APPENDIX A

SEDIMENTATION ADDENDUM

THE SEDIMENTATION STUDY REPORT WAS INCLUDED IN THE DISTRICT'S AUGUST 26, 2010, INITIAL STUDY REPORT FILING AND IS NOT PROVIDED HEREIN.

THIS APPENDIX IS AN ADDENDUM TO THE PREVIOUS FILING.

LOUP RIVER HYDROELECTRIC PROJECT
FERC PROJECT NO. 1256

SEDIMENTATION ADDENDUM

Loup Power District
Hydro Project

FEBRUARY 11, 2011

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
Sedimentation Addendum

February 11, 2011

Prepared by:
Loup Power District
2404 15th Street
Columbus, NE 68602

With assistance by:
HDR Engineering, Inc.
8404 Indian Hills Drive
Omaha, NE 68114

List of Tables

List of Figures

List of Attachments

STUDY 1.0 SEDIMENTATION ADDENDUM

1. INTRODUCTION

This addendum to the Sedimentation Study Report, which was published as Appendix A of the District's Initial Study Report (ISR) on August 26, 2010, describes additional sedimentation studies completed subsequent to submittal of the ISR. Specifically, this addendum describes data collection and analysis related to channel cross-section data from Loup and Platte river ungaged sites. Due to summer flood flows and high winds, the cross-section surveys were not completed until June and July 2010. As a result, there was insufficient time to complete the sedimentation analysis for the ungaged sites prior to submittal of the ISR.

2. GOALS AND OBJECTIVES OF STUDY

The goal of this addendum to the sedimentation study is the same as that of the original study, which 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.

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 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.

---

[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.

Specifically, FERC stated in its Study Plan Determination (SPD) that there is a need for collection and analyses of data at ungaged sites to meet Objectives 1 and 2.

3. STUDY AREA

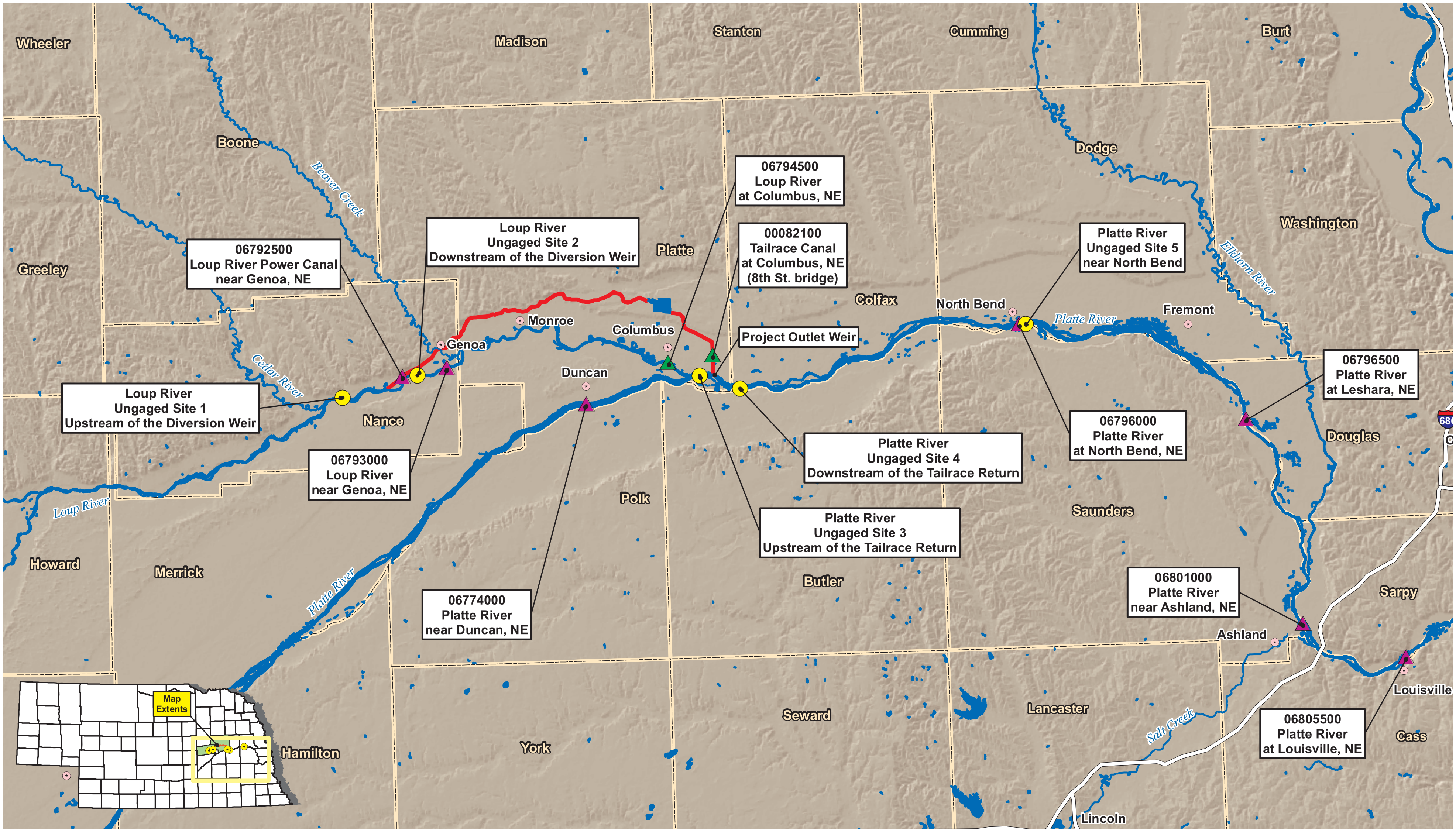
The approved methodology for the sedimentation study included a provision that cross-section surveys and calculations of sediment transport indicators be conducted at three ungaged sites. The hydrocycling and the flow depletion and flow diversion studies required calculations of sediment transport indicators at two additional ungaged sites. The five ungaged sites and the studies with which they are associated are listed below and are shown in Figure 3-1:

1. Loup River upstream of the Diversion Weir (Site 1) – Sedimentation and flow depletion and flow diversion
2. Loup River immediately downstream of the Diversion Weir (Site 2) – Flow depletion and flow diversion
3. Lower Platte River downstream of the Loup River confluence and upstream of the Tailrace Return confluence (Site 3) – Sedimentation, hydrocycling, and flow depletion and flow diversion
4. Lower Platte River within 5 miles downstream of the Tailrace Return confluence (Site 4) – Sedimentation and hydrocycling
5. Lower Platte River near the USGS North Bend gage (Site 5) – Hydrocycling

The original sedimentation study included analysis at the following gaged sites on the Loup and Platte rivers:

- USGS Gage 06793000, Loup River near Genoa, NE
- USGS Gage 06794500, Loup River at Columbus, NE
- USGS Gage 06774000, Platte River near Duncan, NE
- USGS Gage 06796000, Platte River at North Bend, NE
- USGS Gage 06796500, Platte River at Leshara, NE
- USGS Gage 06801000, Platte River near Ashland, NE
- USGS Gage 06805500, Platte River at Louisville, NE

These sites are also shown in Figure 3-1. Results from the gaged site analysis are occasionally referenced in this sedimentation addendum.



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

Sedimentation Study Sites

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

DATE
Feb. 11, 2011

FIGURE
3-1

Z:\Projects\Loup_Power_District\37104_LPD_FERC_Relicensing\map_docs\mxd\Sedimentation_Study_Sites.mxd\jan11\jcm

4. METHODOLOGY

To meet Objectives 1 and 2, as stated in Section 2, Goals and Objectives of Study, the following tasks for the sedimentation study were completed for the ungaged sites:

- Task 1: Data Collection and Evaluation
- Task 2: Sediment Budget
- Task 3: Effective Discharge and Other Sediment Transport Calculations
- Task 4: Stream Channel Morphology

These tasks involved the following steps:

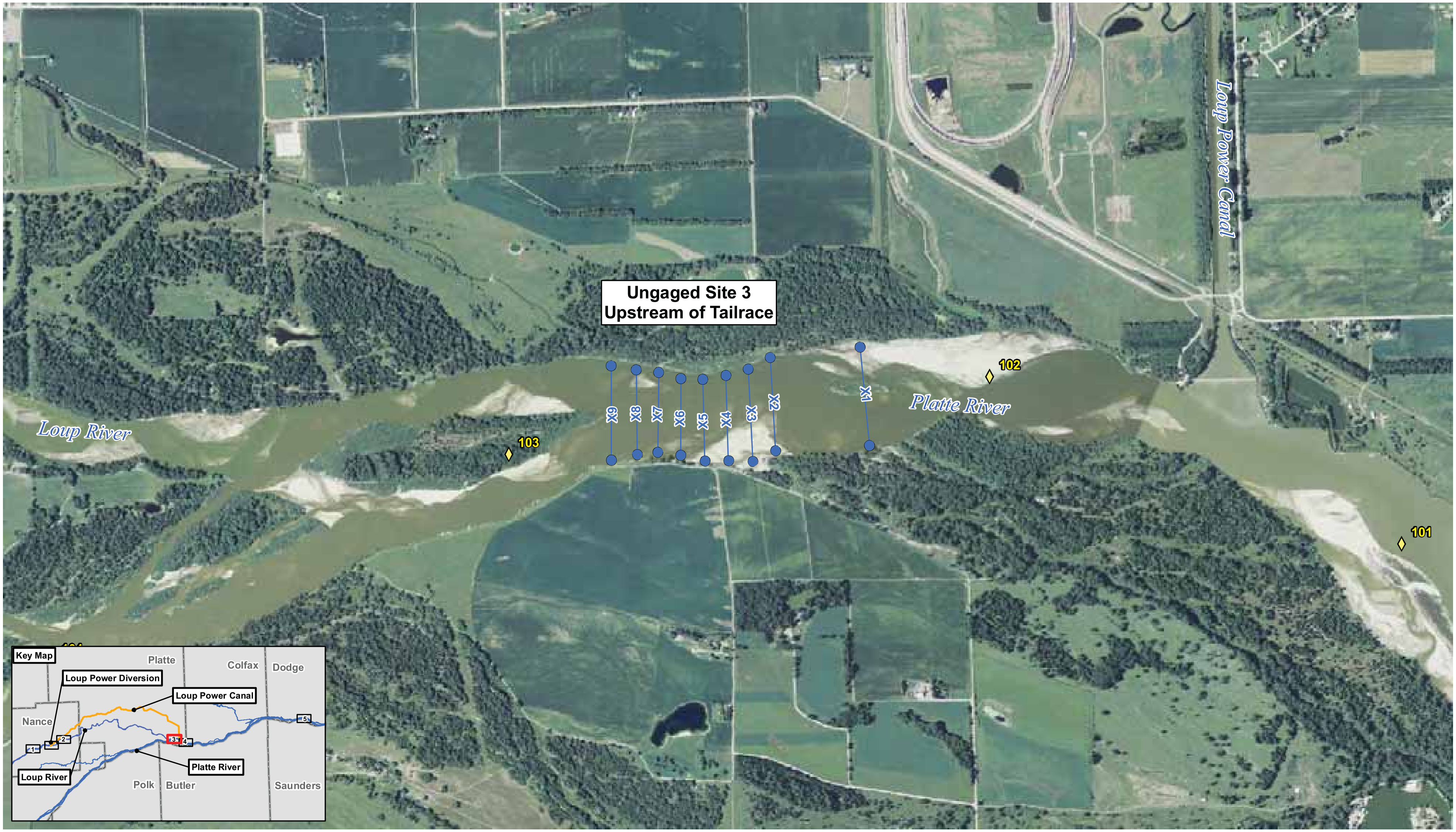
- Determine hydraulic geometry relationships for each ungaged site using a 1-dimensional steady-state model (HEC-RAS).
- Using Yang's equation, previously described in the ISR, Appendix A, Sedimentation Study Report, develop a sediment discharge rating curve for each ungaged site.
- Apply the rating curve to synthesized daily discharges to determine daily discharge capacities to transport bed material sediment.
- Group daily transport capacity values to determine which discharges transport the greatest amount of sediment and are thereby "effective" or "dominant" in shaping the morphologies (and habitat) of the Loup River bypass reach and the lower Platte River.
- Determine annual sediment transport capacities for the study periods evaluated and compare with adjusted MRBC average annual sediment yield estimates.
- Apply regime theory to the effective or dominant discharges at the ungaged sites to assess whether the morphologies of the Loup River bypass reach and the lower Platte River are transitioning to another form or remain in dynamic equilibrium.

4.1 Task 1: Data Collection and Evaluation

The final selection of cross-section locations for each ungaged site was determined by the District in coordination with USFWS and NGPC by examining aerial photographs. The District surveyed nine or ten cross sections at each of the ungaged sites on at least two occasions: May to July 2010 and September to October 2010. The survey methodology is discussed further in the Second Initial Study Report, Appendix B, Hydrocycling Study Report.

Cross-section locations for each ungaged site are shown in Attachment A. A representative figure showing the cross-section locations for Site 3 is provided below as Figure 4-1. Although the SPD directed that streamflow measurements be taken, this was not possible due to high flow. However, water surface elevations during each day's measurements were recorded for use in calibrating the HEC-RAS models, as described in Section 4.1.2, Hydraulic Geometry Relationships among Discharge and Channel Width, Depth, and Velocity for Ungaged Sites.

The dates when data collection occurred at each cross section are provided in Table 4-1. The times when data collection occurred are not included; multiple rovers and site conditions caused many cross sections to be surveyed in portions at varying times of day. Graphs of the cross sections comparing the spring and fall measurements at each location are included in Attachment A.



1,000 500 0 1,000
Feet

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

Legend

◆	River Mile
●	Surveyed Bank Station
—	Cross Section

Ungaged Site 3

Sheet 3 of 5

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

DATE
Nov. 30, 2010

FIGURE

Table 4-1. Cross-Section Data Collection

Location	Data Collection Effort	Cross Section 1	Cross Section 2	Cross Section 3	Cross Section 4	Cross Section 5	Cross Section 6	Cross Section 7	Cross Section 8	Cross Section 9	Cross Section 10
Site 1 – Upstream of the Diversion Weir	Spring	6/3/2010	6/3/2010	6/3/2010	6/3/2010	6/3/2010	6/3/2010	6/2/2010	6/2/2010	6/2/2010	
	Fall	10/5/2010	10/5/2010	10/5/2010	10/5/2010	10/5/2010	10/5/2010	10/5/2010	10/5/2010	10/5/2010	
Site 2 – Downstream of the Diversion Weir	Spring	4/15/2010	4/15/2010	4/15/2010	4/15/2010	4/15/2010	4/15/2010	4/15/2010	4/15/2010	4/15/2010	
	Summer	8/5/2010	8/5/2010	8/5/2010	8/5/2010	8/5/2010	8/5/2010	8/5/2010	8/5/2010	8/5/2010	
	Fall	9/28/2010	9/28/2010	9/28/2010	9/28/2010	9/28/2010	9/28/2010	9/28/2010	9/28/2010	9/28/2010	
Site 3 – Upstream of the Tailrace Return	Spring[1]	5/2/2010 or 5/3/2010	5/2/2010 or 5/3/2010	5/2/2010 or 5/3/2010	5/2/2010 or 5/3/2010	5/2/2010 or 5/3/2010	5/2/2010 or 5/3/2010	5/2/2010 or 5/3/2010	5/2/2010 or 5/3/2010	5/2/2010 or 5/3/2010	
	Summer	8/11/2010	8/11/2010	8/11/2010	8/11/2010	8/11/2010	8/11/2010	8/11/2010	8/11/2010	8/11/2010	
	Fall	9/29/2010	9/29/2010	9/29/2010	9/29/2010	9/29/2010	9/29/2010	9/29/2010	9/29/2010	9/29/2010	
Site 4 – Downstream of the Tailrace Return	Spring[2]	6/30/2010	6/30/2010	7/1/2010	6/30/2010	6/29/2010	6/29/2010	6/29/2010	6/29/2010	6/30/2010	7/1/2010
	Fall	9/7/2010	9/7/2010	9/7/2010	9/7/2010	9/7/2010	9/8/2010	9/8/2010	9/8/2010	9/8/2010	9/8/2010
Site 5 – Near North Bend	Spring	7/8/2010	7/8/2010	7/8/2010	7/8/2010	7/8/2010	7/9/2010	7/9/2010	7/9/2010	7/9/2010	
	Fall	9/21/2010	9/21/2010	9/21/2010	9/22/2010	9/22/2010	9/22/2010	9/22/2010	9/22/2010	9/22/2010	
Headworks	Spring	6/3/2010	6/3/2010	6/3/2010							
	Summer	8/5/2010		8/5/2010							

Notes:

[1] Data were collected on May 2 and May 3, but the exact date when data was collected at each cross-section location is unknown.

[2] The following cross sections were surveyed on multiple days: Cross section 3 (6/30 and 7/1); Cross section 4 (6/30 and 7/1); Cross section 7 (6/29 and 6/30); Cross section 8 (6/29 and 6/30); Cross section 9 (6/29 and 7/1).

In order to develop sediment transport parameters for the ungaged sites, daily discharges for the study period were synthesized using data from the gaged sites on the Loup and Platte rivers. The methodology for the synthetic hydrograph development is detailed in the Second Initial Study Report, Appendix B, Hydrocycling Study Report, Section 4.2. Because cross-section data were measured only in 2010 and discharge measurements at gaged sites were available only through 2009, the assessment of sediment transport parameters at the ungaged sites was restricted to using synthesized discharges during only the most recent calendar year—namely 2009, which was rated as a normal year, as discussed in Second Initial Study Report, Appendix B, Hydrocycling Study Report, Section 4.2.3.

The resulting 2009 synthetic hydrographs are presented in the Second Initial Study Report, Appendix B, Hydrocycling Study Report, Section 4.2. As discussed in Section 4.1.2, Hydraulic Geometry Relationships among Discharge and Channel Width, Depth, and Velocity for Ungaged Sites, the assumption was made that the cross sections taken in 2010 were the same as the geometries that existed throughout 2009. The implications of this assumption are addressed in detail in Section 4.1.3, 2009 Daily Transport Capacity at Ungaged Sites.

The goal of this sedimentation addendum was to provide values of the same sedimentation transport indicators at the ungaged sites for current operations in context with the gaged sites, and not to evaluate alternative operations. Both the hydrocycling study and the flow depletion and flow diversion study required, per FERC's SPD, comparisons of current operations with alternative operations for wet, dry, and normal years; those sections include analyses of the transport parameters for each year from 2003 to 2009 as well as averages for that 7-year period.

4.1.1 Energy Slope, Grain Size, and Other Parameters at Ungaged Sites

Parameters for use in Yang's sediment transport capacity equation were developed for the ungaged sites. Similar to the approach for the gaged sites, the energy slope, equated with the channel slope, at each location was obtained from Bentall (1991). Median grain sizes for sediment being transported at each were determined by either the nearest gage location or through an average of the nearest gaged sites or through a regression analysis. This approach was considered to result in comparable and commensurate estimates of the "composite" grain sizes that had been adopted for use at the gaged sites (see the ISR, Appendix A, Sedimentation Study Report, Section 4.3.1). All other parameters required by Yang's equation were entered based on hydraulic geometry relationships, as discussed in Section 4.1.2. Table 4-2 provides the results for the ungaged sites.

Table 4-2. Parameters Used in Yang's Equation at the Ungaged Sites

Location	d_{50}		Slope	
	Value (mm)	Source	Value (ft/mile)	Source
Site 1 – Upstream of the Diversion Weir	0.24	Mean d_{50} from the dredged material	8	Same as the Genoa gage
Site 2 – Downstream of the Diversion Weir	0.20	Same as the Genoa gage	8	Same as the Genoa gage
Site 3 – Upstream of the Tailrace Return	0.29	Average between the d_{50} for Duncan and Genoa	5.9	2nd Order Polynomial regression from slopes from all Platte River study sites
Site 4 – Downstream of the Tailrace Return	0.23	Linear regression from d_{50}s from Platte River sites	5.8	2nd Order Polynomial regression from slopes from all Platte River study sites
Site 5 – Near North Bend	0.23	Same as the North Bend gage	4.9	Same as the North Bend gage

4.1.2 Hydraulic Geometry Relationships among Discharge and Channel Width, Depth, and Velocity for Ungaged Sites

Although the SPD directed that streamflow measurements be taken at the ungaged sites, this was not possible due to high flow and inaccessibility for wading the entire stream. Because hydraulic geometry relationships among channel width (W), depth (D), and velocity (V) for a range of discharges are needed for Yang's sediment transport equation, synthetic relationships for each parameter were developed using HEC-RAS. The cross-section measurements from high bank to high bank were input to develop HEC-RAS models at each ungaged site, and runs were made using the synthesized ungaged-site discharges, measured water surface levels, and synthesized flow rates for the dates of the surveys. For a more detailed description of the model development, see the Second Initial Study Report, Appendix B, Hydrocycling Study Report, Section 4.6.5.

In addition to inputting synthesized flow rates on the dates of the cross-section surveys, testing ranges of input parameters to HEC-RAS was conducted, followed by comparing the modeled water surface profiles with observed water surface elevations. Parameters providing the best fit to the measurements were adopted. These calibration values were also compared with previous studies in the area by USACE and others and agreed well within standard limits of calibration.

Once the HEC-RAS models were calibrated to match measured water levels, runs were made over a wider range of discharge values to derive discharge (Q) versus W, D, and V curves. This approach assumed a fixed bed geometry (using measured cross sections) over the full range of discharges tested. It further assumed that the cross sections in 2010 adequately represent geometries during the 2009 study period. Either or both of these assumptions can introduce bias into any sediment transport calculations. As shown by the comparisons of the spring and fall cross sections in Figures 4-2, 4-3, and Attachment A, the channel cross sections are not fixed and instead experience significant variations over short periods of time and over short distances at the same time.

Graphs of Q versus W, D, and V from the USGS measurements at gaged sites were presented in the ISR, Appendix A, Sedimentation Study Report. Similar graphs for the ungaged sites are included in Attachment B. Both sets show that even for the same discharge value, the W, D, and V values can vary by two to three orders of magnitude.

It is important to reiterate that cross-section geometry on any day is not a function of the flow that day, but instead is the result of the history of flows and other factors occurring for days, weeks, months, or even years leading up to that date. It is very likely that on any two days with the same discharge, the channel geometry and hydraulic properties could vary at least by as much as is demonstrated in the ISR, Appendix A, and by the raw USGS data at the gaged sites. However, using the best-fit curves for the historical data, as was done in the ISR, statistically provides the best estimate for prediction of any of the parameters. The average is a measure of the central tendency of the long-term trends in the channel geometry parameters.

Figures 4-2 through 4-5 are samples of the cross-section measurements and hydraulic properties for one of the ungaged sites (Site 4). They clearly illustrate the non-uniform nature of the channel geometry over a 3-month time span and over short distances at the same time, as well as the resulting diversity of hydraulic geometry results that HEC-RAS gives (Q versus W, D, and V) for the variable cross-section geometries. Figure 4-2 shows that from June to September 2010, the bed geometry experienced dramatic changes. This example is among, but not the most dramatic of, the most extreme cases. To further illustrate the variability of channel geometry within a short distance at the same time, Figure 4-3 shows three of the nine cross sections taken at Site 4 in June 2010. This particular comparison is typical of what was found at all the ungaged sites. All other cross sections are included in Attachment A.

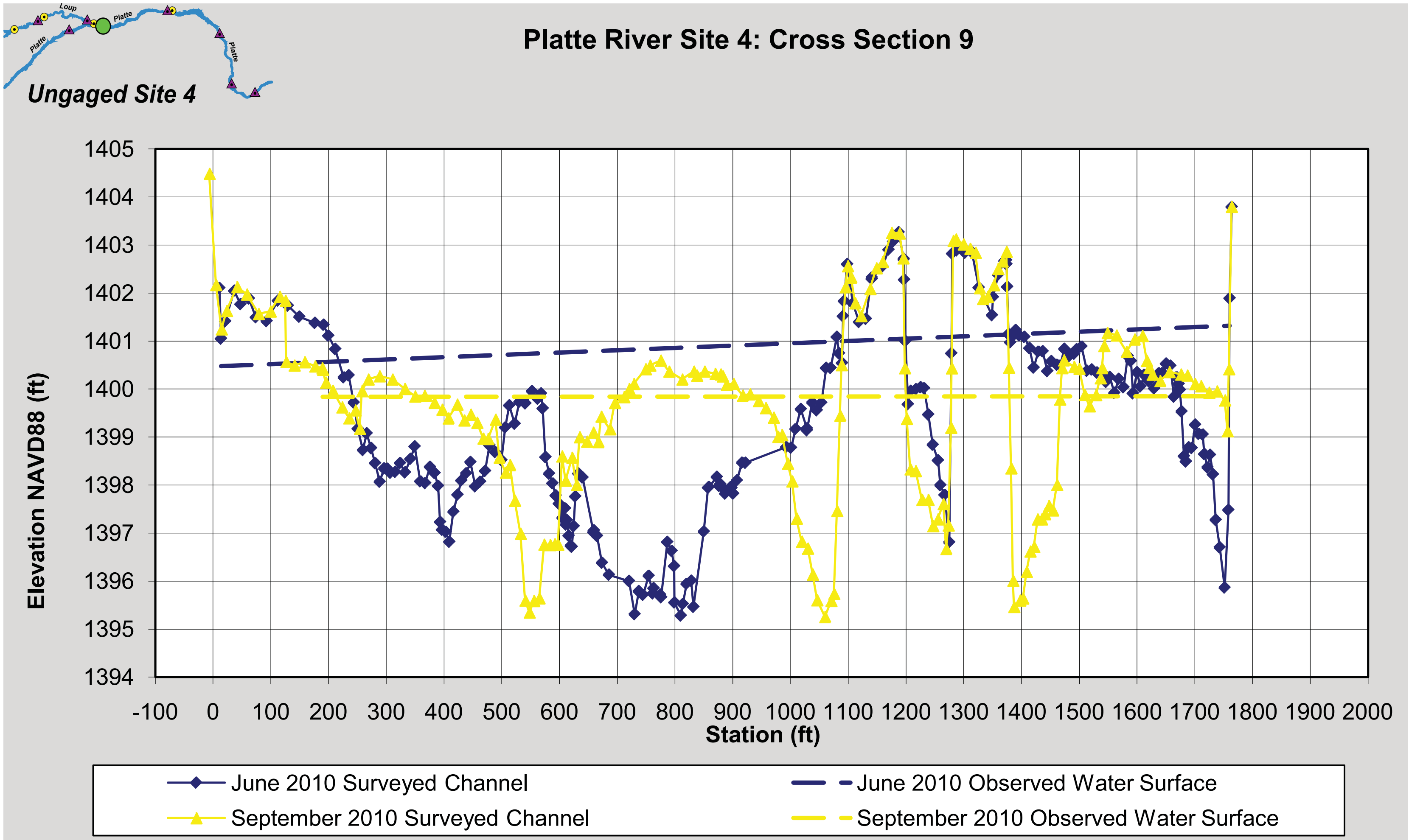


Figure 4-2. June and September Cross Sections at Site 4, Platte River Downstream of the Tailrace Return, Location 9

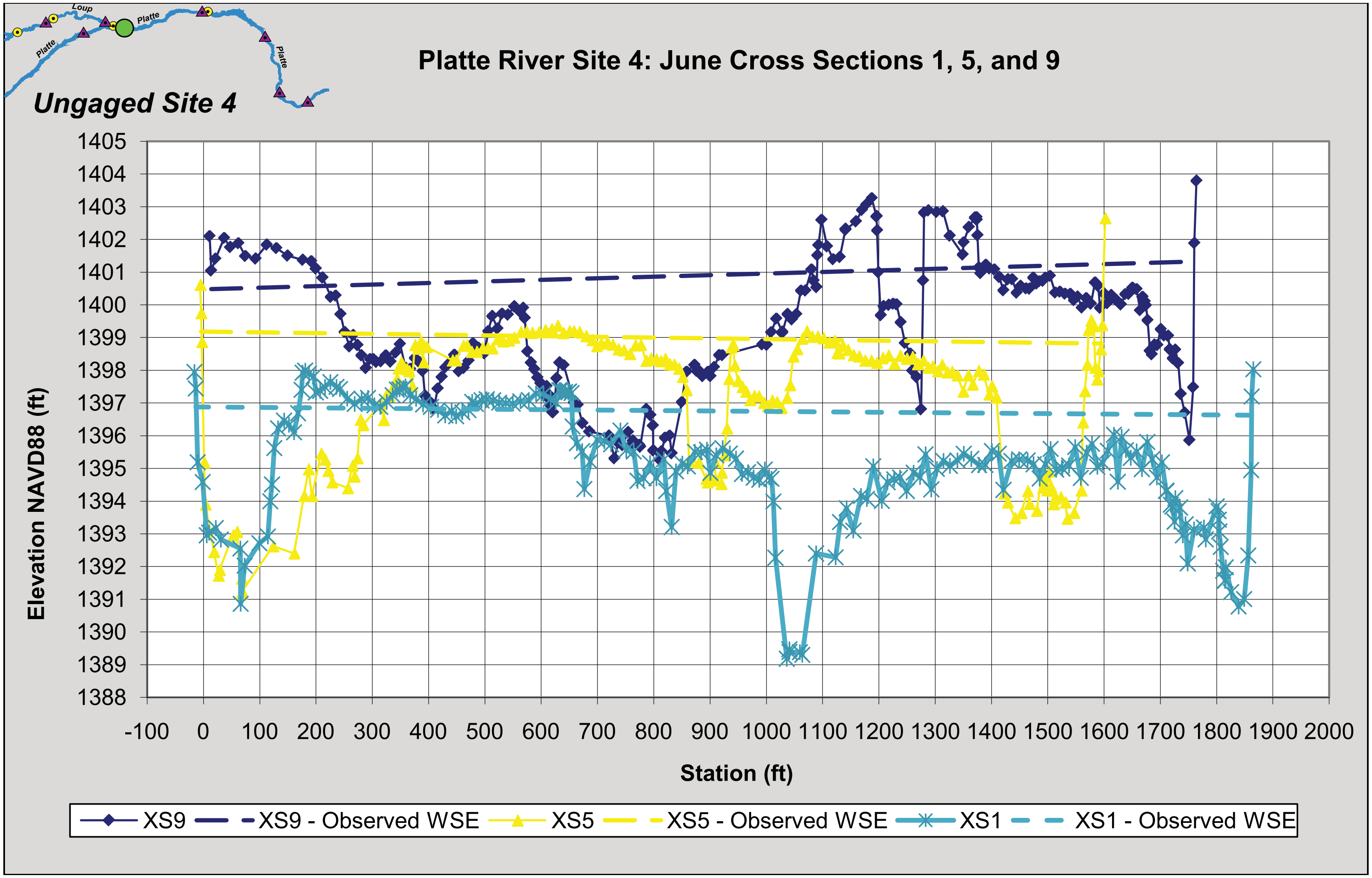


Figure 4-3. June Cross Sections at Site 4, Platte River Downstream of the Tailrace Return, Locations 1, 5, and 9

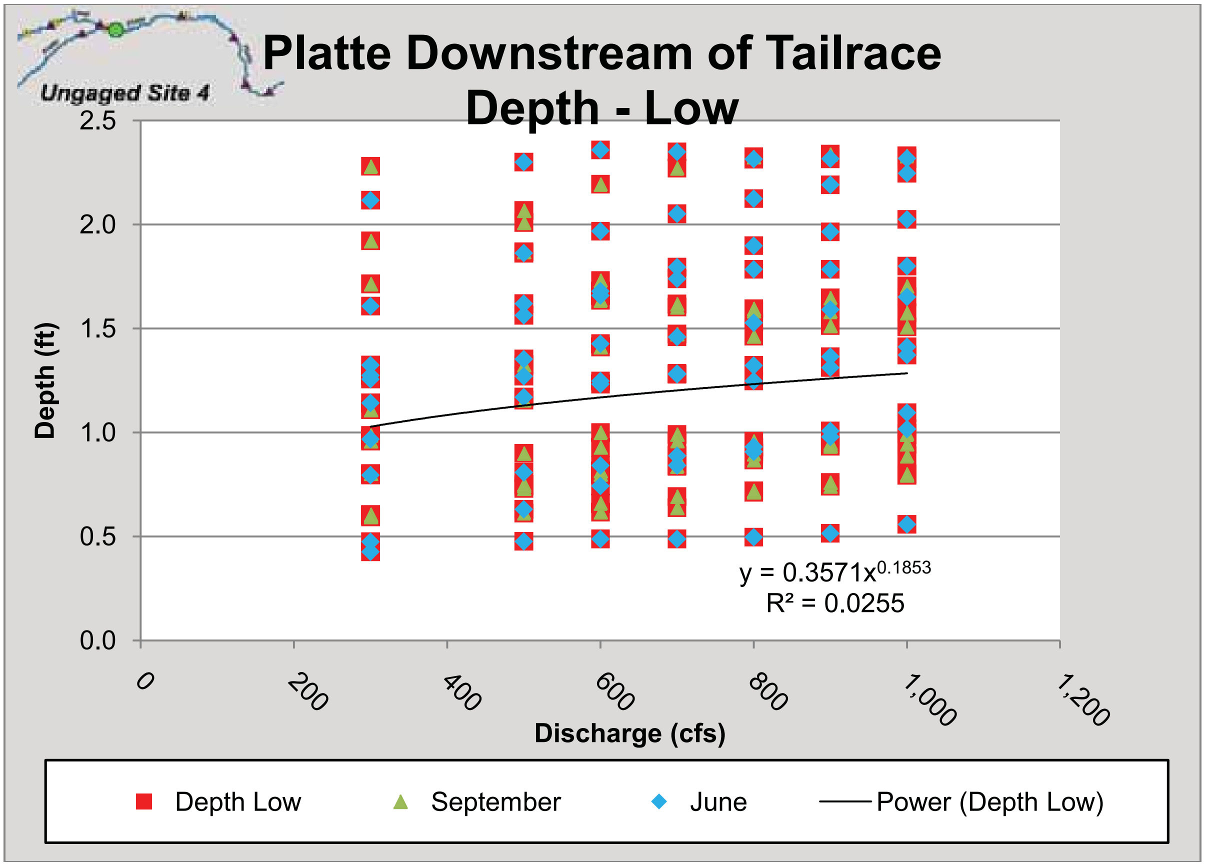


Figure 4-4. HEC-RAS Depth-Discharge Graph at Site 4 using June and September Cross-section Geometries at Locations 1 through 9, Flows up to 1,000 cfs

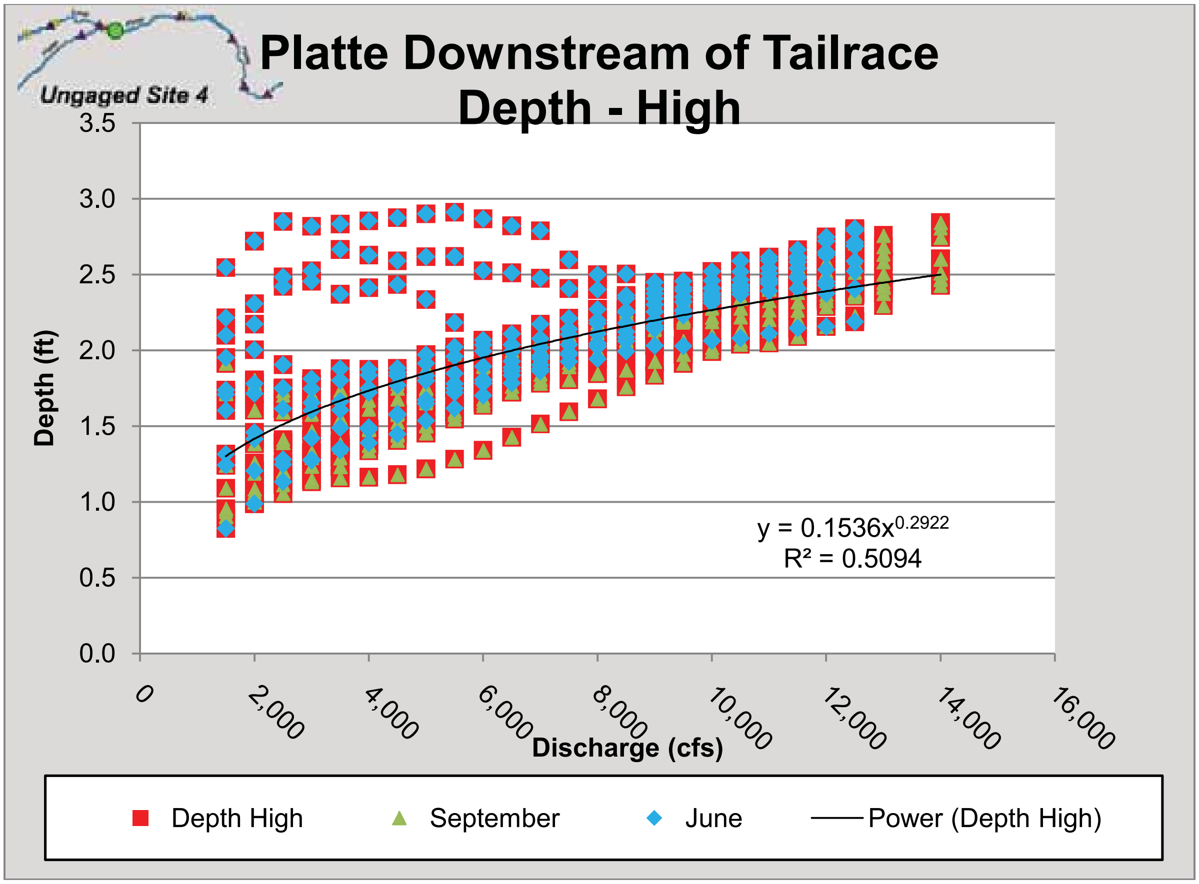


Figure 4-5. HEC-RAS Depth-Discharge Graph at Site 4 using June and September Cross-section Geometries from Locations 1 through 9, Flows Greater than 1,000 cfs

Although best-fit curves are included in Figures 4-4 and 4-5, they demonstrate the uncertainty introduced in using a rigid-bed assumption and steady-flow routines over a wide range of discharges in HEC-RAS to estimate W, D, or V for a braided river. For each discharge rate across the graphs, the wide range of depths plotted illustrates that the natural changes in shape of the cross sections in June versus September can result in dramatically different depths (and other hydraulic parameters). More importantly, the at-the-same-time variability in shape of cross sections within a few hundred feet of each other (shown in Figure 4-3) has a similar impact on predictability of depth for any discharge. Examination of the W, D, and V graphs in Attachment B for all five ungaged sites shows that the examples included here are typical.

Because each daily calculation of sediment transport capacity requires a D and V, and because the estimates were obtained from best-fit curves through widely scattered values illustrated above, the variability in the raw data of Figures 4-2 and 4-3 and the impacts of this variability on hydraulic geometry relationships (Figures 4-4 and 4-5) suggest that all single values of any of these variables contain uncertainties. This uncertainty is compounded when the sediment transport rates are calculated.

The ranges of W, D, and V for the gaged and ungaged sites were similar, exhibiting a wide range of parameters for any given flow rate. This illustrates the indeterminate nature of a braided river. In addition to variability in W, D, and V at the gaged sites, the variability in cross-section geometry within a few hundred feet discovered at the ungaged sites probably also exists at the gaged sites.

The variability of important parameters discovered here is not necessarily a reflection of error or even bias introduced by assuming rigid-bed geometries in HEC-RAS over a wide range of flows. A significant amount of the variability from section to section, date to date, and discharge to discharge demonstrated here is a reflection of the dynamics of a braided river and its ability to defy sub-daily micro-level replication of its geometry with numerical models. The indeterminate nature of a braided river's geometry, much less morphology, has been analyzed in the literature (Maddock, November 1970; ASCE, 1998a and 1998b).

Sediment transport indicators and regime methods are far more reliable because they use physical process algorithms that average these variabilities over the long term in a way that provides reliable tools for assessing braided river morphologies and allowing reliable interpretations of variabilities in the morphology indicators.

4.1.3 2009 Daily Transport Capacity at Ungaged Sites

Yang's equation was applied to the daily synthesized flows at each ungaged site for calendar year 2009. As shown in the Second Initial Study Report, Appendix B, Hydrocycling Study Report, Section 4.2.3, the Platte River flows in 2009 classified it as a "normal" year using the wet, dry, and normal year criteria approved in the RSP. Using the same class analysis described in the ISR, Appendix A, Sedimentation Study Report, the sediment transport capacities for each flow rate were developed for the ungaged sites. These are shown in Attachment B.

4.2 Task 2: Sediment Budget

To estimate the average annual yields at the ungaged sites, the adjusted MRBC average annual yields at the gaged sites, shown in the ISR, Appendix A, Sedimentation Study Report, Table 5-3, were "parlayed" to the ungaged sites using the same methodology described in the ISR. Table 5-3 compared the average annual MRBC yields with average annual (1985 to 2009) values of total sediment transported at capacity. However, only the 2009 total transport values were derived at the ungaged sites. These should be compared with 2009 values at the gaged sites rather than average annual values at the gaged sites.

4.3 Task 3: Effective Discharge and Other Sediment Transport Calculations

Effective discharges for 2009 at the five ungaged sites were derived from the daily transport rates. Effective discharges were developed by grouping the transport rates in bins and determining "modal" values and ranges of the discharges that transport the greatest amounts of sediment. This is the same methodology used in the ISR, Appendix A, Sedimentation Study Report. The histograms are provided in Attachment B. As stated in the ISR, Appendix A, Sedimentation Study Report, the dominant discharge is found by first dividing the total sediment transported over time by the number of days in the 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.

Only the 2009 values, rather than long-term averages, are included for the gaged sites in order to compare commensurate values. Using the same methods employed for the gaged sites in the ISR, Appendix A, values of the 2009 dominant discharges at each ungaged site were also determined.

4.3.1 Spatial Analysis

The spatial analysis of sediment transport indicators performed for the gaged sites was described in the ISR, Appendix A, Section 5.2.2. Data for the ungaged sites have been inserted with the results for the gaged sites to allow expanding the spatial analysis and interpretations to include the ungaged sites.

For the gaged sites, transport capacities were determined over the entire 25-year study period, allowing average values to be determined and compared with the revised MRBC average annual sediment yields.

4.3.2 Regime Analysis

The final test of whether either the Loup or Platte River or any location within either river is transitioning to another form can best be accomplished through regime analysis. The 2009 data for the ungaged sites were plotted on Chang's and Lane's regime morphology graphs (see the ISR, Appendix A, Figures 5-3 and 5-5). Because of the subjectivity of determining effective discharges from the sediment transport histograms, especially for seasonal or single-year data, the 2009 dominant discharges at the ungaged sites were input along the abscissa of each graph.

4.4 Task 4: Stream Channel Morphology

The methodology adopted in the ISR, Appendix A, Sedimentation Study Report, for testing whether the gaged sites were in dynamic equilibrium was applied to the ungaged data. This included determining the daily transport capacity at each site based on synthesized flow data, determining the 2009 sediment transport indicators for each ungaged site, comparing the indicators with the 2009 indicators at the gaged sites (spatial analysis), and plotting the ungaged site data on the regime graphs described in the ISR, Appendix A.

This combined use of effective and dominant discharge and regime theory at both the gaged and ungaged sites 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 potential changes, whether climatic or operational, could impact any river's morphology.

5. RESULTS AND DISCUSSION

The results of the collection and analysis of data at ungaged sites are summarized below, and a full discussion of the analyses related to each task follows.

5.1 Summary of Results

The body of literature cited in the ISR, Appendix A, Sedimentation Study Report, and the supplemental analyses at ungaged sites 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 in the ISR, Appendix A, 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 characteristic (W and D) changes over time.

The collection and analysis of data at ungaged sites supports the conclusion in the ISR, Appendix A, that sediment availability and yield throughout the study area by far exceed the capacity of the flow to transport sediment as well as greatly exceed even the upper limits of 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 a dynamic equilibrium condition, with supplies in excess of transport capacity and 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).

The results of the collection and analysis of data at ungaged sites show for both the Loup River bypass reach and the lower Platte River at all locations studied are clearly not supply limited. This is consistent with the findings at the gaged sites, as detailed in the ISR, Appendix A, Sedimentation Study Report. As noted in the methodology described in the ISR, Appendix A, 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.

Effective discharge methods applied to the ungaged sites and other sediment transport and hydraulic geometry calculations, combined with river regime theory, support the conclusions in the ISR, Appendix A, for the gaged sites that the channel geometries are "in regime" with the long-term flows shaping them. The current channel hydraulic geometries match the width and depth calculations for flow rates matching the effective and dominant discharge rates. Nothing appears to be constraining either the Loup or Platte River from maintaining the braided river hydraulic geometry associated with the effective discharges.

The cross-section data at the ungaged sites described in Section 4.1 reveal that the braided channel geometry of both rivers is not only widely diverse over a few hundred feet of length, but highly subject to dramatic changes over a few months' time. The cross sections both upstream and downstream of the Tailrace Return exhibited similar cross-section changes. Any measured or calculated adjustment in geometry cannot be readily attributed to any other cause than the natural dynamics of a braided river.

The methodology described in the ISR, Appendix A, Section 4, 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 gaged stations as well as all ungaged sites result in all locations being well within braided river morphologies, with none being near any thresholds of transitioning to another morphology.

5.2 Task 1: Data Collection and Evaluation

The results of Task 1: Data Collection and Evaluation were used in completing Tasks 2 through 4 and are presented in Section 4.1.

5.3 Task 2: Sediment Budget

The methodology described in the ISR, Appendix A, Section 4, established that 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.

The long-term (1985 to 2009) annual sediment transport capacities at the gaged sites and 2009 values are compared with updated MRBC estimates of sediment yields in Table 5-1. The addition of ungaged site data reveals that both the long-term average and 2009 transport capacities are all considerably below the estimated average annual yields at both the ungaged sites and at the adjacent upstream and downstream gaged sites.

Revised 03/08/11

Table 5-1. Sediment Capacity at Gaged and Ungaged Sites, using both 1985 to 2009 and 2009 Discharges, Compared with Average Annual Adjusted MRBC Yield Estimates

USGS Gage Number	Gage Name and Location	Annual Sediment Data (tons/year)		
		Average 1985 to 2009 Capacities	2009 Capacity	Updated MRBC Average Annual Yield
Site 1	Loup River Upstream of the Diversion Weir	NA	2,870,000	4,180,000
Site 2	Loup River Downstream of the Diversion Weir	NA	890,000	2,030,000
06793000	Loup River near Genoa, NE	1,760,000	1,280,000	2,030,000
06794500	Loup River at Columbus, NE	1,260,000[1]	950,000	2,960,000
06774000	Platte River near Duncan, NE	747,000	410,000	1,870,000
Site 3	Platte River Upstream of the Tailrace Return	NA	1,160,000	4,900,000
Site 4	Platte River Downstream of the Tailrace Return	NA	2,960,000	5,250,000
Site 5	Platte River near North Bend	NA	2,026,000	5,770,000
06796000	Platte River at North Bend, NE	2,890,000	2,050,000	5,770,000
06796500	Platte River at Leshara, NE	2,800,000	2,240,000	5,850,000
06801000	Platte River near Ashland, NE	4,080,000	3,720,000	10,610,000
06805500	Platte River at Louisville, NE	4,930,000	4,590,000	12,780,000

Note:

NA = Not available.

[1] Channel geometry for Columbus was measured only in 2008 and 2009; flows at Columbus from 1985 through 2009 were synthesized as described in the ISR, Appendix A.

Because transport capacity at the ungaged sites was only calculated based on 2009 synthesized hydrographs, values of transport capacity for any single year are not necessarily comparable to average annual adjusted MRBC yields. Similarly, Table 5-1 shows that 2009 estimates of transport capacity at gaged sites are not necessarily comparable to average annual transport capacities, even though 2009 was a relatively "normal" flow year.

As concluded for long-term average annual values at the gaged sites, the 2009 total transport values at capacity for the ungaged sites all fall considerably below the MRBC yield estimates, confirming that neither the gaged nor the ungaged sites are supply limited. Thus, the inclusion of ungaged site data does not alter the conclusions regarding sediment availability described in the ISR, Appendix A, Sedimentation Study Report.

5.4 Task 3: Effective Discharge and Other Sediment Transport Calculations

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 under current operations and lower Platte River are not transitioning to another form, it would be further affirmed that the Loup and Platte 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 Loup and Platte rivers are currently not in dynamic equilibrium. Furthermore, if the analysis of the morphology under current operations indicates that the Loup River bypass reach and lower Platte River are in dynamic equilibrium and not supply limited based on the adjusted yields and sediment transport capacity calculations, then no alternatives relative to sediment augmentation would be evaluated.

Comparison of the long-term dominant discharges from the ISR, Appendix A, Sedimentation Study Report, Table 5-2 with the 2009 dominant discharges in Table 5-2 in this sedimentation addendum reveals that the 2009 values for both the Loup and Platte rivers are all less than the long-term averages at gaged sites at and upstream of Leshara, and are nearly equal to the long-term values downstream near Ashland and at Louisville. Table 5-2 in this sedimentation addendum is a replication of Table 5-2 from the ISR, Appendix A, Sedimentation Study Report, but with the results at the ungaged sites inserted. The mean daily discharges at the ungaged sites were synthesized as described in the Second Initial Study Report, Appendix B, Hydrocycling Study Report, Section 4.2.

Table 5-2. Sediment Transport Indicators and Hydrologic Characteristics for 2009 Flows at Gaged and Ungaged 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)
Site 1	Loup River Upstream of the Diversion Weir	2,910	3,100	2,930	3,250	2,930
Site 2	Loup River Downstream of the Diversion Weir	910	1,900	1,620	2,070	1,070
06793000	Loup River near Genoa, NE	920	1,700	1,620	1,840	1,150
06794500	Loup River at Columbus, NE	1,100	2,500	2,420	2,670	1,290
06774000	Platte River near Duncan, NE	1,400	2,900	2,800	2,990	1,565
Site 3	Platte River Upstream of the Tailrace Return	2,600	3,500	3,130	3,890	2,700
Site 4	Platte River Downstream of the Tailrace Return	4,640	4,900	4,710	5,120	4,760
Site 5	Platte River near North Bend	4,240	4,200	3,680	4,610	4,000
06796000	Platte River at North Bend, NE	4,240	3,900	3,680	4,140	4,440
06796500	Platte River at Leshara, NE	4,610	5,100	4,900	5,380	4,870
06801000	Platte River near Ashland, NE	7,400	8,000	7,650	8,440	7,365
06805500	Platte River at Louisville, NE	8,720	9,900	9,410	10,300	8,995

This is attributed to the apparent 2000 to 2009 declining annual flows described in the ISR, Appendix A. As was shown in the ISR, Appendix A, Figures 5-6 to 5-12, no permanent or adverse deviations from the long-term morphology have occurred at the gages over the 1985 to 2009 study period. The apparent downward trend in annual flows since around 2000 is not indicative of the actual trend, as shown in the ISR, Appendix A, Figure 5-13. 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 operation does not impact flows at Duncan, which experienced even steeper reductions in annual flow during the same 25 years.

As with values of dominant discharges in Table 5-2, the 2009 transport totals at the gaged sites in Table 5-1 are lower than long-term average annual values in about the same proportion as the dominant discharges—with the differences decreasing in the downstream direction.

The 2009 dominant discharges at Genoa are 15 percent lower than the 1985 to 2009 long-term values, and the 2009 value at Duncan is 30 percent lower. These percent differences decrease in the downstream direction. The best indicator of equilibrium channel morphology is related to the long-term values of effective and dominant discharges and total sediment transported at capacity.

Although the current (2009) values are lower than the long-term values, the ISR, Appendix A, showed that these and the associated fluctuations in hydraulic geometry are normal, and should not be deemed as evidence of either adverse or beneficial morphologic changes, especially if the regime analysis shows all the fluctuations as falling well within braided river morphologies.

At the Columbus gage, a relatively large difference between the effective and dominant discharges occurs for both the long-term averages and 2009. A similarly large difference between effective and dominant discharge occurs on the Platte River at Duncan, which was also observed for the long-term analysis in the ISR, Appendix A, Table 5-2. Because flows at Duncan are highly variable every year, including evidence of sub-daily fluctuations, the 1985 to 2009 annual fluctuations in both effective and dominant discharge, as well as total sediment transported at capacity, are considered normal. Flows at Columbus are not as variable, but a similar result (moderate annual fluctuations and moderate difference between effective and dominant discharge) is probably due to the limited data for that gage.

Even if effective discharge is substituted for dominant discharge at Columbus, smaller increases in dominant discharge on a per-mile basis occur on the Loup River than the Platte River. This is probably indicative of relatively small intervening drainage areas and drainages between the Diversion Weir and Columbus compared to drainage area sizes between the Platte River gages. In any case, there is no absence of sediment available for transport at any of the study sites, whether gaged or ungaged.

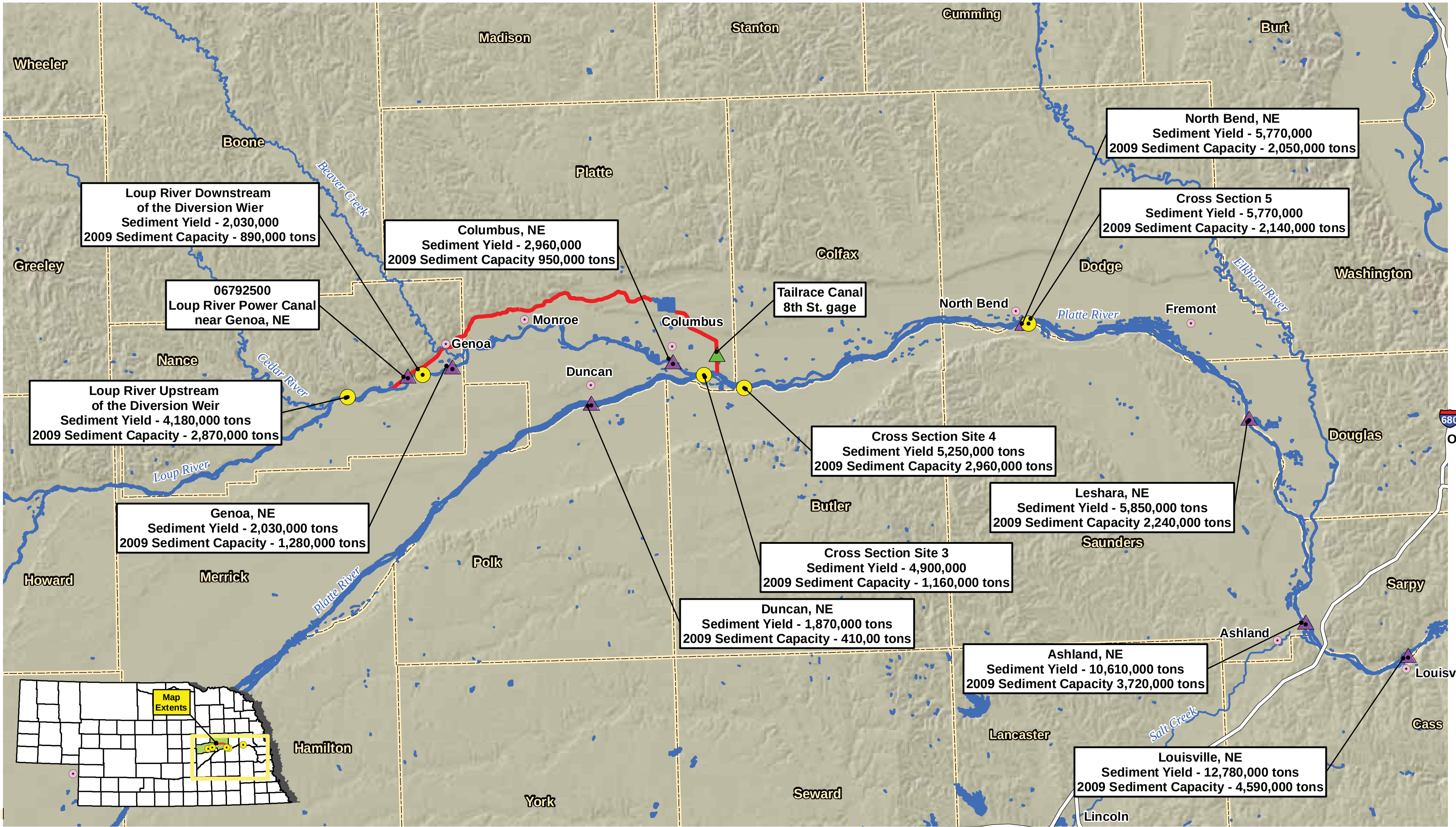
5.4.1 Spatial Analysis

Tables 5-1 and 5-2 and Figures 5-1 and 5-2 allow inclusion of the ungaged site results in the spatial analysis described in the ISR, Appendix A, Sedimentation Study Report, at least for 2009. Due to the subjective nature of selecting effective discharges from the sediment transport histograms, the dominant discharges are used in this integration of results from ungaged and gaged sites. As demonstrated in Table 5-2, effective discharges tend to be proportionately higher than dominant discharges, particularly for the Loup River when compared with the Platte River, but both indicators generally increase in the downstream direction.

For the Loup River, the 2009 dominant discharge of 2,930 cfs upstream of the Diversion Weir drops to 1,030 cfs across the Diversion Weir. This is expected because both annual flow hydrographs and affiliated sediment transport capacities at the two locations are altered by the Diversion Weir and Settling Basin. With the exception of bypassing most of the flow on flood flow days, diversions average 1,600 cfs, which is about equal to the difference in dominant discharge. The impact on sediment transport of the bypasses during flood flows is incorporated because the bypass amounts, and their transport capacities, would be reflected in the synthesized flows.

From just downstream of the Diversion Weir to Genoa and Columbus, the dominant discharges increase in the same increasing pattern described for the Loup and Platte rivers in the ISR, Appendix A. For the Platte River, the 2009 effective and dominant discharges shown in Table 5-1 reveal that no discernable discontinuity in either indicator occurs from just upstream to just downstream of the Tailrace Return. Thus, the results of including the ungaged sites in the spatial analysis for the Loup River are consistent with the findings described in the ISR, Appendix A, and with others' studies of rivers in this region (literature described in the ISR).

The total sediment transport amounts at capacity shown in Table 5-1 reveal that a quantum increase in transport capacity (from 1,160,000 to 2,960,000 tons per year) occurs just below the Tailrace Return, followed by a reduction to 2,060,000 tons per year downstream at North Bend. In the absence of the Project, it would be consistent with river dynamics to expect the total transport at a location just below the Tailrace Return to be slightly less than the 2,060,000 tons per year value at North Bend. The results for 2009 show it to be about 900,000 tons per year higher. This is expected because the flows immediately downstream of the Tailrace Return include the diverted amounts, and an increase in transport capacity across the junction would be expected because of the increase in flow rates.



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

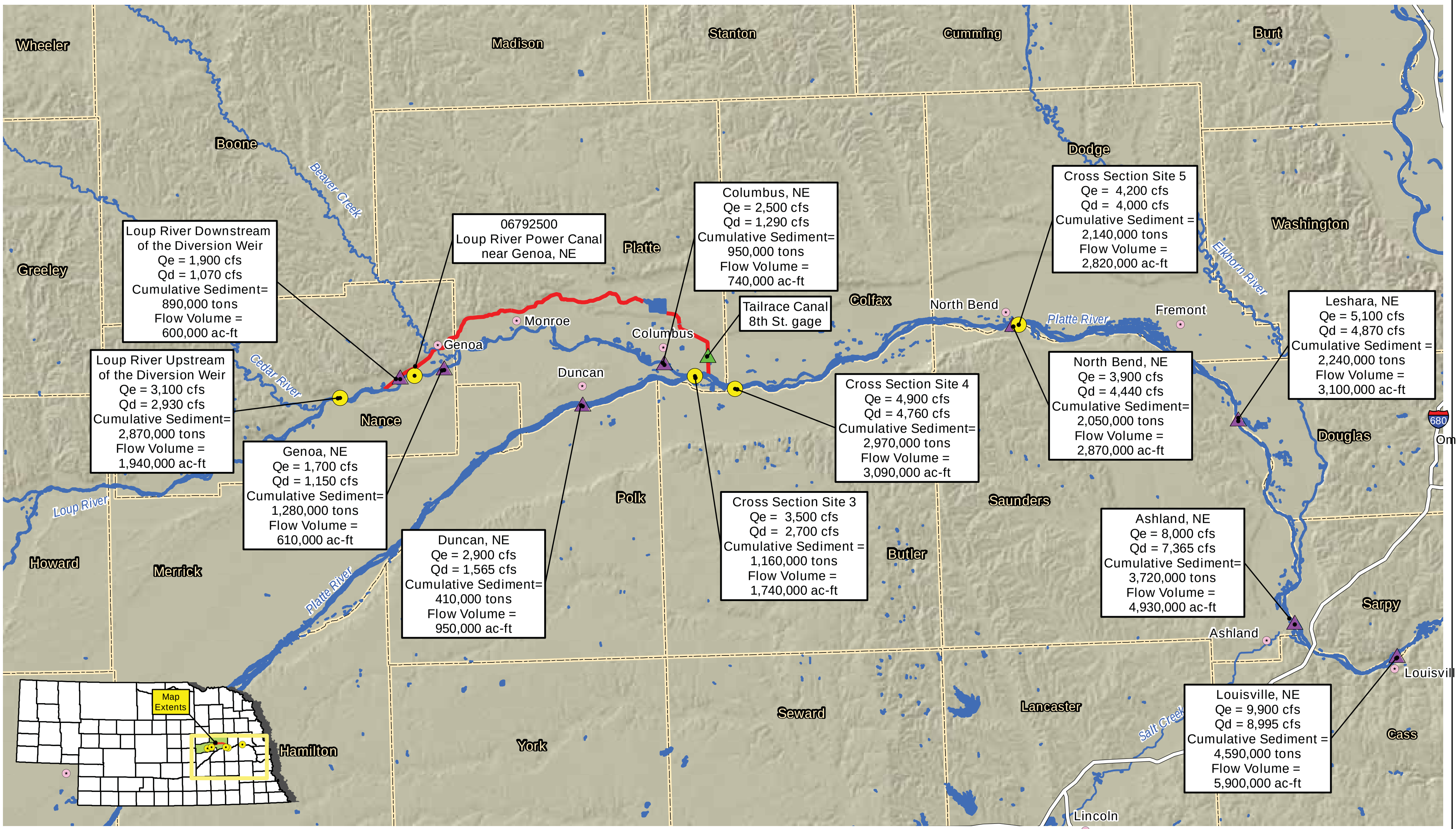
2009 Sedimentation Analysis Capacity and Yield

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

DATE
Feb. 11, 2011

FIGURE
5-1

Z:\Projects\Loup_Power_District\37104_LPD_FERC_Relicensing\map_docs\mxd\Sedimentation_Ungaged_Capacity-Yield_2009_CurrentOps.mxd



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

2009 Sedimentation Analysis

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

DATE
Feb. 11, 2011

FIGURE
5 - 2

It should also be noted that the mean daily discharge at Site 4 is higher than the mean daily discharge at North Bend. As demonstrated in the Second Initial Study Report, Appendix B, Hydrocycling Study Report, Section 5.4.1, the dominant and effective discharges at Site 4 for the 7-year period of 2003 to 2009 do not experience this quantum increase. As noted earlier, use of longer-term data is superior to use of data for any individual year.

The amount of sediment that could be transported at capacity is directly linked to the amount of flow passing any point. An increase in the capacity to transport just downstream of the Tailrace Return because of the increase in flow should not be considered evidence of possible degradation. No physical data or studies by others, including the cross-section measurements by the District, reveal a problem with degradation at this location. The appropriate measure of Project impacts is whether the morphology, measured by the effective discharge, is impacted by the return.

As shown above, the capacity to transport sediment increases just downstream of the Tailrace Return, but the effective and dominant discharges (and analysis by other observers described in the ISR, Appendix A) show that morphology is not being impacted. The fact that the effective and dominant discharges just downstream of the Tailrace Return are not abnormal relative to the overall river pattern indicates that morphology is not being impacted by this localized increase in transport capacity. The flow rates that transport the most sediment (effective or dominant rates) would need to be significantly “out of kilter” with the river’s pattern in order to conclude that aggradation or degradation is occurring. The flow rates controlling the river’s width, depth, and overall morphology do not appear out of ordinary across this junction.

One other relevant observation regarding Table 5-2 is that the total sediment that would be transported at capacity at Duncan and Columbus add up to being within 17 percent of the value at Site 3, downstream of the confluence of the Loup and Platte rivers. Although not recommended (see discussion below), it is somewhat intuitive that transport below any confluence should be about equal to the sum of capacities upstream. Deviations from this rule (total = sum of the parts) would be either because the actual daily transport by both rivers is frequently above or below capacity (see graphs of USGS suspended load transport data in the ISR), or because of temporary additions or subtractions from storage of sediment among the three locations.

Prior to having the ungaged analysis, the sum of Loup and Platte river transport amounts at capacity could be compared with the value at only the North Bend gage, which showed a 2009 difference of 31 percent. By including Site 3, the data reveals that the sum of upstream transport rates differ with the North Bend amount by 17 percent, or about half of the difference arises between Duncan and the Tailrace Return. This is essentially proportionate with the river distances.

Adding transport capacities upstream of river confluences in a spatial analysis in order to estimate capacities in the main stream may seem intuitive, and in this case may even appear reasonable, but it is not recommended. Total sediment transport at any location is determined by adding daily values of transport assuming that actual amounts match Yang's capacity equation. As shown in the ISR, Appendix A, and in this addendum, USGS measurements at the gaged sites reveal that suspended load transport rates for any given discharge vary by several orders of magnitude.

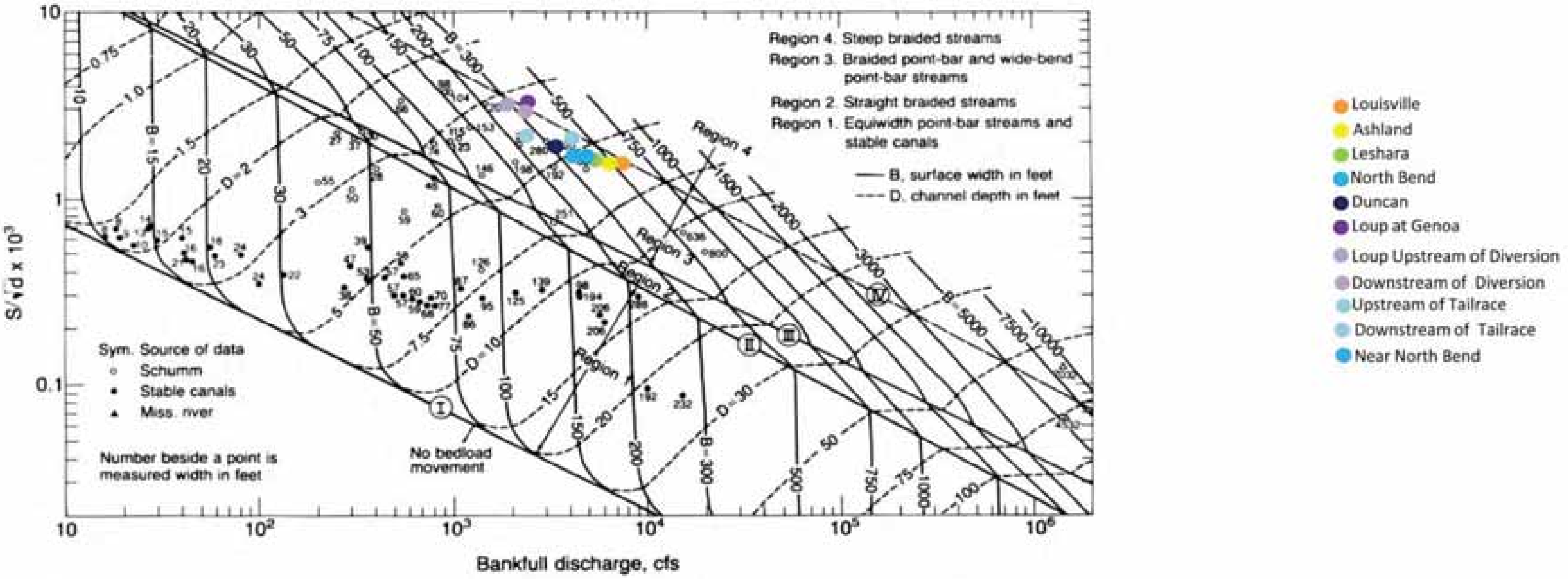
Any differences, even on the order of 17 or 31 percent, in comparing upstream and downstream total transport assuming transport at capacity are not of use in assessing equilibrium conditions through typical sediment "budget" accounting (inflow – outflow = change in storage). Even if the values reported in Table 5-1 were precise, the reach inflows and outflows in any given year, such as 2009, would never be expected to match downstream transport rates in a braided river because of the dynamic physical processes involved with sediment being continually drawn from and deposited to temporary storage in the stream bed. Longer-term analysis would be required. This process of continual (and moderately dramatic) change in channel geometry (and accompanying change in sediment being stored and removed) is readily seen in the graphs showing the June to September cross sections illustrated in Figures 5-3 and 5-4 in Section 5.4.2, as well as in the other data at other stations and times included in Attachment A.

In conclusion, the spatial analysis, now updated to include the ungaged sites, reveals that the effective and dominant discharges as well as annual transport capacities, based on use of synthesized flows for 2009, do not support any conclusion that the Platte River's morphology downstream of the Tailrace Return or elsewhere is impacted by the Project, and instead, the morphology, measured by the effective and dominant discharges, is consistent with natural river processes. The measures of morphology at the ungaged and gaged sites are consistent with values reported by Kircher and Karlinger (1981), USGS (1983), and Parsons (May 2003) for Middle Platte River stations. Thus, the incorporation of the ungaged site data does not alter the conclusions made in the ISR, Appendix A.

5.4.2 Regime Analysis

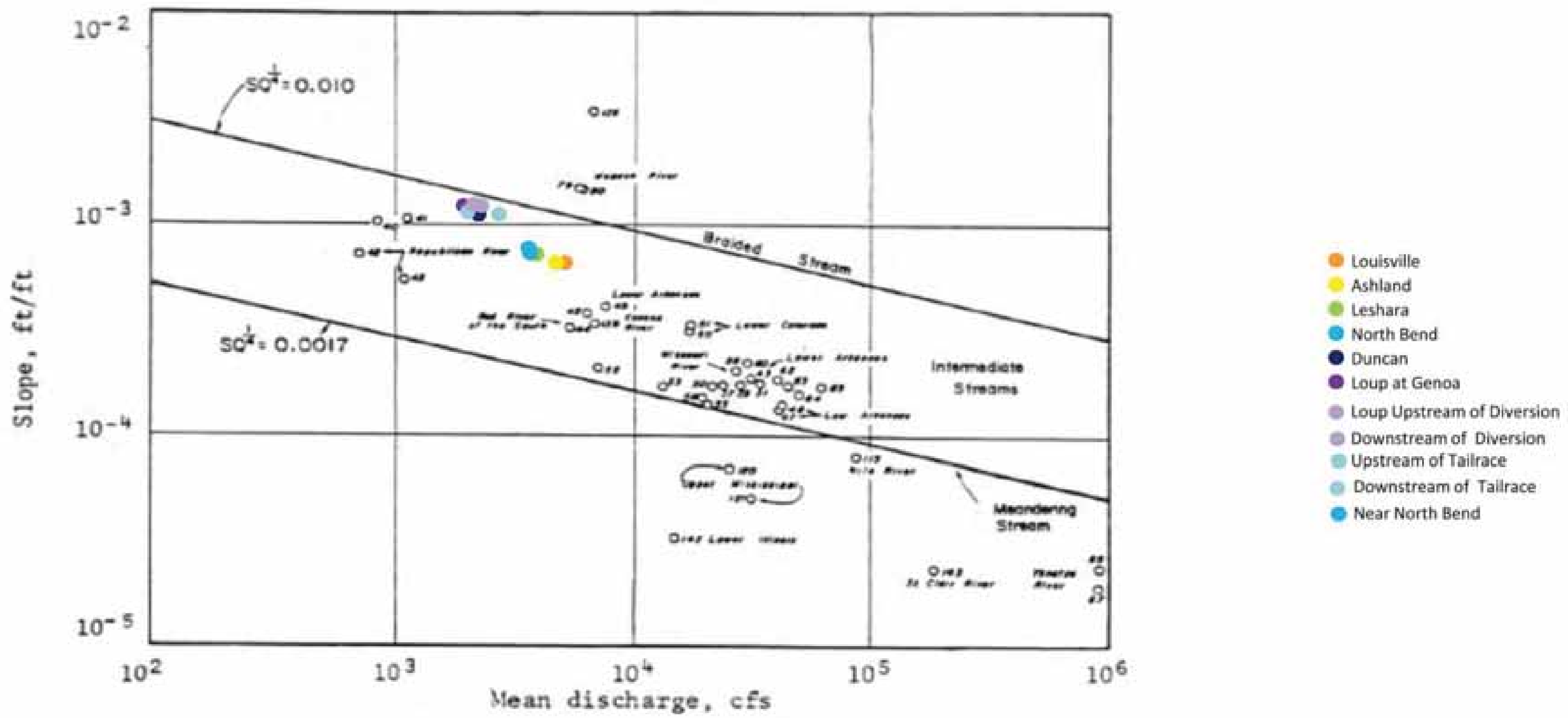
As noted in Section 4.3.1, Regime Analysis, the final test of whether either the Loup or Platte River or any location within either river is transitioning to another form can best be accomplished through regime analysis.

Figures 5-3 and 5-4 were plotted using 2009 data for the ungaged sites. Because of the subjectivity of determining effective discharges from the sediment transport histograms, especially for seasonal or single-year data, the 2009 dominant discharges at the ungaged sites were input along the abscissa of each graph. As shown, all of the points plot in positions well within braided river morphology zones, with none being near any thresholds of transitioning to another morphology.



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



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 5-4. Lane's (1957) Regime Morphology Chart for Sand Bed Rivers with Ungaged Site Sedimentation Study Results Plotted

5.5 Task 4: Stream Channel Morphology

The methodology described in the ISR, Appendix A, Section 4, 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.

The methodology adopted in the ISR, Appendix A, Sedimentation Study Report, for testing whether the gaged sites were in dynamic equilibrium was applied to the ungaged site data as shown in Tables 5-1 and 5-2, as well as in Figures 5-3 and 5-4.

Although 2009 estimates of sediment yields are not available, the 2009 estimates of transport capacity shown in Table 5-1 are well below the adjusted average annual MRBC yields, supporting the earlier conclusion that none of the sites are supply limited, and the inclusion of sediment transport indicators at the ungaged sites reveals that the morphology is in dynamic equilibrium.

6. REFERENCES

ASCE Task Committee on Hydraulics, Bank Mechanics, and Modeling of River Width Adjustment. September 1998a. "River Width Adjustment I: Processes and Mechanisms." *Journal of Hydraulic Engineering* 124(9):881-902.

ASCE Task Committee on Hydraulics, Bank Mechanics, and Modeling of River Width Adjustment. September 1998b. "River Width Adjustment II: Modeling." *Journal of Hydraulic Engineering* 124(9):903-917.

Bentall, R. 1991. Facts and Figures about Nebraska Rivers. Water Supply Paper No. 73. University of Nebraska, Conservation and Survey Division, Lincoln, Nebraska.

Chang, Howard H. March 1985. "River Morphology and Thresholds." *Journal of Hydraulic Engineering* 111(3):503-519.

Kircher, J.E., and M.R. Karlinger. 1981. "Changes in Surface-water Hydrology, Platte River Basin in Colorodo, Wyoming, and Nebraska Upstream from Duncan, Nebraska." USGS Open-file Report 81-818.

FERC. August 26, 2009. Letter from Jeff C. Wright, Director, Office of Energy Projects, FERC, to Neal D. Suess, President/CEO, Loup Power District, regarding Study Plan Determination for the Loup River Hydroelectric Project.

Lane, E.W. 1957. A Study of the Shape of Channels Formed by Natural Streams Flowing in Erodible Material. Missouri River Division Sediment Series No. 9, U.S. Army Corps of Engineers, Missouri River Division, Omaha, NE.

Loup Power District. August 26, 2010. Initial Study Report. Loup River Hydroelectric Project. FERC Project No. 1256.

Maddock, Thomas, Jr. November 1970. "Indeterminate Hydraulics of Alluvial Channels." *Journal of the Hydraulics Division, ASCE* 96(11):2309-2323.

Parsons. May 2003. Platte River Channel Dynamics Investigation. Prepared for the States of Colorado, Nebraska, and Wyoming. Denver, CO. Available online at http://www.platteriverprogram.org/PubsAndData/ProgramLibrary/Platte%20River%20Channel%20Dynamics%20Investigation.pdf.

USACE. July 1990. Platte River Cumulative Impacts Analysis. Report No. 5. Special Studies Unit, River & Reservoir Section, Hydrologic Engineering Branch, Engineering Division, USACE-Omaha.

USGS. 1983. "Hydrologic and Geomorphic Studies of the Platte River Basin." USGS Professional Paper 1277. Washington, D.C.: U.S. Government Printing Office.