PLATTE RIVER CHANNEL DYNAMICS INVESTIGATION

Prepared For

States of Colorado, Nebraska, and Wyoming

May 2003

Prepared By

PARSONS

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INTRODUCTION

A team composed of representatives of the U.S. Fish and Wildlife Service and U.S. Bureau of Reclamation is preparing an Environmental Impact Statement (EIS) for proposed habitat restoration and preservation activities in the Platte River from Lexington to Grand Island, Nebraska. In January 2001, the Platte River EIS team issued a draft technical report titled, "*Platte River Channel: History and Restoration*" (Murphy and Randle, 2001). This report is more commonly known as the EIS Team's "White Paper."

After reviewing the White Paper and attending presentations by the EIS Team on its content, representatives of various agencies in Colorado, Wyoming and Nebraska identified a number of concerns regarding some of the assertions, assumptions, and conclusions presented. Representatives of the states agreed to hire a consultant to independently evaluate the issues. They retained a consultant team headed by Parsons and asked the team to:

- provide a critical review of the assertions, assumptions, and conclusions presented in the White Paper;
- evaluate the methods used by the EIS team in conducting their investigations into conditions on the Platte River;
- evaluate the technical information on which the conclusions of the White Paper were based; and
- where appropriate, develop alternative hypotheses to explain some or all of the changes that have occurred in the morphology, hydrology, hydraulics, and extent of vegetation expansion of the Platte River system.

The Parsons Team initiated the states' "Platte River Channel Dynamics Investigation" in April of 2001 and provided preliminary conclusions in the form of 12 separate technical memorandums to the states and Governance Committee in December 2001. Comments on the DRAFT technical reports were provided by the states, and have been incorporated in final versions of the 12 reports. The primary findings are summarized here.

WHITE PAPER CONCEPTUALIZATIONS OF CHANNEL DYNAMICS

The 23-page White Paper depicts, either directly or by inference, the EIS Team's conceptualization of the channel dynamics. To allow comparison with Parsons' findings in each of the issue categories, the key conceptualizations of the channel dynamics trends and processes identified in the White Paper are listed in Appendix A. These provide a sample of the primary assumptions that have been questioned most critically by the participants from the three states.

INVESTIGATION DESIGN

The investigations were designed to focus on three specific channel dynamics issue categories; namely, 1) trends, 2) processes, and 3) potential restoration activities. Each was designed to identify current trends in key channel characteristics; then investigate the physical processes that govern the interaction between flow, sediment, and vegetation; and finally, provide a basis for evaluation of proposed restoration activities which would ensure their long-term success.

Following discussions with the state and other stakeholder representatives, Parsons developed a list of their collective concerns with the concepts and conclusions presented in the White Paper (Parsons, 2001). The list included over 300 questions in more than 20 categories. Because all the concerns could not be addressed within the time limits, 12 categorical investigations were selected from the issue list by considering the following:

- Which issues are the most critical,
- Which issues are most likely to be enhanced or resolved by new or supplemental independent analysis, and
- Which issues can be thoroughly evaluated within the time frame and budget allowed?

Because several of the investigations addressed common technical topics, the issues were grouped into four topical categories, namely:

1. Channel Narrowing or Deepening Issues (5 papers)
2. Sediment Transport Issues (3 papers)
3. Vegetative Encroachment Issues (2 papers)
4. Climate Affects and Natural Variability Issues (2 papers)

Separate, individual technical reports have been written for each of the 12 investigations (Parsons, 2003).

PRIMARY FINDINGS

The following is a brief description of the 12 studies and primary findings relative to the White Paper. Only issues over fundamental, conceptual understandings of channel dynamics trends and processes are addressed here. Full presentations of the investigations and evaluations of a wider range of specific issues are included in the twelve technical reports.

A1 - Evaluate Current Morphology and Stability of the Platte River Channel.

The purpose of this investigation was to evaluate past and present morphologic conditions and identify possible threshold events affecting the river form and degree of stability of the braided form.

The foundational concern here is that the EIS Team did not include either a Geomorphologist or Paleoclimatologist, resulting in failure to recognize a significant body of relevant literature from these fields. The White Paper also suggests that the river is unstable, and will continue to degrade its bed and narrow its channels.

The White Paper disregards climate change and its known effect on peak and mean annual flows, sediment supplies, and channel morphology. Instead, it holds diversion and storage projects responsible for all the changes in the river and does not address the possible effects of climate or proximity to geomorphic thresholds. Little or no discussion of other possible causes is included, reflecting a predisposition to a single cause. This bias was most likely originated by Williams (1978), and as shown by Parsons' A3 study, it was an incorrect starting point.

The investigation shows that a braided river is an unstable, incipient form of a meandering river, and that any number of factors could have caused the expansion of vegetation and the transition (metamorphosis) from a braided form to an anabranched form in some reaches. The investigations also reveal that the river is geomorphologically more stable now than in the mid- to late-1860's.

Climate cycles have raised and lowered the Platte by tens of feet over time and shifted it through numerous thresholds, and are recognized by the majority of experts as the primary factor affecting morphology of Great Plains Rivers. The literature documents the existence of geomorphic thresholds (borders between different planforms and profiles) and of dramatic geomorphic changes known to be singly associated with climate changes in the Great Plains. The White Paper does not consider the possibility that the observed changes might have been due to climate cycles or natural excursions across thresholds from one planform and profile to another.

The investigation reveals that climate swings produce the kind of far-reaching changes that have occurred in the river, and that storage and diversion projects do not, and cannot, produce the same far-reaching morphologic changes cited in the White Paper as being caused by these facilities. As shown in the A1 technical report, climate-driven changes in planform and vegetation expansion offer a more scientific explanation of the far-reaching changes observed in the last 100 years.

A2 – Evaluate Historical and Current Sediment Supplies to the Platte River

The purpose of this task was to analyze historical and current sediment supplies and identify changes in quantity and nature of sediment supplies.

The foundational concern here is that the enormous reductions in sediment supply alleged by the White Paper cannot be scientifically established from the limited data.

The A2 technical report reveals that gaps and other deficiencies in historic sediment gradations and transport data render it inappropriate to make management decisions regarding supply reductions, coarsening of sediment, or cause-effect associations between sediment supply or sediment character and channel morphology and vegetation expansion.

A3 - Develop and Analyze Comprehensive Database of Platte River Cross-Sections.

This task objective was to assess all available cross section data and compare it to the data utilized by the EIS team in reaching their conclusions regarding channel width changes and allegations of widespread degradation.

The foundational concern here is that a significant overemphasis has been placed on Williams' 1978 study of channel width changes since the 1860's. Williams notes that his study was a *reconnaissance-level study*, but it has been cited in EIS Team circles as the "definitive work" on the subject and was dogmatically adopted as a foundational truth in developing the White Paper. Another concern is that the use by the EIS Team of sparsely-spaced cross sections in the SEDVEG model do not adequately represent the dynamics of flow and sediment transport or the effects on morphology and vegetation of known variations in channel cross-section or slope.

The data strongly refute the long-standing hypothesis that there has been a significant loss of morphologically-relevant channel width. The only scientific conclusions that can be made from the data used by Williams and others (i.e., 1860's General Land Office surveys and aerial photographs) is that vegetation has expanded into greater portions of the meander corridor and that some reaches have converted to an anabranched form. The foundational assumption that unvegetated portions of the river are morphologically relevant is completely refuted by the A3 technical report.

The A3 report shows that the foundational assumption by the White Paper that changes in the unvegetated portions of the meander corridor can be used to measure morphologic change is unscientific and misleading. Claims of channel narrowing are based on reductions in unvegetated areas observed in aerial photographs. One cannot determine geomorphologically-defined "channel width" from these photos, yet this error has been rampant and has misled the EIS Team. The photos only give the amount of open versus vegetated areas. All one can ascertain is the amount of vegetation expansion and the amount of anabranching, but not the amount of "channel" narrowing in a geomorphologic framework. In fact, even the amount of vegetated expansion is suspect, because all one can see from photos is the canopy width, which depends on season and maturity of the plants.

A long-standing assumption regarding the between-banks precision of the original GLO surveys is disproved in the A3 report, invalidating many of the consequent cause-effect hypotheses and clarifying greatly the issue of long-term changes in the river's channels. The GLO maps did not accurately record the islands and bars or the extent of vegetative growth between the meander lines. Consequently, any width measurements based on the maps over-estimate the effective channel width at the time.

Williams states that he discounted climate effects on morphology, and more importantly, the A3 report discloses that the 1860's cadastral surveys did not adequately document the land forms or the extent of vegetative growth between the outer meander lines of the river. Evidence discovered by Parsons regarding these surveys essentially voids all estimates of "unvegetated channel width" in the 1860's, and discusses the errors in Williams' interpretations and the consequences of those errors.

Detailed data discovered by Parsons at Kearney support a hypothesis that, other than some vegetation expansion, there has been little change in the configuration in the long term. Islands, bars, and other features in 1870 and 1998 at Kearney are exceptionally similar. An 1877 railroad map indicates that substantial vegetation existed even then. The A4 report reveals that effective (channel forming) discharges have not significantly changed, and that changes over time in the width of the corridor occupied by the effective discharge are minor.

It is concluded that except for properly documenting changes in the extent of vegetative expansion or extent of anabranching, the actual geomorphologically-relevant changes in channel geometry from historic to current conditions have not been accurately quantified by previous investigators.

It is also concluded that erroneous interpretations have been made in quantifying changes in "unvegetated width" (the differences between the meander corridor width and the vegetated portion) and associating them with geomorphologic changes in channel width. This in turn has led to flawed interpretations of physical and correlative cause-effect relationships. The use of unvegetated width as a geomorphologic indicator is unprecedented and misleading. The unvegetated width of a river is not a measure of its equilibrium width, effective discharge width, or "active" channel, and changes in this width should not be correlated with anything except vegetative expansion. Other far more relevant measures of width are available but were not used.

Regarding sufficiency of the SEDVEG model cross-sections, variation in channel shape and incision depths at a single location during several months of measurements during different flow rates is greater than the variation in long-term bed elevation used by the White Paper to allege that degradation is occurring. Channel area (a strong correlate of both unvegetated and active channel width) has increased in most reaches of the Platte River during the last decade and a half in the absence of flow management.

Regarding effects of slope on morphology, the A3 report includes a detailed assessment of changes in river profile over time and concludes that extreme variations in bed slope exist. Though slope is known to control morphology through creation of the energy required for flow and transport, no assessment of this dynamic is included in the White Paper.

A4 - Develop Channel Width Predictive Tool

This investigation was designed to evaluate the relationship of the flow and channel widths for a hypothetical condition of a river without vegetation. The information allowed analysis of what corridor and effective-discharge channel widths could be expected if vegetation expansion could be reversed.

The foundational concern here is that the EIS Team has concluded that only peak annual flows affect channel width and that width adjustments in the Platte can only be ascertained by developing a computer model of the flow, sediment transport and vegetation expansion in the river. The states are not only concerned with the accuracy of such a tool, but also with the use of new and untested theories in the model. Other geomorphologic methods are available, and may be the only tool that can be used for management decisions.

A significant foundational problem is the single-focus of the EIS team on peak flows. Their claim that "the majority of sediment is transported during the few days of peak flows during the year" (p. 17) and other statements such as "the channel narrowing was caused directly by a reduction in peak flows" (p. 19) and about 60 other such claims in one 23-page document that the Platte channel shape is formed and maintained by peak annual flows have been a long-standing concern. If one assumes from the start that reductions in peak flows caused the problem, the natural solution is to institute a program of peak flows. It is noteworthy that Williams did not credit peak flows with the changes, but instead attributed them to reductions in mean annual flows. The concern is that any program is only as good as its foundational conceptual assumptions.

Although the width of an equilibrium stream may change due to the impact of a large flood, the stable, pre-flood width is recovered following such perturbations.

Associated with this peak flow theory is the use by the EIS team of indirect measures of high flows around the turn of the century prior to implementation of stream gauging programs. Many have long felt that even if the estimates are representative, their use as a baseline or "reference for targeting" is foundationally incorrect. Associated with the disregard of climate effects on peak flows is a substantial body of evidence reported in 1900 in *Scientific American*, as well as detailed studies by the U.S. Forest Service, that deforestation associated with settlement of the region produced abnormally high peak flows at exactly that point in time.

The 20-year period centered approximately on the year 1915 was by far the wettest period in the Great Plains for the past 300 years. Therefore, the identification by the White Paper of the period 1902 – 1909 as representative of average baseline conditions on the Platte River system prior to construction of significant numbers of retention or diversion structures is inappropriate and biases their conclusions regarding the need to restore annual and peak flows based on this overstatement.

The USGS established that there is a direct correlation of effective discharge and the associated channel width, yet the White Paper does not rely on this relationship. Instead, the unvegetated width (which in no way reflects a geomorphologic measure) is correlated with annual peak flows. The A3 investigation relied on this relationship and concluded that the effective discharge has not changed substantially, and that the associated effective-discharge channel and river corridor widths closely match 1938 conditions, with some evidence that they are not too different than conditions in the 1860's.

A5 - Qualitatively Affirm Channel Width Predictive Tool

The purpose of this investigation was to test whether the qualitative and quantitative geomorphic relationships established in investigation A4 are corroborated by standard literature.

Findings of the A4 study were corroborated, and the study further indicated that experts in analyzing river width adjustments have proven that no fluvial hydraulic river model such as SEDVEG are available for use in making management decisions.

B1 - Comprehensive Evaluation of Sediment Gradation Data

This investigation was designed to assess whether available sediment gradation data supports the EIS team position regarding sediment gradation (coarsening) changes and the impact on channel morphology.

The foundational concern here is that conclusions regarding general coarsening of sediment in the downstream direction cannot be ascertained from the limited available gradation data. The rationalizations in the White Paper regarding morphologic effects of alleged coarsening are also questioned.

The Parsons study concludes that there may have been an increase in sediment size through time at some locations, but not to the extent assumed by the EIS team. The allegation that the bed now classifies as coarse sand is disproved by Parsons. The bed sediment was a medium sand in 1930 and remains a medium sand in the year 2000.

The variability of sediment sizes in the river, variability in the data, uncertainties due to single-sample bias, and lack of uniform, comparable, and scientific sampling methods do not allow a definitive resolution of the "coarsening" hypothesis. There is definitely insufficient certainty to base significant management actions on the coarsening theory. To emphasize this point, it was found that variability in sediment gradations measured across single cross-sections is greater than that being used to allege coarsening in the downstream direction.

The scientific value of the data used in the White Paper is questioned based on the subjectivity of what material is "bed" material, lack of a common protocol for sampling, the failure to repeat measurements at the same locations, the high variability of parameters on the same day at the same transect, absence of within-year samples to reflect seasonal variations, absence of data on sample locations within macroforms (which has been proven to be highly variable), unknown depths of sample below bed surface, unknown adequacy of volumes of samples, and other problems.

B2 - Independent Assessment of SED Concepts in SEDVEG Model

The objective of this investigation was to review the conceptualization of the model, methods chosen to model hydraulic and sediment transport physical processes, theoretical development, algorithms written, boundary conditions, constraints, time steps, input data requirements and quality, assumptions made, sensitivity of results to key parameter changes, calibration, and overall adequacy of the SEDVEG model for the purposes intended by its developers. The version evaluated in this investigation was that provided by the USBR at the onset of the investigation in April 2001, and has since undergone numerous revisions.

The foundational concern here is that the system is too complex and too large to sanction the use of a new and untested model of the hydraulic, sediment transport and vegetation expansion processes. The predictive ability of the model is described in the Task B3 report, with a significant finding that the model is predisposed to calculate degradation.

The April 2001 model contains key processes needed to simulate sediment movement, but many of the actual algorithms used in the simulation have not been adequately refined and tested, and the spacing of cross-sections does not adequately represent the lateral and slope variations known to affect channel morphology. New and untested theories are used in the model. The sediment transport algorithms are primarily for modeling vertical aggradation and degradation, and without incorporation of lateral erosion/deposition processes, the model has limited or little applicability. Review of the code revealed that many of the model algorithms were hard-wired to impose constraints that were apparently imposed when the processes being modeled exceeded acceptable bounds. The model should not be used for management decisions.

Because the SEDVEG model predicted degradation during the years since storage and diversion structures were installed, it would be expected in reaches that have grade control and diversion structures that modifications would have to have been made in these structures to allow them to meet water supply and water rights requirements. No such modifications have occurred.

No recent versions of the model have been reviewed, but the course toward injecting sediment and passing pulse flows down the river was set by the original model results, which predicted long-term degradation throughout the habitat area. We understand that recent changes in the algorithms of SEDVEG for simulating bed material transport were made, and that when the revised model was run over the test period, simulated amounts of vegetative expansion experienced a "China Syndrome" effect, and that the vegetative expansion algorithms are being modified as a result. The concern is that the model is being used to validate one underlying predisposition regarding the causes of the changes in the river. Because the model was conceptualized on the basis of this predisposition, it is questioned whether it could even be used as a tool to further examine and test hypotheses of the alternative causative factors.

B3 - Evaluate Predictive Capabilities of SEDVEG Model

Task B3 included an examination of the results of simulations of the SEDVEG model over various periods of record and a comparison of the end results with actual configurations of the channel.

The foundational concern here is that calibration of the model was described as being satisfied by "general" agreement with bed profiles, and that width adjustments predicted by the model did not need to match cross-section data. It is also known that the algorithms used in the model are designed for predicting aggradation and degradation, and that the width adjustment processes used were literally "created" for the first time for use in this model. Finally, the best available research on sediment transport in the Platte reveals that movement is by large macroforms, having significant variations in sediment gradation in their leading and tailing edges. The model described by the White Paper does not recognize this fundamental process of bed material transport.

Review and statistical analyses of the output from the model runs indicate that elevations of the base channel calculated in model simulations are in relatively poor agreement with elevations of the actual channel base surveyed along the actual transects. Further, the model is shown to be statistically predisposed to degradation. Tests of the SEDVEG model prove that it invariably calculates channel degradation of greater magnitudes than actually occur and is biased in its construction in such a way as to over-predict channel degradation.

The comparison of SEDVEG model cross sections and all available USBR cross sections raise a number of questions regarding adequacy of SEDVEG for making management decisions about channel width and vegetation changes, both historical and projected. A total of 55 USBR cross sections are available in the reach modeled. SEDVEG uses 16 of these. The selection of the 16 sections may have introduced bias in the results. In six of the reaches, the width used in SEDVEG is narrower than the average width in the reach, with differences of over 50 percent in two cases. The number and locations of reaches with underestimated width do not offset the reaches with overestimated widths. For one 19 mile segment in the center of the modeled reach, the modeled widths are about 30 percent narrower than the average actual channel widths.

The SEDVEG model, in its reviewed form, is not a reliable predictor of the evolution of fluvial channels, and in particular is not functional for simulating changes in a river with the variability in slope, width, planform, bed forms, and sinuosity known to exist in the Platte River.

C1 - Alternative Vegetation Expansion Theories

This study reviewed factual evidence regarding the degree of vegetation present in the river in predevelopment periods and possible reasons for expansion by vegetation into the river channel in the post-development period.

The foundational concern here is that the White Paper's description of vegetation expansion entirely credits reductions in peak flows with the expansion. The process is entirely too complex to be relegated to any single cause, and numerous other potential causes, many credible, have been suggested but were disregarded.

The interpretation that the Platte River was inherently inhospitable to trees because of severe flooding and sedimentation is incompatible with the evidence presented in Johnson and Boettcher (2000). Riparian woodland is a natural feature of the Platte River ecosystem. It was present on islands of all sizes and scattered along the main banks before settlement and water development. The scouring theory fails as a single factor to explain vegetation expansion. Expansion of vegetation is attributed completely by the

White Paper to "reductions in annual peak flows." Parsons reports prove that this explanation is entirely oversimplified and unsupported by demographic and effective discharge studies.

Other factors such as extensive deforestation of mountain watersheds in the basin were not considered important, yet are known to have created artificially high annual peak flows occurring at exactly the same time period used in the White Paper to establish a "baseline" of high flows.

Expansion of vegetation in the river corridor is considered in the White Paper to be a morphologic effect, and all unvegetated areas have been equated with "active" channel. The Platte River is in dynamic equilibrium with respect to the balance between floodplain woodland and open, unvegetated channel area. The historic woodland expansion has been driven primarily by changes in climate.

Finally, the expansion observed in the past is not likely to continue. Dynamic equilibrium has resulted from a new balance between processes that affect vegetation establishment and removal. This equilibrium has been reached by reduced plant recruitment and higher rates of plant mortality, particularly by ice.

C2 - Evaluate VEG Assumptions and Algorithms of SEDVEG

This investigation was structured to evaluate the validity of assumptions and algorithms built into the SEDVEG model regarding plant growth, desiccation, scouring of seedlings, and other processes associated with the mechanics of vegetative encroachment.

The foundational concern here is that no industry standard for determining plant growth in a river floodplain exists, so the EIS Team appears to have created a new, untested algorithm for simulating this process. The White Paper incorrectly credits peak flows as having a majority influence on the removal of vegetation. This predisposition was clearly instrumental in designing a vegetation algorithm that removes plants by this mechanism. The predisposition, rather than scientific knowledge of processes, appears to have controlled the design.

In a wide, shallow condition, the Platte River did not historically have high, unvegetated sand bars due to the limited range of water surface elevations dictated by such geometry and the propensity for vegetation to colonize higher areas. The Platte River's stage, in both its present and former (pre-development) states, has a narrow vertical range (2.8 feet between drought and flood in the 1890's) compared to other large rivers. As a result, high, dry, and unvegetated sandbars are not a characteristic feature of the central Platte's channel.

The White Paper position greatly overemphasizes the significance of the peak flows relative to vegetative clearing by "overtopping and mobilization" and ignores significant impacts at all flows year round, including the significant effects of ice. Considerable data regarding vegetation expansion was also discounted by the White Paper, as was the existence of an equilibrium between unvegetated and vegetated widths.

The Platte River, in the mid- to late 1800s, was affected by extreme drought and significant disturbance of the watershed (buffalo, fire, extensive timber harvesting) that resulted in potential large sources of wind-blown sand that may have significantly affected the morphology and vegetation of the river. Such a state cannot reasonably be used as a model for proposed future conditions of the river.

D1/D2 - Macro-Historical Evaluation of Surficial Processes and Climate Change

The purpose of this investigation was to ascertain whether the effects of naturally occurring changes on the morphology of the Platte River can be distinguished from the effects of water development activities within the system.

The foundational concern here is that both Williams and the White Paper disregarded climate effects on both the hydrology and geomorphology of the river.

The White Paper does not recognize climate as a factor in morphology, which overlooks a significant body of scientific truth. The substantial and known contribution of climate on morphology, and disproportionate focus by the White Paper on storage and diversion structures, conveys scientific bias. Limited and far-reaching changes must be separated and attributed to appropriate causes in order to accurately portray the forces shaping channel morphology and vegetation.

Far-reaching morphologic effects such as true narrowing of the active (effective discharge) channel, or true degradation of the bed, or true coarsening of sediment throughout this length of river would most-definitely be climate related. Morphologic changes over limited distances, such as the documented incision for about 13 miles downstream of Kingsley Dam or for a few miles below the J-2 return, would likely be related to storage and diversion.

If the expansion of vegetation is regarded as geomorphic as alleged by the EIS Team (this is strongly disputed by the Parsons study), then it must also be concluded that it is driven in its greatest extent by climate. If it is not geomorphic, (as strongly proven in the D1/D2 report) then the unvegetated width cannot be equated with "active" channel or any other morphologic measure.

The A3 report disproves the assumption that vegetation expansion is a morphologic effect, and the D1/D2 study proves that the far-ranging vegetation expansion in the river that has taken place in the past 100 years is best explained, scientifically, as a response to climate changes. Effects of storage and diversion have been documented, but known relationships describing the limited extent of these facilities does not allow inference that the far-reaching expansion of vegetation, or the alleged far-reaching geomorphologic effects, can be attributed to these causes. This principle offers a means of assessing relative contributions of climate and storage-and-diversion facilities. Impacts of diversions and storage are known to be much less extensive and have been documented. The far-reaching extent of the observed changes cannot be linked by any acceptable geomorphic or physical-process explanation to diversion and storage projects.

Climate changes, on the other hand, are known to produce the kinds of far-reaching changes that have occurred. The Paleoclimatology of Great Plains Rivers has been extensively studied, documenting this fact. The possibility that natural processes of climate and surficial erosion and deposition resulting from climate swings were completely disregarded in the White Paper. The preponderance of literature supports a conclusion that historic, surficial processes, driven by climatic change, exceed by far the relatively local changes that can be scientifically attributed to storage and diversion.

The D1/D2 report also shows that in general, a shift to more humid climatic conditions in the Great Plains appear to result in channel incision; and conversely, a change to more arid conditions typically causes vertical channel aggradation. Drought conditions appear to occur more frequently in the Great Plains, and to last for longer periods of time than do relatively wetter conditions. Therefore, because aggradation seems to be associated with dry conditions, the geomorphic behavior of Great Plains streams probably follows a pattern of aggradation for relatively long periods of time, interspersed with moderately rapid incidences of incision.

IMPLICATIONS OF FINDINGS ON PROPOSED PROGRAM

It is concluded that substantial differences in foundational understandings of the river's dynamics exist, and that the appropriate way that the Proposed Program should proceed is to incorporate investigative actions and pilot programs that address the states' concerns and test the key differences in conceptualizations.

In fact, this is precisely what is currently planned as part of the first increment of the program. Parsons and the EIS Team were asked by the Governance Committee to jointly identify differences in foundational assumptions and develop a program of pilot studies and investigations to resolve the major channel dynamics and vegetation issues. The investigation document was prepared (Parsons/EIS Team, 2003) and has been approved by both teams and by the Governance Committee. Adoption of such a program underlines the fact that the scientists concur that controversies over foundational hypotheses exist and need to be resolved.

Investigations were described in four categories, Sediment, Vegetation, Geomorphology, and Restoration Treatments. The investigation program was developed and reviewed with the Governance Committee, who agreed to adopt its recommendations during the first few years of the first increment of the Proposed Program. Schedules for each step were provided, with some extending through the 13-year period established as the first increment of the Program. Costs estimates were provided, broken down by labor, other direct charges, and third-party contract costs. Total costs by year are given, and priorities of the investigations were assessed and tabulated.

Priorities were established by adopting criteria for ranking the investigations and applying the criteria to the lists of tasks. The priorities identified revealed a strong concurrence among the Parsons and EIS team members. The team was highly successful in excluding investigations not deemed to be necessary and sufficient for resolving the uncertainties, and recommended that all the highest priority investigations be included in an Integrated Management and Research Program.

In a subsequent workshop, state and other Governance Committee representatives were asked by the Executive Director to rank the importance of the research and restoration questions, rather than ranking the investigations. The results, available from the Executive Director, reveals that the states and districts tended to give preference to process and trend investigations, and the environmental and federal agency participants favored restoration activities. Significantly, none of the investigations were tagged by these stakeholders as unnecessary or redundant.

Probably the greatest benefit of the work product developed by the Parsons/EIS team is the degree to which continued debate regarding channel-dynamics hypotheses has been obviated. The misgivings still exist, but the effort resulted in a plan that proposes that the hypotheses should and will be tested before being accepted as fact in planning, management, and regulatory actions.

The Parsons-EIS Team views full implementation of the tasks identified in the first increment investigations as having minimal potential negative impacts to downstream landowners, water users, and others along the river; while at the same time offering maximum positive gains in understanding, and working in concert with, the physical processes of the Platte River.

ACKNOWLEDGEMENTS

The Parsons Team requested thorough reviews of the work products of these investigations from internal team members, particularly those who did not work on the task, and from a number of outside professionals. The external reviewers included Rick Brown, Colorado Water Conservation Board; Ann Bleed, Nebraska Department of Natural Resources; Mike Bessen and Mike Purcell, Wyoming Water Development Commission; Frank Kwapnioski, Nebraska Public Power District; and Mike Drain, Central Nebraska Public Power and Irrigation District. The outside reviewers provided materials and discussions that aided greatly in the final preparation of the documents, and their assistance is gratefully acknowledged.

BIBLIOGRAPHY

Murphy, P.J., and T.J. Randle, 2001. *Platte River Channel: History and Restoration.* U.S. Bureau of Reclamation and U.S. Fish and Wildlife Service. Draft. January.

Parsons. 2001. Questions Regarding White Paper Concepts and Conclusions. Prepared by Parsons, Denver, Colorado. June.

Parsons. 2003. Technical Memoranda, Results of Investigations A1 Through D2, Platte River Channel Dynamics Investigation. Prepared for the States of Colorado, Wyoming and Nebraska.

Parsons/EIS Team. 2003. Final Report, Parsons/EIS Joint Team River Process Investigations Analysis. Prepared by Joint Parsons/EIS Teams. January 16.

APPENDIX A

CONCEPTS AND CONCLUSIONS REGARDING PLATTE CHANNEL DYNAMICS AS HYPOTHESIZED BY THE WHITE PAPER

(Sources of the listed items are identified by page numbers from the White Paper, and the general results of Parsons investigations are provided in italics)

Channel Width Trends and Processes

1. The active channel, defined as the unvegetated portion of the river, has narrowed as much as 80 to 90 percent over the last 100 years (p. 1). *(Refuted by Parsons)*

2. The active channel is still slowly narrowing in some reaches (from the abstract). *(Refuted by Parsons)*

3. The recent ASCE Task Committee papers on modeling of width adjustments in streams can be considered the "best available information" (p. 1). *(Supported by Parsons)*

4. The channel narrowing was caused directly by a reduction in peak flows (p. 19). *(Strongly refuted by Parsons)*

5. The Platte River channel has become narrower, deeper, and heavily encroached by vegetation in response to water resources development in the basin (p. 19). *(Strongly refuted by Parsons)*

Channel Degradation Trends and Processes

1. The reduction in the supply of medium sand causes [vertical] erosion because the outflow of sand is greater than inflow (p. 5). *(Refuted by Parsons)*

2. Coarsening of the sand has occurred and results in higher velocities, lower flow area and deeper and narrower channels (p. 9). *(Refuted by Parsons)*

3. Sediment sizes will continue to coarsen in a downstream direction, resulting in further degradation in those reaches (p. 9). *(Refuted by Parsons)*

4. The coarsening has imbalanced the transport process and the resulting net erosion would only cause the river to degrade (p. 14). *(Strongly refuted by Parsons)*

Sediment Transport Trends and Processes

1. The reduction in the supply of medium sand causes a decrease in the mobility of the braided bed (p. 5). *(Inconclusive)*

2. Sediment transport near Chapman is still based mainly on the finer sand left over in the bed from the 1800's (p. 9). *(Inconclusive)*

3. As medium sand is replaced with coarse sand from Kearney to Grand Island, the river channel will narrow (p. 10). *(Refuted by Parsons)*

4. Medium sand forms a wider equilibrium channel than coarse sand (p. 14). *(Inconclusive)*

5. Sand bars of a braided river must be overtopped to "activate" the sand (p. 16). *(Refuted by Parsons)*

6. Sand on top of the bars in a braided river can be activated by overtopping them (p. 16). *(Supported by Parsons)*

Vegetative Encroachment Trends and Processes

1. Historical late spring floods maintained the wide, shallow, braided channel and kept the river relatively free of vegetation (p.2). *(Strongly refuted by Parsons)*

2. Clearing islands and channel areas of trees has not widened the active width of the channel (p. 15). *(Inconclusive)*

3. Vegetation encroachment prevents flood flows from mobilizing the higher sand and maintaining a wider channel (p. 19). *(Refuted by Parsons)*

Climate Affects and Natural Variability Concepts

1. The White Paper does not address climate effects or natural paleoclimatologic erosion and deposition processes.

TECHNICAL MEMORANDUM

RESULTS OF INVESTIGATION A1 - EVALUATION OF CURRENT MORPHOLOGY AND STABILITY OF THE PLATTE RIVER CHANNEL

PLATTE RIVER CHANNEL DYNAMICS INVESTIGATION

Prepared For

States of Colorado, Nebraska, and Wyoming

May 2003

Prepared By

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TECHNICAL MEMORANDUM

INVESTIGATION A1 -- EVALUATION OF CURRENT MORPHOLOGY AND STABILITY OF THE PLATTE RIVER CHANNEL

PREFACE

This report describes the procedures used in and results of an evaluation of the literature on geomorphic thresholds and the current morphology and stability of the Platte River channel. The investigation addressees a number of technical issues regarding this subject which had been identified by the sponsors as needing detailed examination to allow them to make scientifically-based decisions regarding the Cooperative Agreement (CA) work products.

This document describes only the data collected, analyses made, and scientifically-supportable findings regarding the issues, written in a manner which generally follows the guidelines of professional journals of the respective authors' technical expertise. The relevance of the findings to the specific issues confronting the sponsors is discussed in each task memorandum, but only as far as the data and results are deemed by the author(s) to be scientifically supportable in resolving or illuminating the issue.

ISSUES AND PURPOSES OF INVESTIGATIONS

The technical evaluations completed by the Parsons team were conducted as a series of 14 complementary investigations divided into four categories that would address general issues identified by the three states. The following issue categories were identified:

- A: Questions Regarding Channel Narrowing or Deepening
- B: Questions Regarding Sediment Transport
- C: Questions Regarding Vegetative Encroachment
- D: Questions Regarding Macro-Historic Natural Variability

This Technical Memorandum describes the results of Task A1, the first of five tasks comprising Issue Category "A."

Through many years of debate regarding conditions on the Platte, no comprehensive geomorphic assessment of the short- or long-term stability of the braided form has been completed, nor has the possibility been examined that geomorphic thresholds are being induced or naturally crossed for segments of the river. The purpose of Task A1 is to conduct an evaluation of past and current morphologic conditions of the Platte River, and identify possible threshold conditions affecting the river.

HYPOTHESES REGARDING PRE-DEVELOPMENT HYDROLOGY AND CAUSES OF CHANGES IN GEOMORPHOLOGY OF THE PLATTE RIVER SYSTEM

Murphy and Randle (2001a) developed a draft report entitled "*Platte River Channel: History and Restoration*." They concluded that prior to the development of water resources within the Platte River basin, the Platte River channel was wide, shallow, and braided in geomorphic configuration. Annual flood peaks were high – commonly greater than 10,000 cubic feet per second (cfs), sediment loads were large, and the median grain size of the river bed was fine sand. Overall channel widths including active (flowing) and inactive (dry) channels, and intervening braid-bar systems, were on the order of one mile, and the shifting sand bars of the braided river system kept the channel relatively free of vegetation. Other statements and conclusions were:

"During the period 1902-1909, the average annual peak flow (average annual maximum of mean daily flows) at the stream gage near Overton, Nebraska was 20,500 ft^3/s, and the mean annual flow rate was 2,900 ft^3/s. (Murphy and Randle, 2001a, p.2)

"The Central Platte River before the 1900s was dynamic, changing from year to year, and may have been slightly aggrading in certain reaches. The river is nearly straight, with a channel slope equal to the valley slope. … Overall, the channel was likely in a natural state near dynamic equilibrium … (Murphy and Randle, 2001a, p.2)

"Floods and droughts would come and go and the river would change in response to these flow changes, but the channel effects of these flow variations would fluctuate around average channel parameters that described the long-term-average properties of the river." (Murphy and Randle, 2001a, p. 3)

During the first few decades of the 1900's, large storage reservoirs were constructed in the Platte River watershed to provide water for irrigation. These reservoirs were (and are) used to store water during periods of high streamflow, for release during later periods of low streamflow, or as needed. Murphy and Randle (2001b) developed a draft of their report entitled "*Platte River Sediment Transport and Riparian Vegetation Model*." Their conclusions regarding the impact that this pattern of reservoir storage had on the river were:

[The development] "*significantly reduced the annual peak flows and the application of water to agricultural lands reduced annual flows within the river channel. The large storage reservoirs also trapped the sediment load of the North Platte River and significantly reduced the sediment supply to the Platte River downstream.*

The reductions in annual peak floods, annual river flow, and sediment supply resulted in a significantly narrower river channel, and vegetation colonized areas of the formerly active river channel. In general, river channel widths have [been] reduced to about one-fifth or less of the former historic channel. The reductions in annual flood peaks alone would account for a large portion of the channel narrowing; however, the reduction in sediment supply and the growth of dense riparian vegetation have also played a significant role. A simple reduction in annual flood peaks would result in a narrower river channel, but still leave the channel in a braided condition with a bed of fine sand. However, the large decrease in the sediment supply resulted *in a few feet of river-bed erosion across separate subchannels. Through the selective erosion of finer sediment particles, the erosion process also resulted in a coarser sediment size on the eroded river bed. The vertical incision, over portions of the formerly active river channel, also aided in the abandonment of the remaining wide, river channel. Once portions of the former river bed degraded, river flow were more frequently contained within the narrower, but deeper, channel. Thus, river flows were not as frequently available to mobilize sediments of the formerly wide and higher river channel. With fewer frequent flows to mobilize these sediments, the remaining portions of the formerly wide river channel were ideal for colonization by riparian vegetation ..."* (Murphy and Randle, 2001b, p.2)

Narrowing of the Platte River channel has been attributed by Murphy and Randle (2001a) to conversion from a braided system to a transitional form, or more specifically, to an anabranched pattern. This conversion is alleged to have been a direct consequence of reductions in peak flows and in sediment transported by the river, due to construction of retention and diversion structures for water development (e.g., Murphy and Randle, 200a, p. 4ff). The remainder of this report discusses, from a geomorphologic stance, whether there are other explanations to the morphologic transition, and whether this particular cause is precedented and credible.

GEOMORPHIC THRESHOLDS AND STABILITY OF BRAIDED STREAMS

Background material on factors that can alter the geomorphology of rivers was collected at the beginning of this investigation. A number of relevant definitions of terms and descriptions of types of streams and physical processes were compiled and are included in Appendix A to this report. The Appendix is suggested reading for readers not familiar with geomorphologic literature. Because the primary issue in this investigation is change in Platte River morphology and its causes, the material presented in this section addresses the instability and transitional nature of braided systems and describe the effect that climate has had on the morphology of Great Plains streams..

The equilibrium states described in Appendix A have limits, called *thresholds*, at which something tangible happens to the system. Threshold conditions may occur rapidly, or may develop in response to gradual, often imperceptible, changes within the system. These can either be extrinsic (caused by external factors such as climate change) or intrinsic (such as changes in erosion or drainage patterns within the basin).

Investigation Task “A1” consisted of in-depth review of the available information regarding stable rivers, geomorphic processes, and extrinsic and intrinsic thresholds that can represent discontinuities between morphological patterns separating straight, meandering, and braided regimes. Information pertaining to the existence of geomorphic thresholds and the characteristics of braided and other streams was obtained from federal and state agencies, independent researchers, and the published literature, and is described in the following sections.

Extrinsic Threshold Drivers, Particularly Climate

Classical literature on braided streams (e.g., Thornbury, 1954; Ruhe, 1975; Ritter, 1978), and specific research such as work by Schumm and Lichty (1963) and Schumm (1981), indicates that braided streams are unstable, that they are transitional, that they require a perpetual oversupply of sediment, that some reaches can be braided while others are not, and that they respond to minor shifts in geomorphic thresholds that can be induced by factors other than a coarsening of sediment. Some researchers (e.g., Lane [1955]) suggest that sediment gradation may not be relevant at all.

In the braided planform characteristic of some fluvial systems, streamflow through a particular channel cross-section occurs in multiple channels, divided by islands or bars that consist of exposed accumulations of sediment (Brice, 1982; Summerfield, 1991). Islands are usually vegetated, and are relatively long-lived features, whereas bars are less stable, being composed of unvegetated sand or gravel. Bars within the channel have no consistent relation to bank stability (Brice, 1982). Bars visible at normal stage indicate that bedload, either sand or gravel, is a prominent part of the stream's total load. The degree of braiding of a channel increases with the frequency of mid-channel bars. Because of the shifting of these bars, and of the channel braids between them, a braided stream has an unstable bed, but the banks are not necessarily unstable (Brice, 1982).

The properties of each stream type described in Appendix A, as indicated by the dimensional characteristics of width, depth, and sinuosity (see Figure A1-1), change gradually from one to the next, and some properties have a definite trend. For a stream of a particular size, as measured by bankfull discharge, effective discharge, or other hydraulic metric, channel width tends to increase from equiwidth to braided streams, and sinuosity tends to decrease.

The dimensional properties associated with each stream type also have a relative degree of stability associated with them. For example, the stability of certain features associated with the equiwidth point-bar type of stream varies from "low" (channel width) to moderately high (lateral stability), indicating that the channel width of an equiwidth point-bar stream is particularly subject to change, but that the axis of the stream channel is unlikely migrate great distances laterally. According to this classification system (Brice, 1982), the dimensional stability of most features of braided streams range from "moderate" to "low" (also shown in Figure A1-1).

Because channel properties are gradational from one stream type to the next, a particular stream may lie at the boundary between two types. For example, it may be difficult to decide whether a stream is of the equiwidth or wide-bend type if channel width is greater at some bends than at others, or if the width at bends does not clearly exceed the width at straight reaches. A borderline stream probably is gradational in stability characteristics between two categories.

Although many alluvial channels can be described as "stable," in that they currently are not experiencing a dramatic change in form, *some* change is an inevitable element of the behavior of all alluvial channels, since they are (at least partly) composed of material which is eroded or deposited as the hydraulic stress exerted on the channel bed and banks by the flowing water changes over time (Summerfield, 1991). A number of interrelated variables, including discharge, flow velocity, sediment concentration and size, and channel gradient, any or all of which can change in response to extrinsic factors (climatic, tectonic or anthropogenic), or intrinsic factors (e.g., changes in erosion or drainage patterns within the basin), will promote changes in channel pattern. Therefore, the morphology of many or most streams may change with time. Such changes can occur in various ways, including the downstream migration of bars, the gradual shifting of meanders, and the rapid alteration of course through cut-offs or channel diversions. Anthropogenic activities, such as clear-cutting of mountain forests, clearing of a floodplain or construction of a dam, may bring rapid changes in stream type and behavior. However, as pointed out by Brice (1982), anthropogenic activities do not necessarily lead to a decrease in stability.

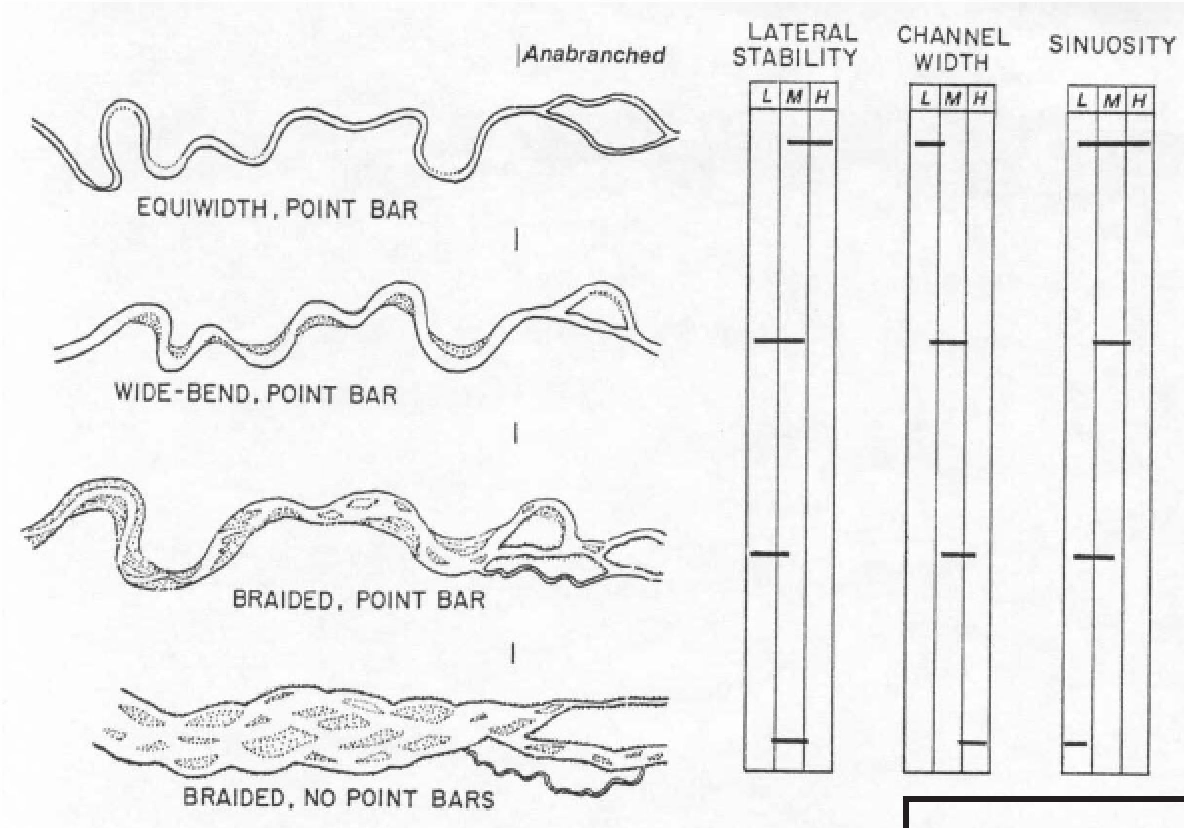
During the past 15,000 to 18,000 years, substantial changes of the whole environment have occurred, usually described as a shifting of the climatic-vegetational zones as a consequence of the worldwide transition from glacial conditions (during the most recent Ice Age) to post-glacial conditions. These changes created new fluvial systems or initiated large-scale transformations of the basic parameters of existing hydrologic regimes, including river discharge, sediment load, basin area, channel length, and gradient (Starkel, 1991a). Climatic fluctuations have continued up to the present, and consequently have produced a sequence of changes in the hydrology and geomorphology of numerous fluvial systems, which have been superimposed on, and have modified, the pre-existing systems (Sundborg and Jansson, 1991; Starkel, 1991b). Thus, the current geomorphology of the Platte River basin consists of an Ice-Age topography, somewhat modified by the forces resulting from changing climates of the past 15,000 years.

Numerous investigations illustrate three types of behavior of fluvial systems in the geologic and historic record:

- stability, indicated by the dominance of a particular state over long periods of time and exemplified by the widespread occurrence of meandering morphology throughout most of recent time;
- rapid change, as indicated by switches in morphology over a relatively short period from meandering to braided and back, or from aggrading to degrading conditions, with consequent formation of terraces; and
- oscillations between states.

These three behaviors usually are ascribed to changes in external conditions (primarily climate), which, in light of the known changes in global climatic conditions and their oscillations, seems perfectly reasonable (Thornes and Gregory, 1991).

Episodic occurrences of fluvial erosion and deposition in the American Midwest were examined by Brakenridge (1980). Stratigraphic analyses were combined with radiocarbon dating of paleosols and terrace surfaces to develop an alluvial chronology of the Pomme de Terre River in central Missouri (Figure A1-2), which was related by Brakenridge (1980) to changes in climatic conditions. Periods of slow or fast floodplain



After Brice (1982).

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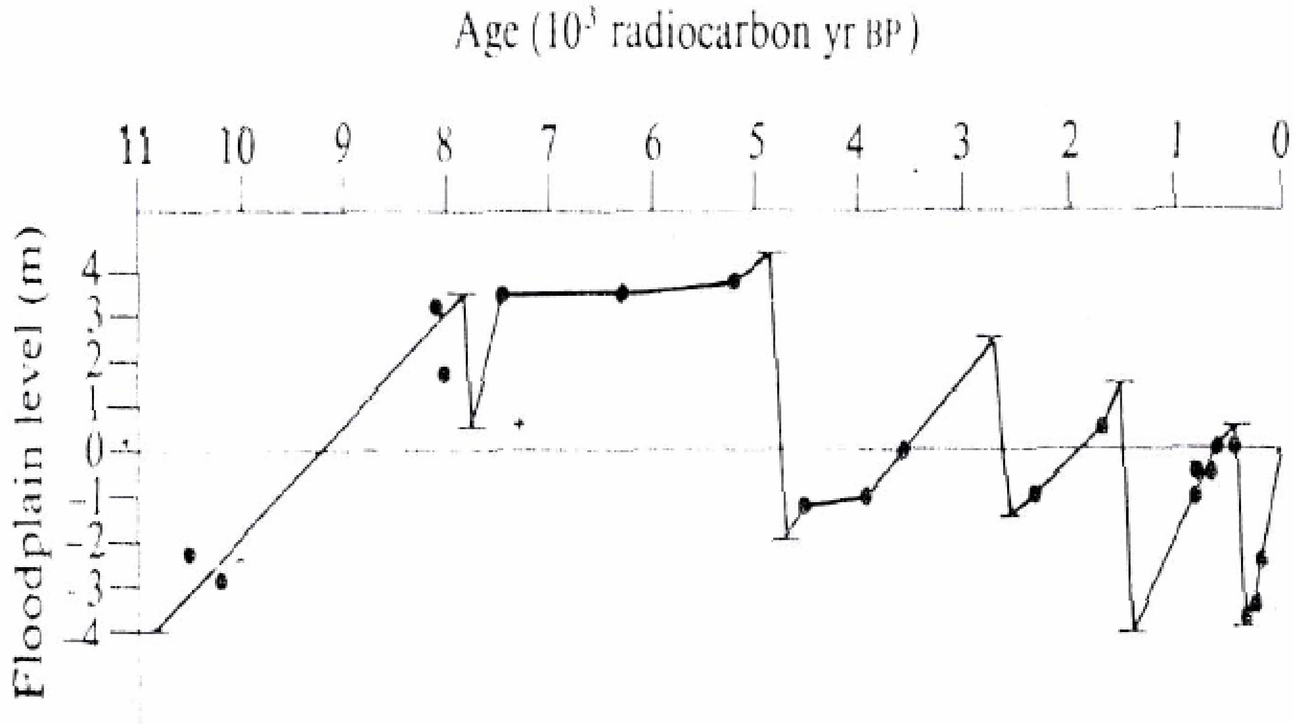
FIGURE A1-1

PRINCIPAL FLUVIAL CLASSIFICATIONS AND RELATIVE DEGREES OF STABILITY

Platte River Channel Dynamics Study

PARSONS
Denver, Colorado



After Braxenridge (1980).

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FIGURE A1-2

TERRACE ELEVATIONS OF POMME DE TERRE RIVER

Platte River Channel Dynamics Study

PARSONS
Denver, Colorado

aggradation, stability, and degradation are immediately evident and produced, at various times, floodplains having surface elevations ranging from about 12 feet (4 meters) below the elevation of the current floodplain, to more than 12 feet (4 meters) above the current floodplain. One facet of the fluvial history that is particularly apparent is that conditions of "grade" or stability have prevailed for only limited periods of time since the end of the Ice Ages (Figure A1-2). Instead,

- a major aggradational event occurred between 10,500 and 8,100 years before the present time (yr BP);
- following a brief erosional event between 8,100 and 7,500 yr BP, the river rapidly re-adjusted its grade;
- floodplain stability prevailed from 7,500 to about 5,000 yr BP;
- by 4,600 yr BP a major change in long-term stream regime had occurred; and
- since that time, rapid aggradation has alternated with closely-spaced intervals of erosion. This last period, characterized by lack of long-term stability, continues to the present.

Brakenridge (1980) related these dramatic geomorphic changes to regional long-term climatic trends, derived on the basis of the regional vegetational history as deduced from analysis of pollen (palynology), and concluded that if climatic conditions typical of the recent past continue, they will be accompanied by widespread episodes of stream erosion.

Peak flood discharges of elevated magnitude and low frequency were regarded as potential threshold events by Knox (1983), who also noted that severe droughts, which reduce vegetative cover on a basin-wide scale, tend to increase surface runoff, thereby causing larger floods from a precipitation event of a given intensity.

This view that climate is the primary factor in the oscillatory behavior of fluvial systems described above is developed fully in the Task D1-D2 report and is in contrast to the approach used by the Williams (1978) and by Murphy and Randle (2001a), who by the absence of discussion of climate affects apparently regarded the possible hydrologic and geomorphologic effects associated with changing climatic conditions as unimportant in the functioning of the Platte River system.

Thresholds Intrinsic to Hydraulics of Fluvial Systems

In addition to thresholds arising as a consequence of changes in extrinsic conditions (e.g., climate), several researchers also identify geomorphic thresholds that are inherent in the physics of fluvial hydraulics. In particular, Chang (1985 and 1986) contends that in considering the relationships among channel pattern, channel geometry, hydraulic slope, and bankfull discharge (see Figure A1-3 in Appendix A), at least four thresholds can be identified; and that these thresholds occur as a direct consequence of such factors as the critical slope for bed load movement. These intrinsic hydraulic thresholds divide the universe of channel regimes into 4 hydraulic "regions", within which natural river channels will adopt characteristic morphologies:

Region 1 – Equiwidth point-bar streams

Region 2 – Straight braided streams

Region 3 – Braided point-bar and wide-bend point-bar streams

Region 4 – Steep braided streams

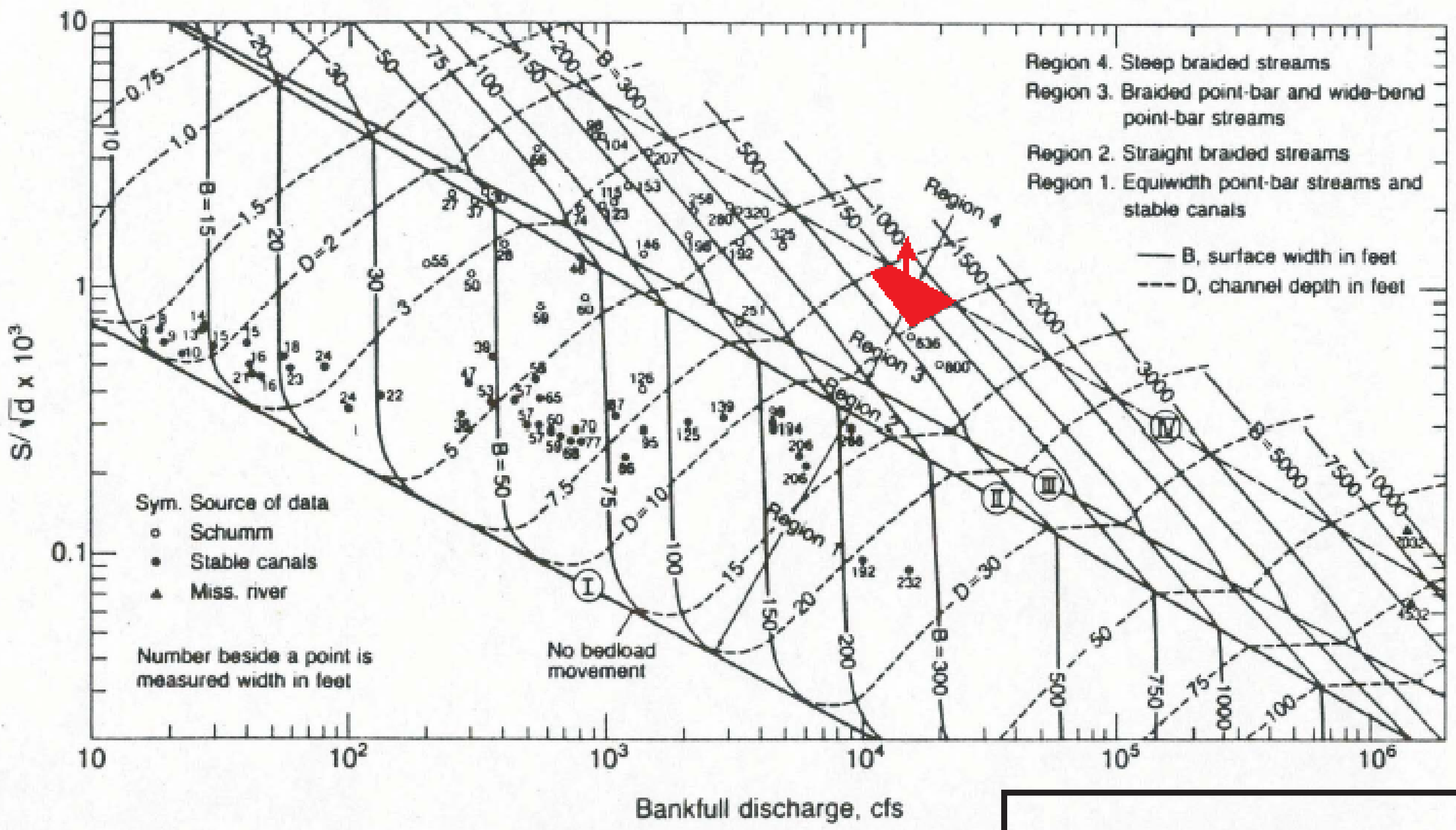
As a consequence of the configuration of its channel (wide and shallow) and its relatively steep hydraulic gradient (greater than 0.001), the Platte River is generally considered to be a "steep braided stream" (Region 4) (Murphy and Randle, 2001a). However, Chang (1985) notes that another possible stable channel geometry can occupy Region 4 of channel regimes, and that this configuration is not braided, consisting of alternating riffle and pool sections, similar to the configuration of wide-bend point-bar streams (Region 3).

Moreover, changes in morphology of a channel that is hydraulically near an intrinsic threshold can readily be induced by relatively minor changes in extrinsic conditions. Consider a channel that has formed in response to hydraulic conditions that place it in Region 3. The anticipated configuration of this channel is that of a braided point-bar or wide-bend point-bar stream (Figure A1-4). Now suppose that some extrinsic change causes the local base level of the stream to be slightly lowered, leading to a slight increase in hydraulic gradient. (Such a lowering of base levels occurred during the last Ice Age, when lowered sea levels caused a general increase in stream gradients throughout the northern hemisphere.) In response to even a slight increase in gradient, the hydraulic condition of the stream crosses an intrinsic threshold (Figure A1-4), and the channel morphology changes to that of a steep braided stream (Region 4). If the hydraulic slope of the river varies in response to the sediment contributions from tributaries, or due to variations in deposition during the geologic past, then the river also will reflect these changes in slope by changing channel pattern (Schumm, 1974).

Similarly, the morphology of a steep braided stream (Region 4) may change in response to extrinsic conditions that cause even slight reductions in discharge, which can shift the hydraulic condition of the stream across an intrinsic threshold into Region 3 (braided point-bar and wide-bend point-bar streams) (Figure A1-5). Such reductions can occur as a consequence of numerous factors, including anthropogenic activities, or climatic change – in particular, droughts. Note that the magnitude of the change in extrinsic conditions required to cross a threshold is sufficiently small that it may not be possible to distinguish the proximate cause of the change in morphology from among all possible causes. It should be noted that the reference here to small magnitudes of extrinsic factors are those that occur throughout the system, and are not pertaining to effects of a single-location condition.

Thresholds and Landform Responses

Review of the technical literature demonstrates that alternating periods of incision (degradation or erosion) and aggradation have affected numerous, and perhaps all streams in the Great Plains region (Wenzel *et al.*, 1946; Leopold and Miller, 1954; Brakenridge, 1980; Osterkamp *et al.*, 1987; Martin, 1992; May 1992) during the past several thousand years. These episodic occurrences have resulted in the addition (or



After Chang (1985).

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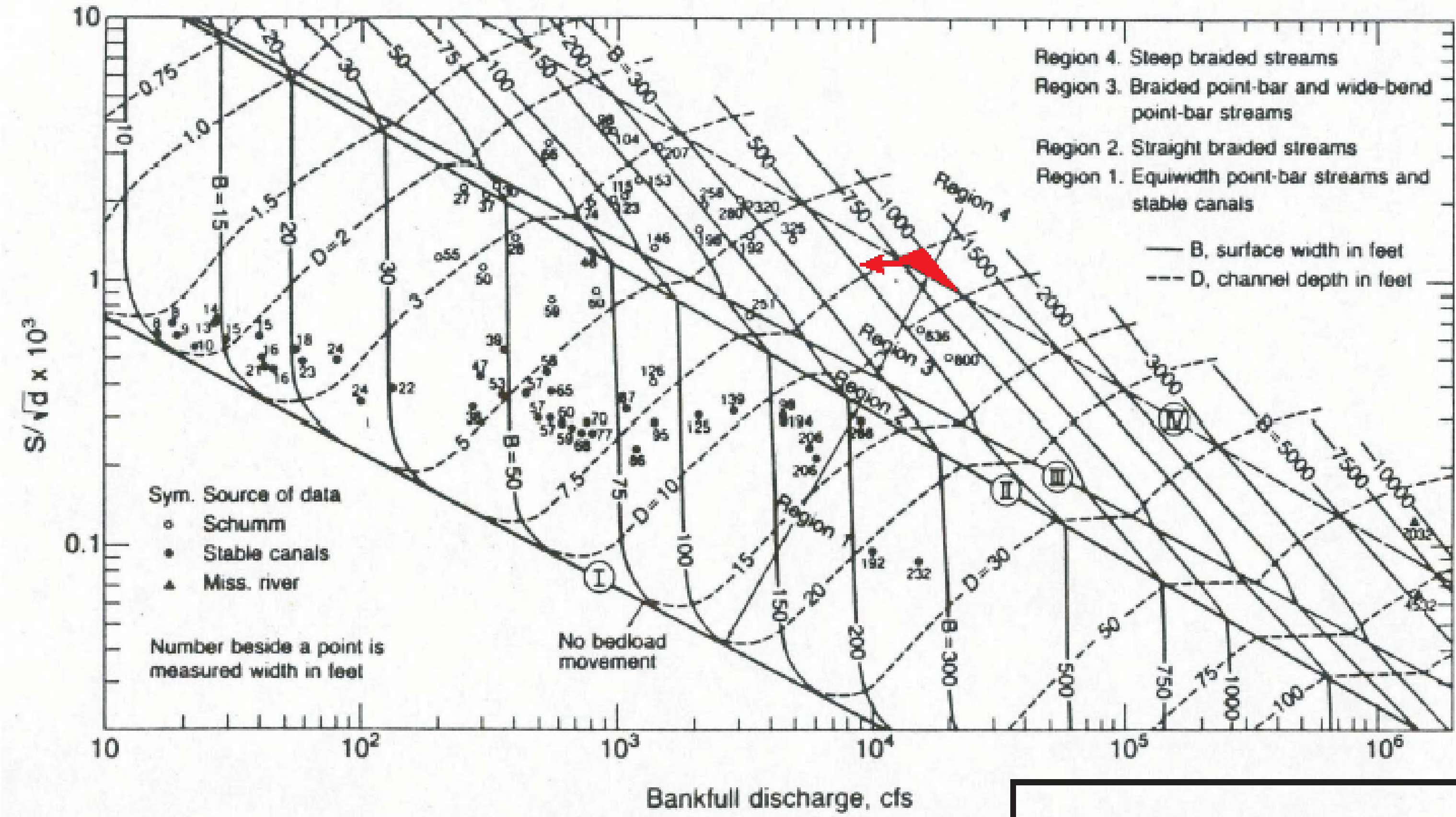
FIGURE A1-4

CHANGE IN CHANNEL MORPHOLOGY RESULTING FROM THRESHOLD INCREASE IN GRADIENT

Platte River Channel Dynamics Study

PARSONS
Denver, Colorado



After Chang (1985).

FIGURE A1-5

CHANGE IN CHANNEL MORPHOLOGY RESULTING FROM THRESHOLD REDUCTION IN DISCHARGE

Platte River Channel Dynamics Study

PARSONS
Denver, Colorado

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removal) of material totaling tens to hundreds of feet in thickness to (or from) floodplains in the region. During the same period, fluvial systems in the temperate zone throughout the world have undergone large-scale changes in hydraulic and hydrologic characteristics, and in planform, changing from braided to meandering planforms (Kozarski, 1991; Baker, 1991; Starkel, 1991b), and sometimes from meandering to braided planforms (Schumm and Lichty, 1963). These transformations may require periods approaching geologic time (Schumm, 1968), but can occur in rapid and dramatic fashion (Chang, 1986; Schumm and Lichty, 1963; Schumm, 1974). Generally speaking, these geomorphic changes appear to occur in response to climatic changes (Thornes and Gregory, 1991). Although climate can function as an extrinsic factor, driving geomorphic processes that eventually produce changes in the configuration and planform of drainage systems, the nature of threshold occurrences is such that even minor changes in extrinsic conditions may cause a system to cross one or more intrinsic thresholds, triggering geomorphic changes of large magnitude (preceding section).

Stratigraphic and geomorphic sequences in the Great Plains have many small to large discontinuities that record repeated changes in the types and rates of surficial processes (Osterkamp *et al.*, 1987). The changes in interactions between climate and geomorphic processes is characterized by sequences of incision, lateral erosion, deposition, and landform stability, perhaps with significant soil development. Periods of slow or rapid aggradation, stability, and degradation are evident in the stratigraphic record; but it is apparent is that conditions of "grade" or stability have prevailed for only limited periods of time since the end of the Ice Ages. The relatively rapid rates at which geomorphic changes appear to have occurred suggest that most landform evolution in the Great Plains region has occurred in response to threshold excursions.

SYNOPSIS OF LITERATURE REVIEW – GEOMORPHOLOGY, HYDROLOGY, AND THRESHOLDS IN THE PLATTE RIVER SYSTEM

Technical literature and other information regarding hydrologic and geomorphic conditions in the Great Plains and similar areas were reviewed by the Parsons team as part of Task A1. Relevant literature regarding the Platte and other Great Plains rivers has been cited in the bibliography, and is summarized in this section. Other streams, including the Cimarron River in Kansas have experienced similar changes, and studies of these streams are described in Appendix A.

Wenzel *et al.* (1946) completed an evaluation of the geology and groundwater resources of the Platte River valley near Scottsbluff, Nebraska, which included an assessment of the geomorphology of the North Platte River and nearby areas. Wenzel *et al.* (1946) identified nine terraces bordering the river, having elevation differences between the lowest and highest terrace of nearly 1,000 feet. Several of the highest terraces were developed during Ice Age time; but later in its history, the North Platte River apparently incised channels to depths greater than 200 feet below its present floodplain elevation; these channels later were backfilled by the river. The terraces, erosion surfaces, and channel deposits represent the visible results of alternating periods of erosion and deposition, occurring from the end of the Ice Ages through the present time, which Wenzel *et al.* (1946) ascribe to threshold excursions, including changing climatic conditions, tectonic uplift, or both.

Leopold and Miller (1954) examined the geomorphology of several alluvial valleys in eastern Wyoming, including the North Platte River, in an attempt to reconstruct the sequence of events that produced alluvial terraces bordering the valleys at different levels. On the basis of stratigraphic evaluation and comparison of the relative elevations of terrace deposits, channel-fill deposits, and erosion surfaces, Leopold and Miller (1954) identified several periods of alternating deposition and erosion in eastern Wyoming, beginning at the end of Ice-Age time. Erosional processes resulted in channel incision to depths of several tens of feet, which was followed by a cycle of deposition, in which the incised channels were backfilled with sediments to nearly their pre-erosion level. Leopold and Miller (1954) related these cyclic geomorphic occurrences to climatic changes that have occurred since the end of the Ice Ages. The authors concluded that while some of the recently-occurring channel incision and erosion observed in eastern Wyoming was a consequence of threshold conditions associated with changing land use (overgrazing resulting in removal of vegetation), much of the modern erosion also could be a consequence of climatic variability; and the observed rates of erosion represent the net result of some interaction between land use and varying climate.

The planform of the Platte River in Nebraska, and the processes active in shaping the river, were examined by Smith (1970 and 1971). Unlike many braided streams, particularly those associated with glacial features or located in glacial outwash plains, the Platte River in Nebraska carries a dominantly sand bedload. In streams carrying coarser-grained bedload material, especially those with poorly-sorted gravel beds, braiding is caused by the construction during period of high discharges of low, linear, mid-channel mounds. Formation of the mounds requires only that a stream at some point becomes unable to transport part of its coarsest load. The coarse sediment is deposited and traps additional sediment causing the mound to be built upward and in a downstream direction. The resulting deposit is elongate in the direction of the stream current, convex upward or slightly inclined on top, and it usually displays a pronounced fining trend in sediment gradation in the downstream direction. These mounds divide the channel into smaller branches as high flows recede and the mounds become exposed. Such linear mounds (called *longitudinal bars* by Smith [1970]) dominate the upper reaches of the South Platte River in Colorado, and in many other coarse-bed streams.

In braided streams that carry well-sorted, sandy sediments, however, bars are more typically transverse, with wide, flat-topped tabular bodies and sinuous to lobate depositional fronts. Bars of this type characterize the braided reaches of the lower Platte in Nebraska (Smith, 1970 and 1971). Braiding in reaches of the Platte River in which sand-sized material comprises most of the bedload is an intermediate-to-low discharge phenomenon, which occurs primarily by dissection of transverse bars. Transverse bars form by aggrading to a profile of equilibrium and expand laterally by additions of sediment to avalanche faces. Bars formed during the high annual spring discharges are the first to become exposed. Those that escape complete removal by waning currents following high-discharge events are soon overgrown by vegetation to become semi-permanent features unless destroyed by subsequent high-discharge events.

Several factors determine the shape of an evolving transverse bar (Smith, 1971), including cross-sectional shape of the bar mouth, proximity to stable banks, direction and power of adjacent currents, steadiness of flow, and depth distribution of the floor over which the bar is growing. The ideal bar pattern is a bilaterally symmetrical lobe shape with currents radially distributed from the mouth over the surface. Such lobate forms are fairly common during high discharges in the Platte River and during early stages of bar growth during lower discharges. Ordinarily, however, the bars take on a wide variety of asymmetric and irregular patterns soon after their initiation, as a result of one or more of the listed factors.

Braiding begins when flow passing through the bar mouth decreases to the point where it is unable to sustain sediment transport over the entire bar surface (Smith, 1970). The flow then becomes to one or more channels which begin to dissect the bar surface. During waning stages of flow, smaller transverse bars may merge with or override the original bar. These new bars and their accompanying smaller-scale bedforms, combined with both lateral and downward dissection by surface and adjacent currents, produce a complex depositional and erosional history for the original bar area after flows have diminished or stopped completely. Thus, according to Smith (1971), most exposed bars, especially the larger ones, separating anabranches in the Platte River during periods of low discharge, are not simple exposed transverse bars at all, but rather are complex depositional and erosional features which merely began as transverse bars.

Cyclic occurrence of general aggradation and degradation processes in the Great Plains was described by Osterkamp *et al.* (1987), who determined that the morphology of the Great Plains is a product of the dramatic climatic changes that have characterized the period of time following the conclusion of the Ice Ages. In particular, because of the relationship between climatic variation and the resulting geomorphic processes, landforms on the Great Plains appear to have developed in a complex cyclic manner:

1. Stratigraphic and geomorphic sequences in the Great Plains have many small to large discontinuities that record repeated changes in the rates of surficial processes (fluvial, aeolian, pedogenic). Commonly, the change in rate of one process as compared with another became large enough to change the type of surficial process that was dominant during a given episode.

2. The cyclicity of the interactions between climate and geomorphic processes is characterized by sequences of incision, lateral erosion, deposition, and landform stability, perhaps with significant soil development. These cycles are known as “erosion-deposition-stability” (EDS) cycles. All stages of this sequence are observable in different parts of the Great Plains.

3. In the Great Plains, EDS cycles were induced by climate changes, because tectonic processes are negligible in this relatively stable region.

4. Four time-duration classes of EDS cycles appear to have operated in the past: microcycles lasting 10 to 100 years; mesocycles, lasting 1,000 to 10,000 years; macrocycles, approximately 100,000 years in length; and megacycles, 400,000 to 500,000 years in length.

5. At least four megacycles, and probably the beginning of a fifth, are apparent in the geologic history of the past 2 million years. The initiation of each megacycle is indicated by a period of prolonged alluvial downcutting. The Great Plains appears to be entering a fifth process megacycle, and Great Plains rivers currently are downcutting their channels.

6. The fundamental climatic- and surficial-process controls of the EDS cycles, including various feedback mechanisms, are poorly understood, especially the extrinsic threshold controls of the longer cycles. Shorter cycles were driven over low thresholds at short intervals by relatively small changes in process intensity. The high thresholds of the megacycles required large changes in process intensity, and were accompanied by major geomorphic-stratigraphic changes.

Martin (1992) and May (1992) examined the paleohydrology of the Republican River and South Loup River, respectively – two stream systems in the near vicinity of the Platte River. Apparently, two episodes of incision (degradation) of stream channels, one beginning about 4,200 yr BP, and the other occurring after 1,100 yr BP, were widespread across the central Great Plains (Martin, 1992). The earlier episode was associated with a shift to relatively wetter conditions (a threshold event), whereas the later episode was preceded and followed by dry conditions. Three episodes of floodplain aggradation have been identified in the South Loup River valley (May, 1992). The first episode of aggradation occurred beginning prior to about 3,500 yr BP and continuing until at least 3,000 yr BP. This followed a period of deep incision of the valley, perhaps corresponding to the earlier episode of incision identified by Martin (1992). The second interval of slow aggradation on the floodplain, accompanied by formation of soil on terrace surfaces, occurred between 1,800 and 1,050 yr BP. A third, rapid episode of valley-bottom aggradation occurred sometime after 1,050 yr BP. Episodes of floodplain erosion during high-magnitude floods occurred before, between and after these intervals of aggradation. The intervals of aggradation documented for the South Loup River valley appear to have been synchronous throughout the Loup River basin (May, 1992).

Threshold events that have affected the fluvial geomorphology of rivers originating in the Front Range of Colorado were examined by Wohl (2001), who noted that a threshold event separates two distinct modes of operation of a river system. Often, there appears to be a lag period before a river responds to a change in water or sediment discharge; and this lag may be caused by the existence of a threshold. As an example, Wohl (2001) notes that a severe forest fire may destroy the vegetative cover that tends to stabilize hillslope soils. The first heavy rainfall following the forest fire may destabilize the hillslope and cause a landslide that introduces large quantities of sediment to the river. Because the river discharge is not capable of transporting all of the newly-introduced sediment downstream immediately, over a period of months to years the morphology of the river may change from a meandering to a braided pattern. This new pattern may persist for decades to centuries until sufficient sediment has been removed and the river once again crosses a threshold and assumes a single-channel planform. However, the response of a river to some threshold process or external change may not be synchronous along all reaches of the river. Downstream parts of a drainage basin may be affected by changes upstream, and vice versa. It thus becomes important to consider how changing conditions in one part of the basin may affect the remainder of the basin. Wohl (2001) describes and characterizes the changes in Colorado streams and rivers that have occurred in historic time as a consequence of anthropogenic activities, including beaver trapping, deforestation, mining, and the introduction and expansion of irrigated agriculture.

SUMMARY AND CONCLUSIONS

The existence and nature of threshold geomorphic processes were investigated, and the possibility of their past occurrence in the Platte River was examined. Based on examination and evaluation of the compiled literature, geomorphic trends and the possible existence of past transitions through thresholds for the Platte River were identified.

Uncertainties arise in considering the occurrence and timing of threshold conditions affecting the geomorphology of the Platte River system. Examination of the terrace geomorphology and stratigraphy of streams in the Great Plains, including tributaries of the Platte River (Wenzel *et al.*, 1946; Leopold and Miller, 1954; May 1992) leaves little doubt that the Platte River has crossed intrinsic and extrinsic thresholds in the geologic past, probably on numerous occasions; and that these threshold excursions likely have left geomorphic signatures of their occurrence. However, the literature dealing with the geomorphology and geologic history of the main stem of the Platte River proper is limited; and specific threshold events on the Platte River, and their resulting geomorphic consequences, have yet to be identified. Therefore, although it is certain that threshold geomorphic events have occurred throughout the Platte River system, the exact nature and timing of these events currently cannot be identified.

As has occurred in numerous other rivers worldwide, the configuration of the Platte River has changed in response to changes in water and sediment discharges, resulting from climatic change and other factors. The time scale for adjustment of a channel varies with the sensitivity of the channel to changing conditions. A significant adjustment in stable humid-zone rivers may require centuries; but in semi-arid areas (such as the Platte), the time scale for fluvial adjustments can be much shorter, close to the time scales required for the random response to a single catastrophic event (Chang, 1986). The rapidity of the response of the fluvial system to changes in extrinsic conditions is a measure of the relative stability (or lack thereof) of the channel type, with respect to particular conditions.

Analysis of the morphology and behavior of the Platte and other rivers shows that there are a number of identifiable and quantifiable fluvial states (Schumm, 1968, 1974, and 1981; Thornes and Gregory, 1991). The principal morphological taxonomy of rivers identifies straight, meandering, and braided channels; the principal hydraulic taxonomy identifies wide, shallow channels and narrow, deep channels; and the principal behavioral taxonomy identifies aggrading, graded (regime) and degrading (eroding) channels.

There is ample evidence to show that different reaches of the same river can (and commonly do) occupy different morphological, hydraulic, and behavioral states (Thornes and Gregory, 1991), but that a particular reach tends to spend relatively long periods of time in the same state. The detailed at-a-station analysis described in the Task A3 report demonstrated that this was strongly evident at Kearney.

Despite these uncertainties, the following summary statements can be made regarding threshold events and geomorphic responses in the Platte River system.

1. Geomorphic changes usually occur in response to changes in threshold conditions. Geomorphic thresholds may be extrinsic (occurring in response to

an external change) or intrinsic (inherent in the system). Threshold conditions may occur rapidly, or may develop in response to gradual, often imperceptible, changes within the system. Similarly, the geomorphic response to threshold conditions may be gradual, or abrupt.

2. The Platte River has crossed intrinsic and extrinsic thresholds in the geologic past, probably on numerous occasions; and that these threshold excursions likely have left geomorphic signatures of their occurrence. However, the details of threshold excursions in the Platte River system remain largely unknown.

3. Dramatic geomorphic changes have occurred in the Great Plains region within the past 1,000 to 2,000 years. These have included episodes of aggradation and degradation, which have resulted in the addition (or removal) of tens to hundreds of feet of material to (from) channel systems. These changes are recorded in the stratigraphy of alluvial deposits, and in the morphology of fluvial terrace systems throughout the Great Plains.

4. Climatic change appears to be the most significant external factor driving geomorphic change in this region. Significant time lags can occur between climate change and adjustment of the resulting landforms to changing conditions. Extreme climate excursions that cause accelerated threshold-limited erosion or deposition seem likely to occur and to leave very long-lived morphological evidence.

5. A braided system is a transitional form and inherently unstable. That any braided stream experiences excursions to other forms, either locally or throughout, is not surprising, and can be destabilized by relatively minor extrinsic or intrinsic factors.

6. The morphology of the Great Plains is a product of the dramatic climatic changes that have characterized the period of time following the conclusion of the Ice Ages. In particular, because of the relationship between climatic variation and the resulting geomorphic processes, landforms on the Great Plains appear to have developed in a complex manner.

7. In addition to thresholds arising as a consequence of changes in extrinsic conditions, intrinsic geomorphic thresholds may be inherent in the physics of fluvial hydraulics. Changes in morphology of a channel that is hydraulically near an intrinsic threshold may be induced by relatively minor changes in extrinsic conditions; and the magnitude of the change in extrinsic conditions required to cross a threshold may be sufficiently small that it may not be possible to distinguish the proximate cause of the change in morphology from among all possible causes.

Based on historical accounts of the river's morphology and knowledge of its present morphology, it is clear that it has transitioned in the past 100 years or so from one with numerous braided segments to one with fewer such segments and a higher incidence of anabranched reaches. The long-term geomorphologic record establishes that wide swings in base level have occurred, but does not allow microscopic evaluations of smaller transitions such as those occurring in the recent past. A threshold between the pre- and post-development forms has not been identified, nor have drivers other than climate been identified as instrumental in causing these types of changes in this region, but it is reasonably concluded that the river is in a greater state of dynamic equilibrium than it was in its pre-development form.

Murphy and Randle (2001a, p. 4ff) hypothesized that the transitions experienced by the Platte are a direct consequence of reductions in peak flows and in sediment transported by the river, due to construction of retention and diversion structures for water development. The literature on long-term conditions reveals that even more dramatic changes have occurred on numerous occasions, and none are associated with these causes. The long-term climatic changes described in the Task D1-D2 report, and the more recent evaluation of swings in climate presented in the Task A3 report indicate that climate strongly controls shifts in the Platte's morphology and should not be discounted as was done by Williams (1978) and Murphy and Randle.

BIBLIOGRAPHY

Baker, V. R. 1991. A Bright Future for Old Flows, in Starkel, L., Gregory, K.J., and J.B. Thornes (eds.) *Temperate Palaeohydrology*. John Wiley & Sons, Inc. London. pp. 497-520.

Brakenridge, G.R. 1980. Widespread episodes of stream erosion during the Holocene and their climatic cause. *Nature* 283:655-666.

Brice, J.C. 1982. *Stream Channel Stability Assessment*. Federal Highway Administration, Office of Research and Development. U.S. Department of Transportation. Washington, D.C. Report No. FHWA/RD-82/021. January.

Chang, H.H. 1985. River morphology and thresholds. *Journal of Hydraulic Engineering* 111(3):503-519.

Chang, H.H. 1986. River channel changes -- Adjustments of equilibrium. *Journal of Hydraulic Engineering* 112(1):43-55.

Gordon, N. 1995. *Summary of Technical Testimony in the Colorado Water Division 1 Trial.* U.S. Department of Agriculture. U.S. Forest Service General Technical Report RM-GTR-270. September.

Knox, J.C. 1983. Responses of River Systems to Holocene Climates, *in* Wright, H.E. Jr., (ed.) *Quaternary Environments of the United States – Vol 2: The Holocene*. University of Minnesota Press. Minneapolis, Minnesota. pp. 26-41.

Kozarski, S. 1991. Warta – A Case Study of a Lowland River, *in* Starkel, L., Gregory, K.J., and J.B. Thornes (eds.) *Temperate Palaeohydrology*. John Wiley & Sons, Inc. London. pp. 189-215.

Lane, E.W. 1955. *A Study of the Shape of Channels Formed by Natural Streams in Erodible Material*. M.R.D. Sediments Series No. 9. U.S. Army Corps of Engineers, Engineering Division, Missouri River District. Omaha, Nebraska.

Leopold, L.B., and J.P. Miller. 1954. *A Postglacial Chronology for Some Alluvial Valleys in Wyoming.* U.S. Geological Survey Water-Supply Paper 1261.

Martin, C. 1992. The response of fluvial system to climatic change: An example from the central Great Plain. *Physical Geography* 13(2):101-114.

May, D. 1992. Lake Holocene valley-bottom aggradation and erosion in the South Loup river valley, Nebraska. *Physical Geography* 13(2):115-132.

Murphy, P.J., and T.J. Randle. 2001a. *Platte River Channel: History and Restoration.* U.S. Bureau of Reclamation and U.S. Fish and Wildlife Service. Draft. January.

Murphy, P.J., and T.J. Randle. 2001b. *Platte River Sediment Transport and Riparian Vegetation Model.* U.S. Bureau of Reclamation and U.S. Fish and Wildlife Service. Draft. January.

Osterkamp, W.R., Fenton, M.M., Gustavson, T.C., Hadley, R.F., Holliday, V.T., Morrison, R.B., and T.J. Toy. 1987. Great Plains, *in* Graf, W.L. (ed.). *Geomorphic Systems of North America.* Geological Society of America Centennial Special Volume No. 2. Boulder, Colorado.

Patton, P.C., and S.A. Schumm. 1975. Gully erosion in northwestern Colorado – A threshold problem. *Geology* 3(2):88-90.

Rinaldo, A., Dietrich, W.E., Rigon, R., Vogel, G.K., and I. Rodriguez-Iturbe. 1995. Geomorphological signatures of varying climate. *Nature* 374:633-635.

Ritter, D.F. 1978. *Process Geomorphology*. Wm. C. Brown Company, Publishers. Dubuque, Iowa.

Ruhe, R.V. 1975 *Geomorphology – Geomorphic Processes and Surficial Geology*. Houghton Miflin Company. Boston, Massachusetts.

Schumm, S.A. 1968. *River Adjustment to Altered Hydrologic Regimen -- Murrumbidgee River and Paleochannels, Australia.* U.S. Geological Survey Professional Paper 598.

Schumm, S.A. 1974. Geomorphic Thresholds and Complex Response of Drainage Systems, *in* M. Morisawa, (ed.). *Fluvial Geomorphology: Proceedings of the Fourth Annual Geomorphology Symposia Series, Binghamton, New York.* George Allen & Unwin, Inc. Boston, Massachusetts. pp. 299-310.

Schumm, S.A. 1980. Some Applications of the Concept of Geomorphic Thresholds, *in* Coates, D.R. and J.I. Vitek (eds.) *Thresholds in Geomorphology*. G. Allen and Unwin Publishers, Ltd. London. pp. 473-485.

Schumm, S.A. 1981. Evolution and Response of the Fluvial System – Sedimentologic Implications, in Society of Economic Paleontologists and Mineralogists Special Publication No 31. pp. 19-29.

Schumm, S.A., and R.W. Lichty. 1963. *Channel Widening and Flood-Plain Construction Along Cimarron River in Southwestern Kansas.* U.S. Geological Survey Professional Paper 352-D.

Smith, N.D. 1970. The braided stream depositional environment: Comparison of the Platte River with some Silurian clastic rocks, north-central Appalachians. *Bulletin of the Geological Society of America* 81(10):2993-3014.

Smith, N.D. 1971. Transverse bars and braiding in the lower Platte River, Nebraska. *Bulletin of the Geological Society of America* 82(12):3407-3420.

Starkel, L. 1991a. Characteristics of the Temperate Zone and Fluvial Paleohydrology, *in* Starkel, L., Gregory, K.J., and J.B. Thornes (eds.) *Temperate Palaeohydrology*. John Wiley & Sons, Inc. London. pp. 1-12.

Starkel, L. 1991b. Long-Distance Correlation of Fluvial Events in the Temperate Zone, *in* Starkel, L., Gregory, K.J., and J.B. Thornes (eds.) *Temperate Palaeohydrology*. John Wiley & Sons, Inc. London. pp. 473-495.

Starkel, L. 1991c. The Vistula River Valley – A Case Study for Central Europe, *in* Starkel, L., Gregory, K.J., and J.B. Thornes (eds.) *Temperate Palaeohydrology*. John Wiley & Sons, Inc. London. pp. 171-188.

Summerfield, M.A. 1991. *Global Geomorphology*. Longman Scientifica and Technical Publishers, Ltd. Harlow, Essex, Great Britain.

Sundborg, A., and M. Jansson. 1991. Hydrology of Rivers and River Regimes, *in* Starkel, L., Gregory, K.J., and J.B. Thornes (eds.) *Temperate Palaeohydrology*. John Wiley & Sons, Inc. London. pp. 13-29.

Thornbury, W.D. 1954. *Principles of Geomorphology*. John Wiley & Sons, Inc. New York, New York.

Thornes, J.B., and K.J. Gregory. 1991. Unfinished Business – A Continuing Agenda, in Starkel, L., Gregory, K.J., and J.B. Thornes (eds.) *Temperate Palaeohydrology*. John Wiley & Sons, Inc. London. pp. 521-536.

Wenzel, L.K., Cady, R.C., and H.A. Waite. 1946. *Geology and Ground-Water Resources of Scotts Bluff County, Nebraska*. U.S. Geological Survey Water-Supply Paper 943.

Williams, G.P. 1978. *The Case of the Shrinking Channels - the North Platte and Platte Rivers in Nebraska*. Geological Survey Circular 781. U.S. Department of the Interior. United States Government Printing Office. Washington D.C.

Wohl, E.E. 2001. *Virtual Rivers – Lessons from the Mountain Rivers of the Colorado Front Range*. Yale University Press. New Haven, Connecticut.

APPENDIX A

SUMMARY OF GEOMORPHIC CONCEPTS AND PROCESSES

Landforms represent the results of some interaction between driving forces and resisting forces (this discussion is condensed from Ritter, 1978). Driving forces in geomorphology include climate, gravity, and other forces generated inside the earth. Resistance to driving forces is provided by the geologic framework. Driving forces and resisting forces interact via process mechanisms, which are the methods by which one thing is produced from something else, or are the vehicles by which a quantity of one system is transferred into, and participates in, the mechanics of another system (e.g., erosion and movement of sediment in a fluvial system).

All natural fluvial systems exist in a state of *dynamic equilibrium* – that is, all landforms within a fluvial system (such as a drainage basin) are mutually adjusted to reflect an equilibrium condition between the framework (geology, soils) and the prevailing processes. The equilibrium landforms will last as long as the controlling factors are not changed, because all elements of the surface will downwaste at the same rate. Thus, in the ideal case, landforms become independent of time. Changes do occur, but only in response to altered process or geology. Because a new equilibrium form will be established rapidly (in the sense of geologic time) whenever changes occur, most topography should be adjusted to present conditions. However, geomorphic responses to altered conditions do not always proceed at the same rate.

Landforms may be considered as part of an open system, in which energy and mass are constantly supplied and removed. Losses and gains of energy or mass are kept in a steady state by continuous adjustment of forms within the system. Landforms serve as regulatory agents to balance gains and losses. For example, a drainage basin is a system composed of many parts (slopes, valleys, floodplains, soils, rivers, etc.), each of which can logically be considered as a separate subsystem. The subsystems may contain even smaller parts (soil profiles, stream channel cross-sections), which themselves function as identifiable systems. The Earth's surface thus consists of a hierarchy of systems, each in instantaneous equilibrium.

Each system or subsystem can be defined by measurable variables or parameters (velocity, slope angle, grain-size distribution) which, taken together, indicate the character of the system at the time of measurement. Under equilibrium conditions, these variables are totally adjusted to each other and to the external forces that provide or remove energy and mass. Realistically, exact equilibrium may never be attained in the steady state because each system responds to continuously changing external variables (variables outside the system boundaries), and most systems are interdependent. That is, changes in external variables cause reactions within systems, and a change of parameters in one system may require adjustments throughout the entire hierarchy. For example, assume that a long-term cooling in climate (an external force) causes accumulation of ice near the poles, at the expense of water in the world ocean. The resulting decline in sea level causes entrenchment to begin in the lower reaches of major rivers. The downcutting may gradually propagate upstream, causing a similar erosional response in each tributary basin. Slopes are re-graded to new elevations. Groundwater tables are lowered. In regions underlain by limestone, a lowered water table may cause a series of solution features, and eventually the surface may collapse. In short, one external change initiates a chain reaction of adjustments in the interrelated subsystems.

Even if external factors could be held constant forever (they cannot), some alteration of the system must occur with time. Because mass, in the form of sediment and dissolved solids, is continually being removed from regional systems, some changes in form are inevitable. However, changes in landforms (like all systems) reflect the net effects of external forces on the defining variables. Each parameter within a system responds to the external controls at a different rate, and in a different way.

Any concept proposing equilibrium inherently implies a contrasting state of disequilibrium. If variations in external factors demand a response within the system, there must be a period of readjustment during which process and form are out of equilibrium. Landslides, subsidence, and gully erosion are examples of disequilibrium generated when the variables of process and/or geology are altered so they can no longer maintain a balanced relationship. They represent events that occur as the interrelated systems move to re-establish a new equilibrium condition. Such events can happen suddenly or can proceed toward equilibrium over a long period of time, depending on how great the disequilibrium is, and how much energy is involved.

The best-known thresholds in hydraulics are described by the Froude and Reynolds numbers, which define the conditions at which flow becomes supercritical or turbulent. If a moving liquid is very close to one of the threshold conditions described by the Froude or Reynolds number, only slight changes in flow velocity will cause an exceedance of the threshold, which can lead immediately to spectacular changes in the characteristics of the liquid system. In examples of this type, an <u>external</u> variable changes progressively, thereby triggering abrupt changes within the affected system (Schumm, 1974). Responses of a system to an external influence occur at what are referred to as *extrinsic thresholds* – that is, the threshold exists within the system, but it will not be crossed and change will not occur without the influence of an external variable.

Thresholds also may be exceeded when input is relatively constant – that is, the external variables remain relatively constant, yet a progressive change of the system itself renders it unstable, and some type of more-abrupt change occurs. In many cases of this type, the threshold represents a deterioration of resistance, rather than an increase in driving forces. For example, a region characterized by periodic heavy rains may have stable slopes for a long time, but continuous freeze-thaw cycles or other soil-forming processes may gradually reduce the cohesion of the slope material. Eventually, one storm, no more severe than thousands that have preceded it, triggers slope failure. Following failure of the slope, a long period of preparation ensues before failure can occur again. Such *intrinsic thresholds* probably are common in natural systems (Schumm, 1974).

These types of geomorphic thresholds may be inherent in the development of landforms. Until the system has evolved to a threshold condition, adjustment of the system will not occur. It is when thresholds are exceeded that things begin to happen, and many apparently deleterious events may be nothing more than nature’s way of reestablishing a geomorphic equilibrium. Considerable experimental work and numerous field observations support the concept of geomorphic thresholds, which has been used to explain the development of arroyos, channel aggradation and degradation, and variations in channel patterns in particular fluvial systems (Schumm, 1974). However, it may not always be clear whether the system is responding to geomorphic thresholds or to an external influence.

Implicit in the concept of threshold are the ingredients of cause and effect in nature, a dual relationship that is basic to geologic thinking. Cause and effect are essential components of geologic history, where the effects are commonly preserved in rocks, sediments, or landforms, and the cause becomes the object of investigation and interpretation.

Braided channels are characterized by several factors – a steep channel gradient, a large proportion of sediment being transported as bed load, and readily-erodible bank material which enables channels to shift with relative ease (Summerfield, 1991).

If a channel contains islands whose width is greater than three times the total width of wetted channel at mean discharge, the stream is described as *anabranching*. The anabranches, or individual channels, are more widely and distinctly separated and more fixed in position than the channels of a braided stream. An anabranch does not necessarily transmit flow at normal stage, but is an active and well-defined channel, not blocked by vegetation (Brice, 1982).

A third type of channel pattern is termed *anastomosing*. Anastomosing channels consist of distributaries which branch and rejoin, superficially resembling a braided pattern. Braided channels, however, are single-channel forms in which the flow is diverted around obstructions in the channel itself, whereas anastomosing patterns consist of discrete, interconnected channels which are separated by bedrock or by expanses of stable alluvium. While braided channels are primarily depositional forms, anastomosing channels are essentially erosional in nature, since material between the channels is resistant to transport, except by exceptional flows (Summerfield, 1991).

Four major fluvial types – equiwidth with point bars; wide-bend with point bars; braided with point bars; and braided, no point bars – can be distinguished primarily on the basis of variability of channel width, nature of point bars, and degree of braiding (Figure A1-1, after Brice [1982]). Any of these stream types may be anabranched, locally or generally (Brice, 1982). A stream is unlikely to be of the same type throughout its length. Most streams change pattern in a downstream direction, and some change from place to place along their courses. For example, any meandering stream is likely to include some locally straight or nearly straight reaches.

In many circumstances, the landforms comprising current topography are an expression not only of current conditions – the interaction between the driving forces (climate, tectonics) and the geologic framework – but also contain relict features that resulted from past conditions (Brice, 1966; Schumm, 1968; ibid., 1974; Rinaldo *et al.*, 1995). In the Great Plains as in much of the Northern Hemisphere, climate is the primary force acting to produce and shape landforms from the geologic framework (Wenzel *et al.*, 1946; Leopold and Miller, 1954; Brakenridge, 1980; Sundborg and Jansson, 1991). Changes in the hydrologic regime and sediment load in areas formerly affected by glacial climatic conditions caused a shift from bedload to mixed-load rivers, and then to suspended-load rivers (Schumm, 1981). These paleogeographical changes in the temperate zone were superimposed on river valleys, which yet retain some characteristics associated with past conditions.

Schumm (1974) examined the occurrence of geomorphic threshold conditions in natural systems, and found that in a complex system, one event can trigger a complex morphologic reaction as the components of the system respond progressively to change. Schumm (1974) felt that this observation provided an explanation of the complexities of alluvial chronologies, and suggested that infrequently-occurring events, though performing little of the total work within a drainage system, may in fact be the catalysts that cause the crossing of geomorphic thresholds and the triggering of complex sequences of events that will produce significant modifications to landscapes.

In Schumm's evaluation, landscape discontinuities, or what appear to be abrupt changes in the morphologic evolution of drainage systems, are not always a consequence of external influences; and the evolution of landforms, at least in semiarid and arid regions, need not be progressive in the sense of constant and orderly development – in fact, change may occur progressively and also by rapid shifts from one state of dynamic equilibrium to a new one. It appeared very possible to Schumm (1974) that, without the influence of external variables and over long time spans, progressive development of a landscape will be interrupted by periods of rapid readjustment, as geomorphic thresholds (extrinsic and intrinsic) are exceeded. Readjustment of the system will be complex as morphology and sediment yields change with time. The timing of these changes may be related to events of low frequency but large magnitude; but such events may only be the catalyst that induces temporary change at a particular time, with eventual recovery to the morphology prior to the event. The existence of geomorphic thresholds, and the complex feedback mechanisms of geomorphic systems, permit events of moderate magnitude to play a major role in landscape evolution. According to Schumm (1974), these concepts are not in conflict with the concept of dynamic equilibrium, but rather supplement it.

Schumm (1980) also found that in general, stream gradients and floodplain configurations do not change progressively (in linear fashion) through time; rather, relatively brief periods of instability and incision are separated by long periods of relative stability, when the system is in equilibrium and "at grade". Therefore, a landscape having a very complex evolutionary history may be the norm, in the geomorphic sense.

Patton and Schumm (1975) examined the causal factors of development of gullies and arroyos in stream valleys in northwestern Colorado, and determined that the slope along the longitudinal axes of valleys in the region represented an intrinsic threshold. If the slope exceeded some critical value in a localized segment of a valley, a discontinuous gully was likely to develop in that segment. Patton and Schumm (1975) considered the exceedance of a critical slope value to represent a condition of valley instability, which could result in rapid alteration of the drainage basin by erosion.

Chang (1985) examined the regime geometry and channel patterns of sand-bed rivers, using an energy approach, and identified four general morphologic types of streams, on the basis of distinct characteristics related to morphologic balance achieved between flow resistance and stream power. The four morphologic types – equiwidth point-bar streams, straight braided streams, braided point-bar and wide-bend point-bar streams, and steep braided streams – are separated by energy thresholds that result from differences in the stream energy gradient and bankfull discharge characteristics of each stream type (Figure

A1-3). According to Chang (1985), the formation of braided channels reflects in part a river's adjustment in expenditure of stream power, which in turn affects the channels stability. For streams having the typical longitudinal riffle-and-pool configuration, a non-braided channel is more stable for "pool" sections, but the braided and unbraided channel types are approximately equal in stability in the "riffle" sections. Chang (1985) noted that because non-braided reaches appear to be more stable than braided reaches under most circumstances, wide streams in reality usually are braided as a consequence of high sediment loads, bank erosion, and physical heterogeneities, rather than representing a stable configuration that has resulted from lowered expenditure of stream power.

Chang (1986) also used energy and stream power to develop a method of predicting a river channel's adjustments of equilibrium to changing conditions of discharge, slope, sediment size, and channel width and depth. The evolution of fluvial systems was compared with a feedback system in which the effect (river channel formation) and the cause (stream discharge) are inter-related and interdependent. Chang (1986) found that streams having a braided configuration were most sensitive to changes in slope or discharge or both, so that a change in slope or discharge could be associated with large changes in channel width. Rating curves on the Platte reveal that the entire range of flows normally experienced occur over a few feet of vertical stage.

Rinaldo *et al.* (1995) developed a mathematical model of geomorphic processes and used the model to simulate the development and evolution of various landforms under conditions corresponding to tectonic uplift and climatic variability. On the basis of the results of a series of numerical simulations, Rinaldo *et al.* (1995) concluded that significant time lags can occur between climate change and adjustment of the resulting landforms to changing conditions. In particular, extreme climate excursions that cause accelerated threshold-limited erosion seem likely to occur and to leave very long-lived morphological evidence.

In hydrology, changes in state usually are thought to indicate changes in the controlling variables, and most commonly are taken to indicate extrinsic changes, such as changes in the hydrologic regime. In turn, these may be attributed, for example, to changes in vegetation cover, snowmelt, or precipitation. Various authors have demonstrated that changes in state also may come about without alteration of the external conditions as the controlling variables pass through internal (structural or intrinsic) thresholds in the systems (Schumm, 1974; Chang, 1986). The prevailing view is that under conditions of dynamic equilibrium, river channels adjust the values of state variables (which describe the condition of the fluvial system) more or less continuously to the slope, and to sediment and water supplied to the channel (Thornes and Gregory, 1991).

Fluvial terraces are evidence for naturally-occurring episodes of channel degradation, and most alluvial streams, including streams in the Great Plains, are bordered by terraces. A terrace is an abandoned floodplain, the surface of which is rarely inundated because the stream channel has gradually cut below it. Most terraces probably are formed at rates of degradation too slow to be observed at human time scales; nevertheless, low terraces along a stream are noteworthy, because they suggest that the stream has been vertically unstable in the past, and that such instability may readily be induced (Brice, 1982). Floodplain deposits are evidence for naturally-occurring episodes of channel aggradation;

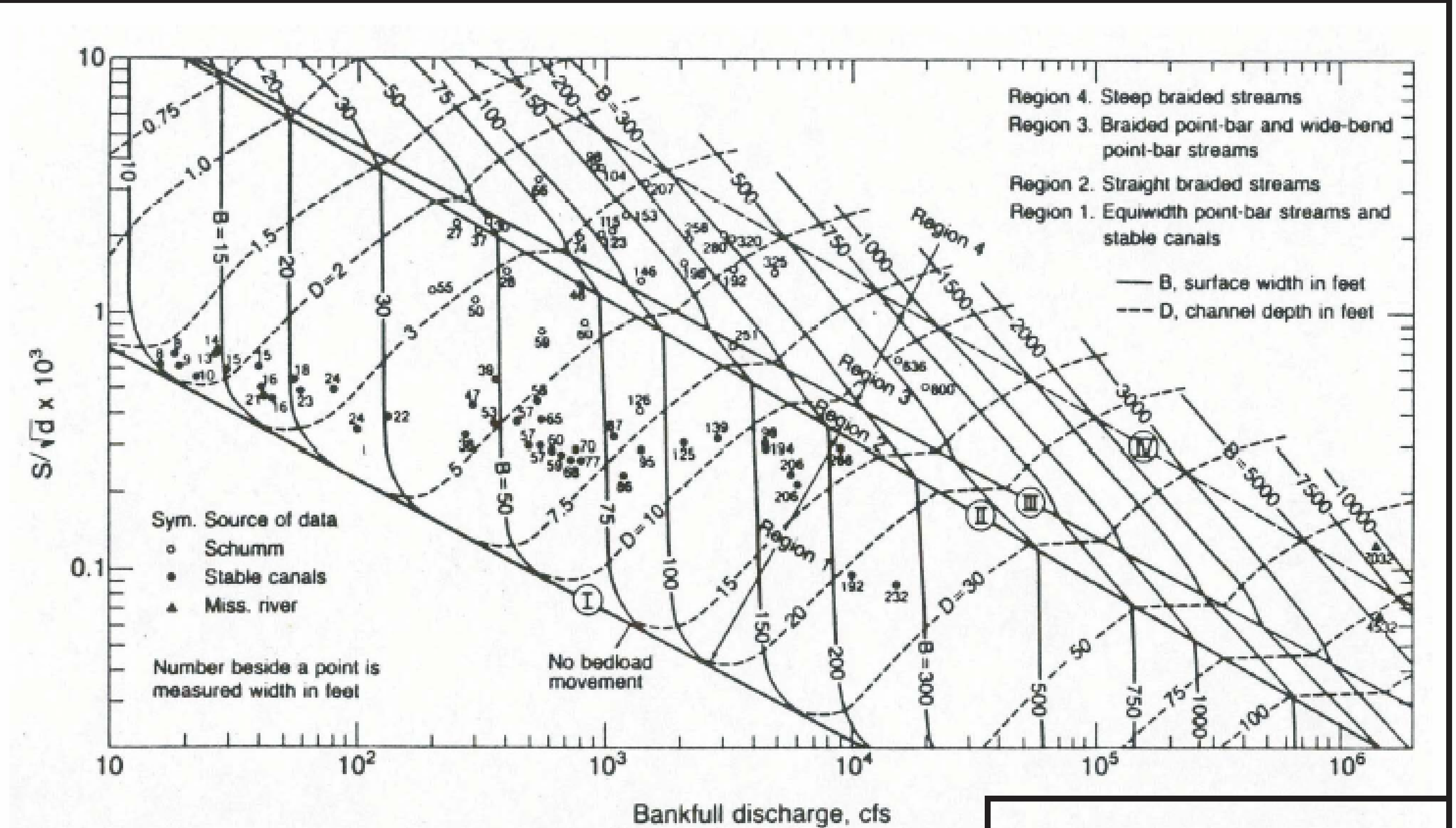

FIGURE A1-3

REGIME CHANNEL GEOMETRY FOR SAND-BED RIVERS

Platte River Channel Dynamics Study

PARSONS
Denver, Colorado

After Chang (1985).

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Figure A1-3 Regime Channel Geometry for Sand-Bed Rivers

and depending upon the geologic history and geomorphology of a particular region, deposits associated with terraces also may record periods of aggradation.

Within a complex natural system, a single event or change in condition can trigger a complex reaction (morphologic and/or stratigraphic) as the components of the system respond progressively to change (Schumm, 1974). This principle provides an explanation of the complexities of alluvial morphologies and chronologies, and suggests that an infrequent event, although performing little of the total work within a drainage system, may in fact be the catalyst that causes a fluvial system to cross a geomorphic threshold, with a consequent triggering of a complex sequence of events leading to significant landscape modification.

OTHER STUDIES OF SIGNIFICANT GEOMORPHOLOGIC CHANGES

Schumm and Lichty (1963) used historical records and modern channel measurements and observations to evaluate morphologic changes in the channel of the Cimarron River in Kansas during the period 1874 to 1960. During the period 1874 – 1914, the Cimarron River apparently had the planform of a meandering point-bar stream, with a channel averaging approximately 50 feet in width through 6 counties of southwestern Kansas. The floodplain of the river was vegetated, and the morphology of the river in general was relatively stable. Beginning in 1914, and continuing intermittently through 1942, the channel of the Cimarron River widened, until almost all of the floodplain had been removed. The channel widening apparently began during a major flood event (a threshold excursion) that occurred in the spring of 1914. This flood was the greatest of record on the Cimarron River; however, other flood events that occurred between 1914 and 1942 were of sufficient magnitude to further widen the channel, until it reached its greatest average width of about 1,150 feet, and the former floodplain was completely removed.

The new floodplain is composed of a complex of coalesced islands, abandoned branch channels, and areas of floodplain constructed adjacent to the low-water channel. Large parts of the wide channel were not occupied by low-water flows, and these areas became sites of vegetation growth. The increased plant cover reduced flow velocities over these areas and promoted additional sediment deposition. The authors concluded that floods in semi-arid and arid regions may be tremendously destructive to river channels and floodplains (Schumm and Lichty, 1963). This destruction by floods may be a characteristic of erosive processes in drier regions where climatic fluctuations are common, and the streams are ephemeral or carry very low flows during long periods of time. Often these streams cannot adjust as readily as streams in more humid environments to a change in stream regimen or climatic fluctuation. Large floods may trigger an adjustment by initiating periods of severe erosion or deposition, and as a result, large changes in fluvial morphology can occur in relatively short periods of time. However, in fluvial streams this change normally reverts to the pre-flood condition because flows cannot support the maintenance of the enlarged channel.

The geologic history of the Murrumbidgee River, in a relatively arid part of New South Wales, Australia, was deduced by Schumm (1968), who found that traces of old aggraded and abandoned river channels or paleochannels were present on the floodplain of the modern river and on the surface of the bordering plain. At least two generations of the ancestral river preceded the modern river. The modern Murrumbidgee River has a meandering planform, is relatively narrow and deep, and transports relatively small quantities of sediment. In contrast, the earliest paleoriver of which there is evidence on the Murrumbidgee plain was relatively straight, wide, and shallow. Later, the paleoriver came to more nearly resemble the modern river in planform, but was much larger than the modern river. Schumm (1968) ascribes these dramatic changes in fluvial morphology to the effects of climate changes on the hydrologic regime of the drainage basin. The earliest channels (wide, straight, and braided) appear to have been developed during a relatively drier period, when a reduction in vegetation cover would have allowed additional sediment to be moved from the floodplain, and less-frequent flood events, but possibly of greater magnitude than at present, would have transported relatively large quantities of sediment for short periods of time. A later, more humid climatic regime, corresponding to a threshold excursion, would have promoted vegetation growth, reducing the quantities of sediment available for transport, while simultaneously increasing the mean annual discharge. A climate of this type would have resulted in the development of a narrower, deeper channel having a more meandering planform. In contrast to the effects of past climatic change, anthropogenic regulation of the river in modern times, through construction of water diversion and retention structures, has caused relatively little change in the planform and dimensions of the channel, and the changes that have occurred have been neither progressive nor systematic. Schumm (1968) concluded that the modern channel of the Murrumbidgee River, though somewhat influenced by diversion and control structures, has responded primarily to climatic threshold excursions and erosional conditions in the drainage basin.

The proximate causes and modes of evolution of a number of fluvial systems were evaluated in conjunction with a project of worldwide scope -- the International Geological Correlation Programme (IGCP) Project 158 (Starkel, 1991a). For example, the Vistula River in central Europe had a narrow, anastomosing planform at the end of the last Ice Age (Starkel, 1991c). By about 13,000 yr BP, the upper reaches of the Vistula had become meandering, and the lower reaches were braided, primarily as a consequence of the dramatic climatic changes (a threshold event) that occurred following the retreat of glacial ice. Subsequently, the river channel became straighter, and a cycle of downcutting was initiated. Most recently (within the past several hundred years), aggradation of the channel has occurred, accompanied by a buildup of floodplains and valley floors by channel deposits.

The Warta River in the lowlands of Poland was braided at the end of Ice Age time (Kozarski, 1991), but evolved in successive stages to the meandering point-bar planform of modern times. This evolution probably was a consequence of changes in climatic conditions, accompanied by a concomitant increase in vegetation within the drainage basin, which stabilized soils and reduced the amount of sediment potentially available for transport. This general pattern of evolution was followed by most rivers during the transition from Ice-Age to modern conditions, and fluvial metamorphosis has continued in recent times with more subtle changes in flow characteristics, sediment types and loads (Baker, 1991). Cyclic changes in hydrologic regime occurred over similar periods throughout the temperate zone.

TECHNICAL MEMORANDUM

RESULTS OF INVESTIGATION A2 - EVALUATION OF HISTORICAL AND CURRENT SEDIMENT SUPPLIES

PLATTE RIVER CHANNEL DYNAMICS INVESTIGATION

Prepared For

States of Colorado, Nebraska, and Wyoming

May 2003

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TECHNICAL MEMORANDUM

INVESTIGATION A2 - EVALUATION OF HISTORICAL AND CURRENT SEDIMENT SUPPLIES

PREFACE

This report describes the procedures used in and results of an evaluation of the literature on geomorphic thresholds and the current morphology and stability of the Platte River channel. The investigation addressees a number of technical issues regarding this subject which had been identified by the sponsors as needing detailed examination to allow them to make scientifically-based decisions regarding the Cooperative Agreement (CA) work products.

This document describes only the data collected, analyses made, and scientifically-supportable findings regarding the issues, written in a manner which generally follows the guidelines of professional journals of the respective authors' technical expertise. The relevance of the findings to the specific issues confronting the sponsors is discussed in each task memorandum, but only as far as the data and results are deemed by the author(s) to be scientifically supportable in resolving or illuminating the issue.

ISSUES AND PURPOSES OF INVESTIGATIONS

The technical evaluations completed by the Parsons team were conducted as a series of 14 complementary investigations divided into four categories that would address general issues identified by the three states. The following issue categories were identified:

- A: Questions Regarding Channel Narrowing or Deepening
- B: Questions Regarding Sediment Transport
- C: Questions Regarding Vegetative Encroachment
- D: Questions Regarding Macro-Historic Natural Variability

This Technical Memorandum describes the results of Task A2, the second of five tasks comprising Issue Category "A."

The purpose of Task A2 is to conduct an analysis of historical and current sediment supplies in the Platte River, and identify changes in the quantity and nature of the supplies.

INTRODUCTION

The Platte River is an alluvial system and as such its morphology is influenced by its sediment transport processes. The Platte River Basin extends from the high peaks of the

Rocky Mountains on the west and flows through steep rocky canyons down to the plains. On the plains, the river flows through alluvial material consisting primarily of sand with some gravel and small amounts of finer material. The Platte River is affected by various factors primarily in the plains region because, at least in recent times, an excess of sediment supply from the mountains is not as abundant (the erosion/glaciation processes appears to have slowed significantly). On the plains, sediment is introduced to the river through normal riverine transport processes and is, or has been, supplemented via Aeolian processes as affected by a variety of historic factors (including buffalo, fire, agriculture, drought, etc.). Thus, based on Schumm's (1977) idealized fluvial system, the Platte River extends from what is known as the sediment supply zone in the mountains (now limited by geologic stability/control and some reservoirs), through the sediment transfer zone of the alluvial plain.

One of the key questions to be addressed in understanding geomorphic and vegetation issues on the Platte River is the extent to which changes in sediment supply impact channel morphology and vegetation. Changes or imbalances in sediment supply can result in aggradation or degradation, which affects channel morphology (profile and shape of the channel) and the response of vegetation to these changes or the response of the river to vegetation expansion. Leopold, et al. (1964) characterize this process as follows:

> The shape of the cross-section of a river channel at any location is a function of the flow, the quantity and character of the sediment in movement through the section, and the character and composition of the materials making up the bed and banks of the channel. In nature, the last will usually include vegetation.

The issue of the effect of sediment supplies on channel morphology and vegetation can be separated into three main questions. These are (1) have there been changes in the quantity and character of sediment supplies to the Platte, (2) how have the channel geometry and presence of vegetation changed, and (3) how has any channel geometry change subsequently affected vegetation, or vice versa? Critical to the latter two is whether vegetative expansion caused the morphologic change, or whether it was the river's response to changes in the morphology. The evaluation of historical and current sediment supplies in this report focuses first on the availability of data and then on these fundamental questions.

EVALUATION OF HISTORICAL AND CURRENT SEDIMENT SUPPLIES

Several key pieces of information have been compiled by others regarding historical and current sediment supplies on the Platte River (Murphy and Randle, 2001a). The initial focus of this investigation is on the availability of sediment transport data, followed by an evaluation of the relationship of changes in sediment supply and transport mechanisms to changes in morphology and vegetation.

Suspended and Bedload Transport Measurements

No known sediment transport data were collected in the Platte River Basin prior to about 1930, nor was there a period of significant Aeolian transport when concurrent sediment transport data were collected (except to some degree during the drought of the 1930s). Agricultural activities became significant in the late 1800s and 1900s which, along with other general development, undoubtedly changed supplies of sediment to the river. It could only be speculative as to the potential quantitative significance of historic drought, disturbances (buffalo, fires, pioneers, timber removal), and other sediment supply mechanisms such as wind-blown transport on the form and response of the river.

Had some combination of factors resulted in an increased sediment supply, it would be expected that the river would have a wide, braided form (wider than may be normally expected within some dynamic range). This transitional form existed during the late 1800s and in many segments into and through much of the 1900s. Changes that occurred during the 1800s significantly increased supplies of sediment due to disturbances such as buffalo, fire, drought and wind-blown effects.

The lack of historic sediment transport data limits the possibility of quantifying and better understanding historic geomorphic processes. Even current data on sediment properties and sediment transport are very limited, but within limits, the data can be used to improve the understanding and quantification of sediment-transport-related processes that could be used to replicate current characteristics of the river and extrapolate them to assess futures. Current channel conditions are significantly different from historic conditions, most notably based on the expansion of vegetation. Some of the changes occurred after 1930; thus, it is appropriate to focus the evaluation of sediment supply on data and information that represent transitional (leading up to current) and current characteristics of the Platte River.

A complete assessment of available data on gradations of bed sediment samples and trends of changes in sediment properties is provided in the Task A3 document. The available sediment transport data for the Platte River and principal tributaries were primarily collected in the early 1930s, with another focus of effort in the 1970s-1980s. Some general sediment data collection also occurred over the decades from the 1940s through the present, but as noted in the Task A3 document, significant gaps exist. Data from a variety of sources were obtained and compiled as part of the effort in preparing the Task A2 and A3 reports.

Very little measurements of bedload material transport have been collected on the Platte River system. Most of the data collected on sediment-in-transport was suspended sediment transport data, with only limited sampling of rates of bed material transport. Only about 50 measurements were discovered on the North Platte, South Platte, and Platte Rivers combined. Suspended sediment data show that, in general, a relatively high percentage of this load consists of silt and clay sized particles (<0.0625mm).

As shown in the Task A3 report, bed material data collected in 1931 revealed that silt and clay sized particles (<0.0625mm) were not found in any appreciable quantities in the bed (i.e., less than 3 percent by weight). Recent data show that an even smaller percentage of the bed consists of silt and clay sized particles.

In the 1980s, both the USBR and Simons & Associates concluded that the bed material is predominantly sand, since only a small percentage of the bed is finer than sand. They also found that changes or imbalances in bed material load (transport of sediment sizes found in the bed) were much more important than trends or imbalances in finer material such as is predominantly carried in suspension.. Such is the case since imbalances in bed material sand translate into changes in bed elevation and corresponding change in cross-section geometry, whereas washload consisting of silt and clay, which is not found in appreciable quantities in the bed, do not translate into significant channel geometry changes as such sizes of sediment are typically transported downstream in suspension.

As a result, there is very little available sediment transport data that is directly pertinent to correlating changes in transport with any changes in channel geometry or geomorphic responses of the Platte River.

Sediment Inflow Estimates

In evaluating sediment transport modeling, including SEDVEG, it is important to understand how estimates of sediment supply rates are utilized in the modeling process since an error in an upstream boundary condition such as the incoming sediment supply can significantly affect model results. The amount of upstream supply is adjusted by a parameter related to channel width that can create a wide range of sediment supply from a condition of under-supply and subsequent degradation to an over-supply and subsequent tendency towards aggradation (at least in the upstream reaches).

The only available estimate of pre-development sediment supply is based on total sediment load, including suspended and bedload, is by Simons & Associates (2000). It comes in the form of an average annual amount of 7.8 million tons per year and was characterized as a “crude” value. It is based on available sediment transport data from the 1900s as related to flow and reservoir sedimentation data (a summary of these data are found in Simons & Associates, 1990 and 2000). This estimate does not include any potential additional component of sediment supply that could have occurred as a result of Aeolian transport on a watershed disturbed by fire, buffalo, or other factors.

To our knowledge, there is no quantitative estimate of the effect of such factors on sediment supply but it is possible that they could have had a substantial influence on pre-development sediment supply, assuming that disturbed conditions could have existed in the 1800s or earlier. Pre-development sand inflow (representing bed material load without washload since, as discussed above, washload does not play a very important role in channel geometry processes on the Platte River) presumably averaged about 12.2 million tons per year **(**Murphy and Randle, 2001b**)**. This value is (12.2 – 7.8)/7.8 or about 56% higher than the Simons & Associates estimate of sediment inflow. Neither is being offered here as definitive, but it would be reasonable to expect that the initial estimate of 7.8 million tons per year may be low considering the potential effect of historic disturbance factors with the 12.2 million tons per year estimate possibly representing conditions that include such disturbance factors.

An estimate of current sediment supply (total load) was made (Simons & Associates, 1990 and 2000) of about 1 million tons per year. A similar transition calibration over a

104-year period ending in 1969 (Murphy and Randle, 2001b) produced an average inflow of about 1.2 million tons per year.

The EIS team utilized some of the sediment transport relationships reported in Simons & Associates (1990 and 2000) to compute potential aggradation or degradation over various time periods (Murphy and Randle, 2001b). This was done to provide an overall perspective on general sediment transport. It was also developed in order to compare with transport rates input to and predicted by the SEDVEG sediment transport model.

The SEDVEG sediment transport model computes its own upstream sediment supply based on Yang's equation for total sand load which equates to the capacity of the flow to transport sediment (focusing therefore on the most important component of the total sediment load relevant to changes in the channel through aggradation or degradation processes). The 4/7/01 version of output described in Murphy and Randle (2001b) was set up with an over-supply pre-development condition for the supply reach, resulting in significant aggradation occurring in the upstream reach of the model (just below the supply reach).

It is not possible to quantitatively and definitively determine whether or not the historical sediment supply exceeded Yang's sediment transport capacity due to lack of quantitative sediment transport data. The probability that such was the case in the pre-development time period is quite high, however, based on the braided character of the river (which is often attributed to an overload of sediment), the description of the river as being muddy, turbid and transporting heavy sediment loads by travelers and other early observers of the river, and the possibility of potentially large sediment influx from Aeolian processes and other disturbances (buffalo, fire, etc.) acting on watershed areas during a period of very significant drought in the mid- to late 1800s (see the D1&D2 Task report). Regarding the current condition based on the existence of a number of mainstem dams on the North Platte, diversions with dredging operations, locations of known scour of the riverbed, and observations of armoring where little or no bedload transport is occurring (at least periodically or temporarily); it can be concluded that the current sediment supply is some amount less than sediment transport capacity.

Assuming that the above estimates of pre-development and current Platte River sediment supply are reasonably accurate, the ratio of sediment transport to flow in pre-development conditions is 2.8 (7.8 million tons/2.8 million acre-feet). Under current conditions, the same ratio is 0.7 (1 million tons/1.4 million acre-feet). Thus, there is an apparent four-fold decrease in the sediment-to-flow ratio. This would tend to support the contention that the Platte River under current conditions is likely to be in an under-supplied condition with respect to sediment, and it could be that it is at, or has passed through, one of the thresholds described in the A1 and D1&D2 Task reports. However, the affect of this condition over the long-term or potential need for increased supply has not been quantified and determined due to the lack of necessary and sufficient data.

Channel Aggradation and Degradation

The EIS team has reasoned that there has been some incision of the bed of the Platte River (Murphy and Randle, 2001a and 2001b). This is partially based on analysis of data at stream gages (Williams, 1978 and USGS, 1983) as well as sediment budget concepts. Both the Williams and USGS analyses show changes in stage or bed elevation by comparing rating curves or other similar data at stream gages over time. Most, if not all of the stream gages are located at or very near bridges, which have artificially constricted the flow. Constrictions cause contraction scour as noted in Simons & Associates (2000). These data are therefore considered biased (tending to show degradation) and probably do not represent the general condition of the river. As shown in the Task A3 report, considerable variation in the thalweg elevation occurs at these bridges for moderate differences in flow rates during the same season. Even with the built-in bias towards degradation, the channel changes described by the EIS team are not large (see Appendix A). Simons & Associates (2000) noted that Williams himself did not consider his analysis to be very accurate.

As documented by Williams, channel bed fluctuations have been on the order of a few tenths of a meter or about a foot or two. The largest amount of degradation he noted occurred at Cozad and was 1.5 m, or about 5 feet. He mentions fluctuating levels of aggradation, as well as degradation. At most stations, Williams states that the bed has been *"fairly stable," "reasonably stable," "remained about the same," "fluctuated about +/-0.2 m since 1938,"* and *"the river bed has been fairly stable, fluctuating +/-0.1 m since 1936."* Thus Williams supports the fact that some degradation has occurred but of a relatively small magnitude. It is important to note that Williams himself gave some caution regarding the accuracy of the analysis. He stated that the analysis was, *"far from perfect"* and incorporates *"an unmeasurable amount of error,"* and that "*day-to-day shifts in measured elevations are comparable to long-term ones."*

Regarding the sediment budget, the Murphy and Randle reasoned that if there were some increase in the vertical elevation difference between floodplain elevation and the channel bed that some incision of the bed had to occur. This is due to the fact that the quantity of sediment required to raise the entire floodplain through aggradation is significantly greater that the quantity of sediment required to incise the bed by degradation. This does not preclude any aggradation on the floodplain, but emphasizes degradation or incision of the channel bed as the dominant process of channel geometry change. Aggradation or degradation is caused by an imbalance of sediment transport. Thus, significant differences in sediment transport through a reach of river are required to cause significant amounts of aggradation or degradation.

Some analysis of the sediment budget was presented by Murphy and Randle; however, it utilizes total sediment load equations rather than bed load or bed material load, and as a result, does not focus on the type of material which results in channel change, i.e. the bed material. A deepening of channel by one foot over a width of 1000 feet for the length of the Platte River from the confluence of the North and South Platte to Grand Island (mile 314 to mile 167 = 147 miles) requires an imbalance of bed material load of 38.8 million tons (assuming a sediment density of 100 pounds per cubic foot). Using wider or narrower widths would result in greater or lesser quantities of sediment. The calculation presented above can be used as a simple guideline as to the effect of potential differences in bed material load on changes in channel geometry. Aggradation or degradation of the river has not been accurately quantified based on differences in sediment transport. Estimates of differences in sediment transport along the Platte River would only be consistent with relatively small changes in bed elevation. The current state of relative balance in sand load indicates that future changes in channel geometry would be quite small under the current flow and operational regime.

The linkage between channel geometry changes induced by differences or imbalances in bed material load transport and riparian vegetation has not been fully or clearly established. Williams (1978) relegates the effect of sediment transport as a significant factor in channel change to a secondary status behind flow when he stated, *"In the absence of any significant climatic shifts, the various channel changes described above most likely are due to the rather systematic decrease in water discharge (and possibly sediment discharge) that has occurred."* Furthermore, Simons & Associates (2000) again raised the issue that the expansion of vegetation on both the North and South Platte Rivers are similar yet the reduction in sediment transport is much more significant on the North Platte compared to the South Platte. This is potentially a significant argument against the prevailing hypothesis that reduction in sediment supplies are single-handedly instrumental in vegetative expansion. Runs of the VEG portion of SEDVEG have been made with and without sediment transport, thereby leaving channel geometry unchanging while reasonably matching known changes in vegetation. This seems to demonstrate the relatively smaller influence of sediment compared to other factors. Such evidence suggests that the linkage of channel geometry changes to imbalances in bed material load and vegetation expansion may not be as presumed by Murphy and Randle (2001b), or at least has not been resolved.

CONCLUSIONS

It is concluded that the extent to which sediment supply or sediment transport issues have affected channel morphology and vegetation is a significant question but remains unresolved and is in need of further analysis before implementation of actions based on any of the prevailing hypotheses. Lack of resolution of the issue is due primarily to the lack of historic and recent sediment transport data. Collection of additional bed material transport data, along with detailed studies of macroform development and movement, are suggested.

Even with this lack of resolution, some qualitative and quantitative conclusions regarding the issues identified in the introduction of this report can be proffered, based on the evaluations of historical and current sediment supplies conducted during this investigation.

Very little sediment data that is directly pertinent to the issue of channel change induced by bed material load imbalance along the Platte River are available. No quantitative information is available regarding Aeolian transport or the effect of watershed disturbances (buffalo, fire, timber removal, drought) on the supply of sediment to the river.

Pre-development sediment supply estimates are crude and are based on data collected in the 1900s. It is important to note that based on the climatic information (see the Task D1&D2 report), the mid- to late 1800s was one of the driest periods while the early 1900s was one of the wettest periods, neither one being representative of long-term average conditions. This could have resulted in potentially dramatic shifts in flow and sediment transport. The combination of extreme drought coupled with fire and the effects of large herds of buffalo, could have led to a geologically-temporary, large oversupply of sediment to the river considering the phenomenon of Aeolian transport, both by blown sediments falling on the river and by movement of land dunes into the waterway. Other anthropogenic disturbances due to the timber operations of the railroads and general use of timber by settlers and travelers affected sediment supply and vegetation in the immediate time period prior to water resources development.

While there are indications that the pre-development Platte River was oversupplied with sediment and the river in current conditions has an excess of sediment transport capacity, it is not possible to accurately quantify either of these conditions based on available data.

The potential changes in the channel bed due to imbalances in bed material load have not and perhaps cannot be quantified accurately with available data.

Bed elevation change data come primarily from USGS gaging stations, which are primarily located at or near bridges. These data are biased towards degradation due to contraction scour, they are significantly sensitive to antecedent flows (see Task A3 report), and they are not representative of the river in general.

Sediment budget calculations presented by USBR (Murphy and Randle, 2001b) do not provide sufficient information to adequately support the amount of channel incision being used as a target for SEDVEG modeling. Simulations of bed elevation changes downstream of the J-2 return and at bridges were used as a basis for calibration of the model. This conclusion is made due to the scarcity of quantitative information that can be considered representative of the channel in general. The current state of near equilibrium in transport and bed elevation change (Simons & Associates, 1990 and 2000) indicate that future channel changes based on recent data may be quite small raising the question of the need for sediment augmentation. Better data are needed to support whether there is a need for sediment augmentation or not.

The SEDVEG sediment transport model focuses on the appropriate type of sediment; namely, the material found in the bed that is affecting channel geometry changes.

The linkage between channel geometry changes induced by imbalances in bed material load and trends in riparian vegetation has not been clearly established. Data presented in the Task C1/C2 report discounts the prevailing hypothesis and reveal the existence of an equilibrium between vegetative expansion and unvegetated portions of the river.

Many remaining questions regarding the sediment supply remain, imbalances in sediment transport along the river, and linkage to vegetation that must be addressed in order to adequately understand this important issue.

BIBLIOGRAPHY

Leopold, L.B., M.G. Wolman, and J.P. Miller, 1964, Fluvial Processes in Geomorphology, W.H. Freeman and Company, San Francisco, CA.

Murphy, P.J., and T.J. Randle. 2001a. *Platte River Channel: History and Restoration.* U.S. Bureau of Reclamation and U.S. Fish and Wildlife Service. Draft. January.

Murphy, P.J., and T.J. Randle. 2001b. *Platte River Sediment Transport and Riparian Vegetation Model.* U.S. Bureau of Reclamation and U.S. Fish and Wildlife Service. Draft. January.

Schumm, S.A., 1977, The Fluvial System, Wiley Interscience, New York.

Simons & Associates, 1990d, *Platte River System Geomorphic Analysis,* Appendix V, Geomorphology, Joint Response, May 5, 1990.

Simons & Associates, 2000, *Physical History of the Platte River in Nebraska: Focusing upon Flow, Sediment Transport, Geomorphology, and Vegetation*, an independent report prepared for the Platte River EIS Office, U.S. Department of the Interior.

U.S.G.S 1983. *Hydrologic and Geomorphic Studies of the Platte River Basin*, Professional Paper 1277, U.S. Government Printing Office.

Williams, G.P. 1978. *The Case of the Shrinking Channels - the North Platte and Platte Rivers in Nebraska*. Geological Survey Circular 781. U.S. Department of the Interior. United States Government Printing Office. Washington D.C.

APPENDIX A

SUMMARY OF RELEVANT STATEMENTS FROM WILLIAMS (1978)

To understand what Williams actually reported regarding changes in bed elevation, the following material from Williams' report is provided for clarification:

> *The complete records of the 12 U.S. Geological Survey gaging stations within the study reach were examined. Most of these records begin in the mid-1930s, as mentioned above, which means that most stations have records for about the past 40 years. (Several stations actually were established around the turn of the century but not at the present site. Such data were acceptable for the hydrology analysis presented earlier but can't be used for present purposes.) Bed elevations, in meters above mean sea level, were determined as described above. Relative elevation changes with time were then computed for each station to reveal any aggradation or degradation.*
>
> *RESULTS*
>
> *Table 4 lists, and figure 29 shows, the data obtained. The complex history of water regulation and diversion upstream from and within the study reach, together with the shifting and unstable sand bed, complicate the interpretation of the data. Comments will be restricted to pointing out major changes in bed elevation with time at each station.*
>
> *From 1936 to 1976 the streambed at the Minatare station has gradually degraded. The amount of degradation for this period is about 0.7 m.*
>
> *At Bridgeport the bed eroded about 0.5 m from 1931 to 1967 but seems to have filled about 0.2 m around 1967 and has not changed much since.*
>
> *The Lisco station has remained essentially stable since 1933.*
>
> *The Lewellen station is only about eight kilometers upstream from Lake McConaughy. The bed at this station (two channels) has aggraded noticeably since about the mid-1940s. (Lake McConaughy, formed by Kingsley Dam, was created in 1941.) Fill in the north channel at Lewellen has amounted to about 0.6 m and in the south channel to about 0.3 m.*
>
> *The gaging station near Keystone is located just downstream from Kingsley Dam and from the diversion dam of the Sutherland Reservoir supply canal, which began operation in November 1937. The station has been at its present site since mid-1944. During the 10 years from 1944-54, the bed scoured about 0.6-0.8 m. (The channel had also been degrading during the previous several years. According to U.S. Geological Survey notes.) The bed level fluctuated over a range of about 0.2 m from the mid-1950s until the late 1960s. Since the late 1960s, it seems to have gradually aggraded about 0.4 m.*

The channel of the North Platte near Sutherland has gradually eroded approximately 0.5 m since about 1940.

At North Platte the riverbed elevation seems to have been fairly stable over the past 45 years.

The North Platte at Brady today flows mainly in two channels. The bed level in the north channel has undergone periodic fluctuations of several tenths of a meter during the period of record (1939-present). Today (1977) the bed is about 0.5 m lower than it was in 1939-40. The south channel scoured about 0.3 m from 1939-49, then regained 0.1-0.2 m of this over the next 10 years (to 1959) and has remained fairly stable since 1959.

Near Cozad the Platte also flows in two channels. Both of these have scoured over the period of record (1940-present). The north channel has degraded about 0.7 m, the south channel about 1.5 m. The latter degradation represents the largest amount of change of the 12 stations studied.

The Platte River near Overton was reasonably stable from 1930-49. From 1949-57 it scoured about 0.3 m and has remained at about that same elevation since.

Near Odessa the bed of the river has fluctuated about +/-0.2 m since 1938.

At Grand Island the river bed has been fairly stable, fluctuating within +/-0.1 m since 1936.

The various and inconsistent changes of bed elevation with time mean that the gradient of the river bed has also changed with time in a similarly complex way. The same is true of the channel depth although any changes have not been very large.

TECHNICAL MEMORANDUM

RESULTS OF INVESTIGATION A3 - DEVELOP AND ANALYZE COMPREHENSIVE DATABASE OF PLATTE RIVER CROSS-SECTIONS

PLATTE RIVER CHANNEL DYNAMICS INVESTIGATION

Prepared For

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TECHNICAL MEMORANDUM

INVESTIGATION A3 – DEVELOP AND ANALYZE COMPREHENSIVE DATABASE OF PLATTE RIVER CROSS-SECTIONS

PREFACE

This report describes the procedures used in and results of an evaluation of available cross-sections and profiles of the Platte River channel. The investigation addressees a number of technical issues regarding this subject which had been identified by the sponsors as needing detailed examination to allow them to make scientifically-based decisions regarding the Cooperative Agreement (CA) work products.

This document describes only the data collected, analyses made, and scientifically-supportable findings regarding the issues, written in a manner which generally follows the guidelines of professional journals of the respective authors' technical expertise. The relevance of the findings to the specific issues confronting the sponsors is discussed in each task memorandum, but only as far as the data and results are deemed by the author(s) to be scientifically supportable in resolving or illuminating the issue.

ISSUES AND PURPOSES OF INVESTIGATIONS

The technical evaluations completed by the Parsons team were conducted as a series of 14 complementary investigations divided into four categories that would address general issues identified by the three states. The following issue categories were identified:

- A: Questions Regarding Channel Narrowing or Deepening
- B: Questions Regarding Sediment Transport
- C: Questions Regarding Vegetative Encroachment
- D: Questions Regarding Macro-Historic Natural Variability

This Technical Memorandum describes the results of Task A3, the third of five tasks comprising Issue Category "A."

The objective of Task A3 is to establish whether qualitative and quantitative geomorphic relationships in standard literature corroborate the relationships between effective discharge and width developed in Task A4. A few relevant publications regarding channel width adjustments were evaluated and described here.

All task reports focus on three specific types of issues: 1) trends, 2) processes, and 3) cause-effect relationships. It is necessary to first identify current trends in key channel characteristics. Understanding processes that govern the interaction between flow, sediment, and vegetation provides a basis for development of appropriate restoration approaches. As cautioned in Simons & Associates (2000a), *". . . it is necessary to develop a sufficient understanding of the factors that may affect the morphology of the Platte River and associated vegetation. Without an understanding of the fundamental factors or causes of change, it is not possible to [*neither*] develop appropriate mitigation measures nor understand their effect."* Conducting investigations that answer key questions covering trends, processes, and the cause-effect relationships themselves will provide necessary information for the states to evaluate the EIS Team products.

Task A3 was scoped to assess all available cross-section data and compare and contrast it with that being used by the EIS team. Other goals were to analyze available channel profile data to assess whether overall aggradation or degradation is clearly occurring, to determine if the river bottom profile varies over distance, and to determine the channel width changes over time by examining several definitions of "width." Also, the project called for an assessment of whether the SEDVEG model's cross-section segment spacing adequately represents the river's diverse topology and channel geometry. All of the assessments described in this report focus on morphologic evaluations. The effects of sediment transport, sediment properties, climate, and changes in the river's hydrology or hydraulics on channel geometry are mentioned but not fully analyzed in this report. Other task reports address these aspects in greater detail.

DATA COLLECTION

The compilation of data for this task included 46 sources of information on past studies of the Platte channel width and changes over time. This information was given to Parsons by the EIS team and supplemented with data from Parsons' library and the United States Bureau of Reclamation (USBR), Nebraska Department of Roads (NDOR), United States Geological Service (USGS), Whooping Crane Trust, Union Pacific Railroad, Central Nebraska Public Power and Irrigation District (CNPPID), and Nebraska Public Power District (NPPD).

The results of the literature review are summarized in Table 1. Sixteen of the 46 sources of information were found to be useful in assessing the topographic changes in the Platte River. The most recent comprehensive set of cross section data was surveyed by the USBR in 1989.

Thirty of the 46 sources were determined to be insufficient for assessment of the morphologic changes in the Platte River. These sources and the reasons they were deemed insufficient are listed in Table 2.

CHANNEL WIDTH DEFINITIONS

Before discussing channel morphologic changes and causes, some terms are defined. Much ado over alleged changes in channel widths has been presented in recent literature. Definitions of "width" vary, and estimates of width over time using different types and sources of data have been made without adopting a common definition.

For a river in dynamic equilibrium (often the term "in regime" is used to mean the same thing), many of it morphologic attributes and a significant part of its conveyance is formed and maintained by the "effective discharge" (see Task Memo A4). *Effective channel width* is defined here as the total width of water conveyance when the flow matches the effective discharge. *River corridor width* is the transverse distance across the channel and floodplain between higher terraces or meander lines, and may include islands, braided segments, or primary and secondary anastamotized channels. Though there is a relationship between effective channel width and river corridor widths, the former is more-easily related to flows, while the latter is governed more by other factors such as sediment supplies or topographic or geologic constraints to lateral movement of the channel.

TABLE 1

RESULTS OF LITERATURE SEARCH ON PLATTE RIVER CHANNEL WIDTHS

References Used	Type of Information
USBR (1989). Platte River Cross Sections	88 surveyed cross sections, 16 of these were used in the SEDVEG Model.
Cochran (1931). State of Nebraska, Department of Public Works, Bureau of Irrigation, Power, and Drainage Stream Flow Measurements.	Overton in 1925, 1927, and 1928 G.I. in 1928 Fremont in 1928 Columbus in 1928 Duncan in 1928 Gothenburg in 1928 and 1930 Cozad in 1929 and 1931 Plattsmouth in 1929 Brady in 1928 and 1931 Elm Creek in 1931
Williams (1978). *The Case of the Shrinking Channels*. USGS Circular 781.	Bed elevations at 5 locations, channel widths at 12 locations.
Eschner *et al.* (1983). *Hydrologic and Geomorphic Studies of the Platte River Basin*. USGS Paper 1277-A.	Channel widths for 3 locations.
Simons & Associates, Inc. (1987a). Aerial Photograph Analysis Summary Memorandum.	Water width and water and sand widths for six locations.
Simons & Associates, Inc. (2000b). *Historical Trends of the Channel Width of the Platte River System.*	Same information as the Aerial Photograph Analysis Summary Memorandum (Simon & Associates, 1987a), but used map to located data.
Becker (1986). *A Grid Analysis of Channel and Island Change in the Platte River in Dawson, Buffalo and Hall Counties for the Years 1976, 1982, 1983, 1984 and 1985.*	Tabulated channel widths measured from infrared air photographs in the Big Bend reach.
FERC (1990a). Appendix III. Vegetation and Channel Change for Project No. 1417 and 1835.	Mean channel widths at four locations.
Hall (1954). *Evaporation Losses from the North Platte and Platte Rivers – Keystone to Cozad*. CNPPID.	Width of water surface and flows at Brady.
Platte River EIS Office (2001b). 1998 Platte River color-infrared digital orthophotos.	Used as background in ArcView database.
USGS (2001). Cottonwood Ranch cross-sections of the Platte River	Compared USGS (2001) general monitoring section to USBR (1989) section.
Zelt and Frenzel (1996). Physical habitat characteristics of the Platte River, Nebraska-assessment using surveys and spatial analyses.	Includes 1995 cross sections at Brady and Grand Island.
Platte River Management Joint Study Hydrology Work Group (1989a). *Evaluating Management Alternatives: Sediment, Flow and Channel Geometry Considerations.*	Channel widths from Lyons and Randle (1988).
Platte River EIS Office (2001a). 1938 black and white aerial photography of the Platte River	1938 photographs used in ArcView database.
Nebraska Mid-State Division (1971). Mid-State Diversion Dam Contour Map	Used contour map to create cross-section at Lexington.
U.S. Reclamation Service (1923). Engineer transit book, Nebraska, Tri-county secondary, Plum Creek Reservoir supply canal diversion dam across Platte River.	1923 cross-section at Plum Creek Reservoir Supply Canal to Midway – 1938+09 to 1973+90.

TABLE 2

DATA EXCLUDED FROM EVALUATION

References Not Used	Review Comments
USBR (1980). 1980s Platte River cross-sections.	Cross-sections are from the mid to late 80s. Comparing these to 1989 cross-sections would have shown very little change because difference is only a few years.
Simons & Associates, Inc. (1992). *Additional Analysis of Sediment Transport at Korty Diversion Dam.*	On North Platte (not in major focus of study). May be set aside for further study.
Union Pacific Railroad. BR 282.03 over the North Platte River, near North Platte.	Only shows ground between abutments, not full-valley or bank-to-bank cross-section.
Union Pacific Railroad. BR 282.08 over the North Platte River, near Denman.	Only shows ground between abutments, not full-valley or bank-to-bank cross-section.
Union Pacific Railroad. BR 124.29 over the North Platte River, near South Bayard.	Bad condition.
Union Pacific Railroad. BR 18.30 over North Platte River, near Nevens.	Ground data not shown.
Union Pacific Railroad. BR 72.60 over Platte River, near Central City.	Bad condition.
Union Pacific Railroad. BR 2.10 over Platte River, near Valley.	Ground data not shown.
Union Pacific Railroad (1982). Bridge 54.13 over North Platte River near South Morrill, Nebraska.	Ground data not shown.
Simons and Associates, Inc. (1987b). *Cross-section Plots of Joint Study Data (Vegetated Points Marked).*	Cross-sections are from 1985 and 1986. Comparing these to 1989 cross-sections would have shown very little change because difference is only a few years.
Platte River Whooping Crane Maintenance Trust, Inc. (1992). *Channel Monitoring Report.*	Method of how the channel widths were obtained was not provided and precise location of the numerous transects is not provided.
Simons & Associates, Inc. Assorted memos and confidential attorney work products regarding Projects 1417 and 1835 - impacts of project development on channel widths in the Platte River system.	Same data as in Simons & Associates, Inc. (1987a) and Simons & Associates, Inc. (2000b).
FERC (1995). Attachments to Accompany New Evidence and Comments on NPPD on Recent Agency Filings for Project No. 1417 and 1835.	Same data as in Platte River Management Joint Study Hydrology Work Group (1989), except data has been rounded and has explanations.
U.S. Department of Interior (1955). *Sediment Investigations of the Platte River Near Overton, Nebraska, January 1950 to September 1953.*	Arbitrary vertical datum.
Murphy and Randle (2001). *Draft Platte River Channel: History and Restoration.*	Channel widths are graphed and are averages using Williams (1978), Lyons and Randle (1988), and Simons & Associates, Inc (1987b) data. This does show widths for 1983 and 1998, but these are also averages. Information about the averaging was not provided.

TABLE 2 (Continued)
DATA EXCLUDED FROM EVALUATION

References Not Used	Review Comments
State of Nebraska (1926). Bridge plans at the South Brady bridge over the Platte River.	Only a partial cross-section.
FERC (1990b). Appendix V, Geomorphology for Project No. 1417 and 1835.	Water and sand widths information is the same as in references Simons & Associates, Inc. (1987a) and Simons & Associates, Inc. (2000b). Channel widths are relative, bed elevations show essentially no change (+/- 0.1 ft typical)
Channel narrowing paper relating to projects 1417 and 1835	Channel widths are only given as percent of the 1865 widths. 1865 widths not provided.
Platte River Management Joint Study Hydrology Group (1989b). *Draft Hydrology Work Group Report on Task 10 – Identify Flushing and Scouring Flows.*	Draft of Platte River Management Joint Study Hydrology Group (1989a).
Lyons and Randle (1988). *Platte River Channel Characteristics In the Big Bend Reach: Prairie Bend Project.*	Repeat of unvegetated channel widths from aerial photograph analysis.
Unidentified Source (1986). Aerial photos from North Platte to Grand Island.	Already have aerial photograph analysis in other studies.
State of Nebraska Department of Roads (1963). Bridge cross-section.	Not a complete cross-section.
U.S. Army Corps of Engineers (1989). *Platte River Cumulative Impacts Analysis. Quantitative Analysis of Hydrogeologic Impacts from Bank Stabilization.*	Unknown but likely a copy of 1989 cross-section from the USBR.
HDR (1983). *Quantitative Analysis of Morphologic Changes in the Platte River and Miscellaneous Water Resources Aspects of the Proposed Prairie Bend - Twin Valley Project.*	There is no topographic geometry information. Data is all based on effective discharges.
USGS (1990). *Discharge Measurements Summary Sheet for Platte river near Overton, Nebraska.*	Data only shows flow widths and areas, velocities, and discharges.
Peake *et al*. (1985). *Interpretation of Vegetation Encroachment and Flow Relationships in the Platte River by use of Remote Sensing Techniques.*	Channel widths are only given as percent of the 1865 widths. 1865 widths not provided.
Simon & Association (2000a). *Historic Observations of the Platte River Conditions.*	Same as in the White Paper.
Osterkamp (1977). *Effect Of Channel Sediment on Width-Discharge Relations with Emphases on Streams in Kansas.*	Data set does not include the Platte River.
Chen *et al.* (1999). *Trends in Channel Gradation in Nebraska Streams*, Water Resources Investigations Report 99-4103.	Analyses assume that if stage changes for a given discharge that channel has degraded. The assumption is questionable. Results contradict known changes in bed elevations.

TABLE 2 (Continued)

DATA EXCLUDED FROM EVALUATION

References Not Used	Review Comments
McCormick (2001). COHYST stream flow measurement study on the Platte river, work in progress (Excel spreadsheet).	Study uses widths and depths from 1971 to 1975 and applies them to discharge measurements from 1947 to 1997. For our purposes, this method makes flawed assumptions.

The river corridor width, often called the *meander belt width*, reflects the valley width over which the effective channel roams.

Active channel width is a term being used in the Cooperative Agreement process. It appears that the use of the term may be considered by some to be analogous to the effective channel width, while others appear to define it as any unvegetated portion of the river. It is generally used contextually in reference to that part of the river corridor that is continuously re-shaped by the river flows. Some of these references appear to perceive that only (and all) of the unvegetated portion of the river corridor is "active." On the contrary, unvegetated river corridors, especially braided corridors, are known to have river corridor widths that range from 2.7 (Leopold and Wolman, 1960) to 4.5 (Zeller, 1967) times the effective-discharge width, so any perception that the unvegetated width is the same as the effective-discharge or active channel width is incorrect.

The term "active channel width" is not used in this report because its definition appears to range by its contextual use from a single "main" channel width to the full river corridor width, depending apparently on the presence or absence of vegetation. Murphy and Randle (2001) use the term to describe that portion of the corridor width that is "activated" by annual spring peak flows, but appear to gage their reported values of this width on the basis of unvegetated width observed in aerial photographs.

The effective-discharge channel width in a river that is "in regime" is measured as the total wetted top width of any low ground occupied by a flow equal to the effective discharge. This is not the same as the total unvegetated width. Though the channel locations and shapes occupied by this width can change over time, the effective discharge can shape and maintain only the width of channel it occupies, not the entire unvegetated width of the braided or other type of corridor. If the effective discharge has freedom to laterally shift, greater widths of reshaped and unvegetated portions are possible, but the perception that water needs to occupy the entire unvegetated portion (or the entire river corridor as assumed by some) to accomplish this reshaping is not supported by geomorphologic literature or principles.

The term *unvegetated channel width* is discussed in the remainder of this report. The definition adopted here is the sum of all unvegetated portions of any transect across the river corridor width.

UNVEGETATED WIDTH CHANGES OVER TIME

A perspective on unvegetated channel width not yet referenced in the debate was developed by Bentall (1991). He used USGS topographic maps to plot cross sections of the entire Platte River Valley (not just the river corridor), spaced about 15 miles apart, from the mouth to North Platte, and up the North Platte River to Lake McConaughy. The

Platte River valley width, as defined by Bentall, probably reflects the true corridor over which the channel has shifted over geologic time. These maps are not reproducible but reveal several important aspects. One is that the Platte River valley width in Hall, Buffalo and Dawson County, defined as the generally low area between topographic upland areas to the north and south, is 10 to 25 miles wide. Near the eastern edge of Hall County, this valley extends laterally over 25 miles all the way to the north bank of the Middle Loup River. On this scale, the "effective channel width" and "river corridor width," as defined above, are indistinguishable from the valley bottom. Further, the Platte is elevated above other rivers in the valley, such as the Wood River and Prairie Creek. Any observer attempting to define the "unvegetated width" prior to vegetation expansion should possibly include all unvegetated lands in the entire valley. The extreme limits at which "channel" or "corridor" are distinguished from "valley" is subjective, especially in a braided stream. The extreme limits that are "active" (influenced by flow) during any period of time are even more subjective.

Previous investigators have attempted to use historical General Land Office (GLO) survey information and more recent maps and photographs to graph the changes over time in "width" of the Platte River (Williams, 1978 and Simons & Associates, 2000b). Though not consistently defined, it is believed that these reports used some form of measure of the "unvegetated channel width." Some have interpreted these measures to be the same as the "active channel width." As noted above, the unvegetated width may not be indicative at all of geomorphic processes, but changes in the measure have been cited as having been caused by changes in flow and sediment associated with reservoir construction.

It can be shown that this definition is not relevant to the river's geomorphology, and that this conclusion was reached without scientifically establishing exactly what was controlling the unvegetated width at each point in time. Other measures of channel width that are geomorphologically significant were described above, and would have been superior in reaching cause-effect conclusions had they been applied. For this reason, a summary of past reports on changes in "width" is provided here, but our study does not endorse either the data or the interpretations as geomorphologically relevant. Following this summary of the changes reported by others, we provide a discussion of possible interpretation errors that have occurred. Figures 1 through 8 summarize others' interpretations of maps and photos, but as shown below, they do not use the same definitions of width, and some of the data was probably not adequate to provide true channel widths, nor was it reliable for the interpretations made. Thus, we are summarizing the data, but do not concur that they characterize the geomorphologic cause-effect relationships purported by others, or even that they accurately document the changes in unvegetated width.

The "unvegetated channel width" is subjective, but presumed here to be the width of open water plus width of unvegetated sand bar areas in any section across the river valley, presumably between meander limits. Williams (1978) defined this as the "bank-to-bank width of the cross section" where he measured the bank-to-bank width and subtracted the width of "stabilized" islands covered with perennial vegetation. He does not describe how he distinguished stable islands from unstable ones or how he ascertained perennial vegetation, because the latter is not shown on the maps. This also appears to be the definition adopted in measuring widths from the original plats by Simons & Associates (1987a). For the 1860's GLO plats, Williams apparently selected the solid exterior lines along the river as the “banks.” These are called out as “meander lines” on some of the plats.

The unvegetated channels widths from Williams and Simons & Associates and from some of the other sources listed in Table 1 are graphed in Figures 1 through 8. The first seven graphs show the measurements at Grand Island, Odessa, Kearney, Overton, Cozad, Gothenburg, and Brady. Figure 8 includes the data for all of these locations. These are plots of the reported “channel width” (definitions vary) in feet verses year of observation. Following procedures by Williams, data points in the graphs, sometimes decades apart, are arbitrarily connected by straight lines, giving a general trend but not necessarily explaining what actually occurred between measurements. Note that there are gaps in the data set from 1866 through approximately 1930, or about 65 years.

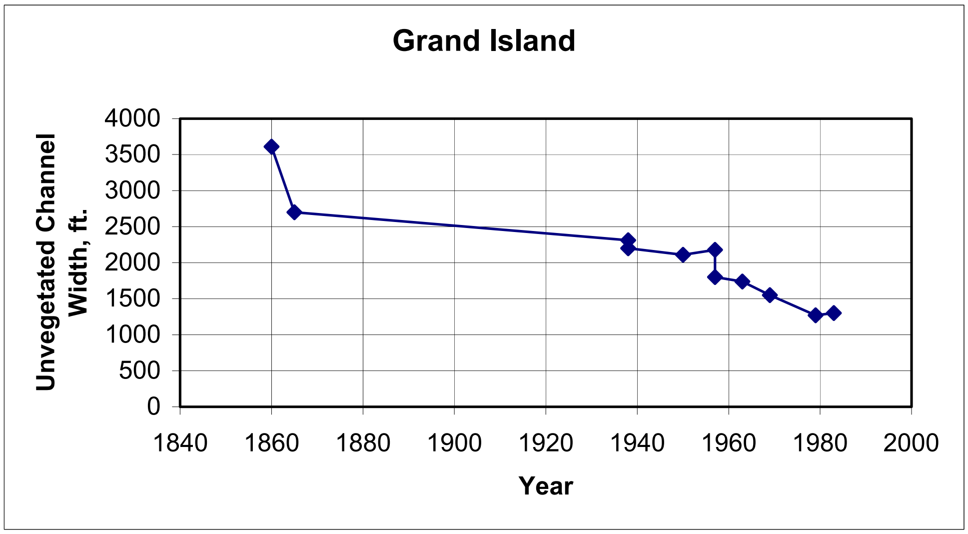

Figure 1. Unvegetated Channel Width Changes at Grand Island

At Grand Island, the unvegetated channel width appears to have declined 909 feet (ft) between 1860 and 1865. This is obviously incorrect because only one set of data, the GLO maps, were available. Two of the investigations listed in Table 1 recorded substantially different widths from the same GLO map data, and one of the investigators dated the widths at the beginning of the surveys and the other (Williams, 1978) dated them at the end of the survey period. The width apparently reduced another 390 ft between 1865 and 1938. It reduced 132 ft between 1938 and 1957. Then it reduced an additional 378 ft in 1957. From 1957 to 1978 it reduced 530 ft. Between 1979 and 1983 the unvegetated channel width widened 30 ft. Recent data, not included in this report, reveals that this upward trend has continued to the present.

A similar graph was prepared for the recorded widths at Kearney, shown as Figure 2. At this location, the unvegetated channel width apparently decreased by 259 ft between 1860 and 1865. As noted earlier, this is not considered to be a documented change, but instead is more likely that two of the investigations listed in Table 1 recorded different widths from the same GLO map data, and that one of the investigations dated the maps at the beginning of the surveys and the other (Williams, 1978) dated them at the end of the survey period.

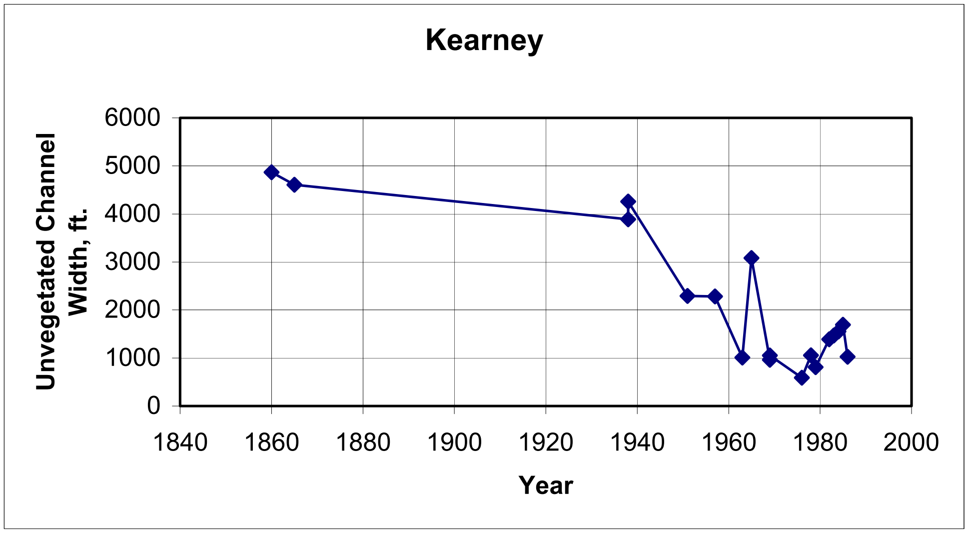

Figure 2. Unvegetated Channel Width Changes at Kearney

The unvegetated channel width at Kearney apparently reduced 351 ft between 1865 and 1938. It reduced 1969 ft between 1938 and 1951 and reduced 1280 ft between 1951 and 1963. Then it widened 2074 ft in 1965. It reduced 2123 ft between 1965 and 1969. From 1969 to 1986 it varied in width from 590 ft to 1690 ft and generally widened with the exception of the reduction from 1985 to 1986.

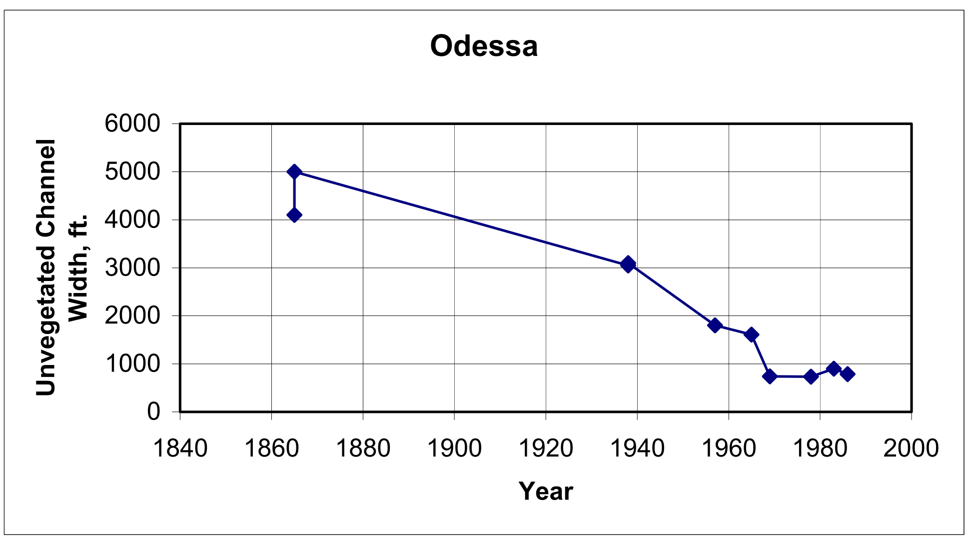

Figure 3. Unvegetated Channel Width Changes at Odessa

As shown in Figure 3 for Odessa, the unvegetated channel width measurements differed by 900 ft in 1865. Depending on which width is used from 1965, the unvegetated channel width apparently reduced by 1900 ft to 1050 ft between 1865 and 1938. It reduced 1300 ft between 1938 and 1957. It reduced 192 ft between 1957 and 1965. It reduced 569 ft between 1965 and 1969. Then, it generally leveled off from 1969 through 1986 to an average width of 790 ft.

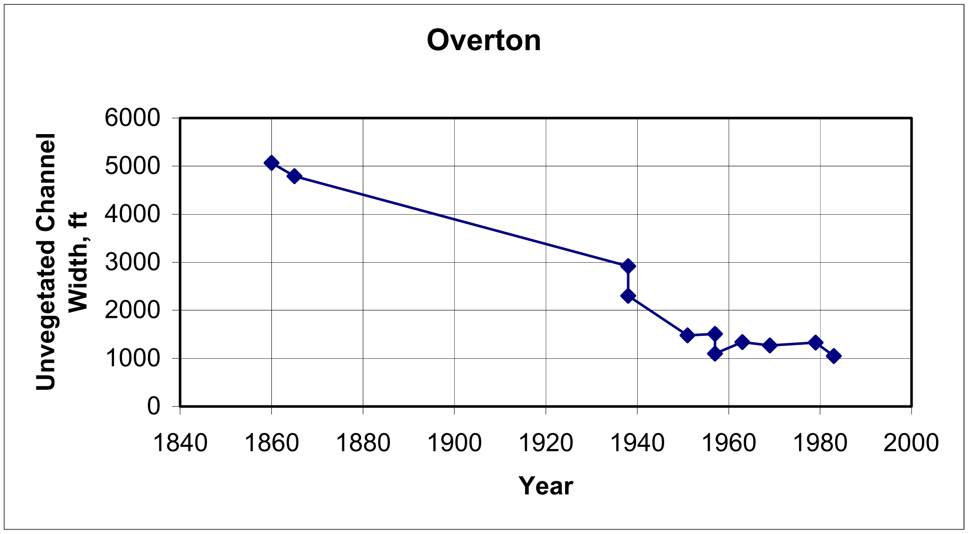

Figure 4. Unvegetated Channel Width Changes at Overton

At Overton, Figure 4, the unvegetated channel width measurements differed by 280 ft for the 1860 and 1865 plotting dates. The unvegetated channel width apparently reduced 2,490 ft between 1865 and 1938. It reduced 790 ft between 1938 and 1957. Then it reduced an additional 409 ft in 1957. From 1957 to 1983 it reduced 50 ft.

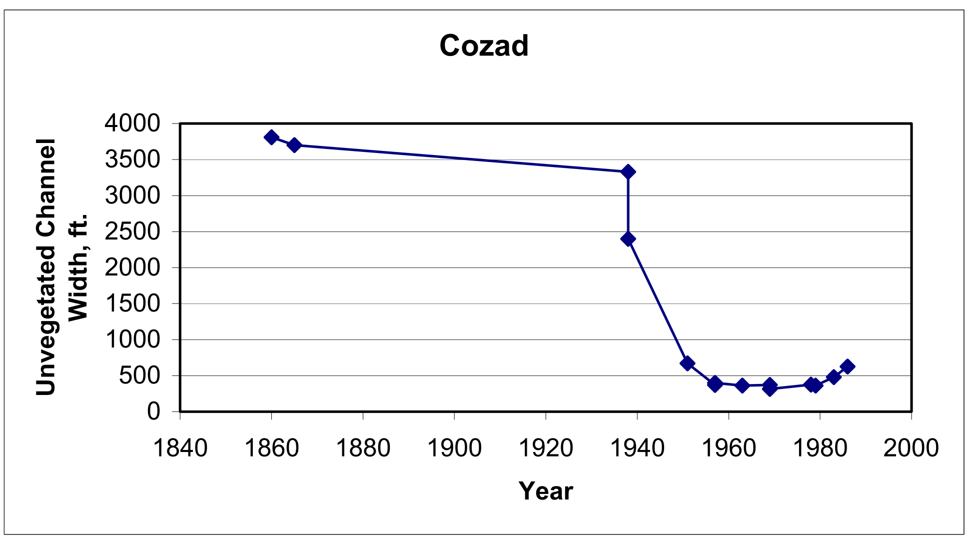

Figure 5. Unvegetated Channel Width Changes at Cozad

Figure 5 shows the trend at Cozad, where the unvegetated channel width measurements differed by 109 ft for the 1860 and 1865 plotting dates. The unvegetated channel width apparently reduced 400 ft between 1865 and 1938. Then it reduced and additional 900 ft in 1938. It reduced 1,731 ft between 1938 and 1951. From 1951 to 1957 it reduced 269 ft. From 1957 to 1986 it widened 225 ft.

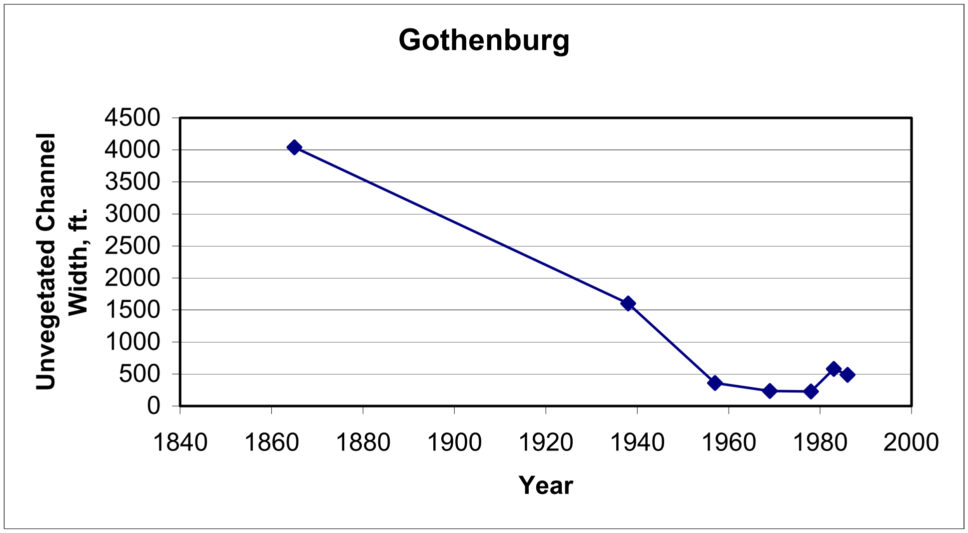

Figure 6. Unvegetated Channel Width Changes at Gothenburg

At Gothenburg, Figure 6, the unvegetated channel width apparently reduced 2,440 ft between 1865 and 1938. It apparently reduced 1,240 ft between 1938 and 1957 ft. From 1957 to 1986 it widened 126 ft.

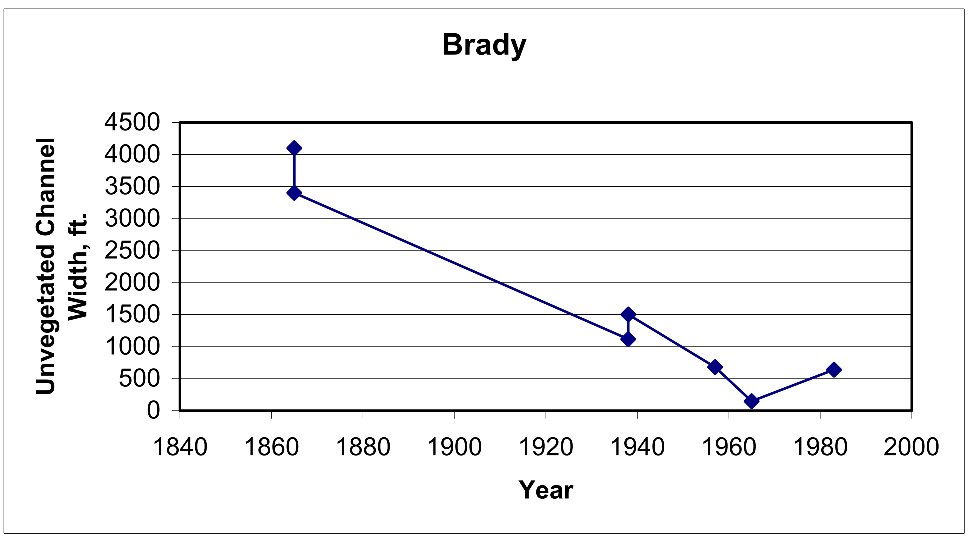

Figure 7. Unvegetated Channel Width Changes at Brady

Figure 7 shows that the unvegetated channel widths at Brady differed by 700 ft for the 1860 and 1865 plotting dates. Depending on which width is used from 1865 to 1938, it reduced 1,900 ft or 2,986 ft. It reduced at most 820 ft between 1938 and 1957. It reduced 532 ft between 1957 and 1965. From 1965 to 1983 it widened 492 ft.

Figure 8 combines the data from Figures 1 through 7. It is important to repeat our earlier comment that these are graphs of the unvegetated width of the channel, and are not considered by Parsons to reflect geomorphic changes and instead reflect only the amount of vegetative expansion that has occurred between the meander limits of the river. As proven below, the meander corridors have not changed widths, and any expansion of vegetation within these corridors would directly reduce the unvegetated width. Unvegetated width is not a geomorphologic term.

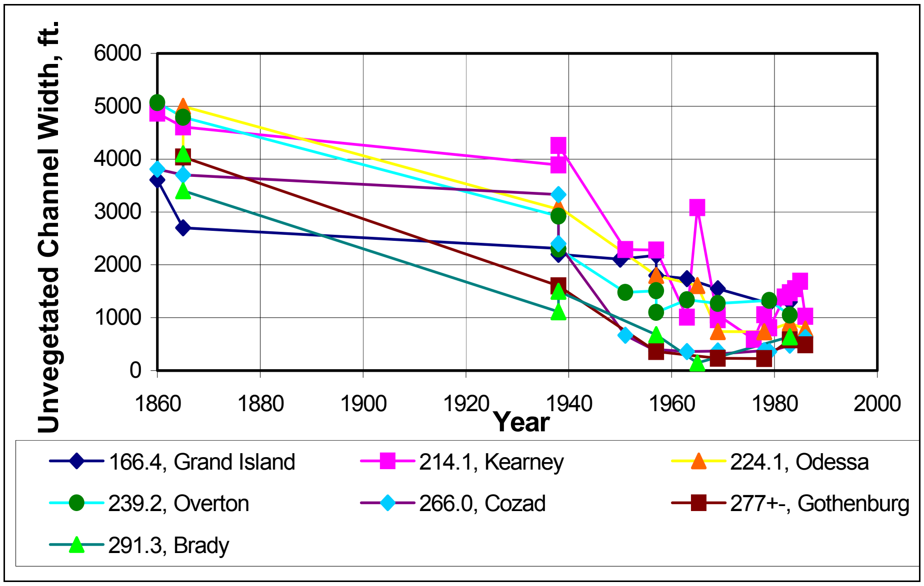

Figure 8. Unvegetated Channel Width Changes at all Stations

Assuming consistent definitions and procedures, and assuming commensurate data, the width of unvegetated channel has experienced both declines and increases over the study period. The unvegetated width apparently declined the most from 1865 to 1938. The rate of width decline increased to its steepest rate between 1938 and 1951 at which time the rate of decline decreased until about 1970 when a general trend of constant or increasing width at all locations was evident to 1986. As shown below, measurements after the mid-1980's are available, and indicate that the unvegetated channel width is continuing to widen at most locations.

It is not scientifically sound to conclude that these changes in unvegetated width are necessarily caused by changes in flow or sediment transport characteristics of the river. Numerous other explanations have been promulgated, and no definitive proof of any cause exists. Vegetative expansion is normally credited to minimization of environmental constraints, increases in seed and nutrient loads, or when additional resources have been made available (light, space). Further, occupation of channels by vegetation does not necessarily obliterate the channel. The channel can continue to exist beneath the vegetation, and should not be given "non-channel" status. The issue may be as much related to the causes of increases in vegetated channel width as it is to decreases in unvegetated channel width. The point is that most investigations of morphologic changes fail to add the vegetated channel portions of the river to the total available channel width.

DETAILED AT-A-STATION ANALYSIS OF HISTORICAL CHANNEL WIDTHS

As developed above, at least two key technical issues arise from the use of "unvegetated channel width" as a substitute for a geomorphologic term. One is the lack of established relationships between this particular measure and physical processes. Numerous other metrics are available that have known relationships between the morphology and driving factors. The second is the question of commensurability of this metric when data from the 1860's GLO maps are compared with current aerial photographs and maps. Much of the data on historical widths is from the original GLO cadastral surveys, which did a good job of documenting the river corridor width, locations of larger islands, and locations of primary bifurcated channels, but it has been discovered that the maps do not adequately document the between-bank conditions and should not have been used by Williams and others to determine channel widths in the 1860's. It is also questioned whether any or all vegetation between the meander lines on the GLO maps was recorded (as shown below, records were discovered regarding vegetative cover at Kearney in 1870, which is not indicated on the GLO map), and whether the entire river corridor shown on any of the maps, including both historical and recent maps was "active."

To assess these issues, this detailed at-a-station analysis is provided for a river segment at Kearney, Nebraska, within the critical habitat area. The segment is about 460 miles downstream of the Nebraska-Wyoming line. Williams (1978) analyzed changes in the river "channel" at the east edge of T8N R16W, which is 458.7 miles from the state line, and reported the following channel width changes:

Year	Total Channel Width (ft)	Source
1865	4,610	GLO Survey
1938	3,888	1938 Photo
1965	3,084	1965 Photo

Williams concluded that by 1965, the channel width was less than 20 percent of its 1865 width upstream of the Johnson Power Plant return, and about 70 percent of the 1865 widths below the return. Kearney, and most of the critical habitat, is downstream of the return. Some historical photographs taken from the banks during floods show a wide plain occupied by water (Williams, 1978), but extent of vegetation, scale, and flow rates cannot be determined from the photos. Comparable flow rates in today's river may extend laterally just as much as in the historical photographs, or possibly more if floodplain and channel roughness have increased. It is also possible that the channel is still there, but is vegetated. This is not apparent from aerial photos or USGS topographic maps. None of the data sources used in plotting Figures 1 through 8 incorporated this concept, and as noted earlier, they are provided only as a summary of previous investigators' hypotheses.

The material presented below will allege that the 1865 width at Kearney was over-estimated by Williams, and that the 1938 and 1965 "channel" widths cannot be established from the photographs. In fact, it will be shown that the river at all three times, and in a few other maps and photos not evaluated previously, is virtually unchanged except for the expansion of vegetation in low areas.

With regard to whether the GLO maps included between-bank details of smaller islands and bars, a typical example of the GLO maps is shown in Figure 9. Though some of the GLO maps included added detail between the meander lines, this figure is representative of the majority, showing very little detail other than the larger islands.

To research whether the GLO maps accurately document the between-bank conditions in the river, records of the survey system were evaluated. White's (1926) "A History of the Rectangular Survey System" includes copies of manuals of surveying instructions beginning as early as 1804, with updates published in 1855, 1881, 1890, 1894, and 1902.

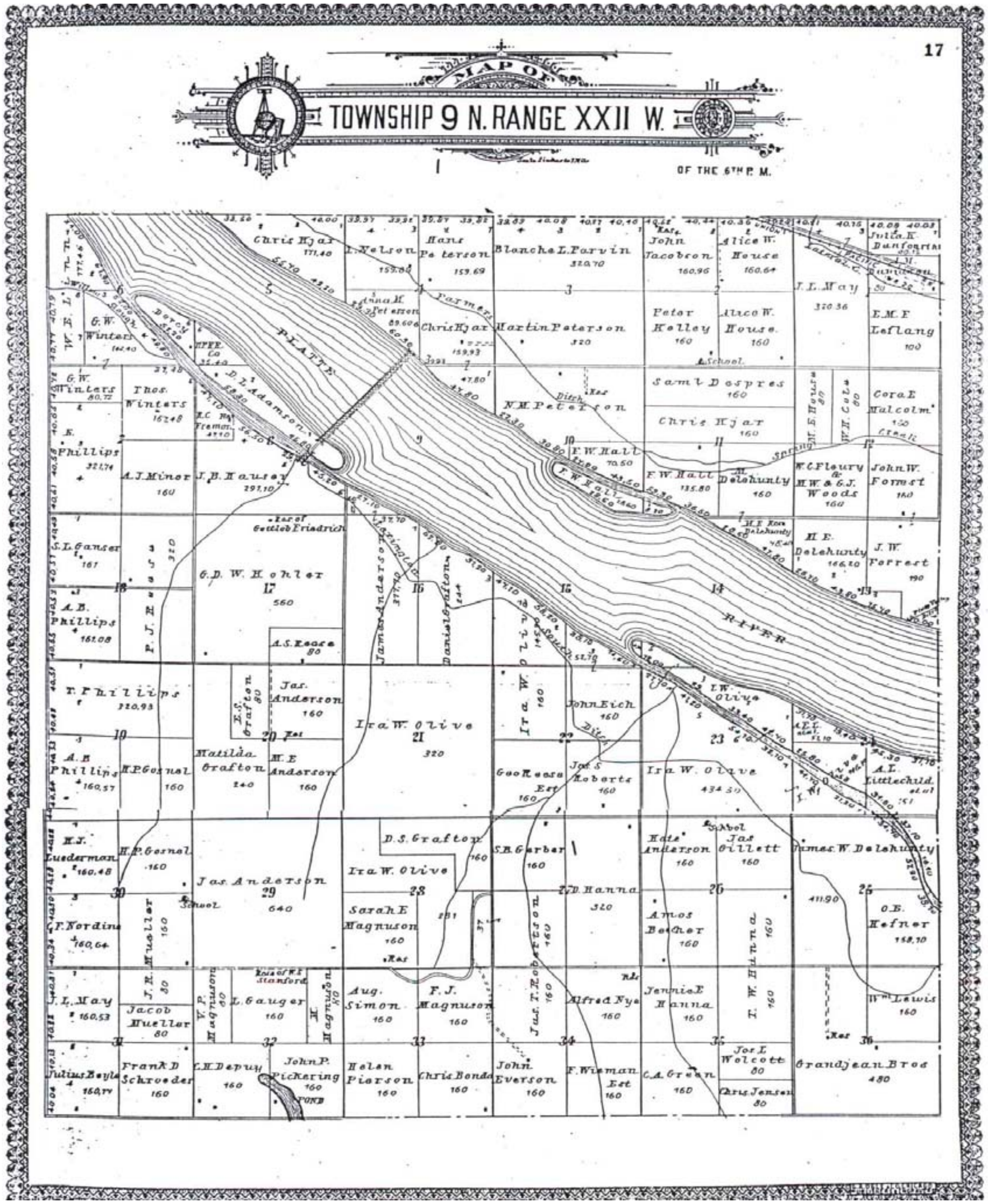

Figure 9. Example of 1860's GLO Survey Map, Showing T9N, R22W

Other manuals have been published since, but the 1855 manual is considered the operative rule when the Platte River was surveyed. Large streams such as the Platte were considered navigable. Regarding surveying of islands in navigable streams, the 1855 manual provides the following instructions (White, 1926, p. 464):

- Both banks of navigable rivers are to be meandered by taking the courses and distances of their sinuosities.
- At those points where either a township or section lines intersect the banks, meander corners (posts or mounds of earth and stone) are to be established.

- Beginning at each corner on the township line, the course of the meander corners is to be taken by measuring the distance between the meander corners.
- The crossing distance between the meander corners is to be ascertained by triangulation, in order that the river may be protracted with entire accuracy.

In a township made fractional by the river, precise relative positions of all islands are to be determined trigonometrically by sighting to a flag or other fixed object on the island and to calculate the distance across the island.

This indicates that islands were to be located by trigonometric methods, which means that the streams were not necessarily traversed, which would provide much greater between-bank detail. More important, the manual clearly focuses on the accuracy of the meander lines (meander belt extremities), the accuracy of boundaries of adjacent lands (not lands in the river), and on the "crossing distance" (i.e., the corridor width). No requirements were made for surveys of bars or macroforms, and the use of the term "island" implies that it refers to any large, vegetated landform separated by channels. Large unvegetated macroforms were most likely omitted because they would have been considered as having little property value.

An 1865 amendment to the manual (White, 1926, p. 503) contains the statement,

> *Many applications are received at this office for the purchase of small unsurveyed islands which were omitted when the adjacent lands were surveyed. These islands are usually of too little value to justify the Government in incurring the expense of survey.*

Based on this statement, it is established that many islands were not surveyed. This means that even landforms that fall within the definition of "islands" were omitted. The likelihood that unvegetated bars or even small or moderate size islands were surveyed is small in light of these records. From the typical map shown in Figure 9, and from a cursory examination of other GLO maps of the river, it appears that very few islands were considered "of value to justify the expense." These maps tend to show only islands over a mile long (see example in Figure 9). This is logical because establishing the island length by trigonometric methods would require that it be visible from more than one meander corner. Islands hidden behind the islands that are visible from the meander corners would also be omitted.

The "History" document goes on to describe the procedure by which any party desiring a survey of islands "omitted" in the original survey can make application and pay for the survey. Because the railroad survey (described later) was completed in 1870, it likely constituted one of these supplemental surveys of the "many islands" omitted in the original surveys. As shown below, this map provides much greater detail of the between-bank conditions that existed at that time.

Other sources of historical channel widths and possible evidences of significant vegetation existing in the 1860's were discovered in this investigation for the study segment. These had not been identified or used by Williams or by any other investigators to date. The maps and photographs described here provide the most reliable documentation at any single location in the river of changes in vegetation, and lack of changes in morphologic conditions, from the 1860-1870's to the present. Of further importance is that they are at a location within the critical habitat area where extreme morphologic changes throughout have been alleged. The maps, when compared with present conditions, suggest a completely different conclusion and prove that very little change in the channel, other than a substantial increase in vegetation, has occurred.

The first map shown in this series is Figure 10, which is an 1877 map of T8N, R15W near Fort Kearney, Nebraska. This is not the same as the 1860's GLO maps, and instead was prepared by the Nebraska Surveyor Generals Office and is titled, "Meanders of the Platte River." A search for the original 1860's GLO map for this township was made, including a request to the EIS Team, but only this map was found, so it is evidently the only available historical map of this township. Besides outlining Evarts Island, Figure 10 shows that little detail is provided inside the meander lines at the west boundary of the map where Williams obtained and reported a "channel" width of 4,610 ft. Our scaling of the digital imagery produces a channel width of 4,980 ft, or 8 percent greater.

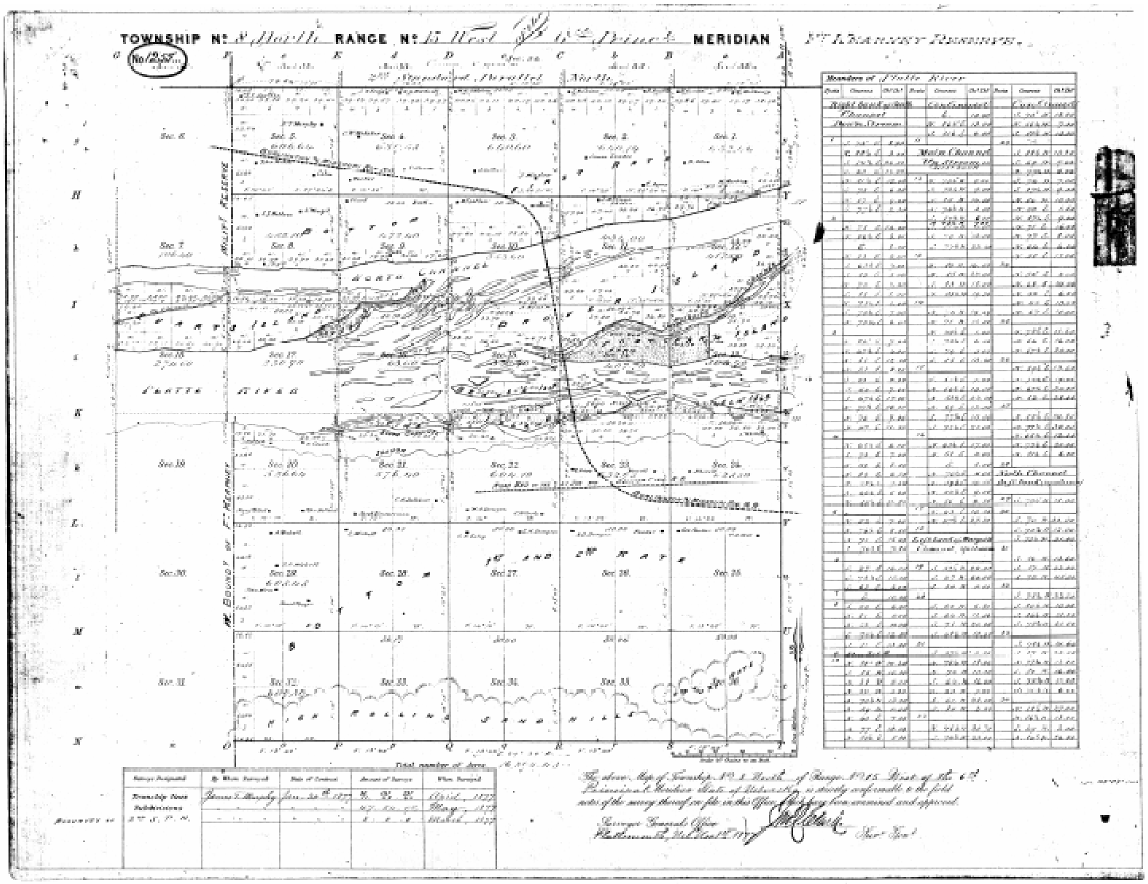

Figure 10. November 1, 1877 Nebraska Surveyor Generals Office Map of "Meanders of the Platte River" for T8N R15W

Williams did not use the map shown in Figure 10 for his measurements. He measured the channel at the eastern edge of a map of T8N R16W. This map was provided by the EIS Team and is shown in Figure 11. Note that the channels and islands at the eastern edge of Figure 11 are somewhat different than at the western edge of Figure 10. This suggests that an 1860's GLO map had been drawn for T8N R15W because the maps would be identical at the match line, but as noted earlier, this map could not be found. The important question is whether the detail of center bars is missing at the match line of these maps.

Note that considerable in-channel detail is shown on Figure 10 for about two miles on either side of the then-existing Burlington and Missouri Railroad bridge across the river. Based on the typical detail from GLO maps shown on Figure 9, and the highly-detailed data for the bridged portion of Figure 10, it is possible that the map does not reveal the true between-bank detail at the township line (the western border in this figure) where Williams reportedly made his measurements.

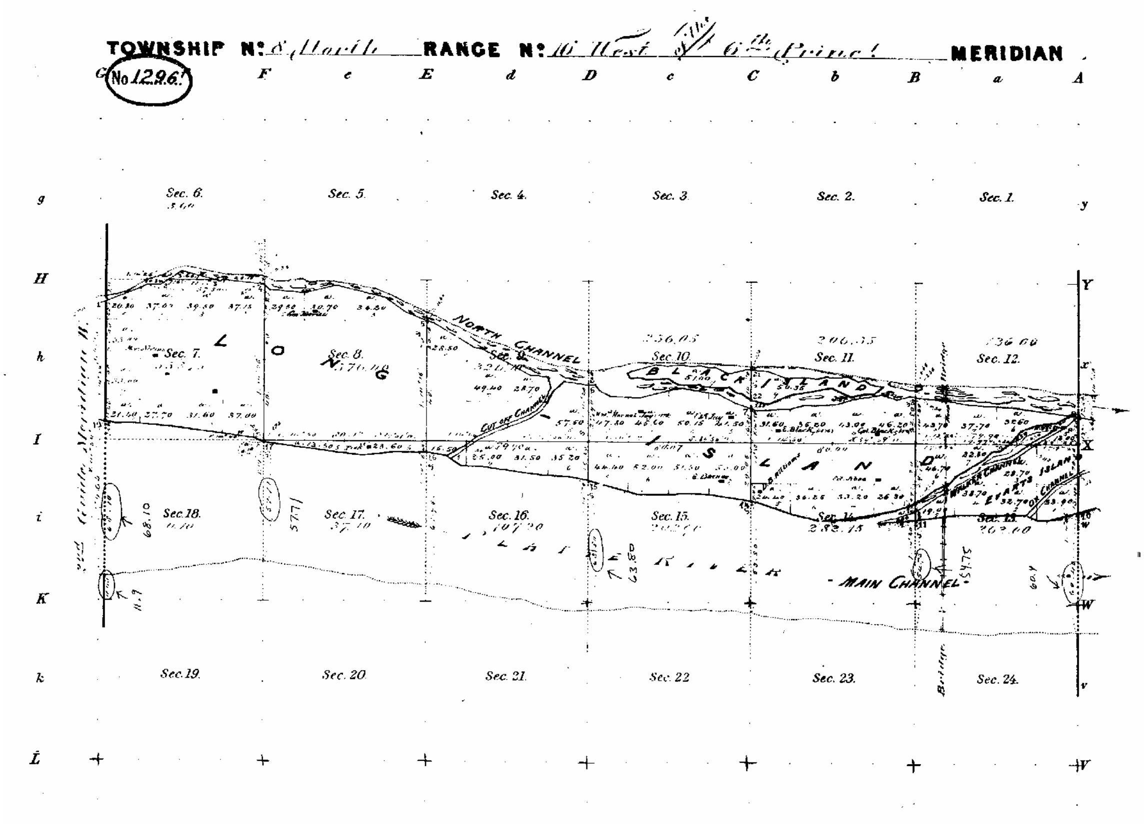

Figure 11. GLO Map of T8N R16W Used by Williams

Had Williams used the next adjacent GLO township map, T8N R15W, shown in Figure 10, he would have seen that considerable detail was provided near the crossing of the railroad, extending for two miles each way. It is hypothesized here that the general GLO maps did not show this kind of detail, and it was only provided by the surveyors for a short distance on either side of bridge crossings. The density of large bars and medium sized islands that existed at that time near the railroad bridge is not shown on the western edge of the map or on other GLO maps such as Figure 9. Either the bars didn't exist, or the other maps did not include this much detail. White (1926) reveals that the latter conclusion is applicable. Because this detail was omitted, measuring channel widths from these maps overstates the width. As demonstrated earlier, White's history of instructions for surveys of public lands for the 1860's reveals that the surveyors were required to survey large islands, and the rest of the detail between banks was not surveyed. This is a significant finding, as both Williams and Simons et. al, and possibly others, have assumed for years that the surveys accurately reported the conditions in the river.

A test of this missing-detail hypothesis can be made from geomorphologic principles. The effective width, which is geomorphologically relevant, should be about the same throughout a river reach even if the location and number of islands and bars varies. Past studies of effective discharge and effective width (see Task A4 Report) reveal that both are relatively the same in the reach from Overton to Grand Island. Lewis (1984) further demonstrated that neither had changed significantly from 1910 to 1983. The channel width at the bridge location in Figure 10, counting all true channel segments across the river, is only 3,140 ft. Williams' scaled 4,610 ft at the township's western edge, which is 1,470 ft wider. The principle that the effective width should not change this much in this short distance corroborates the theory that lack of detail lead Williams to overestimate the channel width.

The map of Figure 10, published in 1877, was drawn at a scale of 40-chains-to-the-inch. It shows that the railroad tracks cross portions of several named islands including Drover Is., Fort Farm Is., Beaver Is., and Vine Is. The map does not indicate presence of vegetation, but bank and bar lines and established islands are shown in detail, along with metes and bounds descriptions of the bank lines and acreages of the tracts of island lands cut off by the channels. Measuring along the railroad alignment, where the detail is available, reveals that the corridor between the "meander lines" was 8,750 ft wide**,** made up of 3,140 ft of channel and 5,610 ft of islands and bars. Had Williams used the detail available at this location, he would have also concluded that the 1865 channel was 3,140 ft versus 4,610 ft wide. It does not seem appropriate to define the 1865 channel width as 4,610 ft when a nearby, highly detailed cross-section has a 3,140 ft channel.

The next figure in this series is a hand-colored map of the B&M Railroad Route across the Platte River at the same crossing shown in Figure 10, near the Fort Kearney Reservation. This map was discovered by the Nebraska Public Power District (NPPD) in the National Archives. The National Archives would not check it out, but a color slide of the map was acquired, with the center portion shown as Figure 12. The notes on the full-size map indicate that it was prepared by the Chief Engineer of the railroad and is dated July 24, 1872. The note paralleling the track centerline in Figure 12 reads, "Magnetic Course S26^{o}20'E Taken August 10, 1870." Thus, the vegetation and channel detail shown on the map are those that existed in 1870. An aerial photo would probably not provide better information.

To allow scaling from this map, NPPD prepared and provided a 1 inch = 2,000 ft scale map of the slide. The full size map shows the river corridor limits for about 6 mi to the west and east of the bridge, but includes detailed delineation of the channels, islands and bars for only about a mile each way from the bridge. It is apparent that the between-bank details were truncated at these limits, and probably extended both ways but were not mapped. Blue shaded areas in this two-mile zone indicate the portion occupied by water, and vegetated portions are colored green. Two shades of green are used, with the darker shade along the southern edges of the islands and bars. The smaller islands and bars are all green, but the larger islands have green fringes but are otherwise uncolored.

Based on typical drafting standards, a completely vegetated island may have been indicated by coloring only the fringes. The widest open-water channels have only the fringes colored in blue, so it can be concluded that this standard may also have been applied to the islands and bars.

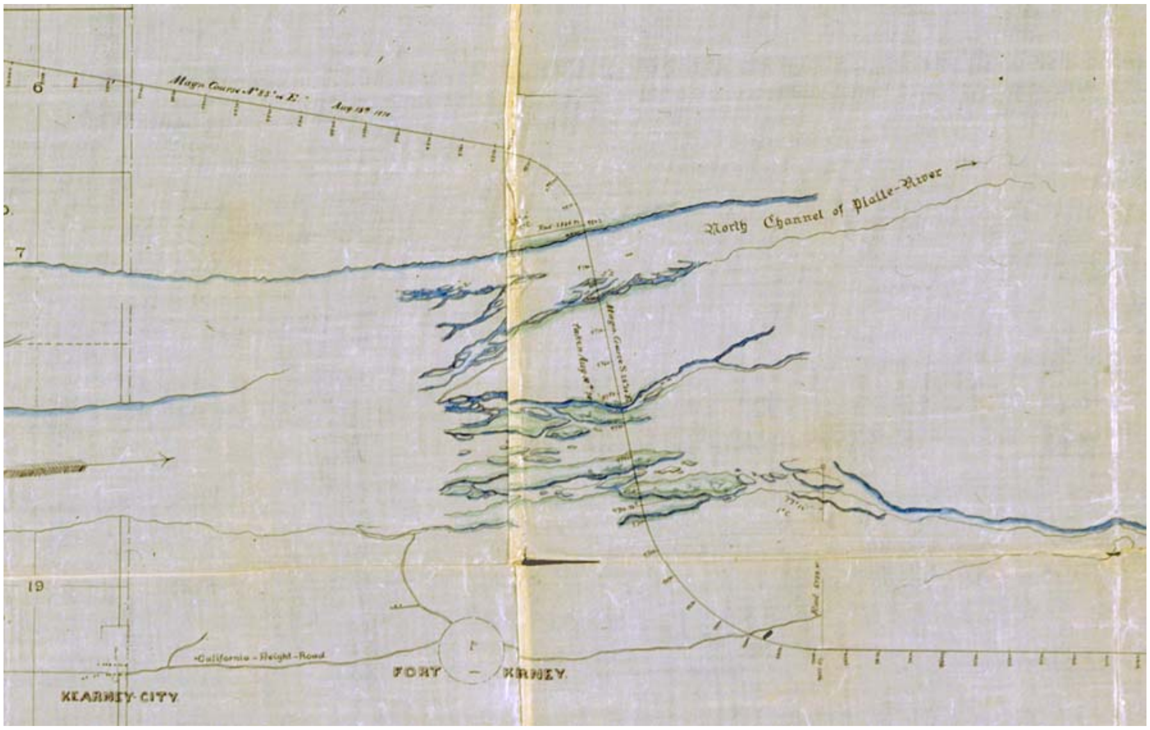

Figure 12. August 10, 1870 Map of B&M RR Crossing of Platte River at Kearney

The digital image was scaled along the railroad alignment and shows that the river corridor width (the most-external blue lines) was 8,960 ft, and the total width shown as occupied by water in 9 branches was 3,330 ft, with 5,630 ft of islands and bars. The 3,330 ft of water-occupied channel agrees well with the 3,140 ft of channel measured from Figure 10. Areas completely filled in with green entail 2,300 ft, but the vegetated width, assuming that colored fringes indicate the inclusive extent of vegetation, could be as much as the entire islands and bars, or 5,630 ft.

A 1938 photo shown in Figure 13 reveals that the position, shape, size and orientation of islands and bars at the railroad crossing (where the only between-bank detail existed in the earlier maps) are nearly identical to the same features in the detailed 1870 and 1877 maps. Scaling from Figure 13 along the railroad alignment, the total corridor width is 8,800 ft, suggesting that there has been an 8 percent increase over the corridor width in the 1860's.

Changes from the 1860's to 1938 in the "channel" width are not as easily determined as changes in the corridor width. Note in Figure 13 that water at the north end of the railroad crossing occupies only a narrow portion, scaled as 300 ft from the imagery. The southerly water-filled channel scales at 880 ft, totaling 1,180 ft. Williams data indicates that the 1938 channel width at the township line was 3,888 ft. The apparent reduction from his 1865 width of 4,610 ft to 3,888 ft is likely due to the absence of between-bank detail in 1865 that was available for his viewing in the 1938 photograph. This is suggested by the fact that the between-bank detail at the railroad bridge in the 1938 photo is practically identical to that shown in the 1860's maps. It would not be likely that the channel would change to the extent claimed by Williams at the township line, yet not change at the railroad location. It is concluded that these in-channel bars probably existed in 1865 at the township line, but weren't mapped by the GLO.

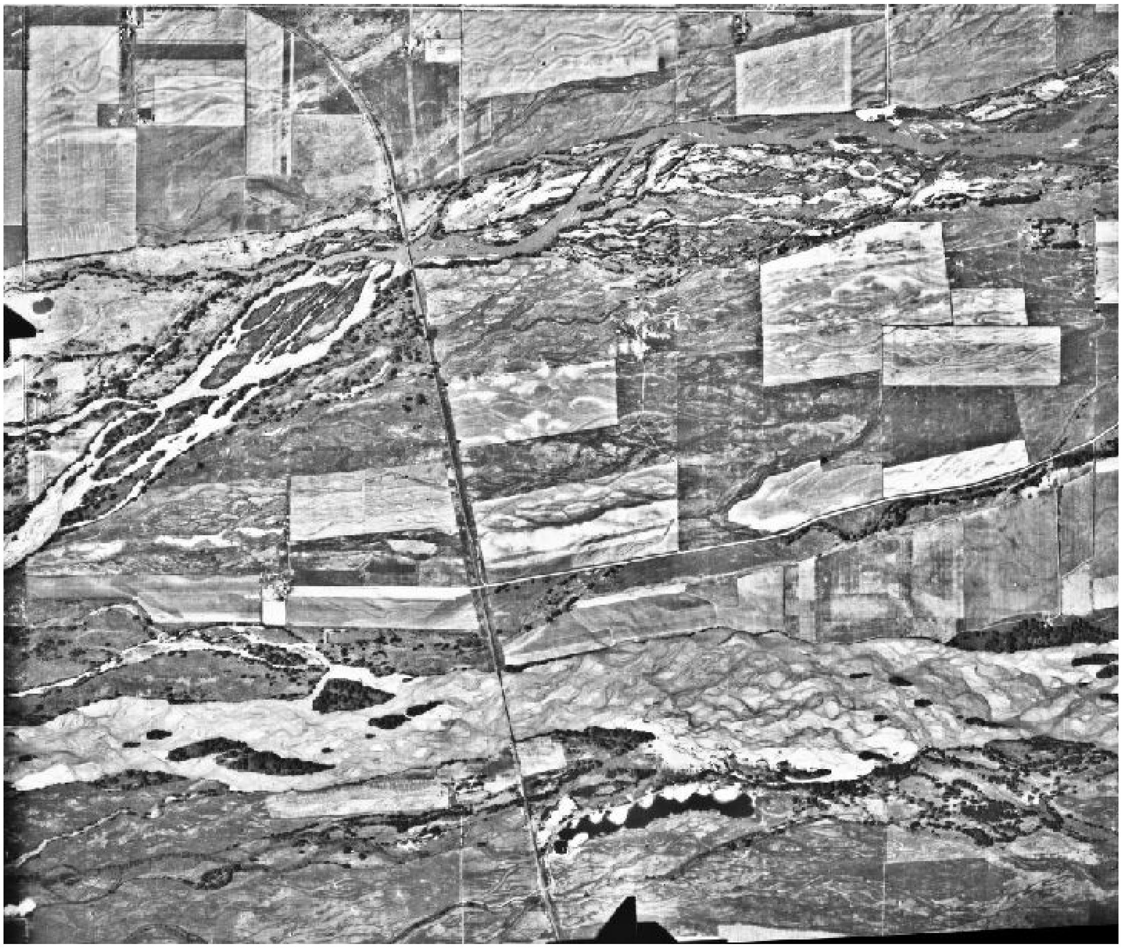

Figure 13. 1938 Aerial Photograph of Railroad Crossing in T8N, R15W

Williams used a photo taken around 1965 to conclude that the channel at the township line was 800 ft narrower than in 1938. This photo was not available for evaluation in the current study. The potential problem with both measurements is that there may be considerably more "channel" in his 1938 and 1965 photos than the width of open water and unvegetated areas. Note that the center third and north half of the corridor width in the 1938 photo has numerous interlaced branches, and much of the land between the branches is free of vegetation, particularly on the east side of the track. These branches, and the vegetated or unvegetated bars between them, are still "channel."

If Williams had excluded all vegetated areas, including low areas, in the 1965 photo analysis, he would naturally arrive at a smaller width. Our earlier assertion that unvegetated areas are not geomorphic indicators of channel is repeated. Flow rates are not compared, and the ground elevation across these vegetated braids is probably at the same elevation it was in the 1860's. The only visible difference is that more of this low ground is occupied by vegetation. Based on this, it is concluded here that defining channel width as the part of the unvegetated corridor occupied by water or sand from an aerial photo on any given day is not, and should not be used as, a measure of channel width.

The next photo in this series is a 1998 digital infrared photograph of the same location as Figures 10, 12, and 13. The image is shown as Figure 14. The former railroad bridge is now used as a people-path, and remnants of the track alignment are visible on the north and south sides of the river. Measuring the visible "wetted" and unvegetated portions and suggesting that the total represents the only remaining "channel" would be as inappropriate for this photo as it was with the 1938 or 1965 photos. Even more of the low ground is occupied by vegetation, and a gravel pit has been excavated just south of the north channel. Vegetative expansion in the low areas is increased, but it should not be concluded that the vegetated low areas are no longer "channel." The braids in the center third and northern half of the corridor are still there, and the position, shape, size and orientation of islands and bars are nearly identical to the same features in the detailed 1870 and 1877 maps.

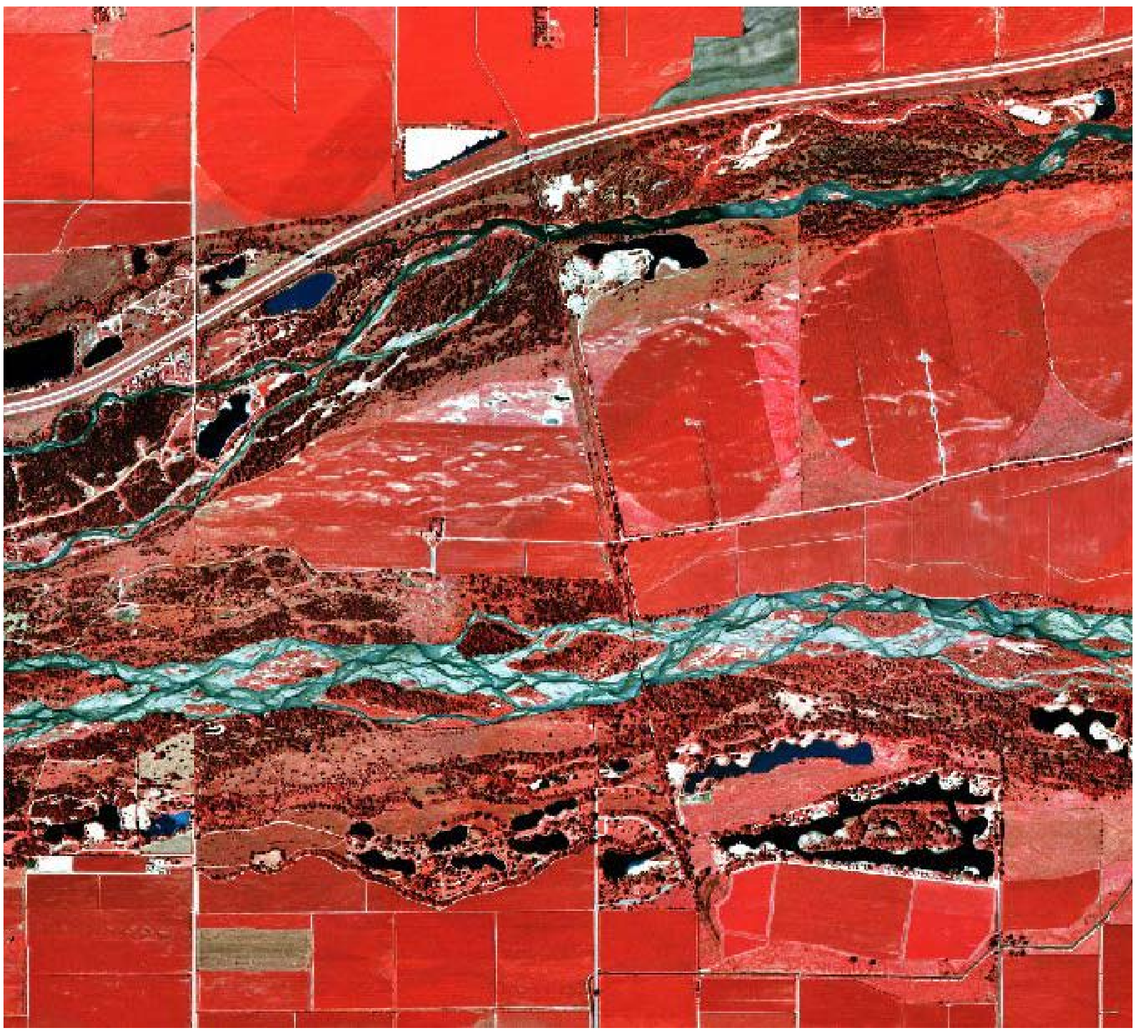

Figure 14. 1998 Digital Infrared Photograph of Railroad Crossing in T8N R15W

Scaling from Figure 13 along the railroad alignment, the total corridor width is found to be 8,950 ft, which is within measurement error of the 8,960 ft value from the 1870 map.

The various widths scaled from Figures 10, 12, 13 and 14 are compared in Table 3. The top half of Table 3 compares the channel widths at the eastern edge of T8N R16W and the bottom half relates to the railroad alignment. Williams' data is also shown in Table 3. The 129 years of maps and photos spanned by these figures reveal that the islands are permanent, and that the channel dimensions and planform morphology have been relatively unaffected by all natural or manmade activities during this period. Expansion of vegetation has occurred, but the premise that vegetated low areas are no longer channel is challenged.

TABLE 3

COMPARISON OF VARIOUS WIDTH MEASUREMENTS AT KEARNEY

Figure	Source	River Corridor (ft)	Measured "Channel" Width (ft)	Probable Channel Width (ft)
	Widths along Railroad Alignment [a/]			
10	1877 SGO Map	8,750	3,140	3,140
12	1870 RR Map	8,960	3,330	3,330
13	1938 Aerial Photo	8,800	NA [b/]	NA [b/]
14	1998 Infrared Photo	8,950	NA [b/]	NA [b/]
	Widths along East Edge of T8N R16W and West Edge of T8N R15W			
11	1865 Williams[c/]	Unstated	4,610	3,240 [d/]
11	1877 Parsons SGO	8,000	NA [e/]	3,240
10	1865 Parsons GLO	7,970	NA [e/]	3,240
	1938 Williams	Unstated	3,890	3,890
13	1938 Aerial Photo	8,210	NA [b/]	3,890 [f/]
	1965 Williams[c/]	Unstated	3,080	NA [b/]
14	1998 Infrared Photo	8,210	NA [b/]	NA [b/]

[a/] All measurements along the railroad alignment are by Parsons. Williams did not measure corridor or channel widths along this alignment.

[b/] NA = Not available, channel widths are not recorded by Parsons from aerial photos because vegetated areas mask channel areas.

[c/] Williams (1978) estimates of channel width at Kearney are located at the eastern edge of the GLO map for T8N R16W.

[d/] Probable actual channel width at the township boundary is estimated as the average of Parsons' two accurate measurements at the railroad bridge, assuming that effective width is constant in this reach.

[e/] Channel widths at the township boundary cannot be established due to lack of between-bank detail in GLO maps at this boundary.

[f/] Williams' estimate of the 1938 channel width is adopted as the probable width in 1938, but this value could not be affirmed by Parsons from attempts to scale the photo in Figure 13.

The far right column in Table 3 provides what Parsons believes are the most reliable estimates of channel width over this time period. Parsons believes that the channel width in the 1860's at the township line is less than alleged by Williams, and have recorded the estimate of the probable width as the average of two accurate widths at the railroad crossing. This assumes that the effective channel width remains relatively constant over a reach this short. Henningson, Durham & Richardson (HDR, 1983) showed that the 1930-1941 effective discharges between Overton and Grand Island, a distance of about 55 miles that brackets Kearney, were about 6 percent different, and the corresponding effective discharge widths increased downstream at about 3 ft per mile.

Because it is not possible to distinguish vegetated channel from unvegetated channel from aerial photos, we do not believe that channel width can be determined, and have recorded only channel widths scaled from the 1860’s maps in Table 3. The only values reported from photos are Williams’ estimates in 1938 and 1965. We attempted to scale from the 1938 photo, and cannot confirm his 1938 estimate. Nor can we confirm what vegetated portions he determined in 1965 were no longer channel.

CONCLUSIONS REGARDING WIDTH CHANGES AT KEARNEY

Though a 210 ft difference was noted in corridor width between the 1870 railroad map and 1877 SGO map (see Table 3), it is concluded that this is due to different surveys, and that the river corridor width along the railroad alignment is unchanged in 128 years. Note that the 1998 photo and the 1870 railroad map agree within 10 ft. This is not considered to be due to control by the abutments of river corridor width because the corridor in both images is the same for some distance upstream and downstream of the bridge.

Corridor widths along the north-south township line were 30-ft different between the 1870 and 1877 GLO maps, which is not significant, but the width appears to have widened by 210 ft by 1938 and stayed at that width since. A reduction in corridor width would be expected due to cultivation encroachment by agriculture, but the widening is not easily explained, and may be the result of measurement error, or that the corridor has widened due to one or more of the braids having shifted against the 1860’s meander line.

It is concluded, in the absence of cross-sectional data, that the channel morphology that existed in the 1860’s is potentially relatively unchanged, and the only documented change is in expansion of vegetation. Islands, bars, and other features in 1870 and 1998 are exceptionally similar. The basis of this is the remotely-sensed absence of change in morphology along the railroad alignment, where the only complete record was found for a detailed at-a-station analysis. Detailed surveys along the township line and railroad crossing under present conditions should be performed to further assess this preliminary finding. So also should similar comparisons be made between 1860’s GLO maps and recent surveys of cross-sections such as the 1989 USBR data. Additional expansion of vegetation has definitely occurred at Kearney, but the river corridor width and channel widths have not changed to the extent hypothesized in the reconnaissance-level effort described by Williams.

The analysis also reveals that estimates of “channel” widths from the GLO maps may be similarly overstated at other locations. Morphology at the railroad crossing has remained constant, and proof that it would not have remained the same a few miles away at the township line has not been provided and is scientifically refuted here.

CORRELATION OF WIDTH, PRECIPITATION AND FLOW

Considerable debate has ensued since Williams (1978) analyzed changes in unvegetated widths of the river. His discussion points out that he was conducting a reconnaissance-level study, yet many have adopted his results as dogma. More than one writer has called his article the “definitive work” on the subject, which does not agree with his own appraisal. He concluded that alleged decreases in channel width are caused by a 70-percent depletion in water discharge, but this cause-effect relationship was not fully demonstrated by his data or publication. Though a significantly high annual flow occurred in the early 1970's, Williams made a decision to disregard this phenomenon in arriving at his conclusions.

His analysis further concluded that "any long-term changes in streamflow probably are not attributable to changes in climate." These climate trends were not reported in his paper, and this claim is refuted somewhat here, and in depth in the Task D1/D2 report. The question of whether such depletions have occurred due to development in the basin, or whether any actual morphologic changes simply reflect swings in climate, is discussed in greater detail in the Task D1 and D2 report. As a means of assessing whether the 1865 to 1962-72 period studied by Williams was a homogeneous climatic period, Kwapnioski and Dekleva (1997) acquired basin wide precipitation records dating back to 1869 and graphed the departures from normal. His resulting graph is shown in Figure 15.

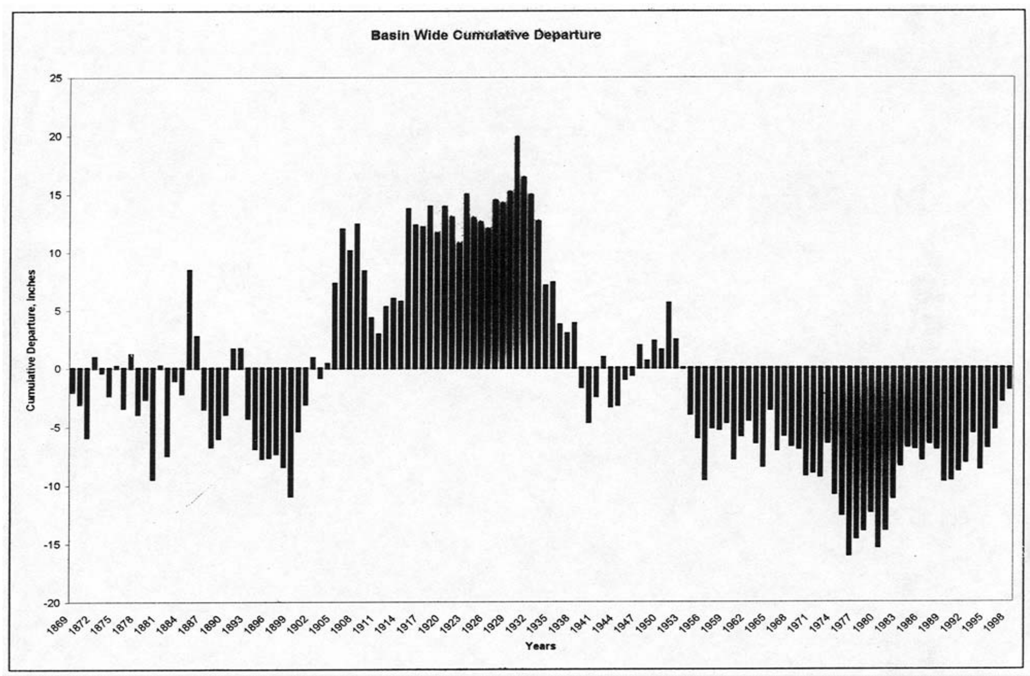

Figure 15. Cumulative Departure of Basin Wide Precipitation from 1869 to 1999 (after Kwapnioski and Dekleva, 1997)

Reliable streamflow data were not available until around 1914. Prior to the implementation of continuous water stage recording and streamflow measurements, estimates of peak flows were made by indirect methods, or when measurements were made, considerable periods of time between measurements were filled in with estimates of flows. Draft copies of Williams (1978) paper were reviewed and revealed that he originally left gaps in his charts and subsequently filled in the blank periods.

To assess the correlation of precipitation with continuous discharge records, Kwapnioski acquired streamflow records starting in 1914 and graphed departures from average flows with precipitation departures for this period. His results are shown as Figure 16.

The graph reveals a strong graphical correlation and indicates that extreme swings in climate occurred during the recorded history. Further, it shows that the climatic and hydrologic conditions during Williams' study period were far from homogeneous. A wet period was experienced, beginning around 1900 and continuing to about 1930, accompanied by steeply-sloped increases in cumulative departures from average flow conditions. Figure 8 reveals that the channel width declines alleged by Williams were the greatest during this period.

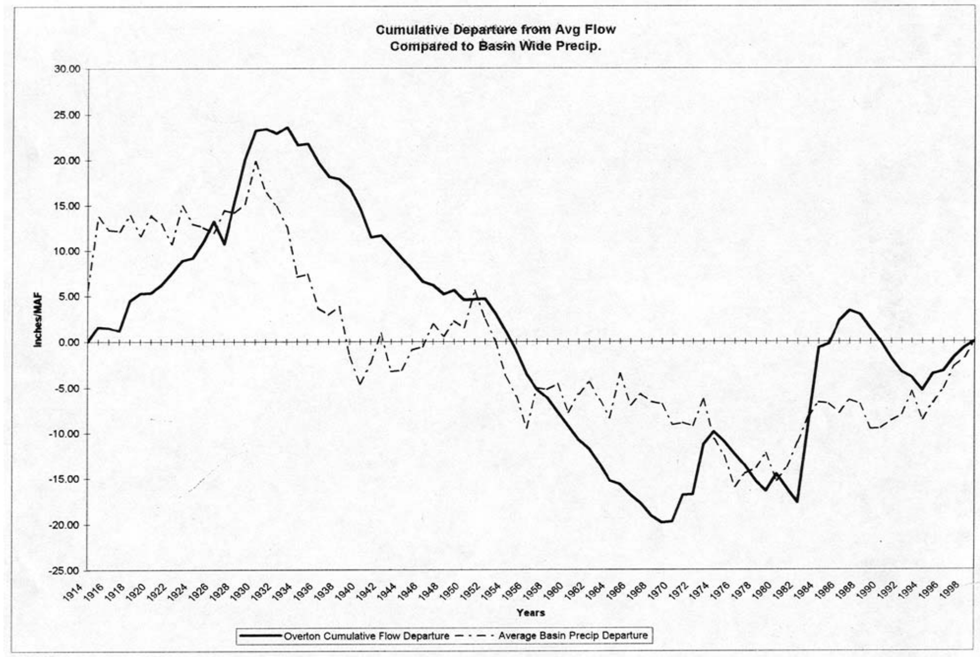

Figure 16. Comparison of Basin Flow with Basin Wide Precipitation (after Kwapnioski and Dekleva, 1997)

To analyze Williams' hypothesis in greater depth, Kwapnioski and Dekleva (1997) graphed average annual flow at the Overton gage, superimposed on Williams' graph of width change at the same gage, as shown on Figure 17. Kwapnioski and Dekleva (1997) also included annual flow data from 1977 through 1998, which was not available at the time Williams made his assertions.

The figure reveals that a downward swing in annual flows occurred between 1926 and 1940, which was paralleled by the width reduction of that period. As soon as that well-known drought ended and annual flows ceased to decline, the channel width graph (and all the other graphs of Figures 1-7) made a sharp turn to horizontal. The horizontal lines then began their upswing in the 1970's and early 1980's. This wet period is clearly evident in Kwapnioski's graphs, shown here as Figures 15 and 16.

Figure 17 suggests that the average annual flows have recovered. If the reductions cited by Williams were related to development, flows would not have increased because the diversions and storage still exist. It is suggested by this updated data that the channel widths are definitely influenced by cycles of climate, and that the widths themselves are cyclic. Climatic changes and their effects on the stream morphology are detailed in the Task D1/D2 report. Climate cycling was clearly instrumental in the changes in slope of these curves. Other explanations have not shown this high degree of correlation.

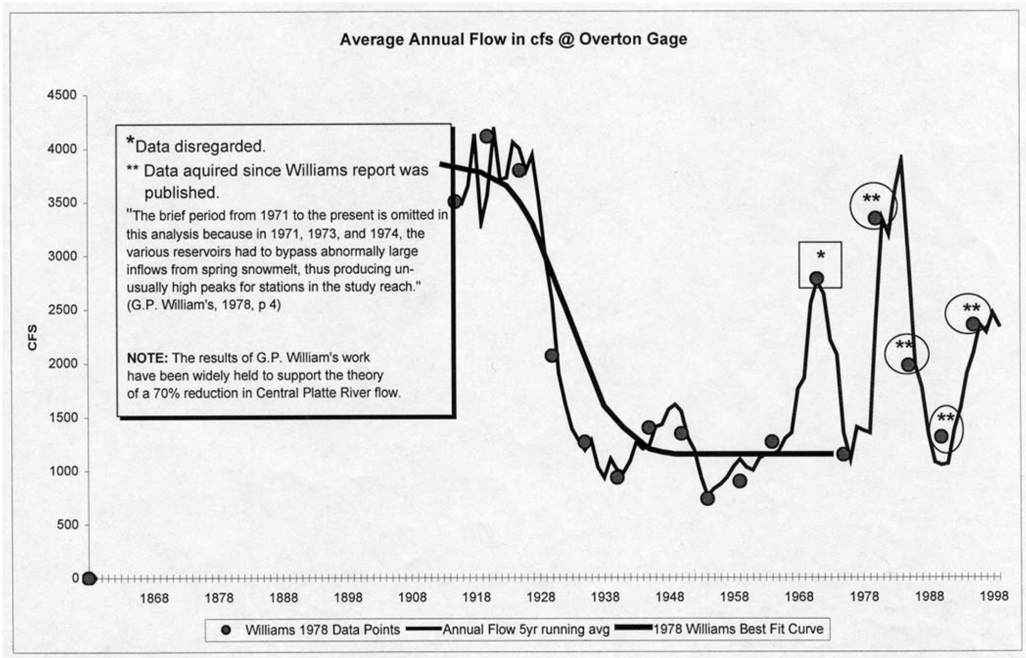

Figure 17. Comparison of Annual Flow Changes with Width Changes

CORRELATION OF WIDTH WITH PEAK FLOW RATES

Williams (1978) concluded that decreases in channel width were due to depletions in streamflow. He did not specifically attribute the width reductions to changes in peak flows. More recently, Murphy and Randle (2001) focused their investigations on the effects of reductions in annual peak flows on reductions in the width of the “active” channel, defined as that part of the meander width that is “activated” when high flows surpass the tops of bars and mobilize the sediments that are supporting emergent vegetation which had grown on the banks and bars since the last annual spring peak. The 23 page document contains 61 references to “peak,” “high,” or “large” flows as related to causing the reductions in active channel widths. They concluded that “the channel narrowing…was caused directly from a reduction in peak flows” (Murphy and Randle 2001, p. 19). Though they do not use the term, their descriptions appear to support the hypothesis that the width of the channel in the Platte is permanently affected by and controlled by evulsions associated with flood events.

Murphy and Randle’s proposed remedy is that the channel width could be practicably increased by increasing annual peak flow. The empirical relationship they proposed for width management is $W = Q_p^{0.41}$, where Q_p is the annual peak value in cubic feet per second (cfs). The equation was attributed by Murphy and Randle (2001) to Yang (1991). Their calculations with this equation led them to conclude that the active channel downstream of the Johnson-2 return (Kearney falls in this segment) could be widened by 20 percent over its current value through implementation of annual peak discharges between 6,000 and 8,000 cfs. It should be noted that the 20 percent estimate of possible restoration matches the amount of 1865 to 1965 width reduction noted by Williams for this same reach. No discussion is provided of the well-known process by which temporarily evulsion-widened channels return to their former morphology, or of the fact that effective discharges control equilibrium morphology.

The narrowing of the active channel is attributed by Murphy and Randle to the expansion of vegetation allowed by less-effective scouring due to reduced annual spring floods. Though numerous other potential causes of vegetation expansion have been identified by others, only scouring was discussed by Murphy and Randle. Their explanation regarding the role of peak flows was not reconciled with Williams' conclusion that reduced annual flows caused the width reductions.

As a note on the subject of reductions in annual flows from the 1860's to 1965 reported by Williams, the earlier discussion of effects of fire and timber harvesting in the 1800's are relevant. Troendle and Nankervis (2000) conclude that the recovery of the forests from this "damage," and the associated evapotranspiration (ET) by the replacement growths, have resulted in estimated decreases in annual yields of 140,000 acre-feet (ac-ft) or more. They also note that timber stands in the North Platte River Basin have been impacted by natural disaster (fires) and human intervention (harvesting) "more that many other places in the National Forest Service Region 2."

Murphy and Randle used indirect estimates, sums of peak flows from the North and South Platte Rivers, and direct ratings of peak annual flows to graph annual peak flows at Lexington and Overton from 1903 to 1998. The graph reveals an apparent "norm" around 15,000 cfs from 1903 to about 1935, followed by a relatively quantum decline to about 7,500 cfs afterward. Though no data were provided prior to 1903, they concluded that "as annual peak flows continued to reduce over the period of 1865 to 1960, so too did the width of the active river channel." In the absence of data for peak flows between 1865 and 1903, this conclusion could not be verified and is considered unfounded. It is apparent from the context of their statements that Murphy and Randle assumed that the high but declining peak flows from 1903 to about 1935 represented a continuation of an undocumented trend between 1865 and 1903. This assumption, if made, is unfounded as well. Also, analysis of the 1870 to 1900 precipitation records suggested that the 1870's peaks would have been lower than normal because of the sub-normal precipitation.

Some additional research into the literature on basin yields and peak flows in the 1800's was conducted during this investigation. Several references were discovered describing the effects on the annual runoff and peak flow rates by destruction of the forests from timber harvesting and careless fires set in the 1800's by "swarms" of outing parties each summer (Crafts, 1900). Crafts (1900, p. 133) describes efforts by farmers in Northern Colorado to preserve the forests as a means of sheltering snow in order to "prevent their too sudden melting and consequent waste by excessive floods." Other similar scientific accounts of the effects of man's need for timber, recreation and irrigation in the early to late 1800's caused severe, and presumably unnatural, flooding, which apparently culminated in the actions typified by that taken around 1900 to set aside the Medicine Bow Reservation. Troendle and Nankervis (2000) report that ET losses due to recovery of the forests in the North Platte Basin over their condition 140 years earlier (i.e. 1860) has resulted in a decrease in annual flow of 185,000 ac-ft or more. The U.S. Department of Agriculture (USDA, 1997a) report that the two most influential factors on yield in the Platte Basin are timber harvest and fire. In addition, they observed that the effects of these factors persist for about 80 years. A similar document (USDA 1997b) assessed the same phenomenon of increased yields from forest harvests in the Routt National Forest, resulting in the conclusion that this causes "the peak flow to increase in intensity and duration above baseline conditions."

These studies, combined with other documents, reveal that significant harvest of the mountain timber in Platte River watersheds occurred with settlement and development in the 1800's, strongly suggest that the spring mountain runoff toward the end of the 1800's would be abnormally high (above baseline conditions).

More detailed analysis of effects of (actually the "value" of) timber harvest on increasing peak flows and water yields is provided by Troendle and Nankervis (2000). They observed in the North Platte Basin that the largest increases in seasonal flows occurred during the wettest years following timber harvest. They further observed that the smallest increases in seasonal flow following harvest usually occurred during the driest years, leading to their "mandate" that adequate storage be made available to make the increases in yield available during periods of low flow. Drought and wet cycles are indicated in Figure 9, and much greater analysis of short and long term variations in precipitation are provided in the Tasks D1 and D2 report.

The point of this section is that the moderately high annual peak flows around the turn of the century may be abnormal, resulting from man's impact on forest watersheds. Murphy and Randle's hypothesis that the high peak flows around 1903 are indicative of natural, long-standing pre-development conditions is contradicted by the scientific evidences of Crafts (1900) and Troendle and Nankervis (2000). The latter strongly suggest that the occurrence of abnormally high annual peaks around this time were the result of extreme intentional and unintentional losses of forests that occurred in the mid- to late 1800's. Flash floods being experienced in New Mexico's and Colorado's eastern slopes from recent fires, and a significant volume of other research, support the hypothesis that accelerated loss of wooded areas from fires produce abnormally high flood runoff rates.

CHANGES IN CHANNEL GEOMETRY AT USBR CROSS SECTIONS

Four locations having historical cross sections at or near the 1989 USBR sections were available in the literature or were created to examine the changes of cross section geometry over time. Figures 18 through 21 are plots of the cross section at Elm Creek, Grand Island, Lexington, and just west of Brady, each drawn at two different points in time. Discharge rates are not known for the dates of measurement, so the interpretation of change with time is subjective. As shown later, rather dramatic changes can occur in the same cross section for various flow rates over relatively short periods of time. Figures 22 and 23 were prepared to demonstrate this variability of cross section shape with discharge rate during any given year. The latter two graphs were created from streamflow measurements taken within a relatively short period of time.

Figure 18 is a comparison of cross sections located at Elm Creek in 1989 (thin line) and 2001 (thick line). This graph suggests that the channel has degraded slightly at the lowest channel braid but aggraded for the majority of the cross section at the braid locations on the right. As noted previously, the dates of the sections were not always available, so flow rates could not be compared.

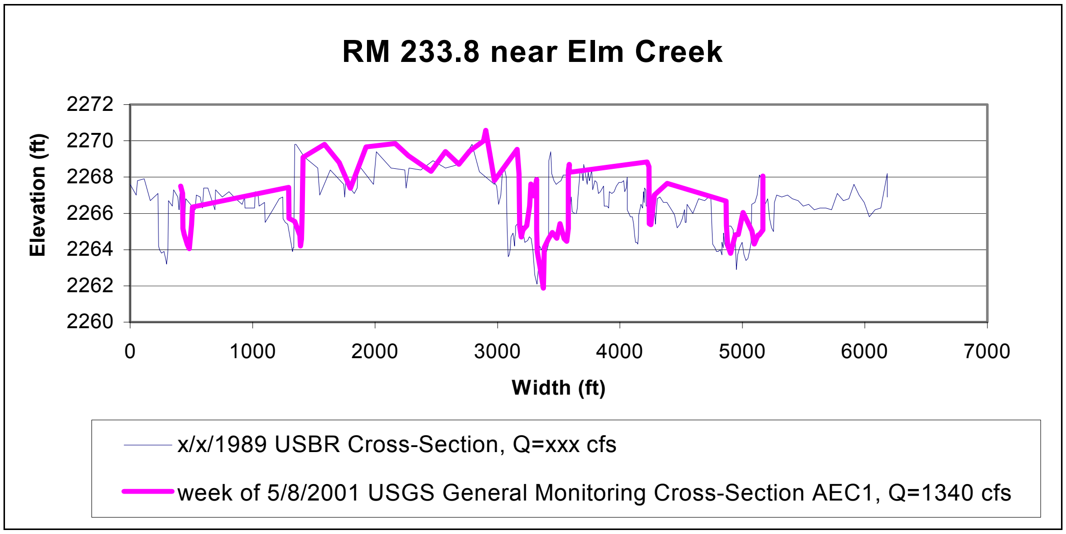

Figure 18. Changes in Platte River Cross Section at Elm Creek between 1989 and 2001

Figure 19 is a comparison of cross sections location near Grand Island in 1989 (thin line) and 1995 (thick line). The 1995 cross section is relative to an arbitrary datum and is at a location approximately 3500 upstream of the 1989 cross section. Though plotted here, the graph is not used in any conclusions of this investigation because of the distance between them and because of the unknown vertical correspondence and flow rates.

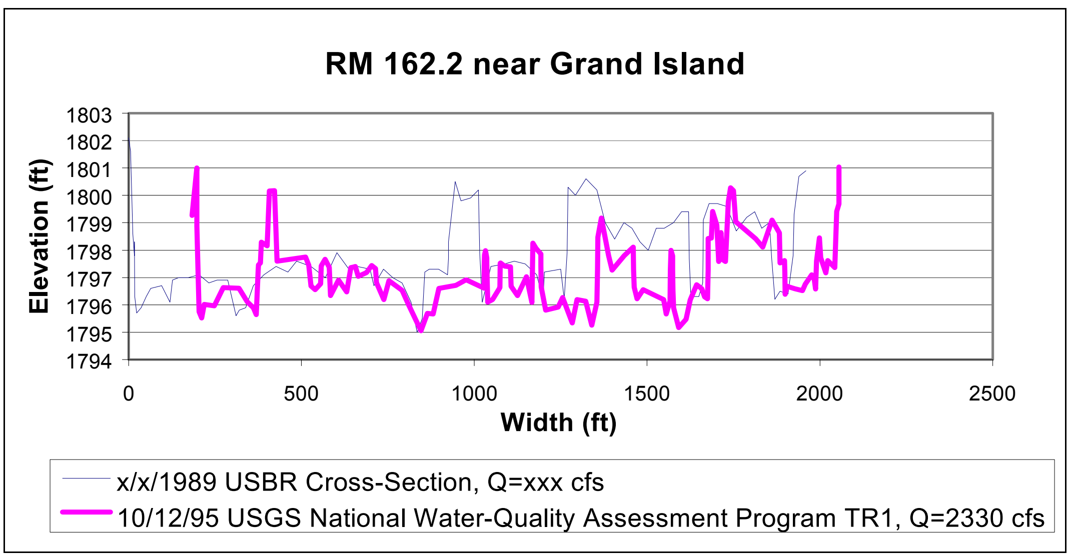

Figure 19. Changes in Platte River Cross Section at Grand Island between 1989 and 1995

Figure 20 is a comparison of cross sections located near Lexington in 1989 (thin line) and 1971 (thick line). This graphs suggests that the larger channels have become wider and may have degraded.

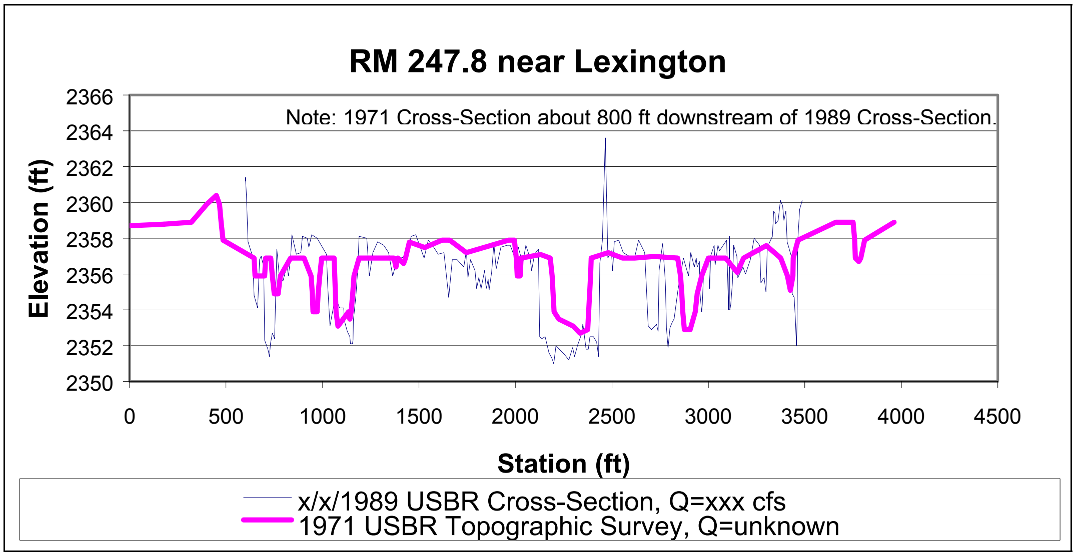

Figure 20. Changes in Platte River Cross Section at Lexington between 1971 and 1989

Figure 21 is a comparison of cross sections located west of Brady in 1989 (thin line) and 1923 (thick line). Only the main channel was surveyed by USBR at this location in 1989. Though a width of over 4 mi is indicated by the 1923 survey, this cross section was extended out of the Platte River corridor into Plum Creek on the far left. Thus the portion considered to be Platte River corridor is the segment from about station 15,500 to 19,300. The vertical datum is the same but the horizontal datum is arbitrary for the 1923 cross section. This graph suggests that the main channel is wider than any single segment in 1923, and that it may have degraded.

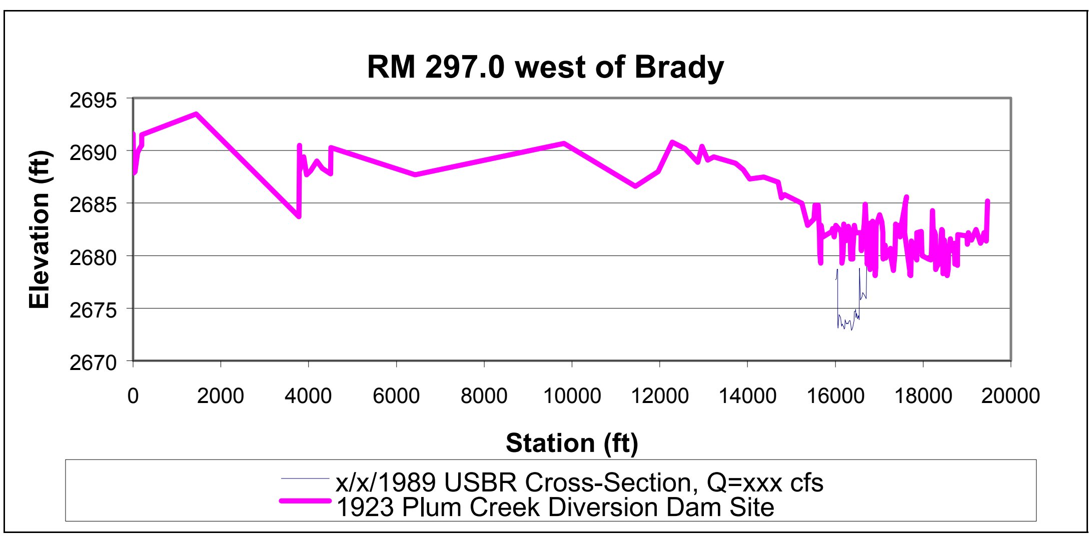

Figure 21. Changes in Platte River Cross Section at Brady between 1923 and 1989

Figure 22 shows four cross sections that were created from streamflow measurement data at Grand Island. The measurements were made within a two-month period in 1928 at different flow conditions. The graphs show that the depth and total width of channel occupied by water increases with flow rate. The lowest point of the channel (thalweg) becomes about 6 ft deeper between discharges of 19,944 cfs and 2,480 cfs. It is known that when high flows occur, the bed material mobilizes and a depth measured during the event would be for a scoured condition that likely abates during the recession of the flood hydrograph. The differences in channel thalweg elevation for the three smaller flows indicates that comparing cross sections without recognizing the flow rate differences could lead to incorrect conclusions regarding aggradation and degradation.

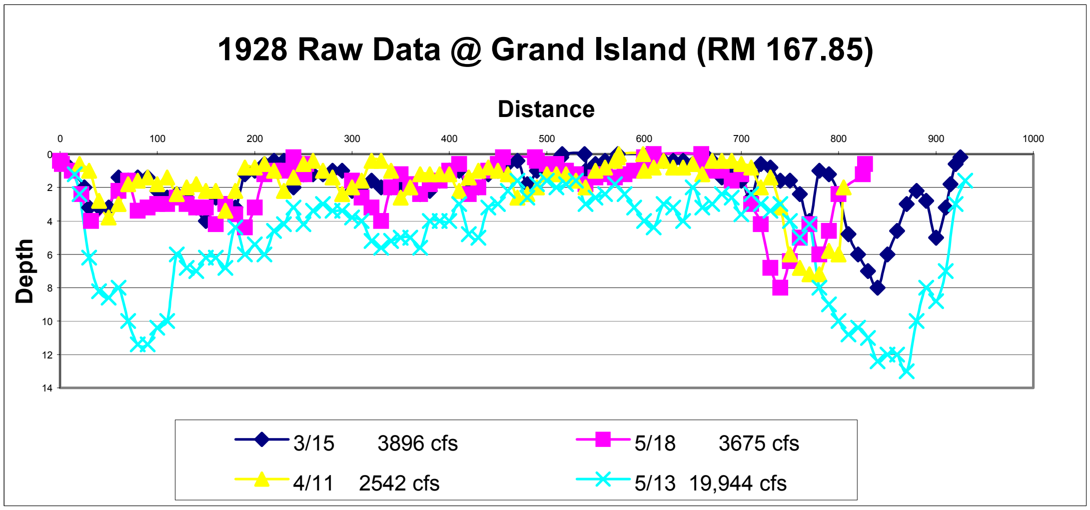

Figure 22. Effect of Flow Rate on Channel Cross Section at Grand Island

Figure 23 shows cross sections that were created from 12 streamflow measurements at Overton within in a nine-month period in 1928 at different flow rates. The graphs show that the width occupied by water stays relatively constant at this location, and that the channel thalweg is about 10 ft deeper at 13,296 cfs than at 3,480 cfs. Thalweg elevations for the other flow rates vary considerably, again demonstrating that conclusions regarding aggradation and degradation can only be made when comparing cross sections taken at comparable flow rates.

CROSS SECTION SEGMENT SPACING OF THE SEDVEG MODEL

Sixteen of the 1989 USBR cross sections were used by the EIS Team in developing the SEDVEG model. Examination of the data provided by the EIS Team reveals that relatively closely-spaced readings were used in the channel portions, and overbanks were much less detailed, sometimes being represented by straight lines between bank elevations at the channel locations. It is not known whether raw USBR data at any cross section was edited or abbreviated for use in the SEDVEG model.

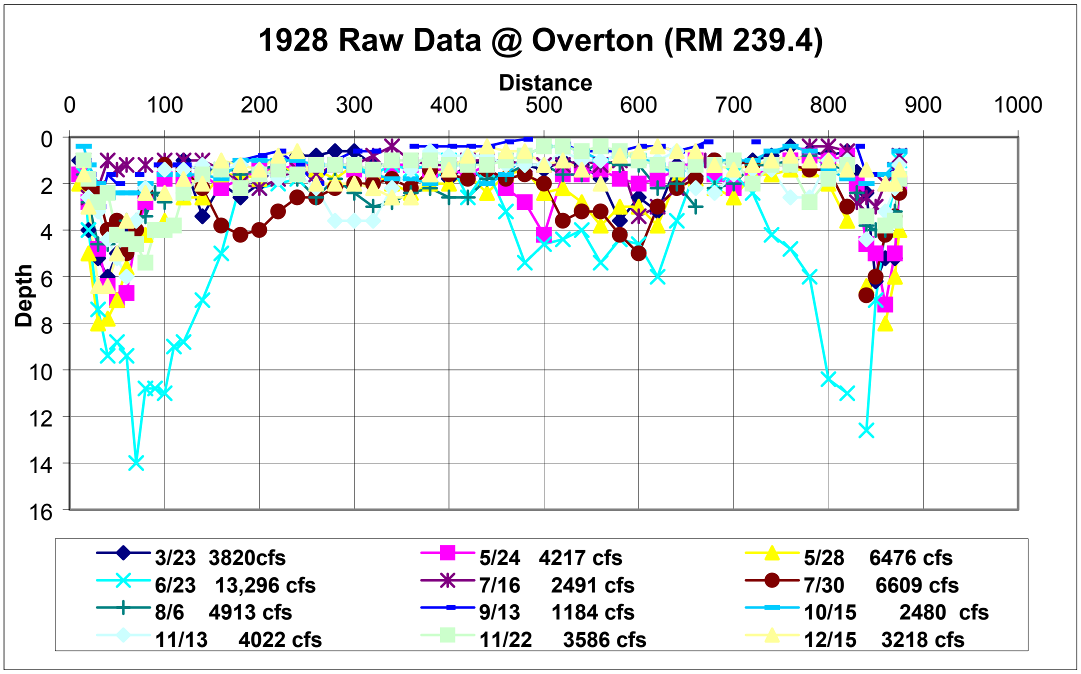

Figure 23. Effect of Flow Rate on Channel Cross Section at Overton

Table 4 lists the SEDVEG cross sections, their river mile, the distance to the upstream cross section, the distance to the nearest upstream bridge and the distance to the nearest downstream bridge. The cross sections are numbered from east to west, with the most downstream cross section being the lowest river mile. Excluding the distance between river mile 258.3 and 310.2, the average cross section spacing is 6.86 mi. The smallest distance between sections is 0.7 miles and the largest distance is 51.9 mi. The distances from the sections to bridges are all greater than 0.5 mi.

TABLE 4

SEDVEG MODEL CROSS SECTIONS

Cross-Section #	River Mile	Distance to Next Upstream Section (mi)	Distance to Nearest Upstream Bridge (mi)	Distance to Nearest Downstream Bridge (mi)
1	162.2	8.1	3.5	5.0
2	170.3	8.1	1.5	2.5
3	178.4	4.8	3.5	2.5
4	183.2	5.1	4.0	1.0
5	188.3	11.2	8.0	1.0
6	199.5	3.8	2.5	3.5
7	203.3	6.5	3.5	1.5
8	209.8	10.0	5.0	2.0
9	219.8	8.9	5.0	4.0
10	228.7	8.8	2.5	4.5
11	237.5	6.5	2.0	6.5
12	244.0	5.8	8.0	4.5

TABLE 4 (Continued)

SEDVEG MODEL CROSS SECTIONS

Cross-Section #	River Mile	Distance to Next Upstream Section (mi)	Distance to Nearest Upstream Bridge (mi)	Distance to Nearest Downstream Bridge (mi)
13	249.8	0.7	2.5	10.0
14	250.5	7.8	1.0	11.5
15	258.3	51.9	8.0	0.5
16	310.2	N/A	> 2.0	9

To evaluate whether the particular cross sections selected for use in SEDVEG are representative of the river, Parsons compiled all the 1989 USBR cross sections and extracted various dimensions for comparison. Table 5 lists statistical data extracted from all USBR cross sections within the SEDVEG model reaches. For each SEDVEG rive mile, starting downstream, the section width is compared with widths for all other USBR cross sections halfway between respective SEDVEG section locations. A "reach" is defined as half the distance to the next upstream and downstream SEDVEG cross sections. The bank-to-bank (river corridor) width at each SEDVEG cross section is compared in the table with the average width within the reach, the percent difference between the cross section's width and the average for the reach, the number of cross sections within the reach, and the minimum and maximum width within the reach.

TABLE 5

CHARACTERISTICS OF SEDVEG MODEL CROSS SECTIONS

River Mile*	Total Width (ft)	Avg Total Width for Reach (ft)	Percent Difference	# of Sects.	W_{min} (ft)	W_{max} (ft)
162.2	1960	N/A	N/A	1	N/A	N/A
170.3	6683	5294	26%	5	2235	10529
178.4	9815	9587	2%	4	7988	10896
183.2	8756	N/A	N/A	1	N/A	N/A
188.3	3081	2885	7%	2	2688	3081
199.5	2563	3023	-15%	5	1966	4837
203.3	6300	N/A	N/A	1	N/A	N/A
209.8	6369	7662	-17%	4	5877	9500
219.8	3012	3692	-18%	2	3012	4372
228.7	1292	3018	-57%	5	1292	5150
237.5	5740	4662	23%	3	2064	6181
244.0	5075	4639	9%	3	2229	6612
249.8	706	1796	-61%	2	706	2885
250.5	1187	N/A	N/A	1	N/A	N/A
258.3	4445	3628	23%	6	597	6703
310.2	1107	1117	-1%	10	456	2906

* Note: Cross-sections within one bridge length upstream and Two bridge lengths downstream are excluded from this list.

No additional USBR cross sections were available at river mile 162.2, 183.2, 203.3 and 250.5. Therefore none of the analyses were performed for these reaches.

Figure 24 is a plan view of an ArcView® file of river miles 170.3 through 162.2, prepared to compare the locations of the SEDVEG and other USBR cross sections with details of the river planform. The cross sections surveyed and used in the SEDVEG model are highlighted with a dark line. The cross sections surveyed by the USBR but not used in the SEDVEG model are highlighted with a light line. These cross section locations were superimposed onto a 1998 Digital Infrared Photograph.

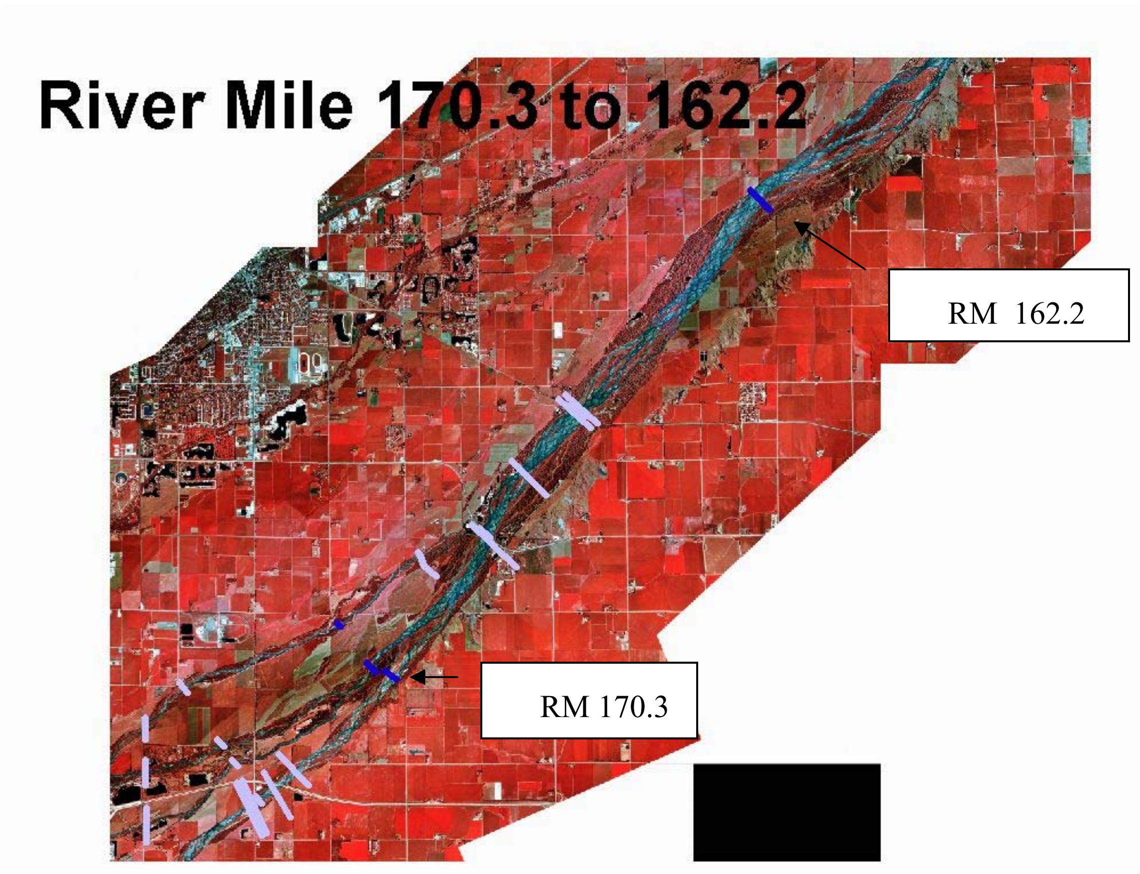

Figure 24. Locations of SEDVEG Model Cross Sections Relative to Available USBR Cross Sections.

The cross sections identified on Figure 24 are plotted in Figure 25. The graph was prepared to allow examination of the variability of cross sections in the river segment of Figure 24 between the two adjacent USBR cross sections used in the SEDVEG model. The cross section at river mile 162.2 is quite different than the cross section at river mile 170.3. At river mile 162.2 the Platte is a single branch that is narrower than the three anabranches at river mile 170.3. The section at river mile 162.2 is the second narrowest cross section on the figure.

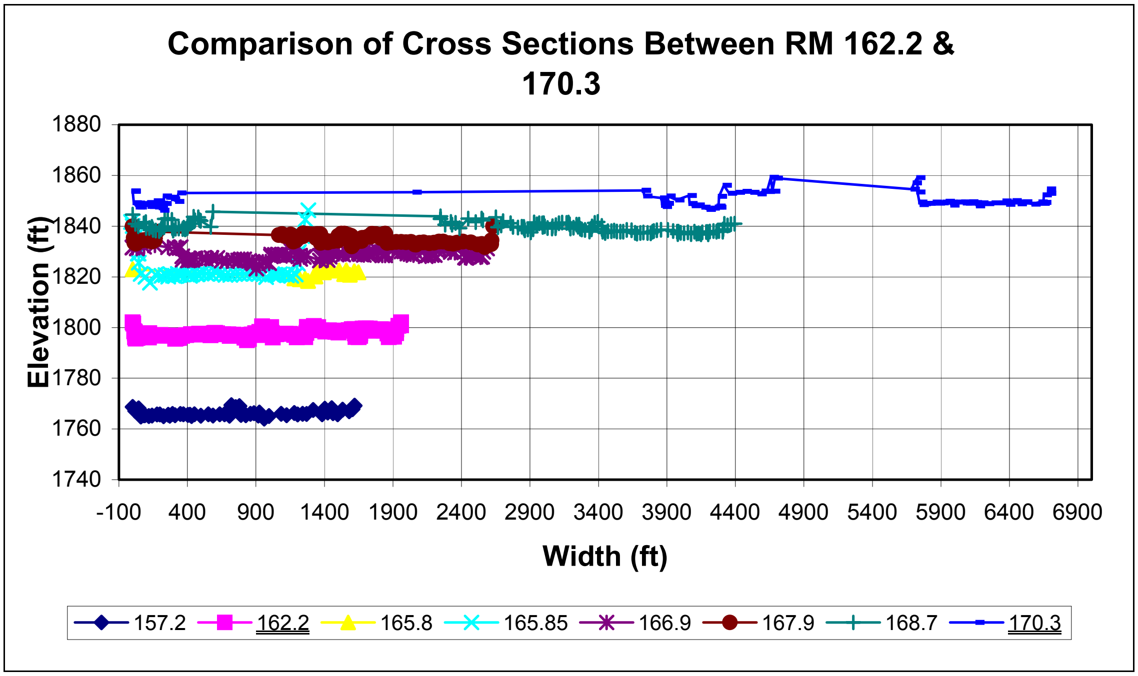

Figure 25. Variation in Channel Cross Section Shape between SEDVEG Cross Section Locations Shown on Figure 24.

Though outside the range of the SEDVEG model, the USBR cross section at river mile 157.2 is plotted on Figure 25 to show that the channel at the first section in the model, river mile 162.2, is similar to the nearest downstream cross section. The cross section at river mile 162.2 (second from the bottom) is considerably different than the cross section at river mile 170.3 (top line). This graph confirms that at river mile 162.2 the corridor of the Platte is a single braided channel that is much narrower than the sum of the three braided segments at river mile 170.3. The other sections shown confirm that the river widens and narrows between the modeled limits, and that the number of branches and intermediate high ground areas vary widely between the two sections used in the model.

Figure 26 is a plan view of an ArcView® file of river miles 228.7 through 219.8. The cross sections surveyed and used in the SEDVEG model are highlighted with a dark line. The cross sections surveyed by the USBR but not used in the SEDVEG model are highlighted with a light line. These cross section locations were superimposed onto a 1998 Digital Infrared Photograph.

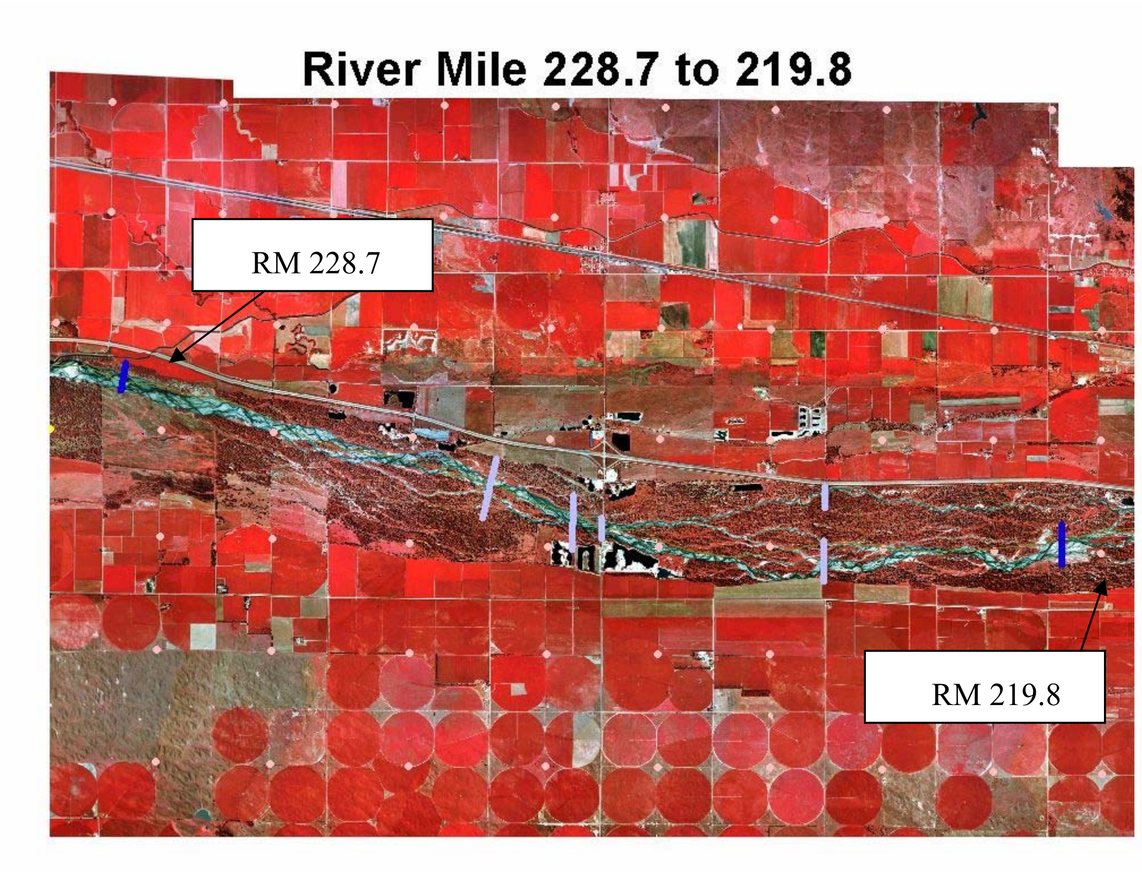

Figure 26. Locations of SEDVEG Model Cross Sections Relative to Available USBR Cross Sections.

Figure 27 is a 1938 black and white photograph of same location depicted in Figure 26 of river miles 228.7 through 219.8. The ArcView® file of cross-section locations were also superimposed on top of the photo.

Figure 27 was also used to examine the variability in the plan form of the river between two adjacent USBR cross sections used in the SEDVEG model. It allows determination of whether the segment spacing used in SEDVEG is representative in 1998 as well as in earlier years because the model spans this period of time. At river mile 228.7 the river is narrower than at the adjacent cross section (in light purple) to the east. Figure 27 reveals that the full width of the channel in 1938 was not surveyed in later years at either river mile.

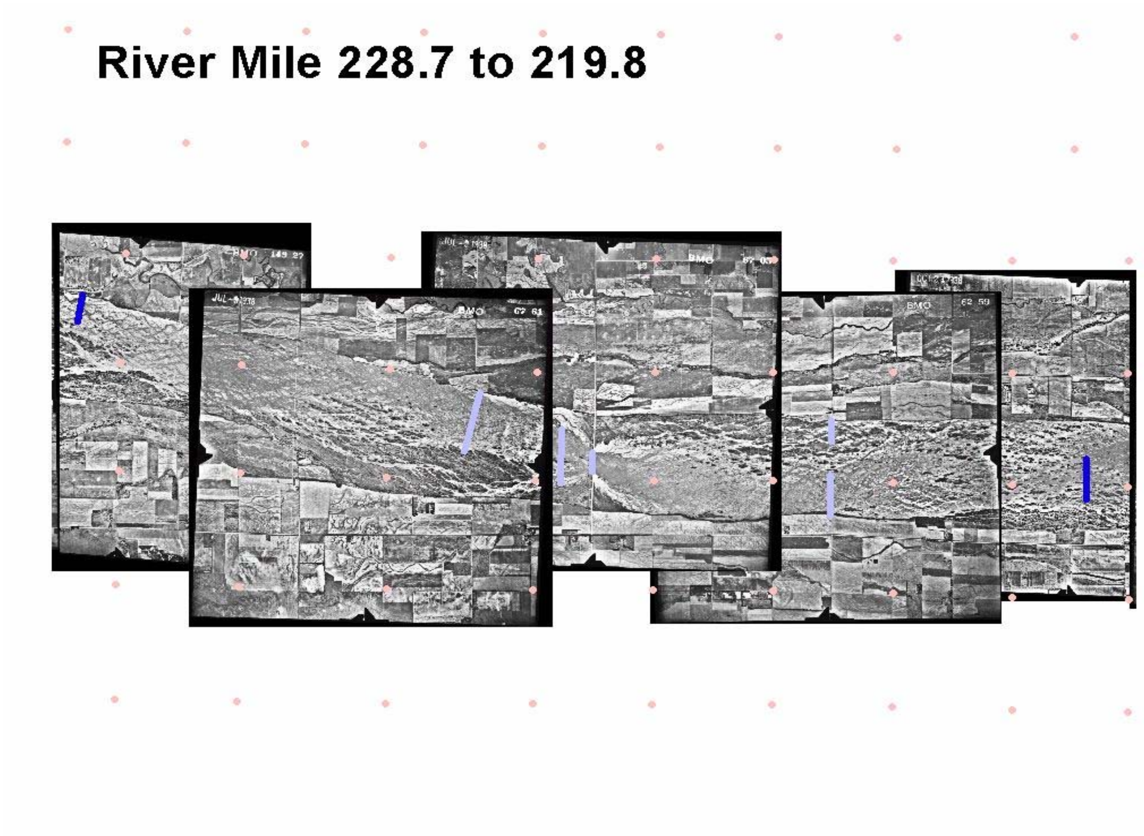

Figure 27. Locations of SEDVEG Model on 1938 Photos

Figure 28 shows the cross sections that are located on Figures 26 and 27. It was used to examine the changes in the plan view of the river between two adjacent USBR cross sections used in the SEDVEG model. The cross section at river mile 228.7 (in bright blue) at the left is quite different than the cross section at river mile 219.8 (in bright blue) at the right. At river mile 228.7 the Platte River is a single branch that is narrower than the multiple branches at river mile 219.8. At river mile 219.8 one of the branches to the north was not surveyed.

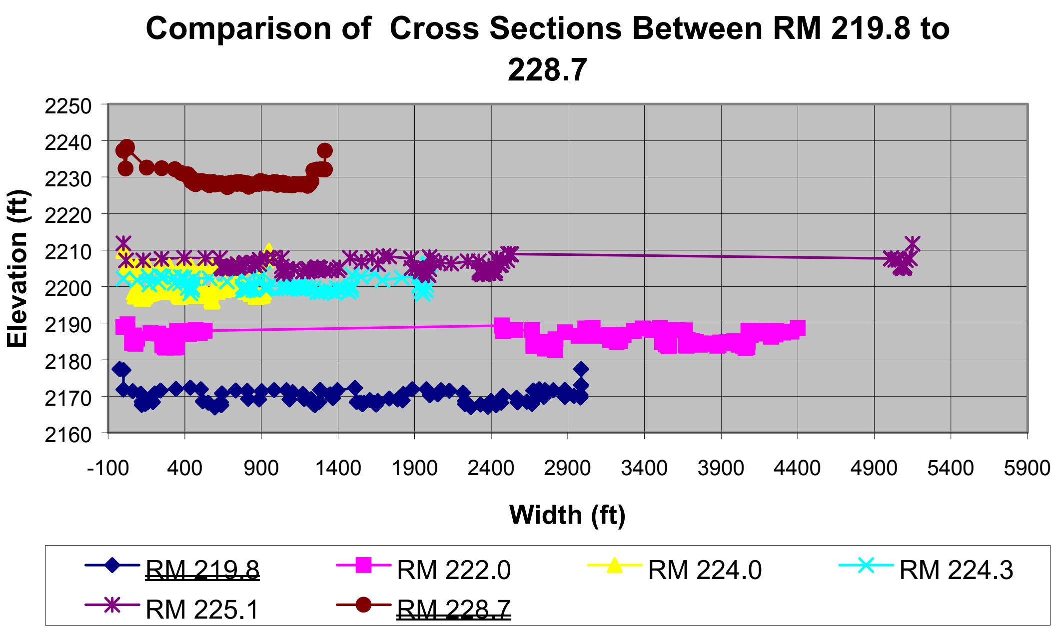

Figure 28. Variation in Channel Cross Section Shape between SEDVEG Cross Section Locations Shown on Figure 26.

The cross section at river mile 228.7 at the top of the figure is different than the cross section at river mile 219.8 at the bottom. This graph confirms that at river mile 228.7 the Platte River is a single branch that is narrower than the multiple branches at river mile 219.8.

CHANGES IN PLATTE RIVER PROFILE

Changes in profile of a river can be responsible for changes in cross section and planform. It is highly likely that a detailed analysis of planform variability in the river would reveal a high correlation with slope changes. Slope provides the energy for movement of water and sediment, and it would be expected that planforms could be associated with slope where other factors are absent. Two earlier investigations were discovered that contained profiles of the Platte River. The oldest was by Gannett (1901). He used "atlas sheets of the USGS" to develop the profile shown in Figure 29. His data are shown in Table 6 for the reach from Central City to North Platte.

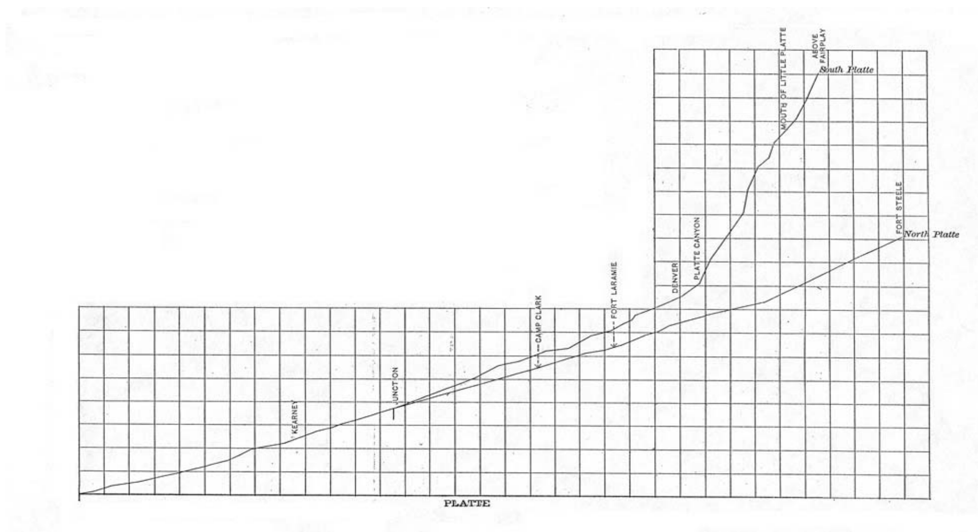

Figure 29. 1901 Profiles of the Platte River System (after Gannett 1901)

TABLE 6
1901 PROFILE OF PLATTE RIVER (AFTER GANNETT, 1901)

Locality	Distance from Mouth (mi)	Height above Sea (ft)	Fall per mile (ft)
Central City	149	1,700	---
	161	1,800	8.3
	176	1,900	6.7
	191	2,000	6.7
	206	2,100	6.7
Kearney	221	2,200	6.7
	237	2,300	6.3
Lexington	253	2,400	6.3
	270	2,500	6.9
	282	2,600	8.3
	300	2,700	5.6
North Platte	315	2,800	6.7

In his narrative, Gannett describes the slope below North Platte as “remarkably uniform,” about 6 feet per mile (ft/mi), and that the river is “peculiar in that it has a relatively steep slope and an extremely straight course, while at the same time it is building up its bed.” He further hypothesizes that this is due to the fact that it is an overloaded stream, about a mile in width in Spring and almost or quite dry at other times of the year. Though he describes the slope as uniform, Figures 29 and Table 6 suggest otherwise. USGS Quadrangle maps also show this variation. Note that the slope steepens to 8.3 ft/mi between river miles 149 and 161 and between miles 270 and 282. It also had a relatively flat segment between mile 282 and 300 (5.6 ft/mi).

Bentall (1991) used USGS contour crossings from topographic maps to develop longitudinal profiles of most major Nebraska streams. A summary of the slopes in ft/mi is shown in Figure 30. Both his diagram and narrative describe the Platte from its mouth to North Platte as progressively steepening in the upgradient direction. Figure 30 contains slopes for relatively long reaches, and does not have even the resolution of break points of those in Gannett's report.

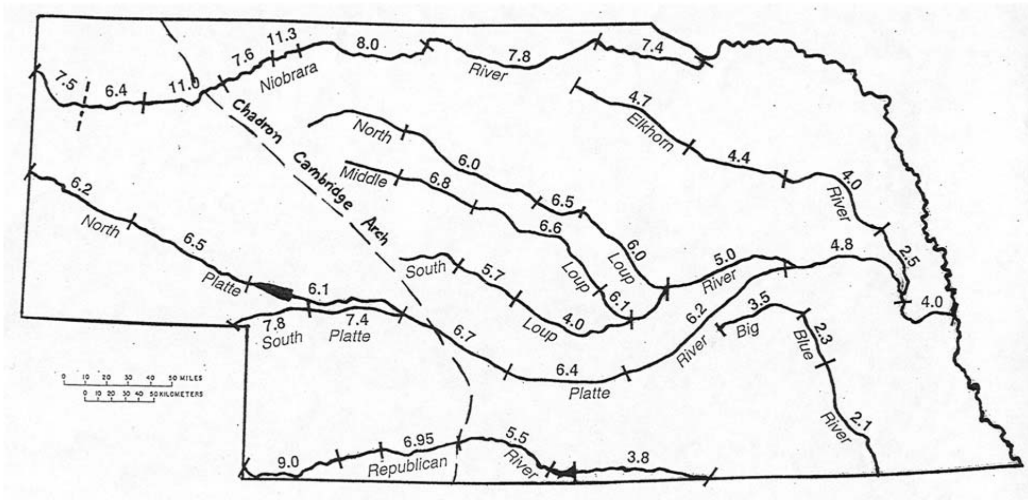

Figure 30. 1991 Profiles of Nebraska Streams (after Bentall, 1991)

Examination of the actual data in Bentall's study reveals that he logged at least eight locations upstream of Columbus where flatter slopes become steeper (contrary to the progressive steepening conclusion) These occurred around river mile 109 (near Columbus), and at river miles 138, 165, 186, 226, 238, 276, 293, and 308. Also, Bentall's (1991) data shows steeper segments between river miles 135 and 140, 160 and 166 (data at river mile 166 is consistent with Gannett), 183 and 190, 220 and 228, 238 and 250, 268 and 277, and 283 and 293 (the data at river mile 293 is also consistent with Gannett's). These data reveal that the Platte does not have a uniformly flattening slope, and that it contains segments that are both steeper and flatter than the average fall. Though not performed here, these segments of changing slope should be compared with planform changes to identify any significant relationships.

Because the USBR 1989 data included the streambed elevations, a profile could be developed that did not incorporate the disadvantages of using contour crossings. Low point elevations at a total of 57 cross-sections between river mile 157.2 (mouth of Wood river) and 310.5 (North Platte) were graphed in Figure 31. Channel elevations at full 10 mile stations were interpolated from adjacent USBR cross sections, and the slopes between the 10-mile stations were calculated and are provided in Table 7.

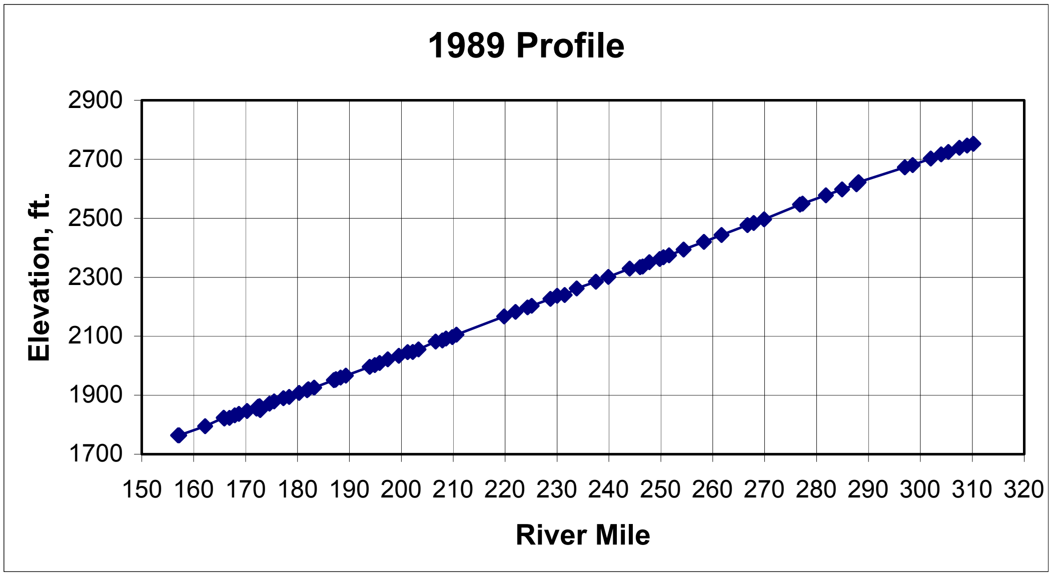

Figure 31. Platte River Thalweg Profile Based on 1989 USBR Surveyed Cross Sections

TABLE 7

1989 PROFILE OF PLATTE RIVER FROM USBR CROSS SECTIONS

Distance from Mouth, mi	Fall per mile, ft
160.0	-
170.0	6.3
180.0	6.1
190.0	6.5
200.0	6.6
210.0	6.2
220.0	6.9
230.0	6.9
240.0	6.5
250.0	6.2
260.0	6.8
270.0	6.6
280.0	6.9
290.0	6.7
300.0	5.7
310.0	6.1
Average	**6.5**

The scale of Figure 31 renders it unusable in assessing the River's profile. Both Figure 31 and the values in Table 7 indicate that when bed elevations rather than water surface contour crossings are used to profile the river, the river demonstrates a much more uniform slope than indicated in the previous two investigations. The USBR data does, however, demonstrate similar segments of flatter and steeper portions. For example, all three sets of data show relatively flatter segments around river miles 180 and 300, and there is similar correspondence of the locations of the steeper segments.

Though the 1901 profile was developed from water surface contour crossings of the stream, a comparison of the 1901 profile with interpolated USBR bed elevations from the same river mile locations is made in Table 8. As before, the profile from the 1989 USBR data does not exhibit the variability when points at considerable distance apart are plotted. Further, the comparison in Table 8 is subjective, and should not be used to conclude that changes in the vertical profile of the river have occurred.

TABLE 8

COMPARISON OF 1901 PROFILE AND 1989 PROFILE AT SAME LOCATIONS

Locality	Distance from Mouth, mi	1989 Fall per mile, ft	1901 Fall per mile, ft
Central City	149	--	---
	161	--	8.3
	176	6.2	6.7
	191	6.4	6.7
	206	6.4	6.7
Kearney	221	6.8	6.7
	237	6.7	6.3
Lexington	253	6.3	6.3
	270	6.7	6.9
	282	6.8	8.3
	300	6.2	5.6
North Platte	315	--	6.7
Average 176 - 300		6.50	6.69

The USBR data at the 57 cross-sections actually contains highly variable slopes between individual cross sections. A tabulation of this variability is included in Appendix A. The table contains three segments with adverse slopes (the bed rises in the downstream direction). It also has six moderately long segments with steep slopes between 10 and 20 ft/mi; two are over 20 ft/mi, and thirteen segments have flat slopes between 1 and 5 ft/mi, some of which are over 2 miles long.

Because the USBR cross-sections are spaced between 0.1 and 3.0 miles apart, they may still not reflect vertical variations between sections. No continuous profile of the thalweg of the Platte River was discovered in this investigation. However, portions of the North and South Platte channels have been surveyed longitudinally. Figure 32 is a plan and profile of part of the South Platte River between the Korty Dam and the Paxton Siphon, surveyed by NPPD in 1991. Spacing between thalweg survey points was with high resolution. A similar graph is available for portions of the North Platte channel. The graph, if typical, probably is the best depiction available of the variations in the thalweg. Numerous undulations in the thalweg profile reflect the bar and macroform heights and density. The profile immediately to the right of the Korty Dam (the left-most point of the profile) reveals that a scour hole about 4 ft deep has occurred just downstream of the dam.

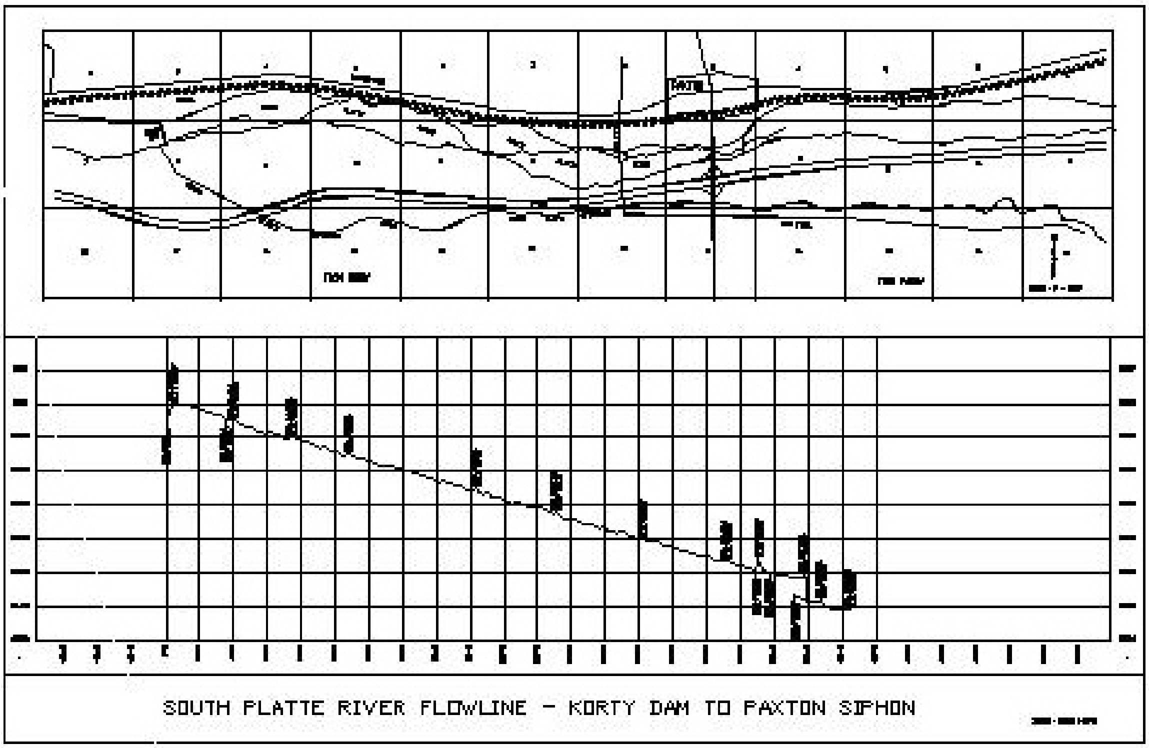

Figure 32. South Platte River Thalweg Profile from Korty Dam to Paxton Siphon (after NPPD, 1991)

It is concluded here that extreme variations in slope exist along the river, and both the width and slope variations are very likely to be important in analyzing and understanding the effect that these variations may have locally on sediment transport, morphology, and geomorphic response to expansion of riparian vegetation. Relatively close cross sections would be required in any model to reflect these variations.

Even with the precision of the USBR cross sections, tabulating and graphing the thalweg elevations over 10- to 20-mile segments as shown in Figure 31 does not accurately depict the variability in slope that is seen when the data are examined on a smaller scale. Modeling the river with this spacing could similarly misrepresent the variability, both laterally and vertically.

CONCLUSIONS

A number of significant findings have been uncovered in this investigation, clarifying many of the issues that have been long-standing over the Platte's channels. Key findings are reported here, while others are interspersed throughout the report. One of the most significant scientific findings is the result of the At-A-Station analysis at Kearney, Nebraska, which is within the critical habitat reach. This is possibly the only location where the detail discovered in this report is available, and analysis of the detail shows that no significant morphological changes have occurred over 128 years. Even expansion of vegetation is questioned by the data, and no significant morphological changes are manifest.

A second highly significant finding is that a long-standing assumption regarding the original GLO surveys has been disproved, invalidating many of the consequent cause-effect hypotheses and clarifying greatly the issue of long-term changes in the river's channels. The GLO maps did not accurately or adequately record the islands and bars, or the extent of vegetative expansion, between the meander lines. Consequently, any width measurements based on the maps over-estimate the channel width at the time, and estimates of unvegetated width are unfounded. Our At-A-Station analysis reveals that the channel width reported by Williams (1978) is as much as 1,500 ft too large, and that when the actual 1860's width is compared with present values, no significant change has occurred.

It is concluded that except for properly documenting changes in the extent of vegetative expansion, the actual geomorphologically-relevant changes in channel geometry from historic to current conditions have not been accurately quantified by previous investigators. It is also concluded that erroneous interpretations have been made in quantifying changes in "unvegetated width" (the differences between the meander corridor width and the vegetated portion) and associating them with geomorphologic changes in channel width. This in turn has led to flawed interpretations of physical and correlative cause-effect relationships.

Significant new data was discovered that strongly suggest that the high peak annual flows around 1903 used by Murphy and Randle (2001) as the basis of most of their conclusions regarding changes in active channel width are abnormal and not indicative of pre-development (1800-1860) conditions.

This study shows that previous investigations are lacking in relevant (geomorphologic) definitions of channel width, that the choice of "unvegetated width" has nothing to do with geomorphology, that different investigators differ by as much as 1,000 ft in their interpretations of the same unvegetated width data, that the 1860's GLO maps do not provide sufficient within-bank detail for determining historic channel widths, that measurements from aerial photos of channel width cannot provide accurate channel widths (they only provide vegetated and unvegetated portions), and that as a consequence, many promulgated conclusions regarding amounts and causes of reduction in channel width are not valid, especially in a geomorphologic sense.

It is shown that use of unvegetated width as a geomorphologic indicator is unprecedented and misleading, and that the association of this change with flow reduction does not correlate, especially in recent years. The unvegetated width of a river is not a measure of its equilibrium width, effective discharge width, or "active" channel, and changes in this width should not be correlated with anything except vegetative expansion. Other far more relevant measures are available but were not used. Use of the unvegetated width as a measure of geomorphic change is unscientific, especially in light of the difficulty of interpreting what is or isn't a channel from aerial photos. Vegetation occupies channels, which does not render them unable to carry water.

Figures 1 through 8 illustrate the variations that different investigators can have in results using the same data and presumably the same definition of channel "width." The two readings shown in the figures in the 1860's are the result of independent interpretations, and differ by as much as 900 ft. Two sets of data do not exist for that period. Similarly, a number of the plots in Figures 1 through 8 show two width measurements for the same year in a number of other years, especially for 1938. The concurrence in time of the measurements doesn't reflect changes within that year, but instead reflect the range of measurements possible by different investigators given the same photos and maps. From this data, it is suggested that the width determinations from the 1860's maps have at least a 25 percent interpretative uncertainty, and widths from photos appear to have even greater subjectivity.

If the hypothesis that vegetation was nearly absent in the 1800's and earlier was made from anecdotal data, the observers would not be able to establish the channel width because there would be no clear visible definition of channel edges from adjacent lands, causing a likely error in estimation of width. The GLO surveys did not document actual vegetative cover, and any conclusions regarding vegetation expansion from the surveys is questioned, especially by comparing the presence of vegetation in the railroad survey and the absence of any such notes on the GLO map of the same location. Precision of the estimates of unvegetated widths in the 1860's has been challenged by others as being based on land surveys that disregarded vegetated portions (Simons and Associates, 2000b). The data presented here also confirms that the GLO maps do not provide the needed detail within the meander lines of the surveys to define actual channel widths, and measurements of width from these maps most likely overstate the channel widths.

Notwithstanding our objection to use of the term, Figures 1 through 8 suggest that the "unvegetated channel width" has decreased 3,000 ft to 4,000 ft, depending on location and source of data, from the 1860's to around 1955. The hypothesis that true channel width has decreased is largely based on measurements of unvegetated portions from aerial photographs, and it could be as easily concluded that this is largely a measure of vegetative expansion effects rather than channel width changes. In the more recent years (1955 to 1986) the width of unvegetated portions of the Platte River has been increasing, and this increase is not explained by development as alleged by Williams or Murphy and Randle because the development is still there. This report and material in the A2 and D1/D2 reports suggest that climate changes are a strong candidate for explaining morphologic cycling of the Platte.

Representative samples of the available data on channel shape are shown in this report, including comparisons of cross-sections at four locations representing changes over periods varying in time from several months to several decades. A highly technical report developed by the Office of the Chief Engineers of the U.S. War Department (Markham, 1933) includes detailed descriptions of sediment transport and channel geometry properties of the Platte River observed in the early 1930's. Among other relevant comments, the report notes (p. 380) that "localized bottom changes (variations in the elevation of the bed at individual points) amounting to….10 feet at Duncan in 1 day, were observed." These records of cross-sections reveal that large variations in channel shape and thalweg elevation occur during changing flows, even over one day. These relatively rapid changes, and the noted recovery of former thalweg elevations, exceed the amounts of gradual change predicted by the SEDVEG model over the entire period of record.

Observations of bed elevations spanning decades or even shorter periods of time are not reliable indicators of true geomorphologic adjustments in vertical profile unless comparable measurements of discharge and sediment transport rates are made. Discharge rates for many of the observations of channel cross-section width and depth described in the literature are not revealed. A better metric of channel cross-section change, and of aggradation or degradation, would be to graph the wetted channel width and other geometric characteristics over time at equal effective discharge rates. Streamflow measurements are abundant, and flow-duration data and sediment rating curves are available, which could be entered into the convolution integral to provide considerable insight to this issue.

The discussion of streamflow measurement data shows that the channel profile, as indicated by thalweg elevations at the same cross-section can vary up to 10 ft within a few months' time, depending on the flow rate alone. Unless associated with flow rates, thalweg elevations should not be used to conclude whether the channel has degraded, aggraded, or has stayed the same. This is especially true if the only data is at cross-sections, rather than from detailed longitudinal surveys of the thalweg.

The few available detailed longitudinal surveys of slope of the Platte River reveal that this parameter is highly variable, with evidence of adverse slopes, probably reflecting the large-scale macroforms known to exist in the system. This finding is important because the question of slope variability of the river's profile and its possible effects on the channel geometry can be as significant as hydrologic, water storage and diversion, or sediment transport relationships. For example, the wider river at Grand Island and the narrower river near Gibbon are not attributed to any coarse variance in the profile of the river bottom. Extreme local slope variations exist, however, which may play a strong role in channel geometry and vegetative response differences at these locations.

Regarding the use in SEDVEG of selected cross sections, it was noted that sixteen cross sections over a distance of 148 miles, spaced on average 6.8 miles apart were used in the SEDVEG model. The analysis reported here reveals that the total widths within each of the reaches vary significantly from the total widths of the cross sections that were selected to represent that reach. The spacing of 6.8 miles does not adequately represent the variations in the river's geometry. Other problems with this spacing, particularly in regard to calculations of sediment transport, are described in the reports for Task B1 and B2.

BIBLIOGRAPHY

Becker, A.S. 1986. *A Grid Analysis of Channel and Island Change in the Platte River in Dawson, Buffalo and Hall Counties for the Years 1976, 1982, 1983, 1984, and 1985*. Department of Geography, Kearney State College. Kearney, Nebraska.

Bentall, R. 1991. *Facts and Figures about Nebraska Rivers.* University of Nebraska, Conservation and Survey Division, Lincoln, NE. February 22.

Chen, A.H., D.L. Rus, and C.P. Stanton. 1999. *Trends in Channel Gradation in Nebraska Streams*, 1913-95. Water-Resources Investigations Report 99-4103.

Cochran, R.L. 1931. *Special Survey Report of the Department of Public Works Bureau of Irrigation, Water Power and Drainage*. State Engineer. Lincoln, Nebraska.

Crafts, H.A. 1900. The snowfall and water supply of the Rocky Mountains. *Scientific American.* March 3.

Eschner, T.R., R.F. Hadley, and K.D. Crowley. 1983. *Hydrologic and Geomorphic Studies of the Platte Rive Basin in Colorado, Wyoming, and Nebraska: A Historical Perspective*. Geological Survey Professional Paper 1277 A. U.S. Department of the Interior. United States Government Printing Office. Washington D.C.

Federal Energy Regulatory Commission (FERC). 1990a. *Appendix III – Vegetation and Channel Change for Project No. 1417 and 1835.* United States Department of Energy. Washington, D.C.

FERC. 1990b. *Appendix V – Geomorphology for Project No. 1417 and 1835*. United States Department of Energy. Washington, D.C.

FERC. 1995. *Attachments to Accompany New Evidence and Comments of NPPD on Recent Agency Filings for Project No. 1417 and 1835*. Green, R.A., W.J. Madden, J.A. Whittaker, and Winston & Strawn. United States Department of Energy. Washington, D.C.

Gannett, H. 1901. *Profiles of Rivers in the United States*. U.S. Geological Survey, Government Printing Office, Washington, D.C.

Hall, A.W. 1954. *Evaporation Losses from the North Platte and Platte Rivers - Keystone to Cozad*. The Central Nebraska Public Power and Irrigation District.

Henningson, Durham, & Richardson (HDR). 1983. *Quantitative Analysis of Morphologic Changes In the Platte River and Miscellaneous Water Resources Aspects of the Proposed Prairie Bend - Twin Valley Project*. Prepared for the Central and Twin Platte Natural Resources Districts.

Kwapnioski, F.S. and E.J. Dekleva, Jr. 1997. The myth of Platte River water depletion: A work in progress. In: *Platte River Basin Ecosystem Symposium*. Kearney, Nebraska. February 18 and 19.

Leopold, L.B. and M.G. Wolman. 1960. River meanders. *Bulletin of the Geological Society of America*. 71:769-794.

Lewis, G.L., 1984. The shrinking Platte River channel - hydrologic implications. *Proceedings, ASCE Hydraulics Division.* 1984 Specialty Conference, Couer d'Alene, Idaho. August.

Lyons, J. and T. Randle. 1988. *Platte River Channel Characteristics In the Big Bend Reach: Prairie Bend Project*. U.S. Department of the Interior Bureau of

Reclamation, Sedimentation and River Hydraulics Group Technical Service Center. Denver, Colorado.

Markham, E.M. 1933. *Platte River, Colo., Wyo., and Nebr. – Letter from the Secretary of War to Congress*. U.S. Government Printing Office. Washington, D.C. November 2.

McCormick, C. 2001. COHYST stream flow measurement study on the Platte River, work in progress. Central Platte Natural Resources District. (Excel spreadsheet).

Murphy, P.J. and T.J. Randle. 2001. *Draft Platte River Channel: History and Restoration*. U.S. Bureau of Reclamation. Sedimentation and River Hydraulics Group. Denver, Colorado.

Nebraska Mid-State Division. 1971. Mid-state Diversion Dam contour map.

Nebraska Public Power and Irrigation District (NPPD). 1991. Plan and profile map of South Platte River flowline – Korty Dam to Paxton siphon.

O'Brien, P. 2000. Review of central Platte sediment and vegetation model. Memorandum dated October 13, 2000 to Paul Currier. Tetra Tech, ISG.

Osterkamp, W.R. 1977. *Effect of Channel Sediment on Width-Discharge Relations, with Emphasis on Streams in Kansas*. U.S. Geological Survey. Kansas Water Resources Board. Bulletin Number 21.

Peake, J., M. Peterson, and M. Laustrup. 1985. *Interpretation of Vegetation Encroachment and Flow Relationships in the Platte River by Use of Remote Sensing Techniques*. Remote Sensing Applications Laboratory. University of Nebraska at Omaha. Omaha, Nebraska.

Platte River EIS Office. 2001a. 1938 black and white photography of the Platte River: MrSID format. (Compact disc of GIS coverages).

Platte River EIS Office. 2001b. 1998 Platte River color-infrared (CIR) digital orthophotos (DOQs): MrSID format. (Compact disc of GIS coverages).

Platte River Management Joint Study Hydrology Work Group. 1989a. *Draft Evaluating Management Alternatives: Sediment, Flow, and Channel Geometry Considerations*.

Platte River Management Joint Study Hydrology Work Group. 1989b. *Draft Hydrology Work Group Report on Task 10 - Identify Flushing and Scouring Flows.*

Platte River Whooping Crane Maintenance Trust, Inc. 1992. *Channel Monitoring Report*. U.S. Army Corps of Engineers Permit No. NE 2SB OXT 2 8184. Grand Island, Nebraska.

Simons & Associates, Inc. 1987a. Aerial photograph analysis summary memorandum. January. Confidential attorney work product in response to 12/1/86 C&M letter. Fort Collins, Colorado.

Simons & Associates, Inc. 1987b. Cross-section plots of joint study data (Vegetated points marked). Confidential attorney work product. Fort Collins, Colorado.

Simons & Associates, Inc. 1992. *Draft Additional Analysis of Sediment Transport at Korty Diversion Dam*. Fort Collins, Colorado.

Simons & Associates, Inc. 2000a. Historic observations of Platte River conditions. Handouts from August 30, 2000 workshop at Denver Water, Denver, Colorado.

Simons & Associates, Inc. 2000b. *Historical Trends of the Channel Width of the Platte River System*. Fort Collins, Colorado.

Simons & Associates, Inc. no date. Assorted memos and confidential attorney work products regarding Projects 1417 and 1835 - impacts of project development on channel widths in the Platte River system. Fort Collins, Colorado.

State of Nebraska, Department of Public Works, Bureau of Irrigation, Power and Drainage. Stream gage readings for 1925 to 1952.

State of Nebraska, Department of Public Works, Bureau of Roads and Bridges. 1926. South Brady Bridge over the Platte River.

State of Nebraska Department of Roads. 1963. Engineering drawings for bridges on the Platte River. Bridge Design Section. Lincoln, Nebraska.

Troendle, C.A., and J.M. Nankervis. 2000. *Final Report – Estimating Additional Water Yield from Changes in Management of National Forests in the North Platte Basin*. Submitted to Platte River Office, Bureau of Reclamation. May 12.

Unidentified Source. 1986. Platte River aerial photos: North Platte to Grand Island.

Unidentified Source. No date. *Channel Narrowing*. Confidential attorney-client privilege.

Union Pacific Railroad. 1982. Bridge 54.13 (North Platte River) near South Morrill, Nebraska.

Union Pacific Railroad. Various Dates. Bridge 124.29 South Morrill Subdivision (North Platte River) near South Bayard, Nebraska.

Union Pacific Railroad. Various Dates. Bridge 18.30 South Morrill Subdivision (North Platte River) near Nevens, Nebraska.

Union Pacific Railroad. Various Dates. Bridge 2.10 Beatrice Branch (Platte River) near Valley, Nebraska.

Union Pacific Railroad. Various Dates. Bridge 282.03 North Platte Terminal (North Platte River) at North Platte, Nebraska.

Union Pacific Railroad. Various Dates. Bridge 282.08 Marysville Subdivision (Platte River) near Denman, Nebraska.

Union Pacific Railroad. Various Dates. Bridge 72.60 Stromsburg Branch (Platte River) near Central City, Nebraska.

U.S. Bureau of Reclamation (USBR). 1980. 1980s Platte River cross-sections.

USBR. 1989. Platte River cross-sections.

U.S. Army Corps of Engineers. 1989. *Platte River Cumulative Impacts Analysis: Quantitative Analysis of Hydrogeologic Impacts from Bank Stabilization*. Omaha District, Engineering Division. Omaha, Nebraska.

U.S. Department of Agriculture (USDA). 1997a. *Final Environmental Impact Statement, Arapaho and Roosevelt National Forests and Pawnee National Grassland*. Rocky Mountain Division.

USDA. 1997b. *Final Environmental Impact Statement, Routt National Forest*. Rocky Mountain Division.

U.S. Department of the Interior. 1955. *Sediment Investigations of the Platte River near Overton, Nebraska, January 1950 to September 1953*. Geological Survey, Water Resources Division. No source location.

U.S. Geological Survey (USGS). 1990. *Discharge Measurement Summary Sheet for Platte River near Overton, NE.* U.S. Department of the Interior. U.S. Government Printing Office. Washington.

USGS. 2001. Cottonwood Ranch and general monitoring cross-sections of the Platte River.

U.S. Reclamation Service. 1923. Engineer transit book, Nebraska, Tri-County secondary, Plum Creek Reservoir supply canal diversion dam across Platte River.

White, C.A. 1926. *A History of the Rectangular Survey System*. U.S. Department of the Interior, Bureau of Land Management, U.S. Government Printing Office, Washington, D.C. 20402.

Williams, G.P. 1978. *The Case of the Shrinking Channels - the North Platte and Platte Rivers in Nebraska*. U.S. Department of the Interior. United States Government Printing Office. Washington D.C. Geological Survey Circular 781.

Yang, C.T. 1991. Reference Materials for the International Association for Hydraulic Research and UNESCO International Hydrological Programme. U.S. Bureau of Reclamation.

Zelt, R.B. and S.A. Frenzel. 1996. Physical-habitat characteristics of the Platte River, Nebraska - Assessment using surveys and spatial analyses. *Proceedings of the 1996 ESRI User Conference*. Palm Springs, California.

Zeller, 1967. *International Association of Scientific Hydrology Symposium Proceedings*.

APPENDIX A

THALWEG PROFILE FROM 1989 USBR CROSS SECTIONS

River Mile	River Station	Channel Bottom Elev.	Fall, ft/mi Between USBR Stations	Fall, ft/mi Between 10-mile Segments	Fall, ft/mi Between 1901 Stations
157	828960	1763.92			
157.2	830016	1764.13	1.1		
160		1781.43			
161		1788.69			
162.2	856416	1795.02	6.2		
165.8	875424	1823.52	7.9		
165.9	875952	1820.71	-28.1		
166.9	881232	1823.33	2.6		
167.9	886512	1831.76	8.4		
168.7	890736	1836.79	6.3		
170.0		1844.49		6.3	
170.3	899184	1846.27	5.9		
172.1	908688	1854.6	4.6		
172.4	910272	1861.1	21.7		
172.6	911328	1860.5	-3.0		
172.6	911328	1860.5	0.0		
172.7	911856	1862.93	24.3		
172.8	912384	1849.55	-133.8		
174.6	921888	1871.5	12.2		
175.5	926640	1878.8	8.1		
176.0		1881.40			6.2
177.3	936144	1890	6.2		
178.4	941952	1893.9	3.5		
180.0		1905.61		6.1	
180.3	951984	1907.8	7.3		
181.9	960168	1917	5.9		
182.1	961488	1919.9	11.6		
183.2	967296	1925.57	5.2		
187.0	987360	1951.3	6.8		
187.3	988944	1952.41	3.7		
187.4	989472	1954.3	18.9		
188.3	994224	1959.53	5.8		
189.3	999504	1966.5	7.0		
190.0		1970.97		6.5	
191.0		1977.26			6.4
193.9	1023792	1995.88	6.4		
194.9	1029072	2001.8	5.9		
195.8	1033824	2009.31	8.3		
197.4	1042272	2021.38	7.5		
199.5	1053360	2033.45	5.7		
200.0		2037.05		6.6	
201.2	1062336	2045.7	7.2		
202.2	1067616	2046.38	0.7		

APPENDIX A (Continued)

THALWEG PROFILE FROM 1989 USBR CROSS SECTIONS

River Mile	River Station	Channel Bottom Elev.	Fall, ft/mi Between USBR Stations	Fall, ft/mi Between 10-mile Segments	Fall, ft/mi Between 1901 Stations
203.3	1073424	2055.3	8.1		
206.0		2072.91			6.4
206.6	1090848	2081.56	8.0		
207.9	1097712	2085.3	2.9		
208.6	1101408	2091.94	9.5		
209.8	1107744	2097.04	4.2		
210.0		2098.99		6.2	
210.6	1111968	2104.82	9.7		
219.8	1160544	2166.96	6.8		
220.0		2168.39		6.9	
221.0		2175.27			6.8
222.0	1172160	2182.67	7.1		
224.3	1184304	2198	6.7		
225.1	1188528	2203.1	6.4		
228.7	1207536	2227.25	6.7		
230.0	1214400	2237.23	7.7	6.9	
231.5	1222320	2240.07	1.9		
233.8	1234464	2262.1	9.6		
237.0		2282.72			6.7
237.5	1254000	2284.87	6.2		
239.9	1266672	2301.4	6.9		
240.0		2302.09		6.5	
244.0	1288320	2329.6	6.9		
246.0	1298880	2334.6	2.5		
246.5	1301520	2336.7	4.2		
247.8	1308384	2351	11.0		
249.8	1318944	2361.99	5.5		
250.0		2363.77		6.2	
250.5	1322640	2368.21	8.9		
251.6	1328448	2374.73	5.9		
253.0		2384.20			6.3
254.4	1343232	2393.9	6.8		
258.3	1363824	2420.053	6.7		
260.0		2431.73		6.8	
261.7	1381776	2443.4	6.9		
266.7	1408176	2476.84	6.7		
267.9	1414512	2484.2	6.1		
269.9	1425072	2496.6	6.2		
270.0		2497.32		6.6	6.7
276.8	1461504	2546.35	7.2		
277.3	1464144	2549.71	6.7		
280.0		2566.50		6.9	
281.8	1487904	2577.7	6.2		
282.0		2578.98			6.8

APPENDIX A (Continued)

THALWEG PROFILE FROM 1989 USBR CROSS SECTIONS

River Mile	River Station	Channel Bottom Elev.	Fall, ft/mi Between USBR Stations	Fall, ft/mi Between 10-mile Segments	Fall, ft/mi Between 1901 Stations
284.9	1504272	2598.2	6.6		
287.7	1519056	2615.4	6.1		
288.1	1521168	2622.29	17.2		
290.0		2633.09		6.7	
297.0	1568160	2672.9	5.7		
298.5	1576080	2680.5	5.1		
300.0		2690.06		5.7	6.2
302.0	1594560	2702.8	6.4		
304.0	1605120	2716.6	6.9		
305.4	1612512	2724.6	5.7		
307.5	1623600	2738.8	6.8		
309.0	1631520	2746.4	5.1		
310.0		2751.36		6.1	
310.2	1637856	2752.35	5.0		

TECHNICAL MEMORANDUM

RESULTS OF INVESTIGATION A4 - DEVELOP CHANNEL WIDTH PREDICTIVE TOOL

PLATTE RIVER CHANNEL DYNAMICS INVESTIGATION

Prepared For

States of Colorado, Nebraska, and Wyoming

May 2003

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TECHNICAL MEMORANDUM

INVESTIGATION A4 - DEVELOP CHANNEL WIDTH PREDICTIVE TOOL

PREFACE

This report describes the procedures used in and results of an evaluation of a geomorpholgically-based method of evaluating the channel and river corridor widths in the Central Platte River. The investigation addressees a number of technical issues regarding this subject which had been identified by the sponsors as needing detailed examination to allow them to make scientifically-based decisions regarding the Cooperative Agreement (CA) work products.

This document describes only the data collected, analyses made, and scientifically-supportable findings regarding the issues, written in a manner which generally follows the guidelines of professional journals of the respective authors' technical expertise. The relevance of the findings to the specific issues confronting the sponsors is discussed in each task memorandum, but only as far as the data and results are deemed by the author(s) to be scientifically supportable in resolving or illuminating the issue.

ISSUES AND PURPOSES OF INVESTIGATIONS

The technical evaluations completed by the Parsons team were conducted as a series of 14 complementary investigations divided into four categories that would address general issues identified by the three states. The following issue categories were identified:

- A: Questions Regarding Channel Narrowing or Deepening
- B: Questions Regarding Sediment Transport
- C: Questions Regarding Vegetative Encroachment
- D: Questions Regarding Macro-Historic Natural Variability

This Technical Memorandum describes the results of Task A4, the fourth of five tasks comprising Issue Category "A."

The objective of Task A4 is to evaluate the relationship between flow and the associated effective discharge channel widths for an unvegetated (or nearly unvegetated) condition, and then to use this tool to investigate the question of what channel and river corridor widths the present-day or proposed program flows and sediment supplies could form (and possibly maintain) if vegetation was not present.

SCOPE OF WORK

One proposal being considered as part of the Proposed Program for the Platte River is an artificial clearing of vegetation from portions of the river. Another is to create annual pulse flows that would presumably widen the river "channel" and create high sand bars. A key question is whether the river would have a different planform or width if vegetation was not present. Earlier studies (HDR 1983) had concluded that channel formative processes had not substantially changed, and that vegetation was limiting the river's effective-flow channel and corridor widths. Task A4 was designed to evaluate these relationships and to develop a tool that could be used to evaluate channel widths for other future flow and sediment-supply scenarios.

Once the relationship between discharge and effective-flow channel width was developed using flow and sediment rating data for the relatively unvegetated condition in 1938, it was applied to an equal length record of more recent historical conditions, specifically 1970-1998, to estimate the probable river morphology if vegetation had not expanded from the condition documented around 1938, assuming other channel formative processes are fixed. Results are compared with actual present-day widths to estimate the morphologic influence that vegetation may have had. In addition to estimating equations for channel widths at Grand Island and Overton, approximations of the river corridor widths that might be associated with the flows are developed and presented.

EFFECTIVE DISCHARGE

Among the most recognized channel-forming and maintaining characteristics is the "effective" or "dominant" discharge (Q_e). Both names are used interchangeably. *Effective discharge* is defined in this report as the modal value of the relationship between total sediment transported by any given flow and the corresponding flow rate. Other investigators use the mean or median of the distribution in their definitions, but others (USGS 1981, Corps of Engineers 1989) have used the modal value in recent Platte River Studies, so this precedent is adopted.

The meaning of effective discharge is sometimes defined as the equivalent steady discharge that would produce the same morphologic dimensions as the range of flows encountered, but it should not be inferred that steady discharges are needed or proposed for any morphology. This investigation defines the effective discharge as the statistical measure of central tendency (the mode is used here) of daily discharges that transport the largest fraction of the total sediment load over a period of time.

Other investigators report that the effective discharge is approximately the same as the bankfull discharge for many natural channels. This method is an approximation and would only be used in the absence of flow and sediment transport data, and would not generally produce sufficient precision for management decisions. Also, a large body of literature addresses the complexity of determining bankfull, channel-forming discharge, especially for braided rivers which often exceed the elevation of the most-active sand bars, and all the reports require that the point-bar and floodplain-building formative processes be observed in the channel in order to determine which bankfull level is responsible for shaping the channel or mobilizing the highest alluvial sandbar on the riverbed. This is not always the bank-to-bank width of a river. Further, sand bed streams mobilize their beds during high flows, increasing the conveyance, and cross-sectional measurements of channel capacity during low-flow conditions tend to underestimate the bankfull rate. Because this method is approximate, a bankfull flow analogy was not adopted as the primary definition of effective discharge in this investigation.

RELATIONSHIP OF EFFECTIVE DISCHARGE TO STREAM MORPHOLOGY

For prediction of width or other characteristics of streams, the flows that transport the largest fraction of total sediment load are widely accepted in geomorphologic literature as the flows that result in the average morphologic characteristics of the channel. Support of this, specifically addressing the Platte River, is presented in Kircher (1981), Professional Paper 1277 (USGS 1983), HDR (1983), Hydrology Work Group (1989), Corps of Engineers (1989) and U.S. EPA (1988).

For a river in dynamic equilibrium (often the term "in regime" is used to mean the same thing), many of it morphologic attributes and a significant part of its conveyance is formed and maintained by the effective discharge. *Effective channel width* is defined here as the total width of conveyance when the flow matches the effective discharge. *River corridor width* is the transverse distance across the channel and floodplain between higher terraces, and may include islands, braided segments, or primary and secondary anastamotized channels. For the older surveys, dating back to the mid-1860's, this is the same as the distance between the "meander lines" noted on those plats. Though there is a relationship between effective width and river corridor widths, the former is more-easily related to flows, while the latter is governed more by other factors such as sediment supplies or topographic or geologic constraints to lateral movement of the channels.

Active channel width is a term being used in the Cooperative Agreement process. It appears that the use of the term may be analogous to the effective flow channel width, and is generally used contextually in reference to that part of the river corridor that is continuously re-shaped by the river flows. Some of these references appear to perceive that only (and all) of the unvegetated portion of the river corridor is "active." On the contrary, unvegetated river corridors, especially braided corridors, are known to have river corridor widths that range from 2.7 (Leopold and Wolman, 1960) to 4.5 (Zeller, 1967) times the effective-discharge width, so any perception that only the effective channel can or will remain free of vegetation is incorrect.

The river corridor width reflects the valley width over which the effective flow channel roams. The bankfull or effective flow in a braided stream is not the discharge that would occupy the river corridor width. The term "active channel width" is not used in this report because it appears to range by its contextual use from a single "main" channel width to the river corridor width, depending apparently on the presence or absence of vegetation.

The effective channel width in a river in regime is measured as the total wetted top width of any low ground occupied by a flow equal to the effective discharge. This is not the same as the total unvegetated width. The effective discharge can shape and maintain only the width of channel it occupies, not the entire unvegetated width of the braided or other type of corridor. If the effective discharge has freedom to laterally shift, greater widths of reshaped and unvegetated portions are possible, but the perception that water needs to occupy the entire unvegetated portion (or the entire river corridor as assumed by some) to accomplish this reshaping should be discounted.

METHODS OF DETERMINING EFFECTIVE DISHCARGE

Estimating the effective discharge allows investigators to assess what range of flows govern (and governed) the shape of the Platte River channel, what range of flows transport the greatest amount of sediment in the Platte River, what effective and river corridor widths might be created and maintained by any set of prescribed flows if the vegetation was removed, and to what extent vegetation is limiting the effective and corridor widths that would exist under today's flow in the absence of vegetation.

Standard methods of determining effective discharge, and of correlating effective discharge with an associated "equilibrium" or effective channel width, require that the method be applied to conditions that exist or existed for a relatively unvegetated condition. Though less reliable data are available prior to the turn of the century, the relationship used in this analysis is developed from reliable discharge records from about 1910 to 1939, when the river corridor was considerably less-occupied by deep-rooted vegetation on the banks, islands and floodplains.

Numerous methods exist for defining, and estimating, the effective discharge. The mathematical definition of effective discharge is the mathematical convolution of probability of any given flow rate with bed material transport by those flows, resulting in the discharge that corresponds with the maximum value of the product of $p(Q_i)*G_s$ as the effective discharge (this is consistent with the modal-value definition described earlier). This is seldom the most frequent flow or the highest annual flow, because they may not transport the most sediment. The convolution integral cannot be solved analytically because the flow duration probability function for natural rivers is seldom described mathematically. Instead, convolution is accomplished by standard class-analysis techniques described below.

Two quantitative methods appear in most publications, and employ the same standard statistical class analysis methods of approximating the shape and characteristics of the sediment transport density function with a histogram of sediment transported by intervals of discharge rates. Both result in a histogram, giving the distribution of total (or percent of total) sediment transported by respective class intervals of flows.

The effective discharge is the central tendency of this distribution, assessed as either the mean (centroid), mode (peak), or median (50 percentile point) of the histogram. The most widely used approach for determining the effective discharge from the histogram is to select the discharge that corresponds with the maximum (mode) value of the histogram as the effective discharge. The Corps of Engineers (1989) recommends this choice and describes it as one of the most-often used methods in equating the effective discharge with the peak value of the class analysis distribution. This modal value definition is consistent with the mathematical definition of effective discharge described earlier.

The first of the two standard methods of performing the class analysis, herein called the flow-duration-weighted method, involves multiplying the probability of any given flow, $p(Q_i)$, obtained from a flow duration curve, by the sediment transported by that flow, G_s, and plotting the product as the ordinate (total sediment transported) corresponding to left, center, or right plotting position of that flow class interval. In class analysis, either the cumulative function or density function is estimated by discretizing the flow rates into equal-width class intervals and plotting the product of flow recurrence and sediment transport per flow unit as the ordinate for that class interval.

The second method, herein called the equal interval method, accomplishes the same desired convolution by adding all the sediment transported by each flow class interval using actual daily flows and their associated recurrences and sediment transport rates. Statistically, both should provide nearly identical distribution histograms, depending only on the accuracy of the flow duration curve and on the level of discretization of either the range in flows, or in the range of flow probability represented by each sediment transport rate used in developing the individual ordinates of the histogram. Use of actual daily flows eliminates the unexplained variance in the flow duration curve, and for this reason, is superior to using the flow-duration curve which only represents the data but does not statistically explain the variability of the data.

It should be noted that the so-called "USBR Method" is neither of the above. It is illustrated by Strand (USBR 1982), who in turn refers to a method of computing sediment yield developed by Miller (1951). For that method, which was originally published for use in estimating watershed sediment yield and later used for estimating sediment inflow to reservoirs, various unequal weightings are given to the probability ranges of the flow duration curve before multiplying by the associated sediment transport rate for the flow represented by the weighted probability interval.

LITERATURE REVIEW – SUMMARY OF PREVIOUS Q_e ESTIMATES

A relatively large number of previous investigations provide discussions of, or estimates of, effective discharge at various locations in the Platte River and its tributaries. A range of techniques, years, and sediment transport relationships were applied. Rather than discussing all of them, some are simply summarized here, and the results of the current investigation are discussed later in the context of results from the previous investigations.

In chronological order, these investigations include Marlette and Walker (1968), USGS Open File Report 81-53 (1981), USGS Professional Paper 1277C (1983), USGS Professional Paper 1277E (1983), HDR Engineering (1983), O'Brien (1986), Battelle (1988), Lyons and Randle (1988), Hydrology Work Group (1989), U.S. Army Corps of Engineers (1990), Murphy and Randle (2000), and Samad and Randle (2000).

In addition to the above, the EIS team recently estimated the effective discharges at Overton and Grand Island by the USBR method and the equal interval method, and reported the results of the USBR method during their July 2001 presentation to the CA work groups. The results of both methods have been supplied to Parsons, but no accompanying documentation has been distributed. Absent the documentation, it is difficult to comment on the results. From the results supplied, there is a dramatic difference between the USBR method and the equal interval method, with the USBR method giving much higher values (see Table 1). As noted below in the discussion of the Parsons estimates, the USBR method was not developed for purposes of estimating effective discharge. Further, it disagrees with all other methods shown in Table 1, including Lyons and Randle. Randle should be queried as to why his previously published values disagree so strongly with his recent application of the USBR method.

Parsons also recently computed effective discharge estimates at Overton and Grand Island for representative pre-Kingsley and recent conditions. The recent Parsons and EIS team results are summarized along with all other estimates in Table 1.

TABLE 1
EFFECTIVE DISCHARGE ESTIMATES AT VARIOUS LOCATIONS IN THE PLATTE RIVER

Source	Other, cfs	Overton, cfs	Grand Island, cfs
Marlette and Walker (1968)	Ashland 6,500	-	-
	N. Bend 8,000	-	-
USGS Open File Report 81-53 (1981)			
Yrs 1950-1980	-	1,450	1,950
N. Platte R. at N.P.	1,695	-	-
S. Platte R. at N.P.	5,580	-	-
HDR Engineering (1983)	-	-	-
Yrs 1930-1941	-	3,100	3,500
Yrs 1954-1982		3,500	3,600
USGS P.P. 1277C (1983)	-	3,800	3,800
USGS P.P. 1277E (1983)			
Yrs 1950-'80 (Repeated O.F.R. 81-53)	-	1,444	1,950
Yrs 1950-'80 May – Aug Flows Only	-	5,569	-
Lyons and Randle (1988)			
Years 1926-1939			
Years 1940-1957			
Years 1958-1986	-	3,900	-
	-	1,650	-
	-	1 K to 10 K	1 K to 10 K

**TABLE 1 (Continued)
EFFECTIVE DISCHARGE ESTIMATES AT VARIOUS LOCATIONS IN THE PLATTE RIVER**

Source	Other, cfs	Overton, cfs	Grand Island, cfs
Hydrology Work Group (1989)			
Yrs 1926-1939	-	3,900	-
Yrs 1940-1957	-	1,650	-
Yrs 1958-1986	-	1,600	-
COE Omaha (1989)	1,049-10,700 N. Platte to Kearney	-	-
Murphy and Randle (2000)			
N. Platte R. at N.P.	1,930	-	-
S. Platte R. at N.P.– cfs	9,340	-	-
Samad and Randle (2000)			
Two methods for N. Platte R. at N.P.	343 & 1,930	-	-
O'Brien (1986)	8,300-10,800 "Platte"		
EIS team Presentation (2001), USBR Method			
Yrs 1865-1909	-	9,395	8,203
Yrs 1910-1939	-	5,674	5,100
Yrs 1940-1969	-	2,040	2,250
Yrs 1970-1998	-	4,020-7,880	4,330-7,610
EIS team Transmittal to Parsons (2001)[1]			
Equal Interval Method, 1910-1939		≅ 3,000	≅ 2,700
Equal Interval Method, 1970-1998		≅ 2,000	≅ 2,200
Parsons (2001) Independent Evaluation[1]			
Equal Interval Method, 1910-1939	-	3,500	2,500
Equal Interval Method, 1970-1998	-	1,500	2,500

[1]Values given in this table for EIS team and Parsons are modal (peak) values. EIS team values were not provided but were approximated from the plotted distributions.

EFFECTIVE FLOW HISTOGRAMS

Tabulation of single values of effective discharges does not reveal the full information contained in the distributions. To allow comparisons of skew, amount of sediment transported by high flows, relative robustness of the histograms, and other characteristics, several of the histograms from previous investigations are presented here.

HDR Engineering

HDR (1983) evaluated approximate values of effective discharge using monthly mean flows and a standard bedload transport equation. As seen in Figure 1, eighty-four percent of the bed material sediment transport before 1941 occurred for flows of 4,000 cfs or less. The predominant channel-forming flow during that period must have been below 4,000 cfs. Similarly, 69 percent of the bed material sediment transport occurs in the same discharge range for the post-Kingsley period evaluated. The results also show that "current" conditions have a higher percent of the total transport for flows over 4,000 cfs (31 percent versus 17 percent). HDR used the median value to estimate the effective discharge and concluded that there has not been a significant change between the two periods evaluated. It is clear that there has been some redistribution of bed material transport, but the majority of the bed material sediment transport occurs in both periods in the 1,000 to 4,000 cfs range for both periods of time.

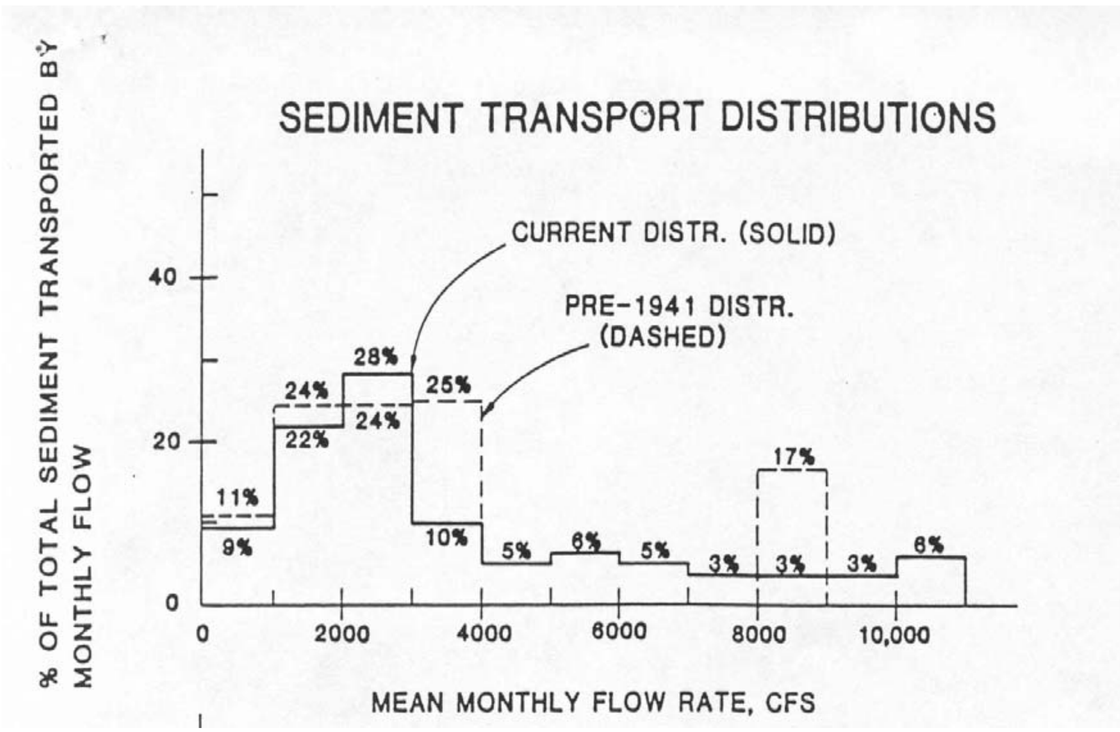


Figure 1: HDR Sediment Transport Distributions at Grand Island (after HDR 1983)

USGS Open File Report 81-53 (1981)

This open file report presented Kircher's effective discharge calculations and distribution graphs for the years 1950-1980 (see Figure 2). At Grand Island, Kircher found the effective discharge to be 55 m^3/s (1,950 cfs). For Overton, he obtained a value of 40.9m^3/s (1,450 cfs) as the effective discharge for the period 1950-1980. The mean annual discharge for the same period at Overton was 39.4 m^3/s (1,391 cfs), which he notes is very close to the effective discharge.

Kircher used a modified logarithmic flow-duration-weighted method to generate the graphs, but tested several methods of discretization of flows or logs of flows, discovering that the results could vary by as much as 33 percent. This process subdivides the flow-duration curve into *N* equal intervals. The greater the value of *N* the closer the result is to the "true" value. The value of *N* was found to affect the effective discharge quite significantly. In addition to the value of *N*, the type of interval use (arithmetic or logarithmic) further affects the outcome. Kircher defined his reported values of 1,950 and 1,450 cfs, respectively, at Overton and Grand Island as the "average" values.

Kircher selected the peak value of the distributions shown in Figure 2 as effective discharges. As noted in the figure, he estimated values of effective discharge for the suspended sediment discharge, for bedload discharge, and for total *measured* sediment discharge. At both Overton (see Figure 2) and Grand Island, the choice of suspended, bedload or total measured discharge did not affect the location of the peak of the respective distribution graphs, thereby making the calculation of effective discharge apparently independent of the type of sediment transport being represented by the distribution graphs.

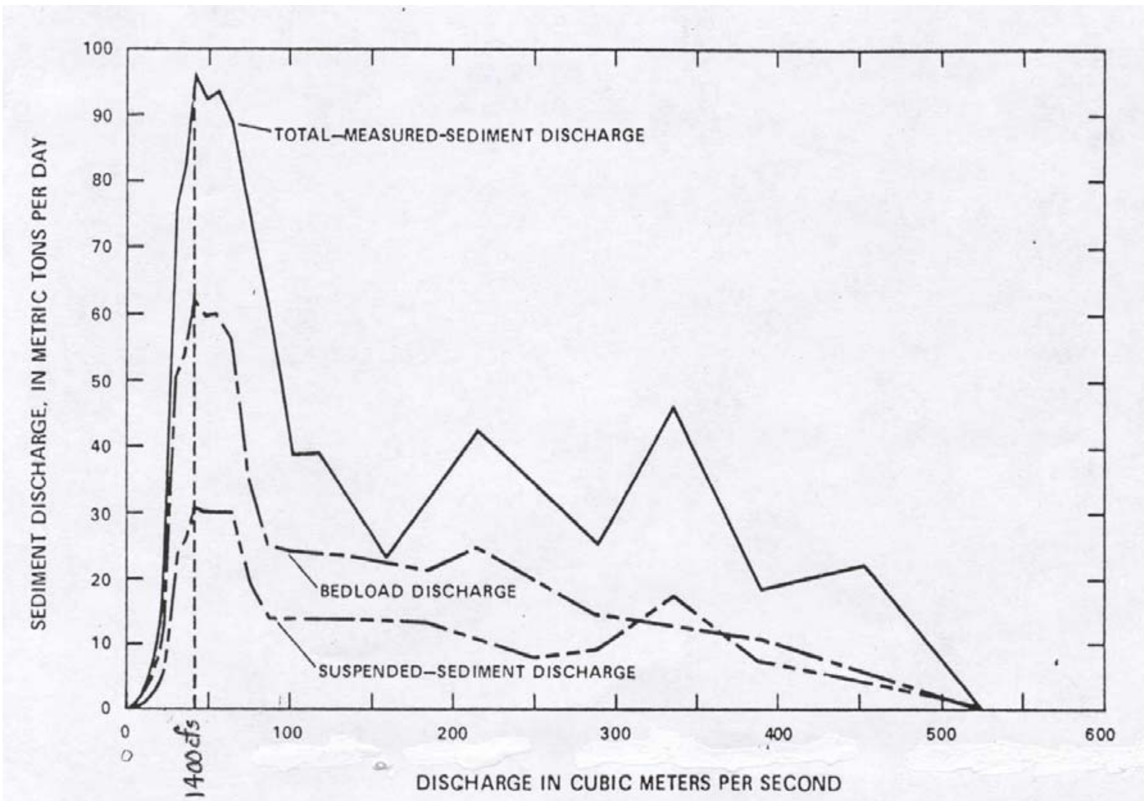


Figure 2. USGS Open File Report 81-53 Sediment Transport Distributions (after USGS 1981)

USGS Professional Paper 1277C (1983)

Paper 1277C by Karlinger and others does not present distribution graphs, but describes the application of theoretical equations developed by Parker (1978) to estimate the discharge necessary for maintaining cross-sectional characteristics of the Platte River channel. The discharge determined necessary for the maintenance of the 180 m (591 ft) channel, a value considered equivalent to the effective discharge, was 107.6 m^3/s (3800 cfs). The calibration of the equations has been challenged in subsequent reviews, so this estimate is not considered to be completely valid for this discussion even though the value falls within the range reported by the majority of the investigations.

USGS Professional Paper 1277E (1983)

This paper did not add any distribution graphs, but included an analysis of effective discharge for the period from1950 to1980 for the months of May to August. The May to August months were evidently selected because it is during this time interval that germination occurs and which the effective discharge during that period was hypothesized as preventing germination and removing small seedlings. The effective discharge at Overton for these months was determined to be 157.7 m^3/s (5,569 cfs).

Lyons and Randle (1988)

The distribution graph presented in this report is shown in Figure 3. The peaks (effective discharges) for the periods 1926 to 1939, 1940 to 1957, and 1958 to 1986 occur at discharges of 3900 ft^3/s, 1650 ft^3/s, and 1600 ft^3/s, respectively. Because the distribution for 1958 to 1986 had relatively high percentages over the full range of flows, Lyons and Randle reported that flows of 1,000 to 10,000 cfs provide a span of what they consider to be the channel-forming flows at work during the latter period.

Hydrology Work Group (1989)

The Hydrology Work Group referred to channel formation as being done by formative discharge and describe the concept of formative discharge as an index of the channel-shaping flows. The work group defined the effective discharge "as the increment of sediment-transporting discharge that transports the largest fraction of the total sediment load over a period of years." In this paper, the effective discharge computed for the Platte River by Lyons and Randle (1988) was re-plotted in the form shown on Figure 4. This is merely a bar-graph representation of Figure 3. The effective discharge for the Overton area was determined for three periods, 1926 to 1939, 1940 to 1957, and 1958 to 1986 as 3900 ft^3/s, 1650 ft^3/s, and 1600 ft^3/s, respectively.

U.S. Army Corps of Engineers (1989)

The method used by the COE to determine the effective discharge was the flow-duration-weighted method. An analysis was performed for several locations on the Platte River. The COE discovered that a range of discharges have all transported equivalent mass volumes of sediment since the mid-1900s, and as a result, described the effective discharges not as a single value but as a range of discharges as dominating the river regime. The effective discharges range from approximately the mean annual discharge (1,049 cfs) to the bank-full discharge (10,700 cfs) and result in essentially all of the bed material transport. The bank-full discharge of 10,700 cfs is representative of an average bank-full discharge for the reach extending from North Platte to Kearney. Further, they note that bank erosion contributes less than 5 percent of the total bed material sediment load.

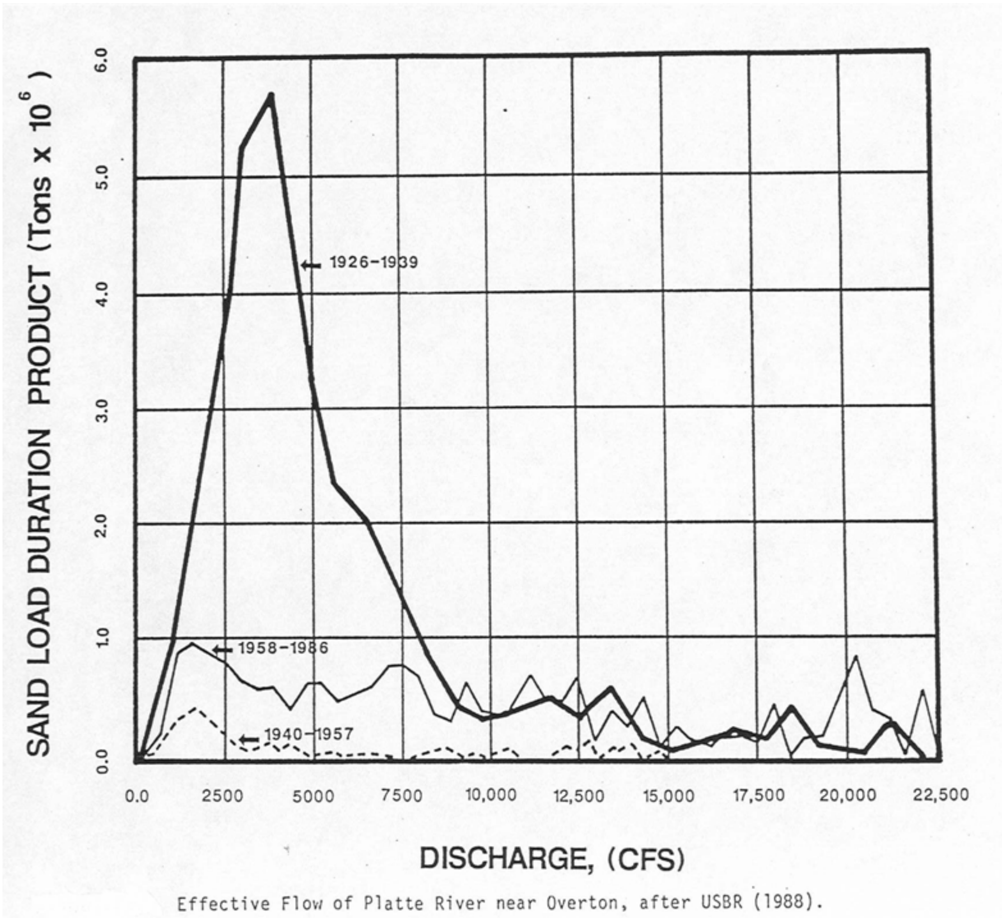


Figure 3. Lyons and Randle Sediment Transport Distribution Graphs at Overton for Three Periods Evaluated (after USGS 1983)

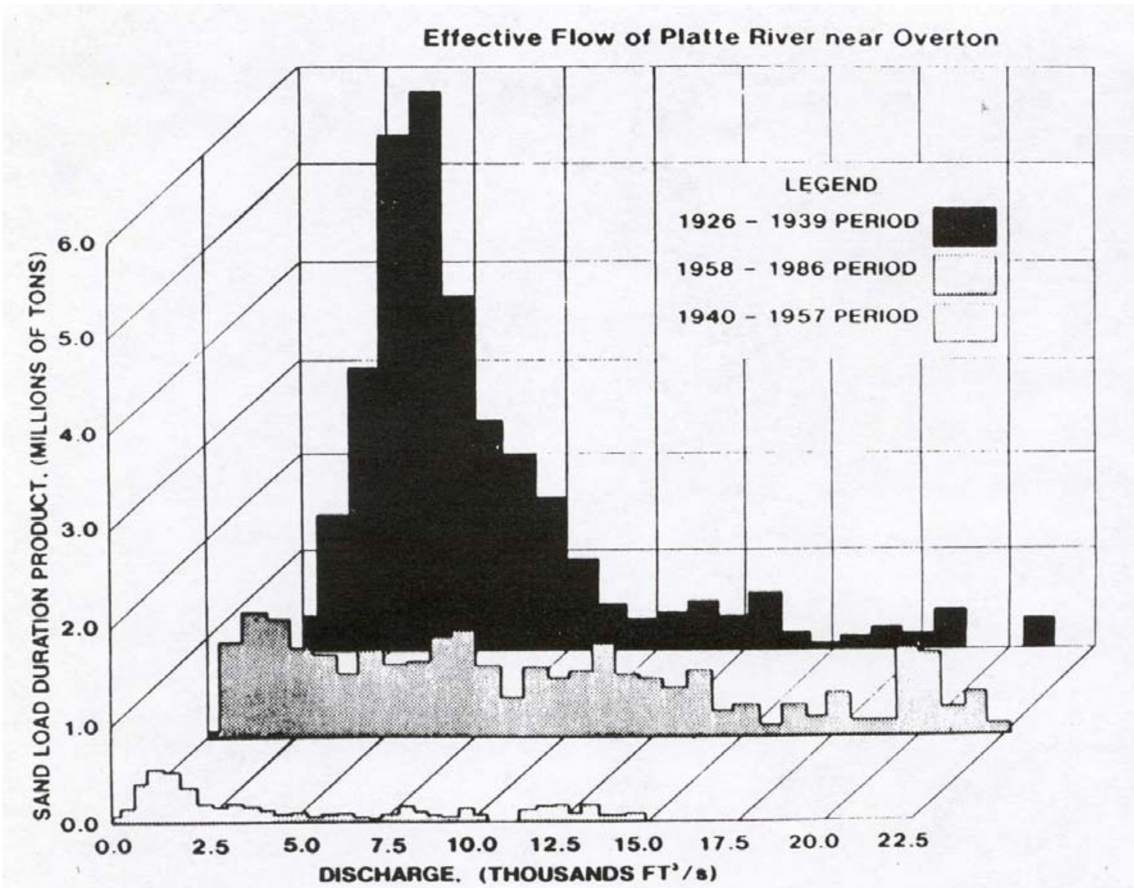


Figure 4. Hydrology Work Group Sediment Transport Distributions (Lyons and Randall 1989)

EFFECTIVE DISCHARGE CALCULATIONS BY PARSONS

The original scope of work for this task called for Parsons to request effective discharge calculations from the EIS team for specified periods of time, then make interpretative conclusions based on the EIS results. The intent was to update the HDR calculations, using either the flow-duration-weighted method or the equal interval method. After viewing the July presentation of the EIS estimates using the USBR method, it was decided to conduct independent evaluations of the effective discharges. The reasons included the concern that the USBR method was not developed for calculating effective discharge, the EIS team used the SEDVEG model to determine the sand-load transport for any given discharge, the SEDVEG model gives a moderately wide range of sediment transport rates for the same discharge rate especially in the lower range, SEDVEG's algorithms for sediment transport are still being evaluated and have not been adopted yet by the scientific community, and it was felt that sediment rating equations based on measurements (rather than energy-capacity equations) should be used until such time that the SEDVEG estimates are confirmed.

The two periods evaluated by Parsons are 1910 to 1939 and 1970 to 1998, using the same logic adopted by HDR, namely, that the pre-Kingsley data provides a method of calibrating a width predictive tool for relatively unvegetated conditions that could be used to estimate what the river might look like today in the absence of vegetation, assuming that other channel formative processes are unchanged. River discharge rates and sediment transport measurements prior to 1910 are non-existent or not confirmed as reliable by the scientific community. Very good data, including sediment transport measurements, are available for the 1910 to 1939 period. The period from 1939 to 1970 is considered by most to be a transition period, or period of changing versus regime conditions (this was confirmed by the EIS team presentation of USBR method results), so no calculations for that era were completed.

Daily discharge records provided by the EIS team were adopted for these two periods. Rather than using the SEDVEG estimates of sediment transport for any river discharge, Parsons reviewed the available options and found that several alternative methods were available, including the following:

- HDR '30-41 (Frijlink's Eq. for Bedload)
- HDR '54-82 (Frijlink's Eq. for Bedload)
- Simons & Associates, Regression Eqns. for Bedload
- USGS 1277, Regression Eqns. for Total/Suspended/Bedload
- USGS 1277/Simons & Associates Regression Eqns
- USGS-WRD Eqns.
- Lyons & Randle '26-'39, Adjusted Yang's
- Lyons & Randle '40-'57, Adjusted Yang's
- Lyons and Randle '58-'86 Sandload Eq.
- Lyons and Randle '65-'80 Modified Einstein
- Lyons and Randle '52-'56 Modified Einstein

For pre-Kingsley conditions, Parsons adopted the Lyons and Randle 1926-1939 rating equations. For current conditions, the USGS Professional Paper 1277 equations were adopted.

Depending on availability of rating equations, sediment transport (bed material, suspended, and total) rates were determined from these equations for each day in the record. Sediment load (tons per day) was then determined, and all transport during the period within 37 equal 1,000 cfs wide classes of flow rates were summed and plotted as transport distributions. Similar graphs, showing percent of total transport versus load transported, were plotted within each class.

The four graphs showing relative percentages of total sediment transported at Overton and Grand Island, respectively, for the 1910-1939 and 1970-1998 periods are included in Appendix A. No differences were found if bedload, suspended load, or total load equations were used nor if total load versus percent of total load were plotted. Both the modal (peak) and median (50 percentile) values of central tendency of the distributions are shown on the graphs and tabulated in Table 2.

TABLE 2

PARSONS' INDEPENDENT ESTIMATES OF EFFECTIVE DISCHARGE

	Overton		Grand Island	
Period Evaluated	Q_e – Mode, cfs	Q_e – Median, cfs	Q_e – Mode, cfs	Q_e – Median, cfs
1910-1939	3,500	4,078	2,500	3,626
1970-1998	1,500	3,534	2,500	3,668

While the modal values from Parsons evaluation were reported in Table 1 (so that comparison could be made with the EIS and others' modal values) Parsons review of the shapes of the histograms in Appendix A suggests that the median values better represent the central tendency of channel-shaping flows. Thus, median values given in Table 2 are suggested as better estimates of the effective discharges.

PREDICTING CHANNEL WIDTH FROM EFFECTIVE DISCHARGES

The channel width associated with the effective discharge is the channel width that was formed and is being maintained by the variable flow and sediment transport processes. As noted earlier, this is not the same as the unvegetated width of the river corridor. Kircher, in Open File Report 81-53 (1981) states, "Changes in the channel characteristics of the Platte River can be examined by considering the effective discharge at each site." And further concludes that "A direct relationship exists between channel size and effective discharge [for the Platte River]."

HDR (1983) generated what are called characteristic equations relating the width, depth, and velocity with the river discharge for both the pre-Kingsley and "current" periods analyzed in that study. Log-linear regression equations for each were obtained from least square fits to measured values acquired from USGS and DWR streamflow measurements located away from bridges. The squared bivariate linear correlation coefficients ranged from 0.70 to 0.92.

The pre-Kingsley effective-flow widths were then calculated for Overton and Grand Island as shown in the first two columns of Table 3. These were felt to be representative of conditions that existed when the river was relatively less encroached than presently.

The relationship between effective-flow channel width and river corridor width for unvegetated rivers has been described elsewhere. Leopold and Wolman (1960) found that the total bank-to-bank width is about 2.7 times the effective discharge width. Zeller (1967) similarly reported that the average sediment-transporting stream has a total width of 4.5 times the width corresponding to the controlling discharge rate. These ratios, found in natural streams that are unrestricted by significant vegetation expansion, are interpreted here to mean that a river's effective discharge creates the main channel character, and that the corridor width created and maintained by the unrestrained shifting of the main channel across its floodplain will be 2.7 to 4.5 times the effective discharge width.

HDR tested these ratios for pre-Kingsley conditions at two locations on the Platte as shown in Table 3. Measurements of the river corridor widths in 1938 were acquired and divided by the calculated (actual) effective flow widths. The resulting ratios of measured river width to calculated effective width of 4.3 and 2.7 fall in the 2.7 to 4.5 range presented by Leopold and Wolman and Zeller.

TABLE 3

HDR CALCULATIONS OF WIDTHS FOR PRE-KINGSLEY CONDITIONS

Station	Pre-Kingsley Effective Discharge Q_e, cfs	Corresponding Effective Width at Q_e, feet	Measured Corridor Width, USGS 1938	Ratio: Corridor Width to Effective Width
Overton	**3,100**	**680**	**2920**	**4.3**
Grand Island	**3,300**	**860**	**2310**	**2.7**

HDR then calculated the effective-flow widths for the "current" flow and sediment transport conditions, ignoring vegetation effects. These are shown in Table 4. From the calculated effective widths, the probable river widths that would exist without vegetation were calculated using the above ratios. These are compared in Table 4 to the actual 1979 measured braided widths reported by the USGS where it was reported that there was a 47 to 57 percent narrowing of the river corridor, presumably caused by vegetation.

TABLE 4

HDR ESTIMATES OF EFFECTS ON CHANNEL WIDTH OF VEGETATION

Station	Post-Kingsley Effective Discharge Q_e, cfs	Corresponding Effective Width w/o Vegetation	Probable Braided Width w/o Vegetation	Actual Braided Width, USGS 1979, ft	Apparent Reduction in Corridor Width due to Vegetation
Overton	**3,500**	**713**	**(x 4.3=)3070**	**1330**	**57%**
Grand Island	**3,600**	**884**	**(x 2.7=)2390**	**1270**	**47%**

As shown above, Parsons developed new estimates of the pre-Kingsley and current effective discharges at Overton and Grand Island (see Table 2). Parsons also re-visited the availability of characteristic equations for use in estimating the effective-flow channel widths that would be maintained by the effective discharge. Several had been developed since the 1983 HDR study, and Parsons also acquired a large number of additional streamflow measurement records to evaluate. For pre-Kingsley and current conditions, the following records were acquired:

TABLE 5

SOURCES OF WIDTH vs. DISCHARGE DATA FROM DISCHARGE MEASUREMENTS "AWAY" FROM BRIDGE OPENING AT OVERTON AND GRAND ISLAND

		Overton				Grand Island			
Period	Source	Dates	No. Msmts	Qmin	Qmax	Dates	No. Msmts	Qmin	Qmax
Pre-Kingsley	HDR, 1983	1936-1941	9	260	8830	1934-1940	6	35	3300
	Lyons & Randle, 1988	1931-1941	unknown	unknown	unknown				
	Parsons, 2001	1928-1941	22	260	13926	1928-1940	10	35	19944
Post-Kingsley	HDR, 1983	1978-1981	5	450	5410	1969	4	1540	2570
	Parsons, 2001	1965-1993	117	153	11630	1969-1982	7	966	2570

Note: Parsons data sources include the following:
- HDR,1983
- Lyons & Randle,1988 additional data from Table 5
- 1982 additional data from Gary Lewis' testimony
- Nebraska DWR and Nebraska Dept. of Roads & Irrigation discharge measurement records (early years)
- USGS discharge measurement summary sheets (later years)

From this data, the following characteristic equations were developed:

TABLE 6

CHARACTERISTIC EQUATIONS FOR WETTED CHANNEL WIDTH IN THE PLATTE RIVER AT OVERTON AND GRAND ISLAND

Period	Source	Overton Equation	Overton R^2	Grand Island Equation	Grand Island R^2
Pre-Kingsley	HDR, 1983	$W = 40.3Q^{0.352}$	0.70 to 0.92	$W = 39.7Q^{0.379}$	0.70 to 0.92
	Lyons & Randle, 1988	Q<2500 cfs, $W = 36.5Q^{0.404}$ Q>2500 cfs, $W = 722.1Q^{0.020}$	not published		
	Parsons, 2001	$W = 69.3Q^{0.301}$	0.76	$W = 83.0Q^{0.278}$	0.83
Post-Kingsley	HDR, 1983	$W = 23.8Q^{0.390}$	0.70 to 0.92	$W = 43.1Q^{0.342}$	0.70 to 0.92
	Parsons, 2001	$W = 49.9Q^{0.318}$	0.76		

Finally, estimates of the effective-flow width, W_e, and corresponding river corridor widths, W_b, were developed from the Parsons equations listed above for current flow and sediment transport conditions, assuming that vegetation effects had not occurred. River widths were estimated using a multiplier of 3.5, which is the average of the values reported by Leopold and Wolman, and Zeller. The results, using both Parsons and the EIS team estimates of effective discharge are as follows:

TABLE 7

PROBABLE CORRIDOR WIDTH ESTIMATES FOR GIVEN EFFECTIVE DISCHARGES

Basis of Width Estimate[a]	W_e[b], ft	W_b, ft (3.5 times We)
Using Parsons 2001 median-value estimates of Q_e = 3534 cfs at Overton		
HDR, 1983	715	2502
Lyons & Randle, 1988	850	2976
Parsons, 2001	811	2837
Using Parsons 2001 median-value estimates of Q_e = 3668 cfs at Grand Island		
HDR, 1983	891	3117
Lyons & Randle, 1988	N/A	N/A
Parsons, 2001	813	2845
Using EIS-USBR Method estimates of Q_e = 4020-7880 cfs at Overton		
HDR, 1983	748-948	2618-3318
Lyons & Randle, 1988	852-864	2982-3024
Parsons, 2001	843-1032	2950-3612
Using EIS-USBR Method estimates of Q_e = 4330-7610 cfs at Grand Island		
HDR, 1983	948-1174	3318-4109
Lyons & Randle, 1988	N/A	N/A
Parsons, 2001	851-996	2978-3486

a Active channel is that width associated with the effective discharge.
b To represent unvegetated width-discharge relationships, the Pre-Kingsley characteristic equations were used.

As noted earlier, the ratios of effective discharge width to river corridor width found in natural streams that are unrestricted by significant vegetation expansion are interpreted here to mean that a river's effective discharge creates the main channel character, and that the corridor width created and maintained by the unrestrained shifting of the main channel across its floodplain will be 2.7 to 4.5 times the effective discharge width. All methods shown in Table 7, regardless of the method adopted for calculation of the effective discharge, support the hypothesis that an unvegetated river corridor having a width comparable to the 1938 condition, and possibly earlier conditions, is possible with current day flows and sediment supplies if vegetation was not restricting the maintenance of the open corridor.

It should also be noted that significant variations in channel slope occur in the Platte (see Task A3 report). Considerable variation in planform also occurs, with some reaches braided, some anabranched, and some with a single meandering channel. Slope provides the energy for water and sediment flow, and is known to affect channel morphology and vegetation expansion. None of the EIS team products recognize this possible explanation for the variety of planforms and wide swings in vegetation expansion seen in the river.

TASK A4 CONCLUSIONS

The questions addressed in this task included the following:

1. What range of flows transport the greatest amount of sediment in the Platte (and thereby govern the shape of the channel)?

2. What effective and river corridor widths might be created and maintained by current flows if vegetation was not present?

Note that the questions addressed here in Task A4 are for a hypothetical case of a vegetation-free river corridor. Causes of vegetation expansion in the Platte River, and its effects (or lack of effects) on morphology are described in other task reports. Responses to Question No. 1 include:

- Daily flows in the range of 500 cfs to 4500 cfs transport (and transported) the majority of the sediment in the reach from Overton to Grand Island in both the periods from 1970 to 1998 and 1910 to 1939.

- Defensible estimates of the effective discharge in this reach for both periods of time fall in the range of 1,500 to 4,100 cfs. The preponderance of data best supports the use of Q_e in this range.

- Though sediment supply and transport has decreased over time, the flows that transported the majority of sediment (the effective discharge) in the periods from 1910 to 1939 and 1970 to 1998 are not significantly different.

Responses to Question No. 2 include:

- Daily flows experienced from 1970-1998, and the corresponding effective discharge of around 3,650 cfs at Overton and Grand Island, would create and maintain an effective-flow channel width of 800 ft in the Overton to Grand Island reach. The corresponding river beltway from daily flows experienced from 1970-1998 would be 2,100 to 2,800 ft wide in the absence of vegetation. Effective channel widths in 1938 (at Q = 3,600 cfs) at Overton and Grand Island were 680 and 860 ft, respectively, and the river beltway widths at Overton and Grand Island in 1938 were 2,920 ft and 2,310 ft (based on 1938 cross-sections).

- The current-day effective discharge of 3,650 cfs has the capacity (in the absence of vegetation) to support an effective channel of 800 ft and a river beltway width of 2,100 to 2,800 ft, nearly matching the 1938 conditions. The 1979 braided beltway widths at Overton and Grand Island were 1,330 ft and 1,270 ft (1979 cross-sections), or about half of what they would be if vegetation was not present. This quantifies the effect that vegetation has had.

Other related questions addressed were:

3. Does most sediment transport occur "during the few days of peak flows during the year?"

4. Are annual peak flows primarily responsible for shaping and maintaining the channel?

5. Have reductions in annual peak flows occurred, and if so, where the reductions in peaks primarily responsible for most of the narrowing of the unvegetated channel?

6. Are pulse flows and addition of sediment needed in order to shape and maintain a wider channel once vegetation is removed?

7. Have "effective" flows, and the associated effective channel widths, changed?

8. How wide would the effective channel and river corridor be without vegetation?

9. To what extent is vegetation limiting the effective and river corridor widths that would exist under today's flows without the presence of vegetation?

Regarding the remaining questions, the hypothesis that most sediment transport occurs "during the few days of peak flows during the year" is not at all supported by the data, including the EIS team data. This may have been a reference to the suspended sediment load, but it is not clear. Suspended sediment load would not be instrumental in shaping the channel. The hypothesis that annual peak flows are primarily responsible for shaping and maintaining the channel is not supported by relevant literature or by the data.

The hypothesis that alleged reductions in annual peak flows have been primarily responsible for most of the narrowing of the unvegetated channel is contradicted by the results of this analysis. It is also possible that the estimates of pre-1914 peak flows by indirect methods have a significant error and are being treated with comparable precision to current-day measurements. It is, however, possible that the annual peak flows were effective in removing vegetation (but not in shaping the channel), and that the expansion of vegetation following reduction in peak flows has resulted in a condition in which the effective discharge is not maintaining either the effective channel or river corridor widths. Though this issue continues to be debated (see Reports C1 and C2), the data analyzed in this report suggests that reductions in annual peak flows are not as significant as other changes in controls of vegetation expansion, such as ice jams. It is undisputed that annual peak flows, however large, transport an extremely small amount of the annual sediment load and any morphologic, episodic changes arising from such events would be temporary.

This analysis suggests that the effective-flow channel, and corresponding river corridor, would be about 800 ft, and 2100 to 2800 ft, respectively, nearly matching 1938 conditions.

The Proposed Program includes pulse flows and the addition of sediment, following a one-time removal of existing and new vegetation. It is assumed here that the existing and new vegetation would be mechanically removed. This analysis suggests that once vegetation is removed, the flow and sediment regime that has existed since 1970 is adequate to provide a 1938 effective flow channel width. Effective flows have decreased slightly at Overton, but the associated effective-flow channel widths have not dramatically changed at either Overton or Grand Island. If the median values of Parsons independent analysis are valid, they reveal a 13 percent reduction in effective flow at Overton and a slight increase (not considered statistically significant) at Grand Island. The change at Overton translates to a change in effective width from 846 ft to 811 ft, or only a four percent reduction in channel width. That the unvegetated portion of the river beltway has decreased in width is not disputed. This suggests that this dimension is about half of what it could be in the absence of vegetation. This also proves that defining the past or current "active" channel as being equal to the unvegetated portion of the beltway is not supported by the scientific community or the standard literature.

The extent that vegetation is limiting the effective and river corridor widths that would exist under today's flows and sediment transport ratings without the presence of vegetation is illuminated by this analysis. The primary conclusion is that the effective-channel width is about the same as it would be without vegetation, but the river corridor width is about half of what it could be.

COMPARISON OF PARSONS AND EIS TEAM RESULTS

As noted above, the EIS team presented results of their use of the USBR method at the July 2001 presentation. In subsequent discussion and correspondence, it was discovered that they had also calculated the sediment transport histograms by a second method; namely the equal interval method used by Parsons. As a means of comparing Parsons' results with the two EIS team methods, Figures 5 through 8 were developed. They reveal that the Parsons results and the EIS team results using the same method are extremely collaborative, considering that the only element in common was the daily discharge values. Completely different sediment transport relations were used, different class intervals were used, and curve fitting was not the same, yet the graphs show surprising concurrence on shape and location of the peak and median values.

Entries on the Parsons graphs in Appendix A reveal that the total amount of sediment transported during the two periods have decreased with time, but not to the extent hypothesized in other reports. A reduction in sediment transported can occur without affecting the effective discharge, as appears to have occurred here. If the condition becomes supply-limited, the effective discharge could decrease, followed by a reduction in effective and river corridor channel widths.

The entries in Appendix A further suggest that for the same period of time, there is about 10 to 15 percent less total annual sediment transported at Grand Island, compared to Overton. It is possible that this reflects the cumulative error in the sediment rating curves and discharge records, rather than suggesting that aggradation must be occurring in the habitat reach. These differences were not considered sufficiently large, and if corrected, it is likely that the modal values of the distributions would not shift to the right or left, meaning that the estimates of effective discharges would not change.

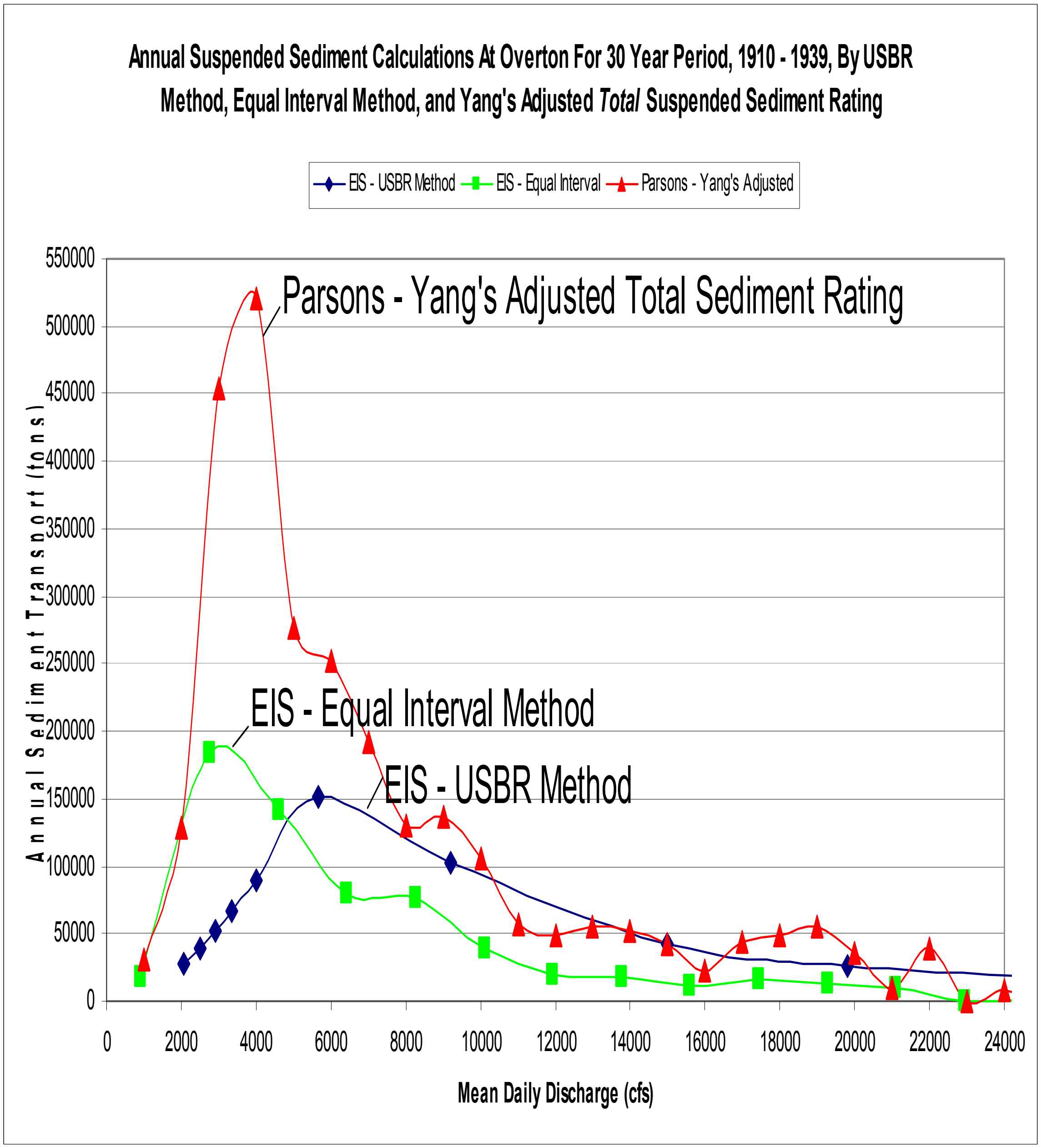


Figure 5. Comparison of Parsons and USBR Sediment Transport Histograms at Overton for the Period 1910-1939

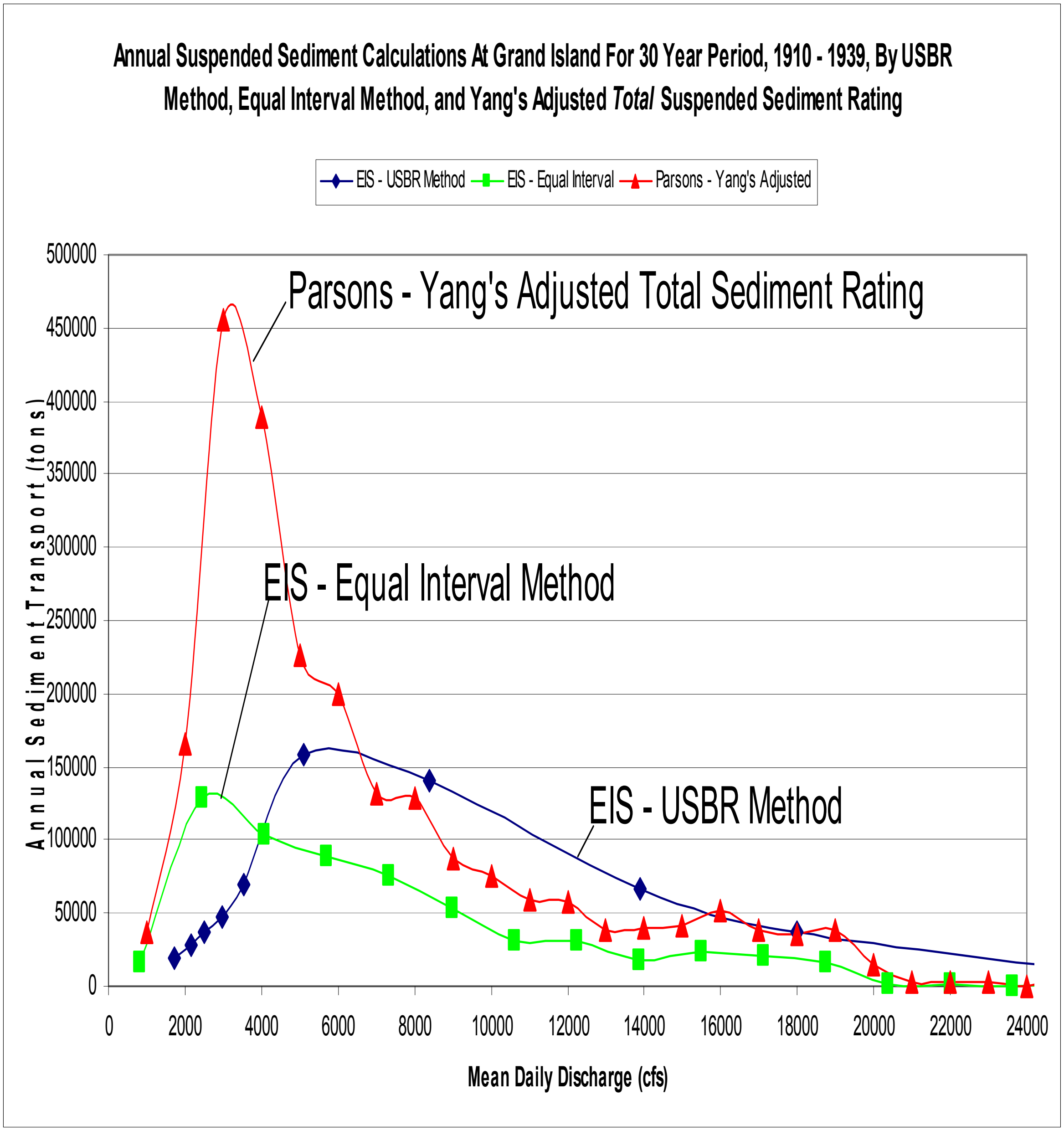


Figure 6. Comparison of Parsons and USBR Sediment Transport Histograms at Grand Island for the Period 1910-1939

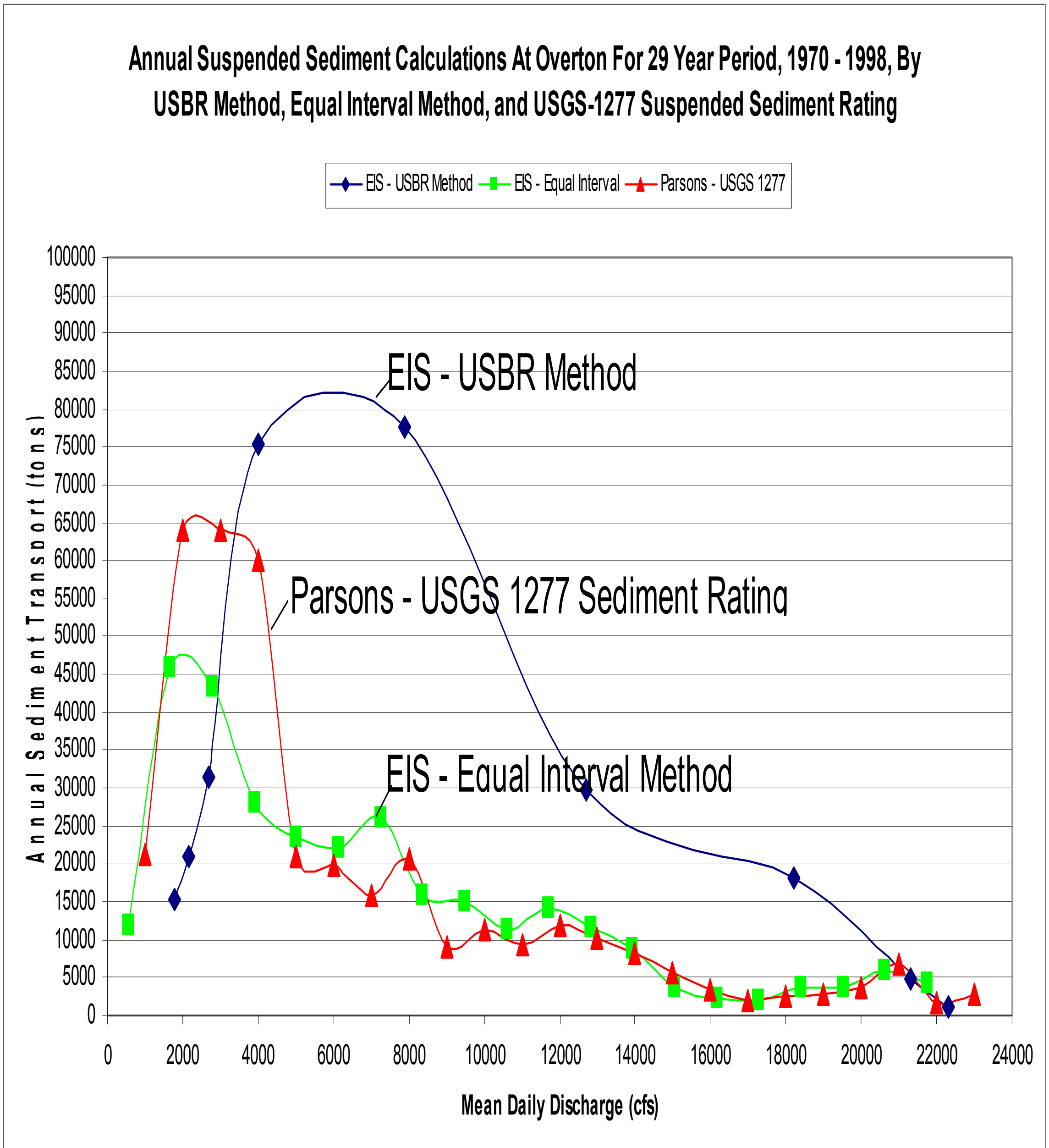


Figure 7. Comparison of Parsons and USBR Sediment Transport Histograms at Overton for the Period 1970-1998

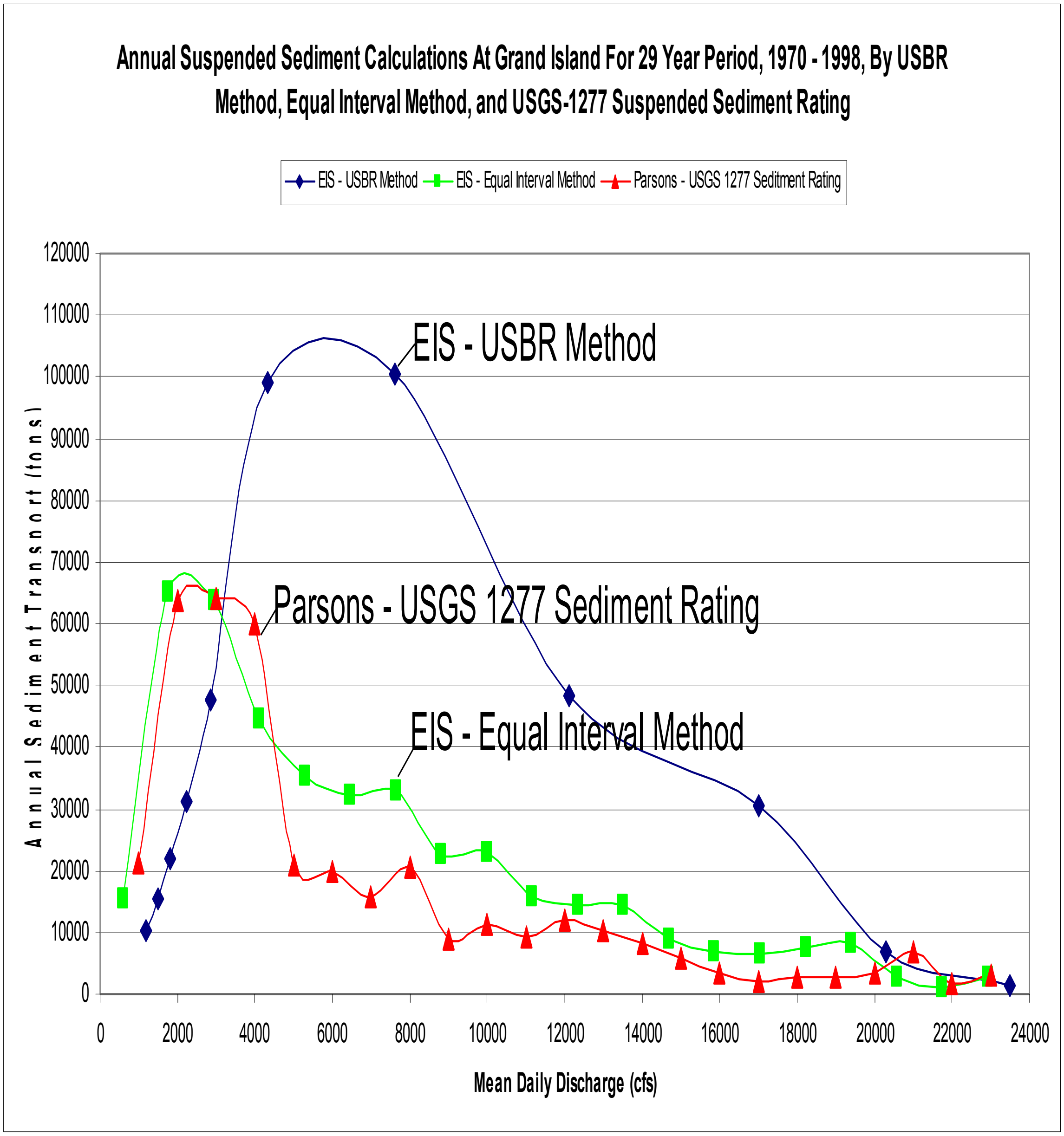


Figure 8. Comparison of Parsons and USBR Sediment Transport Histograms at Grand Island for the Period 1970-1998

BIBLIOGRAPHY

Battelle, 1988. *Flushing and Scouring Flows for Habitat Maintenance in Regulated Streams,* U.S. Environmental Protection Agency – Criteria and Standards Division, Nelson, R.W., Dwyer, J.R., and W.E. Greenberg, Contract No. 68-01-6986.

HDR Engineering, 1983. *Quantitative Analysis of Morphologic Changes in the Platte River and Miscellaneous Water Resources Aspects of the Proposed Prairie Bend – Twin Valley Project*, September.

Hydrology Work Group, Platte River Management Joint Study, 1989. *Evaluating Management Alternatives: Sediment, Flow, and Channel Geometry Considerations,* December.

Leopold and Wolman, 1960. Bulletin of the Geological Society of America, Vol. 71.

Lyons, J. K. and T. J. Randle, 1988. *Platte River Channel Characteristics in the Big Bend Reach*, *Prairie Bend Project*, Bureau of Reclamation, Denver, Colorado, 28 p.

Marlette, R. R. and T. Walker, 1968. *Dominant Discharges at Platte–Missouri Confluence,* ASCE Journal of Waterways and Harbors, February.

Miller, C.R., 1951. *Analysis of Flow-Duration, Sediment-Rating Curve Method of Computing Sediment Yield*, Bureau of Reclamation, Denver, Colorado.

Murphy, P.J. and T.J. Randle, 2001. *DRAFT Platte River Channel: History and Restoration*, U.S.B.R., Denver, CO, Jan 30.

O'Brien, J.S. 1986. *Estimating Channel Maintenance Flows for the Platte River: A Research Proposal To Establish A Minimum Streamflow Hydrograph,* November.

Samad and Randle, 2000. *DRAFT Platte River Historic Perspective of Sediment Transport*, U.S.B.R., September.

U. S. Army Corps of Engineers, Omaha District, 1989. *Platte River Cumulative Impacts Analysis – Quantitative Analysis of Hydro-Geologic Impacts from Bank Stabilization*, Engineering Division, June.

U.S. Army Corps of Engineers Omaha District. 1989. *Platte River Cumulative Impacts Analysis Report No. 4, Quantitative Analysis of Hydro-Geologic Impacts from Bank Stabilization,*. River & Reservoir Engineering Special Studies Unit, July.

U.S.B.R., 1982. *Reservoir Sedimentation – Technical Guideline for Bureau of Reclamation*, Strand R. I. And E. L. Pemberton, Denver, **Colorado**, October.

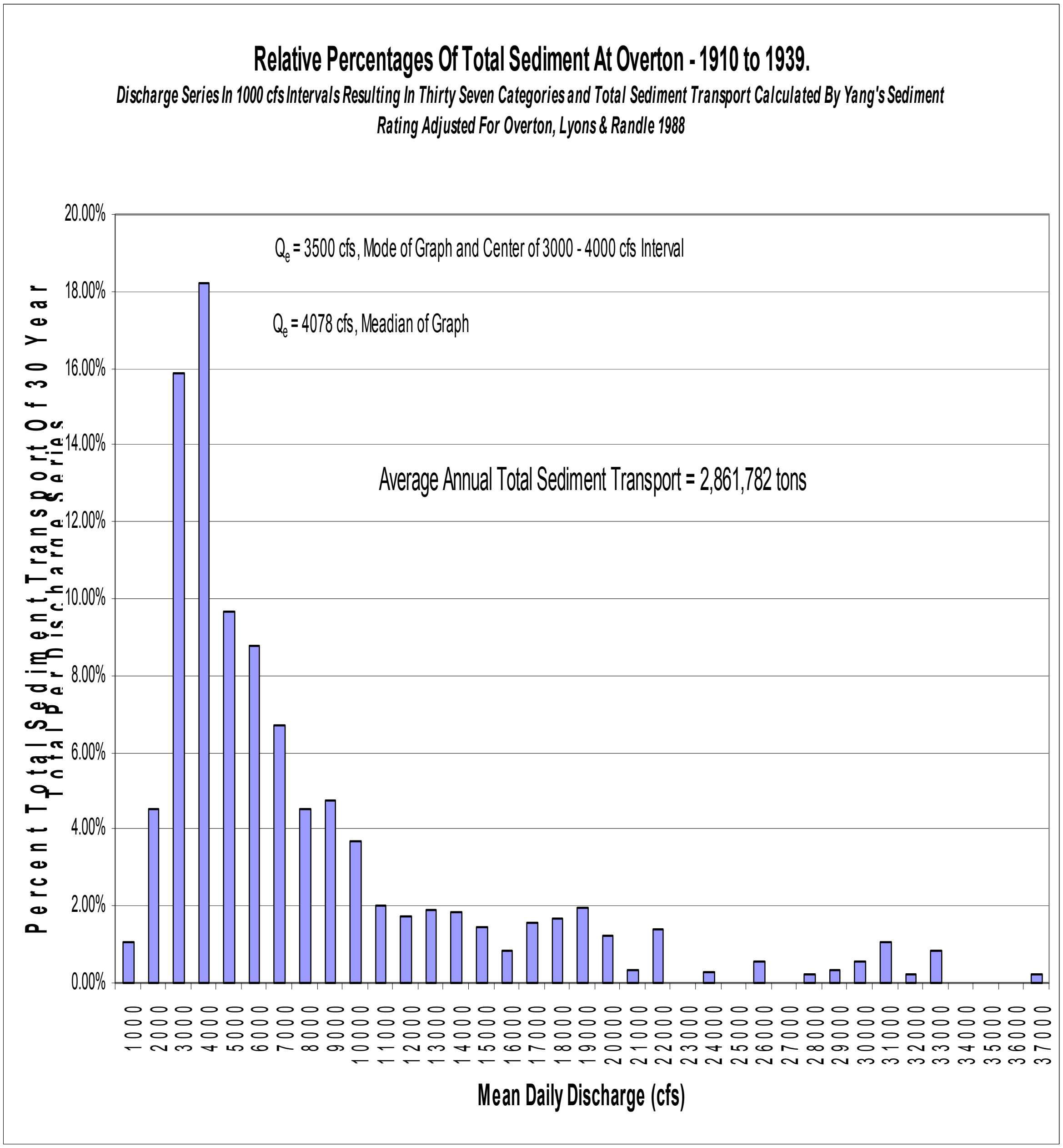
U.S.G.S. Open File Report 81-53, 1981. *Sediment Transport and Effective discharge of the North Platte, South Platte, and Platte Rivers in Nebraska*, Kircher, J. E..

U.S.G.S Professional Paper 1277E, 1983. *Relation of Channel-Width Maintenance to Sediment Transport and River Morphology: Platte River*, Karlinger, M.R., Eschner, T.R., Hadley, R.F., and J.E. Kircher, South-Central Nebraska.

U.S.G.S. Professional Paper 1277C, 1983. *Hydraulic Geometry of the Platte River Near Overton South-Central Nebraska,* Eschner, T.R.

Zeller, 1967. International Association of Scientific Hydrology Symposium Proceedings.

APPENDIX A


Relative Percentages Of Total Sediment At Overton - 1910 to 1939.
Discharge Series In 1000 cfs Intervals Resulting In Thirty Seven Categories and Total Sediment Transport Calculated By Yang's Sediment Rating Adjusted For Overton, Lyons & Randle 1988
Qe = 3500 cfs, Mode of Graph and Center of 3000 - 4000 cfs Interval
Qe = 4078 cfs, Meadian of Graph
Average Annual Total Sediment Transport = 2,861,782 tons
Percent Total Sediment Transport Of 30 Year Total Per Discharge Series
20.00%
18.00%
16.00%
14.00%
12.00%
10.00%
8.00%
6.00%
4.00%
2.00%
0.00%
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
13000
14000
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17000
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23000
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25000
26000
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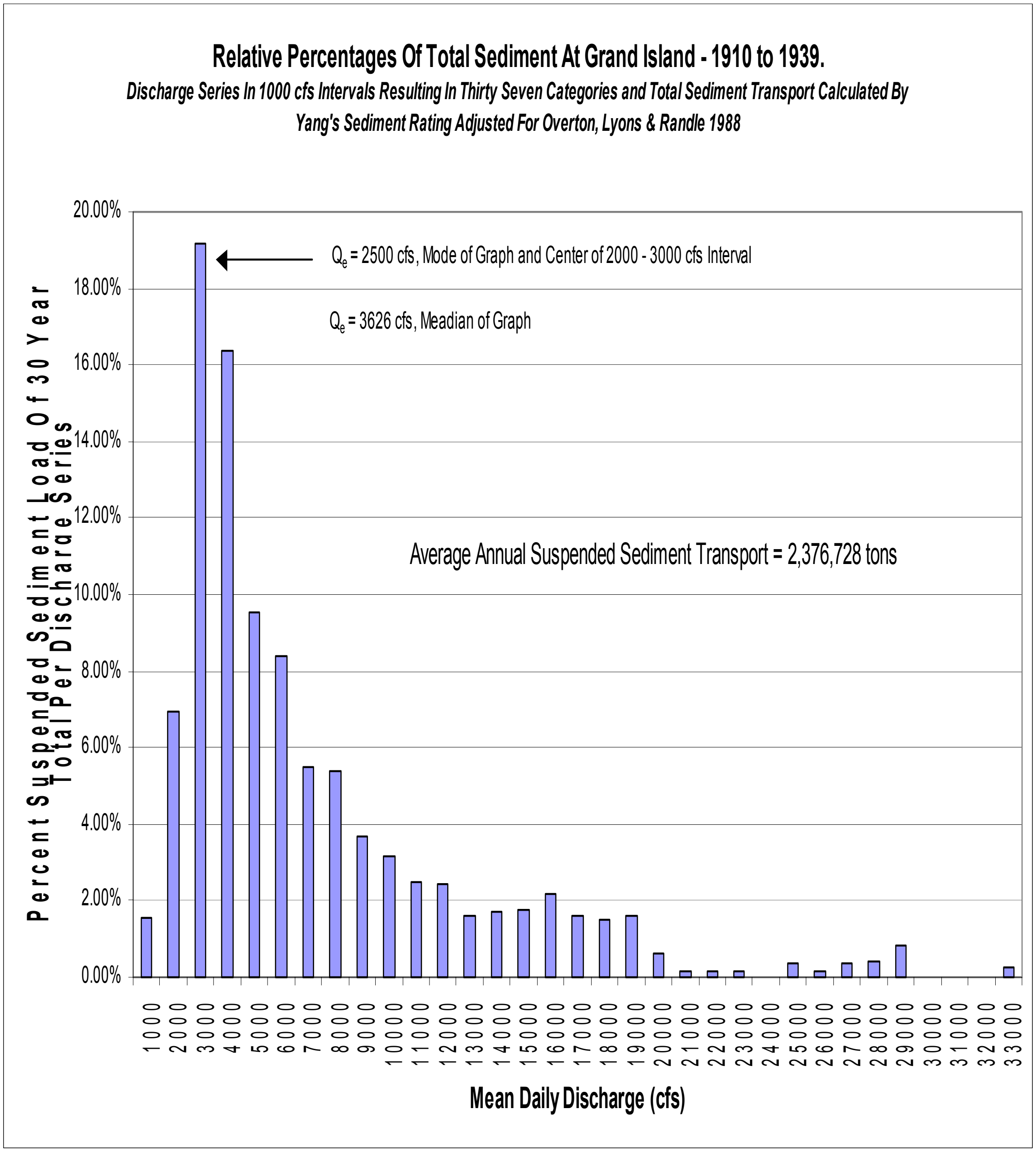
28000
29000
30000
31000
32000
33000
34000
35000
36000
37000
Mean Daily Discharge (cfs)


Relative Percentages Of Total Sediment At Grand Island - 1910 to 1939.
Discharge Series In 1000 cfs Intervals Resulting In Thirty Seven Categories and Total Sediment Transport Calculated By Yang's Sediment Rating Adjusted For Overton, Lyons & Randle 1988
Q_e = 2500 cfs, Mode of Graph and Center of 2000 - 3000 cfs Interval
Q_e = 3626 cfs, Meadian of Graph
Average Annual Suspended Sediment Transport = 2,376,728 tons
Percent Suspended Sediment Load Of 30 Year Total Per Discharge Series
20.00%
18.00%
16.00%
14.00%
12.00%
10.00%
8.00%
6.00%
4.00%
2.00%
0.00%
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2000
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4000
5000
6000
7000
8000
9000
10000
11000
12000
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19000
20000
21000
22000
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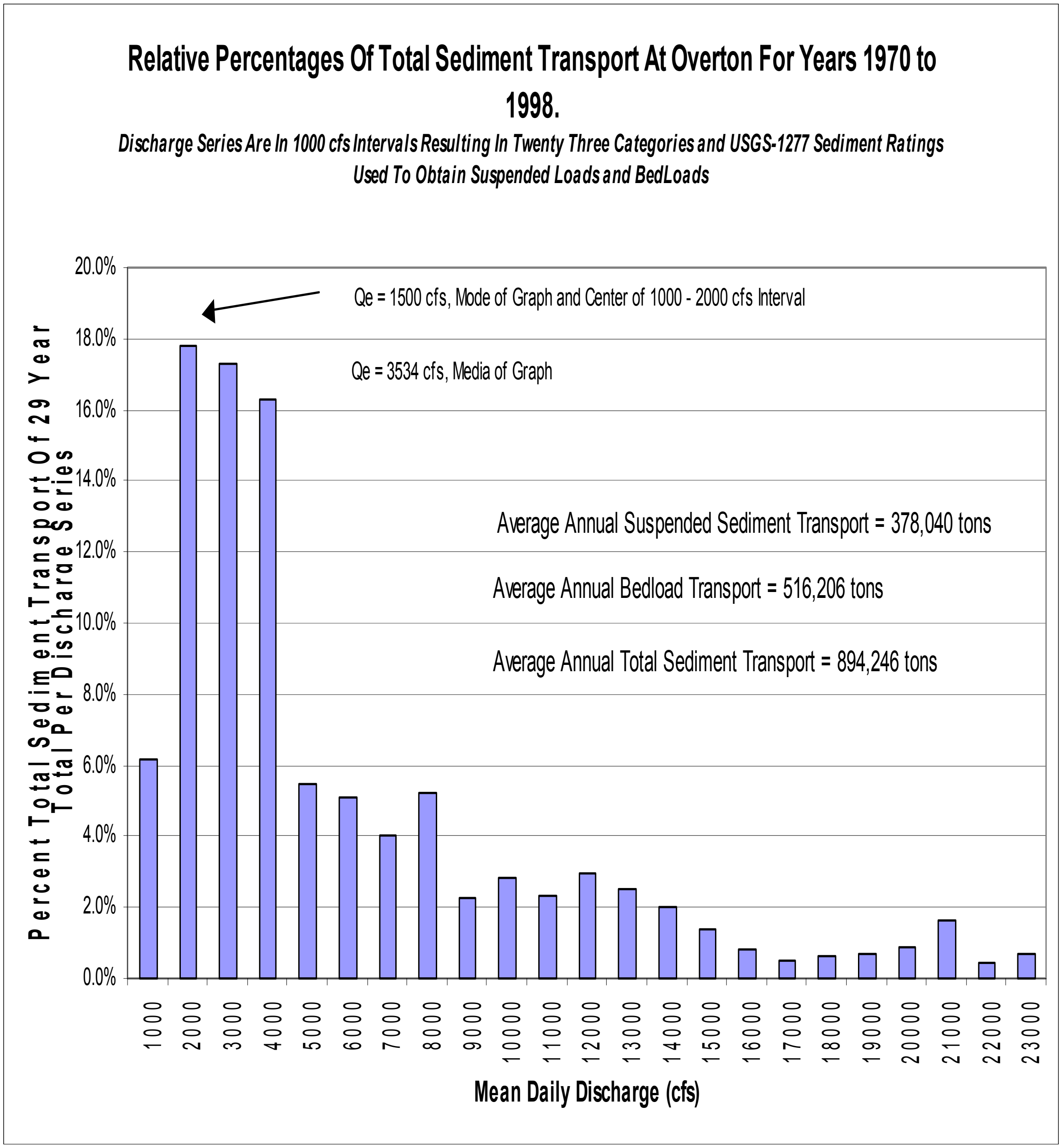
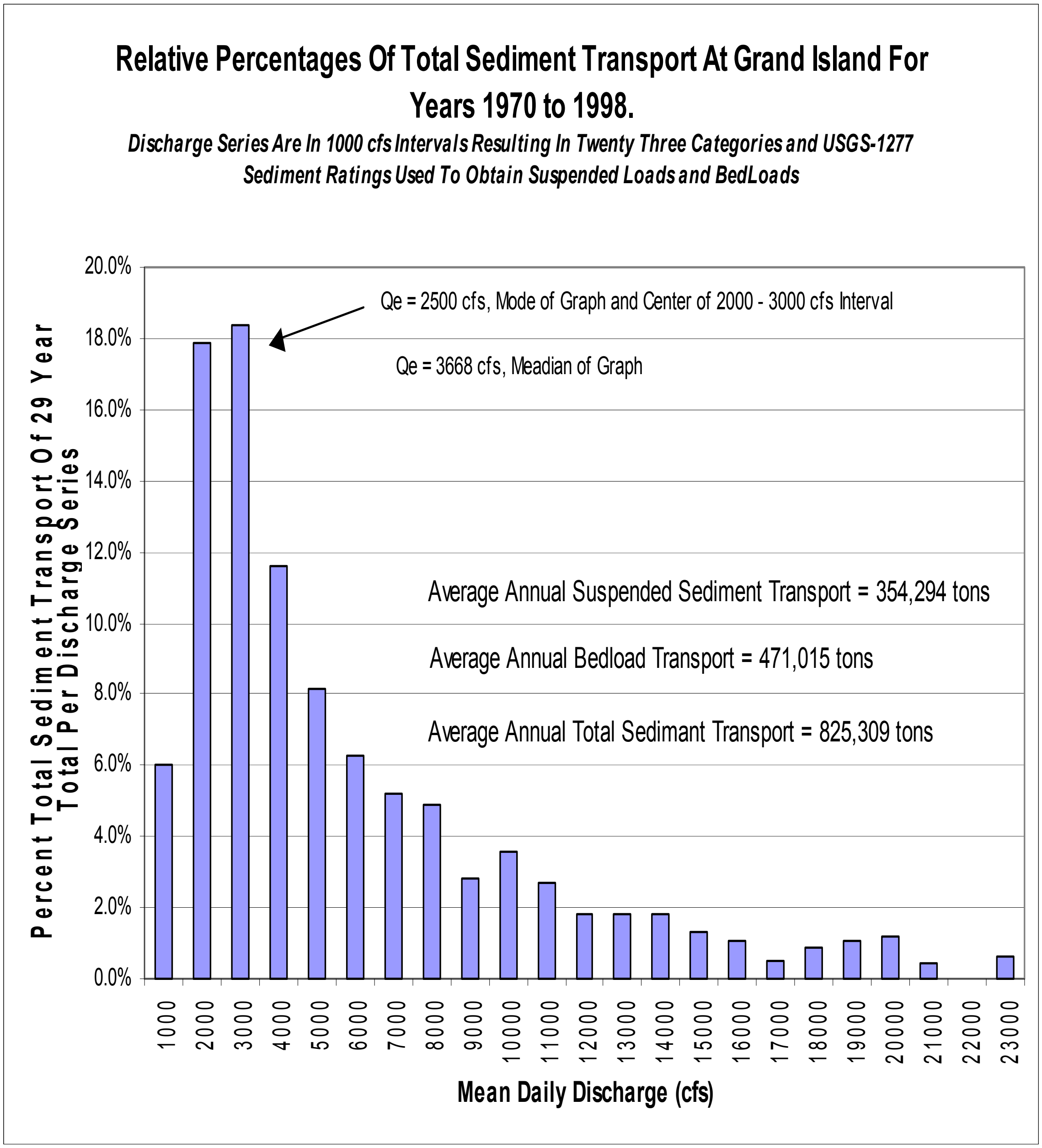
26000
27000
28000
29000
30000
31000
32000
33000
Mean Daily Discharge (cfs)


Relative Percentages Of Total Sediment Transport At Overton For Years 1970 to 1998.
Discharge Series Are In 1000 cfs Intervals Resulting In Twenty Three Categories and USGS-1277 Sediment Ratings Used To Obtain Suspended Loads and BedLoads
Qe = 1500 cfs, Mode of Graph and Center of 1000 - 2000 cfs Interval
Qe = 3534 cfs, Media of Graph
Average Annual Suspended Sediment Transport = 378,040 tons
Average Annual Bedload Transport = 516,206 tons
Average Annual Total Sediment Transport = 894,246 tons
Percent Total Sediment Transport Of 29 Year Total Per Discharge Series
20.0%
18.0%
16.0%
14.0%
12.0%
10.0%
8.0%
6.0%
4.0%
2.0%
0.0%
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
13000
14000
15000
16000
17000
18000
19000
20000
21000
22000
23000
Mean Daily Discharge (cfs)


Relative Percentages Of Total Sediment Transport At Grand Island For Years 1970 to 1998.
Discharge Series Are In 1000 cfs Intervals Resulting In Twenty Three Categories and USGS-1277 Sediment Ratings Used To Obtain Suspended Loads and BedLoads
Qe = 2500 cfs, Mode of Graph and Center of 2000 - 3000 cfs Interval
Qe = 3668 cfs, Meadian of Graph
Average Annual Suspended Sediment Transport = 354,294 tons
Average Annual Bedload Transport = 471,015 tons
Average Annual Total Sedimant Transport = 825,309 tons
Percent Total Sediment Transport Of 29 Year Total Per Discharge Series
20.0%
18.0%
16.0%
14.0%
12.0%
10.0%
8.0%
6.0%
4.0%
2.0%
0.0%
1000
2000
3000
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5000
6000
7000
8000
9000
10000
11000
12000
13000
14000
15000
16000
17000
18000
19000
20000
21000
22000
23000
Mean Daily Discharge (cfs)

TECHNICAL MEMORANDUM

RESULTS OF INVESTIGATION A5 -- QUALITATIVELY AFFIRM CHANNEL WIDTH PREDICTIVE TOOL

PLATTE RIVER CHANNEL DYNAMICS INVESTIGATION

Prepared For

States of Colorado, Nebraska, and Wyoming

May 2003

Prepared By

PARSONS
1700 Broadway, Suite 900
Denver, CO 80290

TECHNICAL MEMORANDUM

INVESTIGATION A5 - QUALITATIVELY AFFIRM CHANNEL WIDTH PREDICTIVE TOOL

PREFACE

This report describes the procedures used in and results of an evaluation of the literature on predictability of channel widths and compares them with the method developed in Task A4. The investigation addressees a number of technical issues regarding this subject which had been identified by the sponsors as needing detailed examination to allow them to make scientifically-based decisions regarding the Cooperative Agreement (CA) work products.

This document describes only the data collected, analyses made, and scientifically-supportable findings regarding the issues, written in a manner which generally follows the guidelines of professional journals of the respective authors' technical expertise. The relevance of the findings to the specific issues confronting the sponsors is discussed in each task memorandum, but only as far as the data and results are deemed by the author(s) to be scientifically supportable in resolving or illuminating the issue.

ISSUES AND PURPOSES OF INVESTIGATIONS

The technical evaluations completed by the Parsons team were conducted as a series of 14 complementary investigations divided into four categories that would address general issues identified by the three states. The following issue categories were identified:

- A: Questions Regarding Channel Narrowing or Deepening
- B: Questions Regarding Sediment Transport
- C: Questions Regarding Vegetative Encroachment
- D: Questions Regarding Macro-Historic Natural Variability

This Technical Memorandum describes the results of Task A4, the fourth of five tasks comprising Issue Category "A."

The objective of Task A5 is to establish whether qualitative and quantitative geomorphic relationships in standard literature corroborate the relationships between effective discharge and width developed in Task A4. A few relevant publications regarding channel width adjustments were evaluated and described here.

SCOPE OF WORK

Numerous references on geomorphology and sediment transport are available for guidance regarding natural active channel widths and depths of braided, anabranched, and transitional sand-bed streams for various index flow rates and sedimentation conditions. The scope of work for Task A5 included compilation of some of this information followed by evaluation, and interpretations for conditions in the Central Platte River. The Parsons team would then develop qualitative guidelines for assessing channel geometry, river morphology and dynamic equilibrium for historical, current, and proposed program future conditions, if known. Results are contrasted with the predictive tool developed in Investigation A4. The Parsons team will also provide a summary of standard literature references to the geomorphic technologies available for predicting channel geometry, particularly in the Platte River's setting. The results are summarized in this technical memorandum.

All analyses planned for this task have been completed. Samples of the best available science regarding processes and mechanisms of river width adjustment have been reviewed and reported here. An independent assessment has been made of one of the potentially weakest links in the computations completed for Task A4 (the characteristic equations). The channel width predictive tools developed in Task A4 are affirmed, and applicability to the current, vegetated river corridor is described.

RIVER WIDTH ADJUSTMENT PROCESSES

The EIS team's "white paper" (Murphy and Randle 2001) references a recent American Society of Civil Engineers Task Committee report on this subject. The two-part publication (ASCE 1998a and 1998b) addresses the processes and mechanisms of river width adjustment and modeling of river width adjustments, respectively. The publications were compiled by the Task Committee on Hydraulics, Bank Mechanics, and Modeling of River Width Adjustment, made up of an international panel of expert researchers and practitioners in this field. A number of findings in the reports are extremely relevant to the issue of whether the physical processes in the Platte River can be modeled with a tool like SEDVEG or any other method.

Findings of the reports considered to be relevant to state of the art analysis of the Platte River channel-shaping processes are:

1. Most mathematical models neglect time-dependent channel width adjustments and do not adequately simulate processes of bank erosion or deposition.

2. Although changes in channel depth caused by aggradation or degradation of the river bed can be simulated with mathematical models, changes in width cannot.

3. In braided rivers, bank erosion by flows directed around growing braid bars is a primary cause of widening [and this process should therefore be incorporated in any models]. The USBR SEDVEG model is a vertical aggradation/degradation model and does not directly simulate this process.

4. Morphological adjustments involving channel narrowing are diverse. Rivers may narrow through the formation of in-channel berms or benches at the margins. Encroachment of riparian vegetation into the channel is often identified as contributing to the growth, stability, and, in some cases, the initiation of these berm or bench features. Bank advance takes place through sediment accumulation as a berm or bench in the channel, often accelerated by invasion of pioneer riparian vegetation.

5. In braided channels, narrowing may result when a marginal anabranch in the braided system is abandoned; sediment is deposited in the abandoned channel until it merges into the floodplain.

6. Braid bars or islands may become attached to the floodplain, especially following a reduction in the effective discharge.

7. Although the width of an equilibrium stream may change due to the impact of a large flood, the stable width is eventually recovered following such perturbations.

8. Predicting the time-averaged morphology of equilibrium channels remains a difficult problem.

9. Rivers in arid and semiarid regions of the American West change their morphologies drastically as the volume of annual precipitation, frequency of flood events, and other factors vary, and perpetually enlarge rapidly during periods of relatively high flows and contract during periods of less than average runoff.

10. It is unlikely that a single method can be developed to predict the trends and rates of width adjustment for all rivers.

11. Characteristic equations relation channel top width with discharge exhibit surprising universality, particularly the one for channel width, which has been found to have an exponent of approximately 0.5 for rivers with widely varying flow and sediment characteristics.

12. Vegetation may be either a positive or negative influence on bankline stability and retreat rate.

13. As a general premise, users of sediment transport models must accept a fair discrepancy between their problem and the model.

14. Compound channels in dynamic equilibrium have a dynamic balance between the sediment transport capacity and sediment supply for the effective discharge channel.

15. A particular limitation for width adjustment modeling applications is that most sediment transport equations are valid only for bed surfaces inclined at low angles.

16. Relatively few numerical models of width adjustment have been developed to date, and many processes of width adjustment have never been successfully quantified.

    Possibly the most relevant and significant finding of the Task Committee is summarized in the statement,

17. "Existing [numerical] models of channel width adjustments are research tools and are not yet ready to be adopted in widespread engineering practice."

This finding closely corroborates statements made a number of years earlier by John F. Kennedy (Kennedy, Undated) in his keynote address to ASCE titled, "Whence and Whither of River-Sediment Research." He notes:

1. Sediment transport modeling is complicated by bed forms, sorting of bed material, secondary currents, armoring, degradation and aggradation, and by the "importance of accurately calculating the rate of sediment transport, preferably by size fraction."

2. Energy transfer methods have "shortcomings in their logic."

3. Progress in modeling can be considered to be "disappointing."

4. The increased emphasis on models "will only heighten the need for more river data."

   Similarly, the most relevant and significant finding of Kennedy is that,

5. "Our ability to formulate the key processes…is still so limited that blind application of curve fitting provides superior predictors."

These findings strongly suggest that estimating width changes by models is not considered in this industry as the best available science (i.e. as noted by the ASCE reports, "they are research tools and should not be used in management decisions"), and that "curve fitting" methods such as those described in Task A4 are state of the art tools.

APPLICABILITY OF THE CHARACTERISTIC EQUATIONS

One of the prevailing concerns with use of streamflow measurement records for characterizing the width, depth, and other geometric features of rivers as functions of discharge is that they are generally obtained at or near bridge sections, which artificially contract the river. Arguments in favor of the use of the width equations, at least, are that they would definitely not over-predict the width for a given discharge. Thus, the width estimates in the Task A4 report obtained from the derived characteristic equations are possibly narrower than values that might be obtained if the equations were available for "open" reaches of the river.

As a means of verifying the estimates provided in the Task A4 report, two independent tests of the widths corresponding to the effective discharge were obtained and compared with the widths predicted by the characteristic equations. Only discharge is needed to estimate width, depth, area or other characteristics from these equations. For the first case, the entire record of streamflow measurements was evaluated for dates when the discharges were around 3600 cfs, which is suggested by the Parsons evaluation as the pre-Kingsley and present-day effective discharge. The results are compared in Table 1 with the width estimates from the characteristic equations described in the Task A4 memorandum.

TABLE 1
COMPARISON OF ACTUAL WIDTHS AT FLOW RATES OF APPROXIMATELY 3,600 CFS WITH CHARACTERISTIC EQUATION ESTIMATES

Location	Date of Measurement	Measured Discharge, cfs	Measured Top Width, ft	Estimated Top Width, ft
Overton	11/22/28	3,586	875	718
	5/23/91	3,420	700	663
Grand Is.	5/18/28	3,675	777	891
	3/17/69	2,570 (largest available)	820	632

With the exception of pre-Kingsley conditions at Grand Island, the table shows that the characteristic equations under-predict the width for flows approximating the effective discharge. Because these four measurements were also used in developing the regression equations, the differences illustrate the variance in the data around the regression line.

To better test the issue of active channel width at 3,600 cfs and the concern over proximity to bridges, four of the 1989 USBR cross-sections used in the SEDVEG model (which were all selected to be unaffected by bridges) were located in the river profile and average channel slopes were obtained. One cross-section upstream and one downstream of the Overton and Grand Island gages were selected, and normal flow depth and width were estimated from Manning's equation. Assuming that the effective discharge of 3,600 cfs would fall fully within the channels, an n-value of 0.035 was applied across the whole section to determine the flow depth and top width of flow at this discharge rate. The results are provided in Table 2.

TABLE 2
CHANNEL TOP WIDTHS AT 1989 CROSS SECTIONS FOR A FLOW RATE OF 3,600 CFS

Location	River Mile	Calculated Width at 3,600 cfs, ft	Average at Two Locations, ft
Overton	237.5	1,316	
	239.9	1,175	1,246
Grand Island	170.3	1,398	
	168.7	1,389	1,394

The table reveals that the characteristic equations for present-day conditions probably under-estimate the widths that would be expected for the given effective discharge. Recall that the estimates of effective-flow widths from the Task A4 report were around 800 ft for a 3,600 cfs flow rate. This moderately large difference may be a result of the effects of bridges on the characteristic equations, but also confirms the hypothesis that the estimated river widths for given effective discharges given in the Task A4 paper are definitely not over-stated. Even wider active channels, perhaps 50 percent greater, and correspondingly wider river corridor widths may be produced between bridges by removal of vegetation. The choice of n-value is also considered to be conservative. Had larger values been used, or had a mix of n-values been used to reflect channel and floodplain roughness, the flow depths would be deeper, resulting in even wider top widths for the same discharge rate. Plots of the four cross sections reveal that the water level at 3,600 cfs is predominantly within multiple channels and not flowing over floodplain or vegetated areas.

OTHER RELATIONSHIPS

Among others, the following qualitative and quantitative methods are available for testing the reasonableness of the width-predictive tool developed in Task A4:

- Lane's Law of River Adjustment
- Rubey's Corollary to Lane's Law (includes a Form Factor, allowing assessments of width adjustments)
- Lane's Quantified Relation (includes width and depth)
- Yang's "Basic Equation"
- Chang's Regime Channel Geometry for Sand-bed Rivers
- Numerous Other Regime and Threshold Geometry Relationships

Even less-quantitative methods can be applied for reasonableness testing. Standard texts on rivers such as Richards (1982) provide state-of-art discussions and contain numerous general statements regarding processes and characteristics of braided and anabranched streams. For example, Richards notes that for semi-arid environments with variable flow regimes (which certainly describes the Platte), about 40 percent of sediment is transported by events of less than a 10-yr return period. This appears to corroborate the findings in Task A4. Though frequency of flood flows and daily discharge values are difficult to compare, Richards point is that the work done by a river in shaping itself is maximized by events of intermediate magnitude and frequency. He further adds that extreme events transport large sediment loads, but occur too rarely to be of long-term significance. This is a fundamental difference of understanding between the EIS Team members and the literature. The phrase "peak flow" and its link to channel width are mentioned over 60 times in the white paper (Lyons and Randle 2001). The supposition of the paper is that annual peak flows determine the channel width.

Regarding the present vegetated state of the river, Richards adds the interesting observation that research shows that an even larger percent (he cites 90 percent) of sediment transport in humid, vegetated environments is by the *frequent* events. Another possibly relevant point made by Richards is that the effective flow is lower in magnitude if the stream carries suspended sediment in addition to bed material transport.

Though not developed for the Platte River, these standard, published explanations of river processes in general should be incorporated as reasonableness tests of the specific conclusions regarding the Platte.

If deemed necessary for further confirmation of the Task A4 estimates, the average morphologic dimensions of segments of the Platte can be established and entered into these and other relationships for evaluation of the reasonableness of the estimates.

CONCLUSIONS

It is concluded that if vegetation was not present, the river from Overton to Grand Island would have very much the same morphology that was documented in 1938.

The second most significant finding of this investigation is the discovery of the consensus among experts in analyzing river width adjustments does not support the EIS Team choice of SEDVEG for predictive or regulatory purposes. Instead, curve-fitting or channel regime equations are recommended. Additionally, much of the literature researched does not support their conceptualization of the physical processes being evaluated with models or curve-fitting methods. Further concerns with the methods used and code written for SEDVEG are detailed in the Task B2 report.

The tools developed in this investigation are valid estimators of the river corridor and effective discharge channel widths that would exist under today's hydrologic, sediment transport, and dynamic equilibrium conditions. They also accurately quantified the effect that vegetation has had in limiting the river corridor widths.

While it is affirmed that the tools developed in Task A4 are reliable predictors of the effective channel and river corridor widths for unvegetated streams, their applicability to streams with greatly expanded vegetation is limited. Thus, no predictions of the effect that any proposed program would have on channel or river corridor width can be reliably made. However, it has been suggested that the proposed program could entail extensive artificial removal of vegetation, in which case the tools would be considered very reliable.

BIBLIOGRAPHY

ASCE Task Committee on Hydraulics, Bank Mechanics and Modeling of River Width Adjustment, 1998a. *River Width Adjustment I: Processes and Mechanisms*, Journal of Hydraulic Engineering, ASCE, Vol. 124, No. 9, pp. 881-902.

ASCE Task Committee on Hydraulics, Bank Mechanics and Modeling of River Width Adjustment, 1998b. *River Width Adjustment II: Modeling*, Journal of Hydraulic Engineering, ASCE, Vol. 124, No. 9, pp. 903-917.

Chang, H.H., 1985. *Channel Width Adjustment During Scour and Fill*, J. Hyd. Engr., ASCE, Vol. 111, No. 10, October.

Kennedy, J.F., Undated. *Keynote Lecture – Whence and Whither River-Sediment Research*, Iowa Institute of Hydraulic Research, The University of Iowa.

Lane, E.W., 1957. *A Study of the Shape of Channels Formed by Natural Streams Flowing in Erodible Material*, U.S. Army Engineer Division, Corps of Engineers, Omaha, NE.

Murphy, P.J. and T.J. Randle, 2001. *DRAFT Platte River Channel: History and Restoration*, U.S.B.R., Denver, CO, Jan 30.

Richards, K., 1982. *Rivers – Form and Process in Alluvial Channels*, Nethuen Co.: London and New York, 361 p.

TECHNICAL MEMORANDUM

RESULTS OF INVESTIGATION B1 - COMPREHENSIVE EVALUATION OF SEDIMENT GRADATION DATA

PLATTE RIVER CHANNEL DYNAMICS INVESTIGATION

Prepared For

States of Colorado, Nebraska, and Wyoming

May 2003

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TECHNICAL MEMORANDUM

INVESTIGATION B1 - COMPREHENSIVE EVALUATION OF SEDIMENT GRADATION DATA

PREFACE

This report describes the procedures used and results of an evaluation of changes in sediment gradations in the Platte River and its major tributaries. The investigation addressees a number of technical issues regarding this subject which had been identified by the sponsors as needing detailed examination to allow them to make scientifically-based decisions regarding the Cooperative Agreement (CA) work products.

This document describes only the data collected, analyses made, and scientifically-supportable findings regarding the issues, written in a manner which generally follows the guidelines of professional journals of the respective authors' technical expertise. The relevance of the findings to the specific issues confronting the sponsors is discussed in each task memorandum, but only as far as the data and results are deemed by the author(s) to be scientifically supportable in resolving or illuminating the issue.

ISSUES AND PURPOSES OF INVESTIGATIONS

The technical evaluations completed by the Parsons team were conducted as a series of 14 complementary investigations divided into four categories that would address general issues identified by the three states. The following issue categories were identified:

- A: Questions Regarding Channel Narrowing or Deepening
- B: Questions Regarding Sediment Transport
- C: Questions Regarding Vegetative Encroachment
- D: Questions Regarding Macro-Historic Natural Variability

This Technical Memorandum describes the results of Task B1, the first of three tasks comprising Issue Category "B."

COARSENING HYPOTHESIS AND PROJECT OBJECTIVE

Murphy and Randle (2001a) performed an earlier study of sediment data and concluded that construction of retention and diversion structures on the Platte River significantly affected the hydrologic and sediment-transport processes that ultimately shape the river. In particular they report:

The large storage reservoirs also trapped the sand load of the North Platte River and significantly reduced the sand supply to the Platte River downstream. Almost all of the sand supply to the South Platte River is downstream from the large reservoirs on that watershed. Thus, the South Platte River became the principal source of annual peak flows and sand to the central Platte River, but with a coarser grain size. (Murphy and Randle, 2001a, p. 3)

[T]he reduction in the supply of medium sand (relative to the outflow of medium sand at Chapman, Nebraska) [has] also played a significant role in channel narrowing on the Central Platte River. ... The reduction in the supply of medium sand has two effects: it causes erosion because the outflow of medium sand from the Central Platte is greater than its inflow, and it causes a decrease in the mobility of the braided bed because the medium sand is replaced by coarse sand and coarser particles are harder for the flow to move ... (Murphy and Randle, 2001a, p. 5)

The objective of Task B1 is to assess whether the available sediment-gradation data support the hypothesis that sediment gradation has changed through time, resulting in a coarsening of bed sediment from medium to coarse sand that has adversely affected the channel morphology.

METHODS OF INVESTIGATION

All sediment data discovered during a literature search at the beginning of this study were collected for the Platte River and tributaries. Some additional data collection programs were ongoing, such as by the Nebraska Cooperative Hydrology Study (COHYST) and at Nebraska Public Power District's (NPPD's) Cottonwood Ranch, but only parts were acquired in time for incorporation in this study. Any other data collected as time passes would be useful in validating the results of this study. Sources of sediment data included the Environmental Impact Statement (EIS) Team records, NPPD, Central Nebraska Public Power and Irrigation District (CNPPID), COHYST, U.S. Geological Service (USGS), and Parsons' technical library. The information that was utilized in the Task B1 investigation is listed in Table B1-1, together with the sources of the data.

The change in sediment gradation with distance along the channel was evaluated for both current and historical data. A regression and statistical analysis was performed on the acquired data to determine whether there have been apparent and/or statistically significant sediment gradation changes over time and to qualitatively assess possible explanations for any changes noted.

Data Analysis

In most cases, the sediment-gradation data consisted of the results of sieve analyses of the collected bed material. This information is in the form of the percent of the sediment material by weight that passes through a sieve having a given opening size ("percent passing"). These data then are plotted to obtain a sediment-gradation curve from which attributes can be determined and compared.

An example of a sediment-gradation curve is provided in Figure B1-1, obtained from the Platte River bed at the bridge crossing near Chapman, Nebraska. For this sample, approximately 10 percent of the material is smaller than 0.22 millimeters (mm); approximately 50 percent of the material is smaller than 0.41 mm; and approximately 60 percent of the material is smaller than 0.46 mm. These sizes are referred to as the d_{10}, d_{50}, and d_{60}, sizes, respectively.

TABLE B1-1

SEDIMENT GRADATION DATA SOURCES

SOURCE	BIBLIOGRAPHY	TYPE OF DATA
EIS Team	Murphy (2001) and Simon (2001). 1.44 MD Disk of SEDVEG Files: Murphy - Sedveg 5/8/01 and Simons - 15apr.zip	Electronic
EIS Team	U.S. Army Corps of Engineers (1934). Silt investigations in the Missouri River Basin, main stem of the Missouri River and minor tributaries in *Sediment Characteristics of the Platte River, Missouri River*, 73rd Congress, 2nd Session, House Document 238, Appendix XV, Supplement V.	Publication
EIS Team	Lawson (2002). U.S. Bureau of Reclamation, Great Plains Region, Mills, Wyoming, Central Platte River Transect Data (memo and attached raw data). Memorandum dated April 5. 2001 to P. Murphy of the Sediment and River Hydraulics Group, Denver, Colorado.	Raw Data
NPPD	Simons & Associates, Inc. (1992). *Additional Analysis of Sediment Transport at Korty Diversion Dam.*	Report
NPPD	U.S. Geological Survey (1955). *Sediment Investigations of the Platte River near Overton, Nebraska, January 1950 to September 1953.*	Publication
NPPD	Missouri River Basin Commission (1975). *Land Conservation and Sedimentation.*	Publication
COHYST	COHYST (2001). Sediment gradation data	Raw Data
NPPD	Flo Engineering (1992). *North Platte River Channel Stability Investigation Downstream of Keystone Dam,* Prepared for Twin Platte Natural Resources District, North Platte, Nebraska.	Report
CNPPID	CNPPID (2001). *Geologic and Soils Report of the Upper Diversion Dam Site*, *Hastings, Nebraska.*	Report
Parsons	Kircher (1982). *Interpretation of Sediment Data for the South Platte River in Colorado and Nebraska, and the North Platte and Platte Rivers in Nebraska.* U.S. Geological Survey Professional Paper 1277-D, 1982.	Publication
EIS Team	Murphy and Randle (2001b). *Platte River Sediment Transport and Riparian Vegetation Model,* Draft Technical Report, U.S. Bureau of Reclamation, Sedimentation and River Hydraulics Group, Denver, Colorado..	Publication and Electronic

Rather than using statistical measures of central tendency and variability, such as the mean, median, and the standard deviation, sediment uniformity is normally described by a "uniformity coefficient" (Holtz and Kovacs, 1981). The uniformity coefficient, C_u, is the ratio of the D_{60} size to the D_{10} size

$$C_u = \frac{D_{60}}{D_{10}} \qquad \text{(Equation B1-1)}$$

where D_{60} and D_{10} are, respectively, the diameters for which 60 and 10 percent by weight of the material is smaller. Lower case letters are used interchangeably with upper case in defining these parameters in the literature. A sediment sample with only one grain size will have a uniformity coefficient of 1.0. The d_{10} size for the sample shown in Figure B1-1 is 0.22 mm and the d_{60} size is 0.46 mm, giving a coefficient of 2.1.

If the EIS team's premise that the sediment gradation in the Platte River is becoming coarser through time is correct, the median diameter should be increasing and the uniformity coefficient should be decreasing through time. As the finer sand is washed out of the Platte River system only the coarser sand remains, leaving a sand with a more uniform (and coarser) gradation.

The sediment size and gradation of samples taken at a particular point in time can vary greatly among samples collected along a transect across the channel. Few of the measurements reported here represent more than a single sample at any station on the River. Figure B1-2 shows the variation in a series of bed material samples that were collected for the COHYST project along a single transect across the Platte River near Brady, Nebraska, on August 31, 1999. The d_{50} size collected at various locations along the transect ranges from 0.4 mm to 1.7 mm. These results demonstrate that the range in bed material size is greater than 1 mm, and sampling only a single point in the bed at any transect can bias any conclusions regarding longitudinal and temporal sediment gradation changes. To reduce the potential bias of location-error in the lateral direction, the values for the d_{10}, d_{50}, d_{60}, and C_u were averaged at locations where multiple sediment samples were collected, resulting in a single "sample" having these average values. Thereafter, only a single set of gradation values was used for each location and for each point in time in subsequent evaluations.

Median (D_{50}) values of the single samples and at-a-station-averaged sample data are shown in Figure B1-3 from the confluence of the Platte with the Missouri River to the Nebraska and Wyoming State lines. The graph reveals that a moderately good representation with distance was obtained. The same data are plotted on Figure B1-4, but the abscissa in this case is the month and year that the sample was taken. Representation in this case is not as good, showing that a significant gap of any measurements from 1936 to 1981. The dates shown for the reports listed in Figure B1-4 are the publication dates, and do not reflect the years for which the reports provide or discuss data. Before discussing our statistical evaluation of changes in sediment size, it should be noted from Figure B1-4 that virtually all of the data points in the 1930 to 1936 portion and the majority of data points in the 1981 to 2000 portion of the graph fall within the 0 and 2 mm sizes, with only four points above this maximum in the later years. Further, there is an absence of measurements below about 0.3 mm in the later years, and only about a dozen in the earlier years. An initial observation from this graph is that the majority of data points (excluding those above 2 mm and below 0.3 mm) do not readily support any conclusion regarding coarsening (or fining) of the sediment sizes. The interpretation of reasons for the absence of samples with median diameters less than 0.3 mm is deferred until later where an evaluation of the 10 percent fraction is provided.

To reduce the potential bias of location-error in the longitudinal direction, and in order to assist in the evaluation of changes in sediment gradation from a large number of measurements at scattered and non-monumented locations through time, the river was divided into reaches where it was assumed that the average characteristics of samples in the reach during any era were applicable throughout the reach. This approach was intended to smooth longitudinal variations in sampling, analytical, or reporting differences and inaccuracies. Just as high variability in channel thalweg slope was demonstrated on a micro scale in the Task A3 report, the gradation of the bed material in the Platte may in fact be highly variable, with both upward and downward swings, depending on whether the sample was obtained at the lead or tail end of the large macroforms known to define bed forms in the river. Thus, any conclusions of this study should be tempered by the potential that this smoothing process may have overly-generalized the natural (or modified) longitudinal variability.

Table B1-2 provides a description of the river reaches. The reach boundaries were selected largely on the basis of uniform lengths of reaches where previous reports identified temporal sediment changes, or by reaches alleged to be stable, aggrading or degrading, but no serious analytical considerations of geomorphic or other factors were included in segregating the river into these reaches.

TABLE B1-2

REACH DESCRIPTIONS

REACH	RIVER	FROM	TO
1	Platte River	Confluence with Missouri River	Columbus, NE
2	Platte River	Columbus, NE	Grand Island, NE
3	Platte River	Grand Island, NE	Kearney, NE
4	Platte River	Kearney, NE	Cozad, NE
5	Platte River	Cozad, NE	Confluence of the North Platte River and the South Platte River
6	North Platte River	Confluence of the North Platte River and the South Platte River	Downstream of Lake McConaughy
7	North Platte River	Downstream of Lake McConaughy	Nebraska-Wyoming Stateline
8	South Platte River	Confluence of the North Platte River and the South Platte River	Greely, CO

Time-series plots of the assimilated and at-a-station-averaged sample statistics (d_{10}, d_{50}, d_{60}, and C_u) were generated first for only those reaches upstream of Columbus (the Loup flows into the Platte at this point) and downstream of the confluence of the North and South Platte Rivers; namely, Reaches 3, 4 and 5. A regression line was calculated for each statistic and plotted through the data using least-squares methods (Rock, 1988). Figures B1-5 through B1-11 provide the results for these reaches. Plots for Reaches 6 through 8 are described later.

The first graph, Figure B1-5 shows the changes in d_{10} over time. Long-term sediment-gradation data were available only in Reaches 3 and 5 from 1931 to 2000, and the solid lines in the figure were fitted though this entire period. Both have slightly upward trends of about 0.15 mm. Because no data were collected in Reach 4 before 1979, a second set of regression lines were was also plotted for all three reaches, using only the period from 1979 to 2000. These are shown as dashed lines, and are essentially horizontal. This suggests that any increase in d_{10} most likely occurred before 1979 and ceased thereafter.

Similar graphs for the d_{50} and d_{60} sizes are shown on Figure B1-6 and B1-7. Linear regression produced the lines shown. Other than Reach 3 from 1979 to 2000 (Kearney to Grand Island), the regression lines indicate upward trends. The vertical scales on these figures are exaggerated, with the majority of the data points ranging only over about 3 mm, but the apparent increases in sizes are about 0.3 mm for the d_{50} values and 0.5 mm for the d_{60} values. The relatively large number of points suggest that bias may be absent, but recalling that the variation across any cross-section ranged up to 1 mm (Figure B1-2), it could be possible that the apparent increases are not statistically significant. Examination of all the data points on the d_{50} graph shows that with three extraordinary exceptions, the range has not varied other than the notable absence of median sizes in the latter data described earlier. With one possible high outlier, the data on the d_{60} graph exhibit the same properties – similar ranges, but an absence of samples with d_{60} values below 0.5 mm in the latter years. Outlier tests and re-runs with removal of the possible high outliers were not conducted but would reduce the slope of these lines.

Uniformity coefficients for the samples in Reaches 3, 4 and 5 are plotted on Figure B1-8. The long-term trends in this parameter show no change in Reach 5 and a decline from 4.7 to 3.7 in Reach 3. Reach 5 is considerably far upstream of Reach 3, and Reach 3 is downstream of the J-2 return.

After temporal trends had been generated for the sediment-gradation data for Reaches 3, 4, and 5, a 95 percent confidence interval (Miller, 1986) was created for the d_{50} sediment size trend within each reach. These are shown separately for the three reaches in Figures B1-9, B1-10 and B1-11. The regression line represents the most likely relationship, but the actual relationship may be some other line. The confidence interval brackets a wider range of possible solutions to the changes in sediment size through time. A discussion of whether these limits support the upward trends is provided later, though it is even clearer in Figure B1-9, for example, that two or three extremes in 1931 and four extremes in 1986 contribute much of the upward trend. As noted earlier, none of the data points were tested as outliers, and none were deleted. More detailed analysis of these particular samples should be conducted to assess their relevance to the trend analysis.

Reaches 6, 7, and 8 are upstream of the study area. Reaches 6 and 8 are on the North Platte and South Platte, respectively, just upstream of North Platte, NE. Time-series plots of the sample-gradation data (d_{10}, d_{50}, d_{60}, and C_u) were generated for Reaches 6, 7, and 8, and a linear least-squares regression line was fitted through the data for each time series. Gradation data for Reaches 6 and 7 were available through the entire period from 1931 to 2000. No data were collected in Reach 8 prior to 1979; and the lines for Reach 8 are for the period from 1979 to 2000.

ANALYSIS

The size of the fine-grained sediment bed material (d_{10}) in the mainstem of the Platte (Reaches 3, 4, and 5) displays an almost negligible increase through the past 70 years, and there is essentially no difference in the d_{10} size between reaches. In general, throughout the entire study area, the d_{10} size is about 0.25 mm, and has remained nearly constant through time (Figure B1-5). When the sediment-gradation data only for the time period from 1979 through 2000 are examined, the d_{10} size displays a slight decreasing trend through time, but essentially the d_{10} values have remained the same through the entire period.

The median sediment bed material (d_{50}) in the study area apparently has increased in size from about 0.6 mm to 1.0 mm through the past 70 years, and there also appears to be a small difference in the d_{50} size between Reach 3 and Reach 5 (Figure B1-6). Although the trendline for Reach 4 displays a sharply-increasing slope, this is considered to be a result of several relatively coarse-grained samples that were collected in 2000 and the d_{50} sizes obtained for samples collected from Reach 4 during the period 1979 through 1986 are similar to those obtained for samples from Reaches 3 and 5. When the sediment-gradation data only for the time period from 1979 through 2000 are examined, the d_{50} size apparently has remained constant in Reach 3 through that period, but the d_{50} size for Reach 5 (North Platte to Cozad) has decreased.

The size of the coarser-grained fraction of the sediment bed material (d_{60}) in the study area has, in general, increased from about 0.8 mm to 1.4 mm through the past 70 years, and there is apparently a small difference in the d_{60} size between Reach 3 and Reach 5 (Figure B1-7). The trendline for Reach 4 displays a sharply-increasing slope, also considered to be the result of several relatively coarse-grained samples that were collected in 2000, but the d_{60} sizes obtained for samples collected from Reach 4 during the period 1979 through 1986 are similar to those obtained for samples from Reaches 3 and 5. When the sediment-gradation data only for the time period from 1979 through 2000 are examined, the d_{60} size apparently has remained constant in Reach 3, but the d_{60} size for Reach 5 has decreased.

The uniformity coefficient for the entire study area is about 5, and the majority of samples show that it has changed little over the past 70 years (Figure B1-8). In Reach 3, the uniformity coefficient appears to have decreased from 5 to 4 from 1931 to 2000, but during the period 1979 to 2000, the uniformity coefficient for Reach 3 increased from 4 to 5. In Reach 4, the uniformity coefficient has increased greatly, but this result is skewed by the several coarse-grained sediment samples that were collected in 2000. The uniformity coefficient in Reach 5 has remained nearly constant at 5 through the entire 70-year period.

Changes in Classification

According to the Unified Soil Classification System (USCS), the grain diameter of a fine sand ranges from 0.075 mm (a #200 sieve) to 0.425 mm (a #10 sieve). The USCS grain diameter of a medium sand ranges from 0.425 mm (a #40 sieve) to 2.0 mm (a #10 sieve), and USCS grain diameter of a coarse sand ranges from 2.0 mm to 4.75 mm (Holtz and Kovacs, 1981). The size of the d_{10} sediment during the earliest-recorded sample-collection events (1931) corresponds to a fine sand, and remained a fine sand into the year 2000. Similarly, the sizes of the d_{50} and d_{60} sediments in 1931 corresponded to medium sand, and remained medium sand into the year 2000. From this, it is concluded that no changes in classification have occurred.

Confidence Associated with Apparent Trends in Bed Material Size

A relatively large number of samples were available in Reach 3. The d_{50} size values for all Reach 3 samples are similar, so the 95-percent confidence interval is relatively narrow (Figure B1-9). The d_{50} size of the samples from Reach 3 apparently has increased through time but the orientation of the confidence interval is such that the trendline could potentially display no change or even a slight decrease in the d_{50} size through time.

The d_{50} size values for samples collected from Reach 4 are more variable than d_{50} size values for samples from Reach 3 or Reach 5, and the confidence interval is correspondingly wider for this reach (Figure B1-10). The d_{50} size of the samples from Reach 4 apparently has increased through time, but the orientation and width of the confidence interval is such that the trendline could potentially display no change or a slight decrease in the d_{50} size through time.

Relatively few samples were collected in Reach 5 during 1930; therefore, the confidence interval for the d_{50} size is wider during the earliest part of the period of record for this reach (Figure B1-11). More samples were available for recent times, showing that the d_{50} size values are relatively consistent. Thus, the confidence interval is correspondingly narrower. The d_{50} size of the samples from Reach 5 apparently has increased through time, but the orientation and width of the confidence interval is such that the trendline could potentially display no change or a slight decrease in the d_{50} size through time.

Comparison of Sediment Size With Model Input Data

Only the gradations described above for 1931 can be compared with the gradation of the bed material used in the SEDVEG model developed by the EIS team (Murphy and Randle, 2001b). The reason is that sediment data used in the SEDVEG model were based on gradation results generated from samples that were collected in 1931, and are not allowed to vary through time in the model simulations.

The temporal trends in the d_{10} sediment sizes of samples that were collected in Reaches 6, 7, and 8 were compared with the d_{10} values used in SEDVEG to simulate sediment from the North Platte and South Platte Rivers (Figure B1-12). There is little apparent difference between the gradation data compiled by the Parsons team and the d_{10} sediment size used in the SEDVEG model to simulate sand entering the Platte River from the major tributaries, although the d_{10} values generated from the actual samples appear to increase through time. The comparison of the d_{10} size for Reach 6 with the d_{10} size for Reach 7 (upstream of Lake McConaughy) indicates that the d_{10} size is larger (i.e., sediment is generally more coarse) downstream of Lake McConaughy.

Similarly, the temporal trends in the d_{50} sediment sizes of samples that were collected in Reaches 6, 7, and 8 were compared with the d_{50} values used in the SEDVEG model (Figure B1-13). There is little apparent difference between the gradation data compiled by the Parsons team and the d_{50} sediment size used in the SEDVEG model to simulate sand passing North Platte from upstream during the early part of the period of record (1930), although the d_{50} values generated from the actual samples appear to increase through time. This temporally-increasing trend in d_{50} sediment size is not accounted for in the model. The comparison of the d_{50} size for Reach 6 with the d_{50} size for Reach 7 indicates that the d_{50} size also is larger downstream of Lake McConaughy than upstream.

Finally, the temporal trends in the d_{60} sediment sizes of samples that were collected in Reaches 6, 7, and 8 were compared with the d_{60} values used in SEDVEG (Figure B1-14). There is little apparent difference between the gradation data compiled by the Parsons team and the d_{60} sediment size used in SEDVEG to simulate upstream sand entering the mainstem Platte River during the early part of the period of record (1930). However, the d_{60} values generated from the actual samples appear to increase significantly through time; and this temporally-increasing trend in d_{60} sediment size is not accounted for in the model. The comparison of the d_{60} size for Reach 6 with the d_{60} size for Reach 7 indicates that the d_{60} size also is larger downstream of Lake McConaughy.

The uniformity coefficients calculated from sediment-gradation data compiled by the Parsons team were compared with those used by the EIS team in the SEDVEG model (Figure B1-15). The uniformity coefficient used by the EIS team in the model remains constant through the duration of the time period simulated in the model. The data compiled by the Parsons team indicate that the uniformity coefficient on both the North Platte and South Platte has decreased slightly through time.

CONCLUSIONS

Ideally, sediment-gradation data should have been collected at the same locations, using the same sampling procedures, from the same depth below the surface, during a number of equally-spaced time periods, at one or more stations over a year (winter and summer), at different flow rates, using different sample column heights (to reflect true "bed" samples), and collected at several locations across all channel transects to reduce single-sample bias. The gradation data were not collected in this manner, and accordingly there is some uncertainty in the accuracy of the data and in the conclusions regarding trends resulting from evaluation of the data. Resolution of the coarsening theory would require a forward-moving, scientifically designed sampling procedure. Backing up through the limited available data may not meet this criterion. The question is whether the past data collected adequately matches the requirements of this scientific approach, had it been implemented in the beginning.

The Parsons team believes that the variability of sediment sizes in the river, variability in the data, uncertainties due to single-sample bias, and lack of uniform, comparable, and scientific sampling methods do not allow a definitive resolution of the "coarsening" hypothesis. The scientific value of backing through this data and equating it with a scientific study of bed sediment changes is questioned based on a host of uncertainties and inadequacies, including:

- the subjectivity of what material is "bed" material,
- lack of a common protocol for sampling,
- failure to repeat measurements at the same locations,

- unknown flow at the time of sampling,
- unknown antecedent flow conditions preceding the sampling,
- the high variability of parameters on the same day at the same transect (Figure B1-2),
- absence of within-year samples to reflect seasonal variations,
- absence of data on sediment sizes within macroforms (which have been proven to be highly variable),
- unknown locations and depths of sample below bed surface, and
- unknown adequacy of volumes of samples.

Taking the leap of assuming that the problems created by these deficiencies are random, sufficient samples were found to make reserved estimates of the average characteristics of sediment by reaches, and of trends in these averages, but no other conclusions are supported.

In order to reduce the uncertainties associated with the evaluation, gradation data for samples collected from defined reaches of the rivers were combined, rather than being treated as individual sampling points. Inherent in this approach is the assumption that gradation data collected in each reach remains the same throughout the reach, which is not supported by the evidence in the Task A3 report or by the extreme variability of planform in the river. The Parsons team felt that this step would reduce sample bias, because sampling errors associated with data collected at different locations by different workers at different times of the year (winter samples would likely show different grain sizes) are likely to be random and therefore unbiased. In addition, gradation data for multiple samples collected at a single location and at one point in time were averaged and treated as a single data point in the analysis.

The sediment entering the mainstem Platte River from both the North and South Platte Rivers has apparently increased in size through time. It should be noted that this is based on only two samples in recent years on the South Platte. This apparent increase in size of sediment originating at these distant upstream sources would naturally contribute to a coarsening of sediment in the mainstem Platte River. No scientific studies of changes in tributary sediments have been completed, and it is not reasonable to conclude that washing of fines in the mainstem is the only operative process. Detailed evaluations are needed of changes that may have occurred in the gradation of the sources of sediment supplied to the river. Vegetative expansion throughout the headwaters is certain to have trapped fines that would have arrived in less-vegetated years. These comprehensive studies should also include studies of wind blown contributions of fines that are known to have occurred during droughts, and may explain much of the coarsening if it is shown that this source has been diminished by cultivation or other extrinsic controls.

Given the precautions of the above paragraphs, the results of the Task B1 evaluation indicate that the size of sediment in the reach of the Platte River from North Platte to Grand Island probably has increased through the time period from 1930 to 2000. Little increase in sediment size is apparent between1979 and 2000, so any physical processes resulting in this change have appeared to stabilize. If these increases are accepted, then it must also be concluded that the size of sediment in Reach 5 (Kearney to Grand Island) decreased slightly between 1979 and 2000.

The hypothesis that the bed has become "coarse sand" is not supported by this study. Temporal changes in classifications of sediment size were not revealed. The bed sediment was a medium sand in 1930 and remains a medium sand in the year 2000. Through this period, the uniformity coefficient has changed only slightly, indicating that the small size fraction of the sediment (d_{10}) and the large size fraction (d_{60}) are increasing in size at about the same rate within the mainstem reach.

Although the gradation of sand from the North Platte and South Platte Rivers used to simulate pre-development (1930) sediment input to the Platte River in the SEDVEG model are confirmed by our data, the model currently does not account for the temporal increase in size of sediment entering the Platte River. The model also does not account for several other factors that may affect the coarsening of sediment in the Platte River, including possible effects associated with coarser sediments entering the South Platte and North Platte Rivers, from intervening tributary streams (some with significant flows and sediment loads), and as wind-blown material.

Despite the apparent (small) increase in sediment size through time, the Parsons team does not believe that the sediment in the Platte River can be categorized as a coarse sand. It historically has been, and remains, a medium sand. The sand in the Platte River between Kearney and Grand Island (Reach 5) may actually have decreased in size between 1979 and 2000, but this may be a consequence of transport of finer sand from upstream locations into the reach. If a greater proportion of the sediment arriving at the upstream end of the Reach 5 is fine sand, the sediment size in the reach could gradually decrease over time until it is flushed out of the reach.

BIBLIOGRAPHY

Central Nebraska Public Power and Irrigation District (CNPPID). 2001 *Geologic and Soils Report of the Upper Diversion Dam Site.* CNPPID. Hastings, Nebraska. May.

Cooperative Agreement Hydrologic Study Team for the Platte River Basin (COHYST). 2001. Electronic files of sediment gradation data. August.

Davis, J.C. 1986. *Statistics and Data Analysis in Geology*. John Wiley & Sons, Inc. New York, New York. 2nd ed.

Flo Engineering, Inc. 1992. *North Platte River Channel Stability Investigation Downstream of Keystone Dam.* Unpublished report prepared for Twin Platte Natural Resources District, North Platte, Nebraska. June.

Holtz, R.D., and W.D. Kovacs. 1981. *An Introduction to Geotechnical Engineering*. Prentice-Hall, Inc. Englewood Cliffs, New Jersey.

Kircher, J.E. 1982. *Interpretation of Sediment Data for the South Platte River in Colorado and Nebraska, and the North Platte and Platte Rivers in Nebraska*. U.S. Geological Survey Professional Paper 1277-D.

Lawson, J.H. 2001. U.S. Bureau of Reclamation, Great Plains Region, Mills, Wyoming, Central Platte River Transect Data (memo and attached raw data). Memorandum dated April 5, 2001 to P. Murphy of the Sediment and River Hydraulics Group, Denver, Colorado.

Miller, R.G. 1986. *Beyond ANOVA -- Basics of Applied Statistics.* John Wiley & Sons, Inc. New York, New York.

Missouri River Basin Commission. 1975. *Land Conservation and Sedimentation*. September.

Murphy, P. 2001. Electronic 1.44 Mb disk of SEDVEG data files. Transmitted May 8, 2001

Murphy, P.J., and T.J. Randle. 2001a. *Platte River Channel: History and Restoration.* U.S. Bureau of Reclamation and U.S. Fish and Wildlife Service. Draft. January.

Murphy, P.J., and T.J. Randle. 2001b. *Platte River Sediment Transport and Riparian Vegetation Model.* U.S. Bureau of Reclamation and U.S. Fish and Wildlife Service. Draft. January.

Rock, N.M.S. 1988. *Numerical Geology*. Springer-Verlag, Inc. New York, New York.

Simons, R. 2001. Electronic data files (*15apr.zip*). Transmitted April 15, 2001.

Simons & Associates, Inc.. 1992. *Additional Analysis of Sediment Transport at Korty Diversion Dam*. February.

U.S. Army Corps of Engineers. 1934. Silt Investigations in the Missouri River Basin, Main Stem of the Missouri River and Minor Tributaries, *in Sediment Characteristics of the Platte River*. Missouri River, 73rd Congress, 2nd Session, House Document 238, Appendix XV, Supplement V.

U.S. Geological Survey (USGS). 1955. *Sediment Investigations of the Platte River near Overton, Nebraska, January 1950 to September 1953*. U.S. Geological Survey, Water Resources Division.

FIGURES

FIGURE B1-1: SEDIMENT GRADATION CURVE -PLATTE RIVER
@ CHAPMAN BRIDGE (11/89)

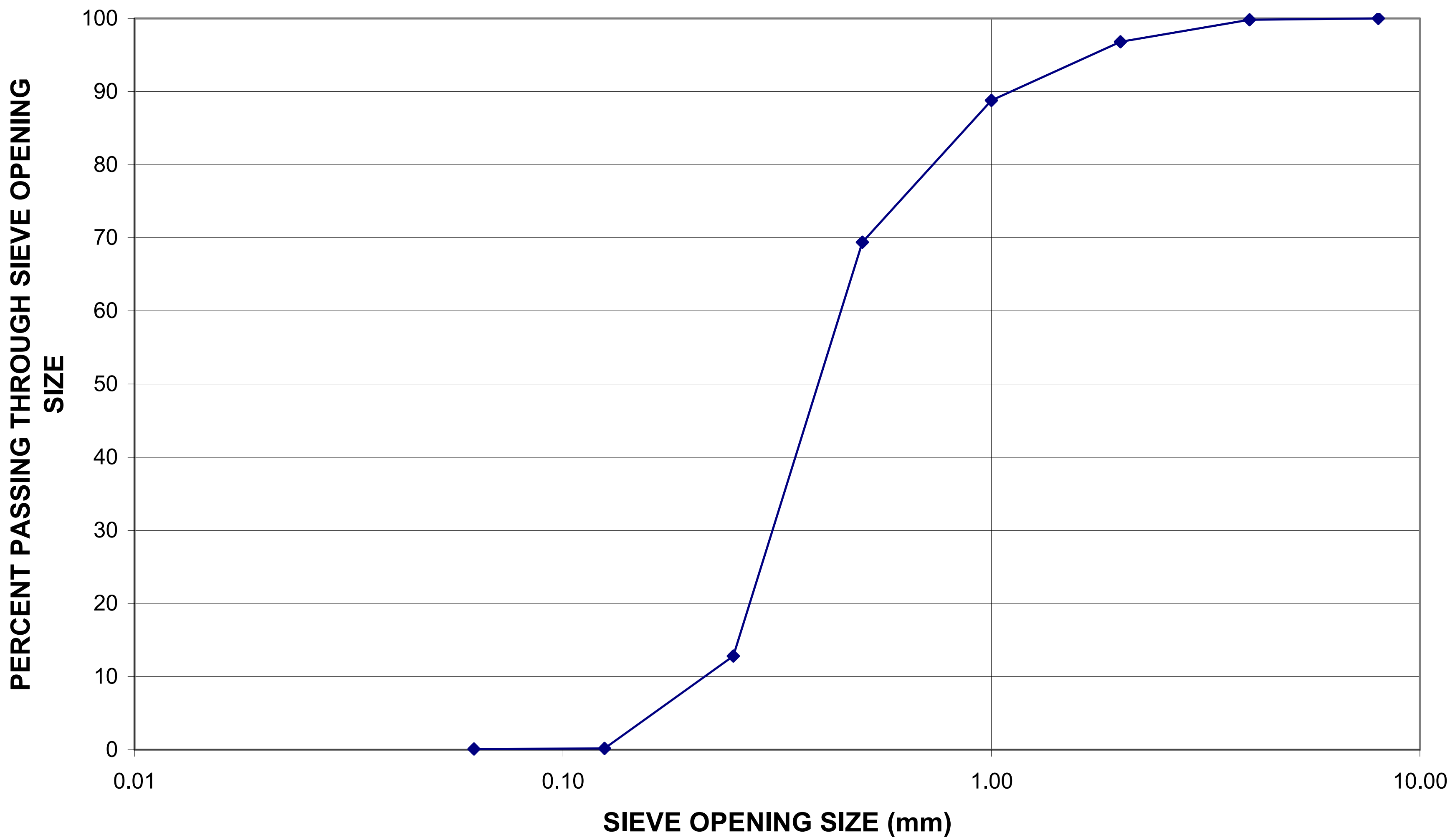


FIGURE B1-2: PARTICLE SIZE (d_{50}) IN PLATTE RIVER NEAR BRADY AT SAME LOCATION AND ON SAME DAY

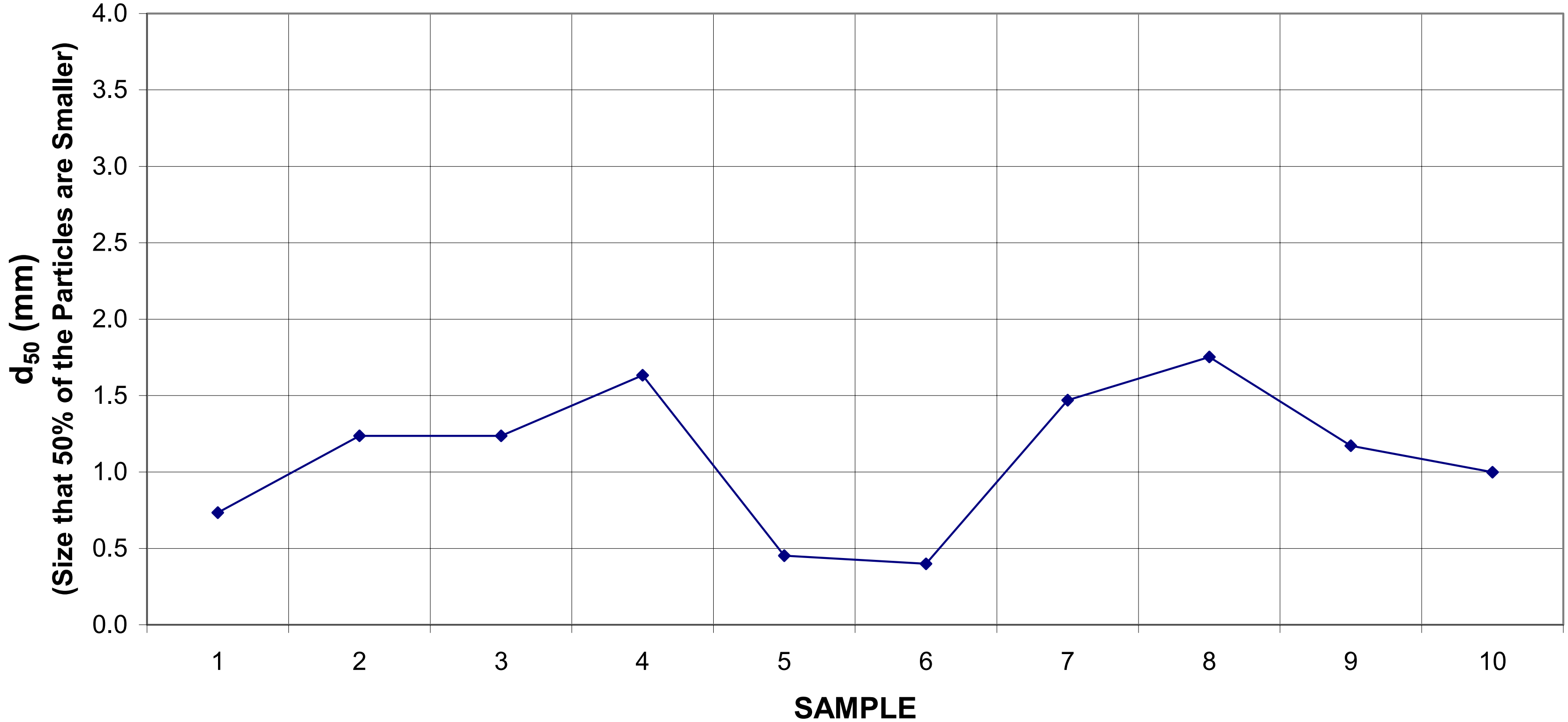


FIGURE B1-3: BED MATERIAL SAMPLES (D50) TAKEN IN THE PLATTE RIVER OVER DISTANCE

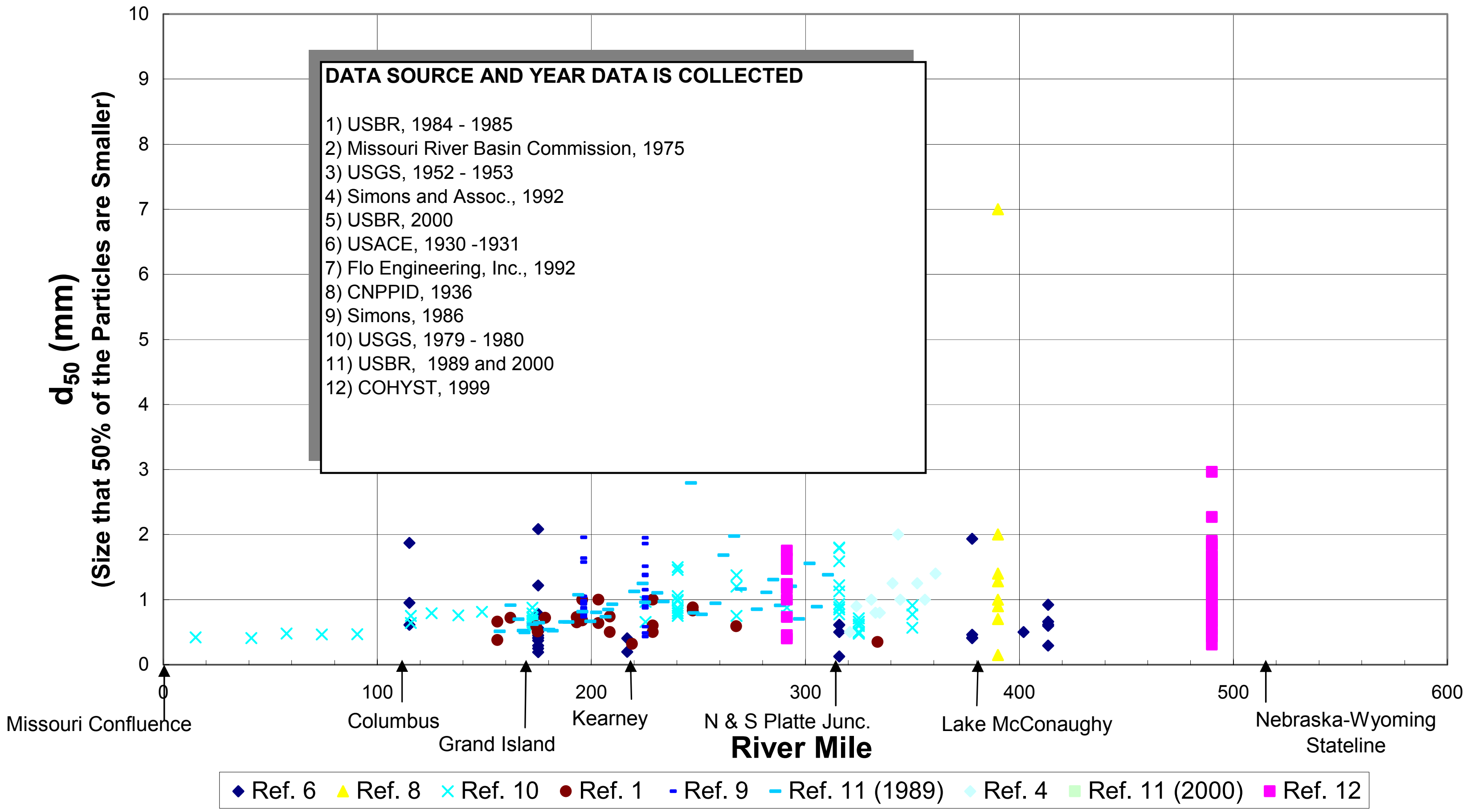
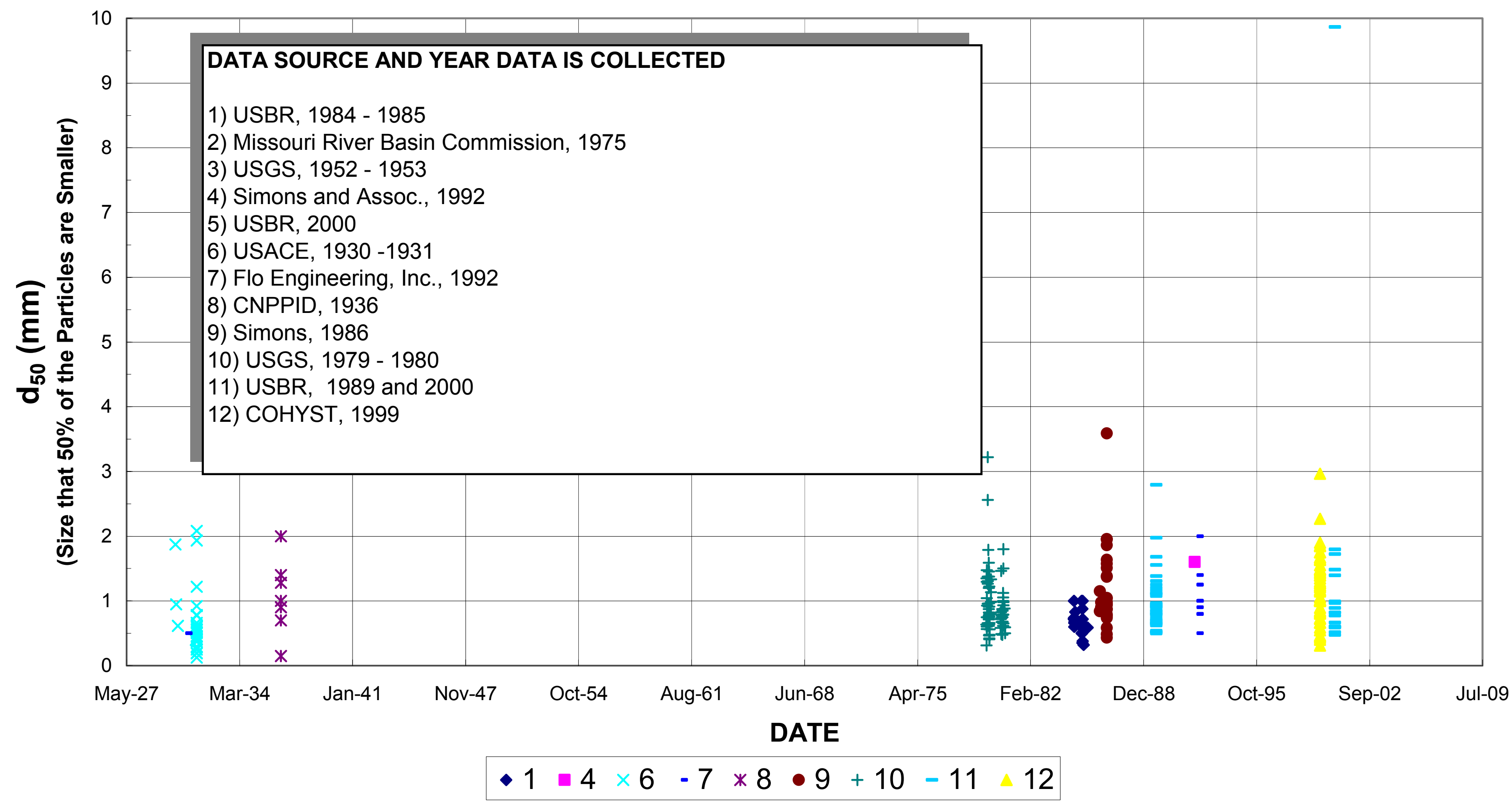


FIGURE B1-4: BED MATERIAL SAMPLES (D_{50}) TAKEN IN THE PLATTE RIVER OVER TIME



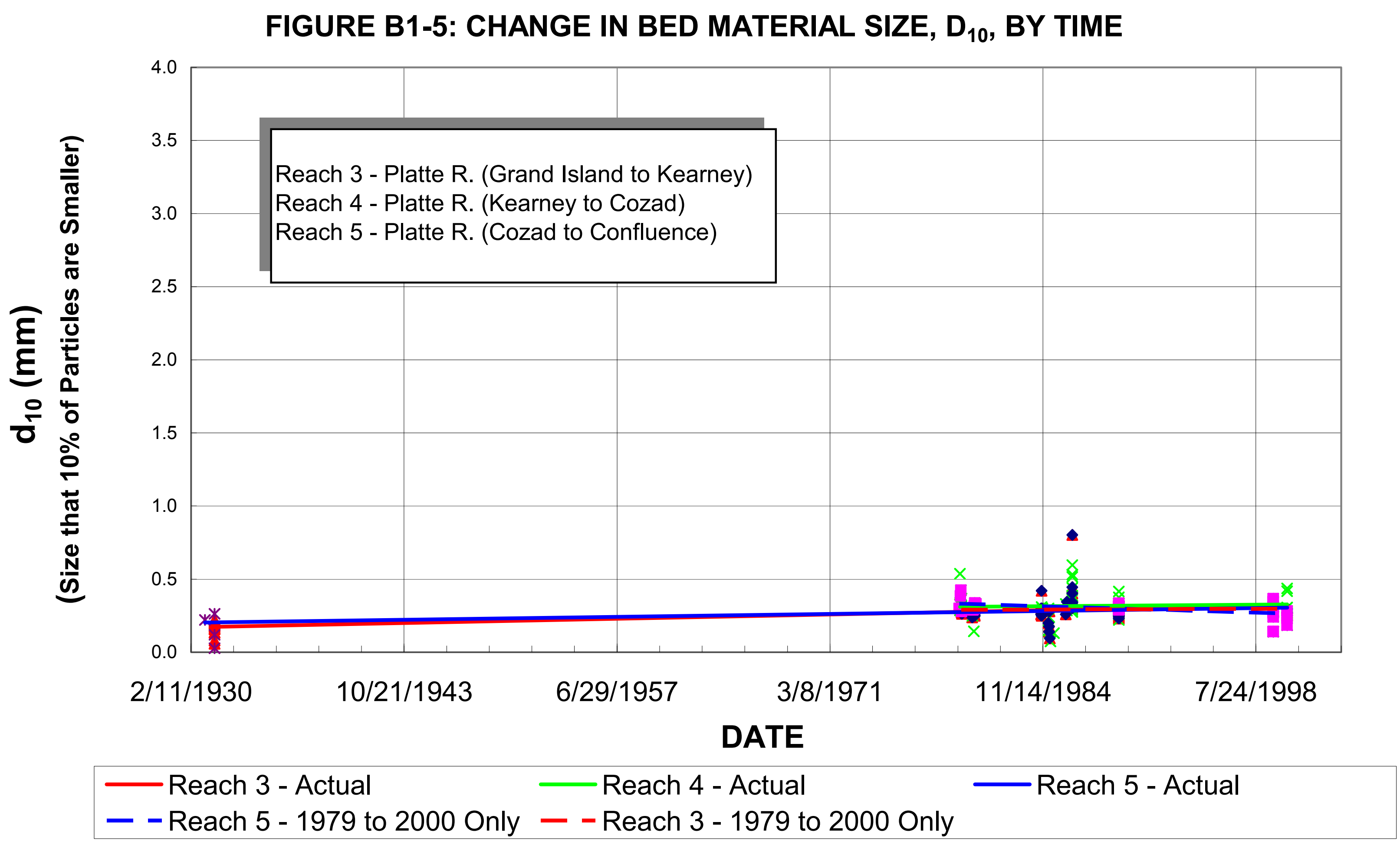


FIGURE B1-5: CHANGE IN BED MATERIAL SIZE, D10, BY TIME
Reach 3 - Platte R. (Grand Island to Kearney)
Reach 4 - Platte R. (Kearney to Cozad)
Reach 5 - Platte R. (Cozad to Confluence)
d10 (mm)
(Size that 10% of Particles are Smaller)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
2/11/1930
10/21/1943
6/29/1957
3/8/1971
11/14/1984
7/24/1998
DATE
Reach 3 - Actual
Reach 4 - Actual
Reach 5 - Actual
Reach 5 - 1979 to 2000 Only
Reach 3 - 1979 to 2000 Only

FIGURE B1-6: CHANGE IN BED MATERIAL SIZE, D_{50}, BY TIME

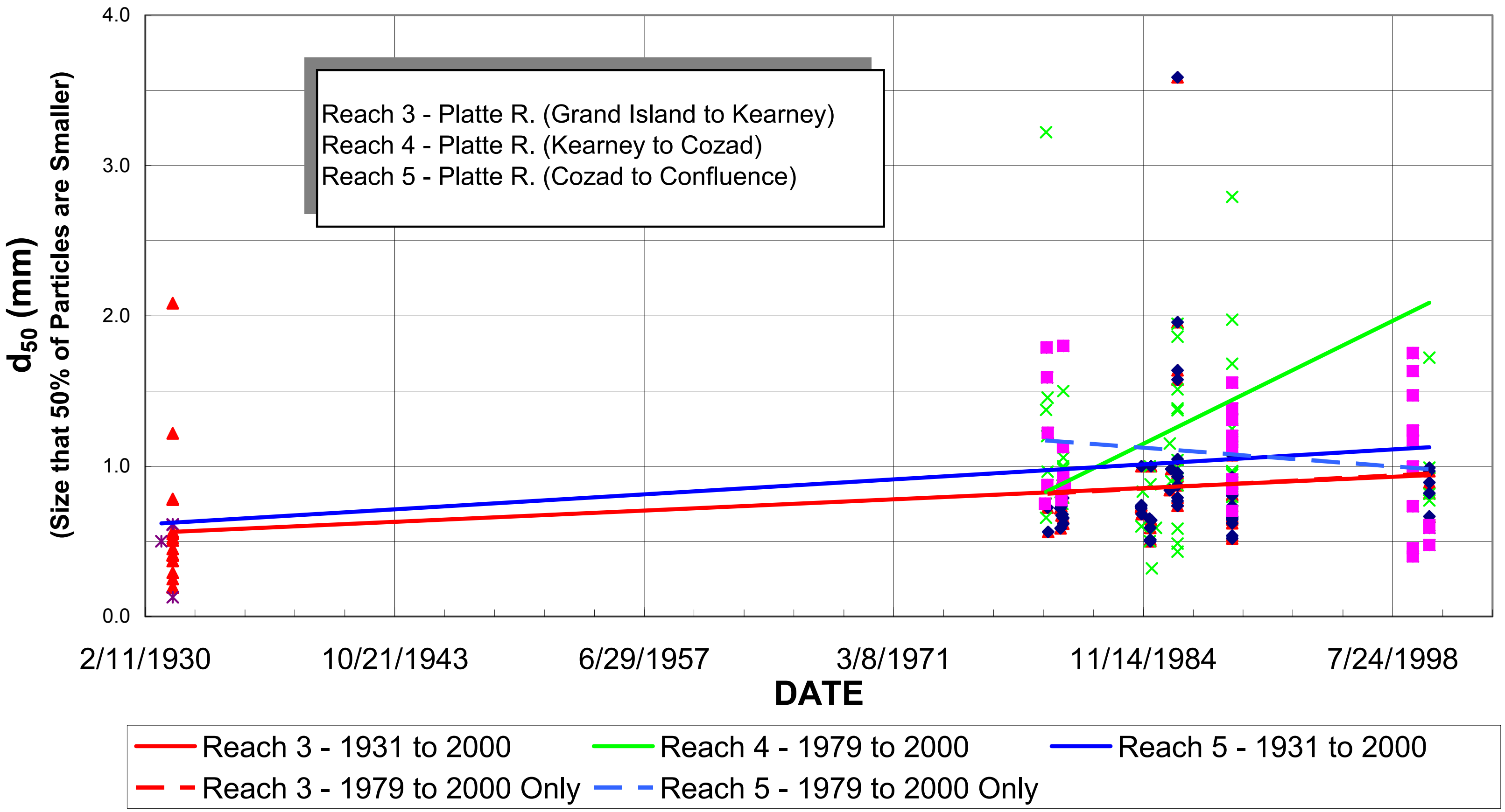


FIGURE B1-7: CHANGE IN BED MATERIAL SIZE, D_{60}, BY TIME

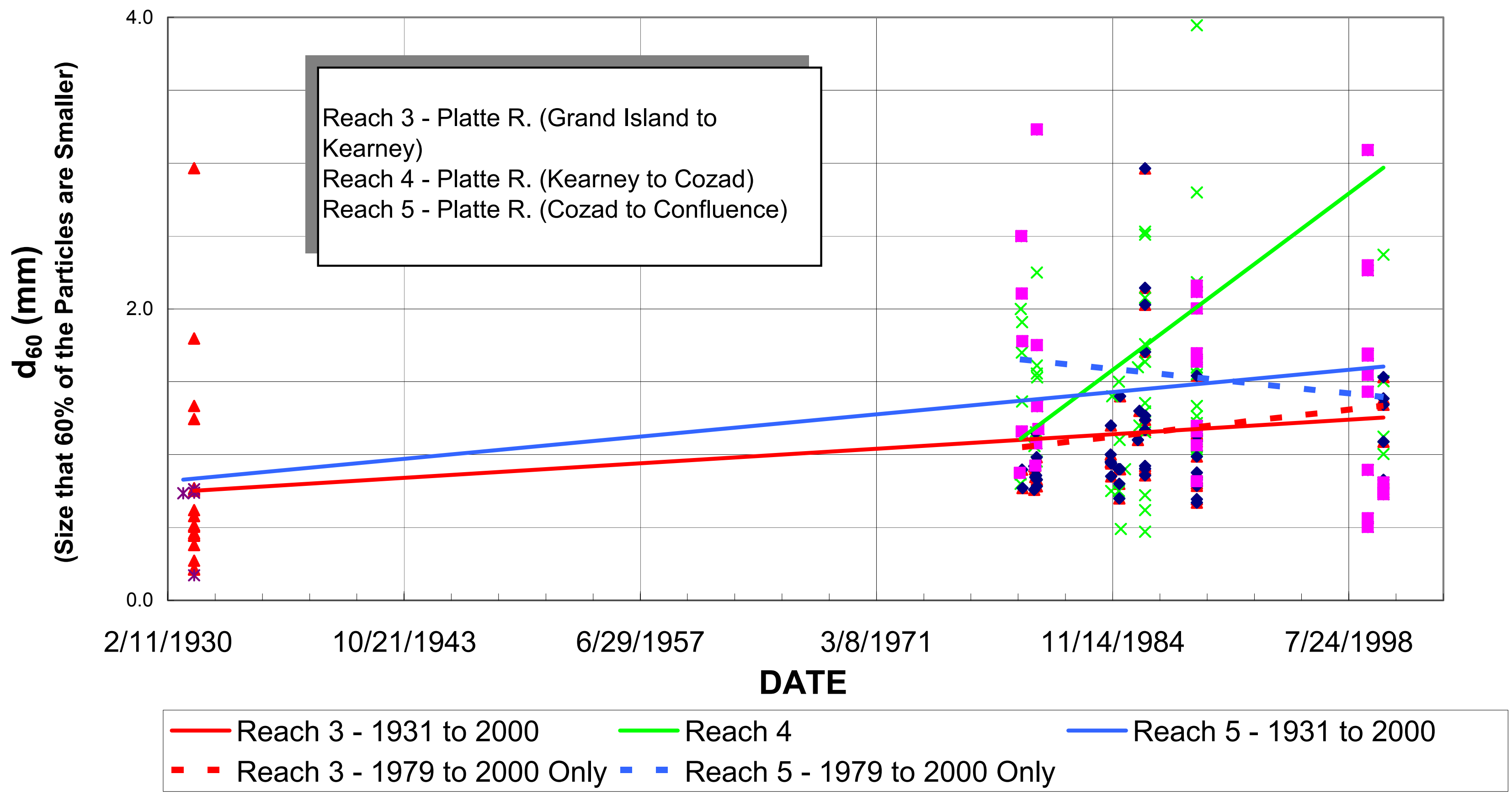


FIGURE B1-8: CHANGE IN BED MATERIAL UNIFORMITY, C_u, BY TIME

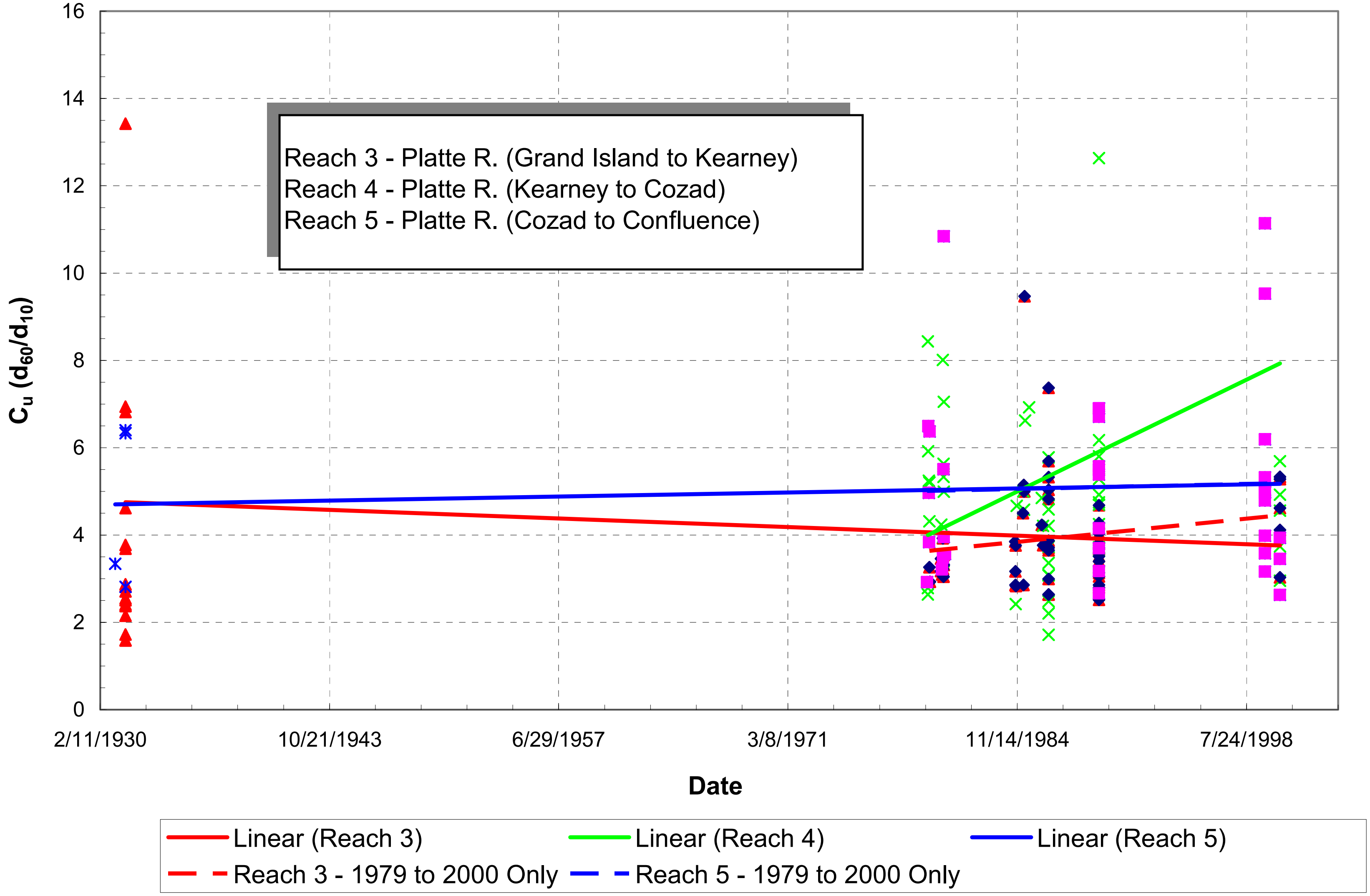


FIGURE B1-9: CONFIDENCE LIMITS OF BED MATERIAL SIZE CHANGE - REACH 3

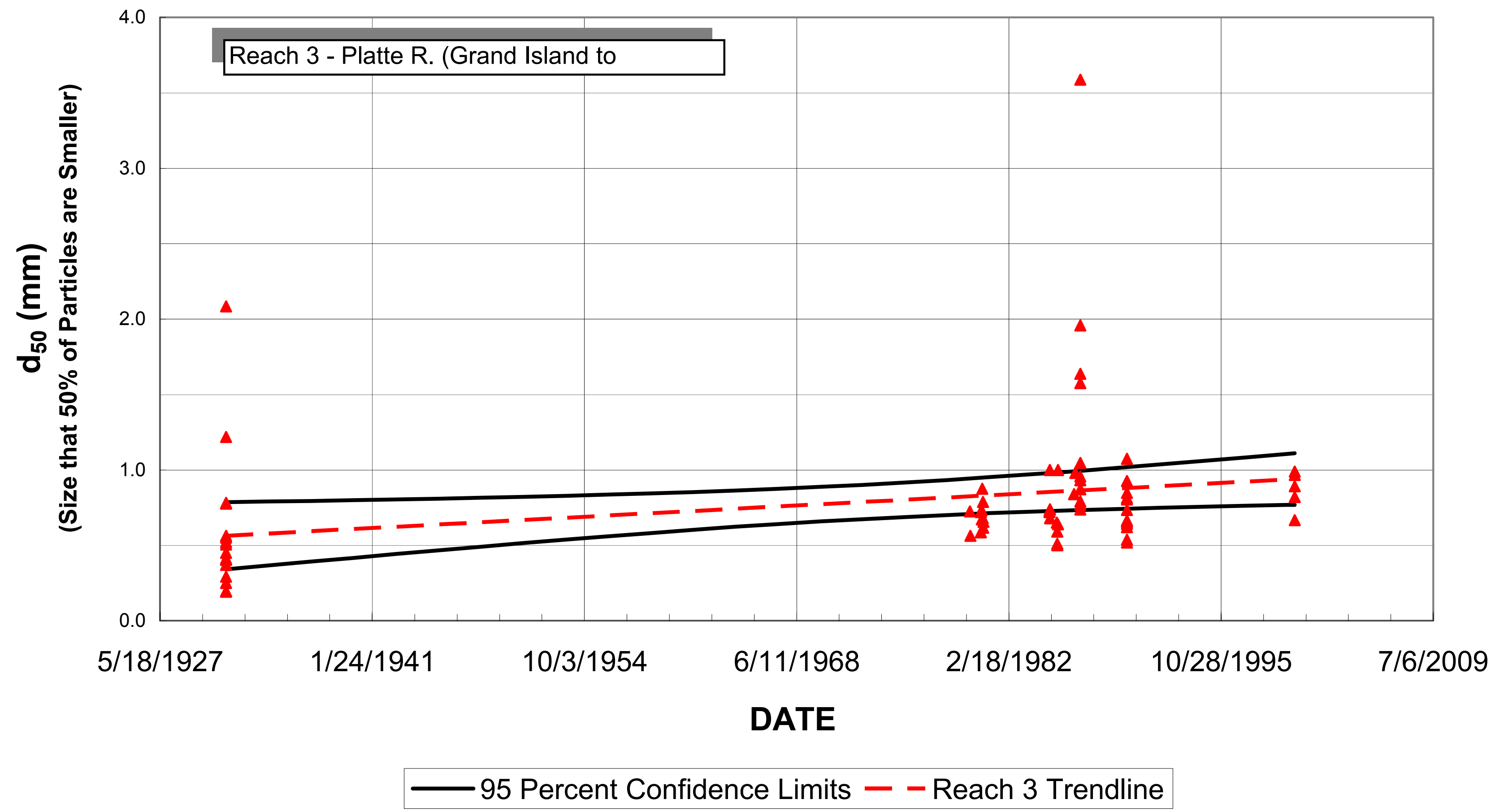


FIGURE B1-10: CONFIDENCE LIMITS OF BED MATERIAL SIZE CHANGE - REACH 4

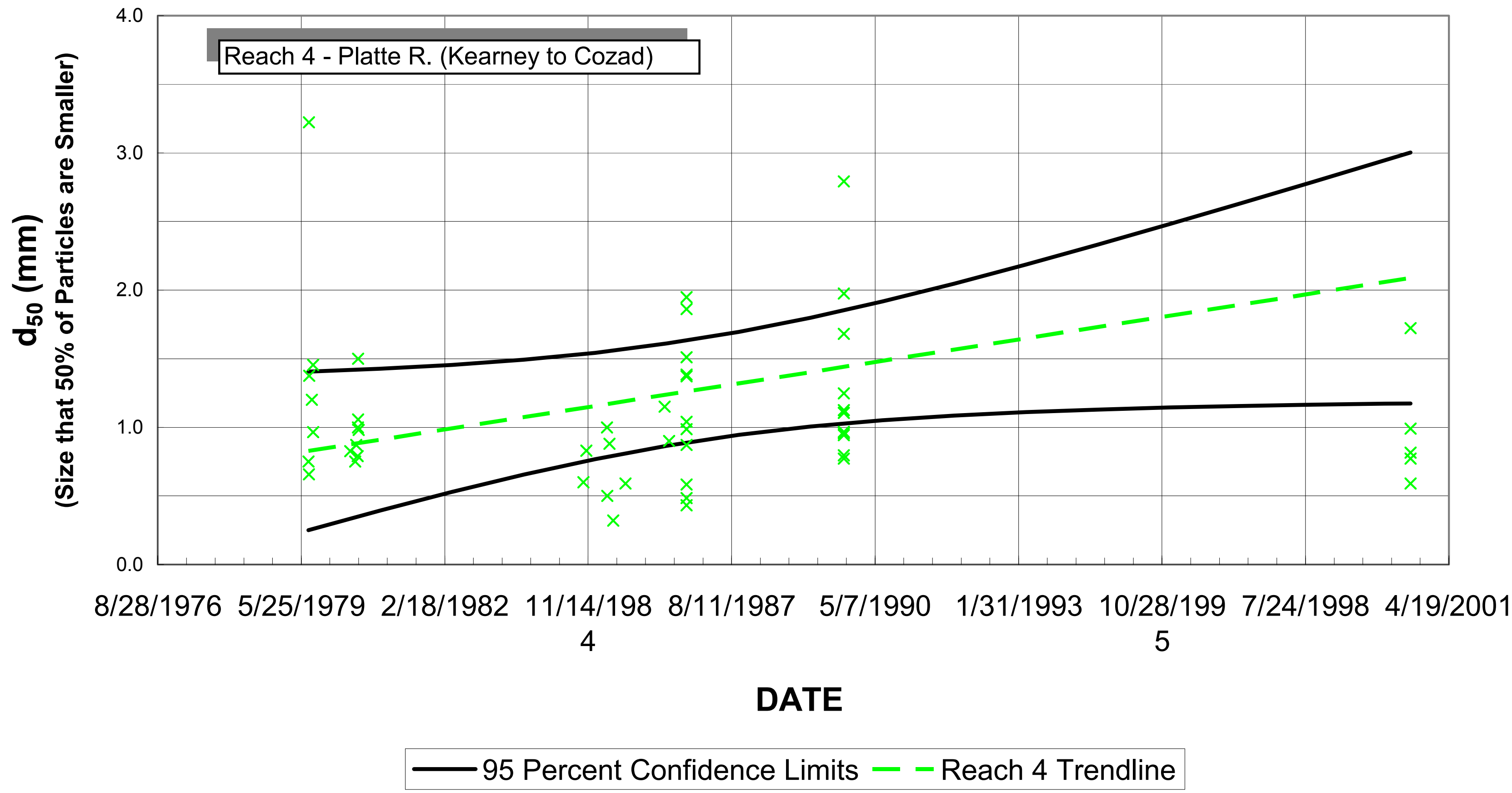


FIGURE B1-11: CONFIDENCE LIMITS OF BED MATERIAL SIZE CHANGE - REACH 5

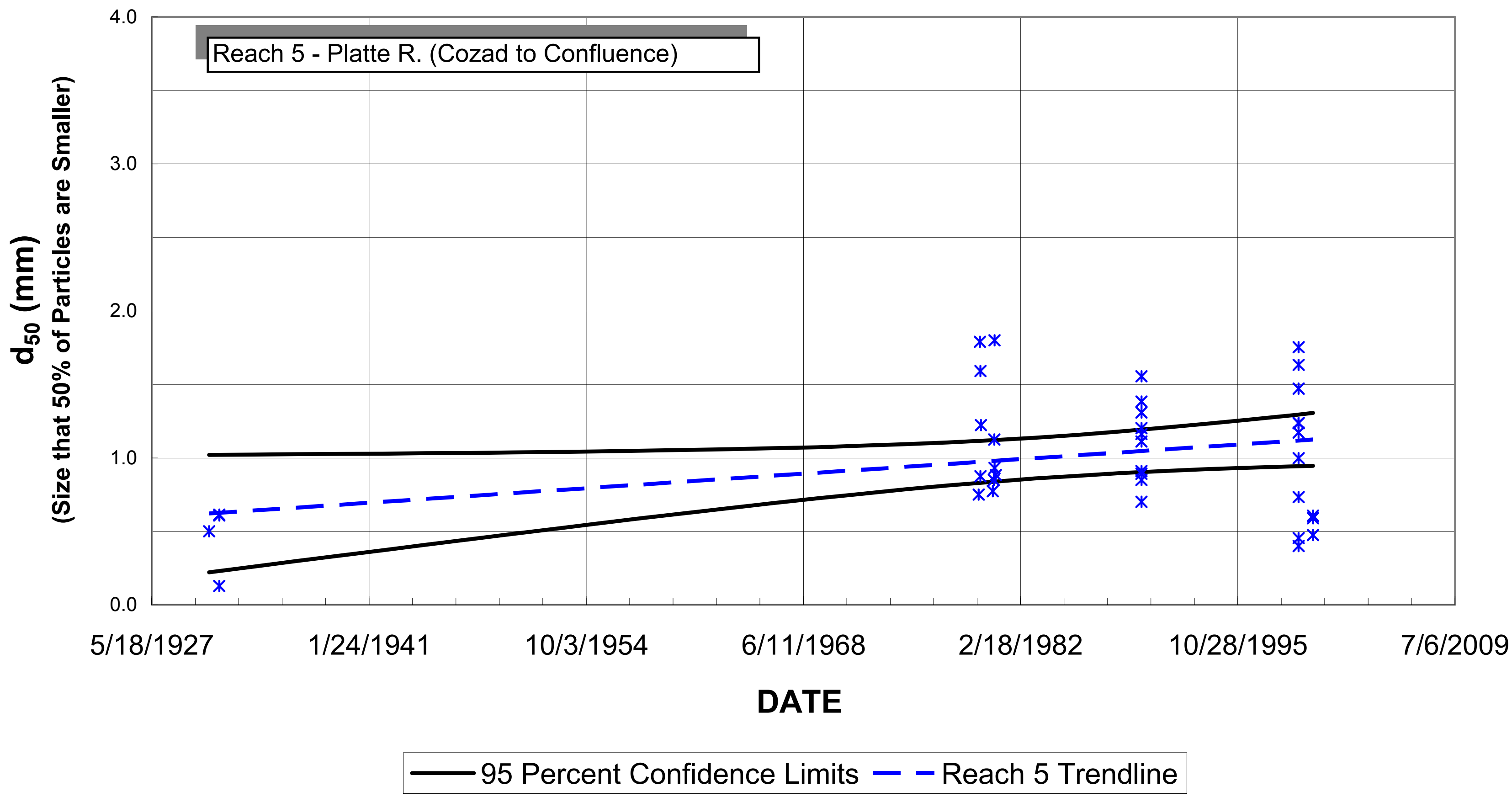
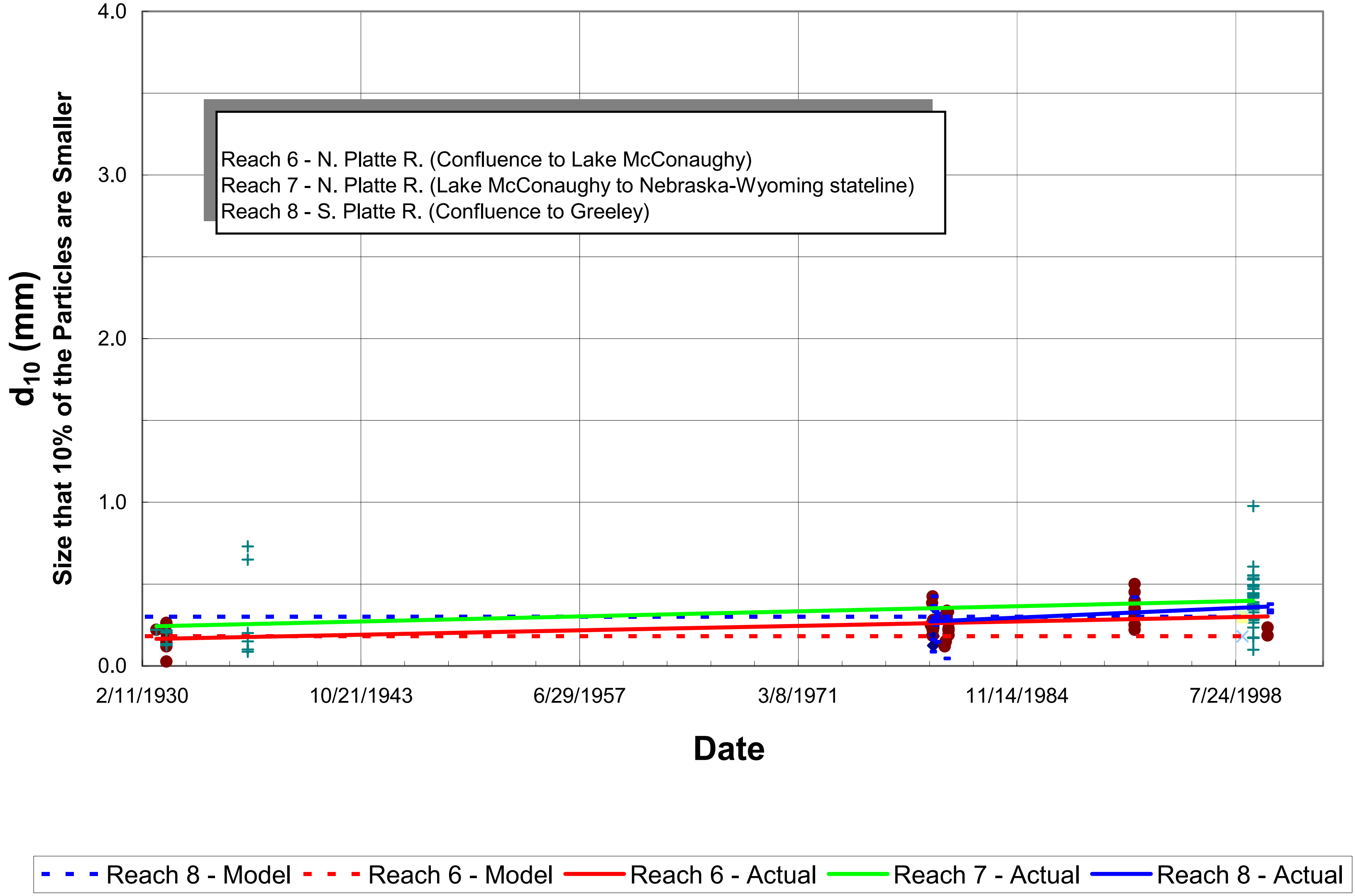


FIGURE B1-12: TEMPORAL CHANGE IN BED MATERIAL SIZE, D_{10}



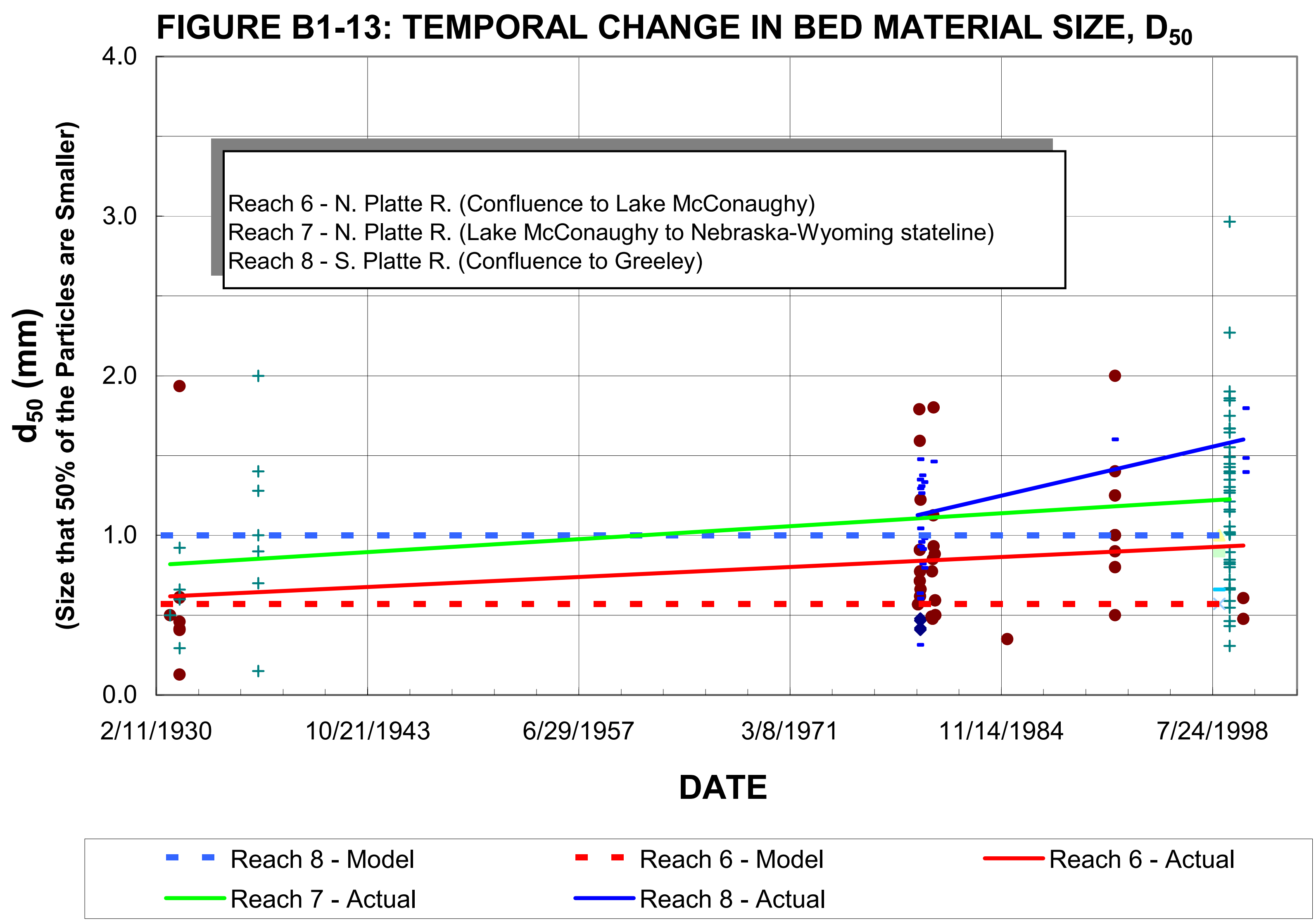


FIGURE B1-13: TEMPORAL CHANGE IN BED MATERIAL SIZE, D_{50}
Reach 6 - N. Platte R. (Confluence to Lake McConaughy)
Reach 7 - N. Platte R. (Lake McConaughy to Nebraska-Wyoming stateline)
Reach 8 - S. Platte R. (Confluence to Greeley)
d_{50} (mm)
(Size that 50% of the Particles are Smaller)
4.0
3.0
2.0
1.0
0.0
2/11/1930
10/21/1943
6/29/1957
3/8/1971
11/14/1984
7/24/1998
DATE
Reach 8 - Model
Reach 6 - Model
Reach 6 - Actual
Reach 7 - Actual
Reach 8 - Actual

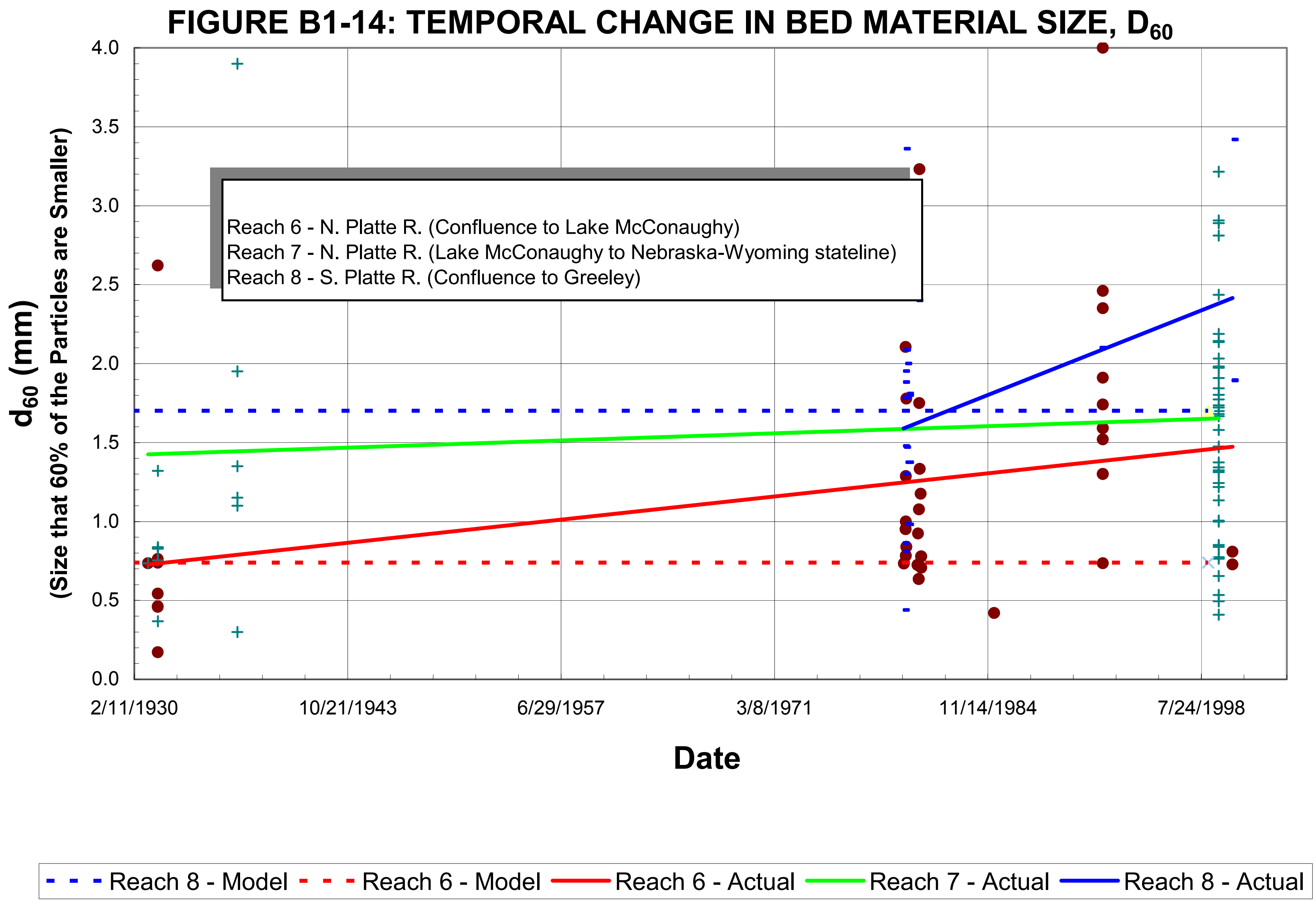
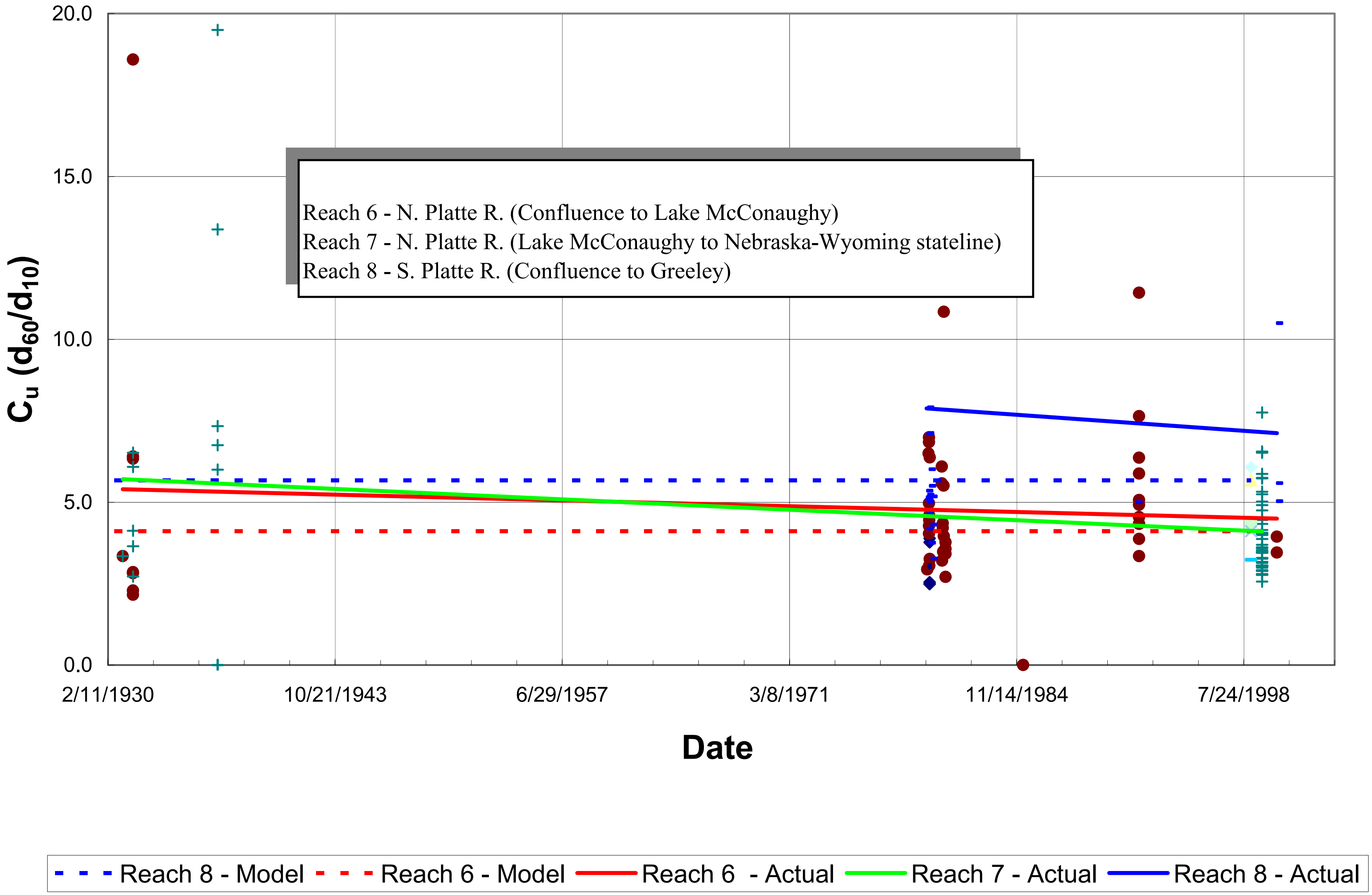


FIGURE B1-14: TEMPORAL CHANGE IN BED MATERIAL SIZE, D60
d60 (mm)
(Size that 60% of the Particles are Smaller)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Reach 6 - N. Platte R. (Confluence to Lake McConaughy)
Reach 7 - N. Platte R. (Lake McConaughy to Nebraska-Wyoming stateline)
Reach 8 - S. Platte R. (Confluence to Greeley)
2/11/1930
10/21/1943
6/29/1957
3/8/1971
11/14/1984
7/24/1998
Date
Reach 8 - Model
Reach 6 - Model
Reach 6 - Actual
Reach 7 - Actual
Reach 8 - Actual

FIGURE B1-15: TEMPORAL CHANGE IN BED MATERIAL UNIFORMITY, C_u



TECHNICAL MEMORANDUM

RESULTS OF INVESTIGATION B2 – INDEPENDENT ASSESSMENT OF "SED" CONCEPTS IN SEDVEG MODEL

PLATTE RIVER CHANNEL DYNAMICS INVESTIGATION

Prepared For

States of Colorado, Nebraska, and Wyoming

May 2003

Prepared By

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TECHNICAL MEMORANDUM

INVESTIGATION B2 - INDEPENDENT ASSESSMENT OF "SED"CONCEPTS IN SEDVEG MODEL

PREFACE

This report describes the procedures used and results of an evaluation of the sediment transport concepts and algorithms incorporated by the U.S. Bureau of Reclamation in the SEDVEG model. The investigation addressees a number of technical issues regarding this subject which had been identified by the sponsors as needing detailed examination to allow them to make scientifically-based decisions regarding the Cooperative Agreement (CA) work products.

This document describes only the data collected, analyses made, and scientifically-supportable findings regarding the issues, written in a manner which generally follows the guidelines of professional journals of the respective authors' technical expertise. The relevance of the findings to the specific issues confronting the sponsors is discussed in each task memorandum, but only as far as the data and results are deemed by the author(s) to be scientifically supportable in resolving or illuminating the issue.

ISSUES AND PURPOSES OF INVESTIGATIONS

The technical evaluations completed by the Parsons team were conducted as a series of 14 complementary investigations divided into four categories that would address general issues identified by the three states. The following issue categories were identified:

- A: Questions Regarding Channel Narrowing or Deepening
- B: Questions Regarding Sediment Transport
- C: Questions Regarding Vegetative Encroachment
- D: Questions Regarding Macro-Historic Natural Variability

This Technical Memorandum describes the results of Task B2, the second of three tasks comprising Issue Category "B."

The objective of Task B2 is to review the conceptualization of the model, methods chosen to model hydraulic and sediment transport physical processes, theoretical development, algorithms written, boundary conditions, constraints, time steps, input data requirements and quality, assumptions made, sensitivity of results to key parameter changes, calibration, and overall adequacy of the SEDVEG model for the purposes intended by its developers. The predictive ability of the model is described in the Task B3 report. Because the model is in constant revision, the version evaluated in this investigation was that provided by the USBR at the onset of the investigation in April 2001. The sediment model has been and continues to be modified after the April 7, 2001 submission of the model and the accompanying report. Another version of the model was provided on July 13, 2001, which is the version described here. Samples of data inputs, samples of output files, and documents describing the analytical conceptualization were provided along with the model code.

SEDVEG MODEL

The SEDVEG model combines the sediment transport and riparian vegetation processes as they interact within the overall process of channel dynamics. The model is basically subdivided into the two main components of sediment transport and vegetation. The sediment transport component computes the rate of sediment transport and subsequent changes in channel geometry. The vegetation component predicts the germination, establishment, and either growth or removal of vegetation as affected by flow and sediment transport. Thus, the model attempts to simulate the overall geomorphic and plant growth processes that integrate the flow of water, transport of sediment, and subsequent response and interaction with riparian vegetation. A brief assessment of the sediment transport components of the model is presented in this document. Task B3 addresses the predictive capabilities of the sediment algorithms in the model, while another assessment (Task C2) focuses on the vegetation aspects.

EVALUATION OF "SED" PORTION OF THE 13 JULY 2001 MODEL

The SEDVEG model consists of two key components: 1) sediment transport, and 2) vegetation processes. While these two key components are being evaluated independently, there are some significant interactions beyond the basic hydraulic interaction between channel geometry, hydrology, and riparian vegetation processes: primarily the effect of vegetation on resistance to flow and the transport of sediment and associated change in channel geometry that affect the survival and potential re-establishment of vegetation. This evaluation focuses on the sediment component of the model. A preliminary evaluation of some key technical aspects of the model was made in March 2001 and is provided in an appendix to this section.

Even during discussions with the modeling team of the USBR in late July and early August, 2001, the USBR indicated that the model continues to be modified on virtually a daily basis. Some or all of the comments evaluating the model version reviewed by Parsons may or may not be valid depending on the evolution of the model as time goes on. It must be concluded that the version of the model reviewed here is still in the development stage, has not been calibrated or verified in anything more than a preliminary state, and has not yet been applied in its final state to analyze and evaluate various questions for which it was developed. Everything seen to date must be considered very preliminary in nature and indicative only of the model development and evolution process. Primary concepts of the model, however, have remained relatively static.

The sediment transport model uses a normal depth hydraulic computation using mean daily flows to compute water surface elevation and mean velocity of the flow. This is a relatively simple one-dimensional modeling approach to a complex issue; however, a number of adjustments are then made to recognize the multi-dimensional nature of the river and geomorphic interaction between flow, sediment, and riparian vegetation.

Cross-section data and spacing used in the model are described in the Task A3 report, where it is noted that that sixteen 1989 USBR-surveyed cross sections over a distance of 148 miles, spaced on average 6.8 miles apart. The analysis reported in the A3 report reveals that the widths and shapes of channels within each of the reaches vary significantly from the shapes and widths of the channel cross sections that were selected to represent that reach. The spacing of 6.8 miles does not adequately represent the variations in the river's geometry. Other problems with this spacing, particularly in regard to calculations of sediment transport, are described below.

Sediment transport capacity is computed first using the mean velocity of the flow and then distributed into sub-sections (point by point) laterally across the channel with the sum of the sub-sections forced to equal the total based on the initial mean velocity calculation. This is a reasonable approach.

The total sediment transport capacity is computed by multiplying the decimal percentage sediment size distribution of the active layer for each size class, reducing the unlimited sediment transport capacity in each size class by this factor, and summing the results for each size class together. The active layer is a layer of sediment on the surface of the riverbed. It lies on top of the original, or parent bed material. The size distribution of the bed is used as input for the initial time step of a model run. The size distribution of the active layer is recomputed and updated through time as the model proceeds through the model time steps.

The active layer is commonly defined as a layer of sediment that is in the active mode of exchange with the sediment being transported, through processes of erosion or deposition. The depth of the active layer, as set up in the model, can only increase over time and doesn't represent the depth of sediment that may be disturbed or in some mode of active exchange with the flow for each given individual time step and associated magnitude of flow. It should be noted that there is a future intention to utilize this latter definition of an active layer in that it is related to each individual flow for each time step as a means to better represent the process of removal of vegetation by scour. This would incorporated the concept that if the active layer progresses far enough into the root zone, this may result in removal of the vegetation, for example, at a high rate of flow that inundates vegetated portions of the channel geometry. For the model assessed, this concept had not been adequately developed for incorporation in the model.

Sediment transport capacity is computed based on the size distribution in the active layer. This distribution does not account for the size distribution of the incoming sediment supply from the reach immediately upstream. This may cause some unrealistic oscillation or pulsation in sediment transport capacity calculations from one time step and/or reach to the next meaning that for one time step or model reach the transport capacity would be too high resulting possibly in excessive scour while the next time step or reach may have a transport capacity that is too low resulting in excessive deposition rather than a more gradual, non-oscillatory response to changing upstream supply.

The model accounts for armoring of the riverbed using an approach that limits erosion of the bed based on the percentage of the bed covered with non-moving particles. A calibration parameter controls the armoring process with a decimal percentage that ranges from 0 to 1 (with 1 meaning that the bed needs to be covered with 100% of one non-moving particle thickness for armoring to be effective, 0.5 meaning 50% of the bed needs to be covered with one non-moving particle thickness for armoring to be effective, etc.). Thus, the armoring process can readily be controlled by adjusting the parameter. For each time step, a new armor layer is computed and an evaluation is made regarding the extent to which armoring is or is not effective.

The actual development of an armor layer is typically time dependent. In other words, it takes some finite amount of time for an armor layer to form, which may be either shorter or longer than the time step used in the model. This concept is not accounted for in the model and could over-estimate the effect of armoring on channel processes. It is assumed that the armor layer forms within the given time step. To some degree, this may be one of the hidden concepts that may be accounted for in the calibration parameter.

The model does not retain any memory of the armor layer from any previous time step. Any armor layer that may develop during one time step is brought into the general depth of the active layer and accounted for as part of the active layer over the sequence of time steps in the model.

The lateral distribution of sediment size distribution at points across a cross-section is controlled by an application of Rouse's equation. Rouse's equation was developed and has been used to describe the vertical distribution of a range of sediment sizes that is transported by flowing water. Apparently, this is a new application of this concept rotated from vertical to lateral. The model simply applies Rouse's vertical size distribution approach to each individual point across the channel to compute lateral differences in size distribution across the channel based on the variable depth of flow at each point. The result is that, as the cross-sections evolve over time, the sediment sizes on the floodplain become finer than the average size of sediment moving or deposited and the sediment sizes on the bed becomes coarser. The application of Rouse's equation in a lateral fashion is controlled by a parameter (KAPPA). The model input, as it exists at the time of this review, starts out with a uniform size distribution at all points across the channel. Discussions indicated that the modelers intend to change the model input so that it allows different size distributions at each point across the channel. This parameter has been calibrated such that sediment size distributions on the floodplain as they have evolved over the time period modeled have become finer, resulting in a median size of about 0.2 to 0.3 mm (compared to an initial median diameter of about 0.5 mm), while the bed has coarsened from about 0.5mm to about 1 mm.

The model limits erosion by preventing the lowering of any point in such a way that an excessively steep transverse slope is created, which typically does not occur in nature except perhaps as caused by an obstruction to the flow such as a bridge pier or a focusing of flow by localized ice jamming. Transverse slope is simply the difference in elevation between two points in a cross-section divided by the distance between the two points. A limiting transverse slope parameter prevents any such erosion, thereby limiting any transverse slope to be less than the allowable amount. This was done to prevent the so-called "China syndrome," when extreme amounts of erosion were being calculated at points within a cross-section before the constraint was added. Discussions with the USBR indicated that this approach may not be needed in the future as a result of other changes that have been made in other portions of the model. The USBR may run a test with this parameter set such that no control occurs to test whether or not this type of limit is still necessary.

Erosion of riverbanks or edges of bars or islands can occur in the model resulting in what could be called lateral erosion. This occurs when erosion is indicated at a point that is under water but adjacent points that are above water lie along a slope that is steeper than some allowable critical slope, such as the angle of repose. Different allowable critical slopes are given for dry or partially dry banks and for completely submerged slopes. It should be noted that this critical slope is not the same as the limiting transverse slope described in the previous section. When such a case develops, erosion occurs at the point or possibly multiple points above water. This can cause a bank point to degrade, resulting in the lateral movement (or transfer) of a bank to an adjacent point. Thus, the concept and mechanism of bank erosion and lateral movement is indirectly built into the model, however, no evaluation of specific instances of such an occurrence have been conducted nor has the reverse process of bank building been incorporated.

Few models of river width adjustments exist, and none have been universally adopted. In review of existing approaches to modeling river width adjustments, the ASCE Task Committee on Hydraulics (1998) published a series of two papers entitled, "Bank Mechanics and Modeling of River Width Adjustment, River Width Adjustment I and II" in which they concluded that adequate width prediction tools that they considered reliable enough as a basis for management decisions do not exist.

As noted earlier and in the Task A3 report, the spacing of cross-sections used in SEDVEG is quite large, primarily due to the computational time required for convergence and the extensive requirements of data for the initial conditions for the model runs. Compared with the detail normally used in sediment transport models, it is likely that the widely-spaced model cross-sections used in SEDVEG do not represent the range of hydraulic and sediment transport conditions that exist along the Platte River. Sensitivity tests may have been conducted but were not evaluated. It is also possible that calibration and validation problems may occur due to the potential lack of consistency between the time and space steps in the Exner equation. This is the equation that is used to compute channel bed changes based on changes in sediment transport over time and space. An expanded discussion of the Exner equation is provided in the Appendix. The issue is whether or not the quantities of sediment calculated using the sediment transport equation can actually move over the distances between cross-sections during the given length of the time steps (1 day) in the model. This is not considered likely given the large spacing between cross-sections. Time of travel studies of water discharges in the Platte indicate that velocities are such that distances of about 7 miles (the average spacing of the cross-sections) are traversed in about 1 day. Because the bulk of sediment moves at a lower velocity than the flow transporting it, the cross-section spacing may be problematic.

Calibration of the model reviewed had been conducted, covering the time period from 1865 to 1998. This was done to cover a wide range of hydrologic conditions and corresponding river response (including a pre-development period of potential dynamic equilibrium with wide, braided conditions, a period of water resources development and drought when the river experienced significant change to one with significant expansion of riparian vegetation and reduced sediment loads, and a period of potential dynamic equilibrium representing current conditions).

If data are available for calibration, this approach would provide a good test of the model over the wide range of conditions and river responses. The input data set used in the model and the calibration/verification process is quite limited due to the fact that desired data sets for such tasks are limited since ideal amounts (both spatially and temporally) of data were not collected over the past century, particularly during the pre-development era. As a result, model input data and the calibration/verification processes are constrained by availability of real data as well as the fabrication of some synthesized data, especially in the 1800's. To the credit of the modelers, this was done using generally appropriate techniques by estimating channel dimensions from historic maps, old aerial photos, and survey data. Unfortunately, there is no way around the issue of the sparseness of historic data. Given this situation, the overall initial calibration and verification approach appears to be reasonable; however, it could be improved by a more detailed effort in order to focus calibration on shorter periods of time involving more adequate data. Following calibration, predictive runs involving simulation of potential future conditions particularly related to any potential program of channel maintenance/enhancement can be compared to a non-action alternative.

Hydraulic calibration appeared to focus on a comparison of predicted and actual rating curves that relate flow to stage (or water surface elevation). An example is shown in Figure 4.45 of the SEDVEG model report. Since velocity is a key component of the sediment transport and vegetation modeling, it would be useful to compare available velocity data (from historic USGS measurements or other sources) in the hydraulic calibration process. This would require using input channel geometry consistent with sections where hydraulic data are already available or collection of new hydraulic data at specific model cross-section locations.

Regarding sediment transport rates, no direct comparisons between flow and sediment transport were provided in the 4/07/01 report in order to adequately evaluate how the model computations compare with such data. Calibration of channel bed elevation changes from the late 1800's to recent times was accomplished by comparing model results against apparent trends in changes in bed elevation at USGS gages (typically located at bridges), which may not be representative of the river in general and has not been universally accepted nor independently confirmed.

Comparisons were provided between the initial and final cross-sections computed by the model with recent survey data. In general, the model (based on 4/7/01 graphical output) tends to under-predict changes in the channel geometry (i.e., predicted changes tend to be less than measured changes) and does not necessarily predict the correct direction of change on a cross-section by cross-section basis as discussed further in the Task B3 Technical Memorandum. It is unknown to what extent the actual data comparisons are valid or what effect ongoing modifications to the model may have in improving these predictions.

The EIS team has focused calibration on averaging results from the various cross-sections together rather than focusing attention on specific responses at specific locations. While this may be justified to some degree by the sparseness of data, it may minimize discovery of key aspects of the model that may require improvement. In addition to a more detailed effort, more complete data could be collected in the future to test, calibrate, and verify the model in a more refined way while using the initial work as a base. For example, some sediment transport and cross-section data are available from the 1980s and 1990s. These data should be used to further test, calibrate, and verify the model, comparing measured and computed hydraulic variables such as velocity, sediment transport rates, and changes in cross-section geometry and bed material size distributions. Some of this can be done with existing data but additional data collection would be useful in completing a thorough calibration and verification effort.

CONCLUSIONS

Several conclusions can be drawn from the independent assessment of the "SED" portions of the SEDVEG model:

- The SEDVEG model is still in the development stage, with changes and refinements being made during the review process. A final version of the model is not yet available.
- The model reviewed in this report contains the key processes that need to be considered in simulating the Platte River (hydraulics, sediment transport, armoring, channel bed elevation erosion/deposition, lateral erosion); however, the various algorithms used in the simulation have not been adequately refined and tested. While the model code and structure generally provide a good framework

for understanding and simulating these processes, additional testing and evaluation of specific algorithms will be required to address the reliability of the model in simulating channel bed elevation changes, lateral changes in the banks or island/bar margins, island, bar and floodplain building processes, and changes in particle size distributions laterally across the channel through evaluation of a more detailed calibration/verification effort.

- It is too early to judge the reliability of the SED model since it is still in the development process and has not undergone adequate calibration and verification. It can be stated, however, that it is based on a primarily aggradation/degradation model and unless sufficient incorporation of lateral erosion/deposition processes are included, it may have limited applicability.
- The original calibration/verification process was constrained by the sparseness of historic data. While it remains important to use the available data to calibrate the model over historic conditions (since it is useful to ensure that the model properly responds to a time period when dynamic equilibrium potentially existed with a wider channel of the pre-development era – prior to the mid- to late 1800s, as well as when the channel experienced significant change during the time period of water resources development and drought – from the early 1900s to 1970), calibration/verification should extend to included recent historic data of the 1980s to the present as well as future time periods when more complete data can be collected and utilized in the process. A more detailed and thorough calibration and verification effort is warranted as previously described.
- Adequate testing has not been conducted regarding the linkage between sediment transport and subsequent channel geometry changes. Neither has testing been conducted regarding channel geometry as it affects vegetative response. The version of the model described in the 4/7/01 document utilizes the permissible velocity concept (scouring vegetation when permissible velocities are exceeded by age and type of vegetation) rather than relating scour of vegetation to scour or activation of the channel bed. The latter concept and approach are known to be preferred by the modelers and known to be in the works for future versions of the model. The potential effect of sediment transport and channel geometry change on vegetation has not been directly linked with vegetative response in terms of scour such that the question of how important sediment issues are in the vegetative scour process is not yet well understood, documented, and simulated.
- Another factor that is not included in the model is mortality of vegetation due to excessive sediment burial (known to be a significant mortality factor based on Carter Johnson's observations during the demography studies). This is another sediment-based factor that should be considered in the future.
- Attempting to analyze and simulate these sediment transport, geomorphic, and vegetation issues through the modeling process that forces attention on key linkages is a reasonable and effective way (if conducted properly – see details in the Task B2 report) to begin to develop an adequate understanding and potentially provides a tool for prediction of the effects of management alternatives. The modeling process may provide a framework to collect additional data and to ensure that an understanding of the key geomorphic/vegetative processes and linkages are adequately understood and simulated. When such an understanding is developed and simulated, the causes of channel change and vegetative response

will be better understood; and appropriate maintenance and enhancement measures can subsequently be developed.

Considerable discussion of the complexity of the physical processes and difficulties in accurately modeling them is provided in the ASCE papers (1998), where the Task Committee reports that, at that time, no acceptable models of channel width adjustments are available for use in making management decisions. Using this assessment of the ASCE Task Committee, and considering the new and untested algorithms in SEDVEG such as the rotated Rouse method, one could conclude that SEDVEG (in the 4/7/01 version reviewed) should not be used for management decisions regarding water, sediment and vegetative expansion processes in the Platte River.

On the other hand, evaluation of the sediment transport, geomorphic and vegetative issues involved in the Platte River must be accomplished, requiring development of an acceptable approach of analysis and evaluation. It must also be recognized that other standard methods (such as effective discharge) do not consider the complexities of the physical and biologic processes that are necessary in developing detailed management plans for controlling releases or adding sediment on a seasonal basis. Where consequences of inaccurate predictive tools are as great as exist here, standard methods should be applied as well as techniques specifically and properly developed to address the necessary complexities of the sediment/vegetation interaction through appropriate testing and evaluation. This comprehensive approach, defined in the three-level process (see Appendix B) provides the greatest possibility of success, with any physical process model such as SEDVEG requiring significant additional effort before such a tool can be demonstrated to be sufficiently reliable and accurate for management purposes.

APPENDIX A

Preliminary Evaluation of Sediment Component of SEDVEG Model

Mathematical models for sediment processes in a river system are based on a sediment transport equation and the sediment mass continuity equation also known as Exner Equation. The models are formulated as finite difference equations, which can result in conceptual errors.

Model Formulation

The sediment transport equation computes the sediment transport capacity of the flow (the mass of stream boundary material and suspended particles that the flow can potentially move in an instant of time). For the SEDVEG model, the transport equation is a regression-type of equation, which computes the amount of sediment possible to be carried by the flow based in the hydraulic characteristics and the availability of sediment in the cross section at the time of the measurement. The USBR developed this equation by measuring the hydraulic characteristic of the flow, the bed material, and the sediment transported by the flow and then correlating these variables. In application, sediment transport is assumed to be instantaneous as it is for water flow rating curves. For a given flow condition and sediment availability the equation determines the amount of sediment been transported.

The SEDVEG model expands the use of this equation to one more dimension, i.e. the modeling includes the routing, or the time dimension. In order to account for the time involved in the routing, the Exner or continuity equation is used.

The Exner Equation can be understood by thinking in terms of a conveyor belt. Think of “G” as the rate that sand is supplied to the conveyor, “X” as the length of a conveyor segment, and “B” as the width of the belt. For a given belt speed, the conveyor will travel a segment in time “T”. The depth of sand on the conveyor “Y” will vary depending on the conveyor speed, width and the supply rate.

A simplified version of the Exner equation has the following differential format:

$$\frac{dG}{dX} + B\frac{dY}{dT} = 0 \qquad \text{Equation 1}$$

where

G = Sediment transport rate,

X= Distance along the channel,

B = Width of movable bed,

Y = Depth of sediment in control volume, and

T = Duration of time step.

In the differential equation time and space dimensions are dependent, since there is feedback between changes in channel shape and grade that affect transport capacity and visa versa. However, for modeling this dependency is typically neglected, which it is the case in the SEDVEG algorithms.

This leads to the finite difference form of the Exner equation:

$$\frac{DG}{DX} + B\frac{DY}{DT} = 0 \qquad \text{Equation 2}$$

However, if this equation is used in the model to maintain continuity of mass, the model may have a conceptual misrepresentation in the computation of the sediment transport capacity. The support for this statement is explained below.

Computational Problem – Lateral Instability

SEDVEG divides the computation of the flow and sediment transport dynamics in a river reach by segments of a cross-section. The objective is to mimic the lateral dynamics through the riverbed by using the distribution of conveyance in the cross-section. However, the model does not include a process for the lateral migration of the banks. This approach can create an inconsistency in the calculation if additional bank stability thresholds are not included.

The division of the cross section into several segments tends to concentrate the scour of the riverbed where the river is the deepest. Since, the highest velocity or largest stream power concentrates in the area at the deepest segment of the cross-section, the scour also concentrates at this segment of the river. By virtue of this positive feedback in the calculation, the depth increases at this segment and further concentrates the flow and the local scour at this part of the cross section, resulting on a uneven cross sectional profile, resulting in what is known computationally as the " China Syndrome". This cross section has negligible erosion in most of the channel and a relative canyon just a few feet away.

The objective is to verify the methodology adopted to control the concentration of the scour in just one portion of the channel, and also to check the strength of the assumptions made to reproduce the geometric dynamic of the cross section.

Conceptual Problem – Sediment Size Oscillation

As explained before, the sediment transport capacity is dependent on the availability of material for transport. The transport equations base this availability on the field measurements of bed material size and quantity.

The approach generally used in calculation of bed material exchange is to determine the availability of material in the streambed relative to the sediment supply and the bed material sizes in a thin layer at the streambed. This is the so-called active layer of the streambed. There are several methods to determine the active layer; most of them consider the formation of a layer of non-moving particles (an armor layer) as the limitation condition. However, SEDVEG ignores the dynamics of the active layer and uses a constant active layer thickness.

The sediment supply is included in the sediment availability because it could otherwise cause an inconsistency in the calculation of the sizes been transported. For example, consider the estimation of sediment transport without considering the sediment supply into the reach. For an armored riverbed, the model would predict that the flow could transport only the cobble-sizes that available on the bottom of the stream, and would deposit sand, silt and clay being supplied to the reach for that period of time. The only reason for these smaller sizes are not being transported is because they are not available on the riverbed, since the sediment transport equations refer to the bed material to determine the sizes that can be transported. As the transport capacity is related to the size of the material, the total transport capacity is underestimated.

On the next time step, these sizes would be available on the stream bottom and the calculation would probably transport all sizes and the transport capacity would be larger even with the same hydraulic conditions. This inconsistency in the calculation results in pulsating transport of sediment and is a misrepresentation of the physical processes encountered in the nature.

To solve this instability of fine and coarse material been moved at subsequent time steps, SEDVEG includes the sediment supply as available together with the active layer to determine the transport capacity. However, the introduction of sediment supply in the sediment availability determination opens the problem of the dependency between time and space, which is not accounted for in the basic formulation of the Exner equation. As a result, the dependency between the distance between cross sections, and the time step used in the model becomes important.

In order for the Exner equation to be applicable, the model time step and the distance from one cross section to the next, needs to be consistent. The consistency is only obtained if the relationship between time step and travel time of the flow through the reach is consistent. This presents a problem in sediment modeling, because the time step or the distance in between cross section becomes part of the calibration it self. Additionally, the value of one of these two variables would change from one time step to the next because they are dependent in the flow velocity on the reach through the hydrograph.

Computational Problem – Time/Space Resolution

Another important aspect to verify in the model is the time and space resolution. It is well known that most of the sediment transport and geomorphic changes occur during short periods of time during large events. Therefore, if the model uses a time resolution that is too large, it will not be able to mimic the physical processes governing the channel formation. Additionally, in order to have an acceptable representation of longitudinal and lateral features of the channel geometry it is necessary to have an adequate density of cross sections. The survey of river reaches and channel sections needs to have enough points to well represent the channel geometry.

Computational Problem – Scour Damping / Armoring

Sediments models have a general tendency to over predict sediment scour from the streambed. The typical approach is to damp the rate of scour using some sort of procedure to limit the scour. Most of the time this procedure does not have a theoretical support, which could invalidate the use of the model itself. This situation is going needs to be verified in the SEDVEG model.

Another important issue to be verified is the formation of armoring in parts of the cross sections. In reason of the diverse combination of transport capacity and bed material and supply parts of the cross section will have bed material composed of fine sediment (usually on the concave shallow side of bends), larger armored bed material on the deepest convex side of the bank.

Recommended Evaluation

Certainly, the time and space dependency needs to be verified during the review of sediment model. This verification will be checked through a sensitivity analysis, and the verification of the code of the model. The sensitivity analysis will compare the model results for several synthetic hydrograph routings, which will include but not limited by the following combinations:

- Change the reach length between cross section while the time step remain the same
- Change the time step duration while maintain the reaches lengths the same
- Change both

The results will be then compared to determine any inconsistency on the amount of sediment been transported.

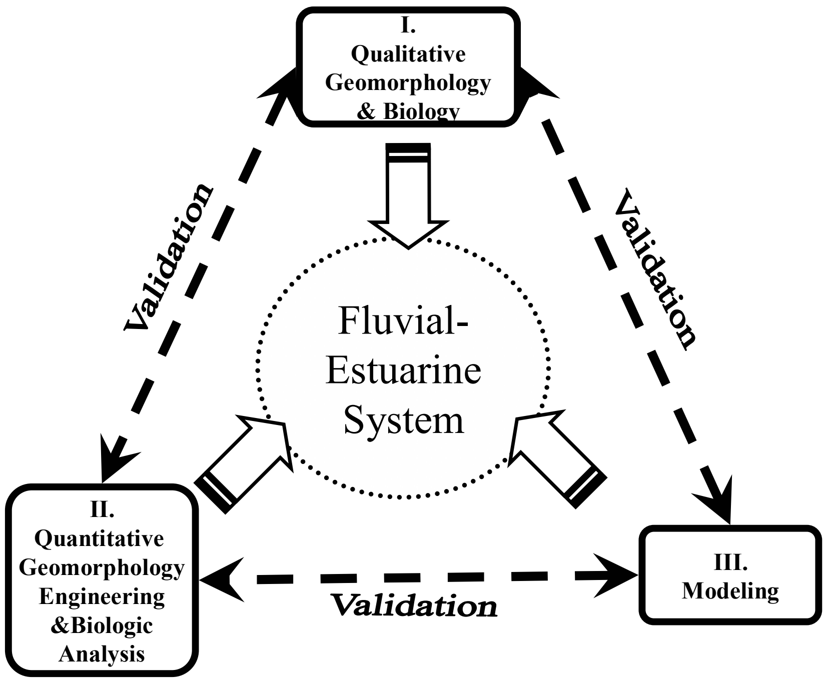
The verification of the code will also isolate the sediment continuity code component of the model and verify the consistency of the model logic to the theoretical approach used to compute the sediment transport. To verify the validity of the model the verification the following issues will be addressed:

- The validity of the logic through the model
- The consistency of the equations;
- The transport capacity;
- The sediment availability, the bed material and supply;
- The Active Layer;
- The computed Bed load and suspended load;
- The sediment load by size fraction;
- The armoring process.

APPENDIX B

Three Level Approach

Qualitative geomorphic analysis is the first level of a three-level process developed by Simons & Associates incorporating: qualitative geomorphic analysis, quantitative engineering and geomorphic analysis, and quantitative computer modeling analysis (see Figure B-1). This approach ensures a proper understanding of physical processes governing the flow of water, transport of sediment, river form and response, and interaction with infrastructure is developed; and mutually supportive, scientifically justifiable results are obtained. Each subsequent level of analysis builds on the understanding developed by the previous level. Any inconsistencies are reconciled so as to arrive at mutually supportive conclusions. A significant benefit of this approach is that the qualitative geomorphic level of analysis provides an understandable basis for more technical or complex analyses serving as a foundation for understanding and communication as the other levels of analysis are conducted. This approach ensures that an appropriate understanding of the watershed and river system as they interact together as a system. It also ensures that important governing geomorphic principles are considered and that the results of more technical and detailed analyses are consistent with these universal principles.



A conceptual schematic of the three-level approach for determining geomorphic, sediment transport and biologic response . Validation must occur between all three levels to assure that reasonable results have been achieved.

Figure 1. Conceptual Schematic

Figure B2-1. Three-Level Approach

TECHNICAL MEMORANDUM

RESULTS OF INVESTIGATION B3 -- EVALUATION OF PREDICTIVE CAPABILITIES OF SEDVEG MODEL

PLATTE RIVER CHANNEL DYNAMICS INVESTIGATION

Prepared For

States of Colorado, Nebraska, and Wyoming

May 2003

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TECHNICAL MEMORANDUM

INVESTIGATION B3 - EVALUATION OF PREDICTIVE CAPABILITIES OF SEDVEG MODEL

PREFACE

This report describes the procedures used and results of an evaluation of changes in sediment gradations in the Platte River and its major tributaries. The investigation addressees a number of technical issues regarding this subject which had been identified by the sponsors as needing detailed examination to allow them to make scientifically-based decisions regarding the Cooperative Agreement (CA) work products.

This document describes only the data collected, analyses made, and scientifically-supportable findings regarding the issues, written in a manner which generally follows the guidelines of professional journals of the respective authors' technical expertise. The relevance of the findings to the specific issues confronting the sponsors is discussed in each task memorandum, but only as far as the data and results are deemed by the author(s) to be scientifically supportable in resolving or illuminating the issue.

ISSUES AND PURPOSES OF INVESTIGATIONS

The technical evaluations completed by the Parsons team were conducted as a series of 14 complementary investigations divided into four categories that would address general issues identified by the three states. The following issue categories were identified:

- A: Questions Regarding Channel Narrowing or Deepening
- B: Questions Regarding Sediment Transport
- C: Questions Regarding Vegetative Encroachment
- D: Questions Regarding Macro-Historic Natural Variability

This Technical Memorandum describes the results of Task B3, the third of three tasks comprising Issue Category "B."

The objective of Task B3 is to conduct an examination of the results of simulations of the SEDVEG model over various periods of record and to compare the predicted end-results with actual configuration of the channel.

SEDVEG MODEL SUMMARY

Murphy and Randle (2001b) describe in general terms the development of a numerical model (the "SEDVEG model"), used to simulate the process linkages among fluvial hydrology, river hydraulics, sediment transport, and vegetative expansion/contraction for the Platte River in Nebraska. The model was designed to simulate the ways in which stream discharge and sediment supply affect channel characteristics (width, depth, configuration, vegetative growth) through time.

The model input includes hydrographs of mean daily river discharge at various locations along the channel, river cross-sections to define the channel geometry, channel roughness and sediment grain size at each channel cross-section location, initial composition and density of vegetation species at each channel cross-section location, vegetation growth rates, and removal criteria for each species of vegetation. The model simulates the evolution of channel geometry, changes in grain size of transported sediment, and vegetation growth/removal for each indicator species during any selected simulation period.

The results of simulations include cross-sections depicting changes in channel geometry at each cross-section location, sediment removal, transport, and deposition rates, water-surface elevation at each cross-section location, and the location of vegetation relative to the channel bed. These results produced by the *SEDVEG* model have been used to evaluate changes in the configuration of the Platte River channel and purportedly demonstrate that incision (erosion) and narrowing of the channel have occurred as a consequence of a number of factors, including reductions in peak flows, changes in sediment supply, and encroachment of vegetation. In turn, these changes in channel configuration have resulted in degradation of habitat quality for various threatened and endangered species of birds and fish.

The model code continues to be modified, and though some calibration work has been completed, it is functional but incomplete. Even though the SEDVEG model remains in development, the fact that it has been used to forecast degradation of the stream bed and that management plans based on this finding are being promulgated, requires that the predictive capabilities of the model be independently evaluated.

EVALUATING PREDICTIVE CAPABILITIES OF SEDVEG MODEL

Comparison of predicted results with actual conditions is standard practice in evaluating predictive simulations of any kind (e.g., American Society for Testing and Materials [ASTM], 1993; Spitz and Moreno, 1996). In practice, for systems having spatial or temporal variability (such as fluvial systems), one or more system variables is identified, values of the variable(s) are calculated at particular points in space and/or time, and the calculated values are compared with the actual values of the variable at the same location/time.

Transects of the channel of the Platte River were surveyed in 1989 at 88 locations, beginning at about river mile 162.2 (near Grand Island, Nebraska) and continuing to river mile 310.2, immediately downstream from Kingsley Dam at Lake McConaughy, Nebraska. Fifteen of these were used in the SEDVEG model (Table B3-1). The locations of transects are referenced to "river miles," which represent the distance along the axis of the river channel, measured in the upstream direction from the confluence of the Platte River with the Missouri River, near Omaha, Nebraska. Transect lines apparently were laid out transverse to the river channel, and a number of stations were occupied sequentially along each transect. The distance (in feet) from the point of beginning of the transect, and the absolute elevation (referenced to the National Geodetic Vertical Datum of 1929 [NGVD, equivalent to mean sea level]) were measured at each station occupied during the survey along each transect (Table B3-1). This information was used by the Platte River EIS team to construct a number of cross-sections, each depicting the configuration of the river channel(s) at the location of the transect (Figures B3-1 through B3-10). The transect survey information and cross-sections that had been constructed using that information were conveyed by the Platte River EIS team to Parsons in electronic format on a CD-ROM, in conjunction with the transfer of other information regarding the SEDVEG model, which occurred on April 18, 2001.

Nine of the 15 surveyed transect locations were re-occupied and re-surveyed on one subsequent occasion between 1998 and 2000 (see Table B3-1), and one of the transect locations (at river mile 170.3) was re-occupied and re-surveyed in both years. Though shown to be important (see Task A3 report), it is not known whether the re-surveys were accomplished at the same time of year or after the same antecedent flow conditions as in 1989. The Task A3 report provides cross-sections taken a few months apart, showing that significant changes in the thalweg elevation and other attributes occur for different flow rates. Although the number of transects is limited, these surveyed transects represent an extant physical record of changes in the configuration of the Platte River channel(s) that occurred between 1989 and 1998 (or 2000), depending upon the date of the most recent survey at each location and disregarding the effects of different flow rates.

The SEDVEG model has been used by the Platte River EIS team to simulate hydraulic conditions and changes in river channel configuration and vegetative expansion for several periods of time, including the period from 1989 through 1998 (Murphy and Randle, 2001b). The results of simulations completed using the SEDVEG model include cross sections depicting changes in channel geometry at each cross-section location. For the purposes of calibrating the model, the investigators on the EIS team conducted simulations of the hydraulics of the Platte River for the period 1989 through 1998. Model input consisted of mean daily river discharge at various locations along the channel through the period of the simulation (1989 through 1998); initial river cross-sections (the cross-sections constructed using the transects surveyed in 1989) to define the 1989 channel geometry; channel roughness and sediment grain size at each channel cross-section location; initial composition and density of vegetation species at each channel cross-section location; vegetation growth rate parameters; and vegetation removal criteria for each species of vegetation that was simulated. The model was used to simulate the evolution of channel geometry and vegetation expansion for the period 1989 through 1998. The predictive results of simulations (model output) completed using the SEDVEG model included channel cross-sections calculated to have resulted at the end of 1998 (these are reproduced as red line in Figures B3-1 through B3-10) as simulated in the model.

The surveyed low-point elevations of the river channel(s) at each station on a transect, and the simulated elevations of the low points at the same locations along the same cross-section represent some of the variables that should be related if the model is functioning properly in a predictive capacity. Other comparison factors are the widths of channels and extent of vegetation. Comparison of the simulated and surveyed elevations of the low points of the river channel(s) at each station on a transect was selected as the initial method of evaluating the predictive capabilities of the model.

TABLE B3-1
TRANSECT LOCATIONS AND SURVEY INFORMATION
PLATTE RIVER CHANNEL DYNAMICS STUDY

Transect Location[a/]	Year Surveyed	Number of Survey Stations	Horizontal Transect Distance (ft[c/]) [b/]	Notes
162.2	1989	107	3,959.88	
	2000	212	1,959.88	
170.3	1989	107	8,683.11	
	1998	106	4,508.00	Only North and Middle channels surveyed
	2000	108	994.50	Only South channel surveyed
178.4	1989	124	13,826.07	No surveys subsequent to 1989
183.2	1989	171	12,755.54	No surveys subsequent to 1989
188.3	1989	90	2,688.00	No surveys subsequent to 1989
199.5	1989	124	6,563.36	
	2000	235	2,602.50	
203.3	1989	179	10,300.10	
	2000	97	1,342.44	Only North channel surveyed
209.8	1989	127	10,369.45	
	1998	135	6,303.43	
219.8	1989	94	7,011.85	No surveys subsequent to 1989
228.7	1989	94	5,315.13	
	2000	120	1,315.15	
237.5	1989	338	5,747.66	No surveys subsequent to 1989

TABLE B3-1 (Continued)
TRANSECT LOCATIONS AND SURVEY INFORMATION
PLATTE RIVER CHANNEL DYNAMICS STUDY

Transect Location[a/]	Year Surveyed	Number of Survey Stations	Horizontal Transect Distance (ft[c/]) [b/]	Notes
244.0	1989	294	9,290.24	
	2000	372	5,104.83	
250.5	1989	95	1,187.26	
	1998	80	1,186.44	
258.3	1989	175	8,445.30	
	2000	131	4,401.94	
310.2	1989	72	5,108.18	
	1998	88	1,107.15	
325.0	--[c/]	--	--	No surveys; model results only
328.1	--	--	--	No surveys; model results only

[a/] Locations of channel transects indicated in river miles – miles along the river starting from the point of origin at the confluence of the Platte River with the Missouri River.
[b/] Horizontal Transect Distance is the length of the surveyed transect from point of origin to the end of the transect. ft = feet.
[c/] A dash (--) indicates that the information is not applicable or not available.

The Task A3 report described 16 cross-sections used in the SEDVEG model. The one missing here is at River Mile 249.8. When the cross-section data was acquired for the Task B3 work, the cross-section at 249.8 was not included, so it is not included in Table B3-1. It is within 0.7 miles of the next upstream cross section, and was evidently omitted in the model because it was so close to the section at River Mile 250.5.

Variables that are related in time and/or space (e.g., actual and simulated channel-base elevations) also are related by their covariance, the joint variation of two variables about their common mean (Davis, 1986). The degree of association of such related variables is readily evaluated using the coefficient of determination or correlation coefficient (Rock, 1988). The coefficient of determination is the ratio of the covariance of two variables with the product of their standard deviations, and is a measure of association between the two variables (in this case, the surveyed elevation of the base of the channel at a station, and the model-predicted elevation of the base of the channel at the same location). The value of the coefficient of determination can range between 0.0 and 1.0. If there is no association between the variables, the value of the coefficient of determination is 0.0; perfect association is indicated by a coefficient of determination of 1.0. If the variables are directly correlated, the coefficient of determination is positive; if the variables are inversely correlated, the coefficient of determination is negative. These concepts are best visualized by considering a case in which two variables (e.g., actual and simulated channel-base elevations) are perfectly correlated, i.e., if the SEDVEG model were a perfect predictor, the surveyed elevation of the base of the channel at a station, and the model-predicted elevation of the base of the channel at the same location would be identical (Figure B3-11). In this case, all plotted values of actual and simulated channel-base elevations would lie along a straight line, having a slope of one.

In order to compare the predictive results of simulations with actual channel configurations at the conclusion of the simulation period (1998) it was necessary to identify those transects that had been re-occupied and re-surveyed after the initial survey in 1989. Several transects (at river miles 178.4, 183.2, 189.3, 219.8, and 237.5) apparently were only surveyed once, during the initial surveying effort in 1989. Because information from subsequent surveying expeditions was not available for these transects, these transect locations and cross-sections were excluded from the analysis (Table B3-2). Two channel cross-sections that were simulated using the SEDVEG model apparently were not surveyed; these cross-sections also were excluded from the analysis. Thus, the analysis was completed using the remaining 10 cross-sections and transects.

In comparing the actual surveyed and model-predicted elevation of the low point of any channel at a station, it was necessary that the time at which the channel configuration was surveyed should correspond, as nearly as possible, with the simulated time at which the model calculations were completed, and if possible, the flow rates should correspond. The final calculated channel configurations were generated by the SEDVEG model at the end of 1998. Accordingly, the available survey information for that survey effort occurring nearest the end of 1998 was used in the comparison for each transect and cross-section. Flow rates were not provided for either the dates of actual surveys or on the dates of end of simulation. Survey information collected in late 1998 was available for only four transects (river miles 170.3, 209.8, 250.5, and 310.2) and these were used in the comparison of surveyed and calculated channel-base elevations. Survey information collected in 2000 was used for the other six transects and cross-sections, which are compared here but it should be noted that the simulations were not run to 2000 so the comparison is not as germane.

It was also considered necessary that the locations of the actual survey station and the simulated station location in a model cross-section at which the low point elevation was calculated be the same. In general, the locations of actual survey stations in a transect were irregularly spaced along the transect (see, for example, Figures B3-1 through B3-10). The simulated stations at which low point elevations in the model were calculated were regularly spaced along each cross-section. Consequently, the model-calculated low point elevations were interpolated onto locations on each model cross-section corresponding to the actual survey-station locations along each transect. An alternative would have been to compare the low point elevation in the simulated channel with the surveyed low point elevation of the nearest channel. A test of the sensitivity of using interpolated versus nearest-point low points revealed that the results were not significantly different. The actual and simulated elevations of the base of the channel then were compared for each of the ten remaining cross-sections. The results are shown in Table B3-2.

TABLE B3-2
RESULTS OF COMPARISON OF TRANSECT CROSS-SECTIONS WITH MODEL PREDICTIONS
PLATTE RIVER CHANNEL DYNAMICS STUDY

Transect Location[a/]	Survey Year Used in Comparison	Coefficient of Determination (R^2)[b/]	Slope of Best-Fit Line[c/]	Notes
162.2	2000	0.53	0.798	
170.3	1998	0.54	0.848	Only North and Middle channels surveyed and used in comparison
178.4	--[d/]	--		No surveys subsequent to 1989; not used in comparison
183.2	--	--		No surveys subsequent to 1989; not used in comparison
189.3	--	--		No surveys subsequent to 1989; not used in comparison
199.5	2000	0.28	0.499	
203.3	2000	0.90	0.889	Only North channel surveyed and used in comparison
209.8	1998	0.42	0.652	
219.8	--	--		No surveys subsequent to 1989; not used in comparison
228.7	2000	0.72	0.825	

TABLE B3-2 (Continued)
RESULTS OF COMPARISON OF TRANSECT CROSS-SECTIONS WITH MODEL PREDICTIONS
PLATTE RIVER CHANNEL DYNAMICS STUDY

Transect Location[a/]	Survey Year Used in Comparison	Coefficient of Determination (R^2)[b/]	Slope of Best-Fit Line[c/]	Notes
237.5	--	--		No surveys subsequent to 1989; not used in comparison
244.0	2000	0.04	0.168	
250.5	1998	0.67	0.826	
258.3	2000	0.37	0.378	
310.2	1998	-0.24	-0.037	
325.0	--	--		No surveys; model results only
328.1	--	--		No surveys; model results only

[a/] Locations of channel transects indicated in river miles – miles along the river starting from the point of origin at the confluence of the Platte River with the Missouri River.
[b/] Coefficient of Determination or Correlation Coefficient is a measure of the degree of association between two variables (in this case, the surveyed elevation of the base of the channel at a station, and the model-predicted elevation of the base of the channel at the same location). The value of the coefficient of determination can range between 0.0 and 1.0 -- if there is no association between the variables, the value of the coefficient of determination is 0.0; perfect association is indicated by a coefficient of determination of 1.0.
[c/] Slope of Best-Fit Line is the slope of the calculated line that best describes (in the least-squares sense) the relationship between the actual and simulated elevations of the base of the river channel along each cross-section.

[d/] A dash (--) indicates that no comparison was made between surveyed transect elevations and model-predicted elevations, because survey information was not available.

The channel-base elevations calculated along each cross-section were plotted against the channel-base elevations surveyed along the corresponding transect (Figures B3-12 through B3-21). Plots of simulation results versus the actual values measured for the same variable at the same location in space and time are commonly-used modeling tools (e.g., ASTM, 1993; Spitz and Moreno, 1996), and are known as “quality plots.” Quality plots provide a visual means of evaluating qualitatively the degree of association between the configuration of the actual river channel and the calculated channel configuration generated during model simulations. Best-fit lines (in the least-squares sense) and the slopes of those lines were calculated for each quality plot, to provide a graphical indicator of the nature of the relationship between the actual channel configuration and the results of simulations for each channel cross-section.

Coefficients of determination also were calculated for the 10 cross-sections being compared (Table B3-2); these ranged from approximately zero (0.04 for the cross-section at river mile 244.0) to about 0.90 (for the cross-section at river mile 203.3), with 7 of the 10 comparisons having coefficients of determination less than about 0.55. This indicates that the elevations of the base of the channel calculated in model simulations are in relatively poor agreement with the elevations of the channel base surveyed along the actual transects. Visual inspection of the quality plots (Figures B3-12 through B3-21) confirms the relatively poor agreement between the actual channel configurations and the calculated channel configurations generated by the SEDVEG model during simulations.

RESULTS OF EVALUATION

Quality plots were prepared as a means of evaluating the degree of association and relationship between the surveyed elevations of the base of the Platte River channel at a series of stations along several transects, and the model-predicted elevations of the base of the channel at the same locations, along cross-sections corresponding to the transect locations. Coefficients of determination (“correlation coefficients”) also were calculated for the actual and simulated channel-base elevations along each transect and cross-section to enable the results of model simulations to be readily compared with actual surveyed elevations.

Visual inspection of the quality plots provide a means of evaluating qualitatively the degree of association between the configuration of the actual river channel and the calculated channel configuration generated during model simulations. Inspection of the quality plots (Figures B3-12 through B3-21) indicates that the actual channel configurations at the cross-sections simulated in the Platte River are not well duplicated by the calculated channel configurations generated by the SEDVEG model during simulations. This impression is confirmed by the coefficients of determination which were calculated for comparisons of the elevations of the low points of the channel calculated in model simulations at 10 cross-sections with the elevations of the low points surveyed along the actual transects (see Table B3-2). The coefficients of determination ranged from approximately zero to about 0.90, with 7 of the 10 comparisons having coefficients of determination less than about 0.55, indicating that the elevations of the base of the channel calculated in model simulations are in relatively poor agreement with the elevations of the actual channel base surveyed along the actual transects.

Furthermore, the slopes of best-fit lines calculated for each quality plot, which provide a graphical indicator of the nature of the relationship between the actual channel configuration and the results of simulations for each channel cross-section, were all less than one (also shown in Table B3-2), indicating that the model *invariably calculates channel degradation of greater magnitude than actually occurs*. This suggests that the SEDVEG model may be biased in its construction in such a way as to over-predict channel degradation. These results indicate that the SEDVEG model, in its current form, is not a reliable predictor of the evolution of fluvial channels, and in particular is not functional in simulating changes in the channel system of the Platte River.

BIBLIOGRAPHY

American Society for Testing and Materials (ASTM). 1993. *Standard Guide for Comparing Ground-Water Flow Model Simulations to Site-Specific Information*. ASTM. West Conshohoken, Pennsylvania. ASTM Standard D 5490-93.

Davis, J.C. 1986. *Statistics and Data Analysis in Geology*. John Wiley & Sons, Inc. New York, New York. 2nd ed.

Murphy, P.J., and T.J. Randle. 2001a. *Platte River Channel: History and Restoration.* U.S. Bureau of Reclamation and U.S. Fish and Wildlife Service. Draft. January.

Murphy, P.J., and T.J. Randle. 2001b. *Platte River Sediment Transport and Riparian Vegetation Model.* U.S. Bureau of Reclamation and U.S. Fish and Wildlife Service. Draft. January.

Rock, N.M.S. 1988. *Numerical Geology*. Springer-Verlag, Inc. New York, New York.

Spitz, K., and J. Moreno. 1996. *A Practical Guide to Groundwater and Solute Transport Modeling*. John Wiley & Sons, Inc. New York, New York.

FIGURES

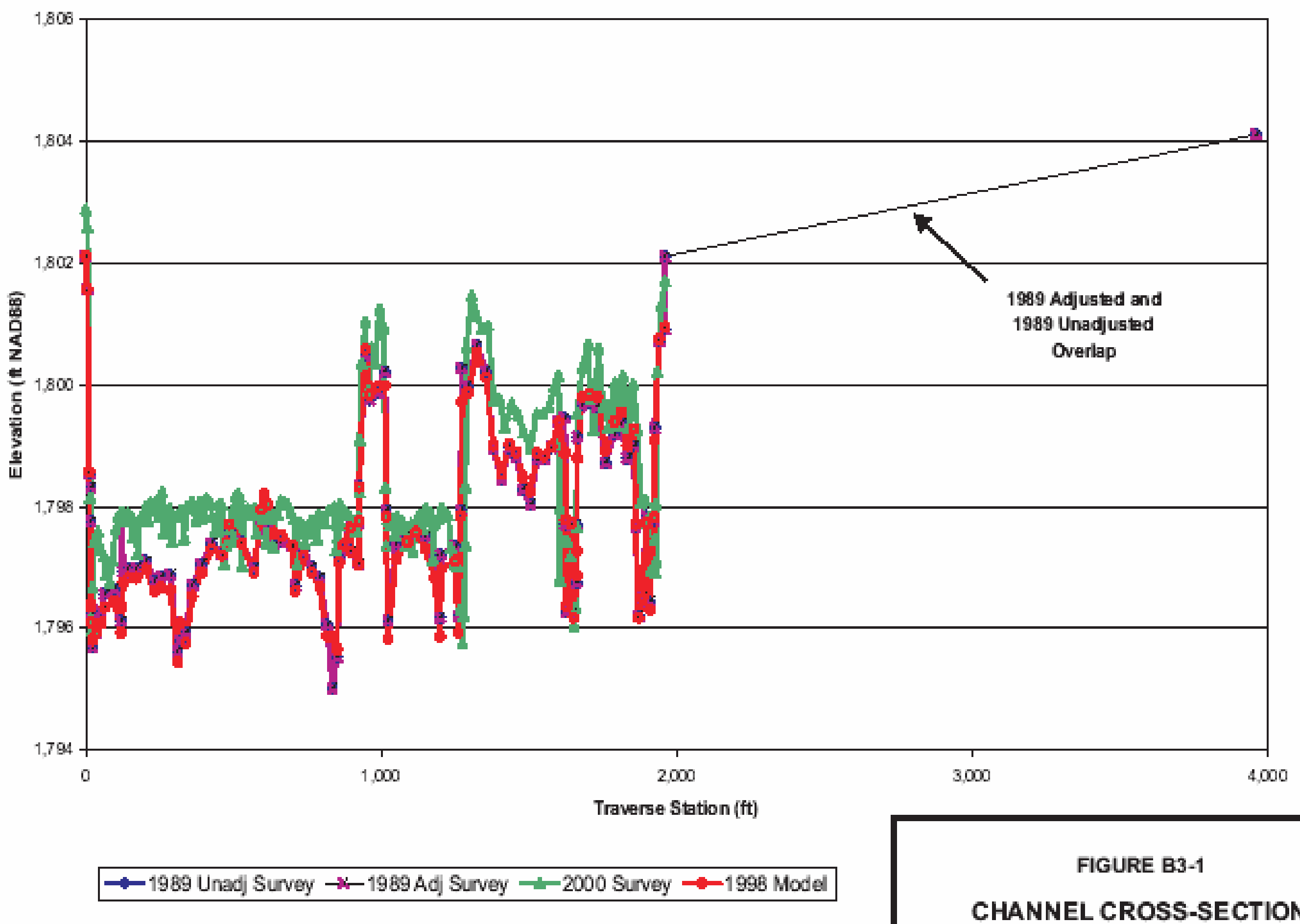


FIGURE B3-1

CHANNEL CROSS-SECTION
RM 162.2

Platte River Channel Dynamics Study

PARSONS
Denver, Colorado

draw\739921b.cdr pg3 bbs 2/5/02

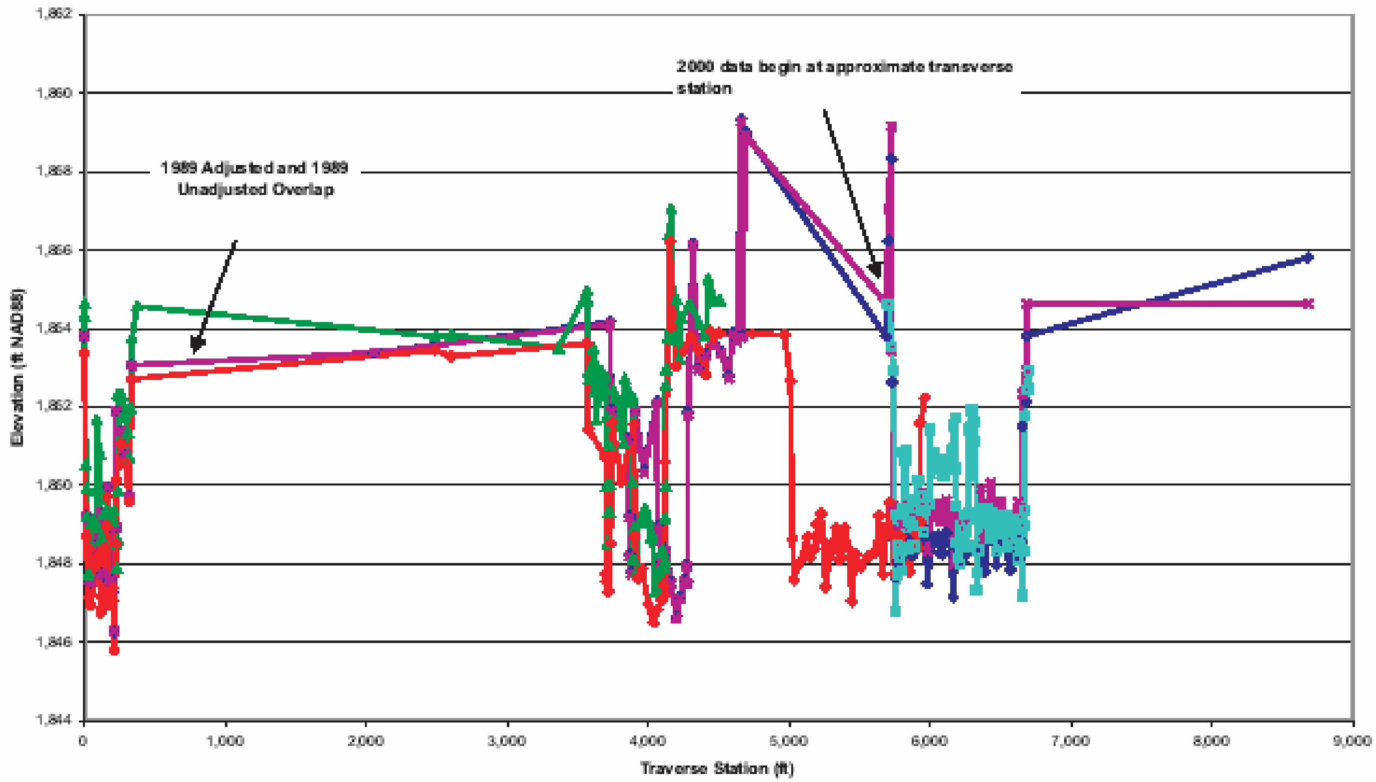


FIGURE B3-2

CHANNEL CROSS-SECTION RM 170.3

Platte River Channel Dynamics Study

PARSONS
Denver, Colorado

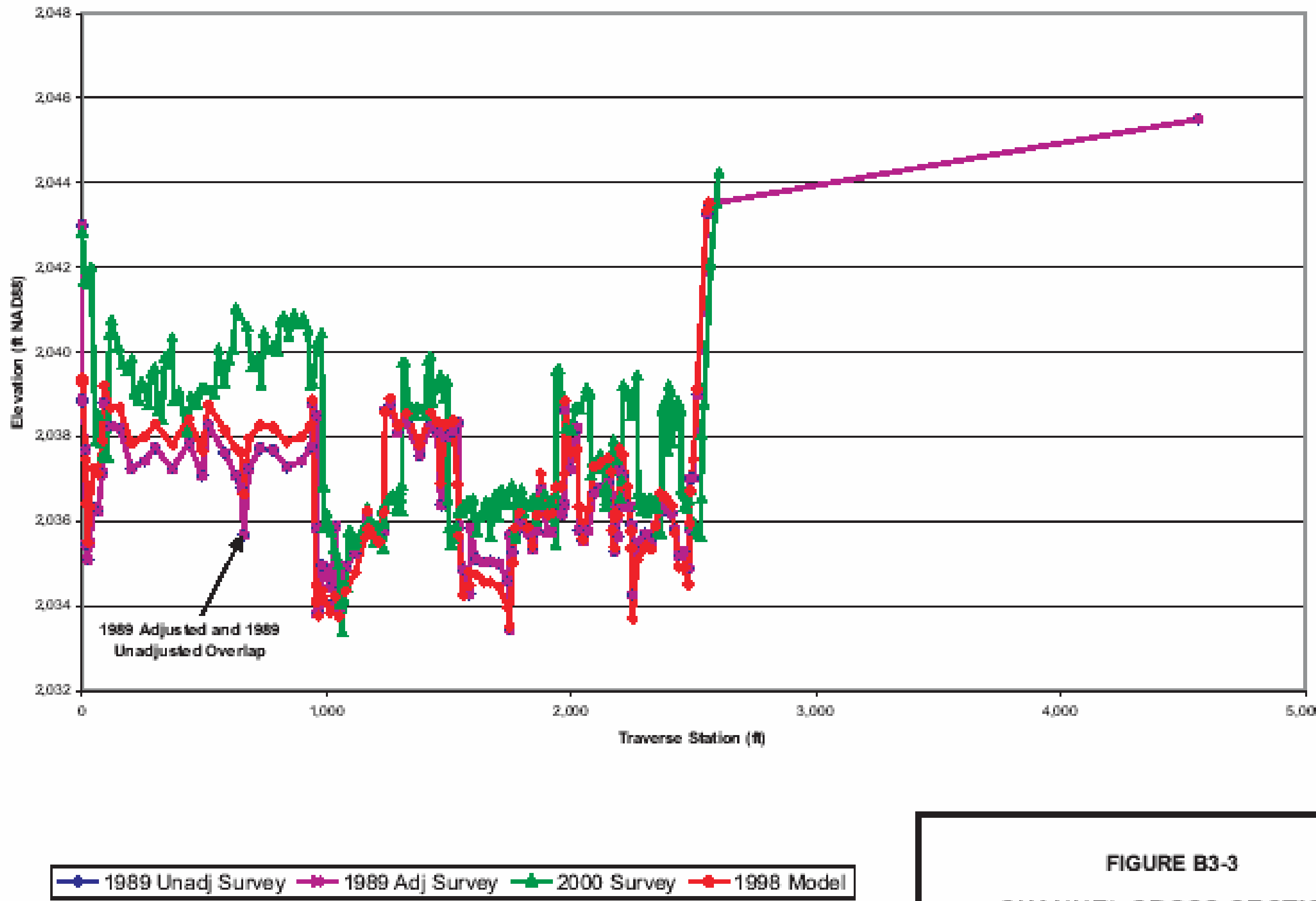


FIGURE B3-3

CHANNEL CROSS-SECTION
RM 199.5

Platte River Channel Dynamics Study

PARSONS
Denver, Colorado

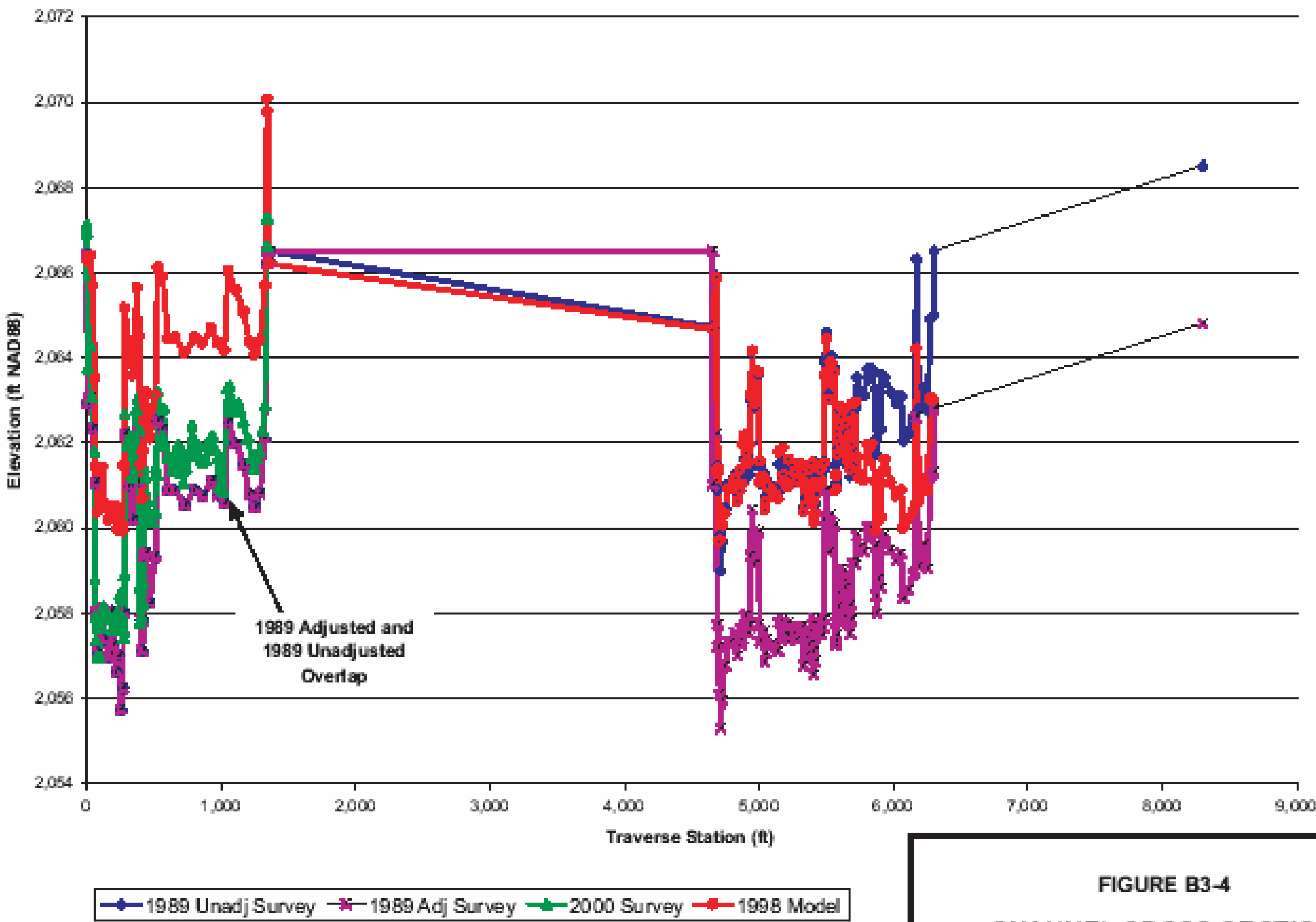


FIGURE B3-4

CHANNEL CROSS-SECTION
RM 203.3

Platte River Channel Dynamics Study

PARSONS
Denver, Colorado

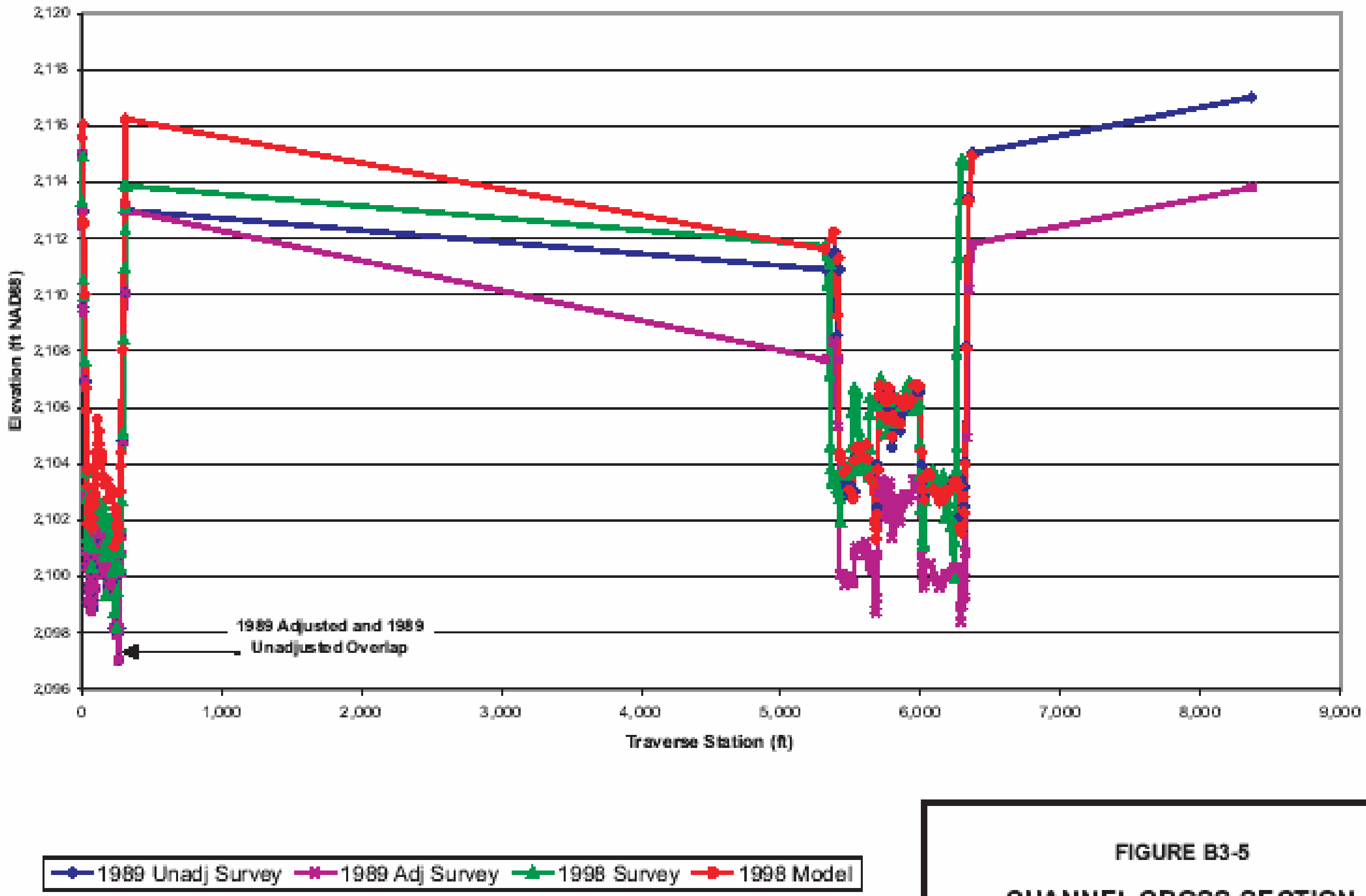


FIGURE B3-5

CHANNEL CROSS-SECTION
RM 209.8

Platte River Channel Dynamics Study

PARSONS
Denver, Colorado

draw/738921b.cdr pg7 bts 2/5/02

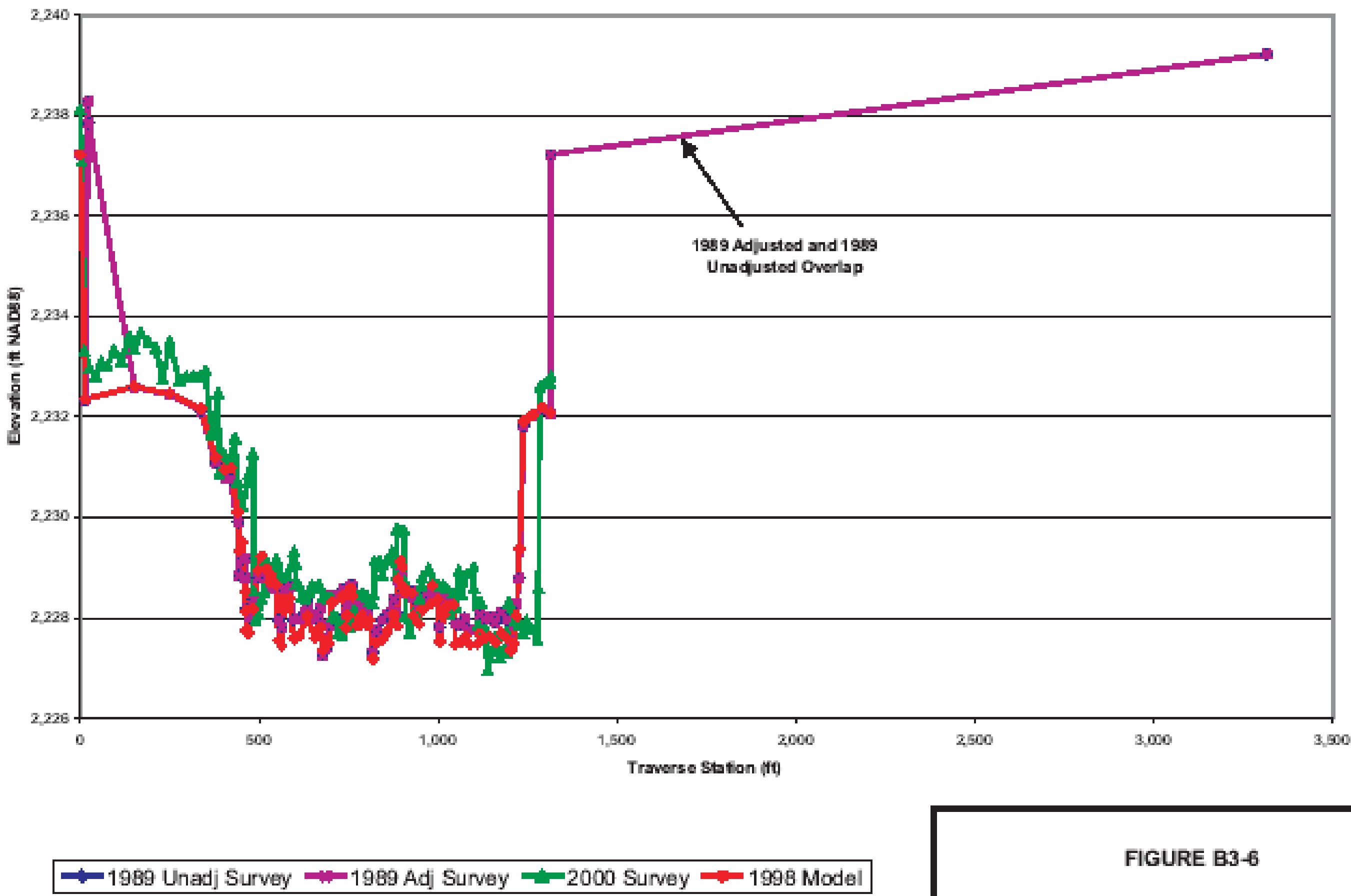


FIGURE B3-6

CHANNEL CROSS-SECTION RM 228.7

Platte River Channel Dynamics Study

PARSONS
Denver, Colorado

draw733921b.cdr pg8 bbs 2/5/02

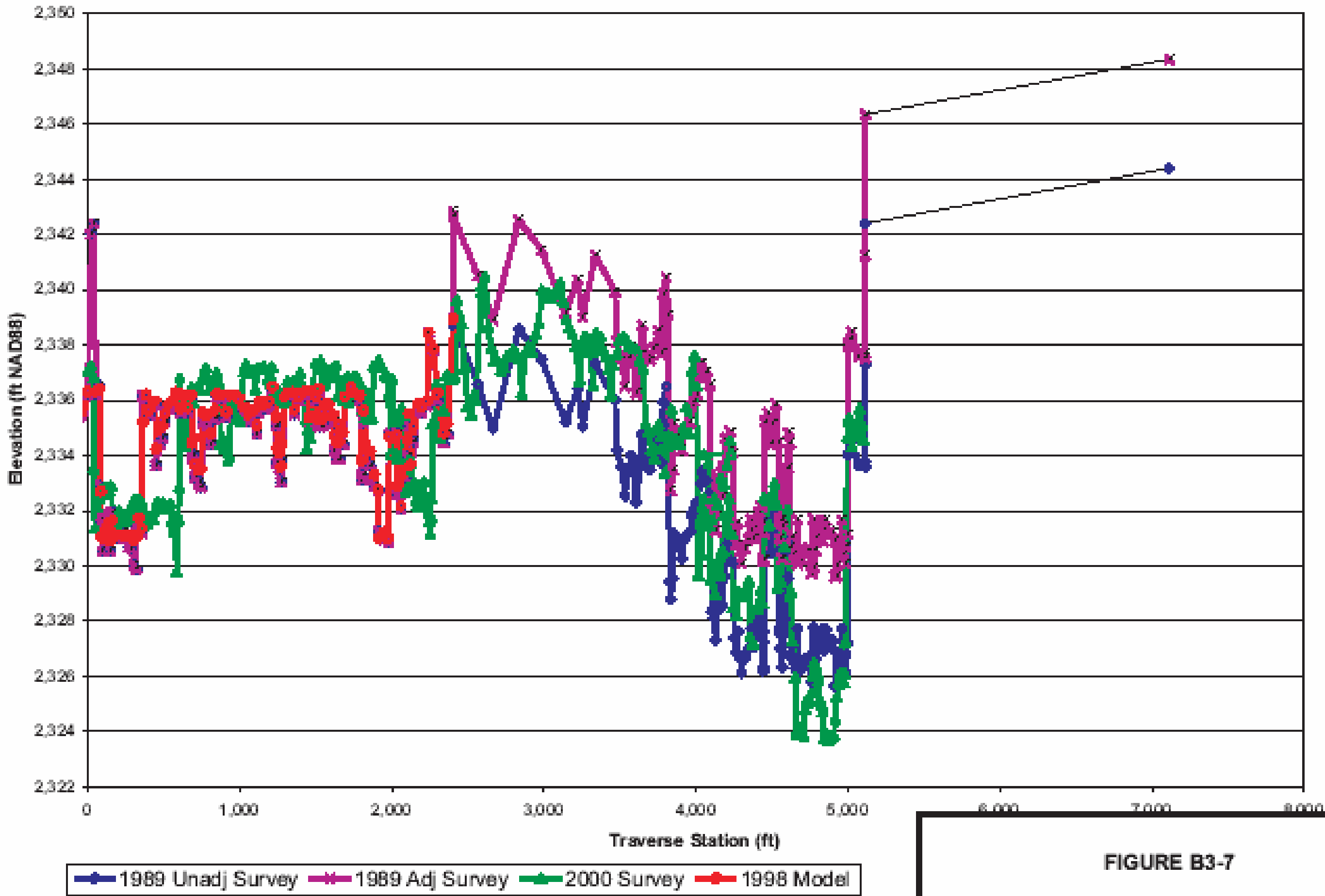


FIGURE B3-7

CHANNEL CROSS-SECTION RM 244.0

Platte River Channel Dynamics Study

PARSONS
Denver, Colorado

draw\739921b.cdr pg9 bbs 2/5/02

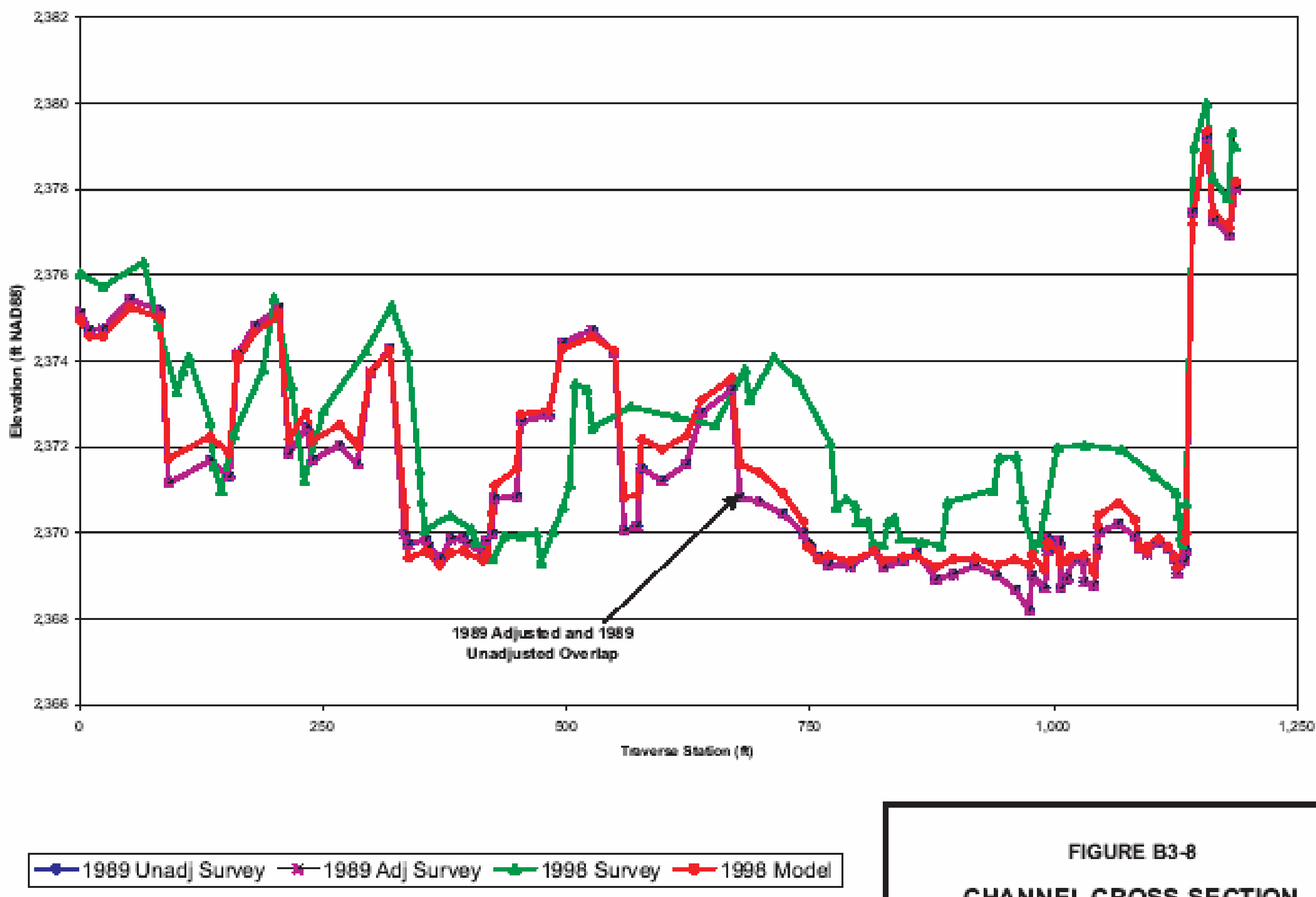


FIGURE B3-8

CHANNEL CROSS-SECTION RM 250.5

Platte River Channel Dynamics Study

PARSONS
Denver, Colorado

draw739921b.cdr pg10 bbs 2/5/02

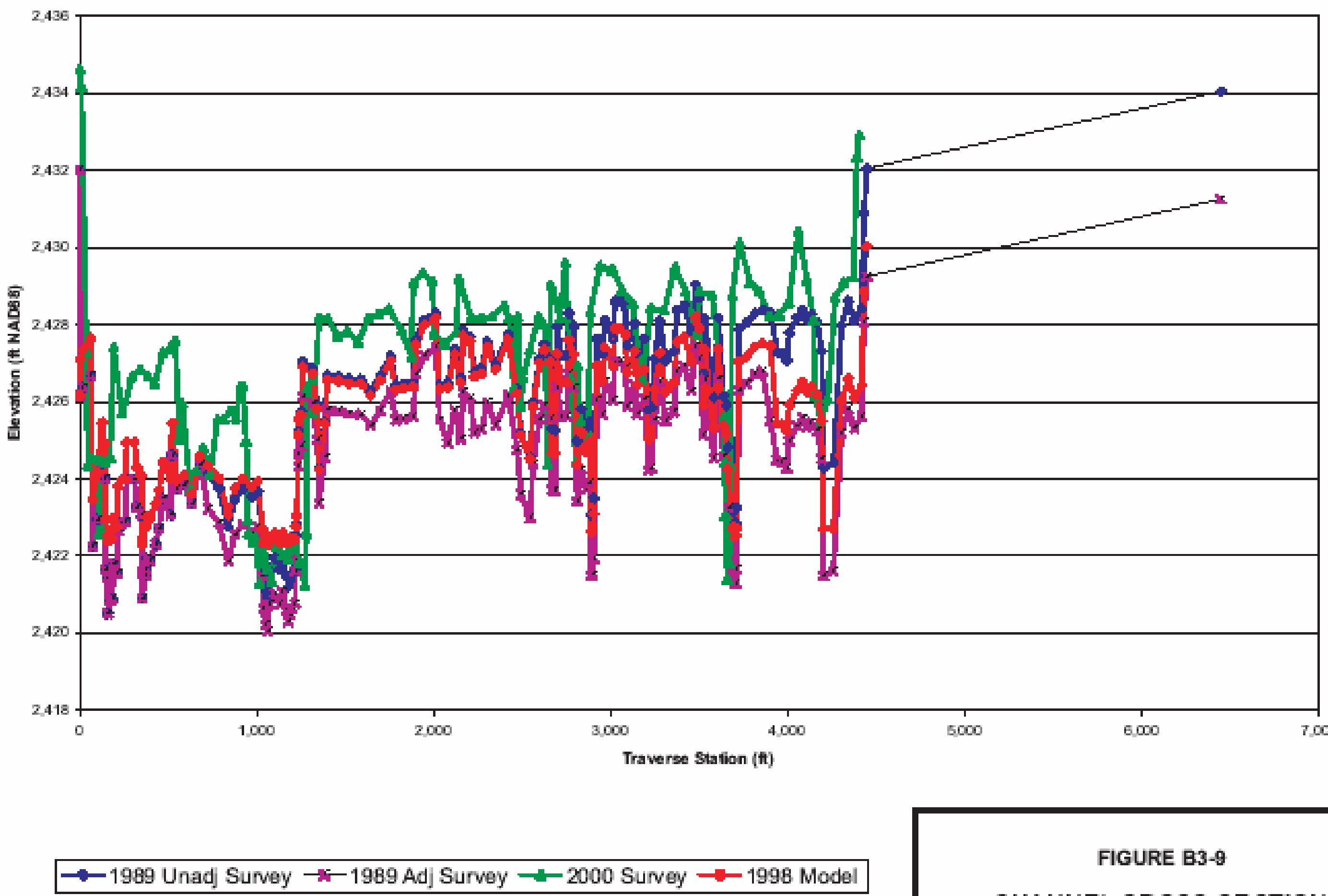


FIGURE B3-9

CHANNEL CROSS-SECTION
RM 258.3

Platte River Channel Dynamics Study

PARSONS
Denver, Colorado

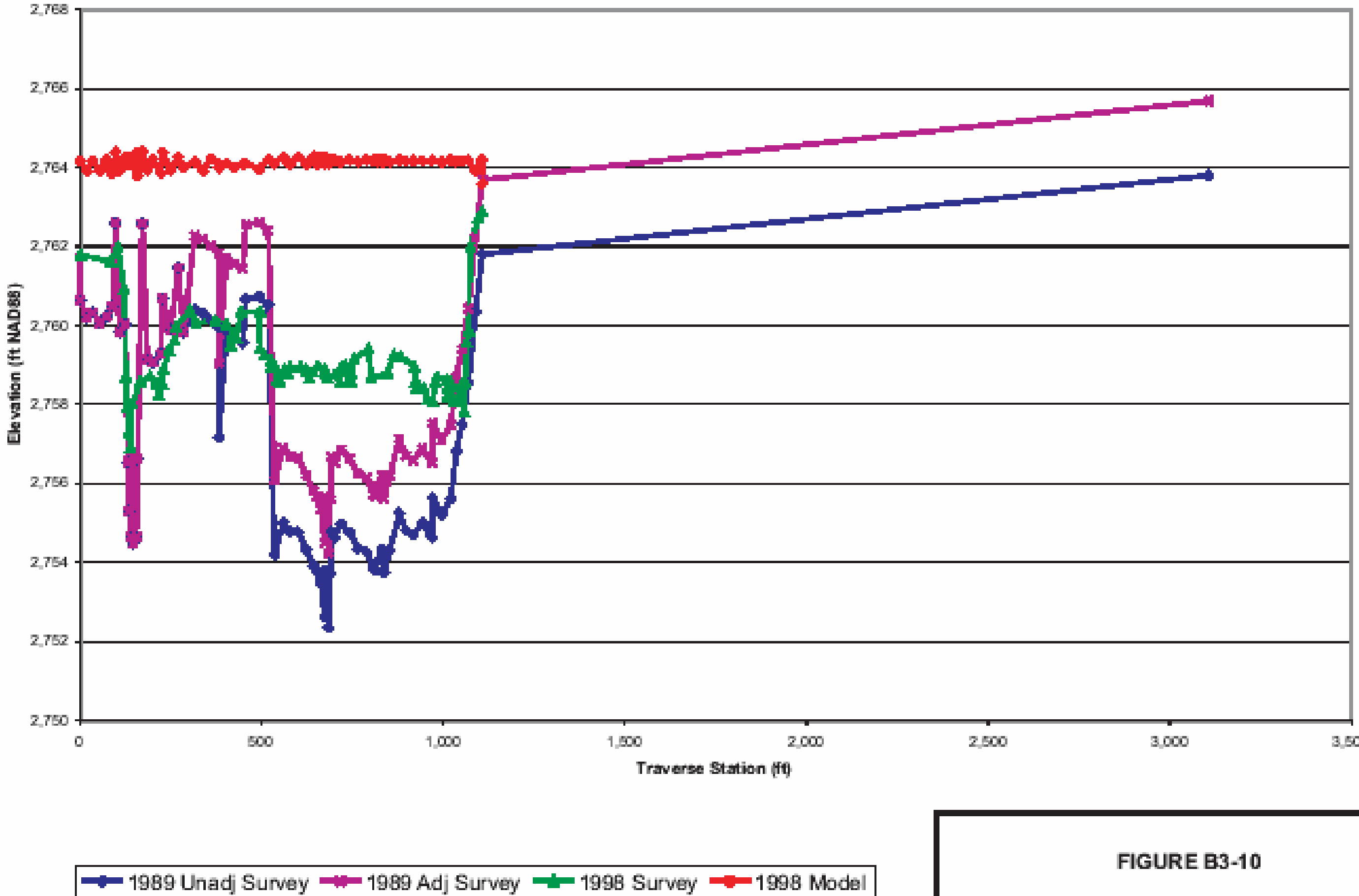


FIGURE B3-10

CHANNEL CROSS-SECTION RM 310.2

Platte River Channel Dynamics Study

PARSONS
Denver, Colorado

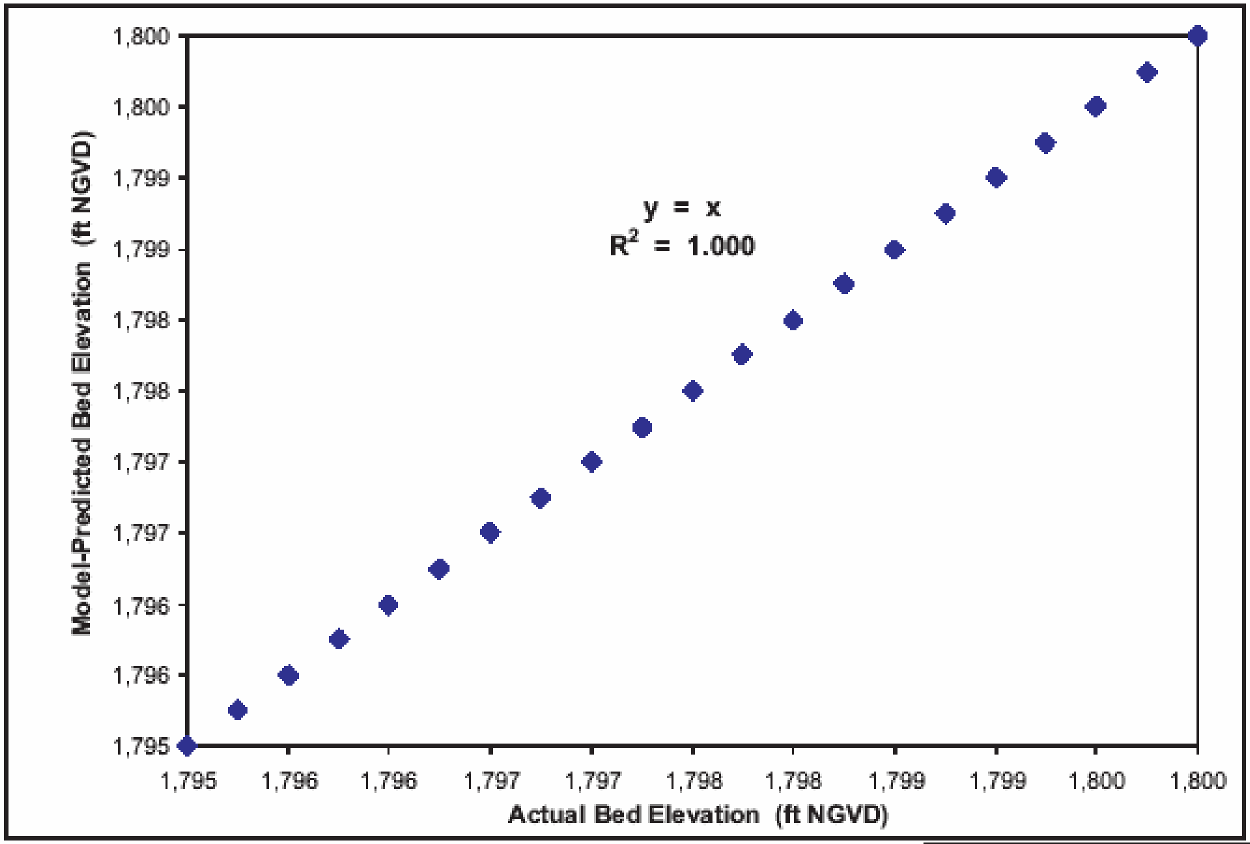


FIGURE B3-11

IDEALIZED QUALITY PLOT

Platte River Channel Dynamics Study

PARSONS
Denver, Colorado

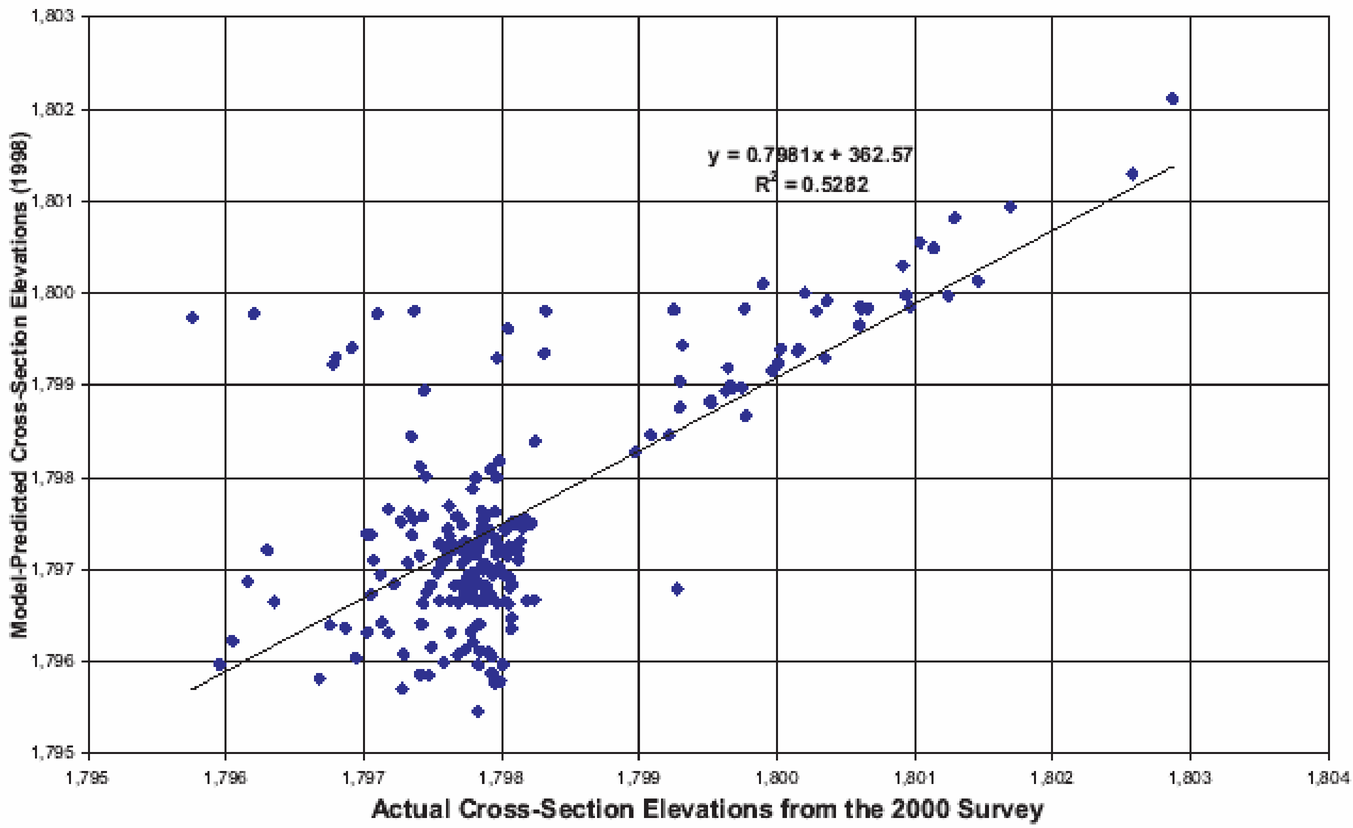


FIGURE B3-12

QUALITY PLOT FOR CROSS-SECTION RM 162.2

Platte River Channel Dynamics Study

PARSONS
Denver, Colorado

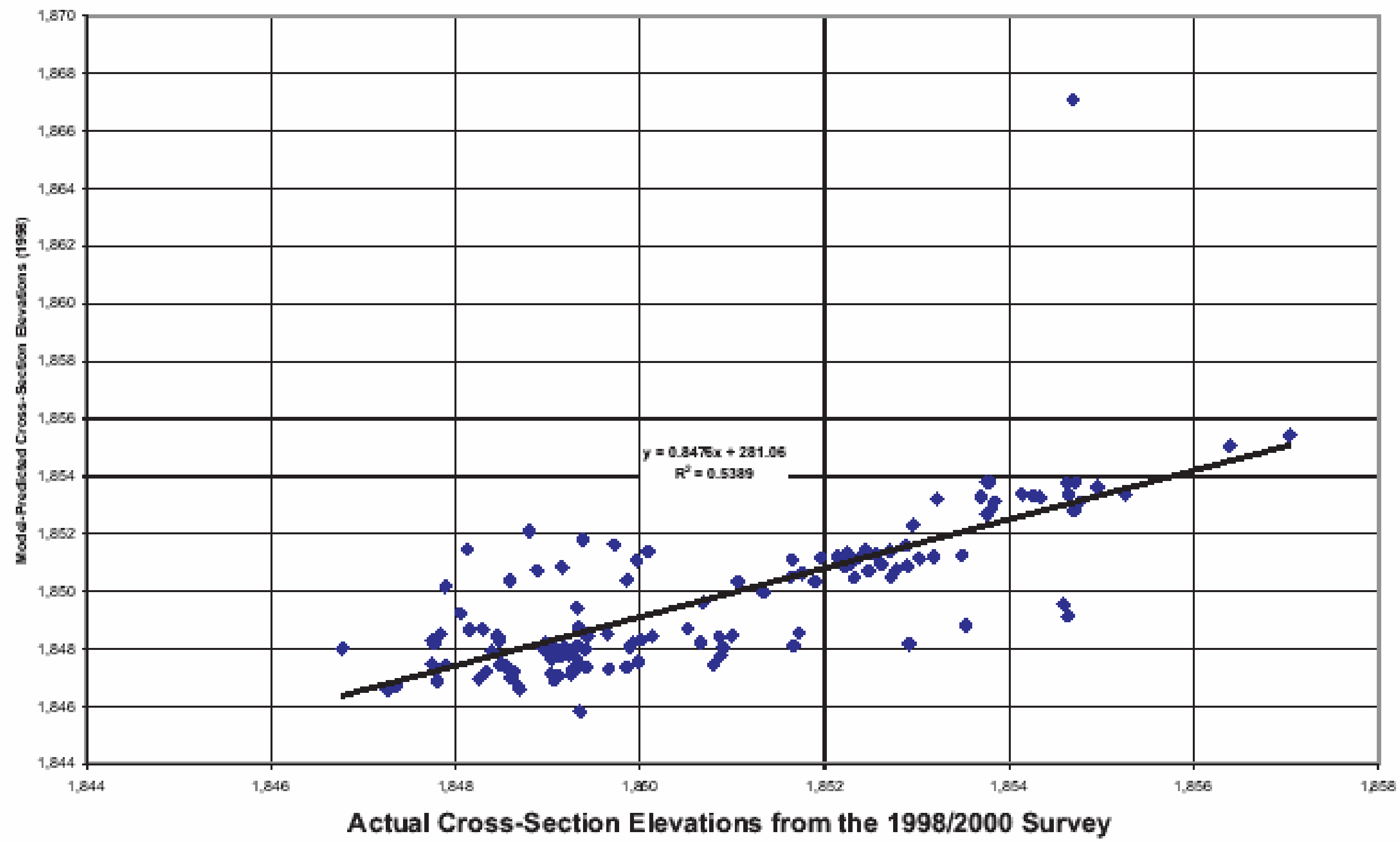


FIGURE B3-13

QUALITY PLOT FOR CROSS-SECTION RM 170.3

Platte River Channel Dynamics Study

PARSONS
Denver, Colorado

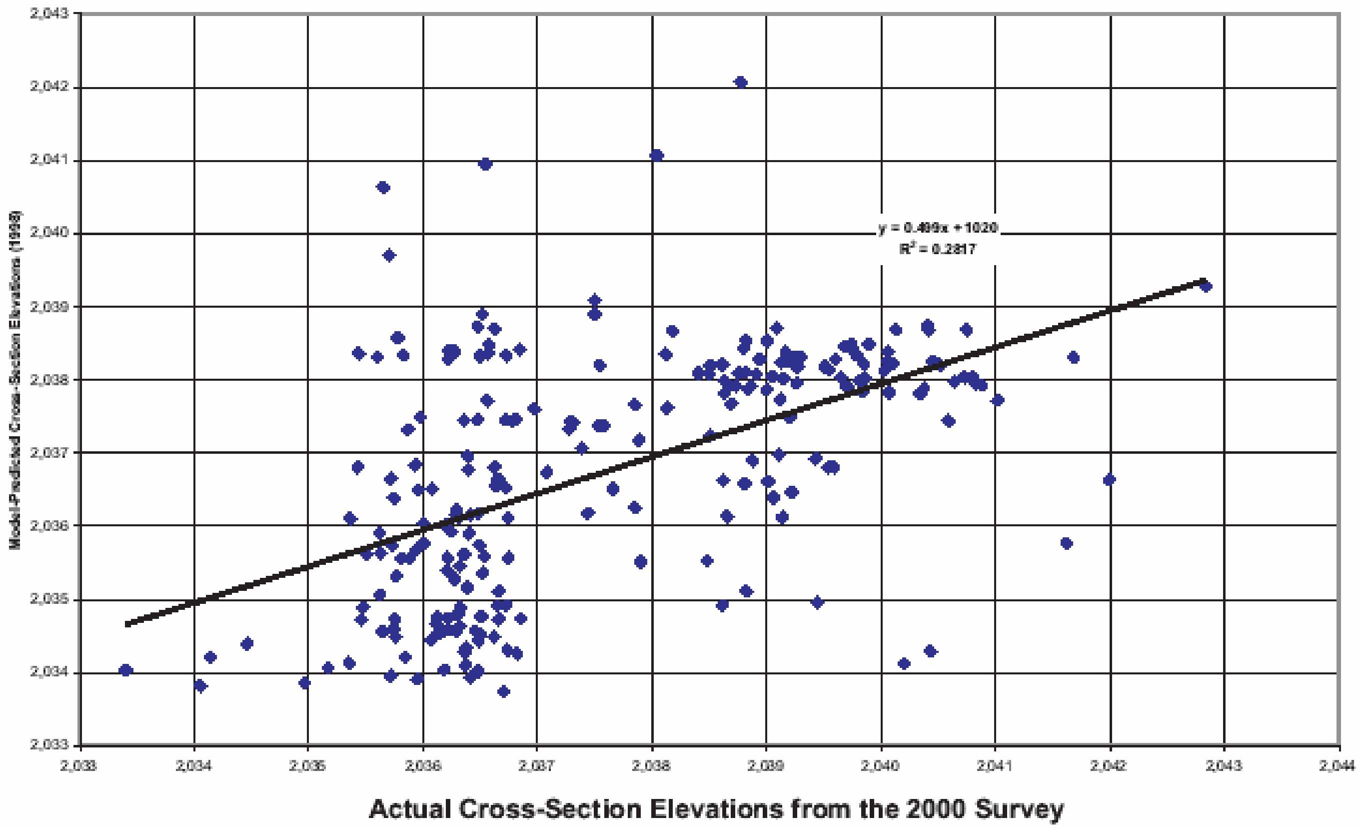


FIGURE B3-14

QUALITY PLOT FOR CROSS-SECTION RM 199.5

Platte River Channel Dynamics Study

PARSONS
Denver, Colorado

draw7392 1a.cdr pg8 bbs 2/5/02

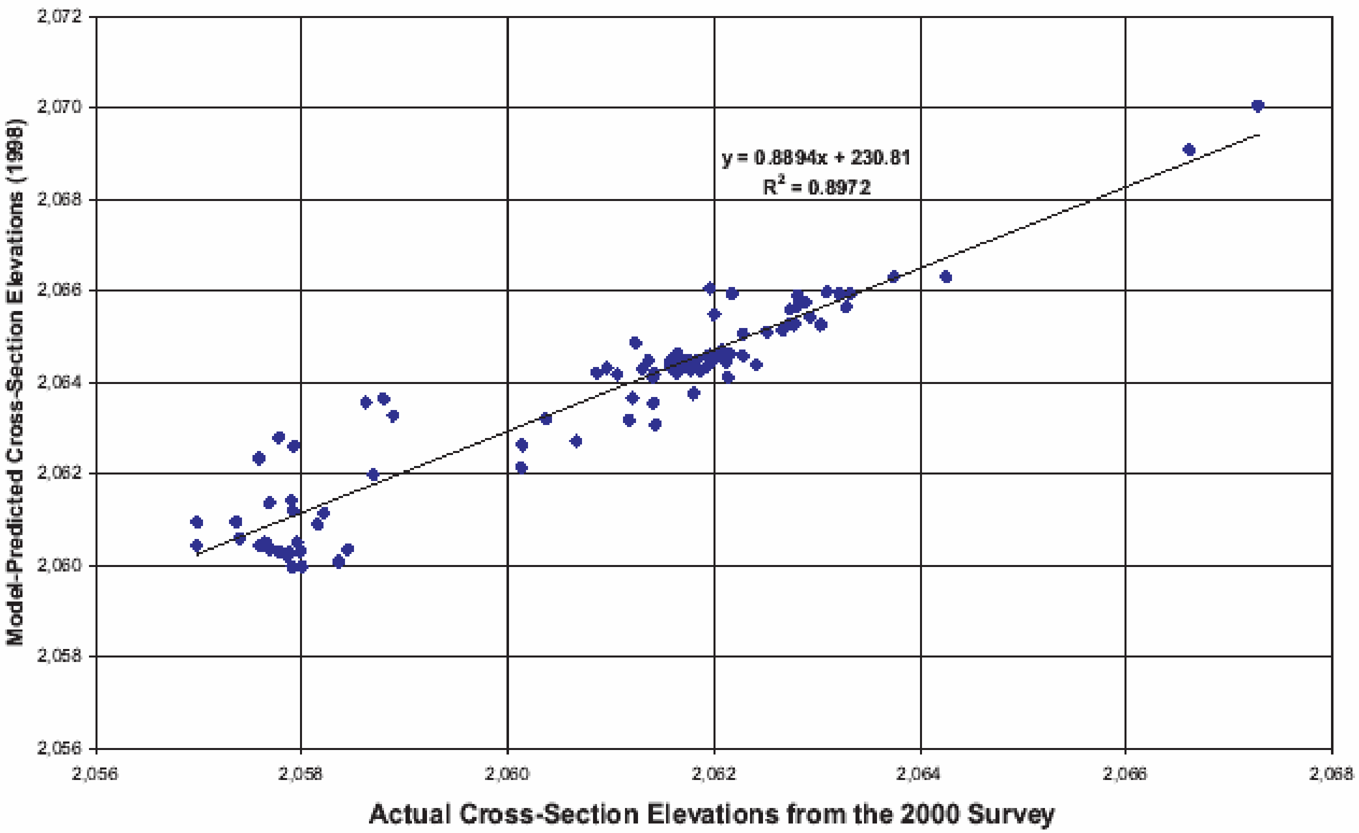


FIGURE B3-15

QUALITY PLOT FOR
CROSS-SECTION RM 203.3

Platte River Channel Dynamics Study

PARSONS
Denver, Colorado

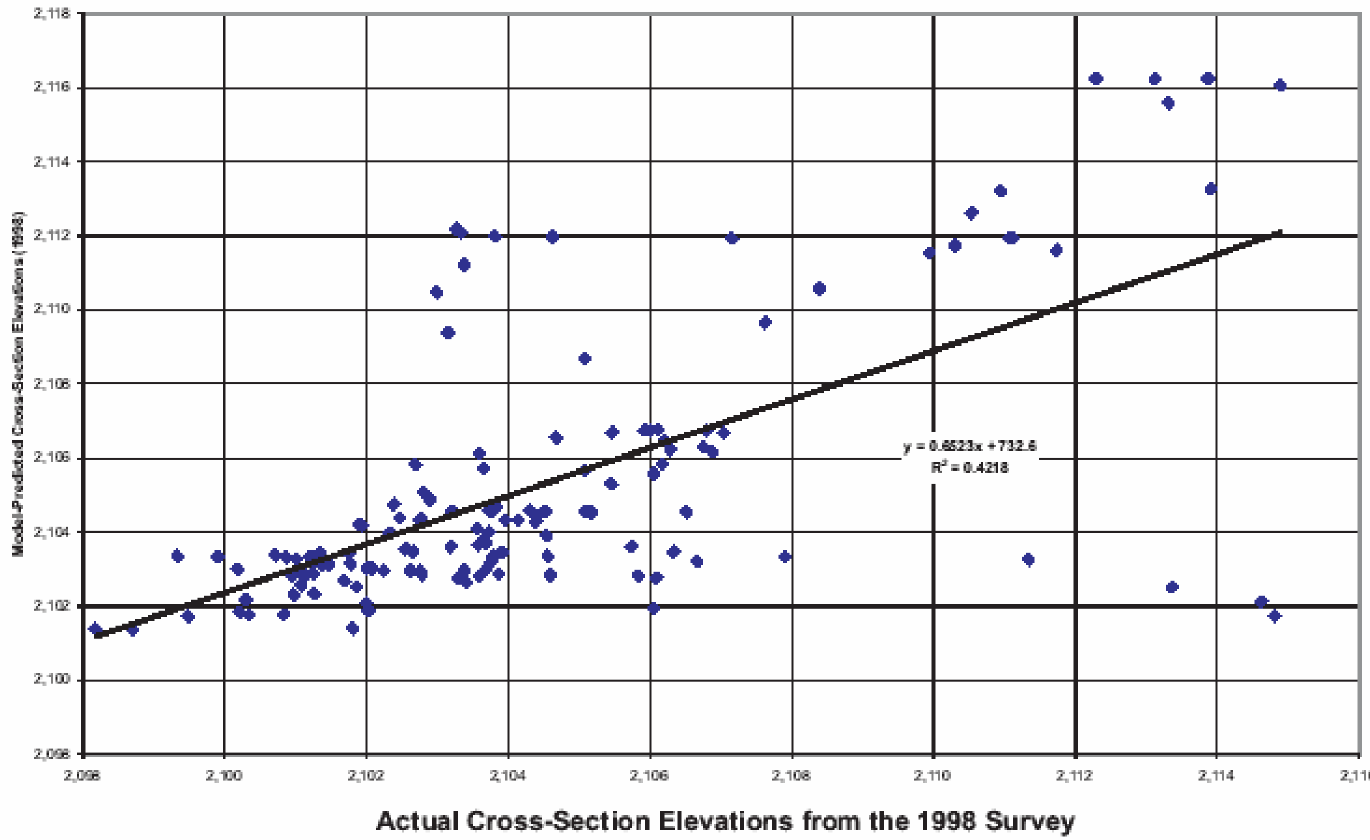


FIGURE B3-16

QUALITY PLOT FOR
CROSS-SECTION RM 209.8

Platte River Channel Dynamics Study

PARSONS
Denver, Colorado

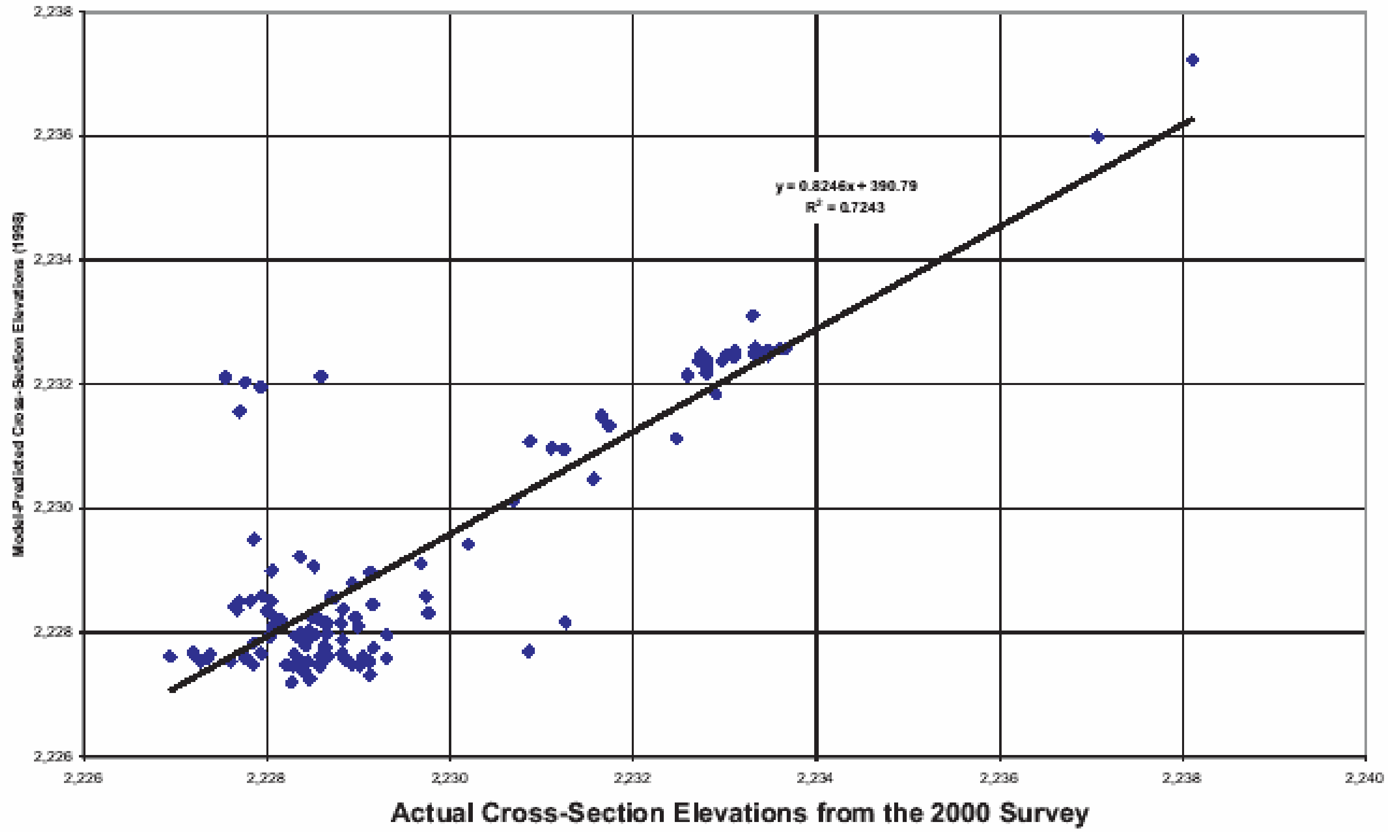


FIGURE B3-17

QUALITY PLOT FOR CROSS-SECTION RM 228.7

Platte River Channel Dynamics Study

PARSONS
Denver, Colorado

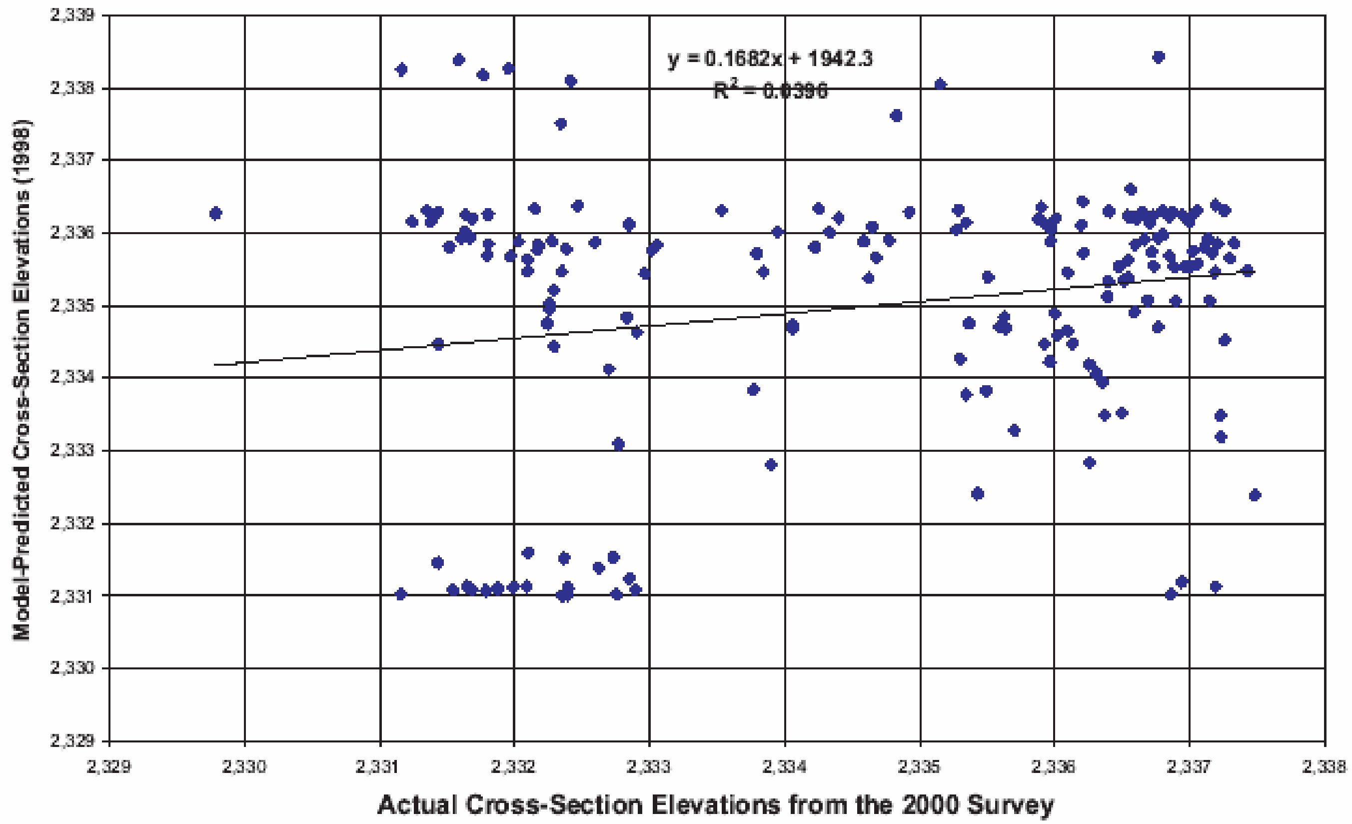


FIGURE B3-18

QUALITY PLOT FOR
CROSS SECTION RM 244.0

Platte River Channel Dynamics Study

PARSONS
Denver, Colorado

draw/739921a.cdr pg4 bbs 2/5/02

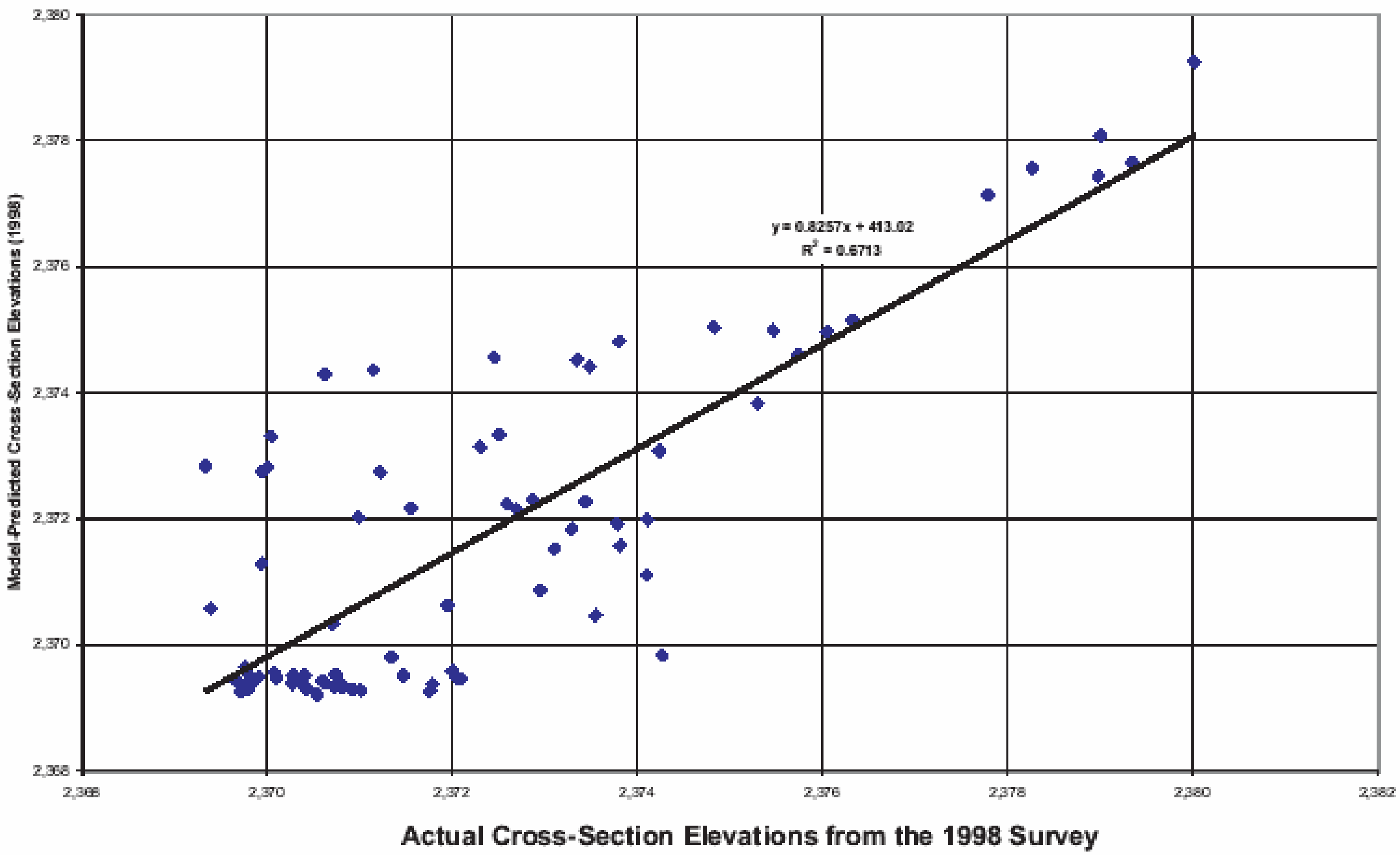


FIGURE B3-19

QUALITY PLOT FOR
CROSS-SECTION RM 250.5

Platte River Channel Dynamics Study

PARSONS
Denver, Colorado

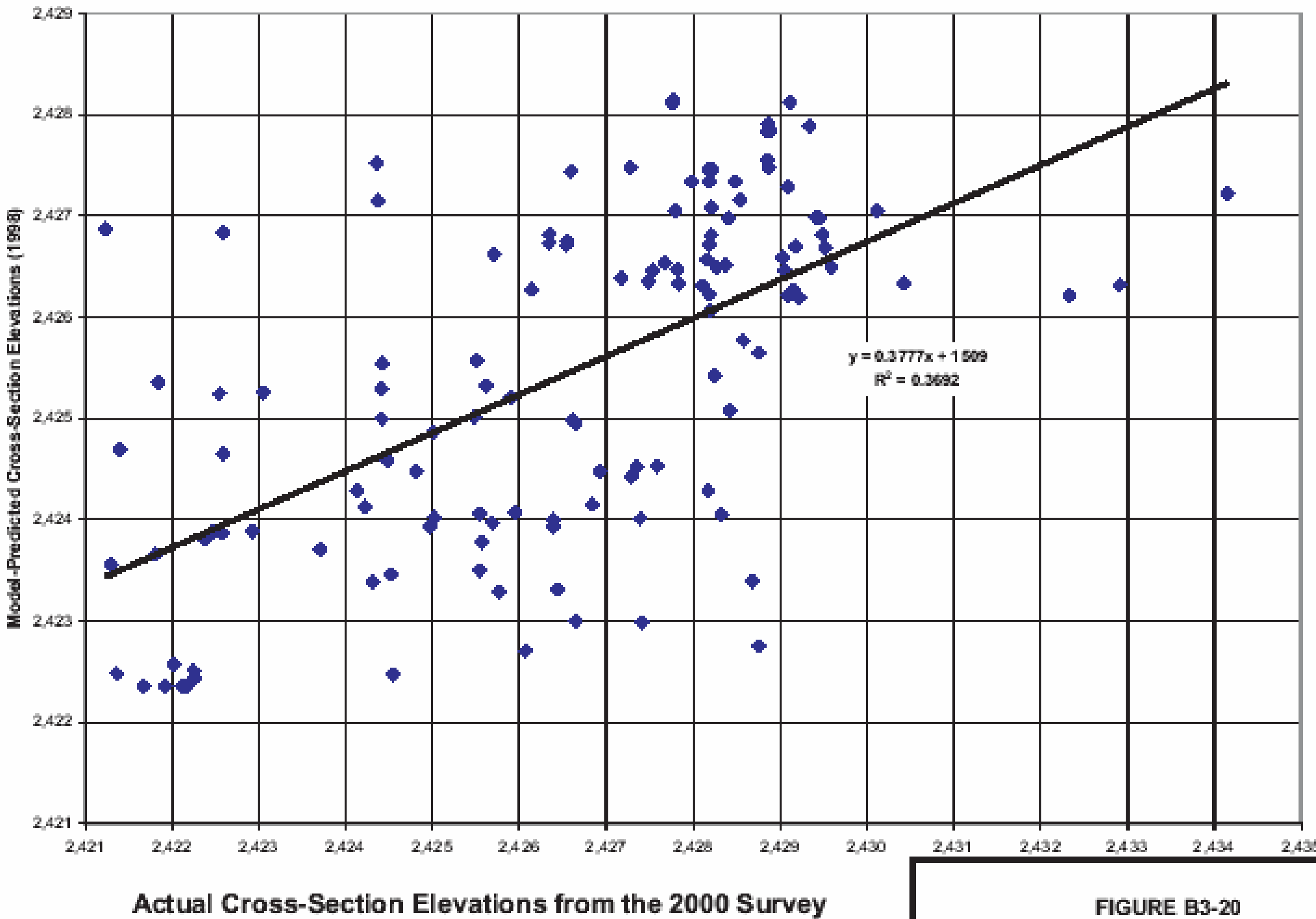


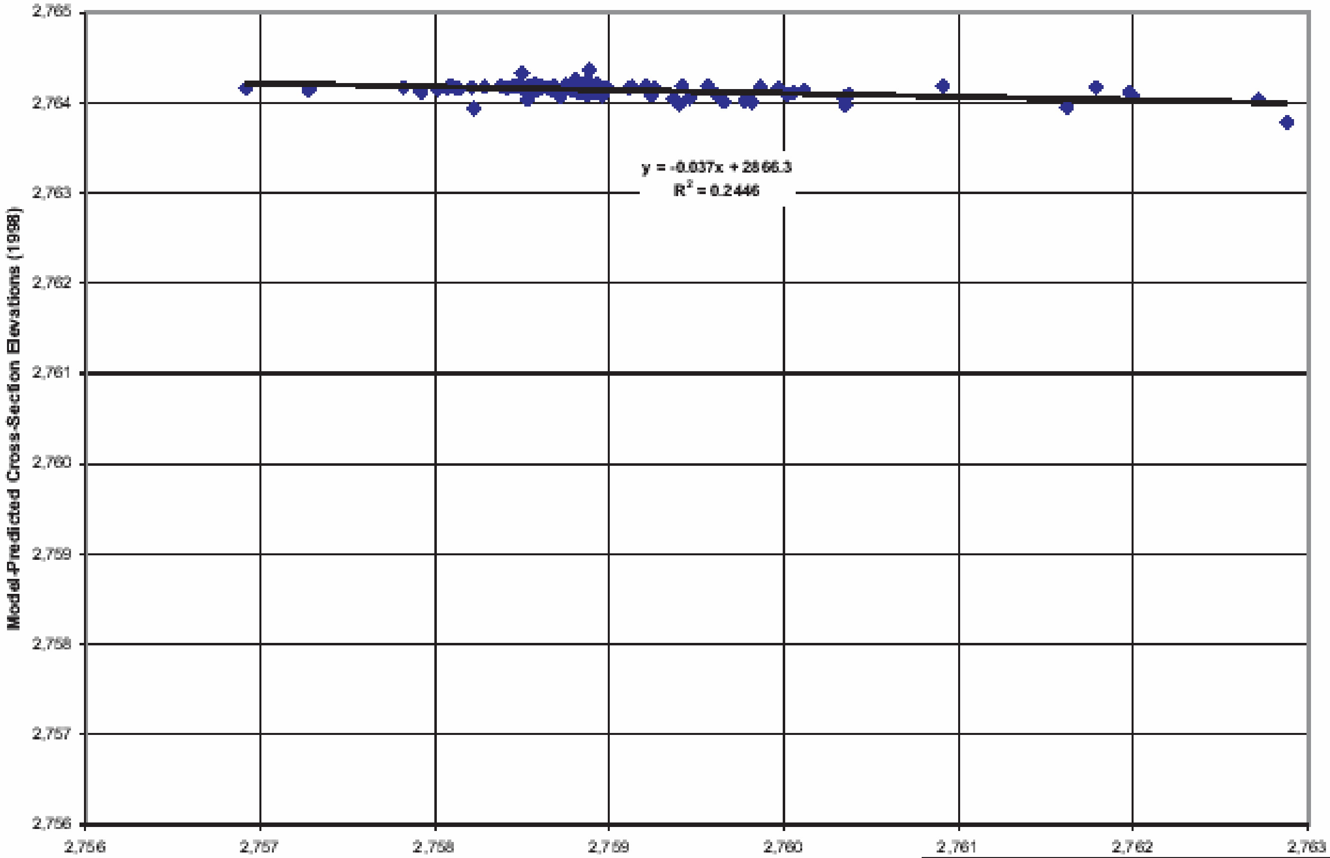
FIGURE B3-20

QUALITY PLOT FOR
CROSS-SECTION RM 258.3

Platte River Channel Dynamics Study

PARSONS
Denver, Colorado

draw\739921a.cdr pg10 bbs 2/5/02



Actual Cross-Section Elevations from the 1998 Survey

FIGURE B3-21

QUALITY PLOT FOR CROSS-SECTION RM 310.2

Platte River Channel Dynamics Study

PARSONS
Denver, Colorado

TECHNICAL MEMORANDUM

RESULTS OF INVESTIGATIONS C1 AND C2 - REVIEW OF ALTERNATIVE EXPLANATIONS FOR VEGETATION EXPANSION IN THE PLATTE RIVER AND EVALUATE "VEG" ASSUMPTIONS AND ALGORITHMS OF SEDVEG MODEL

PLATTE RIVER CHANNEL DYNAMICS INVESTIGATION

Prepared For

States of Colorado, Nebraska, and Wyoming

May 2003

Prepared By

PARSONS
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Denver, CO 80290

TECHNICAL MEMORANDUM

INVESTIGATIONS C1 AND C2 - REVIEW OF ALTERNATIVE EXPLANATIONS FOR VEGETATION EXPANSION IN THE PLATTE RIVER AND EVALUATE "VEG" ASSUMPTIONS AND ALGORITHMS OF SEDVEG MODEL PREFACE

The purpose of Investigations C1 and C2 was to review vegetation issues presented in two draft technical reports entitled "*Platte River Channel: History and Restoration*" (Murphy and Randle, 2001a) and "*Platte River Sediment Transport and Riparian Vegetation Model*" (Murphy and Randle, 2001b), prepared jointly by the U.S. Bureau of Reclamation (USBR) and the U.S. Fish and Wildlife Service (USFWS). The investigations address a number of technical issues regarding this subject which had been identified by the sponsors as needing detailed examination to allow them to make scientifically-based decisions regarding the Cooperative Agreement (CA) work products.

This document describes only the data collected, analyses made, and scientifically-supportable findings regarding the issues, written in a manner which generally follows the guidelines of professional journals of the respective authors' technical expertise. The relevance of the findings to the specific issues confronting the sponsors is discussed in each task memorandum, but only as far as the data and results are deemed by the author(s) to be scientifically supportable in resolving or illuminating the issue.

ISSUES AND PURPOSES OF INVESTIGATIONS

The technical evaluations completed by the Parsons team were conducted as a series of 14 complementary investigations divided into four categories that would address general issues identified by the three states. The following issue categories were identified:

- A: Questions Regarding Channel Narrowing or Deepening
- B: Questions Regarding Sediment Transport
- C: Questions Regarding Vegetative Expansion
- D: Questions Regarding Macro-Historic Natural Variability

This Technical Memorandum describes the results of two key issues regarding vegetation expansion. The first addresses the many theories that exist which could explain the far-reaching and extensive expansion of vegetation into the channels and floodplains, and the second is whether the assumptions and algorithms in the "VEG" component of the USBR SEDVEG model adequately replicate historic changes and whether it can be used for predictive purposes.

All task reports focus on three specific types of issues: 1) trends, 2) processes, and 3) cause-effect relationships. It is necessary to first identify current trends in key channel characteristics. Understanding processes that govern the interaction between flow, sediment, and vegetation provides a basis for development of appropriate restoration approaches. As cautioned in Simons & Associates (2000a), *". . . it is necessary to develop a sufficient understanding of the factors that may affect the morphology of the Platte River and associated vegetation. Without an understanding of the fundamental factors or causes of change, it is not possible to [*neither*] develop appropriate mitigation measures nor understand their effect."* Conducting investigations that answer key questions covering trends, processes, and the cause-effect relationships themselves will provide necessary information for the states to evaluate the EIS Team products.

Investigation C1 was scoped to provide a summary of factual evidence for and against the theories regarding the amount of vegetation present in the river in pre-development periods and possible reasons for expansion by vegetation into the meander corridor (see definitions in Task A3 report). Investigation C2 was scoped to evaluate the validity of the assumptions and algorithms built into the SEDVEG model regarding plant growth, desiccation, scouring of seedlings, and other processes. Because of the interdependence of these two studies, the methodologies and results of the investigations are combined in one report.

INVESTIGATION C1: REVIEW OF ALTERNATIVE EXPLANATIONS FOR VEGETATION EXPANSION IN THE PLATTE RIVER

Many theories have been promulgated regarding the amount of vegetation present in the river in pre-development periods and possible reasons for relatively recent expansion by vegetation in the corridor. These include reductions in peak flow rates, changes in sediment size, reductions in buffalo herds, control of range fires, harvesting by pioneers, etc. An extensive body of literature exists on this subject. Several of the publications are comprehensive assessments, listing all the probable causes and providing the historical and factual evidence supporting or refuting each.

Two single-factor theories dominate the Platte River literature to explain the rapid vegetation expansion during the 20th century. These are: (1) *the desiccation theory* — that trees largely were restricted from growing in the Platte River because the river dried up in summer of most years and any young tree reproduction would die of drought stress; use of the modern river as a conduit for irrigation water has converted the river to a perennial stream more favorable for tree reproduction, and (2) *the scouring theory* — that the pre-development river scoured tree seedlings from the bed during high snowmelt periods; reduction of peak flows in the modern river has reduced scouring, increased tree seedling survival in the riverbed, and allowed woodland expansion into formerly unvegetated channels.

Neither theory alone is sufficient to explain the historic patterns of woodland expansion in the central Platte River. The desiccation theory is deficient as a single-factor explanation for several reasons. First, the field notes from land surveyors strongly indicate that the central Platte River did not often dry up in summer. Nearly all notebook entries referred to a river with shallow, but swift-flowing water (Johnson, 1994). Thus, a dry riverbed could not have been the cause of the presumed scarcity of trees in the pre-development river. Second, even if the riverbed had become dry in the summer of most years prior to white settlement, this may have limited new seedling growth, but may not have limited established tree and shrub growth. The large surface aquifer supporting the river at that time would have sustained the groundwater table, providing a reliable and shallow source of water available to the roots of established trees (Johnson, 1994). Third, the assumption itself that trees were scarce in the central Platte River appears to be false. Johnson and Boettcher (2000) found considerable support for the Platte as a wooded river prior to white settlement; however, soldiers, settlers, and railroad woodcutters had largely depleted the natural woodlands by the 20th century.

Desiccation of the riverbed may have been a more significant factor in limiting trees farther west along the South Platte River, as suggested by Nadler and Schumm (1981). The more arid climate (lower humidity and lower rainfall) of the South Platte River may have allowed more frequent no-flow periods in the river and produced deeper shallow aquifers along the river. Desiccation has been observed to be a mortality factor for tree seedlings in the central Platte River during late spring and summer (discussed below), but it is only a minor factor compared to ice, scouring, and sedimentation (Johnson, 2000).

The scouring theory likewise fails as a single factor to explain vegetation expansion. Currier and Davis (2000) use the scouring theory to argue that the central Platte was a prairie river, not a wooded river. However, large trees and willow shrub were a natural part of the presettlement central Platte River and persisted under the presettlement hydrological regime. Thus, the interpretation that the Platte River was inherently inhospitable to trees because of severe flooding and sedimentation is incompatible with the evidence presented in Johnson and Boettcher (2000).

The scouring theory fails to adequately consider the effect of flow on cottonwood and willow recruitment during the realatively short germination period centered in June. A strong, statistically-significant relationship was found between past June flow and historic rates of woodland expansion in the Platte River (Johnson, 1994). This suggests that flow reductions, largely in June, caused either by climate cycling (see Task A3 and D1/D2 reports) or by upstream storage, have improved the conditions for tree recruitment and initial seedling survival.

Thus, the most quantitative, statistically-significant results available support a multi-factor explanation for woodland expansion, with increased recruitment given the highest weight, followed by reduced scouring and sedimentation (geomorphic action).

A fourteen-year study of tree reproduction and survival in the Platte River (Johnson 2000) identified additional short-term factors that can be important in certain years. The study was initiated in 1985 at two sites near Shelton and Odessa, Nebraska. Seedling mortality was caused by two main factors: summer flow pulses from thunderstorms and moving ice in winter. In the former, short pulses of 3,000-4,500 cubic feet per second (cfs) removed or buried most young-of-the-year seedlings from sandbars. In several instances, these small peaks removed nearly the entire annual cohort of tree seedlings river wide. In the latter, ice was a significant mortality factor in more years of the study (average of 8 of 10 years). A third short-term factor is desiccation mortality. In approximately 2 of 10 years, the combination of summer climatic drought and low flow cause significant mortality of tree seedlings, particularly on high sandbars. Drought mortality was substantial in 1987, 1988, and 2002.

The rapid rates of woodland expansion in the Platte River, characteristic of the first half of the 20th century, have not continued to the present. Johnson (1994) determined from measurements on aerial photographs that approximately half of the unvegetated channel area present in the late 1930's had succeeded to woodland by the late 1950s, but that woodland and unvegetated channel area had been in approximately balance since the 1960s. This led Johnson (1994) to hypothesize that most reaches of the river had reached a dynamic equilbrium with respect to the balance between woodland and unvegetated channel. This is especially well-documented in the Task A3 report. It should be noted that even vegetation expansion cannot be determined from aerial photography, and that all that can be seen is the canopy. Canopy area can increase (i.e., the trees and shrubs become larger), but actual number of plants can remain the same.

The current dynamic equilbrium between unvegetated and woodland channel is maintained by a complex interaction among the above factors: June flows control overall tree reproduction; late summer rainstorms and undiverted irrigation water sometimes create small pulse flows in the river that kill most first tree seedlings; large spring/summer flows such as the 1995 flood, kill young tree seedlings, but few of those greater than 3 years old; weather extremes (low flows, low rainfall, high air temperatures) occasionally kill tree seedlings on high sandbars; ice is now responsible for removing the largest number and size of tree reproduction (Johnson 1994, 1997, 2000).

The causes of past vegetation expansion and the factors that now maintain a dynamic equilbrium between woodland and unvegetated channel are well-studied and well-understood. While there always is more to be learned about these relationships, they are sufficiently known and understood to design and carry out successful flow experiments to manage vegetation in the river, should that be desired.

TASK C1 CONCLUSIONS

If Murphy and Randle (2001a) is to be used as the foundation for making decisions regarding the future management of the Platte River, considerable improvement is needed in understanding the physical processes that have resulted in vegetation expansion as follows:

1. Additional expertise needs to be included on the USBR team to develop a more complete ecosystem view and to expand the analysis from a single-cause approach to the complex interaction of factors listed above. Experts in aquatic avifauna, hydrology, and riparian vegetation are needed to join the sediment engineers who drafted the SEDVEG model and the original white paper. This will create a team able to address the main components of the Platte River ecosystem. Paramenters that will be used in the SEDVEG model (see C2 investigation below), such as types of indicator species, mortaility rates, and growth rates, need to be scientfically-researched and agreed upon by the biological experts.

2. Much of the literature reviewed in the white paper is only tokenly cited (i.e., the citations lack depth and often fail to report the main findings of the study). The findings of Simons and Associates (2000) are not reported accurately. Use of the original papers is preferred over lump-citing Simon's assessments of these papers.

3. The research cited in the white paper is all given equal weight. Reports that are not strictly peer-reviewed seem to be given the same emphasis as those that appear in reviewed journals with strict approval requirements. The white paper should discuss how the wide range of depth, quality, and degree of peer review within the body of literature was handled.

4. The white paper fails to review all sides of the various geomorphologic issues on the Platte River. For example, effects of climate are disregared (see Task Report D1/D2) and the concept of dynamic equilibrium between unvegetated channel and vegetation (see above) is scarcely mentioned, as is the variability of the Platte channel and slope and possibly severe disregard of the local effects of oversupply of sediment downstream of devegetated river sections.

5. The controversy over whether the Platte was a wooded or prairie river should be reported in the white paper (see Johnson and Boettcher, 2000 and Currier and Davis, 2000). Defining the "target" of restoration/rehabilitation efforts requires accurate reconstruction of pre-settlement or pre-development woodland conditions. As shown in the Task D1/D2 report, use of the unnaturally high flows around 1900 as a "target" of baseline hydrology is also inappropriate.

6. The effects of dams and diversions attenuate downstream on all rivers, and in most cases is limited in extent. Extensive and far-reaching (below the structures) adjustments of vegetation in the entire river are not logically or scientifically affiliated with the storage and diversion projects (see Task D1/D2 report).

7. The authors of the white paper have not made a very strong case for channel degradation/incision caused by sediment undersupply except in local areas associated with dams and diversions (see Task B1-B3 reports).

8. The effect of peak flows alone on the channel and its vegetation are significantly overemphasized in the white paper. As noted in the Task A3 report, peak or high flows are mentioned 61 times in the 23-page document. The Platte River is shaped by all of its flows: low flows allow plant reproduction; moderate (effective) flows shape the channel and are often sufficient to prohibit plant reproduction in the channel, remove or bury young seedlings, and undercut vertical banks; and high flows restructure the floodplain by redistributing sediment and removing plants on lower surfaces (see discussion above).

9. Tradeoffs associated with conversion of woodland to open channel are not reported or discussed in the white paper. These could include downstream oversupply of sediment, weed proliferation, loss of habitat for terrestrial species, among others.

10. The relatively high flows from 1993 to 1999 in the Platte River may have provided a clue about the response of the channel to flow augmentation. Have careful measurements of erosion and channel width/area been made during this period? If so, they should be reported or considered as a topic of needed research.

INVESTIGATION C2: EVALUATE "VEG" ASSUMPTIONS AND ALGORITHMS OF SEDVEG MODEL

The development and calibration of a model to simulate channel morphology and vegetation expansion in the central Platte River may turn out to be a worthwhile project. Models of this type allow integration of the numerous factors known to be influential in channel and vegetation dynamics. The formula for success of ecological models usually includes the following characteristics:

- At least several years are required before a model is ready for peer-review;
- The model is developed by a multi-disciplinary team of scientists with intimate knowledge of the ecosystem to be modeled;
- Considerable data are needed both for development and testing; and
- Extensive testing and peer-review are required before such models are seen as reliable in addressing environmental policy.

SEDVEG does not yet meet these guidelines/characteristics. However, by attention to the following suggestions and recommendations, it may become an important tool in the future management of the central Platte River.

Input Parameter Estimates

Improvements to SEDVEG should include re-evaluation of parameter estimates currently in use in the model. For example, the germination season used (Table 2.1 in Murphy and Randle, 2001a) is too long for all four plant species (cottonwood, willow, spike rush, and prairie cordgrass) and the growing season starts too early; maximum plant height is too short for willow, some species of which become trees (i.e., peach-leaved willow); growth rate of willow is not twice that of cottonwood; root growth of willow probably is limited by water table depth, as it is for cottonwood; and root growth rate should be age-specific.

Vegetation Removal Parameters

Several key parameters which affect plant mortality need to be adjusted/corrected (Table 2.3 in Murphy and Randle, 2001a). For example, willows can die from desiccation, and cottonwoods can die from water table declines of considerably less than five feet; burial (sedimentation) is an important mortality factor for young tree seedlings, and as such, cannot be left out of the model (information on this question is stated as "not available" in Table 2.3); death by inundation also is age-specific, and willows are considerably more tolerant of flooding than cottonwoods.

Model Structure

The most significant improvement in SEDVEG can be accomplished by revising the model structure. The current structure uses four species as examples of plants that occupy sandbars in the Platte River. Yet two of the species chosen (spike rush and prairie cordgrass) are not dominant plants on sandbars. Moreover, the dominant plant life form on young sandbars are annual plants (cocklebur, barnyard grass, lovegrass), yet these are not included in the model.

A more satisfying model structure, and one which may be easier to parameterize than the four species model, is to use a plant community approach. In such an approach, young, successional vegetation that colonizes and develops on sandbars would be classified and typed. Each type would have distinguishing physical characteristics (overall height, roughness) that would influence key hydrogeomorphic processes (sedimentation, erosion). Examples of such types could be: annual plants with tree seedlings; annual plants without tree seedlings; transitional vegetation (mixed annual/perennial); perennial vegetation; and young woodland. New parameter estimates would be developed for each vegetation type.

Much, if not all, of the data needed to parameterize a community-type model could be gleaned from a 16-year tree demography data base available from Nebraska Public Power District and Central Nebraska Public Power and Irrigation District. The data base includes seasonal measurements of tree seedling mortality, plant cover, sandbar elevation, and other physical and biological information (Johnson, 2000). Examples of information available from the data base would be: the rate of tree seedling mortality by season versus riverbed (sandbar) elevation; the shear stresses needed to remove vegetation types and age classes; the effect of early summer (June) flows on tree recruitment. The data base could be subdivided to provide one set of data for parameterization and another for testing. The data were collected at four reaches in the central Platte River (Shelton, Odessa, Cottonwood Ranch, and Jeffrey Island). The published data from the Shelton and Odessa sites are discussed in Investigation C1 above. Data for Cottonwood Ranch and Jeffrey Island were being collected at the time this investigation was completed and are not included.

Model Testing

One approach would be to use portions of the tree demography data base to test SEDVEG model output. To illustrate, past seasons with desired flow conditions (low flows, peak flows, and ice) could be selected from the historic data base for one or more reaches. The model could be run using flow and meteorologic conditions specific to each time period. The output of the model (collective changes in vegetation during the period) could then be compared to measured changes in vegetation. Differences between observed (measured) and computed (modeled) vegetation changes would provide the basis for making model improvements. The demography data base was readied for this purpose in late 2002. Some initial tests of the model's ability to simulate vegetation conditions during high flows were made.

TASK C2 CONCLUSIONS

The current version of SEDVEG would be unlikely to pass peer review at this time. If the current four-species structure is retained, considerable work will be needed to successfully parameterize the model. Changing the model structure to represent vegetation community types should be easier to parameterize, especially if the Districts' demography data base is fully used. Continued use of this data base also should improve model testing. A vegetation submodel in SEDVEG that is based on long-term field data from the central Platte River will have a much better chance of passing peer-review by riparian vegetation scientists when the time comes.

BIBLIOGRAPHY

Currier, P.J. and C. Davis. 2000. The Platte as a prairie river: A response to Johnson and Boettcher. *Great Plains Research*. 10:69-84.

Johnson, W.C. 1994. Woodland expansion in the Platte River, Nebraska: Patterns and causes. *Ecological Monographs*. 64:45-84.

Johnson, W.C. 1997. Equilibrium response of riparian vegetation to flow regulation in the Platte River, Nebraska. *Regulated Rivers: Research and Management*. 13:403-15.

Johnson, W.C. 2000. Tree recruitment and survival in rivers: Influence of hydrological processes. *Hydrological Processes*. 14:3051-3074.

Johnson, W.C. and S.E. Boettcher. 2000. The pressettlement Platte: Wooded or prairie river? *Great Plains Research*. 10:39-68.

Murphy, P.J., and T.J. Randle. 2001a. *Platte River Channel: History and Restoration.* U.S. Bureau of Reclamation and U.S. Fish and Wildlife Service. Draft. January.

Murphy, P.J., and T.J. Randle. 2001b. *Platte River Sediment Transport and Riparian Vegetation Model.* U.S. Bureau of Reclamation and U.S. Fish and Wildlife Service. Draft. January.

Nadler, C.T. and A. Schumm. 1981. Metamorphosis of the South Platte and Arkansas rivers, eastern Colorado. *Physical Geogr*. 2:95-115.

Simons and Associates. 2000. *Physical History of the Platte River in Nebraska: Focusing Upon Flow, Sediment Transport, Geomorphology and Vegetation*. Delivery Order No. 114. Fort Collins, Colorado.

TECHNICAL MEMORANDUM

RESULTS OF INVESTIGATIONS D1 AND D2 – MACRO-HISTORICAL EVALUATION OF SURFICIAL PROCESSES AND MACRO-HISTORICAL EVALUATION OF CLIMATE CHANGE

PLATTE RIVER CHANNEL DYNAMICS INVESTIGATION

Prepared For

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May 2003

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TECHNICAL MEMORANDUM

INVESTIGATIONS D1 AND D2 – MACRO-HISTORICAL EVALUATION OF SURFICIAL PROCESSES AND MACRO-HISTORICAL EVALUATION OF CLIMATE CHANGE

PREFACE

This report describes the procedures used in and results of an evaluation of the literature on geomorphic thresholds and the current morphology and stability of the Platte River channel. The investigation addressees a number of technical issues regarding this subject which had been identified by the sponsors as needing detailed examination to allow them to make scientifically-based decisions regarding the Cooperative Agreement (CA) work products.

This document describes only the data collected, analyses made, and scientifically-supportable findings regarding the issues, written in a manner which generally follows the guidelines of professional journals of the respective authors' technical expertise. The relevance of the findings to the specific issues confronting the sponsors is discussed in each task memorandum, but only as far as the data and results are deemed by the author(s) to be scientifically supportable in resolving or illuminating the issue.

ISSUES AND PURPOSES OF INVESTIGATIONS

The technical evaluations were conducted as a series of 14 complementary investigations divided into four categories that would address general issues identified by the three states. The following issue categories were identified:

- A: Questions Regarding Channel Narrowing or Deepening
- B: Questions Regarding Sediment Transport
- C: Questions Regarding Vegetative Encroachment
- D: Questions Regarding Macro-Historic Natural Variability

This Technical Memorandum describes the results of Tasks D1 and D2, the two tasks comprising Issue Category "D."

The purpose of Tasks D1 and D2 is to evaluate the possible occurrence of natural change or cyclicity in the surficial processes and climate of the Platte River Basin, in order to ascertain whether the effects of naturally-occurring changes (e.g., in climate) on the morphology of the Platte River channel can be distinguished from effects associated with water-development activities (e.g., construction of retention and diversion structures).

The two D-series investigations also were designed to evaluate whether changes that have occurred within the Platte River system are within the range of natural variability that might be expected, considering past variability in climatic conditions, and to ascertain whether climatic conditions in the Great Plains region could be correlated with possible changes in hydrology and geomorphology. Because climate change is the most significant force affecting the morphology and evolution of Great Plains rivers (Osterkamp et al., 1987), an assessment of geomorphic processes and landscape evolution must accompany the assessment of climate change; thus, the two "D"-series tasks were completed concurrently.

The occurrence, nature, and rate of climatologic change and its potential association with geomorphic evolution of landscapes in the Platte River basin is evaluated. In particular, the period from 1895 to 1909 is examined in the context of possible climatic change, together with evaluation of conditions during earlier and later periods, in order to obtain insight into the question of whether the river is experiencing natural changes instead of or in addition to impacts associated with development.

LINKAGE OF A1, A2, A3 AND D1/D2 INVESTIGATIONS

An evaluation of the geomorphology and current stability of the Platte was described in the Task A1 document. Historical and current sediment supplies, and causes of changes, were addressed in the A2 report, and a detailed evaluation of the channel geometry was presented in the A3 report. The possibility that the river is being forced by intrinsic or extrinsic factors to pass through the various thresholds described in the A1 document was raised in that study, and it was shown in both the A1 and A3 documents that climate may be the primary driving factor, to a much greater extent than hypothesized by Williams (1978) or Murphy and Randle (2001a).

It was also shown that the river has a history of passing through thresholds, but is more stable now than it was around the late 1800's. This was shown to be due largely to the instability of the braided form that existed at that time, and strong support was documented by a number of investigators that the river has passed through a threshold, and that its current anabranched form is more stable and closer to a state of dynamic equilibrium. Both the A1 and A3 documents raised the question of whether climate may be the primary cause of morphologic changes in this river. This question is addressed in this D1/D2 report.

HYPOTHESES REGARDING PRE-DEVELOPMENT HYDROLOGY AND CAUSES OF CHANGES IN GEOMORPHOLOGY OF THE PLATTE RIVER SYSTEM

Some investigators have attempted to estimate the depletions to the Platte from development of irrigated agriculture in the basin. While not part of the scope of this study, the analysis of climate described here discounts as grossly exaggerated most of the claims. The material in the following seven paragraphs was presented in the introduction to the A1 document. Because of the overlap of emphasis on geomorphology in the A1 report and D-series studies, the hypotheses are repeated here to provide the foundation for issues being addressed by both the A1-A3 and D1/D2 investigations.

Murphy and Randle (2001a) developed a draft report entitled "*Platte River Channel: History and Restoration*." They concluded that prior to the development of water resources within the Platte River basin, the unvegetated part of the Platte River meander belt was wide, shallow, and braided in geomorphic configuration. Annual flood peaks were high – commonly greater than 10,000 cubic feet per second (cfs), sediment loads were large, and the median grain size of the river bed was fine sand. Overall unvegetated channel widths including active (flowing) and inactive (dry) channels, and intervening braid-bar systems, were on the order of one mile, and the shifting sand bars of the braided river system kept the channel relatively free of vegetation. Other statements and conclusions were:

> *"During the period 1902-1909, the average annual peak flow (average annual maximum of mean daily flows) at the stream gage near Overton, Nebraska was 20,500 ft^3/s, and the mean annual flow rate was 2,900 ft^3/s.* (Murphy and Randle, 2001a, p.2)

> *"The Central Platte River before the 1900s was dynamic, changing from year to year, and may have been slightly aggrading in certain reaches. The river is nearly straight, with a channel slope equal to the valley slope. ... Overall, the channel was likely in a natural state near dynamic equilibrium ...* (Murphy and Randle, 2001a, p.2)

> *"Floods and droughts would come and go and the river would change in response to these flow changes, but the channel effects of these flow variations would fluctuate around average channel parameters that described the long-term-average properties of the river."* (Murphy and Randle, 2001a, p. 3)

During the first few decades of the 1900's, large storage reservoirs were constructed in the North Platte River to provide water for irrigation. These reservoirs were (and are) used to store water during periods of high streamflow, for release during later periods of low streamflow, or as needed. Murphy and Randle (2001b) developed a draft of their report entitled "*Platte River Sediment Transport and Riparian Vegetation Model*." Their conclusions regarding the impact that this pattern of reservoir storage had on the river were:

> [The development] "*significantly reduced the annual peak flows and the application of water to agricultural lands reduced annual flows within the river channel. The large storage reservoirs also trapped the sediment load of the North Platte River and significantly reduced the sediment supply to the Platte River downstream.*

> *The reductions in annual peak floods, annual river flow, and sediment supply resulted in a significantly narrower river channel, and vegetation colonized areas of the formerly active river channel. In general, river channel widths have [been] reduced to about one-fifth or less of the former historic channel. The reductions in annual flood peaks alone would account for a large portion of the channel narrowing; however, the reduction in sediment supply and the growth of dense riparian vegetation have also played a significant role. A simple reduction in annual flood peaks would result in a narrower river channel, but still leave the channel in a braided condition with a bed of fine sand. However, the large decrease in the sediment supply resulted in a few feet of river-bed erosion across separate subchannels. Through the selective erosion of finer sediment particles, the erosion process also resulted in a coarser sediment size on the eroded river bed. The vertical incision, over portions of the*

formerly active river channel, also aided in the abandonment of the remaining wide, river channel. Once portions of the former river bed degraded, river flow were more frequently contained within the narrower, but deeper, channel. Thus, river flows were not as frequently available to mobilize sediments of the formerly wide and higher river channel. With fewer frequent flows to mobilize these sediments, the remaining portions of the formerly wide river channel were ideal for colonization by riparian vegetation ..." (Murphy and Randle, 2001b, p.2)

Narrowing of the Platte River channel has been attributed by Murphy and Randle (2001a) to conversion from a braided system to a transitional form, or more specifically, to an anabranched pattern. This conversion is alleged to have been a direct consequence of reductions in peak flows and in sediment transported by the river, due to construction of retention and diversion structures for water development (e.g., Murphy and Randle, 200a, p. 4ff). The remainder of this report discusses, from a geomorphologic stance, whether climate is as or more correlated to the morphologic transition than the alleged reductions in peak flows and sediment supplies.

GEOMORPHIC CONCEPTS, GEOMORPHIC PROCESSES, AND TIME

Background material on qualitative and quantitative geomorphology of rivers was collected at the beginning of investigation A1, particularly in regard to threshold theory and extrinsic and intrinsic factors that can cause morphological change. A number of relevant definitions of terms and background information was compiled and included in Appendix A of the Task A1 report. The Appendix is suggested reading for readers not familiar with these terms. Because the primary issue in this investigation is whether climate cycles explain observed changes in Platte River morphology, the material presented in this section is limited to the effect that climate has had on the morphology of Great Plains streams.

The literature points out that nowhere on earth do surficial processes (including fluvial, aeolian, and pedogenic) act at a steady-state rate. Much of this literature addresses the Great Plains. Several authors (e.g., Brakenridge, 1980; Osterkamp *et al.*, 1987) have documented and dated the natural occurrence of cycles of landscape and river degradation (erosion), aggradation (deposition), and equilibrium (stability) periods for rivers in the Great Plains. Evidences of these changes in surficial processes have been recognized and documented worldwide through stratigraphic analyses and linked to tectonic activity and climate studies (Wenzel *et al.*, 1946; Leopold and Miller, 1954; Brakenridge, 1980; Kozarski, 1991; Starzel, 1991c). Great Plains rivers in particular have experienced wide swings in climate and morphology, especially in recent time (the past several thousand years), mostly as a consequence of extrinsic cyclic climate change.

These swings occur naturally and the data indicate that fluctuations in erosional and depositional conditions occur in periods of time on the order of tens to hundreds of years, easily encompassing the period of development along the Platte River. Each cycle consists of (1) downcutting, (2) lateral erosion, (3) deposition, and finally (4) landscape stability.

Erosional and depositional processes active since the end of Ice Age time in the Medicine Creek drainage, in southwestern Nebraska, were evaluated by Brice (1966), who found that in general, the Medicine Creek basin is representative of the loess-mantled Great Plains. Geomorphic and stratigraphic evidence indicates that the drainage system of Medicine Creek had evolved to approximately its present pattern and extent during an episode of erosion (tentatively assigned to the interval 12,000 years before the present [yr BP] to 11,000 yr BP) that followed the conclusion of the most recent Ice Age in North America. During the subsequent episode of deposition, lasting from about 11,000 yr BP to about 5,000 yr BP, significant alluvial deposits accumulated, and the valley sides were graded. These deposits were incised during a second period of erosion (lasting from about 5,000 yr BP to 4,000 yr BP), and the deposits that subsequently accumulated in the valleys (from 4,000 yr BP to 1,000 yr BP) were later incised (from about 1,000 yr BP to 900 yr BP). The last period of incision was followed by accumulation of the alluvial deposits that form the present floodplain. In some valleys in the basin, these most recent deposits have been eroded intermittently during the past 350 years. Thus, within the past 12,000 years, the valleys in the Medicine Creek drainage have been eroded three times, prior to the erosional episode that is occurring in some valleys at present. Brice (1966) hypothesized that the erosional episodes may be associated with climatic fluctuations.

Leopold and Miller (1954) examined the geomorphology of several alluvial valleys in eastern Wyoming, including the North Platte River, in an attempt to reconstruct the sequence of events that produced alluvial terraces bordering the valleys at different levels. On the basis of stratigraphic evaluation and comparison of the relative elevations of terrace deposits, channel-fill deposits, and erosion surfaces, they identified several periods of alternating deposition and erosion in eastern Wyoming, beginning at the end of Ice-Age time. Erosional processes resulted in channel incision to depths of several tens of feet, which were followed by a cycle of deposition, in which the incised channels were backfilled with sediments to nearly their pre-erosion level. Leopold and Miller related these cyclic geomorphic occurrences to climatic changes that have occurred since the end of the Ice Ages. The authors concluded that while some of the recently-occurring channel incision and erosion observed in eastern Wyoming was a consequence of changing land use (overgrazing resulting in removal of vegetation), much of the modern erosion also could be a consequence of climatic variability; and the observed rates of erosion represent the net result of some interaction between land use and varying climate.

Analysis of the morphology and behavior of contemporary and paleorivers shows that there are a number of identifiable and quantifiable fluvial states (Schumm, 1968, 1974, and 1981; Thornes and Gregory, 1991). The principal morphological taxonomy of rivers identifies straight, meandering, and braided channels; the principal hydraulic taxonomy identifies wide, shallow channels and narrow, deep channels; and the principal behavioral taxonomy identifies aggrading, graded (regime) and degrading (eroding) channels. There is ample evidence to show that different reaches of the same river can (and commonly do) occupy different morphological, hydraulic, and behavioral states (Thornes and Gregory, 1991), but that a particular reach tends to spend relatively long periods of time in the same state. However, if certain conditions change, the response of the river, or of a particular reach, can be sudden and dramatic (Schumm and Lichty, 1963; Schumm, 1968).

Numerous paleohydrologic investigations illustrate three types of behavior of fluvial systems in the geologic and historic record:

- stability, indicated by the dominance of a particular state over long periods of time and exemplified by the widespread occurrence of meandering morphology throughout most of recent time;
- rapid change, as indicated by switches in morphology over a relatively short period from meandering to braided and back, or from aggrading to degrading conditions, with consequent formation of terraces; and
- oscillations between states.

In Paleohydrology, changes in state usually are thought to indicate changes in the controlling variables, and most commonly are taken to indicate extrinsic changes, such as changes in the hydrologic regime. In turn, these may be attributed, for example, to changes in vegetation cover, snowmelt, or precipitation. Various authors have demonstrated that changes in state also may come about without alteration of the external conditions as the controlling variables pass through internal (structural or intrinsic) thresholds in the systems (Schumm, 1974; Chang, 1986). The prevailing view is that under conditions of dynamic equilibrium, river channels adjust the values of state variables (which describe the condition of the fluvial system) more or less continuously to the slope, and to sediment and water supplied to the channel (Thornes and Gregory, 1991).

In the Great Plains as in much of the Northern Hemisphere, climate is the primary force acting to produce and shape landforms from the geologic framework (Wenzel *et al.*, 1946; Leopold and Miller, 1954; Brakenridge, 1980; Sundborg and Jansson, 1991). During the past 15,000 to 18,000 years, substantial changes of the whole environment have occurred, usually described as a shifting of the climatic-vegetational zones as a consequence of the worldwide transition from glacial conditions (during the most recent Ice Age) to post-glacial conditions. Climatic fluctuations have continued up to the present, and consequently have produced a sequence of changes in the hydrology and geomorphology of numerous fluvial systems, which have been superimposed on, and have modified, the pre-existing systems (Sundborg and Jansson, 1991; Starkel, 1991b). Thus, the current geomorphology of the Platte River basin consists of an Ice-Age topography, somewhat modified by the forces resulting from changing climates of the past 15,000 years.

In many circumstances, the landforms comprising current topography are an expression not only of current conditions – the interaction between the driving forces (climate, tectonics) and the geologic framework – but also contain relict features that resulted from past conditions (Brice, 1966; Schumm, 1968 and 1974; Ruhe, 1974; Rinaldo *et al.*, 1995). As has occurred in numerous other rivers worldwide, the configuration of the Platte River system has changed in response to changes in water and sediment discharges, resulting from climatic changes and other factors. However, the time scale for adjustment of a channel varies with the sensitivity of the channel to changing conditions.

A significant adjustment in stable humid-zone rivers may require centuries; but in semi-arid areas (such as the Great Plains), the time scale for fluvial adjustments can be much shorter, close to the time scales required for the random response to a single catastrophic event (Chang, 1986). In some cases, these changes have occurred in periods of time no longer than a few tens of years (Schumm and Lichty, 1963). Therefore, it is apparent that the effects of all short- and long-term climate cycles should be considered in an evaluation of current conditions in the Platte River system.

METHODS OF INVESTIGATION

Investigation Tasks “D1” and “D2” consisted of in-depth review of the available information regarding geomorphic processes and climate change, focusing primarily upon the past 2,000-year period of the geologic and climatologic history of the Great Plains. Information pertaining to macro-historical variability in geomorphic processes and climate was obtained from federal and state agencies, independent researchers, and the published literature, and is described in the following sections.

Hydrologic information and bibliographic references regarding geomorphic conditions and processes within the Platte River basin were obtained from the EIS team. During our initial review of the material provided, it became apparent that climatic variability had not been considered by the EIS team during development of hypotheses regarding causes of changes in the hydrology and channel morphology. After reviewing the EIS team’s data and documents, the review was expanded to include other sources of published data and reports relating to climatic conditions in the Great Plains, with particular emphasis on extrinsic effects on the Platte River morphology.

In addition to literature regarding climatic change and geomorphic response in the Great Plains, published precipitation data, tree-ring data, and stratigraphic reconstructions accompanied by dating studies were compiled and evaluated to define the natural variability of climate and geomorphic processes in this region. Parsons also evaluated current research in the fields of paleoclimatology and paleohydrology, and conducted discussions with workers in those fields, who are associated with the National Oceanic and Atmospheric Administration (NOAA) and U.S. Geological Survey (USGS). Other agencies that were contacted for information included:

- National Climatic Data Center (NCDC), Asheville, North Carolina -- one of three data centers making up the National Environmental Satellite, Data, and Information Service (NESDIS) of NOAA
- NOAA National Geophysical Data Center (NGDC)
- NOAA Paleoclimatology Program, NGDC, Boulder, Colorado
- International Tree-Ring Data Bank (ITRDB) -- a central repository for all types of dendrochronological (tree-ring) data from around the world managed by NGDC (www.ngdc.noaa.gov/paleo/treering.html)
- Colorado Climate Center, Department of Atmospheric Sciences, Colorado State University, Fort Collins, Colorado
- University of Nebraska, Lincoln, Nebraska
- Nebraska State Climate Office, University of Nebraska, Lincoln, Nebraska

- High Plains Regional Climate Center, University of Nebraska, Lincoln, Nebraska.

LITERATURE REVIEW – GEOMORPHIC EFFECTS OF CLIMATE

Technical literature and other information regarding hydrologic and geomorphic conditions in the Great Plains were reviewed as part of Task A1. Literature reviewed in conjunction with Task D1 has been cited in the bibliography, and is summarized in this section.

Direct and indirect climatic and hydrologic data can be used to assess temporal variability in hydrologic conditions. Direct data can be systematic (measured) or historical. Instrumental records of hydrology in the Platte River basin (e.g., stream-gaging records) were not routinely collected at some stations until the 1930s, though estimates of hydrologic conditions exist based on partial records. Filling in ungauged periods from short-term data records creates considerable uncertainty, especially peak instantaneous flows (Jarrett, 1991). In addition to literature and data regarding gauged hydrologic conditions, Parsons compiled and evaluated information regarding the paleohydrology of the Platte River basin and similar systems. Paleohydrology is concerned with a comparison of the present with conditions which prevailed in the past, and deals with the interaction of climate, vegetation, stream regime, and runoff which obtained under climates different from that of the present (Leopold and Miller, 1954). Jarrett (1991) has focused largely on paleofloods, defined as the flow rates obtained by indirect methods that caused high water marks such as slackwater deposits in caves, tree marks, and other indicators of extreme events.

Indirect data, such as pollen, sediment, diatoms, and tree-ring records, are examples of what is known as *proxy data* (Jarrett, 1991). Paleohydrologic analysis uses many types of proxy data to extend climatic and hydrologic records back in time. For example, tree-ring data have been used to reconstruct past precipitation and temperature for several hundred to thousands of years; deep-sea sediment cores have been used to reconstruct long-term, global temperature fluctuations for thousands to hundreds of thousands of years. Evidence of historic and prehistoric floods commonly is preserved in stream channels as distinctive sedimentary deposits or landforms (e.g., fluvial terraces), and also can be preserved as botanical evidence. The interpretation of this evidence provides important supplemental information about the spatial occurrence, magnitude, age, and frequency of hydrologic events (floods, droughts) and also about hydrologic variability. However, each type of proxy data has problems related to its accuracy, which must be considered during evaluation of the data.

Wenzel *et al.* (1946) completed an evaluation of the geology and groundwater resources of the Platte River valley near Scottsbluff, Nebraska, which included an assessment of the geomorphology of the North Platte River and nearby areas. Wenzel identified nine terraces bordering the river, having elevation differences between the lowest and highest terrace of nearly 1,000 feet. Several of the highest terraces were developed during Ice Age time; but later in its history, the North Platte River apparently incised channels to depths greater than 200 feet below its present floodplain elevation; these channels later were backfilled by the river. The terraces, erosion surfaces, and channel deposits represent the visible results of alternating periods of erosion and deposition, occurring from the end of the Ice Ages through the present time, which Wenzel ascribes to changing climatic conditions, tectonic uplift, or both.

Brakenridge (1980) related dramatic geomorphic changes in the Pomme de Terre River in central Missouri (Figure D-1) to regional long-term climatic trends, derived on the basis of the regional vegetational history as deduced from analysis of pollen (palynology), and concluded that if climatic conditions typical of the recent past continue, they will be accompanied by widespread episodes of stream erosion.

Knox (1983) noted that severe droughts, which reduce vegetative cover on a basin-wide scale, tend to increase surface runoff, thereby causing larger floods from a precipitation event of a given intensity. The responsiveness of a river system to climate change was thought by Knox (1983) to increase as vegetative cover becomes less effective as a control on surface runoff and sediment yield.

Cyclic occurrence of geomorphic processes in the Great Plains was described by Osterkamp *et al.* (1987), who determined that the morphology of the Great Plains is a product of the dramatic climatic changes that have characterized the period of time following the conclusion of the Ice Ages. In particular, because of the relations between climatic variation and the resulting geomorphic processes, landforms on the Great Plains appear to have developed in a complex cyclic manner:

1. Stratigraphic and geomorphic sequences in the Great Plains have many small to large discontinuities that record repeated changes in the rates of surficial processes (fluvial, aeolian, pedogenic). Commonly, the change in rate of one process as compared with another became large enough to change the type of surficial process that was dominant during a given episode.

2. The cyclicity of the interactions between climate and geomorphic processes is characterized by sequences of incision, lateral erosion, deposition, and landform stability, perhaps with significant soil development. These cycles are known as “erosion-deposition-stability” (EDS) cycles. All stages of this sequence are observable in different parts of the Great Plains.

3. In the Great Plains, EDS cycles were induced by climate changes, because tectonic processes are negligible in this relatively stable region.

4. Four time-duration classes of EDS cycles appear to have operated in the past: microcycles lasting 10 to 100 years; mesocycles, lasting 1,000 to 10,000 years; macrocycles, approximately 100,000 years in length; and megacycles, 400,000 to 500,000 years in length.

5. At least four megacycles, and probably the beginning of a fifth, are apparent in the geologic history of the past two million years. The initiation of each megacycle is indicated by a period of prolonged alluvial downcutting. The Great Plains appears to be entering a fifth process megacycle, and Great Plains rivers currently are downcutting their channels.

6. The fundamental climatic- and surficial-process controls of the EDS cycles, including various feedback mechanisms, are poorly understood, especially the extrinsic threshold controls of the longer cycles. Shorter cycles were driven over low thresholds at short intervals by relatively small changes in process intensity. The high thresholds of the megacycles required large changes in

process intensity, and were accompanied by major geomorphic-stratigraphic changes.

The proximate causes and modes of evolution of a number of fluvial systems were evaluated in conjunction with a project of worldwide scope by the International Geological Correlation Programme (IGCP) Project 158 (Starkel, 1991a). For example, the Vistula River in central Europe had a narrow, anastomosing planform at the end of the last Ice Age (Starkel, 1991c). By about 13,000 yr BP, the upper reaches of the Vistula had become meandering, and the lower reaches were braided, primarily as a consequence of the dramatic climatic changes that occurred following the retreat of glacial ice. Subsequently, the river channel became straighter, and a cycle of downcutting was initiated. Most recently (within the past several hundred years), aggradation of the channel has occurred, accompanied by a buildup of floodplains and valley floors by channel deposits.

The Warta River in the lowlands of Poland was braided at the end of Ice Age time (Kozarski, 1991), but evolved in successive stages to the meandering point-bar planform of modern times. This evolution probably was a consequence of changes in climatic conditions, accompanied by a concomitant increase in vegetation within the drainage basin, which stabilized soils and reduced the amount of sediment potentially available for transport. This general pattern of evolution was followed by most rivers during the transition from Ice-Age to modern conditions, and fluvial metamorphosis has continued in recent times with more subtle changes in flow characteristics, sediment types and loads (Baker, 1991). Cyclic changes in hydrologic regime occurred over similar periods throughout the temperate zone. Although the alluvial phases do not correlate precisely in time between sites (Starkel, 1991b), there seems to be a consistent pattern of shorter fluvial periods (300 to 500 years' duration) reflecting high flood frequency, alternating with longer periods (1,000 to 2,000 years' duration) reflecting lower flood frequency (Baker, 1991).

Martin (1992) and May (1992) examined the paleohydrology of the Republican River and South Loup River, respectively – two stream systems in the near vicinity of the Platte River. Apparently, two episodes of incision (degradation) of stream channels, one beginning about 4,200 yr BP, and the other occurring after 1,100 yr BP, were widespread across the central Great Plains (Martin, 1992). The earlier episode was associated with a shift to relatively wetter conditions, whereas the later episode was preceded and followed by dry conditions. Three episodes of floodplain aggradation have been identified in the South Loup River valley (May, 1992). The first episode of aggradation occurred beginning prior to about 3,500 yr BP and continuing until at least 3,000 yr BP. This followed a period of deep incision of the valley, perhaps corresponding to the earlier episode of incision identified by Martin (1992). The second interval of slow aggradation on the floodplain, accompanied by formation of soil on terrace surfaces, occurred between 1,800 and 1,050 yr BP. A third, rapid episode of valley-bottom aggradation occurred sometime after 1,050 yr BP. Episodes of floodplain erosion during high-magnitude floods occurred before, between and after these intervals of aggradation. The intervals of aggradation documented for the South Loup River valley appear to have been synchronous throughout the Loup River basin (May, 1992).

Rinaldo *et al.* (1995) developed a mathematical model of geomorphic processes and used the model to simulate the development and evolution of various landforms under conditions corresponding to tectonic uplift and climatic variability. On the basis of the results of a series of numerical simulations, the authors concluded that significant time lags can occur between climate change and adjustment of the resulting landforms to changing conditions. In particular, extreme climate excursions that cause accelerated threshold-limited erosion seem likely to occur and to leave very long-lived morphological evidence.

LITERATURE REVIEW – GREAT PLAINS AND PLATTE BASIN CLIMATE

Technical literature and other information regarding climatic conditions in the Great Plains and the Platte River watershed during historic time and prior to recorded history was reviewed as part of Task D2. Historical documents, including accounts by explorers and settlers, military records, newspaper accounts, and other written records, also contain a wealth of information regarding local climatic conditions during the last century. The historical data can be used in a qualitative comparison with proxy (indirectly-obtained) data from the technical literature. Literature reviewed in conjunction with Task D2 has been cited in the bibliography, and is summarized in this section.

Much of the climatic record for the Great Plains has been reconstructed from proxy data (representing indirect indicators of climatic conditions) using tree rings, fossil diatoms, aeolian deposits, alluvial sediments, and lake sediments. These data represent natural indicators of climatic variability, allowing reconstructions of past climatic conditions to be made, and provide a means of extending instrumental data to periods prior to recorded history. Paleoclimatic reconstructions, the reconstruction and evaluation of past climatic conditions, have been verified by comparing the reconstructions with various types of other information obtained from archeological sites, historical accounts, and instrumental data.

Dendrochronology (the analysis and reconstruction of past conditions using tree rings) is a reliable means of evaluating past climatic conditions, and provides indications of the occurrence of periods of drought prior to recorded climatic history. Several tree-ring reconstructions have been generated for the Great Plains, including the Platte River basin. Many of the tree-ring reconstructions suggest that the droughts of the 1930s and 1950s have been equaled or surpassed by more severe drought conditions in the past several centuries (Woodhouse and Overpeck, 1998).

In comparison with other methods such as early instrumental records, historical accounts, alluvial sediments, and archaeological data, tree rings are the only source which provide continuous records. Although the nature and resolution of dendrochronologic records is such that one year is the shortest period of time that can be recorded, the lengths of dendrochronologic records range from centuries to millennia (Woodhouse and Overpeck, 1998). Dendrochronological reconstructions of streamflows also are possible because trees integrate into their growth rings the same set of factors (e.g., precipitation and evapotranspiration) that influence streamflow (Meko *et al*., 1995; Woodhouse, 2001a). Tree-ring reconstructions are thus a valuable tool in paleohydrology. However, a limitation of tree-ring reconstructions is that they represent dry extremes more reliably than wet conditions (Brockway and Bradley, 1995; Woodhouse and Overpeck, 1998).

A tree-ring chronology, dating back to A.D. 1210, exists for an archeological site in western Nebraska near the town of Lewellen (Champe, 1946; Weakly, 1962). This nearly 750-year dendrochronologic record was reviewed by Weakly (1962), who found that during 269 of the past 748 years (36 percent of the time), annual growth of trees had been below normal indicating relatively drier conditions. In comparison, precipitation records for North Platte, Nebraska from 1875 to 1958 were below average during 42 of the 84 years (50 percent of the time) (Weakly, 1962). Western Nebraska experienced severe drought from 1861 to 1863, with 1862 being an exceptionally dry year (Weakly, 1962).

Mock (1991) conducted a study to verify dendroclimatic reconstructions of nineteenth century conditions and climatic assessments in the Great Plains, and to identify seasonal trends and the occurrence of drought conditions. In his study, Mock (1991) collected weather data from nineteenth-century (1851 to 1890) meteorological stations and compared these data with dendroclimatic evidence of droughts. The results of the study indicated that fluctuations of drought and precipitation showed both regional and temporal variability. However, the dendroclimatic reconstructions and available nineteenth-century precipitation data from the central United States generally agreed.

Meko (1992) compared tree-ring and climate data of the Great Plains, to evaluate whether tree-ring information provided a representative proxy data set for certain climatic variables. The tree-ring data were collected from 58 sites in the Great Plains between 1964 and 1985. Precipitation data covering the period 1904 through 1984 were compared with the tree-ring data. The regional precipitation data and tree-ring variables were highly correlated.

Cook *et al*. (1996; 1997; and 1999) used a large database of tree-ring chronologies to reconstruct summer drought conditions for a set of locations at grid points evenly spaced across the United States, including locations within the Platte River basin (Figure D-2). The grid point reconstructions were created using a principal components regression procedure described in Cook *et al*. (1996) and cover the period 1700 to 1978 (Cook *et al*., 1997).

Dr. Connie Woodhouse of the NOAA National Geophysical Data Center, Paleoclimatology Program, has used dendrochronologic and dendroclimatic techniques to reconstruct streamflows in Clear Creek, and Middle Boulder Creek in Colorado (Woodhouse and Overpeck, 1998; Woodhouse, 2001a; Woodhouse 2001b).

Diatoms have been used to reconstruct the frequency and intensity of drought in the Great Plains through the past 2,300 years. Diatoms are commonly-occurring members of the algal flora of inland lakes and their occurrence is highly correlated with lake salinity, which in turn is associated with the level of water in the lake (Laird *et al.,* 1996). According to Fritz (1996), records of changing lake levels probably represent the clearest evidence for local and regional climatic change.

Sand dunes formed in the Great Plains during prehistoric time currently are inactive and have been stabilized by prairie vegetation. The Nebraska Sand Hills – the most extensive of the Great Plains dune fields -- probably were formed during Ice Age time, but were mobile during several periods of intensive reactivation in some areas during the past several thousand years. Analysis of aeolian deposits in the Nebraska Sand Hills and

Wray Dune Field in eastern Colorado indicates that the most recent episodes of aeolian activity occurred during the past 800 and 400 years, respectively (Muhs *et al*., 1997). Historic accounts report aeolian activity in many areas during the period 1840 through 1865, with other intervals in the late 1700s and early 1800s, as well as at the end of the nineteenth century (Muhs and Holliday, 1995). Although some aeolian activity was reported during the 1930s and 1950s, these twentieth-century droughts were apparently not severe or long enough to cause regional mobilization of dunes (Muhs and Holliday, 1995).

Dry conditions, as indicated by increased movement of aeolian sand, also are indicated for a relatively long period between about 3,000 and 1,500 yr BP (Ahlbrandt and Fryberger, 1980; Muhs, 1985), although the areal extent of aeolian activity is unknown. Future climatic conditions (i.e., a combination of drought and high temperatures) could bring about renewed aeolian activity and reactivation of the dunes by reducing the vegetation cover that currently stabilizes the dunes (Muhs *et al*., 1997).

The Platte River valley borders the southern edge of the Nebraska Sand Hills. Sand-sized material in the Great Plains can be moved by prevailing winds throughout the year, and locally is subject to entrainment and transport, depending upon moisture, vegetation, and wind conditions (Figure D-3). During the winter, northwesterly winds can transport sand from the Sand Hills into the Platte River valley; and during the summer, southeasterly winds from the Gulf of Mexico can transport sand from alluvial deposits bordering the Platte River (bars, abandoned channels) into the Sand Hills (Muhs *et al*., 1997). Movement of sand from the Greeley and Fort Morgan dune fields in Colorado also can affect the flux of sand into or out of the South Platte River valley (Figure D-3).

HISTORICAL CLIMATE AND STREAMFLOW INFORMATION

Paleoclimatology consists not only of the collection of evidence of past climatic conditions, but also includes the investigation of the climate processes causing these conditions. In conjunction with review of the technical literature, and compilation of data from paleoclimatic reconstructions, historical accounts and instrumental records were examined to assist in the evaluation of past climatic conditions and their influence on hydrologic conditions in the Platte River basin.

Continuous recording of weather records in Nebraska was begun in 1850 (Weakly, 1962). In western Nebraska, the earliest records available were collected in 1865, the date of the first precipitation records at North Platte, Nebraska. Prior to that time, many travelers recorded sporadic observations of the climate in Nebraska. Between 1804 and 1806, the Lewis and Clark expedition passed through the general area that now is the State of Nebraska, but recorded little in the way of climatic information. However, in 1807, Lieutenant Zebulon M. Pike explored the Arkansas and Red River valleys to their headwaters, and drew a very vivid picture of the country as he found it. He wrote "*Here a barren soil, parched and dried up for eight months of the year, presents neither moisture nor nutrition sufficient to nourish the traveler.*" Many other early references were made to the desert character of the country, but there also were those who saw it quite differently, as did Mrs. George Donner, who, after traversing the plains in 1846, wrote "*The prairie between the Blue and Platte Rivers is beautiful beyond description. Never have I seen so varied a country, so suitable for cultivation.*"

According to Carlson (1963), the first pioneers traveling across the plains to Colorado in the 1850s found small-scale irrigation farming by Mexican farmers. Carlson (1963) also reported that two settlers cultivated irrigated agriculture using water from the South Platte River during a sequence of dry years during the 1860s. Irrigation along the North Platte River is reported to have been started by the first homesteaders during the 1860s using water from tributary streams (Miller, 1978). A reach of the Farmers and Merchants Canal was completed in 1895, a very dry year, with the remaining parts completed in 1896. The Platte River must have had surface flows in August 1895 and 1896 (dry years) or the canal would not have been built (Miller, 1978). According to Miller (1978), a considerable amount of irrigation was occurring by 1896 above Columbus and North Platte, Nebraska.

A severe drought in 1860 was reported in Kansas newspapers and other sources, which continued to mention the severity of this drought for several decades after the event (Woodhouse and Overpeck, 1998). Teele (1905) interviewed people living along the Platte Valley that indicated the river was dry in places, and for short periods of time, during the years 1863, 1864, 1865, 1866, 1871, 1873, 1874, and 1875. Accounts from Grand Island newspapers noted that 1894 was a "very, very serious drought year" throughout much of Kansas, Colorado, Wyoming, and Nebraska. By August 6, 1894, *"the pastures were completely burnt out and trees were dying"* (Miller, 1978). These writings indicate that alternating periods of drought and abundant precipitation have been the normal condition in the Great Plains for as long as those of European ancestry have been aware of their existence.

Official weather measurements were authorized in 1870 by an act of Congress, requiring all military posts to keep records (Weakly, 1962). Temperature and precipitation records for Nebraska, Colorado, and Wyoming, spanning the period from 1895 until 2000 were obtained in electronic format from the National Climatic Data Center (NCDC, 2000). Average monthly temperatures and precipitation records based on instrumental data for the Denver area from 1872 - 1974 were obtained from the Colorado Climate Center (CCC, 2000). These instrumental records were used to support the validation of the collected reconstructed climatic data.

Considerable data regarding precipitation, historic flows, and drought conditions in the Platte is provided by Teele (1905). His study is extremely relevant because it was *designed to evaluate effects of early upstream irrigation development (circa 1860-1895) on downstream flows, particularly on riparian rights*.

A long-standing theme of the EIS Team has been that the majority of Central Platte water and sediment originates (and historically originated) from snowmelt in the mountain watersheds feeding the Platte system. Return flows and runoff from precipitation in the intervening watersheds below the diversion and storage projects are not considered to be significant in their analysis.

Teele (1905) looked at precipitation variations across the basin to test the theory that all available water is supplied by the mountain snowpack. The prevailing view that water supplies below storage projects are small fails to recognize not only the climatologic differences over the hundreds of miles from the headwaters to the mouth, but also the gains in groundwater flow and the dramatic increase in annual precipitation from west to east. Teele evaluated precipitation changes across the basin, noting that precipitation varies from about 16.47 inches in the high mountains to about 11.74 inches at Ft. Morgan on the South Platte River, and from 9.44 inches at Alcova. By the time both streams reach North Platte, annual precipitation rises to 18.27 inches, which exceeds the high mountain precipitation amounts, and then continues upward to 32.60 inches at Plattsmouth.

Another recurring theme that causes concern is that flow data prior to 1935 are sufficient to establish baseline conditions. Teele (1905) states that "the published reports of early travels and exploration along the South Platte river give little definite information as to its flow," and notes that official records of fall streamflows are available, starting in 1889, but all other information in his report is anecdotal. Regarding the paucity of earlier data he states, "… in the absence of the records of the flow of the stream in early years, it has been necessary to collect the testimony of settlers and travelers as to early conditions." He provides an extensive description of the reports gathered from written accounts and from interviews with residents (many of whom settled before irrigation began) regarding flow changes during their residency. Numerous accounts reveal that there were long-standing (pre- and post-irrigation development) numbers of no-flow days, but that the number of no-flow days has increased. Teele does not credit depletions from irrigation. Drought cycles were definitely evident, with flows in 1894 to 1903 being much wetter, for example than 1889 to 1893.

Teele (1905) notes that there is not just a fixed quantity of water that can be allocated by rights, but instead, return flows and precipitation create considerable amounts of flow downstream in excess of section flows minus diversions. As one example, he documents that by 1905 there were more than sufficient rights in Colorado to exhaust the ordinary flow of the South Platte, but that return seepage is considerable at the State line. One measurement in 1903 revealed that incoming flow to one irrigation district near Denver was 91.85 cfs, yet a total of 134.53 cfs was diverted, and more importantly, flow leaving the reach was 46.36 cfs. Adding the last two values reveals that the amount of water diverted or leaving the reach was twice the amount of incoming flow. Groundwater, intervening rainfall, and return flows are the only possible explanations.

Regarding depletions from irrigation development, Teele (1905) concludes, "With the records showing that the river went dry in many years before irrigation began, it will be practically impossible for a riparian proprietor along this section of the river to prove that any damage which he may suffer from shortage of water is due to the diversion of the water above."

DATA ANALYSIS

As part of Investigation Task D2, instrumental flow data were compiled for four recording stations at representative locations in the Platte River basin – station 6627000 (North Platte River near Saratoga, Wyoming) for the period 1903 through 1987, representative of the Upper North Platte River basin; station 6707500 (South Platte River at South Platte, Colorado) for the period 1896 through 1935, representative of the Upper South Platte River basin; station 6764000 (South Platte River at Julesburg, Colorado) for the period 1902 through 1987, representative of the Lower South Platte River basin; and station 6768000 (Platte River at Overton), representative of the central reaches of the Platte River for the period 1918 through 1987 (Figures D-4 and D-5). Stations were selected based on the location of the reach (to be representative of conditions at different locations within the basin), and length of record. The weather station at Duncan in Platte County was considered, but did not have any readily available data.

Reconstructed flows and instrumental data (measured streamflows) were obtained for Middle Boulder Creek in Colorado, for the period from 1703 through 1987. The instrumental period of record for Middle Boulder Creek extends from 1912 through 1987 (Figures D-4 and D-5), and was used by Woodhouse (2001a) to validate the reconstructed mean annual streamflows for Middle Boulder Creek. Validated reconstructed mean annual flows and instrumental data also were obtained for Clear Creek, Colorado (Figures D-4 and D-5), for the period from 1685 through 1987 (Woodhouse, 2001b).

Dendroclimatic records also can be used to construct long-term records that contrast relatively wetter and drier periods (Woodhouse and Overpeck, 1998). The Palmer Drought Severity Index (PDSI) is a measure of the relative amount of precipitation and soil moisture in a particular area, as compared with long-term average conditions, and was developed to measure intensity, duration, and spatial extent of drought. PDSI values generally range from –6 to +6 with positive values corresponding to relatively wetter periods and negative values indicating relatively drier periods. Large negative values indicate periods of drought. Values are normalized to facilitate comparisons between regions, and can be derived from tree-ring data.

The International Tree Ring Database (NOAA, 2001) provides reconstructed PDSI values for the entire United States (available online at http://www.ngdc.noaa.gov/paleo /pdsi.html). Several grid points for which PDSI reconstructions have been generated lie within the Platte River basin (Figure D-2). Reconstructed PDSI data were obtained for five locations in the basin. Reconstructed PDSI data for Grid Point 79 (southeastern Nebraska) extended from 1696 through 1978 (Figures D-6, D-7, and D-8). Reconstructed PDSI data for Grid Points 68 (southwestern Nebraska), 59 (eastern Colorado), 58 (Colorado-Wyoming border), and 47 (central Wyoming) extended from 1700 through 1978.

Tree-ring chronologies were obtained (unpublished data from C. Woodhouse, June 28, 2001) for three other locations -- New North Park, Colorado (for the period 1354 - 1964), Pumpkin Creek, Nebraska (for the period 1498 - 1979), and Niobrara Valley Preserve, Nebraska (for the period 1589 - 1997). These three locations lie roughly along the valley of the North Platte River from its headwaters to central Nebraska (near the Niobrara River). The tree-ring indices in the database for the three locations represent relative rates of growth but have been normalized, so that the mean index value is 1.0 for all three locations. However, because the tree-ring index data from these locations have not yet been interpreted, these three chronologies could not be used in the current investigation.

In addition to temporal changes in streamflow resulting from drought or other climatic conditions, changes in the rate of evapotranspiration (ET) also can affect hydrologic conditions in a particular area. Evaporative and ET losses from open water and vegetation are affected by climatic factors, including temperature, humidity, and wind. It seems possible that historic changes in the morphology of the Platte River, including reduced peak flows, narrowed unvegetated channel width, and greater amounts of woody vegetation, have resulted in a greater ET loss. However, the results of a study that compared current and historic ET rates in the Platte River system (Nagel and Dart, 1980) indicated that the rates of ET and evaporative losses in the 1930s differed only slightly from loss rates in the 1970s, even though the amount of woody vegetation increased significantly along the Platte River between the 1930s and the 1970s. According to Nagel and Dart (1980), the rates of evaporative losses from open water in the Platte River basin are similar to the rates of ET losses from forested areas. Therefore, expansion of vegetation at the expense of unvegetated channel with exposed water has resulted in little change in total losses due to evaporation and ET. The total annual water loss from the Platte River system due to evaporation and ET between Kingsley Dam and Duncan, Nebraska was estimated to be 379,000 acre-feet (Nagel and Dart, 1980).

CLIMATIC TRENDS FROM CA 2,000 YEARS BP TO PRESENT

Climatic conditions through the past 1,000 to 2,000 years have been evaluated by numerous researchers (e.g., Laird *et al.*, 1996; Woodhouse and Overpeck, 1998; Woodhouse, 2001a and 2001b), primarily for the purpose of predicting future climatic trends. As a consequence of the tendency of proxy records (tree rings, diatoms) to more readily the detection of relatively drier conditions, drought periods are the usual focus of paleoclimatic reconstructions. Available paleoclimatic data suggest that a drought of approximately the magnitude and severity of the 1930s "Dust Bowl" has occurred once or twice each century over the past 300 to 400 years, and a decadal-length drought, of generally greater severity, has occurred on average once every 500 years (Laird *et al.*, 1996; Woodhouse and Overpeck, 1998).

Proxy records, supplemented by archaeological information, have been used to evaluate climatic conditions for the period from A.D. 1 to A.D. 1200 for the Great Plains and western North America. At least four periods of widespread drought occurred during this span of time – a drought extending from about A.D. 250 to A.D. 500, a drought extending from about A.D. 700 to A.D. 900, a drought period centered at about A.D. 950, and a drought at around mid-century A.D. 1100 (Figure D-9) (Woodhouse and Overpeck, 1998). During the period extending from the thirteenth to the sixteenth century, two major episodes of drought (termed "megadroughts") occurred in the Great Plains. Weakly (1962) noted a 38-year drought extending from 1276 to 1313 in the tree-ring chronology for southwestern Nebraska -- the longest continuous drought in the past 750 years (Figure D-10). Two later periods of very severe drought, extending from 1539 to 1564, and from 1587 to 1605, apparently also occurred (Woodhouse and Overpeck, 1998). Reconstructions of regional precipitation in western North America were used (Fritts, 1965) to identify a drought beginning in southwestern North America around 1565 and spreading to all of temperate western North America by 1585.

Proxy records and archaeological information for the Great Plains began to be supplemented by historical accounts, beginning in the 17th century. Consequently, relatively drier periods of the 17th, 18th, and 19th centuries can be identified at a finer degree of temporal resolution than is possible for earlier periods of time (Figure D-11). On the basis of proxy records supplemented by historical accounts, seven years of severe drought have been identified in the Great Plains for the period 1750 through 1900 (Meko, 1992) -- 1751, 1808, 1855, 1861, 1863, 1864, and 1893. During that 150-year period, the most severe drought in the Platte River basin (Colorado, Nebraska, and Wyoming region) occurred during the 1860s, and lasted approximately six years.

Stockton and Meko (1975) determined that the period of 1845 to 1847 was the second-driest three-year period after the period 1934 to 1936 in the past 300 years in western and central North America. Cook *et al.*'s (1996, 1997, 1999) reconstructions of summer droughts indicate that the drought conditions of the 1840s probably had dissipated by 1849 in western and central North America (Woodhouse, 2001a). A drought that occurred in central Nebraska, eastern Wyoming and northeastern Colorado in the early 1870s was most widespread in 1872 and 1873 (Mock, 1991).

Reconstructed PDSI values can be used to refine the drought history of the past 300 years in the Great Plains in the vicinity of the Platte River Basin. Inspection of plots of PDSI values through time (Figures D-6, D-7, D-8, and D-12) indicates that PDSI values fluctuate around the long-term mean value of 0. Through any particular span of time, the area under the PDSI curve and above the zero axis is a measure of the relative degree of moist conditions during that time, and the area below the zero axis and above the PDSI curve is a measure of the relative degree of drought conditions during that time. Because droughts are climatic events that typically extend through periods greater than one year, the sum of the areas above and below the zero axis of the PDSI curve through a multi-year time period (an "integrated PDSI plot") should provide a clearer indication of the occurrence or absence of drought during that period of time.

A plot of multi-year integrated PDSI values was prepared for the period 1700 through 1975, using 25-year moving totals of reconstructed PDSI values for Grid Point 68 (corresponding to southwestern Nebraska) (Figure D-2). Examination of the integrated PDSI values (Figure D-13) indicates that the 10-year period centered on 1852 was the most severe drought in the past 300 years. Other notable droughts occurred between about 1803 and 1820, and about 1727 and 1757. According to this method of PDSI integration, the "Dust Bowl" period of the mid-1930s and the "Dry 50s" were manifestations of the same longer-term drought event, centered on the year 1943 and lasting about 20 years. By contrast, the 20-year period centered approximately on the year 1915 was by far the wettest period in the past 300 years.

These 19^{th}-century drought histories are in relatively good agreement with streamflow reconstructions for the western part of the Platte River basin (Figure D-12). Reconstructed mean annual streamflows for Middle Boulder Creek (Woodhouse, 2001a), were well below the long-term average flow (four years at 75 percent of average) from 1844 to 1852, with the exception of reconstructed mean annual streamflow for 1849, which was slightly above average. Two other notable periods of low mean annual streamflow occur in the Middle Boulder Creek reconstruction – the second-lowest flow in the entire reconstruction occurred in 1879, and the period 1884 to 1890 included seven consecutive years of below-average streamflow, with reconstructed streamflow in four of those years at 70 percent or less of the long-term average (Woodhouse, 2001a). Reconstructed streamflows also indicate that the mean annual streamflows in Middle Boulder Creek and Clear Creek were generally somewhat higher than average near the turn of the 20^{th} century (Figure D-12).

The dendroclimatic evidence suggests that prior to the late 13^{th} century, many droughts were at least decades in duration (Woodhouse and Overpeck, 1998). By contrast, the droughts since the 13^{th} century apparently have tended to be a decade or less in duration, with the exception of the late 16^{th}-century multi-decadal drought in southwestern North America. Droughts in the 20^{th} century have been characterized by moderate severity and comparatively short duration, as compared with the full range of past drought variability.

Examination of an alluvial chronology for a reach of the Republican River in south-central Nebraska, in conjunction with the alluvial and paleoclimatic records of the central Great Plains illustrate some of the problems inherent in relating fluvial activity to climate change (Martin, 1992). The alluvial and climatic records reveal that aerially synchronous incision, occurring through much of the Great Plains around 4,200 yr BP, was correlated with a shift to generally wetter climatic conditions. Aerially synchronous incision after 1,100 yr BP (A.D. 900) cannot be correlated with a dramatic change in climate, but may be a consequence of a multi-century period of relatively drier conditions or drought. Conditions appear to have been dry before and after the period of incision, but paleoclimatic data from that period lack sufficient detail for any but broad generalizations to be made. In addition, the numerous lacunae in the geomorphic and climatic records mitigate against definitive statements regarding the direct association of geomorphic changes with particular climatic events; and the dissimilar temporal resolutions of the alluvial and paleoclimatic records prior to historic time hinder attempts to generalize the response of fluvial systems to climate changes. Over relatively long (hundreds of years) and short (tens of years) time scales, the fluvial response to climatic shifts may depend on variables not discernible in the paleoclimatic record.

PALEOHYDROLOGIC RECONSTRUCTIONS AS SURROGATES FOR GREAT PLAINS HYDROLOGY

Reconstructed mean annual flows for Middle Boulder Creek and Clear Creek, Colorado were compared with mean annual flows derived from instrumental data (measured streamflows) for those streams, through their respective periods of record (1912 through 1987 for Middle Boulder Creek; 1928 through 1981 for Clear Creek) (Woodhouse, 2001a and 2001b). For each stream, the instrumentally-derived mean annual flow for each year in the period of record was compared with the paleohydrologically-reconstructed mean annual flow for the same year, to assess the degree of association between the historic streamflows and the reconstructed streamflows. Variables that are related in time and/or space (e.g., measured and reconstructed streamflows for a given year) also are related by their covariance – the joint variation of two variables about their common mean (Davis, 1986).

The degree of association of such related variables is readily evaluated using the *coefficient of determination* or *correlation coefficient* (Rock, 1988). The coefficient of determination is the ratio of the covariance of two variables to the product of their standard deviations, and is a measure of association between the two variables (in this case, the actual and derived streamflows for a particular year). The value of the coefficient of determination can range between 0.0 and 1.0 -- if there is no association between the variables, the value of the coefficient of determination is 0.0; perfect association is indicated by a coefficient of determination of 1.0. If the variables are directly correlated, the coefficient of determination is positive; if the variables are inversely correlated, the coefficient of determination is negative. In comparing reconstructed streamflows with actual streamflows for all years in the period of record, the value of the coefficient of determination would be 1.0, if proxy data (e.g., tree-ring reconstructions used to generate reconstructed streamflows) were a perfect predictor of actual streamflows.

The coefficient of determination resulting from comparing reconstructed streamflows with instrumentally-derived streamflows for Middle Boulder Creek through the period of record was 0.70 (Woodhouse, 2001a), indicating that the reconstructed mean annual streamflows generated for Middle Boulder Creek using proxy data are a reasonable predictor of mean annual streamflows in Middle Boulder Creek. The coefficient of determination resulting from comparing reconstructed streamflows with instrumentally-derived streamflows for Clear Creek through the period of record was 0.75 (Woodhouse, 2001b), indicating that the reconstructed mean annual streamflows generated for Clear Creek using proxy data also are a reasonable predictor of mean annual streamflows in Clear Creek.

Reconstructed streamflows for Middle Boulder Creek (for the period 1703 – 1937) and reconstructed streamflows for Clear Creek (for the period 1700 – 1935) were compared with reconstructed Palmer Drought Severity Indices (NOAA, 2001) derived for Grid Location 59 in central Colorado (Figures D-2 and D-12) for those periods of time, to assess the degree of association between mean annual streamflow and the relative drought conditions. Inspection of the reconstructed record suggests that reconstructed mean annual streamflows and Palmer Drought Severity Indices are related (Figure D-9); this is confirmed by the coefficients of determination (Table D-1), which indicate a relatively high degree of association between mean annual streamflow and PDSI values, at least for locations near the Colorado Front Range.

The association between mean annual streamflows and PDSI values suggests that reconstructed PDSI values can be used as a surrogate for streamflow conditions in the Great Plains – PDSI values indicating relatively drier conditions also would indicate relatively lower mean annual streamflows, while PDSI values indicating relatively wetter conditions also would indicate relatively greater mean annual streamflows. This conclusion also is in agreement with the qualitative comparison of drought records and streamflow reconstructions presented in the preceding section.

TABLE D-1
RESULTS OF COMPARISON OF RECONSTRUCTED MEAN ANNUAL STREAMFLOWS WITH PALMER DROUGHT SEVERITY INDICES
PLATTE RIVER CHANNEL DYNAMICS STUDY

Reconstructed Mean Annual Streamflow[a/]	Coefficient of Determination (R^2) for Comparison with PDSI Values[b/]
Middle Boulder Creek (1703 – 1937)	0.63
Clear Creek (1700 – 1935)	0.79

[a/] Reconstructed mean annual streamflow data from Woodhouse (2001a and 2001b).
[b/] Palmer Drought Severity Index (PDSI) values reconstructed for Grid Location 59, from NOAA (2001).

Mean annual streamflows derived from instrumental measurements for Middle Boulder Creek and Clear Creek through their periods of record then were compared with mean annual streamflows derived from instrumental measurements for the South Platte River at Julesburg, and for the Platte River at Overton, to assess the degree of association between streamflows in tributaries near the headwaters of the basin, and streamflows at more-distal locations downstream.

Inspection of mean annual streamflows for the period of record (Figure D-4) suggests that headwaters streamflow is related to some degree to streamflow further downstream; this is confirmed by the coefficients of determination (Table D-2) calculated for the various relationships. Mean annual streamflow in Middle Boulder Creek is highly correlated with mean annual streamflow in Clear Creek (coefficient of determination of 0.84); this association becomes less pronounced with increasing distance downstream along the South Platte River and Platte River (Table D-2). Similarly, mean annual streamflow in the South Platte River at Julesburg is highly correlated with mean annual streamflow in the Platte River at Overton (coefficient of determination of 0.85).

Mean annual streamflow in Clear Creek is correlated with mean annual streamflow in the South Platte River at Julesburg to a moderate degree, but is nearly uncorrelated with mean annual streamflow in the Platte River at Overton. Despite the decrease in association with increasing distance downstream from the headwaters, the high degree of correlation between mean annual streamflows in the two headwaters streams (Middle Boulder Creek and Clear Creek), and the moderate degree of correlation between mean annual streamflows in Clear Creek and the South Platte River at Julesburg, suggest that reconstructed streamflows for Middle Boulder Creek and Clear Creek can be used as surrogates for hydrologic conditions through much of the Platte River basin, at least in a qualitative sense.

TABLE D-2
RESULTS OF COMPARISON OF ANNUAL STREAMFLOWS IN HEADWATER AND DOWNSTREAM LOCATIONS
PLATTE RIVER CHANNEL DYNAMICS STUDY

Mean Annual Streamflow[a/]	Coefficient of Determination (R^2) for Comparison			
	Middle Boulder Creek	Clear Creek	South Platte River at Julesburg	Platte River at Overton
Middle Boulder Creek (1908 – 1994)	1.00			
Clear Creek (1928 – 1981)	0.84	1.00		
South Platte River at Julesburg (1903 – 1999)	0.46	0.67	1.00	
Platte River at Overton (1931 – 1999)	0.44	0.39	0.85	1.00

[a/] Mean annual streamflows from U.S. Geological Survey (2001).

RECENT GEOMORPHIC HISTORY OF GREAT PLAINS STREAMS

Review of the technical literature demonstrates that alternating periods of incision (degradation or erosion) and aggradation have affected numerous, and perhaps all streams in the Great Plains region (Wenzel *et al.*, 1946; Leopold and Miller, 1954; Brice, 1966; Brakenridge, 1980; Osterkamp *et al.*, 1987; Martin, 1992; May 1992) during the past several thousand years. These episodic occurrences have resulted in the addition (or removal) of material totaling tens to hundreds of feet in thickness to (or from) floodplains in the region. During the same period, fluvial systems in the temperate zone throughout the world have undergone large-scale changes in hydraulic and hydrologic characteristics, and in planform, changing from braided to meandering planforms (Kozarski, 1991; Baker, 1991; Starkel, 1991b), and sometimes from meandering to braided planforms (Schumm and Lichty, 1963). These transformations may require periods approaching geologic time (Schumm, 1968), but can occur in rapid and dramatic fashion (Chang, 1986; Schumm and Lichty, 1963; Schumm, 1974). Generally speaking, these geomorphic changes appear to occur in response to climatic changes (Thornes and Gregory, 1991).

Two or three periods of aggradation and two periods of degradation or incision appear to have occurred on a region-wide scale throughout the Great Plains within the past 2,000 years (Figure D-14). A period of aggradation, beginning about 1,800 yr BP was noted by May (1992) in the valley of the South Loup River, and may correspond with the terminal phases of a stage of aggradation reported by Brakenridge (1980) for a location in the southern Great Plains (Figure D-1). Aggradation apparently was followed by an episode of rapid incision that occurred between about 1,300 yr BP (Brakenridge, 1980) and 1,100 yr BP (Martin, 1992). A second, rapid period of aggradation began sometime after about 1,050 yr BP (Brakenridge, 1980; May 1992). Rapid incision apparently occurred at about 500 yr BP, and may have been followed by aggradation nearly to the present time (Brakenridge, 1980).

Martin (1992) observed that in general, a long-term shift to more humid climatic conditions on the landscape/watershed scale in the Great Plains appears to result in channel incision, because increased vegetation cover reduces the delivery of sediment to channels, and can reduce the tendency of streams to adapt to changing flow conditions by lateral aggradation/degradation. Conversely, a long-term change to more arid conditions on the landscape/watershed scale typically causes vertical channel aggradation, because the reduction in vegetation cover increases delivery of sediment to channels. Grasslands (which predominate in much of the Platte River basin) where dense, are almost as effective as woodland areas and forests in retarding surface runoff and erosion, but they lose much of their effectiveness during drought conditions. Also during droughts, grasslands become susceptible to severe erosion and deposition by Aeolian processes (Knox, 1983). At the basin scale, this may be an expression of the relationship derived by Langbein and Schumm (1958), in which sediment yield in a basin is directly related to annual precipitation and runoff, until the point that vegetative cover has increased to the extent that it retards erosion, and further increases in runoff and precipitation result in decreasing yields of sediment.

On the other hand, during shorter time periods, and at the river/floodplain scale, the opposite occurs: during dry periods woodland expands into channels as they narrow (i.e., woody vegetation increases). Decreases in vegetation (grassland and upland forest) during dry periods and increases in riparian woodland can occur simultaneously in different parts of the landscape (Johnson, 1994). These differences in scale of time and space need to be appreciated if the interactions among climate, vegetation cover, and geomorphology are to be fully understood. If these observations are correct, then the period of aggradation, beginning about 1,800 yr BP, may be associated with the two-century drought that began around 250 A.D. (Figure D-9). The period of aggradation that began sometime after about 1,050 may be associated with the multi-century drought centered at approximately 1,100 A.D. (Figure D-9), and aggradation through much of the past 300 to 500 years may be a consequence of the generally dry conditions during much of that period (Figures D-9, D-10, D-11, and D-13). Episodes of incision or degradation probably occurred before, between and after these intervals of aggradation. In particular, conditions much wetter than normal apparently obtained after the beginning of the 20th century (Figure D-13), and may have initiated a cycle of degradation.

Drought conditions appear to occur more frequently in the Great Plains, and to last for longer periods of time than do relatively wetter conditions (Figures D-9, D-10, and D-11). Therefore, the geomorphic behavior of Great Plains streams probably follows a pattern of aggradation for relatively long periods of time. However, when wetter periods do occur, degradation apparently occurs at a relatively rapid rate (Brakenridge, 1980).

CONCLUSIONS

Variabilities in geomorphic processes and climate in the Great Plains and western United States through the past 2,000 years were investigated in this study. The technical literature regarding geomorphic processes and change, tree-ring analyses, stratigraphic evidence, and climatic conditions and changes in the Great Plains region was reviewed. Precipitation and tree ring data for the Great Plains were collected and evaluated to identify relatively wetter and drier periods (especially periods of drought conditions) through the 2,000-year period, with particular emphasis on the Platte River basin. Based on examination of the compiled literature and research results, geomorphic and climatic trends for the study area were identified.

The stratigraphy and knowledge of surficial-processes of the Great Plains reveal that significant cycles of erosion, deposition and stability (EDS) occur. As documented here these are ascribed to extrinsic impacts of climate in the Platte River (because tectonic drivers are not operative). In light of the known changes in global and regional climatic conditions and their oscillations, it is perfectly reasonable to attribute far-reaching changes in the Platte with climate influences (Thornes and Gregory, 1991). This view is in contrast to the approach used by the EIS team, who did not include climate in their candidate list of factors causing the extensive changes in hydrology and channel morphology of the entire river (Murphy and Randle, 2001a).

Despite the uncertainties in proxy data and other aspects of paleoclimatic interpretation, the following summary statements can be made regarding climatic cycling and its effects on the morphology of the Platte River system.

1. Dramatic geomorphic and far-reaching changes have occurred in the Great Plains rivers within the past 1,000 to 2,000 years. These have included episodes of aggradation, degradation and stability, which have resulted in the

addition (or removal) of tens to hundreds of feet of material to (from) the channel systems.

2. Generally speaking, these far-reaching geomorphic changes occur primarily in response to climatic changes.

3. Occasionally, the climatic shifts also have been dramatic. Available paleoclimatic data suggest that a drought of approximately the magnitude and severity of the 1930s "Dust Bowl" has occurred once or twice each century over the past 300 to 400 years, and that a decadal-length drought, of generally greater severity, has occurred on average once every 500 years.

4. In general, a shift to more humid climatic conditions in the Great Plains appears to result in channel incision; and conversely, a change to more arid conditions typically causes vertical channel aggradation.

5. Because 1900 to 1930 was much wetter than normal for the Great Plains, this short-term climatic shift may have initiated a natural cycle of channel incision in Great Plains streams.

6. Drought conditions appear to occur more frequently in the Great Plains, and to last for longer periods of time than do relatively wetter conditions. Therefore, because aggradation is associated with dry conditions, occurring over large areas and through extended periods of time, the geomorphic behavior of Great Plains streams probably follows a pattern of aggradation for relatively long periods of time. However, when wetter periods occur, degradation apparently occurs at a relatively rapid rate.

7. The period from 1900 to 1930 was by far the wettest period in the Great Plains for the past 300 years. Therefore, the identification by the EIS team of the period 1902 – 1909 as representative of average baseline conditions on the Platte River system prior to construction of significant numbers of retention or diversion structures is inappropriate and biases their conclusions regarding the need to restore annual and peak flows based on this baseline.

8. Although some of the changes in the Platte River channel undoubtedly are a consequence of past construction of retention and diversion structures, these changes are known to be typically, specifically, and hydraulically limited in extent. System-wide changes such as unvegetated channel narrowing over several hundred miles is more likely a direct consequence of climatic changes.

The Platte River is not homogeneous. It contains highly variable planforms, thalweg slopes, types and extent of vegetative encroachments, channel forms, sediment sizes, bed forms, numbers of channels, and cross-sectional dissimilarities. It courses through a region with highly variable meteorology, being moderately arid in the West and humid in the East. Any conclusions regarding hydrologic and morphologic impacts of water storage and diversion, especially channel incision, cannot be generalized over the length of the river, or even over reaches.

Storage and diversion are known to impact morphology, but experience and even simple analytical tools such as Lane's Law dictate that the extent is limited. In contrast, geomorphic effects of climatic cycling are far-reaching. As shown in this study, entire Great Plains river systems aggrade and degrade with swings in climate, with incision occurring at a significantly faster rate than aggradation.

The most significant conclusion of this study is that this far-reaching versus limited-extent comparison offers a means of assessing the relative contributions of climate versus storage and diversion to morphologic changes. Far-reaching morphologic effects such as true narrowing of the effective discharge channel (see Task A3 report), or true degradation of the bed, or true coarsening of sediment throughout this length of river (see Task A2 report) would most-definitely be climate related. Morphologic changes over limited distances, such as the documented incision for about 13 miles downstream of Kingsley Dam or for a few miles below the J-2 return, would clearly be related to storage and diversion. Though disputed in the Task A3 report, the suggestion that the vegetation expansion which has occurred throughout the entire river length is "morphologic" would mean, by the preponderance of evidence in this report, that it must be *climate-related*. Accepting the "morphologic" argument without recognizing the far-reaching extent, and accepting the evidence that climate is the primary driving force for changes this extensive, and occurring as rapidly as alleged by Williams (1978) and Murphy and Randle (2001a), would deny the tenets of the field of Geomorphology. If one asserts that the vegetation expansion which has occurred throughout the river is morphologic, then the preponderance of geomorphologic literature would require that climate be accepted as the most reasonable, primary cause.

The geomorphologic and fluvial hydraulic literature does not support the assertion that morphologic changes as extensive as observed in the Platte River occur except through the erosion-deposition-stability (EDS) process described in this report. Storage and diversion do not cause changes this extensive. The preponderance of literature supports a conclusion that magnitudes of change due to historic, surficial EDS processes, driven by climatic change, exceed by far the relatively limited-extend changes that can be scientifically attributed to storage and diversion.

It is therefore concluded that only limited-extent morphologic changes that typically occur as the result of storage and diversion should be attributed to these causes, and further investigations should focus in this direction. The extensive changes in the river, if morphologic, can only be described scientifically as part of the natural surficial EDS processes driven by climatic cycles.

BIBLIOGRAPHY

Ahlbrandt, T.S., and S.G. Fryberger. 1980. *Eolian Sedimentation in the Nebraskan Sandhills*. U.S. Geological Survey Professional Paper 1120-A.

Baker, V. R. 1991. A Bright Future for Old Flows, *in* Starkel, L., Gregory, K.J., and J.B. Thornes (eds.) *Temperate Palaeohydrology*. John Wiley & Sons, Inc. London. pp. 497-520.

Bradley, R.S. 1999. *Paleoclimatology: Reconstructing Climates of the Quaternary*. Academic Press, Inc. San Diego, California.

Bradley, R.S. and P.D. Jones (eds.). 1992. *Climate Since A.D. 1500*. Routledge Publishers, Inc. New York, New York.

Brakenridge, G.R. 1980. Widespread episodes of stream erosion during the Holocene and their climatic cause. *Nature* 283:655-666.

Brice, J.C. 1966. *Erosion and Deposition in the Loess-Mantled Great Plains, Medicine Creek Drainage Basin, Nebraska.* U.S. Geological Survey Professional Paper 352-H.

Brockway, C.G. and A. A. Bradley. 1995. Errors in streamflow drought statistics reconstructed from tree ring data. *Water Resources Research* 31(9):2279-2293.

Carlson, M.E. 1963. *The Development of Irrigation in Nebraska, 1854-1910*. University of Nebraska. Lincoln, Nebraska. Doctoral Dissertation.

Champe, J.L. 1946. *Ash Hollow Cave*. University of Nebraska, Lincoln, Nebraska. New Series No. 1.

Chang, H.H. 1985. River morphology and thresholds. *Journal of Hydraulic Engineering* 111(3).

Chang, H.H. 1986. River channel changes -- Adjustments of equilibrium. *Journal of Hydraulic Engineering* 112(1).

Colorado Climate Center (CCC). 2000.

Cook, E.R., D.M. Meko, D.W. Stahle, and M.K. Cleaveland. 1996. Tree-Ring Reconstructions of Past Drought Across the Coterminous United States: Tests of a Regression Method and Calibration/Verification of Results, *in* J.S. Dean, D.M. Meko, and T.W. Swetnam (eds.). *Tree Rings, Environment, and Humanity*. Radiocarbon. pp. 155-169.

Cook, E.R., D.M. Meko, and C.W. Stockton. 1997. A new assessment of possible solar and lunar forcing of the bi-decadal drought rhythm in the western United States. *Journal of Climate* 10:1343-1356.

Cook, E.R., D.M. Meko, D.W. Stahle, and M.K. Cleaveland. 1999. Drought reconstructions for the continental United States. *Journal of Climate* 12:1145-1162.

Davis, J.C. 1986. *Statistics and Data Analysis in Geology*. John Wiley & Sons, Inc. New York, New York. 2nd ed.

Diaz, H.F. 1983. Some aspects of major dry and wet periods in the contiguous United States. *Journal of Climate and Applied Meteorology* 22:3-16.

Fritts, H.C. 1965. Tree-ring evidences for climatic changes in western North America. *Monthly Weather Review* 93:421-443.

Fritts, H.C. and X.M. Shao. 1992. Mapping climate using tree-rings from western North America, *in* R.S. Bradley and P.D. Jones (eds.). *Climate Since A.D. 1500*. Routledge Press, Inc. New York, New York. pp. 269-295.

Fritts, H.C., G.R. Lofgren, and G.A. Gordon. 1981. Reconstructing Seasonal to Century Time Scale Variations in Climate from Tree-Ring Evidence, *in* Wigley, T.M.L., M.J. Ingram, and G. Farmer (eds.). *Climate and History: Studies in Past Climates and their Impact on Man*. Cambridge University Press. Cambridge, England.

Fritz, S.C. 1996. Paleoclimnological records of climatic change in North America. *Limnology and Oceanography* 41(5):882-889.

International Tree-Ring Data Bank. Available on the Internet at http://www.noaa.

Jarrett, R.D. 1991. Paleohydrology and its Value in Analyzing Floods and Droughts, *in* Paulson, R.W., Chase, E.B., Roberts, R.S., and D.W. Moody (eds.). *National Water Summary 1988-89 – Hydrologic Events, Floods, and Droughts*. U.S. Geological Survey Water-Supply Paper 2375.

Johnson, W.C. 1994. Woodland expansion in the Platte River, Nebraska – Patterns and causes. *Ecological Monographs* 64(1):45-84.

Karl, T.R., Knight, R.W., Easterling, D.R., and R.G. Quayle. 2001. Indices of climate change for the United States. Available on the Internet at http://www.ncdc.noaa.gov/gcps/papers/icc.html. NOAA/National Climatic Data Center. Asheville, North Carolina.

Knox, J.C. 1983. Responses of River Systems to Holocene Climates, *in* Wright, H.E. Jr., (ed.) *Quaternary Environments of the United States – Vol 2: The Holocene*. University of Minnesota Press. Minneapolis, Minnesota. pp. 26-41.

Kozarski, S. 1991. Warta – A Case Study of a Lowland River, *in* Starkel, L., Gregory, K.J., and J.B. Thornes (eds.) *Temperate Palaeohydrology*. John Wiley & Sons, Inc. London. pp. 189-215.

Laird, K.R., S.C. Fritz, K.A. Maasch, and B.F. Cumming. 1996. Greater drought intensity and frequency before AD 1200 in the northern Great Plains, USA. *Nature* 384:552-554.

LaMarche, V.C. Paleoclimatic inferences from long tree-ring records. *Science* 183(4129):1043-1048.

Langbein, W.B., and S.A. Schumm. 1958. Yield of sediment in relation to mean annual precipitation. *Transactions of the American Geophysical Union* 39:1076-1984.

Leopold, L.B., and J.P. Miller. 1954. *A Postglacial Chronology for Some Alluvial Valleys in Wyoming.* U.S. Geological Survey Water-Supply Paper 1261

Martin, C. 1992. The response of fluvial system to climatic change: An example from the central Great Plain. *Physical Geography* 13(2):101-114.

May, D. 1992. Lake Holocene valley-bottom aggradation and erosion in the South Loup river valley, Nebraska. *Physical Geography* 13(2):115-132.

Meko, D., C.W. Stockton, and W.R. Boggess. 1995. The tree-ring record of severe sustained drought. *Water Resources Bulletin* 31:789-801.

Meko, D.M. 1992. Dendroclimatic Evidence from the Great Plains of the United States, *in* R.S. Bradley and P.D. Jones (eds.). *Climate Since A.D. 1500*. Routledge Press, Inc. New York, New York. pp. 312-330.

Miller, G. 1978. *History of Platte River Flows*. U.S. Fish and Wildlife Service, Grand Island, Nebraska. Unpublished document.

Mock, C.J. 1991. Drought and precipitation fluctuations in the Great Plains during the nineteenth century. *Great Plains Research* 1(1):26-56.

Muhs, D.R. 1985. Age and paleoclimatic significance of Holocene sand dunes in northeastern Colorado. *Annals of the Association of American Geographers* 75:566-582.

Muhs, D.R., and V.T. Holliday. 1995. Evidence of active dune sand on the Great Plains in the 19th century from accounts of early explorers. *Quaternary Research* 43:198-208.

Muhs, D.R., Swinehart, J.B., Cowherd, S.D., Mahan, S.A., Bush, C.A., Madole, R.F., and R. B. Maat. 1997. Late Holocene eolian activity in the mineraologically mature Nebraska Sand Hills. *Quaternary Research* 48:162-176.

Murphy, P.J., and T.J. Randle. 2001a. *Platte River Channel: History and Restoration.* U.S. Bureau of Reclamation and U.S. Fish and Wildlife Service. Draft. January.

Murphy, P.J., and T.J. Randle. 2001b. *Platte River Sediment Transport and Riparian Vegetation Model.* U.S. Bureau of Reclamation and U.S. Fish and Wildlife Service. Draft. January.

Nagel, H.G. and M.S. Dart. 1980. Platte River evapotranspiration: A historical perspective in central Nebraska. *Transactions of the Nebraska Academy of Sciences* VIII:55-76.

National Climatic Data Center (NCDC). 2000. *Climate of 2000 - Annual Review, Preliminary Report*. Available on the Internet at http://www.ncdc.noaa.gov/ol/climate/research/2000/preann2000/preann2000.html.

National Oceanic and Atmospheric Administration (NOAA). 2001. *The International Tree Ring Database*. Available on the Internet at http://www.ngdc.noaa.gov/paleo/pdsi.html

Northern Prairie Wildlife Research Center. No date. *Platte River Ecology Study: Development of Woody Vegetation*. U.S. Geological Survey. Available on the Internet at http://www.npsc.nbs.gov/resource/othrdata/platteco/vegetate.htm.

Osterkamp, W.R., Fenton, M.M., Gustavson, T.C., Hadley, R.F., Holliday, V.T., Morrison, R.B., and T.J. Toy. 1987. Great Plains, *in* Graf, W.L. (ed.). *Geomorphic Systems of North America.* Geological Society of America Centennial Special Volume No. 2. Boulder, Colorado.

Overpeck, J.T. 1996. Warm climate surprises. *Science* 271:1820-1821.

Phillips, R.L. and J. McGowan. 1994. *Tree Rings: Timekeepers of the Past*. U.S. Geological Survey Circular.

Platte River Watershed Program. 1999. Proceedings of the Tenth Platte River Basin Ecosystem Symposium. Kearney, Nebraska.

Rinaldo, A., Dietrich, W.E., Rigon, R., Vogel, G.K., and I. Rodriguez-Iturbe. 1995. Geomorphological signatures of varying climate. *Nature* 374:633-635.

Ritter, D.F. 1978. *Process Geomorphology*. Wm. C. Brown Company, Publishers. Dubuque, Iowa.

Rock, N.M.S. 1988. *Numerical Geology*. Springer-Verlag, Inc. New York, New York.

Ruhe, R.V. 1975 *Geomorphology – Geomorphic Processes and Surficial Geology*. Houghton Miflin Company. Boston, Massachusetts.

Schulman, E. 1938. Nineteen centuries of rainfall history in the southwest. *Bulletin of the American Meteorological Society*. 19(5): 211-216.

Schumm, S.A. 1968. *River Adjustment to Altered Hydrologic Regimen -- Murrumbidgee River and Paleochannels, Australia.* U.S. Geological Survey Professional Paper 598.

Schumm, S.A. 1974. Geomorphic Thresholds and Complex Response of Drainage Systems, *in* M. Morisawa, (ed.). *Fluvial Geomorphology: Proceedings of the Fourth Annual Geomorphology Symposia Series, Binghamton, New York.* George Allen & Unwin, Inc. Boston, Massachusetts. pp. 299-310.

Schumm, S.A. 1981. Evolution and Response of the Fluvial System – Sedimentologic Implications, *in* Society of Economic Paleontologists and Mineralogists Special Publication No 31. pp. 19-29.

Schumm, S.A., and R.W. Lichty. 1963. *Channel Widening and Flood-Plain Construction Along Cimarron River in Southwestern Kansas.* U.S. Geological Survey Professional Paper 352-D.

Sidle, J.G. and C.A. Faanes. *Platte River Ecosystem Resources and Management, with Emphasis on the Big Bend Reach in Nebraska*. . U.S. Fish and Wildlife Service. Grand Island, Nebraska. Available on the Internet at http://www.npwrc.usgs.gov/resource/othrdata/platte2/platte2.htm

Starkel, L. 1991a. Characteristics of the Temperate Zone and Fluvial Paleohydrology, *in* Starkel, L., Gregory, K.J., and J.B. Thornes (eds.) *Temperate Palaeohydrology*. John Wiley & Sons, Inc. London. pp. 1-12.

Starkel, L. 1991b. Long-Distance Correlation of Fluvial Events in the Temperate Zone, in Starkel, L., Gregory, K.J., and J.B. Thornes (eds.) *Temperate Palaeohydrology*. John Wiley & Sons, Inc. London. pp. 473-495.

Starkel, L. 1991c. The Vistula River Valley – A Case Study for Central Europe, *in* Starkel, L., Gregory, K.J., and J.B. Thornes (eds.) *Temperate Palaeohydrology*. John Wiley & Sons, Inc. London. pp. 171-188.

Stockton, C.W. and D.M. Meko. 1975. A long-term history of drought occurrence in western United States as inferred from tree rings. *Weatherwise* 28(6):244-249.

Stockton, C.W. and D.M. Meko. 1983. Drought recurrence in the Great Plains as reconstructed from long-term tree-ring records. *Journal of Climate and Applied Meteorology 22:17-29.*

Stokes, M.A. and T.L. Smiley. 1968. *An Introduction to Tree-Ring Dating.* The University of Chicago Press. Chicago, Illinois.

Sundborg, A., and M. Jansson. 1991. Hydrology of Rivers and River Regimes, *in* Starkel, L., Gregory, K.J., and J.B. Thornes (eds.) *Temperate Palaeohydrology*. John Wiley & Sons, Inc. London. pp. 13-29.

Teele, R.P. 1905. *Water Rights on Interstate Streams: The Platte River and Tributaries*. U.S. Department of Agriculture, Office of Experiment Stations. Government Printing Office, Washington, D.C. Bulletin No. 157.

Thornes, J.B., and K.J. Gregory. 1991. Unfinished Business – A Continuing Agenda, *in* Starkel, L., Gregory, K.J., and J.B. Thornes (eds.) *Temperate Palaeohydrology*. John Wiley & Sons, Inc. London. pp. 521-536.

U.S. Geological Survey (USGS). 2001. Annual Summary Statistics for Surface-Water Discharges. Available on the Internet at http://water.usgs.gov/nwis/annual /calendar_year

Weakly, H.E. 1962. History of drought in Nebraska. *Journal of Soil and Water Conservation* 17(6):271-274.

Wenzel, L.K., Cady, R.C., and H.A. Waite. 1946. *Geology and Ground-Water Resources of Scotts Bluff County, Nebraska*. U.S. Geological Survey Water-Supply Paper 943.

Wigley, T.M.L., M.J. Ingram, and G. Farmer (eds.). 1981. *Climate and History: Studies in Past Climates and Their Impact on Man*. Cambridge University Press. Cambridge, England.

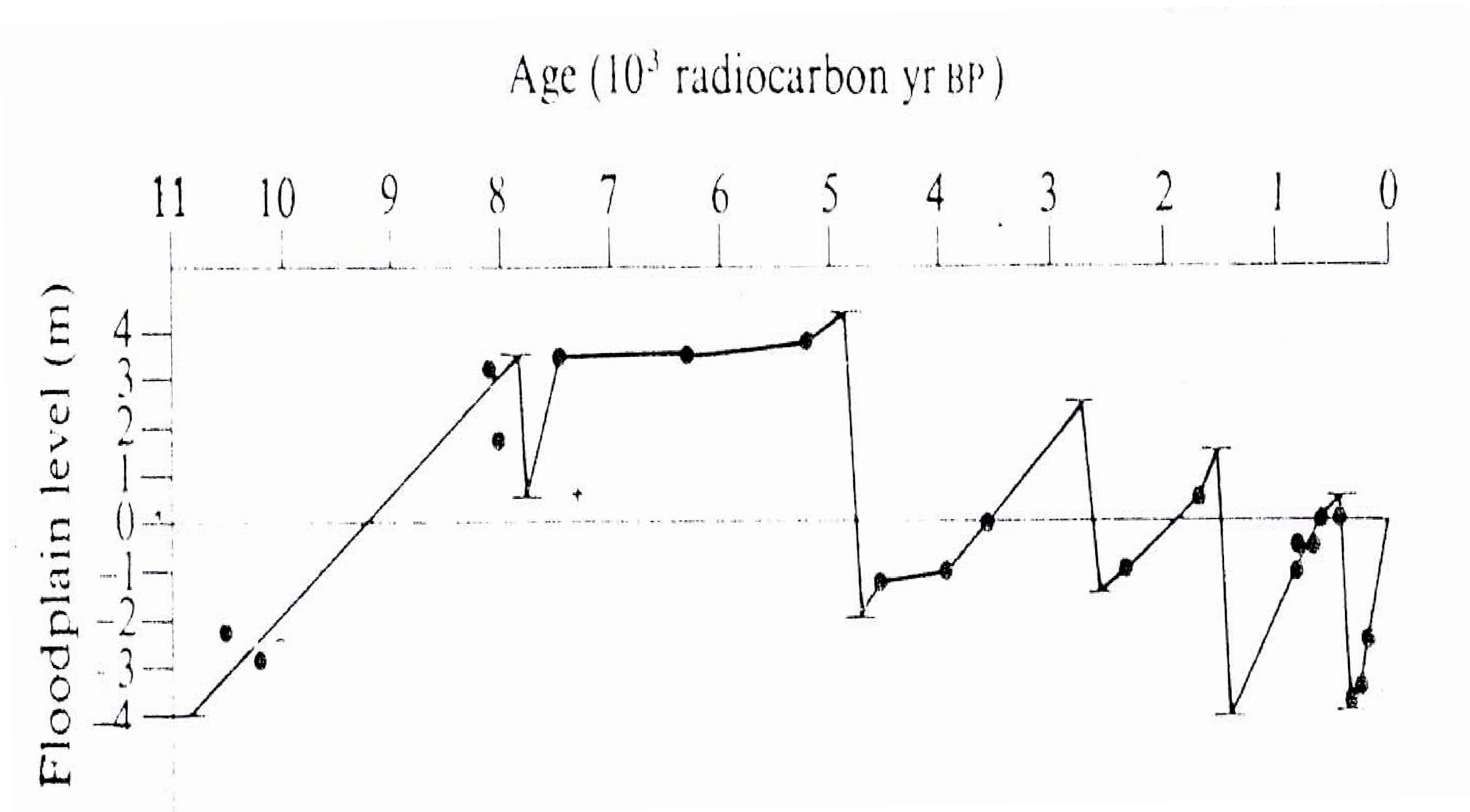
Williams, G.P. 1978. *The Case of the Shrinking Channels - the North Platte and Platte Rivers in Nebraska*. Geological Survey Circular 781. U.S. Department of the Interior. United States Government Printing Office. Washington D.C.

Woodhouse, C.A and J.T. Overpeck. 1998. 2,000 years of drought variability in the central United States. *Bulletin of the American Meteorological Society* 79(12):2693-2714.

Woodhouse, C.A. 2001a. A tree-ring reconstruction of streamflow for the Colorado Front Range. *Journal of the American Water Resources Association* 37(3):1-9.

Woodhouse, C.A. 2001b. Annual Flow Reconstruction for Clear Creek, Colorado. Available on the Internet at http://www.

FIGURES



After Braxenridge (1980).

FIGURE D-1

TERRACE ELEVATIONS OF POMME DE TERRE RIVER

Platte River Channel Dynamics Study

PARSONS
Denver, Colorado

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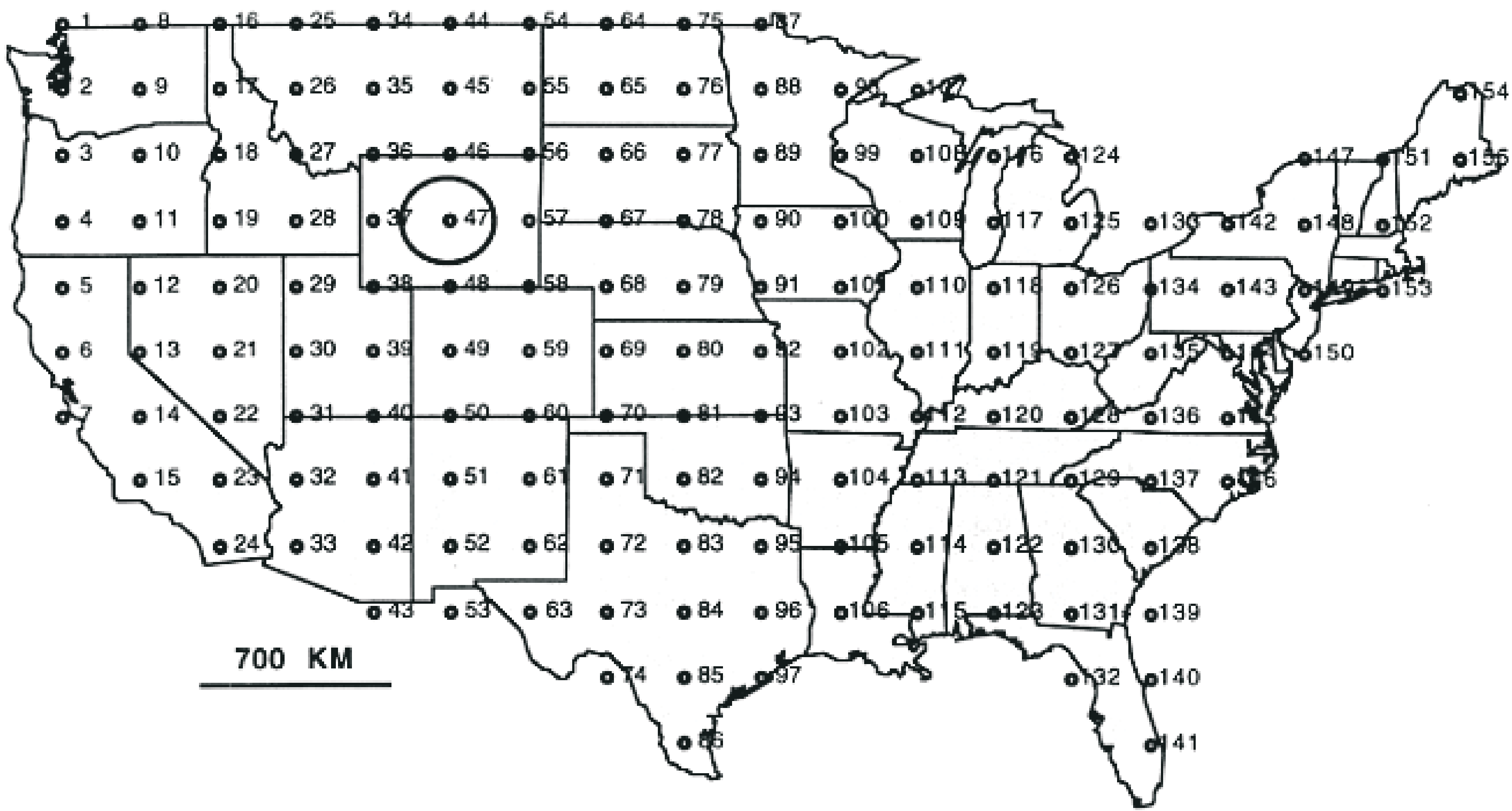


NOTE: Numbered grid points indicate locations of the 2 x 3 degree grid on which Palmer Drought Severity indices (PDSIs) were reconstructed from tree rings. The circle around grid point 47 indicates the size of the 150 kilometer search radius used for locating single-station PDSI records for interpolation to each grid point.

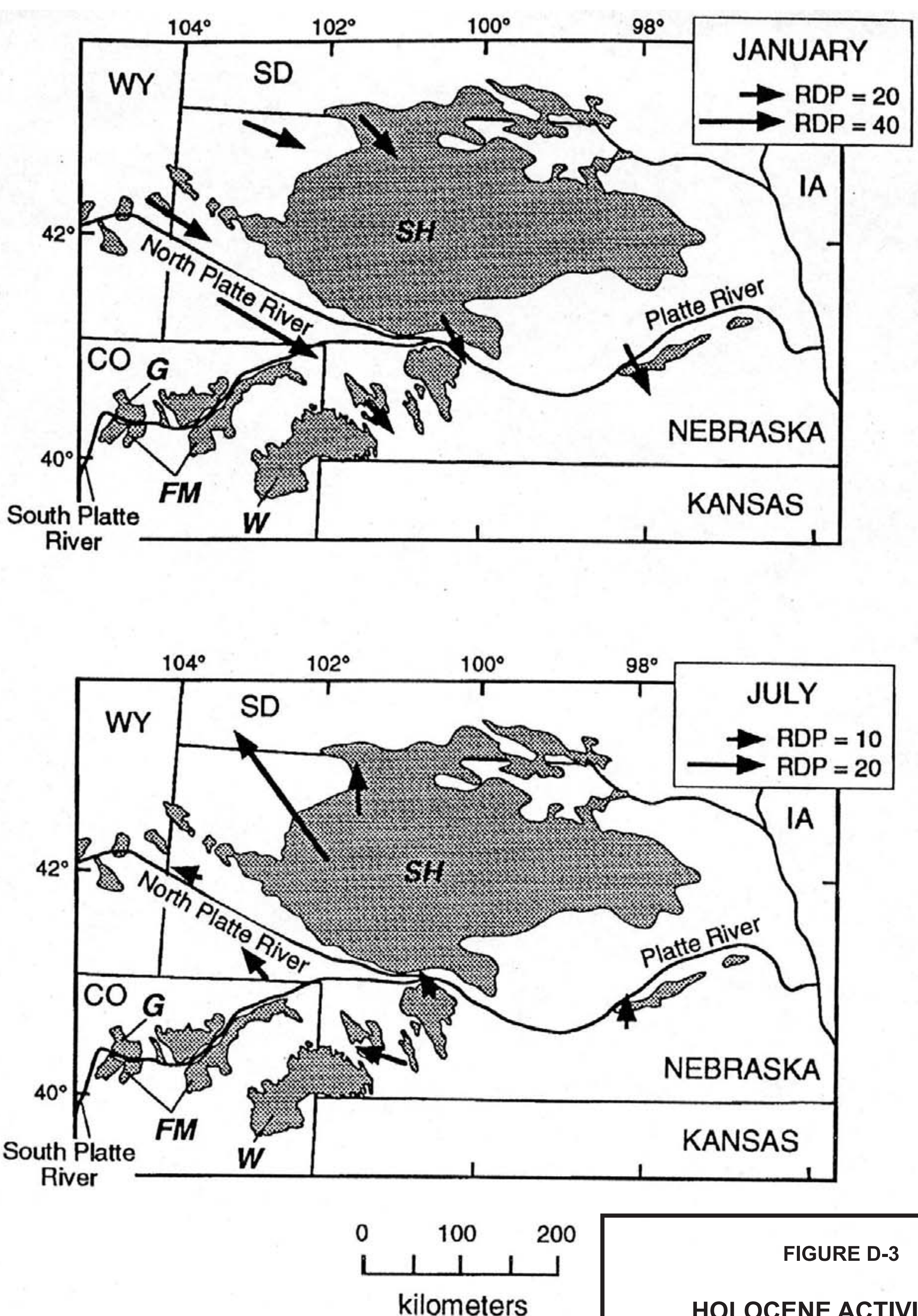
FIGURE D-2

PALMER DROUGHT SEVERITY INDEX MAP

Platte River Channel Dynamics Study

PARSONS
Denver, Colorado

draw\739921c.cdr pg1 ma 4/23/03



Note: RDP →

Relative Drift Potential (RDP) vector indicates relative tendency of sand-sized material to move in a particular direction.

After Muhs, et al., 1997.

FIGURE D-3

HOLOCENE ACTIVITY OF NEBRASKA SAND HILLS

Platte River Channel Dynamics Study

PARSONS
Denver, Colorado

draw\739921e.cdr bbs 2/5/02

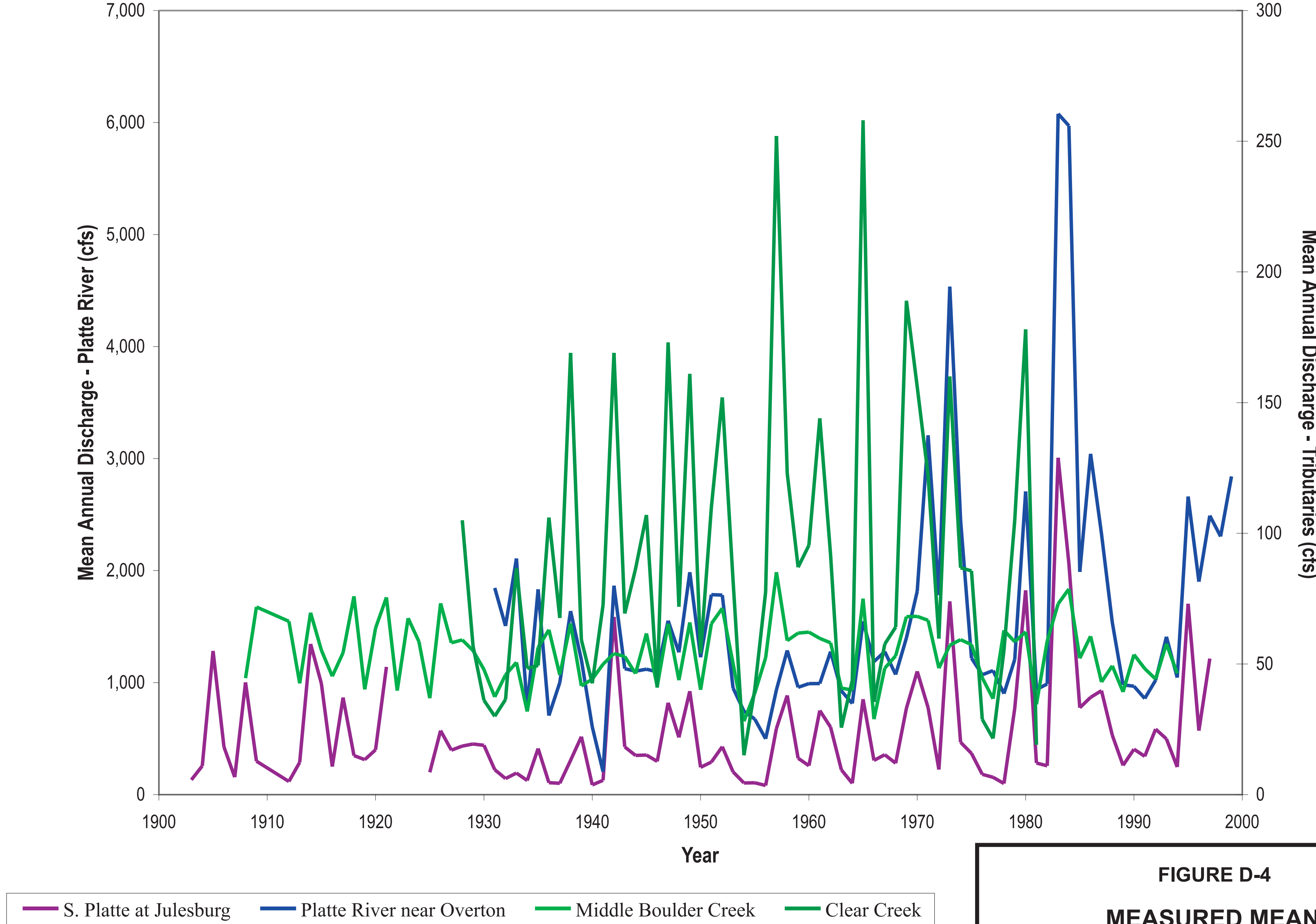


FIGURE D-4

MEASURED MEAN ANNUAL DISCHARGE

Platte River Channel Dynamics Study

PARSONS
Denver, Colorado

draw\739921d.cdr pg1 BBS 2/5/02

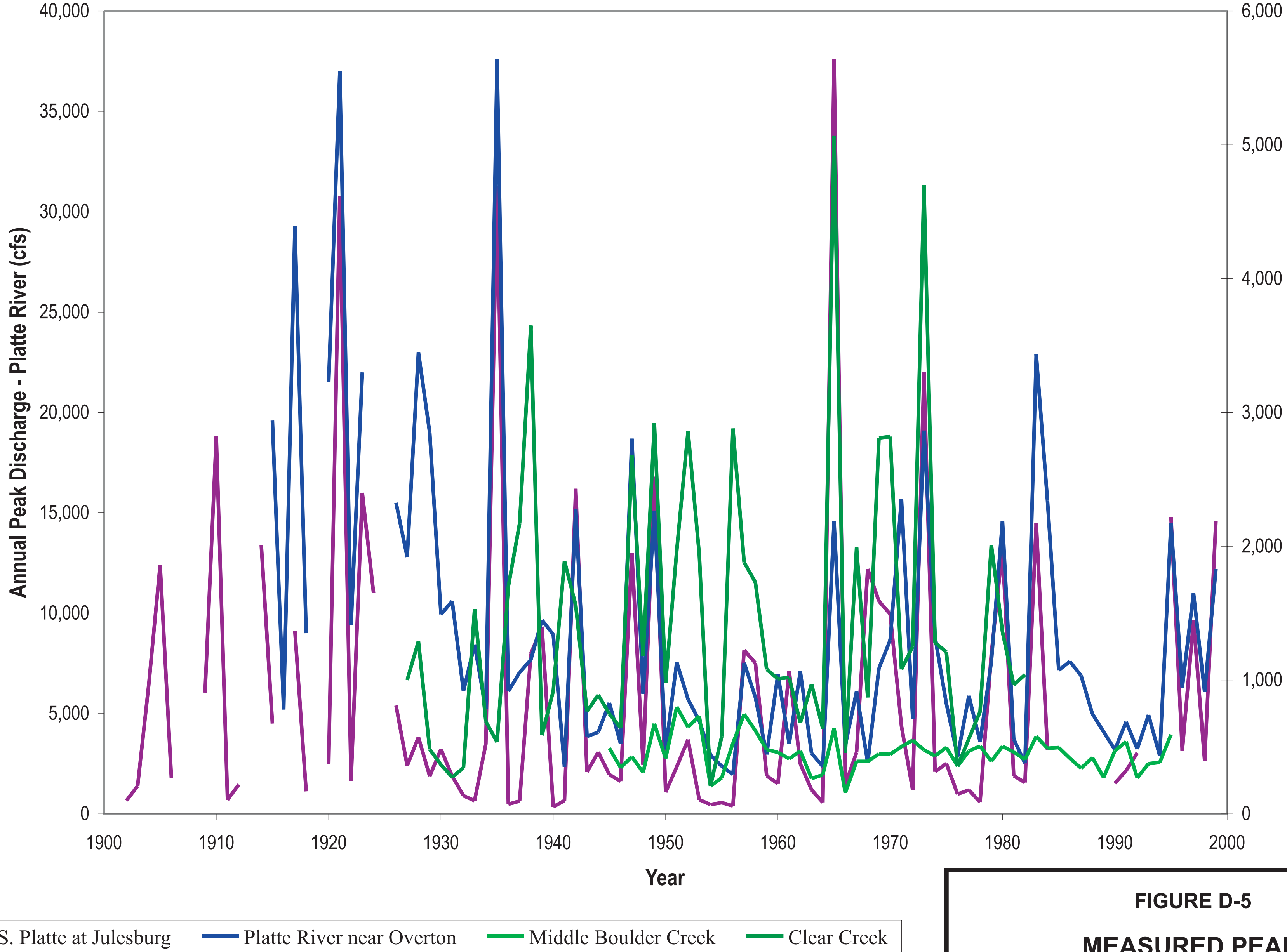


FIGURE D-5

MEASURED PEAK ANNUAL DISCHARGE

Platte River Channel Dynamics Study

PARSONS
Denver, Colorado

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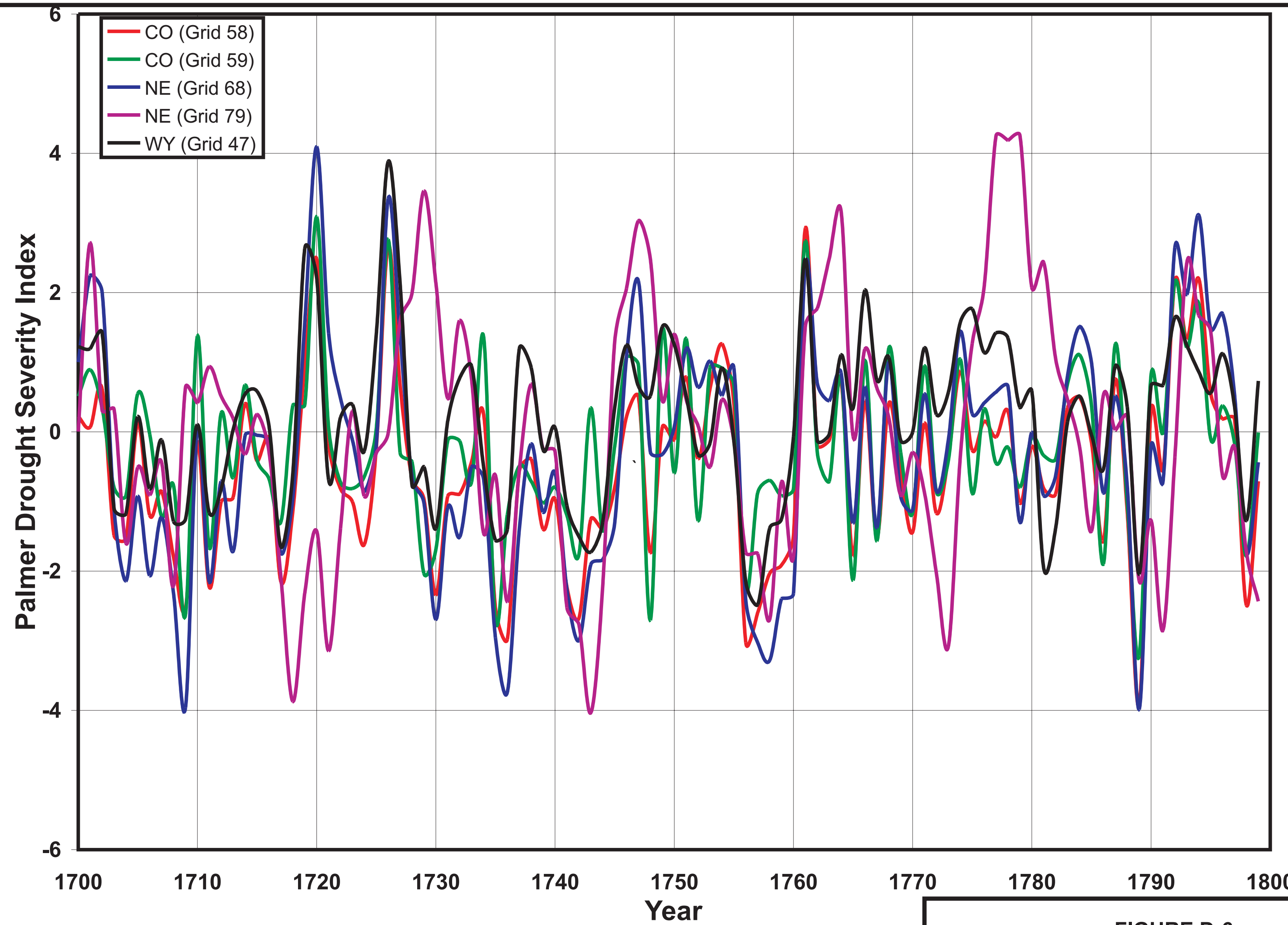

FIGURE D-6

PALMER DROUGHT SEVERITY INDEX 1700-1799

Platte River Channel Dynamics Study

PARSONS
Denver, Colorado

draw\739921c.cdr pg2 bbs 2/5/02

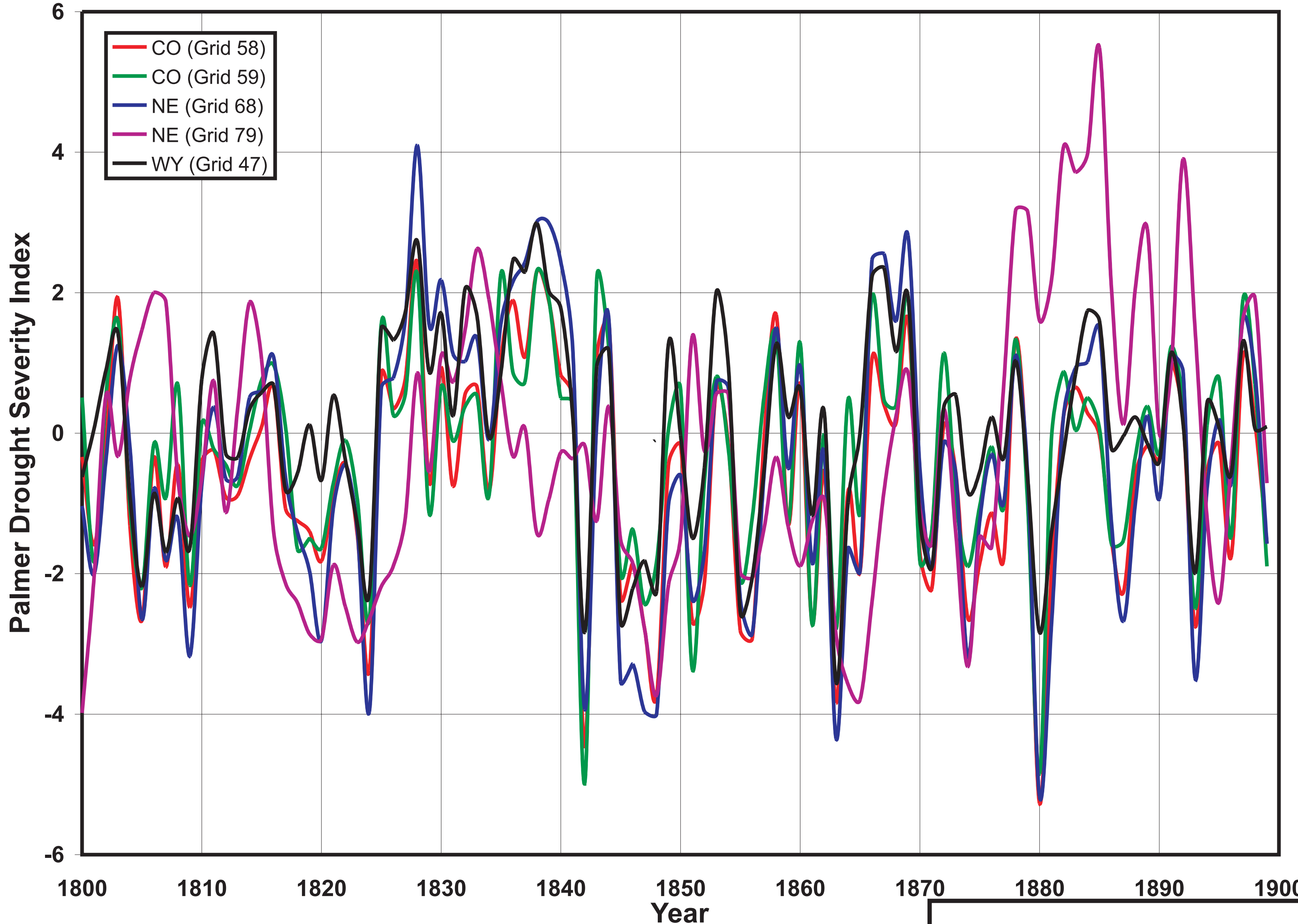

FIGURE D-7

PALMER DROUGHT SEVERITY INDEX 1800-1899

Platte River Channel Dynamics Study

PARSONS
Denver, Colorado

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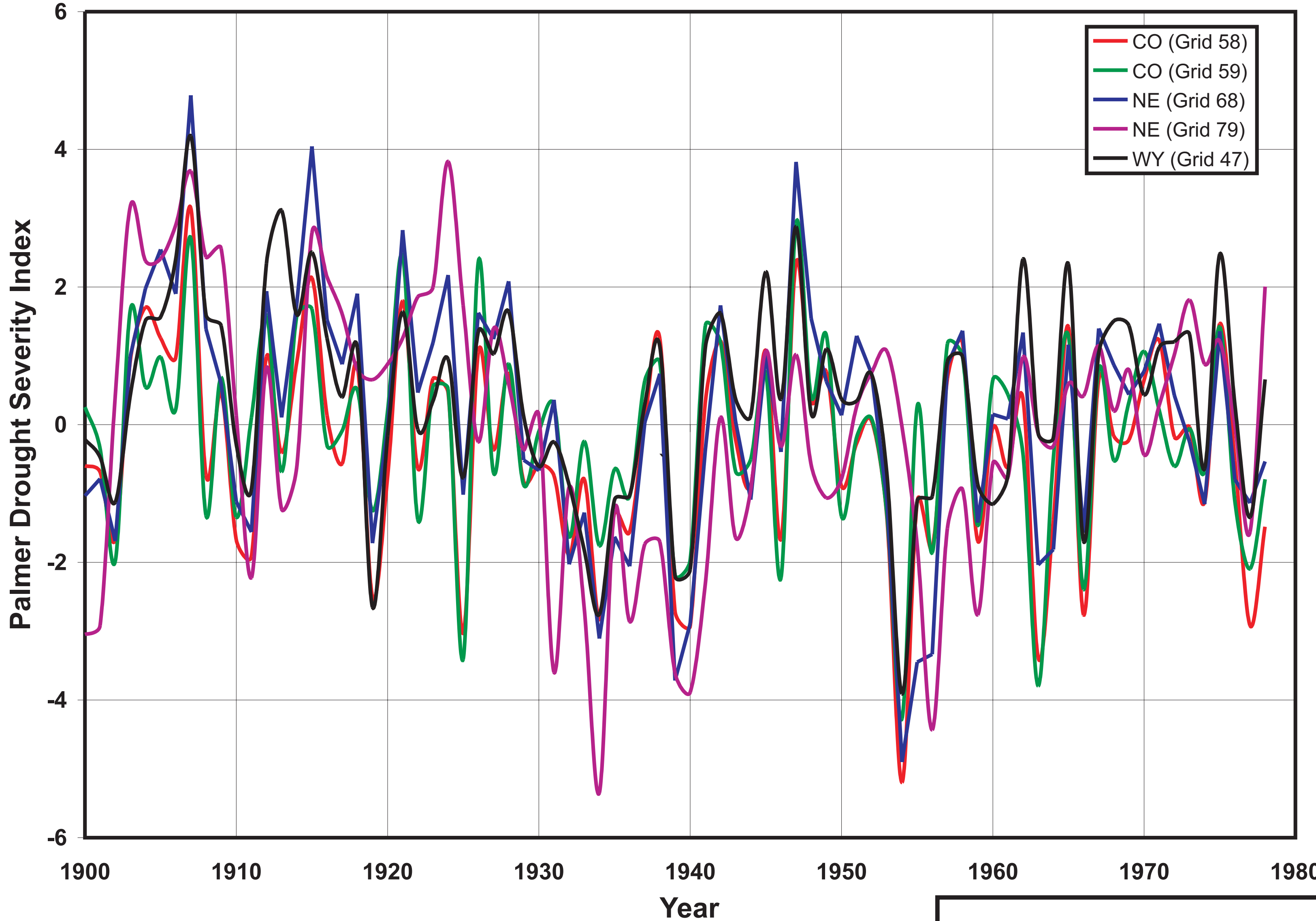

FIGURE D-8

PALMER DROUGHT SEVERITY INDEX 1900-1978

Platte River Channel Dynamics Study

PARSONS
Denver, Colorado

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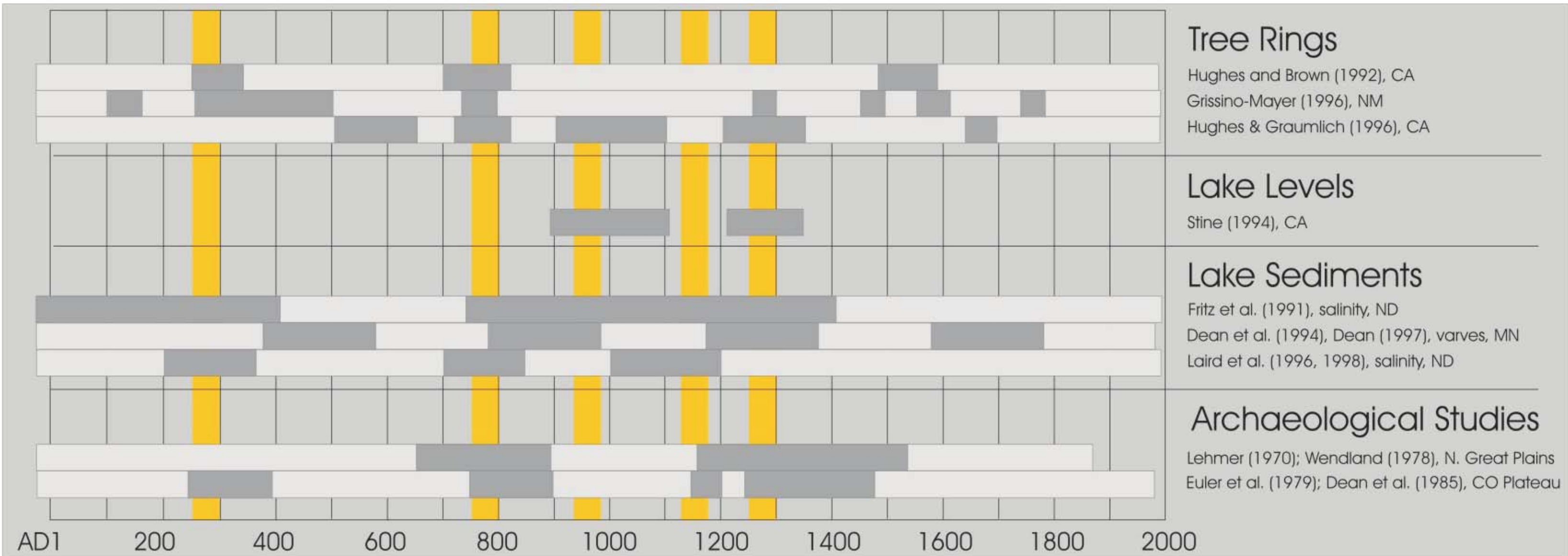

Notes:
Pale gray horizontal bars represent lengths of series.
Dark gray horizontal bars represent periods of drought.
Yellow vertical bars represent widespread, multidecadal droughts.

Source: After Woodhouse and Overpeck, (1998).

FIGURE D.9

PALEOCLIMATIC RECORDS OF GREAT PLAINS AND WESTERN U.S. CENTURY-SCALE DROUGHT

Platte River Channel Dynamics Study

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Denver, Colorado

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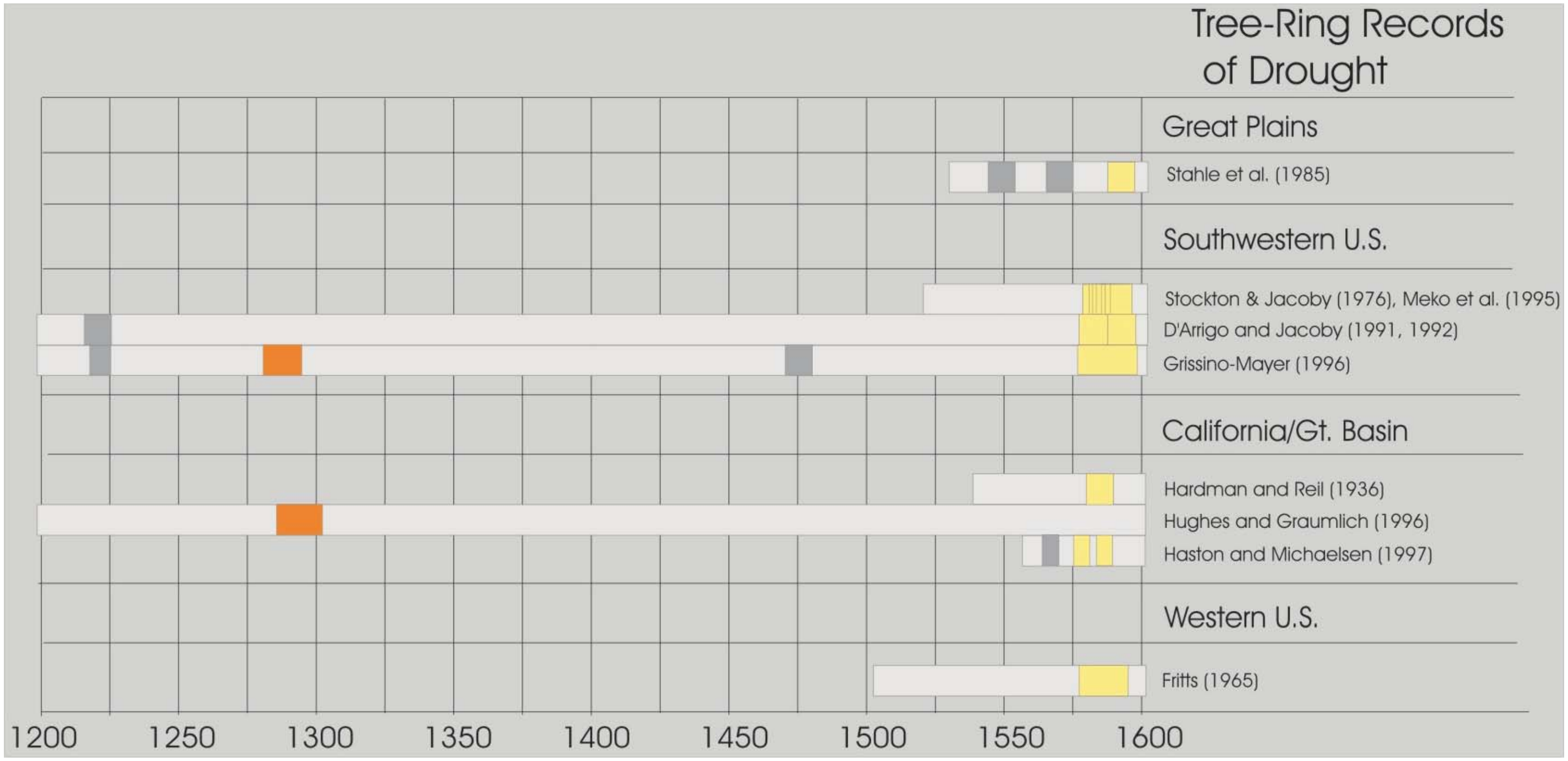

Notes:
Pale gray bars represent lengths of series.
Dark gray and colored bars indicate periods of drought.

FIGURE D.10

PALEOCLIMATIC RECORDS OF GREAT PLAINS AND WESTERN U.S. DROUGHT 1200-1600

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Source: After Woodhouse and Overpeck, (1998).

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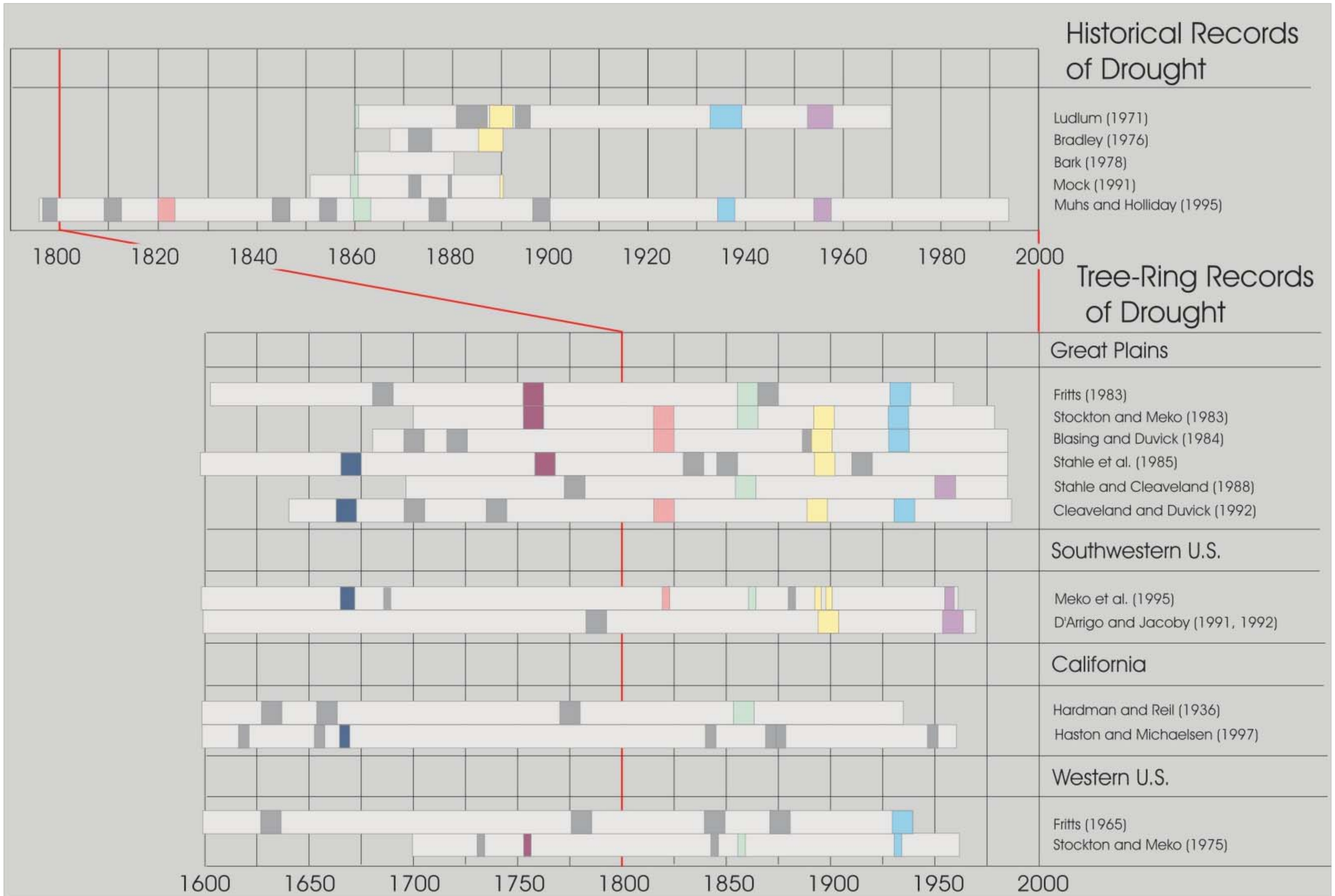

Notes:
Pale gray bars represent lengths of series.
Dark gray and colored bars indicate periods of drought in 3-10 year increments.

Source: After Woodhouse and Overpeck, (1998).

FIGURE D.11

PALEOCLIMATIC RECORDS OF GREAT PLAINS AND WESTERN U.S. DROUGHT 1600-PRESENT

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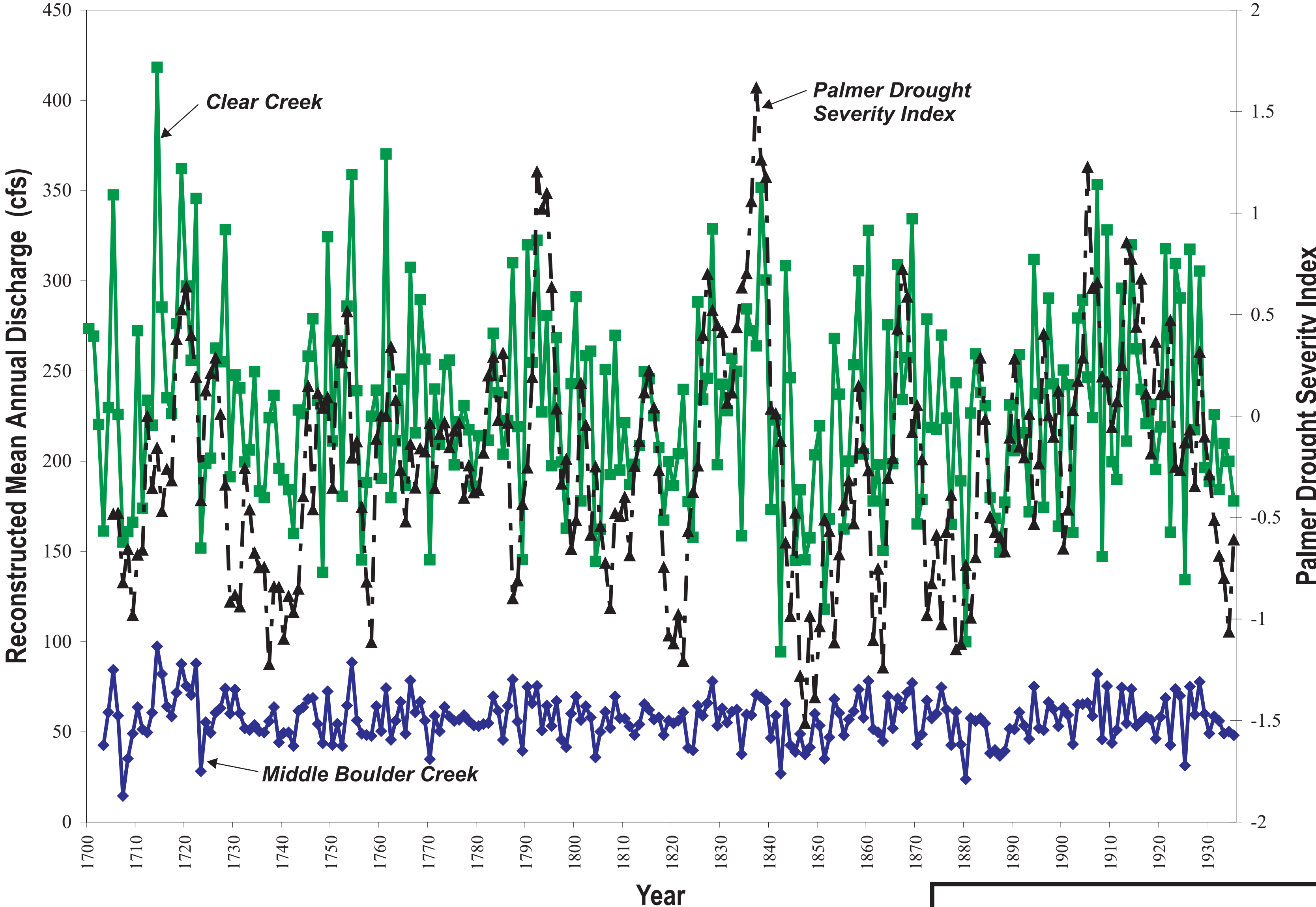

FIGURE D.12

RECONSTRUCTED MEAN ANNUAL DISCHARGES AND PALMER DROUGHT SEVERITY INDEX 1700-1935

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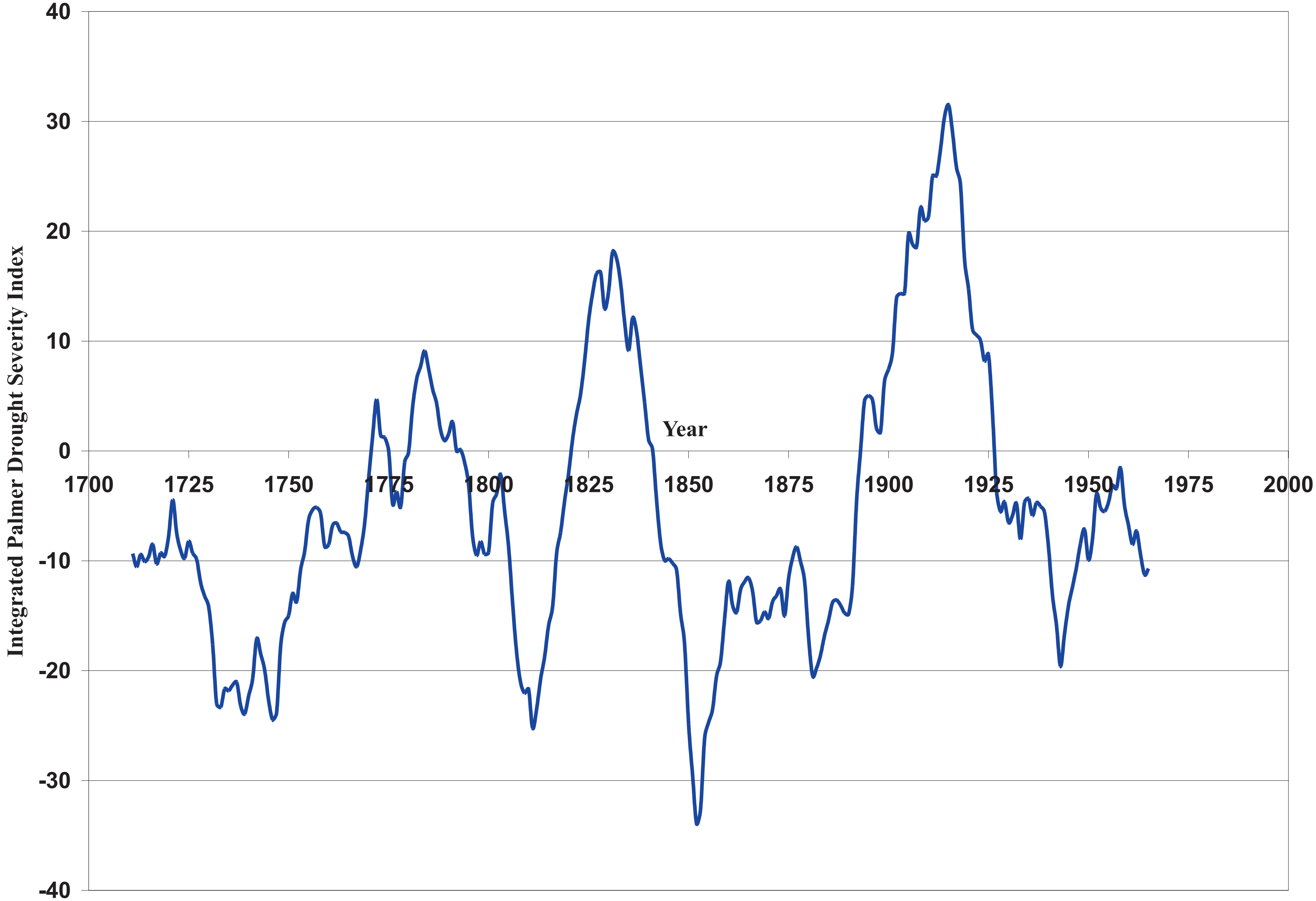

Note:
Multi-year integrated PDSI values calculated for Grid Point 68, corresponding to southwestern Nebraska.

FIGURE D.13

INTEGRATED PALMER DROUGHT SEVERITY INDEX 1700-1975

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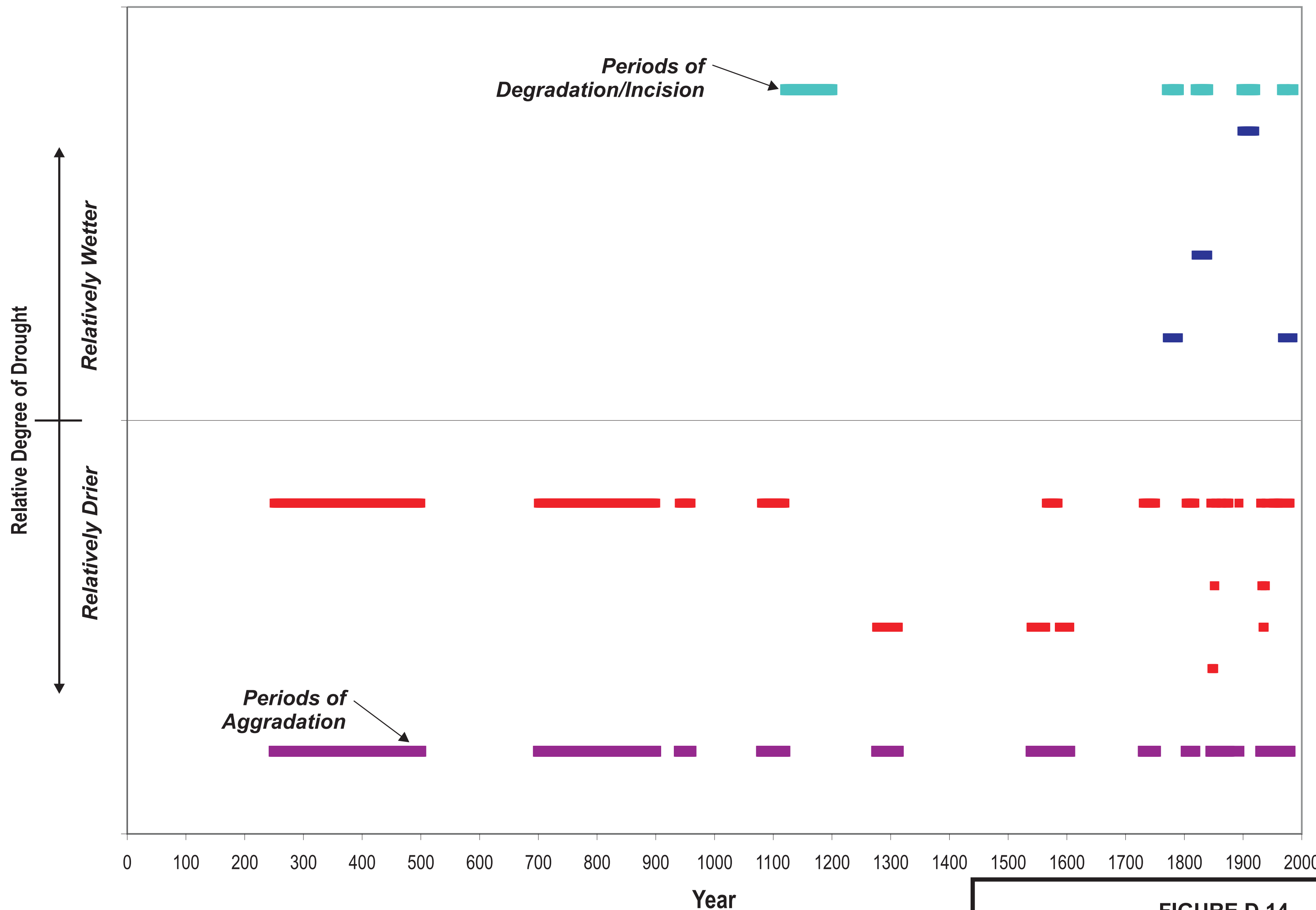

FIGURE D.14

CHRONOLOGY OF CLIMATIC AND GEOMORPHIC CONDITIONS IN WESTERN GREAT PLAINS

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