2009 indicates a slight decline in piping plover numbers in Nebraska during this period; however, after 2009 monitoring efforts, the numbers spiked in 2009, as shown in Figure 3-3 (Brown and Jorgensen, 2009).



Note: No data are included for 1991 and 1995 because those surveys were not conducted during the standardized June summer survey window.

Figure 3-3. Total Number of Piping Plovers Recorded on the Lower Platte River System, 1987 – 2009

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[3] Although the North SMA has been included in the NGPC survey only since 2007, piping plovers have been known to nest at the North SMA since the 1980s.

Prior to 2009, there were no known occurrences of pallid sturgeon in the vicinity of the Project. The most recent survey at that time was performed by Peters and Parham (2008) and documented the nearest pallid sturgeon occurrence in the lower Platte River at the confluence of the Elkhorn and Platte rivers, approximately 69 miles downstream of the Project. On March 31, 2009, in association with the University of Nebraska-Lincoln's (UNL's) Shovelnose Sturgeon Population Dynamics Study within the Platte River, a juvenile pallid sturgeon was captured upstream of the Elkhorn River confluence, near Leshara, Nebraska (approximately 55 miles downstream of Columbus) (Associated Press, April 10, 2009). Since the initial capture upstream of the Elkhorn River confluence, UNL researchers have captured an additional 9 to 11 juvenile pallid sturgeon in this reach of the Platte River; the furthest upstream capture occurred approximately 0.5 mile below the Tailrace Return confluence with the Platte River (UNL, July 14, 2010). In total, and along the entire reach of the UNL study (the Platte River confluence with the Missouri River to an upstream location approximately 30 miles west of Columbus), researchers captured 69 pallid sturgeon in 2009 and 20 to 25 additional pallid sturgeon through mid-summer 2010 (UNL, July 14, 2010). There are no documented occurrences of pallid sturgeon in the Loup River.

4. METHODOLOGY

The methodology used to complete the sedimentation analysis is described below. The results of the sedimentation study are discussed in Section 5, and supporting graphs and tables are included in Attachments A through D. The methodology for the sedimentation study includes six tasks designed to meet the four objectives presented in Section 2, Goals and Objectives of Study. These objectives and the tasks that were conducted to meet each objective are as follows:

- All four objectives
    - Task 1: Literature Review and Data Collection and Evaluation
- Objective 1: To characterize sediment transport in the Loup River bypass reach and in the lower Platte River through effective discharge and other sediment transport calculations.
    - Task 2: Sediment Budget
    - Task 3: Effective Discharge and Other Sediment Transport Calculations
- Objective 2: To characterize stream morphology in the Loup River bypass reach and in the lower Platte River by reviewing existing data and literature on channel aggradation/degradation and cross sectional changes over time.
    - Task 4: Stream Channel Morphology

- Objective 3: To determine if a relationship can be detected between sediment transport parameters and interior least tern and piping plover nest counts (as provided by NGPC) and productivity measures.
    - Task 5: Interior Least Tern and Piping Plover Nesting and Sediment Transport Parameters
- Objective 4: To determine if sediment transport is a limiting factor for pallid sturgeon habitat in the lower Platte River below the Elkhorn River.
    - Task 6: Pallid Sturgeon Habitat

4.1 Task 1: Literature Review and Data Collection and Evaluation

4.1.1 Literature Review

Numerous reports were available from USGS and others regarding the Loup and Platte rivers. All relevant reports were obtained and reviewed and are referenced throughout this sedimentation study report.

Both the Loup and Platte rivers are considered braided rivers; therefore, sediment transport is an important factor in retaining their natural characteristics (Donofrio, 1982). A braided river is defined as a river channel in which water flows around deposited bars and islands. It has been shown that for a given discharge, braided channels slope more steeply than meandering channels, which exist on relatively flat ground and tend to form relatively broad channels that wander back and forth like a snake. Braiding occurs when the steep slopes create high energy for sediment transport, when discharge fluctuates frequently, when the river cannot carry its full sediment load, where the river is wide and shallow, where banks may be easily eroded, and where there is abundant bed material available for transport. The position of the bars is changeable; sediment may be entrained by scour at channel junctions and then be re-deposited down-channel as flows diverge again and new channels are cut by overbank flooding (Mayhew, 2004).

Studies of morphology are important because morphology defines habitat. Ginting, Zelt, and Linard (2008) concluded that "[p]hysical processes that control the streamflow regime and channel characteristics govern the distribution of habitat availability and quality for fish…, and similarly may affect nesting habitat for shore birds…." In addition, Elliott, Huhmann, and Jacobson (2009) state that "geomorphic mediation of flow regime…provides an indirect assessment of sandbar habitat potential for least terns and piping plovers."

The shape and width of a river channel is an ever-changing function of the watershed supply of sediment (yield), flow, the quantity and size of the sediment load, and the character and composition of the materials, including vegetation, composing the bed and banks of the channel (Leopold, Wolman, and Miller, 1964). Streams that experience changes that deviate about average long-term morphologic characteristics are commonly said to be in dynamic equilibrium, quasi-equilibrium, or "in regime."

Watson, Biedenharn, and Scott (July 1999) state that a stable river, "from a geomorphic perspective, is one that has adjusted its width, depth, and slope such that there is no significant aggradation or degradation of the stream bed or significant plan form changes (meandering to braided, etc) within the engineering time frame (generally less than about 50 years). By this definition, a stable river is not in a static condition, but rather is in a state of dynamic equilibrium where it is free to adjust laterally through bank erosion and bar building."

Reviews of the literature on available tools for characterizing flow and sediment processes; utility of sediment budget analyses; validity of effective discharge methods, including the roles of peak flows in shaping channels; and applicability of regime theory are described below.

Tools for Characterizing Flow and Sediment Processes

Among others, the following qualitative and quantitative methods are considered by the scientific community to be state-of-the-art practices used in characterizing a river's morphology and assessing impacts of alternative operations on morphology:

- Sediment Budgets (applying the continuity equation to sediment yield, sediment transport, and changes in sediment storage)
- Hydraulic Geometry Relationships
- Effective Discharge Calculations combined with Regime Analysis
- Chang's Regime Channel Geometry for Sand-bed Rivers
- Leopold and Wolman's Regime Threshold Analysis
- Lane's Regime Method
- Lane's Law of River Adjustment

Standard texts on rivers, such as Richards (1982), provide state-of-the-art discussions of these tools in addition to numerous general observations regarding processes and characteristics of braided and anabranched[4] streams.

Experts not only agree that the above tools are state-of-the-art, but also conclude that computer models are not the preferred method for assessing river channel geometry adjustments due to alternative operations and should not be used for regulatory or management purposes (American Society of Civil Engineers [ASCE], September 1998a and September 1998b; Jacobson, Johnson, and Dietsch, 2009). Instead,

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[4] An "anabranched stream" is a stream that contains one or more secondary branches that rejoin further downstream.

sediment budgets and channel regime methods, especially when supplemented with effective and dominant discharge calculations, are recommended.

Sediment Budget Analyses

Detailed estimates of sediment yields in the Platte River Basin were developed by the Missouri River Basin Commission (MRBC) in September 1975. Although estimates of yield are useful for determining whether a river is flow or supply limited, the literature cautions users of indirect estimates of yield like those used by MRBC in performing aggradation/degradation analyses, noting that they have limited value in making aggradation/degradation conclusions. For example, USACE (July 1990) describes the indirect methods of determining yields as "indicators at best." Because direct measurements consist predominantly of suspended load values, USACE reports that suspended load measurements on average are the most relevant estimates of yields of this material. True yields in the lower Platte River, at least of material matching the river's bed material, are probably much closer to the measured transport rates than estimates by indirect methods.

Although useful for supply- versus flow-limited analyses, the sediment yields estimated by indirect methods by MRBC should not be used to assess whether the Loup or lower Platte rivers are aggrading or degrading. Better indicators of aggradation and degradation are available from long-term cross-section and channel flowline measurements over time as well as from assessments of trends in effective discharge (see Section 5.3 for the discussion of this analysis). Without variation, several independent investigations of long-term trends (see Section 5.3) conclude that the Loup and lower Platte rivers within the study area are neither aggrading nor degrading and have remained "in regime" (in a state of dynamic equilibrium) since the early 1950s (USACE, July 1990) or even longer (U.S. Department of the Interior, Bureau of Reclamation [USBR], April 2004).

Effective Discharge Methods

State-of-the-art tools to quantify and characterize flow and sediment transport in any river include effective and dominant discharge and regime methods. Generally, a small range of daily flows transports the largest fraction of total sediment load. These flows are widely accepted in geomorphologic literature as the flows that result in the average morphologic characteristics of the channel. These are called "effective" or "dominant" discharges. Specific literature addressing previous applications of these methods in the Platte River includes Kircher and Karlinger (1981); USGS (1983); HDR (1983); Parsons (May 2003); Hydrology Work Group (December 1989); USACE (July 1990); and Nelson, Dwyer, and Greenberg (1988).

A standard definition of how best to calculate the effective and/or dominant discharge has not emerged in the literature. However, the majority of references assign the same significance to both of these terms even though the method of calculating them varies.

The various definitions of both terms communicate their significance (that is, their role in shaping and maintaining river morphology), which has virtually universal agreement, as well as how they are calculated, which varies but does not impact the universally adopted significance. Whenever a single value is cited by an investigator for either term, the author is simply providing a single-value measure of the central tendency of channel forming/maintaining flows, all the while recognizing that a range of flows transport the sediment. At least some of the bed sediment in the Platte River is readily moved by all flows (Karlinger et al., 1983).

Calculation of either measure involves the mathematical convolution of day-by-day discharge rates with a sediment transport rating curve so that the entire history of daily discharges is incorporated in assessing what flows are shaping the river. The mechanisms of sediment transport in any river, and of the associated morphologies, are best defined by the entire hydrograph and sediment transport capacity of each day's flows. Effective or dominant discharge rates are simply standard statistical measures (mean, median, or mode) of the central tendency of the distribution of sediment amounts being transported by all the daily flows within the hydrograph. The analyses involve all the daily flow records.

Most investigators define the effective discharge as the modal (peak) value of a histogram developed from a class analysis of a number of equal increments of discharge (or logs of discharge) versus total long-term sediment transported by each class of flows. Kircher and Karlinger (1981) and USGS (1983) adopted this definition.

As often happens, the peaks of these histograms are broad-crested, and some analysts prefer to represent this by reporting a range of flows that transport the majority of the sediment, while others select a mid-point of this range, which may not occur at the overall mode. Uses of the centroid or median values of the histogram are also acceptable measures of central tendency of the discharges that transport the majority of the sediment.

The modal value is only a single-value measure of the central tendency of flows having the greatest impact on channel morphology. The range of flows transporting the majority of sediment generally covers two to four class intervals in the histogram distributed near the mode. USACE (July 1990) defined the effective discharges for Platte River locations as the mid-point of the highest bars in the broad-crested histogram. A similar approach was used by the District.

Some literature contains references to a different method of analyzing what flow rate is responsible for shaping the river. The dominant discharge is defined as the flow rate that, if continued constantly for the long term, would transport the same total load as the actual hydrograph. Dividing the total sediment transported over any time period by the length of the study and finding the corresponding discharge rate that carries that load from the discharge-transport rating curve produces this value. This definition and methodology has the advantage that it does not require separating the flows into discrete class intervals. Because the modal value of an effective discharge transport histogram varies with the number of discrete classes selected (USGS, 1983), the dominant discharge is an alternative method of assessing the channel-forming rate, requiring less qualitative judgment.

Parker (1978), for example, used this definition of dominant discharge for both the Middle Loup and Niobrara rivers. Although the result of this type of calculation is generally different than the effective discharge, his discussion makes it clear that he interprets its significance as being the channel-forming discharge. The terms effective discharge and dominant discharge always have the same significance even though methods of determining the values may vary. The dominant discharges discussed in Section 5.2.2 were determined using Parker's definition.

As an illustration of the industry-wide concurrence regarding the significance of these terms, Kircher and Karlinger (1981) and USGS (1983) determined Platte River effective discharges from North Platte to Ashland. They reasoned that the discharge that is "effective" in transporting sediment and shaping the river is "the mean value of a narrow range of water discharge that, by virtue of its frequency of occurrence and transporting capacity, transports on the average more sediment during the period of record than any other comparable water discharge" (Kircher and Karlinger, 1981). Karlinger et al. (1983) defined the effective discharge as "the water discharge that maintains the present channel cross section."

Thus, the terms effective and dominant discharge are used interchangeably, and although they sometimes differ in calculation method or value, they share the same significance (that is, a measure of the central tendency of flows that shape and maintain a stream's morphology and riverine habitat).

The studies cited above, as well as the results of this sedimentation study, reveal that the flows that are effective in shaping the river channel are moderately small in comparison to the large variability of daily flows, and even smaller in comparison with the high magnitudes of instantaneous floods. Among other investigators, Richards (1982) provides helpful insight into the often-challenged notion that instantaneous peak flows define a river's equilibrium morphology, although it is accepted that floods do have temporary influences. For braided rivers in particular, use of a frequency-based (1.5 year) flood flows or even "bankfull" estimate for the channel-forming discharge is sometimes attempted but never necessary because simple spreadsheet methods are available to determine the physical-process-based, effective (or dominant) discharge values.

Richards' experience with a large number of rivers led him to conclude that "most effective discharge classes in several streams … are well below bankfull stage." He notes that "in humid environments with more consistent flow and lower sediment yield from slopes during extreme events because of the protective effects of vegetation, more than 90% of sediment transport is by frequent events" (Neff, 1967, as cited in Richards, 1982). In summarizing his discussion of effective discharges, Richards concludes that the results “confirm that relatively frequent discharges dominate the transport of sediment.”

Regime Theory

When combined with effective discharge calculations, a methodology known as “regime analysis” provides a potent method of assessing stability of, and impacts of alternative operations on, river morphology (and habitat). As a precedent for use of regime theory in the Platte River Basin, the USBR report titled “The Platte River Channel: History and Restoration” (April 2004) applied regime theory to assess historical changes in plan form of the Platte River and to demonstrate the validity of using regime theory for assessing morphological aspects of the Platte River, as well as impacts of alternative operations.

USBR (April 2004) notes that:

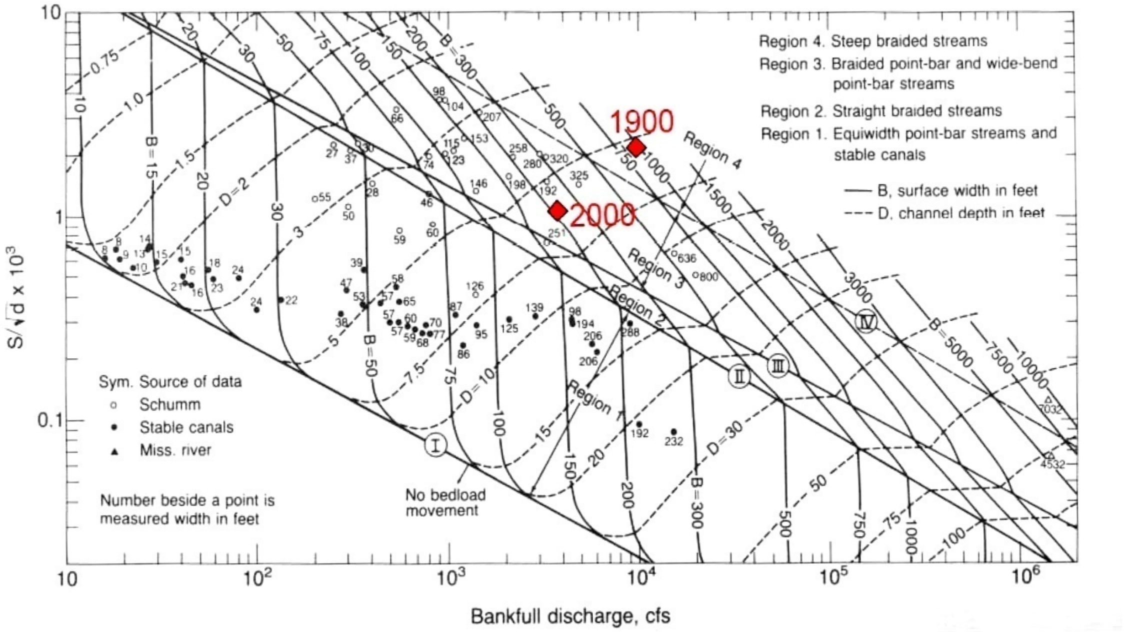
> The association of the quasi-equilibrium channel geometry of natural channels with flow rate, channel slope and sediment properties is called regime theory (ASCE 1998a). The braided pattern typical of the [Platte] river prior to the 1900s, requires a steeply sloped channel or an over supply of sediment. The average channel slope of the Platte River (0.00126) is considered steep for a sandbed river of this size. The slope has not changed during the1900s because a large change in river bed elevation is needed to change the average slope over the length of the river, and because the alignment of the river channel is still relatively straight.

The year 2000 channel bed profile developed by USBR in its April 2004 report is nearly identical to the turn-of-the-century profile developed by Gannett (1901). USBR notes that because the Platte River is relatively straight, extraordinary amounts of sediment would need to be moved in order to affect its profile.

USBR tested three widely adopted regime diagrams (Chang, March 1985; Leopold and Wolman, 1957; Lane, 1957), showing that all three are applicable to assessing the stability of the braided Platte River morphology as well as to assessing impacts of alternative conditions in the Platte River. These graphs are reproduced here as Figures 4-1, 4-2, and 4-3. Even though the horizontal axes of the graphs are either “bankfull” or “mean” discharge, it is clear from the original source documents that the intent was that the user would input the channel-forming discharge.

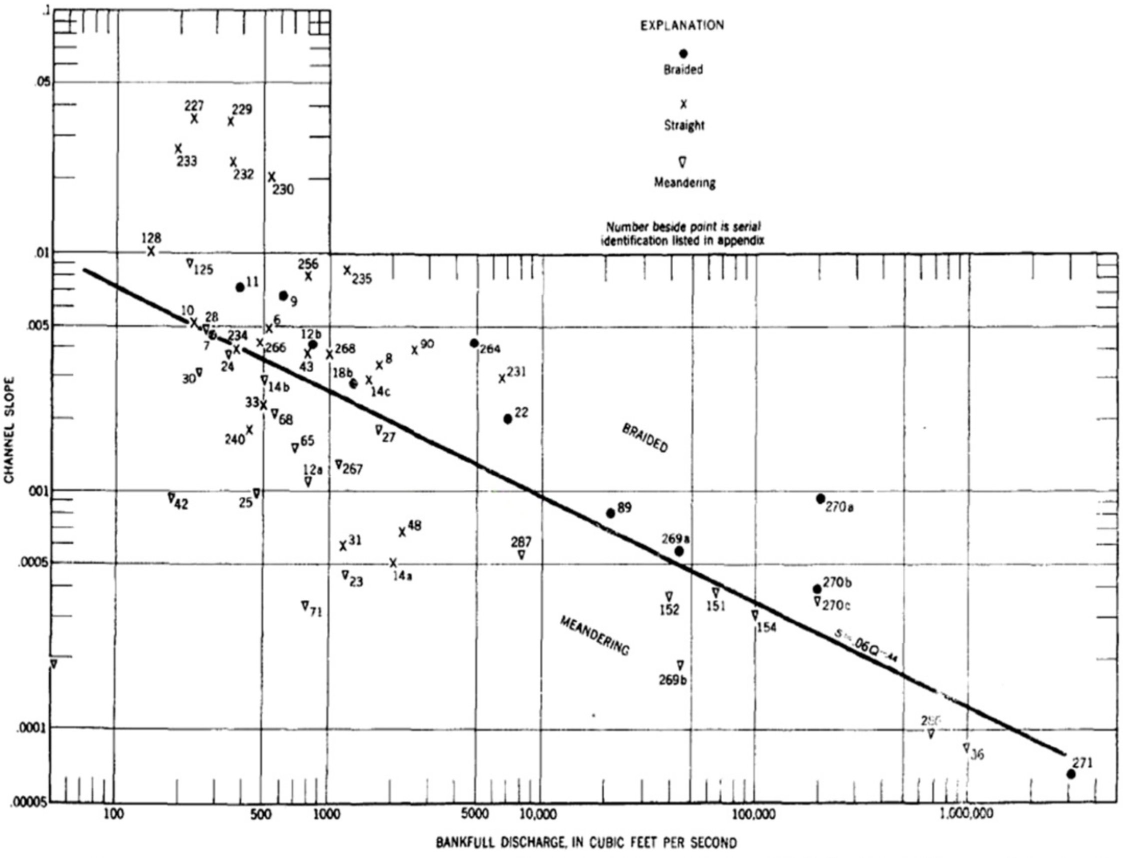
USBR (April 2004) concludes that “[r]egime theory does…provide a guide to the changes in channel geometry that can be expected with changes in the channel-forming discharge, bed slope, and…bed material grain size.” Aerial photos from 1939 to 1998 were evaluated and shown to support USBR’s conclusions about the validity of regime theory.

In its assessment of Platte River channel morphology, USACE (July 1990) adopted a definition of “in regime” that is typical of standards of the industry. The definition adopted by USACE was that a river is in regime “when a balance exists between all of the variables that affect it, and there is no net change in the river conditions.” However, USACE adds that regime is “a state of quasi-equilibrium in which there are fluctuations about a mean value for each of the variables, but there are no long-term changes in mean values.” Finally, USACE adds, “It is a good indication that a river reach is in regime when there is no aggradation, degradation, or change in channel pattern” (USACE, July 1990). Discussions of conclusions by USACE, USGS, and other investigators regarding the current morphological status of the study reaches are described in Section 5, Results and Discussion.



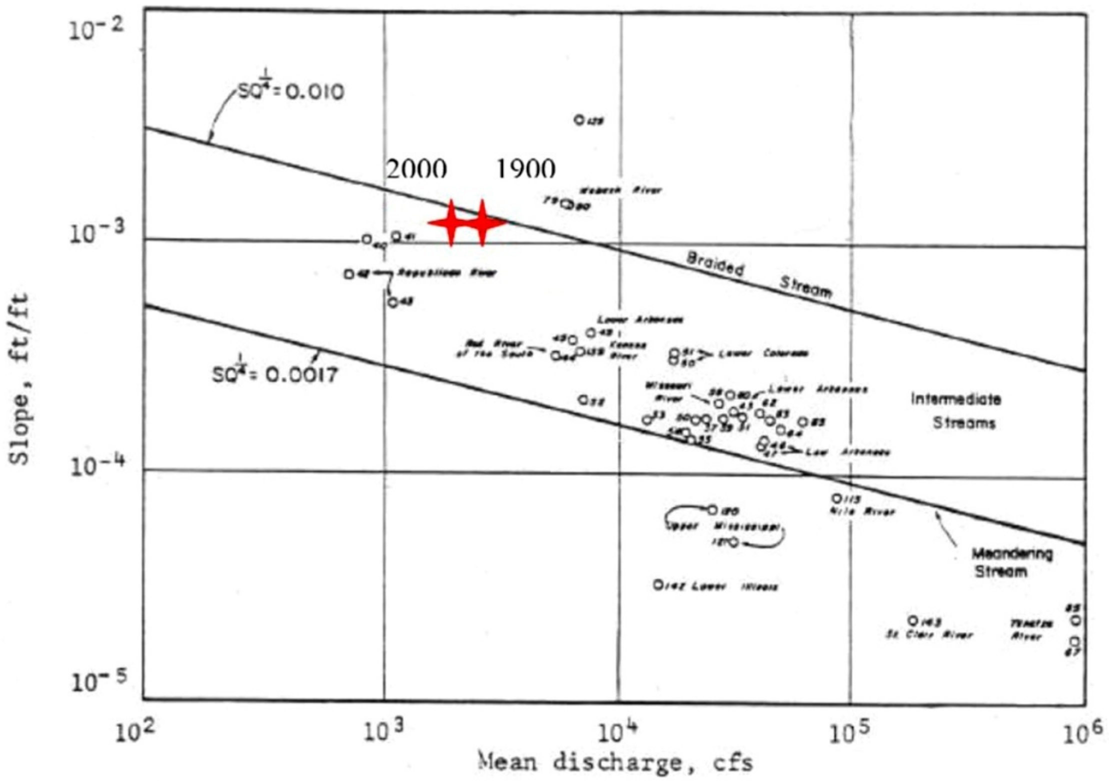
Regime channel bed geometry for sand bed rivers, from Chang (1985). For the historic Platte River channel (1900), the bankfull discharge was about 10,000 cfs, the median grain size was about 0.4 mm, and the slope was 0.00126. Therefore, the term [$(S/d^{0.5})$1000] was equal to 2.0. For the present Platte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

Figure 4-1. Chang’s (March 1985) Regime Morphology Chart for Sand Bed Rivers



Values of slope and bankfull discharge for various natural channels and a line defining critical values which distinguish braided from meandering channels.

Figure 4-2. Leopold and Wolman's (1957) Threshold Chart for Meandering and Braided Rivers



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

Figure 4-3. Lane's (1957) Regime Morphology Chart for Sand Bed Rivers

USBR's (April 2004) regime theory assessment of changes in plan form in the Platte River since 1900 show that parts of the river have changed but are still well within the regime zones for stable, braided rivers. Although the Leopold and Wolman graph (Figure 4-2) suggests that the Platte River has shifted from a braided stream to the threshold divide between braided and meandering, it does not incorporate grain size and does not include data from streams similar to the Platte River. Henderson (November 1961) incorporated particle size and obtained an equation that incorporated median material size.

USBR (April 2004) also assumed in applying Figures 4-1 and 4-3 that the bankfull discharge (which was USBR's interpretation of the channel-forming discharge) reduced from 10,000 cfs in 1900 to 4,000 cfs in 2000 but did not document that either are the effective discharges, especially in the lower Platte River. Meandering rivers are geomorphologically "old" streams. Given enough time, most braided rivers transition to meandering forms with age. Early literature on braided rivers described them as "an incipient form of meandering rivers," but braided rivers are no longer considered necessarily representative of disequilibrium in aggrading systems (Richards, 1982).

4.1.2 Data Collection and Evaluation

Numerous data sets were available from USGS and others regarding the Loup and Platte rivers. All relevant data were obtained and reviewed and are referenced throughout this sedimentation study report. Specific information acquired included streamflow measurement data, daily and subdaily discharges, stages, stage discharge rating curves, and sediment gradation and transport measurement data. Finally, District sediment (dredging and stockpiling) records were also acquired and analyzed.

The approved sedimentation study methodology includes cross-section surveys at three ungaged sites listed in Section 3. The cross sections have been surveyed, and a hydraulic model will be developed to approximate the hydraulics of the ungaged sites. However, due to summer flood flows and high winds, the cross section information was not obtained until June and July 2010. As a result, there was insufficient time to complete the analysis prior to submittal of this Initial Study Report. The results for the ungaged sites will be provided in the updated Initial Study Report in January 2011. The three ungaged study sites are to be used in only the current year spatial analysis. They minimally affect the spatial analysis and do not affect the temporal analysis.

Hydrologic analyses were performed for the study sites listed in Table 3-1 in support of this and other relicensing studies. A full description of the hydrologic analyses will be presented in Study 5.0, Flow Depletion and Flow Diversion. Annual and seasonal flood flow frequencies were calculated, and volume and flow duration curves were developed. The USACE computer program HEC-SSP was used for the analysis.

Interior least tern and piping plover population, nesting, and habitat information were obtained from NGPC for the lower Platte River.

Objective 1: To characterize sediment transport in the Loup River bypass reach and in the lower Platte River through effective discharge and other sediment transport calculations.

4.2 Task 2: Sediment Budget

The first task in characterizing sediment transport was to develop an updated sediment budget. An updated sediment budget was determined based on the sediment budget and sediment yield analysis completed by MRBC in September 1975. In the MRBC report, the Platte River Basin was divided into subwatersheds, one of which was the Loup River Basin. MRBC calculated annual sediment yields for each subwatershed by determining the sediment production from all erosion processes (sheet and rill, gully, and streambank). The MRBC sediment yield analysis was then used to calculate an annual sediment supply available to the river system.

Since approximately 1975, the amount of material (primarily sand) dredged from the Settling Basin has been reduced by nearly half (Loup Power District, October 16, 2008). FERC stated in its Study Plan Determination (FERC, August 26, 2009) that a system-wide reduction in sediment yield may be evidenced by the reduction in material dredged, reaching a fairly constant, but significantly lower, value around 1975. Therefore, the calculated sediment yield for the Loup River and its tributaries downstream of the Diversion Weir as well as downstream of the Tailrace Return was adjusted based on documented reductions from the Settling Basin.

Figure 4-4 shows the amount of sediment dredged from the Settling Basin by the District each year from 1937 through 2009. A table containing the amount of sediment dredged each year is included in Attachment B. This table provides dredged values in cubic yards as well as amounts in equivalent tons assuming the dredged material weighs 120 pounds per cubic foot. The amounts were converted to equivalent tons for comparison with calculated amounts of sediment transport capacities described in Section 5.2.1.

As shown in Figure 4-4, the amount of sediment dredged began to level off in approximately 1975. To adjust the MRBC estimates of yield, the average total dredged amount from 1940 to 1974 was calculated, as was the average total dredged amount from 1975 to 2009. The sediment yield reduction factor was found by dividing the post-1974 average dredged amount by the pre-1974 average dredged amount. Adjustments made to the MRBC yields are described in Section 5.2.1.

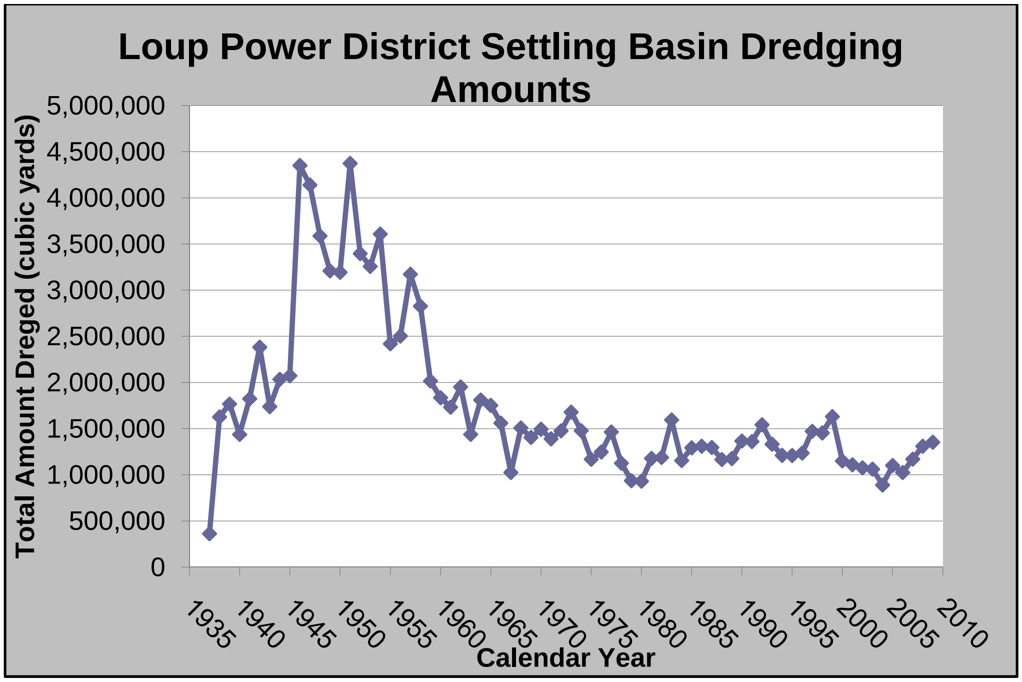


Figure 4-4. Loup Power District Settling Basin Dredging History

The sediment yield accounting presented in the MRBC report was reproduced and then recalculated to include the reduction factor in the Loup River watershed from the Diversion Weir to the Tailrace Return. The current sediment yield at each gaged location was then re-calculated using the reduction factor. The results are presented in Section 5.2.1 in Table 5-1.

The results of the revised sediment yield analysis were compared to the annual sediment transport capacity calculations, described in Section 5.2.2, to assist in determining whether the sites are currently flow or supply limited. In addition, the results will be compared spatially to other sediment transport calculations.

4.3 Task 3: Effective Discharge and Other Sediment Transport Calculations

The second task in characterizing sediment transport was to determine the daily, seasonal, annual, and long-term sediment transport parameters at the study sites listed in Table 3-1. The sediment transport calculations and associated analysis included the following:

- Determining sediment transport parameters, including daily calculations of the capacity of discharges to transport bed material sediment
- Grouping daily transport values to determine which discharges are “effective” or “dominant” in shaping the morphologies (and habitat) of the Loup River bypass reach and the lower Platte River by transporting the greatest amount of sediment

- Comparing cumulative sediment transport capacities with adjusted MRBC annual sediment yield estimates
- Applying regime theory to the effective discharges to assess whether the morphologies of the Loup River bypass reach and the lower Platte River are in dynamic equilibrium

The methodology used was based on gage data and subsequent calculations of daily values of the capacity of flows to transport bed material sediments in shaping the river. First, a relationship was developed between flow and sediment transport, resulting in sediment discharge rating curves. Second, from this relationship, several sediment transport indicators were calculated: total sediment transport capacity, effective discharge, and dominant discharge. These two subtasks are described below.

4.3.1 Sediment Discharge Rating Curves

A sediment discharge rating curve is a relationship between flow in a channel and the capacity that flow has to carry sediment. The rating curve shows the capacity for total sediment transport rate (both bed load and suspended load) in units of weight per unit of time versus discharge on a log-log scale. In analysis, flow is then used to predict sediment carrying capacity. This is useful because there is a more comprehensive record of flow than sediment carrying capacity. Analyses performed by Leopold and Maddock (1953), Yang and Stall (July 1974), Hey (1997), and many others show a relationship between sediment discharge and water discharge through the use of known values such as channel slope, hydraulic geometry, and shear stress. The sediment discharge rating curves that were generated at each study site listed in Table 3-1 and the resulting graphs and best-fit equations are presented in Attachment A.

Several well-established methods allow development of a relationship between sediment discharge and water discharge. Yang and Stall (July 1974) showed that for the Middle Loup River, Yang’s (1972) Unit Stream Power method and the modified Einstein method both adequately predicted sediment discharge capacity as well as adequately predicted USGS measurements of transport. The Unit Stream Power method provides a rating of total bed material transport capacity versus discharge, which is required for sediment transport capacity calculations. The modified Einstein method provides a rating of the total sediment transport rate, including wash load. Wash load, however, does not contribute to the geomorphology of the channel; therefore, the modified Einstein method was not chosen for use in this analysis.

For this sedimentation study, Yang’s (1972) Unit Stream Power method was implemented to generate sediment discharge rating curves. These were then used to determine the capacities for each day’s discharge to transport bed material at each study site.

Stream power is the product of slope and discharge. Slope directly affects flow velocity; consequently, a shallow, meandering stream with low slope generates less stream power, and has lower erosion and sediment transport capacity, than a deep, straight stream. The unit stream power is defined as the rate of potential energy expenditure per unit weight of water.

The following variables are used in Yang's Unit Stream Power method:

- Velocity/flow and depth/flow relationships
- Energy slope
- Particle size
- Kinematic viscosity
- Fall velocity

These variables and the data to support these variables for the study sites listed in Table 3-1 are discussed in detail below. Sediment gradation and transport data were only available for USGS gages at the Loup River near Genoa, Platte River near Duncan, Platte River at North Bend, and Platte River at Louisville. For the study sites with no corresponding USGS sediment data, the closest USGS site with sediment data was used as a surrogate.

The flow data used for the Loup River at Columbus for the study period (1985 to 2009)[5] was developed based on a relationship between the Loup River near Genoa and the Loup River at Columbus. Flow regression equations obtained from USFWS (May 15, 2002) were used to obtain a flow estimate at the Loup River at Columbus from the flow data at the Loup River near Genoa. This regression takes into account all gains and losses within the reach, including the addition of flow from Beaver Creek.

The discussion below describes the District's development of variables for use in Yang's Unit Stream Power method.

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[5] The study period of 1985 through 2009 is a 25-year period that was selected to correspond to those years for which adequate interior least tern and piping plover population information exists, namely 1986 to 2009.

Yang's Unit Stream Power Method

Yang and Stall's (July 1974) equation 19 describes Yang's Dimensionless Unit Stream Power Equation and is as follows:

$$\begin{aligned}\log C_t = {} & 5.435 - 0.286\, log(\omega\, d/\upsilon) - 0.457\, log(U_*/\omega) \\ & + [1.799 - 0.409 \log(\omega\, \mathrm{d}/\upsilon) - 0.314\, log(U_*/\omega)] \\ & \times\, log(V\, S/\omega - V_{cr}\, S/\omega)\end{aligned}$$

Where:

$C_t \equiv$ Total Sediment Concentration (parts per million)
$\omega \equiv$ Fall Velocity of Sediment Particle (ft/sec)
$U_* \equiv$ Sheer velocity
$d \equiv$ particle size – diameter (mm)
$\upsilon =$ kinematic viscosity (ft^2/sec)
$S \equiv$ energy slope (ft/ft)
$V_{cr}S \equiv$ Critical unit stream power required at incipient motion
$V \equiv$ Average water velocity (ft/s)
$V_{cr} \equiv$ Critical Velocity (ft/s)
$\omega\, d/\upsilon \equiv$ Fall Velocity Reynolds number

The sheer velocity (U_*) is calculated by:

$U_* = \sqrt{\frac{\tau_b}{\rho}}$ or rewritten as: $U_* = \sqrt{gravity \times depth \times slope}$

When the critical velocity is divided by the fall velocity, the result is called the Dimensionless Critical Velocity and is defined as:

$$\frac{V_{cr}}{\omega} = \frac{2.5}{log\left(\frac{U_* d}{\upsilon}\right) - 0.06} + 0.66, \qquad 0 < \left(\frac{U_* d}{\upsilon}\right) < 70$$

And

$$\frac{V_{cr}}{\omega} = 2.05, \qquad 70 \le \left(\frac{U_* d}{\upsilon}\right)$$

The results of the equation yield bed material concentration in parts per million by weight. For this sedimentation study, a water density at 15°C was used, which is 1 ppm and is equivalent to 0.00006243 pounds of sediment per cubic foot of water. The results of the equation were converted to tons of sediment per day by multiplying by the flow rate.

Velocity/Discharge and Depth/Discharge Relationships

USGS collects cross sectional data approximately monthly to aid in the continual adjustment of the rating curves used at each gage station. The cross sectional data is then combined so that a single width, area, velocity, and discharge are obtained for each cross sectional measurement event. For this sedimentation study, the water depth was found by dividing the area by the width. The cross sectional measurements used in this analysis were from 1984 through 2008, with 1984 being the earliest year the data was available electronically. All data from 1984 through 2008 were used to develop the velocity/discharge and depth/discharge relationships in order to provide enough data points at both lower flows and higher flows to allow development of the relationships through a large range of flow rates.

To use the surveyed USGS data as input for Yang's equation, the measured velocity and calculated depth were graphed versus measured discharge at each study site. A power equation trend line was fitted for each variable using Microsoft Excel. The trend lines for the depth/discharge and velocity/discharge rating curves did not adequately describe the data for all flow rates. Therefore, the rating curves were split into lower and higher flow curves, which fit the data much better. Figures 4-5 through 4-8 show an example of the velocity versus discharge and depth versus discharge at North Bend. Curves for each study site are shown in Attachment A. Width, depth, and velocity data for the Loup River at Columbus was collected starting in 2007 in preparation for reestablishing this gage in 2008; therefore, the velocity, discharge, and width graphs are not separated into low and high flows.

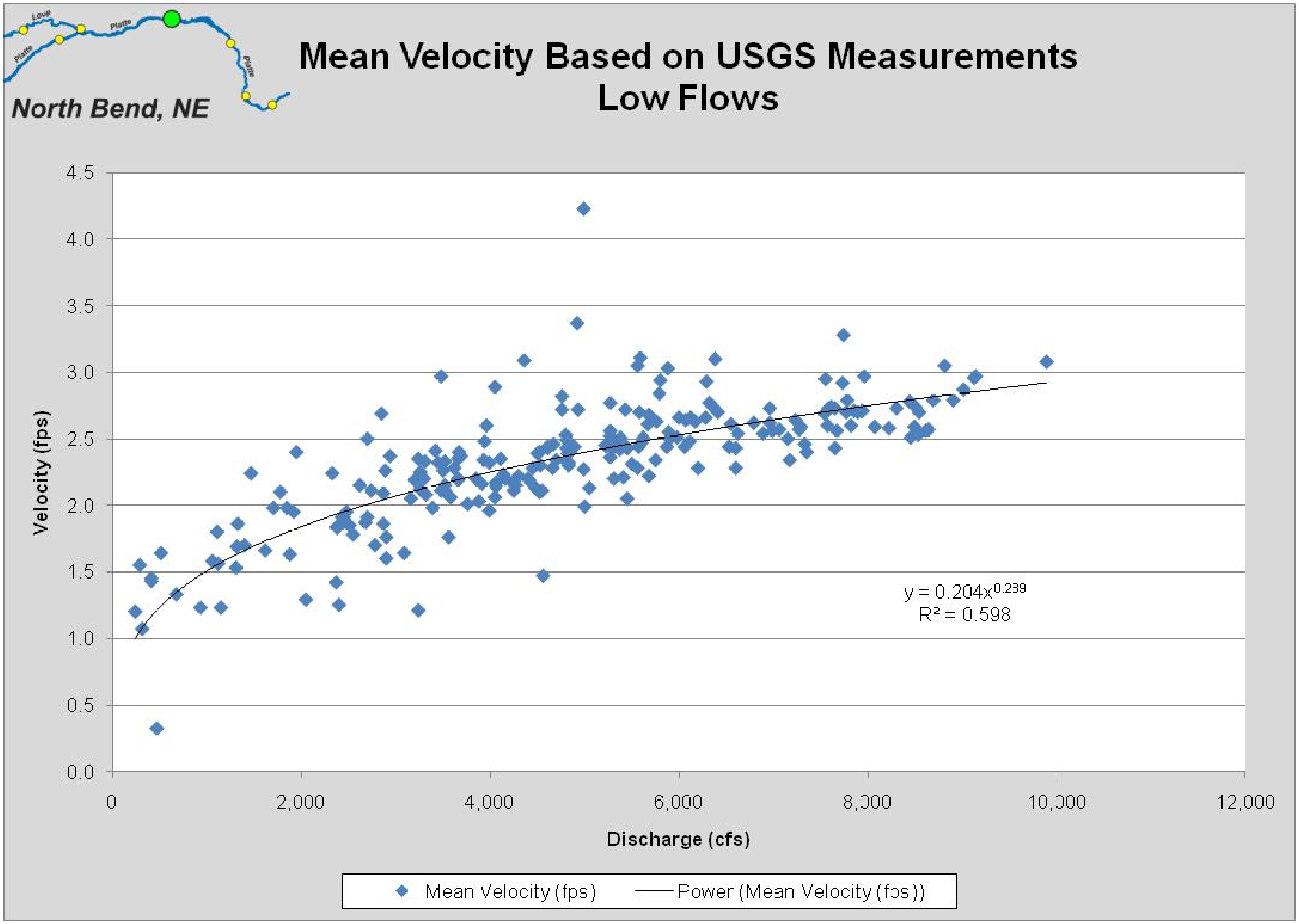


Figure 4-5. Mean Velocity Based on USGS Measurements, Low Flows, at the Platte River at North Bend (USGS Gage 06796000)

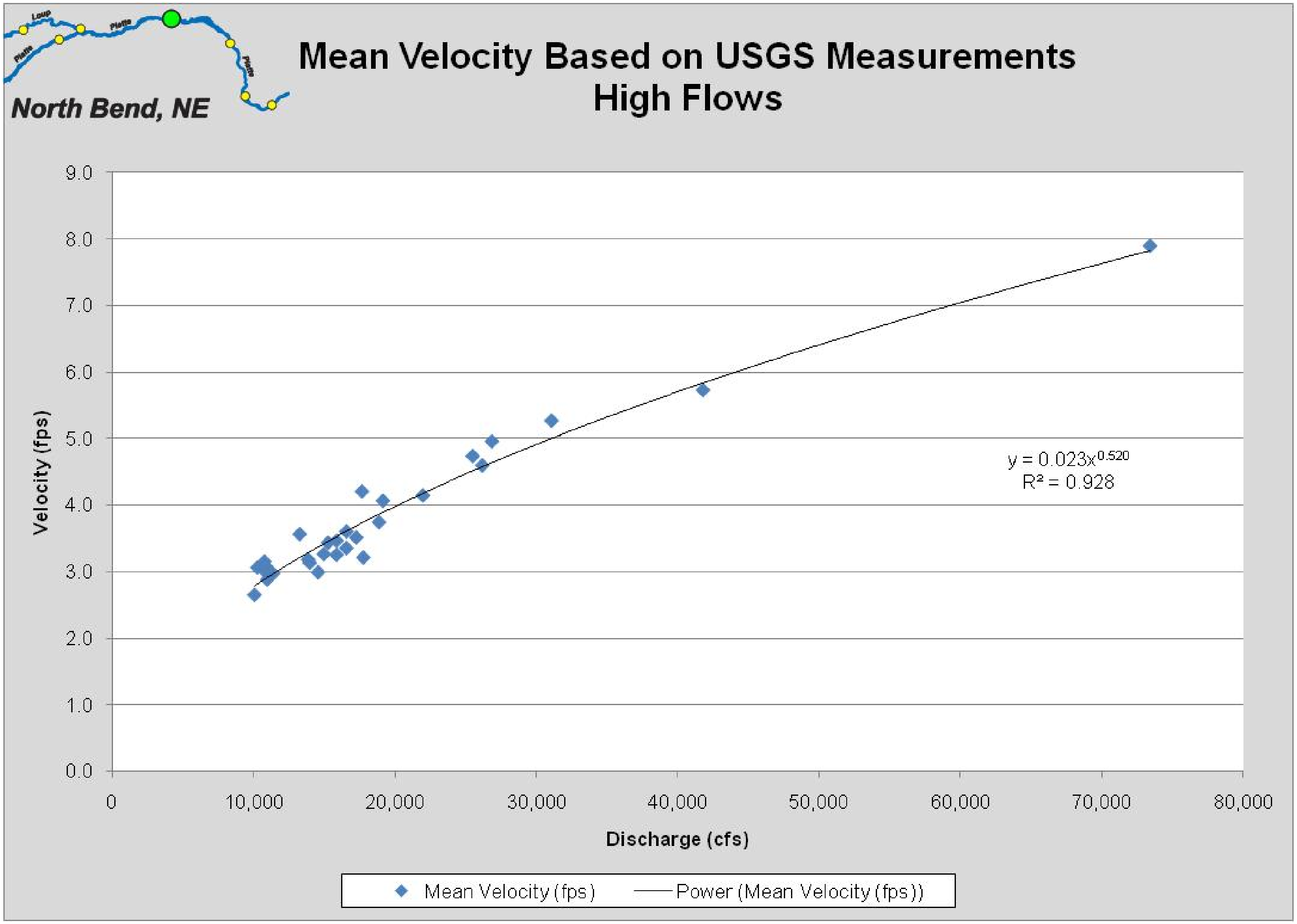


Figure 4-6. Mean Velocity Based on USGS Measurements, High Flows, at the Platte River at North Bend (USGS Gage 06796000)

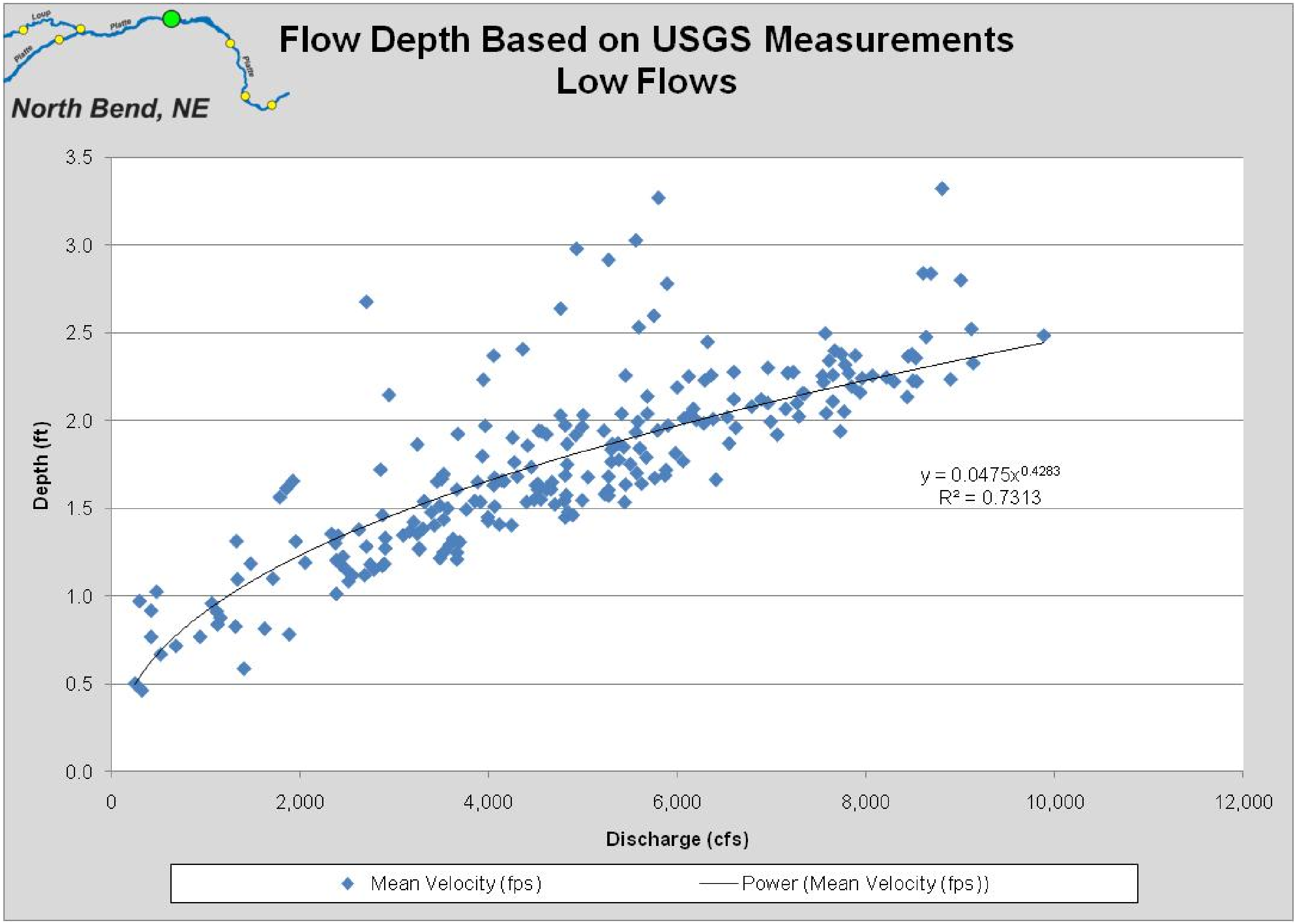


Figure 4-7. Flow Depth Based on USGS Measurements, Low Flows, at the Platte River at North Bend (USGS Gage 06796000)

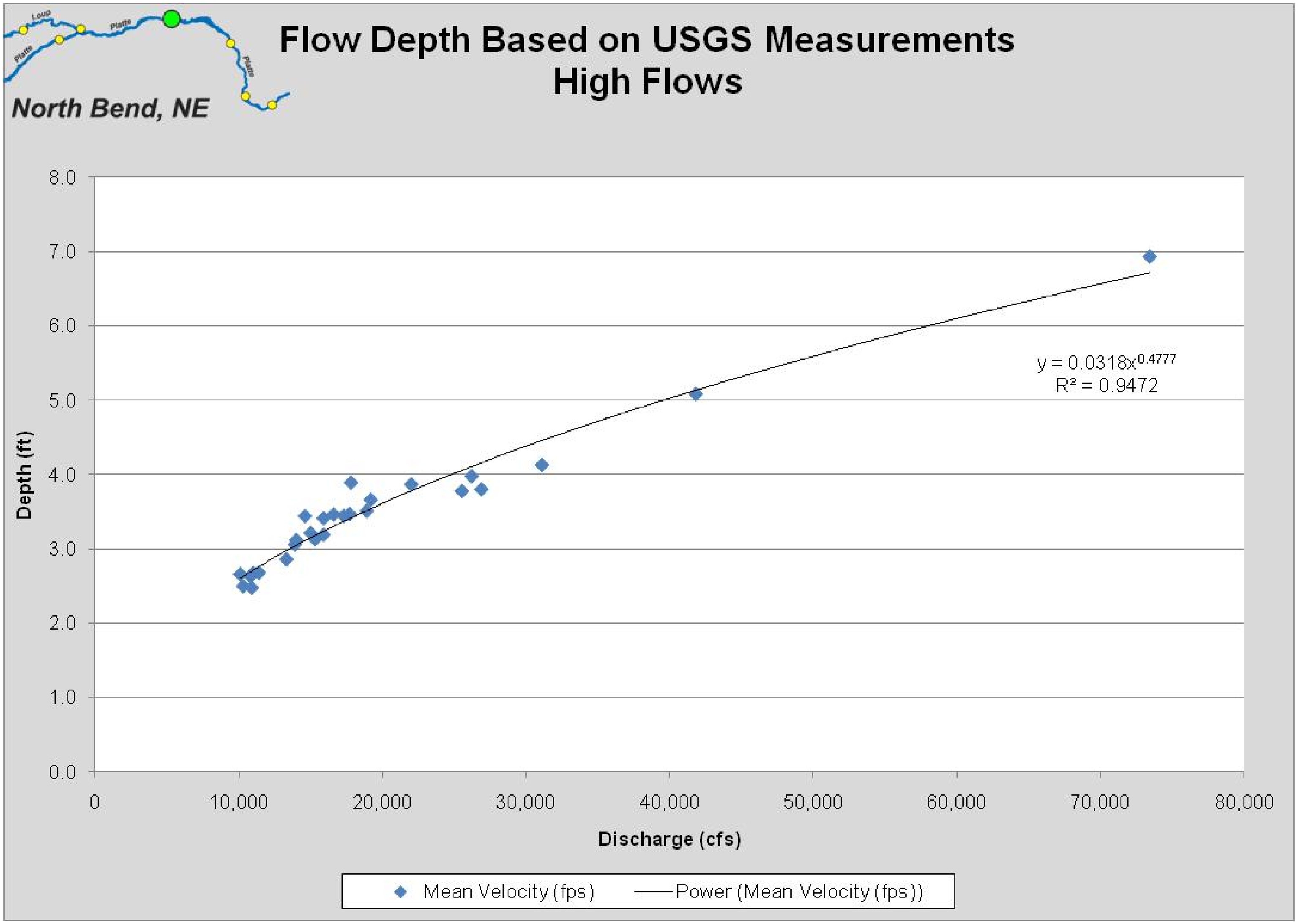


Figure 4-8. Flow Depth Based on USGS Measurements, High Flows, at the Platte River at North Bend (USGS Gage 06796000)

Energy Slope

Energy slope is an important part of the Unit Stream Power equation. Either channel slopes or energy grade line slopes (if available) were obtained from Bentall (1991), USACE Flood Insurance Studies (June 2002, March 2003, and August 2003), and USGS topographic maps. Channel slope was used as an estimation of energy slope, which is an acceptable estimation assuming normal flow. In some instances, the slope was averaged between two sources, which provided the best approximation between measured and predicted sediment transport. Slope data are summarized in Table 4-1.

Table 4-1. Summary of Slopes and Sources[1]

USGS Gage Number	Gage Name and Location	Slope (feet/mile)	Source	Secondary Source
06793000	Loup River near Genoa, NE	8.0 (average)	Bentall (1991)	USGS topographic maps
06794500	Loup River at Columbus, NE	5.3	USGS topographic maps	Bentall (1991)
06774000	Platte River near Duncan, NE	6.2	Bentall (1991)	USGS topographic maps
06796000	Platte River at North Bend, NE	4.9 (average)	Bentall (1991)	USACE Flood Insurance HEC-RAS model
06796500	Platte River at Leshara, NE	4.8	Bentall (1991)	USACE Flood Insurance HEC-RAS model
06801000	Platte River near Ashland, NE	4.0	Bentall (1991)	USACE Flood Insurance HEC-RAS model
06805500	Platte River at Louisville, NE	4.0	Bentall (1991)	USACE Flood Insurance HEC-RAS model

Sources: Bentall, R, 1991, Facts and Figures about Nebraska Rivers, Water Supply Paper No. 73, University of Nebraska, Conservation and Survey Division, Lincoln, NE.
USACE, June 2002, "Hydraulic Analyses Lower Platte River, Nebraska, Flood Insurance Study, Missouri River to Sarpy-Douglas County Line."
USACE, March 2003, "Hydraulic Analysis Lower Platte River, Nebraska, Lower Platte River Flood Insurance Study, Reach from Sarpy/Douglas County Boundary through Fremont."
USACE, August 2003, "Hydraulic Analysis Lower Platte River, Nebraska, Lower Platte River Flood Insurance Study Revision, Reach from Fremont to Columbus."

Note:

[1] Energy grade slopes were available from the USACE HEC-RAS model. All other slopes are channel grades.

Particle Size

Yang's equation results in an approximation of the total transport capacity of bed material. The input for particle size is the median particle diameter (d_{50}) of the bed material. For this sedimentation study, it was assumed that the material dredged from the Project was a reasonable representation of the total bed material. The gradations from 12 test hole sites in the North Sand Management Area were compared to the sediment (suspended and bed material) data at the Loup River near Genoa. The d_{50} of the dredged material for the 12 test hole sites ranged from approximately 0.17 to 0.32 mm, with a median of 0.24 mm. The d_{50} from the suspended measurements was approximately 0.12 mm and ranged in size from 0.009 to 0.357 mm. The d_{50} of the bed material measurements was 0.335 mm and ranged in size from 0.205 to 1.33 mm.

Combining the suspended and bed material measurements results in a composite d_{50}. This was performed by taking the "percent finer than" data for both the suspended and bed sediment data, adding them together, then dividing by 200 percent. This resulted in a new "percent finer than" data set from which a new composite d_{50} was obtained. The composite d_{50} was 0.21 mm and ranged in size from 0.11 to 0.42 mm. The composite d_{50} provided the best approximation of the measured dredged material and was assumed a reasonable surrogate to the total bed material d_{50}. Therefore, a composite d_{50} for all of the remaining sites based on suspended and bed material gradations was used as input in Yang's equation.

The sediment sizes used in Yang's Unit Stream Power equation were cross checked with several different sources. Marlette and Walker (1968) found the d_{50} of the bed sediment in the Platte River at Louisville to be 0.4 mm. The composite d_{50} for this sedimentation study in the Platte River at Louisville was 0.22 mm. USACE (July 1990) reports a median bed size of 0.45 mm in the Platte River at North Bend. In addition, USACE (1990) reports a suspended median particle size of 0.06 mm in the Platte River at North Bend and of 0.02 mm in the Plate River near Duncan and the Platte River at Louisville.

Kinematic Viscosity

Kinematic viscosity, a property of all fluids, is temperature dependent. For this analysis, a constant water temperature of 15 degrees Celsius (°C) was used, resulting in a kinematic viscosity of 1.23E-5 (ft^2/s). As discussed in the sensitivity analysis, this method is insensitive to temperature. USACE (July 1990) used a different transport equation and different constant temperature (21°C) and concluded that results were indistinguishable for temperatures between 10 and 27°C. After reviewing temperature data available at the Platte River at Louisville and taking into account that there are no temperature data available during the winter, 15°C was chosen as a balanced value.

Fall Velocity

The particle fall velocity was calculated from Van Rijn's (1993) equation, which is written as:

$$\omega = \frac{10\upsilon}{d}\left[\left(1+\frac{0.01(s-1)gd^3}{\upsilon^2}\right)^{0.5}-1\right], \qquad 0.1 < d < 1mm$$

Where:

$\omega \equiv$ Fall Velocity of Sediment Particle (ft/sec)
$\upsilon =$ kinematic viscosity (ft^2/sec)
$d \equiv$ particle size – diameter (mm)
$s =$ specific gravity
$g =$ gravity (ft/sec/sec)

For silicon-quartz-based sediment (sand), the assumed specific gravity value used was 2.65.

Summary of Data Developed for Yang's Unit Stream Power Method

The data used for computation of Yang's Unit Stream Power equation are summarized in Table 4-2.

Table 4-2. Data for Computation of Yang's Unit Stream Power Equation[1]

USGS Gage Number	Gage Name and Location	Velocity/Flow Graph	Depth/Flow Graph	Energy Slope (ft/mile)	Particle Size (d_{50}) (mm)	Fall Velocity (ft/sec)
06793000	Loup River near Genoa, NE	Attachment A-1	Attachment A-1	8.0	0.20	0.08
06794500	Loup River at Columbus, NE	Attachment A-2	Attachment A-2	5.3	0.20	0.04
06774000	Platte River near Duncan, NE	Attachment A-3	Attachment A-3	6.2	0.38	0.18
06796000	Platte River at North Bend, NE	Attachment A-4	Attachment A-4	4.9	0.23	0.10
06796500	Platte River at Leshara, NE	Attachment A-5	Attachment A-5	4.8	0.23	0.10
06801000	Platte River near Ashland, NE	Attachment A-6	Attachment A-6	4.0	0.22	0.09
06805500	Platte River at Louisville, NE	Attachment A-7	Attachment A-7	4.0	0.22	0.08

Note:
[1] Kinematic viscosity was held constant at 1.23E-5 ft^2/sec.

Comparison of Sediment Supply and Transport Capacity at UGSG Gage 06793000, Loup River near Genoa, NE

Additional calculations were used to estimate the total sediment supplied to the study site at the Loup River near Genoa, as shown in Table 4-3. Assumptions made include the following:

- The dredged amounts plus amounts carried by the Loup Power Canal and Loup River bypass reach were assumed to equal the entire supply of bed material supplied to the Diversion Weir.
- The split in sediment arriving at the Diversion Weir between the Loup River bypass reach and the Loup Power Canal was assumed to match the split in flow based on data from USGS and NDNR gages on the Loup Power Canal, listed in Table 4-4.
- Sediment amounts in the Loup River bypass reach plus the sediment amounts from the South Sand Management Area were compared with estimates of the capacity at the Loup River near Genoa.

Table 4-3. Additional Analysis of Sediment Capacity at the Loup River near Genoa using Dredging Data from 1975 through 2009

Parameter	Value[1]
Average Annual Sediment Dredged[2]	2,005,000 tons/year
Flow Split Between Loup Power Canal and Loup River Bypass Reach[3]	67%
Average Annual Sediment Carried by the Loup River just upstream of the Diversion Weir	3,000,000 tons/year
Average Annual Sediment Carried by the Loup River Bypass Reach	995,000 tons/year
Average Annual Sediment Dredged to South Sand Management Area	560,000 tons/year
Average Annual Sediment in Loup River Bypass Reach + Dredged Material at South Sand Management Area	1,554,000 tons/year
Average Annual Cumulative Sediment Discharged as Calculated by Yang's Equation	1,758,000 tons/year

Notes:

[1] Values in this table have been rounded.

[2] Assuming the hydraulic dredge captures the vast majority of sediment.

[3] Assuming flow split equals sediment split.

The conclusion from the last two rows is that from 1975 through 2009, a total of 1.55 million tons per year is potentially supplied to the Loup River bypass reach, and Loup River flows are capable of transporting 1.76 million tons. These values are very close to the sediment carrying capacity at the Loup River near Genoa, calculated using Yang's Unit Stream Power Method, giving confidence to the methodology.

Additionally, the assumptions relative to the sediment transport being proportionate to the flow split made in this analysis were conservative. For example, a 67 percent flow split does not necessarily represent a 67 percent sediment flow split. The Diversion Weir holds back water, which causes sediment to fall out, resulting in less sediment being transported into the canal. The District sluices sediment down the Loup River bypass reach several times a month to mitigate this sediment build-up. It is likely that a greater percentage of sediment is transported down the Loup River bypass reach than what is represented by the assumed flow split. Therefore, it is reasonable to conclude that based on this analysis to evaluate the applicability of using Yang's equation, the calculated capacity very nearly matches the potential supply.

Table 4-4. USGS and NDNR Gages on the Loup Power Canal

Gage Number	Gage Name and Location	Drainage Area (sq. mi.)	Mean Daily Discharge (cfs)	Period of Record	Comments
USGS Gage 06792500	Loup River Power Canal near Genoa, NE	NA	1,630	1938 - Present	Available discharge and gage height data from January 1, 1937, to present includes daily and subdaily data.
NDNR Gage 00082100	Loup River Power Canal Return [Tailrace Canal] at Columbus, NE	NA	1,630	2002 - Present	Available discharge and gage height data from October 1, 2002, to present includes daily and subdaily data.

Sediment Discharge Rating Curve Sensitivity Analysis

A sensitivity analysis was performed by varying the parameters used in the creation of the sediment discharge rating curves to determine how changes in each parameter affect the predictive capability of the sediment discharge rating curve, as shown in Table 4-5.

At each of the four USGS gaged sites where sediment discharge data were available, several different scenarios were run where the variables of energy slope, particle size (diameter), and temperature (which alters kinematic viscosity) were varied. Changing those variables affected the observed versus predicted fit and the annual cumulative discharge and the annual dominate discharge. An example of the results provided by this sensitivity analysis for the Platte River at Louisville is shown in Table 4-5. All of the sensitivity analysis tables are located in Attachment B.

Changing the slope up to 25 percent less than or greater than the original slope value resulted in small changes to the sediment discharge rating curve and relatively small changes to the dominant discharge. Together, those small changes resulted in large changes to the annual cumulative sediment values. Similar changes occurred by decreasing the particle diameter by half a standard deviation (SD) and increasing the diameter by one full standard deviation (SD). However, even with large changes in the results given large changes in the input parameters, the outcomes of the flow limited or supply limited question and the regime question reached in this sedimentation study would remain unchanged. Changing the temperature, which alters the kinematic viscosity, yielded only very small changes in the sediment discharge rating curve and associated results.

Table 4-5. Sensitivity Analysis

Scenario Summary	Base Case	Slope -25%	Slope +25%	Diameter -½SD	Diameter +SD	Temperature 20°C	Temperature 10°C
Variables							
Channel Slope	0.0008	0.0006	0.0009	0.0008	0.0008	0.0008	0.0008
Diameter	0.0007	0.0007	0.0007	0.0006	0.0012	0.0007	0.0007
Viscosity	0.000012	0.000012	0.000012	0.000012	0.000012	0.000011	0.000014
Results							
Observed vs. Predicted Regression Slope	0.5972	0.6056	0.5910	0.5947	0.6026	0.5952	0.5993
Observed vs. Predicted Regression Intercept	1.5596	1.3450	1.7209	1.6829	1.3680	1.5595	1.5646
Root Mean Square Error	0.3920	0.4604	0.3909	0.3865	0.4556	0.3946	0.3886
Annual Cumulative Sediment	4,930,000	3,300,000	6,670,000	6,370,000	3,360,000	4,820,000	5,100,000
Dominant Discharge	9,020	9,080	8,970	8,990	9,100	9,010	9,030

4.3.2 Sediment Transport Indicators

Three sediment transport indicators were computed for each study site listed in Table 3-1 to assist in characterizing the sediment transport. The indicators are total sediment transport capacity, effective discharge, and dominant discharge.

The total sediment transport capacity is found by combining the sediment discharge rating curve and a flow hydrograph. The flow hydrograph is based on the period of interest, such as annually, seasonally, monthly, daily, or subdaily. The total sediment transport capacity was determined for each study site on an annual and seasonal basis. For purposes of this sedimentation study, the season from May 1 to August 15 was used to coincide with the interior least tern and piping plover nesting season. Graphs and tables for each study site are located in Attachments A and B, respectively, and are discussed in Section 5, Results and Discussion.

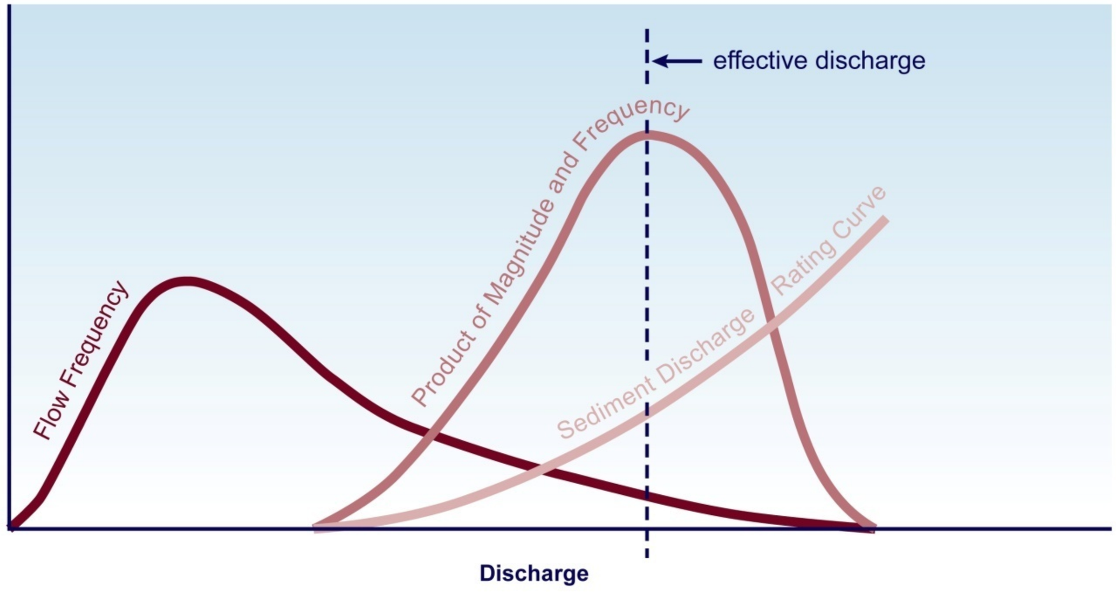
The effective discharge, defined as the mid-value of the narrow range of flows that transports the most sediment (and therefore shapes the channel), is found by developing a collective sediment discharge curve. A collective sediment discharge curve is developed by combining the flow frequency and sediment discharge rating curves. The flow frequency curves that were used in this analysis are graphs of the daily discharge on the x-axis and flow frequency (number or percent of days a particular daily discharge was exceeded) on the y-axis. Study period (1985 to 2009), annual, and seasonal daily flow frequency curves were generated for each study site listed in Table 3-1 using the discharge records.

The collective sediment discharge curve was developed by combining the daily discharge rates and the sediment discharge rating curve to arrive at daily estimates of transport capacity. Then, by grouping the amount of sediment transported into equal increments, a histogram of the sediment capacity was created. The flow corresponding to the peak of the collective sediment discharge histogram is the effective discharge.

As often happens, the peaks of these histograms are broad-crested, and some prefer to represent this by reporting a range of flows that transports the majority of the sediment, while others select the mid-point of this range, which may not occur at the overall mode. Uses of the centroid or median values of the histogram are also acceptable measures of central tendency of the discharge that transports the majority of the sediment.

Previous USGS sedimentation studies (Kircher and Karlinger, 1981; USGS, 1983) and this study adopted the modal definition, but the modal value is only a single-value measure of the central tendency of flows having the greatest impact on channel morphology. The range of flows having the “majority” effect generally covers two to four class intervals in the histogram. USACE (July 1990) defined the effective discharges for its Platte River locations as the mid-point of the highest bars in the broad-crested histogram.

The collective discharge curve can be developed on a daily, monthly, seasonal, or annual basis or for the entire study period (1985 to 2009), if needed. Figure 4-9 illustrates the concept of using the flow and sediment rating curves to create the collective sediment discharge curve.



Adapted From Wolman and Miller, 1960.

Figure 4-9. Effective Discharge Determination from Typical Sediment Rating and Flow Duration Curves

The effective discharge was determined for each study site for Project operations for the study period (1985 to 2009) as well as on an annual and seasonal basis for each year of the study period. These graphs are located in Attachment A and are discussed in Section 5, Results and Discussion. Karlinger et al. (1983), Richards (1982), and others support the calculation of effective discharge for long periods and caution that use of shorter periods may not establish equilibrium conditions because of climatic and other factors.

The dominant discharge is defined as the flow rate that, if continued constantly for the long term, would transport the same total load as the actual hydrograph. It is a geomorphic characteristic of the river, without the subjectivity involved in calculating the effective discharge. The dominant discharge is found by first dividing the total sediment transported over time by the number of days in that time period to obtain the tons of sediment transported per day. Then, by taking that sediment discharge rate and using the calculated sediment discharge rating curve, the flow rate associated with that sediment discharge, defined as the dominant discharge, can be found. The dominant discharge was calculated for each study site listed in Table 3-1 for the study period, annually, and seasonally. The graphs are shown in Attachment A and are discussed in Section 5, Results and Discussion.

The terms effective and dominant discharge are used interchangeably and share the same definition when addressing significance (shaping and maintaining morphology), but vary in methods used to calculate them. The literature contains references to a different method of calculating the "dominant" discharge. This method does not require separating flows into discrete class intervals because transport is determined for every day's flow and may be superior because it has been shown that the modal value of an effective discharge transport histogram varies with the number of classes (USGS, 1983). Parker (1978), for example, used this method of calculating the dominant discharge for both the Middle Loup and Niobrara rivers, but his discussion makes it clear that he interprets its significance as being the channel-forming discharge. As noted previously, others determine the dominant discharge as the modal value of the transport histogram, so the terms "dominant" and "effective" discharge always have the same significance but methods of determining the values vary.

The study period (1985 to 2009) included years with wet, dry, and normal flows, as defined by USFWS (Anderson and Rodney, October 2006). The three calculated sediment transport indicators—total sediment transported, effective discharge, and dominant discharge—were calculated for current conditions, and using regime analysis, they were compared both spatially and temporally. The results of the spatial analysis are discussed in Section 5, Results and Discussion, and are shown in Figure 5-2.

Using the USGS-based depth/velocity/width versus discharge rating curves, the channel characteristics were calculated for each of the following:

- Study period effective discharge
- Annual effective discharge
- Study period dominant discharge
- Annual dominant discharge
- Seasonal effective discharge
- Seasonal dominant discharge

The graphs for each study site are located in Attachment A and are discussed in Section 5, Results and Discussion.

Calculations of the capacity of the flows to transport total bed material sediment were compared to adjusted, indirect estimates of the sediment supply (yield). If the capacity for total bed material sediment transport for a given time period were equal to or less than the sediment yield, it would be concluded that the braided river is not supply limited and is currently in dynamic equilibrium. The term "dynamic equilibrium" means that there can be fluctuations about a mean value for variables but no long-term changes in the mean values (USACE, July 1990). If the capacity for total bed material sediment transport for a given time period were to exceed the sediment yield, it would be concluded that the braided river may be supply limited and possibly degrading. In the latter event, Project operations relative to sediment removal could be impacting morphology. The resolution of the severity of any impacts is dependent on proximity of the current morphology (braided river) to thresholds of morphologic change, which can be established by regime methods.

USBR (April 2004) tested three widely-adopted regime diagrams (Chang, March 1985; Leopold and Wolman, 1957; Lane, 1957), showing that all three are applicable to assessing impacts of alternative conditions in the Platte River. These are discussed in greater detail in Section 5, Results and Discussion. USBR concludes that "Regime theory does provide a guide to the changes in channel geometry that can be expected with changes in the channel-forming discharge, bed slope, and bed material grain size." USBR evaluated aerial photos from 1939 to 1998, which supported its conclusions developed using regime theory. USBR's assessment of changes in plan form since 1900 show that the river has changed but is still well-seated within the regime zones for stable, braided rivers (USBR, April 2004).

Objective 2: To characterize stream morphology in the Loup River bypass reach and in the lower Platte River by reviewing existing data and literature on channel aggradation/degradation and cross sectional changes over time.

4.4 Task 4: Stream Channel Morphology

Stream morphology is a function of a number of physical water- and sediment-related processes and environmental conditions, including the following:

- Stream habit (for example, meandering or braided)
- Daily flows and instantaneous peak flow rates
- Watershed sediment yields
- Composition and erodibility of bed and banks (for example, sand, clay, and bedrock)
- Vegetation and rate of plant growth
- Availability of sediment to be transported
- Size and composition of bed material sediment
- Composition of wash load
- Rate of removal and re-deposition of sediment on floodplain, banks, bars, and bed
- Regional aggradation or degradation due to subsidence or uplift

Stream morphology is the result of water flowing through erodible material. The resulting channel geometry is three-dimensional, where the cross section, planform, and longitudinal profile properties are interrelated and make up the "morphology" (Richards, 1982). In a braided sand-bed stream like the Platte River with an unchanging longitudinal profile (USBR, April 2004), the topological aspects (for example, braids, bars, islands, areas of sand above the water level, and number or locations of bars) of the braided cross section and planform comprise the morphology, which is used as habitat. Maintenance of a braided river's morphology is equivalent to maintenance of its habitat.

The methodology for evaluating the current stream channel morphology included the following:

- Conclusions from studies by others
- Supplemental studies of changes over time
- Annual trends in flows and effective and dominant discharge
- Seasonal trends in flows and effective and dominant discharge
- Annual trends in channel hydraulic geometry
- Seasonal trends in channel hydraulic geometry
- Regime implications of trends

If the literature review, sediment transport parameter calculations, and regime analyses indicate that short-term fluctuations in the morphology of the Loup River bypass reach and lower Platte River are not transitioning to another form, it would be further affirmed that the rivers are currently in dynamic equilibrium. If the literature review and calculations indicate that the Loup River bypass reach and lower Platte River are transitioning to another form and either aggrading or degrading, it would be concluded that the rivers are currently not in dynamic equilibrium.

The characteristic channel morphology associated with the effective discharges was assessed according to the methodology described by Leopold and Maddock (1953) for the Loup and Platte rivers and by Karlinger et al. (1983) for the Platte River. Channel characteristics include channel cross sectional area changes, width changes, channel aggradation/degradation changes, and the rate at which these changes, if any, occur over time. Leopold and Maddock (1953) developed general stream morphology relationships between effective discharge and channel characteristics, and Karlinger et al. (1983) calibrated and applied Parker's (1978) regime equations (similar to Leopold and Maddock's) to the central Platte River.

By definition, a braided river has a surplus of sediment supplies that exceeds its ability to transport the sediment and, as a result, could be (and generally is) gradually aggrading; however, the river would be in dynamic equilibrium even for a relatively wide range of effective discharges, slopes, and bed material sizes if the flows are maintaining its braided morphology. A conclusion that a river is not in dynamic equilibrium would occur only if the river's sedimentation processes have arrived at a threshold of change to a different morphology, such as meandering. Proximity to these thresholds can be assessed using qualitative and quantitative geomorphologic relationships, known as "regime" methods.

Finally, if the analysis of the current condition morphology indicates that the Loup River bypass reach and lower Platte River either are in dynamic equilibrium or are not supply limited based on the adjusted yields and sediment transport capacity calculations, then no alternatives relative to sediment augmentation would be evaluated. However, if it is determined that either the Loup River bypass reach or the lower Platte River is not in dynamic equilibrium or is sediment supply limited, then alternatives would be evaluated to determine if a change in Project operations would beneficially affect the braided river dynamic equilibrium.

Objective 3: To determine if a relationship can be detected between sediment transport parameters and interior least tern and piping plover nest counts (as provided by NGPC) and productivity measures.

4.5 Task 5: Interior Least Tern and Piping Plover Nesting and Sediment Transport Parameters

4.5.1 Interior Least Tern and Piping Plover Data

The NGPC Nongame Bird Program's Nebraska Least Tern and Piping Plover database was used[6] to obtain the most current and comprehensive data available on the occurrences of these species in the state of Nebraska. However, the Nongame Bird Program "makes no warranty as to the fitness of these data for any purpose nor that these data are necessarily accurate and complete" (NGPC, 2009). The database includes information on data location (for example, river segment and river mile), dates and year collected, number of adults observed, number of nests observed, number of eggs, and fate of the nest/chicks. Prior to the use of these data, pertinent literature covering the species' biology and avian survey methods was reviewed to better understand the limitations of the data.

The appropriate use of this species data was also discussed with the NGPC Nongame Bird Program Manager (NGPC, June 9, 2009). Based on the amount of available data for analysis, the adult population counts were determined to be the largest data set. However, because of the mobility of these species and because they also breed on non-riverine habitat adjacent to the Platte River, this number may not accurately reflect the value of the riverine habitat for nesting and breeding. Reproductive

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[6] The Nebraska Least Tern and Piping Plover database was used under a data use agreement signed on June 24, 2009.

success, in the form of fledge ratio,[7] is a standard metric used to quantify interior least tern and piping plover reproduction and to estimate the success of a particular habitat for sustaining and/or growing a population. However, there is a limited amount of this data from only a few years, and there are several problems with using these data as most of the data are based on observations and not on more rigorous methods, such as mark-recapture statistical analysis.

Due to the limitations of adult counts to reflect actual nesting on the Platte River and the scarcity of fledge ratio data, the sedimentation study incorporated the recommendations from NGPC, USFWS, and the Tern and Plover Conservation Partnership that interior least tern and piping plover nest count numbers would be the best available data to use for a trend analysis to determine if there is a relationship between sediment transport parameters and interior least tern and piping plover nesting response. The measurement of nest presence is an effective gage of the relative population size and whether the habitat is actually being used by interior least terns and piping plovers (Parham, 2007). Nest count data do not provide information on successful breeding but rather provide an index of habitat availability.

The portion of the Nebraska Least Tern and Piping Plover database used for this sedimentation study includes nesting locations and nest counts for both interior least terns and piping plovers found within the confines of the lower Platte River from the confluence with the Loup River to the confluence with the Missouri River (River Mile [RM] 106 to RM 0) from 1983 through 2009.[8] The database did not include interior least tern and piping plover data for off-river locations, such as sand and gravel mine sandpits and lakeshore housing developments.

For this sedimentation study, the lower Platte River was divided into the following five segments to correspond with the study sites listed in Table 3-1; the segment of the lower Platte River from the confluence with the Loup River to the Tailrace Return was not analyzed in this sedimentation study because the gage installed 5 miles downstream has no historical hydrologic data:

- Tailrace Return to North Bend
- North Bend to Leshara
- Leshara to Ashland

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[7] The reproductive success of the birds in a given year is often described in terms of fledge ratio, defined as the number of young that survive to fledging age (the age when they can fly) per adult pair. This is calculated by dividing the total number of fledglings by the total number of adult pairs surveyed for a certain area that year.

[8] Data from 2007 and 2009 were provided by NGPC at a later time under separate documents but were incorporated into the master database for the purposes of this analysis.

- Ashland to Louisville
- Louisville to confluence with Missouri River

Since 1987, NGPC has attempted to conduct an official survey annually in June to record locations of interior least tern and piping plover adults, nests, and/or established colonies and to provide an annual census population count for the lower Platte River from RM 106 to RM 0. Due to unknown constraints, not every river mile was surveyed every year. In addition, dependent on river flows and the presence of sandbars, occasionally, the June survey was postponed until July. For several years, additional surveys were done throughout the nesting season to gather population demography information.

In some instances, multiple nest counts may have been at the same site during a single breeding season. In those instances, nest count data used in this sedimentation study were refined to the highest nest count per colony location[9] during a single survey per year and then summed to provide a "cumulative highest nest count river mile per year." The data were further refined to look at the highest nest count per colony location in a single survey per river segment and then summed to provide a "cumulative highest nest count per river segment per year." This method does not account for all nests but does provide an estimate of the maximum number of nests present at the same time.

The interior least tern and piping plover data are continuing to evolve (NGPC, July 16, 2009). For some years, no data were recorded for particular segments of the river. There can be multiple reasons for data gaps, including lack of data or issues relative to the conversion of hard copy reports to electronic data. For records (a particular year for a particular segment) where no data were entered in the database and no comments associated with that record provide information as to the reason for no recorded data, the segment was excluded from the analysis. The years that are not included in the analysis for the associated segment are shown in Table 4-6.

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[9] A "colony location," for the purposes of this sedimentation study, is defined as any location, denoted by river mile (for example, RM 12.5), where one or more interior least tern or piping plover nest has been recorded at that locale. Colony locations are not fixed and may change from year to year as river sandbars shift.

Table 4-6. Years Excluded from Analysis by River Segment

Lower Platte River Segment[1]	Years Excluded From Analysis
Tailrace Return to North Bend (RM 101.5 to RM 72.5)	1995, 1999
North Bend to Leshara (RM 72.5 to RM 48.5)	1995, 1996, 1999, 2000, 2004, and 2005
Leshara to Ashland (RM 48.5 to RM 27.7)	1995
Ashland to Louisville (RM 27.7 to RM 16.5)	1986, 1995
Louisville to confluence with Missouri River (RM 16.5 to RM 0)	1995

Note:

[1] The segment of the lower Platte River from the confluence with the Loup River to the Tailrace Return (RM 106 to RM 101.5) was not analyzed because the gage installed 5 miles downstream has no historical hydrologic data.

4.5.2 Comparison of Sediment Transport Parameters to Interior Least Tern and Piping Plover Data

The following sediment transport and hydrologic parameters were compared to the interior least tern and piping plover data using cumulative highest nest counts per river segment per year (in accordance with the approved study plan, the seasonal timeframe is from May 1 through August 15):

- Annual effective discharge
- Annual dominant discharge
- Seasonal dominant discharge
- Annual cumulative sediment discharge
- Seasonal cumulative sediment discharge
- Annual cumulative flow
- Seasonal cumulative flow
- Annual peak mean daily flow
- Seasonal peak mean daily flow
- Annual flow width from effective discharge
- Annual flow width from dominant discharge
- Seasonal flow width from dominant discharge

- Annual percent diverted flow
- Seasonal percent diverted flow

In an effort to consider all potential combinations of nesting data upstream and downstream of a USGS gage used to establish sediment transport parameters in the vicinity of that gage, all nesting data for each river segment were compared to sediment transport parameters both upstream and downstream of the gage of each river segment. In addition, nesting data on river segments adjacent to a USGS gage location were combined and analyzed. A summary of the analysis performed for each reach is provided in Table 4-7.

Table 4-7. River Segments for Nest Count Correlation Analysis

USGS Gage Used for Sediment Transport Parameter Analysis	River Segment Nest Counts Used for Upstream of Gage	River Segment Nest Counts Used for Downstream of Gage	Combined River Segment Nest Counts for Upstream and Downstream of Gage
North Bend	Tailrace Return to North Bend	North Bend to Leshara	Tailrace Return to Leshara
Leshara	North Bend to Leshara	Leshara to Ashland	North Bend to Ashland
Ashland	Leshara to Ashland	Ashland to Louisville	Leshara to Louisville
Louisville	Ashland to Louisville	Louisville to Missouri River Confluence	Ashland to Missouri River Confluence

All of the comparisons were performed for no lag as well as for 1- and 2- year lags. The purpose of comparing sediment transport parameters to nest counts on a 1- and 2-year lag was to see if what occurred either annually or seasonally in a given year had a relationship with bird nest counts in 1 or 2 years following. Definitions of each of these scenarios are described below:

- No Lag – Sediment Transport Parameter in year X compared to nest counts in year X
- 1-year Lag – Sediment Transport Parameter in year X compared to next counts in year X+1
- 2-year Lag – Sediment Transport Parameter in year X compared to next counts in year X+2

For each of the data sets defined above, a linear regression analysis was performed. A graph was developed for each analysis, and a coefficient of determination (R^2) was generated.

Objective 4: To determine if sediment transport is a limiting factor for pallid sturgeon habitat in the lower Platte River below the Elkhorn River.

4.6 Task 6: Pallid Sturgeon Habitat

The sediment transport data were reviewed to determine if the Project is affecting morphology in the lower Platte River. In accordance with the Revised Study Plan and Study Plan Determination, if it is determined that the Project does not affect morphology in this reach, or that the system is in dynamic equilibrium, it will be inferred that the Project does not affect pallid sturgeon habitat parameters related to sediment transport and that no further analysis is warranted. Furthermore, findings from an ongoing 5-year Shovelnose Sturgeon Population Dynamics Study within the Platte River will be assessed to determine if existing conditions in the lower Platte River provide appropriate pallid sturgeon habitat that supports the growth and development of these fish.

If the analysis shows that the Project is affecting morphology, the magnitude of Project effects will be determined using effective discharge and other sediment transport calculations, as detailed in Sections 4.2 through 4.4. Additionally, the existing condition, with regard to sediment transport and braided river morphology in the lower Platte River, would be compared to habitat characteristics of other rivers used by the pallid sturgeon to determine if changes in Project operations relative to sediment transport could affect pallid sturgeon use of the lower Platte River.

Specifically, information on pallid sturgeon use and corresponding habitat characteristics (flow, sediment transport, and morphology) exists for the upper Missouri River and the Yellowstone River. This information will be used to perform a qualitative assessment of habitat characteristics. These habitat characteristics will be compared to those of the lower Platte River to determine if there is a differentiating factor between the upper Missouri River and the Yellowstone River habitats and the characteristics of the lower Platte River. If a differentiating factor is determined to be a braided river morphology, then Project effects on this morphology will be reviewed in context with the results of Task 3, Effective Discharge and Other Sediment Transport Calculations, and Task 4, Stream Channel Morphology, to determine if a change in Project operations could materially affect braided river morphology in the lower Platte River.

5. RESULTS AND DISCUSSION

The results of the sedimentation study are summarized below, and a full discussion of the analyses related to each study objective follows. The discussion provides representative tabular and graphical data that support this study's conclusions. A complete presentation of these data is included in Attachments A through D.

5.1 Summary of Results

Objective 1: To characterize sediment transport in the Loup River bypass reach and in the lower Platte River through effective discharge and other sediment transport calculations.

This sedimentation study proves that the sediment availability and yield throughout the study area by far exceed the capacity of the flow to transport sediment as well as greatly exceed the actual measured amounts of suspended sediment being transported.

USACE came to the same conclusion. The supply of sediment throughout the Platte River Basin, including the Loup River Basin, is "virtually unlimited" (USACE, July 1990) and is significantly greater than both the Loup and Platte rivers' capacities to move the sediment. This means that the Loup River bypass reach and the lower Platte River can be considered to be in an equilibrium condition, with supplies in excess of transport capacity with no evidence of degradation in the channel. USACE noted that an excess of supply over transport capacity exists, as manifested by sand and gravel deposits along banks and in the stream as sand bars (USACE, July 1990).

As noted in the methodology described in Section 4, if the capacity for total bed material sediment transport for a given time period is equal to or less than the sediment yield, it could be concluded that the braided river is not supply limited and is currently in dynamic equilibrium. The results of this investigation show that both the Loup River bypass reach and the lower Platte River at all locations studied are clearly not supply limited.

Effective discharge and other sediment transport calculations, combined with river regime theory, show that the channel geometries are "in regime" with the long-term flows shaping them. The current channel hydraulic geometries match the width, depth, and velocity calculations for flow rates matching the effective and dominant discharge rates. Nothing appears to be constraining either river from maintaining the braided river hydraulic geometry associated with the effective discharges.

The Section 4 methodology established that if the literature review, sediment transport parameter calculations, and regime analyses indicate that short-term fluctuations in the morphology of the Loup River bypass reach and lower Platte River are not transitioning to another form, it could be further affirmed that the rivers are currently in dynamic equilibrium. The combinations of slopes, sediment sizes, and effective discharges at all of the stations result in all locations being well within braided river morphologies, with none being near any thresholds of transitioning to another morphology.

Finally, the methodology established that if the current condition morphology analysis indicates that the Loup River bypass reach and lower Platte River are in dynamic equilibrium, or are not supply limited based on the adjusted yields and sediment transport capacity calculations, then no alternatives relative to sediment augmentation would be evaluated.

Objective 2: To characterize stream morphology in the Loup River bypass reach and in the lower Platte River by reviewing existing data and literature on channel aggradation/degradation and cross sectional changes over time.

Existing literature, including Platte River studies by USACE, USBR, and USGS; calculations of effective discharges; regime analyses; literature on the channels' profiles; and physical observations indicate that the Loup River bypass reach and the lower Platte River are not experiencing aggradation or degradation. Instead, these analyses, particularly the bed gradation studies by others and the effective discharge and regime analyses, clearly indicate that both the Loup and lower Platte rivers are well within parameters establishing them as dynamically stable, non-aggrading and non-degrading, braided rivers.

Objective 3: To determine if a relationship can be detected between sediment transport parameters and interior least tern and piping plover nest counts (as provided by the Nebraska Game and Parks Commission [NGPC]) and productivity measures.

The sedimentation study concluded that a relationship between interior least tern and piping plover nest counts and sediment transport or hydrologic parameters could not be identified.

Objective 4: To determine if sediment transport is a limiting factor for pallid sturgeon habitat in the lower Platte River below the Elkhorn River.

When the findings of this sedimentation study, which determined that the lower Platte River geomorphology and corresponding riverine habitat are in dynamic equilibrium, are compared to the numbers of shovelnose and pallid sturgeon collected during ongoing capture efforts, it can be inferred that current Project operations relative to sediment removal from Loup River inflows at the Headworks are not acting to limit sturgeon habitat or the success of these species in the lower Platte River.

5.2 Objective 1 – To characterize sediment transport in the Loup River bypass reach and in the lower Platte River through effective discharge and other sediment transport calculations.

The quantity and character of flow and sediment transported along the Platte River have significantly changed during the 20th Century in response to water resource development, droughts, and floods. These changes in flow and sediment transport have a dynamic effect on the river channel width and depth, and on the amount of riparian vegetation present (Lyons and Randle, 1988; Karlinger et al., 1983).

USACE (July 1990) concluded that "the [Platte] river within [all] study reaches is in a state of quasi-equilibrium." The definition adopted by USACE was that a river is in regime "when a balance exists between all of the variables that affect it, and there is no net change in the river conditions," but adds that "regime [is] a state of quasi-equilibrium in which there are fluctuations about a mean value for each of the variables, but there are no long-term changes in mean values." USACE adds, "It is a good indication that a river reach is in regime when there is no aggradation, degradation, or change in channel pattern" (July 1990).

5.2.1 Sediment Budget

Various sources provided the means to update sediment yield estimates completed by MRBC (September 1975). Information from these sources was used to revise the yield portion of the sediment budget as appropriate.

Next, the results of the updated MRBC yield estimates in the sediment budget were compared to the total sediment transport capacity calculations to assist in determining whether the reach is flow limited or supply limited for each flow period or alternative analyzed.

Yang's method (Yang and Stall, May 1976) was used to determine daily estimates of the total sediment transport capacity at all the USGS gaging stations in the study reaches. Yang had previously applied his equations to the Middle Loup River and concluded that "[o]nly the unit stream power equation and the modified Einstein equation can provide good estimates of the total sediment discharge in the Middle Loup River" (Yang and Stall, May 1976). With this and other endorsements of this method's applicability, and using USGS velocity and depth data to create best-fit hydraulic geometry equations, Yang's equation for total transport capacity was applied to the daily flows in this sedimentation study to produce estimates of daily and total bed material transport.

Although it is not recommended that indirect estimates of yield like those employed by MRBC be used to assess whether the river is aggrading or degrading, the estimates are useful but not fully definitive in assessing the question of whether the river is flow versus supply limited.

In order to use the yields for this purpose (flow versus supply limited), adjusted estimates of sediment yields for the post-MRBC report period were needed. Rather than repeating the process used by MRBC of determining present-day net yields by evaluating sheet, rill, gully, and stream bank erosion, adjusted sediment yields were calculated for the Loup River and its tributaries downstream of the Project's Diversion Weir based on documented reductions in dredged material from the Settling Basin in accordance with the Study Plan Determination.

Dredging Records

The District began collecting data on dredged materials from the Project in 1937. Incoming sediment is dredged from the Loup Power Canal on a daily basis. Materials removed from the canal are stockpiled on both banks and differences in repeated bathymetric surveys are used to estimate the amounts dredged.

Figure 5-1 shows the amount of sediment dredged from the Settling Basin annually from 1937 to 2009. This graph is the same as shown in Figure 4-4, with the exception that the vertical scale is in tons per year instead of cubic yards. The assumption was made that the dredged sediment would have a unit weight of 120 pounds per cubic foot.

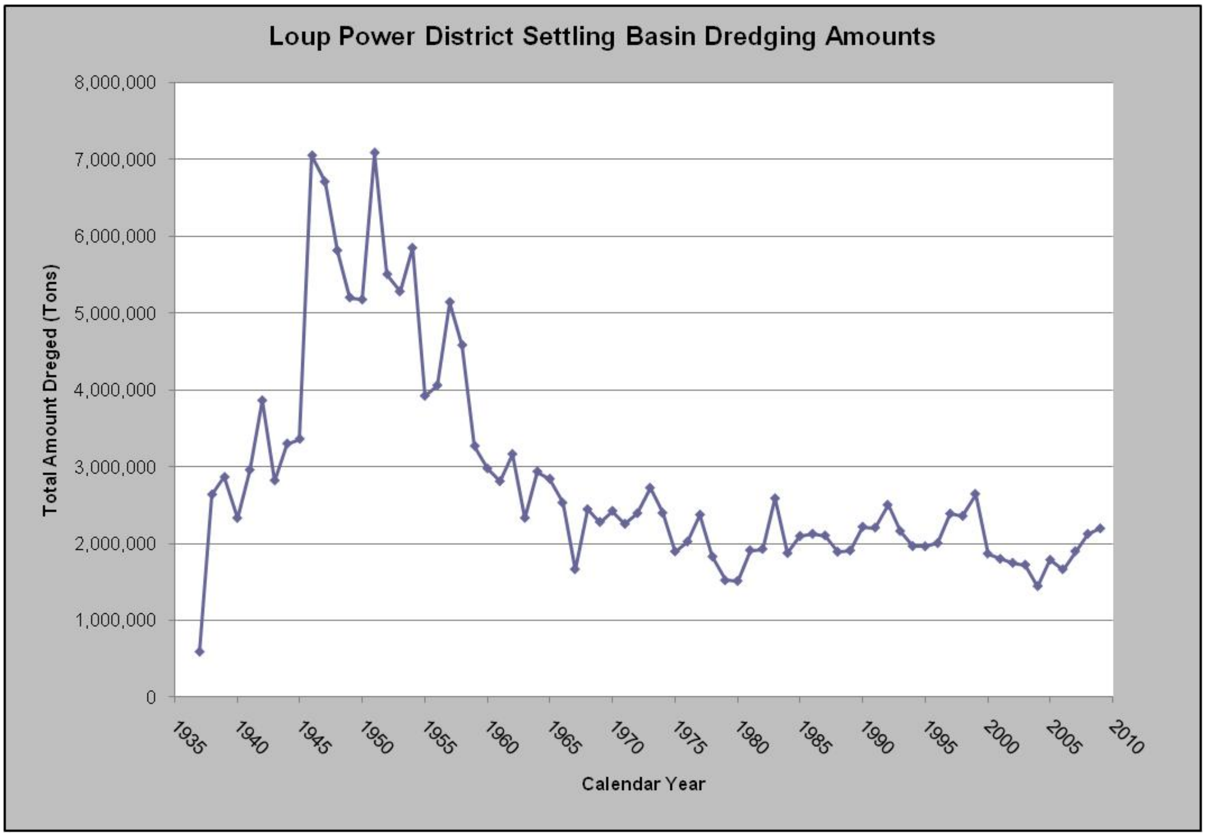


Figure 5-1. Loup Power District Annual Settling Basin Dredging Amounts

The graph reveals that there was a substantial reduction in dredging after about 1974. The earlier record from 1937 to around 1968 shows a steep increase followed by a similarly steep reduction in dredging, with relatively constant dredging between 1968 and 1974, followed by another drop to the horizontal trend line around 1.3 million tons per year since 1975. If these are considered representative of sediment supplies (yields), the river may not have been in equilibrium until around 1975, unless the large pre-1974 fluctuations can be explained by climatic or other influences.

To adjust the MRBC yields (described under Yield Adjustments, below), the ratio of reduction in dredged amounts at the Settling Basin was considered to be representative of the reductions in yield elsewhere in the Loup River Basin. The average dredged amount for 1975 to 2009 was 2.00 million tons per year. The average dredged amount for 1940 to 1974 was 3.75 million tons per year. This gives a ratio of yield reduction of 0.534, which was the basis for adjusting the MRBC yields, as shown in Table 5-1.

The annual range from 1940 to 1974 was from 1.66 to 7.09 million tons per year. An unknown physical process had to be involved during those years because the dredged amounts quickly rose and then fell over several years, reaching an apparent "equilibrium" level around 1975.

Even though the average of fluctuations between 1940 and 1974 were used in determining the ratio for making yield adjustments, the variability is not well represented by an average value. The adjustments in MRBC yields were based on using the 0.534 ratio of average dredging values from 1940 to 1974 in comparison to 1975 to 2009, so it should be recognized that the ratio has a moderate degree of uncertainty due to the high variability in dredged amounts before 1975. However, the conclusion regarding the hypothesis being tested - that is, whether the system is flow or supply limited -would not be likely to change under any alternative assessments of the earlier, highly fluctuating dredging records.

Yield Adjustments

The MRBC estimates from the Diversion Weir downstream to Louisville were intended to be adjusted based on the ratio of pre- and post 1970 dredging. Rather than dividing the data at 1970 as suggested, 1974 was chosen for the reasons provided earlier.

Once the dredging records were used to adjust MRBC estimates of yield from the Loup River basin, and by accepting MRBC's assumptions of how much of the sediment passing down the Loup Power Canal reaches the Platte River, an adjustment could be made of all MRBC yields by "parlaying" the 0.534 adjustment downstream throughout the lower Platte River. The calculations for this are shown in Table 5-1.

Table 5-1. MRBC Yields with Adjustments Based on District Dredging Records

Watershed or Reach Name	Sediment Yield MRBC Accumulative Total (tons/yr)	New Study Total (tons/yr)
Subbasin total above Diversion Weir	7,825,100	4,179,100
Sediment removed from Settling Basin	1,900,000	2,004,800
Sediment passing down Loup Power Canal	700,000	700,000
South Sand Management Area	NA	560,000
Subbasin total below Diversion Weir near Genoa	5,225,100	2,030,000
Loup Watershed below Genoa	1,860,300	993,500
Sediment yield at Columbus	6,970,000	2,960,000
Tailrace Return + Loup bottom	2,210,300	1,343,500
Loup Subbasin yield to Platte River at Columbus	7,435,400	3,373,500
Upper Platte Subbasin total to Platte River at Columbus	1,865,400	1,870,000
Yield of Upper Platte and Loup Subbasins to lower Platte	9,300,800	5,243,500
Subbasins at Columbus		
Yield to Platte (North Bend)	9,885,900	5,770,000
Platte Tributaries (Leshara)	9,956,900	5,850,000
Platte Basin yield including Elkhorn (Ashland)	14,666,600	1,610,000
Yield from Platte Basin at Louisville	16,840,000	12,780,000

5.2.2 Effective Discharge and Other Sediment Transport Calculations

The effective and dominant discharges calculated for the study sites listed in Table 3-1 are provided in Table 5-2. In addition, hydrologic parameters, mean daily discharge, 1.5-year return flow flood rates, and percent chance exceedance from flow duration are listed in Table 5-2 for comparison purposes. As discussed in Section 4.1.2, hydrologic analyses were performed in support of this and other relicensing studies. A full description of the hydrologic analyses will be presented in Study 5.0, Flow Depletion and Flow Diversion.

Effective discharges are always more reliable indicators of the channel-forming flow rates when determined from daily discharges for prolonged periods of time. None of the studies cited in Section 4.1.1 used shorter periods than 20 years. Using long-term daily flows allows the method to incorporate effects of climate and other factors on morphology because the longer records incorporate the natural flow variability in rivers during wet, normal, and dry periods under a variety of historical operating conditions.

Using shorter increments of daily flow data will provide an estimate of the effective discharge during the interval, but comparison of short-term effective discharges should be made with the long-term effective discharges to incorporate the full range of conditions impacting the river's morphology. Even though the effective discharge for a short period of daily flows might appear to suggest a trend toward a non-equilibrium morphology, a river may not have experienced the short-term flows long enough to adjust its "regime" morphology to the sediment transport mechanisms during the interval. Long-term effective discharge values should always be determined and used as the basis for understanding the river's "preferred" morphology. Regime rivers are dynamic, often experiencing short term variability about their mean morphologies.

Effective discharges reported in Table 5-2, Column 4, were determined by locating the mid-points of the peaks in the cumulative sediment transport histograms. This method was illustrated in Figure 4-9. The histograms for all the study locations are included in Attachment A. When single values are reported for effective discharges, it should be recognized that they are estimates of the central tendency of the flows with the highest transport capacities. Selection of single-value estimates based on the peaks of the transport histograms is somewhat subjective, so ranges are provided in Table 5-2, Columns 5 and 6.

Histograms for some of the stations had relatively broad peaks compared to others. But for most cases, the range of flows transporting the most sediment was relatively narrow, and the modal value of the highest single histogram was adopted to represent the central tendency. For other gages, a wider range of flows was found to transport the majority of the sediment, in which case a weighted mean of two to four histogram peaks were adopted. Daily discharges within the ranges provided in Table 5-2 transport the majority of the sediment.

The above analysis shows that a range of flows transports the most sediment is affirmed by USACE (July 1990). The report of findings for the Platte River does not reveal how USACE defined or calculated effective discharges, but USACE states that "[a] single effective or dominant discharge was found not to accurately describe river regime." Instead, USACE notes that a range of discharges between mean annual and bankfull transports essentially all of the bed material (July 1990). This is consistent with findings here. The effective discharges listed in Table 5-2 are not provided as single-value descriptors of regime flows, but instead as central-value indicators of the range of flows that transports the majority of the sediment.

Table 5-2. Sediment Transport and Hydrologic Characteristics at Study Sites

USGS Gage Number	Gage Name and Location	Mean Daily Discharge (cfs)	Effective Discharge (cfs)	Effective Discharge Range Low (cfs)	Effective Discharge Range High (cfs)	Dominant Discharge (cfs)	Approx. Return Interval (years)	1.5 Return Interval Flow Rate (cfs)	Flow Duration % Exceeded - Qe	Flow Duration % Exceeded - Dom
06793000	Loup River near Genoa, NE	950	2,400	1,800	3,000	1,350	<1.01	10,740	7	17
06794500	Loup River at Columbus, NE	1,150	2,400	2,110	2,770	1,500	<1.01	9,330	NA	NA
06774000	Platte River near Duncan, NE	1,850	3,000	2,880	3,200	2,240	1.05	5,140	16	27
06796000	Platte River at North Bend, NE	4,670	5,630	3,440	6,730	5,280	<1.01	17,100	28	26
06796500	Platte River at Leshara, NE	4,830	5,750	4,360	6,450	5,260	<1.01	17,100	29	35
06801000	Platte River near Ashland, NE	6,540	7,000	4,770	9,150	7,360	<1.01	27,000	25	21
06805500	Platte River at Louisville, NE	7,930	7,500	5,830	11,340	9,020	<1.01	30,400	30	20

Note:

NA = Not available.

Spatial Analysis

The methodology for assessing the morphologies of the Loup River bypass reach and the lower Platte River included a spatial analysis to assess whether the sediment transport parameters and regime analysis suggest that the morphological indicators from upstream to downstream at the study sites was consistent with natural river processes. Tables 5-2, 5-3, and 5-4 summarize the sediment transport parameters at all of the study sites. Values of one of these parameters, the average annual capacity of the daily flows to transport bed material, are shown in Figure 5-2, along with each location's value of adjusted MRBC yield.

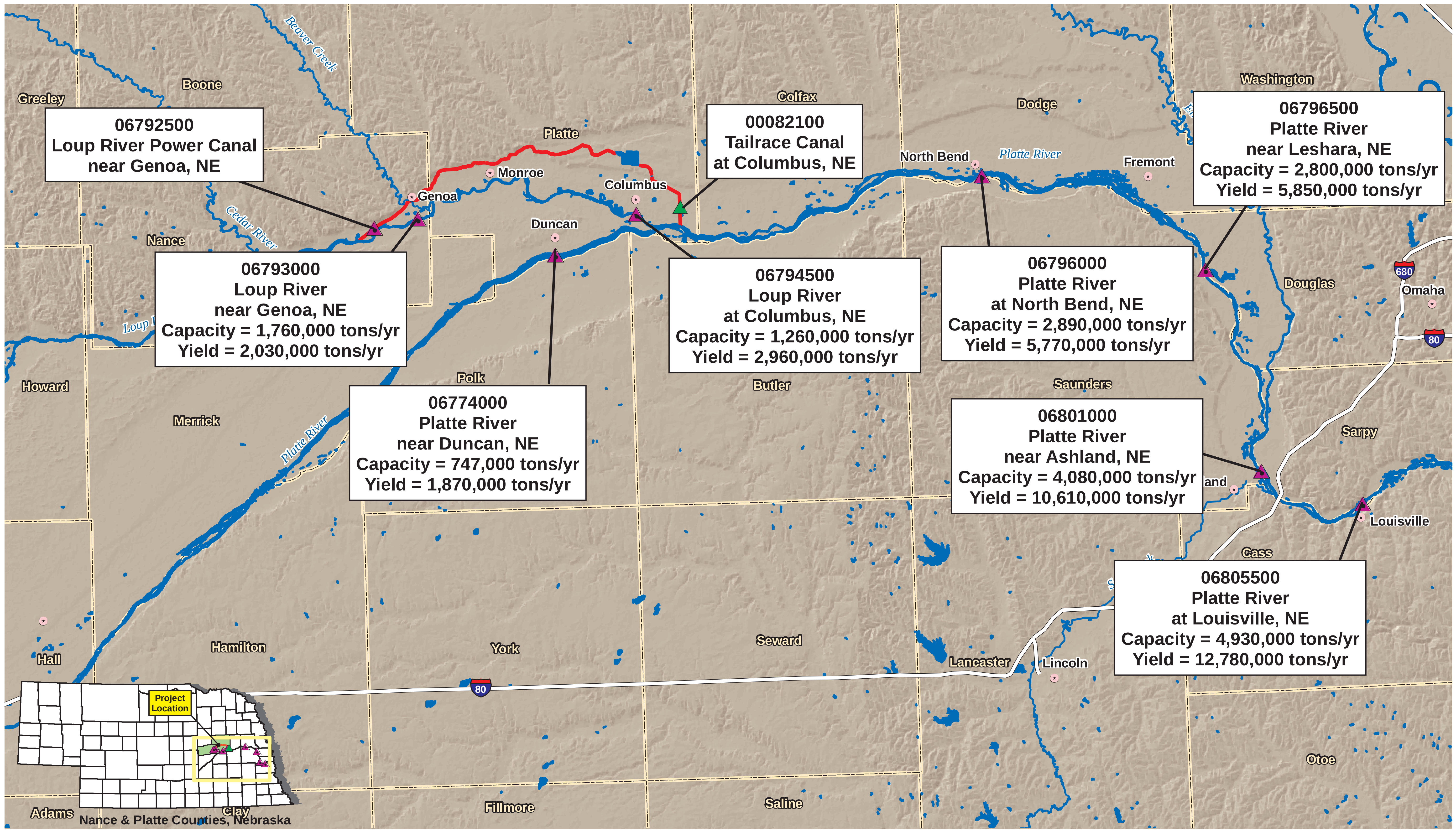
Table 5-3. Sediment Capacity and Sediment Yield at Study Sites

USGS Gage Number	Gage Name and Location	Drainage Area (square miles)	Annual Sediment Data (tons/year)	
			Capacity	Yield
06793000	Loup River near Genoa, NE	14,320	1,760,000	2,030,000
06794500	Loup River at Columbus, NE	15,200	1,260,000	2,960,000
06774000	Platte River near Duncan, NE	59,300	747,000	1,870,000
06796000	Platte River at North Bend, NE	70,400	2,890,000	5,770,000
06796500	Platte River at Leshara, NE	NA	2,800,000	5,850,000
06801000	Platte River near Ashland, NE	84,200	4,080,000	10,610,000
06805500	Platte River at Louisville, NE	85,370	4,930,000	12,780,000

Note:
NA = Not available.

Table 5-4. Seasonal (May 1 through August 15) Values

USGS Gage Number	Gage Name and Location	Mean Daily Discharge (cfs)	Dominant Discharge (cfs)
06793000	Loup River near Genoa, NE	640	1,130
06794500	Loup River at Columbus, NE	910	1,410
06774000	Platte River near Duncan, NE	1,950	2,520
06796000	Platte River at North Bend, NE	4,880	5,770
06796500	Platte River at Leshara, NE	5,350	5,260
06801000	Platte River near Ashland, NE	7,920	9,400
06805500	Platte River at Louisville, NE	9,240	10,910



8 4 0 8
Miles

Source: Stream Gage, Nebraska Department of Natural Resources; Streams/Waterbodies, 2000 Tiger Files

Legend

●	City
▲	NDNR Gaging Station
▲	USGS Gaging Station and Study Site
═	Interstate
—	Stream/River
—	Loup Power Canal
■	Waterbody
☐	County

Loup Power District Hydro Project

Spatial Analysis

Loup River Hydroelectric Project
FERC Project No. 1256
Study 1.0 - Sedimentation

DATE
August 2010

FIGURE
5-2

Z:\Projects\Loup_Power_District\37104_LPD_FERC_Relicensing\map_docs\mxd\Hydrocycling_Spatial_Analysis_Fig_5_2.mxd\Aug2010.tct

Kircher (1981) determined that effective discharges were 1,400 cfs at Overton and 1,900 cfs at Grand Island. Parsons' (May 2003) independently determined values for a different set of daily flows were 1,500 and 2,500 cfs, respectively. Parsons also lists a few other Platte basin investigations showing effective discharges in this same range. The 1985 to 2009 values of effective and dominant discharges in Tables 5-2, 5-3, and 5-4 increase in the downstream direction along the Platte River (from 3,000 cfs at Duncan to 7,500 cfs at Louisville), which is consistent with the USGS trend between Overton (1,500 cfs) and Grand Island (2,500 cfs) as well as with the increasing drainage area and sediment supplies.

Like effective and dominant discharges, the average annual capacities of the daily flows to transport bed material shown in Figure 5-2 increase in the downstream direction consistent with natural river processes, with all results showing that the capacities fall below the adjusted MRBC yields, revealing that the streams are not supply limited.

Table 5-3 provides the results of comparisons of adjusted MRBC sediment yields from Table 5-1 with average annual calculations of total sediment transport capacities. It also provides the long-term effective and dominant discharge calculations at each gage location based on daily calculations of sediment transport capacities for the study period.[10]

The results reveal that the original MRBC and adjusted yields greatly exceed the transport capacity of the flows. This readily answers the question of flow versus supply limitations. Because sediment supplies and transport capacities at all locations are not balanced at all times, any conclusions regarding potential aggradation or degradation trends can only be assessed using long-term measurements, effective discharge calculations, and applications of equilibrium (regime) methodologies.

5.2.3 Regime Theory Results

The effective discharges from Table 5-2 were input as bankfull (channel-forming) discharges on copies of all three of the regime methods previously used on the Platte River by USBR (April 2004). The results are shown in Figures 5-3, 5-4, and 5-5. As discussed in Section 4.1.1, all three methods call for "bankfull discharge" on the horizontal axis (abscissa), but it is clear from the literature cited that the intent was that values entered on the abscissa should be the channel-forming discharges. As also discussed in Section 4.1.1, both the 1.5-year flood and "bankfull" flow are crude estimates of the channel-forming discharge and are particularly inappropriate for braided rivers. For the data shown in the graphs at the sedimentation study sites, effective discharge was considered the appropriate estimate of the channel-forming discharge.

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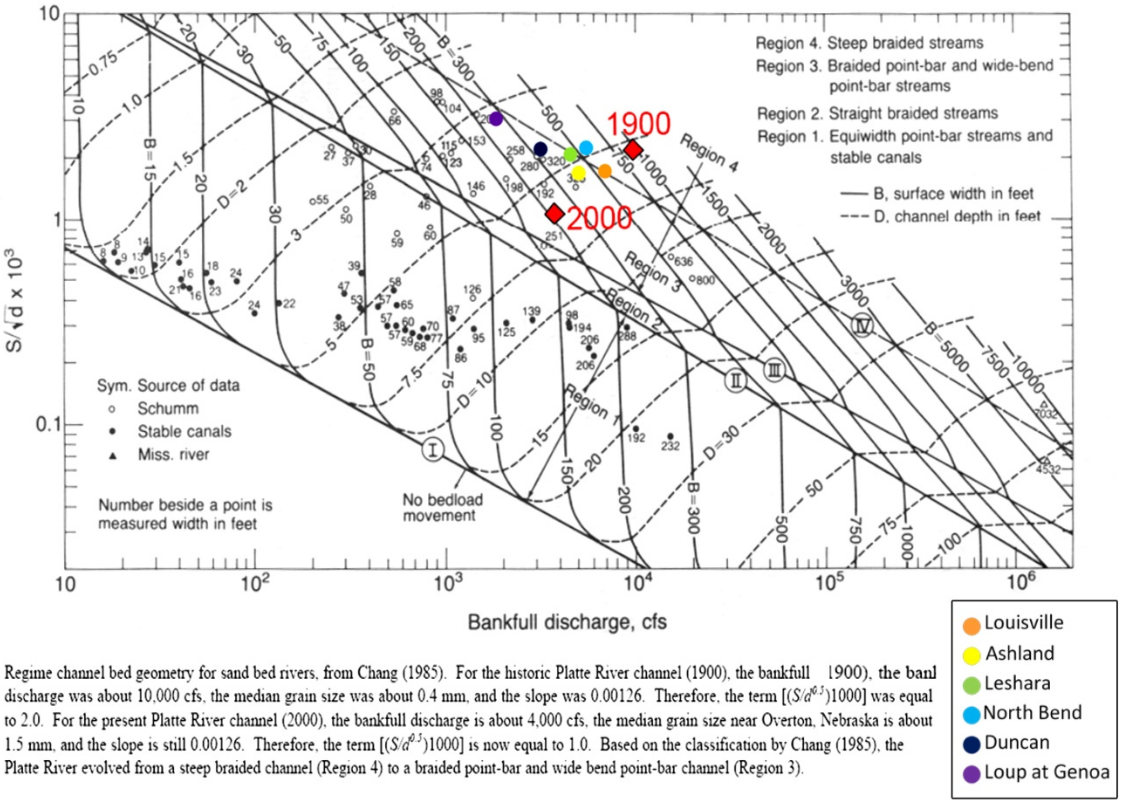
[10] Fewer years of data were available at Leshara and Ashland.

The data points on Chang's graph (see Figure 5-3) show that all six stations for this study are along the borderline between Chang's braided river Regions 4 and 3, with all locations being well-distanced from proximity to any threshold to a different morphology. The two dots labeled 1900 and 2000 were graphed by Chang at Overton and should be disregarded because instead of determining the effective discharge, Chang applied crude estimates of "bankfull" rates in each case.

Although the data points for the six stations shown on Leopold and Wolman's graph (see Figure 5-4) suggest that the Loup and Platte rivers have shifted from a braided stream over the threshold to a meandering morphology, their method does not incorporate grain size and does not include data from streams similar to the Platte River. USBR did not use this graph to evaluate its 1900 and 2000 conditions.

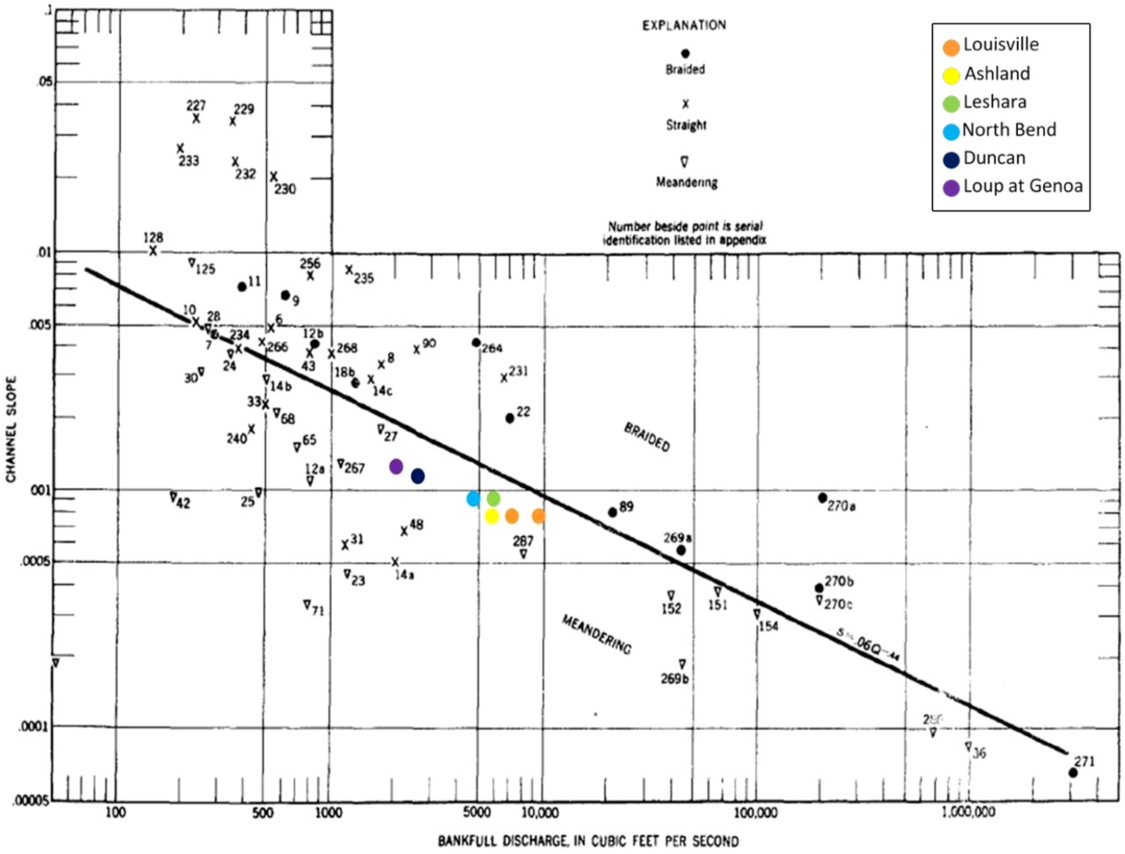
The data points on Lane's graph (see Figure 5-5) lead to the same conclusion indicated by Chang's regime method. All graphed values are well-positioned away from any threshold to a different morphology.

This combined use of effective discharge and regime theory is state of the art and supports the consensus among investigators that the Loup and Platte rivers are in regime. Further, it is the best available technology for determining whether any changes, whether climatic or operational, could impact any river's morphology.



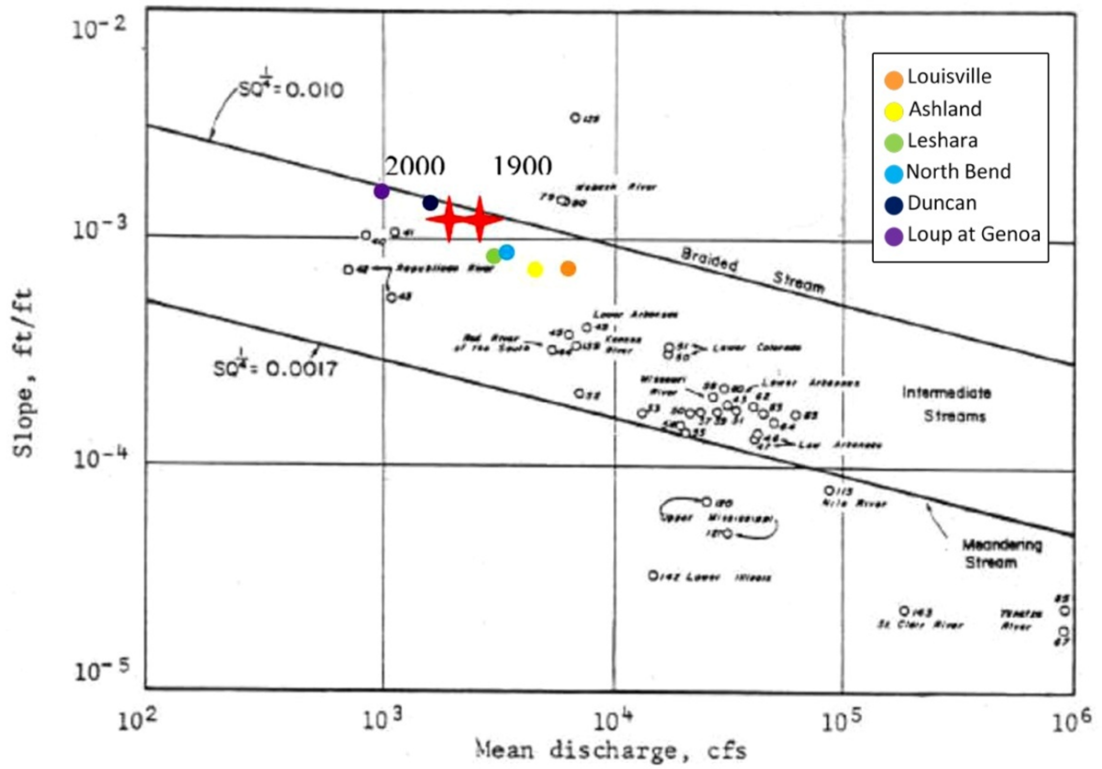
Regime channel bed geometry for sand bed rivers, from Chang (1985). For the historic Platte River channel (1900), the bankfull 1900), the banl discharge was about 10,000 cfs, the median grain size was about 0.4 mm, and the slope was 0.00126. Therefore, the term $[(S/d^{0.5})1000]$ was equal to 2.0. For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

Figure 5-3. Chang's (March 1985) Regime Morphology Chart for Sand Bed Rivers with Sedimentation Study Results



Values of slope and bankfull discharge for various natural channels and a line defining critical values which distinguish braided from meandering channels.

Figure 5-4. Leopold and Wolman's (1957) Threshold Chart for Meandering and Braided Rivers with Sedimentation Study Results



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

Figure 5-5. Lane's (1957) Regime Morphology Chart for Sand Bed Rivers with Sedimentation Study Results

5.2.4 Objective 1 Conclusions

If the capacity for total bed material sediment transport for a given time period were equal to or less than the sediment yield, it would be concluded that the braided river is not supply limited and is currently in dynamic equilibrium. If the capacity for total bed material sediment transport for a given time period were to exceed the sediment yield, it would be concluded that the braided river may be supply limited and possibly degrading.

Analysis of the results shown in Tables 5-2, 5-3, and 5-4 and Figures 5-3, 5-4, and 5-5 supports the following conclusions regarding the character of sediment transport in the Loup River bypass reach and lower Platte River:

1. Both rivers at all locations studied are clearly not supply limited. Table 5-3 shows that the annual watershed sediment yields above the gages ranges from two to six times the average study period capacity of the daily flows

to transport bed material. USACE, after assessing the same question, concluded that "[b]ed material transport for the [Platte] river was found to be capacity limited with a virtually unlimited source" (July 1990). This and literature cited elsewhere in this report supports the fact that the yields in both the Loup and Platte rivers are not lacking in being able to supply more than the transport capacity. This is the nature of a braided river.

2. The spatial analysis of values of effective and dominant discharges and average annual transport capacities shown in Tables 5-2, 5-3, and 5-4 and Figure 5-2 reveal that they increase in the downstream direction in a manner consistent with natural river processes, as well as being consistent with the literature and with values determined using similar methods by Kircher and Karlinger (1981), USGS (1983), and Parsons (May 2003) for the Middle Platte River stations.
3. At least at Ashland and Louisville, data exist that confirm that the effective discharge, and associated braided river morphology, has not changed since 1928. The only previous study of effective discharge in the lower Platte River was by Marlette and Walker (1968). Using a different sediment transport capacity equation and a much shorter period of record, Marlette and Walker calculated the dominant discharge using a histogram normally used in effective discharge methods, but instead of selecting the modal (peak) value of the histogram, he chose the median value above which half of the transport under the transport histogram occurs. Marlette and Walker arrived at values of 6,500 cfs at Ashland and 8,000 cfs at the Platte and Missouri River confluence using data from 1928 to 1967. This sedimentation study used a more common definition of effective discharge as the modal (peak) value of the transport histogram. Table 5-2 reveals that the 1985 to 2009 values (using the modal versus median discharges) are 7,000 and 7,500 cfs, respectively. These differences are not considered to be statistically significant.
4. The assumption that the 1.5-year flood is representative of either the channel forming or bankfull discharge is an approximation often used for smaller, single-channel streams. However, this assumption should not be used in non-episodic streams like the Loup and Platte rivers because the peak instantaneous floods are too infrequent and too short in duration to transport enough of the annual sediment transported to do the work of shaping or maintaining the rivers' morphologies. As demonstrated by the fact that the channel forming flows or effective discharges, calculated here for the Loup and Platte rivers, are significantly less than the 1.5-year flow and "bankfull flow," as shown in Table 5-2. Neither the 1.5-year or poorly defined and difficult to estimate "bankfull flows" should be used to approximate the channel-forming discharges in braided rivers. Effective

discharges determined from daily flow records are relatively easy to calculate, so there is no need to use either of these approximations.

5. The channel geometries are "in regime," with the long-term flows shaping them. As shown in greater detail in Section 5.3.1, the current channel hydraulic geometries match the width, depth, and velocity calculations for flow rates matching the effective discharge rates. Nothing appears to be constraining either the Loup or Platte River from maintaining the hydraulic geometry associated with the effective discharges.
6. The combinations of slopes, sediment sizes, and effective discharges at all of the stations result in all locations being well within braided river morphologies, with none being near any thresholds of transitioning to another morphology.

5.3 Objective 2 – To characterize stream morphology in the Loup River bypass reach and in the lower Platte River by reviewing existing data and literature on channel aggradation/degradation and cross sectional changes over time.

5.3.1 Analysis of Existing Data and Literature on Channel Aggradation/Degradation and Cross Sectional Changes Over Time

Several relatively recent studies, described here, were conducted by others to evaluate aggradation/degradation and cross sectional changes in the Loup and Platte rivers. Some studies had a limited focus on middle-Platte locations upstream of Duncan, while others studies focused on the entire basin, evaluating channel profiles all the way to the Missouri River confluence. Some of the more recent investigations focused on conditions in the lower Platte River.

As discussed in Section 4.1.1, sediment yields estimated using indirect methods like those used by MRBC (September 1975) have value in determining whether a reach is flow versus supply limited, but should not be used to assess whether the Loup and lower Platte rivers are aggrading or degrading or whether the channel cross section is changing over time. Better indicators of geometry changes and aggradation or degradation are available from assessments of trends in effective discharge, which are described below.

By examining conditions in 1900 and contrasting them with conditions in 1990, USACE (July 1990) found that all reaches in the basin (including the lower Platte River) had no notable ongoing long-term aggradation or degradation. USACE's primary conclusion was that "the river within the study reaches is in a state of quasi-equilibrium" (July 1990).

As discussed in Section 4.1.1, both sediment availability (yield) and transport capacity in the Platte River were evaluated by USACE (July 1990). USACE affirmed that bed material transport throughout the study area is not supply limited due to a "virtually unlimited source."

To look at impacts of changes such as removal of vegetation from islands and bars on the longitudinal profile of the Platte River, USACE (July 1990) applied both 1- and 2-D modeling of hydraulics and sediment transport, including the use of 108 cross sections in its "Reach 3" (from Duncan to the confluence with the Missouri River). The HEC-6 and TABS-2 sediment transport models were calibrated to known water surface elevations. Among other tests, simulations were made of the effects of clearing vegetation from islands and bars to create habitat. The models (with removal of vegetation) were run up to 20 years in the future and predicted that a general decline in water elevation could be expected at most discharges but that the average bed elevation would remain relatively unchanged. This illustrates the resiliency of the Platte River to maintain its braided morphology.

Elliott, Huhmann, and Jacobson (2009) also concluded that there is unlimited supply of sediment based on the "extent and persistence of emergent sand bars on the lower Platte River."

For the Platte River, USACE (July 1990) found that all reaches had no notable long-term aggradation or degradation or channel geometry trends. Highly anabranched reaches tended to be less stable than wider, single-channel reaches. The very wide single-channel reaches with no islands exhibited a tendency to aggrade slightly due to lack of transport capacity.

Citing scientific study reports by Peters and Parham (2008) and Parham (2007), NGPC (December 2008) concluded that even though the lower Platte River has been "highly altered" and that centuries-old characteristics have been "tempered" due to development and use of the water resource, the lower Platte River "retains most geomorphic characteristics of the [centuries-old] historic Platte River."

As discussed in Section 4.1.1, USBR (April 2004) tested three widely-adopted regime diagrams (Chang, March 1985; Leopold and Wolman, 1957; and Lane, 1957), showing that all three are applicable in assessing the stability of the braided river morphology. USBR notes that "The braided pattern typical of the [Platte] river prior to the 1900s, requires a steeply sloped channel or an oversupply of sediment. The average channel slope of the Platte River (0.00126)…has not changed during the1900s because a large change in river bed elevation is needed to change the average slope over the length of the river…." The USBR report shows that the Platte River's current-day profile is nearly identical to the turn-of-the-century profile published in 1901 by Gannett (USBR, April 2004).

Even though changes in planform occurred since 1900, USBR's (April 2004) application of regime theory proved that the morphology is still well within the regime zones for stable, braided rivers. USBR concluded that the Platte River is in a greater state of dynamic equilibrium than it was in its pre-development form.

Probably the most relevant publication addressing the question of aggradation or degradation is the USGS report on its study of trends in channel gradation (slopes) in Nebraska streams, including both the lower Platte River and the Loup River at and downstream of the Diversion Weir (Chen, Rus, and Stanton, 1999). By evaluating extensive sets of longitudinal, cross section, and water surface elevation data collected at 145 gaging stations between 1913 and1995, Chen, Rus, and Stanton reported the following conclusions:

- Channel degradation was found at stations downstream of dams.
- No such degradation was found downstream of the Diversion Weir, or "dam."
- A slight aggrading trend was noted at the Loup River at Columbus, but Chen, Rus, and Stanton pointed out that it did not have the same data set as the other gages. Gaging at the site was discontinued in 1978 and not resumed until 2008.
- There was no evidence of any trend in aggradation or degradation in the Loup River at Genoa, Platte River at Duncan, Platte River at North Bend, and Platte River at Ashland.
- A slight degrading trend was noted at Louisville, which was attributed to site-specific circumstances and not considered to be generic.

In a channel stability study, USACE (USACE, October 2009) studies a section of the Platte River near Fremont, Nebraska. Using specific gage analysis on the USGS gages in the area, USGS sediment data, bank line migration information from photographs, and site-specific data, USACE was able to come to three relevant conclusions (USACE, October 2009):

- "No information was discovered to indicate an ongoing change in Platte River dynamic equilibrium within the study reach.
- Specific gage analysis at four gage locations did not indicate a clear increase or decrease in channel stages over time.
- Specific gage plots illustrated stages vary from year to year reflecting natural channel dynamics."

Conclusions from Studies by Others

It is important to note that the channel of a river in regime can and will be "continually changing" (USACE, July 1990), and yet remains in regime as long as there is no long-term change in mean values of the channel geometry indicators. Elliott, Huhmann, and Jacobson (2009) found that the lower Platte River "is an especially dynamic river channel with braid bars and shifting channels that change rapidly at the scale of 10's to 100's of meters…." This is an important aspect in the assessment of impacts of alternative operations on channel morphology (cross section geometry and planform alignment). Before drawing any conclusions, short term morphologic changes predicted in these assessments need to be contrasted with the normal ranges of deviation around the long-term, stable (in-regime) mean values.

Further evidence that yield (sediment entering a reach) in the Platte Basin is best represented by sediment transported is provided by USACE (July 1990), where it is concluded that the quantity of sediment entering each study reach was nearly equal to the sediment leaving when tributaries, diversions, and drains were accounted for.

As shown above, sufficient numbers of scientific studies have been performed regarding the question of aggradation/degradation and cross-sectional changes in the study reaches to thoroughly document that there is no evidence of either process. The number and quality of these studies preclude the need for any new analyses for the purpose of this sedimentation study. The analyses described in Sections 5.2 and 5.3 are considered to be necessary and sufficient for concluding that the reaches are "in regime" and that the system is in a state of dynamic equilibrium (that is, not aggrading or degrading).

Supplemental Studies of Changes over Time

Even though the literature cited above shows a solid consensus by other professionals that all the study reaches are in regime and that no aggradation or degradation is occurring, none of the studies looked at year-by-year or season-by-season trends in channel geometries in reaching this consensus. Some (Peters and Parham, 2008; NGPC, December 2008) suggest that although they agree that the streams are in regime, any additional impacts through new diversions or storage projects would push the system into disequilibrium.

Because effective discharge methods and regime theory allow assessment of natural or alternative-operation changes over time, the work by others described above was supplemented by the District to allow assessment of trends over time in cross section geometry and longitudinal slope (aggradation/degradation).

The purpose of conducting supplemental analyses, in addition to developing tools to assess alternative operations, was to perform a more in-depth examination of possible channel geometry changes that might indicate a departure from the long-term averages of these parameters. In addition, tests were conducted to determine whether any changing conditions might have shifted, or potentially could shift, either river from its current, stable braided morphology toward the threshold of transitioning to another morphologic class, thereby impacting the habitat.

No technologies exist for quantifying the internal topological aspects (for example, braids, bars, islands, areas of sand above the water level, and number or locations of bars) of a braided river for any given flow rate, but relationships do exist between effective discharge and equilibrium values of average hydraulic geometry (average total wetted width, average depth, and average velocity), as described above.

Ample measurements of the hydraulic geometry (water-top-width, average depth, and average velocity) by USGS are available for a range of discharges, but it should not be assumed that these are fixed. The data on these parameters for the study sites are shown in Attachment B, showing that a significantly wide range in each parameter is possible for any discharge.

USGS data on daily discharges, streamflow measurement summaries, and suspended sediment measurements were acquired and evaluated for the calendar years 1985 to 2009. In addition to determining year-by-year effective discharges and their associated channel widths and depths, the District separated daily flows during each year between May 1 and August 15 from the annual records, allowing calculations of effective discharges from year to year during that season along with determinations of the widths and depths associated with the flow rate that shaped the channel in each season evaluated. The dates selected for the seasonal analyses were based on typical times when bird species use river habitat.

Using the best-fit curves through the USGS data on wetted-width, average depth, and average velocity from streamflow measurements, and using Yang's equation for total sediment transport, the day-by-day capacity of the river flow to transport bed material, and the cumulative amounts in transport during each year and each season were calculated. For each calendar year and habitat-use season, the sediment transport histogram was developed and a determination made of the discharge rate that was centered among the flow rates that carried the majority of the sediment for that period. Because this method of determining effective discharge is both subjective and dependent on the number of equal intervals in which the daily flows are grouped, dominant discharges were also determined and tabulated.

Annual Trends in Flows and Effective and Dominant Discharges

Although longer periods of time are normally required to adequately determine which flow rate(s) are shaping the channel, annual and seasonal sequences were used in this part of the investigation. The resulting values of channel geometry during each shorter period are not as reliable as longer-term calculations, but as shown below, the results are helpful in meeting Objective 2 of this sedimentation study.

The 1985 to 2009 year-by-year annual effective and dominant discharges and total sediment transported (in tons) during each period at each study site are tabulated in Attachment B. The results for the May 1 through August 15 seasons are also provided.

Total flow (in acre feet) for each period was also determined and included in the tables. Even though annual or seasonal hydrographs may not have sufficient time to shape a temporarily "stable" geometry, the channel widths, average depths, and mean velocities associated with each effective discharge were calculated and included in all of the tables.

For the annual analyses, the widths, depths, and velocities associated with the dominant discharge are also provided in Attachment B for identification of changes over time. Finally, for reference purposes, the tables also contain the percentage of the flow in the Loup River diverted at the Headworks for each year and each habitat-use season.

The annual effective, dominant, and river discharge data from Tables 5-3 and 5-4 for the seven gaging stations analyzed are graphed in Figures 5-6 through 5-12. Linear trend-lines were graphed for each parameter.

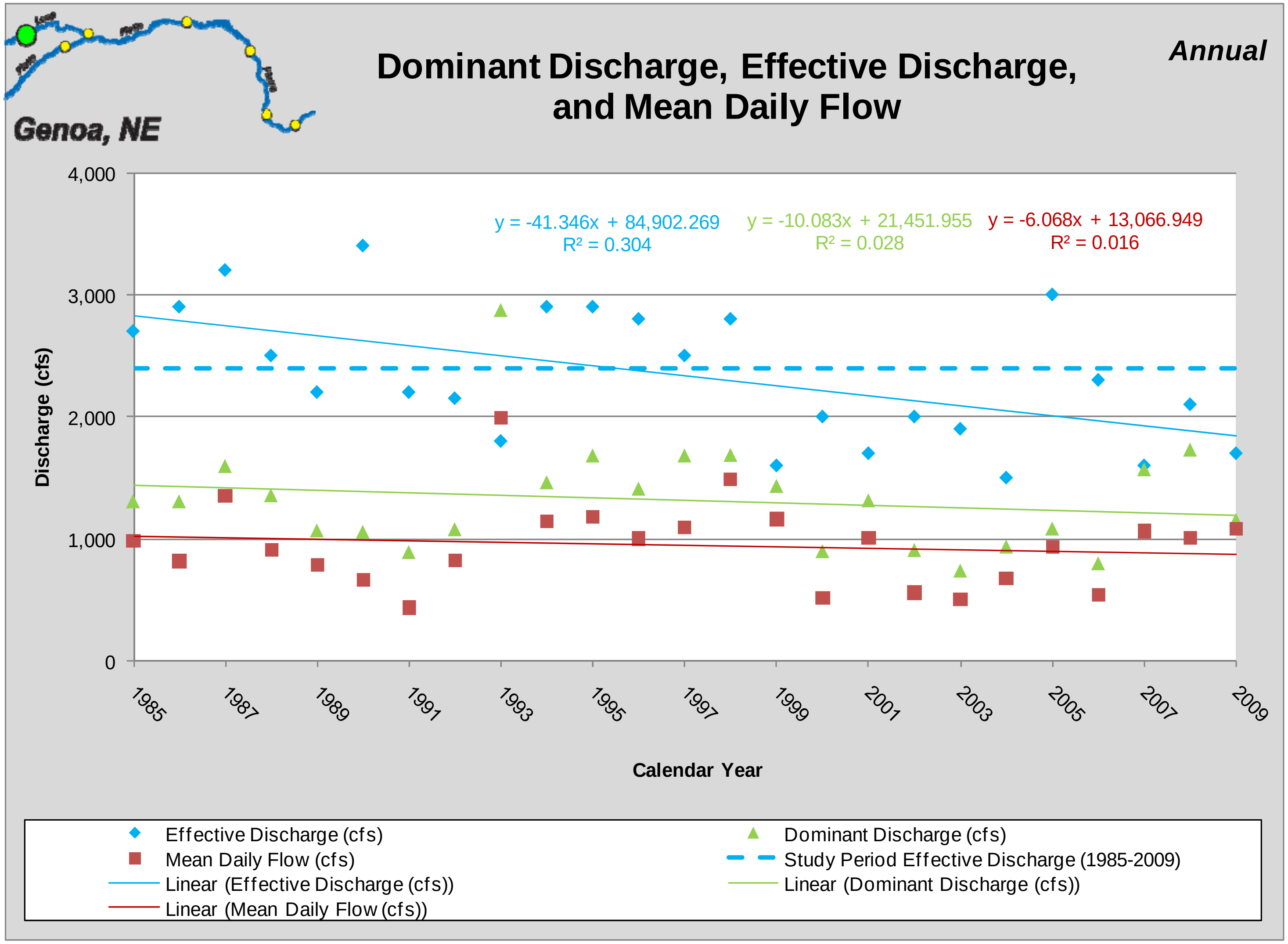


Figure 5-6. Annual Dominant Discharge, Effective Discharge, and Mean Daily Flow at the Loup River near Genoa (USGS Gage 06793000)

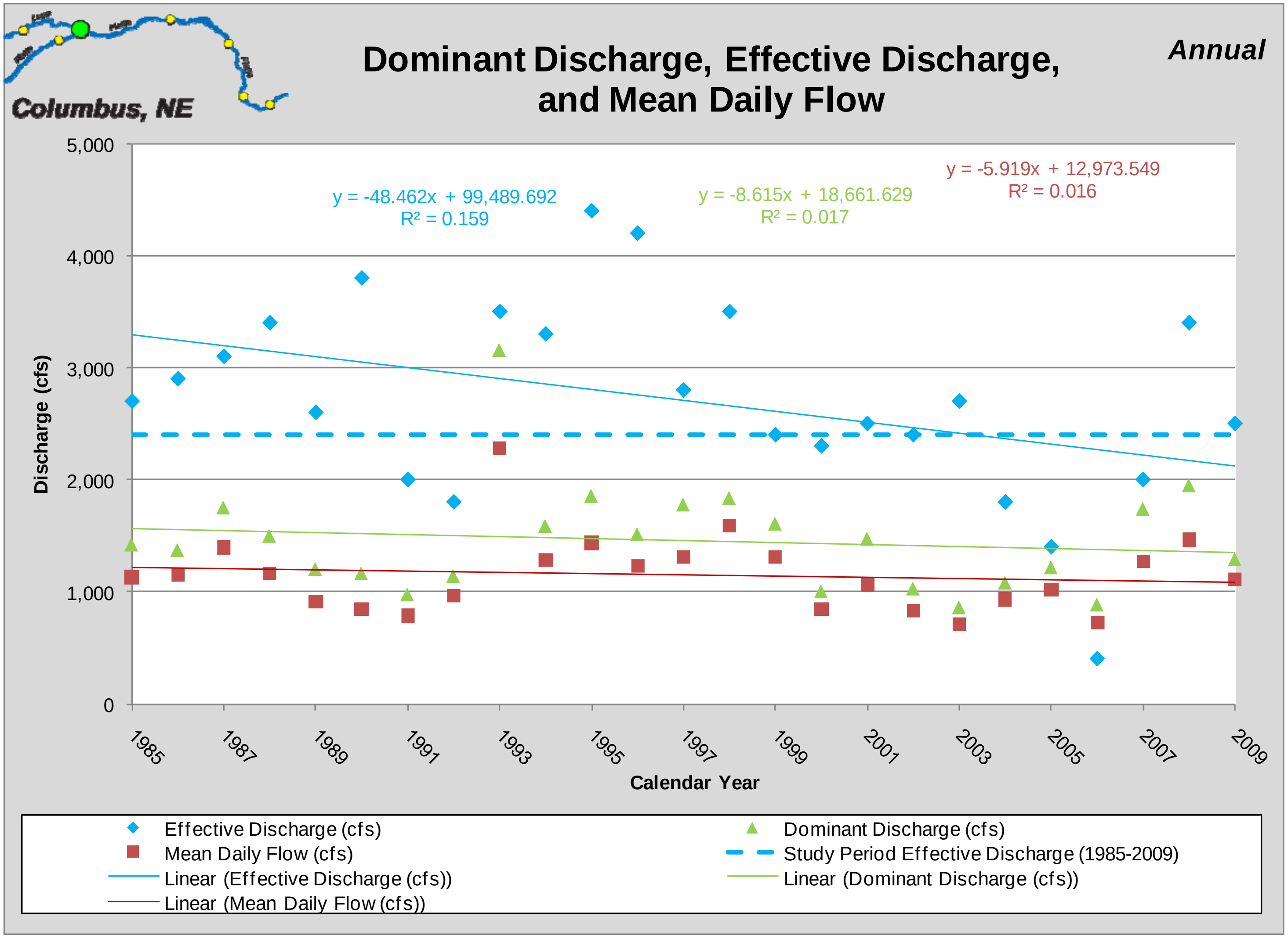


Figure 5-7. Annual Dominant Discharge, Effective Discharge, and Mean Daily Flow at the Loup River at Columbus (USGS Gage 06794500)

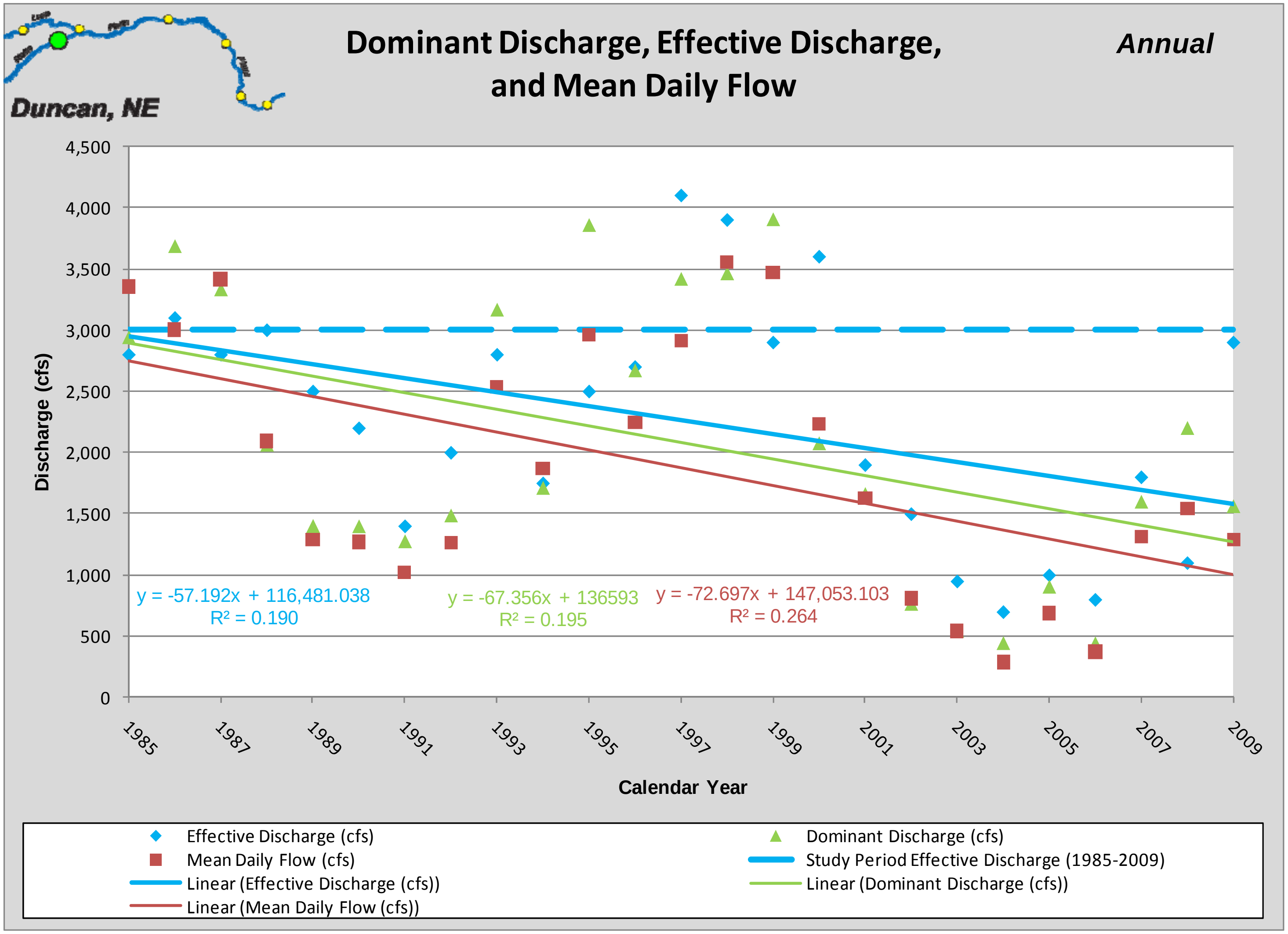


Figure 5-8. Annual Dominant Discharge, Effective Discharge, and Mean Daily Flow at the Platte River near Duncan (USGS Gage 06774000)

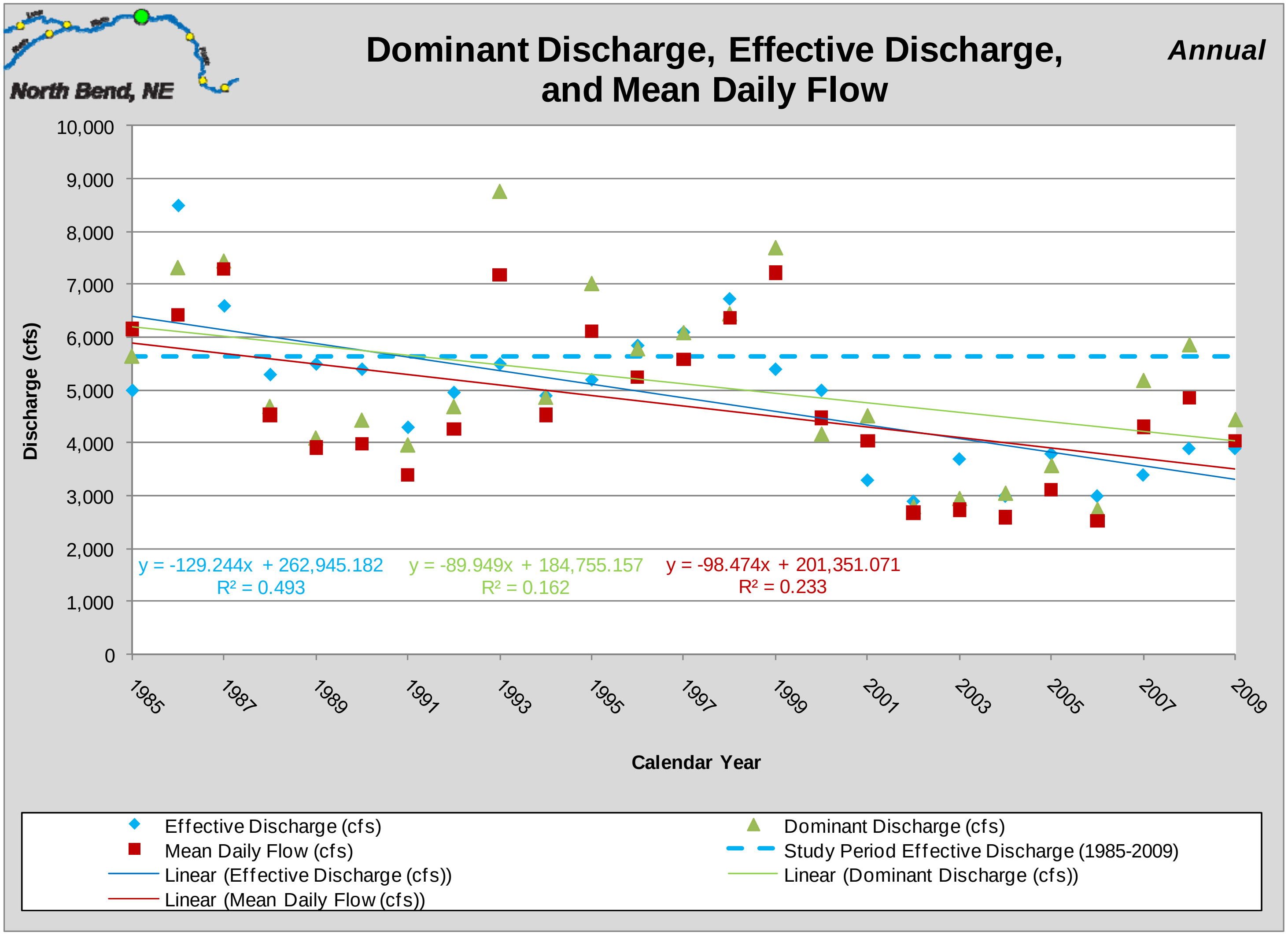


Figure 5-9. Annual Dominant Discharge, Effective Discharge, and Mean Daily Flow at the Platter River at North Bend (USGS Gage 06796000)

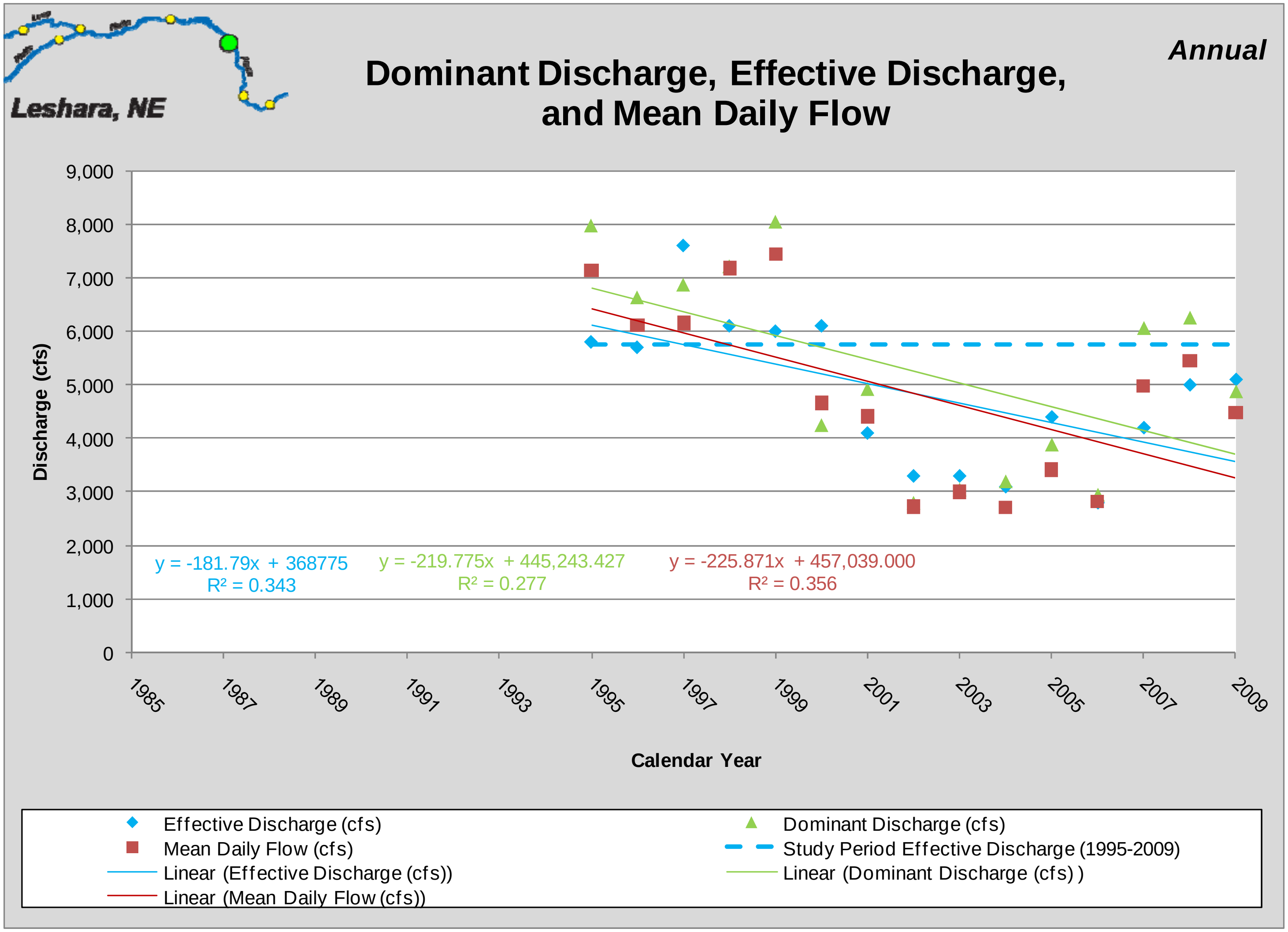


Figure 5-10. Annual Dominant Discharge, Effective Discharge, and Mean Daily Flow at the Platte River at Leshara (USGS Gage 06796500)

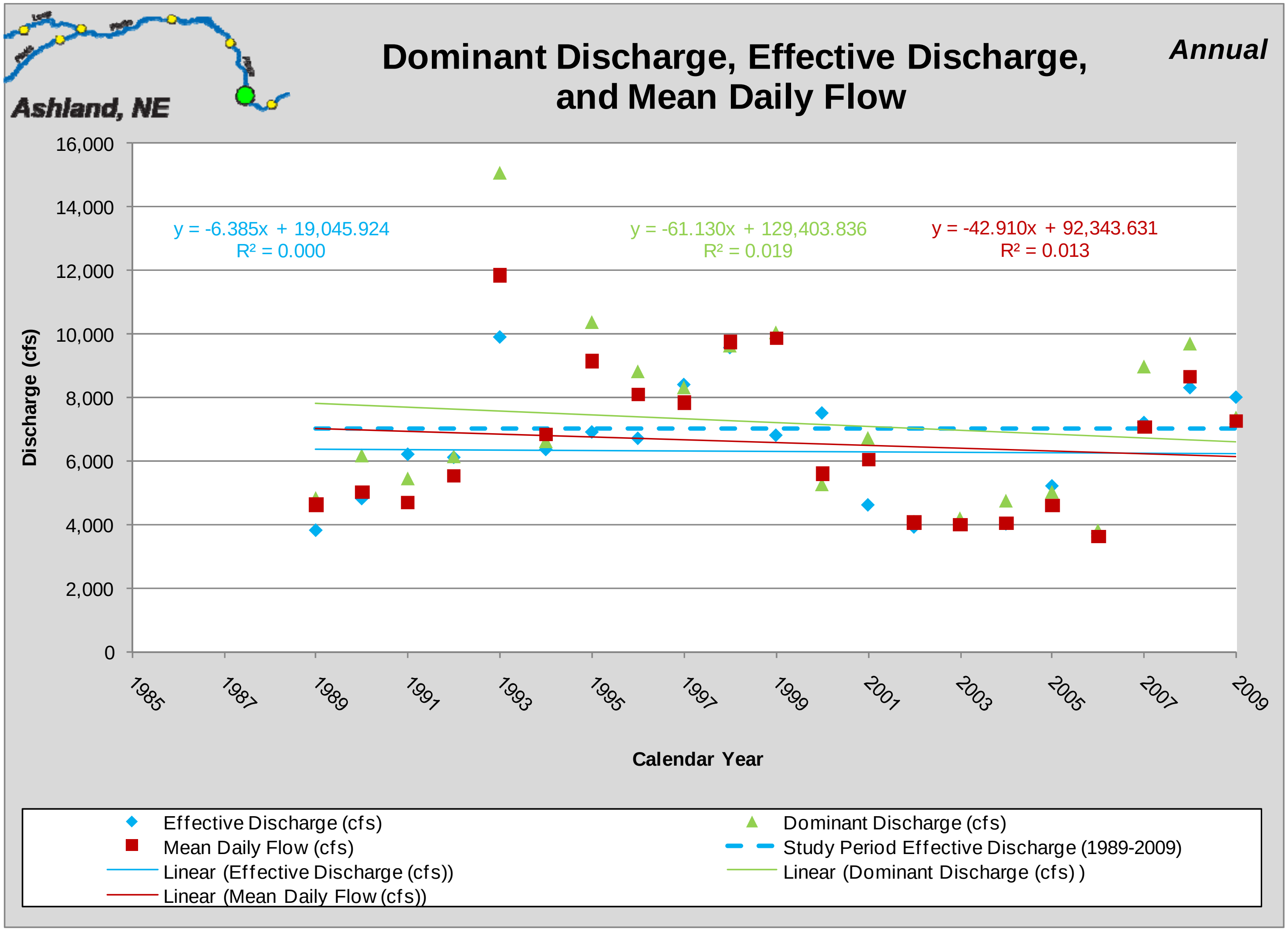


Figure 5-11. Annual Dominant Discharge, Effective Discharge, and Mean Daily Flow at the Platte River near Ashland (USGS Gage 06801000)

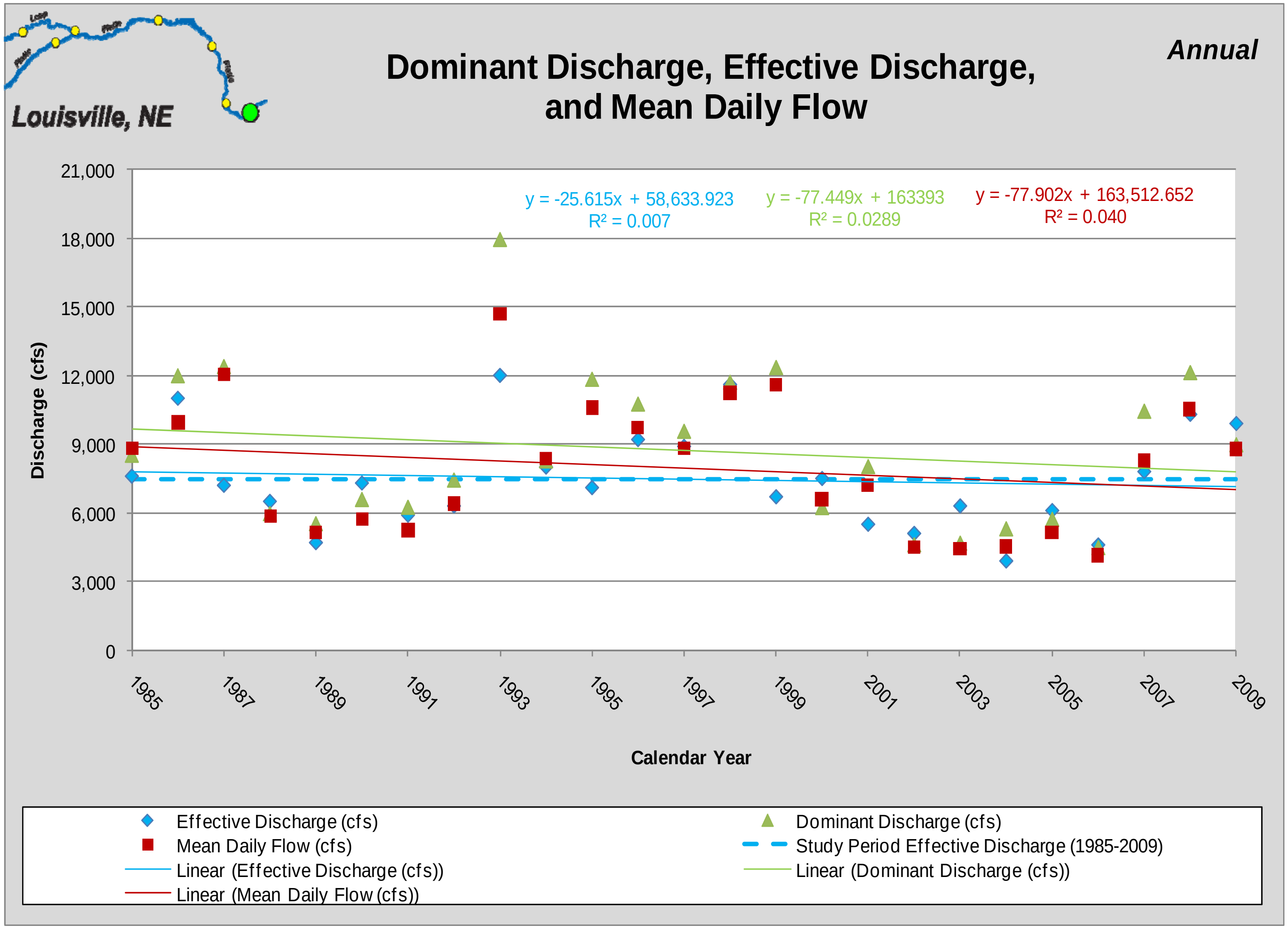


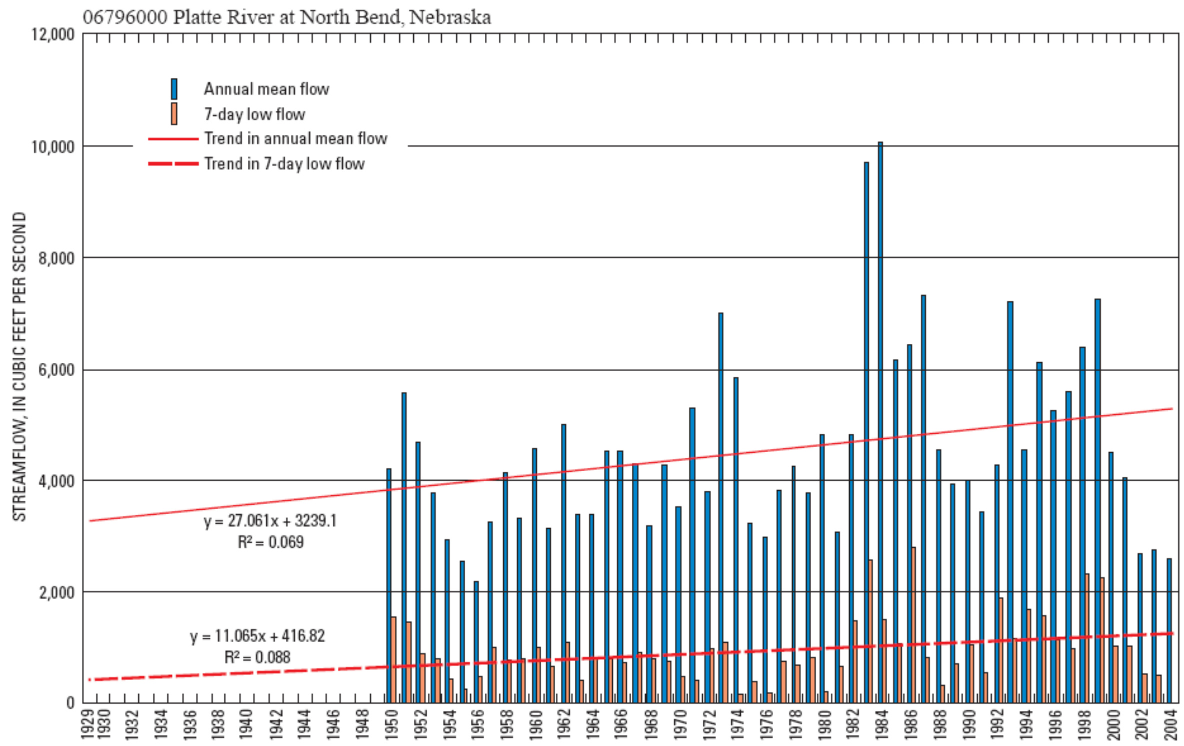
Figure 5-12. Annual Dominant Discharge, Effective Discharge, and Mean Daily Flow at the Platte River at Louisville (USGS Gage 06805500)

Examination of these annual graphs reveals that an apparent (but statistically untested) downward trend in both dominant and effective discharge occurred during 1985 to 2009 at stations from North Bend upstream. The graphs for Ashland and Louisville show slight downward-trending values of both discharge and dominant discharge, but the effective discharge trend-lines are essentially horizontal, matching the long-term (1985 to 2009) effective discharge rates for those two locations.

As expected, years with high annual flows have higher effective and dominant discharges and low-flow years have lower values. Although moderately wide year-by-year fluctuations in flows and effective and dominant discharge values occur, the graphs for Ashland and Louisville show that although some reduction in flow during the period is indicated, the absence of a trend in effective and dominant discharge shows that the reach was in dynamic equilibrium during those years. This corroborates the findings described in Section 4.1.1 in the literature review.

The advantage of having the annual mean daily discharge graphed is that it shows that a trend of declining annual flow also occurred, at least during this period, at all gages upstream of North Bend, including Duncan (where the trend lines have the most pronounced slopes). This apparent downward trend in annual flow is an anomaly of having selected the years 1985 to 2009 for this analysis. Dietsch, Godberson, and Steele (2009) evaluated much longer-term trends in streamflow characteristics for the study sites used here as well as several other locations in the Platte River Basin. An example of their results for the North Bend gage are shown in Figure 5-13. Similar, relatively steep upward trends in both the mean annual flows and 7-day low flows were discovered at Duncan and Louisville, as well as at a number of other gages in the Loup, Elkhorn, and other tributary streams.

By looking at the portion of Figure 5-13 from 1985 to 2004, it is readily seen that the two-cycle period of wet and dry years would reflect a downward trend if these years were examined in isolation from the longer-term records. Note that the dry period starting around 2002 is the second lowest in the record at North Bend. Although not duplicated here, the USGS graph at Duncan, upstream of the Project, has even greater upward slopes, and a much-more pronounced reason for caution in making conclusions regarding trends from just the 1985 to 2009 data.



Source: Dietsch, Benjamin J., Julie A. Godberson, and Gregory V. Steele, 2009, "Trends in Streamflow Characteristics of Selected Sites in the Elkhorn River, Salt Creek, and Lower Platte River Basins, Eastern Nebraska, 1928–2004, and Evaluation of Streamflows in Relation to Instream-Flow Criteria, 1953–2004," USGS Scientific Investigations Report 2009-5011, available online at http://pubs.usgs.gov/sir/2009/5011/pdf/SIR2009-5011.pdf, Appendix 2, Figure 2-2.

Figure 5-13. Annual Mean Flow, 7-day Low Flow, Trend in Annual Mean Flow, and Trend in 7-day Low Flow of the Platte River at North Bend

Of additional interest (and of value in interpreting these 1985 to 2009 graphs) is the fact that in all cases, including Ashland and Louisville, the dominant discharge trend line literally matches the slope of the discharge trend line. Any reduction in flows during any year would result in a reduction in total sediment transported, and by virtue of the definition of the dominant discharge, a reduction would be expected in the discharge rate that would transport the same amount of sediment as the annual hydrograph. If this occurred, any conclusions regarding impact on morphology should be conditioned on what the regime methods show as the result of the change.

Downward trending slopes in effective discharge matched the downward slopes in flow in some cases, while others are either steeper or flatter. The less-subjective linear dominant discharge lines more closely match flow trends. As discussed in Section 4.1.1, effective discharges are more subjective than dominant discharge values (although they have the same significance).

To offset the subjectivity of determining a single value of effective discharge, the ranges of effective discharges that transported the greatest amounts of sediment during the entire 1985 to 2009 period were shown in Table 5-2. Ranges of annual and seasonal values of flows doing the most work in forming the channel were broad enough to encompass the dominant discharges in most cases. As discussed in Section 5.2.2, conclusions about trends are best made from the dominant discharge trend lines on all of these graphs because of the subjectivity in estimating effective discharges, especially for short-term periods.

Examination of the graph in Attachment A for Duncan shows that these apparent downward annual trends in the Platte River were occurring upstream of any Project impact, at least for the years analyzed in this investigation. Data were not available to make the same assessments of Loup River trends upstream of the Diversion Weir, but it is known from the dredging data that a significant drop and leveling off of sediment transport to the Diversion Weir occurred around 1975. Based on this, and the fact that Dietsch, Godberson, and Steele (1999) found no evidence of any trend in aggradation or degradation in the Loup River at Genoa, it is concluded that these trends, if accepted at face value, are more likely the result of climate. In the case of the Loup River at Genoa, it is likely that the trend from 1985 to 2009 does not reflect the longer-term record, as evidenced by the fact that the Dietsch, Godberson, and Steele study did not detect a trend when evaluated over a longer period of time.

As to whether there are enough years to assign significance to the trends, or whether Project operations contributed, the graphs, and tables from which the graphs were generated, reveal several facts that address these questions. First, the actual data points (not the trend lines) in most or all of the seven graphs above (see Figures 5-6 through 5-12) show a definite cycling in the form of a sine-wave, following natural trends in wet, normal, and dry cycles. Both the peak runoff years and lowest runoff years follow an approximately 12-year cycle. Graphs of longer-term data (Dietsch, Godberson, and Steele, 2009) suggest a somewhat longer wave cycling.

Further analysis of both sets of graphs (Attachment A and Dietsch, Godberson, and Steele, 2009) suggests that the apparent annual data trends may be due to the limited number of years used in this investigation and, more importantly, the relatively “wet” cycle from 1985 to 1994 followed by a much drier cycle the rest of the time. All of the graphs in Attachment A show this cycling about every 12 years, and most show that there were two distinct 4- to 5-year-long dry periods occurring from about 1989 through 1992 and about 2002 through 2006.

The graph at Duncan (as well as most others) shows that annual flows in the latter dry period (2002 through 2006) were significantly less than the annual flows in the earlier dry period (1989 through 1992). The longer-term graphs in Dietsch, Godberson, and Steele (2009) show that the second “drought” during this period was second in severity to only one other on record. This is the primary cause of the apparent downward trending lines and should not be considered relevant to the question of flow reductions, changing morphology, or aggradation or degradation. The flow at Duncan in 2004, midway through the second drought, was only 15 percent of the mean annual flow. The flow in 1991, midway through the earlier drought, was 54 percent of the mean annual flow, which is a far less-serious drought.

Graphing any straight line through data containing these two cycles with significantly smaller low flows in the later versus earlier years of the 1985 to 2009 data is the cause of the apparent downward trend. This is more likely caused by two random cycles of wet/normal/dry climatic conditions, with the second cycle being drier than the first. The long-term study by Dietsch, Godberson, and Steele (2009) places these cycles in proper context; that is, this is an anomaly of the 1985 to 2009 climatic conditions, and the long-term, actual annual flows are increasing at all the study sites.

Whether considered significant or not, the apparent downward trend in annual parameters since 1985 has to be attributed to natural climatic cycling of hydrology rather than Project impacts because the Project does not impact flows at Duncan, which experienced even steeper reductions in annual flow during the same 25 years. The Project did not operate significantly differently during either dry period. Project diversions, as a percent of flow available in 1991 and 2006, were 73 and 72 percent, respectively.

Seasonal Trends in Flows and Effective and Dominant Discharges

The graphs in Attachment B are grouped by study site. The graph for each gage station titled “Effective and Dominant Discharge” contrasts the annual effective (and dominant) discharges already described (see discussion of Figures 5-6 through 5-12) with the year-by-year seasonal dominant discharges. For reasons of subjectivity noted earlier, seasonal values of effective discharges were not compiled or graphed. Because dominant discharge is the continuous flow rate that would have transported all the sediment moved during any period, its value would be expected to be in proportion to the seasonal flows.

The graphs show that the seasonal dominant discharges seldom match the annual values, falling either above or below them by as much as 40 percent. These ratios are nearly equal to the ratios of seasonal versus annual flows. Trend lines for seasonal dominant discharge were not included in the graphs because the seasons are not connected in time, as is the case with the annual values (any year’s season does not immediately follow the last years’ values).

If it is assumed that the 3.5 month season is long enough to allow changes in channel geometry to occur, the amounts by which the seasonal dominant discharges vary from the annual would be good indicators of the minor fluctuations of channel geometry (width, depth, area) that would be expected within each year, but not maintained over time. In all of these graphs, the long-term (1985 to 2009) values of effective and dominant discharge are shown as horizontal, dashed lines, and it is important to emphasize that any annual or seasonal variance from this line should not be interpreted as an indication of either short- or long-term non-equilibrium.

In order to better visualize the fact that year-by-year fluctuations in annual effective discharge and cumulative sediment transported fluctuate about a long-term, stable median, the graphs titled "Effective Discharge and Cumulative Sediment" for each study site are provided in Attachment B. Due to their subjectivity, the data points for annual effective discharge show a wider range of scatter about the long-term median than do the data for annual cumulative sediment transport capacity. Both sets of data, however, follow the sine-wave pattern discussed earlier, and lead to the same conclusions made with regard to Figures 5-6 through 5-12.

Separate annual and seasonal graphs contrasting cumulative flows with total capacity of the flows to transport the sediment are also included for each study site in Attachment B. These are titled "Cumulative Discharge and Sediment Load Capacity." The annual graphs show the same trends and draw the same conclusions as the above analysis of annual trends in effective and dominant discharges.

The seasonal "Cumulative Flow and Sediment Load Capacity" graphs comparing flows with seasonal sediment transport parameters are not as easily analyzed with trend lines nor do they follow the sine-wave pattern described above. Seasonal trends matching annual trends would be expected only if the seasonal flows each year were about the same percentage of the annual flows, which is not the case. In some years, a much greater percentage of the annual flow occurred between May 1 and August 15 than other years, resulting in relatively high corresponding values of cumulative sediment transported and dominant discharges during the season. For those stations having relatively high seasonal flows, accompanied by high dominant discharges, channel geometry adjustments may have been more prevalent during the habitat use period, although as noted earlier, 3.5 months of time with a higher channel-shaping discharge may not be sufficient time for any changes to be noticeable. This could be a consideration in assessing whether any relationships exist between sediment transport parameters and nesting data.

Based on the above analyses and literature, particularly the Dietsch, Godberson, and Steele (2009) study of long-term changes in flows, it is concluded that use of the 1985 to 2009 data to make conclusions about downward trends in any of the annual or seasonal parameters studied needs to be viewed in context of the longer-term records. A downward trend in flow and associated, parallel downward trend in dominant discharge occurred during these years, but the Dietsch, Godberson, and Steele (2009) longer-term studies dating back to the late 1920s reveal that trends in annual mean flow and 7-day low flows are definitely on an upward trend, and have been throughout their entire periods of record. For annual hydrographs typical of this region, any upward trend in annual flows will result in an upward trend in dominant discharge, so it can be reasonably concluded that the dominant discharge, when evaluated over the full periods of record at the study sites, would show an upward trend.

Annual Trends in Channel Hydraulic Geometry

In addition to determining and graphing annual and seasonal values of effective and dominant discharge and assessing any trends, corresponding values of the average channel widths, depths, and velocities were determined for each effective (and dominant, in the case of annual flows) discharge. This use of the best-fit curves through the plethora of USGS measurements of these parameters (see Attachment A) is valid because the calculated values are reasonable estimates of the hydraulic geometries that would exist if the effective discharges were maintained for a long period of time.

As with effective discharges, values of width, depth, and velocity for short sequences of daily flows (calendar years or seasons) are not as reliable as long-term values, but helped in meeting Objective 2 of this sedimentation study.

Graphs showing the year-by-year channel geometry parameters for the full or partial year (seasonal) data are provided in Attachment A. Three graphs are included for each study site showing year-by-year values of effective discharge, dominant discharge, and seasonal dominant discharge. The first two graphs show the variability of the geometry parameters with effective flow and dominant flow, respectively. The third graph shows the seasonal geometry based on the seasonal dominant discharges. Effective discharge hyetographs were graphed for the seasonal data, but selection of a single, representative value of effective discharge from the hyetographs was considered too subjective to be useful in evaluating year-by-year trends.

The color-coded horizontal lines show the long-term 1985 to 2009 values associated with the long-term effective and dominant discharges from Table 5-2. The annual and seasonal data points fluctuate around these lines, with less variability than seen on the earlier effective discharge graphs. As noted earlier, analysis of trends is best accomplished using the graphs for dominant discharge (the bottom two graphs on each page).

Because the annual and seasonal flows cycle through wet and dry periods, the corresponding effective and dominant discharges follow the same cycles. All the best-fit channel geometry equations have increasing values of the parameters with increasing daily discharge, so the widths, depths, and velocities rise and fall with the dominant discharge value used in determining them.

Trend lines were evaluated but are not shown in these graphs for two reasons. First, many had slight or no slopes, and none of those with sloping trend lines were considered relevant for the reasons noted above regarding the two cycles of wet/normal/dry sequences. Downward trends in these values are predictable in any period of time when flows are downward trending from a high low-flow period to a much lower low-flow period, but this does not speak to the stability of a river's long-term morphology. Entering any of the yearly values of either effective or dominant discharge in Figure 5-3, 5-4, or 5-5 would demonstrate that if the channel geometry adjusted to the values, the graphs would all show that the river's morphology is still well within the braided river regime. Second, in most cases, including the trend lines made it difficult to distinguish them from the horizontal, long-term 1985 to 2009 values.

Seasonal Trends in Channel Hydraulic Geometry

It is readily evident that the ranges of fluctuations of the geometry parameters around the long-term average seasonal values (the bottom graphs on each page) is much wider than for the graphs showing results using annual dominant discharges (center graphs). This is in large part due to the high variability of daily flows during the habitat season as well as the relatively short period of time for the dominant discharge to establish the associated geometry. The seasonal graphs are misleading, in part because the points are discontinuous (all intervening flows from August 16 to April 30 are disregarded) and one cannot connect the dots.

In general, high seasonal dominant discharges were associated with high annual dominant discharges, but in some years, a high or low percentage of the annual flow occurred during the habitat season, causing the seasonal and annual dominant discharges to vary, with one being greater than the other.

Regime Implications of Trends

If it is hypothesized that the apparent downward trends from 1985 to 2009 in flows and dominant discharges have long-term significance (this should not be theorized), or that the trends during the past 25 years are relevant to habitat, the logical next question is whether either braided river, the Loup or the Platte, is transitioning from its state of equilibrium to a different morphology.

This is a relatively easy test using regime theory. As an illustration, the annual variation in effective discharge at North Bend is shown in Figure 5-9. The effective discharges from 1985 to 2009 ranged from a low of 2,900 to a high 8,500 cfs, which is about the same as the range of the 1985 to 2009 values in Table 5-2. Graphing either of these end values on either Chang's regime graph (see Figure 5-3) or Lane's regime graph (see Figure 5-5) would cause the blue dot (North Bend) to move horizontally only a fraction of an inch either way.

Neither extreme condition, if sustained, would change the conclusion that both rivers are solidly in regime with braided river morphology. In the case of Chang's graph (see Figure 5-3), the effective discharge would need to decline to about 1,000 cfs before the point would move even halfway to the threshold of his Region 1, which is defined as "equiwidth point-bar streams and stable canals." Lane's graph (see Figure 5-5) shows that a much greater decline in effective discharge would be needed to move halfway to a meandering river classification. This not only demonstrates the natural penchant of the Loup and Platte rivers to remain braided, but it also illustrates the magnitudes of changes that would be required to cause any degradation in the braided river morphology or habitat.

The bottom line of the above analysis is best summarized by USBR (April 2004), which concluded that the Platte River is in a greater state of dynamic equilibrium than it was in its pre-development form.

5.3.2 Objective 2 Conclusions

If the literature review, sediment transport parameter calculations, and regime analyses indicate that short-term fluctuations in the morphology of the Loup River bypass reach and lower Platte River are not transitioning to another form, it would be further affirmed that the rivers are currently in dynamic equilibrium. If the literature review and calculations indicate that the Loup River bypass reach and lower Platte River are transitioning to another form and either aggrading or degrading, it would be concluded that the rivers are currently not in dynamic equilibrium. Furthermore, if the analysis of the current condition morphology indicates that the Loup River bypass reach and lower Platte River either are in dynamic equilibrium or are not supply limited based on the adjusted yields and sediment transport capacity calculations, then no alternatives relative to sediment augmentation would be evaluated.

The body of literature and the supplemental calculations demonstrate that the Loup River bypass reach and the lower Platte River are in regime and are seated well within regime zones considered as braided streams. Further, the analyses and other supporting literature cited herein clearly indicate that both the Loup River bypass reach and the lower Platte River at all locations studied are clearly in regime, not supply limited, and not aggrading or degrading, with no indications of channel geometry changes over time.

5.4 Objective 3 – To determine if a relationship can be detected between sediment transport parameters and interior least tern and piping plover nest counts (as provided by the Nebraska Game and Parks Commission [NGPC]) and productivity measures.

5.4.1 Literature Review

In accordance with the Revised Study Plan and Study Plan Determination, if it were determined that the Project did not affect morphology in the lower Platte River, or that the system is in dynamic equilibrium, it would be inferred that the Project does not affect interior least tern and piping plover sandbar nesting habitat parameters related to sediment transport and morphology and that no further analysis would be warranted. As discussed in Sections 5.2 and 5.3, the investigations of channel morphology in the lower Platte River revealed that the lower Platte River is in a state of dynamic equilibrium, well-seated within regime of a braided river. In addition, the literature review in Sections 4.1.1 and 5.3.1 found that several articles affirmed that the habitat is the morphology and that maintaining a braided river morphology maintains the habitat that it provides. However, the methodology as described in Section 4 was performed because this analysis would further the body of knowledge related to interior least terns and piping plovers on the lower Platte River by determining if there are relationships between sediment transport and/or hydrologic parameters and interior least tern and piping plover nest counts.

Although no other studies comparing nest counts with sediment transport parameters have been conducted to date, one USGS study has drawn conclusions and found relationships regarding interior least tern and piping plover nesting on the lower Platte River and geomorphic classification. The USGS study (Elliott, Huhmann, and Jacobson, 2009) found that valley width is an important variable in the geomorphic process from upstream to downstream on the lower Platte River. The study also found that based on nesting data from 2006-2008, interior least terns and piping plovers appear to select those areas of the river with a narrow valley width, as these areas provide a greater potential for emergent sandbar habitat. These conclusions indicate that given the availability of sand in the lower Platte River, the extent and persistence of emergent sandbars is likely limited by discharges that are capable of transporting and destabilizing vegetated sandbars (Elliott, Huhmann, and Jacobson, 2009). This conclusion indicates that, consistent with the analysis performed in this sedimentation study, the lower Platte River is a flow limited system, not a sediment supply limited system. Valley width acts to constrict flow and thereby enhance sediment transport and bar building. In areas with narrow valley width, flood flow constriction could be expected to increase scour and potential re-working of bars, potentially resulting in greater persistence of sandbars for nesting. Conversely, in areas with broad valley widths, containment of flood flows would be minimized, potentially creating persistent vegetated bars and islands.

Confined width was also determined to be a dominant control on channel morphology in the adjacent central Platte River segment (Fotherby, 2009). Fotherby determined that at confined widths of less than 600 meters, fully braided channels were maintained. At widths greater than 600 meters, vegetated islands and an anabranched channel pattern dominated. Fotherby concluded that the success of the interior least tern and piping plover in the central Platte River appears linked to a wide braided main channel.

5.4.2 Analysis of Nest Counts Compared to Sediment Transport Parameters

As discussed in Section 4, Methodology, this sedimentation study compared interior least tern and piping plover nest counts with sediment transport parameters. All of the comparisons were performed for three scenarios—no-lag (that is, sediment transport parameters for year X compared to nest data for year X), 1-year lag, and 2-year lag—to see if the occurrence of a given parameter either annually or seasonally in a given year had a relationship with bird nest counts that year or in the following 2 years. For each of these data sets, a linear regression analysis was performed. Each analysis was graphed and the coefficient of determination (R^2) was generated for linear regression for each scenario for each species seasonally and annually. A total of 1008 graphs (504 graphs for each species) were developed, as shown in Table 5-5.

Table 5-5. Summary of Graphs Generated for Correlation Analysis

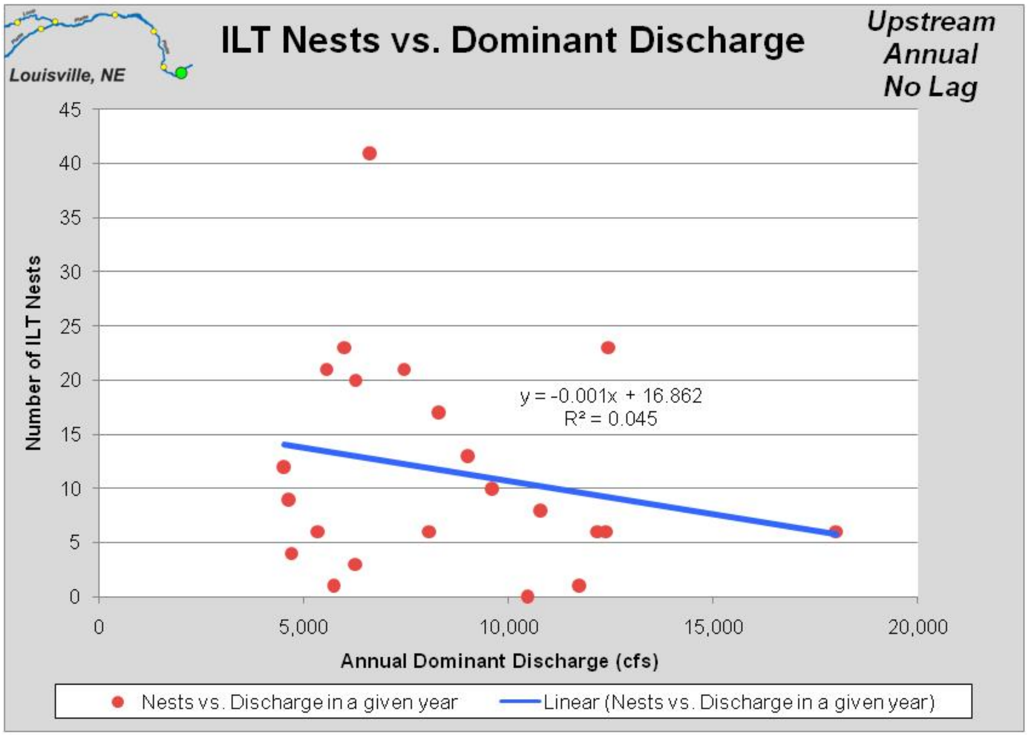
Component of Analysis	Number of Analyses Required
Species Evaluated	2
Sediment and Hydrologic Parameters	14
River Segments Analyzed	4
Comparisons for Each River Segment (Upstream, Downstream, and Combined Segment)	3
Time Series Evaluation (No lag, 1-year lag, 2-year lag)	3
Total graphs generated	1008

Each graph and corresponding R^2 was reviewed to identify relationships between nest counts and the sediment transport or hydrologic parameters. The R^2 value represents the strength of the linear association between nest counts and a particular sediment transport or hydrologic parameter and describes the proportion of the total variation in nest counts that is explained by linear regression of that parameter. R^2 values range from 0 to 1, with a higher number indicating a greater correlation. For example, an R^2 value equal to 0.10 indicates that 10 percent of the total variation in nest counts can be explained by a given parameter. The R^2 tables for all regression analyses are provided in Attachments C and D.

The R^2 values for interior least tern nest counts and sediment transport and hydrologic parameters range between 0.000 and 0.389. A total of 7 of the 504 R^2 values reached 0.300 (representing 30 percent of the total variation in nest counts that can be explained by a sediment or hydrologic parameter variable), and no patterns could be discerned for those that did. The R^2 values that exceeded 0.300 could best be described by the random nature of numbers. When working with a large dataset, it is inevitable that there will be a degree of randomness that explains why some of the numbers align in some degree of association. These few higher R^2 values do not change the conclusion that there are no discernable relationships. Those few graphs that show the higher R^2 values may indicate rejecting the null hypothesis for a statistical relationship; however, because of the large variance of the data and because a large range of number of nests can be found in a small range of sediment transport and hydrologic parameters, these were considered spurious.

The R^2 values for piping plover nest counts and sediment transport and hydrologic parameters range between 0.000 and 0.588. A total of 26 of the 504 R^2 values reached 0.300, with 9 of those occurring in the no-lag scenario downstream of Leshara to Ashland. This segment averaged 6.3 nests a year over a 22-year period. A limited sample size increases the probability of false correlation. In addition, higher R^2 values exist in the Leshara to North Bend reach for piping plover nests when analyzing Year X+1. These higher values are likely attributed to the small dataset for piping plover nest counts. For example, years 1995, 1996, 1999, 2000, 2004, and 2005 were excluded from the data set in this river segment due to lack of data (as described in Section 4). As the amount of data available to correlate decreases, the possibility of spurious correlation increases. Therefore, for reaches where adequate nest count data exists, no relationships with sediment transport and hydrologic parameters were identified. In segments where the data set is small, the analysis between sediment transport and hydrologic parameters is inconclusive.

Figures 5-14 through 5-17 are example graphs that are typical of the 1008 graphs that were generated. Each graph contains the number of nests on the x-axis and the parameter analyzed on the y-axis. Each point on the graph represents the intersection of the number of nests at the parameter analyzed for a given year. Also displayed on the graph is the best fit line from the linear regression analysis (and corresponding slope). Finally, the R^2 value is provided. Consistent with the review of all of the R^2 values, visual observation of the best fit line compared to the points on the graph does not indicate a trend between an increase or decrease in a parameter and resultant change in number of nests for either species.



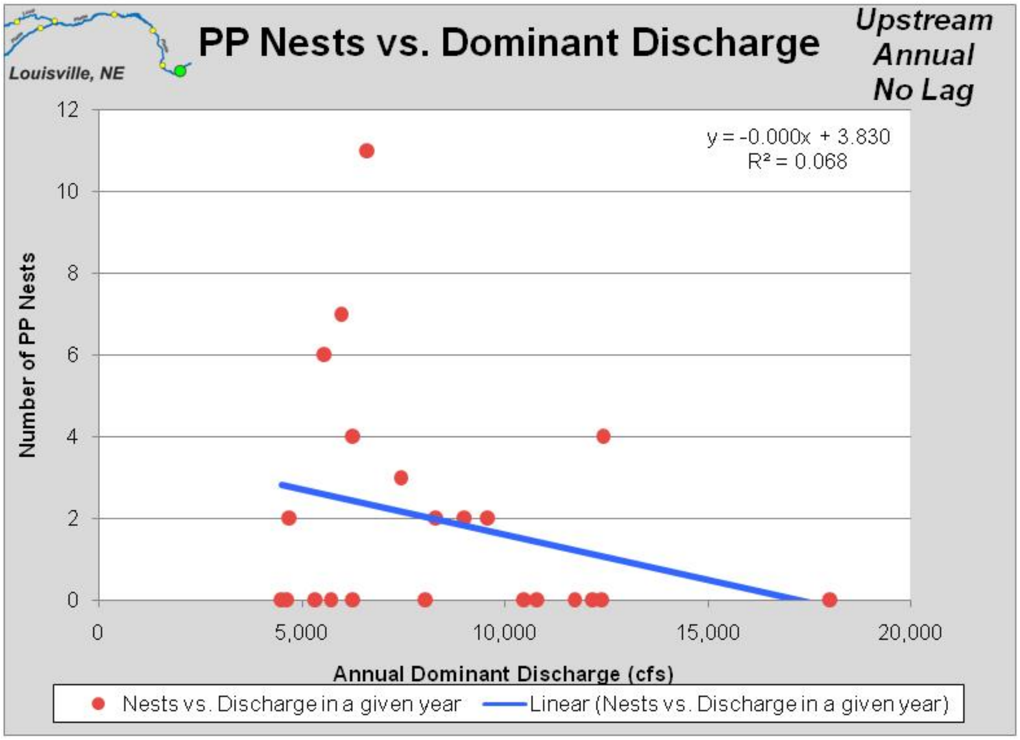
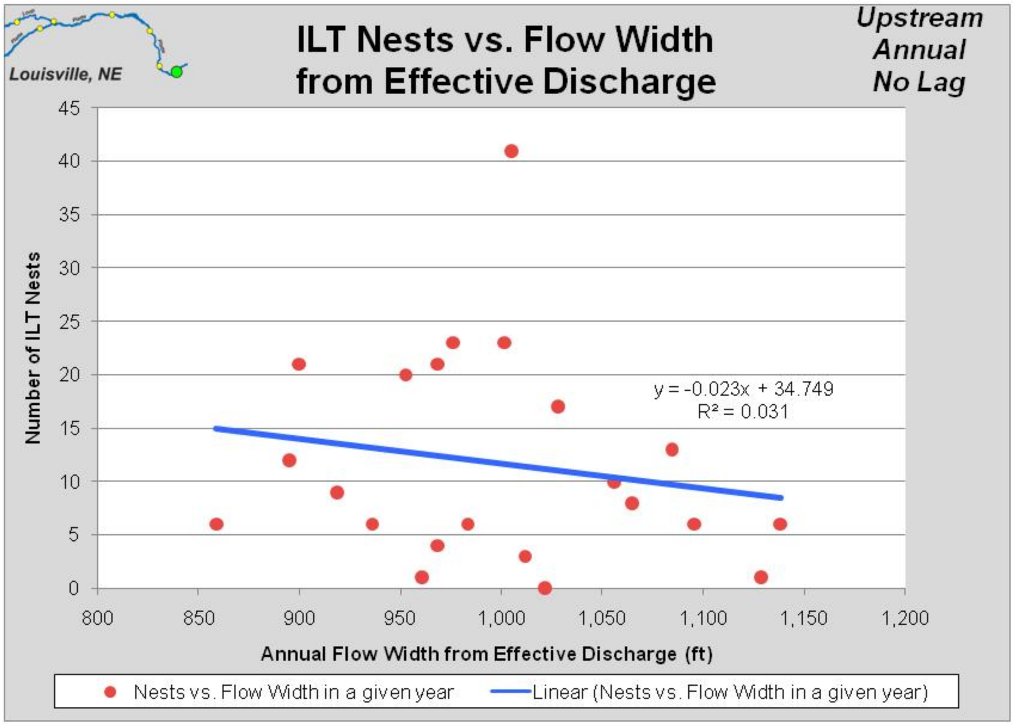


Figure 5-14. No Lag, Upstream of the Platte River at Louisville (USGS Gage 06805500)



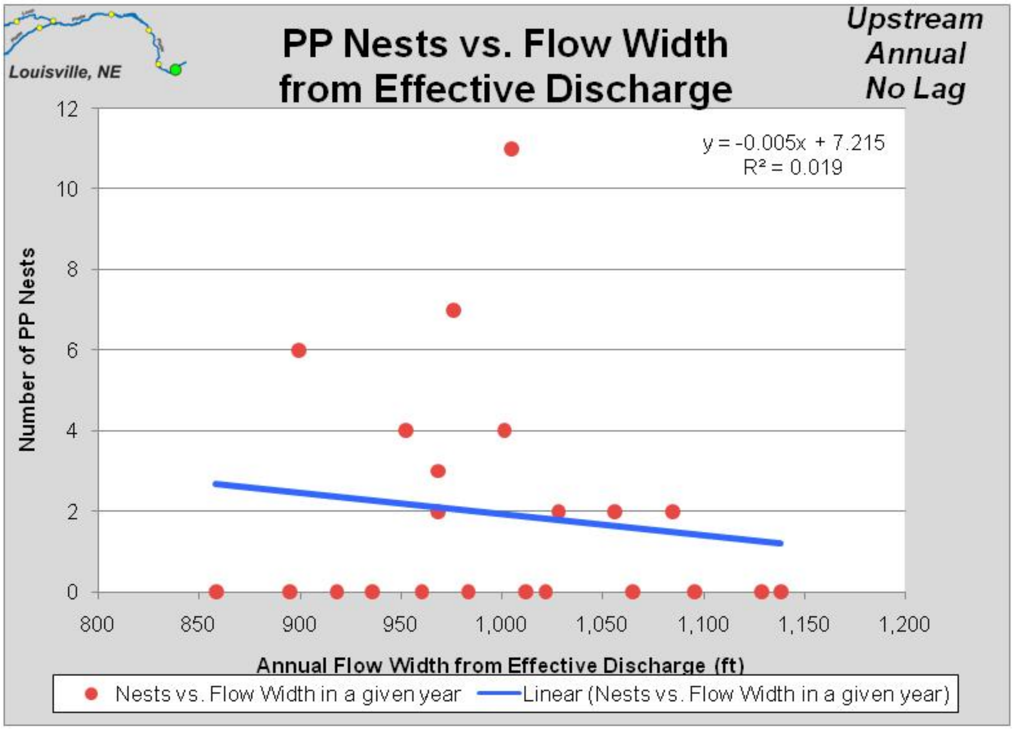
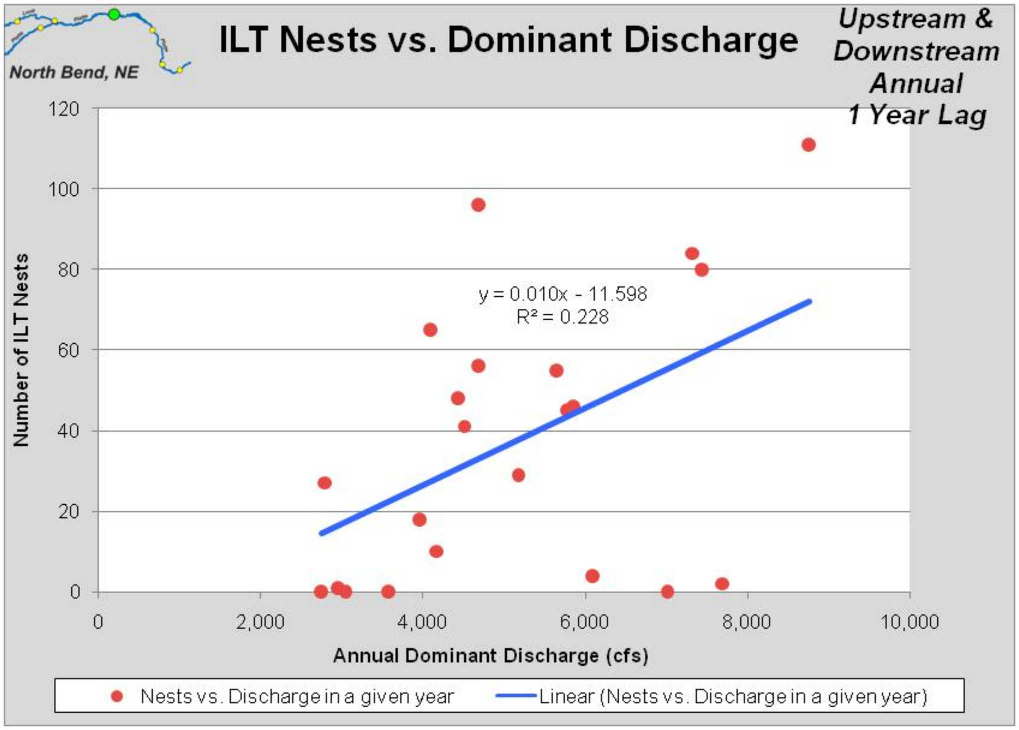


Figure 5-15. No Lag, Upstream of the Platte River at Louisville (USGS Gage 06805500)



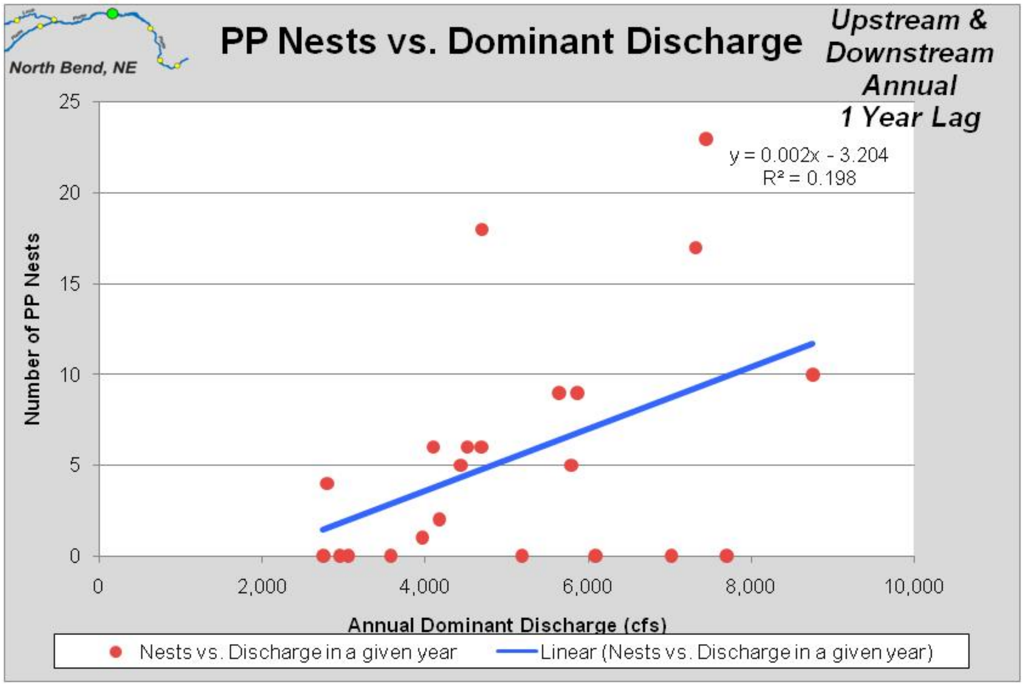
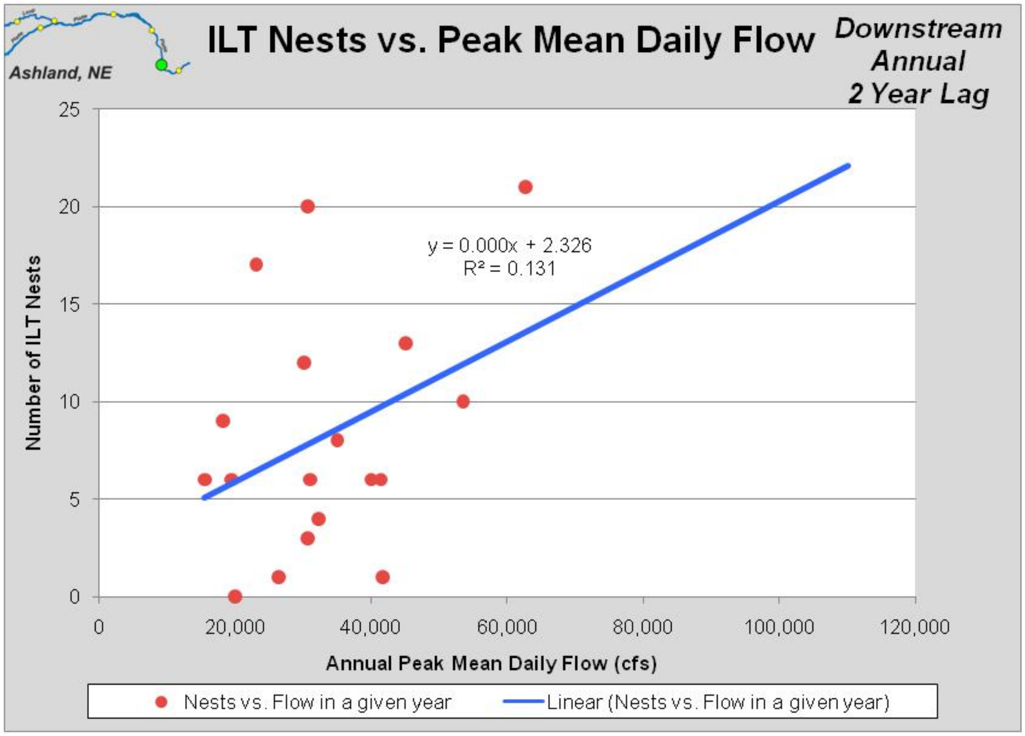


Figure 5-16. 1-year Lag, Combined River Segment Upstream and Downstream of the Platte River at North Bend (USGS Gage 06796000)



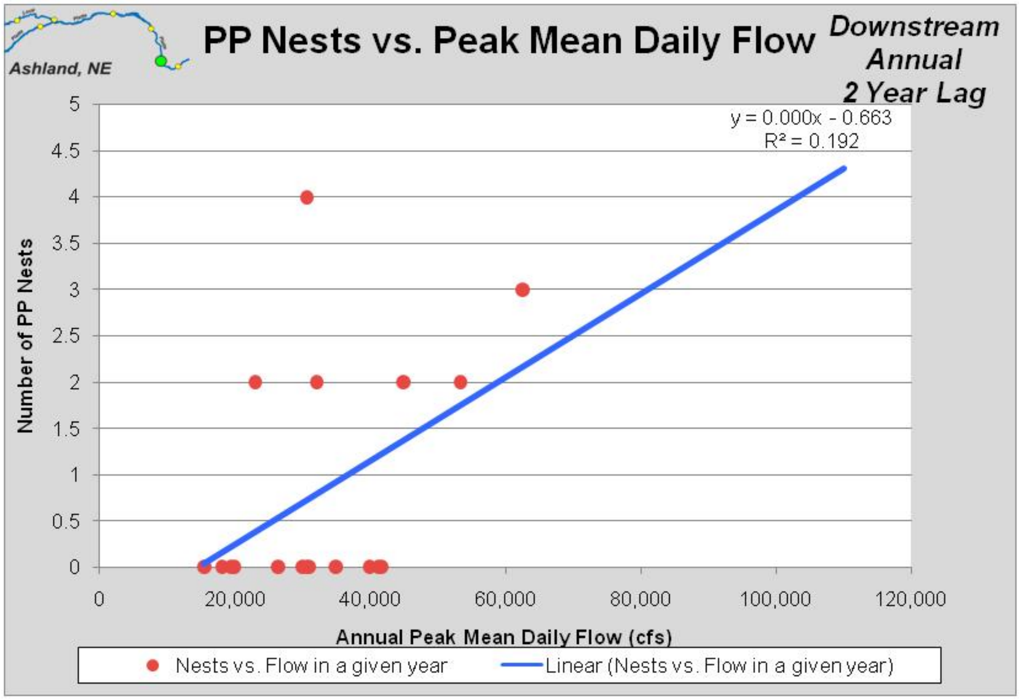


Figure 5-17. 2-year Lag, Downstream of the Platte River near Ashland (USGS Gage 06801000)

5.4.3 Objective 3 Conclusions

All analyses conducted yielded results of no significant relationship between interior least tern and piping plover nest counts and sediment transport parameters. No evidence from these analyses was discovered that would suggest that a relationship exists between nest counts and sediment transport or hydrologic parameters.

The investigations of channel morphology in the lower Platte River revealed that the study reaches are in a state of dynamic equilibrium, well-seated within regimes of braided rivers. The study reaches are in a sediment balance, and review of sediment transport and hydrologic parameters compared to nest counts yielded no discernable correlation.

5.5 Objective 4 – To determine if sediment transport is a limiting factor for pallid sturgeon habitat in the lower Platte River below the Elkhorn River.

5.5.1 Platte River Sturgeon Population Dynamics Study

Researchers at UNL are currently conducting a 5-year Shovelnose Sturgeon Population Dynamics Study within the Platte River that is to end in 2012 (NGPC, April 19, 2009). The study is to document movement and population of shovelnose sturgeon, but a side benefit of the study has also been the capture and documentation of pallid sturgeon as it is subject to the same capture techniques as the shovelnose sturgeon. Because the shovelnose sturgeon is more abundant than the pallid sturgeon, and is morphologically and physiologically similar to the pallid sturgeon, there is the opportunity to use the shovelnose as a useful surrogate model for the less prevalent pallid sturgeon. Because the pallid sturgeon tends to occupy similar habitat, UNL researchers also capture pallid sturgeon during their efforts to capture shovelnose sturgeon.

Capture efforts have been conducted along the Platte River from its confluence with the Missouri River to an upstream location approximately 30 miles west of Columbus. Gear used during these efforts consists of trotlines and drifting trammel nets. In 2009, 69 pallid sturgeon were captured. An additional 20 to 25 pallid sturgeon were captured through mid-summer 2010. No sturgeon have been collected upstream of Columbus; however, several shovelnose sturgeon and a pallid sturgeon were collected approximately 0.5 mile below the Loup Power Canal confluence (UNL, July 14, 2010).

5.5.2 Pallid Sturgeon Use of the Lower Platte River

As more information is gathered on pallid sturgeon life history and movement within the Missouri River system (including tributaries), it is becoming more evident that the lower Platte River is important habitat for the development and growth of the pallid sturgeon. Peters and Parham (2008) stated that “…the fact that we caught pallid sturgeon during spring, summer and fall months of the year indicates to us that the lower Platte River is an important part of RPMA 4…, which includes all of the

Missouri River downstream from Gavins Point Dam to its confluence with the Mississippi River (approximately 800 river miles).” In addition, Peters and Parham (2008) noted that “…the capture of six pallid sturgeon that were stocked into the Missouri River suggests that conditions in the Platte River are attractive to stocked pallid sturgeon.”

Researchers at UNL are currently conducting a 5-year Shovelnose Sturgeon Population Dynamics study within the Platte River that is to end in 2012 (NGPC, April 19, 2009).

Of the 69 pallid sturgeon that were collected in 2009 during the UNL Shovelnose Sturgeon Population Dynamics Study, discussed in Section 5.5.1, only 3 were potential “wild” spawn fish (UNL, July 15, 2010). That is, 95 percent of the captured pallid sturgeon were produced in hatcheries or as the result of state and federal stocking programs. It appears that the lower Platte River, as a tributary to the Missouri River, serves as a feeding and developmental area that young sturgeon seek out and occupy (UNL, July 15, 2010) until water quality such as elevated temperature (≥ 28°F) and dissolved oxygen (≤ 4 ppm) result in the departure from the Platte River back into the Missouri River (USGS, July 15, 2010).

Until further information is collected and as pallid sturgeon continue to mature, it is not known whether adults use the Platte River as a spawning area. Current studies have reported that pallid sturgeon spawning has not been documented in Missouri River tributaries (Bergman et al., May 2008). USFWS (July 16, 2010) further agreed that there is currently no evidence that confirms that sandy bottom tributaries, such as the Platte River, are used for spawning by pallid sturgeon. Additionally, no gravid females have been collected and recaptured to prove there is spawning activity actually occurring within the Platte River (USGS, July 15, 2010). Local fishery experts generally agree that hard rocky substrate spawning sites are limited within the Platte River, unlike the Missouri River with its abundance of revetment works along the shoreline bends and guide structures. Preliminary evidence suggests that pallid sturgeon seek out the revetment areas on the outside bends of the main channel of the Missouri River for spawning (DeLonay et al., 2009). Observations of pallid sturgeon attempting to spawn on riprap in the Missouri River further supports the idea “that availability of habitats with necessary substrate characteristics may not be limiting for sturgeon spawning” (DeLonay et al., 2009).

Despite the preceding discussion, the findings that may suggest that the lower Platte River does not support pallid sturgeon spawning are inconclusive. The “Research Needs and Management Strategies for Pallid Sturgeon Recovery” report states that “Spawning habitat was viewed as special and limited, but researchers now have evidence that…spawning of shovelnose and pallid sturgeon occurs over a wide range of areas” (Bergman et al., May 2008). In addition, Peters and Parham (2008) documented the capture of a female pallid sturgeon that was carrying eggs on May 3, 2001, near Louisville (RM 15.5); however, no confirmation of spawning by this fish was documented. Areas around and along Platte River bridges may be conducive for spawning. There may be scour areas at these locations that result in deep water areas with hard substrate (bedrock) that may allow for the development of spawning habitat. Further, an assessment conducted by NGPC (December 2008) states that "suspended solids concentrations in the lower Platte River increase three- to four-fold during the spring…. These springtime sediment concentrations are equivalent to those found in the Yellowstone River, where other pallid sturgeon populations are concentrated and spawning has been documented." Further, these sediment concentrations may trigger sturgeon spawning in the lower Platte River if adequate spawning substrate is available.

5.5.3 Objective 4 Conclusions

Through the capture of several juvenile pallid sturgeon in recent studies, it has been determined that the lower Platte River provides appropriate pallid sturgeon habitat and supports the growth and development of these fish. The following statement from the Platte River Recovery Implementation Program (PRRIP) Document (PRRIP, October 24, 2006) supports these findings:

> Consistent with the April 28, 2004 finding of the National Academy of Sciences (NAS), it is now agreed that current habitat conditions on the lower Platte River do not adversely affect the likelihood of survival and recovery of the pallid sturgeon because that reach of the river appears to retain several habitat characteristics apparently preferred by the species.

The following excerpts from the noted USGS Scientific Investigations Reports specific to pallid sturgeon in the lower Missouri River indicate that channel morphology, in addition to flow regime, directly corresponds to physical pallid sturgeon habitat:

- Physical components of habitat can be managed directly by changes in flow regime or channel morphology (Jacobson and Galat, 2006, as cited in Reuter et al., 2009).
- Among the stresses imposed on the river, the large magnitude of changes in flow regime and channel morphology have been assumed to be the most influential in species declines, largely through their influence on physical habitat availability (National Research Council, 2002; U.S. Fish and Wildlife Service, 2003, as cited in Reuter et al., 2009)
- In addition to changes in channel morphology that result from purposeful re-engineering of channel, there are complex readjustments of channel morphology that take place as a result of influxes or effluxes of sediment related to seasonal patterns of sediment transport, tributary flows, and large flood events (Elliott and others, 2009, as cited in Jacobson, Johnson, and Dietsch, 2009). These factors can result in background variability in the

quality and quantity of habitat availability to river organisms (Jacobson, Johnson, and Dietsch, 2009).

When the findings of this sedimentation study, which determined that the lower Platte River geomorphology and corresponding riverine habitat are in dynamic equilibrium, are compared to the numbers of shovelnose and pallid sturgeon collected during ongoing capture efforts, it can be inferred that current Project operations relative to sediment removal from Loup River inflows at the Headworks are not acting to limit sturgeon habitat or the success of these species in the lower Platte River.

6. STUDY VARIANCE

Changes to the Sedimentation study plan, which was approved with modifications by FERC in its Study Plan Determination on August 26, 2009, were necessary to produce a more robust report. These variances, the reasons for the variances, and the consequences of the variances are discussed below.

6.1 Dominant Discharge

This sedimentation study was to develop indicators of sediment transport capacity using effective discharge. In the literature, “effective” and “dominant” discharge are used interchangeably to mean the channel-forming discharge, although they require a slightly different calculation.

Because of the interchangeable use of these terms in the literature, this sedimentation study also calculated dominant discharge. The values for both at each of the study sites are provided in Table 5-2. The values compare well, and the differences are insignificant.

6.2 Ungaged Locations

The Study Plan Determination indicated that the sedimentation study was to develop sediment transport calculations at the following three “ungaged” study sites:

- Loup River upstream of the Diversion Weir
- Lower Platte River downstream of the Loup River confluence and upstream of the Tailrace Return confluence
- Lower Platte River within 5 miles downstream of the Tailrace Return confluence

Because no topographic survey information exists at these sites, cross section surveys are required to perform the analysis. However, due to summer flood flows and high winds, the cross section information was not obtained until June and July 2010. As a result, there was insufficient time to complete the analysis prior to submittal of this Initial Study Report. The District is currently developing a hydraulic model to approximate the hydraulics of the ungaged sites. The results for the ungaged sites will be provided in the updated Initial Study Report in January 2011.

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