HDR Engineering, Inc.

In Conjunction With

Mussetter Engineering, Inc.
The Flatwater Group, Inc.
Dr. Mark Pegg, UNL

RECOVERY IMPLEMENTATION PROGRAM
PLATTE RIVER

Lower Platte River Stage Change Study
Final Protocol Implementation Report

Platte River Recovery Implementation Program
Kearney, Nebraska

Version 1.0

December, 2009

Table of Contents

List of Tables

List of Figures

List of Appendices

Introduction

This Protocol Implementation Report details the study effort associated with the lower Platte River Stage Change Study (Study) for the Platte River Recovery Implementation Program (Program) Governance Committee (GC). For purposes of this Study, the lower Platte River is defined as the reach between the Elkhorn River confluence and the Missouri River confluence. The framework for the Protocol Implementation Report is outlined in the "Lower Platte River Stage Change Study, Final Protocol Development Report" (HDR, The Flatwater Group, Mussetter Engineering, and Dr. Mark Pegg, 2008a). The Study objective was to develop information needed to evaluate the potential effects of Program water management activities on water stage and how those stage changes might affect the physical characteristics of the lower Platte River. The following activities are included in this report:

- Data Collection and Field Work
- Hydrology
- Hydraulics and Geomorphology
- Interpretation and Analysis

Data Collection and Field Work

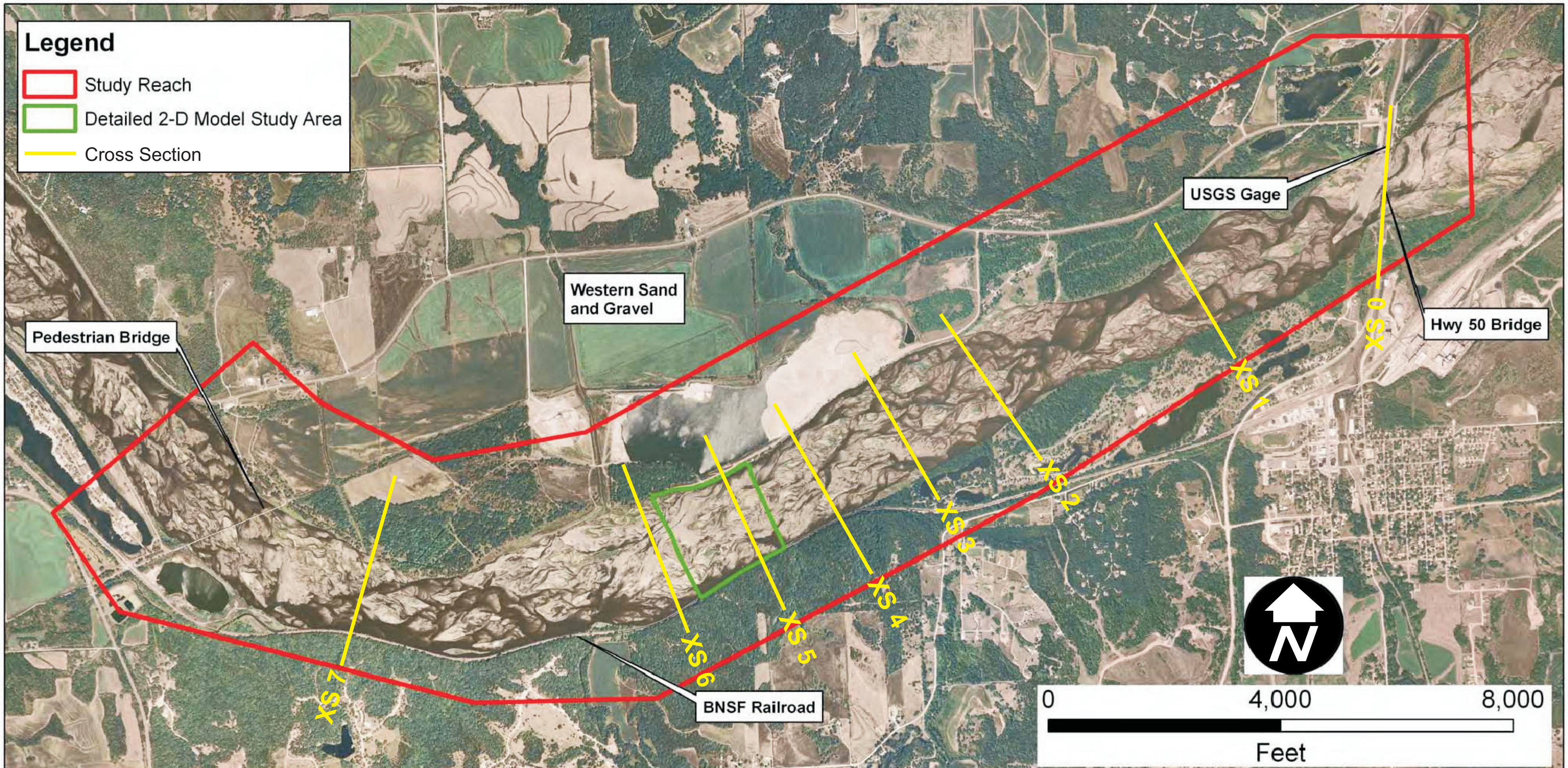
The lower Platte River reach chosen for the data collection effort is located between the Nebraska Highway 50 Bridge and the reclaimed Chicago Rock Island and Pacific Railroad (pedestrian) Bridge (Study Reach) as shown in Figure 1. The intent of the data collection effort was to obtain water surface and water quality information during the high, intermediate, and low flow conditions, and bed topography at low to intermediate flows, in the Study Reach. Details of the historic hydrograph are presented below in Hydrology – Study Flows.

Within the Study Reach, depth, velocity, turbidity, water temperature, dissolved oxygen, and conductivity measurements, as well as bed topography, were obtained during field data collection activities. The Study Reach cross section locations where data were collected are shown in Figure 1. Data were collected during the low flow period in September 2008 and the high flow period in May 2009. Limited data were also obtained in July 2008 during an additional high flow period. Data collection during intermediate flows was suspended for 2008 due to rain events, and these efforts have now been suspended indefinitely due to time and budget constraints. Water surface profiles were also obtained during 2 days in June 2008 on the recession limb of a flood event on the lower Platte River for use in model validation. The data collection effort is detailed in two reports: "Lower Platte River Stage Change Study Final First Progress Report – Field Work Activities" (HDR, The Flatwater Group, Mussetter Engineering, and Dr. Mark Pegg, 2008b) and "Lower Platte River Stage Change Study Final Second Progress Report – Field Work Activities" (HDR, The Flatwater Group, Mussetter Engineering, and Dr. Mark Pegg, 2009).

Hydrology

A hydrologic analysis was performed to analyze the lower Platte River flow regime for the following objectives of this Study:

- Determine the range of flows for the data collection and hydraulic modeling efforts;
- Determine if natural flows can be differentiated from Program activities;
- Evaluate hydrograph translation from Grand Island to Louisville, Nebraska.



HDR
THE FLATWATER GROUP INC.
TETRA TECH
MEI

Study Reach

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date
Dec. 2009

Figure
1

Study Flows

The historic hydrograph for the U.S. Geologic Survey (USGS) Gage 06805500, Platte River at Louisville (Louisville gage), is shown in Figure 2. The gage is located on the Nebraska Highway 50 Bridge, at the downstream end of the Study Reach. Based on information shown in the plot, the flow ranges (in cubic feet per second [cfs]) listed in Table 1 were determined appropriate for the data collection effort.

Table 1. Historic Platte River Flows at USGS Louisville Gage

Historic Flow Condition	Time Period	Median Flow Range (cfs)
High	March - June	6,000 – 8,000
Intermediate	November - December	3,000 – 5,000
Low	August - September	2,000 – 3,000

Consistent with the Program's Adaptive Management Plan, a range of flows was selected to evaluate the effect of changes in river stage on a macro-, meso-, and micro-scale. Based on the period of record for the Louisville gage, the discharges that are of primary interest range from 5,000 to 39,000 cfs. The low end of this range roughly corresponds to the median mean daily discharge (that is, the discharge that is equaled or exceeded about half the time on an annual basis). The upper end of the range corresponds to approximately the 1 percent exceedence flow, which would be exceeded approximately 3.5 days per year, on average. The upper end of the range also has a recurrence interval of approximately 1.5 years on the annual peak flow series. The selected flows are believed to be appropriate for the hydraulic modeling efforts associated with this Study.

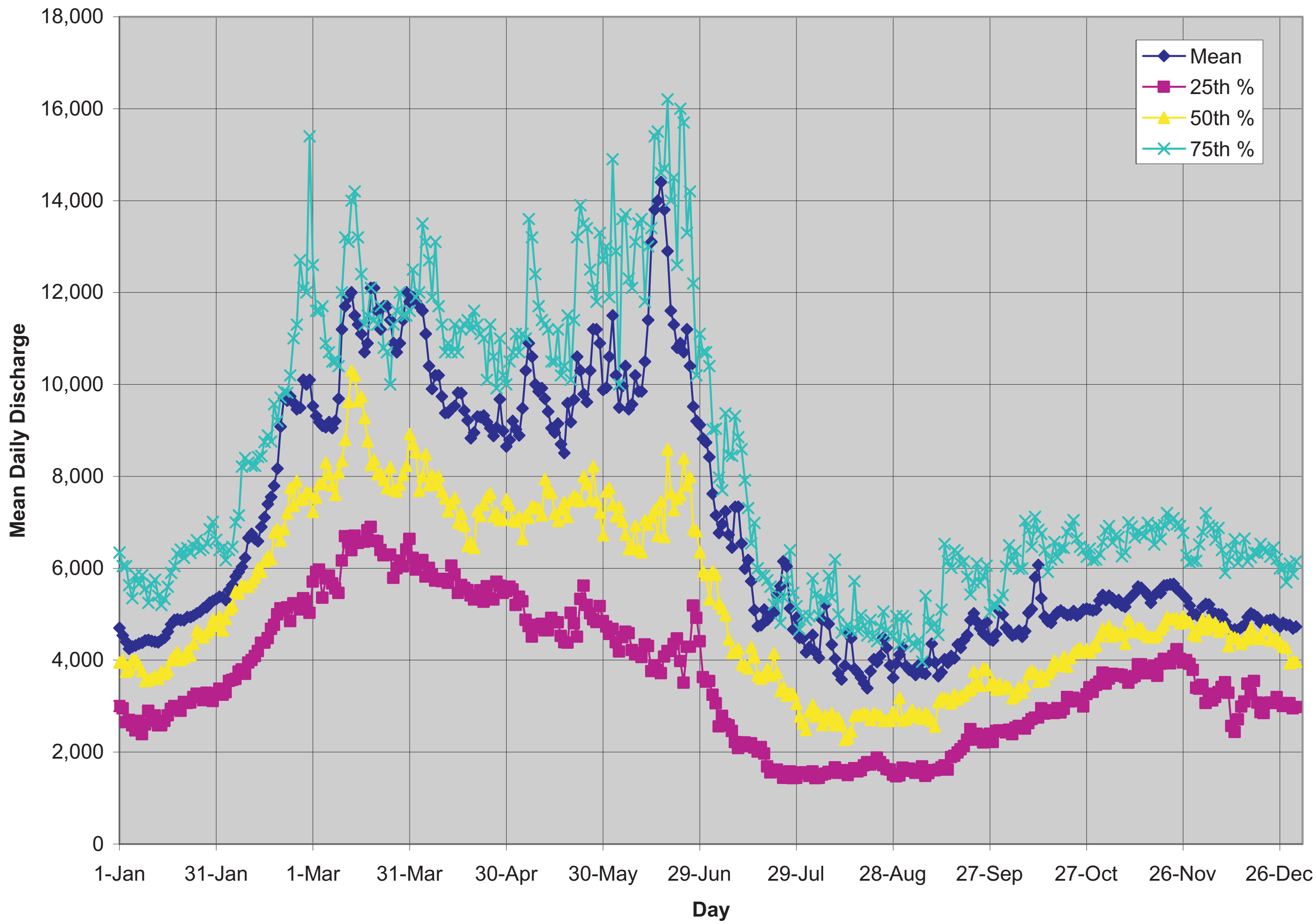
Natural Flows Versus Program Activities

The Program identified the evaluation of USGS gages to determine if Program-related activities are detectable outside the range of variability of the current hydrograph as an important task. The U.S. Fish and Wildlife Service (USFWS), Mountain-Prairie Region (Region 6), in conjunction with the Program's Water Management Committee, completed a preliminary analysis of how changes in central Platte River flow conditions due to proposed Program activities may affect the lower Platte River. The associated analyses are documented in a series of reports, including: "Estimated Historic Losses by Stream Reach in the Platte River Below Grand Island, Nebraska, and Implications for Program-Augmented Flows" (Draft Report) dated May 2002 (USFWS, 2002a) and "Summary Report on the Potential of Changes in Central Platte Flow Conditions to Affect Flows in the Lower Platte" (Draft Report) dated December 2002 (USFWS, 2002b). These two reports are included in this Study as Appendices A and B.

Two phases in the USFWS study that are applicable to this Study are: Estimate historic losses based on daily flow records below Grand Island; and Estimate the likely range of possible effects of Program water at Grand Island on flow in the lower Platte River. Those analyses were extended through Water Year 2008 for this Study, using the travel times estimated in the USFWS studies.

The USFWS analysis segmented the Platte River between Grand Island and Louisville into the following three stream reaches:

- Reach 20 – Platte River from Grand Island to Duncan, Nebraska
- Reach 21 – Platte River from Duncan to North Bend, Nebraska
- Reach 22 – Platte River from North Bend to Louisville, Nebraska



HDR
THE FLATWATER GROUP INC.
TETRA TECH
MEI

Historic Hydrograph @ Platte River Louisville Gage

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date
Dec. 2009

Figure
2

Data Collection

Streamflow Data

USGS daily streamflow data for the lower Platte River system were compiled through Water Year 2008. The data were obtained to overlap the last water year in the USFWS analyses (1994 or 2000) at each location for data set verification. Table 2 summarizes the stream gage locations, USGS site number, stream reach, period of record for the USFWS study, and periods of record used to extend the analysis through 2008.

Table 2. Platte River Basin Gage Location Used for Historic Loss Analysis

Nebraska Gage Locations	USGS Site No.	Stream Reach	Period of USFWS Analysis	Period of Record for Extended Analysis
Platte River at Grand Island	06770500	Reach 20	1975-1994	1995-2008
Platte River at Duncan	06774000	Reach 20/21	1975-2000	2001-2008
Loup River at Genoa	06793000	Reach 21	1997-2000	1997-2000
Loup Power Canal at Genoa	06792500	Reach 21	1997-2000	1997-2000
Loup River at Columbus	06794000	Reach 21	1954-2000	2001-2008
Loup Power Plant Return	Estimated	Reach 21	1997-2000	1997-2000
Shell Creek near Columbus	06795500	Reach 21	1997-2000	1997-2000
Platte River at North Bend	06796000	Reach 21/22	1975-2000	2001-2008
Elkhorn River at Waterloo	06800500	Reach 22	1975-1994	1995-2008
Salt Creek at Greenwood	06803555	Reach 22	1975-1994	1995-2008
Platte River at Louisville	06805500	Reach 22	1975-1994	1995-2008

The Loup River gage at Columbus (USGS Gage 06794000) ceased operation in 1978. Monthly regression relationships between daily flows for the Loup River at Genoa (USGS Gage 06793000) and the Loup River at Columbus (USGS Gage 06794000) were developed for the time period during which both gages were in operation: Water Years 1954 through 1978 (USFWS, 2002a). USFWS used these monthly regression relationships for estimating streamflow for the Loup River at Columbus for the period between 1978 and 2000. The same methodology used by USFWS and described in the May 2002 Draft Report (USFWS, 2002a) was applied to determine streamflow values for this gage from 2000 through 2008.

The USFWS study (USFWS, 2002a) stated that the best estimate of daily flows from the Loup Power Plant Return was based on the amount of hydroelectric power generated at the "Columbus Hydroelectric Powerhouse" (Columbus Powerhouse) during that day. Because daily hydroelectric power generation estimates were compiled only from January 1997 through December 2000, the USFWS analysis at this location as well as the associated Platte River reach (Reach 21) was based on the period of January 1997 through December 2000, consistent with the USFWS analysis (2002a). These flow estimates were assumed equal to the return flows to the Platte River. Due to the limited availability of daily Columbus Powerhouse generation values after 2000, no additional data were obtained for this Study at the Loup Power Plant Return; therefore, the period of analysis for the Loup Power Plant Return and the associated Platte River reach (Reach 21) remained the same as the USFWS analysis: 1997 through 2000.

The Nebraska Department of Natural Resources installed a gage downstream of the Columbus Powerhouse in 2003. This gage would more accurately reflect the Loup Power Plant Return than the analysis described in the USFWS study. However, for consistency in comparing the results to the USFWS study (2002a), the gage data were not incorporated into the analysis.

Evaporation Data

The USFWS study incorporated evaporation data from two weather stations: Grand Island and Omaha. The Grand Island weather station discontinued recording evaporation data, so no evaporation data were available for Grand Island from 2001 through 2008. Therefore, historical monthly averages from the USFWS period of record (1954 through 2000) were used to estimate monthly evaporation values from 2001 through 2008 at Grand Island.

For purposes of this Study, monthly pan evaporation data measurements were collected from the Omaha weather station located in Valley, Nebraska, which is operated by the National Weather Service. Evaporation data at this location were available for May through September for 2001 through 2006. To estimate the Omaha evaporation values for the period of January through April and October through December from 2001 through 2006, historical monthly averages from the USFWS period of record (1954 through 2000) were used. The historical averages for the USFWS period of record (1954 through 2000) were also used in conjunction with monthly averages from the Omaha weather station at Valley (2001 through 2006) to estimate the monthly averages for 2007 and 2008 evaporation values at Omaha.

Methodology and Analysis

Accuracy Assessment of USGS Stream Gage Measurements

The USGS accuracy assessment was performed using the same methodology as described in the USFWS December 2002 Draft Report (USFWS, 2002b) and extending the analysis to include Water Year 2008. The accuracy of the USGS stream gage measurements limits the detectability of flow changes at Louisville. As noted by USFWS (2002b) "the effect of flow changes in the central Platte River for the magnitude currently envisioned under the Platte River Program are not likely to be detectable at Louisville, Nebraska" (USFWS, 2002b).

Data in the USFWS December 2002 Draft Report (USFWS, 2002b) covered Water Years 1975 through 1994 and included mean daily flow in the Platte River at Louisville expressed as a frequency of exceedence. This Study updated previous analyses to include Water Years 1975 through 2008. The uncertainties of USGS mean daily flow measurements in the Platte River at Louisville (cfs plus or minus), expressed at the 95 percent confidence level as frequency of exceedence, presented in the USFWS analysis were also updated to include Water Years 1975 through 2008.

Additional details regarding the methodology used for the accuracy assessment of USGS stream gage measurements are documented in Appendix B (USFWS, 2002b).

Effects on Flows in Lower Platte

The procedures and methodology used by USFWS (2002a) for estimating historic losses by stream reach for the Platte River below Grand Island were applied in this Study for the updated periods of record. A daily mass-balance evaluation (inflow versus outflow) was performed for each of the three stream reaches using USFWS's daily flow tracking and accounting Microsoft Excel spreadsheet.

This spreadsheet calculated reach gains or losses of each reach from a daily-mass balance analysis as follows:

Net loss (-) or gain (+), if any = Outflow at the downstream end of the reach + Estimated daily evaporation and evapotranspiration losses - Lagged inflows at one or more locations

All parameters used in the USFWS analysis were adopted for this Study. They include travel time, evaporation and evapotranspiration methodology, open water surface area, and vegetated riparian areas. The only updated data were the addition of evaporation data for the period of 2001 through 2008, as described above. Based on these inputs, estimates were made for daily reach losses due to evaporation, evapotranspiration, and seepage by extending the Excel spreadsheet formulas.

Estimated conveyance losses or gains by river reach were calculated using the methodology described above and documented in the USFWS Draft Report (USFWS, 2002a). In addition, upper and lower envelopes, representing 25th and 75th percentile years, of estimated conveyance losses in the Platte River between Grand Island and Louisville as percentage of augmented flow were determined and plotted for 100 and 500 cfs of Program water at Grand Island.

Additional details regarding the methodology used for estimating conveyance losses by stream reach for the Platte River below Grand Island are documented in Appendix A (USFWS 2002a).

Water Quality Measures

Several parameters often used to assess water quality for fish habitat were measured during field data collection efforts in 2008 and 2009. Those parameters include water temperature (degrees Celsius [^{o}C]), dissolved oxygen (milligrams per liter [mg/l]), conductivity (micro Siemens per centimeter [µS/cm]), turbidity (Nephelometric Turbidity Units [NTU]), depth (feet), and water velocity (feet per second) and were measured along each cross section (Figure 1) during the data collection effort. The number of samples taken per transect varied but ranged from 2 to 10 sample points, depending on diversity of habitats present along the transect. Data collected from each phase of sampling were then used to conduct a power analysis to determine whether sample sizes were adequate to statistically determine differences between sample periods. This analysis provides insight on whether the water quality data can differentiate between flow conditions.

Results

Accuracy Assessment of USGS Stream Gage Measurements

Based on the updated period of record used in this Study, Table 3 illustrates the mean daily flow by month in the Platte River at Louisville for Water Years 1975 through 2008, expressed as frequency of exceedence. Table 4 displays the differences in mean daily flows between the USFWS December 2002 Draft Report (USFWS, 2002b) and the current Study.

As stated in the USFWS December 2002 Draft Repot (USFWS, 2002b), USGS describes the accuracy of the Platte River stream gage at Louisville as “good,” meaning approximately 95 percent of the reported daily discharges are within 10 percent of their true value. Consistent with the methodology outlined in USFWS 2002b, This accuracy description implies the approximate uncertainties illustrated in Table 5 for USGS mean daily flow measurements in the Platte River at Louisville (cfs plus or minus), expressed at the 95 percent confidence level as frequency of exceedence, Water Years 1975 through 2008. Table 6 displays the differences of the uncertainties in mean daily flows between the USFWS December 2002 Draft Report (USFWS, 2002b) and the current Study.

Table 3. Mean Daily Flow at Louisville - WY 1975-2008 (cfs)												
Percent days exceeding	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
90%	2400	3600	5283	5049	3963	2942	1420	1243	1440	2340	3359	2600
50%	5020	7000	9075	8360	8195	8000	4535	3545	4045	4530	5280	5205
10%	8817	13500	18800	19700	22440	25110	14370	9707	9131	9574	9470	9115

Table 4. Difference in Mean Daily Flow at Louisville - WY 1975-2008 minus WY 1975-1994 (cfs)												
Percent days exceeding	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
90%	-200	0	-342	136	114	372	52	186	-39	210	180	164
50%	320	400	-1125	260	475	1045	400	0	-295	360	445	205
10%	215	-1120	-4060	-2220	630	1790	-1960	487	-1369	-526	-24	-61

Table 5. Uncertainty in Daily Flow at Louisville - WY 1975-2008 (plus-or-minus cfs)												
Percent days exceeding	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
90%	240	360	528	505	396	294	142	124	144	234	336	260
50%	502	700	908	836	820	800	454	355	405	453	528	521
10%	882	1350	1880	1970	2244	2511	1437	971	913	957	947	912

Table 6. Difference in Uncertainty in Daily Flow at Louisville - Uncertainty WY 1975-2008 minus Uncertainty WY 1975-1994 (plus-or-minus cfs)												
Percent days exceeding	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
90%	-20	0	-34	14	11	37	5	19	-4	21	18	16
50%	32	40	-113	26	48	105	40	0	-30	36	45	21
10%	22	-112	-406	-222	63	179	-196	49	-137	-53	-2	-6

Effects on Flows in Lower Platte

As documented by USFWS (USFWS, 2002a), daily evaporation and seepage losses were added together to estimate total Program water loss within each of the three reaches from Grand Island to Louisville. These total daily losses were then summarized for each month in terms of the average daily Program water loss occurring that month.

To estimate cumulative Program water effects from Grand Island to Louisville, Program-augmented flows were "routed" through the three reaches, with the corresponding percent loss subtracted from the flow in each reach. However, this routing could not be done for each month of the period of record because the period of record used for Reach 21 did not overlap with the period of record used for Reaches 20 and 22. Instead, the monthly loss percentages associated with the median, the 75th percentile, and the 25th percentile years were used to route and evaluate "normal," "high-loss," and "low-loss" scenarios, respectively.

The results, assuming 100, 500, and 1,000 cfs of additional Program water at Grand Island, are summarized in Figures 3, 4, and 4a, respectively. As illustrated in Figure 3, the estimated proportion of 100 cfs of Program water that ultimately reaches Louisville ranges from approximately 10 percent (in July and August of the worst years) to over 90 percent (in December, January, March, and April of the best years). From October to June in median years, between 70 and 90 percent of the Program water reaches Louisville. In July to September, this percentage falls to 45 to 55 percent.

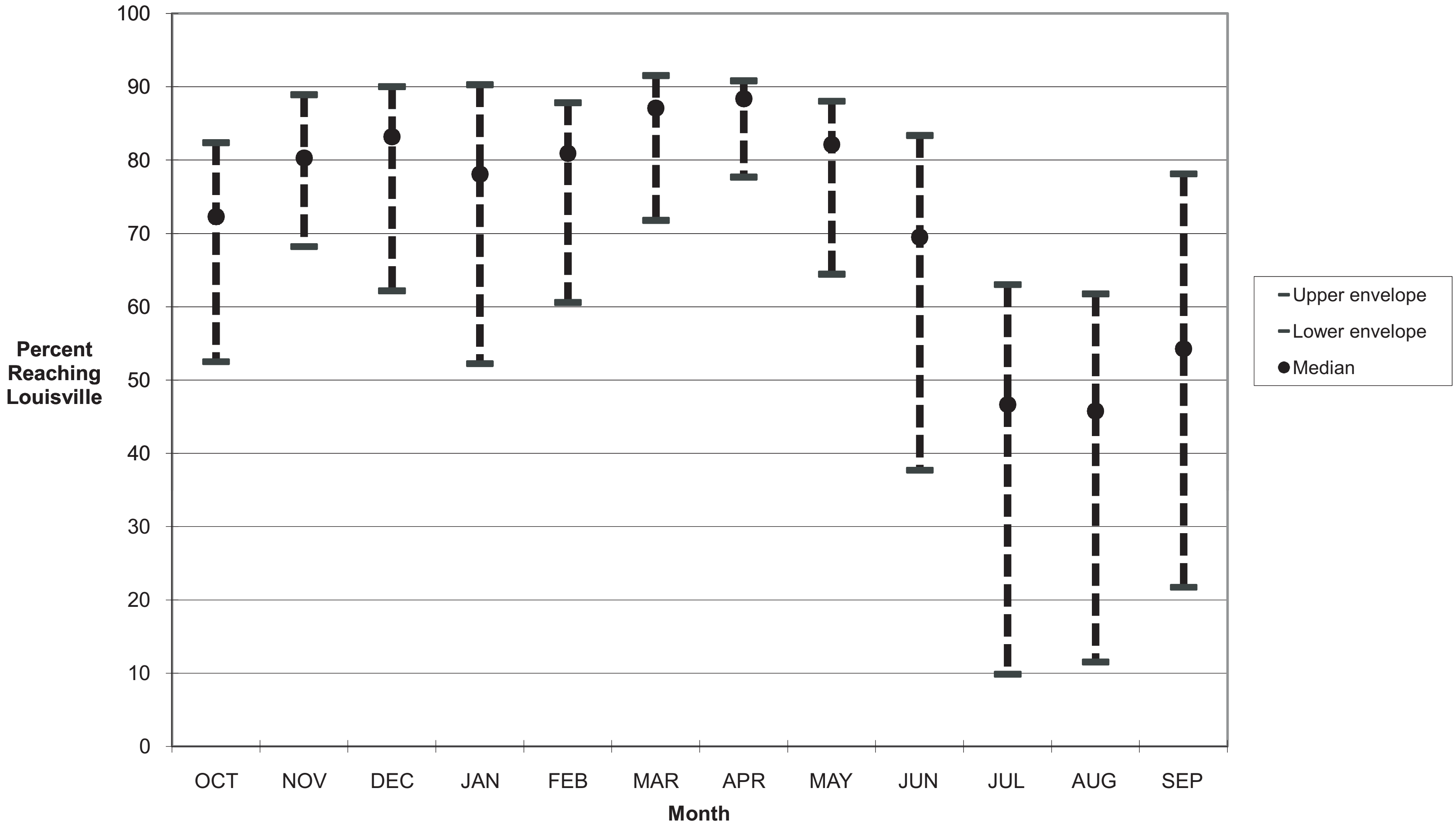
Patterns similar to the 100 cfs of additional Program water are illustrated in Figure 4 for the scenario with 500 cfs of additional Program water at Grand Island. However, relative to the 100 cfs analysis, an additional 1 to 6 percent of Program-augmented flow in October through June of the median year is estimated to reach Louisville, and an additional 9 to 15 percent of Program-augmented flow in July through September of the median year is estimated to reach Louisville.

As noted by USFWS (USFWS, 2002a), this relative increase in percentage of Program-augmented flow reaching Louisville demonstrates that the percentage of Program-augmented flow lost to evaporation will decrease as the amount of Program-augmented flow is increased. It is noted that although the total volume lost would increase with additional Program-augmented flow, the percentage of flow lost would decrease. Furthermore, the percentage of Program-augmented flow lost to evaporation is expected to increase as the amount of Program-augmented flow is decreased.

Comparison with USFWS Analysis

Comparing the results of the extended analysis for the 100 cfs of additional Program water with the USFWS Draft Report (USFWS, 2002b), the lower envelope (25th percentile) values have lowered. From October to May, the lower envelope is about 5 percent lower than the USFWS analysis. A significant drop in the lower envelope values is noticed from June to September, changing from a low of 40 percent reaching Louisville down to only 10 percent. The difference for nearly all of the upper envelope (75th percentile) values is typically less than a few percent.

When comparing the results for 500 cfs of additional Program water, patterns similar to the 100 cfs of additional Program water are evident. Overall the lower envelope (25th percentile) values have decreased for the extended analysis, and the most significant drop occurs from July to September. As with the 100 cfs scenario, the upper envelope (75th percentile) values remain nearly the same for the extended analysis period.

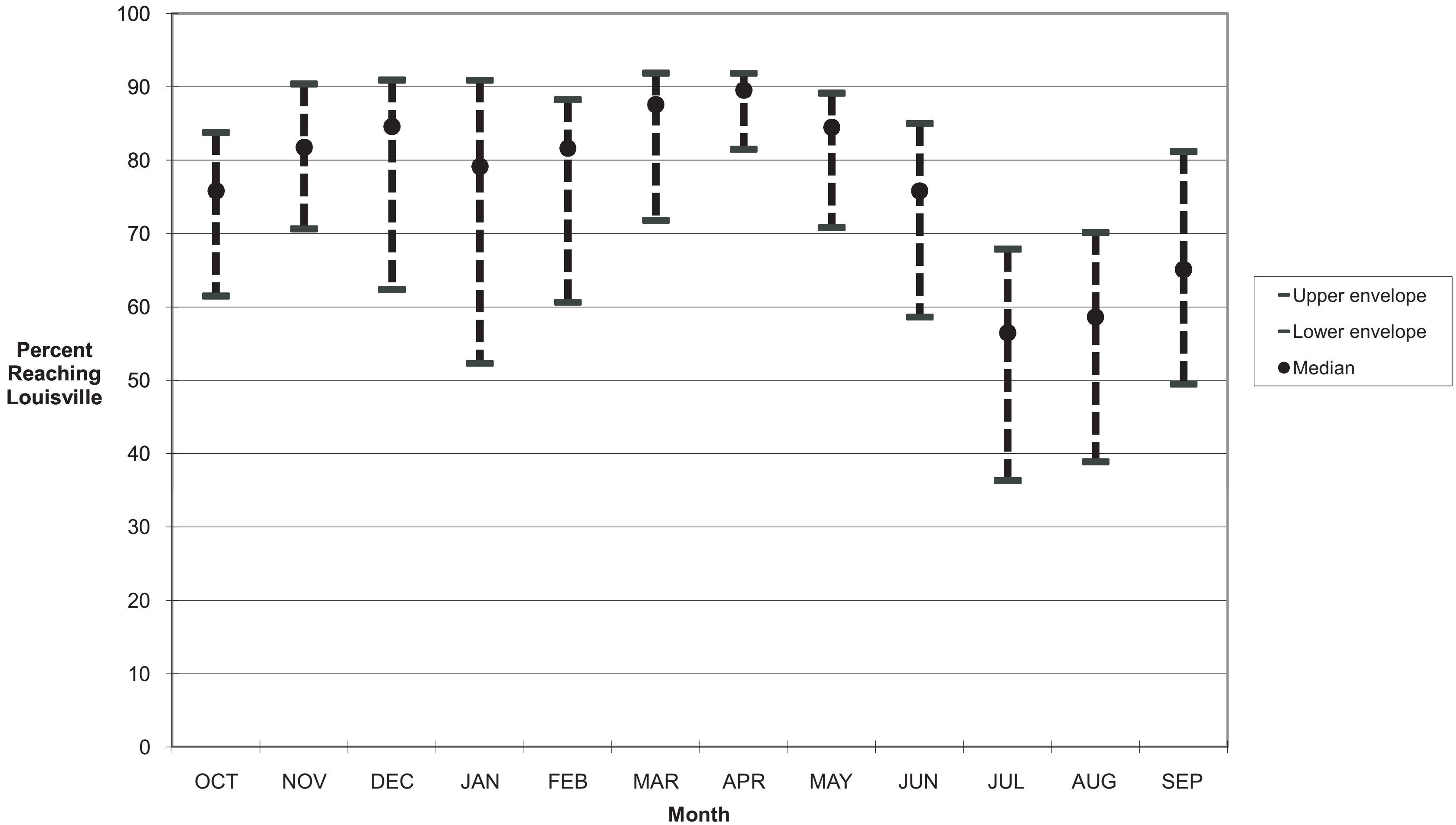


Estimated Percent of 100 cfs Program Water at Grand Island Reaching Louisville after Evaporation and Seepage Losses

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date
Dec. 2009

Figure
3

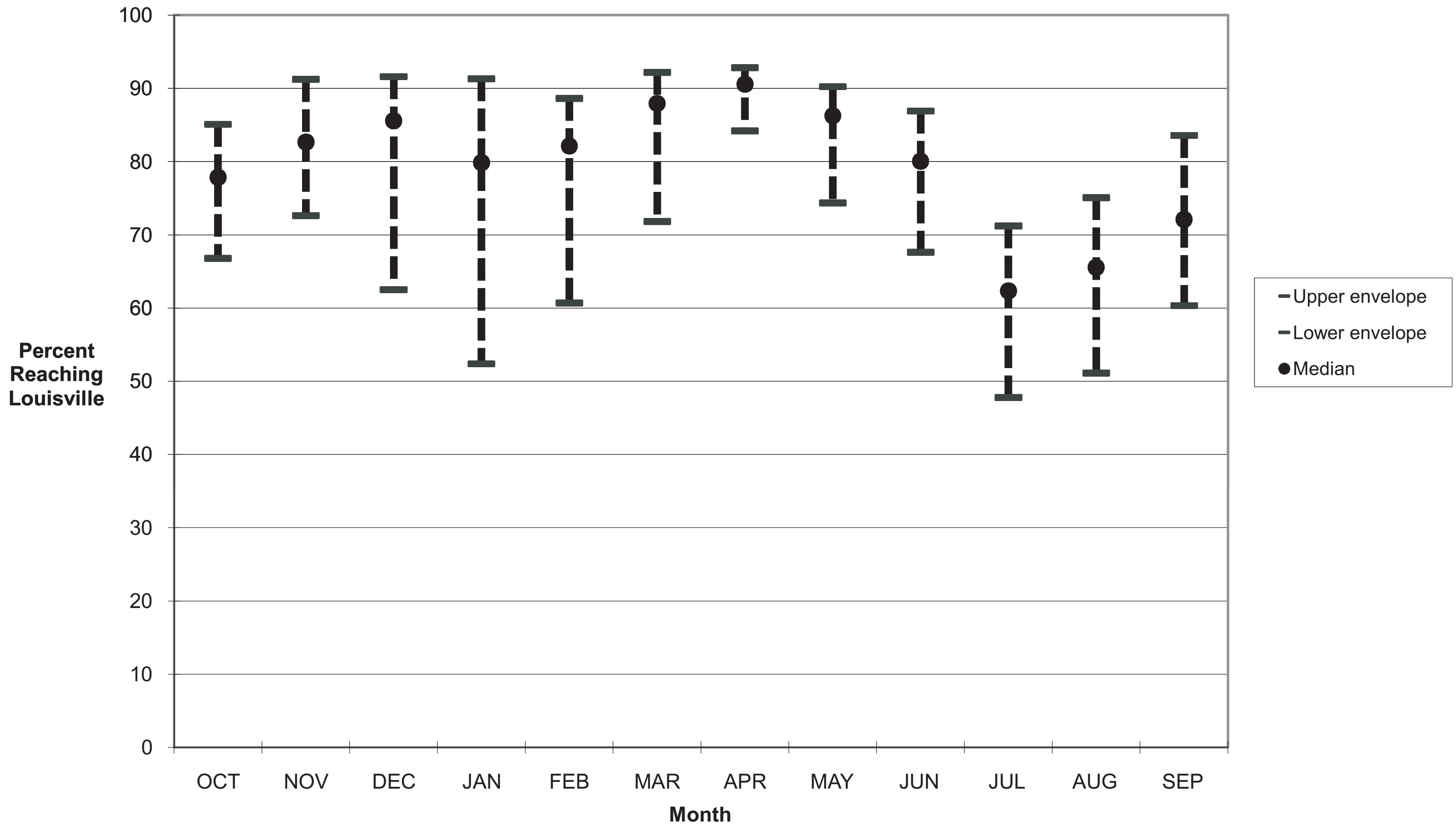


Estimated Percent of 500 cfs Program Water at Grand Island Reaching Louisville after Evaporation and Seepage Losses

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date
Dec. 2009

Figure
4



Estimated Percent of 1000 cfs Program Water at Grand Island Reaching Louisville after Evaporation and Seepage Losses

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date: Dec. 2009

Figure: 4a

Hydrograph Translation from Grand Island to Louisville

The Program initiated a test of environmental account (EA) flows in late April 2009. This test afforded the opportunity to evaluate the translation of a pulse flow to the lower section of the Platte River and, in particular, the Louisville gage. For the analysis, the provisional real-time data was obtained from USGS (2009). Program staff also provided some preliminary information evaluating the pulse flow event to the Grand Island gage.

In general, little precipitation occurred during the time of the pulse flow; therefore, the recorded hydrographs should be reasonably representative of baseflow conditions. There were some minor precipitation events in the lower section of the river that may have affected flow as it moved downstream. The Salt Creek gage at Greenwood (USGS Gage 06803555) recorded a runoff event starting on April 25 and peaking on April 27. While small, this event increased the flow being recorded by approximately 200 cfs. As shown in Figure 5 and explained below, this corresponds with the apparent peak flow at Louisville on April 26, as represented in the mean daily flow.

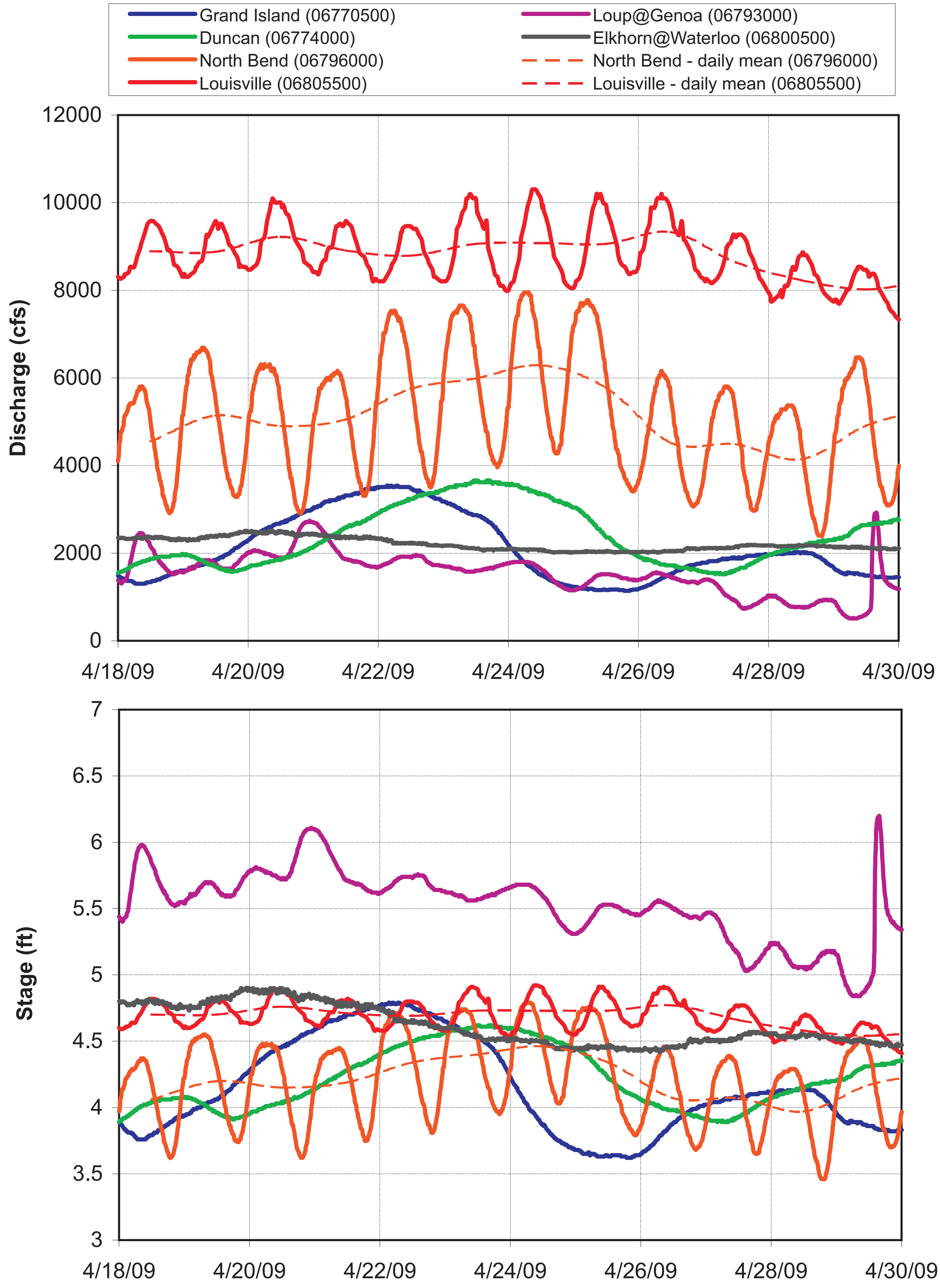
Figure 5 represents the real-time provisional data for six gage locations on the Platte River. These include Grand Island, Duncan, North Bend, and Louisville. Also included are the major tributaries of the Loup River and Elkhorn River. The Ashland gage was omitted from the analysis as key data from April 25 through April 27 was not available from USGS. Plotted data are for the time period of April 18 though April 30. For reference, the flows for April at Louisville and North Bend were at or above the median daily flow statistic for those stations, while Duncan and Grand Island were below (approximately half) the median flow for the time in April leading up to the pulse flow event.

The pulse flow is clearly represented at Grand Island for approximately April 18 through April 25. The peak of the EA flow at Duncan is estimated to be approximately 2,000 cfs above base flows. Based on review of the record, the approximate time of travel of the peak from Grand Island to Duncan is estimated at 35.5 hours. Travel times between gages have been estimated by a number of sources, including USFWS (2002b). In that report, travel time for April was estimated to be 1.7 days, or approximately 40 hours.

In reviewing Figure 5, the most obvious influence to the hydrographs at North Bend and Louisville is the intraday flow variation. For perspective, the intraday flow variation at North Bend for the period of interest is approximately 4,000 cfs. To visually smooth out the daily swings, the daily mean flow for the period was plotted for North Bend and Louisville. Using this information, a small peak can be indentified on April 24 at North Bend and on April 26 at Louisville. This peak may be representing the pulse flow as it moves through the system.

Travel time of the peak from Duncan to North Bend is estimated at 18 hours and from North Bend to Louisville is approximately 46.5 hours. The USFWS report estimates travel times of 26 and 31 hours, respectively for those locations. One observation of the total travel time from Grand Island to Louisville is that the estimated time is 100 hours as compared to the USFWS reported time of 97 hours.

Using the graphed mean data, a slight “bump” of the hydrograph at Louisville in the range of 300 to 500 cfs could be estimated. This additional flow is 15 to 25 percent of the estimated peak passing Duncan. Visual interpretation of the pulse flow hydrograph suggests an attenuating effect from Grand Island to Duncan of perhaps 0.5 days. The effect is not clearly seen as the apparent



Discharge and Stage Curves for the Platte River and Tributaries

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date
Dec. 2009

Figure
5

peak of the hydrograph moves downstream and is influenced by inputs from the Loup and Elkhorn systems.

The results of the hydrograph translation are summarized as follows:

- The amount and timing of this pulse flow is difficult to track with a high level of confidence.
- The small runoff event from Salt Creek could have dampened the effect of the pulse flow.
- Draft review of the data for the pulse flow suggests that approximately 13,000 acre-ft of EA pulse flow passed the Grand Island gage from April 18-25. During the time frame of interest, nearly 19k AF passed the Louisville gage every day.
- While a small peak may be represented within the "noise" of stage and discharge changes at the Louisville gage, this peak is likely within the accuracy of the gage readings.

Hydraulics and Geomorphology

A hydraulic and geomorphologic analysis was performed to assess the river hydraulics within the Study Reach with the objective of evaluating the change in depth and velocity with changes in stage. The analysis was carried out using both one-and two-dimensional (1D and 2D) models. For purposes of this Study, the following definitions were used:

- Macro-scale – Features that represent the reach-scale characteristics of the river, including the planform (i.e., sinuosity and alignment), channel width, gradient, reach-averaged hydraulic conditions (i.e., depth and velocity), and general substrate type (i.e., sand-bed for the lower Platte River). The planform dimensions over which the reach-scale characteristics apply are typically on the order of a one to several channel widths, and their height generally scales with the depth a high discharges.

- Meso-scale – Features that represent the subreach-scale characteristics of the Study Reach, including sandbars, distribution of depths and velocities, variability in substrate, and the individual habitat units. The planform dimensions over which these features apply is typically a fraction of the channel width, and their height typically scales with the flow depth at which they are formed.

- Micro-scale – Local characteristics, including local depths and velocities within individual habitat units, bedforms (i.e., ripples, dunes, antidunes), and local changes in substrate, that are quantified using detailed field measurements and 2D modeling results.

Macro-scale Hydraulic Model

A 1D macro-scale model encompassing the Study Reach was developed to provide reach-scale hydraulic characteristics of the lower Platte River to be used primarily to establish boundary conditions for the 2D meso- and micro-scale model. The U.S. Army Corps of Engineers-Omaha District (USACE-OD) performed a hydraulic analysis of the lower Platte River to update the current flood insurance study (USACE-OD, 2002) using the 1D HEC-2 model. Cross section data from the mid-1970s through 2001 were used for the Study, with the more recent data (1997 through 2001) in the portion of the reach upstream of Interstate 80.

A review of the USGS Platte River gages at Ashland and Louisville shows a relatively stable aggradation/degradation trend over this period. At Ashland, there has been a slight increase in stages of approximately 0.5 foot over the last 20 years at lower flows (approximately 3,000 cfs), suggesting a slight aggradation trend. The gage data shows essentially no change for flows of approximately 10,000 cfs over the same period, indicating that the aggradation is not affecting stages at higher flows. The Louisville gage has shown a mild degradational trend of approximately 1 foot for flows in the range of 3,000 cfs over the past 20 years. The degradational trend is slightly less, 0.5 foot, for flows in the range of 10,000 cfs for the same time period. Based on this information, the use of the USACE-OD model is reasonable as a data source for the macro-scale analysis.

1D Model Setup

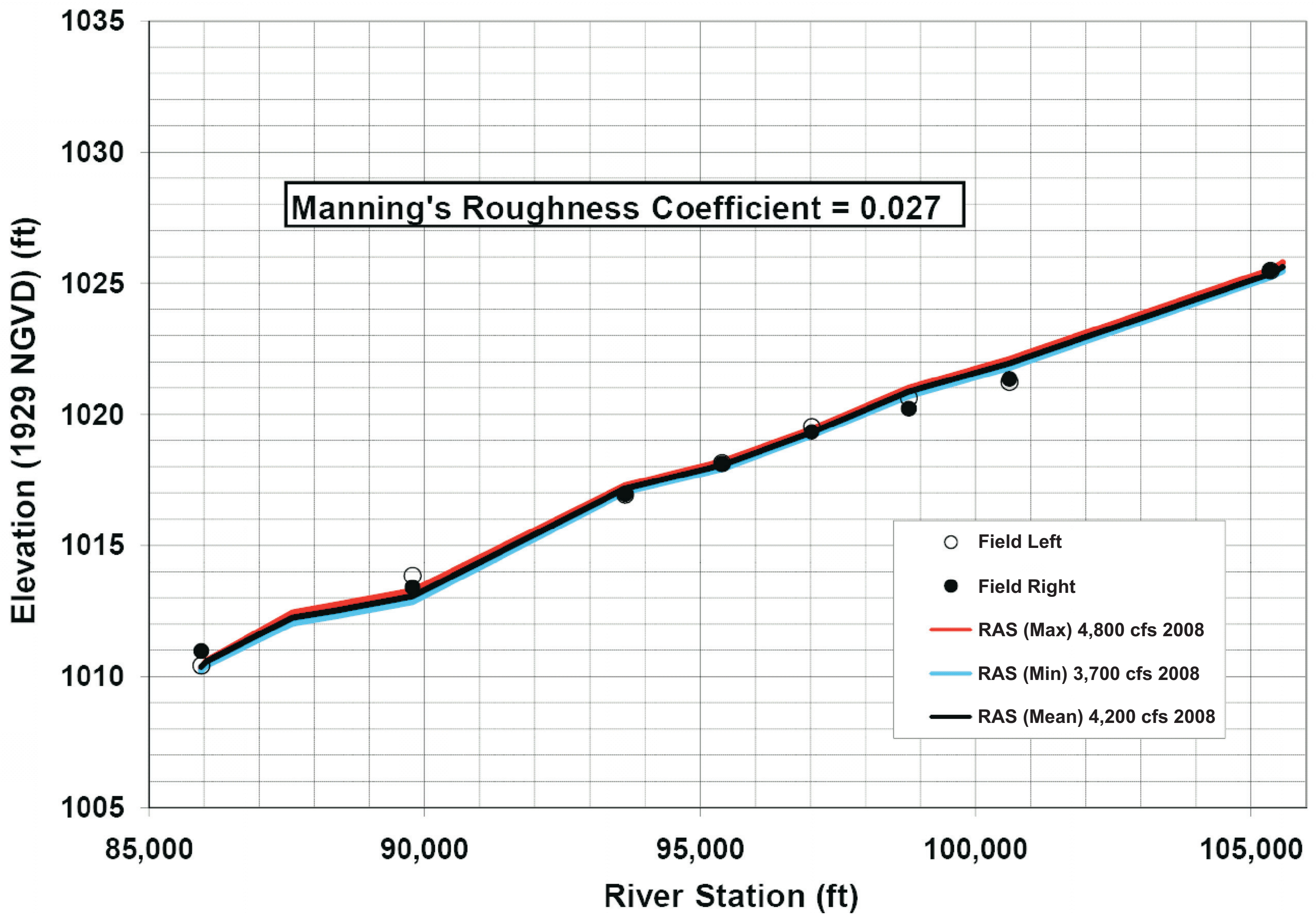
The HEC-2 model was converted to the more current HEC-RAS format (USACE, 2008). HEC-RAS is designed to perform 1D hydraulic calculations for steady and unsteady, gradually varied flow and is the appropriate tool to develop boundary conditions for the meso-scale analysis. For purposes of this Study, the model was only executed in steady mode. The 10-year model run was executed in HEC-RAS and compared to HEC-2 output to confirm proper translation of the model data. The maximum difference occurred at the Nebraska Highway 50 Bridge (-0.56 foot), which is attributed to the difference in bridge algorithms between HEC-2 and HEC-RAS. For all other sections, the maximum difference between the two models was less than ± 0.05 foot between the two models. Therefore, the model was adopted as the data source for the macro-scale analysis and will be referred to as the USACE-OD HEC-RAS model.

1D Model Validation

Topographic and water surface information obtained during the data collection effort were used for model validation purposes. Cross sections in the USACE-OD HEC-RAS model within the Study Reach were replaced with the surveyed cross section information. The surveyed cross section locations are shown in Figure 1. Water surface elevations were obtained at the left and right banks of each respective cross section. Two hydraulic models were developed, one incorporating cross sections from September 2008 and one incorporating cross sections from May 2009. The same Manning's "n" values, contraction and expansion coefficients, and channel stations were used in both version of the model. For the range of flow selected for the Study, all flows are contained within the channel.

Historic Low and High Flow

The September 2008 and May 2009 models were compared to the respective field data. Three water-surface profiles were computed for each model: the average maximum, minimum, and mean discharges at the Louisville gage during the respective data collection period, as shown in Table 7. The resulting predicted water surface profiles were below the measured water surface elevations. The Manning's roughness coefficient in the USACE-OD HEC-RAS model was 0.017 for the channel, which was calibrated for Platte River flows between 160,000 cfs (10-year) and 405,000 cfs (500-year). As described in more detail below under Bedform Analysis, it has been well-documented that the effective Manning's roughness coefficient varies with depth of flow (Chow, 1959). Due to the braided nature of the lower Platte River, it is reasonable to increase the Manning's roughness coefficient upward with decreasing depth of flow. After several iterations, a channel Manning's "n" value of 0.027 provided the best visual fit to the observed data for the September 2008 and May 2009 models for the range of modeled water surface profiles (maximum, minimum, and mean) (Figures 6 and 7). An exact fit to data taken at the banks using a 1D model for relatively low flows is unlikely based on the braided nature and daily flow variability of the lower Platte River and the inherent water-surface elevation difference within a given cross section. Based on these results, a reasonable channel Manning's "n" value for the range of flows sampled is 0.027.



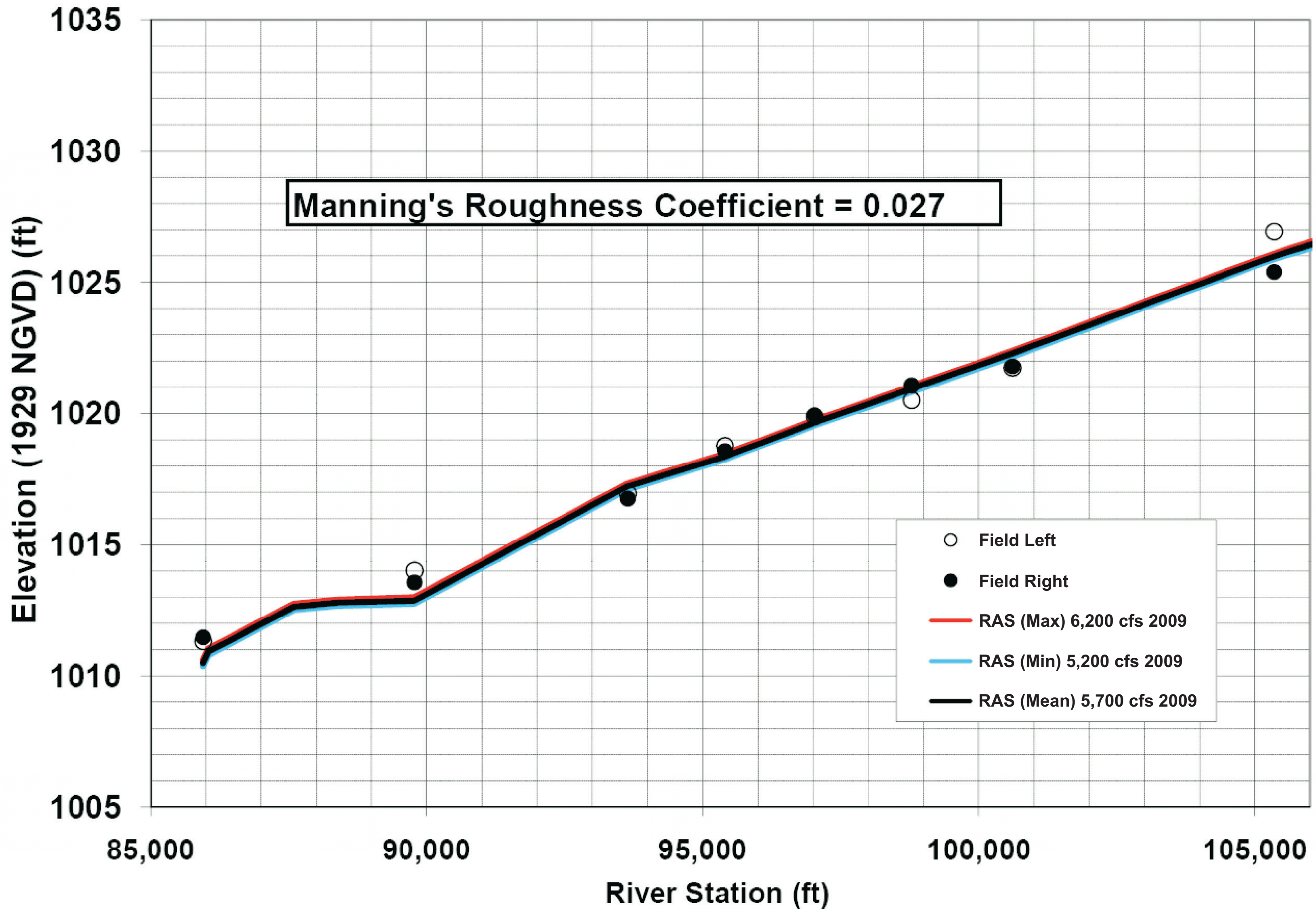
HDR
THE FLATWATER GROUP INC.
TETRA TECH
MEI

1D Model Validation September 2008

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date: Dec. 2009

Figure: 6



HDR
THE FLATWATER GROUP INC.
TETRA TECH
MEI

1D Model Validation May 2009

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date	Dec. 2009
Figure	7

Table 7. Average Maximum, Minimum, and Mean Discharge, September 2008 and May 2009

Data Collection Effort	Average Maximum Discharge (cfs)	Average Minimum Discharge (cfs)	Average Mean Discharge (cfs)
September 2008	4,790	3,670	4,200
May 2009	6,200	5,200	5,720

June 2008 Flood Event

The September 2008 and May 2009 models were then executed for the maximum, minimum, and mean discharges at the Louisville gage on June 16, 2008, as shown in Table 8, and compared to measured water surfaces. The model consistently predicted water surface elevations above the measured values using the channel Manning's "n" value of 0.027. After several iterations, a channel Manning's "n" value of 0.025 provided the best visual fit to the observed data (Figure 8). The September 2008 model predicted slightly higher water surface elevations than the May 2009 model. This is discussed below under Cross Section Comparison.

Table 8. Maximum, Minimum, and Mean Discharge, June 13 and June 16, 2008, at Louisville Gage

Data Collection Effort	Maximum Discharge (cfs)	Minimum Discharge (cfs)	Mean Discharge (cfs)
June 13, 2008	45,300	31,600	37,400
June 16, 2008	27,200	21,600	24,700

Finally, the September 2008 and May 2009 models were executed for the maximum, minimum, and mean discharges on June 13, 2008, as shown in Table 8, and compared to water surface profiles measured in the field. After several iterations, a channel Manning's "n" value of 0.021 provided the best visual fit to the observed data (Figure 9). Again, the September 2008 model predicted slightly higher water surface elevations than the May 2009 model. This is discussed below under Cross Section Comparison.

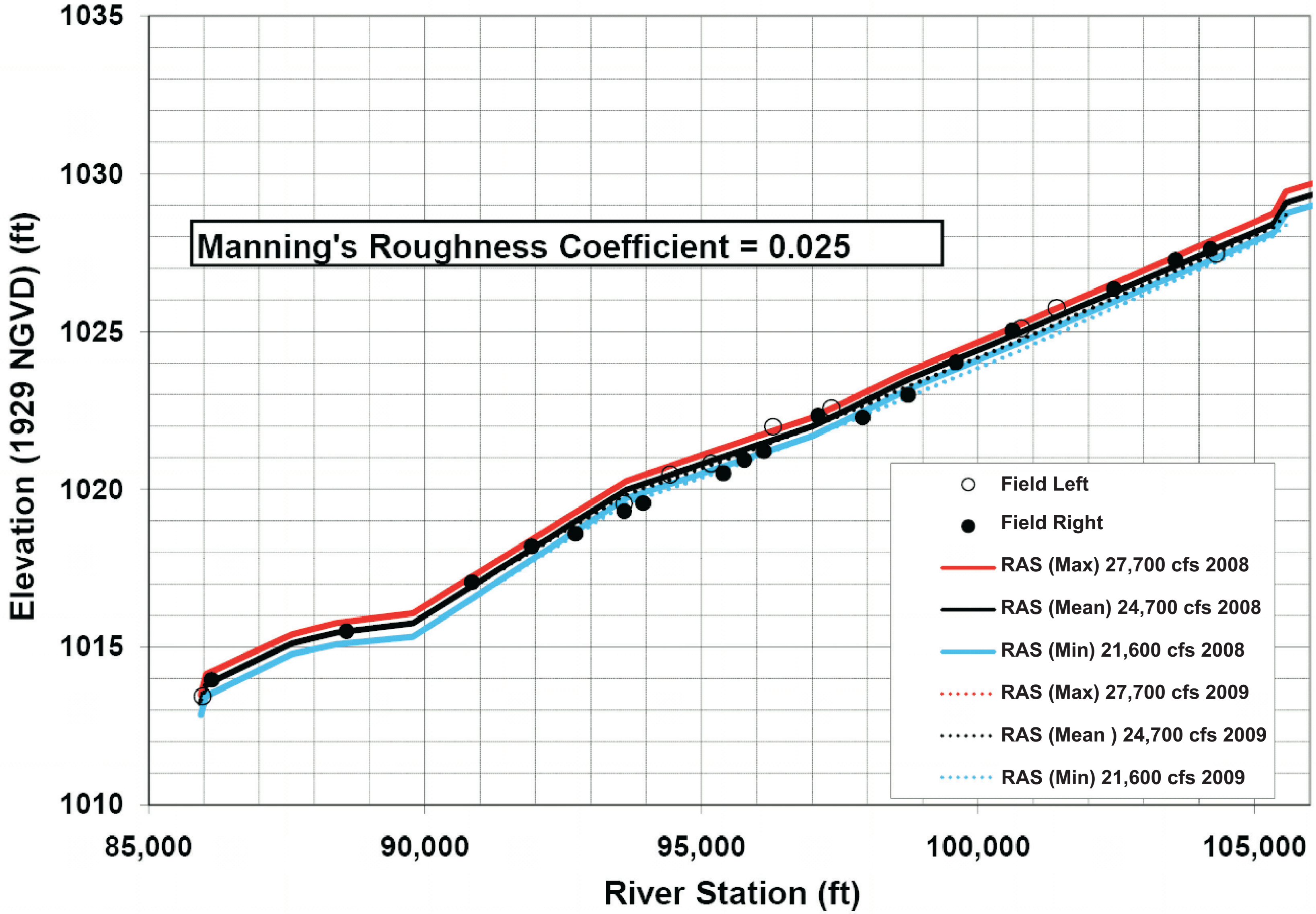
Based on the 1D model validation, the channel Manning's "n" values are reasonable values for the target flows listed in Table 9.

Table 9. Manning's Roughness Coefficient for 2008 and 2009 Discharge Events

Date	Mean Flow at Louisville Gage (cfs)	Manning's Roughness Coefficient in Channel
June 13, 2008	37,400	0.021
June 16, 2008	24,700	0.025
September 22-29, 2008	4,200	0.027
May 20-21, 2009	5,700	0.027

Cross Section Comparison

Cross sections were compared between the data collection efforts listed above, as well as topographic information obtained in October 2009 (Figures 10 through 17). These comparisons indicate that the low-flow channel or channels tended to deepen during the high spring flow events and tended to become shallower in response to periods of low flow. This is most pronounced in Figures 10, 11, 12, 14, and 16. At each of these cross sections, there appears to be a deeper, wider low-flow channel, and higher mid-channel features, suggesting flow



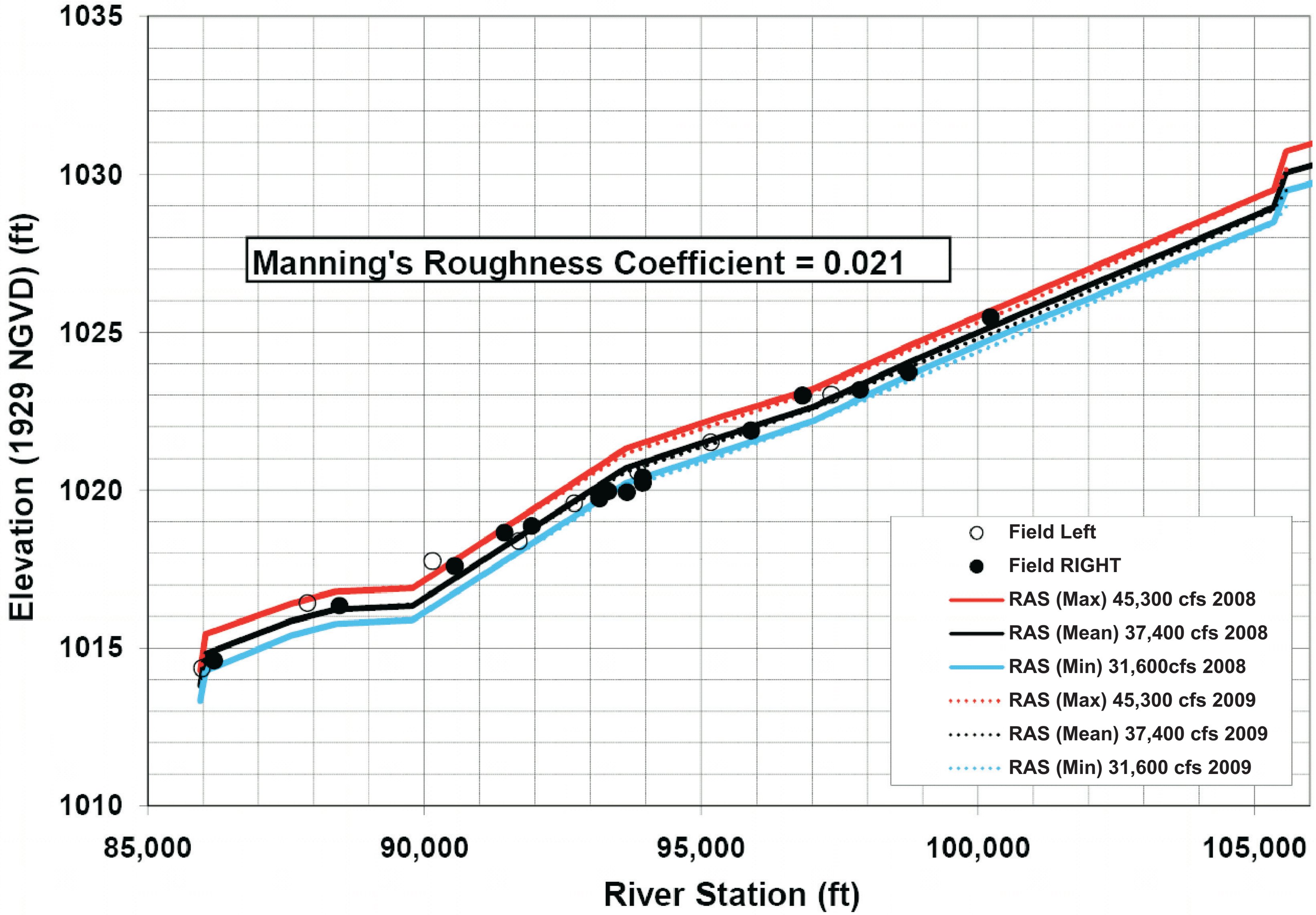
HDR | THE FLATWATER GROUP INC. | TETRA TECH | MEI

1D Model Validation June 16, 2008

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date: Dec. 2009

Figure 8



HDR
THE FLATWATER GROUP INC.
TETRA TECH
MEI

1D Model Validation June 13, 2008

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date
Dec. 2009

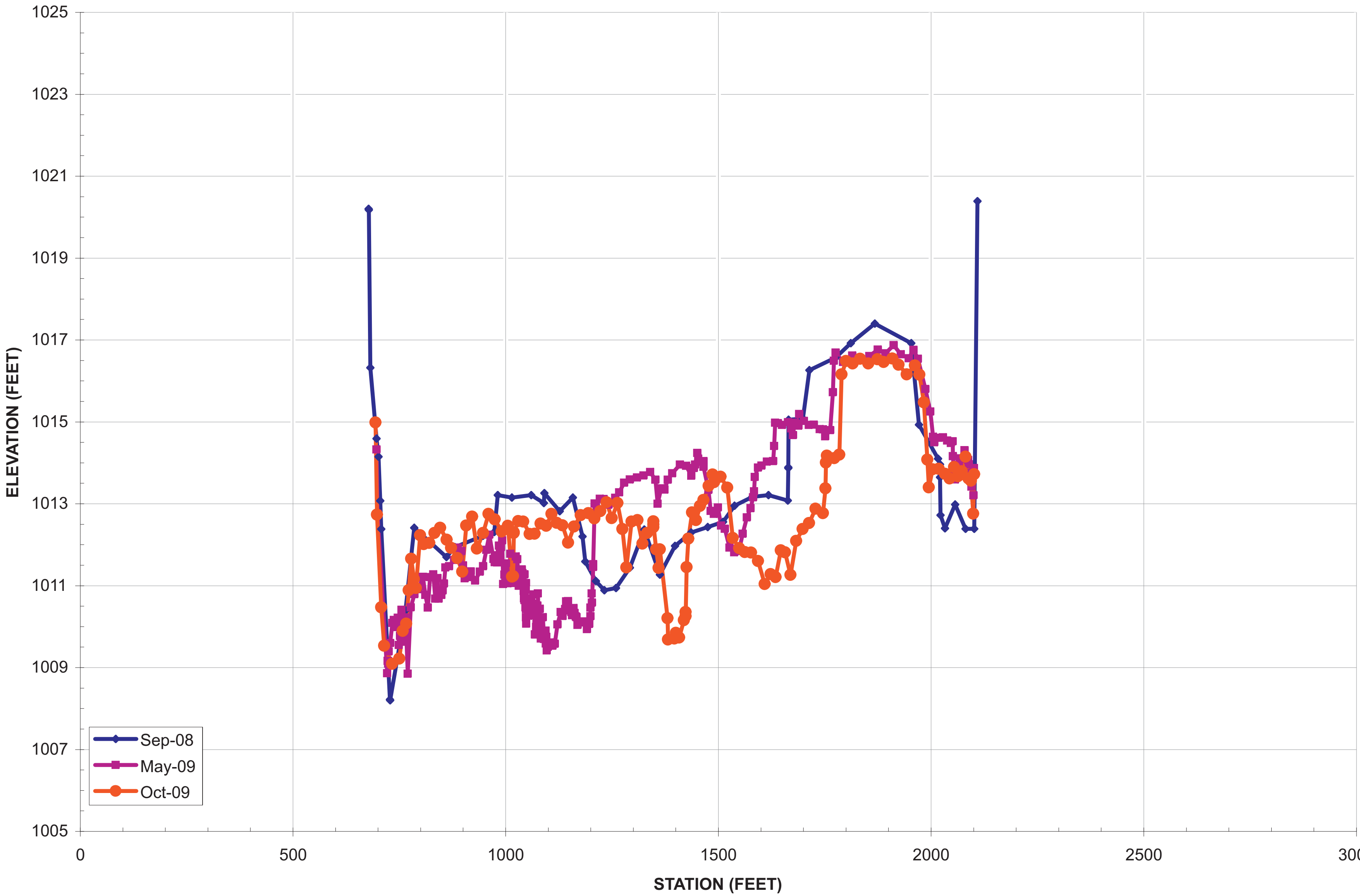
Figure
9

Cross Section 0

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date
Dec. 2009

Figure
10



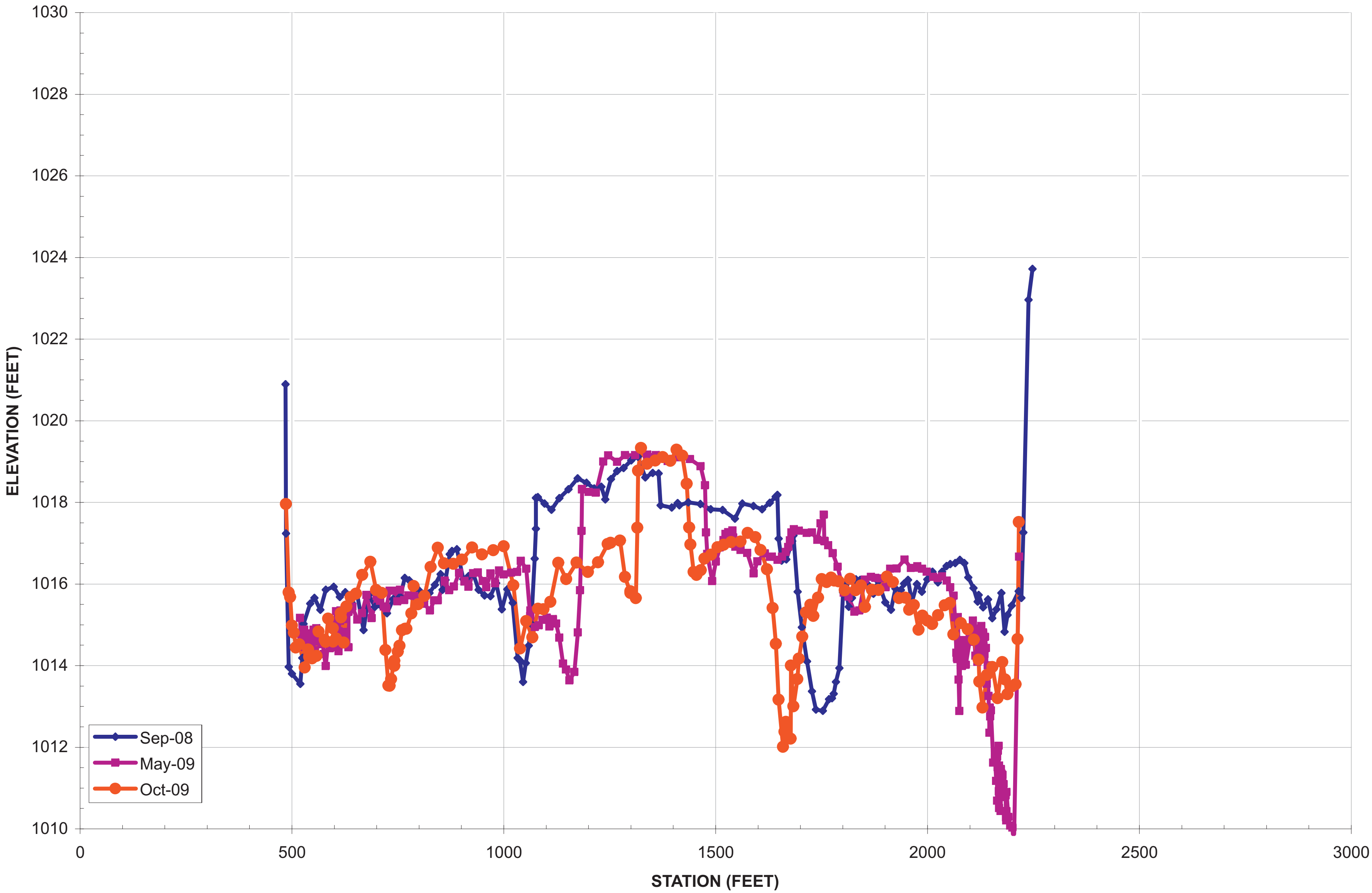
HDR
THE FLATWATER GROUP INC.
TETRA TECH
MEI

Cross Section 1

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date
Dec. 2009

Figure
11



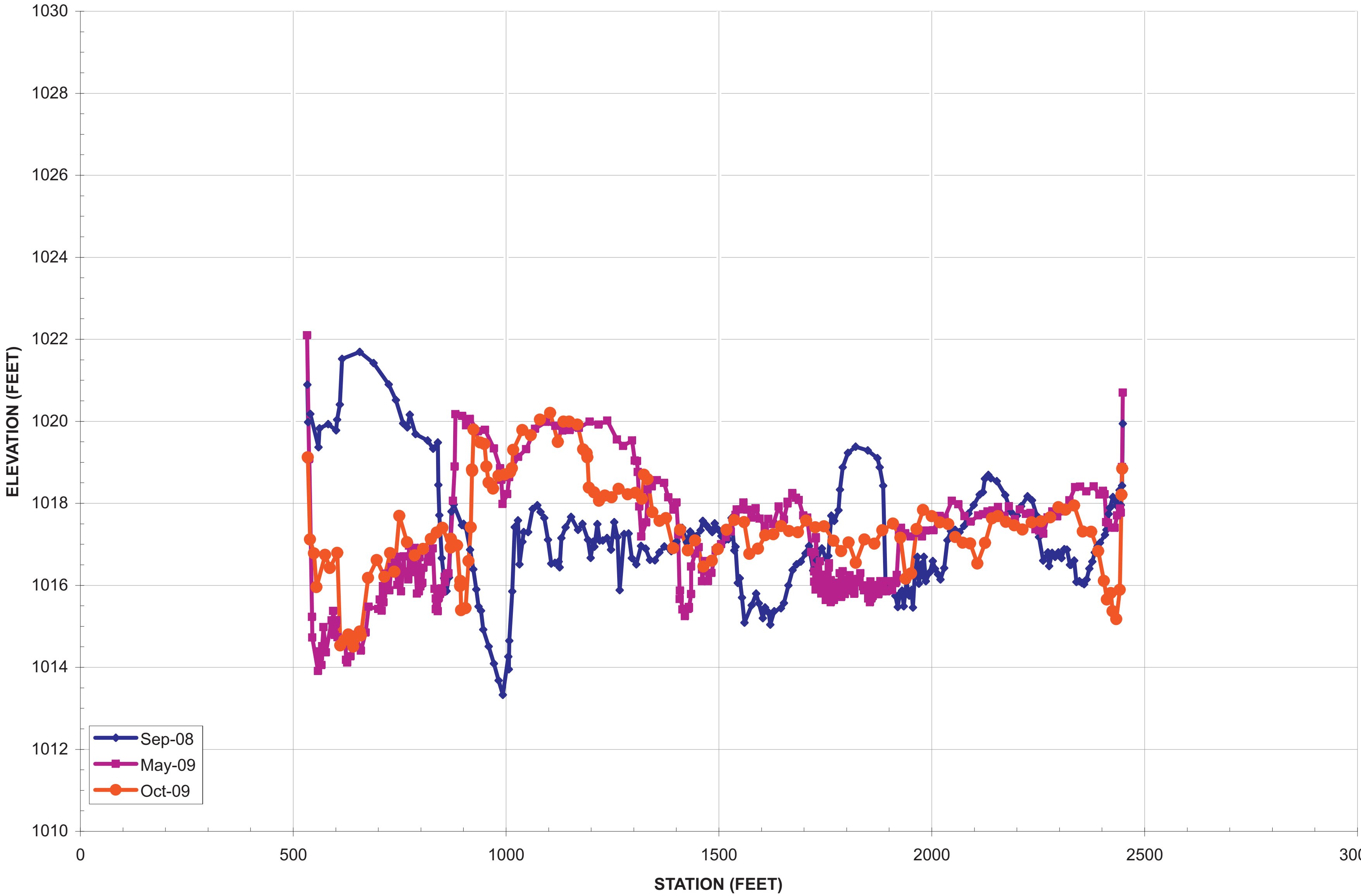
HDR
THE FLATWATER GROUP INC.
TETRA TECH
MEI

Cross Section 2

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date
Dec. 2009

Figure
12



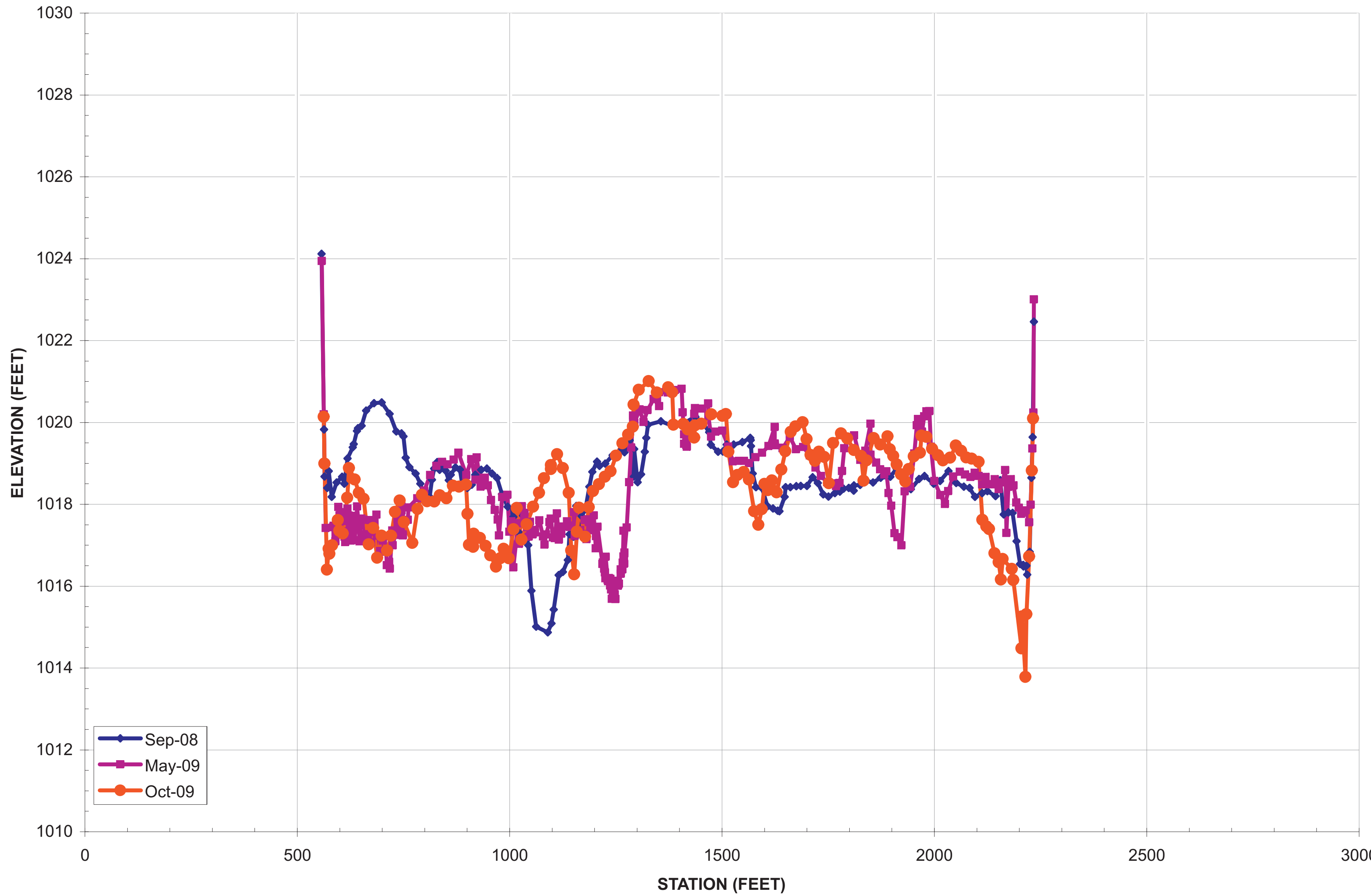
HDR
THE FLATWATER GROUP INC.
TETRA TECH
MEI

Cross Section 3

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date
Dec. 2009

Figure
13



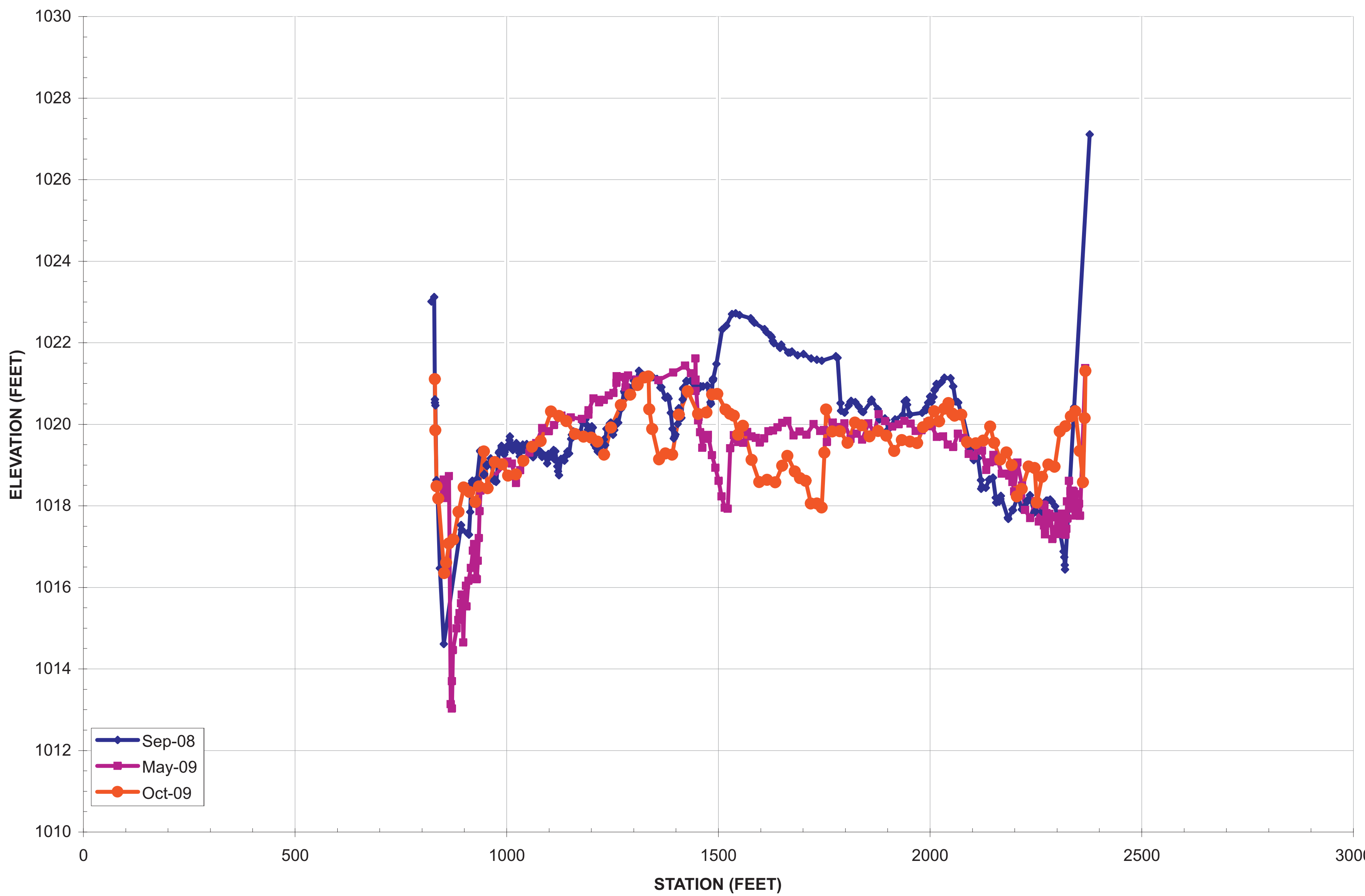
HDR
THE FLATWATER GROUP INC.
TETRA TECH
MEI

Cross Section 4

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date
Dec. 2009

Figure
14

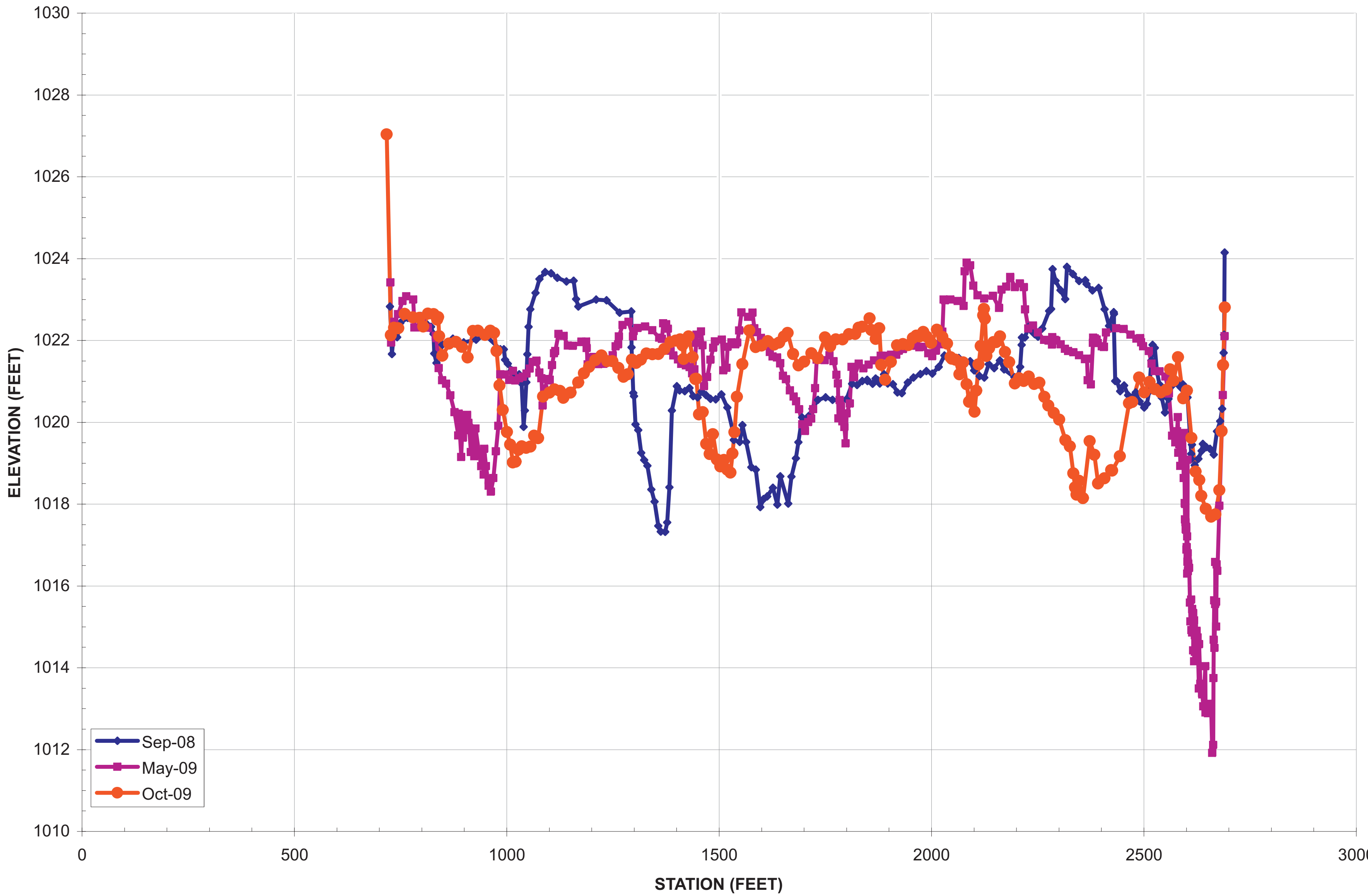


Cross Section 5

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date
Dec. 2009

Figure
15

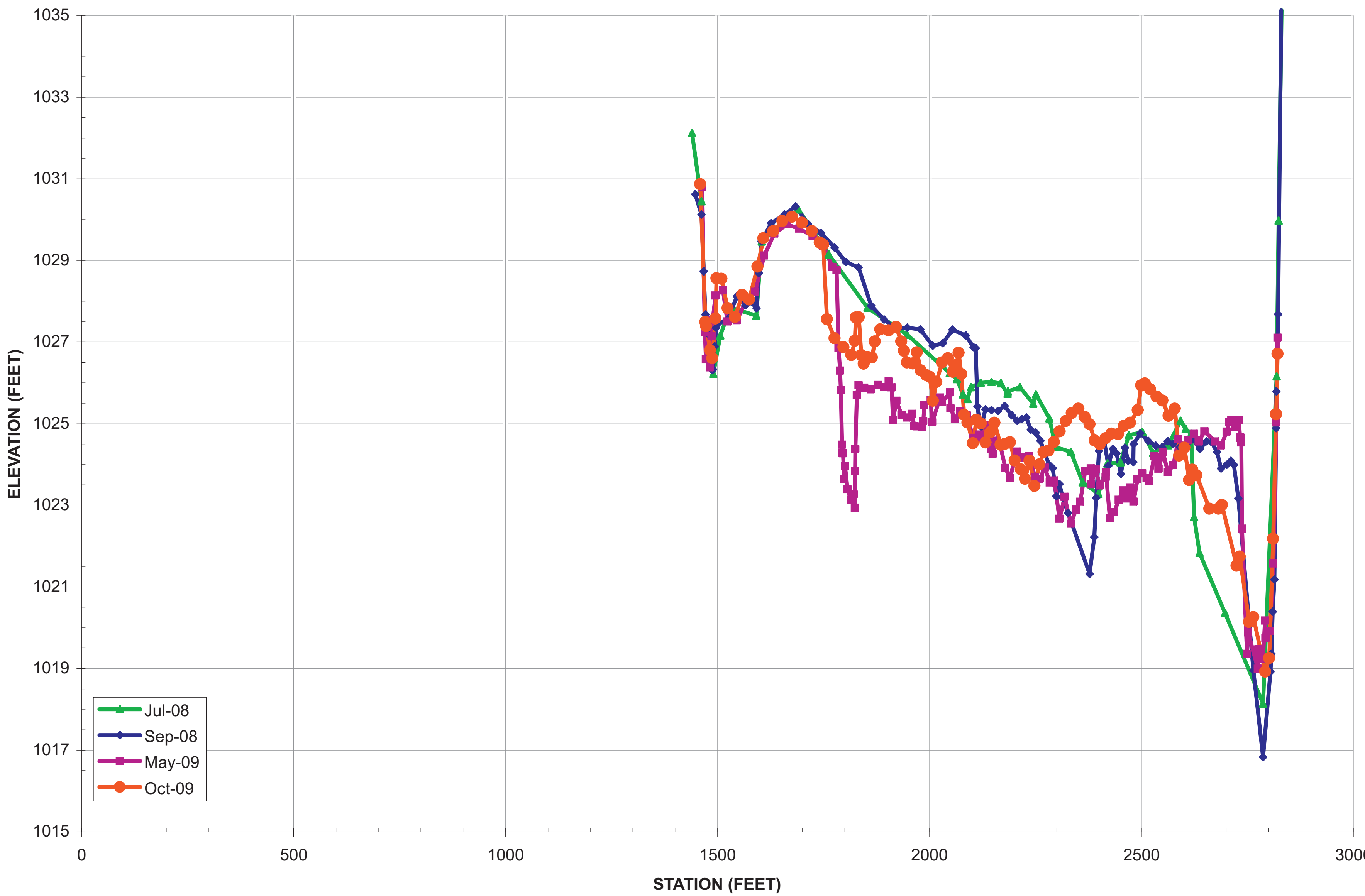


Cross Section 6

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date
Dec. 2009

Figure
16



Cross Section 7

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date
Dec. 2009

Figure
17

concentration for the post high-flow surveys (July 2008 and May 2009). However, for the post low-flow surveys (September 2008 and October 2009) at those sections, there appears to be a shallower low-flow channel or channels, and lower mid-channel features suggesting greater flow distribution across the section. This is reflected in the validation modeling in that the September 2008 model predicted slightly higher water (within 0.2 foot) surface elevations than the May 2009 model.

Meso-scale Hydraulic Model

2D Hydraulic Model

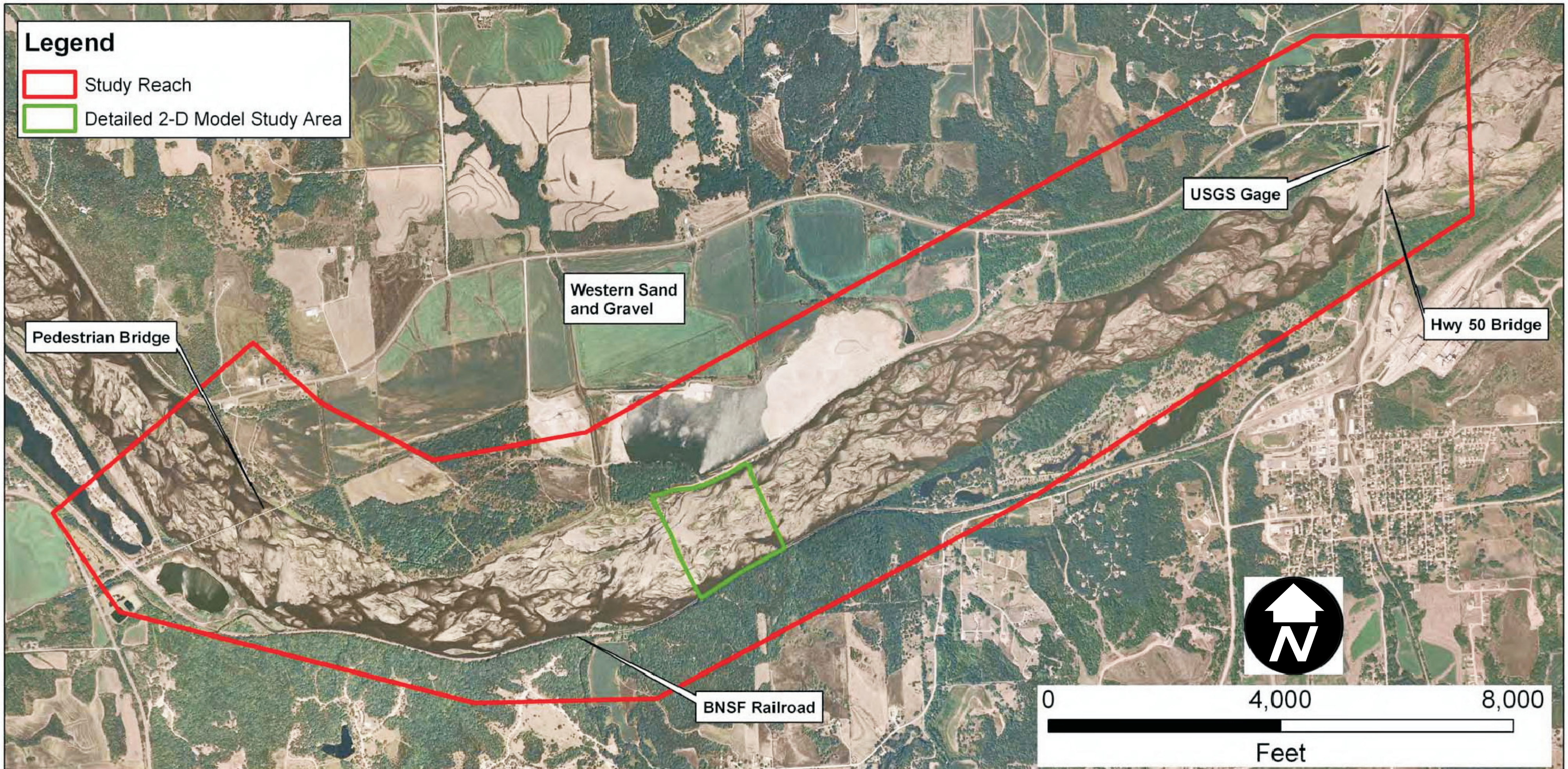
A 2D hydraulic model was developed within the Study Reach to facilitate a meso-scale evaluation of the hydraulic effects associated with variations in stage and discharge (Figure 18). Results from the model runs were used to determine how depth and velocity changes throughout the site over a range of discharges.

2D Model Development

The 2D modeling was carried out using the Bureau of Reclamation's SRH-2D version 2 model (Bureau of Reclamation, 2008) with Aquaveo's Surface Water Modeling System (SMS) Version 10.0 graphical user interface. SRH-2D is a depth-averaged, finite-volume, hydrodynamic model that computes water-surface elevations and horizontal velocity components for sub- and supercritical free-surface flows in 2D flow fields. SRH-2D was selected for this Study because it is a well-tested 2D model that provides a more accurate prediction of the complex flow patterns and hydraulic parameters along the Study Reach than can be obtained from the more simplified 1D models. The model uses a mesh composed of triangular and quadrilateral elements with corner nodes that represent the geometry of the modeled reach, with the channel topography represented by bed elevations assigned to each node in the mesh.

The SRH-2D mesh was established to represent the planform geometry and topography of the Study Reach that was developed from the field work. The modeled reach is approximately 1,700 feet long, and the grid resolution of the model is approximately 10 feet (Figure 19). A high mesh density was selected to represent the complex topography of the river as accurately as possible, resulting in a mesh that contains 29,793 elements.

As discussed in the data collection section, detailed topographic and bathymetric data of the river were derived from surveys conducted by HDR, The Flatwater Group, and Mussetter Engineering on September 23 through 26, 2008, when the discharge ranged from approximately 3,700 to 4,800 cfs (average discharge of the mean daily flows during this time period is approximately 4,200 cfs). Energy losses in the model are described by Manning's n-values that define the boundary friction losses and by kinetic eddy viscosity values that define internal energy losses associated with turbulent exchange. Because roughness values do not account for all of the computed energy loss in most 2D models, Manning's n-values are typically lower than those used in 1D models of the same reach. Due to the complexity of the topography and variation in existing channel bedforms, Manning's n-values at discharges less than about 8,000 cfs ranged from 0.023 in areas with limited bedforms to 0.027 in areas generally characterized by more significant features such as large dunes (Figure 20). To improve calibration at the highest surveyed discharges of 24,700 and 37,400 cfs, Manning's n roughness values in the model were reduced to a constant value of 0.013. Given that the detailed topography in the 2D model that was collected at a flow of about 4,200 cfs, the lower n-value also helps account for topographic changes that occur at the higher discharges. The n-value of 0.013 was derived from empirical relationships developed by Brownlie (1983) and later rearranged by the USACE Waterways



HDR
THE FLATWATER GROUP INC.
TETRA TECH
MEI

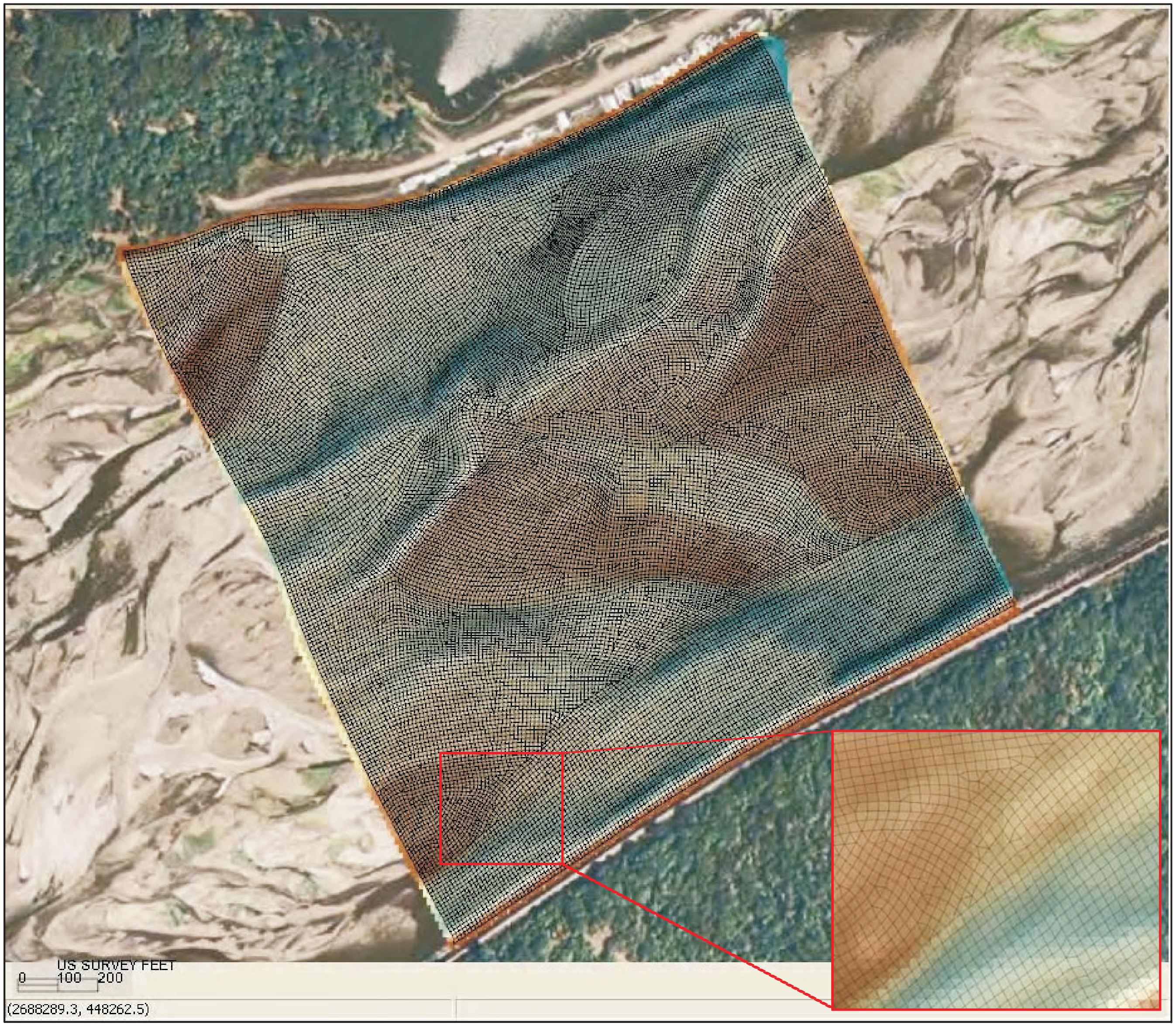
Limits of the SRH-2D Model within the Study Reach

PLATTE RIVER RECOVERY IMPLEMENTATION PROGRAM

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date
Dec. 2009

Figure
18

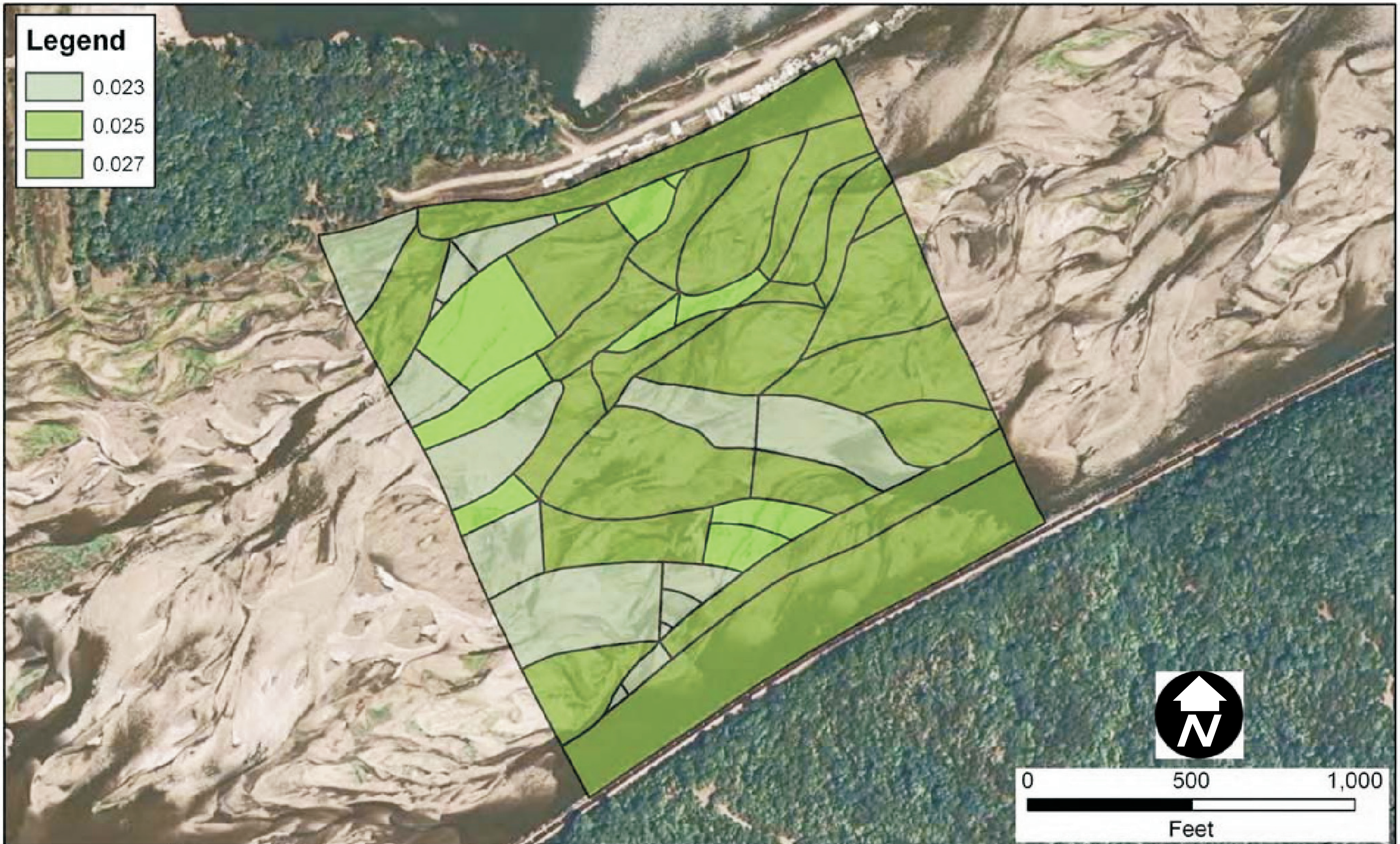


SRH-2D Model Grid in the Detailed Study Reach on the Platte River

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date
Dec. 2009

Figure
19



HDR
THE FLATWATER GROUP INC.
TETRA TECH
MEI

Manning's n Roughness Values used in SRH-2D Model

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date
Dec. 2009

Figure
20

Experiment Station (WES) (USACE, 1991) that relate hydraulic conditions and bed material characteristics to Manning's n-values. Model n-values at flows between approximately 8,000 and 24,700 cfs were interpolated from the bounding values. In addition to the roughness values, the k-ε turbulence model was applied to compute energy losses due to turbulence (Bureau of Reclamation, 2008).

The downstream boundary condition for the 2D model consists of a specified water-surface elevation for the particular discharge that is being modeled. A rating curve for the downstream end of the model was developed from the calibrated 1D HEC-RAS model described in the previous section at model station 98,387 (Figure 21). The upstream boundary condition consists of the total discharge entering the model. Exposed sandbars occur along the upstream model boundary that divide the flow at low to intermediate discharges As a result, it was necessary to divide the total discharge among three separate flow paths. The percentage of flow assigned to each flow path was determined based on the conveyance-weighted discharge in each flow path at an interpolated section in the September 2008 model (Figure 22). At discharges greater than approximately 12,000 cfs, a single discharge was applied to the entire upstream boundary of the model.

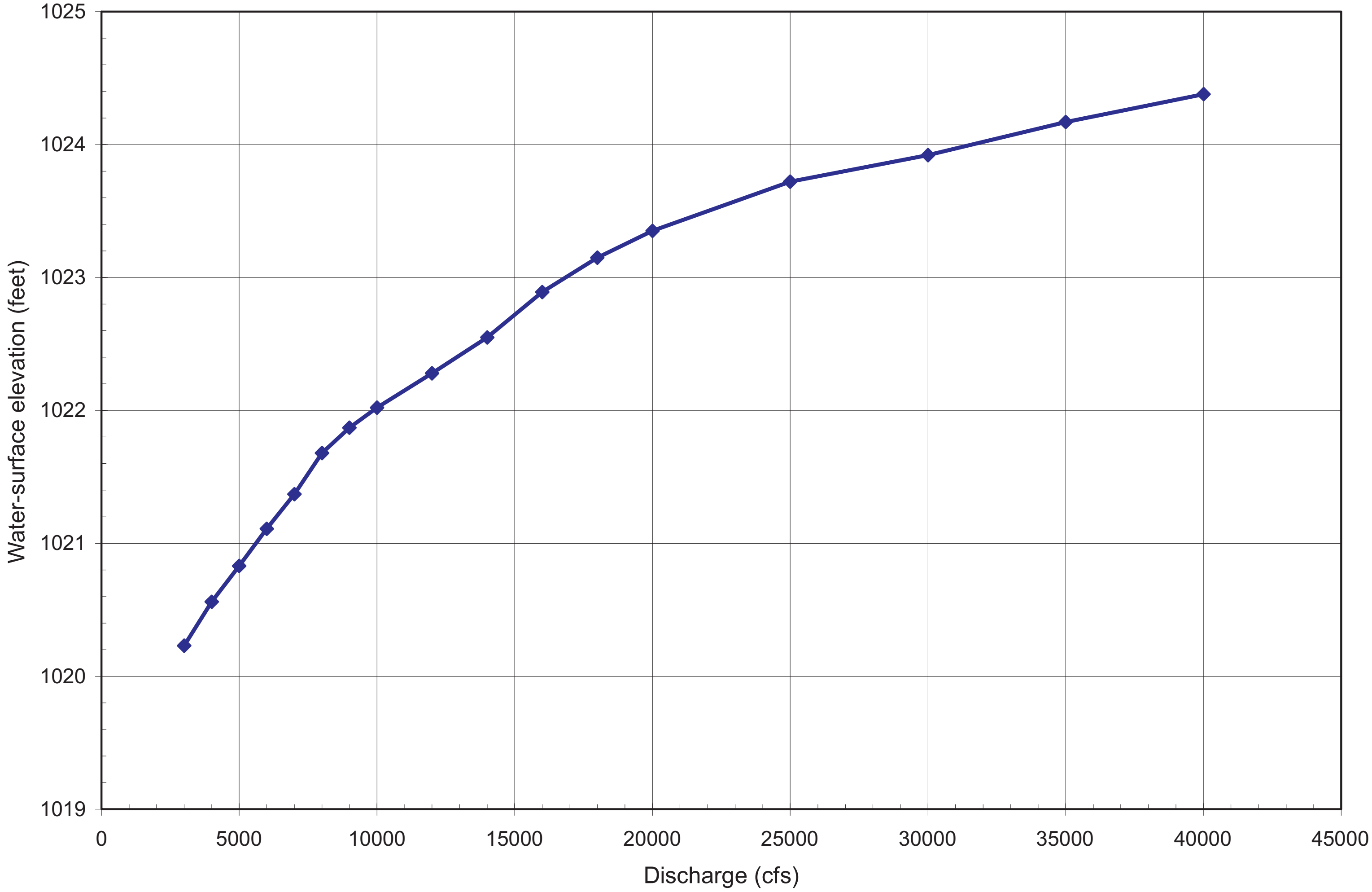
2D Model Calibration

The SRH-2D hydraulic model was calibrated to surveyed water-surface elevations at varying discharges and locations throughout the Study Reach (Figure 23). The model was also validated by comparing modeled and field-measured velocities at specific locations with the mesh. Calibration was achieved by refining Manning's n-values within physically reasonable limits throughout the Study Reach based on the change of roughness due to complex topography and bedforms. To improve calibration, the boundary conditions were refined to more accurately reflect the distribution of flow at the upstream end and the variation in water-surface elevations between the north and south flow paths at the downstream end.

Predicted water-surface elevations for a range of flows from approximately 3,700 to 4,800 cfs are in good agreement with measured values that were collected in conjunction with the topographic data on which the hydraulic model is based (Figure 24). Approximately 98 percent of the computed results are within +/- 0.5 foot of the measured values, and the standard deviation of the residuals is approximately 0.24 foot. Model results at higher discharges also compare well to water-surface elevations that were surveyed during the June 2008 and May 2009 field visits (Figure 25). In addition to evaluating computed water-surface elevations, the model was further validated by comparing the predicted velocities to field measurements collected at the time of the detailed survey (Figure 26).

2D Hydraulic Analysis

Results from the model were used to evaluate the change in hydraulic conditions and bedform characteristics over a range of discharges, and to aid in identifying habitat types based on the local hydraulic characteristics. The range of discharges analyzed corresponds with the average minimum and maximum observed during the data collection effort. In general, the hydraulic results indicate that at lower discharges in the range of 3,700 cfs, channel velocities vary significantly throughout the detailed Study Reach from stagnant flow in backwater areas up to about 5 feet per second (fps) (Appendix C). Channel depths at 3,700 cfs typically range up to 3 feet, but depths of more than 6 feet also occur in localized areas (Appendix D). As expected, flow characteristics within this detailed study reach become more uniform as the discharge increases. At 40,000 cfs, predicted channel velocities range from 2.8 to 9.8 fps, with the majority of the velocities greater than about 4 fps (Appendix C). Predicted depths at this discharge range



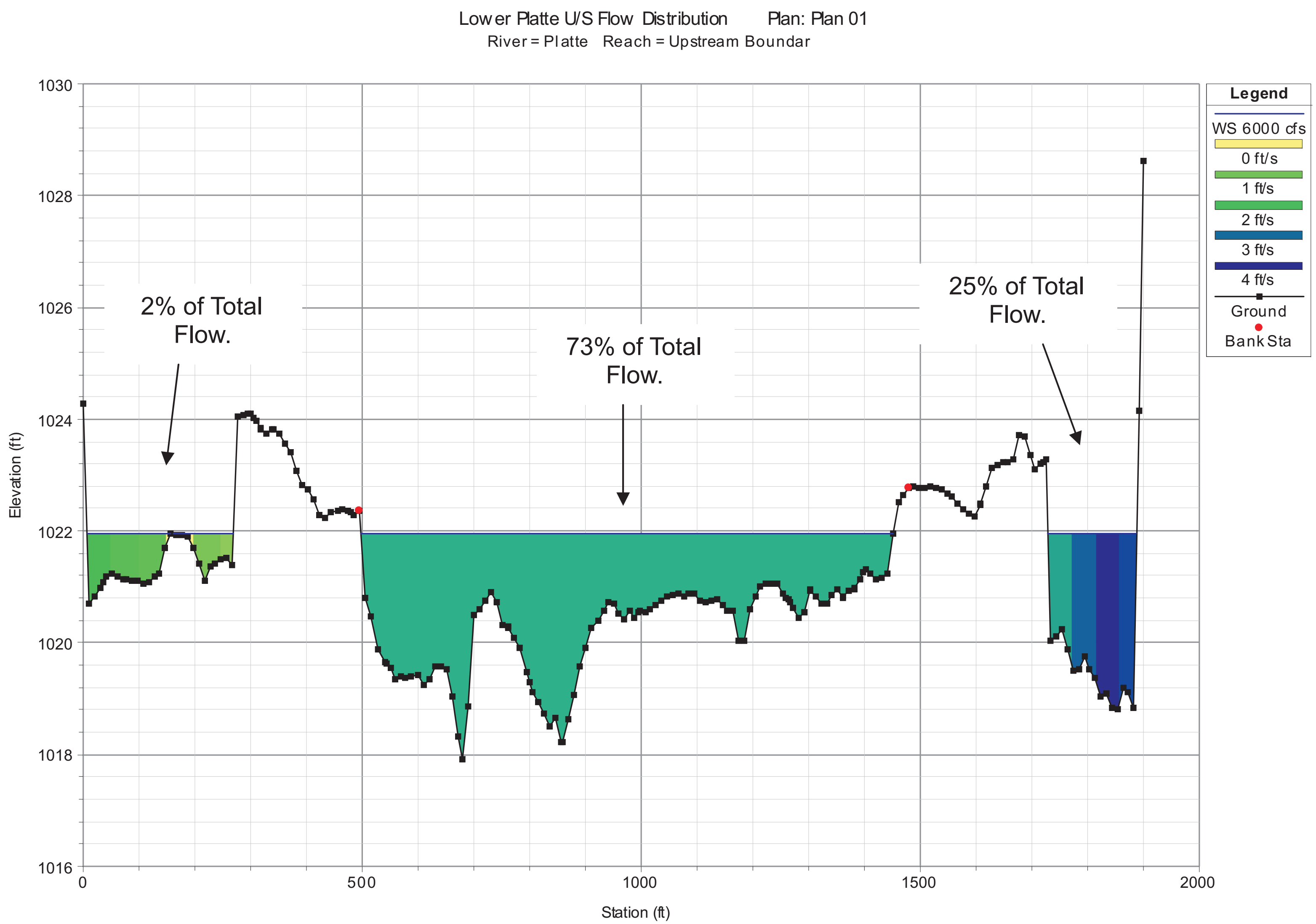
Stage-Discharge Rating Curve used as Downstream Boundary Condition in the 2-D Model

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

HDR
THE FLATWATER GROUP INC.
TETRA TECH
MEI

Date
Dec. 2009

Figure
21



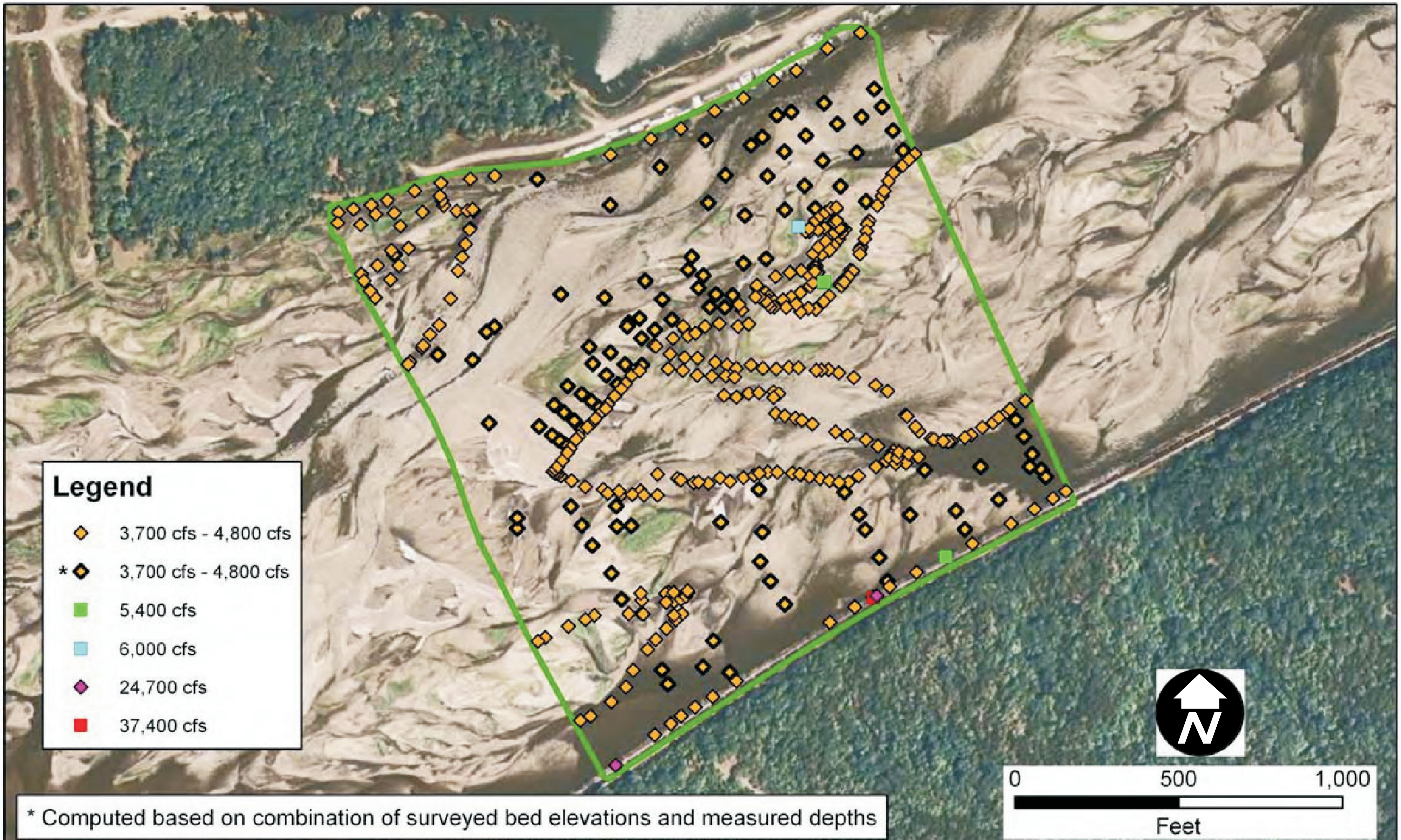
HDR
THE FLATWATER GROUP INC.
TETRA TECH
MEI

Approximate Flow Distribution at the Upstream End of the 2-D Model Study Area

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date
Dec. 2009

Figure
22



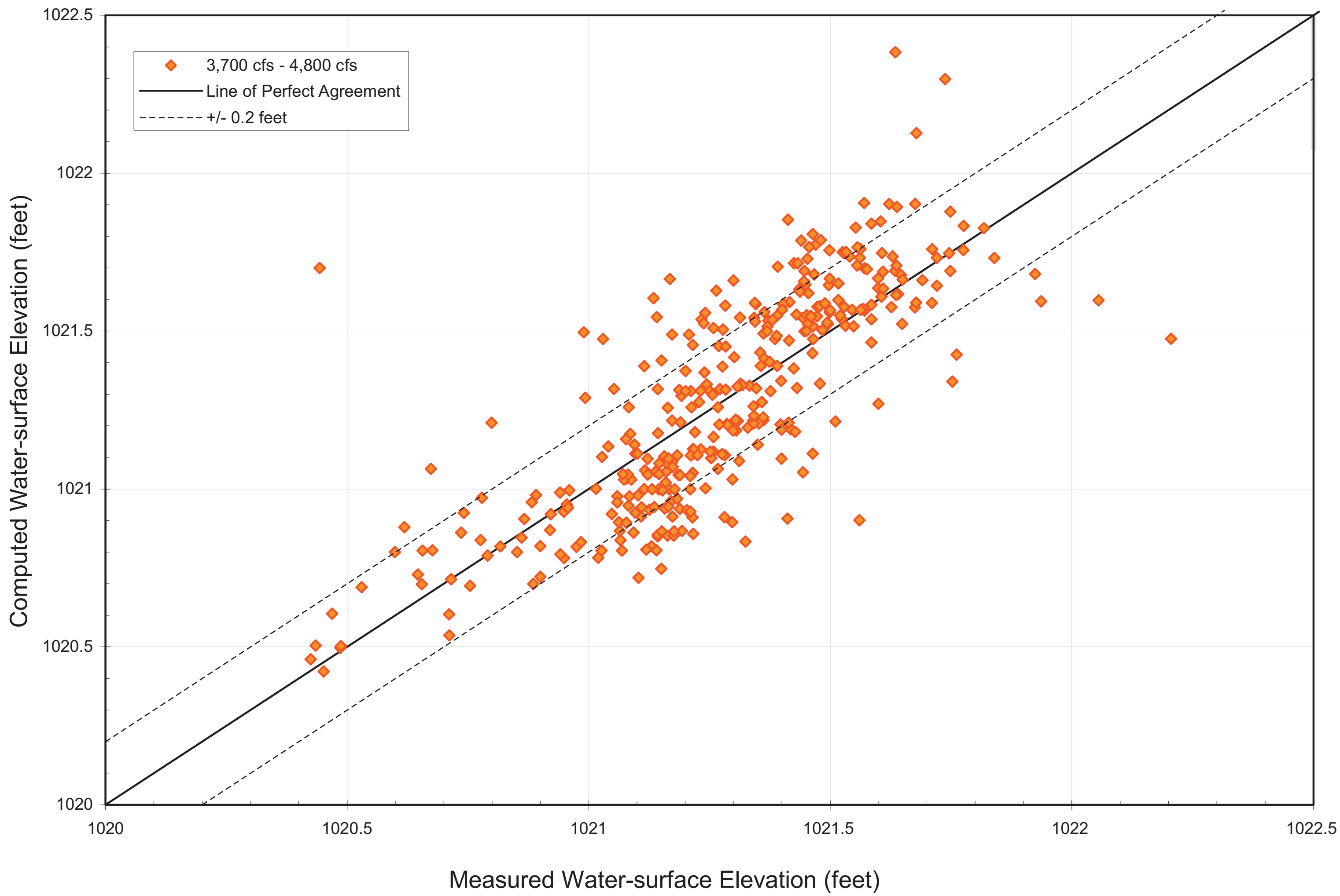
HDR
THE FLATWATER GROUP INC.
TETRA TECH
MEI

Surveyed Water-surface Elevations Used for Model Calibration.

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date: Dec. 2009

Figure: 23



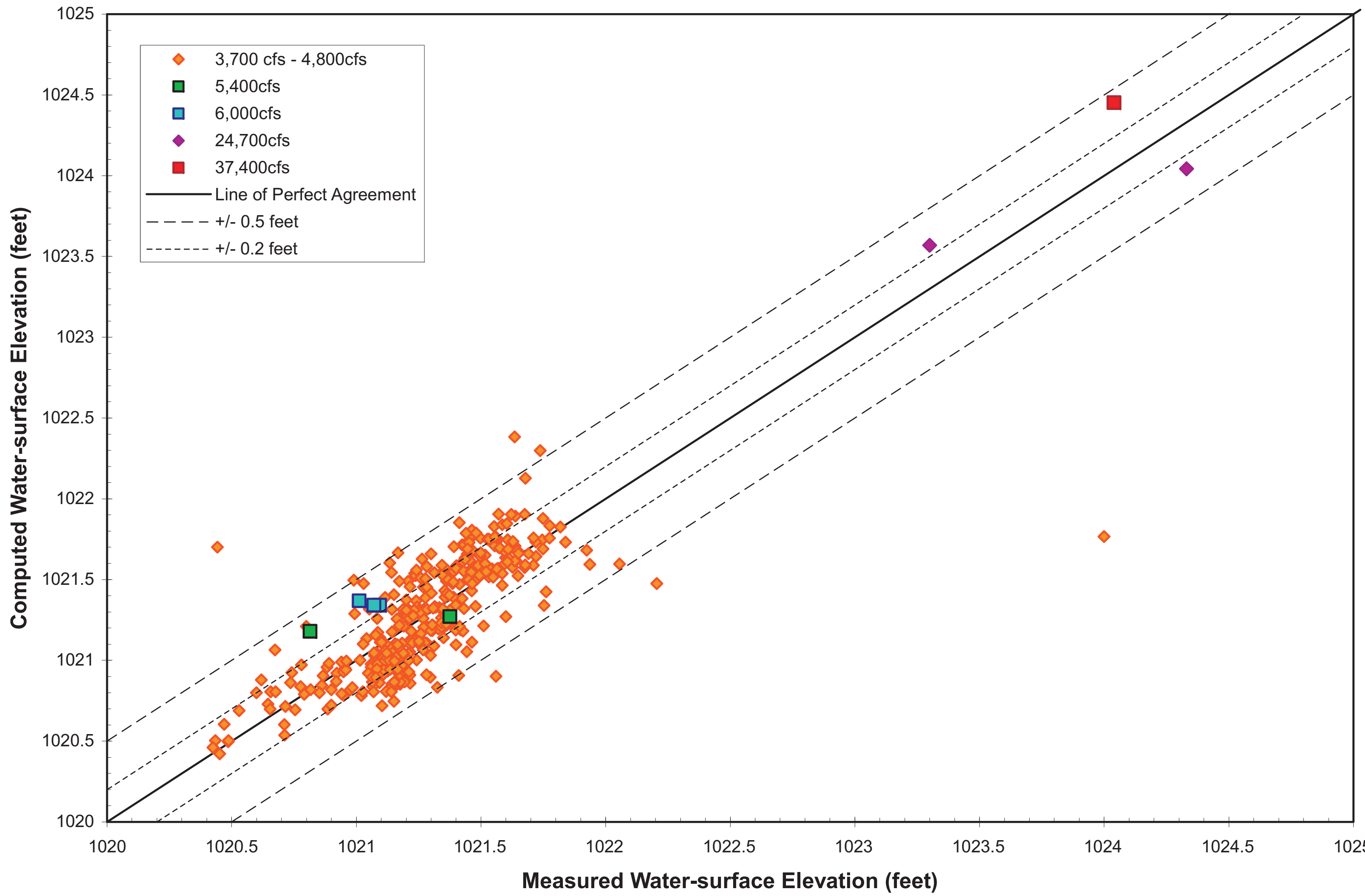
HDR
THE FLATWATER GROUP INC.
TETRA TECH
MEI

SRH-2D Predicted Water-Surface Elevations vs. September 2008 Measured Values

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date
Dec. 2009

Figure
24



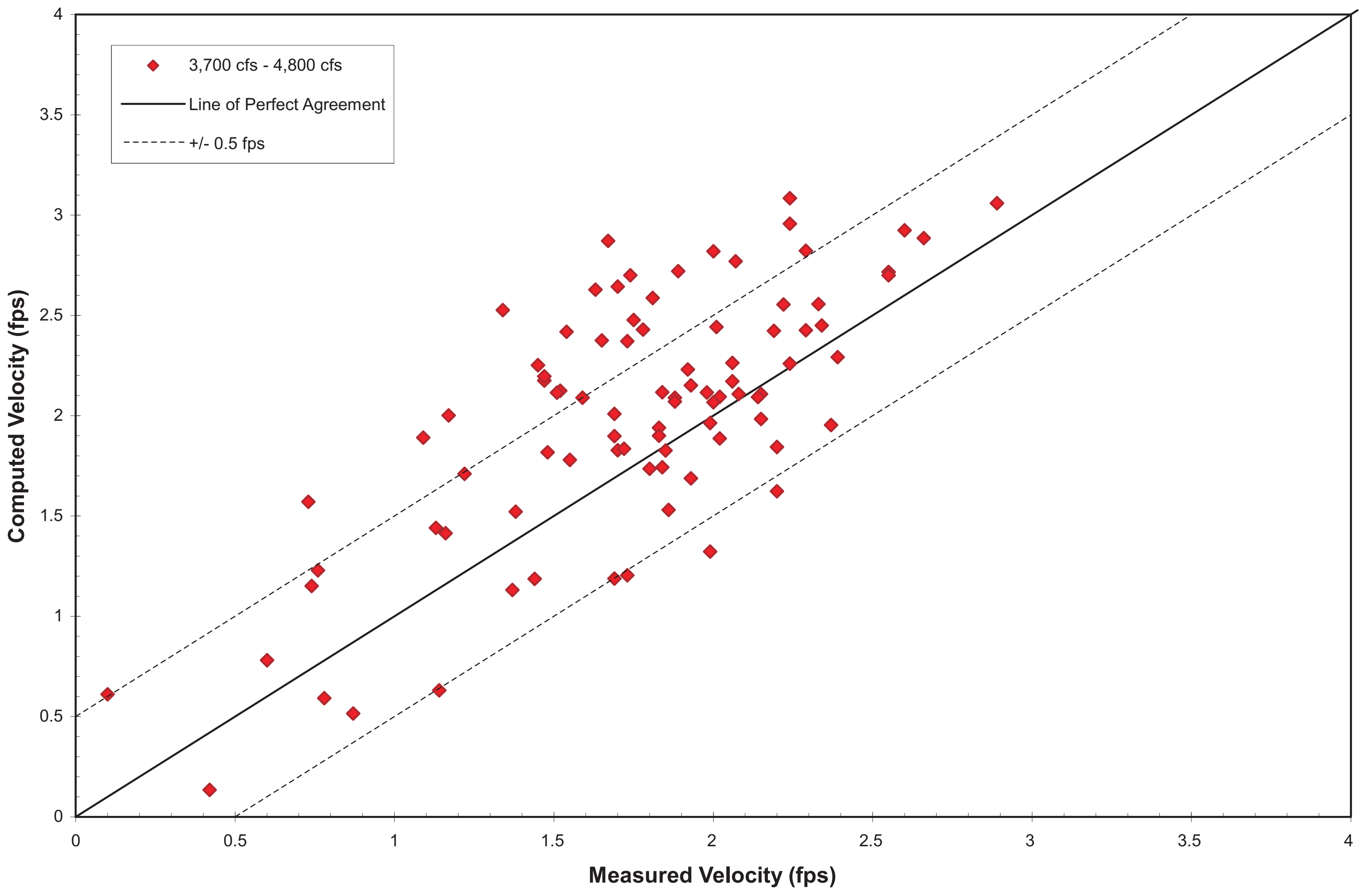
HDR
THE FLATWATER GROUP INC.
TETRA TECH
MEI

SRH-2D Predicted Water-Surface Elevations vs. June 2008, September 2008, and May 2009 Measured Values

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date
Dec. 2009

Figure
25



HDR
THE FLATWATER GROUP INC.
TETRA TECH
MEI

SRH-2D Predicted Velocity vs. September 2008 Measured

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date
Dec. 2009

Figure
26

from about 1 to 11.5 feet, but most are between about 3 and 7 feet (Appendix D). It should also be noted that the topography used in the model represents data collected at a flow of about 4,300 cfs, and because the micro-scale topography of the channel is likely to adjust at higher discharges, resultant depths and velocities could be somewhat different than those predicted by the model.

Bedform Analysis

Overview

Flow over alluvial sediment creates bedforms and bed configurations at a variety of scales that affect the hydraulic and sediment transport characteristics of the flow through their impact on flow resistance, depth and velocity patterns, and the rates at which the sediment is entrained and transported downstream. These bedforms and bed configurations, in turn, affect in stream habitat by creating a mosaic of physical features that are important to the species that are present in the river (Hawkins et al., 1993; Vadas and Orth, 1998; Polivka, 1999; Kehmeier, et al, 2007). Consistent with a hierarchy that was originally introduced by Jackson (1975) and subsequently modified and successfully applied to the sand-bedded Pecos River in New Mexico by Mussetter Engineering, Inc, (2004), three scales of bed configurations are present in the Study Reach. These scales are macro-, meso-, and micro-, as previously defined.

Based on the current knowledge of habitat requirements for the pallid sturgeon (*Scaphirhynchus albus*), diversity in flow depth and velocity associated with meso-scale bedforms (i.e., sand bars) and pockets of deeper and slower flow caused by local scour are the key hydraulic features that determine habitat. In this context, sand bars are defined as bedforms having lengths of the same order as the channel width or greater, and heights comparable to the mean depth of the generating flow (Task Force on Bedforms, 1966). Subaerially exposed mid-channel bars are a necessary feature of braided river patterns, and because of the implicit importance of bars in braided rivers such as the lower Platte River, bar types and the processes of bar development have been the focus of much research. Unfortunately, much of the research has generated confusion regarding processes of bar formation because of the proliferation of bar terminology (Smith, 1978).

In an attempt to classify bedforms into a unified hierarchy, Jackson (1975)[1] introduced the terms macroforms (bars), mesoforms (dunes), and microforms (ripples). He concluded that unlike mesoforms and microforms, macroforms are not directly related to the fluid flow regimes. Crowley (1983) and Blodgett and Stanley (1980) concurred with Jackson's differentiation of the bedforms and clearly characterized linguoid or lobate bars as macroforms. However, actively migrating linguoid bars frequently have actively migrating microforms (ripples) on their stoss sides, and dunes are often present in the channels along the margins of the linguoid bars (Crowley, 1983; Germanoski, 1989).

Smith (1974) and Church and Jones (1982) classified bars into four main types: (1) longitudinal, (2) transverse, (3) point, and (4) diagonal. Longitudinal bars are diamond-shaped, elongate parallel-to-flow features that develop by grain-by-grain accretion of the coarser fraction of the sediment load (Leopold and Wolman, 1957). Transverse bars have a crest that is essentially perpendicular to flow direction, most commonly lobate in shape, and flow diverges radially over them. The lobate bars have also been referred to as linguoid bars (Allen, 1968; Collinson, 1970; Blodgett and Stanley, 1980). Point bars form on the insides of bends and are most often

---

[1] Note that, although Jackson (1975) defined dunes as a meso-scale form, all the forms associated with the progression from ripples to dunes to upper regime flow are defined as micro-forms for purposes of this study.

associated with meandering rivers, but they are also common in braided rivers (Miall, 1977). Diagonal bars have their crests oriented at high angles to flow and commonly form riffles in gravel-bed rivers (Church, 1972; Church and Jones, 1982).

Germanoski (1989) has suggested that in the context of braided rivers, most bars can be classified as either linguoid or braid bars, while recognizing that both point and riffle-forming bars are also present. Linguoid bars are submerged, actively migrating, parabolic- or lobate-shaped positive bed elements that are bounded by an avalanche face along the downstream margin (Figure 27). The bars can occur at both the macro-scale (i.e., spanning the channel width) or at the meso-scale (i.e., spanning the width of individual chute channels between braid bars). The avalanche faces are frequently steeper and have greater overall height on one side of the bar than the other, which may in some cases grade into the channel bed. Although the parabolic or lobate shape is most common, many bars have sinuous or multi-lobed margins that form in response to local variations in the intensity and direction of the main flow paths. Linguoid bars occur in zones of high bed-load transport. The highest velocities over lobate bars typically occur along the centerline of the bar (Figure 27), and flows diverge radially across the bar crest, which promotes deposition on the downstream portion of the bar. Continual scour on the upstream portion and deposition on the downstream portion of the bar allows the bar to retain its overall shape while migrating downstream.

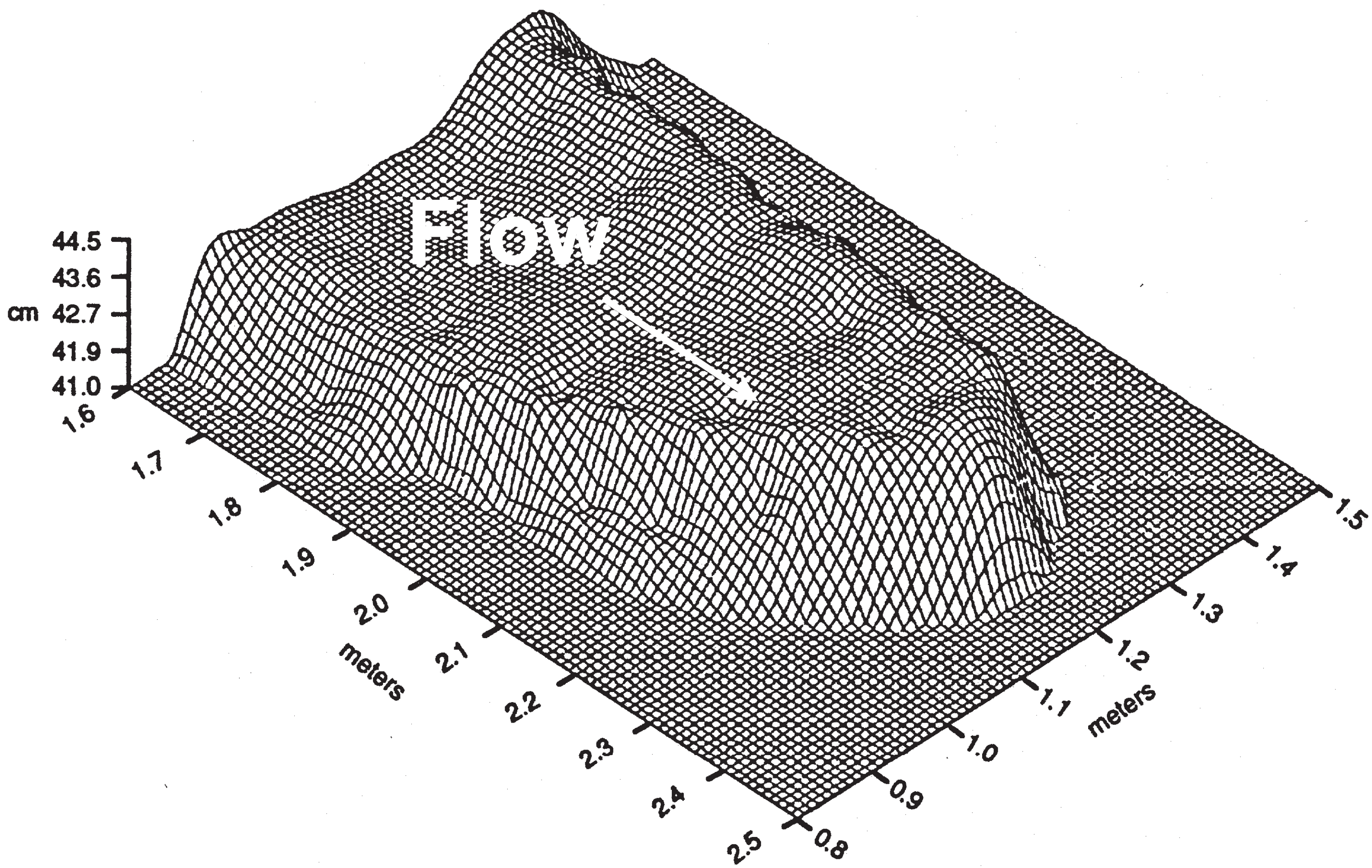
Flume experiments by Germanoski (1989) indicate that there is a direct relationship between sediment supply and linguoid bar development in sand-bed channels. These experiments also showed that the number of bars is a function of sediment supply, which indicates that bar development is supply limited. During high discharges in large, sandy, braided rivers such as the lower Platte River, almost the entire bed is a mobile complex of linguoid bars stacked en-echelon and side by side (Brice, 1964; Blodgett and Stanley, 1980).

Braid bars are stationary, subaerially exposed bars that represent the remnants of the linguoid bars that form at high flows, and they are, therefore, sites of sediment storage at low to intermediate flows. These bars are typically elongate features that are oriented parallel or sub-parallel to the flow, and they separate flows into distinct channels that are often occupied by migrating linguoid bars. Braid bars are formed primarily by dissection of stalled linguoid bars, a dynamic process that results from the interaction between the flow and bar shape that continuously exert a mutual influence on each other. Once the braid bars are formed, they grow by grain-by-grain accretion and accretion of parts of other stalled bars. Once subaerially exposed, braid bars are sculpted by marginal flows into more streamlined, longitudinal forms (Komar, 1983 and 1984). Braid bars are, therefore, sediment storage zones that are formed by both depositional and erosional processes.

The coexistence of the various scales of bedforms indicates that the local flow and velocity distributions created by the presence of the macroform features has a significant effect on the presence and character of the meso- and microforms. At a given discharge, the presence or absence of the meso- and microforms is controlled by the hydrodynamic effects of the macroform. Thus, under low-flow conditions in a sand-bed channel, actively migrating ripples and dunes may be present in some localized reaches and not in others, depending on the location of the actively migrating linguoid bars.

Bedforms

The characteristics of the micro-scale bedforms follow a predictable pattern from low energy to high energy conditions that is directly related to the size of the bed sediment and the hydraulic characteristics of the flow (Figure 28). As a result, the type of bedform that is present at any



Note the scour channel on the stoss (upstream) side and the steep slip face on the lee (downstream) side.

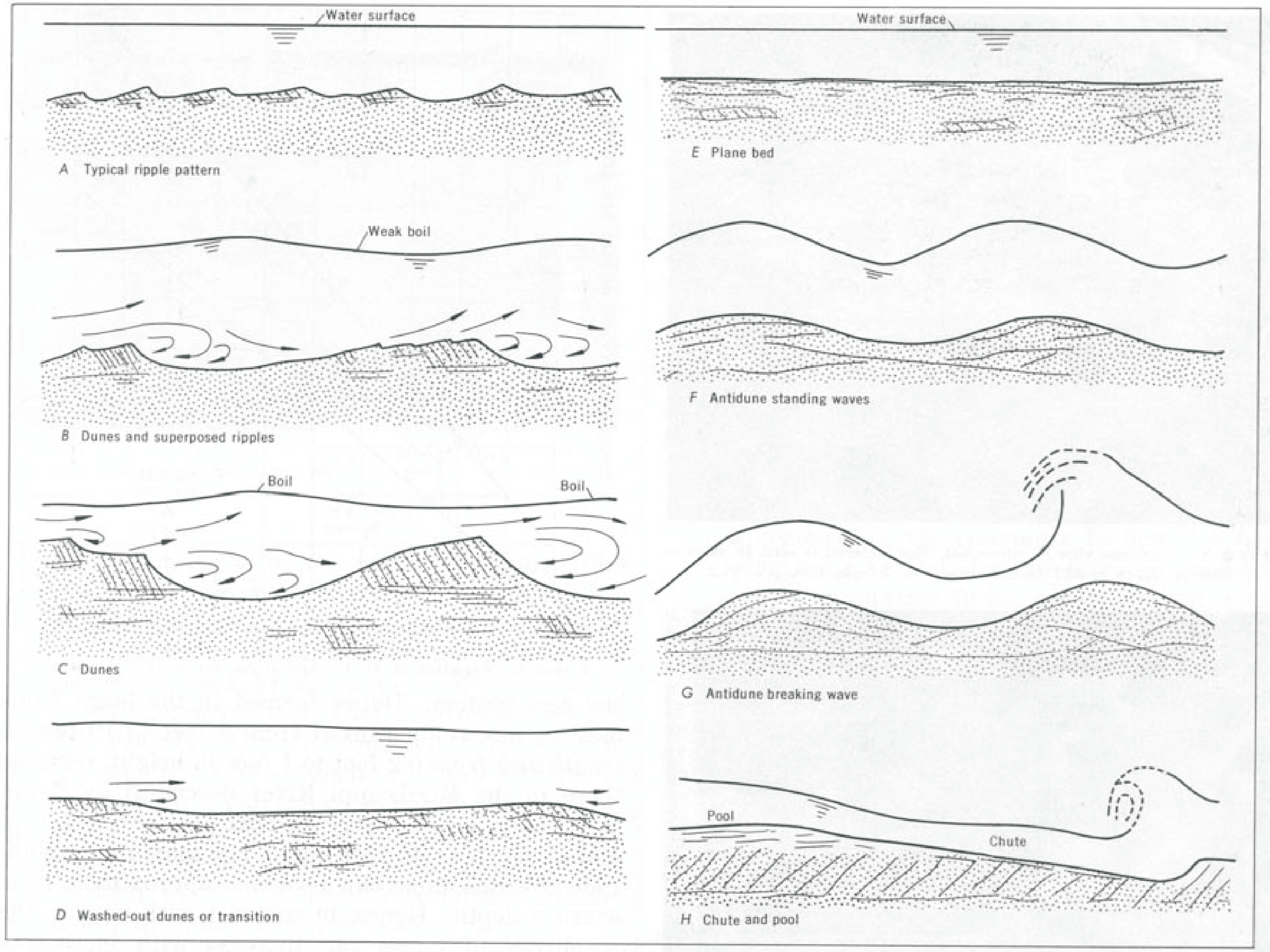
HDR
THE FLATWATER GROUP INC.
TETRA TECH
MEI

Three-dimensional Plot of an Ideal Linguoid Bar

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date
Dec. 2009

Figure
27



from Simons and Richardson, 1966

Forms of Bed Roughness in an Alluvial Channel

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date
Dec. 2009

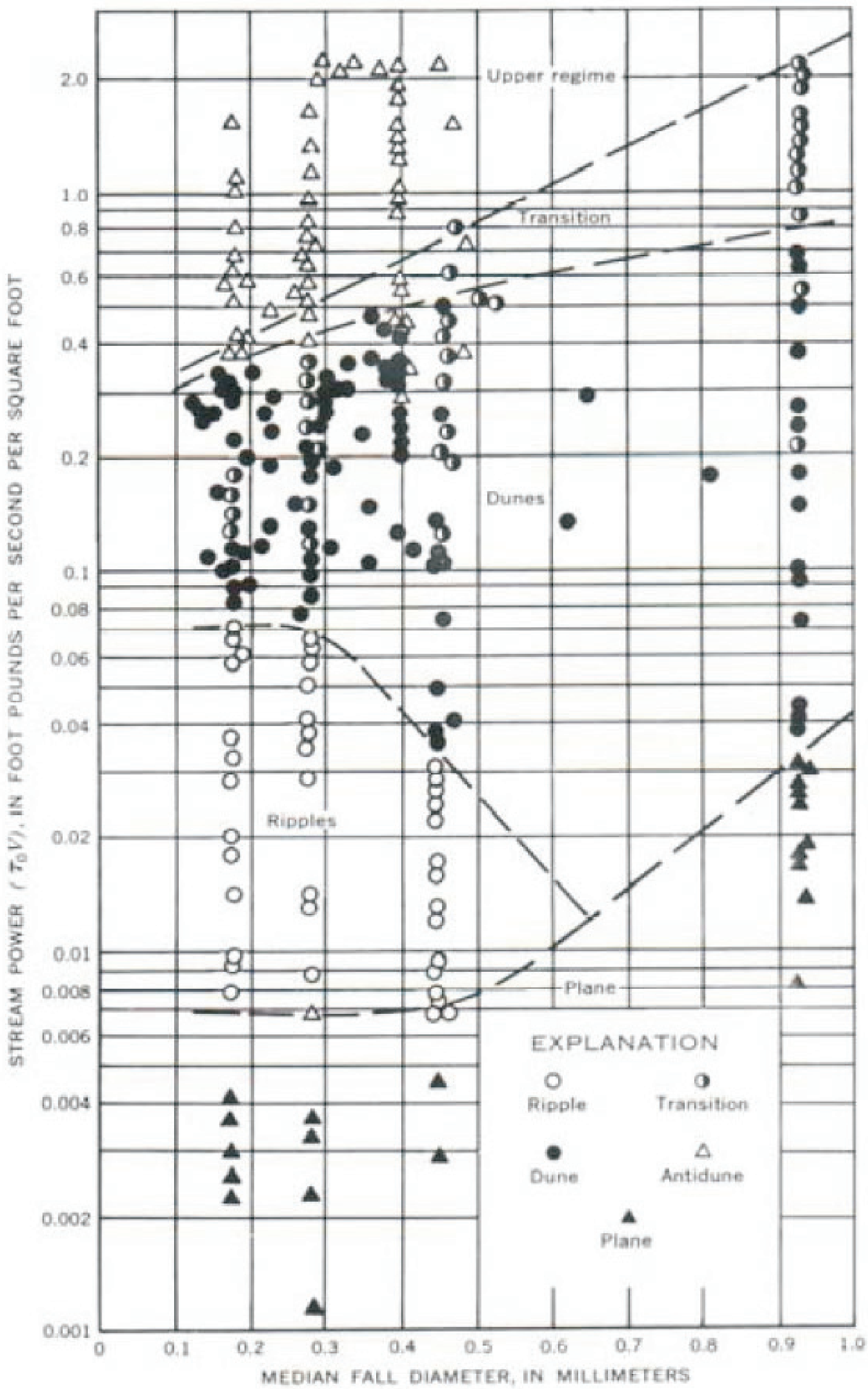
Figure
28

given location varies with time as the discharge changes. The presence and type of bedforms are important to this Study because their effect on hydraulic resistance to flow and, thus, channel stage varies significantly over the continuum of bedform types (Nordin, 1964; Simons and Richardson, 1961: Middleton and Southard, 1984; Bennett, 1995). In addition, bedform type is indicative of the type of meso-scale habitat that is present at any particular location, and the individual bedforms (particularly dunes) can affect habitat by creating hydraulic diversity at the micro-scale.

Numerous methods for predicting bedform type have been presented in the literature based on both laboratory and field data and analytical techniques. One of the most commonly used methods was originally presented by Simons and Richardson (1966) as a phase diagram that relates bedform type to the median fall diameter of the bed sediment and the stream power (Figure 29). The data on which Figure 29 is based were derived from a combination of laboratory and field data from the Elkhorn and Middle Loup rivers in Nebraska, the Rio Grande in New Mexico, the Punjab Canal in India, and a variety of other canal data. This relationship has been criticized because it was presented in dimensional form, and thus, it is subject to scale effects when applied outside the range of the original data, particularly in large, deep rivers such as the Mississippi and lower Missouri. Others, including van Rijn (1984), developed dimensionless relationships that should not be subject to the same scale effects as the Simons and Richardson (1966) relationship. Bennett (1995) adopted the classification scheme of van Rijn (1984) to develop an analytical relationship for predicting bedform type and dimensions as a function of the dimensionless grain size ($d_* = D_{50}\{(SG\text{-}1)g/\nu^2\}^{1/3}$)) and the dimensionless transport strength (S'_*) (Figure 30). The specific boundaries in Figure 30 were established based on a broad range of field and laboratory data from Brownlie (1981), Guy et al. (1966) [the laboratory data set on which the original Simons and Richardson (1966) relationship was, in part, based], and Nordin (1976).

A key feature of the Bennett (1995) relationship is that it quantifies the two well-recognized components of hydraulic resistance (grain resistance and form drag) that were described by Einstein and Barbarossa (1952) and subsequently refined by a number of more recent studies, including Engelund (1966 and 1967) and Smith and McLean (1977). In applying this concept, which is referred to as *shear partitioning*, grain resistance for a particular flow is considered to be the same as that for a plane bed flow at the same depth (van Rijn, 1982 and 1984); thus, it can be quantified using the standard logarithmic vertical velocity profile from basic fluid mechanics, with the characteristic roughness height defined as a multiple of the bed material size. The remaining portion of the flow resistance is caused by form drag that is associated with a variety of factors, including the size and shape of the bedforms, non-linearity of the channel, and in-stream debris, among others. In quantifying grain and form resistance, it is customary to separate the hydraulic radius (or depth in wide channels) into two parts, that due to grain resistance (R’) and that due to form roughness (R’’). Bed material transport rates, and thus, the processes that create the bedforms, are controlled by the grain resistance, while the total channel roughness can be significantly influenced by the form roughness.

Numerous definitions for the characteristic roughness height (k_s) that is necessary to apply the semi-logarithmic velocity profile have been proposed that are typically applicable to a specific range of bed material sizes. In developing his relationship, Bennett (1995) found that the value suggested by Engelund and Hansen (1967) of $k_s = 2.5D_{50}$ (where D_{50} is the median grain size of the bed material) provided the best results for defining the grain shear stress in sand-bedded systems. To estimate the magnitude of the form drag caused by the bedforms, Bennett (1995) used a relationship developed by Nelson et al. (1993) based on the relationship between the average velocity that would exist over the height of the bedform if it were removed from the flow



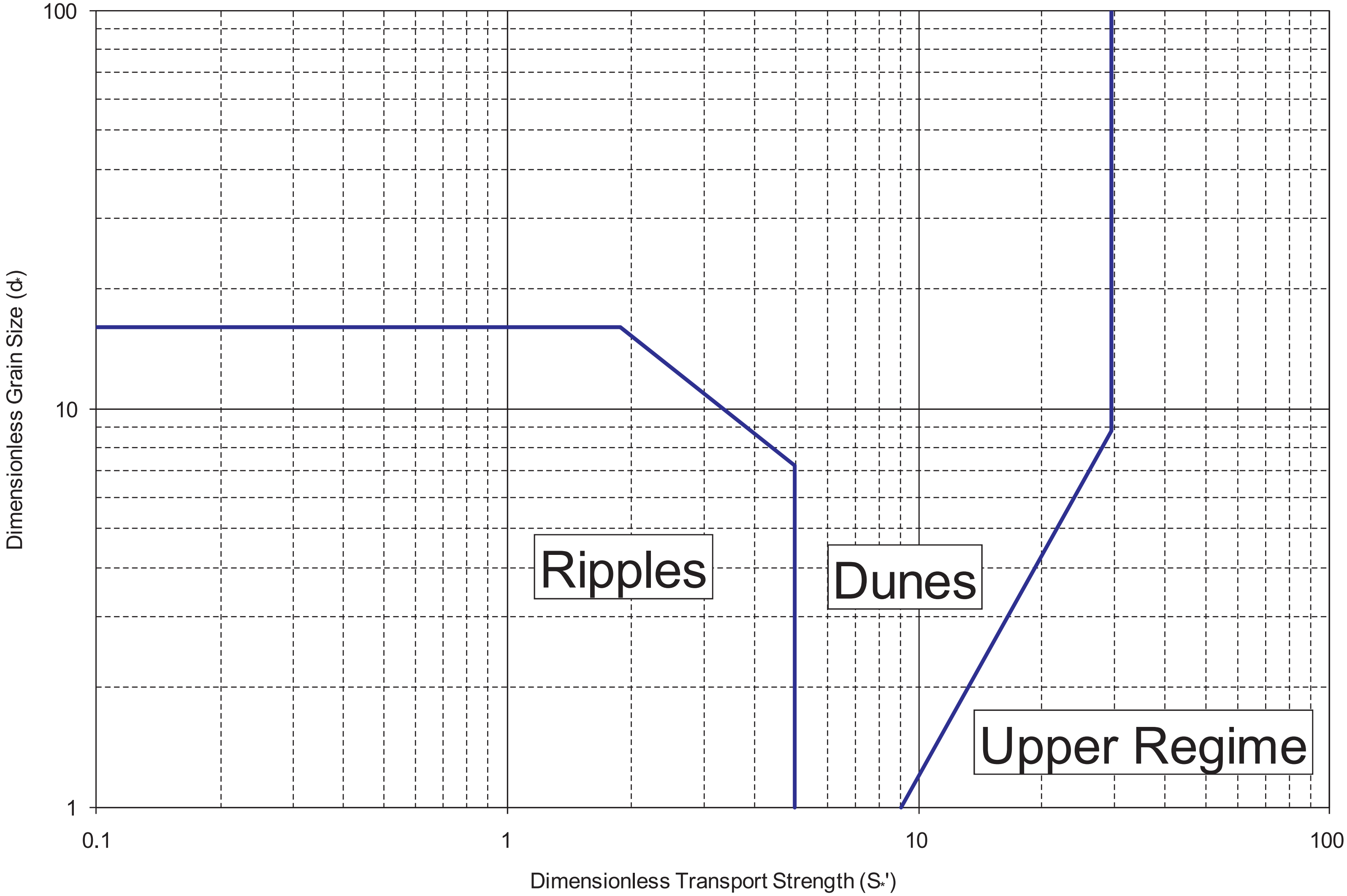
from Simons and Richardson, 1966

Bedform Predictor

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date
Dec. 2009

Figure
29



from Bennett, 1995

Classification Scheme for Bedform Regions

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date
Dec. 2009

Figure
30

field and the average velocity at that location in the presence of the bedform. This relationship is given by:

$$\frac{\tau_0'}{\tau} = 1/(1 + \frac{C_d}{2_{\kappa}^{-2}} \frac{\Delta}{\lambda} ln^2 \frac{11\Delta}{k_s}) \quad (1)$$

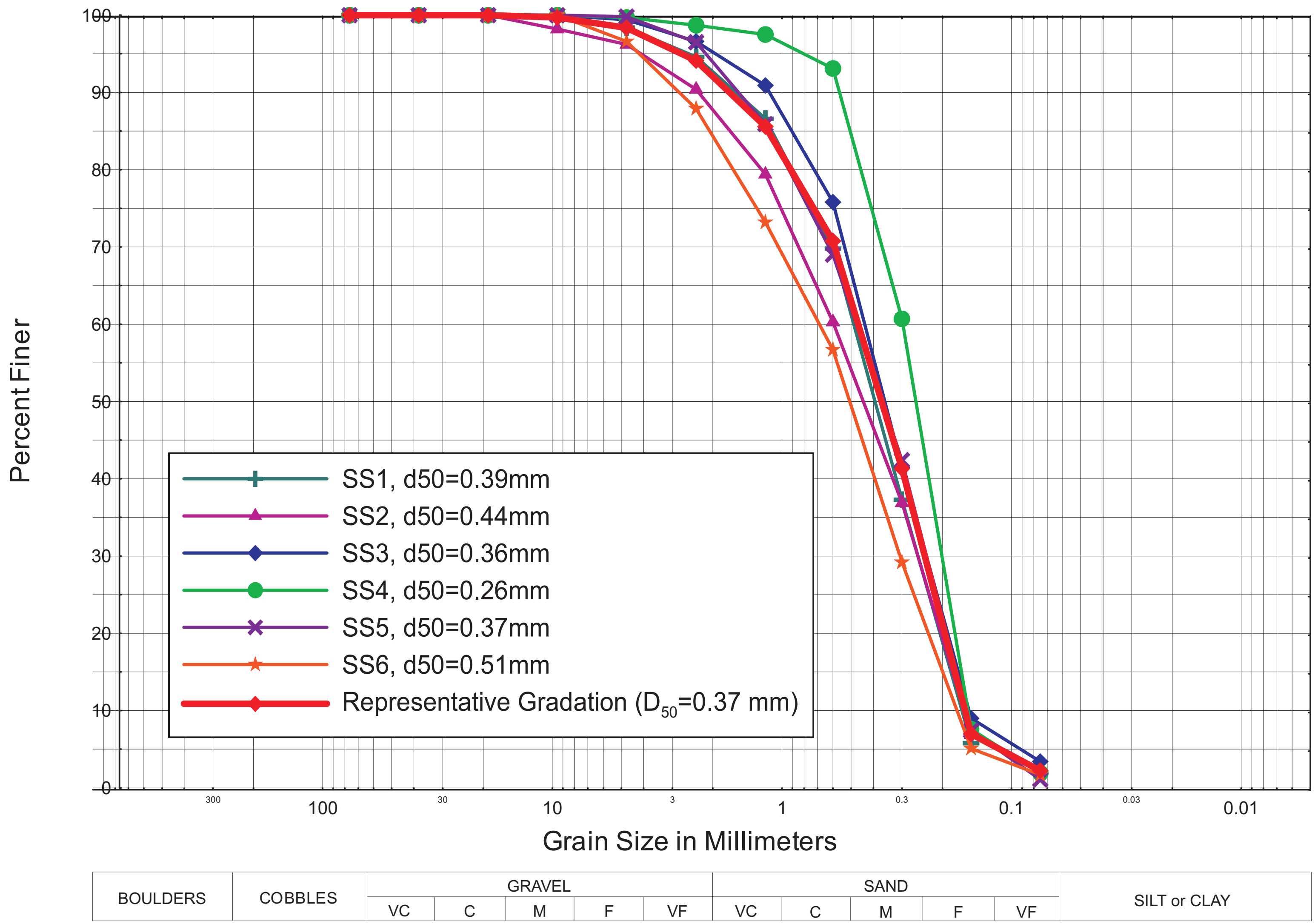
where τ_0' is the shear stress due to grain resistance, τ is the total shear stress, C_d is the drag coefficient = 0.2, κ is the von Karman constant = 0.4, Δ is the bedform height, λ is the bedform length, and k_s is the characteristic roughness height. (As noted above, Bennett assumed k_s = $2.5D_{50}$). In the above relationship, the form drag is simply the difference between the total shear (τ) and the grain shear stress (τ_0'). Ripple size and geometry are primarily associated with bed particle size and are independent of hydraulic characteristics, and the ripple data set used in Bennett's (1995) analysis indicates that ripple length (λ) $\cong 1{,}000D_{50}$ and steepness ratio (Δ/λ) averages 0.074; thus, ripple height $\Delta \cong 74D_{50}$. Dune height, on the other hand, is a function of the hydraulic characteristics, and Bennett (1995) used the following modified form of the relationship originally proposed by van Rijn (1984) to quantify dune height:

$$\frac{\Delta}{h} = A\left(\frac{D_{50}}{h}\right)^{0.3} \left(1 - e^{0.5S_*'}\right)\left[(S_*')_u - S_*'\right] \quad (2)$$

where h is the flow depth, A is a constant suggested to be ~0.11 by van Rijn (1984), but calibrated to a value of 0.164 by Bennett (1995), S'_* is the sediment transport strength defined as (τ'/τ_{cr}-1), and $(S'_*)_U$ is the transport strength at the threshold between dunes and upper regime flow. The critical shear stress (τ_{cr}) is quantified using the Shields relationship given by $\tau_{cr}=F^*(SG-1)\gamma D_{50}$, where F^* is the Shields parameter assumed here to be 0.047 (Meyer-Peter, Muller, 1948), SG is the specific gravity of the sediment (assumed to be 2.62), and γ is the unit weight of water (62.4 lb/ft^3).

For purposes of this Study, the transport strength (S'_*), bedform type, and bedform height (Δ) were estimated for each node in the 2D model grid for each modeled discharge based on the hydraulic conditions predicted by the model and the representative bed material grain size (D_{50}) of the Study Reach. Based on six grab samples of the surface bed material within the reach covered by the 2D model, the median (D_{50}) size of the bed material is about 0.37 mm (Figure 31). For purposes of estimating the bedform characteristics, the median size was rounded up to 0.4 mm. Because of the form of the above equations, it is not possible to solve directly for the grain shear stress and bedform height. A VisualBasic program was therefore developed for this purpose that iteratively solves for the necessary values by initially computing the grain shear stress and bedform height from Equations 1 and 2, above, based on the total shear stress, comparing the resulting value of τ_0' and adjusting the value until the initially assumed value and the computed value match within a reasonable tolerance.

The predicted bedform types from the above procedure were mapped over the model domain for each discharge (Appendix E), and the percentage of the total area of the site and only the portion of the site represented by each type of bedform was then computed based on the spatial distribution of the estimated bedforms (Figures 32 and 33). The results for the 4,300-cfs model run (Appendix E2) are very consistent with the bedforms observed during the field data collection. Based on these results, the subaerially exposed portion of the site varies from about 30 percent at 3,700 cfs to about less than 1 percent at discharges above 20,000 cfs (Figure 32).



Curves for six grab samples of the surface bed material within the reach covered by the 2-D model. Also shown is a representative gradation curve for the reach based on the average of the six samples.

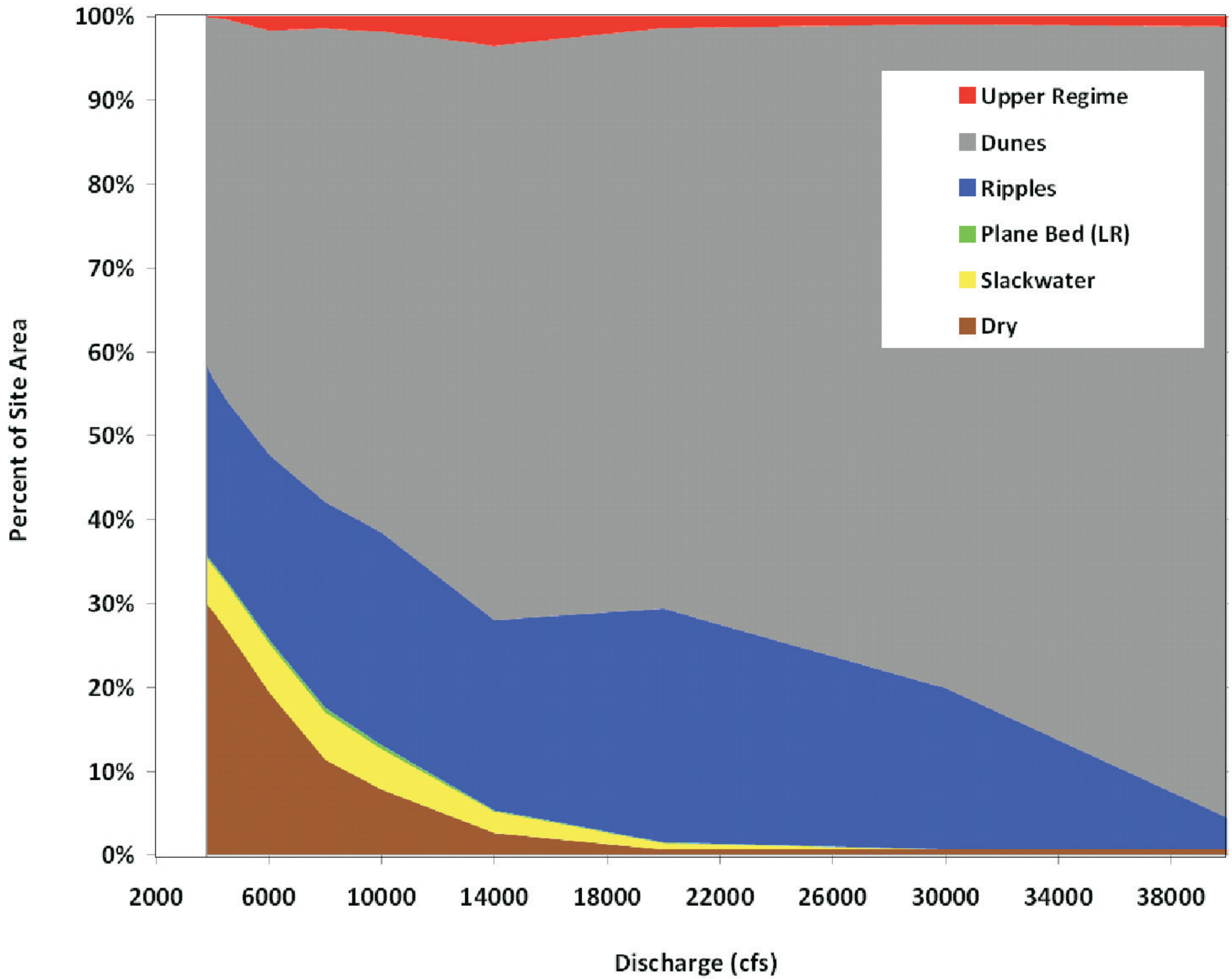
HDR | THE FLATWATER GROUP INC. | TETRA TECH | MEI

Grain Size Distribution Curves

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date: Dec. 2009

Figure: 31



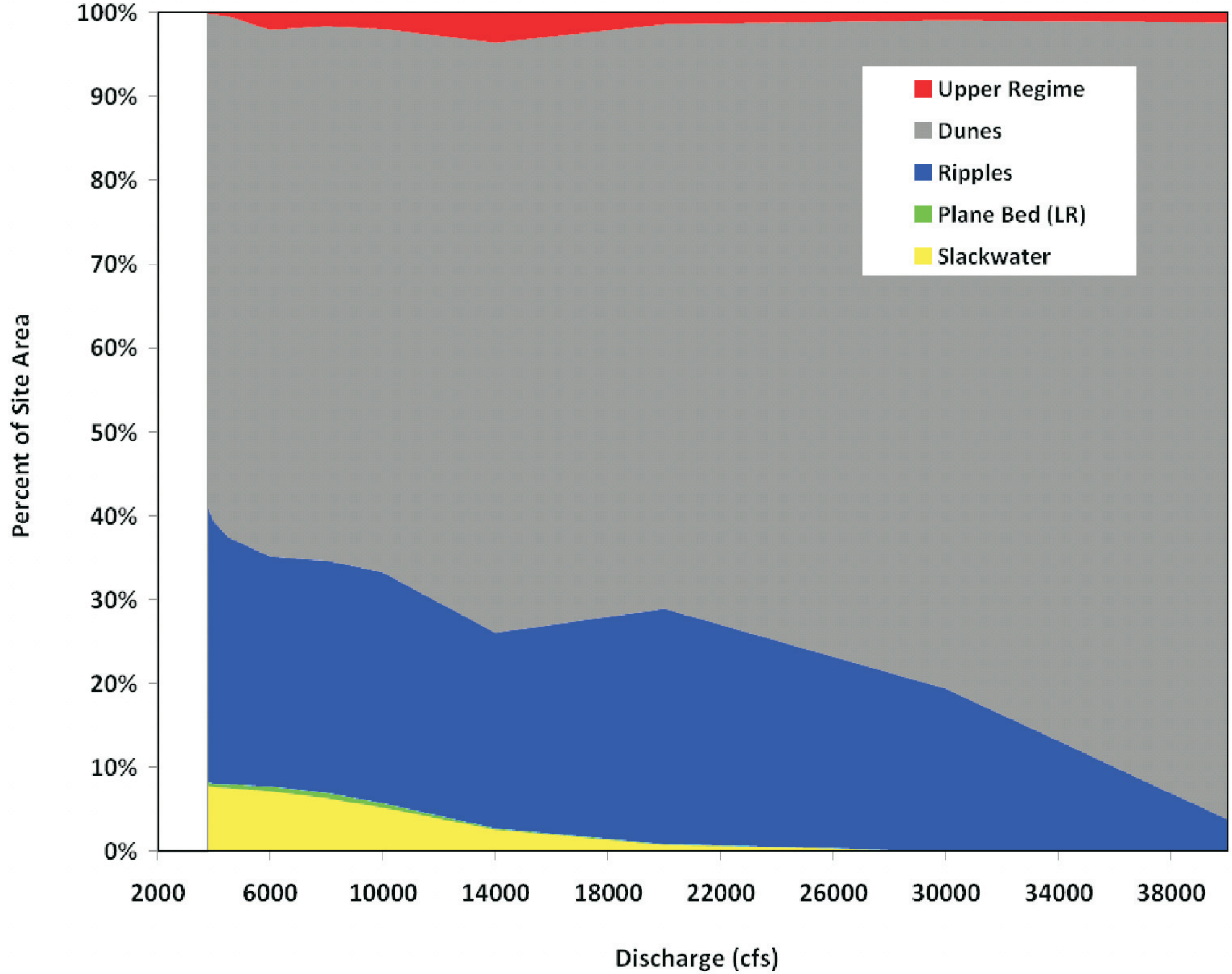
HDR
THE FLATWATER GROUP INC.
TETRA TECH
MEI

Estimated Percentage of the Total Modeled Reach Represented by each Bedform Type

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date
Dec. 2009

Figure
32



HDR
THE FLATWATER GROUP INC.
TETRA TECH
MEI

Estimated Percentage of the Inundated Portion of Modeled Reach Represented by Each Bedform Type

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date
Dec. 2009

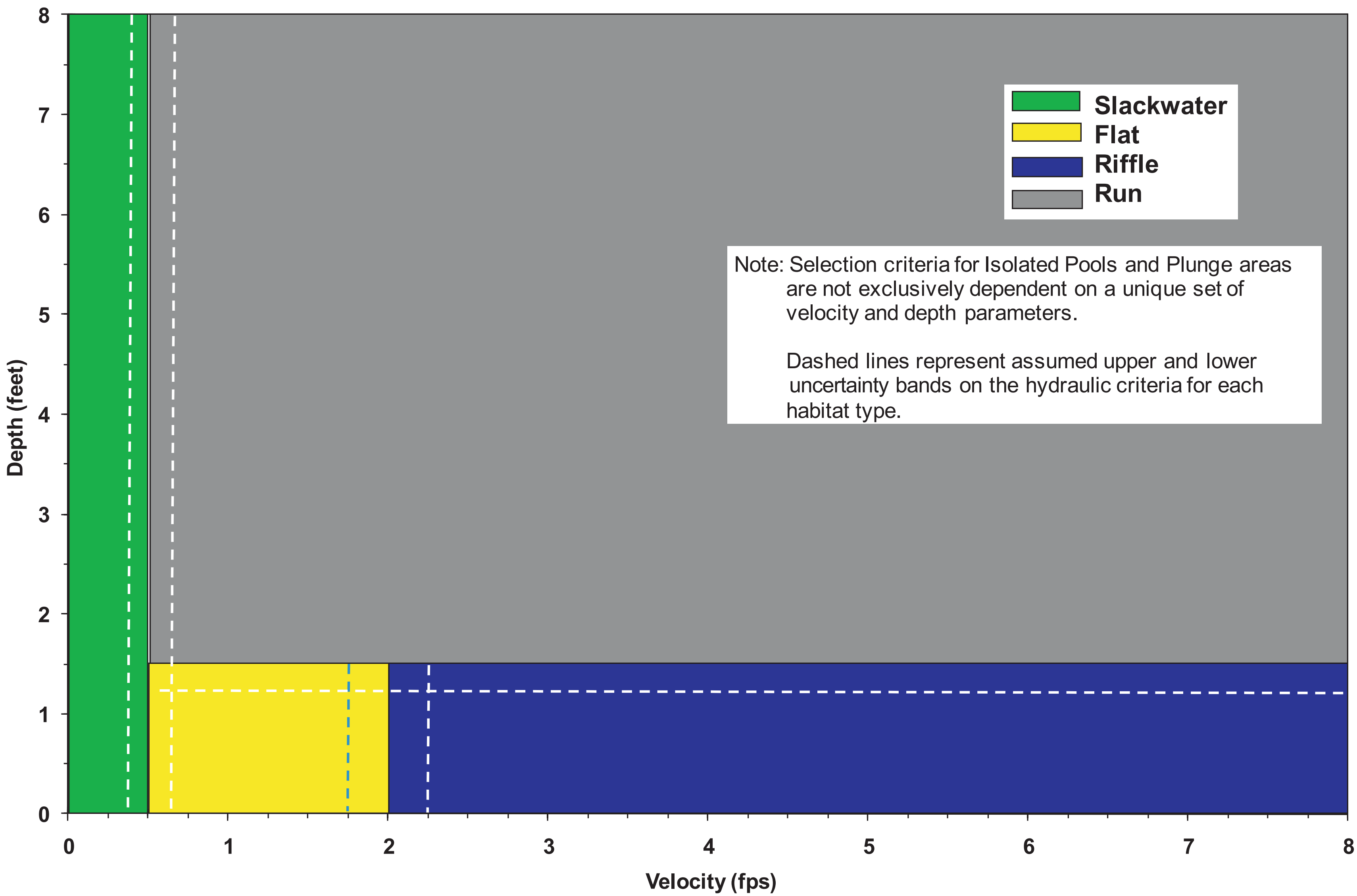
Figure
33

Ripples and dunes represent the largest proportion of the site, with the relative area of ripples in the inundated portion of the site decreasing from about 33 percent at 3,700 cfs to less than 4 percent at the highest modeled discharge of 40,000 cfs, and the area represented by dunes increasing from about 60 to 95 percent over this range of discharges (Figure 33). The slackwater areas also represent a significant portion of the sites at low flows, varying from about 8 percent of the inundated area at 3,700 cfs to about 5 percent of the site at 10,000 cfs, and then essentially disappearing at discharges above 10,000 cfs. Very little of the site is occupied by the plane bed (lower regime) category, even at the lowest modeled flows, because this category represents areas of moving water in which the shear stress is below the threshold for motion for the relatively sand-sized bed material. Somewhat surprisingly, very little of the site is also occupied by upper regime conditions, even at the highest modeled flows. In fact, the largest area of upper regime conditions occurs in the range from about 6,000 to 14,000 cfs, where relatively shallow, rapidly moving flow occurs in locally steep chute channels between the braid bars. The small amount of upper regime conditions at higher flows results from the relatively deep flow and flat overall gradient of the site. Evaluation of the areas occupied by dunes indicates that the median predicted dune height increases from 0.45 feet (~5.4 inches) at 3,700 cfs to 0.81 feet (~10 inches) at 40,000 cfs, with maximum heights ranging from 1.9 to 2.5 feet over this range of discharges.

Habitat Evaluation

Results from the 2D hydraulic model were used to evaluate changes in habitat with discharge and stage based on the local depth and velocity. For purposes of the analysis, six habitat classes were identified through a coordinated effort involving all members of the HDR team, including Dr. Mark Pegg, the fishery biologist who was involved in the field data collection for this Study and has been involved in a significant number of field exercises during which pallid sturgeon were captured, to fully describe the variability within the Study Reach. In developing the habitat classes, criteria based on depth, velocity, and connectivity that reflect the conditions within each habitat class were selected. The resulting classification scheme is described in Table 10 and Figure 34. Slackwater, Flat, Riffle, and Run habitat areas were identified strictly based on the hydraulic criteria and 2D model results. Isolated Pools were identified as any water feature disconnected from the main flow channel based on the assumption that any given discharge was preceded by a higher flow or groundwater connection that could have supplied water to those areas. The Plunge areas represent a complex habitat that is characterized by not only a rapid change of depth, but also its spatial location relative to bars and banklines within the detailed study reach. As a result, the following specific criteria were used to identify the Plunge areas:

1. Potential Plunge areas were visually identified based on a localized and rapid change in topography and locally steep channel bed gradients that occur along the margins of actively migrating bars.
2. Cross section plots of each potential Plunge area were then developed to evaluate the approximate dimensions of the identified feature. Based on the dimensions, a reference depth that represents the approximate depth of the Plunge pool relative to the average channel bed elevation was assigned (Figure 35).
3. Predicted depths from the 2D model were then applied to each potential Plunge area to determine whether the feature should, in fact, be classified as a plunge. In general, a plunge area was selected if:
    a. the depth of flow was sufficient to connect the Plunge area to other portions of the channel, and
    b. the depth of flow was less than three times the reference depth. (This criterion is based on the assumption that once the flow depth reaches three times the Plunge reference depth, the localized change in depth due to the Plunge feature is no longer significant).



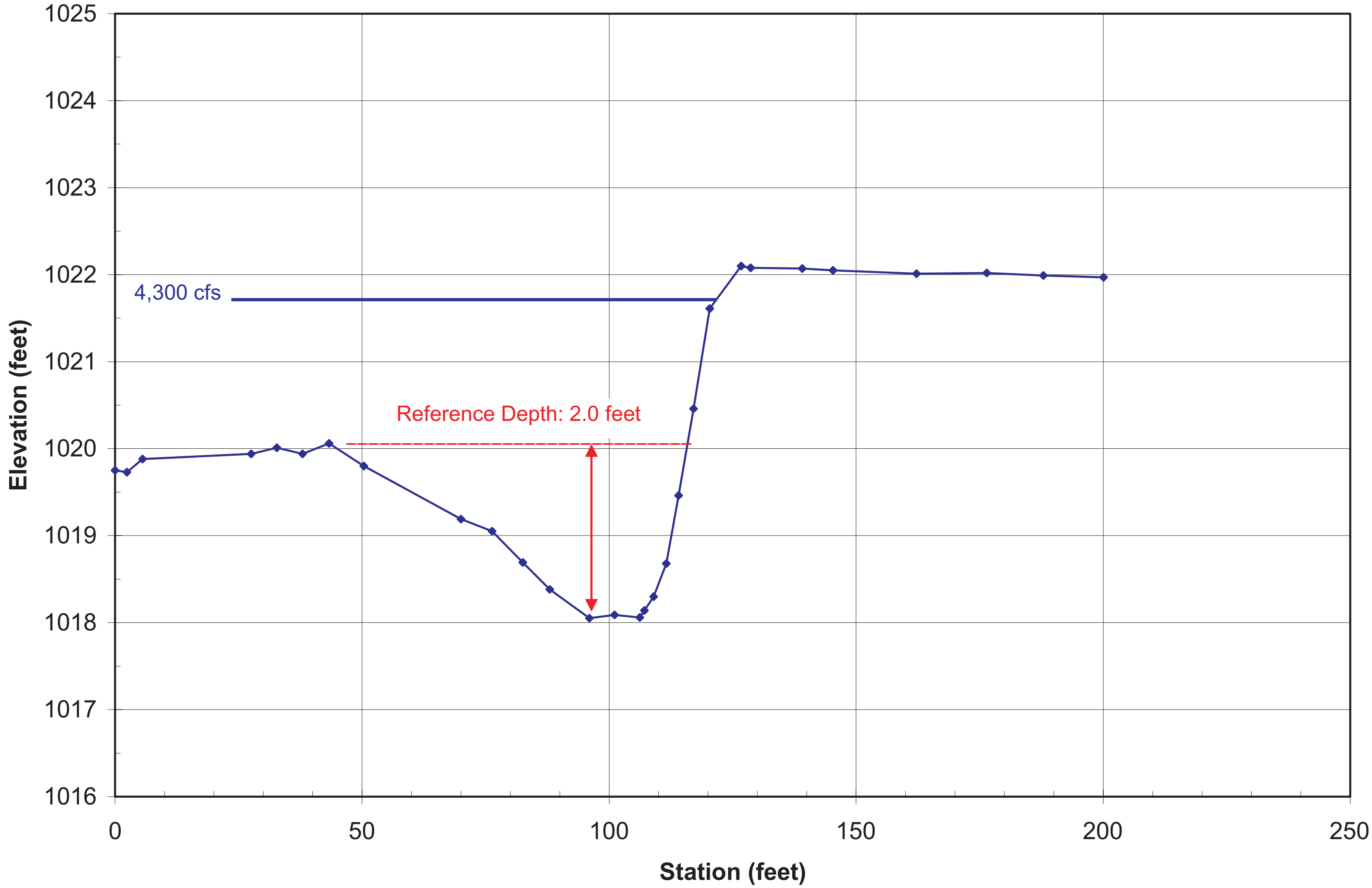
HDR
THE FLATWATER GROUP INC.
TETRA TECH
MEI

Depth and Velocity Criteria used to Specify Habitat Classifications

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date
Dec. 2009

Figure
34



Cross Section Plot of Area

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

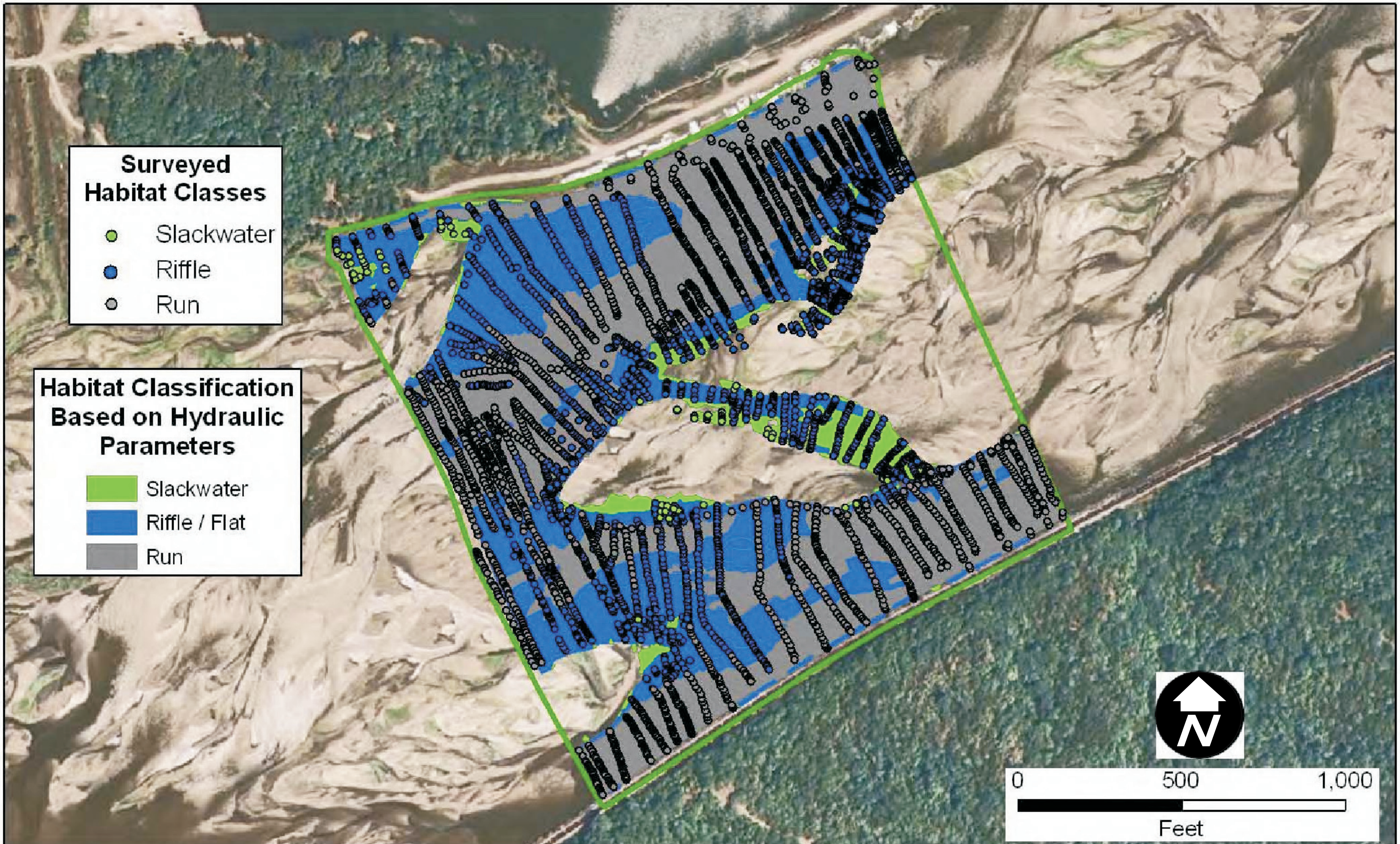
Date	Dec. 2009
Figure	35

The resultant habitat classes based on the above criteria were compared to habitat that was identified during the field survey. Habitat observed during the field surveys was limited to Slackwater, Riffles, and Runs. (Because of the subtle differences between the Riffle and Flat classes, these were combined into the Riffle class). A comparison of the surveyed and estimated habitat indicates that the habitat selection criteria produce results that are in very good agreement with field-identified conditions (Figure 36). The habitat classes are also supported by the bedform analysis results, which indicate that Run habitat generally occurs in areas characterized by Dunes and Riffle habitat generally occurs in areas characterized by ripples, consistent with field observations at a flow of about 4,300 cfs (Appendix E2 and F2).

After validating the habitat identification process, the criteria were applied over a range of discharges between 3,700 and 40,000 cfs. Each habitat class was then converted into polygons and mapped (Appendix F). The total area of each habitat class and the equivalent percentage of the total flow area were estimated for each discharge (Figures 37 and 38). (The procedure used to develop the uncertainty bands in Figures 38a-d are described in the next section.) At flows in the range of 3,700 cfs, Slackwater habitat accounts for approximately 7 percent of the flow area, increasing to less about 9 percent at 6,000 cfs, and then decreasing to less than 1 percent at flows greater than 20,000 cfs. At 3,700 cfs, Flat habitat accounts for just about 37 percent of the area, and decreasing to less than 2 percent above 20,000 cfs (Figure 38). Riffle habitat makes up about 15 percent of the area at 3,700 cfs, decreasing to about 10 percent between 8,000 and 10,000 cfs, increasing back to about 16 percent at 20,000 cfs, and then decreasing back to about 10 percent at 40,000 cfs. The increase in riffle area between 10,000 cfs and 20,000 cfs occurs because areas that become inundated in this range of flows typically fall into the Riffle habitat range. At flows greater than 20,000 cfs, these bars then gradually become more inundated, transitioning into Run habitat (Figure 37 and Appendix F). Run habitat accounts for about 38 percent of the area at 3,700 cfs, increasing to nearly 90 percent at 40,000 cfs. Isolated Pools only tend to appear at discharges less than about 5,000 cfs, representing less than 1 percent of the area at 3,700 cfs. Plunge areas are very dependent on the topography and, based on the identification technique discussed above, account for about 3 percent of the flow area at 3,700 cfs. The Plunge habitat area remains relatively consistent up to approximately 20,000 cfs (Figure 37). As depths continue to increase at discharges greater than 20,000 cfs, many of the Plunge areas are reduced, and they disappear at about 30,000 cfs (Figure 37). Comparison of the bedform and habitat maps in Appendices E and F show remarkable agreement between the bedforms and the habitat types in which they are expected to occur.

Uncertainty in Habitat Evaluation

Although the habitat areas developed from the hydraulic criteria and model results are in good agreement with the field-mapped areas at approximately 4,300 cfs, there is uncertainty in both the hydraulic model results and the precise depth and velocity limits between habitat classes. Uncertainty in the hydraulic model results stems from two primary sources: (1) uncertainty in the hydraulic roughness and eddy viscosity values that control the modeled flow depths and velocities, and (2) uncertainty in the detailed bed topography in this sand-bedded reach that was surveyed at flows in the range of 4,000 cfs. Uncertainty in the hydraulic model results can be quantified by assessing the variability between the measured and modeled data. As discussed in the model development section, uncertainty in the hydraulic roughness and eddy viscosity, and therefore, one component of the uncertainty in depth, were eliminated, to the extent possible, by calibrating the modeled water-surface elevations to a suite of water-surface elevations that were measured at discharges ranging from 3,700 cfs to 37,400 cfs. The mean difference between the modeled and measured values was -0.01 feet with standard deviation of 0.24 feet, indicating that



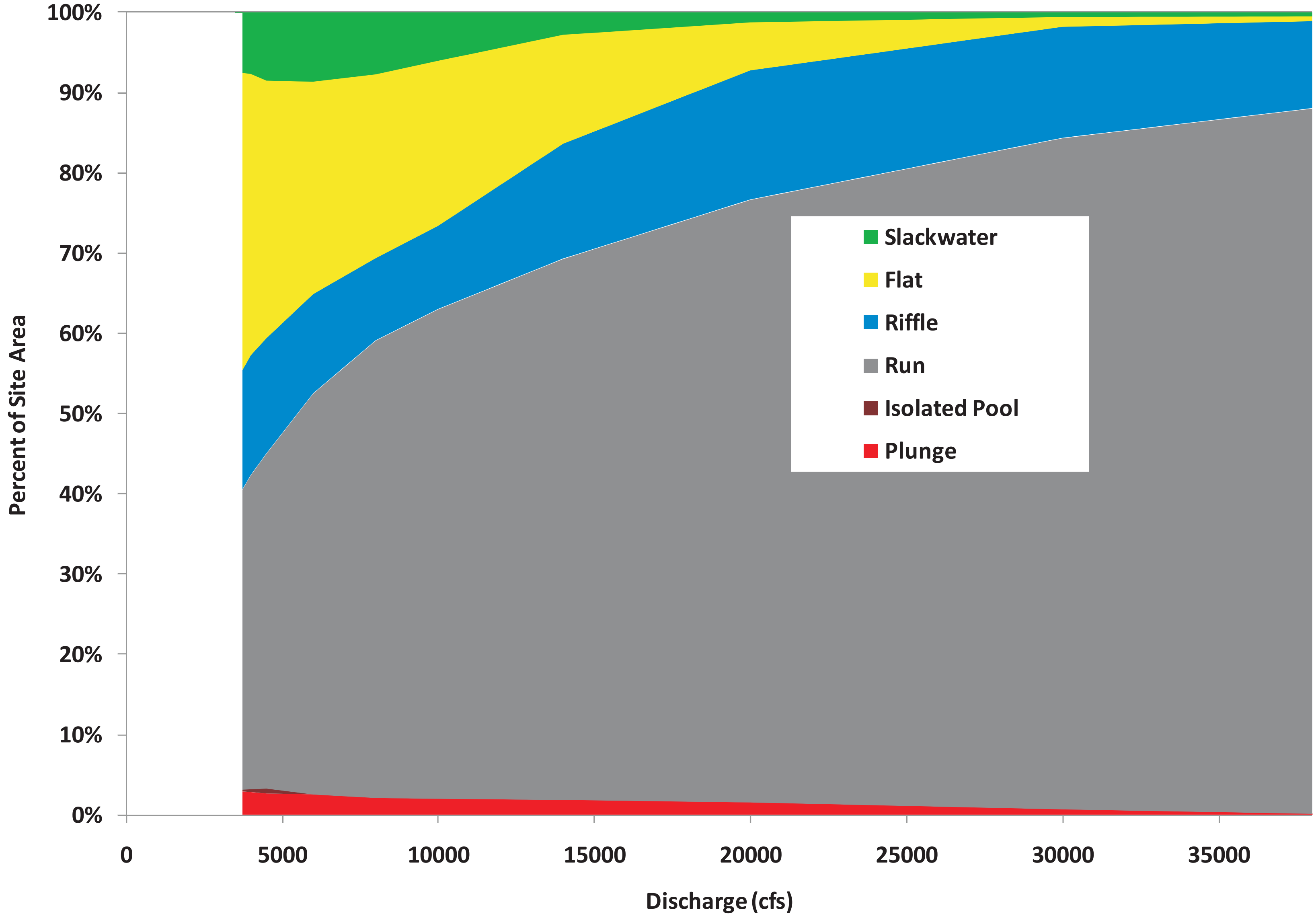
HDR
THE FLATWATER GROUP INC.
TETRA TECH
MEI

Surveyed and Estimated Habitat Classes at 4,300 cfs

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date: Dec. 2009

Figure: 36



HDR
THE FLATWATER GROUP INC.
TETRA TECH
MEI

Percentage of Total Habitat Classification Area vs. Discharge

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date
Dec. 2009

Figure
37

the model is well calibrated (Figures 24 and 25). Unfortunately, specific data are not available to quantify the uncertainty in the depth and velocity criteria for the habitat units.

To assess the overall uncertainty in relative area of the four habitat types that were identified using hydraulic criteria (slackwater, flat, riffle and run), a Monte Carlo simulation was performed using the variability between the measured and modeled hydraulic data and assumed uncertainty in the hydraulic criteria. The results of this analysis should be viewed as a sensitivity analysis since it is not possible to quantify the uncertainty in the hydraulic criteria with the available information. The simulation was performed using the following procedure:

1. The values for the depth and hydraulic criteria shown in Figure 34 were adjusted by adding a normally distributed, random value with mean of zero and an assumed upper and lower 90 percent confidence bound. For purposes of this sensitivity analysis, it was assumed that the upper and lower 90% confidence bounds on the velocity boundary between slackwater and flat/run habitat is +/-0.125 feet (i.e., +/-25%), and between flat and riffle habitat is +/-0.25 feet. It was also assumed that the 90% confidence bounds on the depth boundary between the flat/riffle and run habitat is +/-0.25 feet.
2. The modeled depth and velocity at each of the approximately 120,000 model nodes was adjusted by adding a normally distributed, random value with mean and standard deviation matching the variability between the measured and modeled values. During the field surveys, individual depth and velocity measurements were taken at 87 locations within the site (Figure 26). The differences between the measured and modeled values are normally distributed, with mean and standard deviation of $^{+}$10.6% and +/-30.8%, respectively, for the velocities and $^{+}$5.7% and +/- 45.3%, respectively, for the depths.
3. The area within each of the four habitat types was recomputed based on the randomly adjusted habitat criteria and hydraulic conditions.
4. The above steps were repeated 1,000 times for each modeled discharge to develop composite uncertainty bands about the best-estimate values.
5. The distribution of the resulting habitat areas at each discharge was analyzed to develop overall uncertainty bands on the best-estimate values.

The results of this simulation indicate that the uncertainty bands generally decrease with increasing discharge (Figures 38a through 38d). The uncertainty bands on the slackwater habitat range from +/-2.8 percent at 4,300 cfs to +/-3.8 percent at 6,000 cfs, and this decreases to about +/-0.1 percent at high flows (Figure 44a). Similarly, the uncertainty bands for the flat habitat range from about 6.9 percent at 4,300 cfs to about +/-0.2 percent at 40,000 cfs, +/-5.7 percent at 4,300 cfs to +/-2.9 percent at 40,000 cfs for the riffle habitat and +/-7.8 percent at 4,300 cfs to +/-3.1 percent at 40,000 cfs for the run habitat. A test run for 6,000 cfs results indicates that the uncertainty in the modeled depth and velocities contribute only a very small amount to the overall variability in the estimates; nearly all of the variability is associated with the assumed uncertainty in the hydraulic criteria used to identify the habitat types.

Table 10. Summary of Habitat Classes

Habitat Class	Description	Hydraulic Criteria		
		Depth (feet)	Velocity (fps)	Connection to River
Slackwater	Standing or extremely low-velocity water that is often partially isolated from the primary flow channel and is generally located on the downstream end of exposed bars.	No depth requirement	< 0.5	Yes, but often limited
Flat	Subaqueous bed with relatively shallow depth and low to moderate velocity generally located on the top of an actively migrating linguoid bar. Resembles a mild riffle. Minor ripples are likely to be present along the bed.	< 1.5	< 2	Yes
Riffle	Somewhat shallow area of relatively high velocity. Often located between pools and runs. Typically slightly steeper than a flat with higher velocities. Low amplitude dunes are likely to be present along the bed.	< 1.5	> 2	Yes
Run	Deeper than average flow area with typically higher velocities. Actively migrating dunes are likely to be present along the bed in higher velocity zones; ripples could be present in low velocity zones.	> 1.5	> 0.5	Yes
Isolated Pool	Off-channel area with pooled standing water, no velocity and no connection to other open water habitat. Frequently formed by local scour at higher flows.	N/A	N/A	No
Plunge[1]	Areas of rapid depth increase and typically velocity decrease. Often located along the margins of an actively migrating linguoid bar.	*	*	Yes

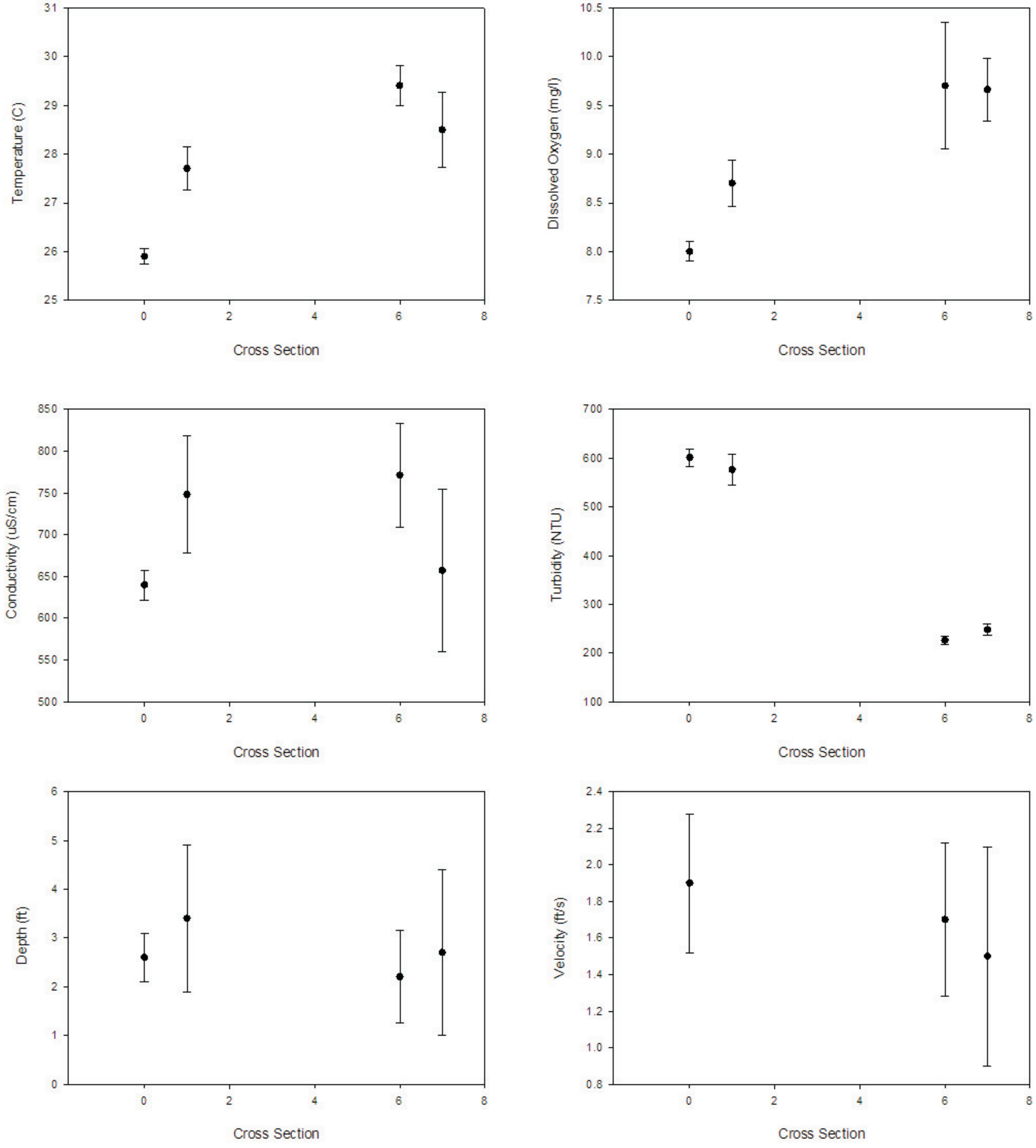
Note:
[1] Plunge areas were identified based on flow depths relative to the depth of the topographic plunge feature (see text).

Water Quality Measures

All water quality parameters exhibited variation among transects and among sample episodes, as shown in Table 11 (Figures 39, 40, and 41). However, analysis of variance results indicate that all water quality parameters were different among sample dates ($P < 0.01$), except for water velocities ($P > 0.95$), as shown in Table 12. The statistical power calculated for each water quality variable was high (Power > 0.99), suggesting that samples sizes were large enough to detect an effect for these variables. These findings corroborate differences identified in the analysis of variance and likely reflect real flow, water quality, and possibly habitat differences among the sampling periods.

Table 11. Mean Values for the Water Quality Parameters Measured on the Platte River, 2008-2009

	N	Temperature (°C)	Dissolved Oxygen (mg/l)	Conductivity (µS/cm)	Turbidity (NTU)	Depth (ft)	Velocity (ft/s)
July 2008	35	27.1	9.0	700	399	2.63	1.76
September 2008	46	21.9	11.1	568	88	1.98	1.81
May 2009	37	21.2	11.6	574	50	1.64	1.80
Power		>0.99	>0.99	>0.99	>0.99	>0.99	>0.99



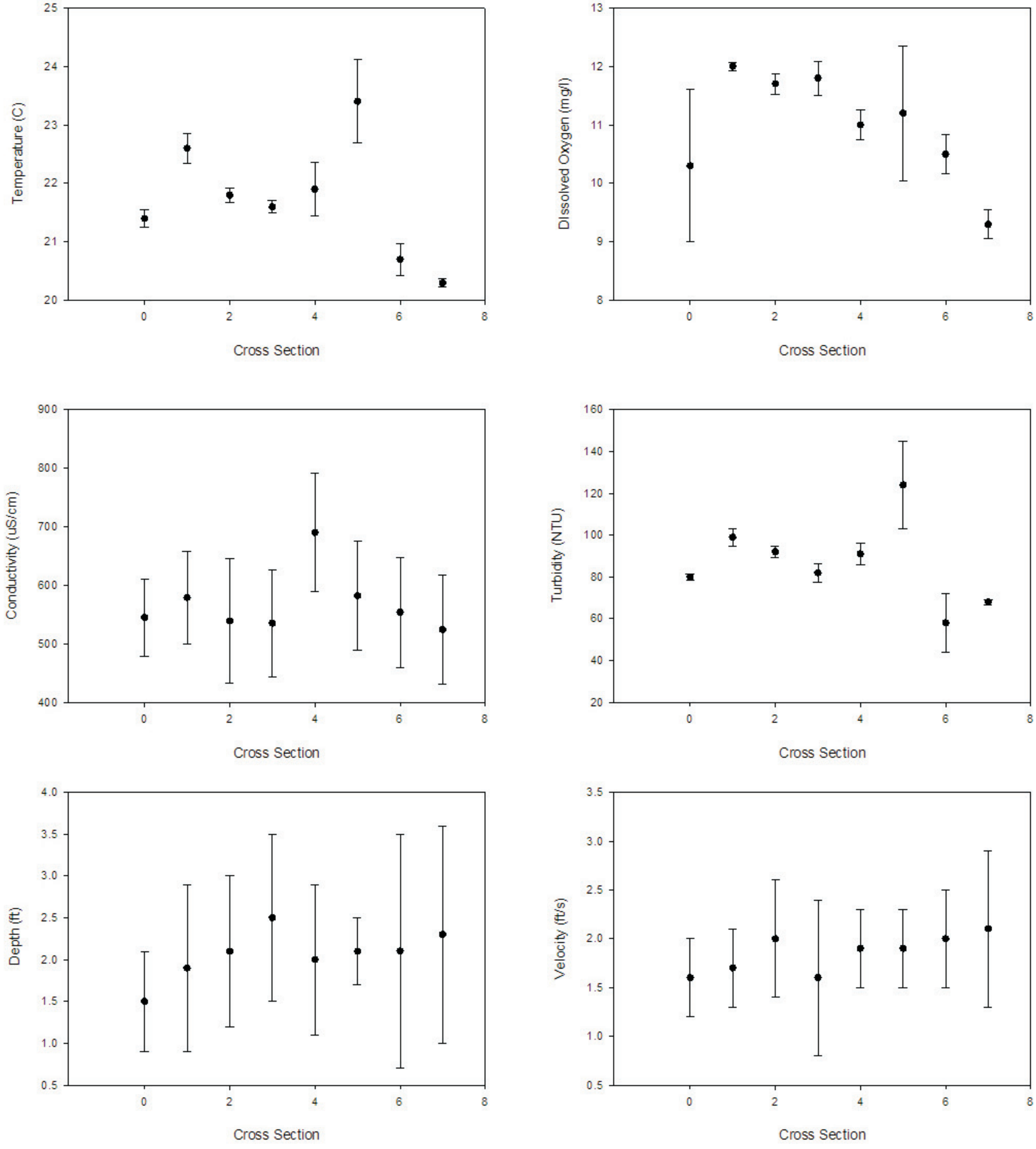
HDR
THE FLATWATER GROUP INC.
TETRA TECH
MEI

Water Quality Samples - July 2008

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date
Dec. 2009

Figure
39

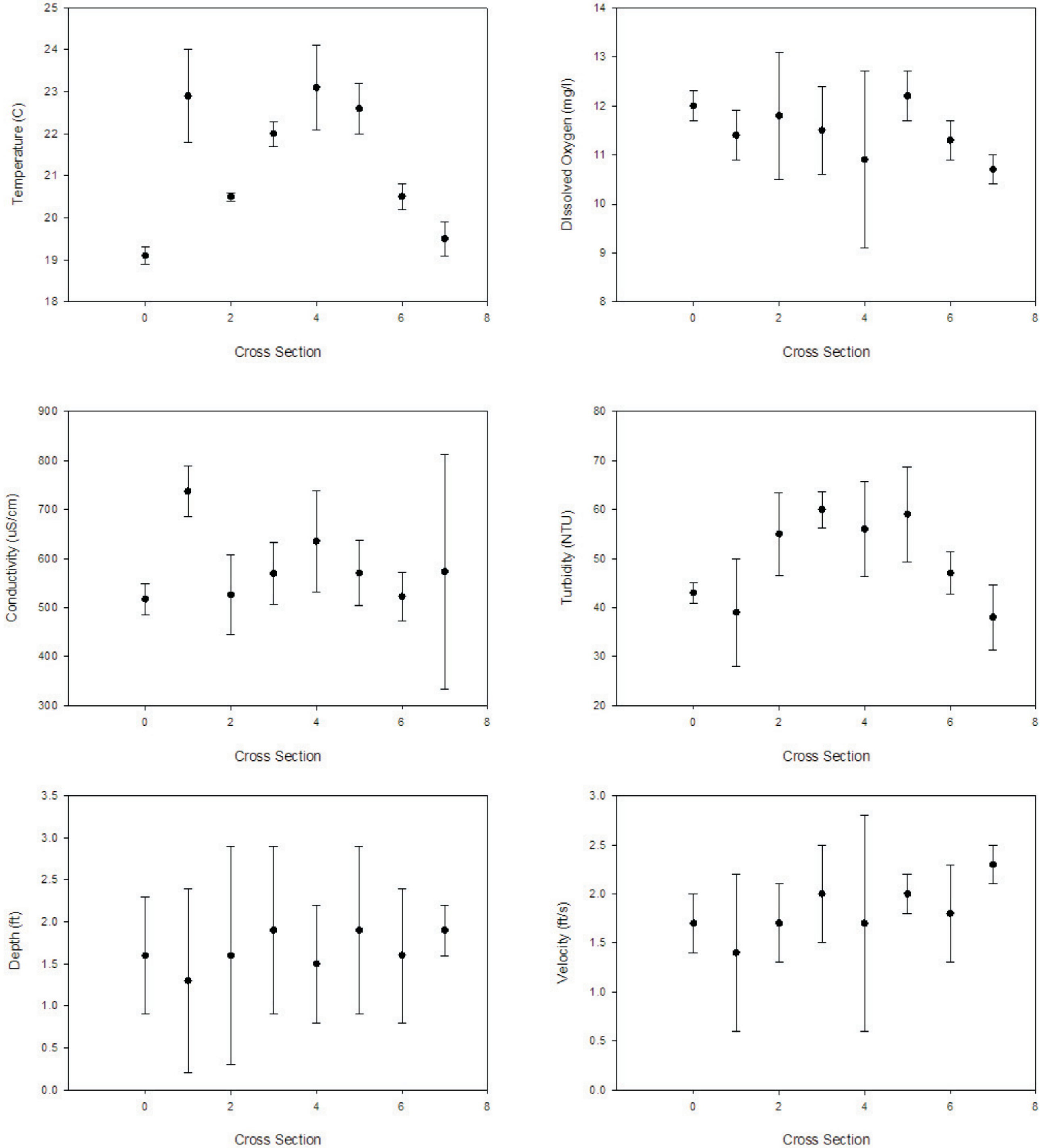


Water Quality Samples - September 2008

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date: Dec. 2009

Figure: 40



Water Quality Samples - May 2009

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date
Dec. 2009

Figure
41

Table 12. Results from Analysis of Variance for Water Quality Parameters Measured on the Platte River, 2008-2009

Variable	P	Phase Comparison[1,2]
Temperature	< 0.001	I > II = III
Dissolved Oxygen	< 0.001	III > II > I
Conductivity	< 0.001	I > II = III
Turbidity	< 0.001	I > II = III
Depth	< 0.002	I = II; II = III; I > III
Velocity	> 0.95	I = II = III

Notes:
[1] Phase I – July 2008, Phase II – September 2008, Phase III – May 2009.
[2] Phase comparisons represent post-hoc Tukeys comparisons to determine differences among Phases.

The water quality data collected during the May 2009 data collection effort was plotted versus discharge. Conductivity versus discharge and Turbidity versus discharge are shown in Figure 42, and Temperature versus discharge and Dissolved Oxygen versus discharge are shown in Figure 43. The respective water quality parameters recorded at the Louisville gage for the mean daily discharge are also plotted on Figures 42 and 43.

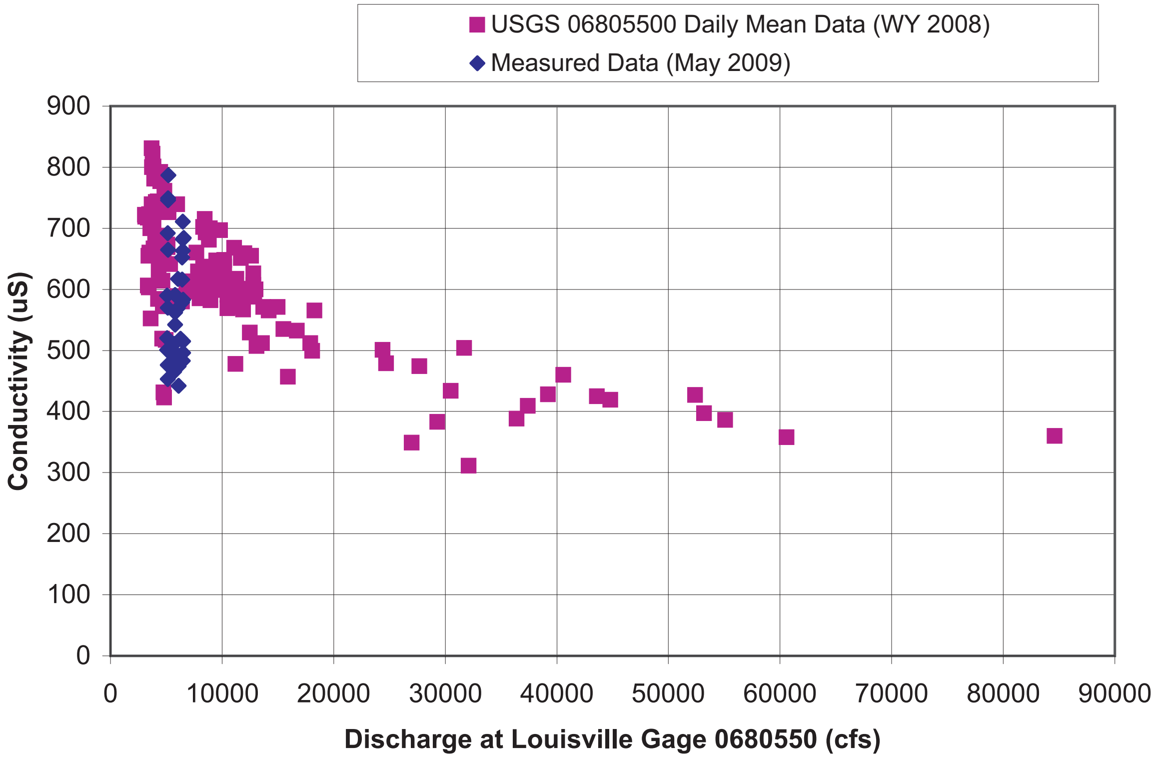
Interpretation and Analysis

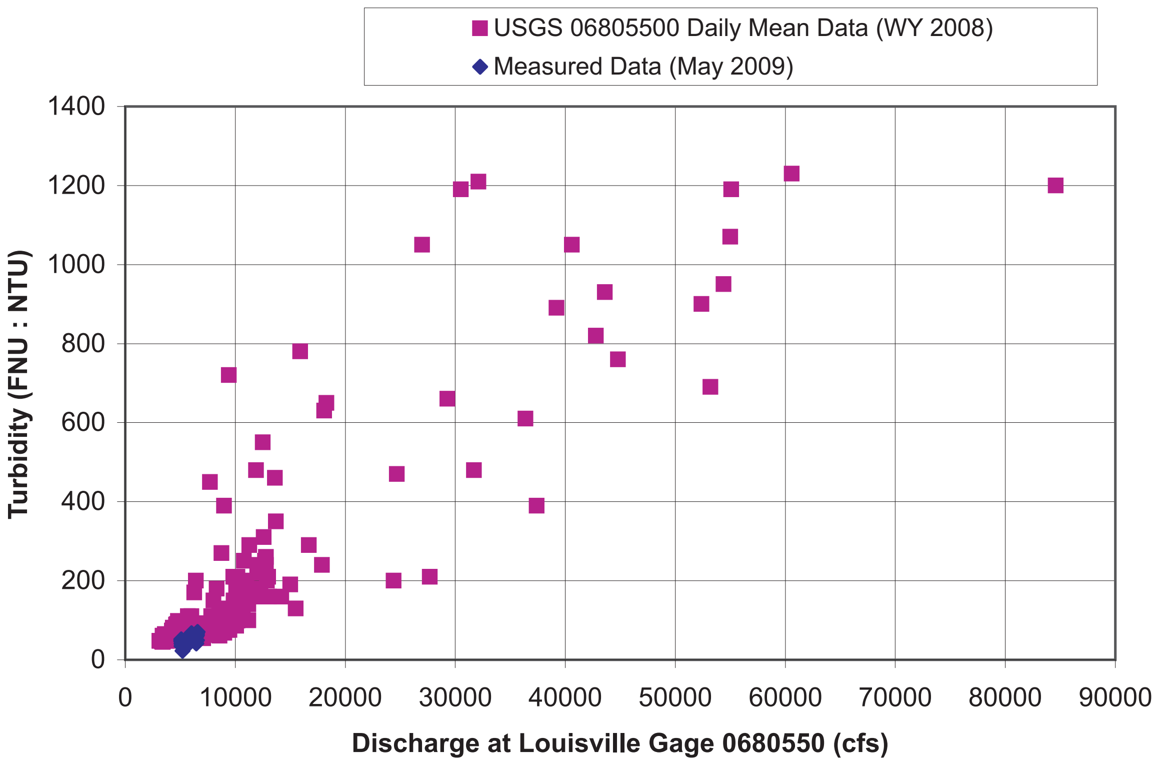
Discussion

This Study used 1D and 2D models to evaluate the distribution of depths and velocities across a range of discharges within the Study Reach between a relatively low flow of 3,700 cfs and the near-bankfull flow of 40,000 cfs. Generally, the amount of relatively deep and swift habitat (i.e., Run habitat) increases with increasing discharge, whereas the amount of shallow and lower velocity habitat (i.e., Slackwater and Flat habitat) decreases with increasing discharge, as expected. These results should provide a means of assessing availability and changes in habitat for species of concern such as the pallid sturgeon with changes in discharge.

Peters and Parham (2008) reported that pallid sturgeon captures most often occurred in the deepest and swiftest areas of the Platte River and that these habitat types were used more frequently than would be expected if used at random. Radio telemetry data further suggests that Platte River pallid sturgeon were typically found in depths ranging from 2 to 5.9 feet and average bottom velocities that ranged from 0.6 to 1.9 feet per second (Peters and Parham, 2008). Pallid sturgeon collected in the Platte River during 2009 were found in a similar range of depths (1.0 to 5.9 feet) and similar to greater bottom velocities (0.9 to 3.1 feet per second) (Pegg, unpublished). The depth and velocity information from these studies suggest that the Run and Plunge habitat classes identified in this study are likely most suitable as pallid sturgeon habitats. Considering this information and the information provided by this Study that evaluates changes in habitat availability with discharge (Figures 37 and 38), it can be concluded that changes in habitat areas as a result of 100 or 500 cfs environmental releases would have a negligible influence on pallid sturgeon habitat in the lower Platte River.

For example, the historical median discharge at Louisville in April, May and June, months during which the pallid sturgeon have been known to migrate and spawn, is approximately 7,000 cfs (Figure 2). Assuming an additional 1,000 cfs of Program water could be delivered to Grand Island, approximately 900 cfs would reach Louisville (Figure 4a). Based on the relationships



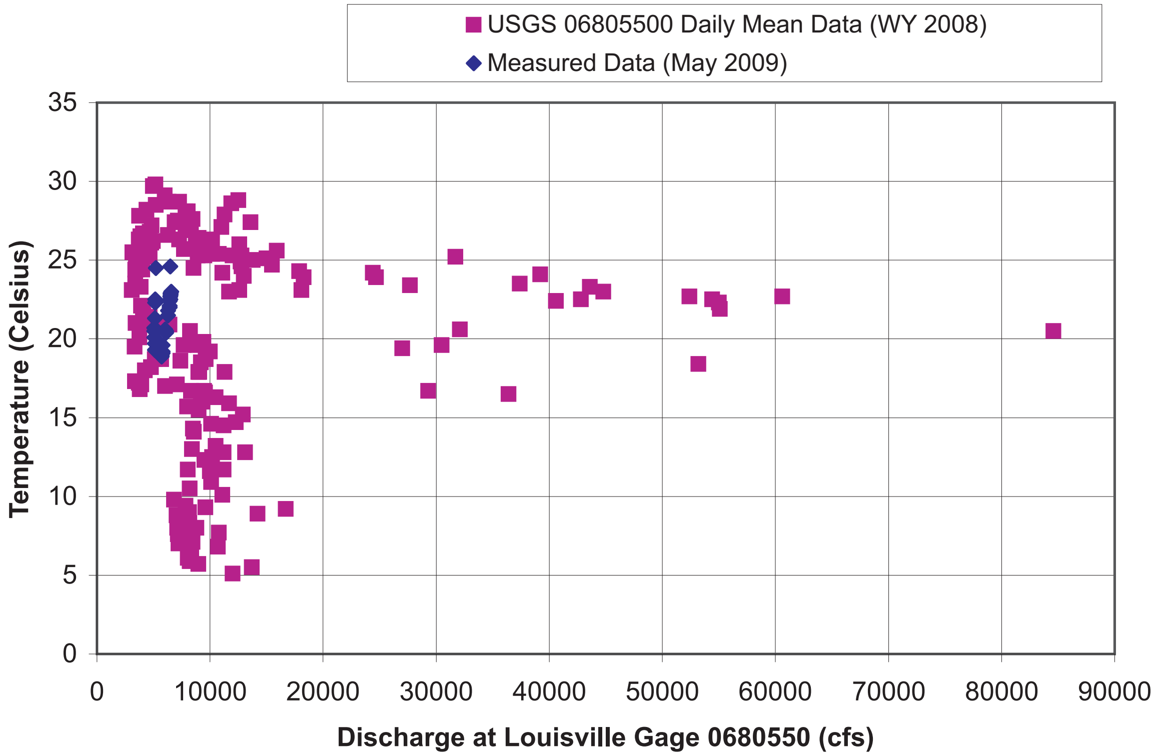


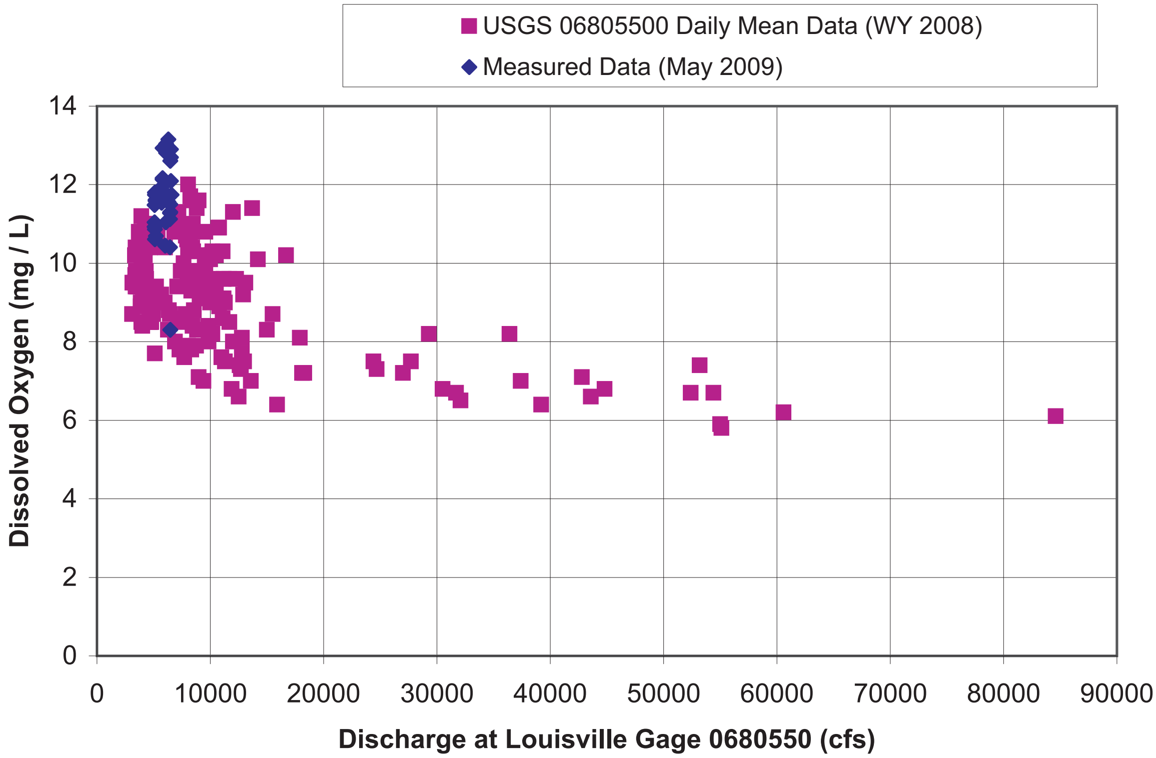
Measured Conductivity and Turbidity vs. Discharge

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date
Dec. 2009

Figure
42





HDR
THE FLATWATER GROUP INC.
TETRA TECH
MEI

Measured Temperature and Dissolved Oxygen vs. Discharge

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date
Dec. 2009

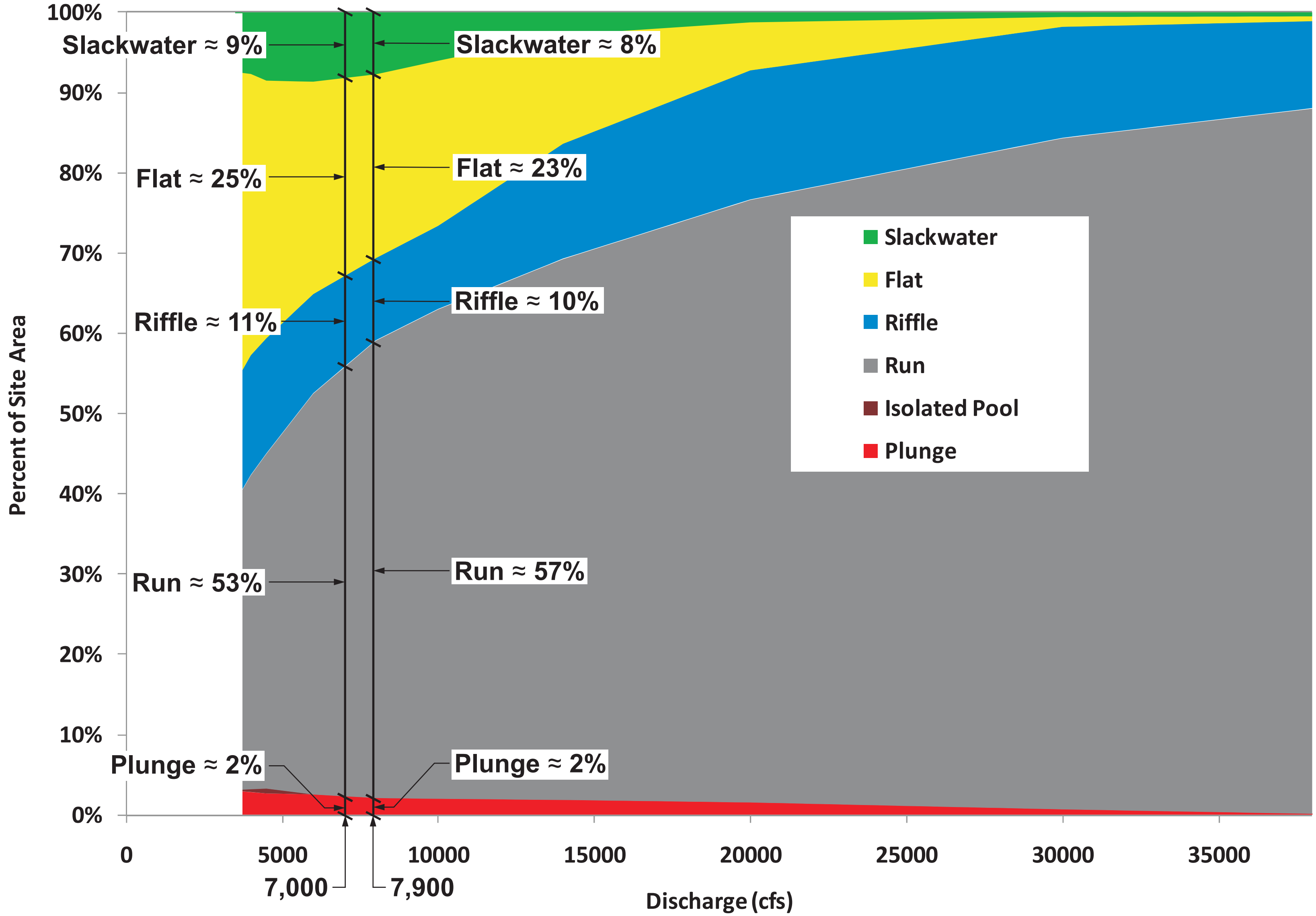
Figure
43

shown in Figures 37 and 38, the Run classification represents approximately 53% (± 7%) of the habitat area at 7,000 cfs and approximately 57% (± 6%) of the area at 7,900 cfs, an increase of about 4%. This is represented graphically in Figure 44. Similarly, the Flat classification represents approximately 25% (± 6%) and 23% (± 5%) of the habitat area at 7,000 and 7,900 cfs, respectively, an approximately 2% reduction. Finally, the Riffle category represents approximately 11% (± 4%) and 10% (± 4%) of the habitat area at 7,000 and 7,900 cfs, respectively, an approximately 1% reduction. In assessing the results of this example, it should be noted that the changes in relative area occupied by each habitat type are within the uncertainty bands of the analysis. In addition, the uncertainty in daily flow at the Louisville gage for the months of April, May, and June is approximately 800 cfs (Table 5); thus, the predicted change in discharge is only slightly larger than the uncertainty. This is not to suggest that the gage would not detect the change in flow, but the magnitude of the change in discharge is subject to the same uncertainty as the overall flow. In addition, based on the flow translation analysis for this Study, it was difficult to differentiate the water pulse flow from other water management activities in the lower Platte River. Finally, the increase in discharge does not move the conductivity, turbidity, temperature, or dissolved oxygen outside the typical range preferred by pallid sturgeon (Figures 42 and 43).

Similarly, a decrease in flow at Grand Island of 1,000 cfs would translate to an approximately 900 cfs decrease in flow at Louisville (Figure 4a). As represented graphically in Figure 45, the Run classification represents approximately 53% (± 7%) of the habitat area at 7,000 cfs, and approximately 50% (± 7%) at 6,100 cfs, a reduction of 3%. The Flat classification represents approximately 25% (± 6%) and 26% (± 6%) of the area at 7,000 and 6,100 cfs, respectively, only a 1% increase. Finally, the Riffle category is approximately 11% (± 4%) and 12% (± 5%) of the habitat area at 7,000 and 6,100 cfs, respectively, an increase of 1%.

Program activities may include regulating or trimming the hydrograph in the central Platte River. One proposed Program action is to divert flows above target in an effort to re-time flows for release during periods of interest or concern. Based on this stage change study, the % habitat in the lower Platte River experiences a relatively high rate of change for flows ranging between 4,000 cfs to 6,000 cfs. In addition, some literature has suggested connectivity concerns at the lower end of this range (Peters and Parham, 2008). In order to estimate the flow affect, and subsequent change in stage, in the lower Platte River for flow regulation, the results of this stage change study were coupled with a review of historic flow records. The analysis is detailed in Appendix G, and is summarized in this section.

Assuming Program diversions would only occur in March, April, October, and November, the days in which the mean daily flow at Louisville was between 4,000 cfs and 6,000 cfs for the period of record were cataloged. This data set was filtered based on the corresponding flows at Grand Island (assuming travel time) being above target flow assuming a dry hydrologic condition. Finally, from this filtered data set, flows in excess of target flows at Grand Island were diverted, and the diversion amount was translated to Louisville and subtracted from the corresponding mean daily flow, again assuming travel time. The following table summarizes the results:



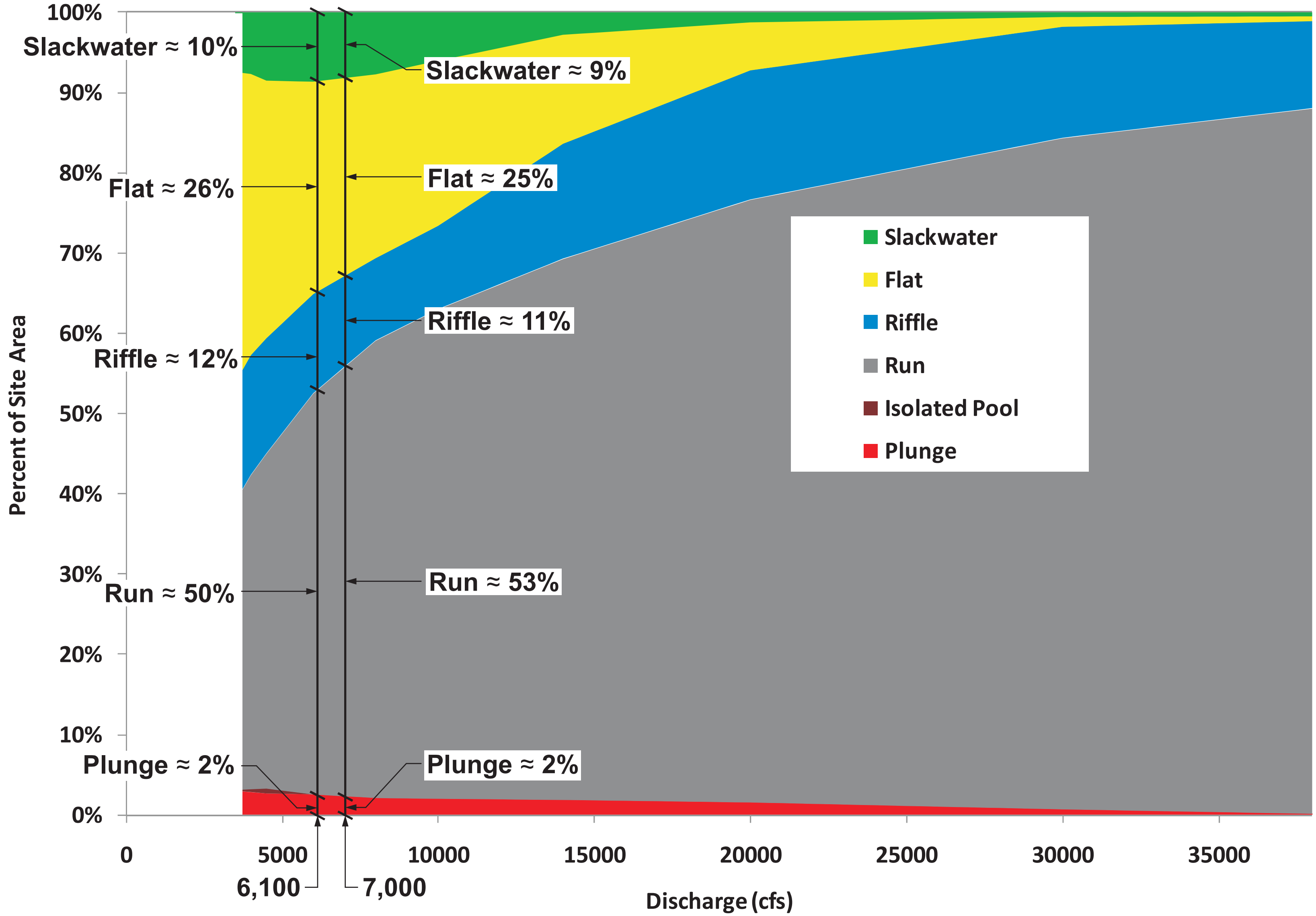
HDR
THE FLATWATER GROUP INC.
TETRA TECH
MEI

Percentage of Habitat Classification Area for Q = 7,000 cfs and 7,900 cfs

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date
Dec. 2009

Figure
44



HDR
THE FLATWATER GROUP INC.
TETRA TECH
MEI

Percentage of Habitat Classification Area for Q = 6,100 cfs and 7,000 cfs

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date
Dec. 2009

Figure
45

Table 13. Excess to Target Flows at Grand Island vs. Flows at Louisville Between 4,000 and 6,000 cfs

Condition	# of Days for Period of Record	# of Days Between 4,000 and 6,000 cfs @ Louisville	# of Target Exceedences @ Grand Island	# of Days Below 4,000 cfs @ Louisville	Range of Flows Below 4,000 cfs @ Louisville	# of Consecutive Days Below 4,000 cfs
Spring	3,976	847	145	11	30 to 950	2 days (once)
Fall	4,017	1127	635	184	9 to 1380	2 days (16 times) 3 days (10 times) 4 days (3 times) 5 days (once) 6 days (2 times) 7 days (once) 8 days (3 times) 14 days (once)

For the March to April period, the largest amount of flow that could have been diverted for the sample set occurred on March 22, 1972. Flow at Grand Island was 3,190 cfs, thereby allowing the program to divert 1,990 cfs above the target of 1,200 cfs. Based on this stage change study, approximately 88% of the flow would have reached Louisville, which would have reduced the flow at Louisville from 5,040 cfs to 3,290 cfs. Utilizing the relationship in Figures 37 and 38, the Run classification would have been reduced from approximately 45% (± 8%) of the habitat area to approximately 34% (± 8%) of the habitat area, a decrease of 1%. The Flat classification would have been increased from approximately 30% (± 7%) to 40% (± 8%) of the habitat area, a 10% increase. Finally, the Riffle classification occupies about 14% (±6%) of the habitat area at both discharges, increasing by less than 1%. The decrease in discharge does not move the conductivity, turbidity, temperature, or dissolved oxygen outside the typical range preferred by pallid sturgeon (Figures 42 and 43).

For the October to November period, the largest amount of flow that could have been diverted for the sample set occurred on November 25, 1972. Flow at Grand Island was 2,550 cfs, thereby allowing the program to divert 1,950 cfs above the target of 600 cfs. Based on this stage change study, approximately 85% of the flow would have reached Louisville, which would have reduced the flow at Louisville from 5,860 cfs to 4,200 cfs. Based on the relationships shown in Figures 37 and 38, the Run classification would have been reduced from approximately 49% (± 8%) of the habitat area to 40% (± 8%) of the area, a decrease of 9%. The Flat classification would have increase from 27% (± 6%) to 34% (± 7%) of the habitat area, a 7% increase. Finally, the Riffle category would have increased from approximately 13% (± 5%) to 15% (± 6%) of the habitat area, a 2% increase. The decrease in discharge does not move the conductivity, turbidity, temperature, or dissolved oxygen outside the typical range preferred by pallid sturgeon (Figures 42 and 43).

Existing and new data collection efforts on the Platte River for sturgeon species (shovelnose and pallid) suggest that these species use the river during spring and fall. Maintaining suitable habitat is critical for spawning (spring) and possibly for staging areas for overwintering or upcoming spawning movements (fall). Spring is likely the most critical period so that should be protected as best possible. However, catch rates during fall 2009 sampling showed a significant pallid sturgeon presence in the Platte River as well. The issue at hand would likely be loss of habitat connectivity that prevents movements should flows be reduced significantly during spring and/or fall during diversion. Diversion of flows would likely be limited to one or a few days during any season given the information above. This duration of diversion would likely not have a long-term influence on habitat connectivity, although short term connectivity could be problematic. However, these data suggest that proper monitoring of water levels in the lower Platte River and corrective actions implemented during diversions could prevent substantial negative impacts.

Not addressed in this scope of work are connectivity and temporal availability issues. From a connectivity standpoint, pallid sturgeon are typically found in deep, swift waters. If sturgeon are not able or willing to move through shallow water environments, then access to some habitat may be limited at smaller discharges. For example, Figure F3 shows that Run and Plunge habitats are mostly connected across the width of the river, or at least could be navigated, at 6,000 cfs. Discharges less than 6,000 cfs may lower water elevations enough to limit access for pallid sturgeon if they will not or cannot move through Flat or Slackwater habitat. This means that all of the potential habitat identified from the model results may not always be accessible.

Seasonal aspects of the hydrograph and use of the Platte River by pallid sturgeon should also be considered. Until recently, the Platte River was believed to be used primarily during spring and early summer (Peters and Parham, 2008). However, pallid sturgeon have recently been captured in the Lower Platte River during the summer and early autumn months (Pegg, unpublished), suggesting that at least some individuals may use the river for longer periods of time than originally thought. This also highlights the need to understand the life-cycles of pallid sturgeon to ensure that timing of releases does not significantly interfere with life-history requirements. For example, pallid sturgeon and many other riverine fishes have evolved to use the natural increase in spring flows to initiate spawning behaviors. Additional water released at this time may be less stressful, whereas water released in late summer could stimulate a behavioral response counter to the needs of the species that could conceivably isolate individuals in marginal or unsuitable habitats when the water releases cease.

Depth and velocity are two important variables in defining useable fish habitat for single or multiple species conservation, and are typically used to define suitable habitat in lotic systems. However, Annear et al. (2004) highlight that these two variables when used alone are not sufficient to fully constitute a species-habitat relationship. Other variables such as those associated with water quality (e.g., nutrients or pollutants), biotic interactions (e.g., predator-prey dynamics), timing of habitat availability, connectivity of appropriate habitats to allow movement, food availability, and appropriate substrate types are also important in defining the number and types of fishes found in a given area. Therefore, the results from this Study should be used as one part of a larger perspective on available habitat rather than an absolute factor in driving conclusions and decisions related to population dynamics.

One of the issues when dealing with water quantity in the lower Platte River is centered on the question “Will pallid sturgeon habitat be influenced by environmental releases that benefit tern and plover nesting activities in the middle Platter River?” and related questions. The information in this report that characterizes the present water management scheme for the lower Platte River predicts the amount of water that reaches the lower end of the system, and assuming careful consideration of the timing of the water releases when they occur in the future, it seems there would be little change to the amount of habitat available to pallid sturgeon in this reach of the river. The implication is not that pallid sturgeon populations will or will not be affected, as this is outside the scope of this Study, but rather that the relative change in habitat would be very small to undetectable and thus these changes should not provide additional stress to the pallid sturgeon population.

References

Allen, J.R.L. 1968. Current ripples: their relation to patterns of water and sediment motion. Elsevier, North-Holland Publishing, Amsterdam.

Annear, T., I. Chisholm, H. Beecher, A. Locke, P Aarrestad, C. Coomer, C. Estes, J. Hunt, R. Jacobson, G. Jobsis, J. Kaufmann, J. Marshall, K. Mayes, G. Smith, R. Wentworth, and C. Stalnaker. 2004. Instream flows for riverine resource stewardship, revised edition. Instream Flow Council, Cheyenne, WY.

Bennett, J.P. 1995. Algorithm for resistance to flow and transport in sand-bed channels. Journal of Hydraulic Engineering, ASCE, v. 121, no. 8, pp. 579-590.

Blodgett, R. H. and Stanley, K.O. 1980. Stratification, bedforms, and discharge relations of the Platte River system, Nebraska. Journal of Sedimentary Petrology, v. 50, pp. 139-148.

Brice, J.C. 1964. Channel patterns and terraces of the Loup River in Nebraska. U.S. Geological Survey Professional Paper 422-D.

Brownlie, W.R. 1981. Compilation of alluvial channel data: laboratory and field. Rep. No. KH-R-43B, W.M. Keck Lab. Of Hydr. And Water Resources, California Inst. Of Technology, Pasadena, California.

Brownlie, W.R. 1983. "Flow Depth in Sand-Bed Channels." *Journal of Hydrologic Engineering*. 109(7):959-990.

Bureau of Reclamation. 2008. "SRH-2D version 2: Theory and User's Manual." Sedimentation and River Hydraulics – Two-Dimensional River Flow Modeling. Bureau of Reclamation Technical Service Center, Denver, Colorado. November.

Chow, Ven Te. 1959. "Open-Channel Hydraulics." New York. McGraw-Hill Book Company, Inc.

Church, M.A. 1972. Baffin Island sandurs: a study of arctic fluvial processes. Canadian Geological Survey Bulletin 216.

Church, M.A. and Jones, D. 1982. Channel bars in gravel-bed rivers. In Hey, R.D., Bathurst, J.C., and Thorne, C.R. (eds.), Gravel Bed Rivers, J. Wiley & Sons, New York, p. 291-338.

Collinson, J.D. 1970. Bedforms of the Tana River, Norway. Geografiska Annaler, v. 52A, pp. 32-56.

Crowley, K.D. 1983. Large-scale bed configurations (macroforms), Platte River Basin, Colorado and Nebraska: primary structures and formative processes. Geological Society of America Bulletin, v. 94, p. 117-133.

Einstein, H.A. and Barbarossa, N.L. 1952. River channel roughness. Transactions, ASCE, v. 117, pp. 1121-1146.

Engelund, F. 1966. Hydraulic resistance of alluvial streams. Journal of Hydraulic Division, ASCE, v. 92, no. 2, pp. 315-326.

Engelund, F. 1967. Hydraulic resistance of alluvial streams: closure. Journal of Hydraulic Division, v. 93, no. 4, pp. 315-326.

Engelund, F. and Hansen, E. 1967. A monograph on sediment transport in alluvial streams. Technical University of Denmark, Copenhagen.

Germanoski, D. 1989. The effects of sediment load and gradient on braided river morphology. Unpublished Ph.D. dissertation, Colorado State University, Fort Collins, CO, 407 p.

Guy, H.P., Simons, D.B., and Richardson, E.V. 1966. Summary of alluvial channel data from flume experiments: 1956-1961. U.S. Geological Survey Professional Paper 462-1, USGS, Washington, D.C.

Hawkins, C.P., Kershner, J.L., Bisson, P.A., Bryant, M.D., Decker, L.M., Gregory, S.V., McCullough, D.A., Overton, C.K., Reeves, G.H., Steedman, R.J. and Young, M.K. 1993. A hierarchical approach to classifying stream habitat features. Fisheries 18(6), pp. 3–12.

HDR, The Flatwater Group, Mussetter Engineering, and Dr. Mark Pegg. 2008b. "Lower Platte River Stage Change Study Final First Progress Report – Field Work Activities."

HDR, The Flatwater Group, Mussetter Engineering, and Dr. Mark Pegg. 2008a. "Lower Platte River Stage Change Study, Final Protocol Development Report." May.

HDR, The Flatwater Group, Mussetter Engineering, and Dr. Mark Pegg. 2009. "Lower Platte River Stage Change Study Final Second Progress Report – Field Work Activities."

Jackson, R.G., II, 1975. Velocity-bedform-texture patterns of meander bends in the lower Wabash River of Illinois and Indiana. GSAB, v. 86, pp. 1511-1522.

Kehmeier, J.W., Valdez, R.A., Medley, C.N., and Myers, O.B. 2007. Relationship of fish mesohabitat to flow in a sand-bed southwestern river. North American Journal of Fisheries Management, no. 27, pp. 750-764.

Komar, P.D. 1983. Shapes of streamlined islands on Earth and Mars: Experiments and analyses of the minimum-drag form. Geology, v. 1, p. 651-654.

Komar, P.D. 1984. The Lemniscate loop-comparisons with the shapes of streamlined landforms. Journal of Geology, v. 92, p. 133-145.

Leopold, L.B. and Wolman, M.G. 1957. River channel patterns: Braided meandering and straight. U.S. Geological Survey Professional Paper 282-B, 47 p.

Meyer-Peter, E. and Müller, R. 1948. Formulas for bed load transport. In Proceedings of the 2nd Congress of the International Association for Hydraulic Research, Stockholm, 2: Paper No. 2, pp 39-64.

Miall, A.D. 1977. A review of the braided-river depositional environment. Earth Science Review, v. 13, p. 1-62.

Middleton, G. V., and Southard, J.B. 1984. Mechanics of sediment movement, 2nd edition. Society for Sedimentary Geology, Tulsa, Oklahoma.

Mussetter Engineering, Inc. 2004. Geomorphic and Hydraulic Assessment of Channel Dynamics and Habitat Formation for Pecos Bluntnose Shiner at Four Sites in the Critical Habitat and Quality Reaches, Pecos River, New Mexico. Prepared for the New Mexico Interstate Stream Commission, Santa Fe, New Mexico, December.

Nelson, J.M., McLean, S.R., and Wolfe, S.R. 1993. Mean flow and turbulence fields over two-dimensional bedforms. Water Resources Research, v. 29, no. 12, pp. 3935-3954.

Nordin, C.F., Jr. 1964. Aspects of flow resistance and sediment transport, Rio Grande near Bernalillo, New Mexico. U.S. Geological Survey Water Supply Paper 1498.

Nordin, C.F., Jr. 1976. Flume studies with fine and coarse sands. U.S. Geological Survey Open-file Report 76-762, USGS, Washington, D.C.

Pegg, M. Unpublished. Ongoing Platte River research.

Peters, E.J., and J.E. Parham. 2008. Ecology and management of sturgeon in the Lower Platte River, Nebraska. Nebraska Technical Series No. 18, Nebraska Game and Parks Commission, Lincoln, Nebraska.

Polivka, K. M. 1999. The microhabitat distribution of the Arkansas River shiner, Notropis girardi: a habitat mosaic approach. Environmental Biology of Fishes 55, pp. 265–278.

Simons, D.B. and Richardson, E.V. 1961. Forms of Bed Roughness in Alluvial Channels. Journal of the Hydraulics Division, ASCE, v. 87, no. HY3, Proc. Paper 2816, May, pp. 87-105.

Simons, D.B. and Richardson, E.V. 1966. Resistance to Flow in Alluvial Channels. U.S. Geological Survey Professional Paper 422-J.

Smith, J.D. and McLean, S.R. 1977. Spatially averaged flow over a wavy surface. Journal of Geophysical Research, v. 84, no. 12, pp. 1735-1746.

Smith, N.D. 1974. Sedimentology and bar formation in the Upper Kicking Horse River, a braided outwash stream. Journal of Geology, v. 82, p. 205-223.

Smith, N.D. 1978. Some comments on terminology for bars in shallow rivers, In Miall, A.D. (ed.), Fluvial Sedimentology, Canadian Society of Petroleum Geologists Memoir No. 5, p. 85-88.

Task Force on Bedforms, 1966. Nomenclature for bed forms in alluvial channels. Proceedings of the ASCE, Journal of the Hydraulics Division, v. 92, pp. 51-64.

USACE. 1991. HEC-6, Scour and Deposition in Rivers and Reservoirs, User's Manual. Hydrologic Engineering Center, Water Resources Support Center, Davis, California.

USACE. 2008. "HEC-RAS River Analysis System, Version 4.0." Institute for Water Resources, Hydrologic Engineering Center. Davis, California. March.

USACE-OD. 2002. "Hydraulic Analyses Lower Platte River, Nebraska, Flood Insurance Study, Missouri River to Douglas-Sarpy County Line."

USFWS. 2002a. "Estimated Historic Losses by Stream Reach in the Platte River Below Grand Island, Nebraska, and Implications for Program-Augmented Flows." Draft Report. U.S. Fish and Wildlife Service, Mountain-Prairie Region (Region 6). May.

USFWS. 2002b. "Summary Report on the Potential of Changes in Central Platte Flow Conditions to Affect Flows in the Lower Platte." Draft Report. U.S. Fish and Wildlife Service, Mountain-Prairie Region (Region 6). December.

USGS. 2009. Personal communication with D. Curtis. September 25.

Vadas, R. L. and Orth, D.J., 1998. Use of physical variables to discriminate visually determined mesohabitat types in North American streams. Rivers 6, pp. 143–159.

van Rijn, L.C. 1982. Equivalent roughness of alluvial bed. Journal of Hydraulic Engineering, ASCE, 108(10), pp. 1215-1218.

van Rijn, L.C. 1984. Sediment Transport: Suspended Load Transport: Part I: bed-load transport. Journal of Hydraulic Engineering, ASCE, v. 110, no. HY11, pp. 1431-1456.

Appendix A

Estimated Historic Losses by Stream Reach in the
Platte River Below Grand Island, Nebraska,
and Implications for Program-Augmented Flows
Draft Report
May 2002

ESTIMATED HISTORIC LOSSES BY STREAM REACH IN THE PLATTE RIVER BELOW GRAND ISLAND, NEBRASKA, AND IMPLICATIONS FOR PROGRAM-AUGMENTED FLOWS

U.S. Fish & Wildlife Service
Mountain-Prairie Region (Region 6)
May 15, 2002 *DRAFT*

Executive Summary

A daily flow tracking and accounting model was constructed for three reaches of the Platte River below Grand Island, Nebraska, in order to evaluate historic evaporation and seepage losses associated with flow in each of these reaches. A key objective of this exercise is to estimate the proportion of potential Platte River Program-augmented flows at Grand Island, Nebraska, that would be expected to reach the Platte River at Louisville under conditions that existed during the period evaluated.

To construct this model, daily stream flow gage data for the lower Platte River system were compiled for water years 1975 through 1994 (and, for one reach, for calendar years 1997 through 2000). In addition, monthly pan evaporation measurements were collected from two Nebraska weather stations (Grand Island and Omaha). For each reach, open-water surface areas and vegetated riparian areas were estimated. Based on these inputs, and based on assumed travel times for flow between the gages, estimates were made for daily reach losses due to evaporation, evapotranspiration and seepage for every day of the period of record.

The results of this analysis are summarized in Figures 9 and 10 of this report. The results suggest that less than 60% (in September of the worst years) to over 90% (in December, January, March, April and May of the best years) of 100 cubic feet per second (cfs) of Program-augmented flow at Grand Island would be expected to reach Louisville. (100 cfs equates to about 6,000 acre-feet/month). In median years, no more than 79% to 91% of this water would reach Louisville from October through June; in July through September, this percentage falls to 65% to 70%. For a variety of reasons described in Section 3 of this report, we believe that these estimates are generous. The actual percentages reaching Louisville are unlikely to be greater than the values presented here, and in many months they may be significantly less.

As the presumed flow augmentation at Grand Island is increased above 100 cfs, the proportion lost to evaporation decreases (particularly in summer months), and the proportion reaching Louisville increases. Conversely, flows of less than 100 cfs are expected to experience higher proportional losses.

This analysis was based on conditions that prevailed over the evaluated time period. To the extent that conditions in the lower Platte River have changed – for example, to the extent that more groundwater is pumped from alluvial aquifers adjacent to the river – the effects on future augmented Program flows in the lower Platte River may not be fully addressed by this analysis.

1. Introduction

This report describes the USFWS analysis of historic daily losses (including evaporative and seepage losses) associated with flow in three Platte River stream reaches downstream of Grand Island, Nebraska, as follows:

- Platte River from Grand Island to Duncan, Nebraska ("Reach 20");
- Platte River from Duncan to North Bend, Nebraska ("Reach 21"); and
- Platte River from North Bend to Louisville, Nebraska ("Reach 22").

These analyses were carried out pursuant to Phases II and III of the USFWS "Plan for Testing the Ability of the Program to Affect Lower Platte River Flows" (hereafter referred to as "the Plan") dated February 28, 2002. That Plan proposed estimating daily losses (evaporation plus seepage) associated with each of these stream reaches during water years 1975-1994, for purposes of developing estimates of the percentage of flow in the Platte River at Grand Island reaching Louisville under various flow conditions. When hypothetical quantities of Program-augmented flow are added to these historic Grand Island flows, the likely effects at Louisville also can be estimated.

For this report, a daily stream flow tracking and accounting spreadsheet was built using daily stream flow records compiled for four locations along the main stem of the Platte River beginning at Grand Island, Nebraska, plus five locations representing major tributaries entering the Platte River below Grand Island. These sites are identified in **Table 1** and illustrated in **Figure 1**. Different periods of record were used for different gages for reasons that are explained in the Methodology section that follows.

Table 1

Platte River Basin Gage Locations Used for Historic Loss Analysis

Nebraska Gage Location	Stream Reach	Period of Record Used in This Analysis
Platte River at Grand Island (06775000)	Reach 20	1975 - 1994
Platte River at Duncan (06774000)	Reach 20/21	1975 - 2000
Loup River at Genoa (06793000)	Reach 21	1997 - 2000
Loup Power Plant Return (estimated from power generation records)	Reach 21	1997 - 2000
Shell Creek near Columbus (06795500)	Reach 21	1997 - 2000
Platte River at North Bend (06796000)	Reach 21/22	1975 - 2000
Elkhorn River at Waterloo (06800500)	Reach 22	1975 - 1994
Salt Creek at Greenwood (06803555)	Reach 22	1975 - 1994
Platte River at Louisville (06805500)	Reach 22	1975 - 1994

2. Methodology

2.1 Daily Tracking and Accounting

The daily flow tracking and accounting spreadsheets used for this analysis were built using Microsoft Excel software. For each of the three stream reaches, a daily mass-balance evaluation (inflow vs. outflow) was performed.

Flows entering the reach (including but not limited to Platte River flows at the top of the reach) were considered subject to two kinds of losses along that reach: (1) losses due to evaporation and evapotranspiration (always greater than zero); and (2) losses due to seepage (which may or may not have occurred on the day being evaluated).

Losses due to evaporation and evapotranspiration (ET) were estimated using procedures described in Section 2.4.

Losses due to seepage (if any) were calculated from daily a mass-balance analysis of the reach, as follows:

Net seepage loss (if any) = Lagged inflows at one or more locations
- Outflow at the bottom of the reach
- Estimated daily evaporation and ET losses

Methods of quantifying the values used in the above equation for daily inflows and outflows, for daily evaporation and ET, and for inflow lag times are described in the following sections of this report. Some important assumptions implicit in this analysis are detailed in Section 3. Application of these estimates to the issue of "the ability of Program-augmented flows to effect flows in the lower Platte" is addressed in Sections 4 and 5 of this report.

2.2 Daily Inflows and Outflows

Mean daily stream flow records for the gages and periods of records listed in Table 1 were incorporated into spreadsheets for the mass-balance analysis described above. In all but two cases, the stream flow values that were used were the official, unadjusted USGS gage estimates. The two exceptions were:

(1) Loup Power Plant Return flows

Flows contributed to the Platte River from the lower Loup River "Columbus Hydroelectric Powerhouse" are substantial, and they vary substantially from day to day. For the 1997-2000 period of available daily data, estimated tailrace flows from this hydroelectric facility exceeded flow in the Loup River at Genoa on most days, especially during non-winter months. Thus, any meaningful analysis of daily gains/losses along this reach of the river should consider daily return flows from the Columbus Powerhouse.

Unfortunately, gaged measurements of return flows to the Platte River from the Columbus Powerhouse do not exist. The closest corresponding site of gaged flows is for diversions from the Loup River to the powerhouse through the Loup Power Canal (USGS gage #06792500). Because substantial capacity exists to store these diversions upstream of the power plant in Lake Babcock, these daily diversions do not correspond well to daily return flows to the Platte River. Thus they were not used in this accounting model. The only way to estimate daily return flows with reasonable accuracy is to estimate tailrace flows based on the amount of hydroelectric power generated during that day. To our knowledge, these daily tailrace flow estimates have been compiled only for the period of January 1997 through December 2000. It is our understanding that these tailrace flow estimates are based on the following formula:

Mean daily tailrace flows in CFS = 5.08 * megawatt-hours generated

For the sake of this analysis, the tailrace flows are assumed to equate to return flows reaching the Platte River. In fact, as noted by Loup Power District President/CEO R.E.White (2001), these estimates do not include "the Lost Creek diversion channel which enters the Tailrace just downstream of the powerhouse", nor do they account for the fact that "there are also three irrigators who remove water from the tailrace".

To cross-check the reasonableness of the hydropower-based tailrace flow estimates, annual diversions to the Loup Hydropower Canal (gage #06792500) were compared against estimated annual tailrace flows from the power plant from 1975 to 1994. On an annual basis, the total tailrace flow estimates were about 12% lower than the total flows through the Loup Power canal. For individual years, differences ranged from 9% to 15% lower. These differences likely reflect, at least in part, conveyance losses and evaporative losses from Lake Babcock.

(2) Loup River at Genoa gage

Daily Loup River flows that are not diverted to the Loup Power Canal historically have been measured at either the Loup River at Columbus, Nebraska (USGS gage #06794000, prior to 10/10/1978) or the Loup River at Genoa, Nebraska (USGS gage #06793000, 4/1/1929 to present). For this Platte River analysis, the former gage location is preferable to the latter because it is approximately 24 miles closer to the Platte River confluence. In fact, daily flows in the Platte River at Columbus were higher than flows in the Platte River at Genoa on 92% of days during the 1954 -1978 period. This is not surprising, given the significantly larger drainage area associated with the lower gage.

In an effort to develop more realistic estimates of daily inflows from the Loup River, USFWS established monthly regression relationships between daily flows at these two gages based on this 25-year period of overlapping record. For dates after 10/10/78, we used these relationships to estimate inflows to the Platte River based on flows measured at Genoa. The details of this procedure are described in **Appendix A**.

2.3 Lag Times

To construct the daily flow tracking and accounting model needed for this analysis, estimates of mean flow travel times between gages are required. These travel time (lag) estimates were developed under Phase I of the Plan (USFWS 2002a, 2002b), and are summarized in Table 2.

Table 2

Estimated Prevailing Travel Times Between Platte River Basin Locations

From-To Gage Locations	Reach Number	Estimated Prevailing Travel Time in Days
Grand Island to Duncan	20	1
Duncan to North Bend	21	1
Loup River (Genoa gage) to North Bend	21	1
Loup Hydropower Plant Return to North Bend	21	1
Shell Creek near Columbus to North Bend	21	0
North Bend to Louisville/Ashland	22	1
Elkhorn River (Waterloo gage) to Louisville/Ashland	22	0
Salt Creek (Greenwood gage) to Louisville/Ashland	22	0

The USFWS analyses producing the above estimates did suggest that prevailing travel times may vary under different flow conditions. For example, the data suggest that travel times in Reach 20 and 22 may be somewhat greater during the July-through-September period in dry years. However, we concluded that the times listed in Table 2 are probably the best general estimates to use for subsequent tracking and accounting models of the lower Platte River.

2.4 Evaporation and ET Losses

2.4.1 Estimated Areas of Open-Water Channel Evaporation and Vegetative Evapotranspiration

In order to estimate losses associated with (1) open-water evaporation and (2) vegetative evapotranspiration (ET) along each of the three Platte River reaches, estimates of the following were required:

- Total open-water area by sub-reach (for a discussion of "sub-reaches", see Section 2.5), and
- Total vegetated island and riparian areas contributing to ET of Platte River water by sub-reach.

Both of these quantities were estimated from 1993 and 1994 digital orthophoto quarter quadrangles (DOQQs) of the lower Platte River corridor. River channel features were digitized on-screen using a subset of 9 approximately evenly-spaced DOQQs, out of a total of 55 DOQQs covering the entire Platte River channel between Grand Island and Duncan (**Figure 2**). This equates to three DOQQs per stream reach. We assume that these DOQQs are reasonably representative of the corresponding reaches.[1]

In order to establish a reasonable range of values encompassing typical Platte flow conditions, "conservative" and "liberal" estimates of open-water areas were made for each stream reach. The conservative estimate excluded all exposed and unvegetated sand islands, sand bars, and beaches. The liberal estimate included these features, under the assumption that they would be inundated under high flow conditions.

DOQQ images used for the channel analysis were taken on one of eight different dates in 1993 and 1994. Each of these dates, and the corresponding flow conditions in the Platte River at Grand Island on that date, are listed in Table 3.

Table 3

Dates of Digital Orthophoto Quarter-Quadrangle (DOQQ) Images and Corresponding Flow Conditions in the Platte River at Grand Island

Image Date	Mean Daily Flow at Grand Island on Image Date (cfs)	Long-term Mean Daily Mean Flow at Grand Island on this Day of Year (cfs)*
4/14/1993	1,490	1,962
4/16/1993	1,140	1,900
4/21/1993	1,440	1,915
4/22/1993	1,740	1,888
5/04/1993	879	1,990
5/13/1993	1,810	2,175
3/21/1994	2,000	2,405
4/18/1994	1,730	1,864

* Based on a 67-year period of record from the USGS Daily Streamflow Statistics Web page, April 2002

For comparison, the mean daily flow in the Platte River at Grand Island has fallen in the range of 1,001 to 2,000 cfs on approximately 31% of days since 1940. Flows were 1,000 cfs or less on approximately 46% of days during this period, and greater than 2,000 cfs on approximately 23% of days (Stroup et al., 2001). Thus, Platte River flows at Grand Island, while somewhat lower-than-average for the specific days on which the DOQQ images were taken, were reasonably representative of river flows on a long-term, year-round basis. For this reason, we consider these acceptable DOQQs for purposes of estimating mean open-water channel widths in the lower Platte River.

For estimates of vegetative ET, the following areas were quantified and summed from the DOQQs (after Nebraska DNR, 2001):

- Vegetated islands less than 20 acres in size (entire area);
- Vegetated islands greater than 20 acres in size (100-foot perimeter area only); and

[1] DOQQ digitization is an ongoing effort; USFWS intends to digitize at least four or five DOQQs per stream reach before finalizing this analysis.

- Both channel shorelines (100-foot channel perimeter area, including the left and right banks).

Rates of evapotranspiration from these areas were estimated as described in Section 2.4.2.

Results of the channel areas analysis using the DOQQs are summarized below. These results are expressed in terms of *mean width* of the river. In other words, the areal estimates are divided by the length of river evaluated.

Note: Table 4 and the subsequent analyses will be updated as USFWS completes additional DOQQs

Table 4

Summary of Estimated Mean Open Water and Vegetative ET Widths For Each Stream Reach

Platte River Reach	Total # DOQQs Evaluated	"Conservative" Open Water Channel (ft)			"Liberal" Open Water Channel (ft)			Vegetative ET Width (ft)		
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
20	3	1,349	1,563	1,445	1,432	1,643	1,536	489	1,010	740
21	3	1,693	2,354	1,957	1,881	2,692	2,252	391	1,125	822
22	3	1,224	1,690	1,505	1,392	1,807	1,639	234	674	463

At all four of the main stem Platte River gages (Grand Island, Duncan, North Bend, and Louisville), average monthly streamflow is higher than the average year-round flow in the months of February through June, and lower than the year-round average in July through January. For this reason, we applied the mean "liberal" estimate of open-water width to all February through June flows in all three reaches to estimate evaporative losses, and the mean "conservative" estimate to all other months. (For example, evaporative losses experienced by flows in Reach 20 in June of 1975 were calculated on the basis of an assumed mean open-water surface width of 1,536 feet, while in July of 1975 a width of only 1,445 feet was assumed).

To estimate additional ET losses associated with the vegetated islands and riparian areas, we applied the same mean width for each reach in all months.

Section 5.2 of this report discusses the sensitivity of the daily flow accounting model to the assumed open-water area. The results indicate that the model is only moderately sensitive to this variable. For this reason, we did not attempt to further refine the areal estimates to account for variations in flow conditions, beyond the high-flow vs. low-flow seasonal adjustments already described.

2.4.2 Estimated Unit-Area Rates of Channel Evaporation and ET

Estimated daily rates of evaporation and evapotranspiration from the Platte River channel were based on monthly "Class A" pan evaporation measurements for the October 1974 - September 1994 period (also January 1997 – December 2000 for Reach 21) from two Nebraska weather stations: Grand Island and Omaha. Records from Grand Island are complete for this period; records from Omaha are complete except for November 1991 through April 1992. For the missing Omaha values, synthetic monthly values were estimated by adjusting Grand Island pan evaporation by the average long-term ratio between monthly pan evaporation rates at the two stations.

Reach evaporation and ET estimates were based on these weather station data as follows:

- Reach 20: based on Grand Island pan evaporation measurements only;
- Reach 21: based on the mean of Grand Island and Omaha pan evaporation measurements;
- Reach 22: based on Omaha pan evaporation measurements only.

Pan evaporation values were adjusted by a pan coefficient factor of 0.70 to estimate the actual monthly rate of evaporation from the Platte River open water surface. For estimates of evapotranspiration loss rates from vegetated areas, an additional factor of 0.5 was applied to estimate ET rates during the winter season (October through April) and 0.8 was applied to estimate ET rates during the growing season (May through September). Our understanding is that these factors are generally consistent with those used by the Nebraska Department of Natural Resources for their Platte River evaluations upstream of Grand Island (Nebraska DNR, 2001).

2.5 Subreach Accounting

In setting up the tracking and accounting spreadsheets, two of the river reaches were further subdivided into shorter sub-reaches. This facilitated accounting for the fact that a substantial portion of the gaged tributary inflow along these reaches occurs a considerable distance downstream from the top of the reach, and thus is not subject to the same evaporative and seepage losses as is Platte River inflow at the top of the reach. Specifically:

- For purposes of accounting for losses, Reach 21 (which totals 41 miles in length) was subdivided into two sub-reaches: Duncan to the Loup River confluence (10 miles), and the Loup River confluence to North Bend (31 miles). Inflows from the Loup River system were subjected to seepage, evaporation and ET losses only over the lower sub-reach.

- For purposes of accounting for losses, Reach 22 (which totals 56.5 miles in length) was subdivided into three sub-reaches: North Bend to the Elkhorn River confluence (38.5 miles), the Elkhorn River confluence to the Salt Creek confluence (9 miles) and the Salt Creek confluence to the Louisville gage (9 miles). Inflows from the Elkhorn and Salt Creek watersheds were subjected to seepage, evaporation and ET losses only for the corresponding lower sub-reaches.

Table 5 Sub-reaches Used for Platte River Flow Accounting	
From-To Locations	**Stream Distance (miles)**
Grand Island to Duncan (Reach 20; no subreaches)	55
Duncan to Loup River confluence (Reach 21, Subreach A)	10
Loup River confluence to North Bend (Reach 21, Subreach B)	31
North Bend to Elkhorn River confluence (Reach 22, Subreach A)	38.5
Elkhorn River confluence to Salt Creek confluence (Reach 22, Subreach B)	9
Salt Creek confluence to Louisville (Reach 22, Subreach C)	9

2.6 Calculating Historic Losses

For purposes of characterizing flows in the lower Platte River, we are interested in the historic portions of Platte River inflows that were lost to evaporation and to seepage in each of the three reaches. In subsequent modeling ("Phase III" of the Plan), total losses due to evaporation will be assumed constant for any given reach on any given day, and evaporation losses associated with any additional Program water will be prorated accordingly. Percent seepage losses associated with additional Program flows will be assumed to be the same as they were for historic Platte flows.

For this reason, a **percent seepage loss** associated with *only the Platte River inflow* at the top of the subject reach was calculated for each day. The seepage loss in cfs associated with the Platte River inflow was assumed to be:

$$\text{Total reach seepage loss (cfs)} \;*\; \frac{\text{Platte River inflow, distance-weighted}}{\text{Sum of all gaged inflows, distance-weighted}}$$

Since Platte River inflow was always subject to seepage losses over the entire length of the reach, the "distance-weighted" factor for Platte inflow was always 1.0 (*e.g.*, 41 miles/41 miles for Reach 21). Therefore the Platte inflow seepage loss was always:

$$\frac{\text{Seepage loss} \;*\; \text{Platte River inflow}}{\text{Sum of all gaged inflows, distance-weighted}}$$

Which was converted to a percentage of Platte River inflow as follows:

$$\frac{\text{Seepage loss} \;*\; \text{Platte River inflow}}{\text{Sum of all gaged inflows, distance-weighted}} \;*\; \frac{100}{\text{Platte River inflow}}$$

Which simplifies to this formula:

$$\frac{\text{Seepage loss * 100}}{\text{All gaged inflows, distance-weighted}}$$

For example: on July 31, 1999, for Reach 21, the analysis was based on the following figures:

1130 cfs	Inflow from the Platte River at Duncan
286 cfs	Inflow from the Loup River at Columbus (estimated; see Section 2.2)
961 cfs	Inflow from the Loup Power Plant tailrace flows (estimated; see Section 2.2)
31 cfs	Inflow from Shell Creek near Columbus
135 cfs	Estimated evaporation and ET losses along entire Reach 21
1730 cfs	Outflow from the Platte River at North Bend (one lagged day later)

Using these figures, the net ungaged (seepage) loss was calculated as:

Inflows – Outflows – Estimated evaporation and ET losses

Or in this case:

(1130 + 286 + 961 + 31) – 1730 – 135 = 543 cfs

The percent seepage loss associated with the Platte River at Duncan inflows (only) was calculated as:

$$\frac{\text{543 cfs loss * 100}}{\text{(41 miles/41 miles)*1130 cfs + (31 miles/41 miles)*(286 + 961 + 31 cfs)}}$$

which equates to 25.9% of the Platte River inflow at Duncan. The "distance-weighted" inflows in the denominator indicate that the Platte at Duncan inflows are subject to seepage losses over the entire length of the reach, while the other three inflows share these losses over only the lower 31 miles of the 41-mile reach. As a result, 293 cfs of the total 543 cfs of seepage losses along this reach on this day were considered losses associated with Platte River inflow at Duncan.

Percent ungaged gains were not calcuated, as this quantity is not relevant to this analysis. When there was no net seepage loss over the length of the reach (*i.e.*, when there was a net gain), then 100% of the Platte River inflow at the top of the was assumed to arrive at the bottom of the reach reach (except for that lost to evaporation and ET), and none was presumed lost to seepage. This is, as discussed in Section 3, a liberal assumption, as seepage losses to inflows may have occurred at some point along the reach, but were overwhelmed by gains occurring elsewhere along the reach.

3. Assumptions

The methodologies described above necessarily incorporate a number of highly simplifying assumptions. In addition to those already described, some major assumptions include:

1. ***Channel flow conveyance characteristics (e.g., rates of loss or gain) were assumed to be relatively constant over the entire length of the examined reach on any given day***. This is perhaps the most problematic assumption, as it presents many opportunities to underestimate

(or fail to identify) losses over subsections of a full reach. In the current analysis, stream flow gages are typically separated by considerable distances (*e.g*., 55 miles between Grand Island and Duncan). Over such distances, it is very possible that some portions of the stream were losing while others were gaining. In such cases, the mass-balance calculation of seepage loss may seriously overestimate the portion of water at the top of the reach which actually reached the bottom, because the extent of losses in some subreaches was partially or fully masked by gains in others. The best "solution" for coping with this limitation (short of installing additional stream flow gages) is to explicitly recognize that, with respect to our mass-balance analysis, the seepage loss estimates are necessarily conservative. That is, to the extent that our other mass-balance quantities are accurate, seepage losses may be considerably greater than we estimated, but would not be less.

2. ***Open water areas in each reach were assumed to be approximately the same every year between February and June, and between July and January***. This was already discussed in Section 2.4.1. Obviously, open water areas will generally be greater during days of higher-than-normal flow, and less during days of lower-than-normal flow. While the option exists to fine-tune our monthly (and daily) evaporation estimates for each reach based on presumed relationships between surface area and rate of flow, our sensitivity analysis (Section 5.2) suggests that such adjustments would have a negligible effect on the final results.

3. ***Evaporation and ET rates per unit area were assumed constant for all days in any given month***. In reality, evaporation and ET rates along each reach vary daily with the prevailing weather conditions. No attempt was made to make daily adjustments; instead, daily values were derived from the corresponding monthly pan evaporation rates at the corresponding weather station(s). For example, if the entire month exhibited a higher-than-normal rate of evaporation, then each day in that month also had a higher-than-normal rate in the mass-balance model.

4. ***Travel times between gages were assumed to be those listed in Table 2 in all months of all years.*** As already mentioned, a previous analysis (USFWS, 2002a) suggests that travel times in Reach 20 and 22 may be somewhat greater during the July-through-September period in dry years. To the extent that travel times are greater, evaporation losses would also be greater than estimated in this analysis. Model runs do indicate that increasing the one-day travel times in this model to two days has a significant impact on the bottom-line Program water loss estimates (see Section 5.2). Thus, this assumption implies that, in certain months of certain years, we may be underestimating expected Program water losses.

5. ***The effects of individual storm/precipitation events were ignored***. In reality, storm events that generate increased stream flow as the result of direct precipitation on the stream channel and ungaged inflow along the reach may partially or fully mask seepage losses to inflow at the top of the reach (see Assumption #1). This is another simplification that suggests our seepage loss estimates are conservative.

6. ***The effects (if any) of adjacent well pumping on river flows were included in seepage losses***. That is, no attempt was made to separately quantify or account for the effects of well pumping near the river channel. If we assume that future Program flows in the lower Platte

River will be subject to comparable well pumping activities near the river, it is reasonable to include this factor in our loss estimates. However, to the extent that pumping from alluvial aquifers has increased or will increase relative to the period modeled, our analysis may again underestimate the losses that will be suffered by Program-augmented flows in the future.

7. ***The 1997-2000 time period evaluated for Reach 21 was assumed to represent conditions roughly comparable to the Water Year 1975-1994 period used to evaluate the other two reaches of the lower Platte River***. In reality, the 1997-2000 period in the lower Platte basin was, on average, somewhat wetter than the 1975-1994 period, based on a comparison of total streamflow measured in the Platte River at Louisville during these years.

8. ***Columbus Powerhouse tailrace flows were assumed to accurately represent (in daily quantity and timing) return flows to the Platte River associated with Loup Power Canal diversions***. As already mentioned, the tailrace flows do not account for water removed from the tailrace by three irrigators. On the other hand, the tailrace estimates do not include inflows to the Platte River from Lost Creek – neither flood flows diverted into the tailrace channel through a flood diversion channel, nor regular Lost Creek flows that eventually enter the Platte River some 20 miles downstream. Without further investigation, we do not know the extent to which this simplifying assumption introduces errors.

At least four of the above assumptions (#1, #4, #5, and #6) are likely to result in an underestimation of losses (either evaporation or seepage or both) in at least some months of some years. The impacts of the other assumptions are either neutral or difficult to determine. Thus, it is our belief that the "percent delivery of Program water to Louisville" estimates presented in this report are probably generous; the actual percentages may be significantly less in many months.

4. Analysis and Results: Historic Losses to Evaporation and Seepage

Additional details regarding the analytical procedures used for each of the three reaches, along with the results of the historic loss analysis, are provided below.

4.1 Grand Island to Duncan, Nebraska (Reach 20)

No stream gage data are available for this reach between the two endpoints of Grand Island (upstream) and Duncan (downstream). Thus, this analysis consisted of direct mass-balance calculations for the entire stream reach between these two gages.

Total estimated daily evaporation + ET losses over the entire length of Reach 20 ranged from a low of 4 cfs (February 1988) to a high of 190 cfs (June 1988). Over the Water Year 1975-1994 period evaluated, the percent of days in each month for which seepage losses were also evident for inflow at Grand Island are summarized in **Figure 3**. The magnitude of these losses, when they did occur, are summarized in **Figure 4** as percent of Platte River inflow at Grand Island.

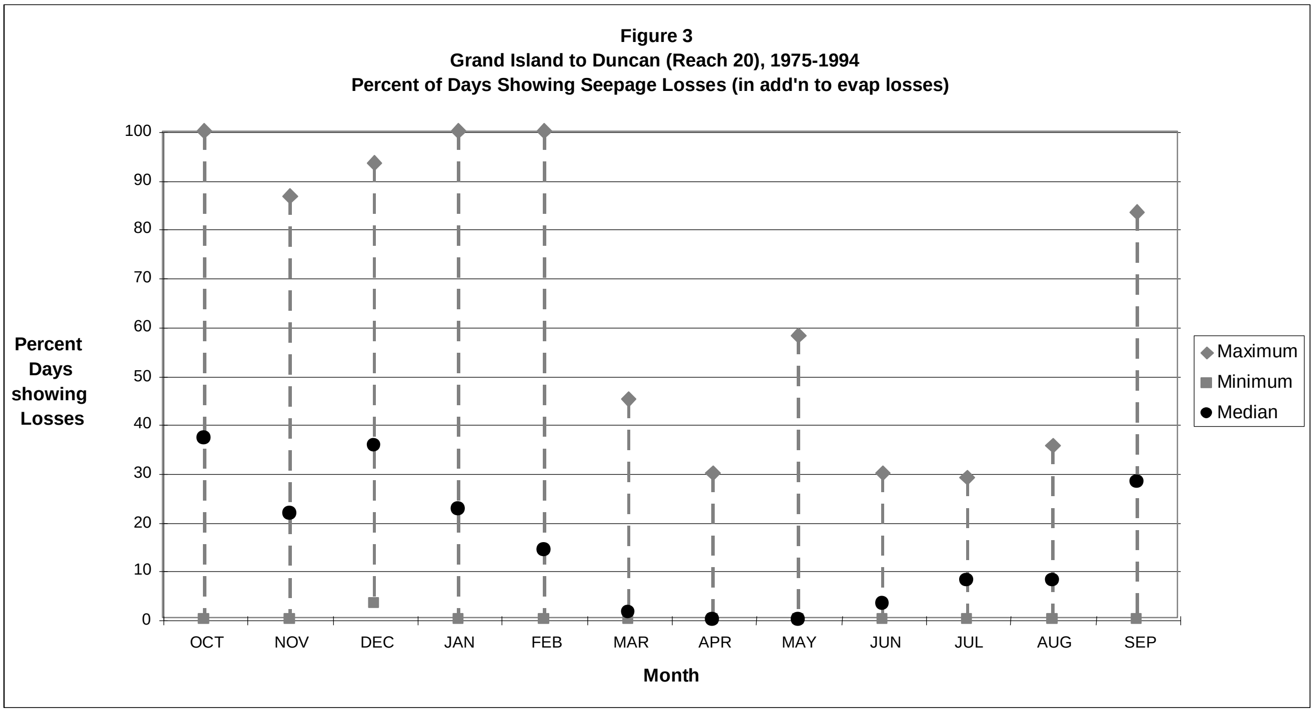


Figure 3
Grand Island to Duncan (Reach 20), 1975-1994
Percent of Days Showing Seepage Losses (in add'n to evap losses)
Percent Days showing Losses
100
90
80
70
60
50
40
30
20
10
0
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
Month
Maximum
Minimum
Median

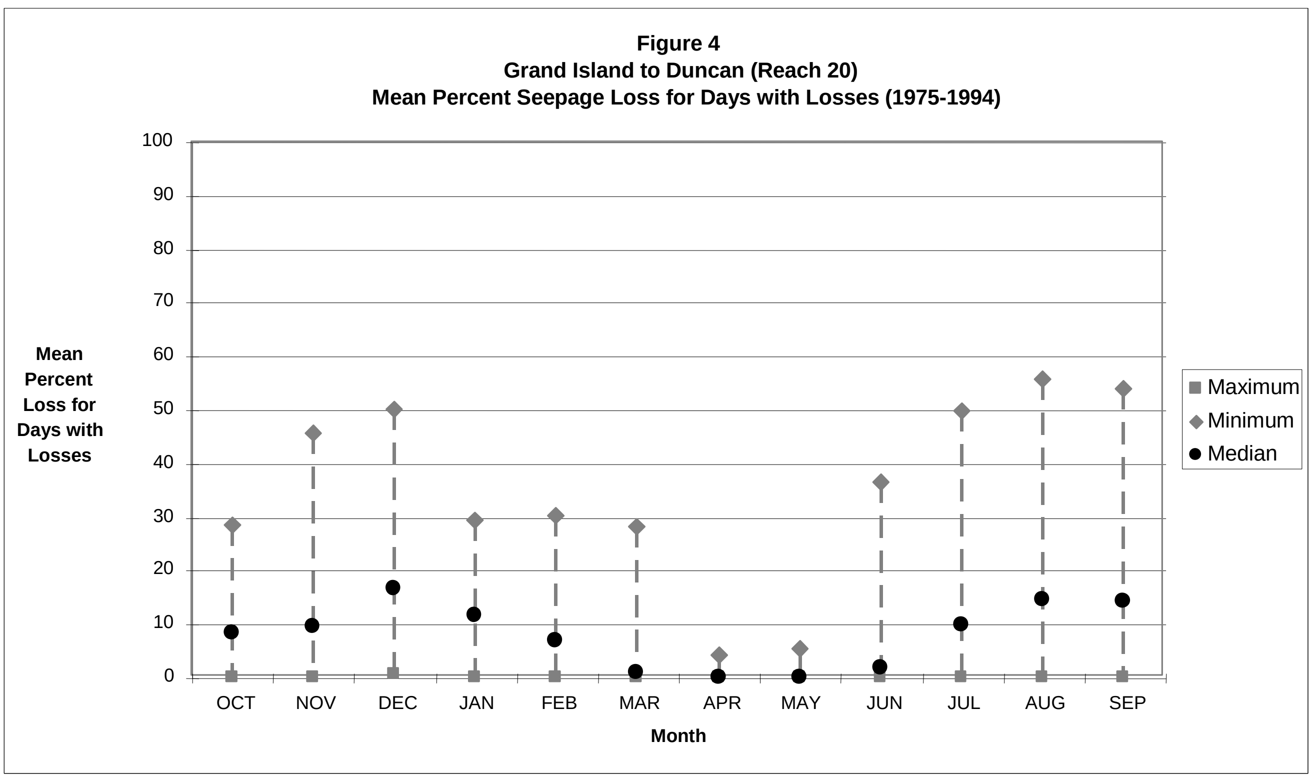


Figure 4
Grand Island to Duncan (Reach 20)
Mean Percent Seepage Loss for Days with Losses (1975-1994)
Mean Percent Loss for Days with Losses
100
90
80
70
60
50
40
30
20
10
0
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
Month
Maximum
Minimum
Median

As indicated by Figure 3, Reach 20 is not typically a losing reach of the Platte River during any month of the year. It is most commonly a losing reach in the months of September through February, and least commonly a losing reach in March through August. In a "typical" (median) year, seepage losses in March, April, May, and June are negligible. When seepage losses do occur (in September through January, this typically occurs on 21 to 38 percent of days), losses are rarely greater than 40 or 50 percent of inflow, and are typically in the range of 9 to 16 percent (Figure 4).

Implications of these characteristics relative to Program-augmented flows are discussed in Section 5.

4.2 Duncan to North Bend, Nebraska (Reach 21)

Stream gage data are available for this reach not only at the two endpoints of Duncan (upstream) and North Bend (downstream), but also at three points of tributary inflow to the reach (the Loup River near Genoa, return flows from the lower Loup basin Columbus Powerhouse, and Shell Creek near Columbus). Thus, this analysis considered four points of inflow to the reach, and evaluated evaporation losses separately for two subreaches (above and below the Loup River confluence). Although the Columbus Powerhouse return flows enter the Platte River a few miles downstream of the Loup River confluence, for simplicity they were assumed to enter the Platte River at the same location as the other Loup inflows, ten miles downstream from Duncan.

Because daily estimates of inflow from the Columbus Powerhouse are available only for the period of January 1997 through December 2000, our analysis for Reach 21 was undertaken only for this 48-month period, rather than the 1975-1994 period used for Reaches 20 and 22.

Total estimated daily evaporation + ET losses over the entire length of Reach 21 ranged from a low of 17 cfs (March 2000) to a high of 150 cfs (June 1998). Over the 1997-2000 period evaluated, the percent of days in each month for which seepage losses were apparent along Reach 21 are summarized in **Figure 5**, and the magnitude of these losses (as a percentage of the Platte River inflow at Duncan) are summarized in **Figure 6**.

As indicated by Figure 5, Reach 21 is commonly a losing reach of the Platte River during most months of the year, at least for the four-year period evaluated. About half or more of the days in eight months of the median year are losing days, exceptions being April, May, June and November. Reach 21 is most commonly a losing reach in the months of March, July, August and September.

On days when seepage losses do occur, Platte at Duncan losses are rarely greater than 20 or 25 percent of inflow, and are typically in the range of 7 to 19 percent (Figure 6).

Implications of these characteristics relative to Program-augmented flows are discussed in Section 5.

Figure 5
Duncan to North Bend (Reach 21), 1997-2000
Percent of Days Showing Seepage Losses (in add'n to evap losses)

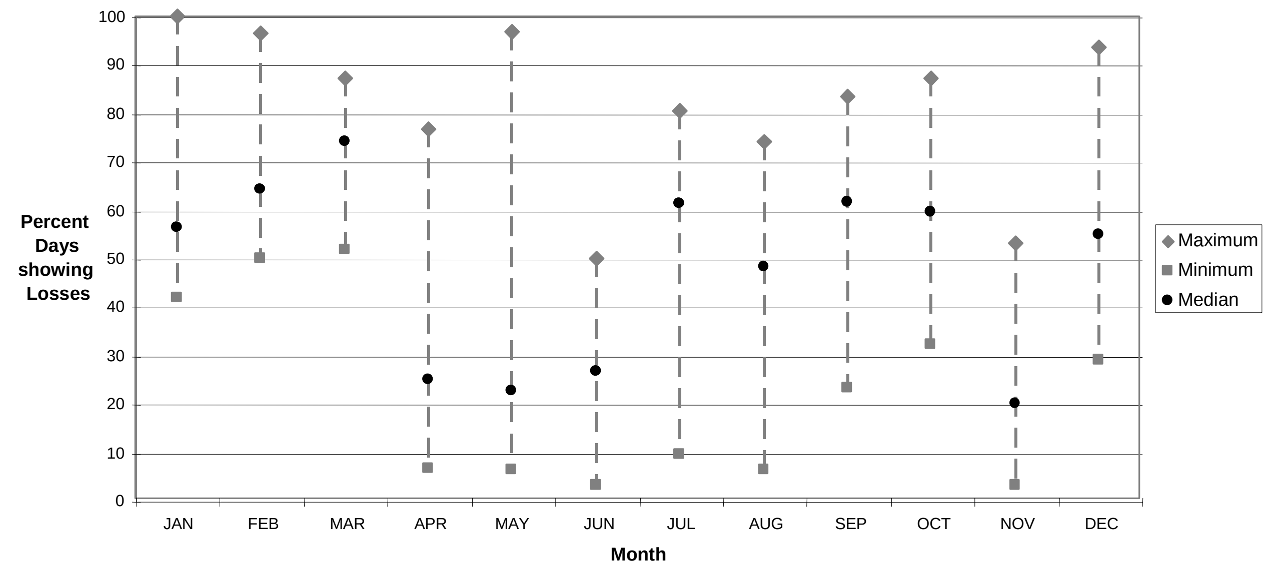
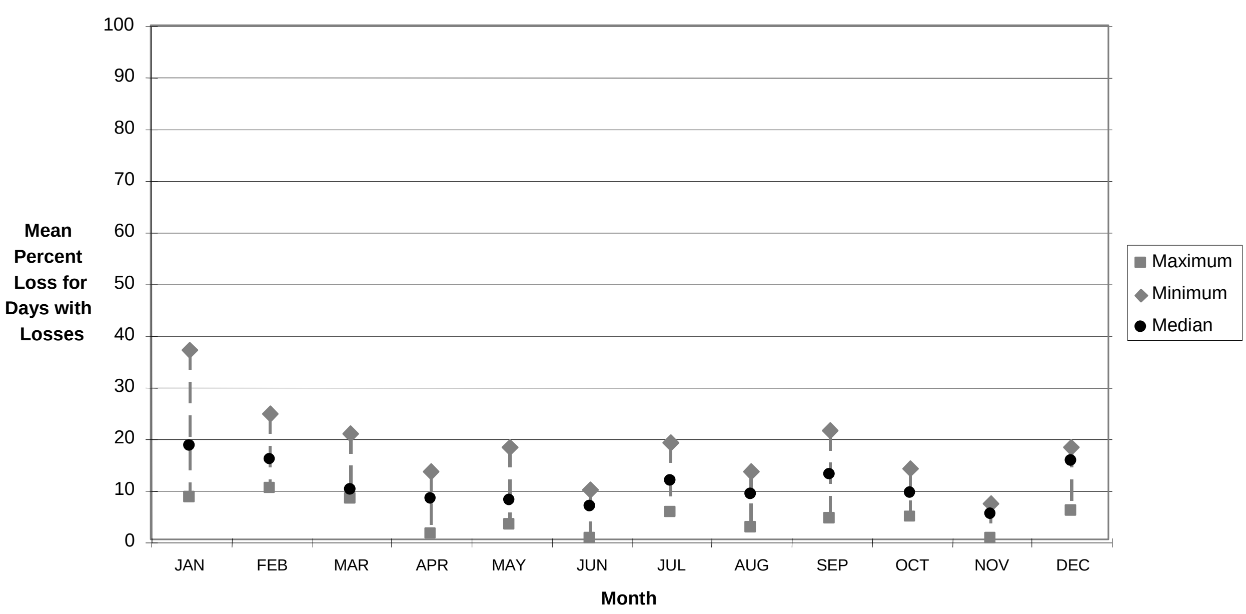


Figure 6
Duncan to North Bend (Reach 21)
Mean Percent Seepage Loss for Days with Losses (1997-2000)



4.3 North Bend to Louisville, Nebraska (Reach 22)

Stream gage data are available for this reach not only at the two endpoints of North Bend (upstream) and Louisville (downstream), but also at two points of tributary inflow to the reach (the Elkhorn River at Waterloo, and Salt Creek at Greenwood). Thus, this analysis considered three points of inflow to the reach, and evaluated evaporation losses separately for three subreaches.

Total estimated daily evaporation + ET losses over the entire length of Reach 22 ranged from a low of 3 cfs (December 1979 and January 1980) to a high of 146 cfs (June 1988). Over the 1975-1994 period evaluated, the percent of days in each month for which additional seepage losses were indicated by the data are summarized in **Figure 7**. The magnitude of these losses, when they did occur, are summarized in **Figure 8** as percent of inflow at North Bend.

As indicated by Figure 7, Reach 22 is not typically a losing reach of the Platte River for most days during any month of the year. However 19 to 37 percent of days are losing days in the median year in all months except April and May, when losing days are less common (about 10 percent). When seepage losses do occur along this reach, they are most commonly the greatest (as a percentage of Platte inflows) from June through September (9 to 17 percent losses for the median year) and the least in April (3 percent losses in the median year). Losses in Reach 22 were never greater than 40 percent of inflow except on rare occasions in July, August, September and October (Figure 8).

Implications of these characteristics relative to Program-augmented flows are discussed in Section 5.

5. Analysis and Results: Estimated Losses of Program-Augmented Flows to Evaporation and Seepage

5.1 Analysis and Results

The ultimate objective of this investigation is to estimate the proportion of Program-augmented flows in the Platte River at Grand Island, Nebraska, one would expect to reach the Platte River at Louisville, under conditions existing during the evaluated period.

To accomplish this, we added various hypothetical quantities (as mean daily cfs) of additional Program water to the historic flows at Grand Island, and estimated the proportion of this added flow lost to a combination of evaporation and seepage between Grand Island and Louisville.

For each day, the **evaporation and ET loss** was estimated by prorating the total evaporation + ET loss in each subreach among all inflows. "All inflows" included (1) the historic Platte River inflow, (2) the additional Program-augmented flow, (3) any other gaged tributary inflows, and (4) a prorated portion of gains, if there were any.

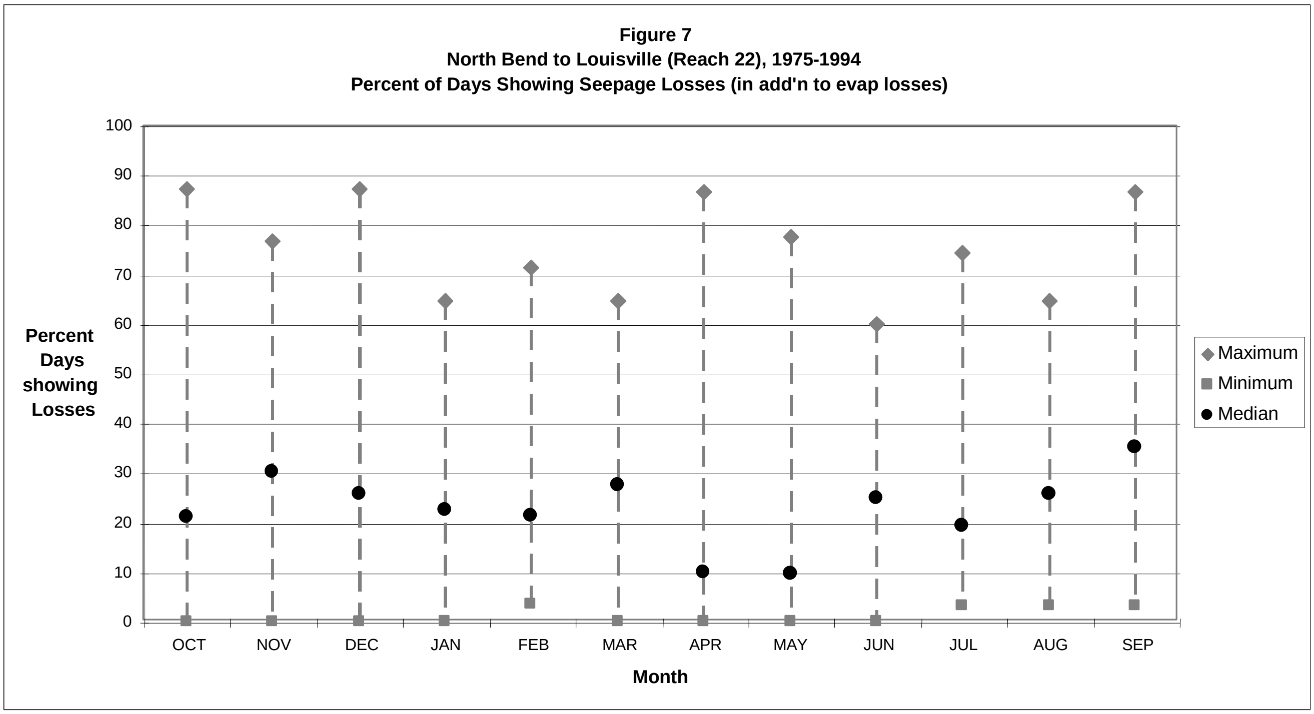


Figure 7
North Bend to Louisville (Reach 22), 1975-1994
Percent of Days Showing Seepage Losses (in add'n to evap losses)
Percent Days showing Losses
100
90
80
70
60
50
40
30
20
10
0
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
Month
Maximum
Minimum
Median

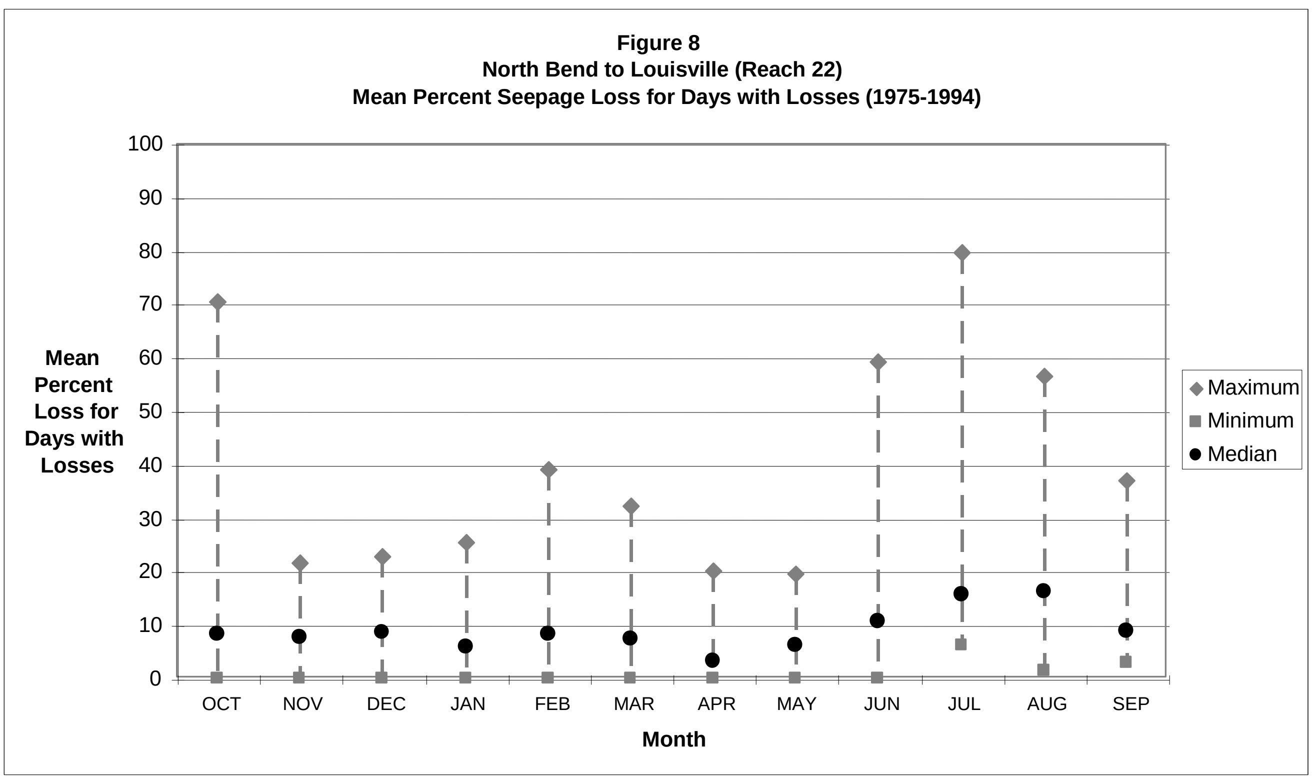


Figure 8
North Bend to Louisville (Reach 22)
Mean Percent Seepage Loss for Days with Losses (1975-1994)
Mean Percent Loss for Days with Losses
100
90
80
70
60
50
40
30
20
10
0
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
Month
Maximum
Minimum
Median

For example, if the Platte River flow at Duncan was 1000 cfs on a particular day, and the evaporation and ET loss for Subreach 21A (above the Loup River confluence) was estimated to be 30 cfs on that day, this loss would be distributed between the historic Platte River inflow and the assumed additional Program-augmented flow. If the assumed Program flow was 200 cfs, then the evaporative loss suffered by Program water in this sub-reach would be 30 cfs * 200 cfs / (1000 + 200 cfs), or 5 cfs. If 500 cfs of additional ungaged gains occurred over the entire Reach 21 on that day, on average one-half of the gain would be subject to evaporative losses[2], and a distance-weighted portion (10 of 41 miles) of that 50% subject to losses over Subreach 21A. This would further reduce the evaporative losses associated with Program water to 30 cfs * 200 cfs / (1000 + 200 + (10/41)*(1/2)*500 cfs), or about 4.8 cfs.

For each day, the **seepage loss** for added Program water was assumed to be the same (in terms of percentage of flow) as the seepage loss experienced by historic Platte River inflow. For example, if 1000 cfs of Platte River inflow at the top of a reach experienced a 12% seepage loss on a particular day, 200 cfs of augmented flow was also assumed to experience the same 12% loss.

For each day, evaporation and seepage losses were added together to estimate **the total Program water loss**. To evaluate the results, these total daily losses were summarized for each month of the year in terms of the average daily Program water loss occurring in that month.

Because evaporation losses are prorated among the various inflows to a reach, evaporation losses suffered by Program water will vary depending upon the assumed Program flows. That is, the greater the quantity of Program water at Grand Island, the greater the proportion of downstream evaporation losses that will be shared by this water. For this reason, the spreadsheet analysis was set up to allow different rates (cfs) of Program water to be evaluated interactively. For simplicity, this report presents results for only two assumed rates of Program water inflow at Grand Island: 100 cfs and 500 cfs.

Table 6 presents a summary of the range of average daily losses over the period of record for each reach, assuming 100 cfs of additional Program water at Grand Island. **Table 7** presents the same information for a presumed 500 cfs of Program water at Grand Island. Both tables show a range of results encompassing the 75-percentile and 25-percentile years.

Finally, in order to estimate cumulative Program water effects at Grand Island, Program-augmented flows were "routed" through the three reaches, with the corresponding percent loss subtracted from the flow in each reach. Because the period of record used for the Reach 21 analysis did not overlap with the period used for Reach 20 and 22, this routing could not be done for each month of the period of record[3]. Instead, the monthly loss percentages associated with

[2] Without additional information, we assume any ungaged gains accrue at a constant, linear rate over the length of the reach. Thus the portion of the total gain subject to evaporation is zero at the top of the reach, 100% at the bottom of the reach, and 50% on average over the entire length of the reach.

[3] For the present analysis, the ideal period of record for Reach 21 would also be water years 1975-1994. Because daily tailrace flow estimates from the Loup District Columbus Powerhouse have not (to our knowledge) been compiled for this period, this cannot be evaluated. Reviewers of this analysis might consider whether it would be worth the effort to compile these data. USFWS estimates it would require at least 4-6 full days of one person's time to assemble this information, not including the additional time required to update the analysis.

the median, the 75-percentile, and the 25-percentile years were used to route and evaluate "normal", "high-loss", and "low-loss" scenarios, respectively. The results are summarized in **Figure 9**.

As is apparent from these figures, the estimated proportion of 100 cfs of Program water ultimately reaching Louisville ranges from less than 60% (in September of the worst years) to over 90% (in December, January, March and April of the best years). In median years, between 79% and 91% of the water reaches Louisville from October through June; in July through September, this percentage falls to 65% to 69%.

For the 500 cfs analysis, the patterns are similar (**Figure 10**). However, relative to 100 cfs, an additional 1 to 4 percent of Program-augmented flows are estimated to reach Louisville in the months of October through June of the median year, and an additional 6 to 10 percent in July through September. This reflects the fact that a smaller percentage of Program-augmented flow will be lost to evaporation as the amount of flow is increased (although the total volume lost will be greater). Conversely, smaller amounts of Program water at Grand Island (e.g., 50 cfs) would be expected to suffer correspondingly greater percentage losses.

5.2 Sensitivity Analysis

The sensitivity of the above "bottom-line" numbers were tested relative to two input values: (1) channel width (and corresponding evaporation/ET losses), and (2) lag time of inflows.

To test the sensitivity of the daily tracking and accounting model to **assumed channel widths**, the mean widths used for open-water areas were increased by 50% for all reaches in all months. This resulted in increased estimates of open-water evaporation losses along each reach. For the 100 cfs Program water analysis, this reduced the estimated amount of Program water at Grand Island reaching Louisville in the median year by about 1 cfs (December through March) to about 5 cfs (in August and September).

To test the sensitivity of the model to **assumed lag times**, the lag times were increased as follows:

- From one day to two days for Grand Island to Duncan flows;
- From one day to two days for Duncan to North Bend flows;
- From one day to two days for all Loup River basin tributary to North Bend flows; and
- From one day to two days for North Bend to Louisville flows.

These lag time adjustments were selected because, as already noted, an earlier analysis (USFWS, 2002a) suggested that under some conditions, travel times between some gage locations may be closer to two days than one. On average, this would not change the difference in inflow and outflow from each stream reach. However, increasing the residence time of flow in each reach increases evaporative losses. Also, changing the evaporation estimates and the timing of inflows and outflows may change the distribution, frequency, and magnitude of the seepage loss estimates.

100 CFS Program Water at Grand Island
Minimum percent of flow lost over length of reach

Reach 20 (Grand Island to Duncan)

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
75 Pctl	16	10	15	6	3	2	7	10	14	22	25	27
25 Pctl	4	2	2	1	1	1	2	4	7	10	12	5
Median	10	6	8	5	3	1	4	6	13	19	23	17

Reach 21 (Duncan to North Bend)

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
75 Pctl	9	12	8	23	16	12	5	8	6	15	9	12
25 Pctl	8	8	3	5	9	6	3	4	4	8	8	8
Median	8	10	4	13	13	8	4	4	5	11	8	10

Reach 22 (North Bend to Louisville)

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
75 Pctl	7	5	4	6	3	4	3	5	5	10	10	8
25 Pctl	1	1	1	1	1	1	1	1	3	5	4	3
Median	4	3	4	2	3	3	1	3	4	8	8	6

Table 6. Estimated minimum percentages total loss per reach of 100 cfs Program water in the median, 25-percentile, and 75-percentile years.

500 CFS Program Water at Grand Island
Minimum percent of flow lost over length of reach

Reach 20 (Grand Island to Duncan)

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
75 Pctl	12	9	14	6	2	2	5	7	10	15	14	18
25 Pctl	3	1	2	1	1	1	2	4	5	7	8	5
Median	8	6	7	4	2	1	3	5	9	13	14	10

Reach 21 (Duncan to North Bend)

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
75 Pctl	9	11	8	23	16	12	5	8	6	14	9	11
25 Pctl	6	7	3	5	9	6	3	3	3	7	6	7
Median	7	9	3	13	13	8	4	4	5	10	7	9

Reach 22 (North Bend to Louisville)

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
75 Pctl	7	5	4	6	3	3	3	4	5	9	9	8
25 Pctl	1	1	1	1	1	1	1	1	3	4	3	3
Median	4	3	3	2	2	3	1	3	4	7	7	6

Table 7. Estimated minimum percentages total loss per reach of 500 cfs Program water in the median, 25-percentile, and 75-percentile years.

Figure 9.
Percent of 100 cfs Program Water at Grand Island
Reaching Louisville after Evaporation and Seepage Losses

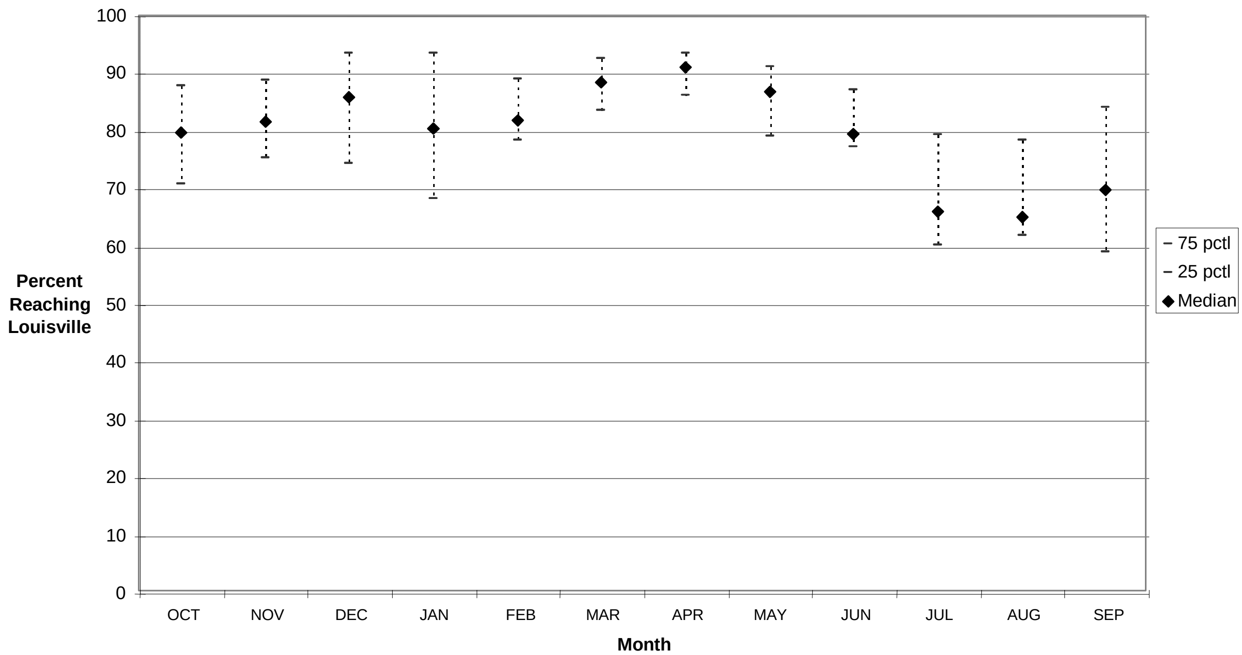
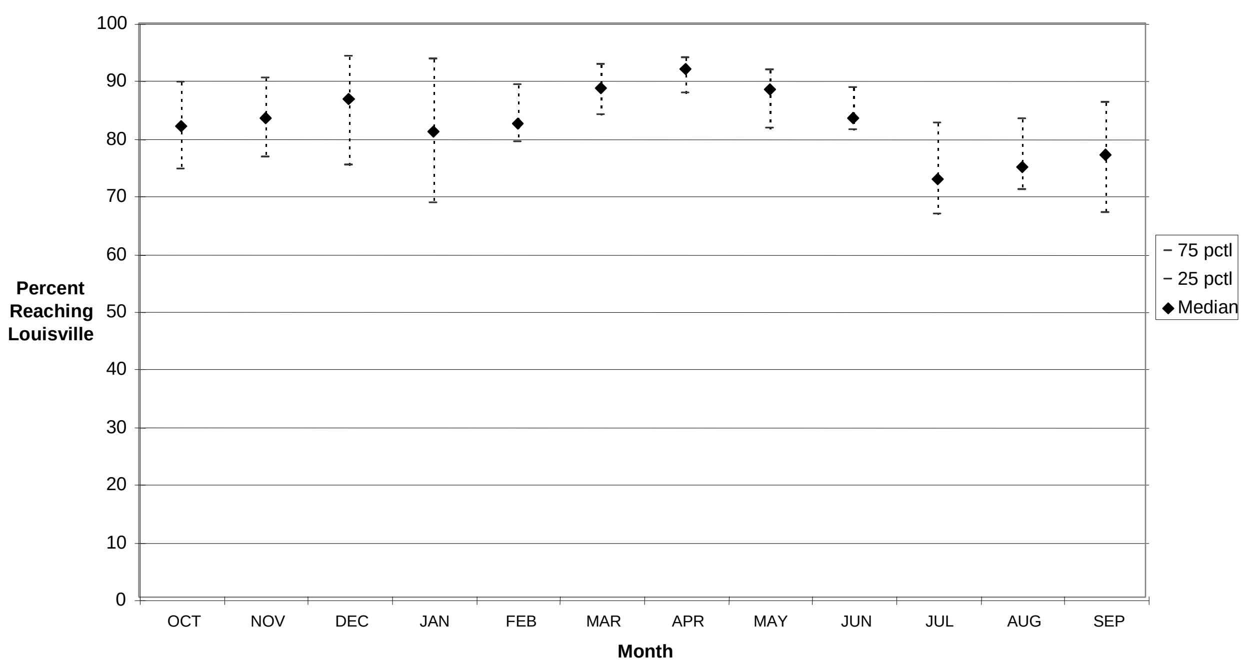


Figure 10.
Percent of 500 cfs Program Water at Grand Island
Reaching Louisville after Evaporation and Seepage Losses



For the 100 cfs Program water analysis, changing all of the above lag times from 1 to 2 days further reduced the estimated percentages of Program water at Grand Island reaching Louisville in the median year by 9 to 17 cfs in each month between May and September, and between 2 and 6 cfs from November to April. Thus, this model is relatively sensitive to assumed travel times, particularly during those months with the highest evaporation rates. To the extent that travel times are closer to two days than one, this suggests a further reason to consider Table 6 and 7 values to be conservative.

6. Summary and Conclusions

Based on an analysis of the available gage data for the lower Platte River system for water years 1975 through 1994 (and for calendar years 1997 through 2000), and an analysis of corresponding pan evaporation records from Grand Island and Omaha, likely percentages of Program-augmented flows in the Platte River at Grand Island which ultimately would have reached Louisville were estimated. The results of this analysis for 100 cfs and 500 cfs of Program flow are summarized in Figures 9 and 10.

The results suggest that less than 60% (in September of the worst years) to over 90% (in December, January, March and April of the best years) of these augmented flows would be expected to reach Grand Island if they were on the order of 100 cfs (about 6,000 AF/month). In median years, a maximum of between 79% and 91% of this water would reach Louisville from October through June; in July through September, this percentage falls to 65% to 70%.

For a variety of reasons described in Section 3 of this report, these estimated percentages are probably generous. The actual percentages reaching Louisville are unlikely to be any greater than the values presented here, and they may be significantly less. For augmented flows in excess of 100 cfs, percentages reaching Louisville would be somewhat higher, especially in summer months. Conversely, for augmented flows of less than 100 cfs, the percentages would be lower.

Compared to many Platte River reaches above Grand Island (WMC, 1998), these estimated losses are modest when considered on a per-mile basis. This is not surprising, for several reasons:

(1) Above Grand Island, unit-area evaporative losses during most of the year are greater than they are in the lower Platte basin;
(2) Below Grand Island, there are several major tributary inflows to the Platte River (including the Loup River, Elkhorn River, and Salt Creek), and these large inflows tend to reduce the portion of evaporative and seepage losses shared by main stem Platte River flows. On an average, year-round basis, only about 25% of flows in the Platte River at Louisville originate from the Platte River above Columbus (Nebraska DNR, 1983);
(3) Below Grand Island, higher flow velocities (which are suggested by the USFWS travel-time analysis, and are consistent with the generally higher rates of discharge) may also reduce opportunities for evaporative loss;

(4) Below Grand Island, there are no major surface-water diversions from the Platte River. Above Grand Island, such diversions and associated consumptive uses can substantially deplete flows along certain reaches.

Current hydrologic models of a possible Platte River Recovery Implementation Program suggest that augmented Program flows at Grand Island will commonly be on the order of those evaluated in this report, *i.e*., seldom more than 6,000 to 30,000 AF/month. In some cases – particularly in May and June of certain years when larger pulse flow releases are made, or unusually high levels of augmented flows are maintained for several weeks – it is possible that more than 30,000 AF/month of Program water will be added to flows at Grand Island. It should be noted that the proposed Program definitely proposes short-term (*e.g*., 1- to 3-day) Program-augmented flows in excess of 500 cfs at Grand Island; the fate of these pulse flows below Grand Island may be assessed by considering our evaluation of ten historic pulse flows in the lower Platte River (USFWS, 2000b).

This analysis is based on conditions that prevailed over the evaluated period of record. To the extent that conditions in the lower Platte River have changed – for example, greater groundwater pumping from alluvial aquifers adjacent to the river – the effects on future augmented Program flows in the lower Platte River may not be fully addressed by this analysis.

REFERENCES

Nebraska Department of Natural Resources (DNR), 1983. Platte River water supply downstream from Columbus. 12 pp.

Nebraska DNR, 2001. Calculations of Conveyance Losses on the North Platte, South Platte and Platte Rivers in Nebraska. 6 pp. plus appendices.

Stroup, D., M. Rodney and D. Anderson, 2001, *Draft Flow Characterizations for the Platte River Basin in Colorado, Wyoming and Nebraska*. Platte River Recovery Program EIS Office, Lakewood, Colorado. 21 pp. plus appendices.

U.S. Fish and Wildlife Service (USFWS), 2002a. Investigation of Flow Travel Times in the Platte River Below Grand Island, Nebraska (Draft). April 15, 2002. 15 pp.

USFWS, 2002b. Ten Case Studies of Pulse Flow Events in the Platte River, Nebraska (Draft). April 15, 2002. 10 pp. plus appendices.

Water Management Committee (WMC), 1998. Determination of monthly loss factors for the Platte River for the historical 1975-1994 Water Year period. 7 pp. plus tables and addendums.

White, R.E., 2001. Letter to Brian Barels Re: Tailrace Flows from the Columbus Powerhouse, 1997 through 2000. May 15, 2001.

APPENDIX A

Adjusted Daily Loup River Inflow Estimates

Daily flows to the Platte River from the Loup River, excluding those flows diverted to the Columbus Hydroelectric Power Canal ("Loup Power Canal"), historically have been measured near Columbus, Nebraska (USGS gage #06794000, prior to 10/10/1978) and/or the Loup River at Genoa, Nebraska (USGS gage #06793000, 4/1/1929 to present). For this analysis, the former gage location is preferable to the latter because it is approximately 24 miles closer to the Platte River confluence. However, gage records are not available for this location for the period analyzed in this report for Reach 21 (1997 through 2000).

For 92% of the days during the 1954 to 1978 period when daily flows were measured at both gages, daily flow in the Loup River at Columbus exceeded daily flow in the Loup River at Genoa, often substantially. This is not surprising, given the significantly larger drainage area associated with the Columbus location and the likely effects of inflows below Genoa. In an effort to develop better estimates of daily inflows to Reach 21 from the Loup River, USFWS developed monthly linear regression relationships between daily flows at these two gages based on the 1954 to 1978 record. Inflows recorded for the Loup River at Genoa for all months except August were then adjusted for use in the accounting model after 10/10/1978, as described below.

The Microsoft Excel spreadsheet function LINEST was used to determine the $y = mx + b$ linear relationship that best described daily flow in the Loup River at Columbus as a function of flow in the Loup River at Genoa on the same date. (Relationships based on one day of lag between the gages were also investigated, but these generally resulted in poorer correlation coefficients and thus were not further evaluated). Because relationships between daily flows are likely to vary under different hydrologic, climatologic, and water use conditions, each month was evaluated separately. The resulting least-squares best-fit linear relationships for each month are summarized below.

	Slope	Y-intercept (cfs)	R^2	Standard Error (cfs)
Jan	1.02	134	0.91	204
Feb	1.04	183	0.90	390
Mar	1.10	251	0.91	986
Apr	0.97	290	0.81	379
May	1.18	204	0.89	502
Jun	1.07	290	0.84	1154
Jul	1.17	143	0.89	276
Aug	0.64	208	0.34	2417
Sep	0.82	126	0.76	232
Oct	1.16	116	0.80	129
Nov	0.80	174	0.71	319
Dec	0.92	192	0.79	373

The coefficient of determination (R^2) expresses the degree to which the variability in daily flows at Columbus is explained by the daily flows at Genoa. For all but one of the twelve months, the Genoa gage explains at least 71% of this variabilty ($R^2 >= 0.71$). In addition, for eight of the twelve months, the standard error was 390 cfs or less, which compares to a year-round mean daily flow at the Columbus gage of about 1,050 cfs. Only for the month of August (with an unusually low R^2 value of 0.34 and an unusually high standard error of 2,417 cfs) does this relationship seem too poor to justify adjustments to the daily flow values.

Examination of residuals associated with these estimates suggests that the linear model is a reasonable one for the purposes of this analysis. The positive y-intercept in all months appears consistent with the generally gaining characteristics of the Loup River between Genoa and Loup. For example: flows at Columbus were typically on the order of at least 20 to 100 cfs, even when stream flow at Genoa was at or near zero.

Based on the above analysis, daily flows for the Loup River at Genoa from January 1997 through December 2000 were adjusted for all months except August to estimate the corresponding daily flow in the Loup River at Columbus. For example, a flow of 600 cfs in the Loup River at Genoa for a particular day in January would be adjusted as follows:

(600 cfs * 1.02) + 134 cfs = 746 cfs estimated inflow at Columbus

and the 746 cfs value would be used to estimate inflow to the Platte River from the Loup River on this day. For August, the daily flows in the Loup River at Genoa were used unadjusted.

Although adjustment of these Loup River flows introduces some additional uncertainty into the daily flow accounting calculations, they generally represent more accurate estimates of Loup inflows to the Platte River. On 73% of days during the 25-year “calibration period” (excluding August), flows at Columbus estimated as described above were closer to the actual measured flows than were the measured flows at Genoa. For this reason the adjusted flows were incorporated into the daily flow tracking and accounting model.

Appendix B

Summary Report on the Potential of Changes in Central Platte Flow Conditions to Affect Flows in the Lower Platte
Draft Report
December 2002

SUMMARY REPORT ON
THE POTENTIAL OF CHANGES IN CENTRAL PLATTE FLOW CONDITIONS TO AFFECT FLOWS IN THE LOWER PLATTE

U.S. Fish and Wildlife Service
Mountain-Prairie Region (Region 6)
December 31, 2002 *DRAFT*

EXECUTIVE SUMMARY

The U.S. Fish and Wildlife Service, working with members of the Water Management Committee, completed a preliminary analysis of how changes in flow conditions in the central Platte River due to proposed Recovery Program activities may affect flows in the lower Platte. This analysis was undertaken to help determine whether Program activities could provide measurable benefits to pallid sturgeon habitat in the lower Platte.

Our analysis considered the effect of both short-duration pulse flows and of sustained augmented flows in the central Platte River. Assessed effects included estimated changes in mean monthly flow, stage, velocity, and width in the Platte River at Louisville, Nebraska, due to Program activities. These estimates were based on modeled effects of the analyzed Program on flows at Grand Island combined with estimated conveyance losses between Grand Island and Louisville. The conveyance loss estimates were derived from a daily flow accounting model constructed from historic streamflow and pan evaporation records.

The estimated range of effects at Louisville of the Proposed Program, as summarized in Table 3 of this document, suggest modest increases in flow at Louisville (20 to 788 cfs) during the critical February-through-July period of most dry-to-normal flow years, as well as increases in flow (287 to 411 cfs) in May of wet years. However, for reasons detailed in this report, large uncertainties are associated with all of these estimates. Moreover, it is unlikely that the flow effects suggested by this study would be clearly detectable at Louisville except under unusual conditions, such as exceptionally low river flows and/or exceptionally large Program water releases.

A more detailed study of flow attenuation and conveyance losses in the lower Platte River system could improve upon this preliminary effort, however we believe a more thorough analysis is not justified unless or until:

- Better and more complete hydrologic data are available for the lower Platte River system;
- Pallid sturgeon habitat needs and the potential benefits of specific timing/quantities of augmented flow in the lower Platte are better understood; and/or
- If and when the Program is able to provide larger volumes of flow to the central Platte than is anticipated under the First Increment of the current Program.

The information presented in this report responds to the *hydrologic* questions raised by Cooperative Agreement Milestone R1A-Ext, but not the remaining biological question of whether these changes in lower Platte flow could "provide measurable benefits to pallid sturgeon habitat".

1. BACKGROUND

This analysis was pursued to partially fulfill Milestone R1a-EXT of the Cooperative Agreement, which reads in its entirety:

> The Governance Committee and the FWS will develop a schedule and implement a plan for obtaining data to determine if changes in flow conditions in the central Platte will affect flows in the lower Platte. If changes can be detected then an assessment of the magnitude of the changes will be completed and a determination will be made regarding the potential for these changes to provide measurable benefits to pallid sturgeon habitat.

The U.S. Fish and Wildlife Service (FWS), working with members of the Program's Water Management Committee (WMC), developed a draft "Plan for Testing the Ability of the Program to Affect Lower Platte River Flows". On March 4, 2002, the Governance Committee gave its approval to implement the February 28, 2002 version of that Plan. The Plan describes a six-phase approach to addressing the Milestone, as summarized below:

Phase I	Estimate travel times for the three reaches between Grand Island and Louisville, and evaluate the attenuation of peak flows;
Phase II	Estimate historic losses by reach based on daily flow records below Grand Island;
Phase III	Estimate the likely range of possible effects of Program water at Grand Island on flow in the lower Platte River;
Phase IV	Translate the likely flow effects to depth/width/velocity effects at Louisville;
Phase V	Compare these effects to existing short-term variations in Platte flows/depths at Louisville.
Phase VI	If necessary, expand the scope of the evaluation.

2. IMPLEMENTATION

The phased analysis described above was undertaken by FWS with guidance and review by various members of the Water Management Committee, in particular the following:

- Ann Bleed, Nebraska Department of Natural Resources (NDNR)
- Mike Drain, Central Nebraska Public Power and Irrigation District (CNPPID)
- Frank Kwapnioski, Nebraska Public Power District (NPPD)

The first five phases of this preliminary evaluation have been completed. FWS and the above individuals do not believe the sixth phase is necessary at this time, because the existing analysis adequately addresses Milestone R1a-EXT.

Our analysis relied heavily on historic daily flow estimates from a number of gaging stations throughout the Platte River basin in Nebraska. Stream gaging locations used in this analysis are shown in **Figure 1**. In addition, records of daily hydroelectric power generation were compiled for the Columbus Powerhouse located near the mouth of the Loup River, in order to estimate the contribution of tailrace flows from the power plant to the Platte.

Below Grand Island, Nebraska, the lower Platte River was evaluated as three separate river reaches, each bounded by corresponding stream flow gaging stations[1]:

- Grand Island to Duncan ("Reach 20")
- Duncan to North Bend ("Reach 21"), and
- North Bend to Louisville ("Reach 22")

As described in this report, FWS considered possible effects on the lower Platte River of two kinds of flow changes in the central Platte:

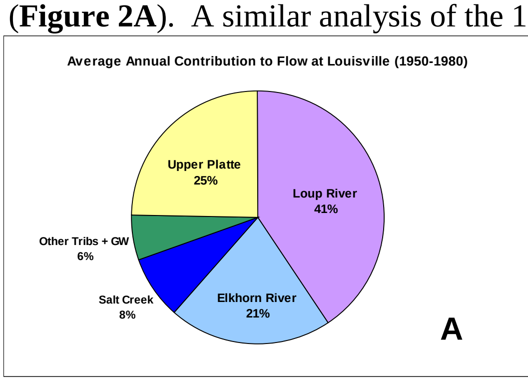
- Short-duration pulse flows, and
- Augmented (or reduced) flow in the river over sustained periods (e.g., weeks or months).

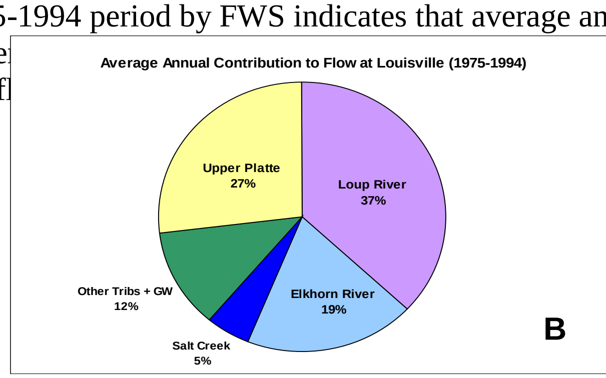
3. CONTEXT: DESCRIPTION OF THE LOWER PLATTE RIVER SYSTEM

The Program's long-term goal is to improve and maintain associated habitats for four target species, one of which is the pallid sturgeon (*Scaphirhynchus albus*). The Cooperative Agreement defines "associated habitat" for the pallid sturgeon as the lower Platte River between its confluence with the Elkhorn River and its confluence with the Missouri River (approximately 33 river miles). The period during which FWS believes elevated flows in the lower Platte are most likely to benefit the sturgeon is February through July (FWS, 1996).

For the investigations described here, the stream gaging station for the Platte River at Louisville, Nebraska (about 16.5 river miles upstream from the mouth of the Platte) was used as the representative location for the lower Platte. This gage is located about halfway along the river reach identified as pallid sturgeon "associated habitat".

Beginning around Columbus, Nebraska (about 104 river miles from the mouth of the Platte), flow in the Platte River is strongly determined by tributary inflows, including the Loup River, the Elkhorn River, and Salt Creek. A study of 1950-1980 data by the Nebraska Department of Natural Resources (Nebraska DNR, 1983) concludes that, on an average annual basis, only about 25% of the flow in the Platte River at Louisville originated from the Platte basin above Duncan (**Figure 2A**). A similar analysis of the 1975-1994 period by FWS indicates that average annual ... we ...). ... infl





[1] Numbering of these reaches begins at 20 to avoid confusion with Reaches 1 through 19 above Grand Island previously defined by the Water Management Committee for a Milestone W14-1 study.

Figure 2. Average annual contribution to flow in the Platte River at Louisville from various sources, as evaluated by the Nebraska DNR for 1950-1980 (A), and by USFWS for 1975-1994 (B).

The contribution of the upper Platte basin relative to all other sources of inflow to the lower Platte hints at the challenges involved in providing flow benefits to pallid sturgeon habitat through upper basin activities alone. Nevertheless, it is important to recognize that the portion of lower Platte flow contributed by the upper basin, particularly during the May-June period, was almost certainly greater in the pre-development era than it is today (*e.g.*, Stroup et al., 2001).

Several studies suggest that the lower Platte River, particularly downstream of Duncan, is generally a neutral-to-gaining river over most of its length for most of the year (Waite, 1949; Lappala et al., 1979; Stanton, 2000). This contrasts markedly with the Platte River above Grand Island, which frequently suffers substantial seepage losses along many reaches over extended periods. From a practical standpoint, this suggests that increases in flow will generally suffer smaller conveyance losses downstream of the Grand Island-to-Duncan reach than they will upstream of that area.

4. STUDY FINDINGS

4.1 How do Changes in Flow Conditions in the Central Platte Affect Flows in the Lower Platte?

4.1.1 Limits of Understanding

Clearly, changes to flow conditions in the central Platte River (*i.e.*, in the Overton-to-Grand Island reach) will have some effect on flows in the lower Platte River. The only time this would not be true is when zero-flow conditions occur at some point below Grand Island, such that no surface flow from the central Platte can reach the lower Platte. From 1975-1994, the focus of our historic analysis, mean daily flow dropped to zero on just 52 days at Grand Island, and 72 days at Duncan.

Estimating the degree to which changes in flow conditions in the central Platte would affect flow in the lower Platte is hampered by limited data and limited understanding of the lower Platte River system. In particular:

- Flow gaging stations are few and far between on the Platte River system below Grand Island, as shown in Figure 1. For the period evaluated by FWS, extended reaches of the river and/or its tributaries were ungaged (for example, 55 miles between the Grand Island and Duncan gages, and 56.5 miles between North Bend and Louisville gages).

- Until recently, tailrace flows from the Columbus Powerhouse near Columbus, Nebraska have not been measured. This is a crucial data gap, as (on an average annual basis) more water returns to the Platte River via the Columbus Powerhouse tailrace than via the Loup River channel itself (from which the powerhouse diverts water). To partially compensate for this gap in this analysis, four years of daily power generation records were acquired, as well as daily records for selected pulse flow evaluation periods. From these records, daily tailrace flows were estimated as a function of daily power generation.

- Where gaging stations do exist, significant uncertainty is associated with the flow measurements. This is particularly true in winter months, when icing is common, confounding reliable estimates. This increases the uncertainty associated with our flow attenuation and conveyance loss models, particularly during winter months.

- Substantial variability and uncertainty is associated with our estimates of flow travel times in the lower Platte. The conveyance loss analysis described in this report relied on velocity measurements taken at a handful of sites, and these were used to estimate flow velocities under "median monthly" conditions between gages. In reality, flow velocities and travel times vary substantially over space and time under different flow and channel conditions. This limits the accuracy of daily conveyance loss estimates.

Within the context of these limitations, efforts were made under Phase I of the Plan to assess the effects of pulse flows in the central Platte River on flows in the lower Platte, and under Phases II and III of the Plan to assess the effect of sustained changes in flow.

4.1.2 Study results

Pulse flows

To assess the **potential effect of pulse flows**, FWS evaluated the historic attenuation of short-duration pulses as they have moved down the Platte River from North Platte, Nebraska to Louisville. Ten "case studies" of pulse flow events occurring between 1949 and 1999 were analyzed. The flow volume under the pulse event hydrographs was tracked through the central and lower Platte to estimate (1) travel times between gages and (2) percentage of the initial volume of the pulse remaining at each gage point downstream.

The FWS analysis took into account the operation of the Tri-County supply canal system, tributary inflows (including Columbus Powerhouse discharges), precipitation events, and changes in the hydrographs from one gage to the next. As a result of these analyses, FWS estimates that, for eight of the ten events considered, the portion of the pulse flow volume at North Platte that remained as a pulse in the Platte River at Louisville (or Ashland) was in the range of approximately 20 to 40 percent. In the remaining two cases, the percentages were about 55 and 65 percent. A summary of the individual events is included as **Appendix A** to this document.

As noted in Appendix A, the peak discharge associated with the evaluated pulse events ranged from 6,850 to 20,900 cfs. Because pulse flows created or augmented by the Program are more likely to be in the range of 6,000 to 8,000 cfs, the attenuation of Program pulses may be greater than for many of the events analyzed in this study.

Sustained flows

To assess the **potential effect of sustained flows**, FWS constructed a daily flow accounting model to estimate historic evaporation and seepage losses along each stream reach. To accomplish this, the following steps were followed:

- Travel times in each reach were estimated for each month of the year under median flow conditions (**Appendix B**);
- Open-water and vegetated island and riparian areas were estimated for each reach, and these areas were used together with historic pan evaporation data to estimate monthly losses to open-water evaporation and vegetative evapotranspiration (ET);
- Daily flow data for each gage were compiled for the 1975-1994 period (1997-2000 for Reach 21, due to the unavailability of reliable estimates of tailrace flows from the Columbus Powerhouse for any other period);
- After accounting for estimated daily evaporation and ET losses along each reach, daily seepage losses or gains along each reach were estimated;
- A distribution of losses by month of year was compiled. Evaporation losses and seepage losses were then summed to estimate a reasonable range of conveyance losses along each reach of the river (**Appendix C**), using methodologies that may somewhat underestimate actual losses.

As summarized in Appendix C, FWS conservatively estimates that at least 8 to 31 percent of sustained Program-augmented flows in the Platte would be lost to seepage and evaporation between Grand Island and Louisville under typical conditions, with a range of 19 to 60 percent more likely using less conservative assumptions. The predicted conveyance losses depend upon the time of year, flow conditions, and quantity of augmented flow. Estimated losses are highest in the summer months (30 to 60 percent in July and August) and lowest in late spring (8 to 25 percent in March and April).

4.2 Can Program Changes in Flow Conditions be Detected in the Lower Platte?

<u>4.2.1 Limits of Detectability</u>

While the effect of central Platte flow changes on the lower Platte was estimated as described above, the likelihood of being able to detect changes (that is, distinguish them from existing variability in flow and uncertainty in flow measurements) is another matter. Changes in flow conditions in the central Platte River *of the magnitude currently envisioned under the Program* are in fact not likely to be detectable at Louisville, Nebraska, except under unusual conditions. These "unusual conditions" include exceptionally low flow in the Platte River at Louisville, and/or exceptionally large Program water releases.

The detectability of flow changes at Louisville is limited for two reasons:

(1) USGS gage measurements are of limited accuracy.

The USGS describes the accuracy of the Platte River stream gage at Louisville, Nebraska as being "good" ("except for estimated daily discharges, which are poor"). This means the USGS believes about 95 percent of the reported daily discharges are within 10 percent of their true value. Over the 20-year period used for the FWS stream flow accounting model, the 10%, 50%, and 90% frequencies of daily flow exceedance at Louisville are as shown in Table 1:

Table 1. Mean daily flow in the Platte River at Louisville, Water Years 1975 through 1994, expressed as frequency of exceedance.

Percent days exceeding	Mean daily flow, WY 1975-1994 (cfs)											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
90%	2,600	3,600	5,625	4,913	3,849	2,570	1,368	1,057	1,479	2,130	3,179	2,436
50%	4,700	6,600	10,200	8,100	7,720	6,955	4,135	3,545	4,340	4,170	4,835	5,000
10%	8,602	14,620	22,860	21,920	21,810	23,320	16,330	9,220	10,500	10,100	9,494	9,176

This implies the following approximate *uncertainties* associated with the corresponding flow measurements at Louisville, at the 95% confidence level:

Table 2. Uncertainty of USGS mean daily flow measurements in the Platte River at Louisville (cfs plus or minus), expressed at the 95% confidence level as frequency of exceedance, Water Years 1975 through 1995.

Percent days exceeding	Uncertainty in Daily Flow, WY 1975-1994 (plus-or-minus cfs)											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
90%	260	360	563	491	385	257	137	106	148	213	318	244
50%	470	660	1,020	810	772	696	414	355	434	417	484	500
10%	860	1,462	2,286	2,192	2,181	2,332	1,633	922	1,050	1,010	949	918

In other words, a change in daily flow of at least several hundred cfs would be necessary under median (50%) flow conditions in any month before that change would exceed the uncertainty inherent in the flow measurement. Under unusually low flow conditions (*i.e.*, at a rate of flow exceeded 90% of the time), a change of 150 cfs would be greater than this uncertainty in July, August, and September; a change of 213 to 563 cfs would be required in other months of the year.

(2) Flows at Louisville vary substantially on an hourly and a daily basis

An example of the hourly and daily flow variability of the Platte River at Louisville is illustrated in **Figure 3**. Mean daily flow at Louisville in this month (May 1997) ranged from 6,720 cfs (May 24) to 12,600 cfs (May 31), which is fairly typical for May. However, as is apparent in Figure 3, there was a strong and regular diurnal cycle in flow, with an amplitude on the order of 1,000 to 2,000 cfs. Diurnal cycles were typical of flows at Louisville throughout the 1996-2000 period evaluated, although they tended to be more apparent and more pronounced in summer months.

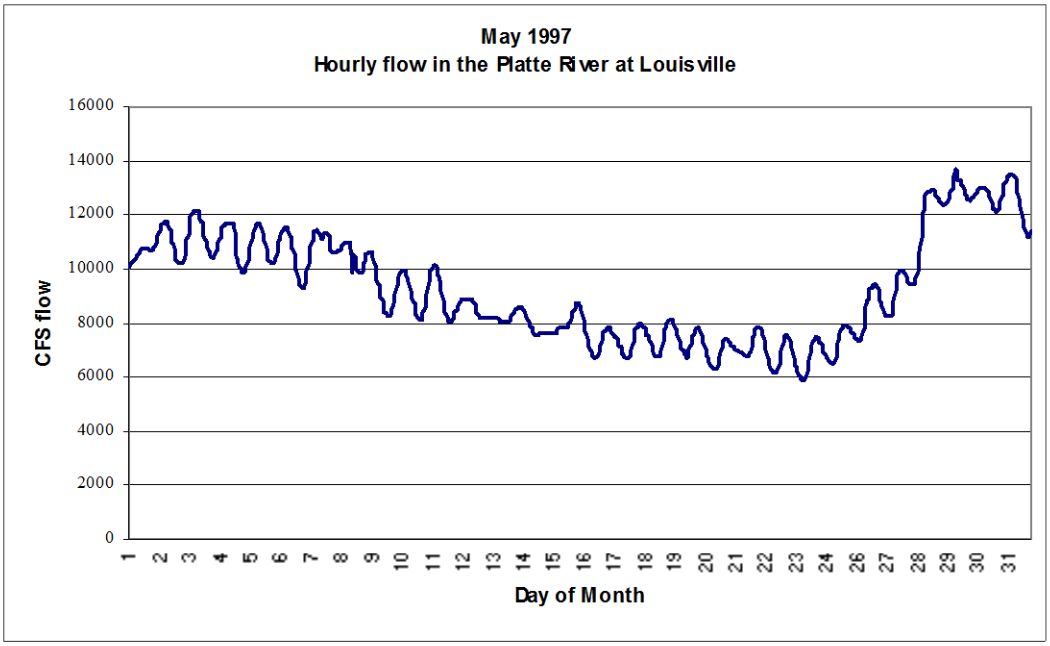


Figure 3. Hourly flow hydrograph, Platte River at Louisville, May 1997.

The diurnal pattern in Figure 3 is characterized by a peak in flows around mid-day, and a trough around midnight. This pattern is likely associated, at least in part, with diurnal cycles of releases made for hydropower generation purposes ("hydrocycling") from the Columbus Powerhouse (Steve Lydick, FWS, personal communication, August 2002). Tailrace flows from the powerhouse enter the Platte near the Loup River confluence, about 87 miles upstream from the Louisville gage.

Figure 4 illustrates the magnitude of the 24-hour range in hourly flows at Louisville in 1996-2000 in terms of frequency of exceedance (FWS, 2002e). As indicated by the figure, ranges in 24-hour flow were lowest in September, December, and January and highest in May and June. Even in the three months least prone to large variations in flow over the course of a day, 90% of days exhibited at least 170 cfs difference betweeen the daily high and daily low flow. In the months of most interest to FWS relative to potential pallid sturgeon benefits (February through July), the 90% exceedance threshold was 520 cfs. In the extreme case of June, 90% of days had a 24-hour range in flows of 1,390 cfs or more.

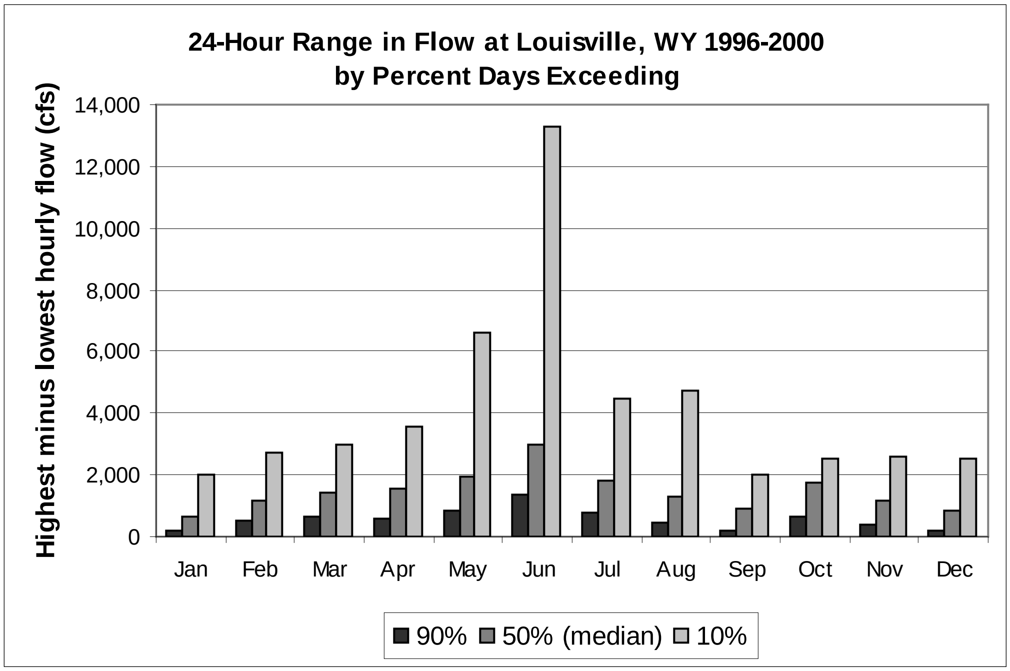


Figure 4. 24-hour range in flows (maximum - minimum hourly flow) in the Platte River at the Louisville gage, 1996 through 2000, expressed as a frequency of exceedance.

4.2.2 Modeled Changes in Lower Platte Flows

As already noted, large distances between key stream flow gages in the lower Platte River system impose limits on our understanding of river behavior between these gages. The location and magnitude of stream gains and losses, for example, is difficult to quantify except at a broad geographic scale. Thus, while the attenuation and conveyance loss estimates developed by FWS represent a valuable starting point for understanding the lower Platte system, they must be interpreted with caution until better data are available.

Keeping these limitations in mind, and using the output from a recent OPSTUDY Model analysis of Program effects on the central Platte, FWS estimated the effect that First-Increment Program activities would typically have on flows at Louisville under "Phase IV" of the analysis (USFWS, 2002d). The results are expressed as a "likely range of effects", as shown in Table 3:

Table 3. Estimated likely range of effects of First-Increment Program activities on flow in the Platte River at Louisville (change in cfs relative to baseline condition). Parentheses denote negative values.

	Delivery Efficiency	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Dry Conditions	Low	(52)	46	133	328	550	281	138	228	254	87	256	(64)
	High	(74)	66	190	470	788	402	197	326	364	125	366	(91)
Normal Conditions	Low	(187)	(55)	171	407	444	72	44	135	185	262	20	(163)
	High	(268)	(79)	245	582	635	103	63	194	264	375	28	(233)
Wet Conditions	Low	(328)	(293)	(205)	(84)	287	(748)	(55)	(27)	16	73	(200)	(273)
	High	(469)	(419)	(293)	(121)	411	(1,070)	(85)	(39)	23	105	(286)	(390)

An explanation of Table 3 follows:

(1) "Dry", "normal" and "wet" conditions were based on historic flow conditions at Grand Island from 1947 through 1994, the period used for the Central Platte OPSTUDY model. The 1/3 lowest-flow months constituted the "dry conditions", 1/3 highest-flow months "wet conditions", and the remainder "normal conditions".

(2) Total monthly flow in the Platte River at Grand Island, Nebraska, was compared for two OPSTUDY model scenarios: "baseline" versus "analyzed Program". Flows modeled for the baseline condition[2] were subtracted from flows modeled for the analyzed Program, and the results (in acre-feet/month) converted to mean monthly cfs.

(3) For each month, a high and low conveyance loss percentage (USFWS, 2002c and Appendix C) was applied to the change in flow at Grand Island determined in Step 2 to estimate the change in flow at Louisville. The "low delivery efficiency" values denote the estimated change at Louisville when liberal conveyance loss estimates are applied; "high delivery efficiency" values denote effects if conservative losses are applied. For various reasons described in the Phase II/III documentation, the higher conveyance losses (*i.e.*, lower delivery efficiencies) are probably more representative of real-world conditions.

A comparison of the estimated flow effects at Louisville (Table 3) to the uncertainties inherent in Louisville flow measurements (Table 2) suggests that changes to flows at Louisville attributable to the proposed Program are unlikely to be within the range of gage uncertainty in most months of most years. An exception is May through September of dry years, when the estimated changes in sustained flow at Louisville due the Program (138 to 788 cfs) are large enough to be "detectable", provided flow at Louisville is unusually low (*e.g.*, in the 10-percentile range). However, under such unusually low flow conditions, the Platte channel may not be wet throughout the Grand Island-to-Louisville reach, and thus changes in central Platte flow would not necessarily affect the lower Platte.

As part of this same analysis, the effects of these flow changes on river stage, velocity, and width at the Louisville gage were estimated. These estimates were based on recent (post-1995) relationships between discharge, stage, velocity, and width measurements made by the USGS at that location. These results are summarized in Appendix D. To cite the most important conclusions of this evaluation:

[2] "Baseline condition" is the condition of the river that would have existed if all of the water projects that were in place in the greater Platte River basin in 1994 had been in place over the entire 48-year period simulated by the OPSTUDY model.

- Projected **change in river stage** at Louisville was as high as +0.2 foot for only one month-of-year and river-condition combination in the entire analysis, that being the dry-condition, low-conveyance-loss scenario for May.

- The projected **change in flow velocity** did not exceed plus or minus 0.1 foot/second for any month in the analysis, and was effectively indistinguishable from zero for most months.

- The greatest **change in channel width** was +22 feet for the dry-condition, low-conveyance-loss scenario for May; most months showed a change in channel width of less than ten feet.

As described in the FWS documentation, very broad assumptions were made for these analyses. For this reason, the results should be interpreted as a "range of possible effects" rather than precise forecasts.

5. SUMMARY, AND IMPLICATIONS FOR THE PLATTE RIVER RECOVERY PROGRAM

1. Our ability to forecast flow changes at Louisville as the result of changes in flow at Grand Island is severely limited for the following reasons:

   - Flow gaging stations are few and far between on the Platte River system below Grand Island, leaving long reaches ungaged and adding uncertainty to our understanding of lower Platte hydrology and our interpretation of gage records;

   - Until recently, there were no measurements of tailrace flows from the Columbus Power Plant near Columbus, Nebraska, further limiting the accuracy of our historic flow accounting models;

   - Where gaging stations do exist, considerable uncertainty is associated with the flow measurements. This is particularly true in winter months, when icing conditions are common. This adds uncertainty to our estimates of historic flow attenuation and conveyance losses;

   - Substantial variability and uncertainty is associated with estimated travel times for flow in the lower Platte River, which limits the accuracy of conveyance loss estimates based on these assumed travel times.

2. Given the above limitations, we developed estimates of pulse flow attenuation and sustained-flow conveyance losses in the lower Platte River based on an analysis of the historic record. This analysis suggests that:

   - Short-duration pulse flow volumes will typically be attenuated by 60 to 80 percent between North Platte and Louisville, although attenuation can be as low as 40 percent under favorable conditions;

- Conveyance losses of sustained augmented flows typically range from 8 to 60 percent between Grand Island and Louisville, depending upon the time of year, flow conditions, and quantity of Program-augmented flow. Conveyance losses are highest in the summer months (30 to 60 percent in July and August) and lowest in late Spring (8 to 25 percent in March and April).

The estimated range of effects at Louisville of the Proposed Program, as summarized in Table 3, would provide modest increases in flow at Louisville from February through November in dry years (ranging from less than 1% to as much as 10% of the median monthly flow); from March through November of normal years (ranging from less than 1% to 8% of the median monthly flow); and in May, September and October of wet years (as much as 5% of the median monthly flow).

3. The "detectability" of changes in flow at Louisville is severely limited by:
   - Limited accuracy of USGS gage measurements at Louisville; and
   - Substantial variability in flows at Louisville on a daily and hourly basis.

   This implies that the Program flow effects indicated by this study are not likely to be clearly detectable at Louisville under most conditions.

4. Completion of Milestone R1A-Ext requires a biological assessment of the "potential for these changes [in flow in the lower Platte] to provide measurable benefits to pallid sturgeon habitat". The analysis described here responds to the *hydrologic* questions raised by Milestone R1A-Ext, but not this *biological* question. Therefore, completion of this Cooperative Agreement Milestone requires additional biological comment.

5. The analysis summarized in this report should be considered preliminary. Nevertheless, to our knowledge, it provides the most thorough analysis of lower Platte River flow attenuation and conveyance losses available to date.

   FWS considers the analysis presented here to be sufficient for purposes of addressing Milestone R1A-Ext. The Water Management Committee concurs, and agrees that a more detailed analysis of flow attenuation and conveyance losses between the central Platte and the lower Platte River may be justified at a later time, for example:

   - When better and more complete hydrologic data are available for the lower Platte River system;
   - Should it be determined that pallid sturgeon habitat extends upriver from the confluence with the Elkhorn River;
   - When we have a better understanding of pallid sturgeon habitat needs and the potential benefits of specific timing/quantities of augmented flow in the lower Platte; and/or
   - If and when the Program is able to provide larger volumes of flow to the central Platte than is anticipated under the First Increment of the current Program.

REFERENCES

FWS, 1996. Draft Biological Opinion on the FERC's Preferred Alternative for the Kingsley Dam Project and North Platte/Keystone Dam Project, U.S. Fish and Wildlife Service, Grand Island, Nebraska. 159 pp. plus figures.

FWS, 2002a. "Ten Case Studies of Pulse Flow Events in the Platte River, Nebraska". April 15, 2002 draft, U.S. Fish and Wildlife Service, Mountain-Prairie Region, Lakewood, Colorado. 10 pp. plus appendices.

FWS, 2002b. "Estimation of Flow Travel Times in the Platte River Below Grand Island, Nebraska." August 26, 2002 draft, U.S. Fish and Wildlife Service, Mountain-Prairie Region, Lakewood, Colorado. 8 pp.

FWS, 2002c. "Estimated Historic Losses by Stream Reach in the Platte River Below Grand Island, Nebraska, and Implications for Program-Augmented Flows". May 15, 2002 draft, U.S. Fish and Wildlife Service, Mountain-Prairie Region, Lakewood, Colorado. 24 pp. plus appendices.

FWS, 2002d. "Effects of Program Water at Grand Island, Nebraska, on River Conditions in the Platte River at Louisville, Nebraska". November 20, 2002 draft, U.S. Fish and Wildlife Service, Mountain-Prairie Region, Lakewood, Colorado. ?? pp.

FWS, 2002e. "A Comparison of Existing Short-Term Variations in Flow Relative to Potential Program Effects on Flow in the Lower Platte River", September 5, 2002 draft, U.S. Fish and Wildlife Service, Mountain-Prairie Region, Lakewood, Colorado. 10 pp plus appendices.

Lappala, E.G., P.A. Emery, and F.J. Otradovsky, 1979. Simulated changes in ground-water levels and streamflow resulting from future development (1970 to 2020) in the Platte River Basin, Nebraska. U.S. Geological Survey water-resources investigation 79-26, 82 pp.

Nebraska Department of Natural Resources, 1983. Platte River Water Supply Downstream from Columbus. February, 1983, 12 pp.

Stanton, J.S, 2000. Areas of Gain and Loss along the Platte River, Central Nebraska, Spring 1999. U.S. Geological Survey Water-Resources Investigations Report 00-4065. One map 47 x 95 cm in folded envelope.

Stroup, D., M. Rodney and D. Anderson, 2001. Draft Flow Characterization for the Platte River Basin in Colorado, Wyoming, and Nebraska. Platte River Recovery Program EIS Office, Lakewood, Colorado. 21 pp. plus appendices.

Waite, H.A., 1949. Progress Report on the Geology and Ground-water Hydrology of the Lower Platte River Valley, Nebraska. Compiled as part of Program of Interior Department for development of Missouri River Basin. Geological Survey Circular 20. 94 pp.

APPENDIX A
HISTORIC PULSE FLOW ATTTENUATION

Ten historic pulse flow events in the Platte River system were evaluated to determine the attenuation in the pulse volume between the North Platte, Nebraska and Louisville. The following tables are taken from USFWS, 2002a.

Examined Pulse Flow Events			
Event[1]	**Peak Discharge**[2] **(CFS)**	**Total Pulse Flow Volume at North Platte**[1,2] **(KAF)**	**Duration of Event (Days)**
June 12-17, 1949	12,400	59.5	5
June 18-22, 1949	17,400	35.4	4
May 17-24, 1957	8,330	67.1	7
May 16-24, 1958	6,850	49.9	8
June 17-23, 1965	20,300	67.7	6
June 16-22, 1970	9,650	56.2	6
May 9-14, 1973	20,900	66.1	5
May 5-10, 1980	11,800	40.6	5
June 10-17, 1986	8,720	60.1	7
May 4-10, 1999	16,000	101.0	6

Notes:
(1) Details and definitions provided in USFWS, 2002a.
(2) Based on Total Platte River Flow at North Platte

Percentage of Total Pulse Volume at North Platte Reaching Louisville[1] for Ten Pulse Flow Events at North Platte			
Beginning of Event (chronological)	Percentage of Total Pulse Volume at North Platte Reaching Louisville	Beginning of Event	Percentage of Total Pulse Volume at North Platte Reaching Louisville (descending order)
June 12, 1949	40.6	May 9, 1973	64.7
June 18, 1949	21.4	June 17, 1965	64.7
May 17, 1957	19.7	June 16, 1970	40.9
May 16, 1958	27.1	June 12, 1949	40.6
June 17, 1965	54.7	May 5, 1980	40.6
June 16, 1970	40.9	May 16, 1958	27.1
May 9, 1973	64.7	June 18, 1949	21.4
May 5, 1980	35.1	May 4, 1999	20.5
June 10, 1986	19.8	June 10, 1986	19.8
May 4, 1999	20.5	May 17, 1957	19.7

Note:
(1) Ashland for Events prior to 1950.

APPENDIX B
TRAVEL TIME ESTIMATES BY RIVER REACH

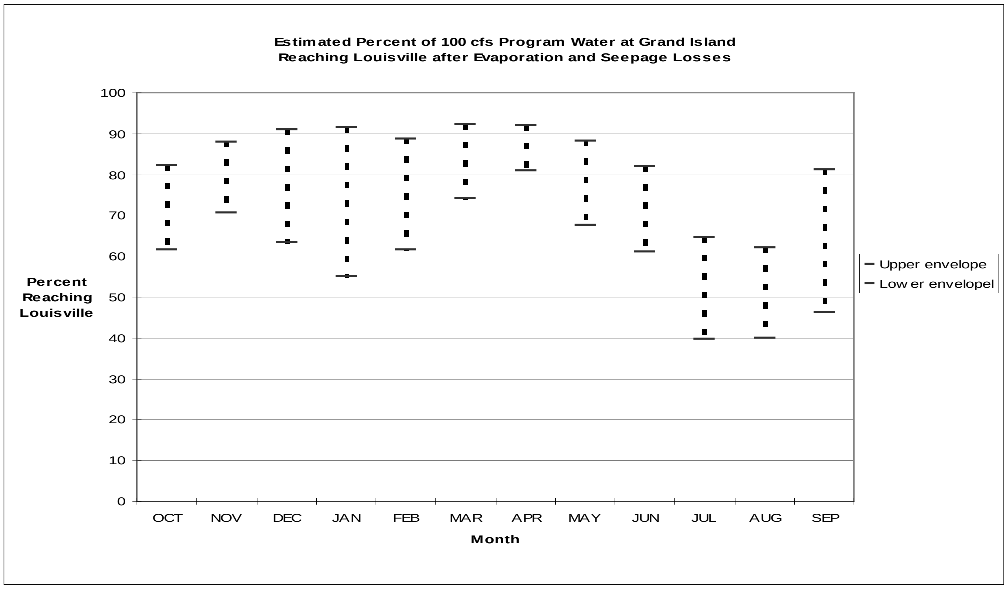
Estimated travel times of flow in the Platte River for three stream reaches between Grand Island and Louisville, Nebraska, based on an analysis of median stream flow conditions, 1975-1994 (USFWS, 2002b).

	Grand Island to Duncan		Duncan to North Bend		North Bend to Louisville	
	Median velocity (ft/sec)	Travel Time (days)	Median velocity (ft/sec)	Travel Time (days)	Median velocity (ft/sec)	Travel Time (days)
Jan	1.80	1.9	1.96	1.3	2.18	1.6
Feb	1.93	1.7	2.19	1.1	2.46	1.4
Mar	2.10	1.6	2.46	1.0	2.84	1.2
Apr	1.96	1.7	2.28	1.1	2.62	1.3
May	1.85	1.8	2.18	1.1	2.55	1.4
Jun	1.67	2.0	2.02	1.2	2.44	1.4
Jul	1.47	2.3	1.71	1.5	2.05	1.7
Aug	1.31	2.6	1.56	1.6	1.95	1.8
Sep	1.46	2.3	1.69	1.5	2.06	1.7
Oct	1.57	2.1	1.85	1.4	2.17	1.6
Nov	1.64	2.1	1.94	1.3	2.26	1.5
Dec	1.75	1.9	1.96	1.3	2.26	1.5

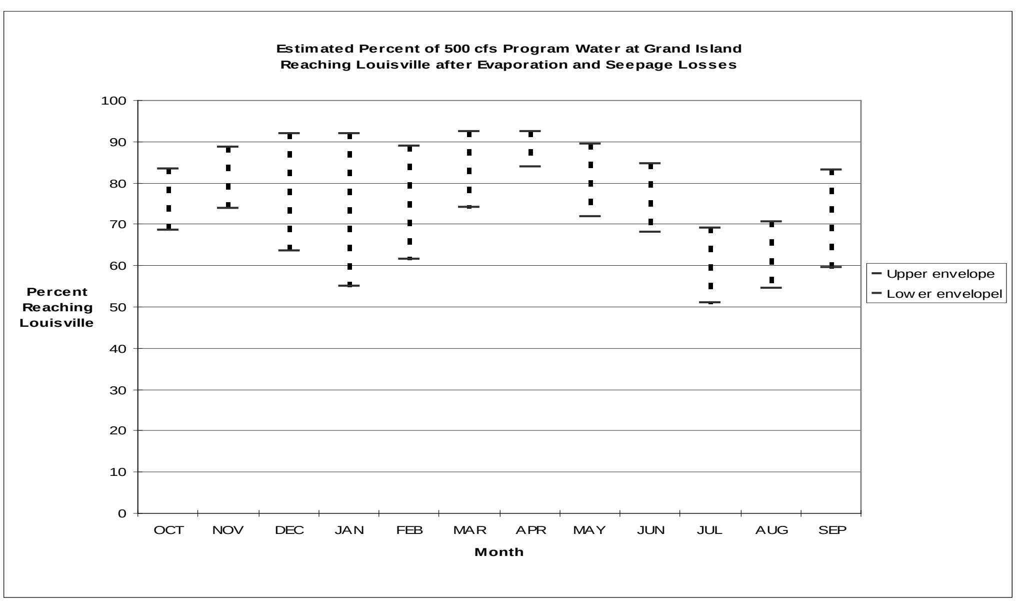
APPENDIX C
ESTIMATED CONVEYANCE LOSSES BY RIVER REACH

The following are estimated conveyance losses in the Platte River between Grand Island and Louisville, Nebraska, as percentage of augmented flow, based on an analysis of historic flows, 1975-1994 (USFWS, 2002c).

"Reasonable ranges" of estimated conveyance losses under typical conditions for **100 cfs** of Program water at Grand Island:



and for **500 cfs** of Program water at Grand Island:



APPENDIX D (Page 1)

ESTIMATED EFFECTS OF PROGRAM FLOW CHANGES ON STAGE, VELOCITY, AND WIDTH OF THE PLATTE RIVER AT LOUISVILLE

Estimated changes in discharge, river stage, mean flow velocity, and channel width at Louisville due to Program-augmented flows, assuming **low-delivery** (high-conveyance-loss) conditions in the Platte River between Grand Island and Louisville, Nebraska. (Details are provided in USFWS, 2002d):

Table 3
Change in River Conditions at Louisville as a Result of Changes in Flow - Low Delivery
Based on OPSTUDY Model Output for the Proposed Program at Grand Island

CHANGE IN MEAN MONTHLY DISCHARGE AT GRAND ISLAND (CFS)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Wet Conditions	-504	-451	-315	-130	442	-1151	-79	-42	24	113	-307	-419
Normal Conditions	-288	-85	264	626	683	111	68	208	284	403	30	-251
Dry Conditions	-79	71	204	505	847	433	212	350	391	135	393	-98

CHANGE IN MEAN MONTHLY DISCHARGE AT LOUISVILLE IN CFS FOR "LOW DELIVERY" YEAR
Based on the flow that will be left at Louisville in 75 percent of years.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Wet Conditions	-328	-293	-205	-84	287	-748	-55	-27	16	73	-200	-273
Normal Conditions	-187	-55	171	407	444	72	44	135	185	262	20	-163
Dry Conditions	-52	46	133	328	550	281	138	228	254	87	256	-64

CHANGE IN MEAN MONTHLY RIVER STAGE AT LOUISVILLE IN FEET

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Wet Conditions	-0.07	-0.05	-0.02	-0.01	0.04	-0.07	0.00	0.00	0.01	0.02	-0.05	-0.07
Normal Conditions	-0.05	-0.01	0.03	0.07	0.08	0.02	0.01	0.05	0.07	0.08	0.01	-0.04
Dry Conditions	-0.01	0.01	0.03	0.07	0.14	0.06	0.06	0.09	0.10	0.03	0.07	-0.02

CHANGE IN MEAN MONTHLY FLOW VELOCITY AT LOUISVILLE IN FT/SEC

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Wet Conditions	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Normal Conditions	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Dry Conditions	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.1	0.0	0.0	0.0

CHANGE IN MEAN MONTHLY CHANNEL WIDTH AT LOUISVILLE IN FEET

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Wet Conditions	-8	-5	-2	-1	4	-7	0	0	2	2	-5	-8
Normal Conditions	-7	-1	3	7	8	2	1	7	9	9	1	-5
Dry Conditions	-1	1	3	8	16	7	8	13	14	4	9	-3

APPENDIX D (Page 2)

Estimated changes in discharge, river stage, mean flow velocity, and channel width at Louisville due to Program-augmented flows, assuming **high-delivery** (low-conveyance-loss) conditions in the Platte River between Grand Island and Louisville, Nebraska. (Details are provided in USFWS, 2002d):

Table 4
Change in River Conditions at Louisville as a Result of Changes in Flow - High Delivery
Based on OPSTUDY Model Output for the Proposed Program at Grand Island

CHANGE IN MEAN MONTHLY DISCHARGE AT GRAND ISLAND (CFS)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Wet Conditions	-504	-451	-315	-130	442	-1151	-79	-42	24	113	-307	-419
Normal Conditions	-288	-85	264	626	683	111	68	208	284	403	30	-251
Dry Conditions	-79	71	204	505	847	433	212	350	391	135	393	-98

CHANGE IN MEAN MONTHLY DISCHARGE AT LOUISVILLE IN CFS FOR "HIGH DELIVERY" YEAR
Based on the flow that will be left at Louisville in 25 percent of years.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Wet Conditions	-469	-419	-293	-121	411	-1,070	-85	-39	23	105	-286	-390
Normal Conditions	-268	-79	245	582	635	103	63	194	264	375	28	-233
Dry Conditions	-74	66	190	470	788	402	197	326	364	125	366	-91

CHANGE IN MEAN MONTHLY RIVER STAGE AT LOUISVILLE IN FEET

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Wet Conditions	-0.11	-0.07	-0.03	-0.01	0.06	-0.11	-0.01	-0.01	0.02	0.03	-0.07	-0.10
Normal Conditions	-0.08	-0.02	0.04	0.10	0.11	0.02	0.02	0.07	0.10	0.11	0.01	-0.06
Dry Conditions	-0.02	0.01	0.04	0.10	0.19	0.09	0.08	0.13	0.14	0.04	0.10	-0.03

CHANGE IN MEAN MONTHLY FLOW VELOCITY AT LOUISVILLE IN FT/SEC

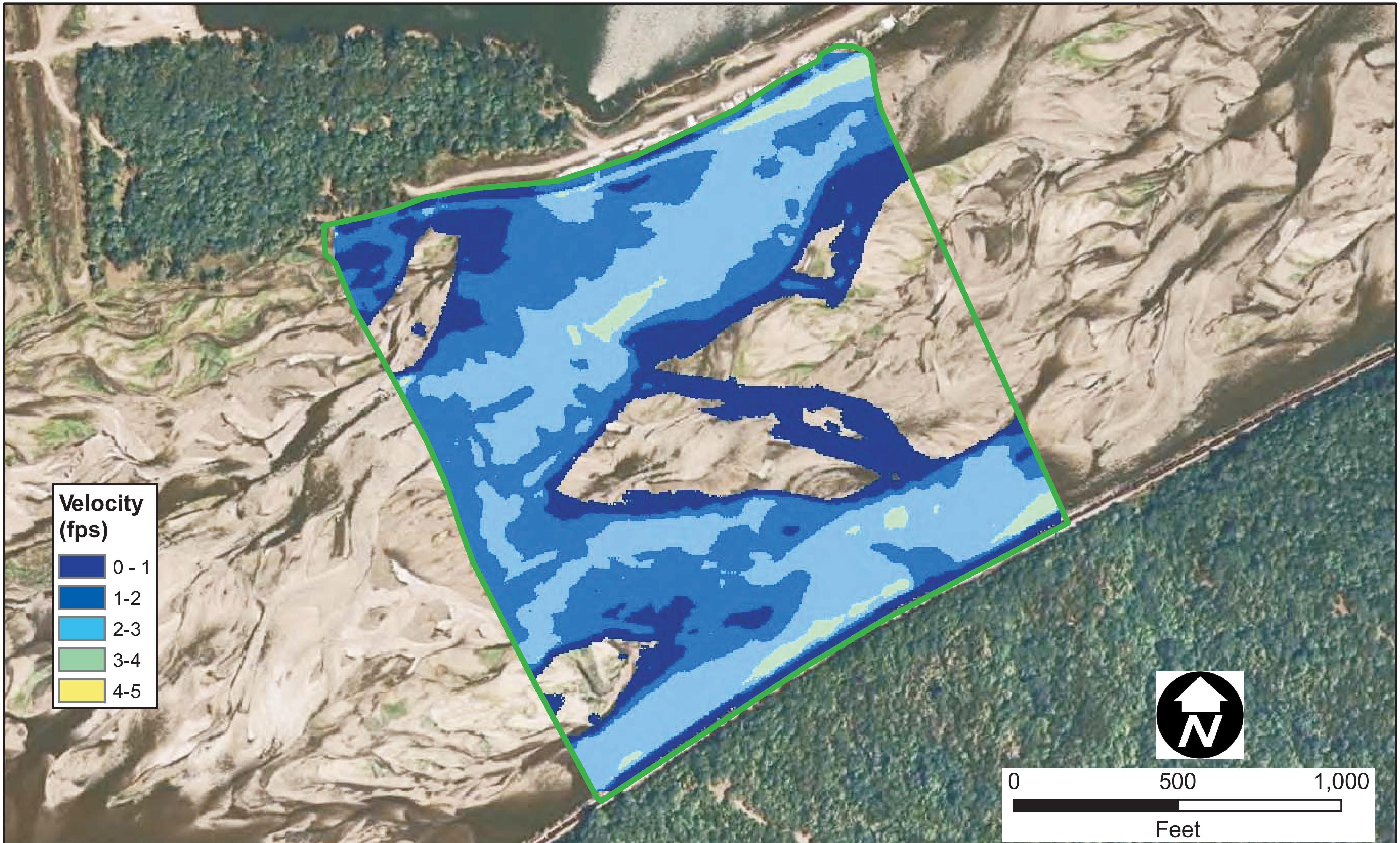
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Wet Conditions	-0.1	0.0	0.0	0.0	0.0	-0.1	0.0	0.0	0.0	0.0	0.0	-0.1
Normal Conditions	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.1	0.1	0.0	0.0
Dry Conditions	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.1	0.1	0.0	0.1	0.0

CHANGE IN MEAN MONTHLY CHANNEL WIDTH AT LOUISVILLE IN FEET

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Wet Conditions	-12	-7	-3	-1	6	-10	0	0	3	3	-8	-11
Normal Conditions	-9	-2	4	10	11	3	2	10	13	13	1	-7
Dry Conditions	-2	1	4	11	22	10	11	18	19	5	12	-4

Appendix C

Spatial Distribution Maps of Computed Channel Velocities from the SRH-2D over a Range of Discharges between 3,700 and 40,000 cfs



HDR
THE FLATWATER GROUP INC.
TETRA TECH
MEI

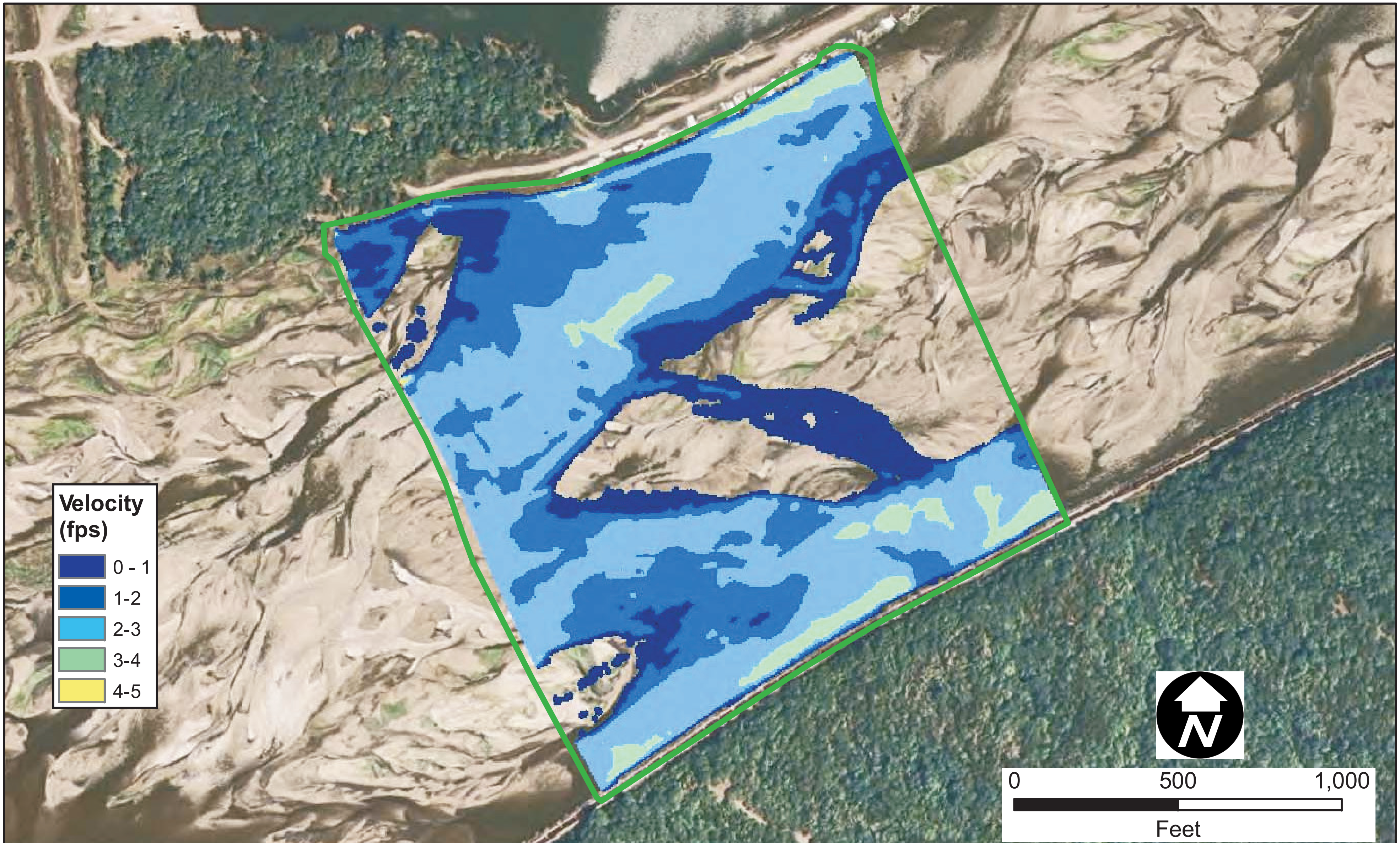
Computed Velocity at 3,700 cfs

RECOVERY IMPLEMENTATION PROGRAM PLATTE RIVER

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date: Dec. 2009

Figure: C1



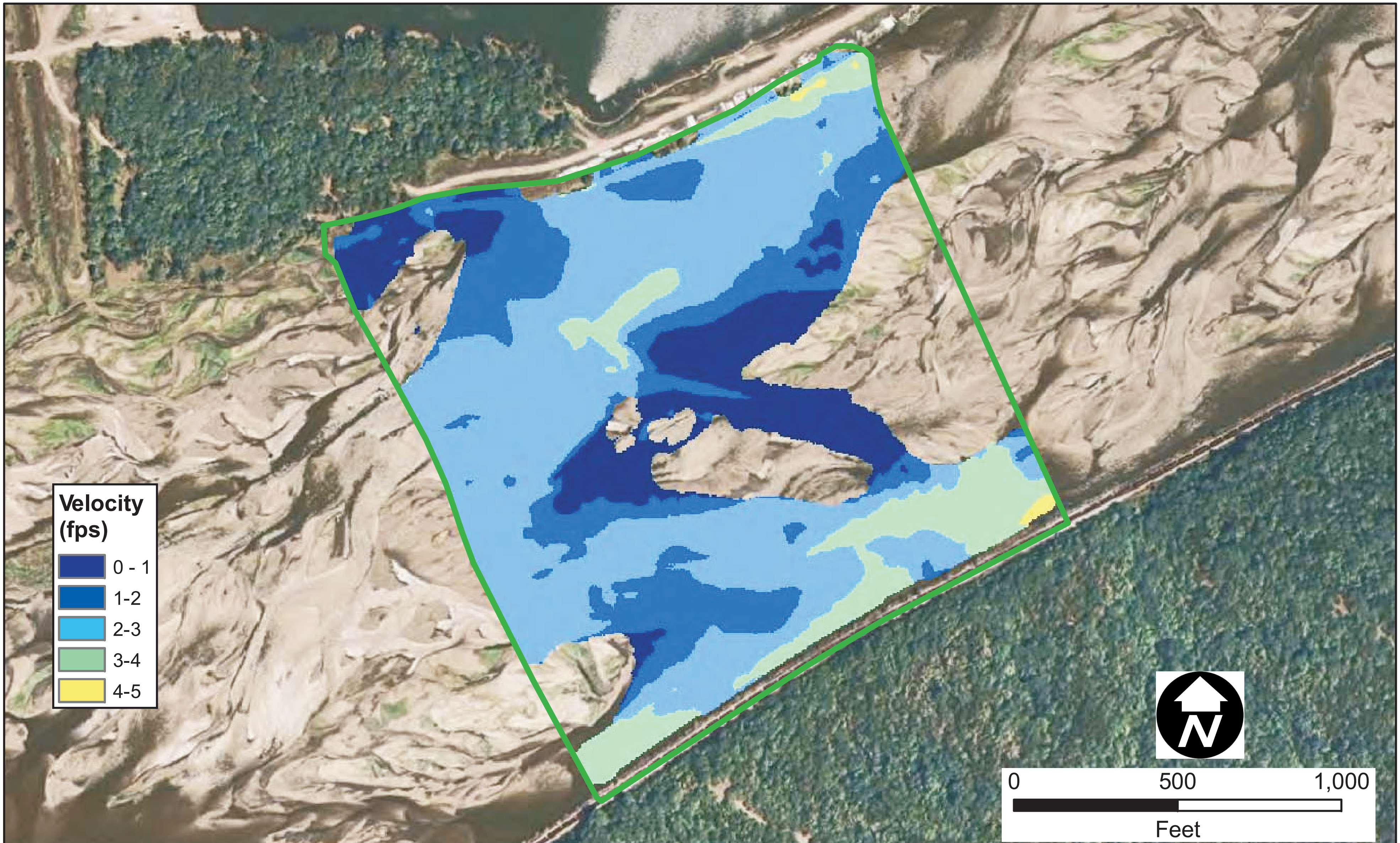
HDR
THE FLATWATER GROUP INC.
TETRA TECH
MEI

Computed Velocity at 4,300 cfs

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date: Dec. 2009

Figure: C2



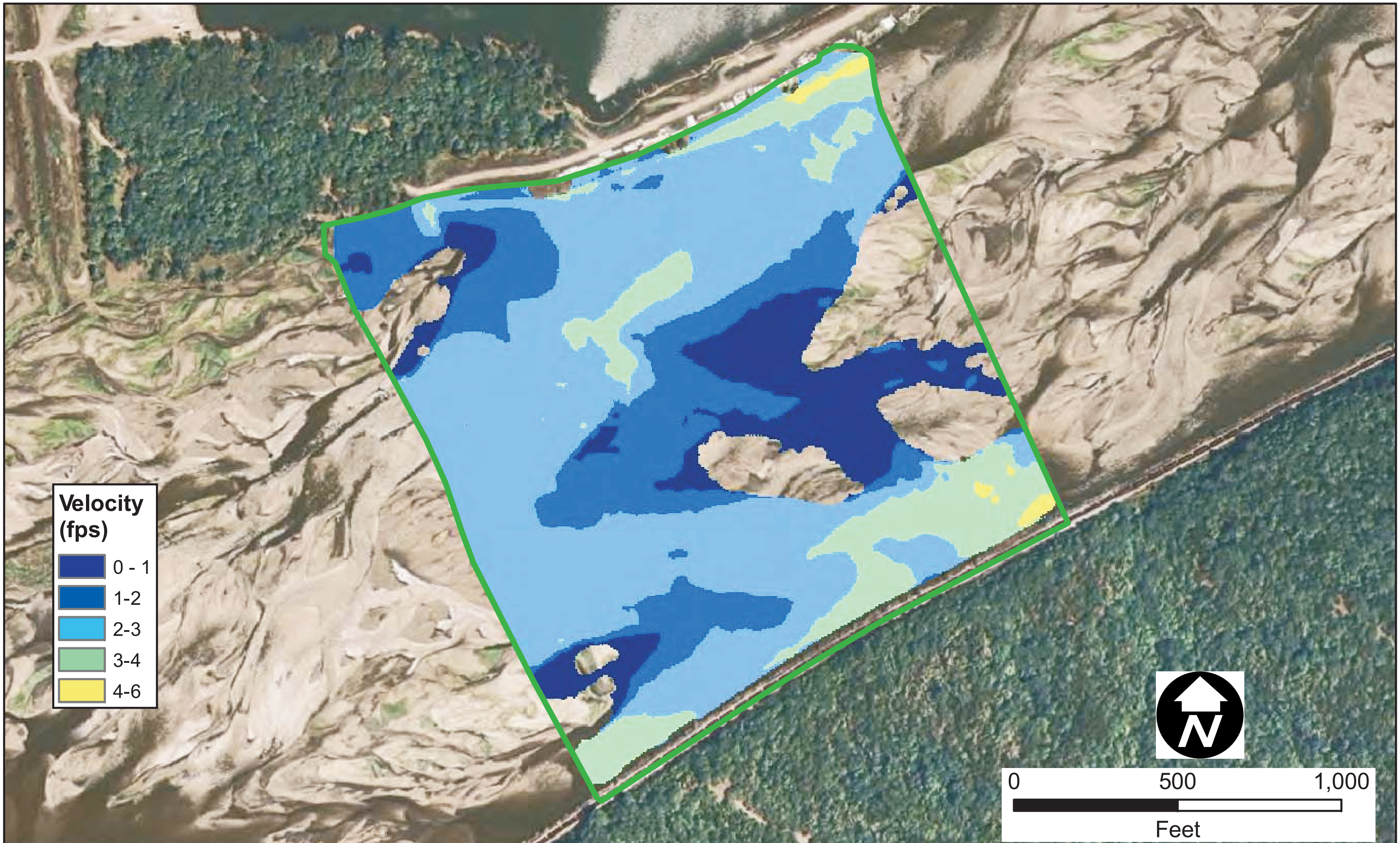
HDR
THE FLATWATER GROUP INC.
TETRA TECH
MEI

Computed Velocity at 6,000 cfs

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date: Dec. 2009

Figure: C3



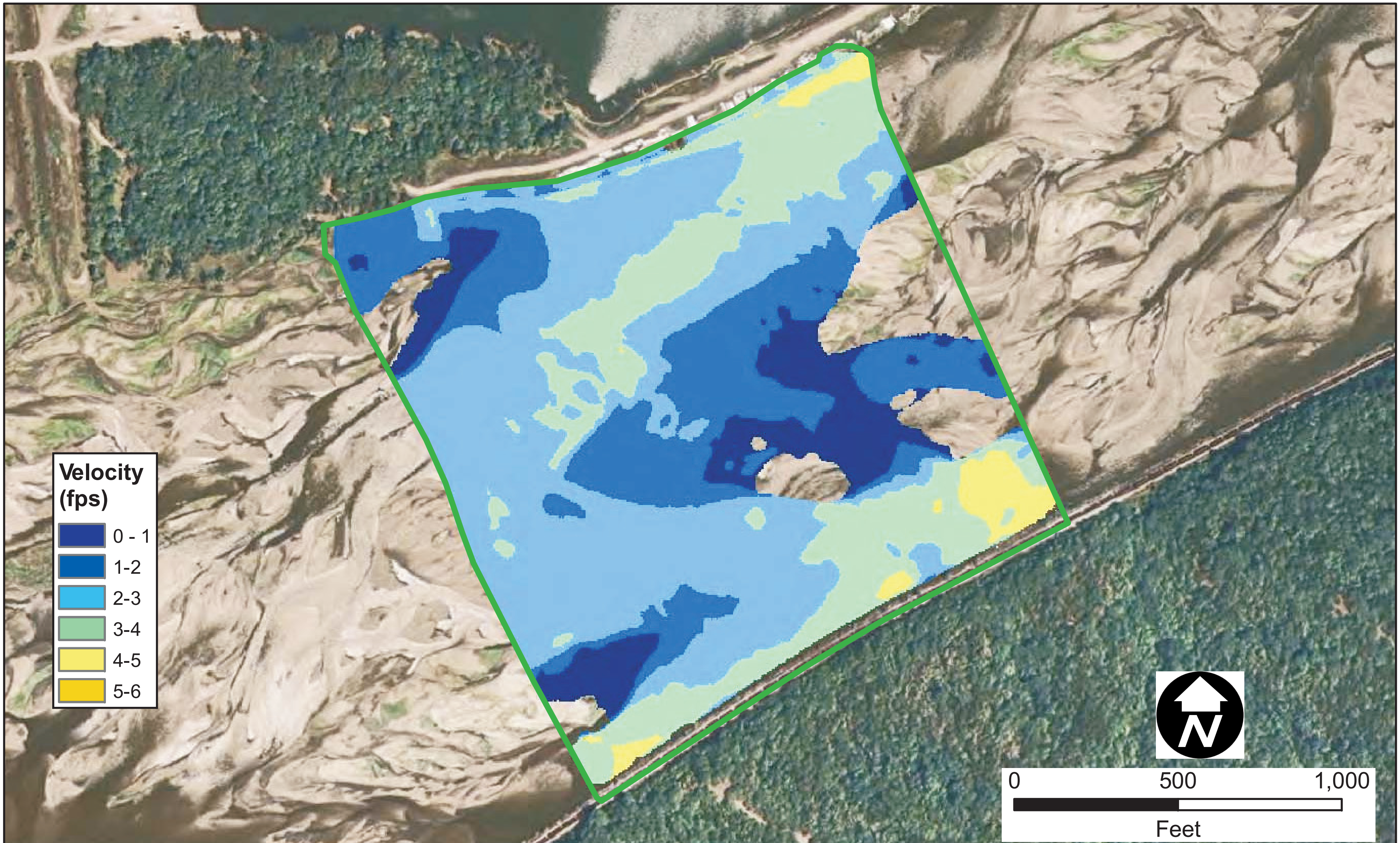
HDR
THE FLATWATER GROUP INC.
TETRA TECH
MEI

Computed Velocity at 8,000 cfs

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date: Dec. 2009

Figure: C4



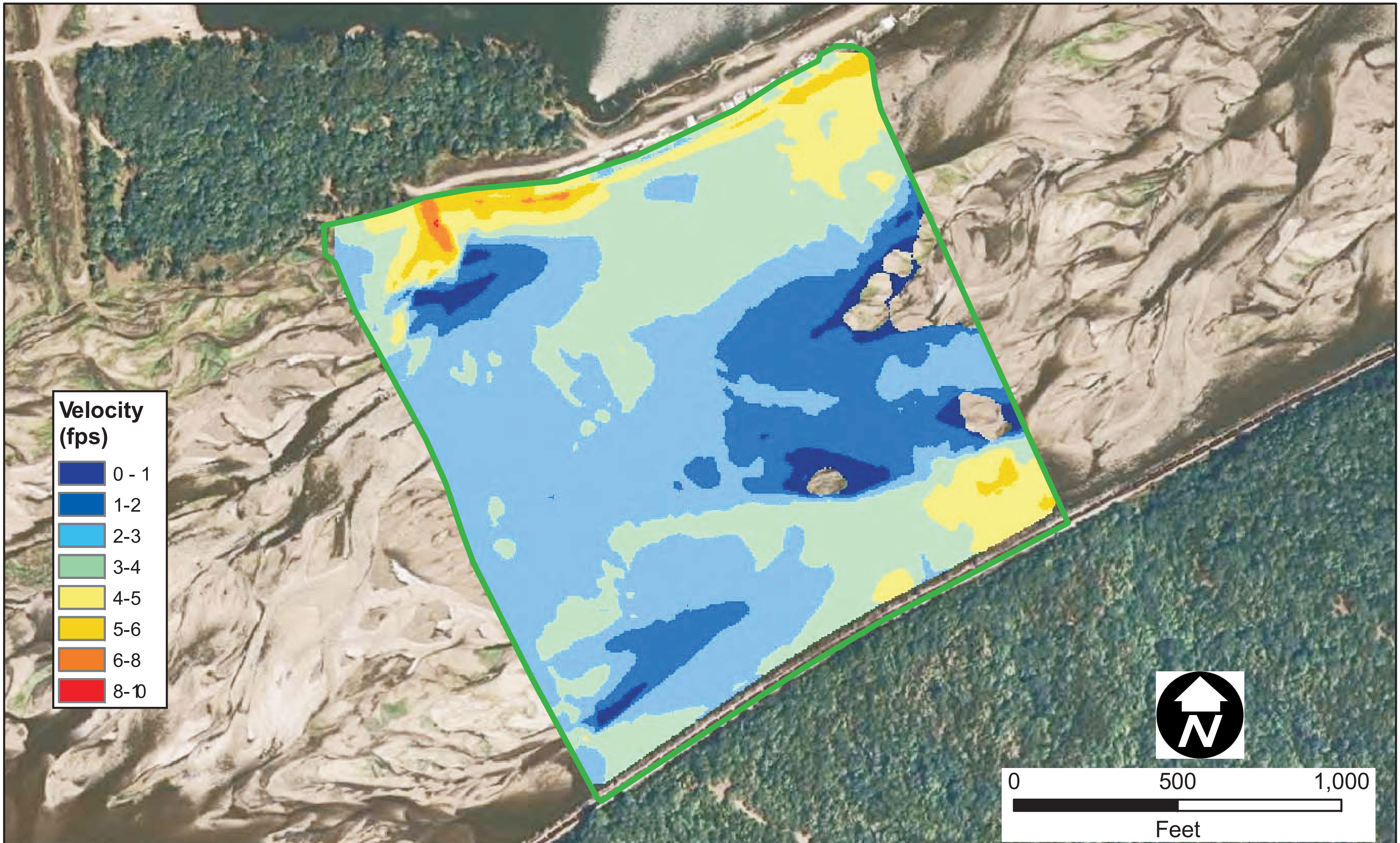
HDR | THE FLATWATER GROUP INC. | TETRA TECH | MEI

Computed Velocity at 10,000 cfs

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date: Dec. 2009

Figure: C5

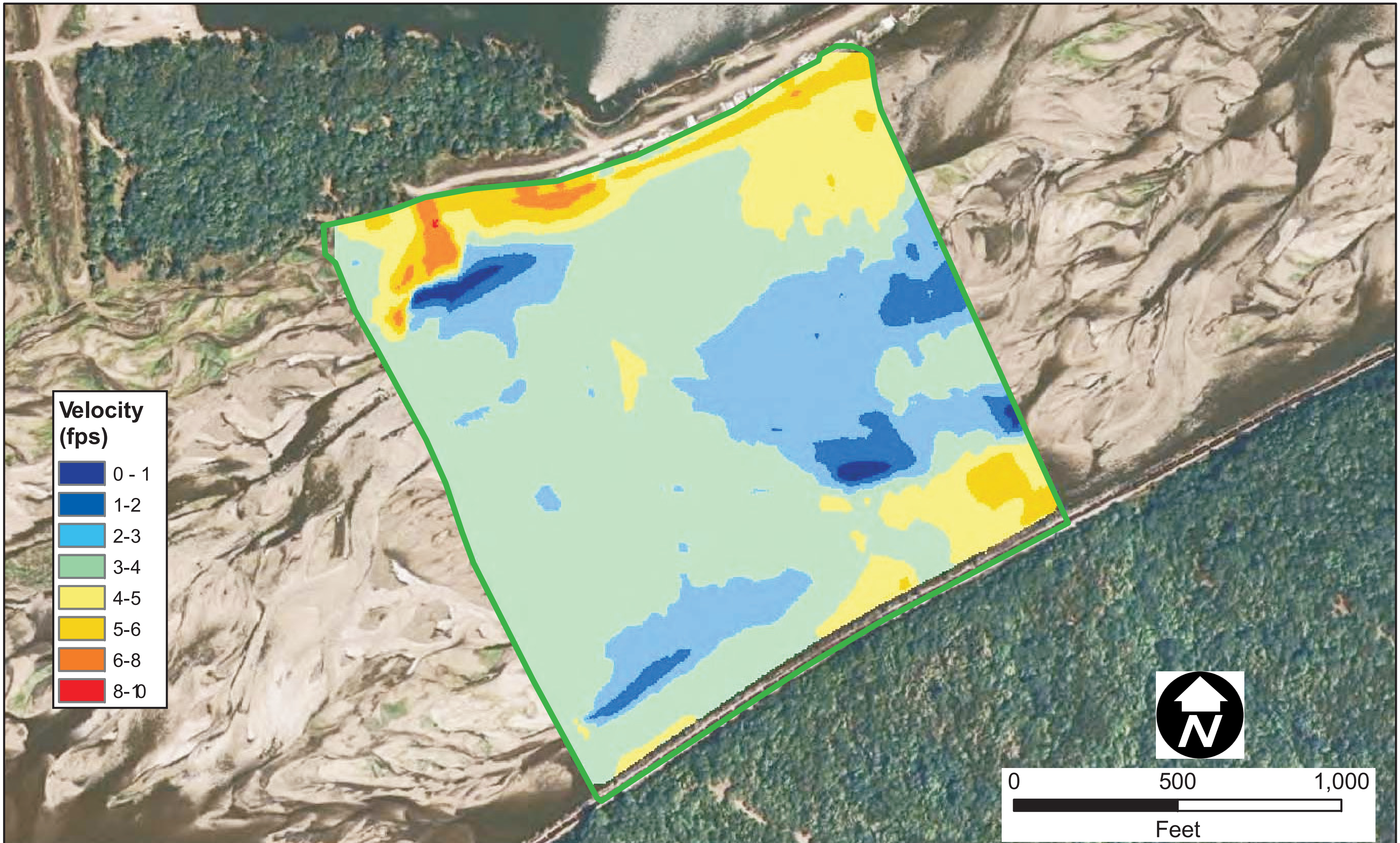


Computed Velocity at 14,000 cfs

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date: Dec. 2009

Figure: C6



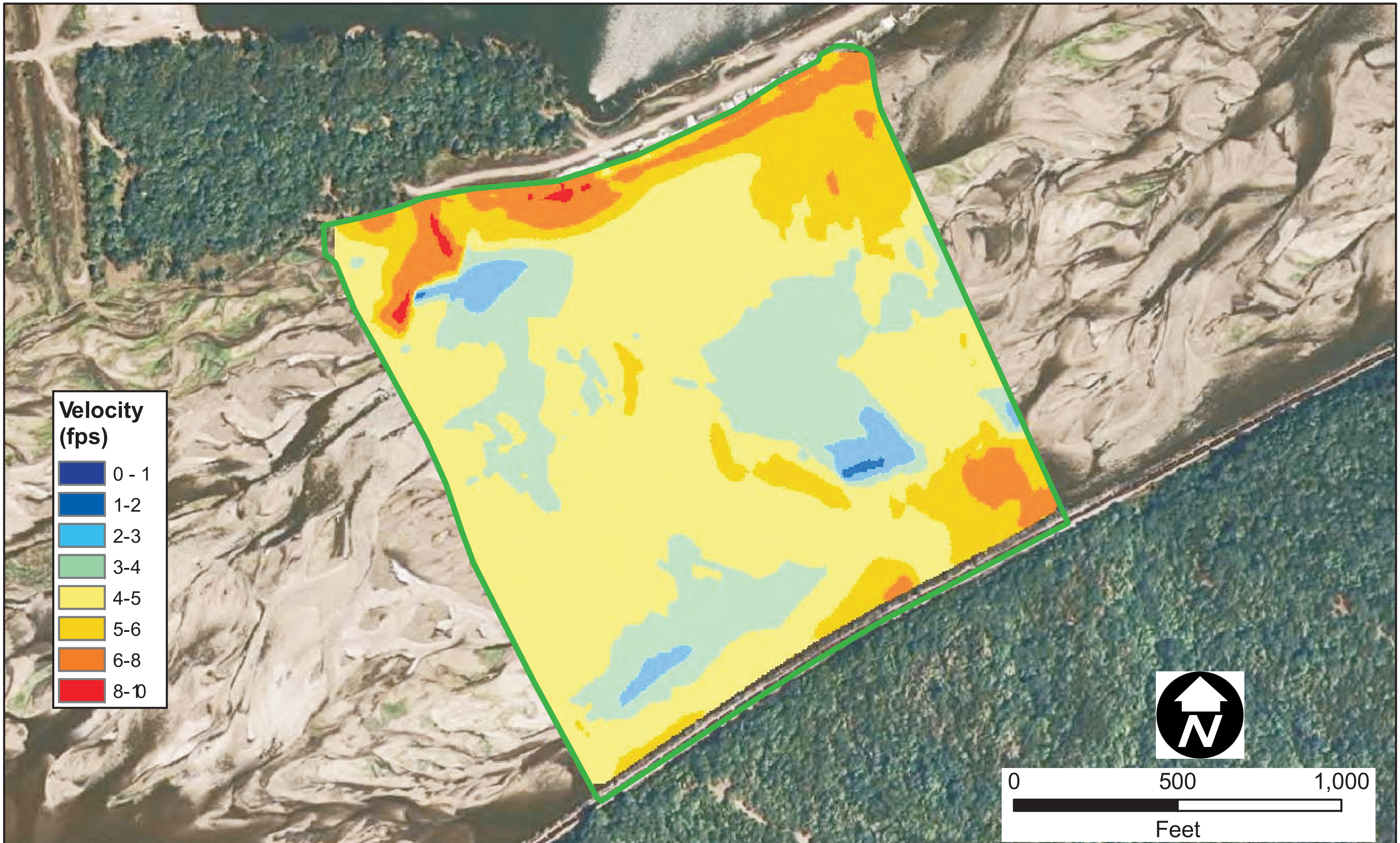
HDR
THE FLATWATER GROUP INC.
TETRA TECH
MEI

Computed Velocity at 20,000 cfs

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date: Dec. 2009

Figure: C7



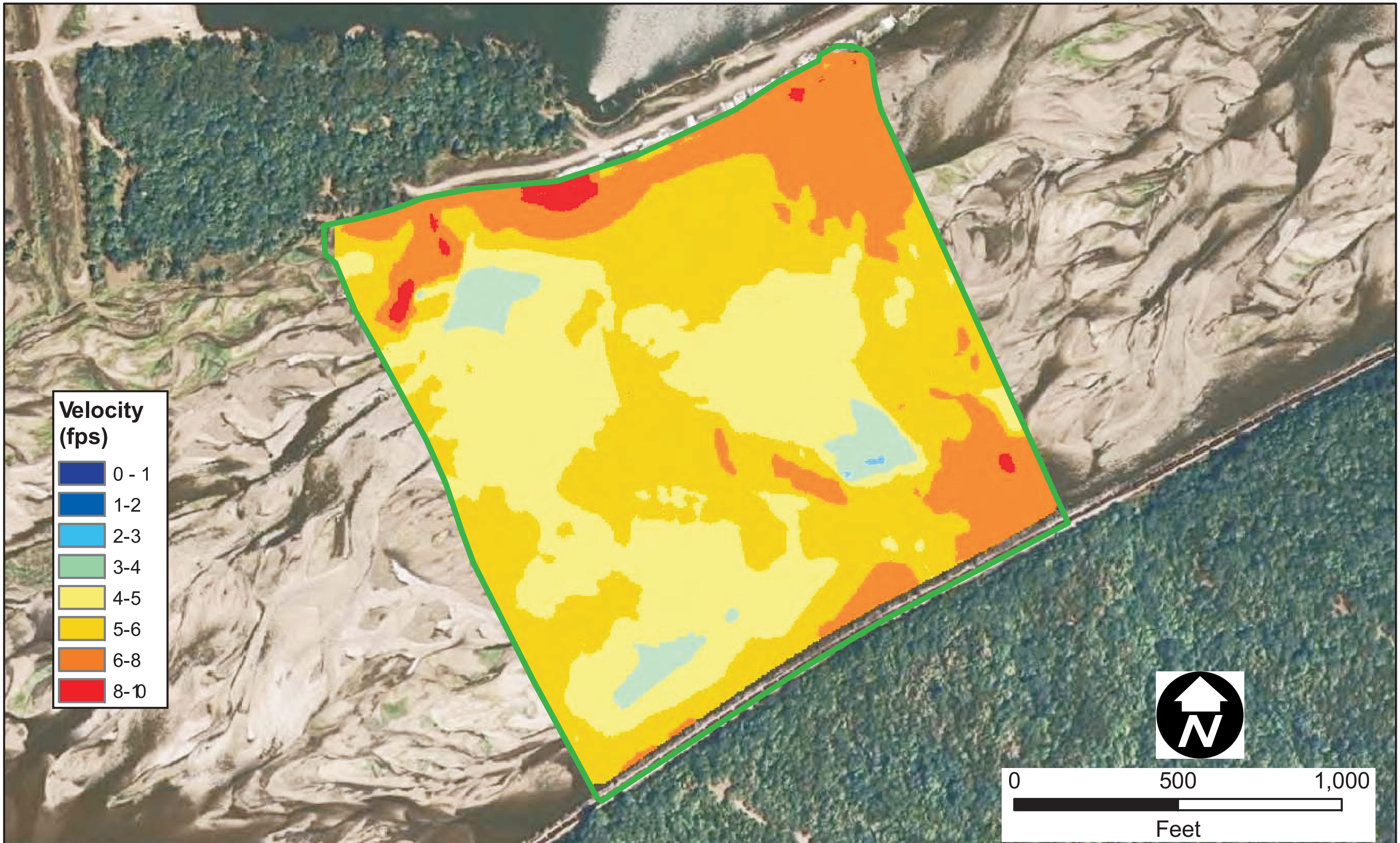
HDR
THE FLATWATER GROUP INC.
TETRA TECH
MEI

Computed Velocity at 30,000 cfs

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date: Dec. 2009

Figure: C8



Computed Velocity at 40,000 cfs

HDR
THE FLATWATER GROUP INC.
TETRA TECH
MEI

RECOVERY IMPLEMENTATION PROGRAM PLATTE RIVER

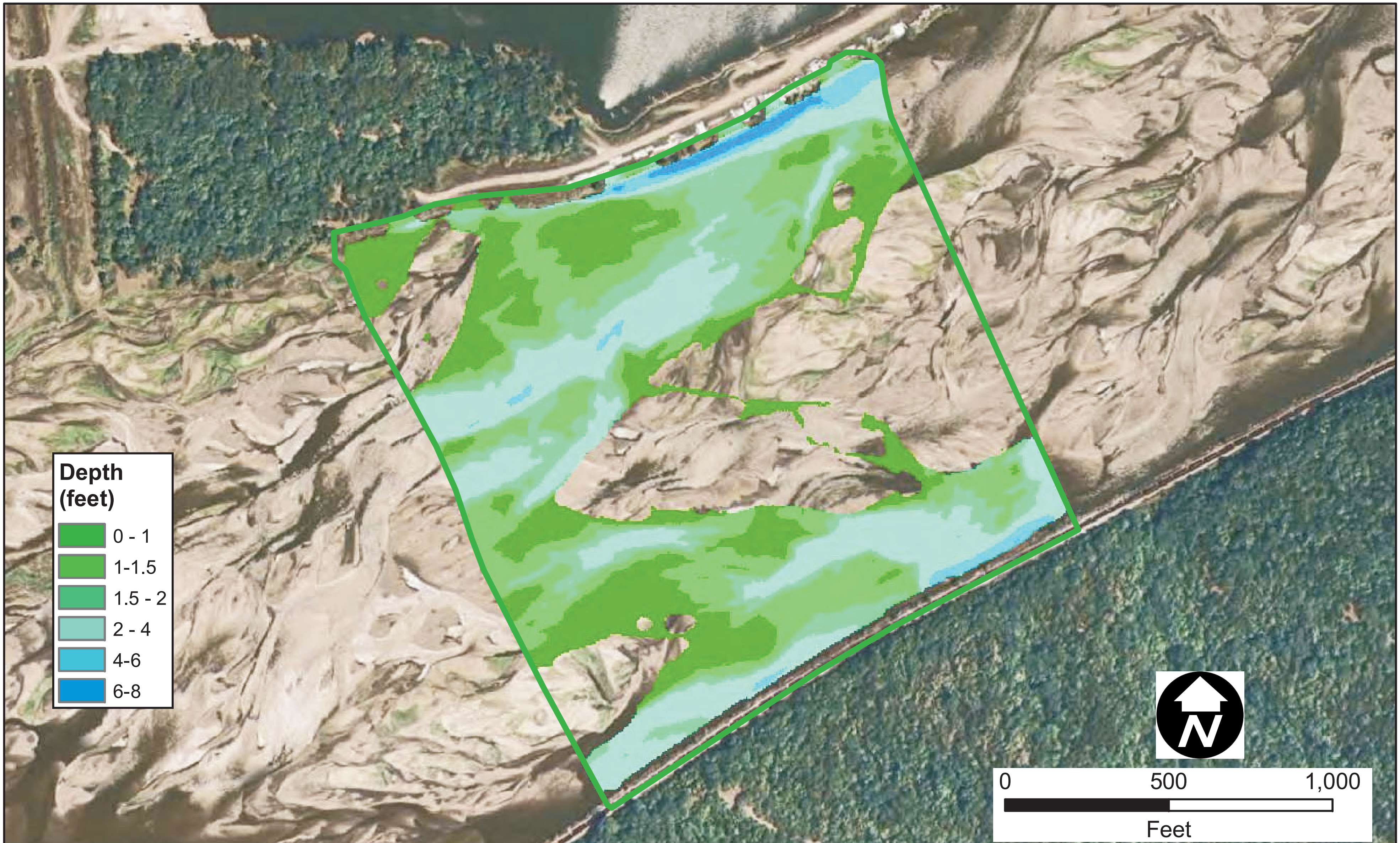
Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date: Dec. 2009

Figure: C9

Appendix D

Spatial Distribution Maps of Computed Channel Depths from the SRH-2D over a Range of Discharges between 3,700 and 40,000 cfs



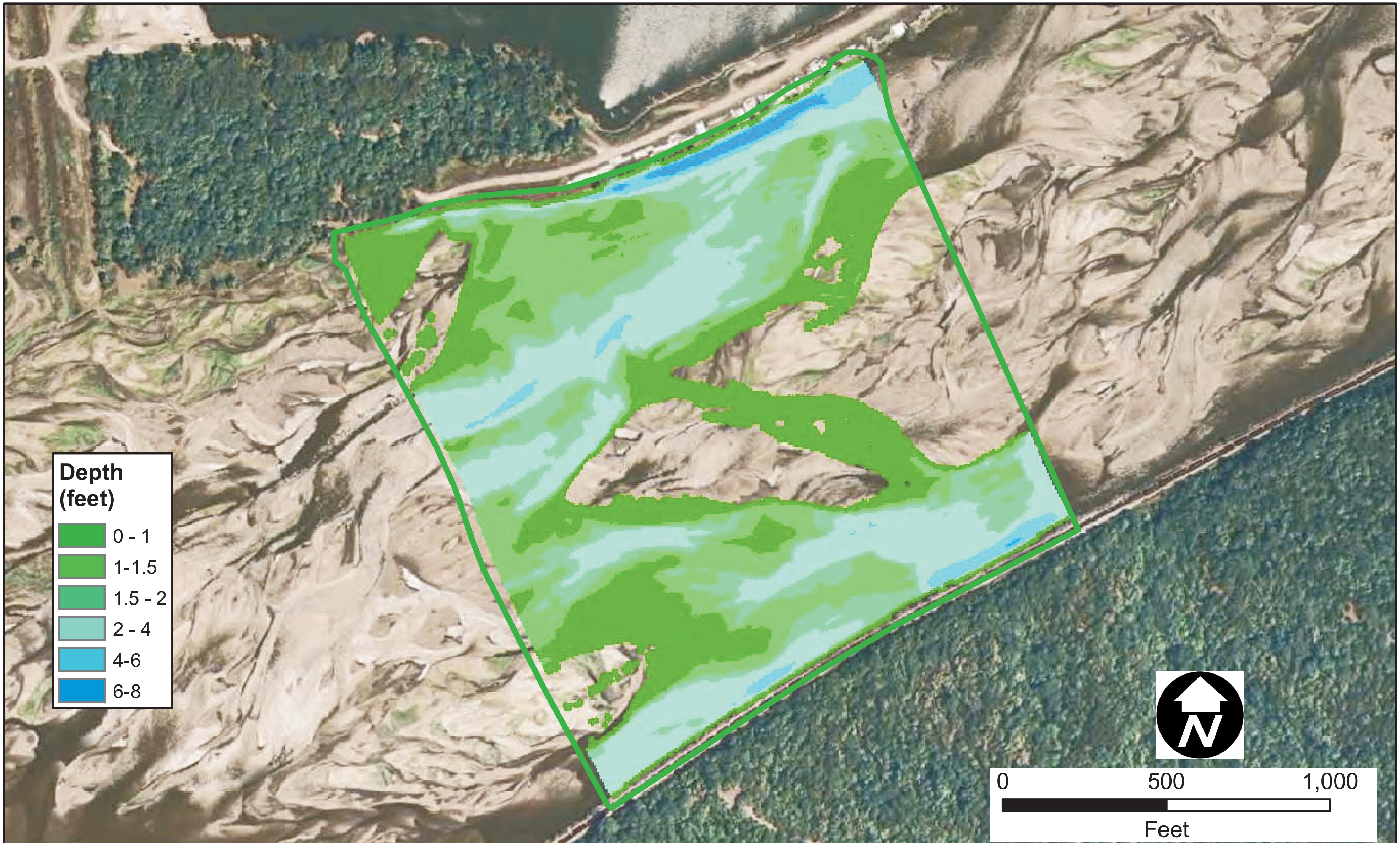
HDR
THE FLATWATER GROUP INC.
TETRA TECH
MEI

Computed Depth at 3,700 cfs

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date: Dec. 2009

Figure: D1



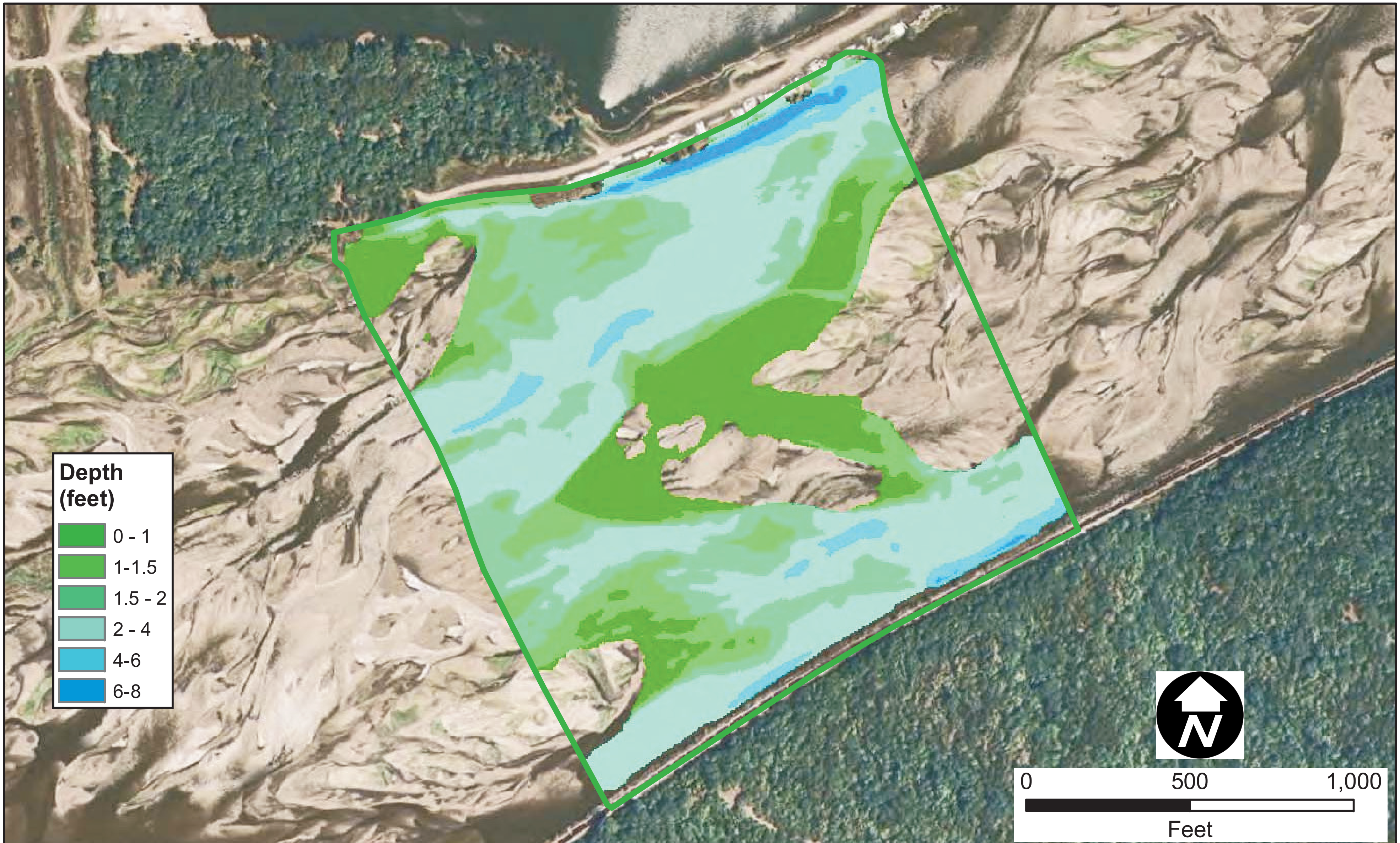
HDR
THE FLATWATER GROUP INC.
TETRA TECH
MEI

Computed Depth at 4,300 cfs

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date: Dec. 2009

Figure: D2

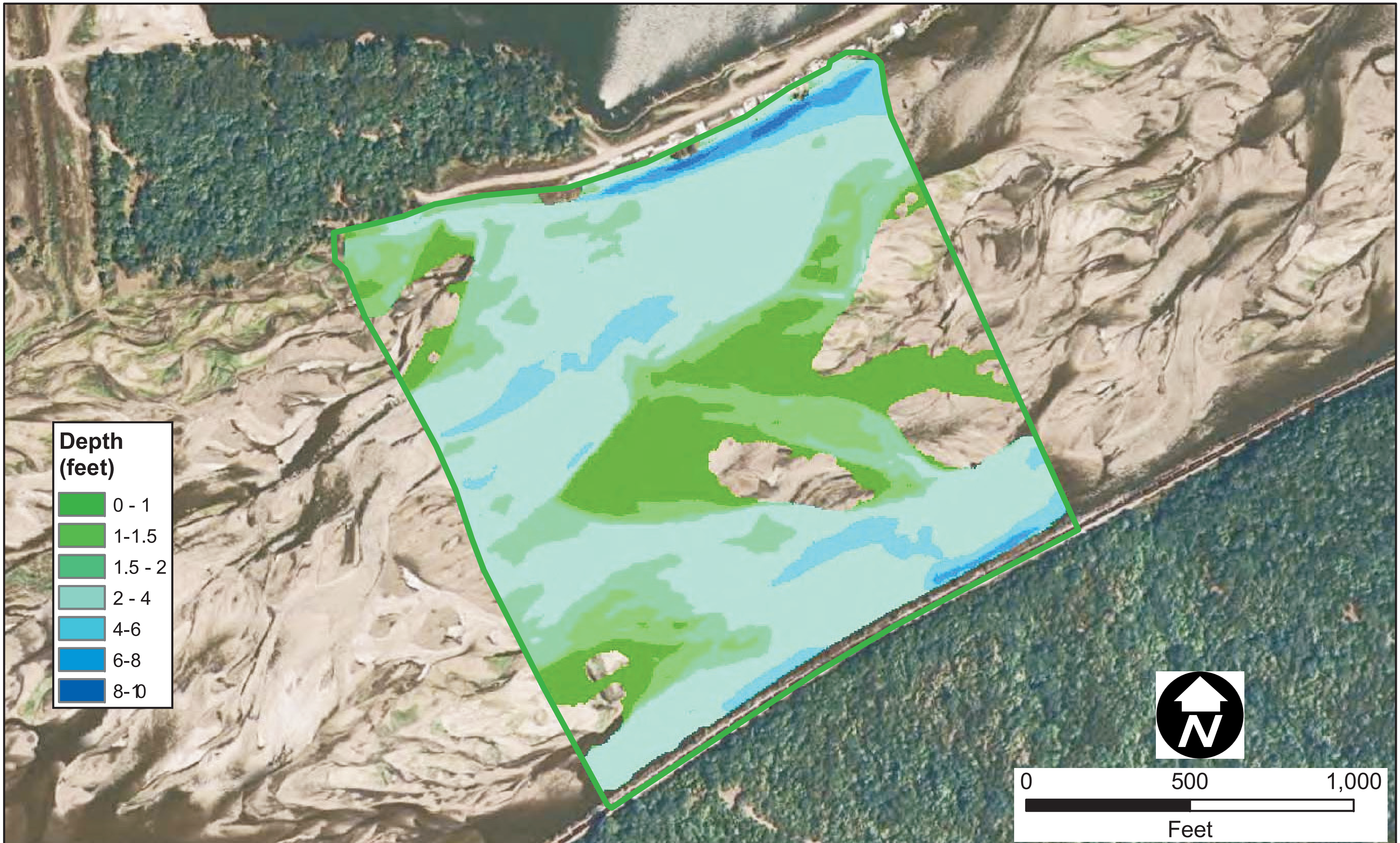


Computed Depth at 6,000 cfs

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date: Dec. 2009

Figure: D3



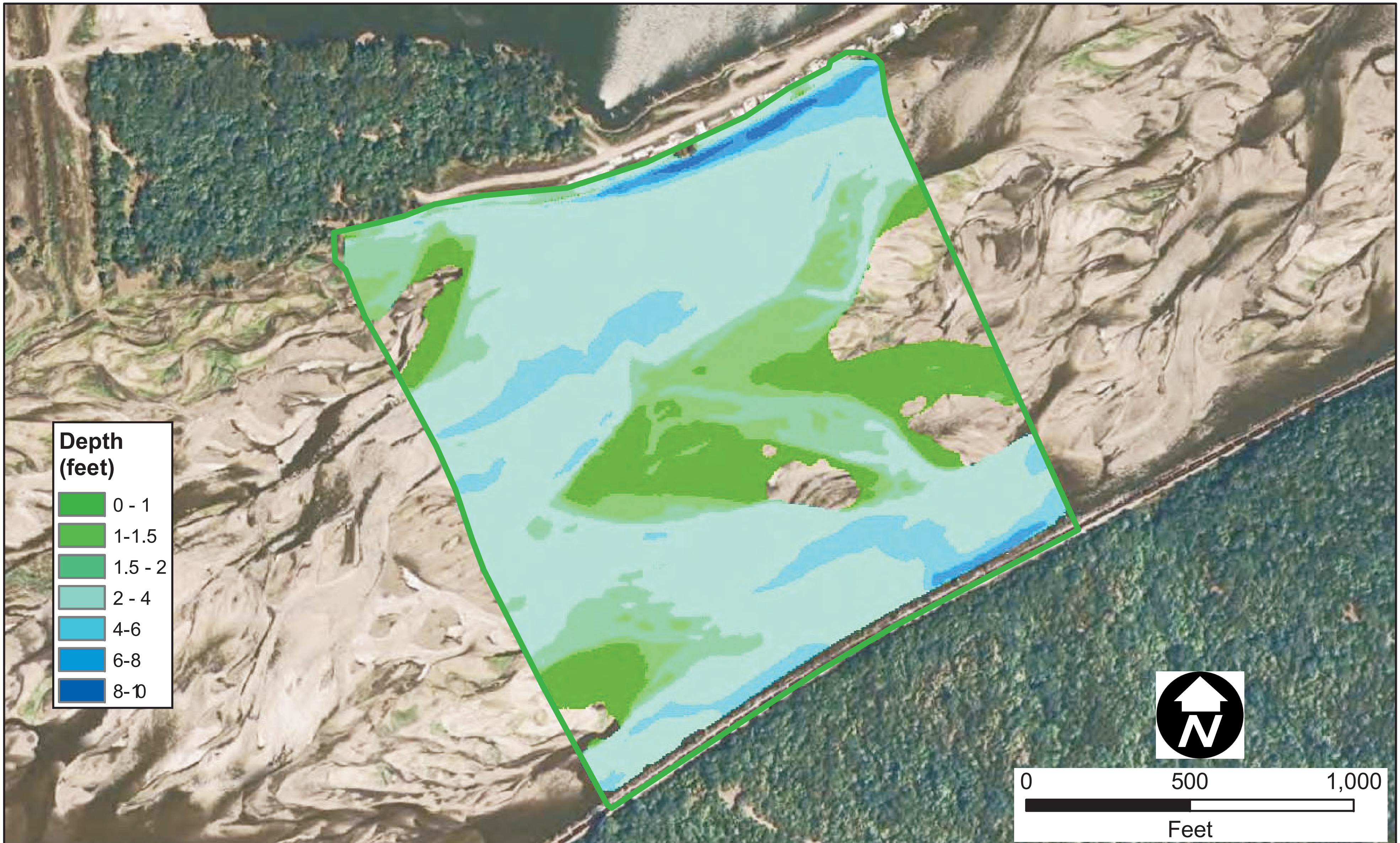
HDR
THE FLATWATER GROUP INC.
TETRA TECH
MEI

Computed Depth at 8,000 cfs

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date: Dec. 2009

Figure: D4

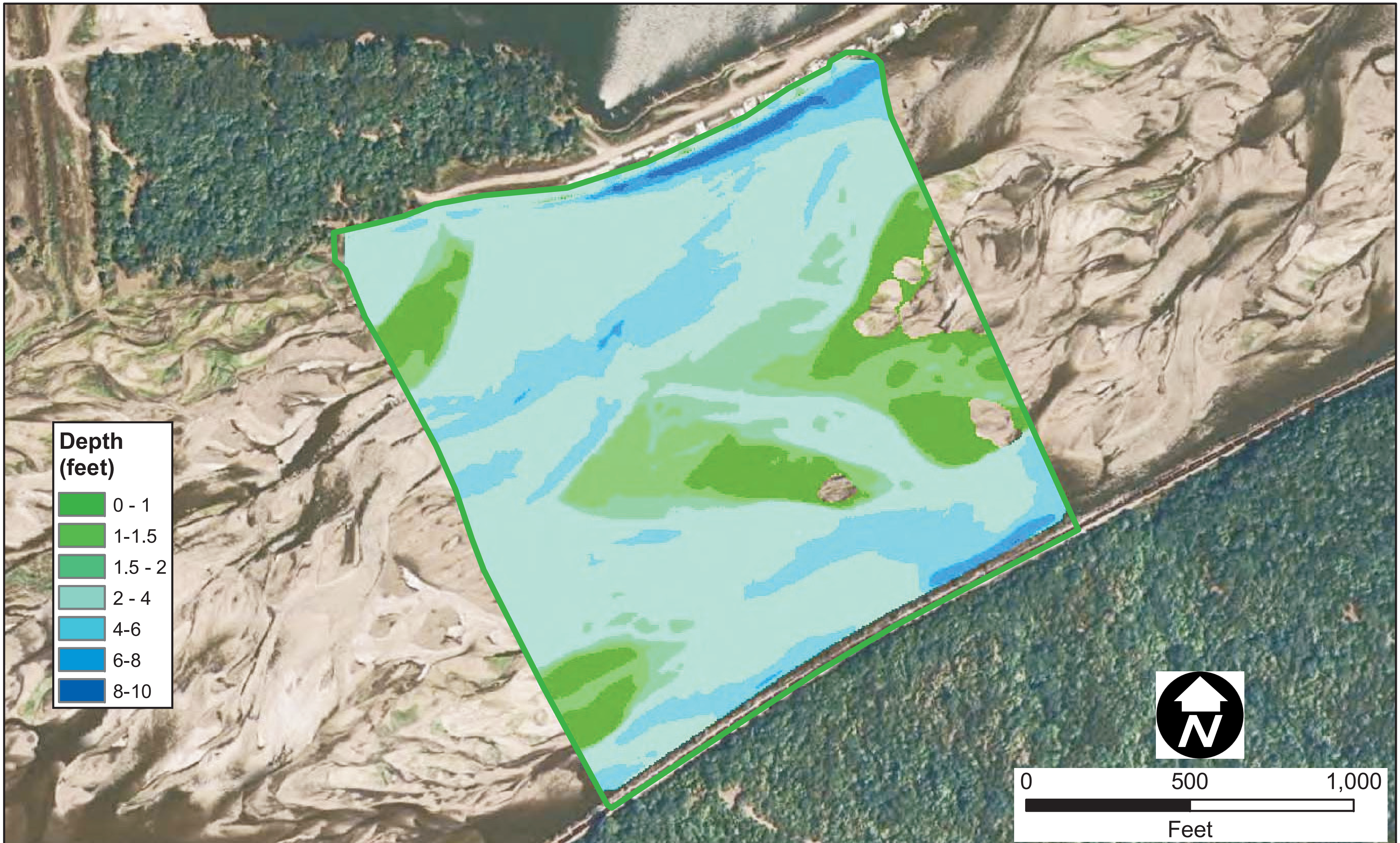


Computed Depth at 10,000 cfs

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date:
Dec. 2009

Figure:
D5



HDR
THE FLATWATER GROUP INC.
TETRA TECH
MEI

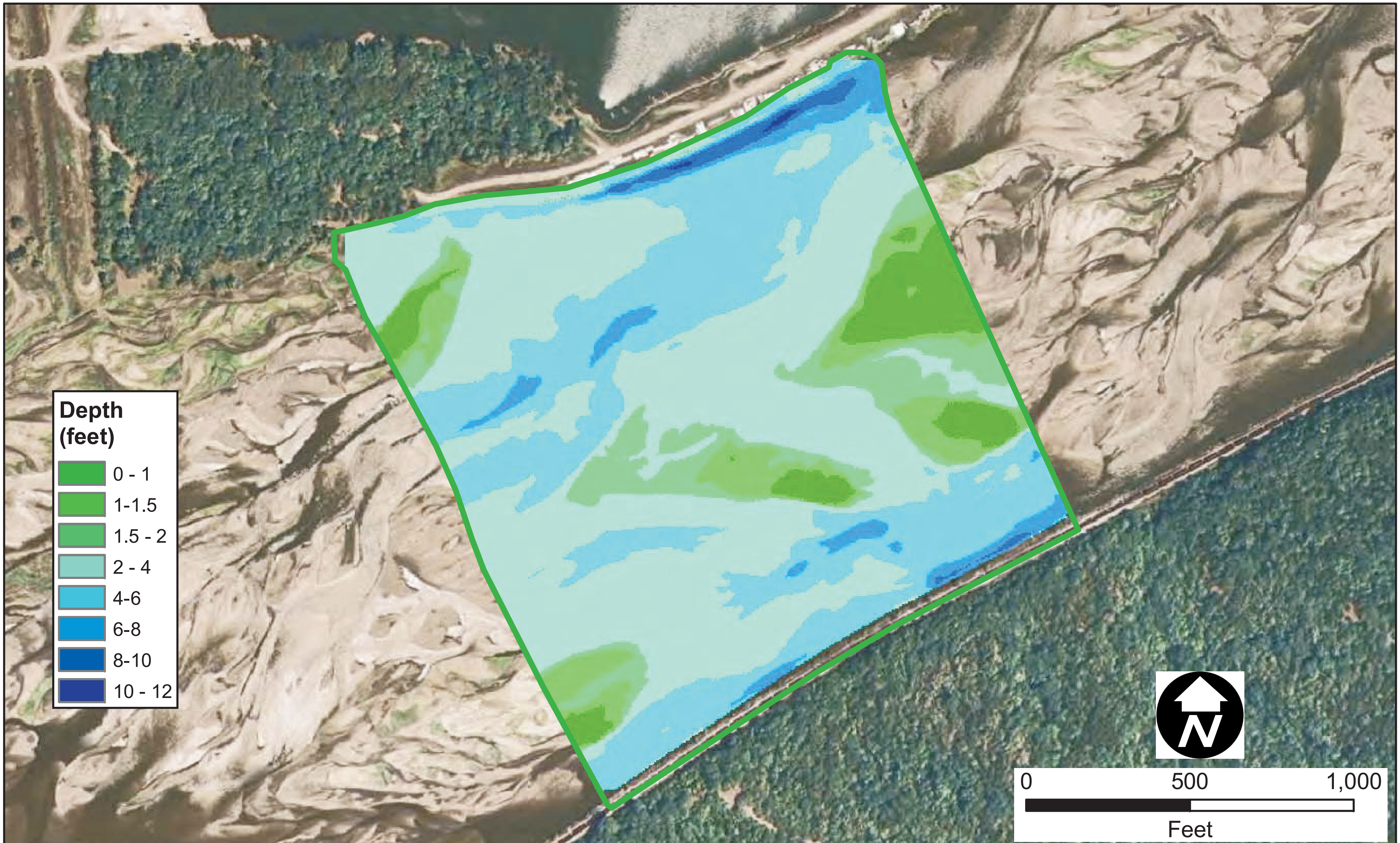
Computed Depth at 14,000 cfs

RECOVERY IMPLEMENTATION PROGRAM PLATTE RIVER

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date: Dec. 2009

Figure: D6



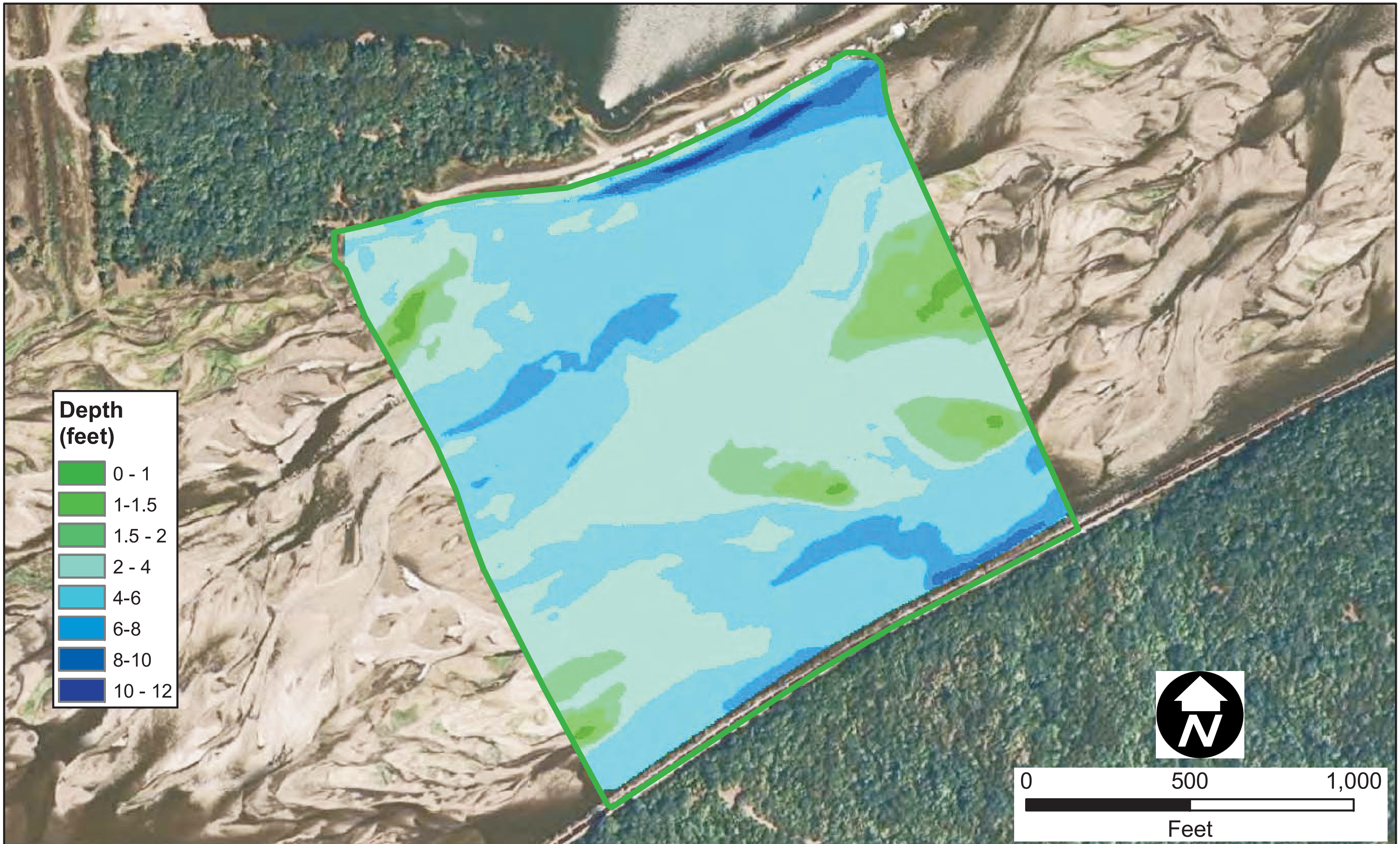
HDR
THE FLATWATER GROUP INC.
TETRA TECH
MEI

Computed Depth at 20,000 cfs

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date: Dec. 2009

Figure: D7



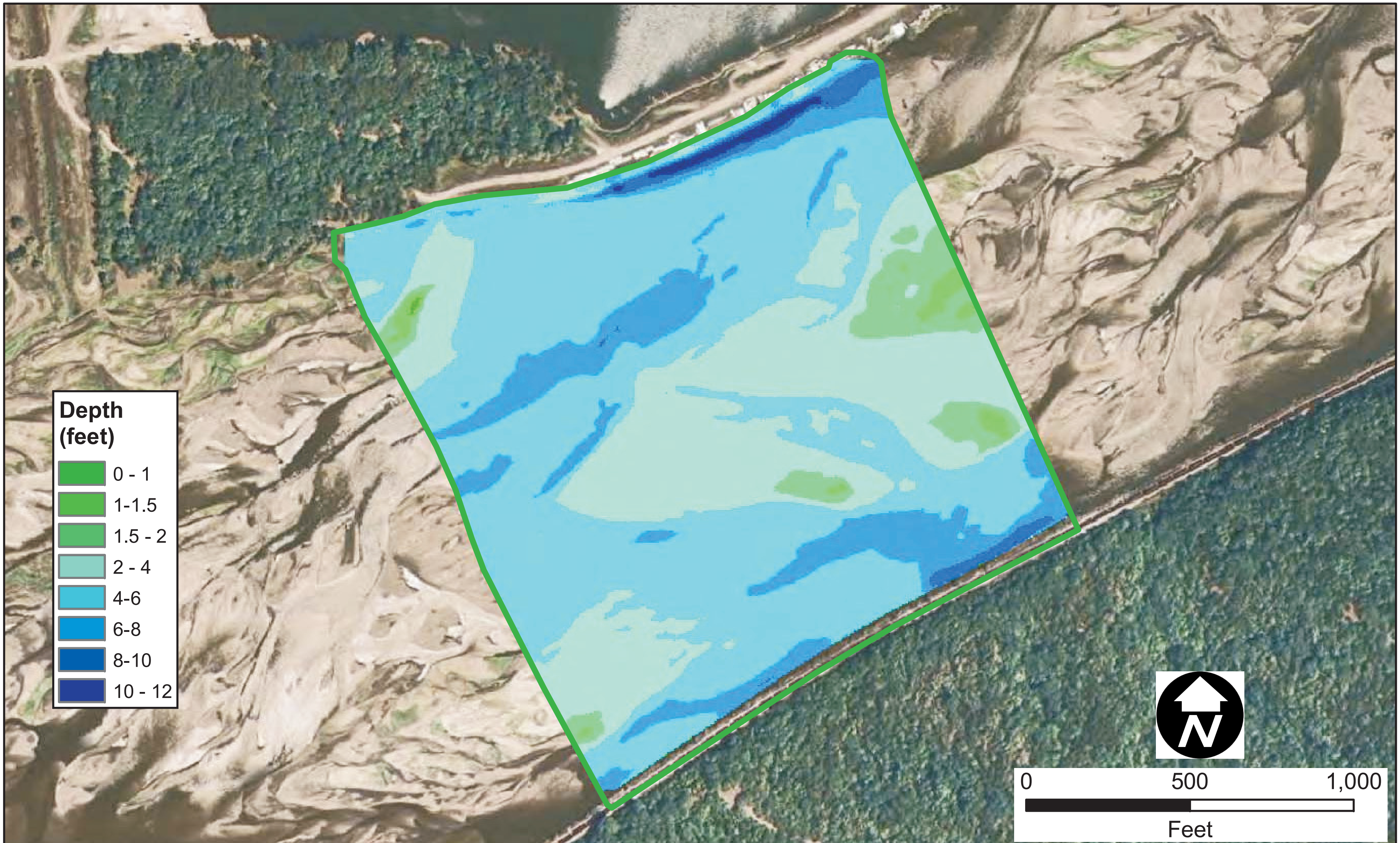
HDR
THE FLATWATER GROUP INC.
TETRA TECH
MEI

Computed Depth at 30,000 cfs

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date: Dec. 2009

Figure: D8



HDR
THE FLATWATER GROUP INC.
TETRA TECH
MEI

Computed Depth at 40,000 cfs

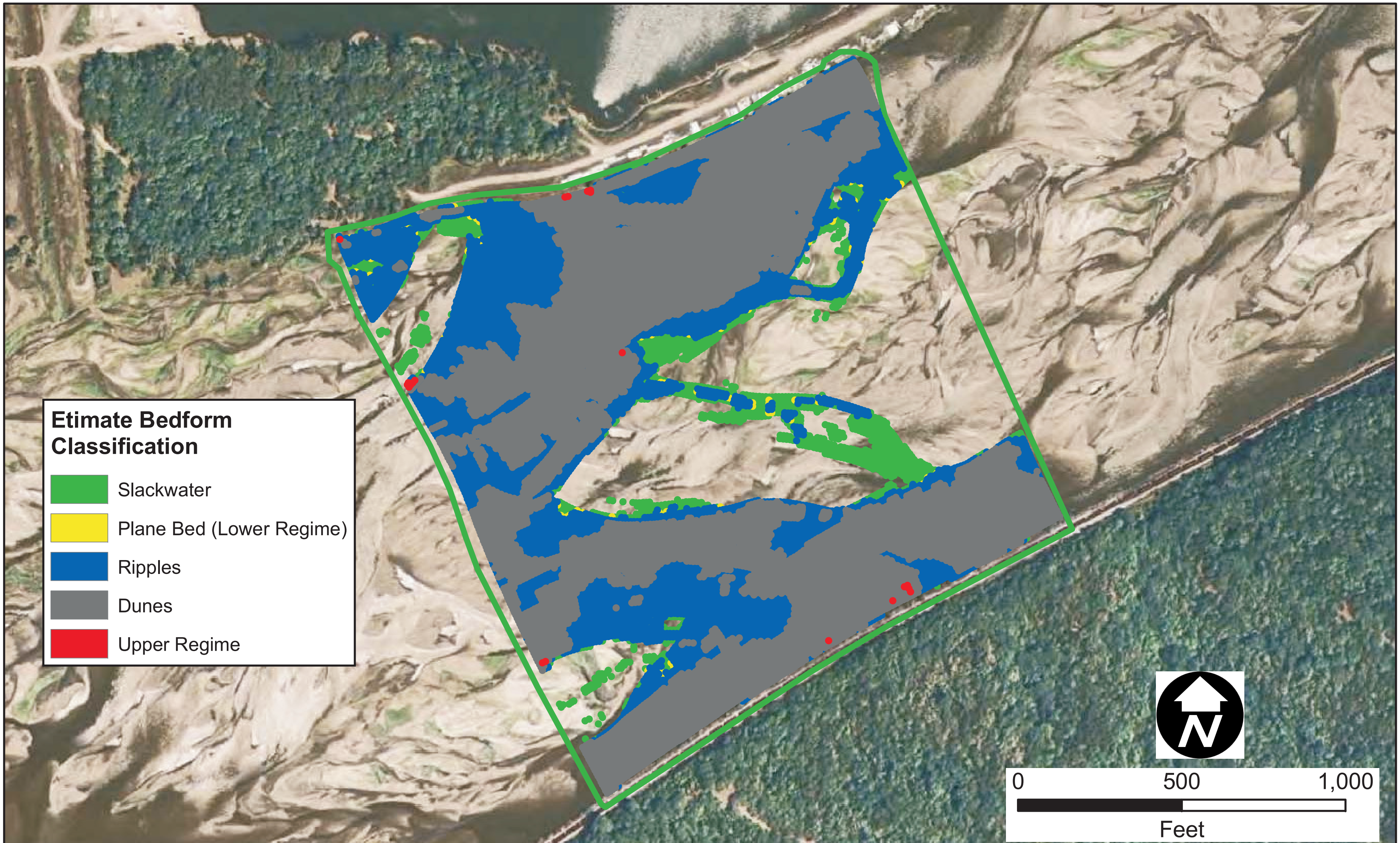
Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date: Dec. 2009

Figure: D9

Appendix E

Spatial Distribution Maps of Estimated Bedform Types over a Range of Discharges between 3,700 and 40,000 cfs



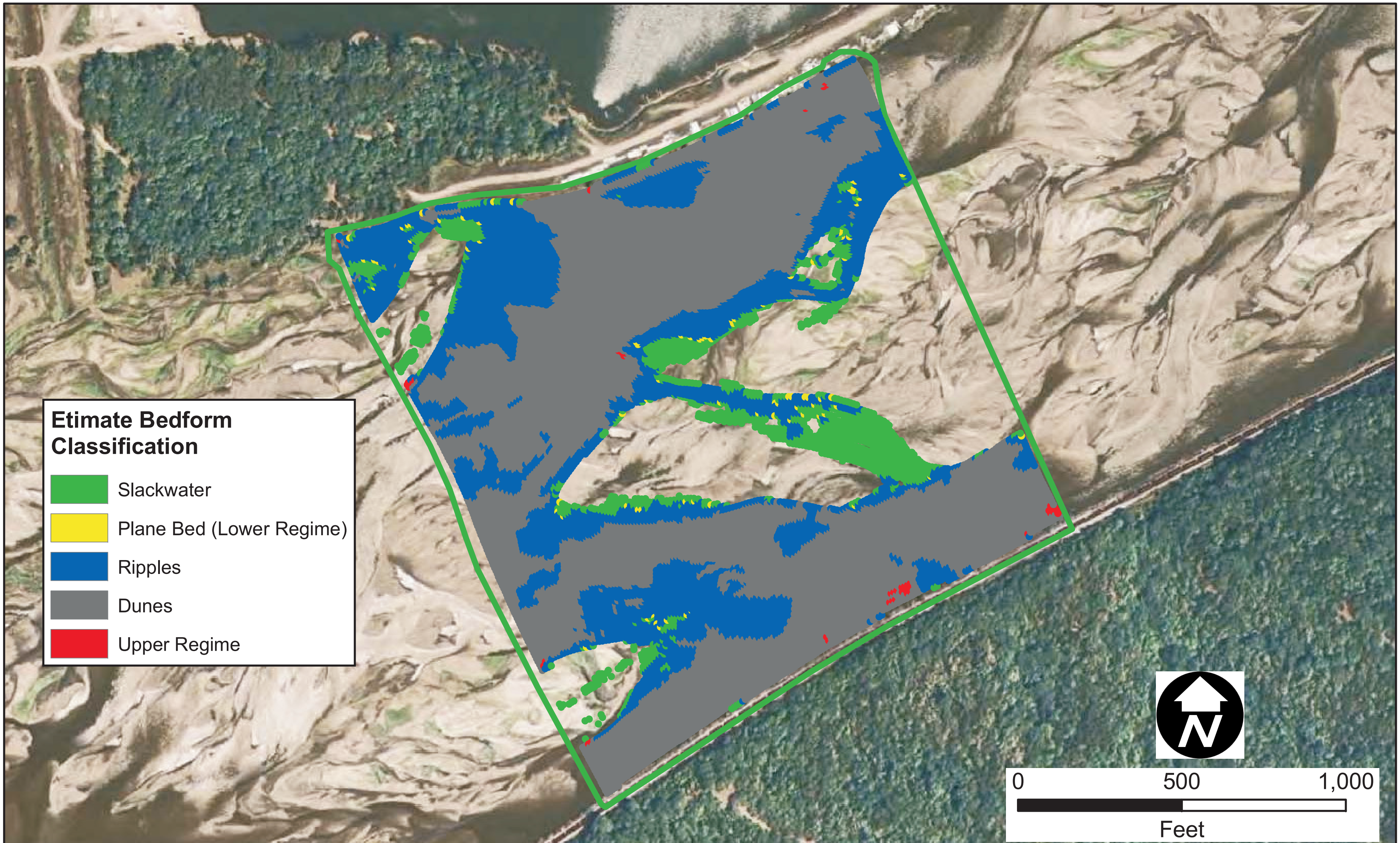
HDR
THE FLATWATER GROUP INC.
TETRA TECH
MEI

Estimated Bedform Classes at 3,700 cfs

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date: Dec. 2009

Figure: E1



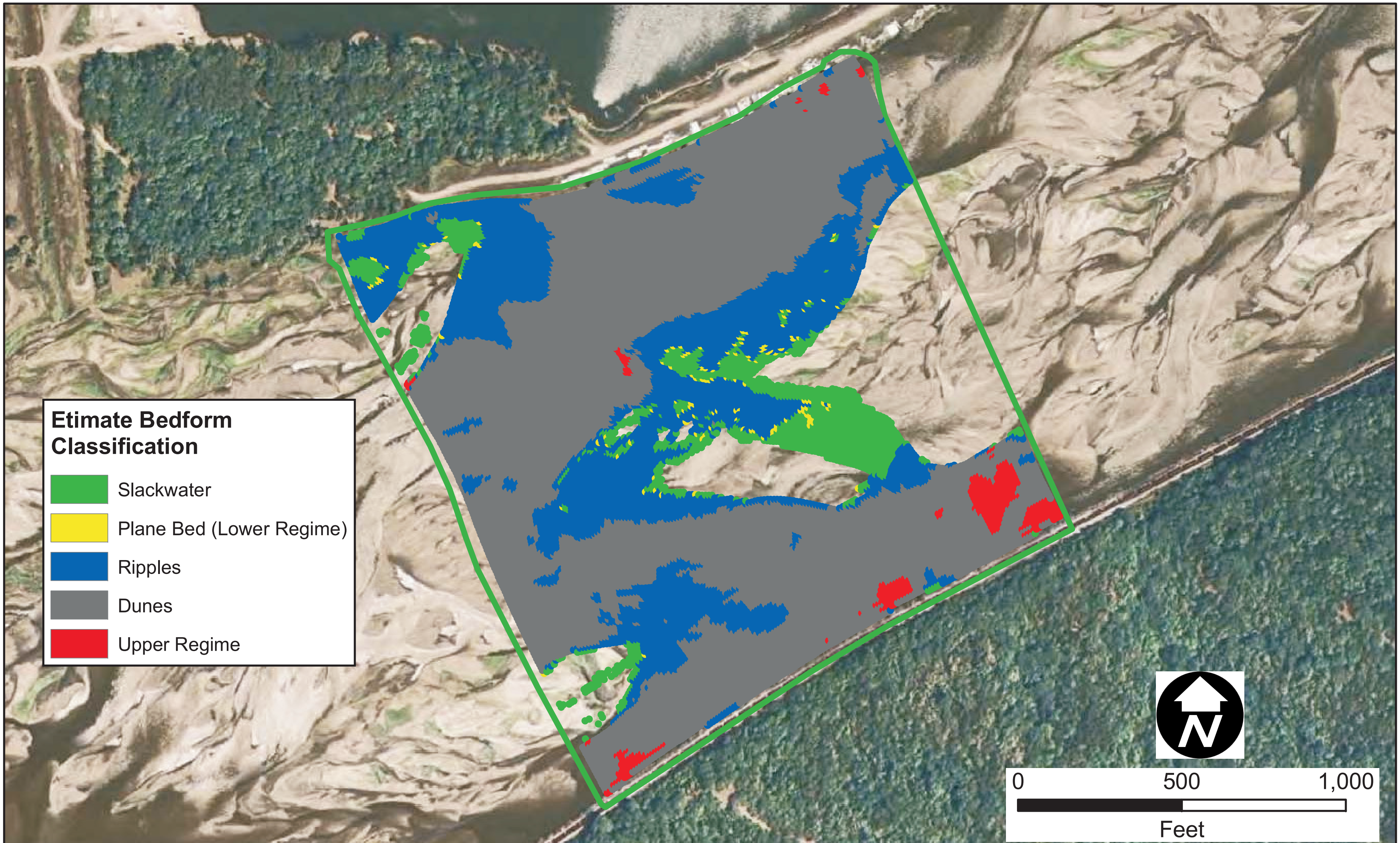
HDR
THE FLATWATER GROUP INC.
TETRA TECH
MEI

Estimated Bedform Classes at 4,300 cfs

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date: Dec. 2009

Figure: E2



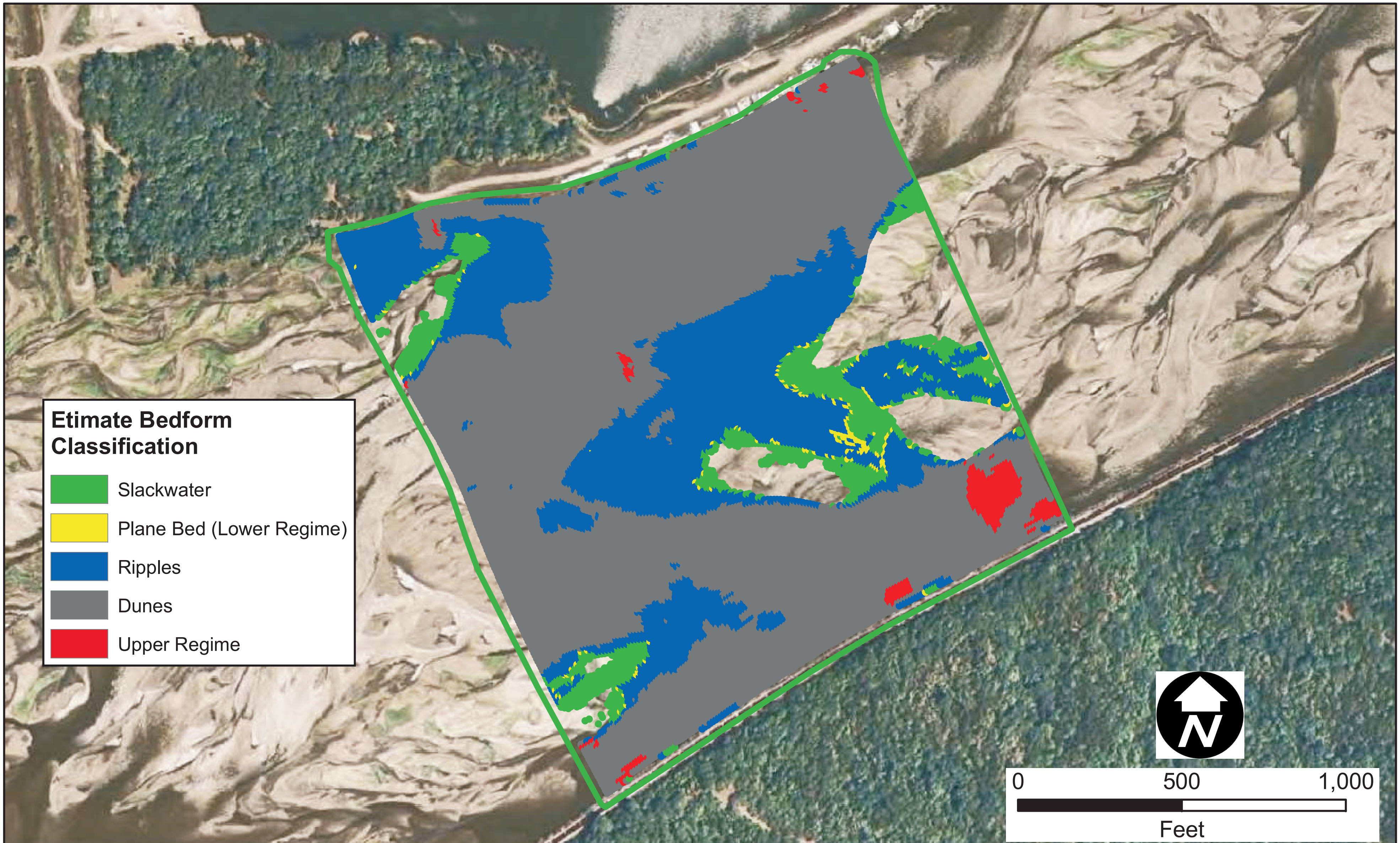
HDR
THE FLATWATER GROUP INC.
TETRA TECH
MEI

Estimated Bedform Classes at 6,000 cfs

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date:
Dec. 2009

Figure:
E3



HDR
THE FLATWATER GROUP INC.
TETRA TECH
MEI

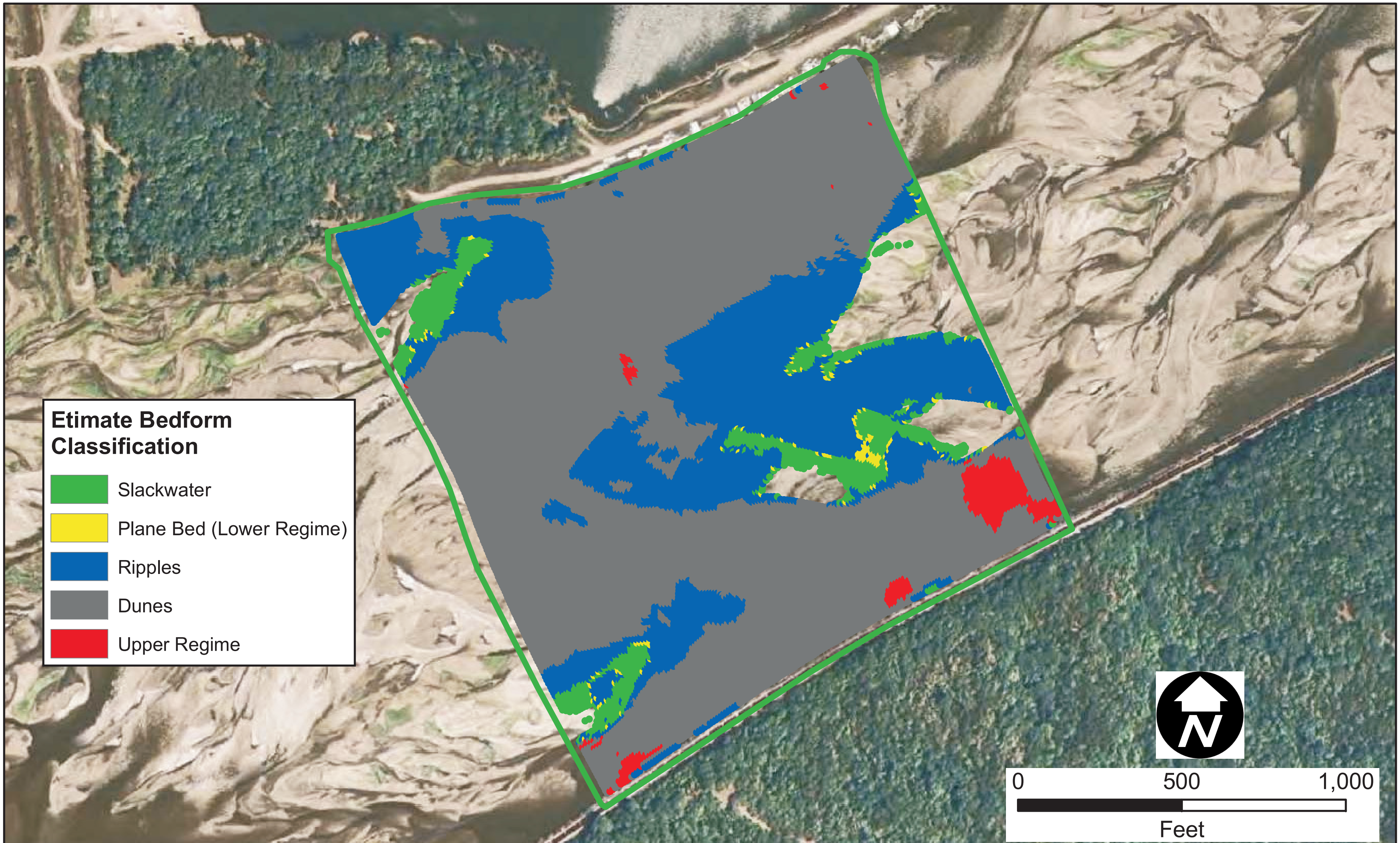
Estimated Bedform Classes at 8,000 cfs

RECOVERY IMPLEMENTATION PROGRAM PLATTE RIVER

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date: Dec. 2009

Figure: E4



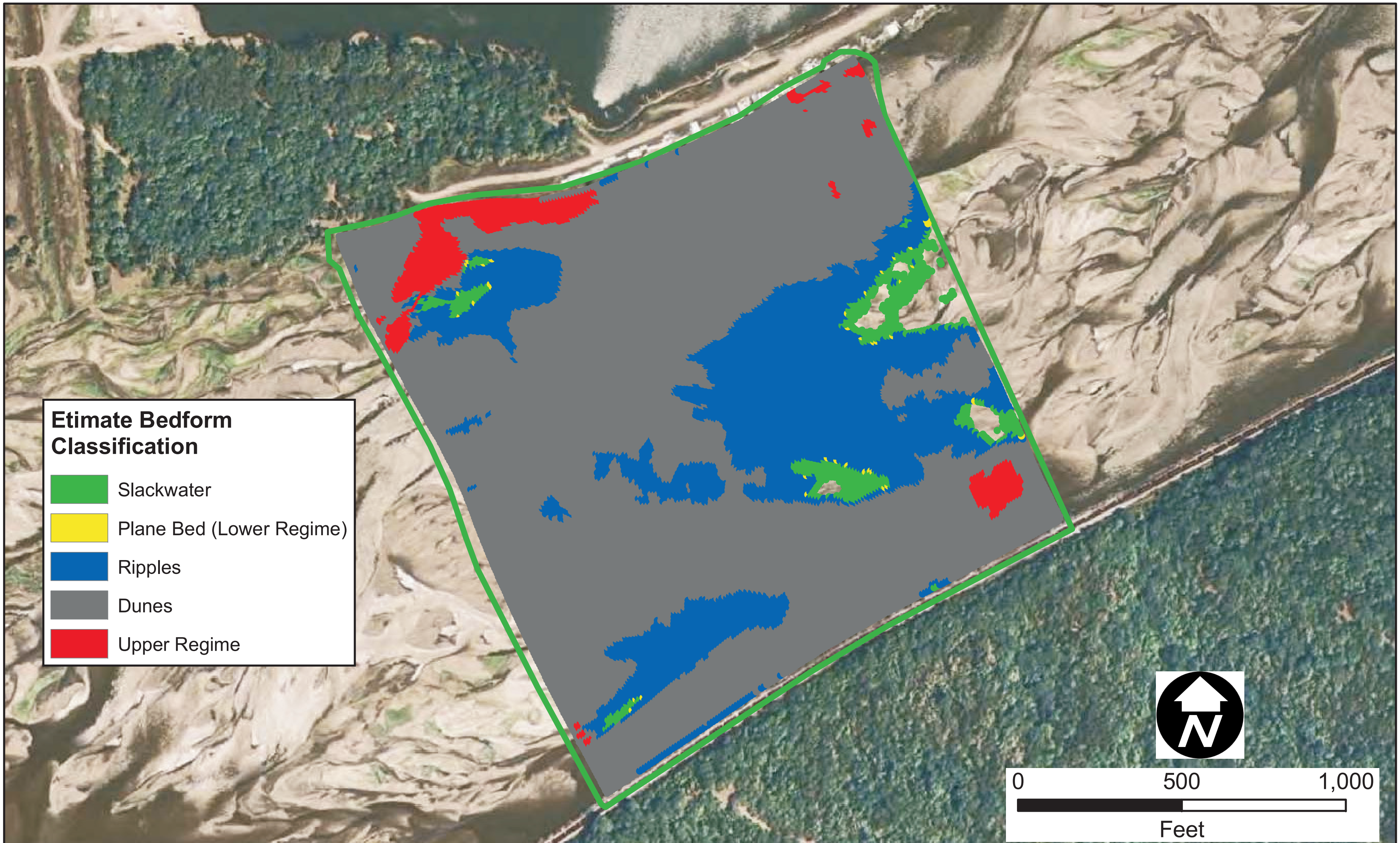
HDR
THE FLATWATER GROUP INC.
TETRA TECH
MEI

Estimated Bedform Classes at 10,000 cfs

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date: Dec. 2009

Figure: E5



HDR
THE FLATWATER GROUP INC.
TETRA TECH
MEI

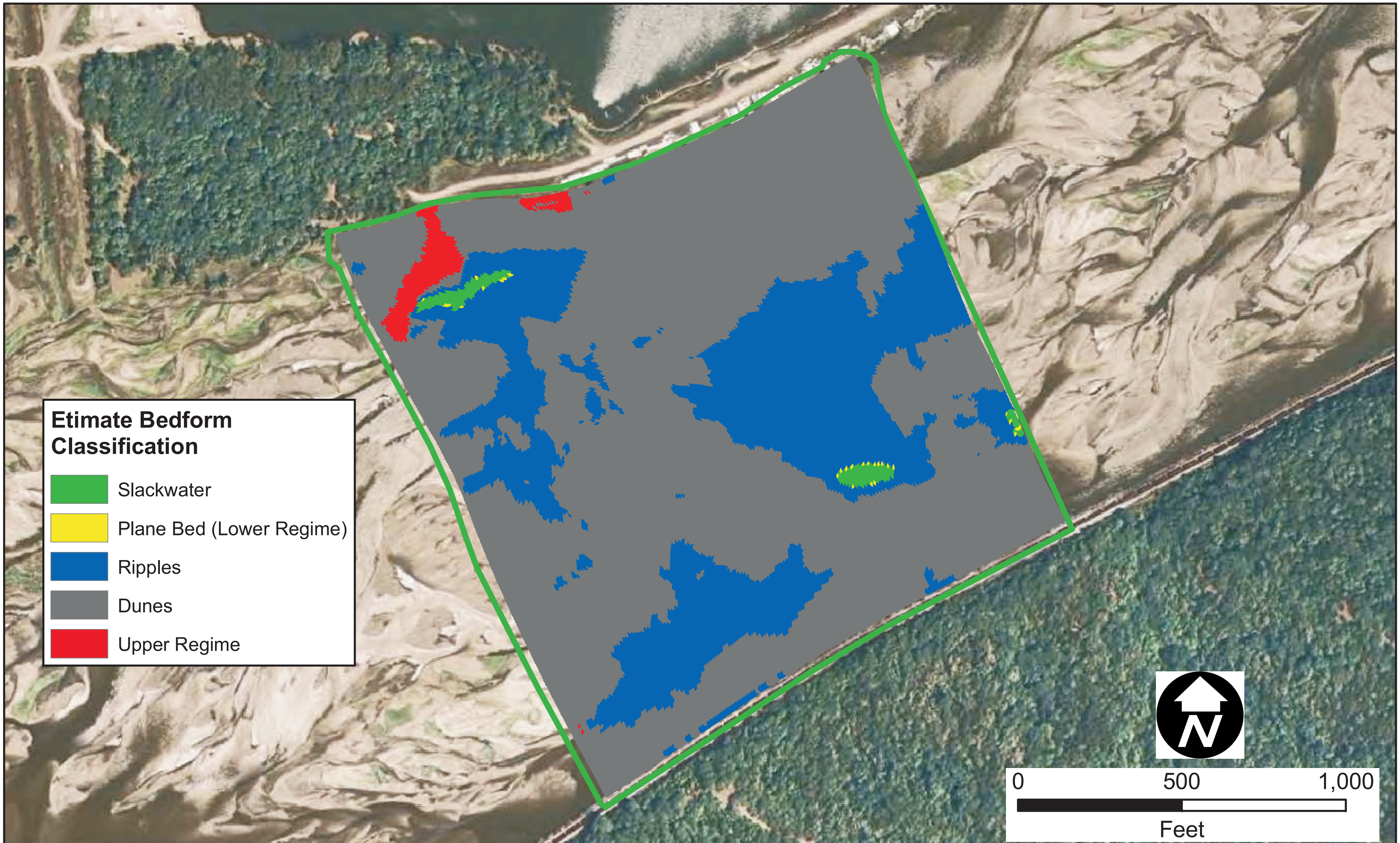
Estimated Bedform Classes at 14,000 cfs

RECOVERY IMPLEMENTATION PROGRAM
PLATTE RIVER

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date:
Dec. 2009

Figure:
E6



HDR
THE FLATWATER GROUP INC.
TETRA TECH
MEI

Estimated Bedform Classes at 20,000 cfs

Lower Platte River Stage Change Study

Final Protocol Implementation Report

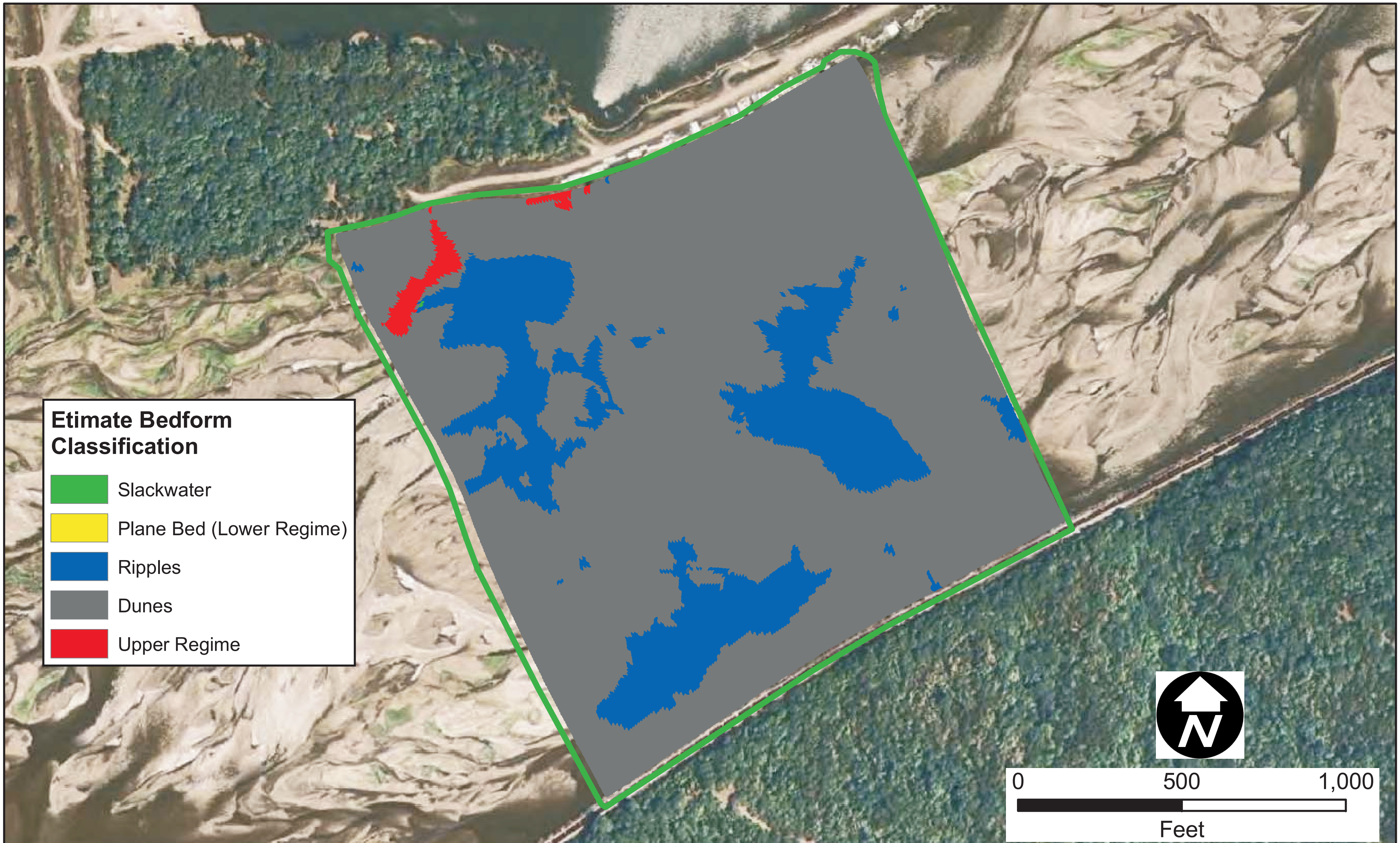
Platte River Recovery Implementation Program

Date:

Dec. 2009

Figure:

E7



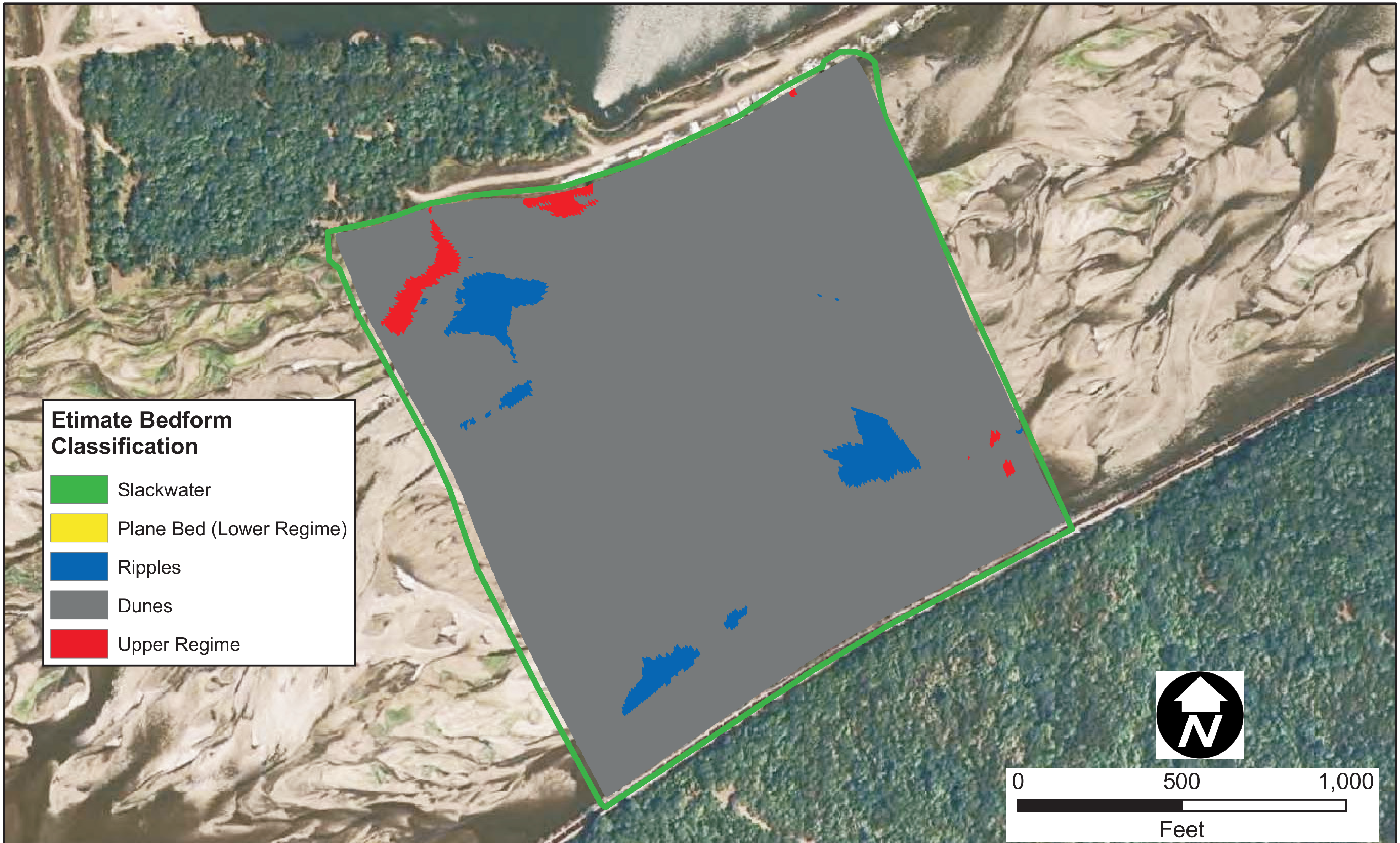
HDR
THE FLATWATER GROUP INC.
TETRA TECH
MEI

Estimated Bedform Classes at 30,000 cfs

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date: Dec. 2009

Figure: E8



HDR
THE FLATWATER GROUP INC.
TETRA TECH
MEI

Estimated Bedform Classes at 40,000 cfs

RECOVERY IMPLEMENTATION PROGRAM PLATTE RIVER

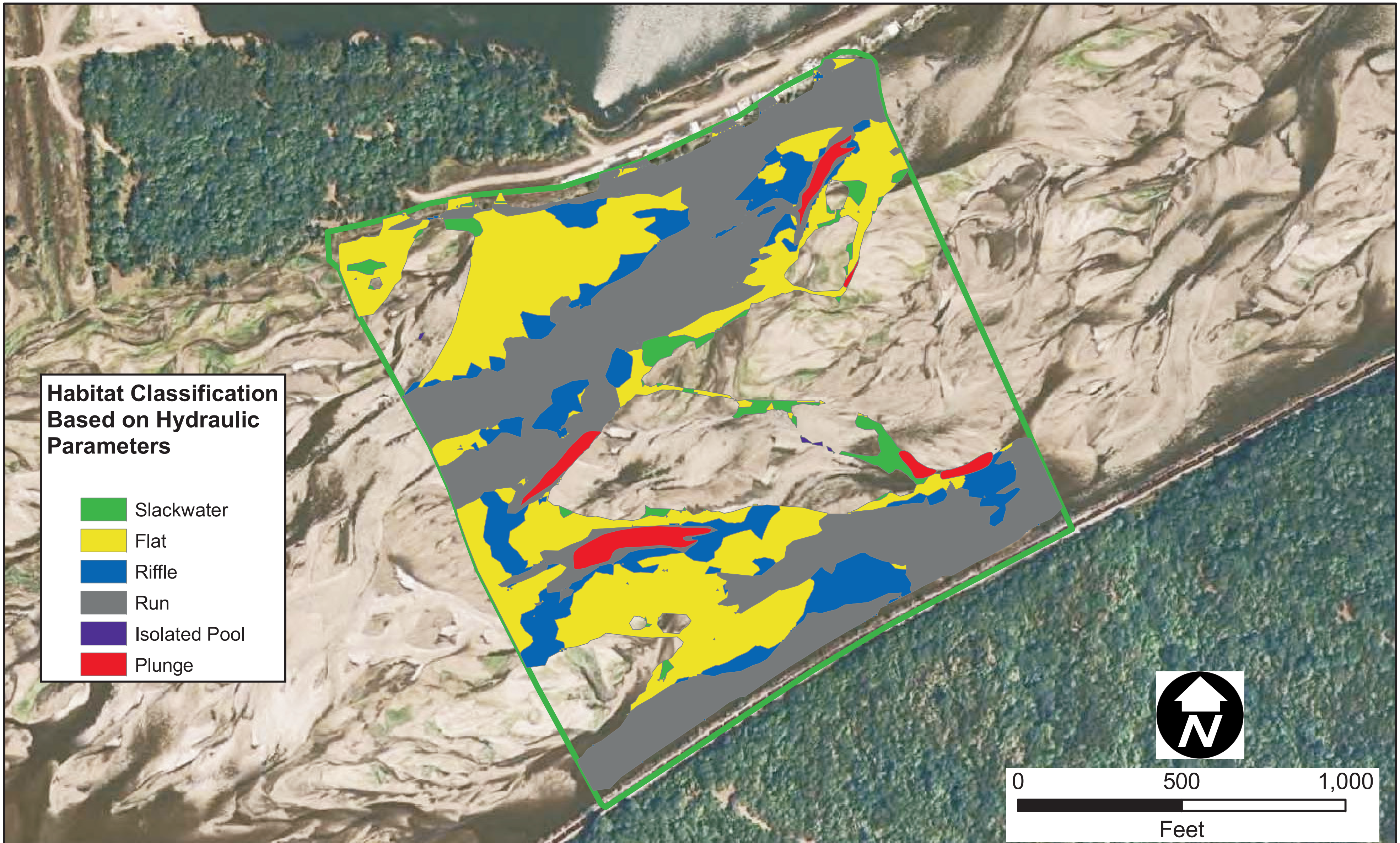
Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date:
Dec. 2009

Figure:
E9

Appendix F

Spatial Distribution Maps of Estimated Habitat Classes over a Range of Discharges between 3,700 and 40,000 cfs

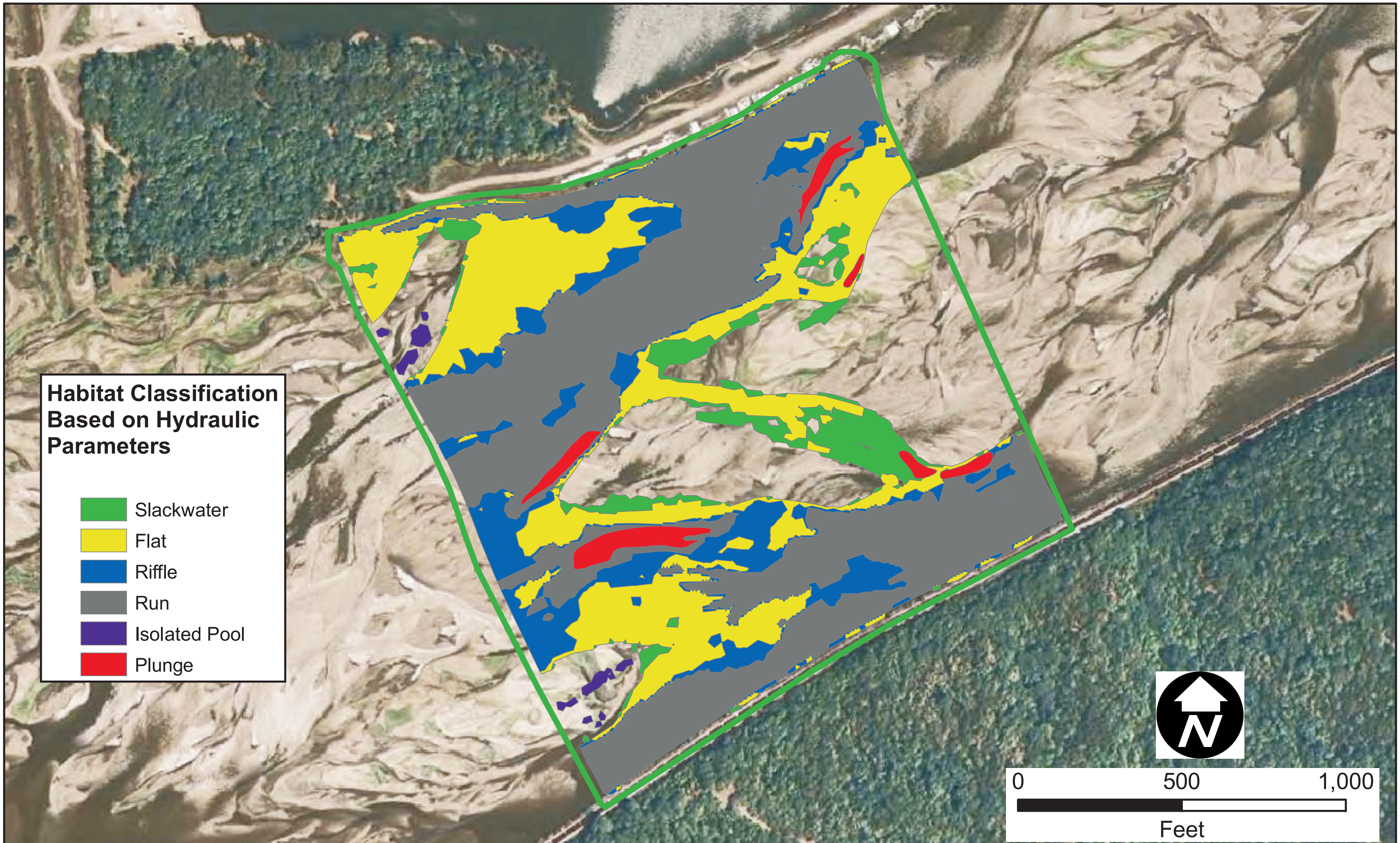


Estimated Habitat Classes at 3,700 cfs

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date: Dec. 2009

Figure: F1



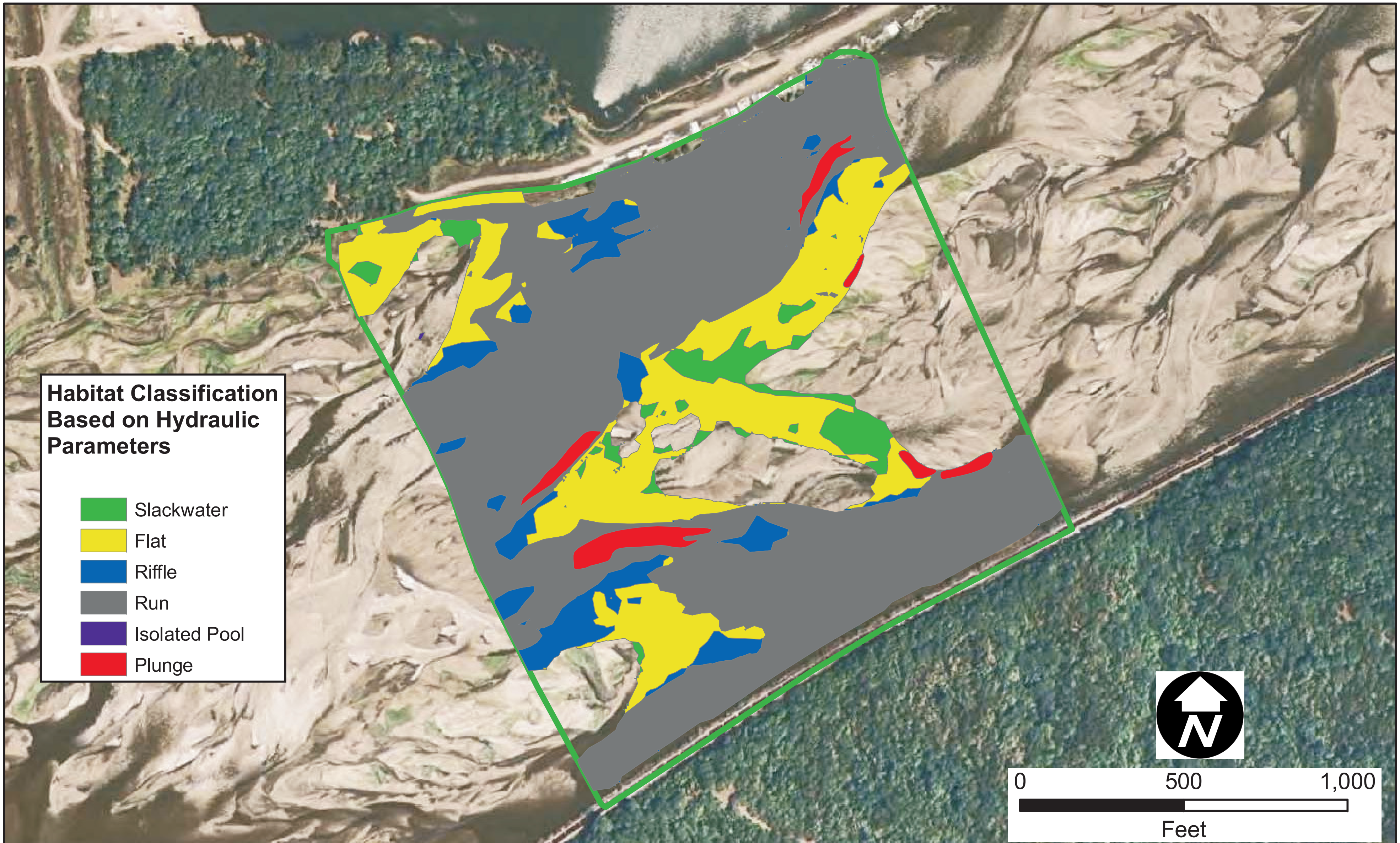
HDR
THE FLATWATER GROUP INC.
TETRA TECH
MEI

Estimated Habitat Classes at 4,300 cfs

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date: Dec. 2009

Figure: F2



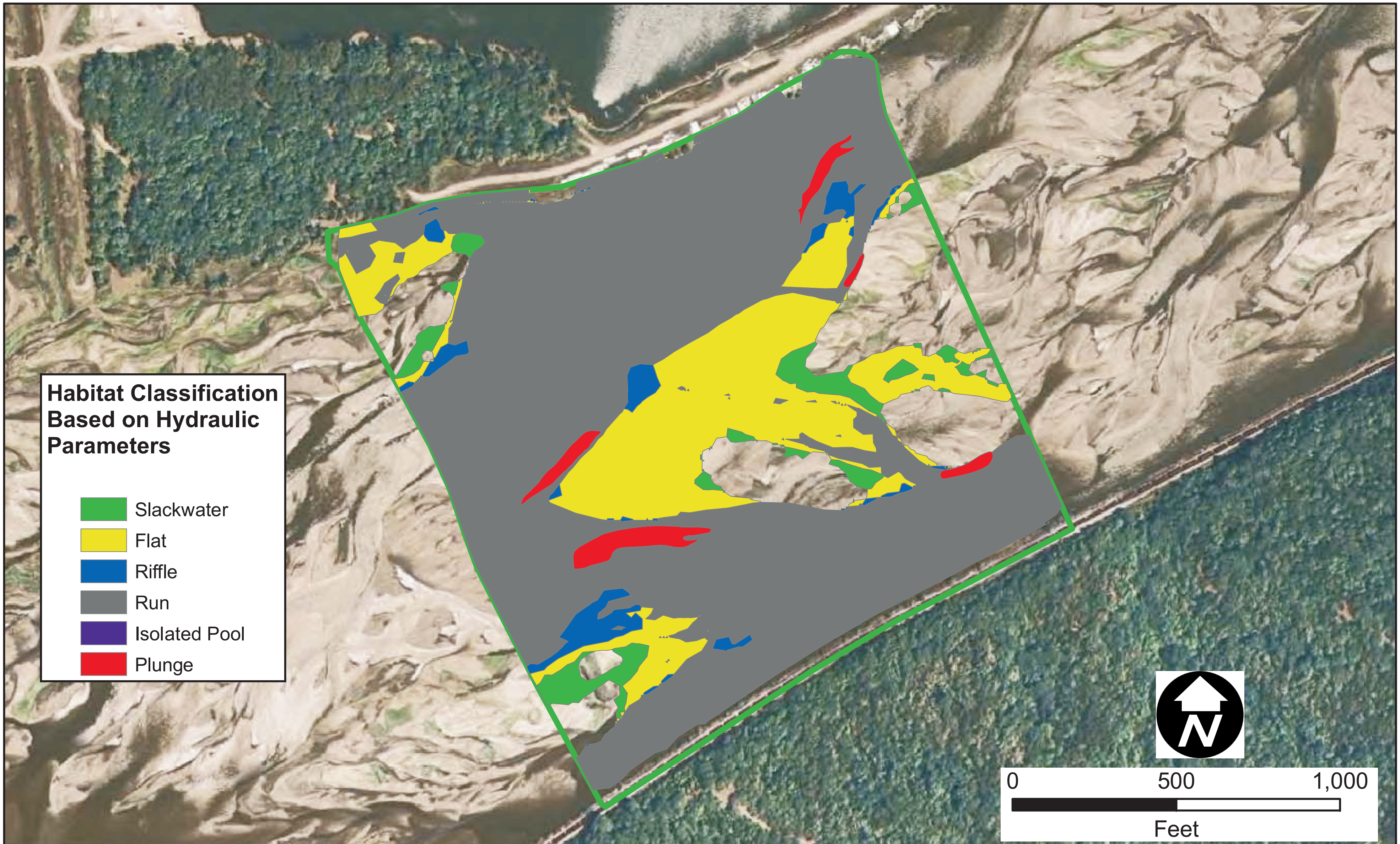
HDR
THE FLATWATER GROUP INC.
TETRA TECH
MEI

Estimated Habitat Classes at 6,000 cfs

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date: Dec. 2009

Figure: F3



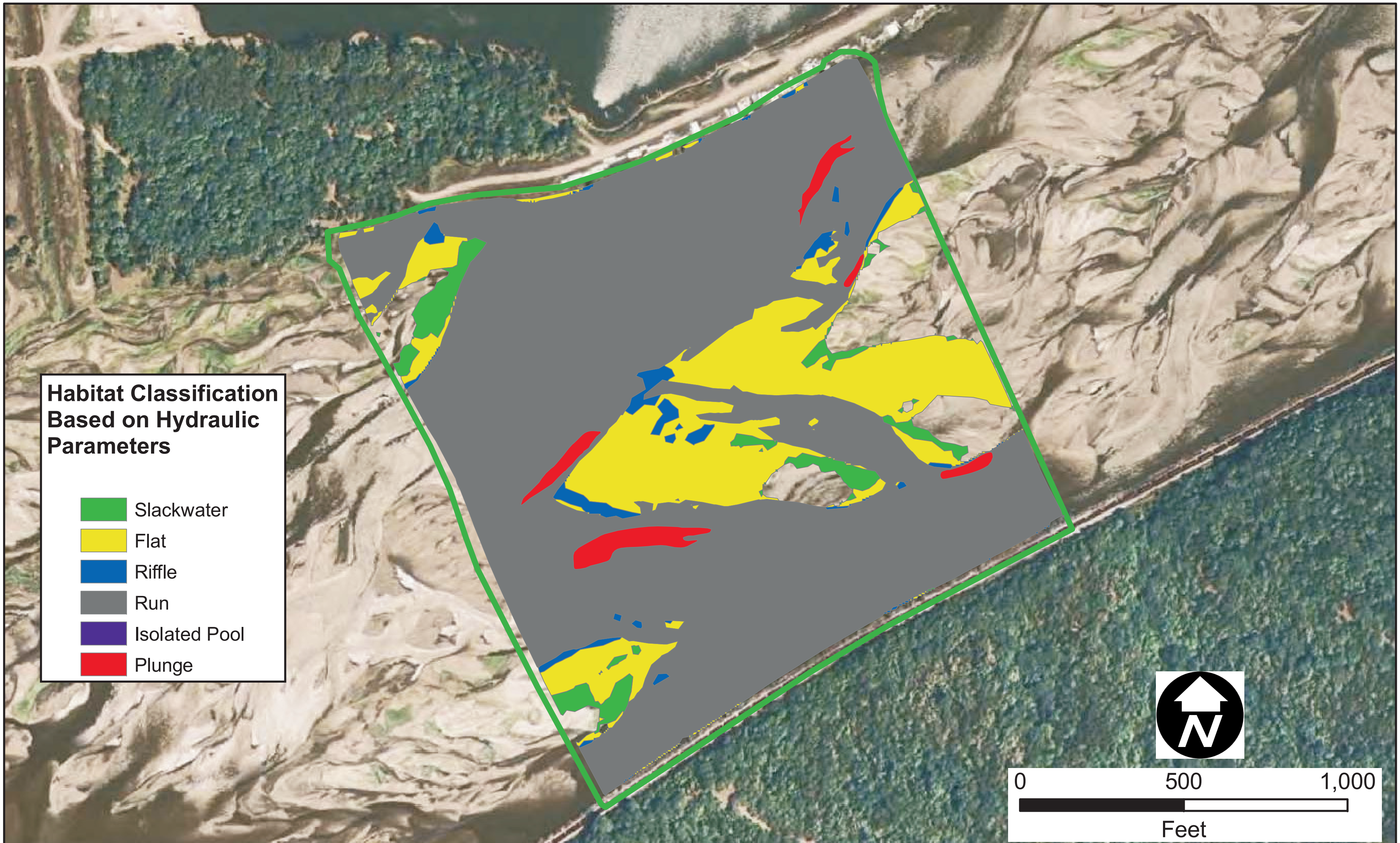
HDR
THE FLATWATER GROUP INC.
TETRA TECH
MEI

Estimated Habitat Classes at 8,000 cfs

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date: Dec. 2009

Figure: F4

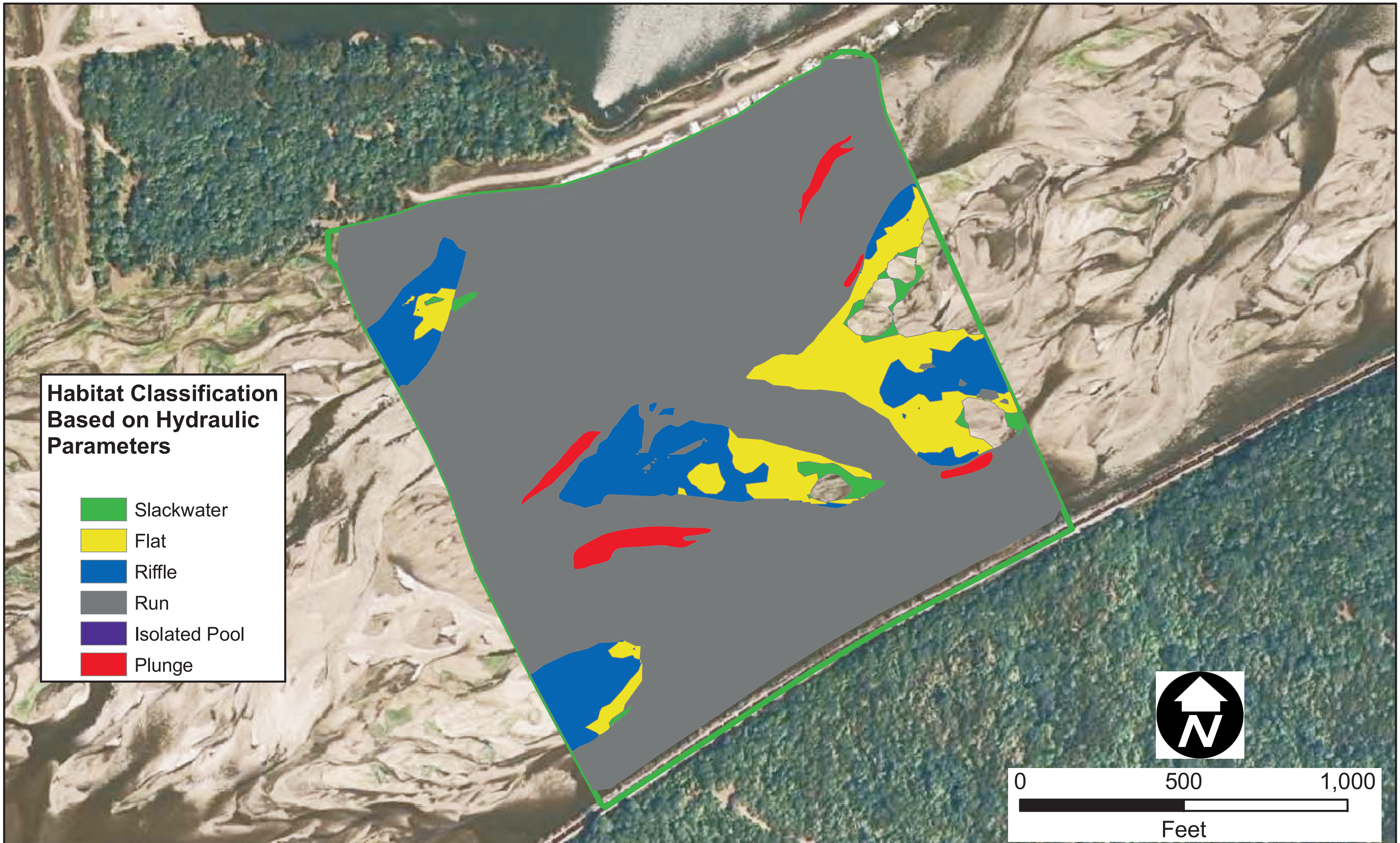


Estimated Habitat Classes at 10,000 cfs

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date: Dec. 2009

Figure: F5



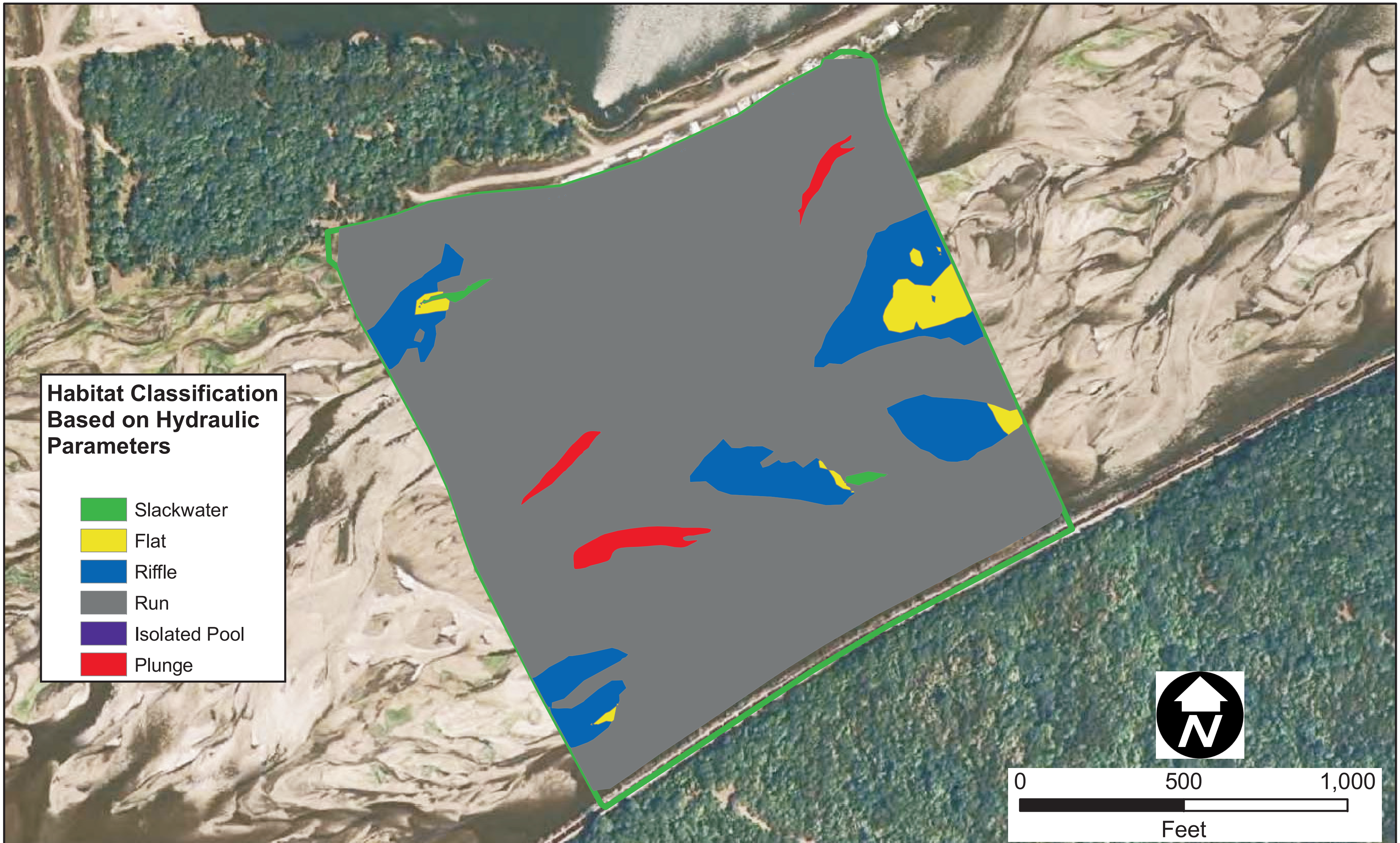
HDR
THE FLATWATER GROUP INC.
TETRA TECH
MEI

Estimated Habitat Classes at 14,000 cfs

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date: Dec. 2009

Figure: F6



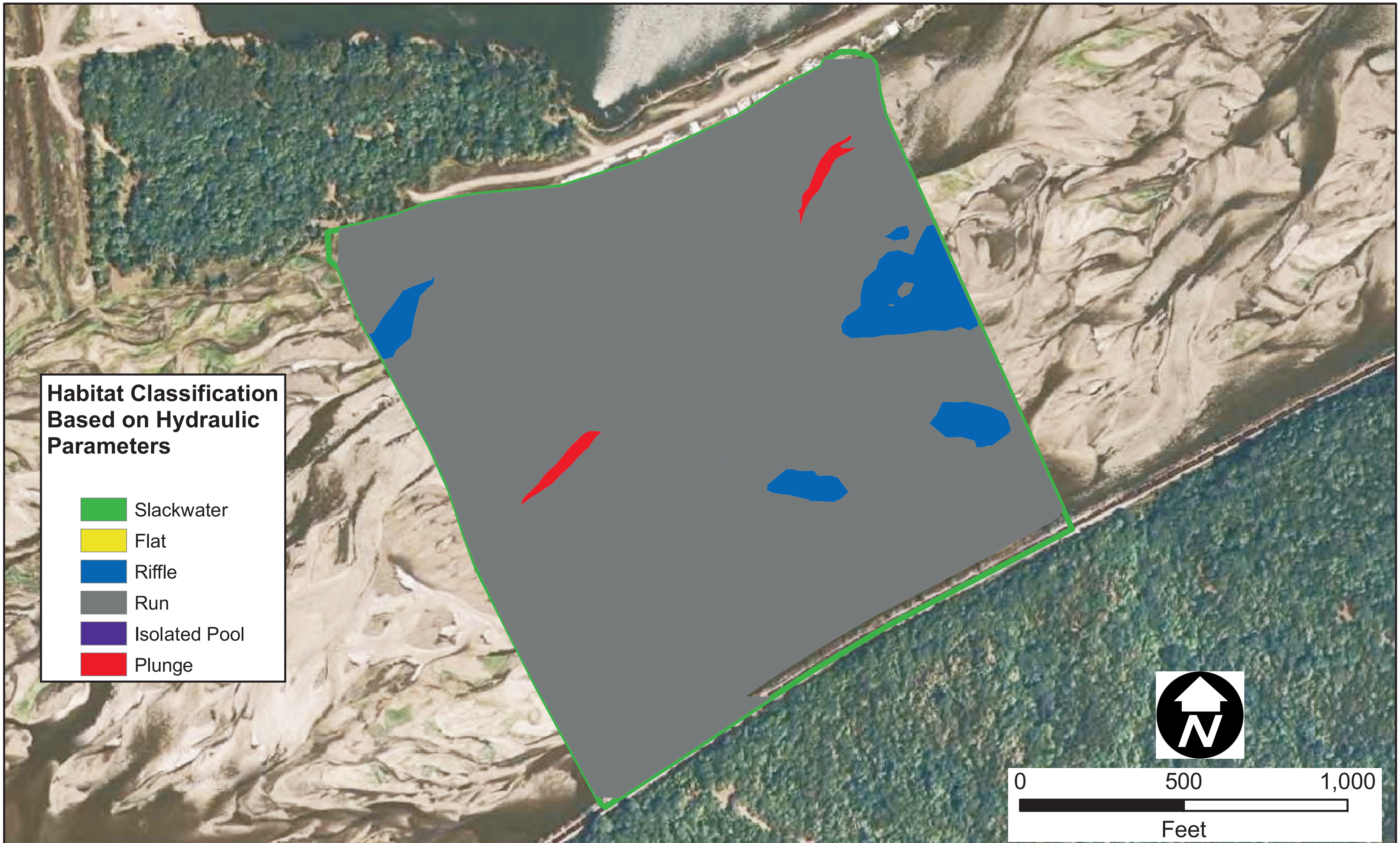
HDR
THE FLATWATER GROUP INC.
TETRA TECH
MEI

Estimated Habitat Classes at 20,000 cfs

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date: Dec. 2009

Figure: F7



HDR
THE FLATWATER GROUP INC.
TETRA TECH
MEI

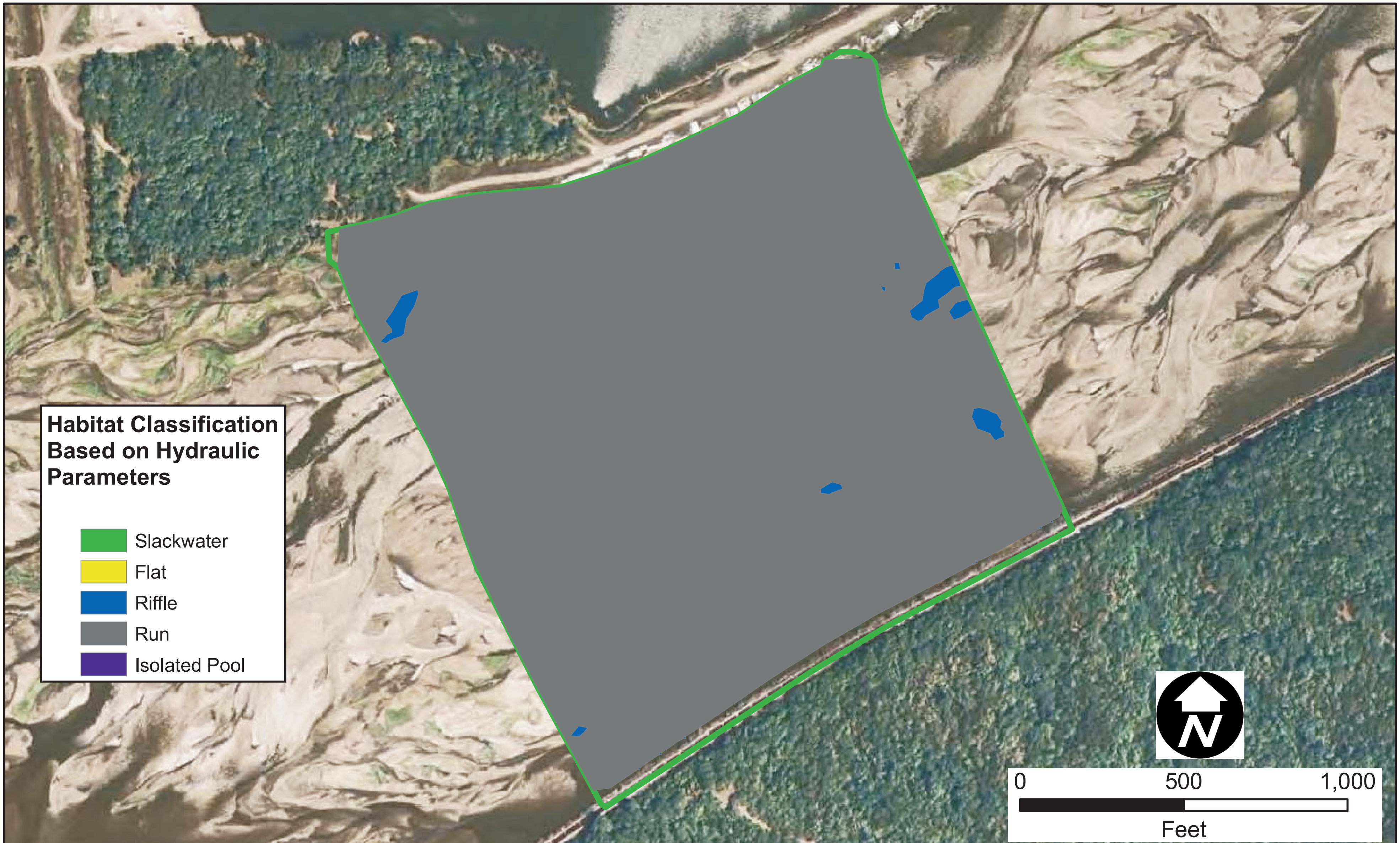
Estimated Habitat Classes at 30,000 cfs

RECOVERY IMPLEMENTATION PROGRAM PLATTE RIVER

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date:
Dec. 2009

Figure:
F8



Estimated Habitat Classes at 40,000 cfs

Lower Platte River Stage Change Study
Final Protocol Implementation Report
Platte River Recovery Implementation Program

Date: Dec. 2009

Figure: F9

Appendix G

Lower Platte River Stage Change Study
Alternative Analysis of Program Activities
Technical Memorandum Presented to Program TAC Committee
Monday, November 23, 2009

Lower Platte River Stage Change Study
Alternative Analysis of Program Activities
Technical Memorandum
Presented to Program Technical Advisory Committee
Monday, November 23, 2009

HDR Engineering Inc., The Flatwater Group, Tetratech, Dr. Mark Pegg

Program activities may include regulating or trimming the hydrograph in the central Platte River which could affect flows in the lower Platte River (as measured at the Louisville gage). To estimate the impacts of this action, and the resultant change in stage, a hydrologic analysis was performed to evaluate a scenario during dry year hydrologic conditions. The analysis is based on Program target flows in the Platte River, the timing in which Program diversions would likely occur, and the system's diversion limitations.

The following tasks were performed: 1.) Determine the number of days that the target flows would be exceeded at Grand Island; 2.) Determine the magnitude of flow that could be diverted above the target flows, taking diversion limitations into consideration; 3.) Determine the impact that the diverted flow would have on the lower Platte River flow (Louisville gage); and 4.) Evaluate the impact of diverted flow on percent habitat classification area based on the analysis outlined in the Lower Platte River Stage Change Study Draft Protocol Implementation Report (Stage Change Report).

For purposes of this technical memorandum, the following assumptions were made: 1.) The Program would divert flows only during the months of March, April, October, and November; 2.) The Program would only divert flows in excess of Program target flows between Lexington and Chapman; and 3.) The maximum flow rate diverted above Grand Island is 4,000 cfs.

Table 1 shows the Program's target flows as set by the Governance Committee for the Lexington to Chapman reach. The gage at Grand Island was used for this analysis to determine the excess to target flows.

Table 1. Program Target Flows (cfs)

Period	Wet Year	Normal Year	Dry Year
February 15 – March 15	3,350	3,350	2,250
March 16 – March 22	1,800	1,800	1,200
March 23 – May 10	2,400	2,400	1,700
September 16 – September 30	1,000	1,000	600
October 1 – November 15	2,400	1,800	1,300
November 16 – December 31	1,000	1,000	600

A period of interest in the lower Platte River is when flows range between 4,000 and 6,000 cfs. It has been suggested in the literature that there are connectivity concerns at the lower end of this range. In addition, results of the Stage Change Study have shown this to be a range where the percent habitat classification area experiences a relatively high rate of change (see the Stage Change Report, Figure 38). Based on this, the gage data for the period of record at Louisville was sorted to catalog the events that were between 4,000 and 6,000 cfs for February 23 through May 5 (spring) and for September 25 through December 5 (fall). For those days at Louisville that had flow between 4,000 and 6,000 cfs, the corresponding flows at Grand Island were cataloged. Travel times of 4 days and 5 days for spring and fall, respectively, were used (USFWS, 2002). From that data set, days at Grand Island that exceeded the target flows were cataloged, and the amount of flow above the target flows (the flow that could be diverted by the Program) was determined. Assuming full translation, and accounting for travel time, the amount of flow diverted upstream of Grand Island was subtracted from the corresponding flow at Louisville. The results of the analysis are shown in Table 2.

Table 2. Excess to Target Flows at Grand Island vs. Flows at Louisville Between 4,000 and 6,000 cfs

Condition	# of Days for Period of Record	# of Days Between 4,000 and 6,000 cfs @ Louisville	# of Target Exceedences @ Grand Island	# of Days Below 4,000 cfs @ Louisville	Range of Flows Below 4,000 cfs @ Louisville	# of Consecutive Days Below 4,000 cfs
Spring	3,976	847	145	11	30 to 950	2 days (once)
Fall	4,017	1127	635	184	9 to 1380	2 days (16 times) 3 days (10 times) 4 days (3 times) 5 days (once) 6 days (2 times) 7 days (once) 8 days (3 times) 14 days (once)

For spring, target flows were exceeded on 145 days when the corresponding flow at Louisville was between 4,000 and 6,000 cfs. Assuming that the entire diverted flow (above target flows) at Grand Island was translated to Louisville (that is, did not account for reach losses), flow below 4,000 cfs would have been incurred on 11 days. Of those 11 days, only one instance would have lasted more than a day. The largest amount that could have been diverted for the sample set occurred on March 22, 1972. Flow at Grand Island was 3,190 cfs, thereby allowing the Program to divert 1,990 cfs above the target of 1,200 cfs. Based on the Stage Change Report, approximately 88 percent of the flow would have reached Louisville, which would have reduced the flow at Louisville from 5,040 cfs to 3,290 cfs. Based on the relationship shown in Figure 38 of the Stage Change Report, the Run habitat classification represents approximately 56 percent of the habitat area at 5,040 cfs and approximately 45 percent of the habitat area at 3,350 cfs, a decrease of 11 percent. It is noted that the lowest flow represented in Figure 38 is 3,700 cfs. Therefore, values relative to flows below that are reported as the values at 3,700 cfs. The Flat habitat classification represents approximately 25 and 35 percent of the habitat area at 5,040 and 3,290 cfs, respectively, a 10 percent increase. Finally, the Riffle habitat classification represents approximately 11 and 13 percent of the habitat area at 5,040 and 3,290 cfs, respectively, a 2 percent increase. In assessing the results of this example, it should be noted that the uncertainty in daily flow at the Louisville gage for the months of March and April is approximately 850 cfs (see the Stage Change Report, Table 5). Finally, the decrease in discharge does not move the conductivity, turbidity, temperature, or dissolved oxygen outside the typical range preferred by pallid sturgeon (see the Stage Change Report, Figures 42 and 43).

For fall, target flows were exceeded on 635 days when the corresponding flow at Louisville was between 4,000 and 6,000 cfs. Assuming that the entire diverted flow (above target flows) at Grand Island was translated to Louisville (that is, did not account for reach losses), flow below 4,000 cfs would have been incurred on 184 days. Of those 184 days, 37 instances would have lasted more than one day, ranging from 2 to 14 days, as shown in Table 2. The largest amount that could have been diverted for the sample set occurred on November 25, 1972. Flow at Grand Island was 2,550 cfs, thereby allowing the Program to divert 1,950 cfs above the target of 600 cfs. Based on the Stage Change Report, approximately 85 percent of the flow would have reached Louisville, which would have reduced the flow at Louisville from 5,860 cfs to 4,200 cfs. Based on the relationship shown in Figure 38 of the Stage Change Report, the Run habitat classification represents approximately 61 percent of the habitat area at 5,860 cfs and approximately 47 percent of the habitat area at 4,200 cfs, a decrease of 14 percent. The Flat habitat classification represents approximately 23 and 31 percent of the habitat area at 5,860 and 4,200 cfs, respectively, an 8 percent increase. Finally, the Riffle habitat classification represents approximately 9 and 14 percent of the habitat area at 5,860 and 4,200 cfs, respectively, a 5 percent increase. In assessing the results of this example, it should be noted that the uncertainty in daily flow at the Louisville gage for the months of October and November is approximately 500 cfs (see the Stage Change Report, Table 5). Finally, the decrease in discharge does not move the conductivity, turbidity, temperature, or dissolved oxygen outside the typical range preferred by pallid sturgeon (see the Stage Change Report, Figures 42 and 43).

Existing and new data collection efforts on the Platte River for sturgeon species (shovelnose and pallid) suggest that these species use the river during the spring and fall. Maintaining suitable habitat is critical for spawning (spring) and possibly for staging areas for overwintering or upcoming spawning movements (fall). Spring is likely the most critical period, so that should be protected as best possible. However, catch rates during fall 2009 sampling showed a significant pallid sturgeon presence in the Platte River. The issue at hand would likely be loss of habitat connectivity that prevents movements should flows be reduced significantly during spring and/or fall during diversion. Diversion of flows would likely be limited to one or a few days during any season given the information above. This duration of diversion would likely not have a long-term influence on habitat connectivity, although short-term connectivity could be problematic. However, these data suggest that proper monitoring of water levels in the lower Platte River and corrective actions implemented during diversion could prevent substantial negative impacts.

Reference

USFWS. 2002. "Summary Report on the Potential of Changes in Central Platte Flow Conditions to Affect Flows in the Lower Platte." Draft Report. U.S. Fish and Wildlife Service, Mountain-Prairie Region (Region 6). December.