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GEOMORPHIC CHANGE IN THE MIDDLE SUSITNA RIVER SINCE 1949

SECOND DRAFT

ARCTIC ENVIRONMENTAL INFORMATION AND DATA CENTER

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SUMMARY

In order to determine the natural geomorphic regime - the balance between aggradation and degradation - of the middle Susitna River, analysis of geomorphic change since 1949 was carried out by studying aerial photography for the periods 1949, 1961-62, and 1977-82. The purpose of the study was to understand how sloughs, which have the best available fish spawning and rearing habitats, have been evolving in recent decades. This information could then be used to forecast the effects of the Susitna Hydroelectric Project on natural slough evolution.

Photographic analysis showed the following:

1. Gravel bars and islands have become more exposed, better stabilized, and increasingly vegetated. Several gravel bars have become attached to shore as new terraces.

2. At eight places in the middle river, the mainstem channel has progressively shifted alignment since 1949, eroding out all or parts of some old, stable islands and shoreline.

3. Many sloughs have become perched, or relatively higher in elevation compared to the water surface at a given discharge. Some sloughs have evolved from side channels to side sloughs, and others from side sloughs to upland sloughs. In a few cases, side channels have evolved all the way to upland sloughs.

The apparent emergence of gravel bars and islands, formation of new terraces, and perching of sloughs is interpreted to be the result of general degradation of the middle river since 1949. As the river slowly eroded its bed, the mainstem water surface elevation at any given discharge lowered, causing nearby topographic features to stand higher above the water. These features are now less easily inundated by high mainstem flows, and vegetation has taken hold and progressed through successional stages.

Changes in flood severity during the period since 1949 do not account for the decreased overtopping of these features. Flooding increased from 1962-72, and then decreased to about the same levels as 1949-61. However, vegetation progressed steadily during these periods.

When a slough evolves, fish habitat conditions within it change. As a side slough forms, conditions may become suitable for fish spawning or rearing. Continued evolution may change those conditions over time and eventually make the slough habitat unsuitable for fish. Meanwhile, however, new side sloughs are being converted from side channels, so that there is probably always some suitable fish habitat available.

The 1952-53 surge of the Susitna glacier does not appear to have had any significant effect on the middle river's geomorphic regime. Any bedload sediments released by the surge were probably deposited in the upper river and have not yet progressed into the middle river. Temporarily increased river flows, caused by the glacier terminus moving farther down into the ablation zone, do not appear to have significantly altered river discharges during the few years after the surge. Statistical analysis of streamflow data show no unequivocal changes in discharge during that period that are not accounted for by precipitation and snowfall records.

The 1964 Alaska Earthquake caused a southward tilt of the Susitna River basin of about 1.5 feet over a distance of 320 miles. This small amount would have, at most, a very minor effect on the river's regime. Additionally, the middle river lies almost exactly perpendicular to the direction of tilt, and the lower river is only slightly less so. The middle river would, therefore, only begin downcutting after the lower river had deepened its valley, and then only near the confluence.

The rate of general degradation throughout the middle river appears to have been steady since 1949, and was probably not significantly affected by the earthquake. However, there has been erosion in the confluence area, but about 1/4 of it had occurred before the earthquake. It appears that the erosion was caused by shifting of the main channel of the Chulitna River at the confluence. Although the earthquake may have exacerbated the erosion, it does not appear to have caused it.

The operation of the Susitna Hydroelectric project would probably stabilize the riverbed and cause the degradation regime in the middle river to cease. After an initial period of riverbed scour below the dams, lasting a few years, evolution of sloughs from one type to another would stop. Slough types would remain the same as they were at the termination of riverbed scouring, and slough fish habitat would no longer be altered through perching of sloughs.

Slough habitat conditions, however, might still change due to project operations. Controlled river flows would prevent overtopping of sloughs that normally occurs during high summer flows. This would prevent the sloughs from being flushed of accumulated fine sediments contributed by small tributary streams, and beaver dams. If geomorphically stable sloughs are made unsuitable for fish habitat by such processes as these, the total amount of suitable slough habitat might be diminished over time since it would not be replenished through slough evolution.

INTRODUCTION

Most river systems undergo a natural process of geomorphic evolution over time. Although their geomorphic regimes - the balance between erosion and deposition over a period of years - may remain relatively stable for a while, river channels often aggrade or degrade to adjust to changes in local climate, runoff, sediment supply, or tectonic effects on land slope. A river usually remains under a given regime until one or more of these factors changes, or until conditions remain stable long enough for the river to aggrade or degrade its channel to an equilibrium condition. A certain regime may last from a few years to thousands of years, depending on the frequency and severity of causative factors.

Since the end of the Pleistocene ice age about 10,000 years ago, the Susitna River in the Devil Canyon-to-Talkeetna reach, (hereafter called the middle river) has undergone general valley deepening and canyon cutting. Most of the middle river is incised into canyons a few hundred feet deep. The modern channel sits well below the level of a series of older sedimentary terraces on either side of the river. However, this general, long-term degradation could have been interrupted by periods of change or even reversal of its regime, and it would be of interest to know what regime has been active in recent decades.

Fish habitat investigations in the middle Susitna River, related to the proposed Susitna Hydroelectric Project development, have concentrated on the river's sloughs, because they constitute the bulk of salmon spawning and rearing habitats for that would be affected by the project. Slough types and their suitability as fish habitat are dependent, in part, on river channel evolution and stability. Aggradation or degradation of the river could alter slough types and cause natural fish habitat transformation. Some sloughs would evolve into more favorable habitat conditions (suitable water depths, temperatures, velocities, and substrate conditions), while others would evolve into poorer habitats. Investigators do not know how long presently-favorable slough habitats have existed, since systematic slough habitat investigations in the middle river, by the Alaska Dept. of Fish and Game (ADF&G), have only been carried out since the mid-1970s.

PURPOSE AND SCOPE

In order to assess natural slough habitat transformation in the middle Susitna River, it is necessary to know whether the river is now aggrading, degrading, or stable, and whether sloughs have evolved from one type to another in recent years. This information could give an index of natural habitat stability that might provide clues to the effects of hydroelectric development on future habitat stability. Project operations would alter the river's natural geomorphic regime by controlling seasonal flows, trapping bedload sediments in the reservoirs, causing riverbed scour below the dams, and changing river ice processes. This altered regime might disturb the natural evolution of the river system, its sloughs, and fish habitat suitability.

Accordingly, we undertook an analysis of aerial photography of the middle river taken in three periods during the past 36 years: 1949 (the first year for which aerial photography was available), 1961-62 (just before the 1964 Alaska Earthquake), and 1977-80. Also used for comparison was the 1982 aerial photography presented in Klinger and Trihey (1984). The purposes of the study were to determine:

1. whether aggradation, degradation, or stability has been the dominant geomorphic regime during the period from 1949 to present;

2. whether significant geomorphic changes, such as alteration of slough types, have occurred during that period;

3. whether there is any apparent evidence of alteration of regime caused by the two natural catastrophic events that occurred in the

Susitna Basin during the period: the 1952 Susitna Glacier surge (Post 1960), and the 1964 Alaska Earthquake (Plafker 1969).

Photography of the entire middle river below Devil Canyon was examined for evidence of general geomorphic changes since 1949, and imagery of several individual sloughs that have been investigated by ADF&G (Friese 1975) was analyzed more closely to discern possible changes in slough types. Three additional sloughs, herein designated 8E, 8F, and 8G, were also examined. These are shown in Klinger and Trihey (1984) between sloughs 8A and 8B (appendix A).

Earlier analysis of 1949-51 aerial photography from old USGS glass slides, discussed in a draft preliminary report of this study in 1984 (AEIDC 1984), appeared to show that there were fewer gravel bars in the middle river at that time than there are now. Further investigation showed that the photography had either been poorly processed or had deteriorated with age, underexposing the river and its features in a way that washed out the presence of unvegetated gravel bars in the river, making those areas appear as open water. New and better photography, all from 1949, was obtained from the USGS for the final phase of the study, and show that the number of gravel bars in the river has not significantly changed. This fact does not change the overall conclusions of the draft report in regard to riverbed degradation and slough perching since 1949, which are substantiated here.

METHODS

For comparison purposes, photographic sets were gathered for the earliest time for which aerial photography was available (1949 USGS black-and-white photography), for very recent years (1977-80 Bureau of Land Management infrared photography, and 1982 black-and-white photography), and for a period about midway (1961-62 USGS black-and-white photography). The middle period was selected for two reasons: (1) it would show whether any identified geomorphic regime was in effect continuously from 1949 to the present, and (2) it would allow examination of the river just before the 1964 Alaska Earthquake.

The year 1949 was also the first year the U. S. Geological Survey (USGS) kept continuous records of river discharge for the middle river. Using these records, we gathered photography for all periods with similar water surface elevations, which gave us a rough elevation base level for comparisons between years. It was possible to obtain photography for most periods with a discharge near the range 23,000-30,000 cfs. The only significantly different year was 1977 with 41,000 cfs; this photography was used only for a short reach of the river near the Susitna/Chulitna confluence. Daily discharges from USGS records for each photo set are shown in table 1.

Table 1. USGS discharge records from Gold Creek station. (Sources: USGS 1957, 1961, 1962, 1978, 1979, 1980, 1981)

Photography date	Discharge (cfs)
August 10, 1949	29,900
August 14, 1949	28,600
July 14, 1961	25,000 (est.)
July 5, 1962	25,900
August 10, 1962	23,000 (est.)
August 11, 1962	23,000 (est.)
June 19, 1977	41,000
August 1, 1980	31,100
August 11, 1980	22,600
June 1, 1982	23,000

(est.) indicates no record for that date; discharge estimated on basis of weather records, and records from other stations.

Since the photography was taken at somewhat different scales, the map sets were adjusted to bring all illustrations to approximately the same scale of 1:60,000 (about one inch to one mile). This was done using a Minolta EP 450Z photocopier with incremental enlarging and reducing capabilities. Slight shifts may be noticed between corresponding parts of the river in the map sets (Appendix A), but these have no serious effect in the generalized portrayal of geomorphic change.

GEOMORPHIC CHANGE

Analysis of aerial photography of the middle river of the Susitna River from 1949 to present shows that geomorphic changes have occurred throughout the reach. The overall evolutionary trend has been as follows:

1. Gravel bars and islands have become more exposed, better stabilized, and increasingly vegetated. That is, they now stand higher above the water surface at a given discharge, are not overtopped and eroded as frequently by floods, and vegetation has taken hold on them and passed through successional stages.

In all parts of the middle river, many old, barren gravel bars have now become more exposed and vegetated. Some are now stabilized, vegetated islands. The vegetation has steadily progressed from initial grassy cover to low brush and finally to high brush cover. In some cases, succession has progressed to low trees. (At the scale of the photography, species identification is not possible without ground-truth information, and was not attempted). Many barren gravel bars that were attached to shore have now become vegetated terraces, and some gravel bars originally near shore have now become attached to shore and are now vegetated. Some of the latter also have become terraces, while others are trending that way but have not yet become fully isolated from the river. Examples of each type of change can be found in appendix C.

Overflow channels in some islands and terraces, that flooded during high flows in 1949, have now emerged so high that they are seldom flooded and have become increasingly vegetated. Also, older forested terraces and islands exist throughout the length of the middle river that have long-abandoned overflow channels, and these are now fully vegetated, sometimes to mature vegetational stages.

On many islands that were already stable and vegetated in 1949, new gravel beaches have become increasingly exposed, especially on their gently-sloped upstream and downstream ends. Vegetation has encroached onto these newly-exposed beaches in a manner similar to that on barren gravel bars. (See appendix C).

These changes are most noticeable in split-channel reaches of the river and are not as apparent in single-channel reaches. This is interpreted to be an artifact of the method of analysis. Increased exposure, or emergence, of features shows up in aerial photography as lateral increases in area, which only occurs on gentle slopes. Features with vertical or very steep slopes show little or no increase in area with emergence. Split-channel reaches of the river have more gravel bars, islands, and terraces with gentle side slopes, while single-channel reaches usually lack these features and have steep banks.

2. At eight places in the middle river, the mainstem channel has progressively shifted since 1949, eroding out all or parts of some old, stable islands or shoreline, while depositing or exposing new gravel bars in the old position of the channel. This happened at river miles (RM) 113.8, 119.5, 125.0-125.5, 130.0, 132.2, 133.6, and 139.0 and 142.4 (appendix A).

Even in these locations, however, the main evolutionary trend has been toward increasing land exposure, stability, and vegetation. This is apparent on nearby gravel bars and islands on all sides of these eroded areas.

3. Some sloughs have come into existence since 1949, some have changed character and/or type, and others have not yet changed enough to be noticeable in the photography. Details of slough changes are shown in table 2. See appendix B for explanations of the differences in slough types.

Table 2. Slough changes, middle Susitna River, since 1949
(Sloughs listed in order ascending upstream)

Slough	1949	1961-2	1977-83	Perched?	Reach type
1	SC	SS	SS	Yes	Split
2	SS	SS	SS	No	Split
Whiskers	SC	SC	SC	No	Split
3A	US	US	US	No	Split
3B	SS	SS	SS	No	Split
4	US	US	US	No	Single
5	US	US	US	No	Single
6	US	US	US	No	Single
6A	US	US	US	No	Split
7	?	?	SS	?	Single
8	SC	SS	SS	Yes	Split
8D	US	US	US	No	Split
8C	SC	SC	SS	Yes	Split
8B	SC	SC	SC	Yes	Split
8E	SS	SS	US	Yes	Split
8F	SS	SS	US	Yes	Split
8G	SC	SC	SS	Yes	Split
8A	SS	SS	SS	No	Split
9	SC	SC	SS	Yes	Split
9B	US	US	US	No	Split
9A	SC	SC	SC	Yes	Split
10	US	US	US	No	Split
11	US	US	SS	No	Split
12	SS	SS	US	Yes	Split
13	SC	SS	SS	Yes	Split
14	SC	SC	SC	No	Split
15	SC	SS	US	Yes	Split
16	SC	SC	SC	No	Split
17	US	US	US	No	Split
19	SS	SS	US	Yes	Split
20	SC	SC	SS	Yes	Split
21	SC& SS	SC& SS	SC& SS	Yes	Split
22	SC	SC	SC	No	Split
21A	SC	SC	SS	Yes	Split

Many sloughs have evolved from side channels to side sloughs, and others from side sloughs to upland sloughs. In a few cases, slough evolution has progressed all the way from side channel to upland slough. Of the sloughs studied, only slough 11, which was observed to be altered by ice jam flooding and erosion in 1976, changed in the opposite direction, from an upland slough to a side slough.

With the exception of slough 11, all sloughs that have changed type have been transformed to a perched condition; that is, they are now higher in elevation relative to the mainstem water surface at a given discharge. Of the 34 sloughs studied, 14 have changed type. Thirteen of those have become perched, while one (slough 11) has been eroded out and lowered in elevation by ice processes (table 2).

Of the 20 sloughs that did not appear to have changed type, 9 were already upland sloughs and would have remained so if they had become further perched. Many side sloughs changed in morphologic character even when they did not evolve enough to change type. At present, they had less wetted surface area at a given discharge, and appear to have higher berm heights separating them from the mainstem than in 1949. At some sloughs, enclosing gravel bars, which separate the sloughs from the mainstem, have grown larger by emergence and/or deposition.

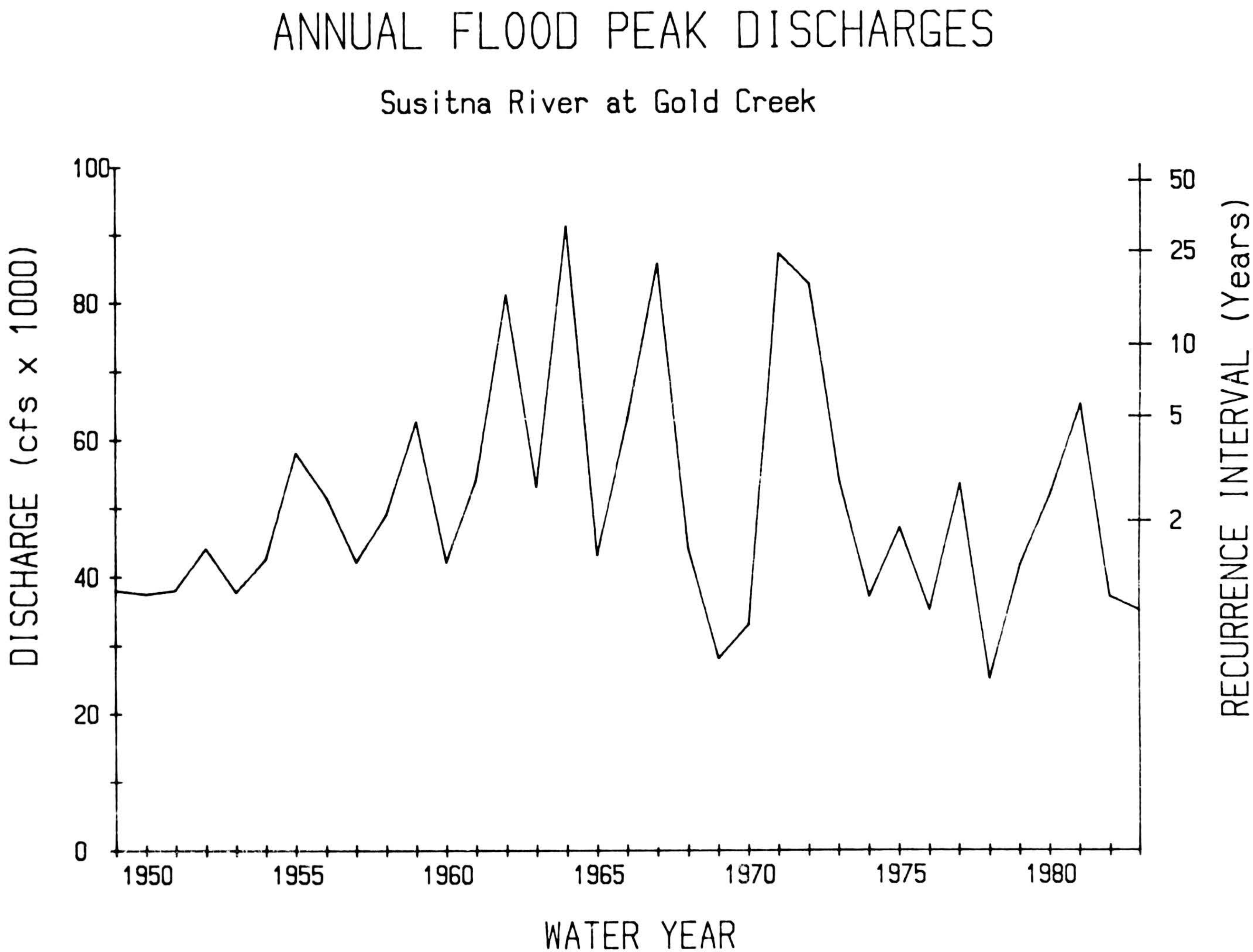
Only one of 10 sloughs below Lane Creek changed type, although 3 of these were already upland sloughs. Even in this area, however, some degree of perching at present is still indicated by decreased wetted surface areas in sloughs and vegetation excroachment on gravel bars since 1949.

PROBABLE CAUSES

The apparent emergence or increased exposure of gravel bars and islands, formation of new terraces, and the perching of sloughs is interpreted to be the result of general degradation in the middle river since 1949. As the river slowly eroded its bed, the mainstem water surface at any discharge lowered. This caused gravel bars, islands, terraces, sloughs, and berms separating sloughs from the mainstem to emerge higher above the water.

These land features are now less easily inundated by high mainstem flows. Emergence has caused some side channels to be converted to side sloughs. Some berms separating sloughs from the mainstem have become too high to be overtopped at all, changing the associated sloughs from side sloughs to upland sloughs (see table 2). Old overflow channels on some islands and terraces now seldom carry flows and are becoming vegetated. Reduced effects of overtopping flood events, which allowed vegetation to take hold, could result either from the emergence of these features to a higher elevation relative to a given discharge, or from a reduction in the severity of flood events. An analysis of flood events (H-E 1985A) shows that the maximum annual flood increased during the period 1962-72, with six of those years having floods between the 10-and 50-year recurrence interval. Maximum floods then declined again during the period 1973-82 to about the same levels as during 1949-61 (figure 1).

Figure 1.



Source: modified from H-E 1985A.

The greater severity of flooding from 1962-72 would have caused increased overtopping of gravel bars and islands if they had remained at the same elevations relative to a given discharge. Photo analysis shows that vegetation of these features progressed at a steady rate during the period 1949-82 and was not affected by increased flooding during 1962-72. Therefore, the increased vegetation coverage of gravel bars and islands is probably due to their emergence, caused by riverbed degradation.

Erosion of gravel bars and islands at eight sites in the middle river was caused by progressive shifting of the mainstem channel alignment in those parts of the river.

POSSIBLE INFLUENCES

During the period from 1949 to present, two natural catastrophic events occurred in the Susitna Basin that could have affected the river's geomorphic regime. These were the 1952 surge of the Susitna Glacier and the 1964 Alaska Earthquake.

SUSITNA GLACIER SURGE

In 1952 or 1953 The Susitna Glacier underwent a surge, a period of rapid forward motion of the glacier, that extended the glacier terminus down valley about 2.5 miles (Post 1960, Meier and Post 1969). When a glacier surges it may have two effects on river regime below it. There may be a large sediment discharge and a temporary (a few years) increase in water production caused by an increased ablation area (area within in the seasonal melting zone) (Harrison et al 1983).

SEDIMENTATION

Most of the sediment released from beneath a surging glacier is probably suspended sediment. It occurs as water rushes from beneath the surging ice and lasts for a short period. The amount of bedload sediment that accompanies the suspended load is unknown, but most of it would probably be deposited a short distance below the glacier terminus due to the abrupt decrease in water velocities upon exiting from beneath the glacier. It would then take a period of time for river flows to move the bedload further downstream. The bedload sediments would eventually be distributed over a certain distance downstream, and the amount deposited would decrease with distance.

The reach of the river investigated in this study begins at the mouth of Devil Canyon, nearly 170 miles downstream from the glacier. The Susitna River apparently has little bedload below Devil Canyon until it reaches the confluence with the braided Chulitna River. Most of the river in this reach is well armored, with little bedload sediment movement (Bredthauer and Drage 1982). Apparently most of the bedload sediment contributed by the glaciers is deposited in the upper river before it reaches Devil Canyon.

Analysis of the aerial photography from 1949 to present indicates that the number of exposed gravel bars has not significantly changed. It seems that little, if any, of the bedload sediment released by the Susitna Glacier surge has reached this part of the river and does not account for the morphologic changes seen since 1949.

TEMPORARILY INCREASED FLOWS

When the Susitna Glacier surged, it moved the glacier terminus forward about 2.5 miles. This put the terminal area at a substantially lower elevation and increased the ablation area of the glacier. Normally, an increase in melting of the glacier would occur, resulting in an increase in its contribution of meltwater to the Susitna River. The increased discharge would probably peak the first summer and then proceed at a decreasing rate for several years until the terminus retreated to approximately its original position.

For several years after 1952-53, then, discharges in the middle Susitna River may have been somewhat higher than they would have been under normal conditions. A cursory look at Susitna river discharge data from Gold Creek did not reveal any notable increase, but climatic variability could have masked it. For this reason a statistical analysis of the data was carried out to look for any important variations in discharge that were not linked to climatic factors.

It was determined that the most meaningful climatic factors to examine to evaluate changes in flow regime due to the 1952-53 glacial surge are total snowpack and liquid precipitation for the open water season. Since the analysis was performed on long-term seasonal climatic factors, the effects of temperature have been neglected. In an analysis of shorter periods, for instance water weeks, the measure of temperature would have an impact on the rate of snowmelt. However, over the entire season all the snow present in the pack, and all the liquid precipitation present, would ultimately drain into the streamflow system regardless of the long term average seasonal temperature.

The period of record, 1952-1979, was divided into seven four-year blocks. For each four-year block, the average open water streamflow values were regressed against total seasonal snowfall and total open seasonal precipitation. If, in fact, the glacial surge caused a notable increase in streamflow during the several years following its occurrence, a reduced value of the explained variance (multiple R, adjusted R^2) for that block of years would appear in the results.

The dependent variable in the multiple regression is the average streamflow rates in ft^3/sec from the Gold Creek station for the open water season (April through October) from 1952 to 1979. The two independent variables used are total seasonal snowfall from Talkeetna for the same period of record, and the total open water season (April to October) precipitation measurements in inches at Talkeetna, 1952 through 1979. This station is the only one present within the basin which has enough detail and period of record to reflect any long-term statistical trends. It would be more desirable for the snowpack data to have measurements of snow depth or water equivalent inches on the ground rather than snowfall data, but none is available within the Susitna drainage basin prior to 1964. It would also be preferable to use snow, precipitation and flow data from stations further upstream nearer to the location of the glacier and nearer to each other. The distance and geographic variability between Talkeetna, Gold Creek and the Susitna Glacier introduces an additional variability and potential error into the regression and analysis. Nevertheless, it is the most comprehensive data available and if an increase in streamflow due to the glacial surge occurred this is the most reasonable available method by which it might be detected.

Our hypothesis states that in the event of a significantly lower explained variance in the correlation with streamflow in the block of years during and immediately following the glacier surge (Case 1), the unexplained variance can be attributed to the glacier surge. Results from the seven four-year cases of the multiple regression analysis are shown in table 3.

Table 3. Correlation coefficients for streamflow multiple regression; four-year blocks: 1952-1979

Case 1 1952-1955

Multiple r = .89 Significant F = .45

r^2 = .79

Adjusted r^2 = .39

Case 2 1956-1959

Multiple r = .87 Significant F = .495

r^2 = .75

Adjusted r^2 = .26

Case 3 1960-1963

Multiple r = .985 Significant F = .17

r^2 = .97

Adjusted r^2 = .91

Case 4 1964-1967

Multiple r = .90 Significant F - .44

r^2 = .81

Adjusted r^2 = .42

Case 5 1968-1971

Multiple r = .99 Significant F = .13

r^2 = .98

Adjusted r^2 = .95

Case 6 1972-1975

Multiple r = .97 Significant F = .25

r^2 = .94

Adjusted r^2 = .81

==

Case 7 1976-1979

Multiple r = .94 Significant F = .33

r^2 = .89

Adjusted r^2 = .67

==

The four-year block with the lowest explained variance (adjusted r^2 = .26) is Case 2, 1956-1959. Case 1, 1952-1955 has the second lowest explained variance (adjusted r^2 = 0.39). The remaining cases 3-7 (1960-63, 1964-67, 1968-71, 1972-75 and 1976-79) have adjusted r^2 values ranging from .42 in Case 4 to .95 in Case 5. Another important statistic to examine is the F test or significant F. This value indicates the level of confidence with which you can trust your result. The lower the F value the higher the confidence level within which your prediction lies. For instance, a significant F of .01 corresponds to the 99 percent confidence interval.

The highest significant F, 1.49, occurs for Case 2, 1956-1959, and the second highest, .45, for Case 1, 1952-1955, our test case. The significant F values for the remaining cases 3 through 7 range from .44 for Case 4 and .13 for Case 5.

The unexplained variance in Case 1 might be attributed, at least in part, to the documented glacial surge. However, since the explained variance for this case is not the lowest, nor the significant F value the highest, the results are not unequivocal. The results from Case 2, 1956-1959 are probably too far removed from the advance of the glacier to have resulted from its impact.

GREAT ALASKA EARTHQUAKE

In April, 1964, the largest earthquake ever recorded in North America rocked southcentral Alaska. With a Richter magnitude of about 8.4, the earthquake was centered in northwestern Prince William Sound, but had effects over a wide area. The land within a radius of hundreds of miles tilted, with subsidence taking place throughout a broad area northwest of the epicenter. Subsidence decreased with distance from the epicenter until reaching the line of zero displacement, which lies near the middle Susitna River (figure 2). North of that, slight uplifts were recorded (Plafker 1969).

Interpolation of measured displacements along the Alaska Railroad and the Richardson Highway where they cross the Alaska Range indicates that the upper Susitna River basin near the glaciers was uplifted about 0.5 feet. Interpolation from measurements along the Alaska Railroad near Wasilla and Anchorage indicate that the river mouth at Cook Inlet subsided approximately 1 foot. Total southward tilt of the river basin, therefore, was approximately 1.5 feet over a distance of 320 miles, increasing the river's gradient very slightly. The zero displacement contour, or hinge line, crossed the upper Susitna River near the Tyone River confluence.

Measured subsidence along the Susitna River, where the Alaska Railroad follows it, showed a range of subsidence in the middle river varying from 0.2 to 0.6 feet from Gold Creek to the Susitna/Chulitna confluence, to a maximum in the lower river of 0.8 feet between Kantishna and Willow (Plafker 1969).

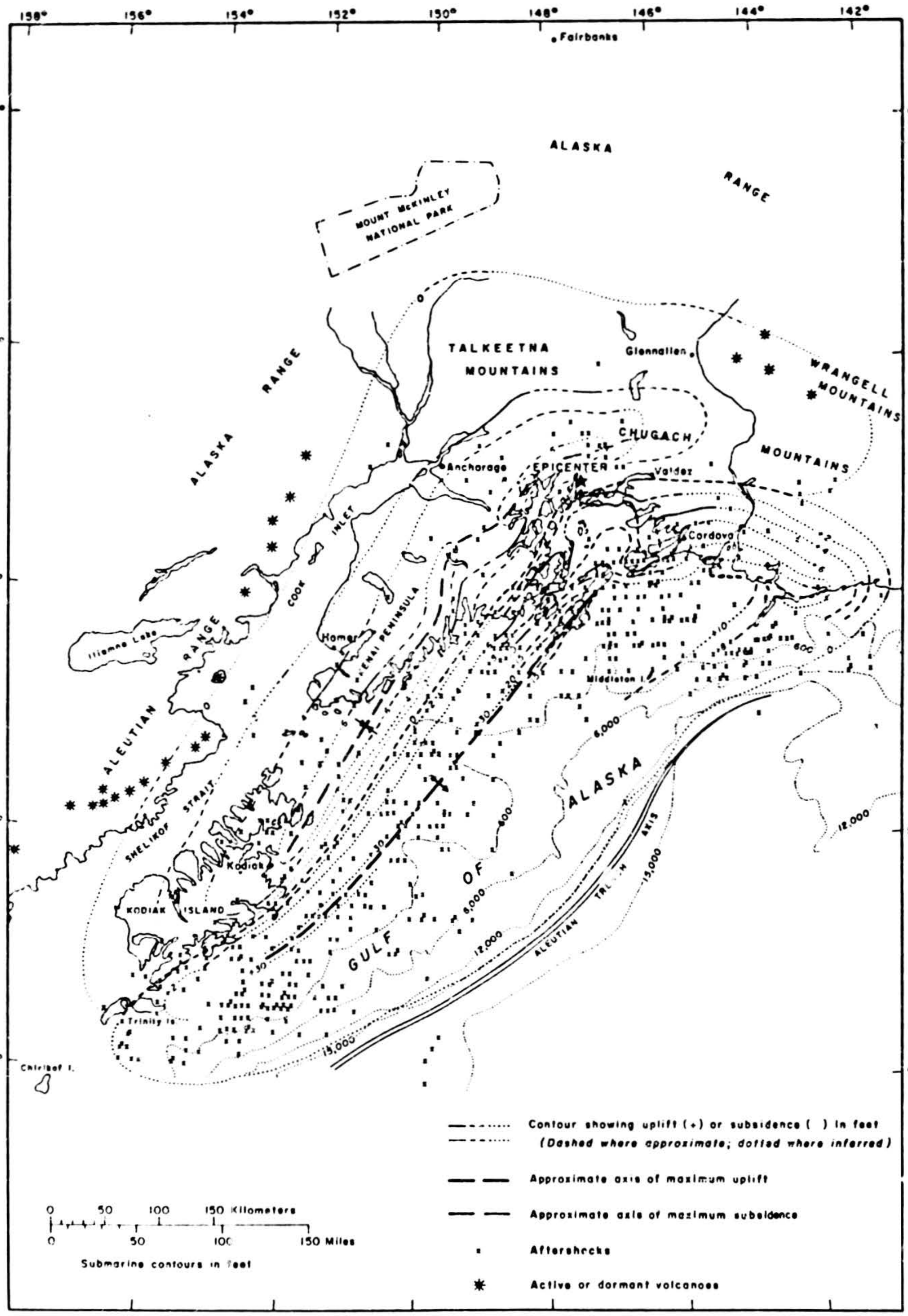


Figure 2. Areas of uplift and subsidence, 1964 Alaska Earthquake.

Source: Selkregg 1974

The upper river, above the Oshetna River confluence, lies parallel to the direction of tilt, while the middle and lower river reaches are aligned perpendicular to the direction of tilt. Normally, the effects of seaward tilting of a river basin cause it to downcut and to deepen its valley. However, the effect is felt immediately only by streams that lie parallel to the direction of tilt. Streams flowing perpendicular to the direction of tilt begin downcutting only after the stream it flows into has deepened its valley, lowering the base level of the first stream and leaving it out of adjustment. Even then the effect is felt only at the mouth of the first stream rather than along its entire length (Thornbury 1954).

Only the upper river flows parallel to the direction of tilt. The total amount of tilt within that reach is about 0.5 feet. Consequently, the upper river may have degraded slightly since 1964 as a result of the earthquake-caused tilt, moving a small amount of sediment into the middle river, but the upper river has not been studied to confirm this.

The middle river lies almost exactly perpendicular to the direction of tilt, while the lower river is only slightly less so. Therefore, only a small rejuvenation effect would be expected in the lower river, a lesser effect might have occurred near the Susitna/Chulitna confluence, and almost no effect should have occurred in the middle river reach.

A large amount of erosion has occurred at the Susitna/Chulitna confluence, especially along the north bank of the Susitna and east bank of the Chulitna, where they join. It appears that this erosion was caused by the main channel of the Chulitna River swinging slowly to the east since 1949. Most of this erosion did occur after the earthquake, but it had begun before that, with perhaps 1/4 of the erosion occurring before 1962. Although the effects of the earthquake may have exacerbated this effect, it does not appear that the earthquake caused it.

Analysis of the time-lapse aerial photography in the middle river shows that the rate of degradation between 1949 and the present has progressed at a steady rate throughout the period. There was no apparent change in rate between 1949-62 and 1962-83. Therefore, it seems that there was little effect on the middle river's geomorphic regime by the 1964 Alaska Earthquake.

CONCLUSIONS

The results of this study appear to indicate that, during the past 36 years at least, the middle river has been slowly degrading its bed as it did during the larger part of its history since the ice age. The amount of degradation since 1949 is not known but probably has not exceeded a few feet. The river appears to evolve naturally through the process of degradation, probably still attempting to reach equilibrium with the valley conditions left after the glacier ice retreated.

As the main channel degrades and lowers its water surface elevation, gravel bars and other depositional features protruding from the riverbed slowly emerge, eventually standing high enough above the water surface that they are seldom overtopped by floods. Those gravel bars near shore often become attached to shore and eventually emerge high enough to become terraces. Vegetation then takes hold on these exposed surfaces and goes through natural succession, eventually becoming mature forests.

As land features emerge, intervening berms between the mainstem and side channels become effectively higher and side channels evolve into side sloughs. As the berms emerge even higher, sloughs are less frequently flooded, until the berms eventually become high enough to prevent any overtopping flows. The sloughs have then evolved into upland sloughs.

When a slough evolves, fish habitat conditions within it change. As a side sloughs forms, it may eventually reach a stage of development in which water depth and temperature, velocity, substrate, and fish passage conditions become, for a time, suitable for fish spawning or rearing. As the slough continues to evolve, those conditions change too, and all or part of a slough may eventually become unsuited for fish habitat. For example, as a slough mouth rises, water depths over the entrance may become so shallow that adult fish passage into the slough is effectively prevented. When a side slough evolves into an upland slough, it is no longer flooded under any circumstances and conditions changing within the slough may make it unsuitable as fish habitat.

Some sloughs may be suitable for both spawning and rearing for a time and then later become useful only for rearing. It is probable that some sloughs never become suitable fish habitat at any time in their evolution. The requisite conditions may never be met. In those sloughs that do become suitable, the length of time they remain suitable is unknown, and probably varies considerably from slough to slough, depending on local conditions.

At any given time in the degradational process, there are probably some sloughs entering the low end of the evolutionary cycle as others leave the top of the cycle. In other words, some side channels are being converted to side sloughs as other side sloughs are being altered to upland sloughs, and some upland sloughs are emerging high enough to be effectively isolated from the river. If this is so, then some amount of suitable fish habitat might always be available in the natural system. The variation in quantity and quality of this habitat over time, however, is unknown because of the short period of record in the middle Susitna River.

EFFECTS OF THE PROJECT

With the Susitna Hydroelectric Project in operation, the river's geomorphic regime would be altered. River flows would be regulated, with discharges being lower than normal in the summer, as water is stored in the reservoirs, and higher in the winter when power demands would be the greatest. Flows would also be more stable than normal, with flood effects reduced or eliminated except in extreme events. Bedload sediments normally carried downriver would be trapped in the reservoirs above the mouth of Devil Canyon. Therefore, little bedload would be carried into or through the middle river.

Studies show that the river would try to adjust itself to a new equilibrium condition. The main channel would tend to become narrower and more confined, and may recede from the heads of some sloughs and side channels. Since the river would be unburdened with bedload and have a greater capacity for carrying sediments, the middle river would initially scour its bed somewhat. This would last for only a few years. The total amount of scour in the mainstem would average about one foot, with the effect most pronounced near the dam face and decreasing with distance downstream. In sloughs and side channels the amount of degradation would range from none to 0.3 foot (H-E 1985b).

After the initial period of scouring below the dams, an armor layer would develop and the riverbed would become more stable (H-E 1985). The main channel would tend to become reduced in width by encroachment of vegetation and sediment near the banks (Bredthauer and Drage 1982). Long-term natural degradation of the riverbed would essentially stop.

As degradation of the middle river ceased, the natural evolution of the sloughs would stop. Sloughs would no longer change from one type to another. The type of each slough would remain the same as it was at the termination of riverbed scouring below the dams. Slough fish habitat would, therefore, no longer be altered through perching of sloughs. However, it cannot be assumed that presently-suitable fish habitat would remain so.

Although slough types would remain unchanged, habitat conditions within the sloughs might still undergo change due to processes other than river degradation. Small streams that are tributary to sloughs would continue to produce sediment and might alter substrate conditions in sloughs, perhaps causing substrate siltation. Reduced flooding in the sloughs, caused by stabilized project flows, might prevent the periodic flushing of silts from the slough substrates. If so, sloughs might eventually become unsuitable for fish spawning. Also, biological processes, such as beaver dam building, might prevent fish passage into sloughs unless they are periodically flushed out.

If geomorphically stable sloughs are slowly made unsuitable for fish habitat by such processes as these, and no new slough habitat is created through slough evolution, the total amount of suitable slough habitat might be diminished over time.

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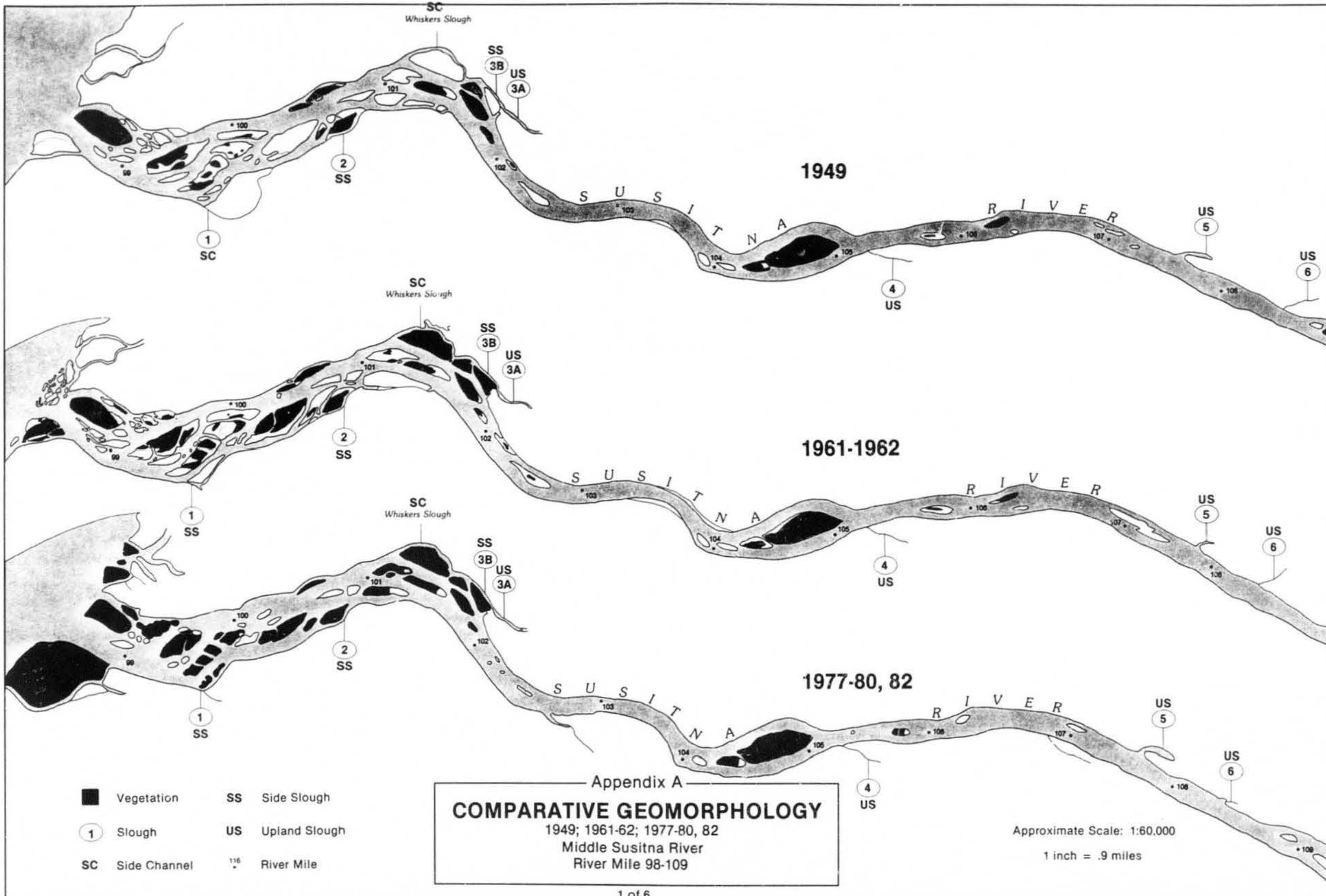
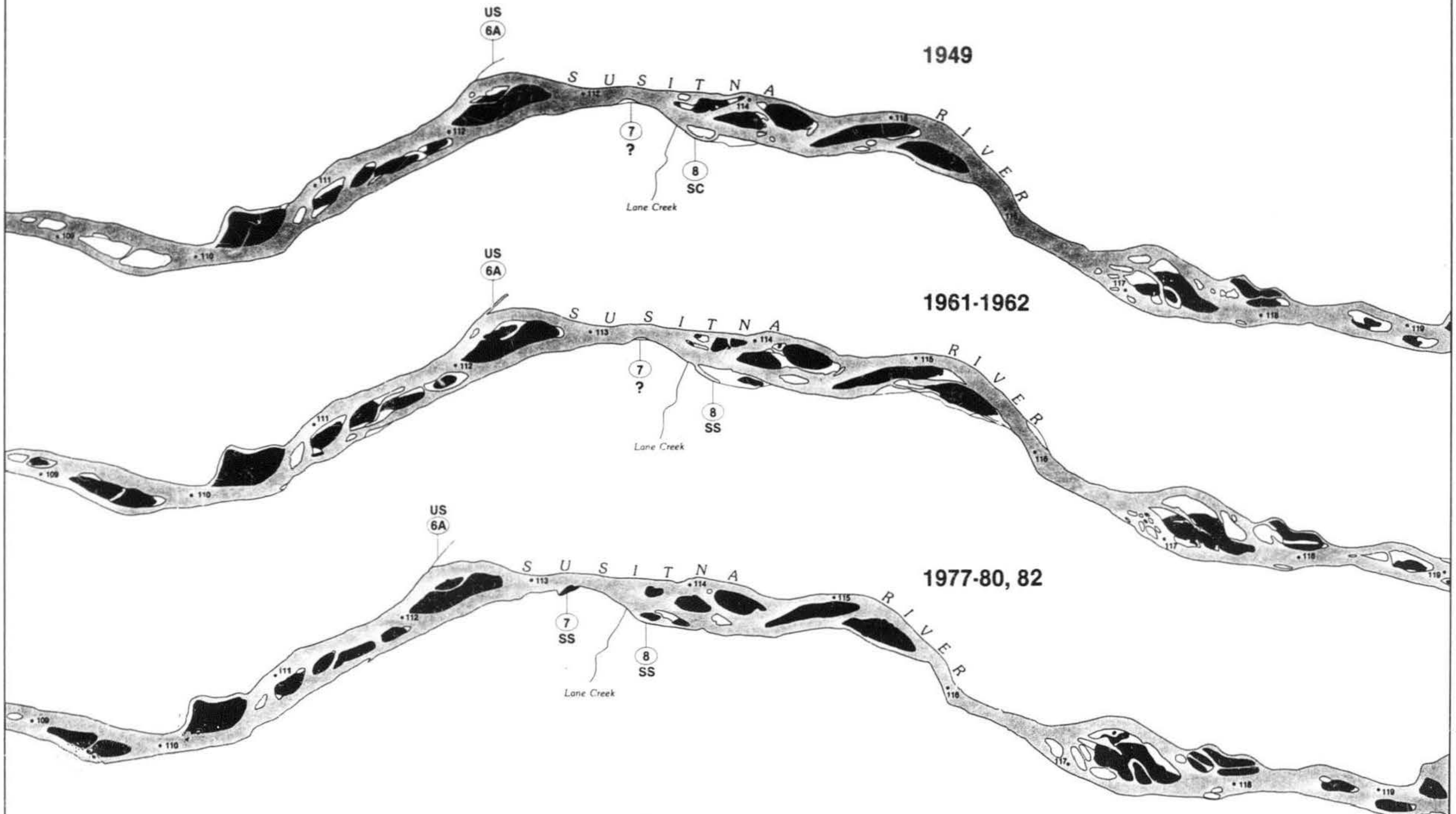


Appendix A

COMPARATIVE GEOMORPHOLOGY

1949; 1961-62; 1977-80, 82
Middle Susitna River
River Mile 98-109



■	Vegetation	SS	Side Slough
(2)	Slough	US	Upland Slough
SC	Side Channel	116 •	River Mile

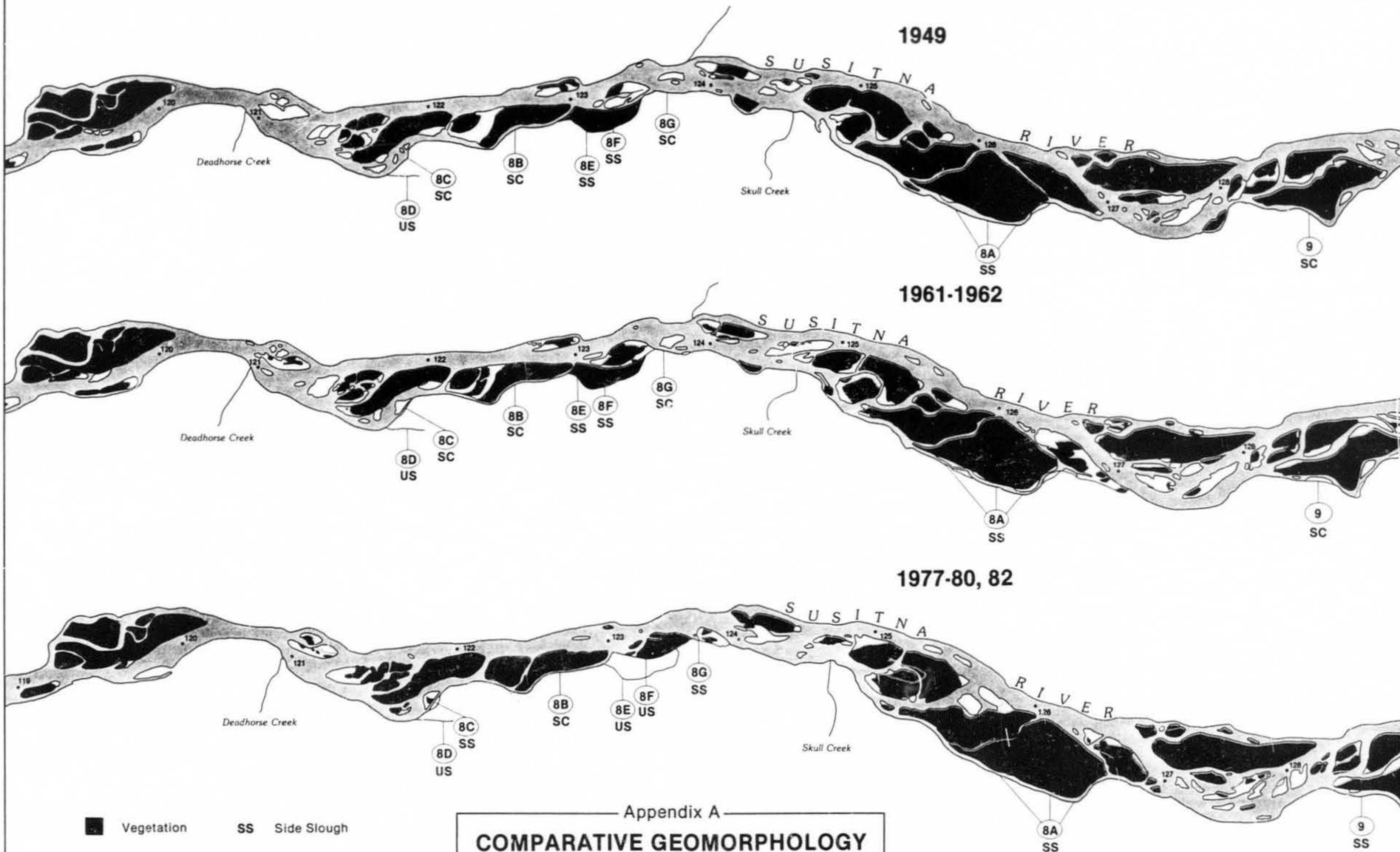
Appendix A

COMPARATIVE GEOMORPHOLOGY

1949; 1961-62; 1977-80, 82
Middle Susitna River
River Mile 109-119

Approximate Scale: 1:60,000

1 inch = .9 miles



■	Vegetation	SS	Side Slough
(3)	Slough	US	Upland Slough
SC	Side Channel	116	River Mile

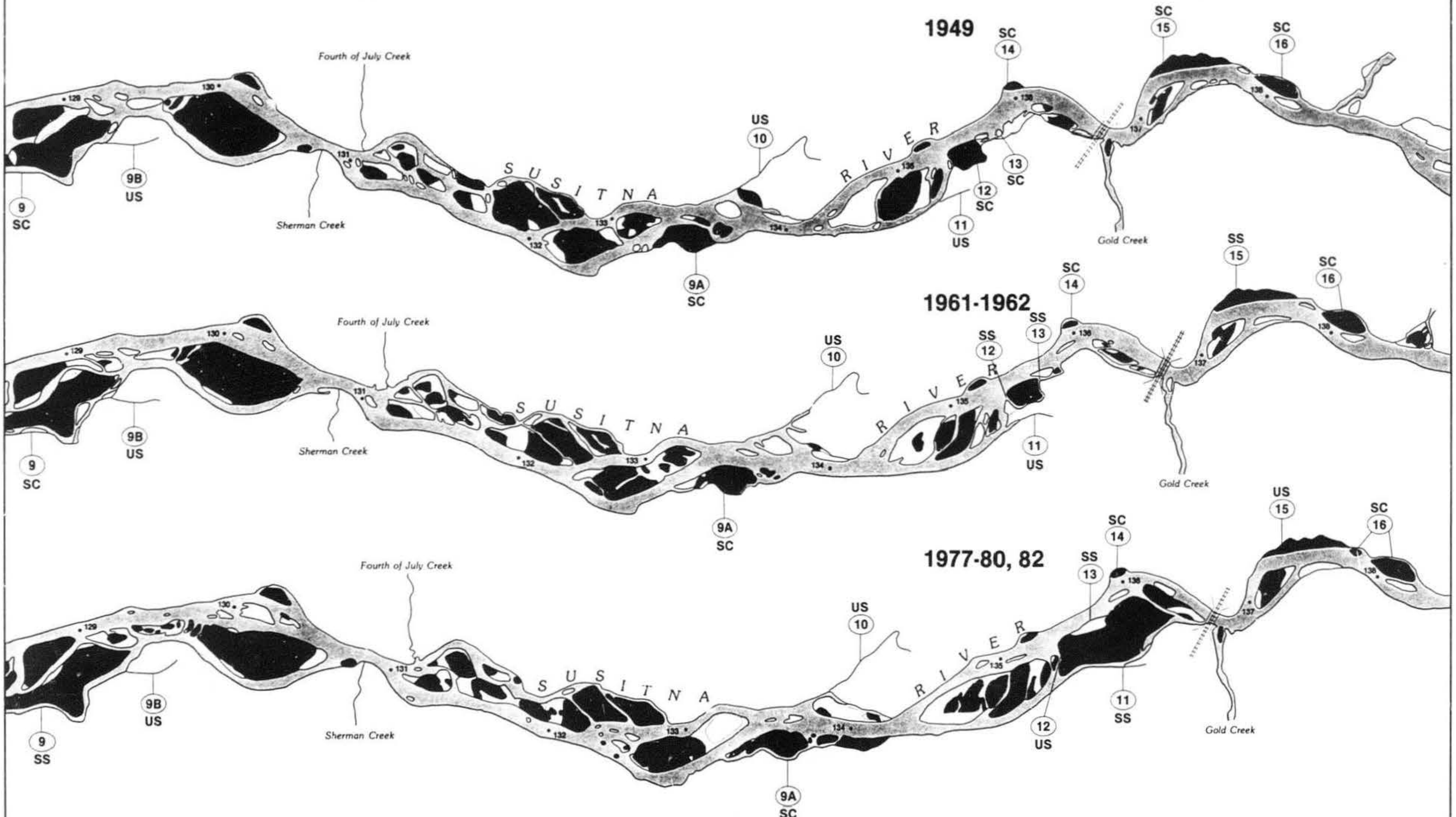
Appendix A

COMPARATIVE GEOMORPHOLOGY

1949; 1961-62; 1977-80, 82
Middle Susitna River
River Mile 119-128

Approximate Scale: 1:60,000

1 inch = .9 miles



■ Vegetation
SS Side Slough
(4) Slough
US Upland Slough
SC Side Channel
116 River Mile

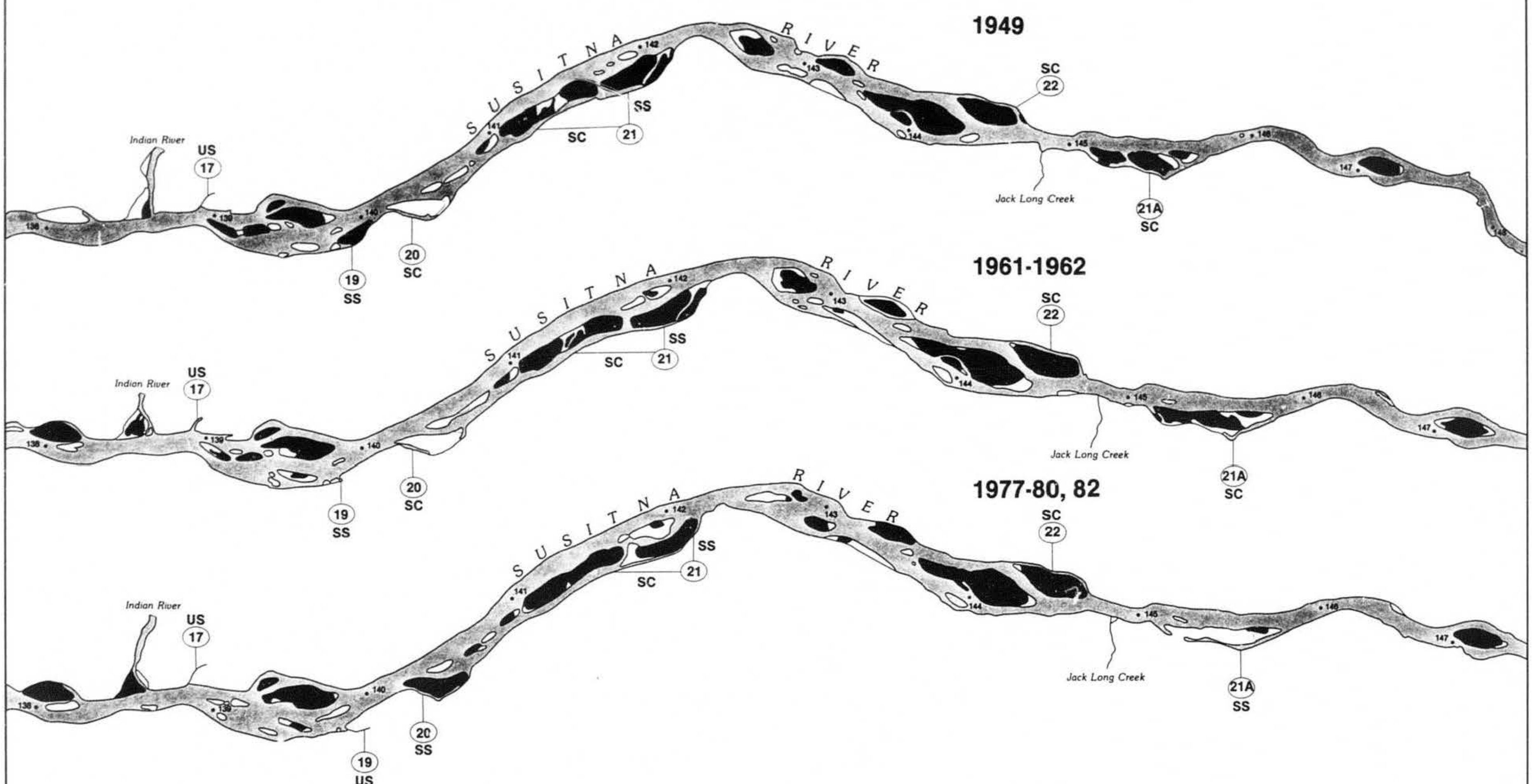
Appendix A

COMPARATIVE GEOMORPHOLOGY

1949; 1961-62; 1977-80, 82
Middle Susitna River
River Mile 128-138

Approximate Scale: 1:60,000

1 inch = .9 miles



■ Vegetation
(5) Slough
SC Side Channel
SS Side Slough
US Upland Slough
116 River Mile

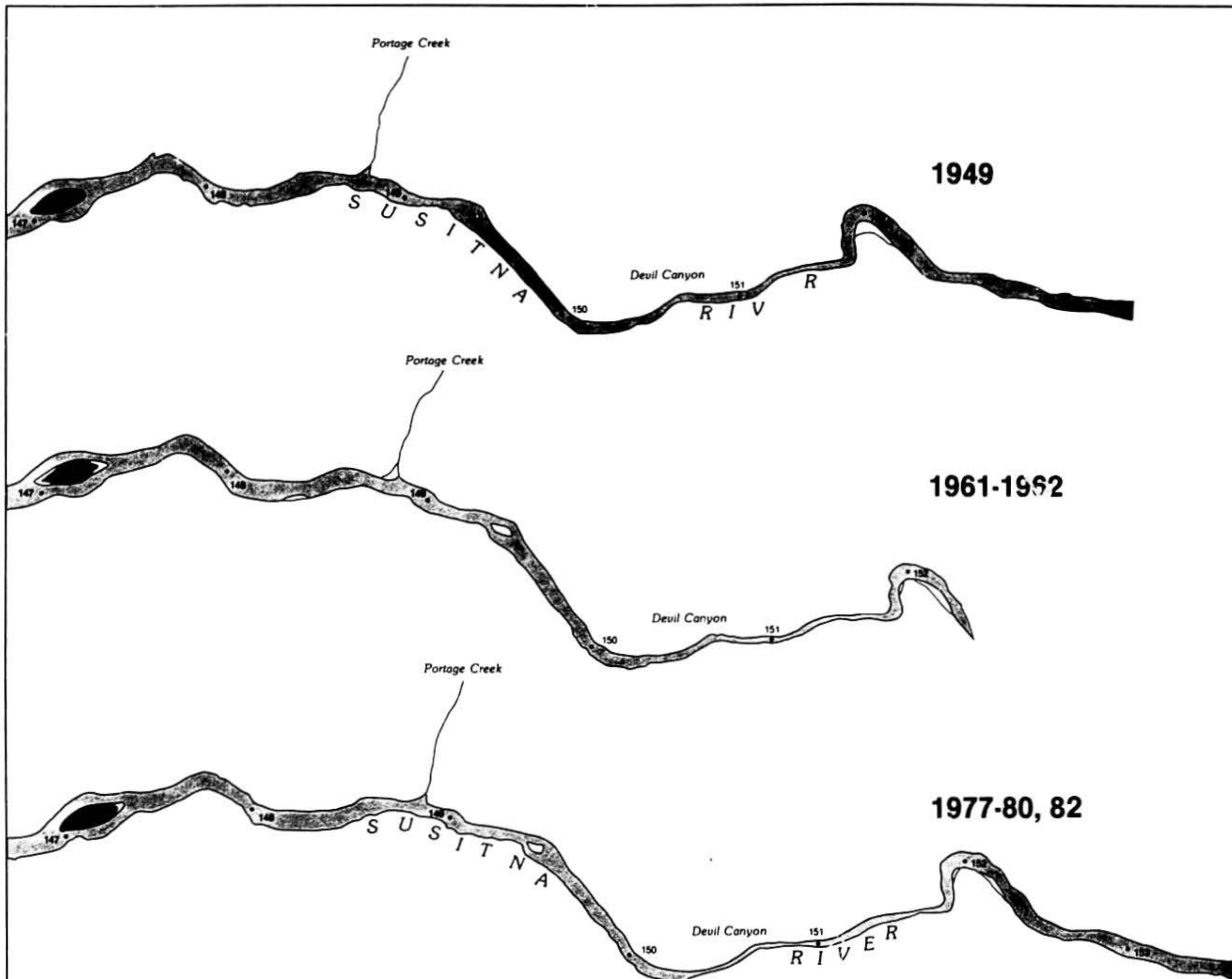
Appendix A

COMPARATIVE GEOMORPHOLOGY

1949; 1961-62; 1977-80, 82
Middle Susitna River
River Mile 138-147

Approximate Scale: 1:60,000

1 inch = .9 miles



■	Vegetation	SS	Side Slough
(6)	Slough	US	Upland Slough
SC	Side Channel	115	River Mile

Appendix A

COMPARATIVE GEOMORPHOLOGY

1949; 1961-62; 1977-80, 82
Middle Susitna River
River Mile 147-153

Approximate Scale: 1:60,000

1 inch = .9 miles

APPENDIX B. DEFINITIONS

(Source: Klinger and Trihey 1984)

SC - Side Channel. These contain turbid, glacial waters, the same as found in the mainstem. These channels convey less than ten percent of the total flow.

SS - Side Slough. These contain clear water. Local surface runoff and upwelling are the primary water sources that supply clear water to the side sloughs. Side sloughs have non-vegetated upper thalwegs that are overtopped during periods of moderate to high mainstem discharge. Once overtopped, side sloughs are considered side channels.

US - Upland Sloughs. These contain clear water and depend upon upwelling and/or local runoff as their clear water sources. Upland sloughs possess vegetated upper thalwegs that are seldom overtopped by mainstem discharge.

APPENDIX C - GENERAL DESCRIPTIONS OF GEOMORPHIC CHANGE SINCE 1949.

RM 98.6. Confluence of Susitna/Chulitna rivers. Chulitna main channel has eroded away about 1000 feet of the land north of the Susitna River and east of the Chulitna River. The Susitna River mouth was widened in the process, as the islands on the south side of it were also removed. About 1/4 of this erosion took place from 1949-61, while about 3/4 took place from 1961-present.

RM 99.5-100.0. Gravel islands in this reach became progressively more vegetated. Most of this occurred 1949-61; only slightly more occurred from 1961-present.

Slough 1. Changed from side channel to side slough from 1949-61. Enclosing gravel bars, particularly near slough mouth, became somewhat vegetated with low brush from 1961-present.

RM 101.0-101.5. Many gravel bars in this reach became progressively more vegetated from 1949-present. They now have low vegetation covers.

RM 111. Gravel bars in this area have shown progressively more brushy vegetation from 1949-present.

RM 111.5. Forested island has new area of vegetation at southeast end. It progressed from no vegetation in 1949 to thick brush at present.

Slough 8. Changed from side channel to side slough from 1962-present. Enclosing gravel bar has grown in area and become vegetated with low brush from 1962-present.

RM 113.7. Gravel bar on south shore has become progressively vegetated from 1949-present. There was no vegetation in 1949, and there is at present a large stand of tall brush.

RM 113.8. Two forested islands were eroded from 1961-present. The upstream island is totally gone, while the downstream island is diminished in size. Also, a small, vegetated island downstream from there disappeared. It appears that the mainstem has shifted its course northward.

RM 117.2. Islands show progressively encroaching vegetation from 1949-present. The southwestern and central islands have doubled their vegetated areas. In 1949 they were about half vegetated; in 1962 sparse brush had grown on the unvegetated areas; and at present there is a dense cover of tall brush. Northwest of there, a gravel bar has grown considerably in area from 1949 to present and has become sparsely vegetated.

RM 117.8. Gravel bar has grown considerably in area and has become sparsely vegetated.

RM 118.7. Forested island has new brushy vegetation along margins, that has increased progressively from 1949-present.

RM 119.1. Forested island has approximately doubled its area of vegetation coverage. The new vegetation is tall brush at present.

RM 119.5. Mainstem channel has swung southward from 1949-present, eroding away part of vegetated island on the south side of the river.

RM 121. Gravel bar has become partly vegetated with brush from 1949-present.

RM 121.3. Gravel bar has become partly vegetated with brush from 1949-present.

Slough 8C. Changed from side channel to side slough from 1962-present. Enclosing gravel bar has increased in size and become sparsely vegetated from 1949-present.

RM 122. Curved, forested island has progressively grown brushy vegetation at west and southwest ends from 1949-present.

RM 122.4. Gravel bar has become attached to south shore of river as a terrace, and has become progressively more vegetated with brush from 1949-present.

Slough 8B. Although slough has not changed type, the enclosing gravel bar has become increasingly vegetated from 1949-present. In 1949 there was almost no vegetation; in 1962 it was about half covered with vegetation; and at present it is fully vegetated with high brush and low trees.

Slough 8E. Changed from side slough to upland slough from 1962-present. Upper part of slough is now fully vegetated.

Slough 8F. Changed from side slough to upland slough from 1962-present. Enclosing gravel bar has shown increasing vegetation from 1949-present. In 1949 there was only a slight coverage of low grasses; in 1962 the bar was about half covered with brushy vegetation; and at present the bar is fully covered with high brush and low trees.

Slough 8G. Changed from side channel to side slough from 1962-present. In 1949, the side channel was behind a small, unvegetated gravel bar in mid-river. By 1962 the gravel bar had grown in area, and the side channel was reduced in size. At present, the gravel bar is larger, connected to the south shore, and is sparsely vegetated.

RM 123.4. Gravel bar near the south shore in 1949 has become attached to shore as a terrace, and has become progressively more vegetated from 1949-present.

RM 123.8. There is a new gravel bar attached to the south shore at present. This bar did not exist in 1949; it was a small in-channel bar in 19[illegible]; and it is a large bar attached to shore and beginning to vegetate at present.

RM 124.1. Gravel bar has become progressively more vegetated from 1949-present, and now has dense brush. Also, new gravel bars to the south of it, formed or emerged since 1949, have progressively increased in area to the present.

RM 124.7. Gravel bar has progressively increased vegetation coverage from 1949-present.

RM 125-125.5. Mainstem channel has shifted position since 1949, eroding away the tips of several old, forested islands. There is a new gravel bar in the old position of the mainstem channel. One old gravel bar, barren in 1949, has become progressively vegetated from 1949-present.

RM 126.6-126.7. Large gravel bar near south shore in 1949 has become attached to the south shore as a terrace. It has also become progressively vegetated with high brush from 1949-present.

RM 127. Gravel beaches on north side of channel have become vegetated since 1949.

RM 128.1-128.4. Gravel bars in mid-channel and attached to south shore have become increasingly vegetated from 1949-present.

Slough 9. Changed from side channel to side slough from 1962-present. Wetted area of slough narrowed from 1949-62. A large gravel bar in mid-slough became larger in area and increasingly vegetated from 1949-present. Another gravel at the lower end of the slough, partly vegetated in 1949, has progressively increased in vegetation cover, and is at present completely covered with high brush and low trees.

RM 129.2-129.5. Gravel bars increased in area from 1949-62, and became increasingly vegetated from 1962-present.

Slough 9A. Slough did not change type, but gravel bar at lower end of slough enlarged in area from 1949-62, and became increasingly vegetated from 1962-present.

RM 130. Mainstem channel shifted southward and widened from 1949-present. New gravel bars have formed in the old position of the mainstem channel and have become increasingly vegetated.

RM 131.2-131.7. Several gravel islands have become increasingly vegetated from 1949-present.

RM 132.2. The mainstem channel shifted position slightly to the northwest, eroding away the southeastern sides of several forested islands. The northern sides of the islands, however, have increased their area of vegetation coverage. Most of the island erosion took place before 1962. There are at present new gravel bars in the old position of the mainstem channel.

RM 133.0-133.3. Forested islands have increased in area by apparent emergence of new gravel beaches at the northeast and southwest ends, and these beaches have become increasingly vegetated, from 1949-present.

RM 133.6. The mainstem channel shifted to the south and eroded out a small, forested island near the south shore. A lengthy gravel bar, which had just started to form or emerge in 1949, now occupies the old position of the mainstem channel, has become attached to the shore as the beginning of a new terrace, and has become increasingly vegetated from 1949-present. Two small, forested islands near the south shore in 1949 have now become attached to the south shore as a terrace, and have become increasingly vegetated with brush, from 1949-present.

RM 134.5. Large gravel bar in mid-river has become increasingly vegetated with brush from 1949-present.

RM 135.3. Two gravel bars have become increasingly covered with low vegetation from 1949-present.

Slough 11. Large ice jam event, observed in 1976, overtopped the terrace on the south side of the river and eroded out a large side slough, known now as slough 11. There was only a small upland slough at the downstream end of the terrace previous to that event.

Slough 12. Changed from side slough to upland slough from 1962-present. Upper end of channel bed is now fully vegetated.

Slough 13. Changed from side channel to side slough from 1949-62. In 1949 the channel was behind a small gravel bar offshore. By 1962 the bar was attached the large terrace remnant enclosing slough 11, and at present the bar is slightly covered with low vegetation.

RM 137.2. Gravel bar has become much more vegetated from 1962-present.

Slough 15. Changed from side channel to side slough from 1949-62, and then to an upland slough from 1962-present.

RM 138.6. Main channel of Indian River has swung porogressively eastward in its delta from 1949-present.

RM 139.2. Mainstem channel has shifted northward from 1962-present, eroding out two small, forested islands. Gravel bar to the south of that has become slightly more vegetated from 1949- present.

Slough 19. Changed from side slough to upland slough from 1962-present.

RM 140. Vegetated island near south shore in 1949 has become attached to the shore as a terrace, and has become increasingly vegetated, from 1949-present.

Slough 20. Changed from side channel to side slough from 1962-present.

RM 140.6. Gravel bar has become increasingly vegetated from 1949-present.

Slough 21. Slough is enclosed by three forested islands, and is composed of both a lower side channel area and an upper side slough area. Overflow berm at upoper end of side slough area has become narrowed and confined by encroachment of vegetation from 1949-present. Channel between first and second island has formed or emerged a gravel bar, almost closing the channel, from 1962-present. Berm between second and third island has become greatly vegetated with low brush from 1949-present. It appears that flow in the lower side channel area has become severely restricted at comparable flows due to emergence of intervening berms.

RM 141.1-141.6. Forested island has become increasingly vegetated, especially in an old, abandoned channel through the center of the island, from 1949-present.

RM 141.9. Gravel island has become larger in area, and has become increasingly vegetated in its center, from 1949-present.

RM 142.4. A large portion of the south shore terraced mainland, and a large portion of a large, forested island in mid-river, have been eroded away. There is a barren gravel bar now in the position of the old south shore terrace. The mainstem channel is now much wider through this reach. This erosion all occured since 1962; the old forested island had been increasing in vegetation coverage from 1949-62.

RM 143.0-143.3. Gravel bar on south shore has become larger in area and increasingly vegetated from 1949-present.

RM 145.2. Gravel bar on south shore has become slightly more vegetated from 1949-present.

Slough 21A. Channel appears to be somewhat less flooded, at similar discharges, from 1949-present.