# SUSITNA HYDROELECTRIC PROJECT

FEDERAL ENERGY REGULATORY COMMISSION
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# GEOMORPHIC CHANGE IN THE MIDDLE SUSITNA RIVER SINCE 1949

PREPARED BY

UNIVERSITY OF ALASKA
ARCTIC ENVIRONMENTAL INFORMATION AND DATA CENTER



UNDER CONTRACT TO

HARZA-EBASCO
SUSITNA JOINT VENTURE

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Report by
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Under Contract to
Harza-Ebasco Susitna Joint Venture

Prepared for
Alaska Power Authority

Final Report
June 1985

NOTICE

ANY QUESTIONS OR COMMENTS CONCERNING
THIS REPORT SHOULD BE DIRECTED TO
THE ALASKA POWER AUTHORITY
SUSITNA PROJECT OFFICE

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## SUMMARY

In order to determine the natural geomorphic regime - the balance between aggradation and degradation - of the middle Susitna River (between Devil Canyon and Talkeetna), 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 provide important 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 apparently become more exposed, and increasingly vegetated and, as a result, better stabilized. Several gravel bars have become attached to the shoreline forming 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 old islands and shoreline.

3. Many sloughs appear or relatively higher in elevation compared to the water surface elevation of the mainstem at a given discharge. Some sloughs have evolved from side channels to side sloughs, and others from side sloughs to upland sloughs. In one case, a side channel has evolved to an upland slough.

The apparent emergence of gravel bars and islands, formation of new terraces, and perching of sloughs is probably due to a number of processes. Some cases may be due to migration or deposition of gravel bars; deposition of new material on old gravel bars, islands, and slough berms; and alteration by ice processes. Analysis of the middle river as a whole, however, leads the authors to believe that general river degradation since 1949 is responsible for much of the noted change. Although some features have been eroded away during that time, and some new gravel bars have appeared, most of the river's features show evidence of emerging higher above the water surface at any given discharge. The existence of several levels of terraces flanking both sides of the middle river indicates that this process has gone on in the past, and suggests that it may be continuing. Floodplain features are now apparently 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, the spread of vegetation progressed steadily during these periods.

When a slough evolves through mainstem degradation, 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 spawning. However, the slough may remain suitable for rearing. Meanwhile, however, new side sloughs are being converted from side channels, so that there is probably always some suitable fish spawning habitat available.

The 1952-53 surge of Susitna Glacier does not appear to have had any significant effect on the middle river's geomorphic regime. Bedload sediments released by the surge were probably deposited initially in the upper river and progress slowly through the middle river without accumulating there. 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.

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 geomorphic regime. Additionally, the middle Susitna river flows almost 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.

After an initial period of riverbed scour, the operation of the Susitna Hydroelectric project would probably stabilize the riverbed and cause the apparent degradation regime in the middle river to slow substantially. Evolution of sloughs from one type to another would stop. Slough types would remain essentially the same as they were at project startup, 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 substantially reduce the frequency of overtopping of sloughs that normally occurs during high summer flows. This would prevent the sloughs from being flushed of beaver dams and accumulated fine sediments contributed by small tributary streams. Unless remedial measures are taken, 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

All 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 at times, 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 below the level of a series of old sedimentary terraces on either side of the river. However, this general, long-term degradation might have been interrupted at times by change or even reversal of its regime, and it is of interest to know what regime has been active in recent decades in order to assess its effects on fish habitat.

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 habitats 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 might evolve into more favorable habitat conditions (suitable water depths, temperatures, velocities, and substrate conditions; see appendix D), while others might 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.

In order to determine geomorphic change in the middle Susitna River since 1949, the date of the earliest aerial photography, a photo interpretive analysis of aerial photography from the beginning, middle, and end of the period was undertaken. This study was conducted as part of the ongoing effort to characterize fish habitats in the Susitna River and to determine the effects of the proposed Susitna Hydroelectric Project on them.

## PURPOSE AND SCOPE

In order to assess natural processes leading to slough habitat changes 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 downstream of the dams, and changing river ice processes. This altered regime might disturb the natural evolution of the river system and fish habitat suitability.

Accordingly, we undertook an analysis of aerial photography of the middle Susitna 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 EWT&A (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).

4. whether the proposed Susitna Hydroelectric Project would have any effect on the geomorphic regime of the middle river, and therefore on fish habitat in sloughs.

## METHODS

For comparison purposes, sets of photographic prints were assembled 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.

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 EWT&A (1984) between sloughs 8A and 8B (appendix A).

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 discharges, which gave us a rough water surface 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, corresponding to dates of aerial photography. (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 of the river was taken at somewhat different scales, the map sets in Appendix A were adjusted to bring all illustrations to approximately the same scale of 1:60,000 (about one inch to one mile).

Earlier analysis of 1949-51 aerial photography from old USGS glass slides, discussed in a draft preliminary report of this study (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.

## GEOMORPHIC CHANGE

Analysis of aerial photography of the middle 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 apparently 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.

Vegetation becomes established on gravel bars when the bars are not flooded frequently or severely enough to erode away the topsoil in which plants grow. If the gravel bars remain unflooded long enough, vegetation succession takes place, in which plants grow to maturity and then are slowly replaced by other species which dominate the site. In the Susitna Basin, vegetation succession on gravel bars usually starts with the establishment of stands of horsetail, horsetail-willow, horsetail-balsam poplar, or dryas. Within 10 to 25 years after a site is stabilized, thinleaf alder succeeds the earlier vegetation, followed within 25 to 55 years after stabilization by immature balsam poplar stands of tall shrubs or trees. Later, 75 to more than 100 years after stabilization, mature balsam poplar dominate the site, followed finally by birch-spruce forest (McKendrick et al. 1982).

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 and small 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 nearshore gravel bars 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, are now emerged so high relative to the water surface of the river that they are seldom flooded and have become increasingly vegetated. Also, older forested terraces and islands that have long-abandoned overflow channels exist throughout the length of the middle river. 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 gentlysloped 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).

All of 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 side 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. In braided reaches, which occur only from RM 102 to the Susitna/Chulitna confluence, rapid and continuous shifting of channels makes this kind of analysis more difficult and less meaningful.

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

Many sloughs have evolved from side channels to side sloughs, and others from side sloughs to upland sloughs. In one case, slough evolution has progressed 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 of the studied sloughs that have changed type appear to have emerged; that is, they, or at least their berms, are now higher in elevation relative to the mainstem water surface at a given discharge. Of the 34 sloughs studied, 15 have changed type. Fourteen of those have emerged, while one (slough 11) has been eroded out and lowered in elevation by ice processes (table 2).

Of the 19 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, some have less wetted surface area at a given discharge, and some appear to have larger berm areas separating them from the mainstem than in 1949, perhaps suggesting higher berm heights. At some sloughs, enclosing gravel bars, which separate the sloughs from the mainstem, have grown larger by emergence and/or deposition, and are often further vegetated.

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 suggested by decreased wetted surface areas in some sloughs and vegetation excroachment on gravel bars since 1949.

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

| Slough | 1949 | 1961-2 | 1977-83 | Emerged? | 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 |
| 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 |

DEFINITIONS
(Source: EWT&A 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.

Emerged - indicates a floodplain feature has risen higher relative to the water surface elevation, at any given discharge, since 1949.

## PROBABLE CAUSES

The apparent emergence or increased exposure of gravel bars and islands, formation of new terraces, and the perching of sloughs could be caused by a number of processes. Some individual cases can probably be explained by the migration of gravel bars; deposition of new gravel bars and new material on old gravel bars, islands, and slough berms; and alteration of features by ice processes. These processes can cause apparent emergence of features with associated reduction in frequency and severity of flood overtopping events. Migration of the mainstem channel across its floodplain can result in decreased flooding of certain floodplain features and consequently an increase of vegetation coverage of those features. Localized aggradation or degradation of the river bed could also account for many of these changes.

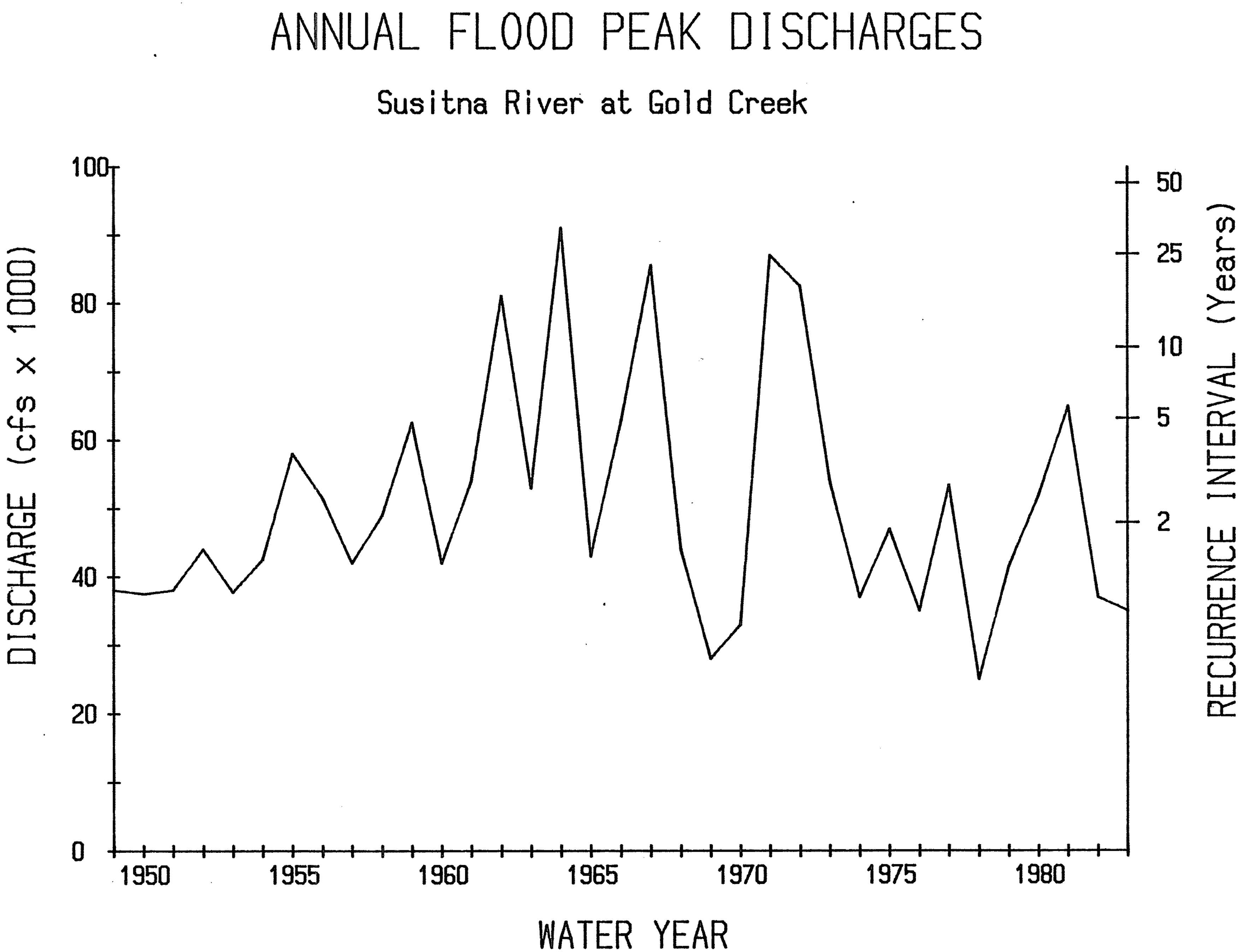
Many of these processes were active during the period studied and probably account for some of the cases of apparent emergence of features reported herein. Analysis of the middle river as a whole, however, leads the authors to believe that general river degradation since 1949 probably is responsible for much of the noted change. Although some features have been eroded away during that time and some new gravel bars have appeared, especially in old positions of the migrating mainstem, most of the reach's features show evidence of emergence. We believe that, as the river slowly eroded its bed, the mainstem water surface elevation at any discharge lowered in relation to floodplain features. The existence of several levels of terraces flanking both sides of the middle river at several places (as many as five levels can be seen at RM 110) indicates that this process has gone on in the past, and suggests that it may be continuing.

These floodplain 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).

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 most features appeared to progress at a steady rate during the period 1949-82 and these features were not affected by increased flooding during 1962-72. Therefore, the increased vegetation coverage of gravel bars and islands is probably due to their emergence.

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. In many of these cases the mainstem in 1949 has been converted to a side channel at present, and a side channel in 1949 has changed to the present mainstem.

**Figure 1.**




Source: modified from H-E 1985A.

## 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 melt 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. 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 conducted to look for any important variations in discharge that were not linked to climatic factors.

Several multiple regression analyses were performed for time blocks of weekly, monthly, and interannual discharge characteristics. In each of the three test cases (weekly, monthly, and interannual) the dependent variable was streamflow rates in $ft^3/sec$ from the Gold Creek station during open water season.

The thrust of the analysis for the two former cases (weekly and monthly) was to observe whether or not a correlation exists between streamflow rates, air temperature, and precipitation. At the onset of the open water season, the fluctuation of the air temperature above and below normal should influence the rate at which the snowpack melts and, thereby, inputs water into the streamflow system. Similarly, the amount of measured precipitation for the respective water weeks and months during open water season would influence the water levels in the system. The analysis was performed for the years 1950 to 1958 and 1970 to 1975.

Our hypotheses stated that these climatic factors should account for the explained variance in the streamflow rates. Any residual unexplained variance in the years following the glacial surge might be attributed to the surge.

In both the weekly and monthly open water cases there was a fairly high correlation between temperature and streamflow ($R^2$ from .54 to .87), and lower correlation ($R^2$ from .19 to .56) between precipitation and streamflow. The variation from year to year for the different weekly and monthly cases did not point to any pattern that might be attributable to the glacial surge during the 1952-53 season. Therefore, the results from these analyses were inconclusive and will not be presented in detail.

The first two test cases did provide some physical insight as to the climatic mechanisms controlling streamflow rates in the basin. The relatively high correlation of temperature, and low correlation of precipitation, to streamflow indicated that the depth and density of the snowpack was probably important as a water source for the system. Thus, a third test case was designed to examine the correlation between total seasonal snowfall, in inches, from Talkeetna, and precipitation measurements, in inches, during open water season (April to October) from Talkeetna, with the average streamflow rates in $ft^3/sec$ from the Gold Creek station for the open water season for the years 1952 to 1979.

Talkeetna is the only station within the basin which has enough detail and period of record to indicate long-term climatic trends. It would be more desirable 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 glacier and nearer to each other, but these do not exist. The distances and geographic variability between Talkeetna, Gold Creek, and the Susitna Glacier introduced potential error to the analysis. Nevertheless, it was the most comprehensive data available, and if a substantial increase in streamflow due to the glacial surge occurred, this was the most reasonable method available by which it might be detected.

Temperature measurements in the interannual case were neglected. We assumed that regardless of short-term variability in local air temperature, that by the end of the open water season, all snow present on the ground would have melted.

In the interannual case, analysis was performed on four-year time blocks beginning in 1952 at the time of the glacial surge and extending through 1979. The adjusted correlation coefficient ($R^2$) ranged from a high of .95 to a low of .26, but the lowest $R^2$ value did not occur in the time period following the 1952-53 season. The second lowest $R^2$, .39, did occur in the years immediately following the glacial surge.

Thus, while the glacial surge might partially account for the variation in streamflow rates in the weeks, months, and years following its occurrence, we were unable to indicate its influence with certainty using a statistical analysis. The lack of climate data from the upper basin makes the results indicative only, and not conclusive.

## GREAT ALASKA EARTHQUAKE

On March 27, 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 Kashwitna and Willow (Plafker 1969).

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, 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 (figure 2). 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.

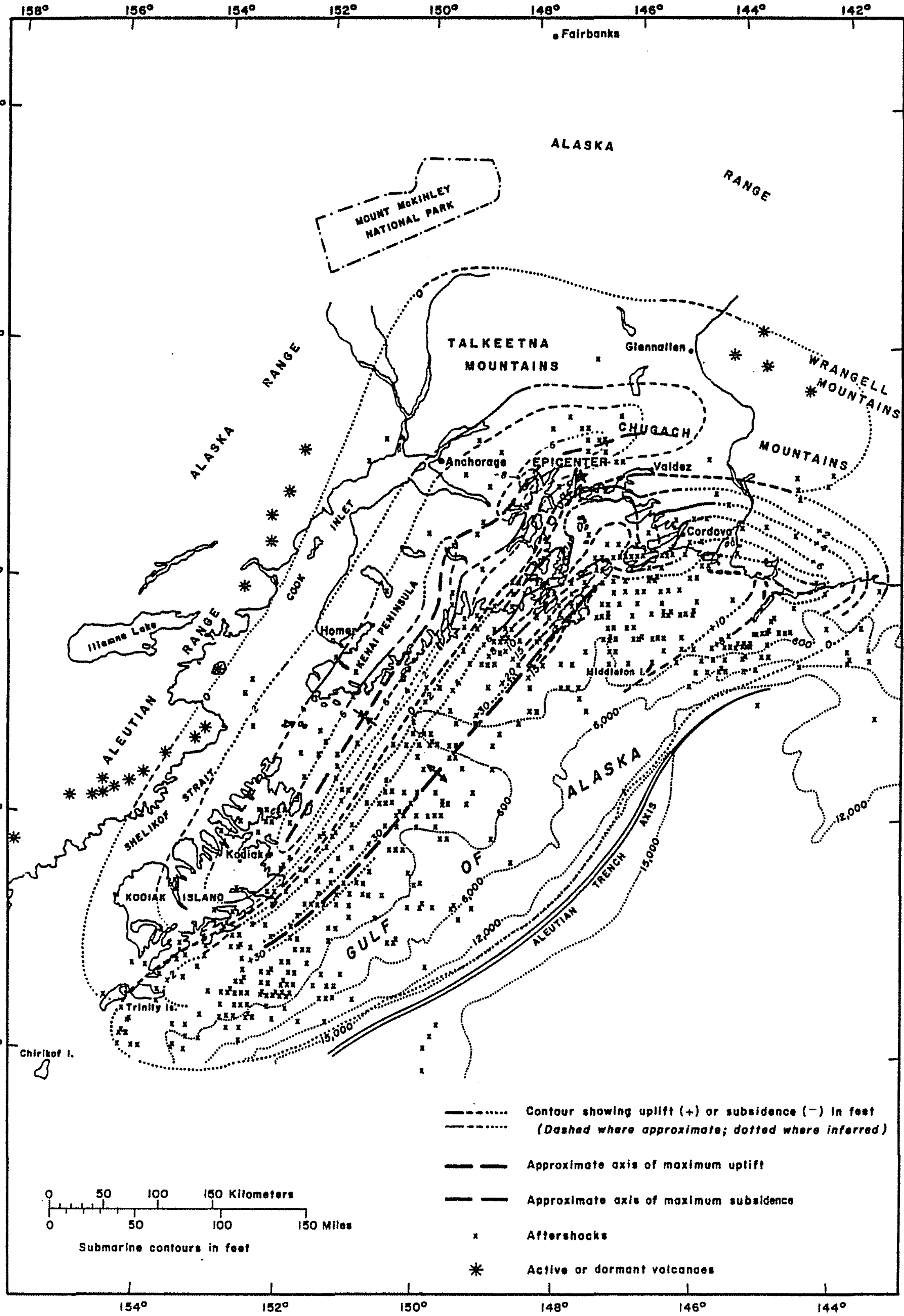



**Figure 2. Areas of uplift and subsidence, 1964 Alaska Earthquake.**

Source: Selkregg 1974

Analysis of the aerial photography in the middle river shows that the rate of apparent degradation between 1949 and the present has progressed continually throughout the period. There was no notable 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

Although some of the geomorphic changes seen in the middle Susitna River since 1949 can be explained by locally important processes, such as localized deposition, mainstem channel migration, or ice processes, 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 is probably in dynamic equilibrium over the short term (a few years). That is, although most bedload movement takes place during high-flow events, about the same amount of bedload sediment is carried into the middle river as leaves it, and any excess local deposition or scour during a given event is adjusted for later by sediment redistribution. However, superimposed upon this regime there appears to be a long-term regime of slow riverbed degradation as the river continually adjusts to glacier downcutting at the head of the basin.

As the main channel degrades and lowers its water surface elevation, gravel bars and other 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 new terraces. Vegetation then takes hold on these exposed surfaces and goes through natural succession, eventually becoming mature forests.

As the mainstem migrates across its floodplain, old side channels often become mainstem and old mainstem positions become side channels. As the river cuts down, intervening berms between the mainstem and side channels become effectively higher and some side channels evolve into side sloughs. As the berms emerge even higher, some sloughs are less frequently flooded, until the berms eventually become high enough to prevent any overtopping flows. These sloughs have then evolved into upland sloughs.

When a slough evolves, fish habitat conditions (appendix C) 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. This probably takes several decades to occur. 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 except at its mouth, and changing conditions within the slough may diminish fish spawning habitat, while it continues as important rearing habitat.

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. Also, some suitable slough habitat probably forms and is later altered through unrelated, short-term sedimentation events, such as deposition or migration of a gravel bar into a suitable position near the shore.

## 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 than normal in the winter when power demands would be the greatest. Flows would also be more stable than normal, with flood effects reduced in severity 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 accelerate scour of its bed somewhat. This would last for only a few years. The total amount of scour in the mainstem would average about 1-1.5 feet, 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 downstream of the dams, an armor layer would develop and the riverbed would become more stable (H-E 1985b). The main channel would tend to become reduced in width by encroachment of vegetation and sediment near the banks (R&M Consultants, Inc. 1982). Long-term natural degradation of the riverbed would be substantially reduced.

As degradation of the middle river ceased, the natural evolution of the sloughs would stop. Sloughs would no longer change by this process from one type to another. The type of each slough would remain essentially the same as it was at project startup. Slough fish habitat would, therefore, no longer be altered by degradational evolution.

However, it cannot be assumed that presently-suitable fish habitat would necessarily 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 and the flushing of beaver dams that trap sediments and can hinder fish passage into sloughs. If so, unless remedial measures are taken, sloughs might eventually become unsuitable for fish spawning.

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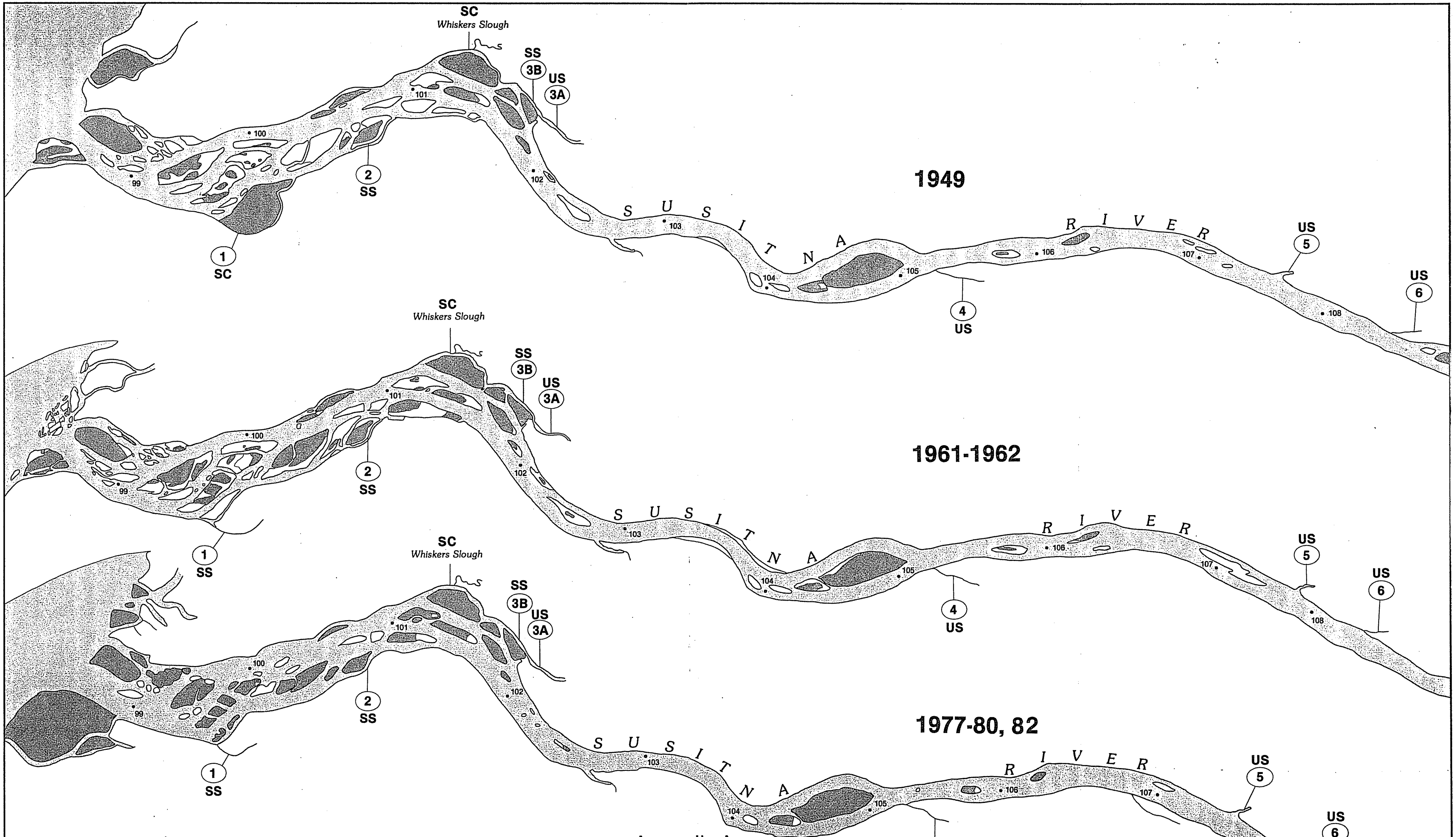
# APPENDICES

# APPENDIX A. COMPARATIVE GEOMORPHOLOGY

The drawing in appendix A are included in this report only to give the reader a very general idea of how the river has evolved since 1949. The drawings were done by a technician independent of the geomorphic analysis of the photography, and each year's set of drawings was done at a different time over the span of almost two years. The scale of the photography is very small and varies considerably between photographic sets, and lighting varies from flat with no shadows to bright with deep shadows. Some of the photography is in black-and-white while others are in false-color infrared, and water discharges varied slightly between years.

Due to these limitations it was difficult and, at times, impossible to portray each river feature accurately. Artistic license was taken at times in order to distinguish important features of the river that would be indistinguishable at true scale, since line widths often exceeded the actual size of features portrayed. The method of portrayal to achieve this end varied somewhat from one part of the river to another, and from year to year. All vegetation stands, regardless of successional stage, are shown on the drawings as black areas.

The drawings were not used by the authors in their analyses, and, in fact, were not finished until after the analyses were completed. The analyses were performed using a magnifying stereoscope utilizing overlapping stereo pairs of photographs. Without the three-dimensional images and magnification of features, many of the reported geomorphic changes could not have been distinguished. Accordingly, although the drawings do illustrate general change in the river, such as increased vegetation coverage and general changes in shape and area of certain features, the drawings should not be used by the reader to attempt to verify each geomorphic change reported in the text.




Appendix A

## COMPARATIVE GEOMORPHOLOGY

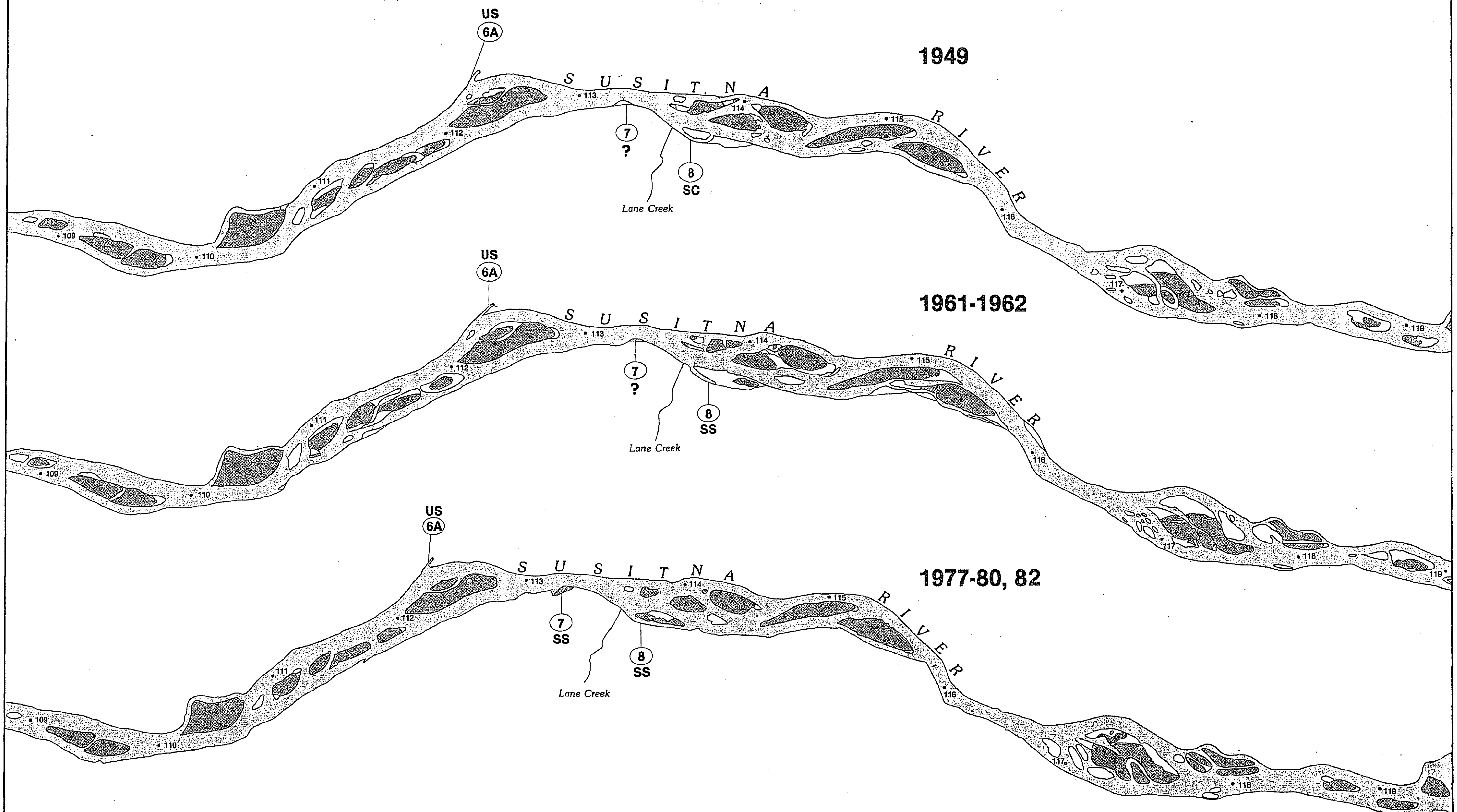
1949; 1961-62; 1977-80, 82
Middle Susitna River
River Mile 98-109

| | | | |
|---|---|---|---|
| (shaded box) | Vegetation | SS | Side Slough |
| (1) | Slough | US | Upland Slough |
| SC | Side Channel | 116 | River Mile |

N

Approximate Scale: 1:60,000

1 inch = .9 miles




| | | | |
|---|---|---|---|
| ▩ | Vegetation | SS | Side Slough |
| (2) | Slough | US | Upland Slough |
| SC | Side Channel | 116 • | River Mile |

## Appendix A

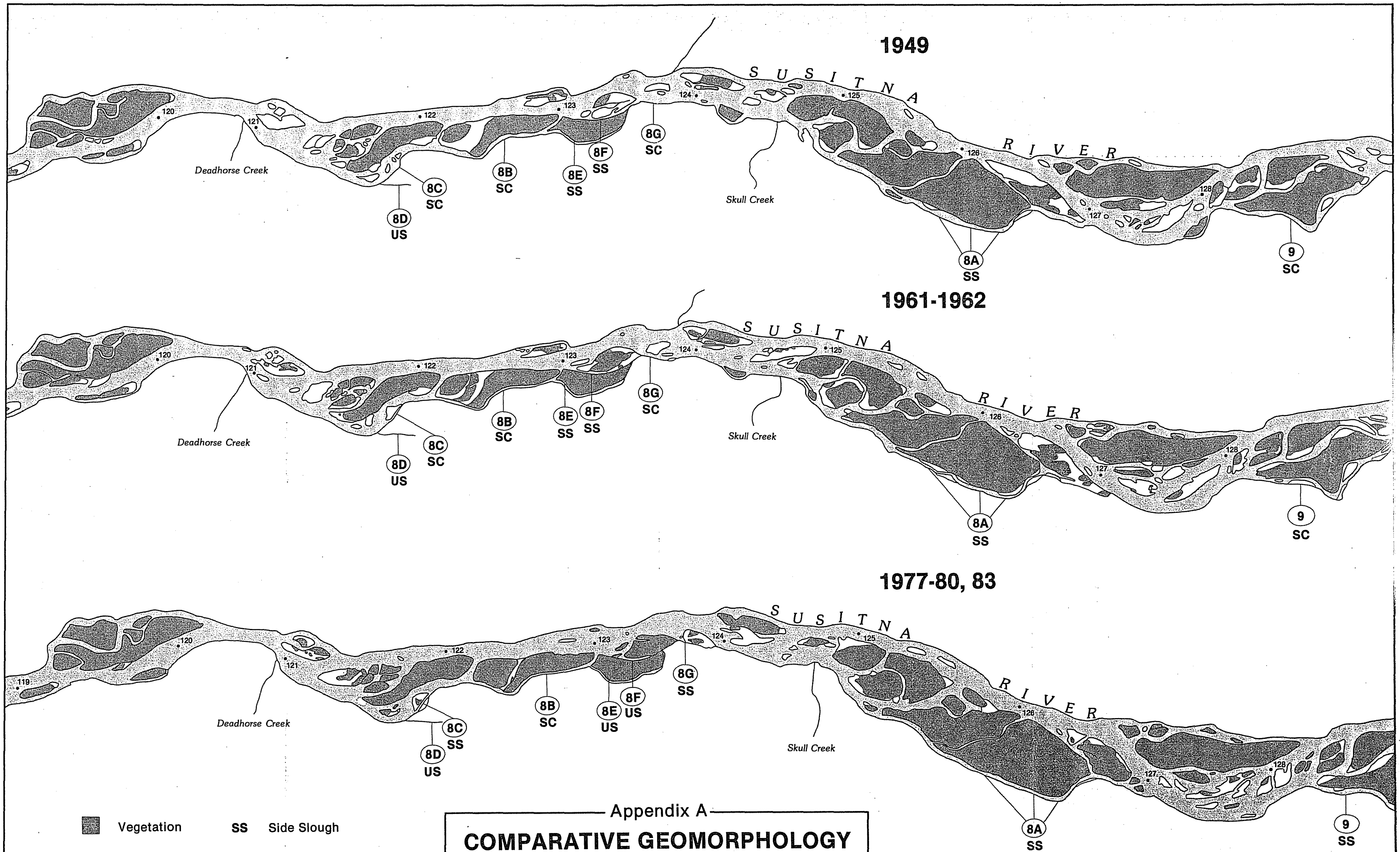
# COMPARATIVE GEOMORPHOLOGY

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

N

Approximate Scale: 1:60,000

1 inch = .9 miles

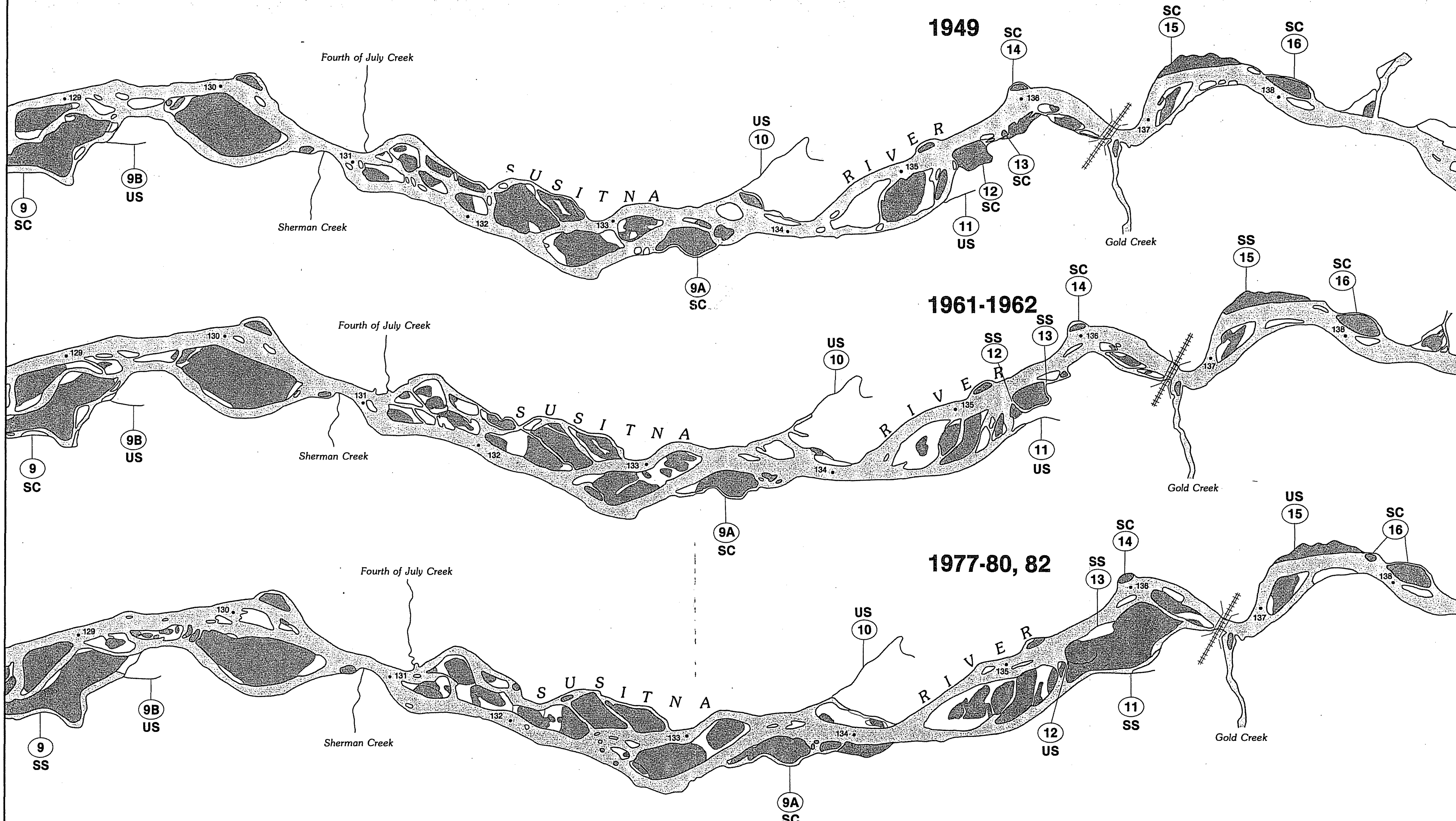



| | | | |
|---|---|---|---|
| (shaded) | Vegetation | SS | Side Slough |
| (3) | Slough | US | Upland Slough |
| SC | Side Channel | 116 | River Mile |

Appendix A

## COMPARATIVE GEOMORPHOLOGY

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




Vegetation

(4) Slough

SC Side Channel

SS Side Slough

US Upland Slough

116 River Mile

Appendix A

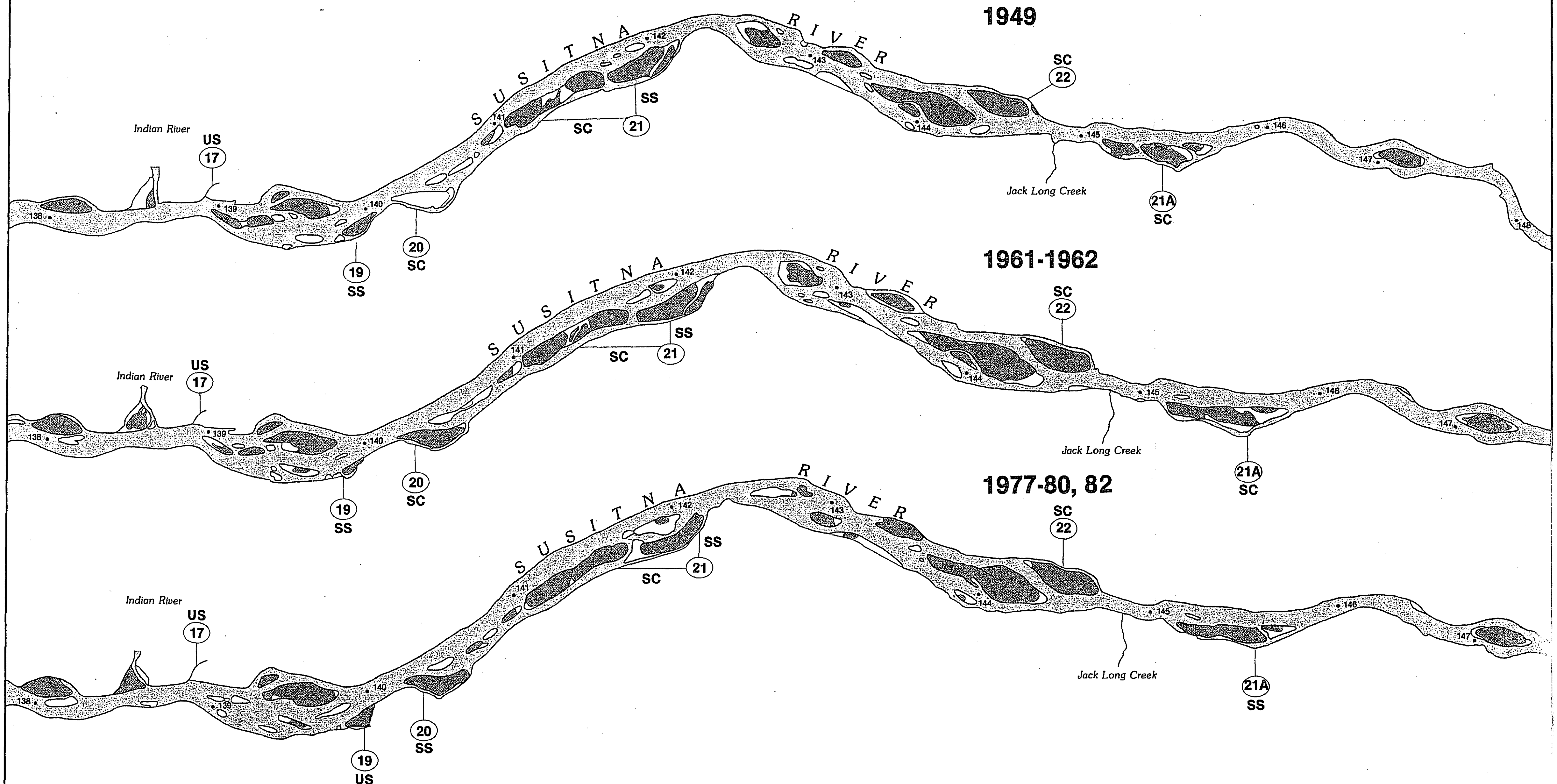
# COMPARATIVE GEOMORPHOLOGY

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

N

Approximate Scale: 1:60,000

1 inch = .9 miles




| | | | |
|---|---|---|---|
| ▪ | Vegetation | SS | Side Slough |
| (5) | Slough | US | Upland Slough |
| SC | Side Channel | 116 • | River Mile |

Appendix A

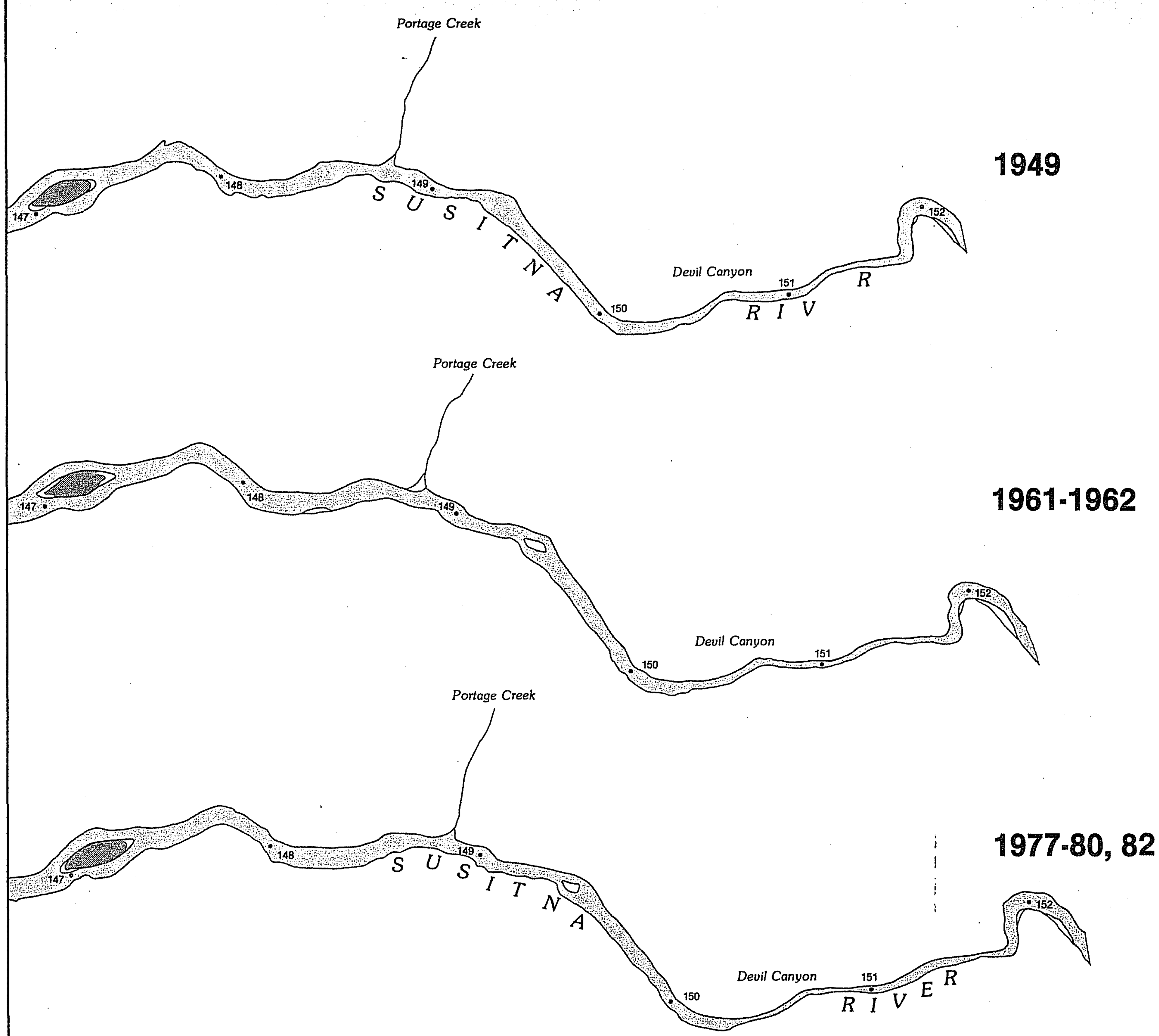
## COMPARATIVE GEOMORPHOLOGY

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

N

Approximate Scale: 1:60,000

1 inch = .9 miles




| | | | |
|---|---|---|---|
| (shaded box) | 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

N

Approximate Scale: 1:60,000

1 inch = .9 miles

## APPENDIX B - 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.

RM 99.5, 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.

RM 113.7, 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. Margins of forested island have new brushy vegetation 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 feature on the south side of the river. This feature, an island in 1949 and 1962, is now connected to the mainland at its upstream end, enclosing a new, unnamed, side slough.

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.

RM 121.8, 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 123.4. Gravel bar attached to south shore of river in 1949 is at present a terrace and has become progressively more vegetated with brush from 1949-present.

RM 122.3, 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.

RM 123.0, Slough 8E. Changed from side slough to upland slough from 1962-present. Upper part of slough is now fully vegetated.

RM 123.3, 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.

RM 123.8, 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 1962; 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 have become increasingly vegetated from 1949-present.

RM 128.3, Slough 9. 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.

RM 133.3, 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.

RM 135.4, 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.

RM 135.3, Slough 12. Changed from side slough to upland slough from 1962-present. Upper end of channel bed is now fully vegetated.

RM 135.6, 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.

RM 137.3, 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 progressively 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 southeast of that has become slightly more vegetated from 1949- present.

RM 139.8, 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.

RM 140.2, Slough 20. Changed from side channel to side slough from 1962-present.

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

RM 141.5, 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 upper 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 141.9. 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 occurred 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.

RM 145.5, Slough 21A. Channel appears to be somewhat less flooded, at similar discharges, from 1949-present.

## APPENDIX C. FISH HABITAT CONDITIONS

Riverine fish habitat in the middle Susitna River occurs in various locations--lakes, tributaries, the mainstem, side sloughs and channels, and upland sloughs. Tributary confluence areas also have unique characteristics which define their importance as fish habitat. Of these areas, side sloughs and tributaries are used most heavily by fish, principally by salmon. From investigations over the past five years, habitat quality in these area is considered highest when certain physical characteristics are present.

The substrate most suitable for salmon spawning and embryo incubation is a medium sized gravel with few fine sands or clay particles. Some coarse cobble or boulder particles will not limit suitability for spawning/incubation unless these large particles are too numerous for fish to successfully excavate redds. Fine particulates are almost always present in suitable streambed gravels, but excessive amounts accumulated over long periods of time can inhibit waterflow through the substrate which is necessary for embryo respiration and evacuation of waste metabolites. Periodic flushing of excessive fine materials by physical disturbance of the gravels, often accomplished by the spawning act of adult fish, or high flows created when high mainstem discharges overtop slough berms, can maintain the quality of spawning and incubation gravel substrates.

Other characteristics of suitable fish habitat include a stable and continuous flow of high quality water which provides depths of about 0.3 to 0.5 ft or more for spawning and sufficient depth to ensure the surface is wetted throughout the incubation period. Velocities of nearly zero to as high as 3 to 5 feet per second are suitable, but such a generalization masks the differences between preference by young fry for lower velocities and adult fish which find higher velocities more suitable because of the role water flow plays during excavation of streambed gravels by spawners. Seasonal flow fluctuations can be beneficial by seasonally washing riparian matter into fish habitats, providing organic food sources to invertebrates. These seasonal high flows also scour streambeds of beaver dams and accumulated fine materials and transport them out, thereby assuring substrates are available for use by fish, and waterflow through gravels can continue to maintain incubating fish embryos. Rapid daily or weekly fluctuations, however, do not permit successful colonization of shorelines by algae or invertebrates.

Groundwater upwelling through streambed gravels ensures a stable incubation environment for fish embryos, particularly during winter when surface flow is significantly reduced and ice formation is extensive. This appears to be most important in side sloughs and channels.

Access to habitat is necessary for adult movement to spawning areas and for juvenile movement to rearing sites. Reaches of low velocity provided by riffle/pool variability, large boulders or instream debris, or sills at entrances to habitat ensure unimpeded movement by fish into or out of preferred habitats.

Juvenile fish rearing occurs year around since chinook, coho, and sockeye salmon spend at least one year in fresh water prior to outmigrating. Invertebrate production is important as these organisms provide food for rearing fish. Rapid daily flow fluctuations, flooding, or other disruptions tend to reduce habitat suitability; physical habitat stability increases its value for rearing. Some form of cover (depth, riparian vegetation, turbidity, instream debris, etc.) is necessary to provide resting places or predator escape for rearing fish. Because of small size, rearing fish rely on low to moderate flow velocities.

Other features contribute to good habitat such as cover for juvenile fish predator escape or resting, high levels of dissolved oxygen, adequate water quality, and suitable water temperatures. Many other biologic characteristics affect the nature of good quality fish habitat, such as the presence of disease, competitors, and predators. However, in the context of this report, the previously described features are the most relevant.