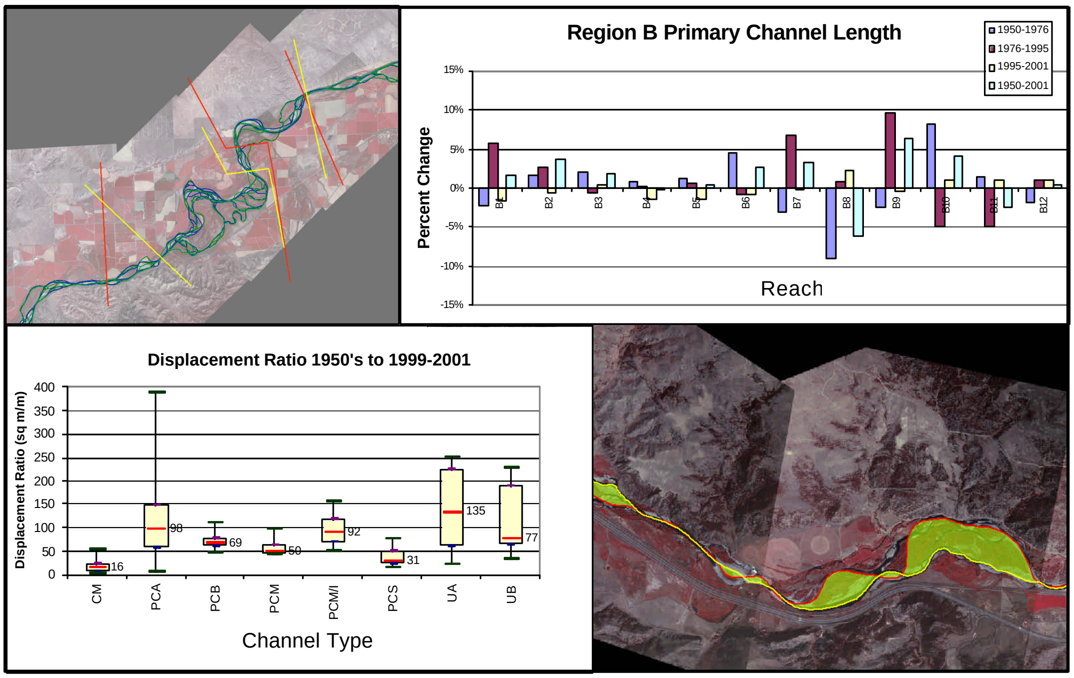
Work Order #1:
Geomorphic Parameters and GIS Development
Yellowstone River



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1 Introduction

The following report describes the results of a data analysis performed in support of the geomorphic scope of work associated with the Yellowstone River Cumulative Effects Study. This work was performed for the Yellowstone River Conservation Districts Council under Work Order 1 of Custer County Conservation District contract YRCDC 012.

The data analysis consists of a GIS-based summary of geomorphic parameters of the Yellowstone River from Park County to the confluence with the Missouri River, a distance of approximately 560 miles. Primary reach breaks and reach classification data reflect those presented in the Yellowstone River Geomorphic Reconnaissance Report (AGI and DTM, Inc., 2004). Additional baseline data used in this analysis include mapped channel centerlines and banklines previously digitized on air photos dated in around 1950, 1976, 1995, and 2001.

The data analysis consists of the following primary tasks:

- Integrate Upper River (Park County) digitized channel centerline data into the main Middle and Lower River GIS project.
- Integrate General Land Office (GLO) maps for Park County.
- Generate linear referencing indices for the primary channel traces.
- Adjust existing reach breaks as necessary to incorporate river behavior trends exhibited by historic channel traces.
- Develop reach breaks for Park County, and classify those reaches using the classification scheme developed in the reconnaissance report.
- Quantify and summarize a series of geomorphic parameters by individual reach for several historic and recent time frames.
- Summarize geomorphic parameters by channel type.
- Summarize geomorphic parameters by time frame.

Each of these tasks are discussed in detail in the following sections.

2 Methodology

The following sections describe the methodologies used to complete this work scope. All data developed in this effort reside in the project Geodatabase. Georeferenced GLO maps for the Yellowstone Corridor are also included with this deliverable. The specific geomorphic parameters included in the analysis and stored in the Geodatabase are described in Sections 3 and 4.

2.1 Disclaimer and Error Assessment

The data tables, graphs, and figures included in this report represent a preliminary exploration and summarization of the data. No interpretation or assessment of the data has been made in terms of its relationship to physical conditions (e.g. river flow) at the time of the base photography, user biases, image georeferencing errors, etc. The data should not be used without a robust review of potential sources of error. The summary values reported in the following sections have not been proven to be statistically significant, as n-values for several of the groupings may not be sufficient for that level of analysis. Rather, summary statistics plotted as box and whisker plots are provided as a means to graphically present the data without inferring complete analysis of statistical significance.

The following topics should be noted prior to using these data:

- Errors associated with the base imagery-
    - The imagery for each of the four time periods has errors associated with it. With the exception of the 1995 DOQ photography, none of the photography has been ortho-rectified. In general, all photography has been georeferenced to the 1995 DOQs. This means that the georeferenced photography will assume the spatial errors associated with DOQs, in addition to the errors associated with the georeferencing process.
    - The photography was taken at a variety of scales with different cameras or sensors. This means that each image will have different distortion that is associated with its collection technique.
    - The imagery was scanned at a variety of resolutions and generally resampled to approximately 1 meter ground resolution.
    - The older imagery may contain additional errors associated with difficulties identifying common points to use for georeferencing.
- Data collection issues-
    - All digitizing of channel features associated with the Yellowstone River features was done at similar scales and have their own spatial errors. The line work was generated through the collaborative efforts of several individuals. Although definitions were developed for the basis of digitizing photography. In attributing each line type, each individual may have biases in applying those definitions.
    - The image quality, shadows, and lighting make interpretation of bank lines difficult in places.
    - Efforts were made to ensure that each data set was reviewed by a single individual to help ensure consistent levels of detail and feature attributes.
- Changes in flow conditions at the time of the base imagery-

- Perhaps the largest variable associated with these data is the flow conditions at the time of the photography. When digitizing the flow lines for each of the time periods, no effort was made to adjust the lines or attributes to account for flow. As such, a channel digitized at low flow may be attributed as a overflow channel, while at higher flows the same channel may be attributed as a secondary channel
- It is known that the data for each time period represent a variety of flow conditions. Additionally, in the older data sets, the flows may vary from frame to frame within a single data set.
- Certain geomorphic parameters such as braiding parameter and River Complexity Index are flow dependent. Thus, prior to making any conclusions from these data, one needs to thoroughly assess the impacts associated with flow.

2.2 Integration of Upper River Data

A large amount of spatial data pertaining to Yellowstone River geomorphology was generated in support of the efforts of the Upper Yellowstone River Task Force. These data include digitized 1948 and 1999 flow lines for the Yellowstone River in Park County, which were provided by Chuck Dalby of the Montana Department of Natural Resources and Conservation (DNRC) for incorporation into the existing Middle and Lower River dataset. It was impossible to simply combine the two datasets, however, as the channel typing protocol and associated level of mapping detail used in the Park County effort differs somewhat from the data collection approach applied downstream. As such, the Park County lines have been re-assessed to make sure that the channel types reflected in the datasets are consistent between Park County and the rest of the project reach.

In general, the basis for identifying and mapping the primary channel trace is consistent between the Park County data and the data collected downstream. As such, the primary channel trace has been directly incorporated into the main dataset. In some cases, where the mapped primary channel splits to indicate relatively equal split flows, one channel was designated as Primary and the other as Secondary to provide consistency with downstream data.

With respect to non-primary channels, the original Park County dataset includes a very high level of channel mapping detail, as well as numerous features that are located outside the active river corridor. In order to make the datasets consistent, all channel features that are not part of the main river system have been excluded from the analysis, including several spring creeks and isolated abandoned channel remnants. Non-primary (secondary, anabranching, and overflow) channels have been screened in terms of their level of detail, and individual segments have been either incorporated or excluded to reflect a level of detail consistent with the Middle and Lower River data. The channel segments that are included from Park County have all been attributed with the same channel types used in the Middle and Lower river datasets (primary, secondary, anabranching, and overflow).

Some modifications were made to the original Park County data to ensure that the GIS-based analytical procedure would be similarly applied to all data. For example, the original Park County dataset does not include direct spatial connections between intersecting channel traces. Rather, intersections are linked by ‘connectors’ to create a channel network. Because of the analytical procedure used, it was necessary to merge all of the connectors as lines and assign the attributes of intersecting channel to those merged segments.

Each suite of digitized centerlines reflects the river conditions present at the time the air photos used in the analysis were taken. For the upper river, the air photos used to map centerlines are dated 1948 and 1999. For the middle and lower river, the photography was taken in the 1950’s, 1976, 1995, and 2001. In the comprehensive dataset, the 1999 Park County linework has been combined with the 2001 data from downstream, while the 1948 linework was combined with the 1950’s era data.

All Park County lines were then merged in with the existing flow line Feature Layers for the lower river. The completed Feature Layers for entire corridor are contained in the Flowlines Feature Dataset:

- flowlines_1948_1950
- flowlines_1948_1950_reach*
- flowlines_1976
- flowlines_1976_reach*
- flowlines_1995
- flowlines_1995_reach*
- flowlines_1999_2001
- flowlines_1999_2001_reach*
- flowlines_GLO

* ”reach” indicates a feature layer that has been split and attributed by reach.

2.3 General Land Office (GLO) Maps

The United States General Land Office (GLO) was formed in 1812 as an organization under the jurisdiction of the Treasury Department that would oversee the surveying of newly-acquired U.S. territories, particularly those of the Louisiana Purchase. This effort stemmed from the Land Ordinance of 1785, which stated the following:

"The surveyors, as they are respectively qualified, shall proceed to divide said territory into townships of 6 miles square, by lines running due north and south, and others crossing these at right angles, as near as may be, unless where the boundaries of the late Indian purchases may render the same impracticable, and then they shall depart from this rule no further than such particular circumstances may require...As soon as 7 ranges of townships and fractional parts of townships, in the direction from south to north, shall have been surveyed, the geographer shall transmit plats thereof to the board of treasury, who shall record the same, with the report in well bound books to be kept for that purpose."

As part of the efforts for the middle and lower river, DTM had acquired and georeferenced the available General Land Office (GLO) maps. To complete the GLO coverage in the GIS, DTM purchased the remaining GLO maps for Park County and georeferenced them to Township corners. These data are included on the CD included with this report.

The GLO maps represent some of the earliest mapping available for the Yellowstone Corridor. As such, they are an important source of information for the characteristics of the river in the late 19th and early 20th centuries. The quality of the mapping varies from Township to Township. Much of the area to the south of the river is simply labeled "Crow Indian Reservation" and has only crude river bank locations. Other sections may be noted as "Unsurveyed Bad Lands" and lack detailed mapping (Figure 2-1). At best, these maps should be used to assess general river location and characteristics such as single or multiple channel threads.

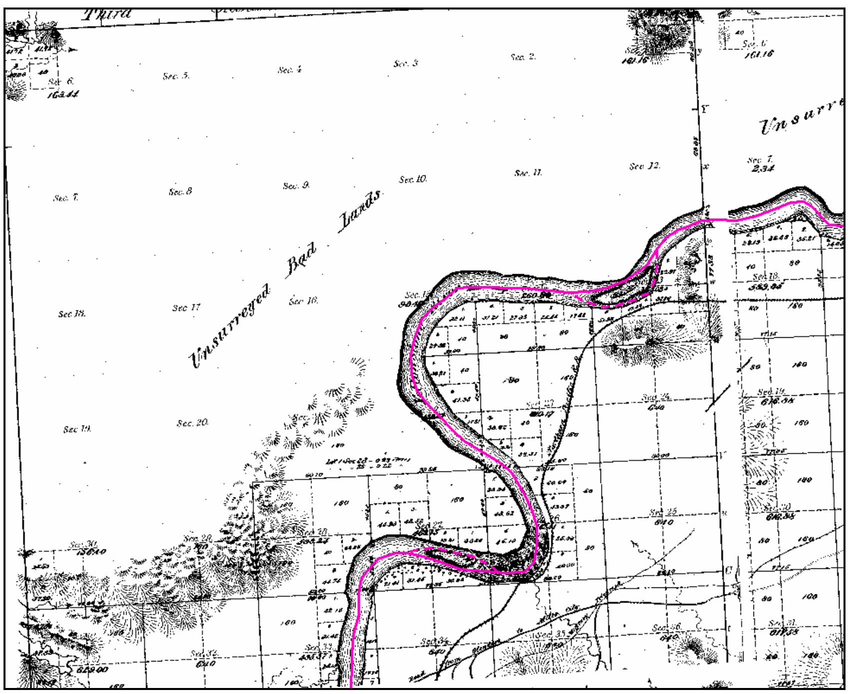

Figure 2-1. General Land Office (GLO) map showing 'Unsurveyed Bad Lands' on the north side of the river and the digitized primary and secondary channel traces.

Channel flowlines were digitized for the entire river corridor from the GLO maps. Only primary and secondary channel types were digitized. These designations were made based on channel width. Several short sections that do not have any mapping have been connected with a straight line (Figure 2-2).

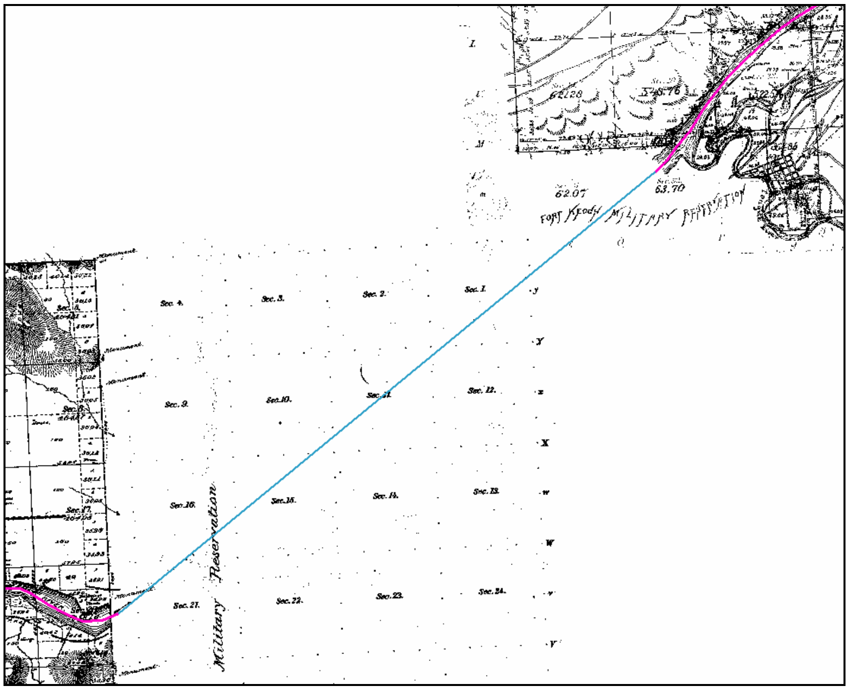

Figure 2-2. General Land Office (GLO) map showing unmapped area.

The completed feature layers for entire corridor are contained in the Flowlines Feature Dataset:

- flowlines_GLO

2.4 Linear Referencing Indices

Linear referencing indices in meters were created for the 1948_1950, 1976, 1995 and 1999_2001 primary channels. All segments of the primary channel trace for each year were merged into a single polyline. This polyline was reviewed to ensure that it was a single part polyline (e.g. no gaps) and that its direction was from downstream to upstream. Each year's flowline was loaded into individual PolyLineM Feature Classes in a new Feature Dataset (Flowlines_M).

The existing 1995 flowlines stopped at the Montana border. To complete the DRG-based dataset, these lines were extended to reach the confluence with the Missouri River in North Dakota. The existing 1999_2001 data covered the entire river and no modifications were necessary.

The existing 1976 flowlines end in Dawson County just downstream of Intake. The start measure for the linear referencing of the 1976 line was adjusted to be consistent with the 1995 and 1999_2001 measures that start at the confluence. The route measures for the 2001 and 1950s lines were averaged in order to determine the average measure to assign to the start of the 1976 flow line.

All measured Primary channel lines are stored in the Flowlines_M Feature Dataset.

- fl_1948_1950_route_primary

- fl_1976_route_primary
- fl_1995_route_primary
- fl_1999_2001_route primary

2.5 Reach Break Adjustments

Between the eastern Park County line and the Missouri River confluence, the Yellowstone River was divided into a series of reaches as part of the 2004 Geomorphic Reconnaissance study (AGI and DTM, 2004). The reach breaks presented in that report primarily reflect changes in the channel form captured by the 2001 CIR imagery. Additional information used to define reach breaks included regional geology, topography, and locations of infrastructure and major tributary confluences. At the time of the original reconnaissance study, channel conditions prior to 2001 were not readily available to help define reach boundaries. As flowlines and banklines have since been generated for the 1950's, 1976, and 1995, the reach breaks were re-assessed as part of this effort. Where historic channel traces supported the shifting of a reach break, modifications were made to the original reach break location. The shifts most commonly reflect the relocation of a break to a position where the historic primary channels are coincident, and where changes in channel patterns are most consistent through time. Additionally, several breaks were slightly rotated to orient the break line perpendicular to the majority of channel traces. Most reach break adjustments were minor and resulted in a slight shift and/or orientation change in order to reflect the river location and characteristics for all of the time frames evaluated. Figure 2-3 displays several of the most substantial revisions in reach break locations.

Figure 2-3. Old reach breaks (red) and adjusted sub reach breaks (yellow) displayed with all channel traces.

For the Park County data, original reach breaks were developed under the same criteria to be consistent with the rest of the river.

The resulting reach break Feature Class is located in the Reach_Breaks Feature Dataset.

- reach_breaks_extended_051606

2.6 Valley Trend Line

Certain geomorphic parameters, such as sinuosity, require a measurement of valley distance, which is typically derived by measuring a trend line that follows the axis of the valley. Although there are no set rules for creating this line, it is critical that the basis for defining the trend line is consistent throughout any given study area. The line is scale-dependent, as at smaller scales, it will be more generalized and therefore shorter. As part of this scope of work, two new valley trend lines were created to represent different scales, and the more detailed line was used for calculating geomorphic parameters.

The more detailed trend line (valley_cl_detail_route) was digitized at a scale of 1:24,000 and the less detailed line (valley_cl_general_route) was digitized at 1:150,000 (Figure 2-4). To ensure a similar level of detail throughout the length of each line, approximately three to five vertices were digitized across each map window. The detailed trend line focused on following the channel migration corridor, crossing the 2001 primary channel trace at each meander wavelength. The less detailed line may cross river terraces and focused on large scale corridor trends. A final detailed trend line (valley_cl_detail_reach_route) that is the detailed trend line, split at the reach boundaries is included in the same Feature Dataset and is used in the data summarization. All of these lines contain route measures in meters and are included in the geodatabase in the Valley_Centerline Feature Dataset.

- valley_cl_detail_route
- valley_cl_detail_reach_route
- valley_cl_general_route

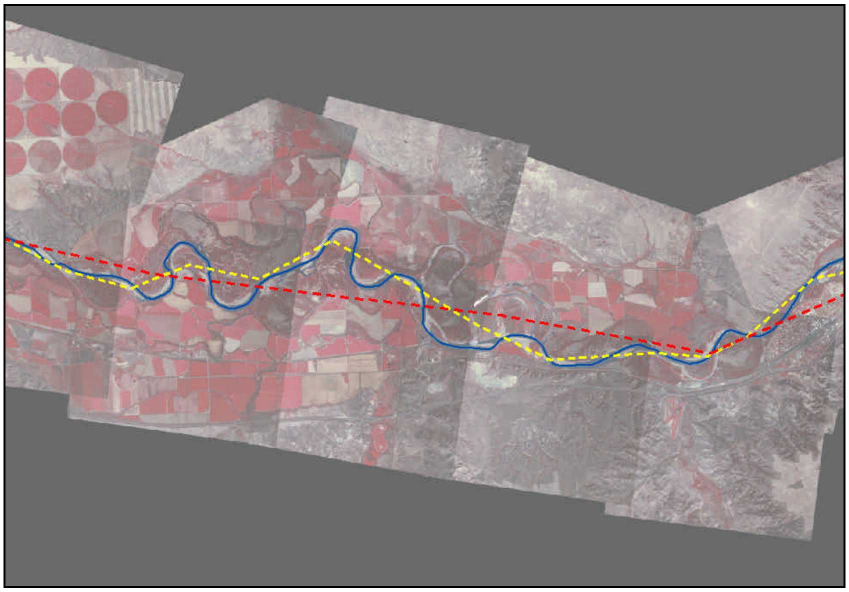

Figure 2-4. Valley trend lines. The detailed trend line (yellow) was digitized at 1:24,000. The general trend line (red) was digitized at 1:150,000.

2.7 Flowline Parameter Summaries

The digitized flowlines were used to calculate a series of geomorphic parameters for each reach. First, each reach was enclosed within a polygon to allow a quantitative assessment of parameters within that polygon. The polygons were created by first generating a 5 mile buffer on either side of the 2001 primary channel trace. This resulted in a continuous corridor polygon. Next, line segments were added to the ends of each reach break line to extend it to be perpendicular to the 5 mile buffer. This technique is similar to defining cross section lines for hydrologic modeling such that they are both perpendicular to the flow of the channel and also perpendicular to the valley edge. The extended lines were used to split the 5 mile buffer polygon and resulting polygons were attributed with the reach identification (Figure 2-5). The channel flow lines for each year were split at each reach break, and each segment was then similarly attributed with its associated reach identification. The Feature Classes for the extended lines (reach_breaks_extended_051606) and the reach polygons (reach_polys_051606) are stored in the Reach_Breaks Feature Dataset.

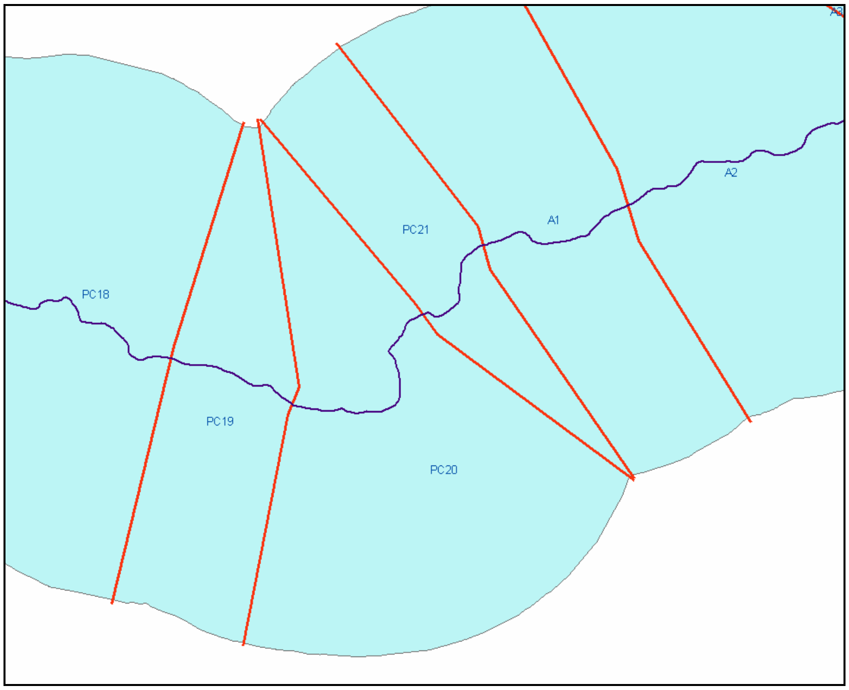

Figure 2-5. Adjusted reach breaks were extended to the edge of a five mile buffer on the 2001 primary channel trace. The buffer was then split to create reach areas.

The geomorphic parameters evaluated within each polygon using the digitized flowlines include the following:

- ***Primary channel length***: length of the main channel thread between reach break lines in kilometers.

- ***Sinuosity***: A ratio of primary channel length to valley distance, used to describe how "tortuous" a river course is. A sinuosity of 2 reflects a channel that is two times longer than the straight valley distance.

- ***Braiding parameter***: A ratio of the total channel length divided by the main channel length used to describe the relative extent of secondary or anabranching channels. A braiding parameter of 1 reflects no side channels, and a braiding parameter of 3 reflects a total channel length that is three times that of the main channel.

- ***River Complexity Index (RCI)***: The RCI has been used to describe the complexity of hydraulic conditions within a reach (Brown, 2002). It is a calculated parameter that that is dependent on both sinuosity and number of side channel junctions. RCI is unitized to valley distance and calculated as the following:

$$RCI = Sinuosity\ (1+nodes^*)/valley\ distance$$

Where nodes = the number of junctions between channels within a given reach.

- ***Channel Displacement***: The channel displacement ratio describes the extent of primary channel migration over the last 50 years in square meters of displacement per meter of channel length. Channel displacement was calculated as the area of a polygon created by intersecting the primary channel threads from the 1950 and 2001 photography. The polygons were split at the reach break lines and attributed with the appropriate reach id. The polygon area per unit 2001 channel length was calculated for each reach (Figure 2-6).

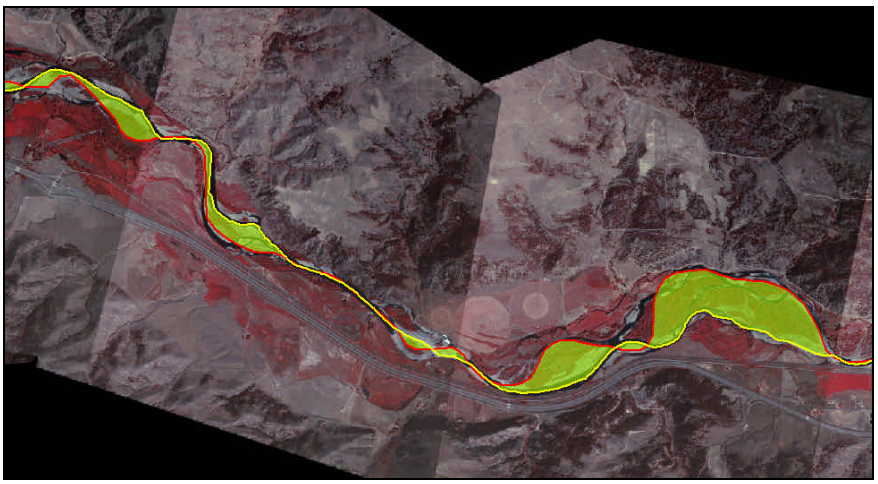

Figure 2-6. Channel displacement polygons created by intersecting the 1950s (red) and the 2001 (yellow) primary channel traces.

All channel traces are stored in the project Geodatabase. If the traces are modified and saved, revised segment lengths are automatically calculated and stored. The Geodatabase is linked to a Microsoft Access database, which allows the generation of a series of Access queries to summarize the data. This allows a new summary table to be automatically created if any changes are made to the underlying GIS data. For example, if a channel type is changed from secondary to anabranching, the Access queries are automatically updated to reflect the change.

3 Framework for Data Summarization

In order to summarize the data in a way that will provide utility for future work, the data have been grouped in terms of region, general timeframe, and channel type.

3.1 Regional Summaries

Spatial and temporal trends have been summarized in terms of the following regions:

1. ***Park County*** extends from near Gardiner, Montana downstream to the Park/Sweetgrass County Line. This region includes the Paradise Valley, and the city of Livingston, and reflects the assessment reach addressed by the Upper Yellowstone River Task Force.
2. ***Region A*** extends from the Park/Sweetgrass County Line to the Clarks Fork of the Yellowstone confluence near Laurel. Similar to Park County, the Yellowstone River in Region A is a dynamic, coarse-grained river that supports a cold-water salmonid fishery. Sweetgrass and Stillwater Counties are within Region A.
3. Between the Clarks Fork and Bighorn Rivers, ***Region B*** lies entirely with Yellowstone County. Along this reach, the river supports both warm and cold water fish species. Increasing quantities of fine sediment occur in the downstream direction.
4. ***Region C*** extends from the Bighorn River confluence to the confluence of the Powder River. In this section, the Yellowstone River supports a plains warm-water fishery, which is characterized by a diverse variety of non-salmonid, warm water species. The channel slope is markedly less than that of upstream regions. The Region C plains zone includes Treasure, Rosebud, and Custer County.
5. Between the Powder River confluence and its terminus at the Missouri River the Yellowstone River in ***Region D*** is a prairie river similar to Region C. The river gradient is relatively flat, and the river is typically more turbid than upstream. Region D includes Prairie, Dawson, Wibaux, Richland, and McKenzie Counties.

3.2 Summaries of Change through Time

The timeframes evaluated for each parameter are variable. In Park County, only two suites of photography were analyzed, from 1948 and 1999. These data were folded into the 1950's and 2001 middle and lower river datasets (Table 3-1).

Table 3-1. Time frames used in the data summary.

Region	*Channel Length*	*Braiding Parameter*	*River Complexity Index*	*Channel Displacement*
Park County	1950-2001 (photos from 1948 and 1999)	1950-2001 (photos from 1948 and 1999)	1950-2001 (photos from 1948 and 1999)	1950-2001 (photos from 1948 and 1999)
Regions A-D	1950-1976, 1976-1995, 1995-2001, 1950-2001	1950's-1976, 1976-1995, 1995-2001	1950's-2001	1950's-2001

3.3 Reach Type Summaries

Between the southern Park County boundary and its confluence with the Missouri River, the Yellowstone River has been broken into a total of 88 reaches. These reach delineations are based on observable changes in general channel form. Each reach has been classified according to its general geomorphic character. The classification approach adopted reflects the overall channel pattern (straight, meandering, braided, or anabranching), as well as the relative role of the valley wall or inset high terraces in confining the river corridor (unconfined, partially confined, confined). A total of 10 channel types have been developed for the entire river (Table 3-2). In order to assess the trends within a given reach type, the geomorphic parameters have been summarized in terms of channel type as well as region.

The channel type datasets are presented in terms of calculated maximum, minimum, median, and quartile values. This allows a graphical presentation of the data in the form of box and whisker plots, which allow an easy comparison of data range (whiskers) and data clustering around the median (box) for a suite of channel type data (Figure 3-1). As discussed in Section 2.1, these data have not undergone analysis for statistical significance. N-values (number of data points) for each reach type are listed in Table 3-2.

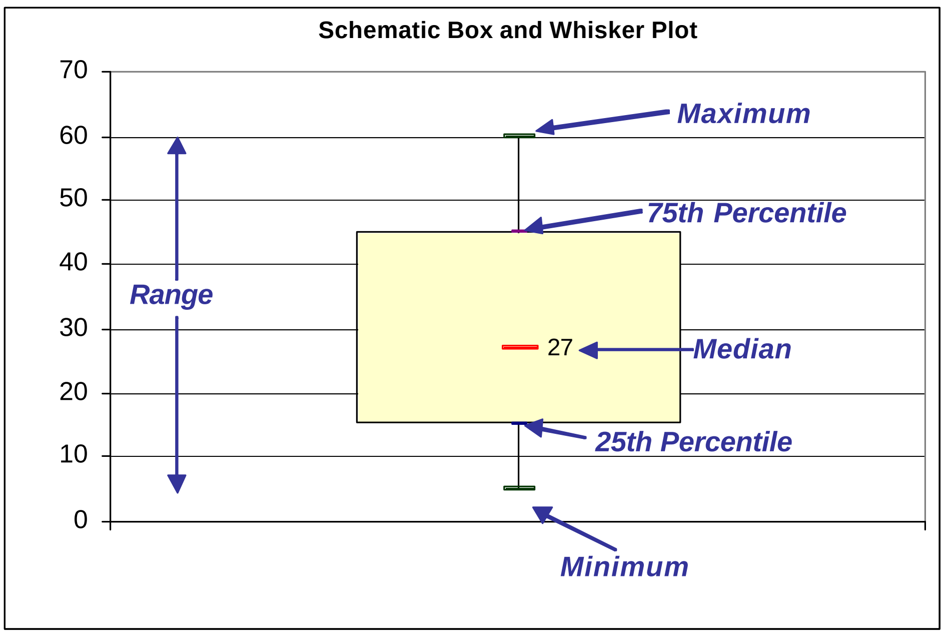

Figure 3-1. Schematic diagram of a box and whisker plot.

Table 3-2. Reach classification summary

Type Abbrev.	*Classification*	*n*	*Slope (ft/ft)*	*Planform/ Sinuosity*	*Major Elements of Channel Form*
UA	Unconfined anabranching	12	<.0022	Mult. Channels	Primary thread with islands that exceed 3X average channel width
PCA	Partially confined anabranching	18	<.0023	Mult. Channels	Partial bedrock control; Primary thread with islands that exceed 3X average channel width
UB	Unconfined braided	6	<.0024	Mult. Channels	Primary thread with gravel bars; Average braiding parameter generally >2 for entire reach
PCB	Partially confined braided	13	<.0022	Mult. Channels	Partial bedrock control; primary thread with gravel bars; Average braiding parameter generally >2
PCM	Partially confined meandering	4	<.0014	>1.2	Partial bedrock control; main channel thread with minimal bar area; average braiding parameter <2
PCS	Partially confined straight	11	<.0020	<1.3	Partial bedrock control; low sinuosity channel along valle y wall
PCM/I	Partially confined meandering/islands	11	<.0007	Mult. Channels	Partial bedrock control; sinuous main thread with stable, vegetated bars
CS	Confined straight	5	<.0001	<1.2	Bedrock confinement; low sinuosity
CM	Confined meandering	7	<.0008	<1.5	Bedrock confinement; sinuous; uniform width; small point bars
US/I	Unconfined straight/islands	1	<.0003	<1.2	Low sinuosity with vegetated bars

A summary reach list, including length, type, and general location of each reach is provided in Appendix A.

4 Results

The geomorphic parameters have been quantified on the reach scale. The lengths, classification, and general locations for each reach are compiled in Appendix A. The geomorphic parameters collected for the each reach are presented in tabular format in Appendix B, and quantified changes through time are presented in Appendix C. Appendix D contains a series of plots depicting individual reach data. Summaries of the data are presented below.

The data summaries reported below reflect a basic compilation of existing data derived from the Geodatabase. Any interpretation of the data with respect to spatial or temporal trends will require further analysis. Perhaps most critically, the braiding parameter and River Complexity Index values, which are flow-dependent measures, require careful scrutiny of flow conditions at the time of the photography. A preliminary assessment of flow conditions at Billings during the various dates of the photography indicates highly variable flow conditions at the time the various photos were taken.

4.1 Channel Length

The length of each reach centerline for each suite of evaluated air photos is shown in Appendix D (Figure D-1 through Figure D-5). These lengths were assessed in terms of the change in centerline length between the various time frames evaluated. The calculated percent change in channel length through time for each reach are summarized in Figure 4-1 through Figure 4-5, and the values from which these plots were created are tabulated Appendix C. In Park County, the most significant change in channel lengths occurred in PC9-PC13, which is between Mallard's Rest and Carters Bridge. In Region A, approximately 10% of channel length was lost in Reaches A9 (just upstream of Reed Point) and A18 (at Laurel) between 1950 and 2001. The most significant changes in channel length in Regions B and C occurred between Reaches B9 (just below Pompey's Pillar) and C7 (Treasure/Rosebud County Line). Measured changes in Region D are typically less than 5% over 50 years; noted exceptions to this occurred in Reaches D5 and D7 (near Glendive).

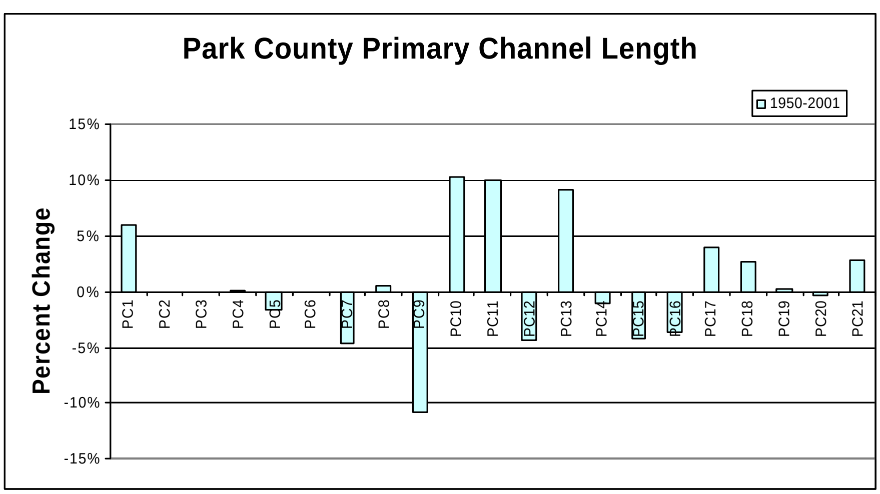

Figure 4-1. Percent change in primary channel length, 1948-1999, Park County

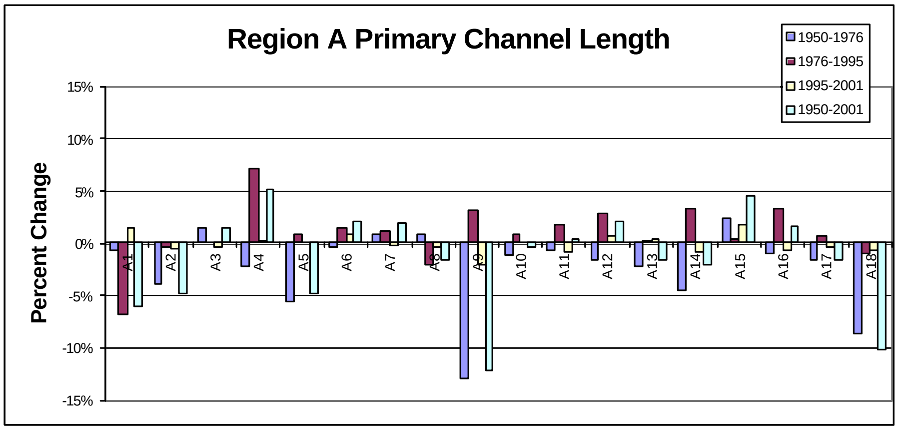

Figure 4-2. Percent change in primary channel length through time, Region A.

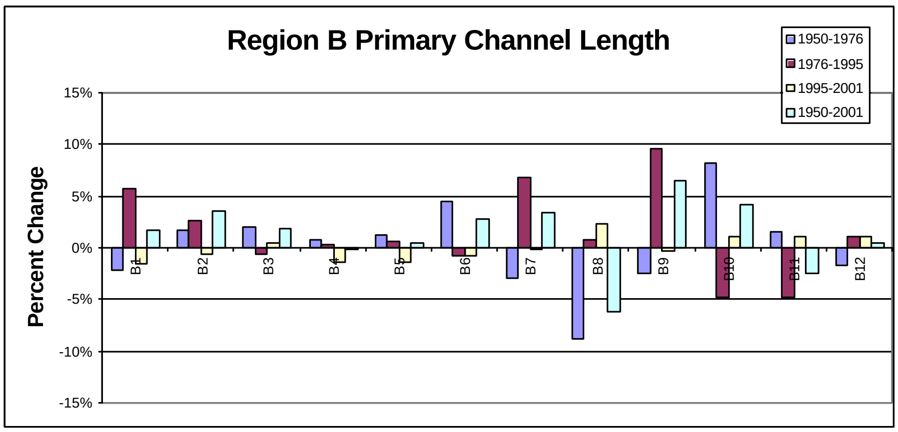

Figure 4-3. Percent change in primary channel length through time, Region B.

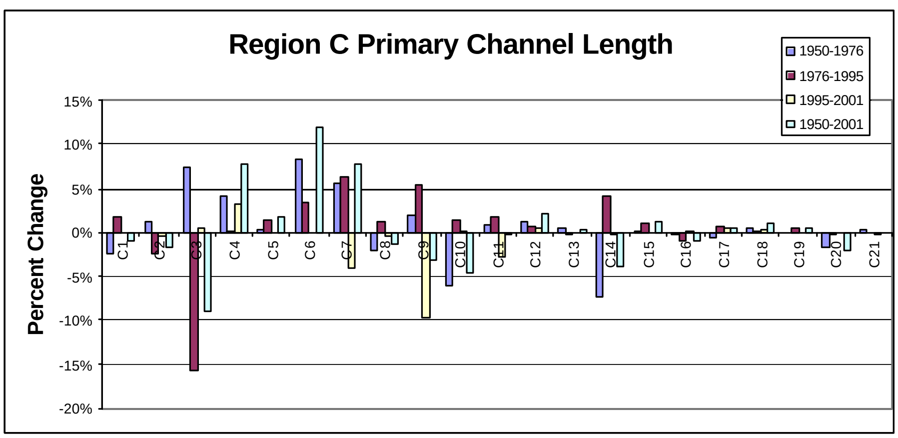

Figure 4-4. Percent change in primary channel length through time, Region C.

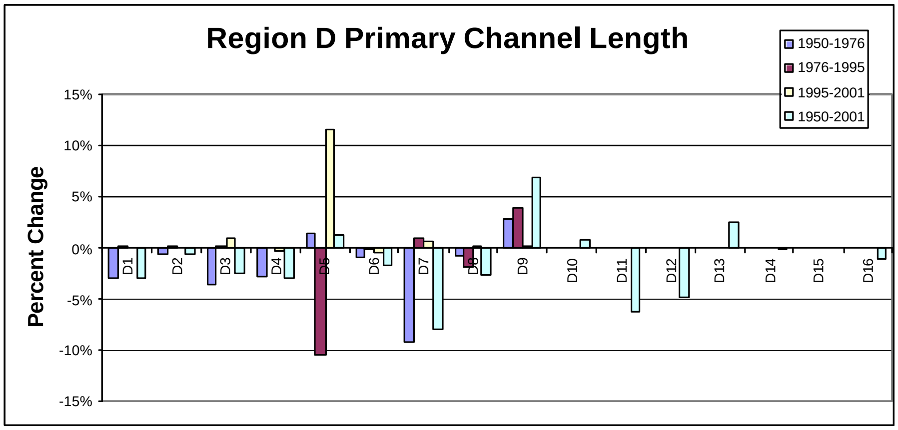

Figure 4-5. Percent change in primary channel length through time, Region D.

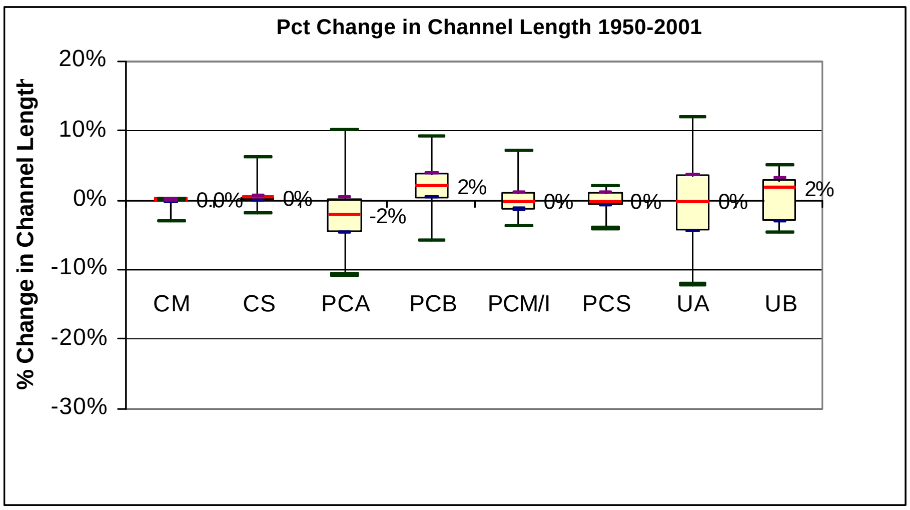

Figure 4-6. Summary of percent change in channel length for each reach type.

4.2 Braiding Parameter

Braiding parameter is a measure of the relative lengths of non-primary channels (side channels and anabranching channels) to the main channel. A high braiding parameter reflects a large extent of non-primary channel length. Measured braiding parameter values for each reach are tabulated in Appendix B and Appendix C, and plots of individual reach values are shown in Appendix D (Figure D-6 through Figure D-10).

Plotted changes in braiding parameter through time are shown in Figure 4-7 through Figure 4-11. The data summary suggests that there has been a general reduction in braiding parameter (side channel length) in Region A (Figure 4-8) and Region B (Figure 4-9), whereas Region C shows an increase in braiding parameter from the 1950's through 1976, and subsequent decrease from 1995 to 2001 (Figure 4-10). As discussed previously however, it is critical that the flow conditions at the time of the photography be considered in any further interpretation of apparent trends in braiding parameter.

The statistical summaries for braiding parameter as a function of channel type are shown in Figure 4-12 through Figure 4-17. The data summary suggests that the highest braiding parameter values occur in the anabranching channel types. The unconfined braided channel type depicts a drop in braiding parameter through time (Figure 4-17).

In several of the plots that show braiding parameter through time based on channel type, it is noted that the 1976 and 1995 data are missing for Park County. This reflects the fact that these reach types occur in Park County, for which no digitized centerlines were available. As such, those time frames are missing Park County data. The 1950's and 2001 box and whisker plots include Park County reaches and thus reflect the changes in calculated values for the entire river, where as the 1976 and 1995 data depict changes from Springdale to the mouth.

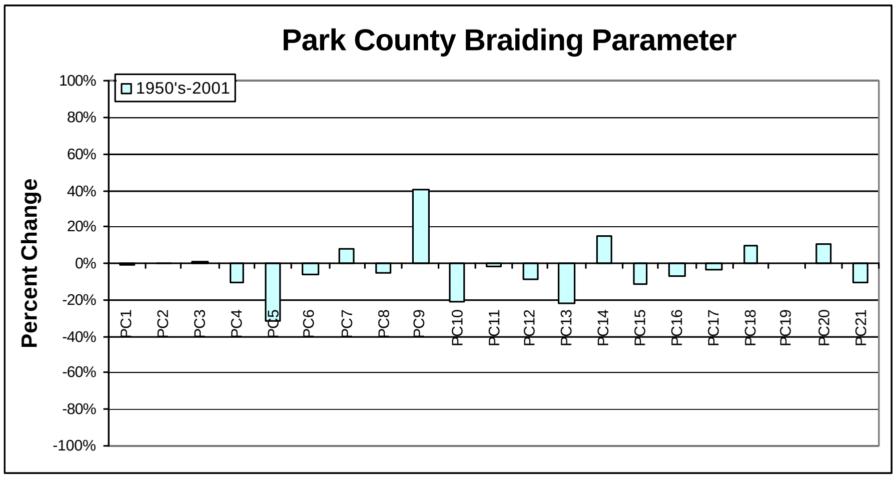

Figure 4-7. Percent change in braiding parameter through time, Park County.

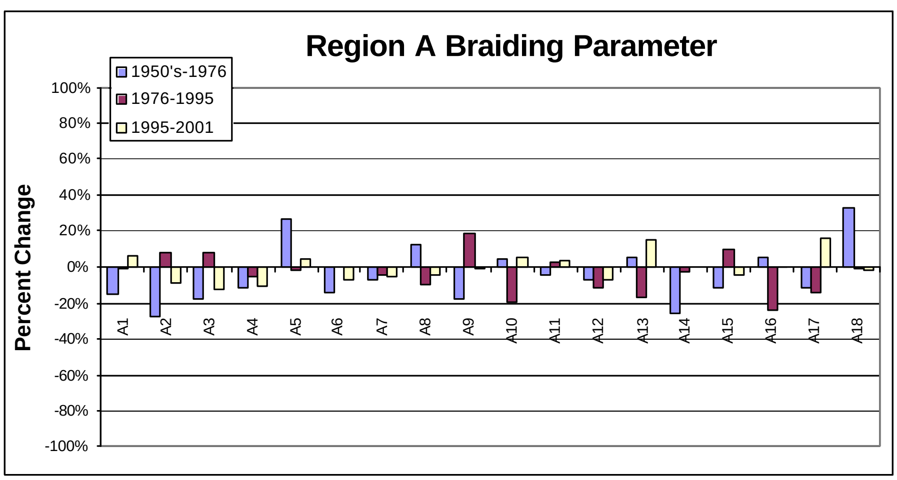

Figure 4-8. Percent change in braiding parameter through time, Region A.

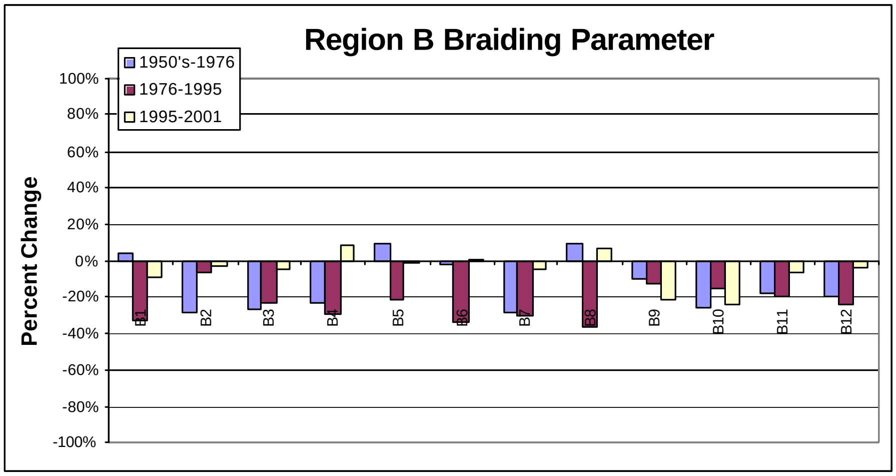

Figure 4-9. Percent change in braiding parameter through time, Region B.

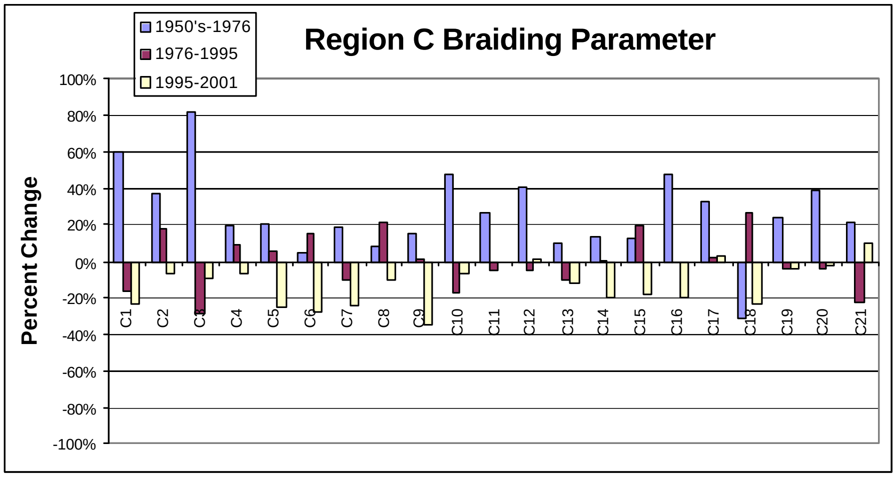

Figure 4-10. Percent change in braiding parameter through time, Region C.

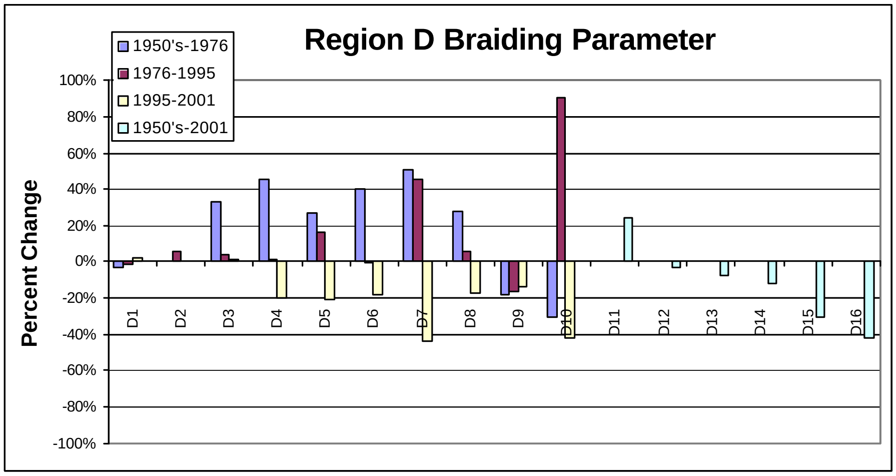

Figure 4-11. Percent change in braiding parameter through time, Region D.

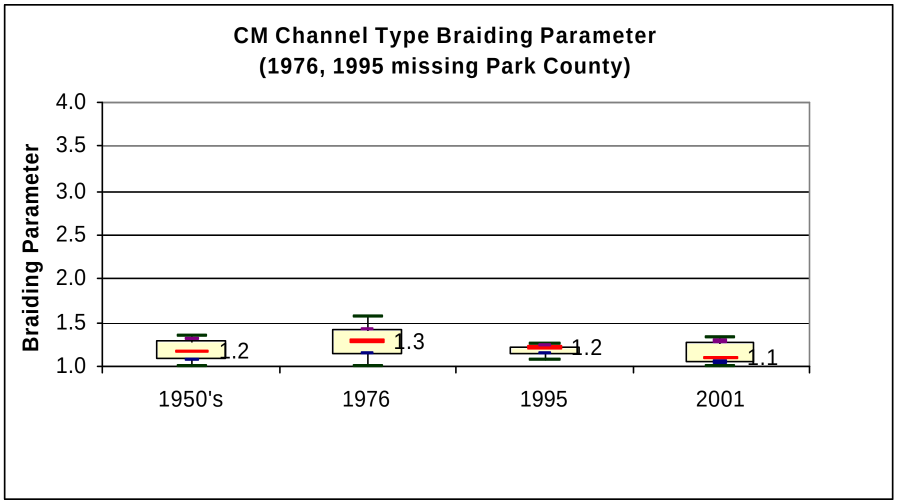

Figure 4-12. Statistical summary of braiding parameter values for Confined Meandering channel type.

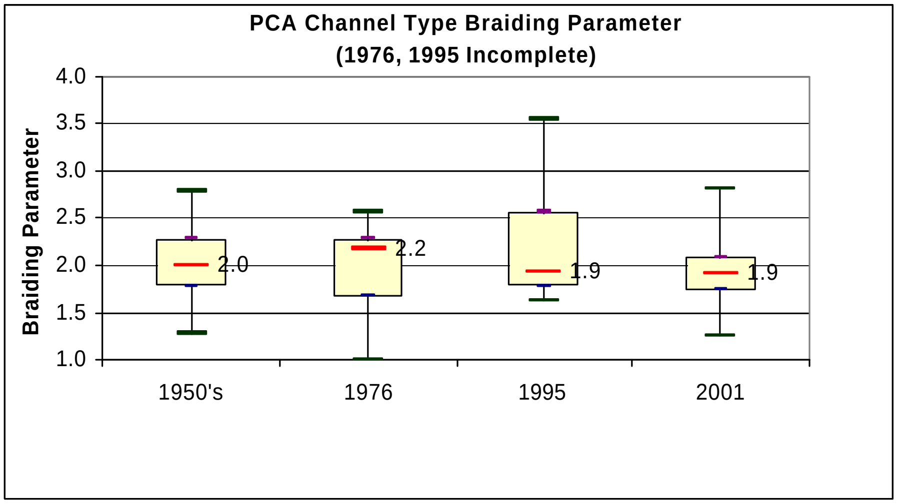

Figure 4-13. Statistical summary of braiding parameter values for Partially Confined Anabranching channel type.

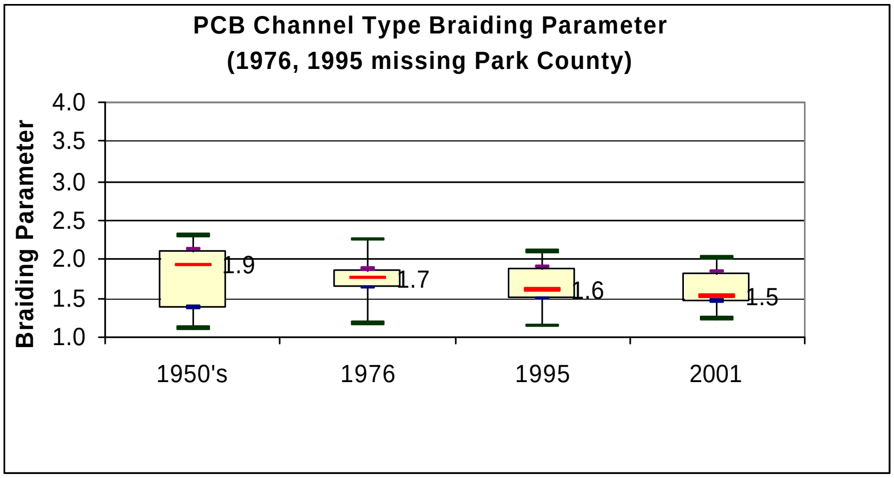

Figure 4-14. Statistical summary of braiding parameter values for Partially Confined Braided channel type.

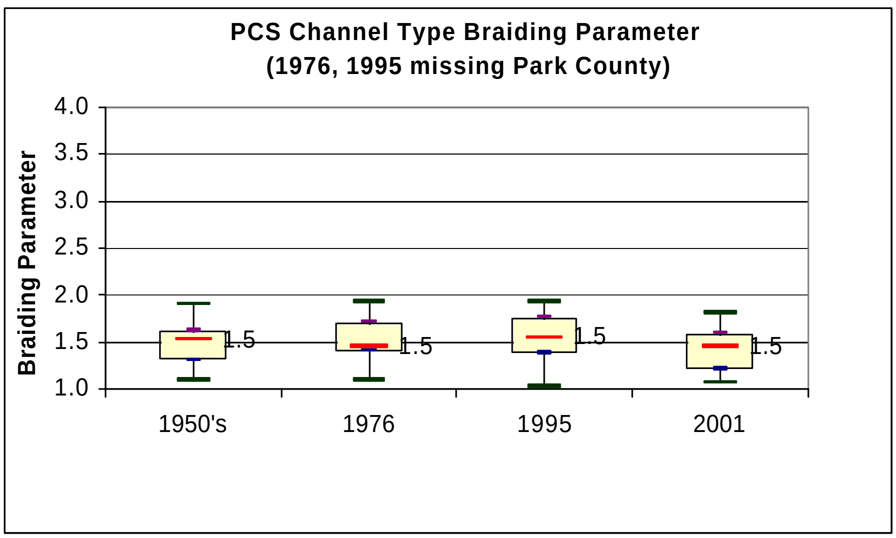

Figure 4-15. Statistical summary of braiding parameter values for Partially Confined Straight channel type.

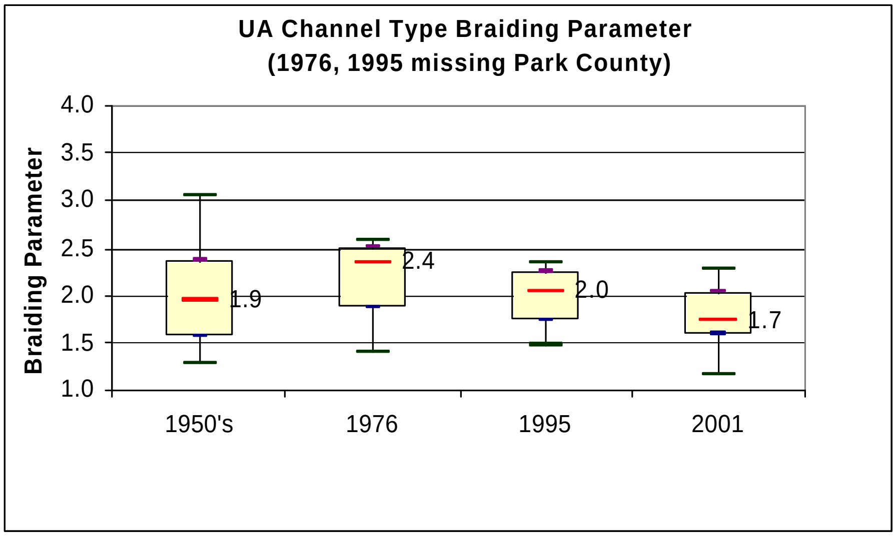

Figure 4-16. Statistical summary of braiding parameter values for Unconfined Anabranching channel type.

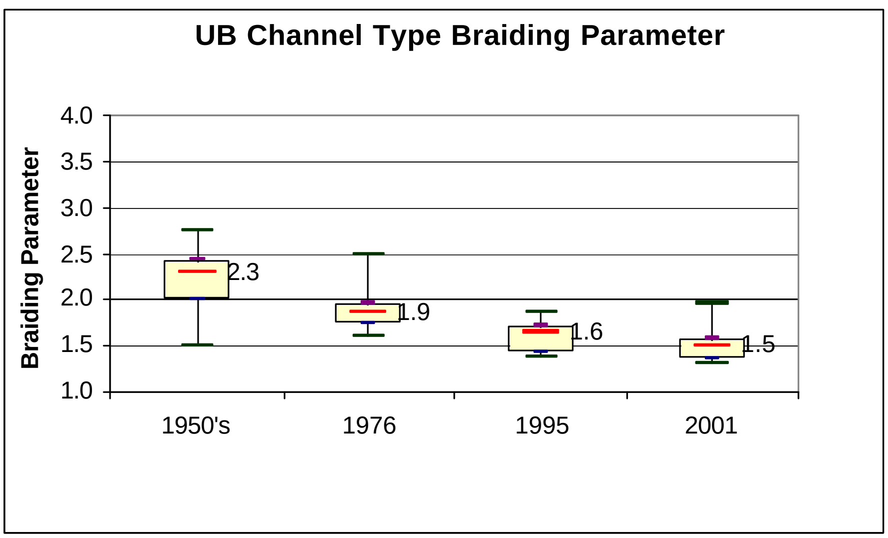

Figure 4-17. Statistical summary of braiding parameter values for Unconfined Braided channel type.

4.3 River Complexity Index (RCI)

River complexity index values for each reach are tabulated in Appendix B; calculated changes through time are listed in Appendix C, and plots showing values for each reach are in Appendix D (Figure D-11 through Figure D-15).

Plots of changes in RCI values between the 1950's and 2001 show that in general, calculated RCI values have decreased through time in Park County (Figure 4-18), Region A (Figure 4-19), and Region B (Figure 4-20). Below the Bighorn River, RCI values have generally increased over the last 50 years (Figure 4-21 and Figure 4-22). Anabranching and braided channel types typically show the highest RCI values (Figure 4-23 through Figure 4-28). The RCI value is based in part on the number of channel intersections (nodes) within a given reach. This value is flow dependent, and as such, flow conditions at the time of photography must be closely scrutinized before trends can be definitively identified.

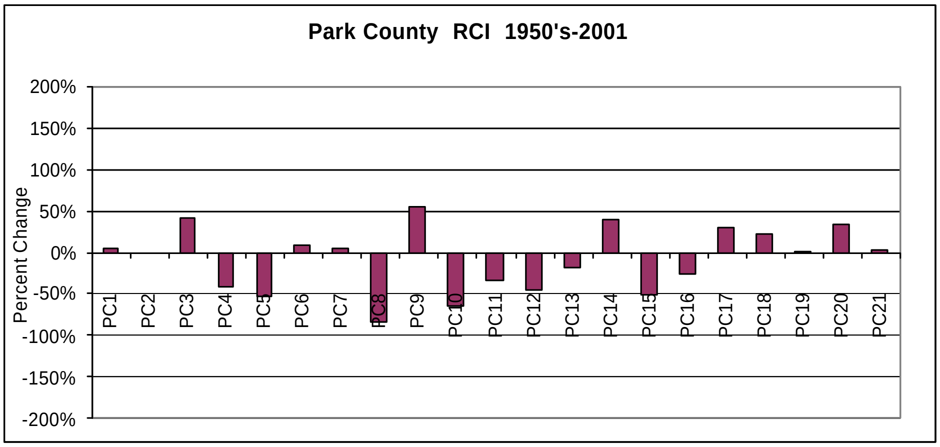

Figure 4-18. Percent change in River Complexity Index from 1950's-2000, Park County.

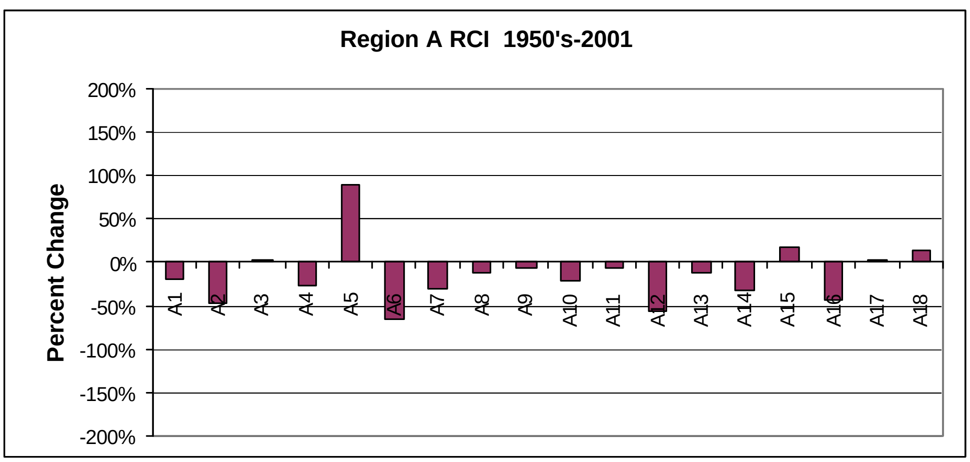

Figure 4-19. Percent change in River Complexity Index from 1950's-2000, Region A.

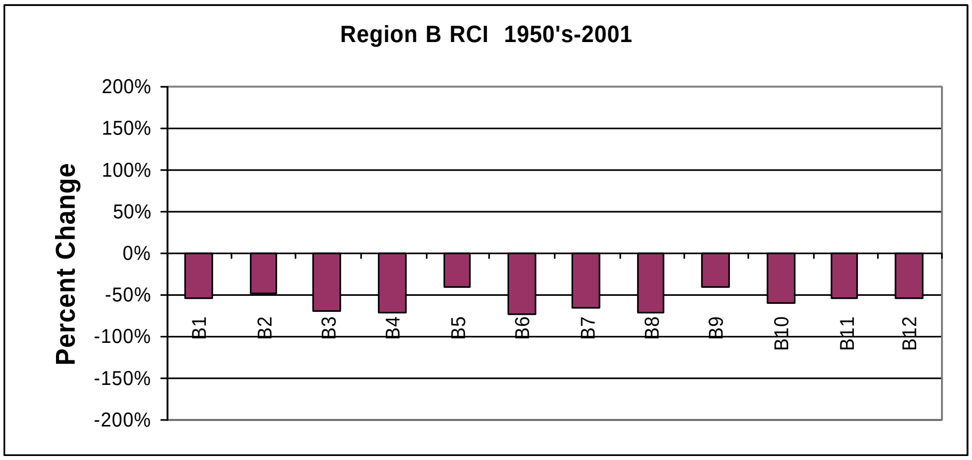

Figure 4-20. Percent change in River Complexity Index from 1950's-2000, Region B.

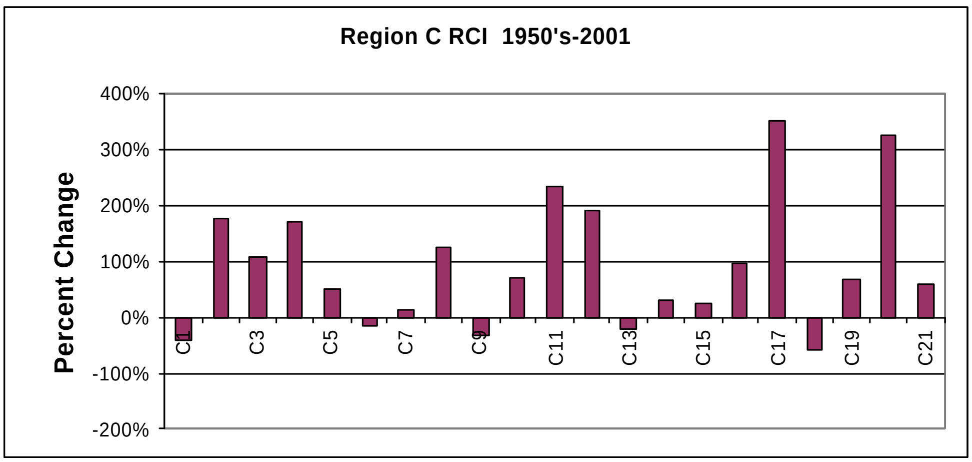

Figure 4-21. Percent change in River Complexity Index from 1950's-2000, Region C.

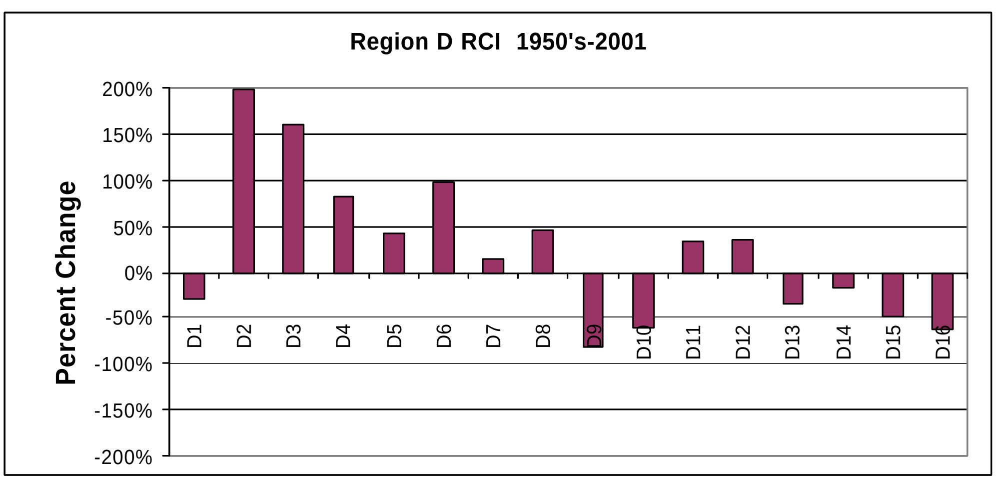

Figure 4-22. Percent change in River Complexity Index from 1950's-2000, Region D.

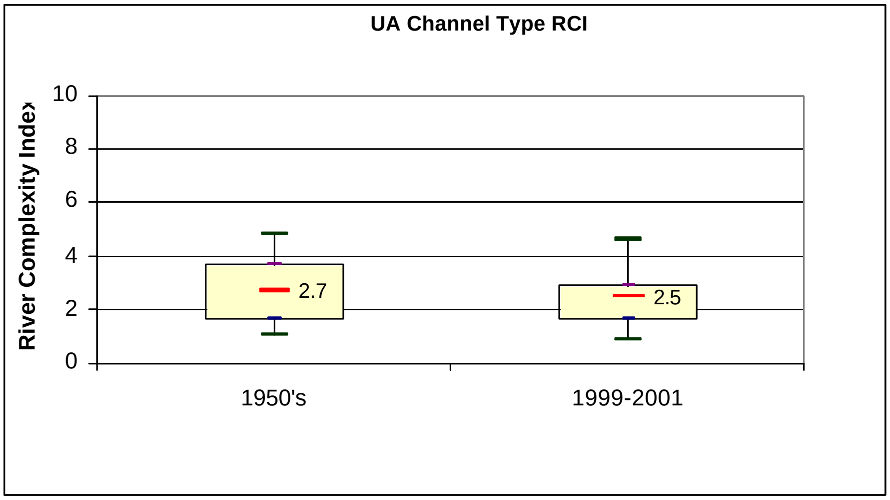

Figure 4-23. RCI summary for Unconfined Anabranching channel type.

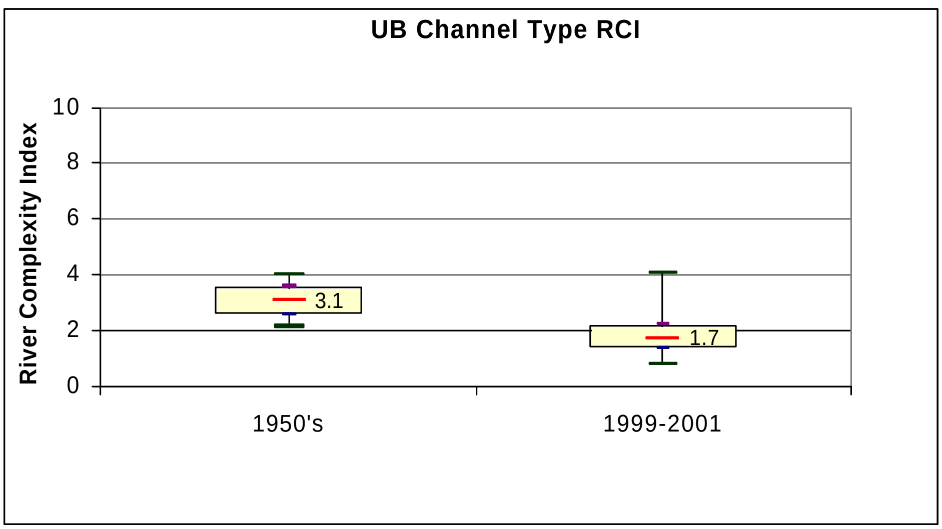

Figure 4-24. RCI summary for Unconfined Braided channel type.

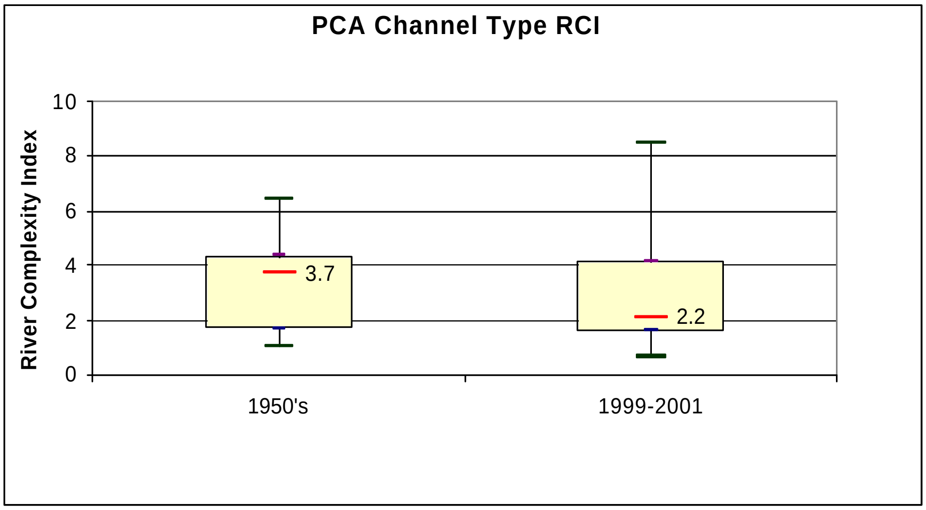

Figure 4-25. RCI summary for Partially Confined Anabranching channel type.

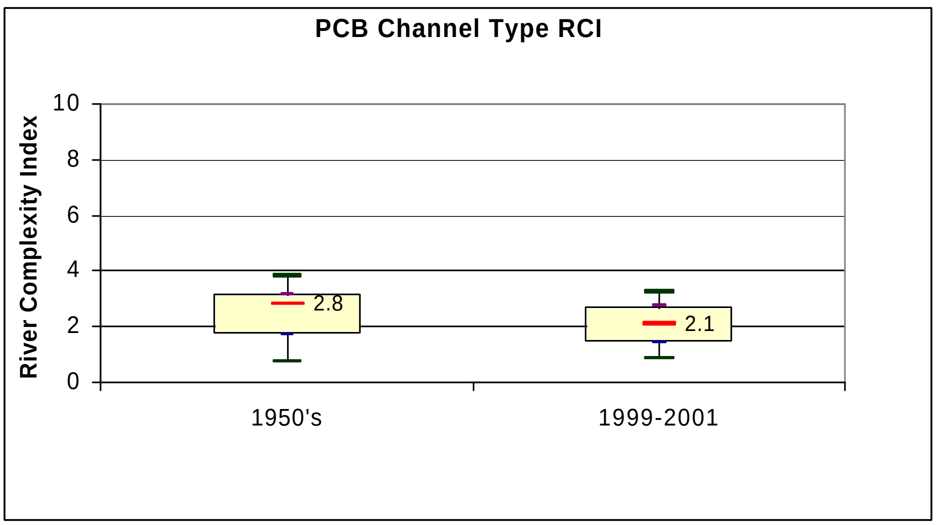

Figure 4-26. RCI summary for Partially Confined Braided channel type

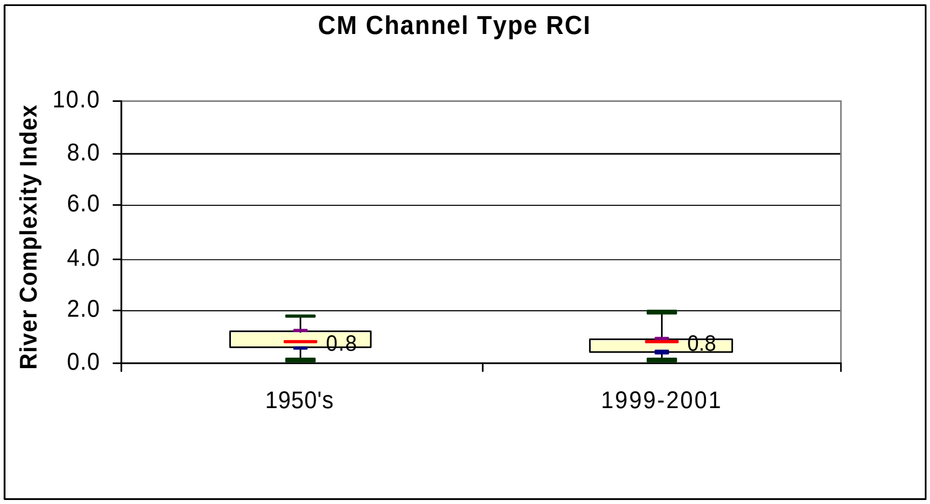

Figure 4-27. RCI Summary for Confined Meandering channel type.

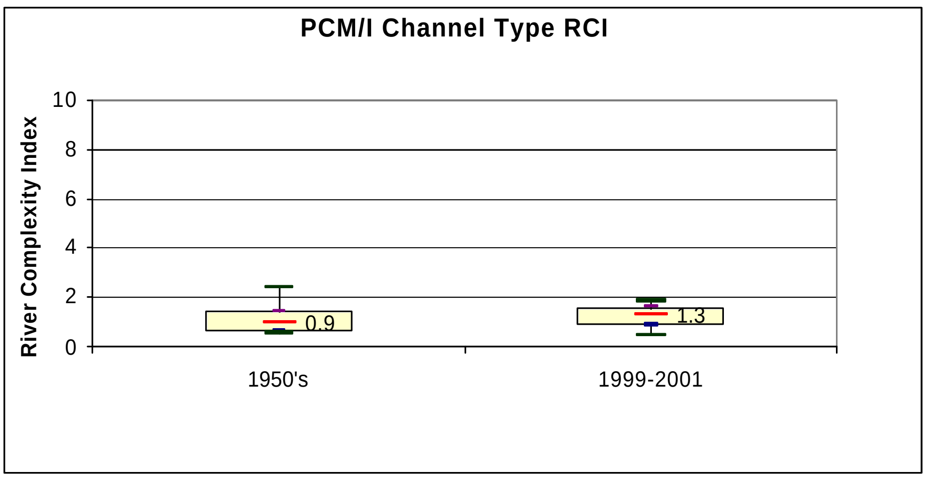

Figure 4-28. RCI summary for Partially Confined Meandering/Islands channel type.

4.4 Channel Displacement

Channel displacement ratios, which reflect square meters of channel migration per meter of channel length, are shown in Figure 4-29 through Figure 4-33. A summary of these ratios by channel type is shown in Figure 4-34. This parameter is largely independent of flow conditions at the time of the photo. As a result, the data summarized below can be interpreted to depict relative rates of channel change. Channel displacement ratios are highest in the anabranching and braided channel types, and partially confined channel types tend to have lower displacement ratios than unconfined channel types (Figure 4-34).

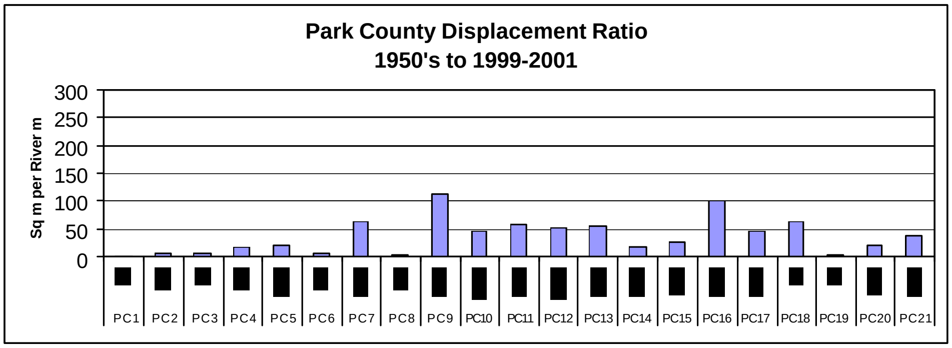

Figure 4-29. Channel Displacement Ratio, Park County.

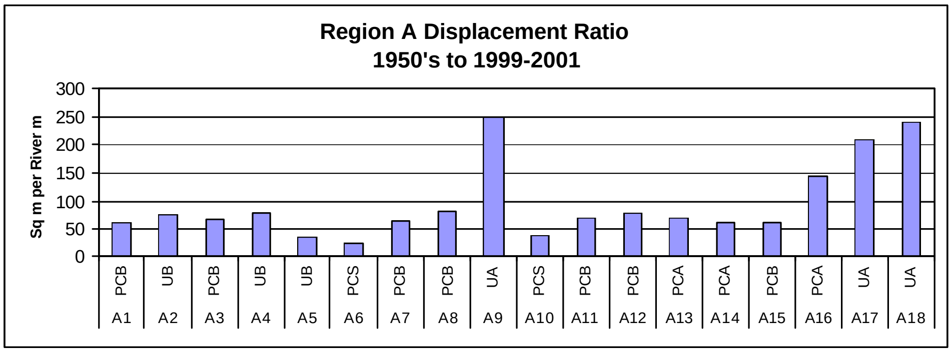

Figure 4-30. Channel Displacement Ratio, Region A.

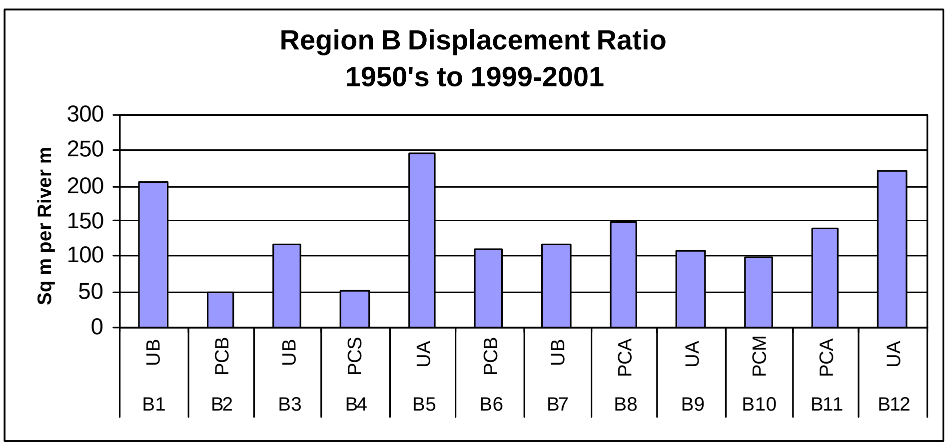

Figure 4-31. Channel Displacement Ratio, Region B.

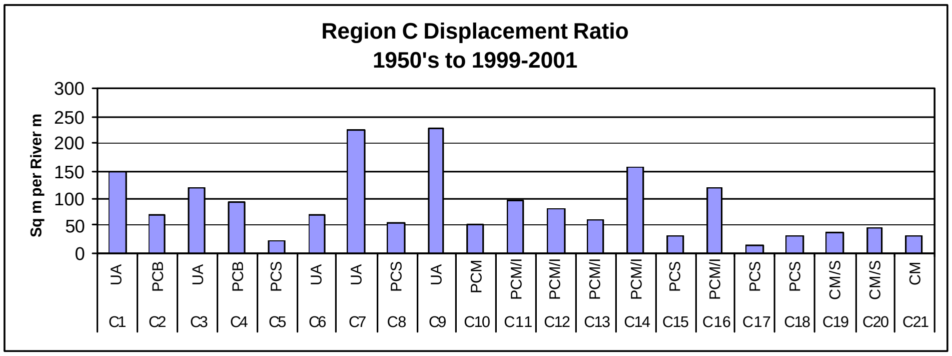

Figure 4-32. Channel Displacement Ratio, Region C.

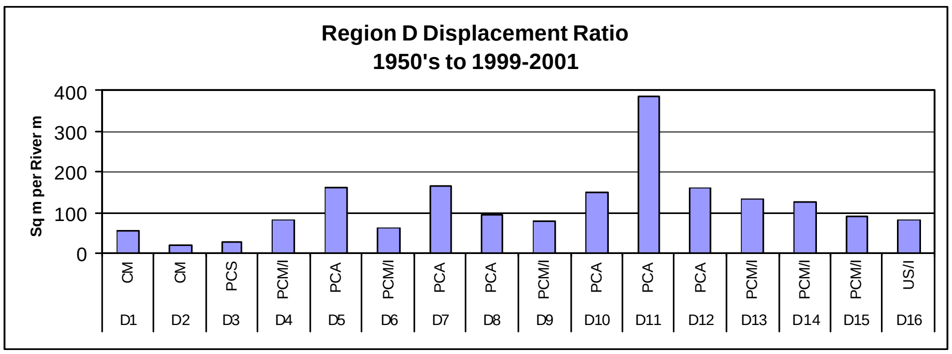

Figure 4-33. Channel Displacement Ratio, Region D

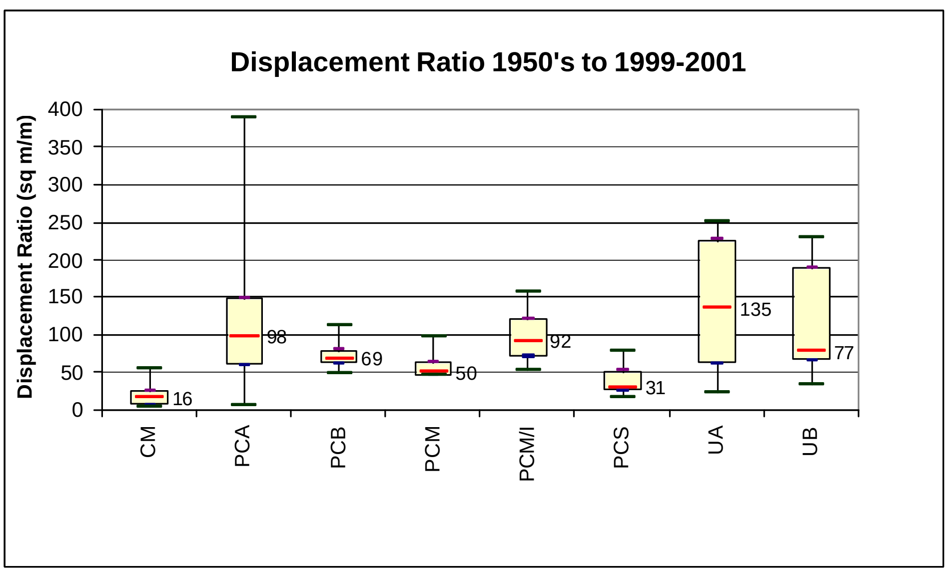

Figure 4-34. Channel Displacement Ratios summarized by channel type.

5 References

Applied Geomorphology, Inc (AGI) and DTM Consulting, Inc. (DTM), 2004. Geomorphic Reconnaissance and GIS Development, Yellowstone River, Montana-Springdale to the Missouri River Confluence: Report prepared for Custer County Conservation District, Miles City, MT, 108p.

Brown, A.G. 2002. Learning from the past: Palaeohydrology and palaeoecology. Freshwater Biology 47 (4): 817-829.

Appendix A: Reach Lengths, Classification, and General Location

Table A-1. Summary of reach types and geographic location.

Reach Identification	*Length (km)*	*County*	*Classification*	*Comments*
PC1	7.6	Park	CS: Confined straight	*Gardiner* to *Little Trail Cr.*
PC2	5.0	Park	CM: Confined meandering	*Devil's Slide* area
PC3	16.6	Park	CS: Confined straight	*Corwin Springs* to *Carbella*; *Yankee Jim Canyon*
PC4	5.8	Park	CM: Confined meandering	*Carbella* to *Hwy 89 Br.*
PC5	6.2	Park	PCA: Partly confined anabranching	*Hwy 89 Br.* to *Big Creek*
PC6	6.9	Park	CM: Confined meandering	*Big Creek* to *Six Mile Cr*
PC7	9.9	Park	PCA: Partly confined anabranching	*Six Mile Cr* to *Grey Owl*
PC8	20.3	Park	CM: Confined meandering	*Grey Owl* to just below *Mallard's Rest*; very sinuous, confined
PC9	3.1	Park	PCA: Partly confined anabranching	To *Pine Creek*
PC10	5.6	Park	PCM: Partially confined meandering	To downstream of *Deep Creek*; *Weeping wall,Jumping Rainbow*; onset of *spring creeks*
PC11	3.8	Park	PCA: Partly confined anabranching	To near *Suce Cr*, Wineglass Mtn to west
PC12	3.2	Park	PCM: Partially confined meandering	To *Carters Bridge*
PC13	2.5	Park	PCB: Partially confined braided	Through canyon upstream of Livingston
PC14	5.6	Park	PCA: Partly confined anabranching	Through Interstate bridge crossing to *Livingston*; multiple threads
PC15	2.9	Park	PCS: Partially confined straight	To *Mayors Landing*; moderate south valley wall control
PC16	6.9	Park	PCA: Partly confined anabranching	To just upstream of *Hwy 89 bridge*
PC17	3.2	Park	PCB: Partially confined braided	Through Hwy 89 bridge crossing to *Shields River*
PC18	8.5	Park	UA: Unconfined anabranching	To below *Mission Creek*; multiple channels
PC19	4.4	Park	CS: Confined straight	To near *Locke Cr*; railroad closely borders to south
PC20	7.2	Park	PCS: Partially confined straight	Moderately confined canyon section; railroad closely borders to south

Reach Identification	***Length (km)***	***County***	***Classification***	***Comments***
PC21	3.7	Park	PCA: Partly confined anabranching	To *Springdale*; multiple threads
A1	5.4	Sweetgrass	PCB: Partially confined braided	*Springdale*: Low primary sinuosity; large open bar area; extensive armoring
A2	11.1	Sweetgrass	UB: Unconfined braided	*Grey Bear* fishing access
A3	8.6	Sweetgrass	PCB: Partially confined braided	Upstream of *Big Timber*; Hell Creek Formation valley wall
A4	5.6	Sweetgrass	UB: Unconfined braided	To *Boulder River* confluence; encroachment at Big Timber; extensive armor
A5	5.2	Sweetgrass	UB: Unconfined braided	Low Qat1 terrace on right bank
A6	4.8	Sweetgrass	PCS: Partially confined straight	Channel closely follows left valley wall
A7	15.9	Sweetgrass	PCB: Partially confined braided	*Greycliff*: Narrow valley bottom with alluvial fan margins
A8	8.2	Sweetgrass	PCB: Partially confined braided	Floodplain isolation behind interstate and R/R
A9	6.2	Sweetgrass Stillwater	UA: Unconfined anabranching	To *Reed Pt*; extensive secondary channels in corridor
A10	6.9	Stillwater	PCS: Partially confined straight	Channel closely follows left valley wall
A11	11.2	Stillwater	PCB: Partially confined braided	High right bank terrace with bedrock toe; *I-90 bridge* crossing
A12	9.8	Stillwater	PCB: Partially confined braided	To *Stillwater* confluence
A13	5.8	Stillwater	PCA: Partly confined anabranching	*Columbus*; extensive armoring, broad islands
A14	12.5	Stillwater	PCA: Partly confined anabranching	Valley bottom crossover
A15	9.5	Stillwater, Carbon	PCB: Partially confined braided	Follows Stillwater/Carbon County line
A16	12.4	Stillwater, Carbon	PCA: Partly confined anabranching	*Park City*: Major shift in land use, and increase in valley bottom width
A17	10.4	Yellowstone Carbon	UA: Unconfined anabranching	To *Laurel;* WAI Reach A
A18	3.8	Yellowstone	UA: Unconfined anabranching	To Clark Fork; land use change to row crops; WAI Reach A
B1	24.6	Yellowstone	UB: Unconfined braided	Extensive armoring *u/s Billings*; WAI Reaches B,C,D
B2	9.8	Yellowstone	PCB: Partially confined braided	*Billings*; WAI Reach E
B3	7.0	Yellowstone	UB: Unconfined braided	Wide corridor d/s *Billings*; WAI Reach F
B4	6.1	Yellowstone	PCS: Partially confined straight	Channel closely follows right valey wall; extensive bank armor
B5	12.0	Yellowstone	UA: Unconfined anabranching	*Huntley:* includes *Spraklin Island*
B6	9.9	Yellowstone	PCB: Partially confined braided	Channel closely follows left valley wall

Reach Identification	***Length (km)***	***County***	***Classification***	***Comments***
B7	13.9	Yellowstone	UB: Unconfined braided	Unconfined reach
B8	14.7	Yellowstone	PCA: Partly confined anabranching	*Pompey's Pillar*
B9	7.5	Yellowstone	UA: Unconfined anabranching	Meander cutoff isolated by railroad
B10	11.6	Yellowstone	PCM: Partially confined meandering	Encroached
B11	13.1	Yellowstone	PCA: Partly confined anabranching	To *Custer Bridge*
B12	7.3	Yellowstone	UA: Unconfined anabranching	To *Bighorn River* confluence
C1	9.5	Treasure	UA: Unconfined anabranching	From *Bighorn* confluence: Includes 1 mile of left bank valley wall control; Extensive bank protection.
C2	8.9	Treasure	PCB: Partially confined braided	To *Myers Br* (RM 285.5); Railroad adjacent to channel on valley wall; low sinuosity
C3	7.6	Treasure	UA: Unconfined anabranching	To *Yellowstone Diversion*: very sinuous; large meanders, extensive bars; historic avulsion
C4	6.1	Treasure	PCB: Partially confined braided	Below *Yellowstone Diversion*
C5	5.1	Treasure	PCS: Partially confined straight	*Hysham*
C6	9.1	Treasure	UA: Unconfined anabranching	*Mission Valley*
C7	14.7	Treasure	UA: Unconfined anabranching	*Mission Valley*
C8	10.4	Treasure Rosebud	PCS: Partially confined straight	Rosebud/Treasure County Line
C9	17.2	Rosebud	UA: Unconfined anabranching	*Hammond Valley*
C10	11.0	Rosebud	PCM: Partially confined meandering	*Forsyth*
C11	18.3	Rosebud	PCM/I: Partly confined meandering/islands	To *Cartersville Bridge*
C12	16.2	Rosebud	PCM/I: Partly confined meandering/islands	*Rosebud*; numerous meander cutoffs
C13	10.8	Rosebud	PCM/I: Partly confined meandering/islands	Valley bottom crossover
C14	19.6	Rosebud Custer	PCM/I: Partly confined meandering/islands	Series of meander bends
C15	6.0	Custer	PCS: Partially confined straight	Very low riparian vegetation
C16	11.6	Custer	PCM/I: Partly confined meandering/islands	to *Miles City*
C17	7.2	Custer	PCS: Partially confined straight	*Miles City; Tongue River*
C18	5.2	Custer	PCS: Partially confined straight	Channel follows left valley wall
C19	17.9	Custer	CS: Confined straight	Confined
C20	12.2	Custer Prarie	CS: Confined straight	Confined
C21	15.2	Custer Prairie	CM: Confined meandering	To *Powder River;* confined

Reach Identification	***Length (km)***	***County***	***Classification***	***Comments***
D1	19.5	Prairie	CM: Confined meandering	To *Terry Bridge*; confined
D2	17.0	Prairie	CM: Confined meandering	To *Fallon, I-90 Bridge*; confined
D3	13.4	Prairie Dawson	PCS: Partially confined straight	Hugs right bank wall; into Dawson County
D4	17.7	Dawson	PCM/I: Partly confined meandering/islands	
D5	20.3	Dawson	PCA: Partly confined anabranching	Long secondary channels; to *Glendive*
D6	8.9	Dawson	PCM/I: Partly confined meandering/islands	*Glendive*
D7	12.3	Dawson	PCA: Partly confined anabranching	
D8	16.4	Dawson	PCA: Partly confined anabranching	To *Intake*
D9	5.6	Dawson	PCM/I: Partly confined meandering/islands	Downstream of *Intake*
D10	18.3	Dawson Wibaux Richland	PCA: Partly confined anabranching	Vegetated islands
D11	10.3	Richland	PCA: Partly confined anabranching	*Elk Island:* Very wide riparian; marked change in channel course since 1981 geologic map base
D12	21.9	Richland	PCA: Partly confined anabranching	Secondary channel on valley wall; Sinuous; long abandoned secondary channel
D13	13.8	Richland	PCM/I: Partly confined meandering/islands	
D14	23.1	Richland, McKenzie	PCM/I: Partly confined meandering/islands	Into *McKenzie County, North Dakota*: High sinuosity
D15	9.6	McKenzie	PCM/I: Partly confined meandering/islands	
D16	11.9	McKenzie	US/I: Unconfined straight/islands	*To mouth*: low sinuosity; alternate bars; vegetated islands

Appendix B: Tabulated Summary of Geomorphic Parameters

Table B-1. Geomorphic parameter values calculated for each reach.

Reach	Class	Valley Distance	1950's						1976		1995		1999-2001					
		2001	Length (km)	Braiding Parameter	Sinuosity	Node Count	RCI	RCI/km	Length (km)	Braiding Parameter	Length (km)	Braiding Parameter	Length (km)	Braiding Parameter	Sinuosity	Node Count	RCI	RCI/km
PC1	CS	7.3	7.13	1.05	1	2	2.9	0.4	N/A	N/A	N/A	N/A	7.56	1.05	1.04	2	3.1	0.4
PC2	CM	4.4	5.00	1.09	1.1	2	3.4	0.8	N/A	N/A	N/A	N/A	5.00	1.10	1.14	2	3.4	0.8
PC3	CS	16.1	16.64	1.04	1	4	5.2	0.3	N/A	N/A	N/A	N/A	16.64	1.06	1.03	6	7.2	0.4
PC4	CM	5.3	5.82	1.16	1.1	4	5.5	1.0	N/A	N/A	N/A	N/A	5.83	1.05	1.1	2	3.3	0.6
PC5	PCA	5.7	6.25	1.82	1.1	22	25.1	4.4	N/A	N/A	N/A	N/A	6.15	1.26	1.07	10	11.8	2.1
PC6	CM	6.6	6.92	1.35	1.1	10	11.5	1.8	N/A	N/A	N/A	N/A	6.92	1.27	1.05	11	12.6	1.9
PC7	PCA	9.1	10.40	2.05	1.1	29	34.2	3.8	N/A	N/A	N/A	N/A	9.92	2.21	1.09	32	35.9	3.9
PC8	CM	15.4	20.19	1.06	1.3	5	7.9	0.5	N/A	N/A	N/A	N/A	20.29	1.00	1.32	0	1.3	0.1
PC9	PCA	2.8	3.44	2.00	1.2	11	14.9	5.4	N/A	N/A	N/A	N/A	3.07	2.80	1.11	20	23.3	8.4
PC10	PCM	3.7	5.06	1.31	1.4	8	12.2	3.3	N/A	N/A	N/A	N/A	5.58	1.04	1.49	2	4.5	1.2
PC11	PCA	3.3	3.44	2.01	1.1	19	21.0	6.4	N/A	N/A	N/A	N/A	3.79	1.97	1.16	11	13.9	4.2
PC12	PCM	2.9	3.29	1.89	1.1	13	15.6	5.3	N/A	N/A	N/A	N/A	3.15	1.73	1.07	7	8.5	2.9
PC13	PCB	2.2	2.29	1.97	1	7	8.4	3.8	N/A	N/A	N/A	N/A	2.50	1.54	1.14	5	6.8	3.1
PC14	PCA	4.8	5.62	1.90	1.2	14	17.5	3.6	N/A	N/A	N/A	N/A	5.56	2.18	1.16	20	24.3	5.0
PC15	PCS	2.8	3.01	1.33	1.1	5	6.4	2.3	N/A	N/A	N/A	N/A	2.88	1.18	1.02	2	3.1	1.1
PC16	PCA	6.3	7.21	2.05	1.1	32	37.7	6.0	N/A	N/A	N/A	N/A	6.94	1.90	1.1	24	27.5	4.4
PC17	PCB	2.8	3.06	1.30	1.1	3	4.4	1.6	N/A	N/A	N/A	N/A	3.18	1.25	1.15	4	5.7	2.1
PC18	UA	7.7	8.27	1.95	1.1	26	29.0	3.8	N/A	N/A	N/A	N/A	8.50	2.14	1.1	31	35.4	4.6
PC19	CS	4.3	4.42	1.07	1	2	3.1	0.7	N/A	N/A	N/A	N/A	4.43	1.07	1.03	2	3.1	0.7
PC20	PCS	6.6	7.24	1.63	1.1	13	15.5	2.4	N/A	N/A	N/A	N/A	7.21	1.81	1.1	18	20.9	3.2
PC21	PCA	3.2	3.55	2.66	1.1	16	19.1	6.0	N/A	N/A	N/A	N/A	3.65	2.39	1.15	16	19.6	6.2
A1	PCB	5.2	5.78	1.37	1.1	7	8.8	1.7	5.74	1.17	5.35	1.15	5.43	1.23	1.04	6	7.3	1.4

Reach	Class	Valley Distance	1950's						1976		1995		1999-2001					
		2001	Length (km)	Braiding Parameter	Sinuosity	Node Count	RCI	RCI/km	Length (km)	Braiding Parameter	Length (km)	Braiding Parameter	Length (km)	Braiding Parameter	Sinuosity	Node Count	RCI	RCI/km
A2	UB	10.4	11.67	2.21	1.1	36	41.5	4.0	11.22	1.60	11.18	1.73	11.12	1.57	1.07	19	21.4	2.1
A3	PCB	7.5	8.47	2.11	1.1	20	23.9	3.2	8.61	1.74	8.61	1.88	8.59	1.64	1.15	20	24.2	3.2
A4	UB	4.7	5.31	1.94	1.1	12	14.6	3.1	5.19	1.71	5.56	1.61	5.58	1.45	1.18	8	10.6	2.2
A5	UB	4.8	5.45	1.51	1.1	8	10.2	2.1	5.14	1.91	5.19	1.87	5.19	1.96	1.08	17	19.5	4.1
A6	PCS	4.5	4.68	1.59	1	13	14.5	3.2	4.67	1.37	4.73	1.36	4.78	1.27	1.05	4	5.3	1.2
A7	PCB	14.6	15.63	1.77	1.1	36	39.6	2.7	15.78	1.64	15.96	1.58	15.93	1.50	1.09	24	27.3	1.9
A8	PCB	7.5	8.29	1.91	1.1	17	21.0	2.8	8.36	2.15	8.18	1.94	8.16	1.85	1.09	16	18.5	2.5
A9	UA	5.4	7.10	2.38	1.3	14	19.8	3.7	6.18	1.94	6.37	2.31	6.25	2.29	1.16	15	18.6	3.4
A10	PCS	6.5	6.89	1.85	1.1	19	21.1	3.2	6.81	1.92	6.87	1.55	6.87	1.64	1.05	15	16.8	2.6
A11	PCB	10.0	11.18	1.87	1.1	27	31.4	3.1	11.11	1.79	11.31	1.84	11.22	1.91	1.12	25	29.2	2.9
A12	PCB	9.0	9.61	1.98	1.1	25	27.7	3.1	9.46	1.84	9.74	1.62	9.80	1.51	1.09	10	12.0	1.3
A13	PCA	5.1	5.88	2.09	1.2	17	20.7	4.0	5.75	2.19	5.76	1.81	5.78	2.09	1.13	15	18.1	3.5
A14	PCA	11.6	12.78	2.43	1.1	34	38.6	3.3	12.21	1.81	12.62	1.76	12.52	1.76	1.08	23	25.9	2.2
A15	PCB	8.3	9.05	2.15	1.1	17	19.6	2.4	9.27	1.91	9.31	2.09	9.47	2.01	1.14	19	22.8	2.7
A16	PCA	10.8	12.15	2.43	1.1	33	38.3	3.6	12.04	2.56	12.44	1.93	12.35	1.94	1.15	18	21.8	2.0
A17	UA	9.2	10.56	1.94	1.2	21	25.2	2.7	10.39	1.71	10.45	1.46	10.40	1.70	1.13	22	26.0	2.8
A18	UA	3.3	4.22	1.77	1.3	6	9.0	2.7	3.86	2.36	3.82	2.34	3.79	2.28	1.15	8	10.3	3.1
B1	UB	21.2	24.18	2.39	1.1	57	66.1	3.1	23.64	2.50	24.97	1.69	24.56	1.54	1.16	25	30.1	1.4
B2	PCB	8.9	9.48	2.24	1.1	23	25.4	2.8	9.64	1.62	9.89	1.51	9.82	1.47	1.1	11	13.2	1.5
B3	UB	6.1	6.92	2.47	1.1	12	14.7	2.4	7.06	1.81	7.01	1.38	7.05	1.32	1.15	3	4.6	0.8
B4	PCS	6.0	6.08	1.89	1	13	14.2	2.4	6.13	1.45	6.15	1.02	6.06	1.11	1.01	3	4.1	0.7
B5	UA	10.1	11.91	2.36	1.2	26	31.8	3.2	12.06	2.57	12.14	2.03	11.95	2.00	1.18	15	18.9	1.9
B6	PCB	9.1	9.62	2.31	1.1	27	29.6	3.3	10.05	2.25	9.96	1.48	9.88	1.49	1.09	6	7.6	0.8
B7	UB	12.2	13.50	2.76	1.1	40	45.4	3.7	13.09	1.98	13.98	1.38	13.95	1.32	1.14	13	16.0	1.3
B8	PCA	12.6	15.66	2.35	1.2	41	52.0	4.1	14.26	2.57	14.36	1.63	14.68	1.74	1.16	12	15.1	1.2
B9	UA	6.2	7.02	2.80	1.1	21	24.7	4.0	6.84	2.53	7.50	2.19	7.47	1.73	1.2	11	14.3	2.3

Reach	Class	Valley Distance	1950's						1976		1995		1999-2001					
		2001	Length (km)	Braiding Parameter	Sinuosity	Node Count	RCI	RCI/km	Length (km)	Braiding Parameter	Length (km)	Braiding Parameter	Length (km)	Braiding Parameter	Sinuosity	Node Count	RCI	RCI/km
B10	PCM	9.6	11.16	2.74	1.2	37	44.0	4.6	12.07	2.04	11.49	1.73	11.61	1.31	1.21	13	16.9	1.8
B11	PCA	11.9	13.39	2.79	1.1	45	51.9	4.4	13.58	2.29	12.92	1.84	13.05	1.73	1.1	21	24.2	2.0
B12	UA	6.0	7.30	3.07	1.2	23	29.0	4.8	7.17	2.46	7.24	1.86	7.32	1.79	1.21	10	13.3	2.2
C1	UA	7.6	9.62	1.56	1.3	9	12.7	1.7	9.38	2.49	9.54	2.08	9.54	1.61	1.26	5	7.5	1.0
C2	PCB	8.6	9.03	1.23	1.1	5	6.3	0.7	9.14	1.68	8.92	1.98	8.87	1.85	1.03	16	17.5	2.0
C3	UA	5.1	8.32	1.28	1.6	3	6.6	1.3	8.94	2.33	7.53	1.66	7.58	1.51	1.49	8	13.5	2.7
C4	PCB	3.8	5.64	1.12	1.5	1	3.0	0.8	5.88	1.34	5.89	1.46	6.08	1.36	1.59	4	7.9	2.1
C5	PCS	4.9	4.99	1.53	1	3	4.1	0.8	5.00	1.84	5.07	1.94	5.07	1.45	1.04	5	6.3	1.3
C6	UA	5.6	8.14	1.34	1.5	3	5.9	1.1	8.81	1.41	9.10	1.62	9.10	1.17	1.64	2	4.9	0.9
C7	UA	10.0	13.61	2.18	1.4	16	23.1	2.3	14.35	2.58	15.28	2.32	14.67	1.76	1.47	17	26.4	2.6
C8	PCS	9.7	10.58	1.34	1.1	6	7.7	0.8	10.36	1.45	10.48	1.76	10.43	1.58	1.08	15	17.3	1.8
C9	UA	12.4	17.75	1.57	1.4	12	18.6	1.5	18.08	1.80	19.06	1.83	17.21	1.18	1.39	8	12.5	1.0
C10	PCM	9.8	11.52	1.24	1.2	4	5.9	0.6	10.83	1.82	10.98	1.50	10.99	1.40	1.12	8	10.1	1.0
C11	PCM/I	14.2	18.33	1.35	1.3	5	7.7	0.5	18.47	1.70	18.80	1.62	18.28	1.61	1.29	19	25.7	1.8
C12	PCM/I	12.9	15.85	1.14	1.2	5	7.4	0.6	16.03	1.60	16.14	1.53	16.20	1.55	1.26	16	21.4	1.7
C13	PCM/I	9.6	10.82	1.50	1.1	8	10.1	1.1	10.88	1.64	10.85	1.47	10.85	1.29	1.13	6	7.9	0.8
C14	PCM/I	15.7	20.36	1.56	1.3	14	19.5	1.2	18.86	1.77	19.61	1.77	19.58	1.42	1.25	19	24.9	1.6
C15	PCS	5.8	5.94	1.25	1	3	4.1	0.7	5.95	1.41	6.01	1.68	6.01	1.38	1.04	4	5.2	0.9
C16	PCM/I	10.6	11.76	1.59	1.1	8	10.0	0.9	11.73	2.34	11.62	2.31	11.64	1.84	1.09	17	19.7	1.9
C17	PCS	6.5	7.13	1.30	1.1	1	2.2	0.3	7.09	1.73	7.13	1.76	7.16	1.81	1.1	8	9.9	1.5
C18	PCS	5.0	5.16	1.60	1	6	7.2	1.4	5.19	1.09	5.20	1.39	5.21	1.07	1.04	2	3.1	0.6
C19	CS	17.3	17.82	1.13	1	5	6.2	0.4	17.81	1.40	17.90	1.34	17.90	1.29	1.03	9	10.3	0.6
C20	CS	11.8	12.41	1.12	1.1	2	3.2	0.3	12.19	1.55	12.16	1.49	12.16	1.45	1.03	12	13.4	1.1
C21	CM	13.8	15.25	1.29	1.1	6	7.8	0.6	15.30	1.55	15.29	1.20	15.25	1.33	1.11	10	12.2	0.9
D1	CM	14.6	20.10	1.32	1.4	14	20.6	1.4	19.48	1.28	19.50	1.27	19.48	1.30	1.33	10	14.7	1.0
D2	CM	15.9	17.15	1.00	1.1	0	1.1	0.1	17.04	1.00	17.04	1.06	17.04	1.06	1.07	2	3.2	0.2

Reach	Class	Valley Distance	1950's						1976		1995		1999-2001					
		2001	Length (km)	Braiding Parameter	Sinuosity	Node Count	RCI	RCI/km	Length (km)	Braiding Parameter	Length (km)	Braiding Parameter	Length (km)	Braiding Parameter	Sinuosity	Node Count	RCI	RCI/km
D3	PCS	12.7	13.79	1.10	1.1	2	3.3	0.3	13.29	1.46	13.30	1.52	13.43	1.54	1.06	7	8.5	0.7
D4	PCM/I	16.5	18.24	1.22	1.1	7	8.9	0.5	17.73	1.77	17.72	1.80	17.68	1.45	1.07	14	16.1	1.0
D5	PCA	17.2	20.07	1.76	1.2	17	21.0	1.2	20.36	2.24	18.22	2.60	20.31	2.05	1.18	24	29.4	1.7
D6	PCM/I	8.4	9.08	1.37	1.1	4	5.4	0.7	9.00	1.92	8.99	1.90	8.93	1.55	1.07	9	10.7	1.3
D7	PCA	11.0	13.36	1.43	1.2	8	10.9	1.0	12.11	2.16	12.22	3.14	12.29	1.77	1.11	10	12.3	1.1
D8	PCA	11.2	16.80	1.28	1.5	7	12.0	1.1	16.67	1.64	16.35	1.72	16.35	1.42	1.46	11	17.5	1.6
D9	PCM/I	4.9	5.26	2.09	1.1	10	11.9	2.4	5.41	1.71	5.63	1.43	5.63	1.24	1.16	1	2.3	0.5
D10	PCA	15.0	18.15	1.72	1.2	20	25.4	1.7	N/A	N/A	18.64	2.27	18.26	1.31	1.22	7	9.7	0.7
D11	PCA	8.7	10.96	1.65	1.3	11	15.2	1.8	N/A	N/A	10.45	3.53	10.27	2.04	1.19	16	20.2	2.3
D12	PCA	17.4	23.00	1.82	1.3	13	18.5	1.1	N/A	N/A	21.62	2.51	21.90	1.77	1.26	19	25.2	1.5
D13	PCM/I	12.3	13.42	1.23	1.1	7	8.7	0.7	N/A	N/A	13.51	2.04	13.75	1.14	1.12	4	5.6	0.5
D14	PCM/I	20.3	23.19	1.77	1.1	28	33.2	1.6	N/A	N/A	23.13	1.75	23.13	1.55	1.14	23	27.4	1.4
D15	PCM/I	9.2	9.62	2.34	1	17	18.7	2.0	N/A	N/A	9.46	1.99	9.62	1.64	1.04	8	9.4	1.0
D16	US/I	11.3	12.05	2.75	1	32	35.1	3.1	N/A	N/A	12.04	2.34	11.91	1.58	1.05	11	12.6	1.1

Appendix C: Tabulated Summary of Temporal Changes in Geomorphic Parameters

Table C-1. Calculated changes in geomorphic parameters through time.

Reach	Class	Displace-ment Ratio (sq m per m)	% Change in River Complexity Index (RCI)	% Change in Channel Length				% Change in Braiding Parameter			
		1950-2001	1950-2001	1950-1976	1976-1995	1995-2001	1950-2001	1950's-1976	1976-1995	1995-2001	1950's-2001
PC1	CS	2.9	6.1%	N/A	N/A	N/A	6.1%	N/A	N/A	N/A	-0.9%
PC2	CM	6.7	-0.1%	N/A	N/A	N/A	-0.1%	N/A	N/A	N/A	0.6%
PC3	CS	6.2	40.0%	N/A	N/A	N/A	0.0%	N/A	N/A	N/A	1.4%
PC4	CM	16.2	-39.9%	N/A	N/A	N/A	0.2%	N/A	N/A	N/A	-9.8%
PC5	PCA	21.7	-52.9%	N/A	N/A	N/A	-1.5%	N/A	N/A	N/A	-31.0%
PC6	CM	6.5	9.1%	N/A	N/A	N/A	0.0%	N/A	N/A	N/A	-6.2%
PC7	PCA	63.0	4.9%	N/A	N/A	N/A	-4.6%	N/A	N/A	N/A	7.8%
PC8	CM	5.7	-83.3%	N/A	N/A	N/A	0.5%	N/A	N/A	N/A	-5.5%
PC9	PCA	112.9	56.1%	N/A	N/A	N/A	-10.8%	N/A	N/A	N/A	40.0%
PC10	PCM	47.1	-63.2%	N/A	N/A	N/A	10.3%	N/A	N/A	N/A	-20.9%
PC11	PCA	58.0	-33.9%	N/A	N/A	N/A	10.1%	N/A	N/A	N/A	-1.7%
PC12	PCM	51.8	-45.3%	N/A	N/A	N/A	-4.3%	N/A	N/A	N/A	-8.7%
PC13	PCB	56.5	-18.2%	N/A	N/A	N/A	9.1%	N/A	N/A	N/A	-22.2%
PC14	PCA	20.8	38.5%	N/A	N/A	N/A	-1.1%	N/A	N/A	N/A	14.8%
PC15	PCS	25.9	-52.1%	N/A	N/A	N/A	-4.2%	N/A	N/A	N/A	-11.6%
PC16	PCA	101.6	-27.1%	N/A	N/A	N/A	-3.7%	N/A	N/A	N/A	-7.2%
PC17	PCB	45.9	30.0%	N/A	N/A	N/A	4.0%	N/A	N/A	N/A	-3.3%
PC18	UA	64.4	21.8%	N/A	N/A	N/A	2.7%	N/A	N/A	N/A	9.6%
PC19	CS	5.4	0.2%	N/A	N/A	N/A	0.2%	N/A	N/A	N/A	-0.2%
PC20	PCS	22.9	35.2%	N/A	N/A	N/A	-0.4%	N/A	N/A	N/A	11.3%
PC21	PCA	40.2	2.8%	N/A	N/A	N/A	2.8%	N/A	N/A	N/A	-10.1%
A1	PCB	59.2	-17.7%	-0.6%	-6.8%	1.6%	-6.0%	-14.9%	-1.2%	6.4%	-10.6%
A2	UB	75.2	-48.5%	-3.8%	-0.4%	-0.5%	-4.7%	-27.7%	8.1%	-8.9%	-28.9%
A3	PCB	66.3	1.4%	1.6%	0.1%	-0.3%	1.4%	-17.7%	8.1%	-12.9%	-22.5%
A4	UB	78.6	-27.2%	-2.2%	7.2%	0.3%	5.1%	-11.8%	-6.1%	-10.0%	-25.4%
A5	UB	34.6	90.5%	-5.6%	0.9%	0.0%	-4.7%	26.7%	-1.9%	4.4%	29.6%
A6	PCS	25.8	-63.6%	-0.3%	1.4%	1.0%	2.1%	-14.0%	-0.4%	-7.1%	-20.4%
A7	PCB	65.2	-31.1%	1.0%	1.2%	-0.2%	1.9%	-7.3%	-4.2%	-4.7%	-15.4%
A8	PCB	80.7	-11.9%	0.9%	-2.1%	-0.3%	-1.5%	12.6%	-9.9%	-4.6%	-3.2%
A9	UA	251.2	-6.2%	-12.9%	3.1%	-2.0%	-12.1%	-18.3%	19.0%	-1.1%	-3.9%
A10	PCS	37.2	-20.2%	-1.2%	0.9%	0.0%	-0.3%	3.9%	-19.4%	5.5%	-11.6%
A11	PCB	68.9	-6.8%	-0.6%	1.8%	-0.8%	0.4%	-4.4%	2.8%	3.7%	2.0%
A12	PCB	77.5	-56.9%	-1.5%	2.9%	0.7%	2.0%	-7.2%	-12.1%	-7.0%	-24.1%
A13	PCA	68.7	-12.6%	-2.2%	0.1%	0.5%	-1.6%	5.1%	-17.3%	15.2%	0.2%
A14	PCA	61.7	-32.8%	-4.4%	3.4%	-0.8%	-2.0%	-25.5%	-2.8%	-0.1%	-27.7%
A15	PCB	61.9	16.3%	2.4%	0.5%	1.7%	4.6%	-10.9%	9.2%	-4.0%	-6.6%
A16	PCA	143.2	-43.2%	-0.9%	3.3%	-0.7%	1.6%	5.3%	-24.4%	0.1%	-20.3%
A17	UA	207.2	3.0%	-1.7%	0.6%	-0.5%	-1.5%	-12.1%	-14.3%	16.3%	-12.4%
A18	UA	241.7	15.6%	-8.6%	-0.9%	-0.7%	-10.1%	33.3%	-0.8%	-2.3%	29.2%
B1	UB	205.3	-54.5%	-2.2%	5.6%	-1.7%	1.6%	4.3%	-32.3%	-8.8%	-35.6%
B2	PCB	48.2	-48.2%	1.7%	2.6%	-0.6%	3.6%	-27.7%	-7.0%	-2.9%	-34.7%
B3	UB	119.0	-68.7%	2.0%	-0.7%	0.5%	1.8%	-26.5%	-23.8%	-4.8%	-46.6%

Reach	Class	Displace-ment Ratio (sq m per m)	% Change in River Complexity Index (RCI)	% Change in Channel Length				% Change in Braiding Parameter			
		1950-2001	1950-2001	1950-1976	1976-1995	1995-2001	1950-2001	1950's-1976	1976-1995	1995-2001	1950's-2001
B4	PCS	51.9	-71.5%	0.8%	0.2%	-1.3%	-0.3%	-23.6%	-29.3%	8.4%	-41.4%
B5	UA	246.3	-40.5%	1.3%	0.6%	-1.5%	0.3%	9.0%	-21.1%	-1.2%	-15.0%
B6	PCB	111.5	-74.3%	4.5%	-0.9%	-0.9%	2.7%	-2.6%	-34.2%	0.6%	-35.6%
B7	UB	117.5	-64.7%	-3.0%	6.8%	-0.2%	3.3%	-28.3%	-30.1%	-4.7%	-52.2%
B8	PCA	147.6	-71.0%	-8.9%	0.7%	2.2%	-6.2%	9.0%	-36.4%	6.7%	-26.0%
B9	UA	108.2	-41.9%	-2.5%	9.5%	-0.3%	6.5%	-9.8%	-13.1%	-21.3%	-38.3%
B10	PCM	98.9	-61.7%	8.2%	-4.8%	1.1%	4.0%	-25.6%	-15.2%	-24.2%	-52.2%
B11	PCA	140.8	-53.4%	1.4%	-4.8%	1.0%	-2.5%	-18.1%	-19.6%	-5.8%	-38.0%
B12	UA	221.5	-54.0%	-1.7%	1.0%	1.1%	0.3%	-19.7%	-24.6%	-3.8%	-41.7%
C1	UA	148.7	-40.5%	-2.5%	1.8%	-0.1%	-0.9%	59.2%	-16.4%	-22.8%	2.8%
C2	PCB	72.0	178.3%	1.1%	-2.4%	-0.5%	-1.8%	37.2%	17.6%	-6.5%	51.0%
C3	UA	120.8	105.0%	7.4%	-15.7%	0.6%	-8.9%	81.4%	-28.9%	-9.1%	17.3%
C4	PCB	94.2	169.5%	4.2%	0.2%	3.2%	7.8%	19.6%	8.9%	-7.0%	21.1%
C5	PCS	22.6	52.5%	0.2%	1.5%	0.0%	1.7%	19.9%	5.3%	-24.9%	-5.2%
C6	UA	71.8	-16.1%	8.3%	3.3%	0.0%	11.9%	4.7%	15.4%	-27.7%	-12.6%
C7	UA	226.2	14.1%	5.5%	6.4%	-4.0%	7.8%	18.1%	-10.0%	-24.3%	-19.5%
C8	PCS	56.7	125.4%	-2.0%	1.1%	-0.5%	-1.4%	8.1%	21.1%	-10.3%	17.4%
C9	UA	228.1	-32.9%	1.9%	5.4%	-9.7%	-3.0%	14.6%	1.4%	-35.2%	-24.7%
C10	PCM	53.8	71.7%	-6.0%	1.4%	0.1%	-4.6%	46.8%	-17.7%	-6.4%	13.2%
C11	PCM/I	95.4	232.6%	0.8%	1.8%	-2.7%	-0.2%	26.0%	-4.9%	-0.5%	19.3%
C12	PCM/I	82.2	189.7%	1.1%	0.7%	0.4%	2.2%	40.7%	-4.7%	1.5%	36.0%
C13	PCM/I	59.8	-22.0%	0.6%	-0.3%	0.0%	0.2%	9.3%	-10.5%	-12.0%	-13.9%
C14	PCM/I	158.2	28.2%	-7.4%	4.0%	-0.2%	-3.8%	13.2%	0.4%	-19.8%	-8.9%
C15	PCS	30.6	26.4%	0.1%	1.0%	0.0%	1.1%	12.7%	19.5%	-18.2%	10.3%
C16	PCM/I	120.2	97.9%	-0.3%	-0.9%	0.2%	-1.0%	47.4%	-1.3%	-20.3%	16.1%
C17	PCS	15.9	352.5%	-0.5%	0.7%	0.4%	0.6%	32.7%	2.3%	2.3%	38.8%
C18	PCS	29.8	-56.7%	0.5%	0.1%	0.3%	1.0%	-31.6%	27.2%	-23.0%	-33.0%
C19	CS	37.6	67.4%	0.0%	0.5%	0.0%	0.4%	23.8%	-4.1%	-4.0%	14.0%
C20	CS	45.8	324.6%	-1.7%	-0.3%	0.0%	-2.0%	38.8%	-4.1%	-2.9%	29.2%
C21	CM	29.3	57.1%	0.3%	-0.1%	-0.2%	0.0%	20.7%	-22.5%	10.2%	3.1%
D1	CM	55.7	-28.9%	-3.1%	0.1%	-0.1%	-3.1%	-2.9%	-1.3%	2.5%	-1.7%
D2	CM	18.9	198.6%	-0.7%	0.0%	0.0%	-0.6%	0.0%	5.9%	-0.3%	5.5%
D3	PCS	28.8	159.9%	-3.6%	0.1%	1.0%	-2.5%	33.1%	3.5%	1.5%	39.8%
D4	PCM/I	82.5	81.7%	-2.8%	0.0%	-0.3%	-3.1%	45.3%	1.8%	-19.5%	19.0%
D5	PCA	163.7	40.5%	1.5%	-10.5%	11.5%	1.2%	27.3%	16.0%	-21.1%	16.5%
D6	PCM/I	61.7	96.6%	-0.9%	-0.2%	-0.6%	-1.7%	39.9%	-1.0%	-18.1%	13.4%
D7	PCA	164.5	12.4%	-9.3%	0.9%	0.5%	-8.0%	50.9%	45.3%	-43.6%	23.6%
D8	PCA	94.0	46.0%	-0.8%	-1.9%	0.0%	-2.7%	27.8%	5.1%	-17.4%	11.1%
D9	PCM/I	78.6	-80.6%	2.8%	3.9%	0.0%	6.9%	-17.8%	-16.3%	-13.6%	-40.6%
D10	PCA	150.0	-61.7%	N/A	N/A	N/A	0.6%	-30.6%	90.5%	-42.3%	-23.7%
D11	PCA	387.6	32.8%	N/A	N/A	N/A	-6.2%	N/A	N/A	N/A	24.0%
D12	PCA	160.8	36.0%	N/A	N/A	N/A	-4.8%	N/A	N/A	N/A	-2.7%
D13	PCM/I	132.2	-35.9%	N/A	N/A	N/A	2.5%	N/A	N/A	N/A	-7.8%
D14	PCM/I	124.1	-17.4%	N/A	N/A	N/A	-0.2%	N/A	N/A	N/A	-12.3%
D15	PCM/I	91.6	-50.0%	N/A	N/A	N/A	0.0%	N/A	N/A	N/A	-30.1%
D16	US/I	80.8	-64.0%	N/A	N/A	N/A	-1.1%	N/A	N/A	N/A	-42.7%

Appendix D: Plotted Results

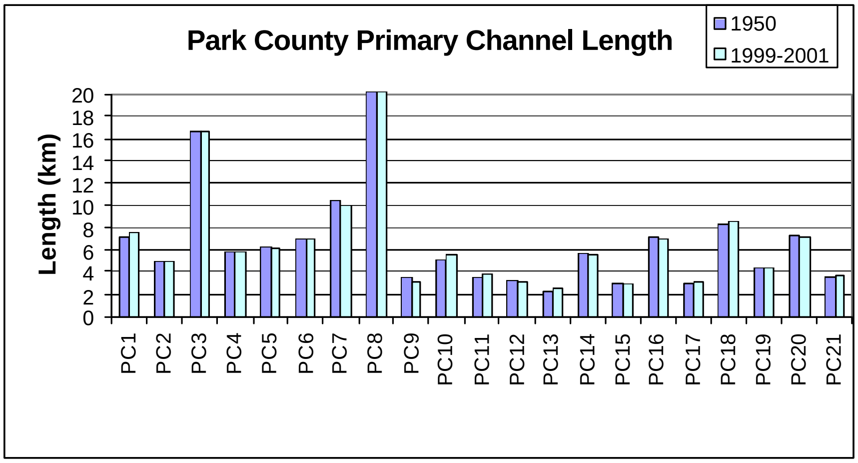

Figure D-1. Primary channel lengths, Park County

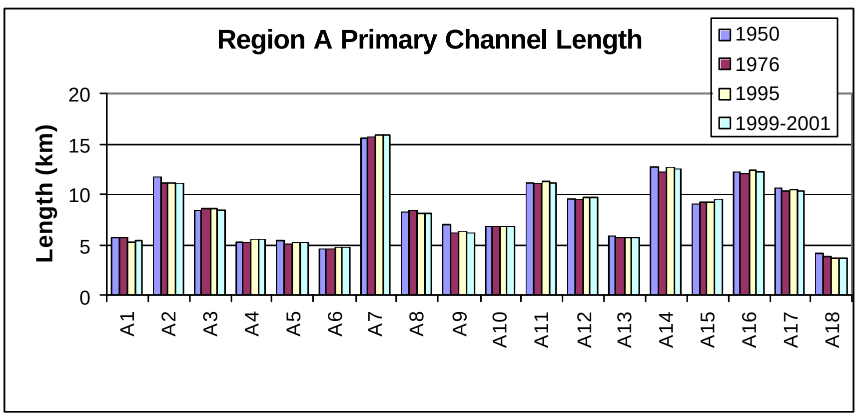

Figure D-2. Primary channel lengths, Region A

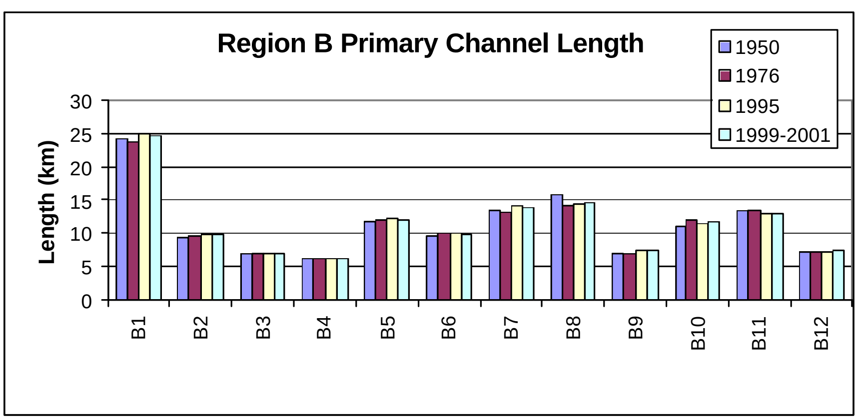

Figure D-3. Primary Channel lengths, Region B

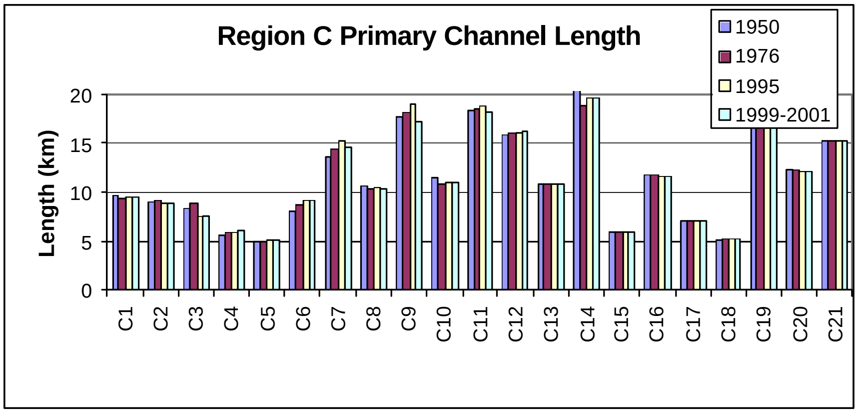

Figure D-4. Primary Channel lengths, Region C.

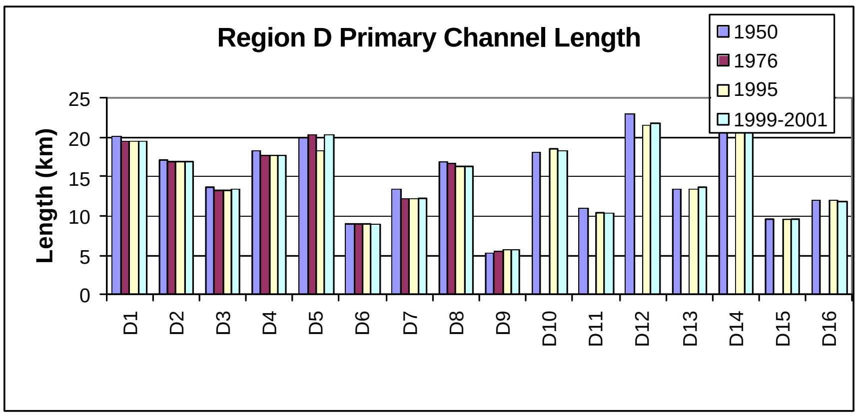

Figure D-5. Primary Channel lengths, Region D.

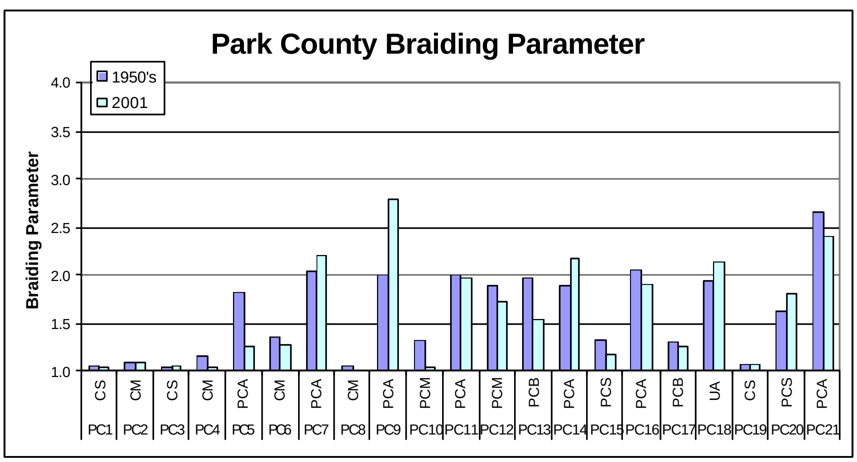

Figure D-6. Braiding Parameter, Park County

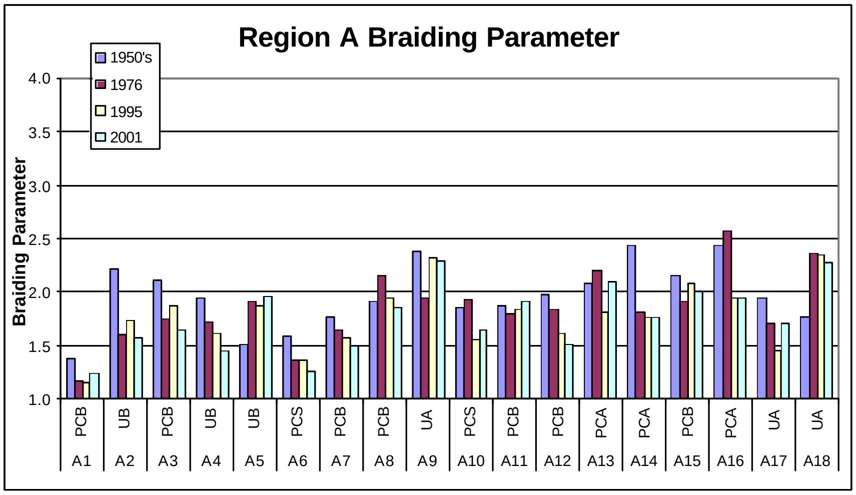

Figure D-7. Braiding parameter, Region A.

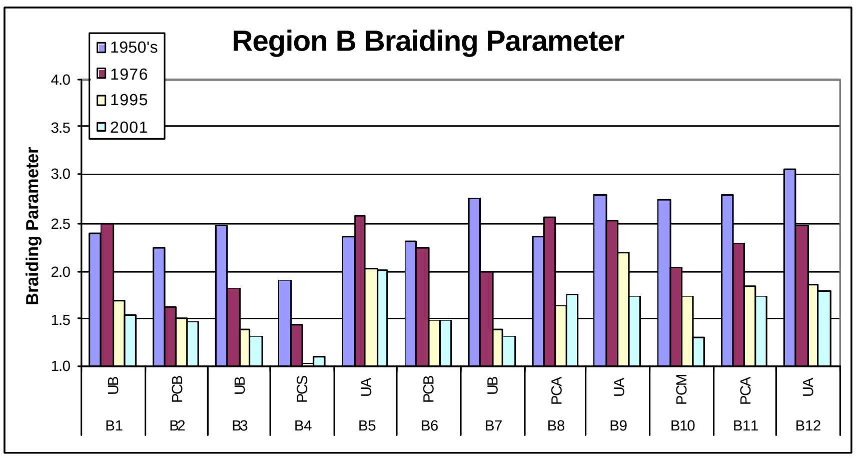

Figure D-8. Braiding parameter, Region B.

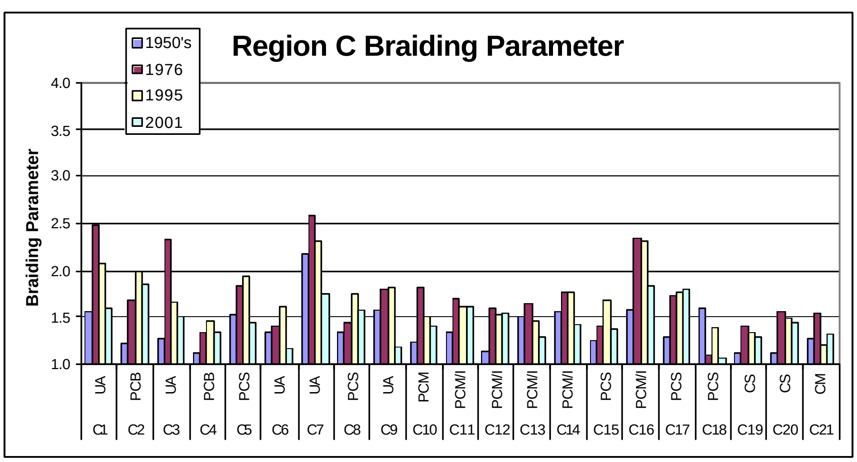

Figure D-9. Braiding parameter, Region C.

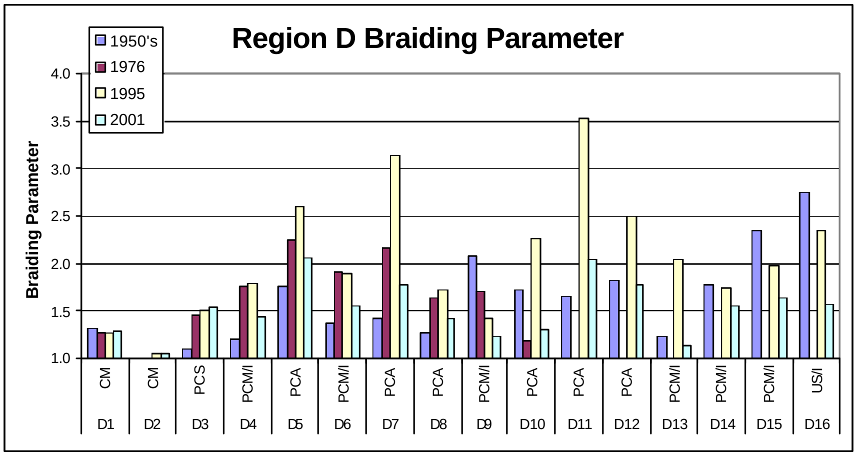

Figure D-10. Braiding parameter, Region D.

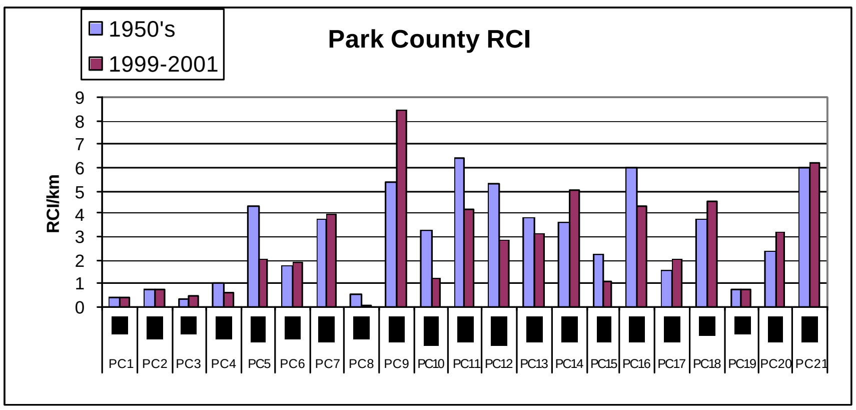

Figure D-11. River complexity index, Park County.

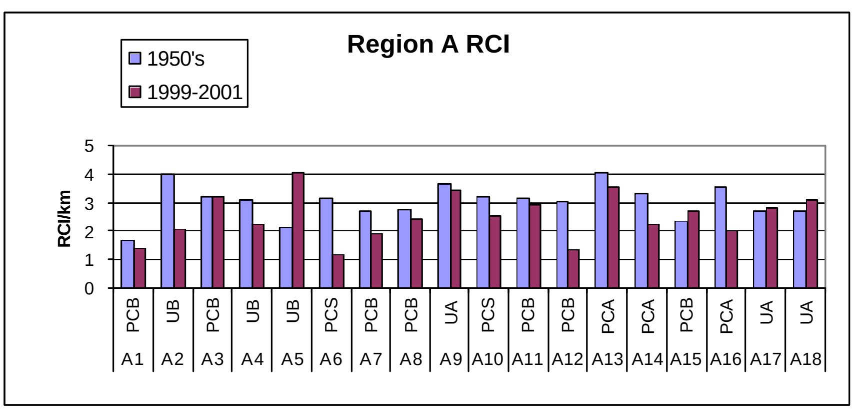

Figure D-12. River complexity index, Region A.

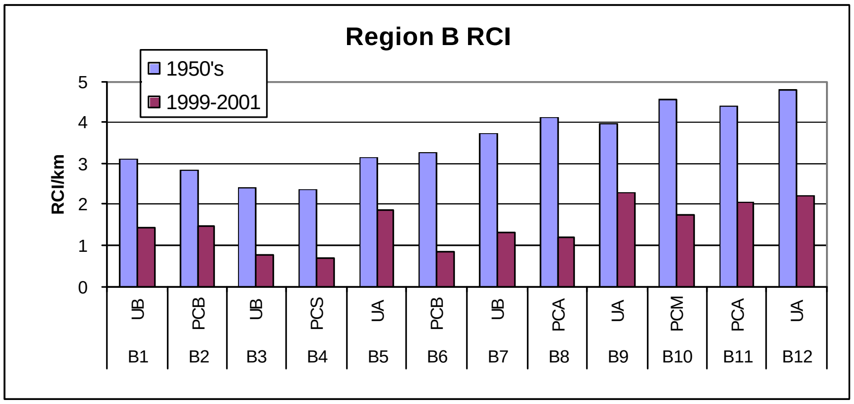

Figure D-13. River complexity index, Region B.

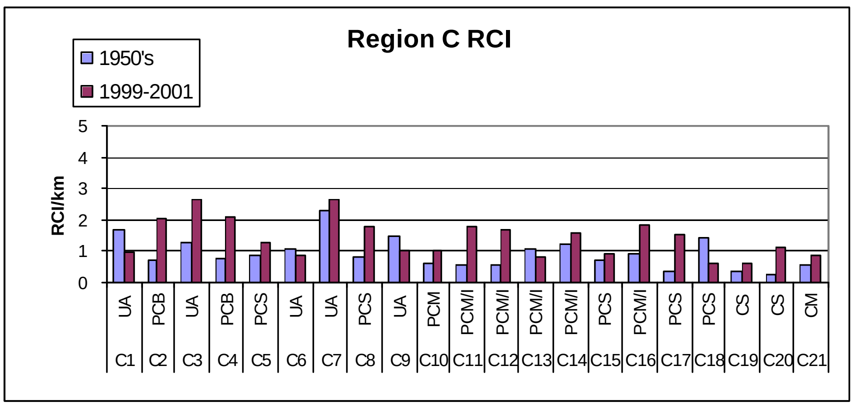

Figure D-14. River complexity index, Region C.

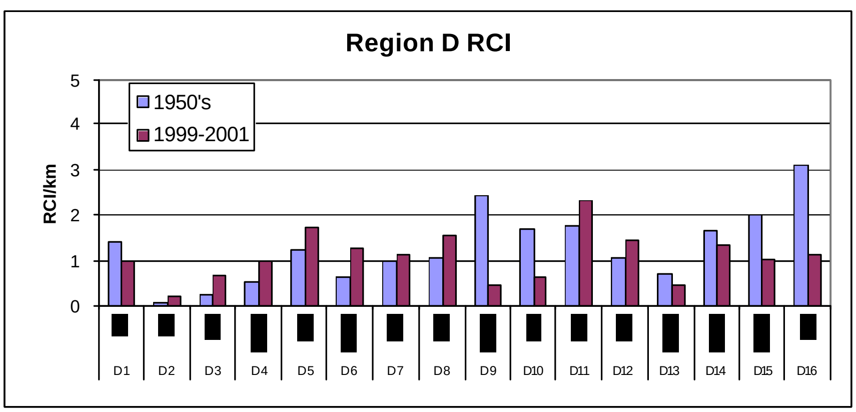

Figure D-15. River complexity index, Region D.