TECHNICAL SERVICE CENTER
DENVER, COLORADO

UPPER GILA RIVER FLUVIAL GEOMORPHOLOGY STUDY

CATALOG OF HISTORICAL CHANGES NEW MEXICO

US Department of the Interior
Bureau of Reclamation

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U.S. Department of the Interior

Mission Statement

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian tribes and our commitments to island communities.

Mission of the Bureau of Reclamation

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

STATE OF NEW MEXICO
NEW MEXICO ENVIRONMENT DEPARTMENT
SURFACE WATER QUALITY BUREAU

RECLAMATION CONTRACT 00-GI 32-0060
JOINT POWERS AGREEMENT 01-667-JPA003

The State of New Mexico and Reclamation are Cost Share Partners in the Upper Gila River Fluvial Geomorphology Study. The views or findings of Reclamation presented in this deliverable do not necessarily represent those of the State of New Mexico.

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NEW MEXICO

PREPARED BY
FLUVIAL HYDRAULICS & GEOMORPHOLOGY TEAM

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FLUVIAL HYDRAULICS & GEOMORPHOLOGY TEAM

The Fluvial Hydraulics & Geomorphology Team from the Technical Service Center is leading the Upper Gila Fluvial Geomorphology Study. The team consists of geomorphologists, engineers, and biologists. The members have expertise in water resources management, fluvial geomorphology, paleohydrology, hydraulics, sedimentation, photogrammetry, mapping, fisheries biology, wildlife biology, and riparian vegetation management.

The team members are:

- Dr. Daniel R. Levish, Geologist. (Paleohydrology, Fluvial Geomorphology)
- Dr. Rodney J. Wittler, Hydraulic Engineer. (Hydraulics, Water Resources Management)
- Ms. Jeanne E. Klawon, Geologist. (Fluvial Geomorphology, Geology)
- Dr. Ralph E. Klinger, Geologist. (Paleohydrology, Fluvial Geomorphology)
- Dr. Blair P. Greimann, Hydraulic Engineer. (Hydraulics, Sediment Transport)
- Mr. Mitchell R. Delcau, Hydraulic Engineer. (Hydraulics, Sediment Transport)
- Ms. Susan C. Broderick, Fisheries Biologist. (Fisheries Biology, Endangered Species Recovery)
- Mr. Larry H. White, Wildlife Biologist. (Wildlife Biology, Riparian Vegetation Management)

STUDY BACKGROUND

The State of New Mexico, Environment Department, Surface Water Quality Bureau (NMED-SWQB) is sponsoring the Upper Gila River Fluvial Geomorphology Study in New Mexico. The Bureau of Reclamation, under a Joint Powers Agreement (JPA) with the NMED, began the fluvial geomorphology study of the Gila River in New Mexico between the Arizona State line and Mogollon Creek, near Cliff, New Mexico in October 2000. This study complements an on-going Reclamation fluvial geomorphology study of the Gila River between San Carlos Reservation and the New Mexico – Arizona state line.

The Reclamation Study Manager is Mary Reece, Phoenix Area Office (PXAO). Co-Principal Investigators from the US Bureau of Reclamation Technical Service Center (USBR-TSC) in Denver, Colorado, are Dr. Daniel R. Levish, Fluvial Geomorphologist, and Dr. Rodney J. Wittler, Hydraulic Engineer.

The goal of this study is to diagnose the fluvial geomorphological attributes of the upper Gila River. These attributes are a function of the physical processes at work in the stream corridor. The stream corridor includes the mainstem of the Gila River at flood stage and the associated riparian area, as well as tributaries within the valley of the mainstem. The purpose of the study is to increase the awareness of these processes enabling improved local, state, and federal management of the stream corridor. The study includes background information gathering, field data collection, photographic analyses, and a variety of topographic, geomorphic, hydraulic, and hydrologic analyses. The study includes a qualitative assessment of the Gila River in the upper box.

The practical downstream limit of the study is the Arizona-New Mexico State line. The practical upstream boundary of the study is the Cliff, New Mexico area, and specifically USGS gage 09430500 Gila River near Gila, NM, at the Hooker Dam site, 1.6 miles upstream from Mogollon Creek, roughly 7 miles northeast of Gila, New Mexico. The length of river channel in the study area, measured from USGS 7.5 minute topographic maps is roughly 66.2 miles.

TABLE OF CONTENTS

List of Figures

List of Tables

CATALOG OF HISTORICAL CHANGES NEW MEXICO

INTRODUCTION

The Catalog of Historical Changes documents changes in the alluvial channel of the Upper Gila River, New Mexico from 1935 to 2001. This task includes an analysis of trends in channel behavior and stability of river reaches based on lateral migration and changes in channel widths.

The Catalog of Historical Changes (Task 7) is an important component of the overall project goals of the Upper Gila River Fluvial Geomorphology Study. This study will combine with the Geomorphic Map (Task 8) to provide the data necessary for the Geomorphic Analysis.

SETTING

The Gila River originates in the Gila River Wilderness in west-central New Mexico and flows south through the Cliff-Gila Valley, and southwest through Redrock and Virden Valleys into east-central Arizona. Narrow v-shaped canyons, or boxes, form constricted reaches between the alluvial valleys (Figure 1). Major tributaries to the Gila River in the study reach include Blue Creek in Virden Valley, Ash Creek in Redrock Valley, and Mangas, Sycamore, Duck, and Mogollon Creeks in the Cliff-Gila Valley.

The study area is located in the Mexican Highlands section of the Basin and Range Province and the Datil-Mogollon Section of New Mexico (Clemons, et al, 1996). The Basin and Range Province is characterized by a series of mountain ranges and intervening broad valleys, the majority of which were formed during the late Cenezoic era (30-5 m.y.) (Kamilli and Richard, 1998). The mountain ranges in the Mexican Highlands section are fairly regular in their orientation, trending north-northwest to north. For the most part, basins had internal drainage throughout the period of Basin and Range deformation (through later Miocene time) (Morrison, 1991). The Datil-Mogollon Section is a transition province between the Basin and Range and Colorado Plateau and is characterized by Miocene to Pliocene volcanic rocks including lava flows and pyroclastic rocks. The physiography in this province consists of block-faulted mountain ranges, and expansive basins and tablelands.

Prominent geologic units in the study area are mainly late Eocene-early Miocene volcanic rocks and Miocene to Holocene sedimentary units and basalt flows. Volcanic rocks range from quartz latite to rhyolite flows, domes, and pyroclastic rocks to basaltic andesite and andesite lava flows. Sedimentary units include the Tertiary Gila group as well as Holocene and Pleistocene alluvium. Precambrian rocks, predominantly gneiss with metasedimentary and metavolcanic rocks, also outcrop through the middle box of the Gila River (Clemons et al, 1996).

Peak discharge records for the upper Gila River show a period of relatively few large floods from the beginning of gage records (~1929) through the 1960's (Figure 2). A notable extreme flood during this period occurred on September 29, 1941 and measured 41,700 ft^3/s at the Gila River below Blue Creek near Virden, NM gaging station.

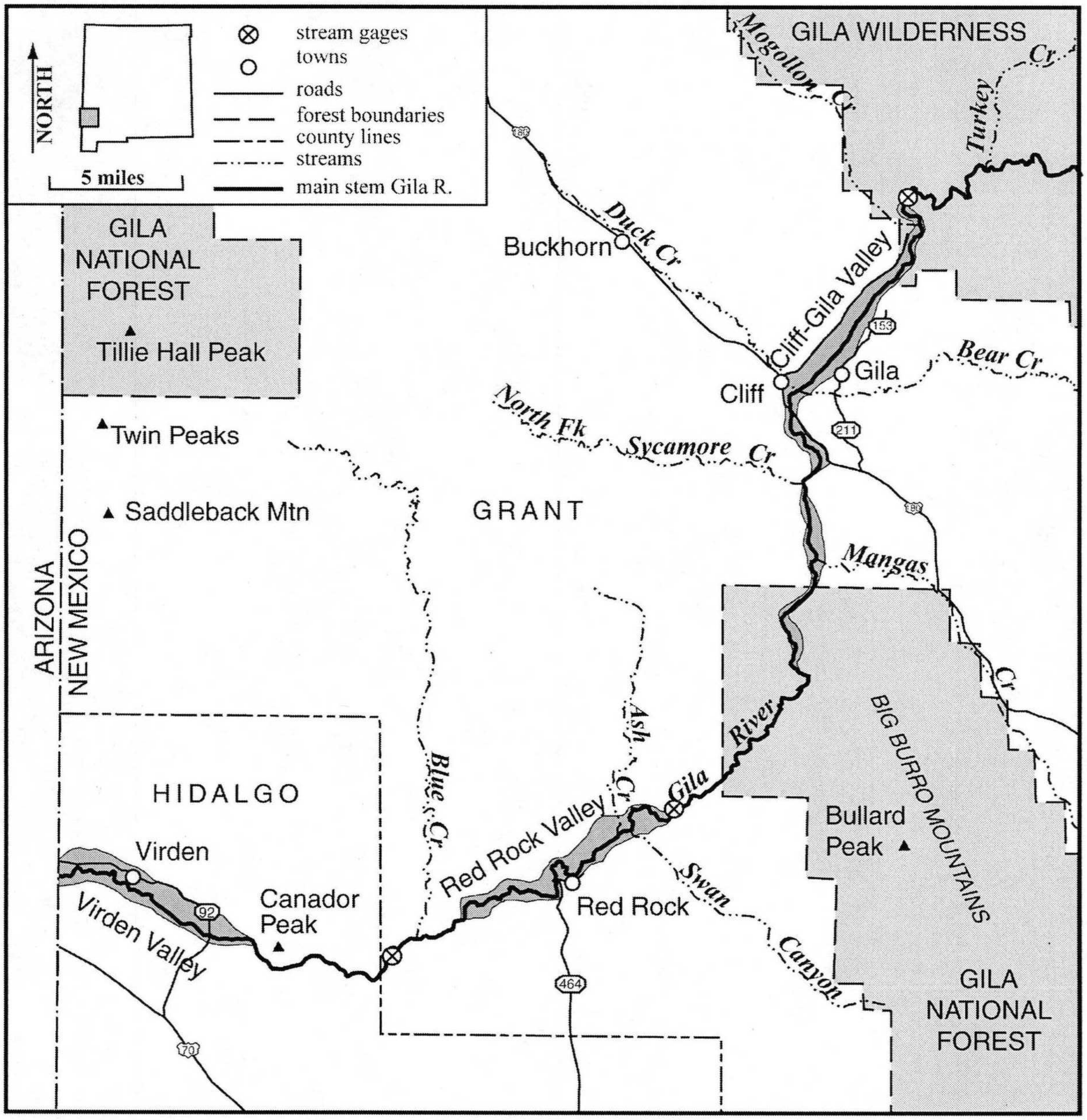


Figure 1. Study area location. *The study area is located in south-western New Mexico and focuses on the alluvial valleys of the Gila River. The alluvial valleys, outlined in gray, include Virden Valley, Redrock Valley, and Cliff-Gila Valley. The river in between these valleys flows through steep and narrow canyons, termed the Middle and Lower Boxes.*

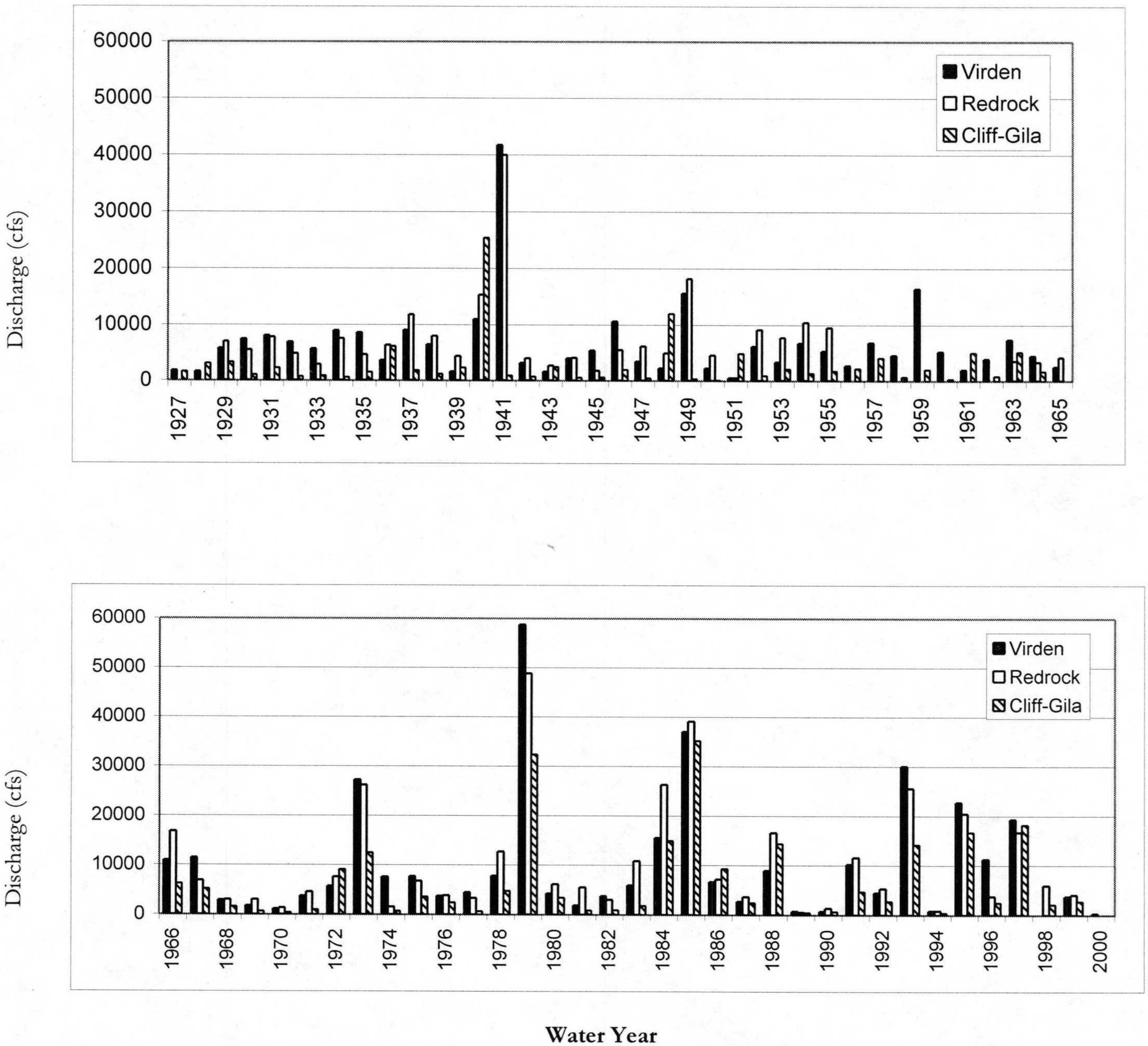


Figure 2. Gage records, Gila River, NM. *Gage records are shown for the three gages located on the main stem Gila River in the study area. Gage no. 09432000 (Gila River below Blue Creek near Virden, NM), 09431500 (Gila river near Redrock, NM), and 09430500 (Gila River near Gila, NM) are used in this analysis.*

Beginning in the late 1970's was a period of more frequent large floods, a pattern that apparently continues. The peak of record in Virden Valley and Redrock Valley occurred in 1978, measuring 58,700 ft^3/s in Virden Valley and 48,800 ft^3/s in Redrock Valley (Table 1). The peak of record in Cliff-Gila Valley occurred in 1984, measuring 35,300 ft^3/s. Although there is limited quantitative information pertaining to floods in the early 1900's, historical accounts state that the 1978 flood is the largest since 1891 (England, 2002). The magnitude of floods varies between valleys. As expected, for the same flood, the magnitude of the peak increases downstream with a few exceptions where the peak at the Redrock gage is larger than at the Virden gage. The most notable of these exceptions occurred on December 28, 1984, where the peak at the Redrock gage measured 39,100 ft^3/s and the peak at the Virden gage measured 37,000 ft^3/s.

Table 1. Largest floods at U.S. Geological Survey streamflow gaging stations (modified from England, 2002).

USGS Gaging Station No.	Station Name	Drainage Area (mi^2)	Period of Record (Water Years)	Largest Peak Discharge and Date	Second Largest Peak Discharge and Date	Third Largest Peak Discharge and Date
09430500	Gila River near Gila, NM	1,864	1928-2000	35,200 ft^3/s 12/28/1984	32,400 ft^3/s 12/18/1978	25,400 ft^3/s 09/29/1941
09430600	Mogollon Creek near Cliff, NM	69	1968-2000	10,800 ft^3/s 08/12/1967	10,100 ft^3/s 12/18/1978	6,430 ft^3/s 12/28/1984
09431500	Gila River near Redrock, NM	2,829	1905, 1911, 1929-1955, 1963-2000	48,800 ft^3/s 12/19/1978	40,000 ft^3/s 09/29/1941	39,100 ft^3/s 12/28/1984
09432000	Gila River below Blue Creek near Virden, NM	3,203	1927-1997, 1999-2000	58,700 ft^3/s 12/19/1978	41,700 ft^3/s 09/29/1941	37,000 ft^3/s 12/28/1984
09442680	San Francisco River near Reserve, NM	350	1959-2000	9,830 ft^3/s 10/01/1983	7,870 ft^3/s 09/30/1983	7,000 ft^3/s 10/20/1972

PREVIOUS WORK

There is very little information available concerning channel changes on the Gila River in New Mexico. Several studies, however, have been conducted on this topic in the Arizona portion of the upper Gila River.

Olmstead (1919) prepared a document in response to concerns about erosion of farmlands during large floods at the turn of the century. Olmstead describes what is known about floods in the 1800's as well as in the early 1900's on the Gila and San Francisco Rivers and documents changes in average channel width through this period. For the period of 1904-1916, he concluded that there were seven major floods. Prior to this period, channel width was approximately 150 to 200 ft wide as recalled by landowners in the area. Following the floods of the early 1900's, the channel in Safford Valley averaged 1,935 ft in width. Olmstead described floods prior to 1900 as non-erosive and as spreading out over the flood plain when the channel was not adequate to accommodate the flow. Flood years, mostly recorded by Pima Indian calendars, include 1833, 1869, and 1884. Olmstead concluded that floods of this period of observation were probably the result of long-duration precipitation events, rather than short-duration high magnitude rainfall in the early 1900's, because they were not erosive in nature like the early 1900's floods.

The Gila Phreatophyte Project, performed in the Safford basin in the 1970's by the U.S. Geological Survey, provides voluminous data on a number of topics. Their goal was generally to evaluate the effects of phreatophytes on water budget in the project area, to describe hydrological and ecological variables, and to test these methods for viable extrapolation to other areas (Culler and others, 1970). As part of this project, Burkham (1972) documented channel changes in Safford Valley from 1846 to 1970 using surveyor's maps for the early periods and aerial photographs for later periods. A stable, narrow, meandering channel with an average width of less than 150 ft existed in 1875 and expanded to less than 300 ft in 1903. From 1905-1917, large floods caused lateral erosion of the floodplain, with most of the widening occurring during 1905-1906 and 1915-1916. The average width increased to 2,000 ft. From 1918-1970, the floodplain was rebuilding and the average width of the channel decreased to less than 200 ft by 1964. This was accompanied by an increase in sinuosity. Salt cedar became a dominant species along the river corridor during 1920-1930 and reached its maximum extent during 1945-1955. In 1965 and 1967, floods caused minor widening of channel and by 1968; the average width measured 400 ft. Burkham concluded that major widening events are coincident with major floods in 1891, 1905-17, and 1965-67, and that grazing was not a major cause in sediment production, as the majority of livestock were below major flood producing source areas; however, he concluded that grazing may have accelerated erosion of flood plain in the lowlands.

Burkham also documented changes in channel patterns caused by alluvial fan deposition. He discussed in detail a tributary near Calva (Burkham, 1972, Plate 4), Salt Creek at Bylas, and the Gila River near Ft. Thomas. Generally, the erosion of the distal parts of alluvial fans during floods of early 1900's caused an increase in fan gradient, and deposition of fan sediment into the main channel. This directed the main channel toward the opposite bank causing erosion of that bank.

Hooke (1996) documented channel change in the Safford basin using aerial photographs. Hooke added to Burkham's study by measuring channel widths from 1982 to 1992 aerial photographs. Channel widening that had been occurring in 1960-70's continued to 1992. Major channel changes resulted from high flows in the 1972, 1974, and 1979 water years with minor changes in response to smaller flows. Hooke concluded that although channel morphology appears to be formed by high flow events, geomorphic response may be complicated by other factors such as vegetation and "…sequences of events and critical combinations of conditions" (p. 191) and that caution should be used when inferring paleohydrologic conditions from channel morphology.

Klawon (2001) documented channel change from 1935 to 2000 in the Safford and Duncan basins. Channel change patterns were similar compared to studies by Burkham (1972) and Hooke (1996) in that widening occurred during periods of multiple large floods and narrowing during periods of few large floods. From 1935 to the early 1960's, the channel narrowed by sedimentation (Burkham, 1972), vegetation growth, and levee, dike, and agricultural development. From the late 1960's to 2000, the channel widened in response to large floods and was approximately the same width on average as it was in 1935. With a few notable exceptions, channel widths at specific channel locations were variable, but not unprecedented in the historical record.

METHODOLOGY

DATA SOURCES

Data for this analysis were derived mainly from aerial photography flown by U.S. government agencies and private aerial survey companies between 1935 and 2001 (Appendix B). At least one aerial photograph set was acquired for each decade, with exception of the 1940s. Photograph sets used for the three valleys include: 1935, 1953, 1965, 1973, 1975, 1980, 1984, 1996, 1998, and 2001. Additional sets including 1950, 1956, and 1995 were used in the Cliff-Gila Valley (Table 2). Refer to Appendix B for details on these aerial photograph sets. A total of ~1,160 channel width measurements are included in this analysis (Appendix D).

Table 2. Availability of aerial photographs for Virden, Redrock, and Cliff-Gila valleys.

Photograph Year	Availability		
	Virden	Redrock	Cliff-Gila
1935	X	X	X
1950			X
1953	X	X	X
1956			X
1965	X	X	X
1973	X	X	X
1975	X	X	X
1980	X	X	X
1984	X	X	X
1995			X
1996		X	X
1998	X		
2001	X	X	X

DATA COLLECTION

Measurements of channel width for the Gila River were made on the aerial photographs using a digital caliper and measured to a hundredth of a millimeter (0.01 mm), which corresponds to a computed ground distance of 0.2 to 0.6 m depending on the scale of the photographs. The 2001channel widths were measured on digital orthophotos. Since the imagery was rectified, no conversion of measurements was necessary for this photography.

To compare measurements from photography of varying scales, it was necessary to convert all measurements to actual ground distances. Conversion factors for aerial photograph measurements to actual ground distance were computed by measuring corresponding distances on USGS 7.5 minute topographic maps and aerial photographs. This option was chosen because the scale of·the photographs was not always known and would account for changes in camera position and distortion from the camera lens on the unrectified photographs. Several segments of varying lengths and orientations for each set of aerial photographs and the topographic maps were used to compute the average conversion factor. A test of error introduced by the user was also conducted by measuring the same point multiple times.

Channel width measurements provide a quantitative means for comparison of the Gila River channel among different years. Channel width measurements were made approximately every kilometer (~0.6 mile) by establishing points from which a width measurement was made perpendicular to flow direction

(Appendix D). The spacing of measurements was based on previous studies by Burkham (1972) and Hooke (1996). With an average channel width of 240 m, this study's measurements should capture lateral changes on the Gila River, including lateral migration as well as expansion and contraction in channel width. Eleven measurement points were established in Virden Valley; eighteen points in Redrock Valley; and thirty-three in Cliff-Gila Valley (Appendix C). The points were established in places such as road intersections or bedrock knobs that could be easily relocated on each set of aerial photographs. A straight line was extended from the measurement point across the channel to a physiographic or geographic feature on the opposite side of the river. Measurements were then made perpendicular to the channel from the intersection of the straight line and left bank. Using this method, the geographic location of channel measurements for different years could remain constant regardless of changes in channel position. For each point, two channel width measurements were made:

(1) Active channel width: that part of the channel that was being reworked by recent flows at the time the photographs were taken.

(2) Flood channel width: that part of the channel that was clearly inundated by high magnitude flows. These widths appeared to be the actual channel width during floods, not the result of lateral migration. In some cases where levees were built to protect structures or land from erosion and damage, the allowable width between levees was considered the flood channel width. In some cases, plowing of fields following floods obscured the evidence of flood modification. Sometimes flood channel width could be inferred from adjacent plots that had not been obscured.

RESULTS AND ANALYSIS

GENERAL TRENDS

AVERAGE WIDTH DATA: COMPARISON OF PHOTOGRAPHS

Flood channel width data show a pattern of decreasing width from the 1930's to the 1960's and increasing width from the 1960's to 1998 (Figure 3). Measurements from 2001 show a decrease in width from the 1998 average width. Active channel width data show a general increase in width from 1935 to 1998. This general increase is punctuated by several reductions in channel width from 1953 to 1956, 1973 to 1975, 1980 to 1984, and 1998 to 2001. Streamflow data from station no. 09430500 on the Gila River near Gila, NM are plotted against channel width data to show any patterns between large floods and channel change (Figure 3). The largest floods occurred in water years 1941, 1973, 1979, 1984, 1985, 1993, 1995, and 1997. Although active channel width measurements show increases in width following large floods, the relationship for flood channel widths is not as simple. A pattern of decreasing width during periods of few large floods is obvious. The channel also appears to have responded to some floods by an increase in width, but this is not the case for some of the largest floods. This will be explored further in the discussion section of this report.

Although in most alluvial rivers, channel width should increase downstream, width appears to decrease downstream, being very similar in Cliff-Gila and Redrock valleys and the narrowest in Virden Valley by about 30 m on average (Figure 4). This decrease in width does not appear to be explained by a comparative decrease in peak. In fact, peak discharges generally increase downstream, although in some cases the magnitude of increase only measures a few thousand cubic feet per second.

MEASUREMENT POINT DATA: COMPARISON OF PHOTOGRAPHS

Analysis of Channel changes

The statistical analysis of channel change identifies the reaches of greatest variability in channel width over the period measured. The standard deviation of the widths for all photograph years at each measurement point was compared relative to other points so that reaches with high variability could be identified. This analysis only includes results for the flood channel width measurements, although the same analysis could be performed for active channel width measurements. Flood channel width measurements appear to be the more important variable to analyze, as these are the widths that impact personal property and land along the Gila River. Low points on figures 5, 9, and 13 reflect low variance in width measurements, while high points reflect high variance in width measurements. The information contained on this chart does not correspond to narrow or wide points in the channel, but rather to those points that experienced very little change in width and those points that experienced greater change in width over the study period. Several case studies document the reaches of greatest variability for each valley. The measurement points in these reaches have standard deviations greater than 60 meters.

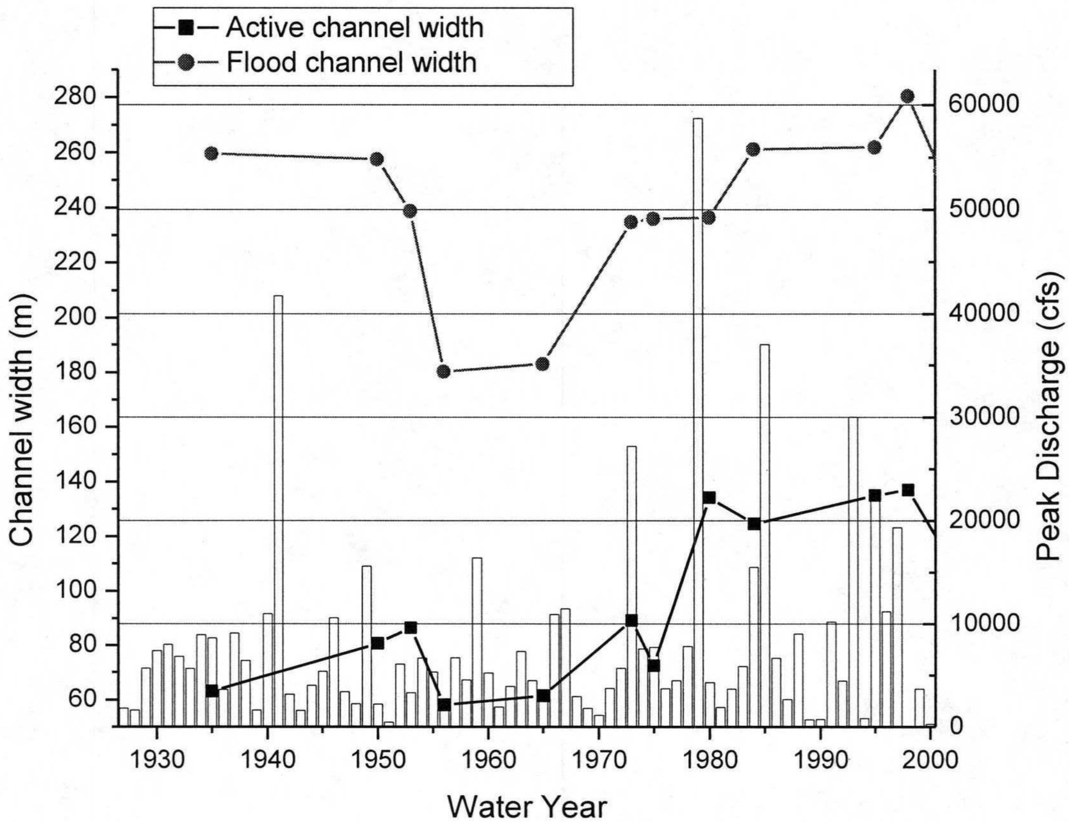


Figure 3. Average width data by photograph year. *Active channel widths and flood channel widths are superimposed on the streamgage record at the Gila River below Blue Creek near Virden, NM.*

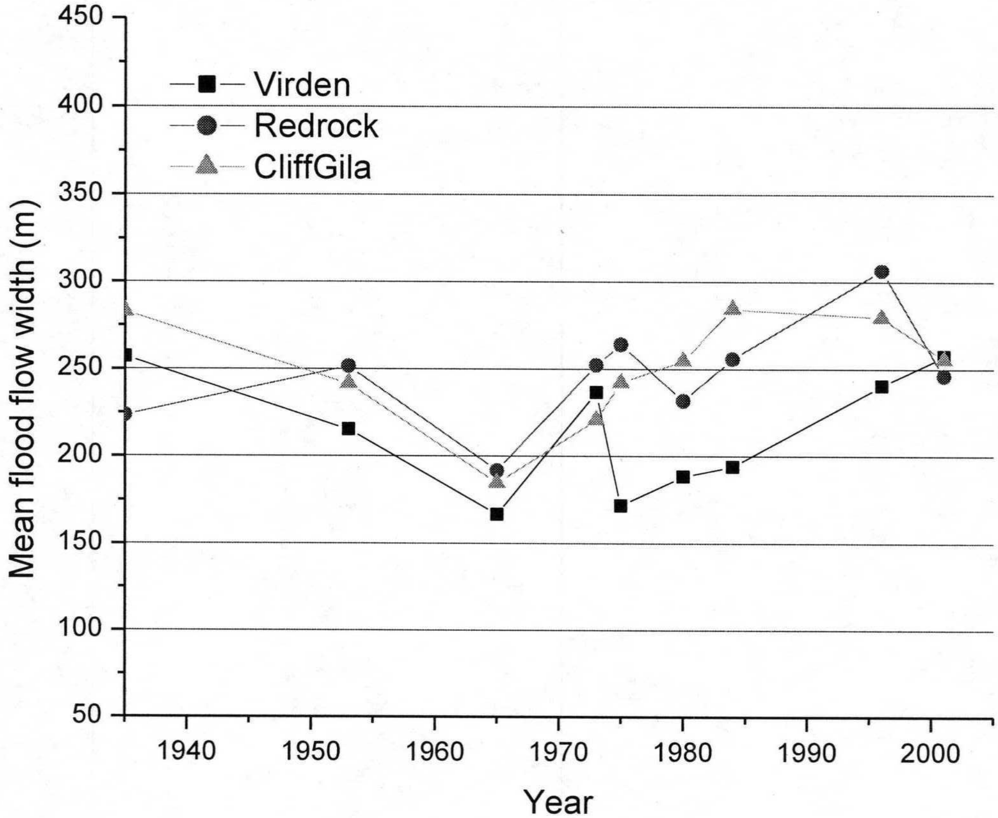


Figure 4. Average flood channel width data separated by valley. *Average flood channel width data are plotted for each alluvial valley by photograph year. Photograph years that were only available for the Cliff-Gila valley were excluded from this analysis. There is a general trend for all valleys that can be observed; however, the Cliff-Gila reach appears to diverge from this trend during the 1970's and 1980's. Redrock valley also appears to have two notable differences in data: a very narrow average channel in 1935 and wide channel in 1996. Note also that channel widths for the Virden reach are comparatively smaller than widths for the Redrock and Cliff-Gila reaches.*

Virden Valley

Reaches of greatest variability in Virden Valley include reaches from Virden, NM to the Arizona-New Mexico border and in the Upper Virden Valley (Figures 5 & 6).

Case Study (1): Virden, NM to Arizona-New Mexico border

From 1935 to 1953, a similar channel pattern existed. By 1965, a levee built on the right bank forced the abandonment of the meander at point A (Figure 7). The 1973 photographs show a similar pattern to that of 1965 with an increase in sinuosity, while 1975 photographs are similar to 1973 with minor additions of berms and levees. By 1980, the channel widened by eroding outside bends. The area outlined in 1975 was now part of the main channel. New levees were built along the entire length of the reach to accommodate the new channel width. Note however that some parts of the new channel have been effectively cut off by the new levees (indicated by arrows). Dramatic shifts in channel position and width can be seen along the reach by 1998. Levees built following the 1978 flood were mostly destroyed by the time this photography was flown. The most dramatic changes occurred upstream of Windham Canyon, downstream of point A on the right bank, and downstream of Moore Canyon. 2001 photography show a channel position similar to that of 1998 with some new vegetation growth in the channel.

Case Study (2): Upper Virden Valley

In 1935, the active channel was positioned close to the right bank, or north side of the larger flood channel (Figure 8). 1965 photographs show a variation in active channel position from 1935 due in part to levees built on the right bank downstream of Johns Canyon, which forced the channel toward the left bank. By 1973, much of the vegetation on channel bars had been eroded and the active channel had migrated to the left bank in the upper reach and to the right bank against the levee downstream of Johns Canyon. The flood channel widened by removing sections of farmland along the right bank. Sedimentation behind the levee is apparent in the white coloration on the photographs as well as head cutting of flood bars at point A near the Hughs Canyon alluvial fan. Between 1973 and 1980, some revegetation of flood bars occurred; this was followed by channel widening in response to the 1978 flood of record. Based on the evidence in the 1980 photographs, the 1978 flood scoured the right bank and eroded the majority of the levee. Directly upstream of the bridge, the flood eroded some of the Hughs Canyon alluvial fan (inset box on Figure 8). New levees on the left bank were constructed presumably in response to the possibility of future erosion. Between 1980 and 1998, lateral erosion of the right bank levee directly upstream of Johns Canyon, the left bank levee and the Hughs Canyon alluvial fan occurred. 2001 photography shows a similar channel position to 1998 with increased sinuosity of the active channel upstream of the Route 92 Bridge.

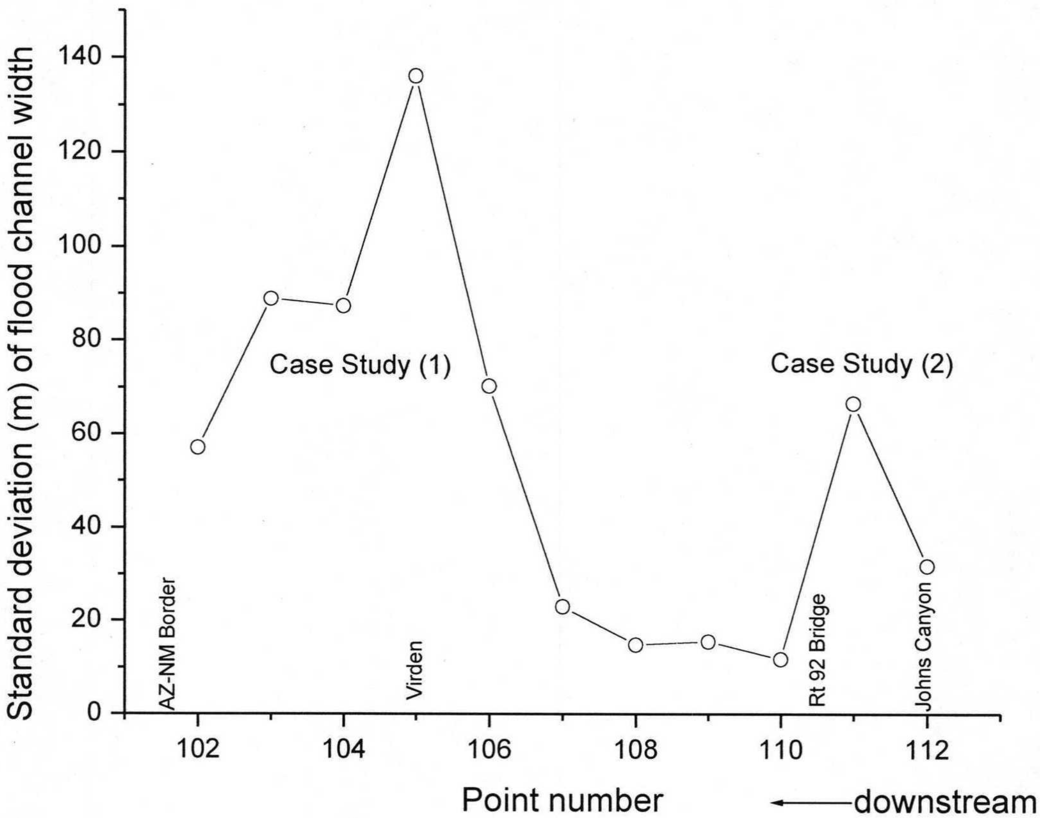


Figure 5. Variability in channel width measurements, Virden Valley.

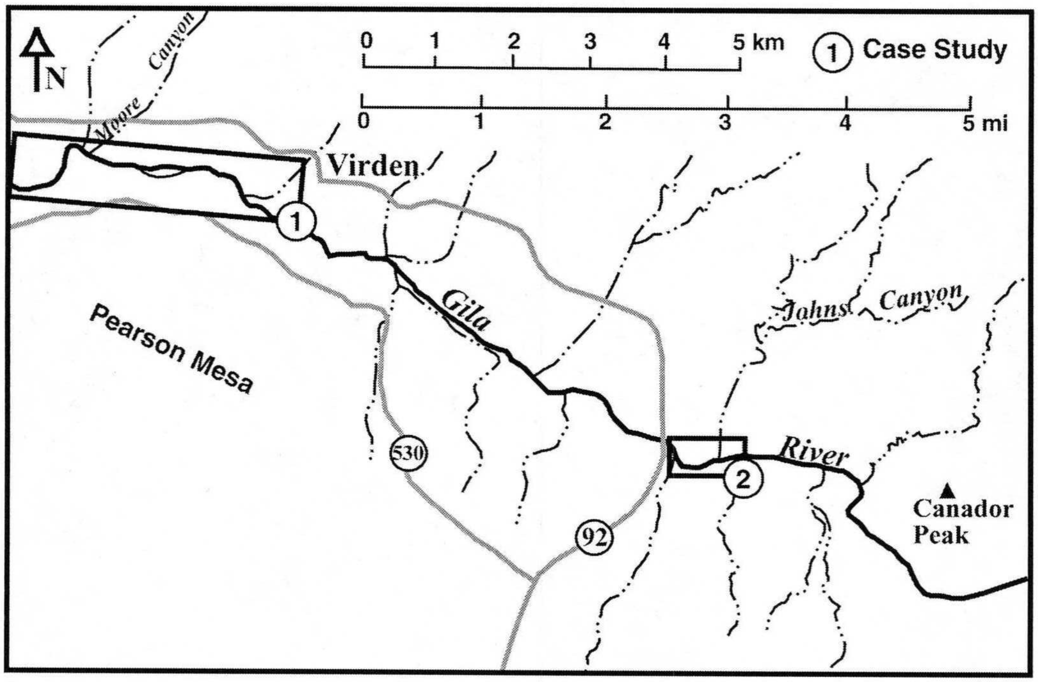
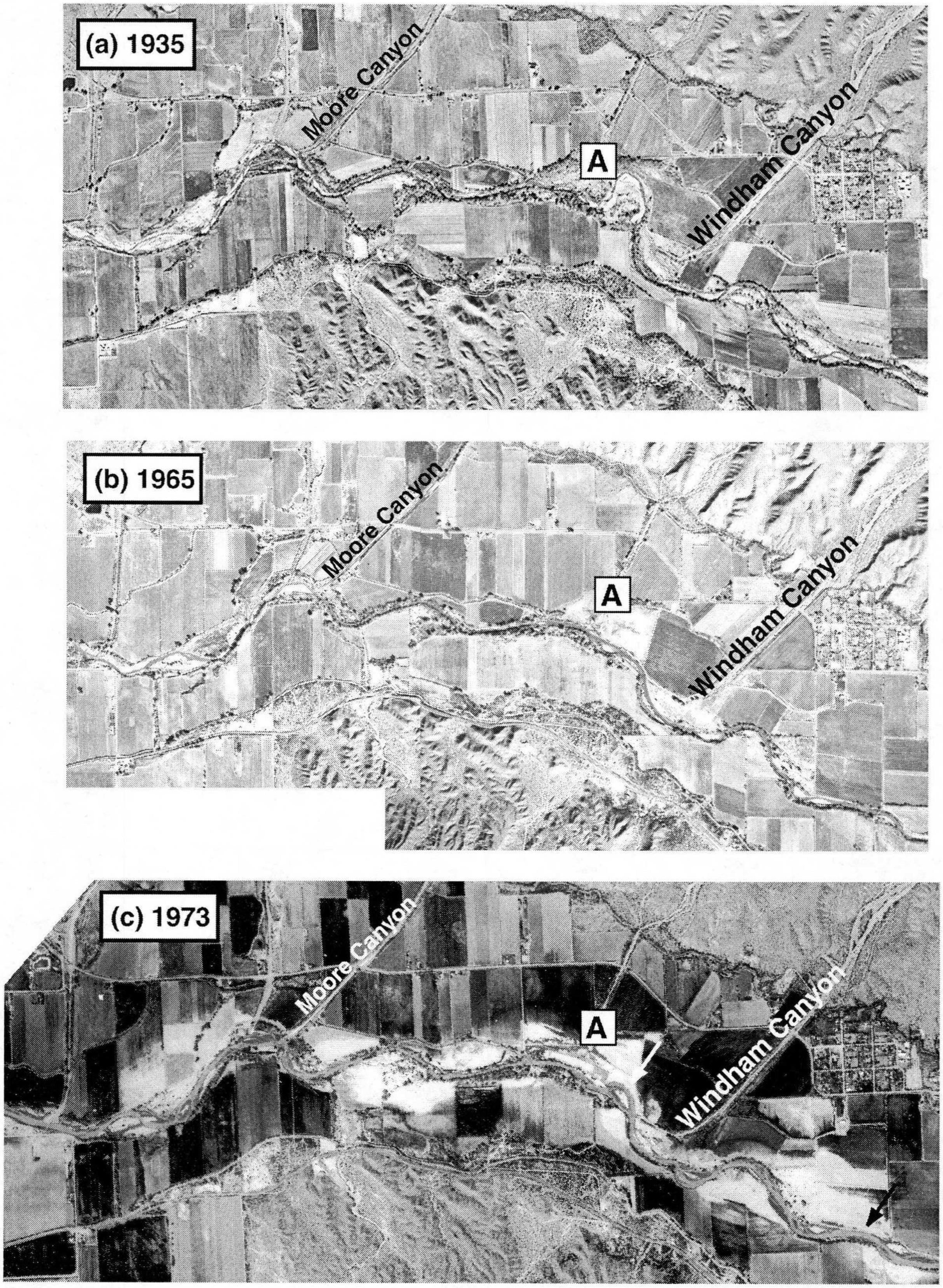
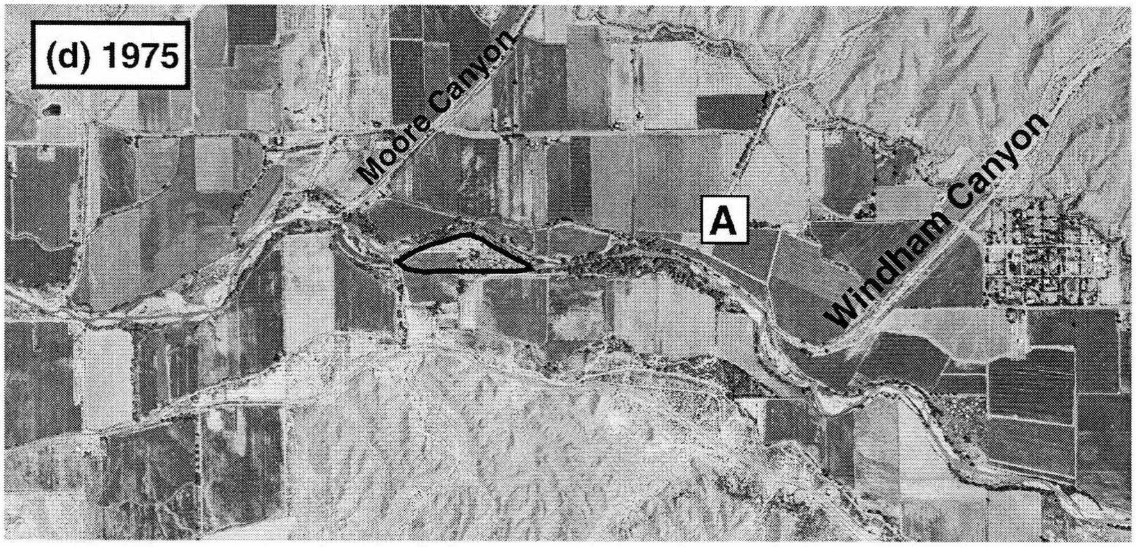
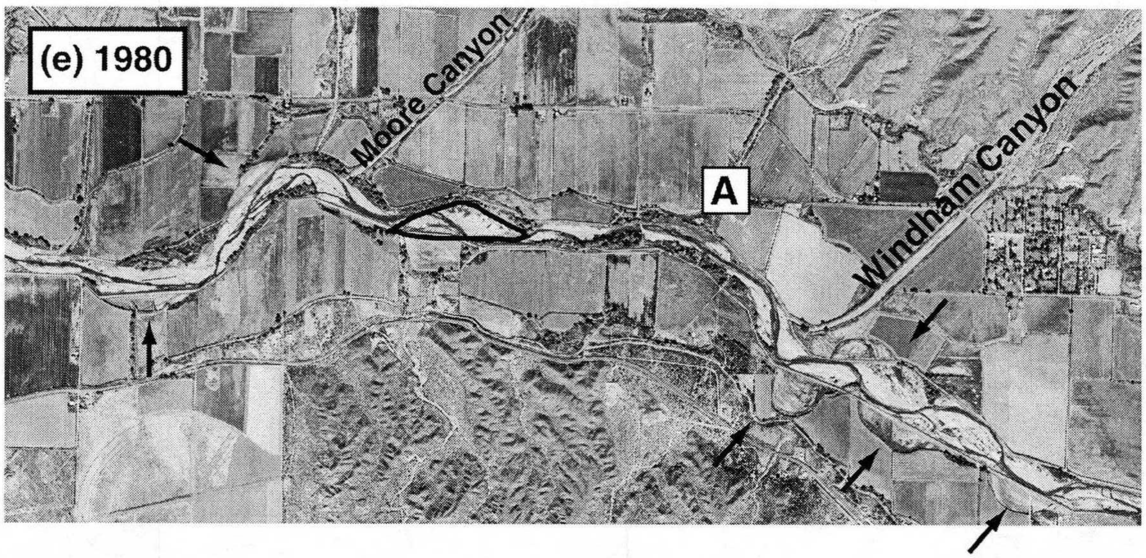


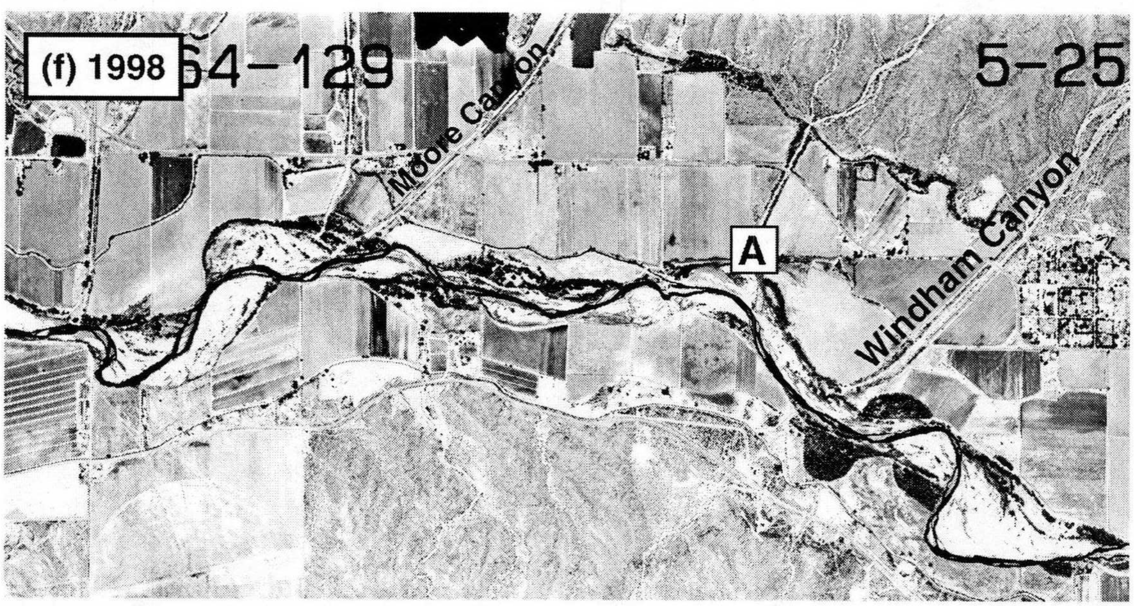
Figure 6. Location of case studies in Virden Valley. *Reaches extend from the Arizona-New Mexico border to Virden, NM (Case Study 1) and from the Route 92 Bridge to upstream of Johns Canyon (Case Study 2). Flow is from right to left.*

Figure 7. Case Study (1): Arizona-New Mexico border to Virden, NM. *(a) 1935. Note channel position at point A; (b) 1965. Abandonment of channel meander at point A with general narrowing throughout reach; (c) 1973. Note overbank sedimentation from 1972 flood and erosion of levees at arrows; (d) 1975. Similar channel position to 1973, note area outlined along the left bank; (e) 1980. Lateral erosion of outside bends. Area outlined in 1975 has now become part of the main channel. Some parts of the new channel have been effectively cut off by the new levees (indicated by arrows); (f) 1998. Dramatic shifts in channel position and width upstream of Windham Canyon, downstream of point A on the right bank, and downstream of Moore Canyon. Flow is from right to left in the aerial photos.*


(a) 1935
Moore Canyon
A
Windham Canyon
(b) 1965
Moore Canyon
A
Windham Canyon
(c) 1973
Moore Canyon
A
Windham Canyon


(d) 1975
Moore Canyon
A
Windham Canyon


(e) 1980
Moore Canyon
A
Windham Canyon


(f) 1998
64-129
5-25
Moore Canyon
A
Windham Canyon

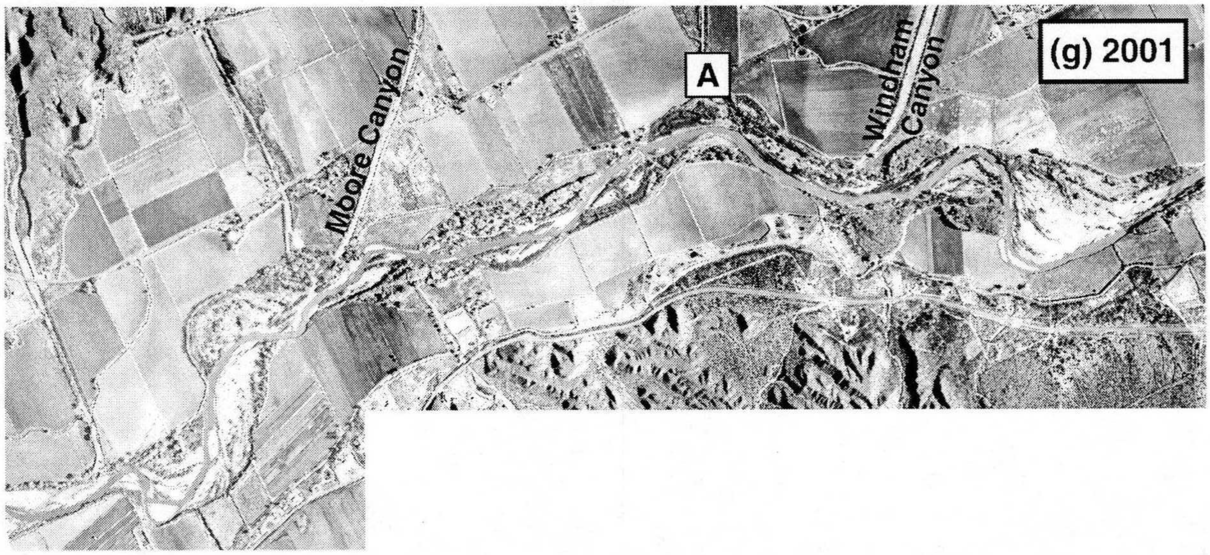
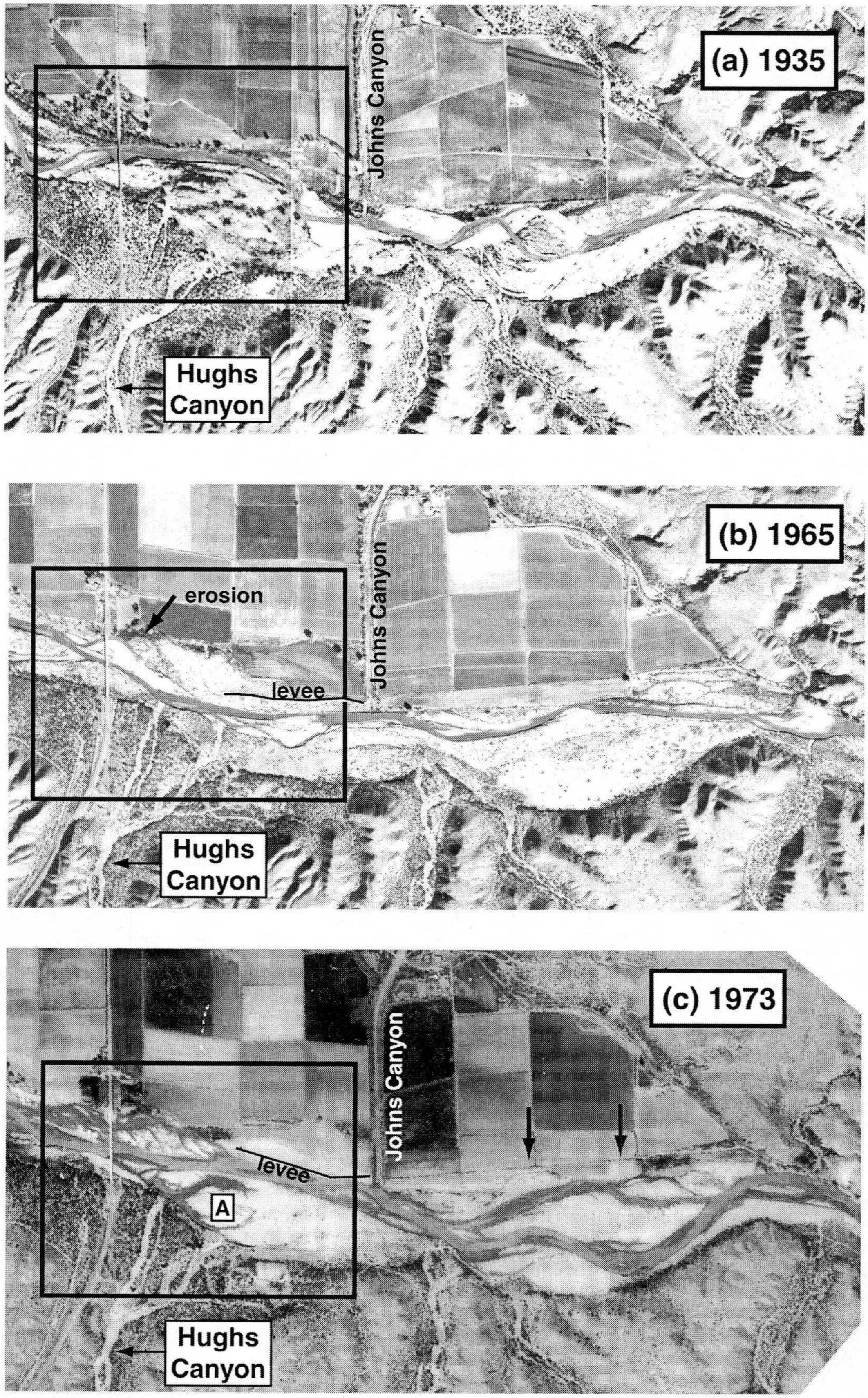
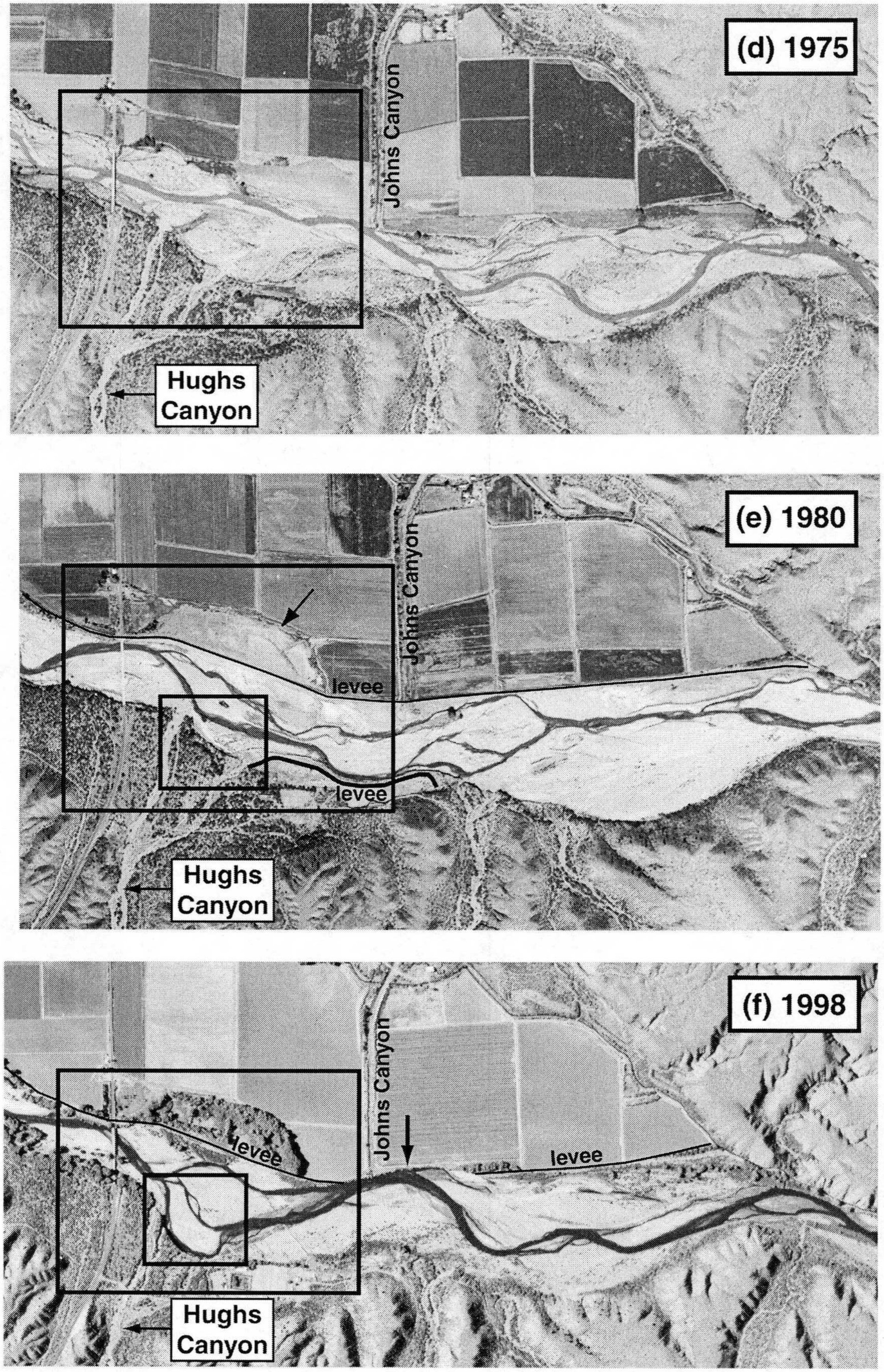
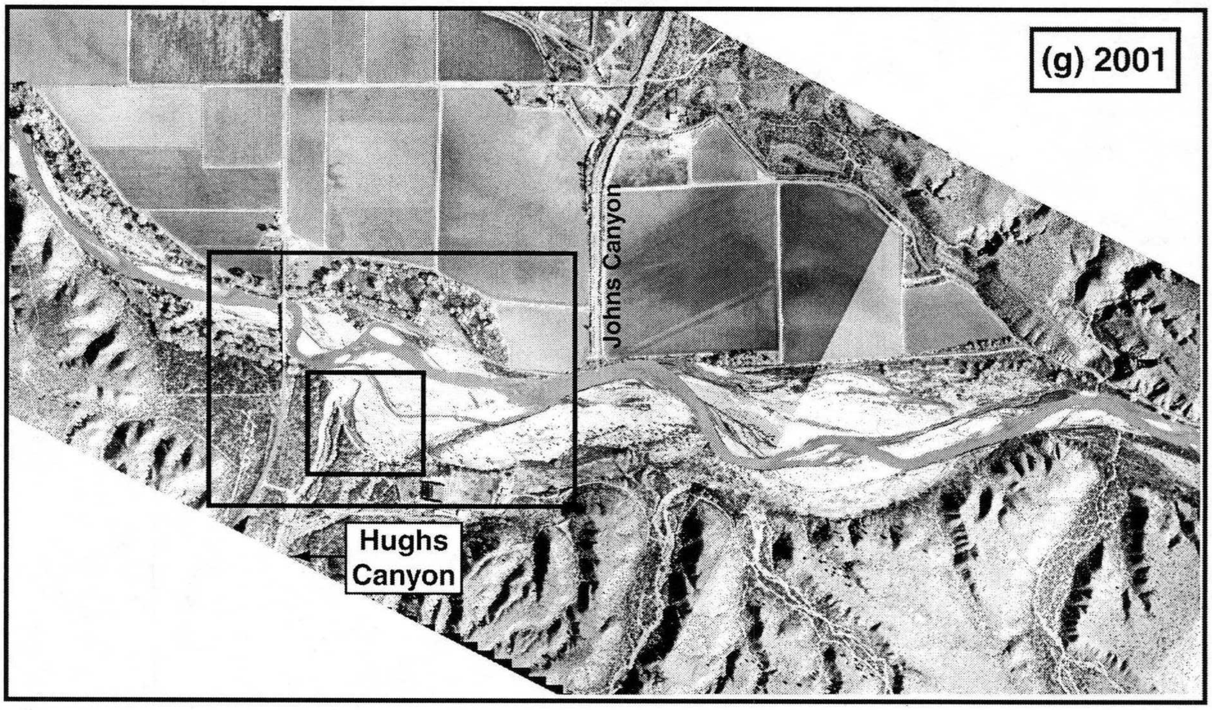

(g) 2001
A
Moore Canyon
Windham
Canyon

Figure 8. Case Study (2): Upper Virden Valley. *(a) 1935. Relatively wide channel with active channel located on the right bank. The boxed region indicated the area of greatest change; (b) 1965. Levees built along right bank upstream of route 92 bridge to mitigate flood damage that occurred between 1935 and 1965 (indicated by arrow); (c) 1973. Inundation behind levee, head cutting of new channels along left bank (point A), scouring of the entire channel width, and lateral erosion along the right bank into previous farmland (indicated by arrows); (d) 1975. Similar channel position to 1973; (e) 1980. Channel widening and erosion of Hughs Canyon alluvial fan (inset box) and the right bank opposite Hughs Canyon. Levees were repaired or newly built along the entire right bank and along the left bank; (f) 1998. Lateral erosion of levees (arrow) and Hughs Canyon alluvial fan (inset box). Eroded farmland from the 1980 photography has been effectively revegetated and stabilized at the expense of the opposing bank; (g) 2001. Increased sinuosity of active channel upstream of Route 92 Bridge. Flow is from right to left in the aerial photos.*


(a) 1935
Johns Canyon
Hughs Canyon
(b) 1965
erosion
levee
Johns Canyon
Hughs Canyon
(c) 1973
Johns Canyon
levee
A
Hughs Canyon


(d) 1975
Johns Canyon
Hughs Canyon
(e) 1980
Johns Canyon
levee
levee
Hughs Canyon
(f) 1998
Johns Canyon
levee
levee
Hughs Canyon


(g) 2001
Johns Canyon
Hughs
Canyon

Redrock Valley

Reaches of greatest variability extend from the head of the lower box to Road Canyon (Case Study 3) and upstream of Ash Creek (Case Study 4) (Figures 9 &10).

Case Study (3): Lower Box to Road Canyon
From 1935 to 1953, the channel was relatively wide; by 1965, the channel had been narrowed with new levees and agricultural encroachment in areas that were previously part of the channel (Figure 11). The most dramatic changes in this reach occurred following 1965, which consisted of increased channel widths and shifts in channel position. Major channel shifts took place following episodes of increasing sinuosity in the active channel. Subsequent large floods widened and straightened the channel pattern, creating abandoned sinuous channels. Major changes that can be observed in the historical aerial photography occurred between 1965 and 1973, 1975 and 1980, and 1984 and 1996. In general, weakly formed secondary or pilot channels became the main channel through the process of overbank splays at the upstream end or head cutting on the downstream end of the geomorphic surface. For example, by 1973 continued lateral erosion and increased channel sinuosity were associated with the abandonment of the channel bend at point A and extensive overbank sedimentation and head cutting at the downstream end of this surface at point B. By 1975, the abandoned channel at point A had revegetated while a weak channel had developed between high flow channel bars and the floodplain at point B. Channel splays breached the levee at point C. The levee at point C was obliterated by flood flow between 1975 and 1980, which modified the floodplain. Additional lateral erosion indicated by arrows is evident in the 1980 photographs, increasing the sinuosity of the channel in the middle of the reach. At point B, a new channel formed. By 1984, a pilot channel had formed across the floodplain at point C and by 1996 a new channel arrangement abandoned the previous main channel at point C, greatly decreasing sinuosity. The majority of channel changes are within the area that has historically (post-1935) been modified by floods on the Gila River. The major exception applies to changes that have occurred in recent decades and observed in the 1984 and 1996 aerial photographs.

Case Study (4): Upstream of Ash Creek
Case Study (4) is located between House Canyon and the mouth of Middle Box. Channel width from 1935 to 1953 was relatively large; from 1953 to 1965, the channel narrowed, at least in part due to an extensive levee constructed on the right bank (Figure 12). This levee was breached prior to 1965, possibly during the 1959 flood. The entire flood channel width as well as the area behind the levee had been recently inundated prior to the 1973 photography, presumably by the 1972 flood. Between 1975 and 1980 photography, floods had modified the majority of the point bar surface. New levees were built to replace the previous structures. The levee was a discontinuous feature by 1996 and must have been eroded following the floods of 1984 and the early to mid-1990's. The position of the active channel varies considerably in this reach; although the diversion at the mouth of the Middle Box may be a minor control on the position of the low flow channel as it enters Redrock Valley, it seems likely that in this reach the channel position is mainly controlled by the orientation of the channel at the mouth of the Middle Box and the bars that are deposited along the right side of the valley during high flows.

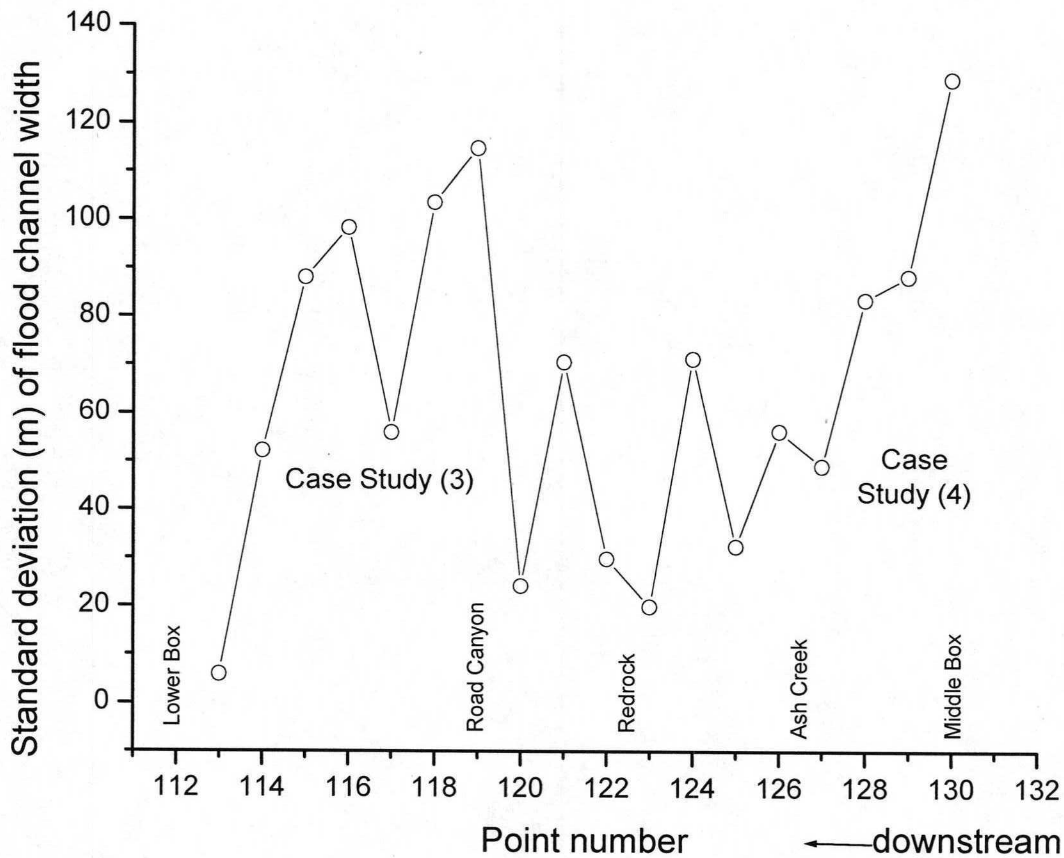


Figure 9. Variability in channel width measurements, Redrock Valley.

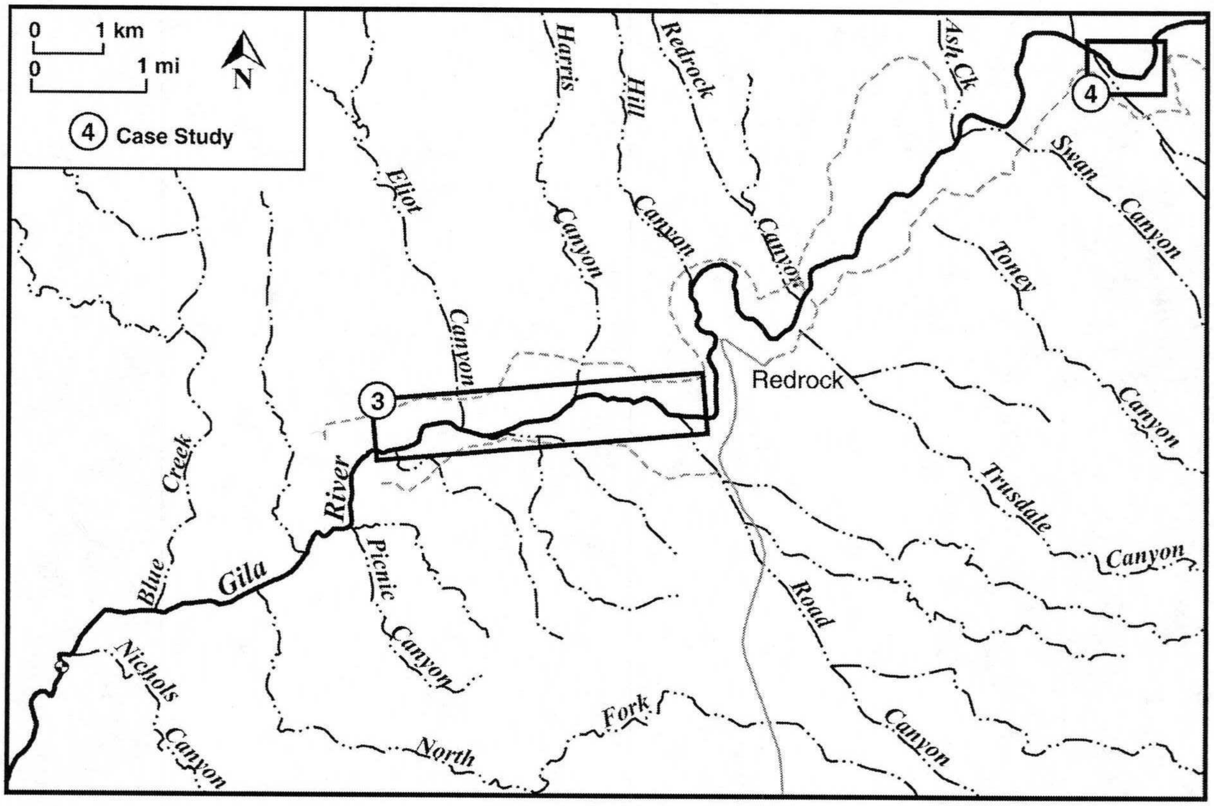
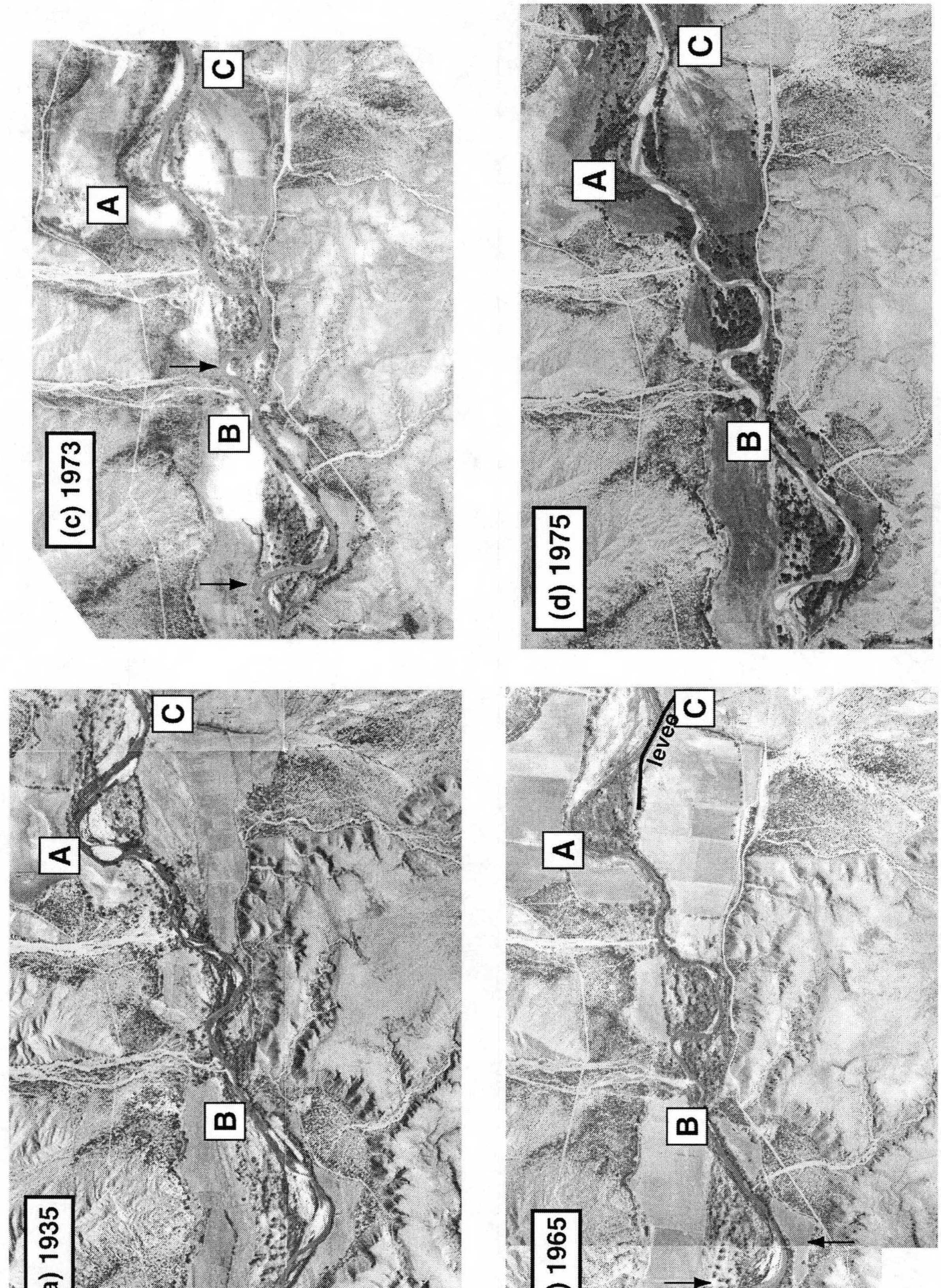


Figure 10. Location of case studies in Redrock Valley. *Reaches extend from the Lower Box to Road Canyon (Case Study 3) and from House Canyon to the mouth of the Middle Box (Case Study 4). Flow is from right to left.*

Figure 11. Case Study (3): Lower Box to Road Canyon. *(a) 1935. Relatively wide channel and sinuous pattern. Note points A, B, and C; (b) 1965. Lateral erosion at arrows and increased sinuosity. Note levee constructed at point C; (c) 1973. Continued lateral erosion indicated by arrows, increasing channel sinuosity. Note the abandonment of the channel bend at point A and extensive overbank sedimentation and head cutting at point B; (d) 1975. Abandoned channel has revegetated at point A. Weak channel formed at point B. Channel splays breached the levee at point C; (e) 1980. General channel widening. Levee at point C obliterated by flood flow. Increased sinuosity of the channel in the middle of the reach. New channel formed at point B; (f) 1984. Formation of pilot channel across floodplain at point C. Erosion and lateral migration of channel indicated by arrows; (g) 1996. Channel widening along entire reach; abandonment of previous main channel at point C and at arrow; (h) 2001. Similar channel position to 1998 with increased sinuosity and lateral erosion (indicated by arrow). Flow is from right to left in the aerial photos.*


(a) 1935
A
B
C
(b) 1965
levee
A
B
C
(c) 1973
A
B
C
(d) 1975
A
B
C

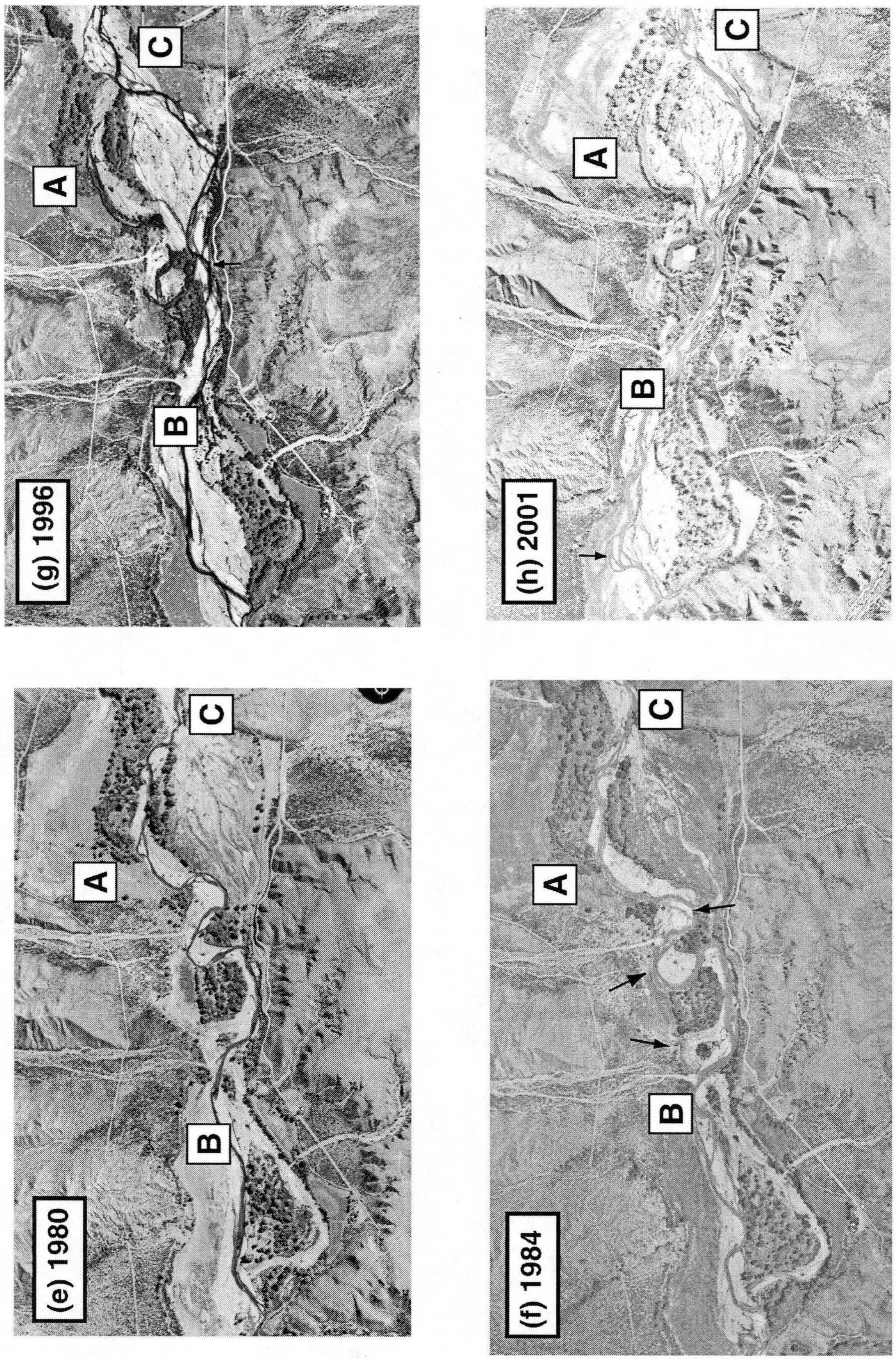
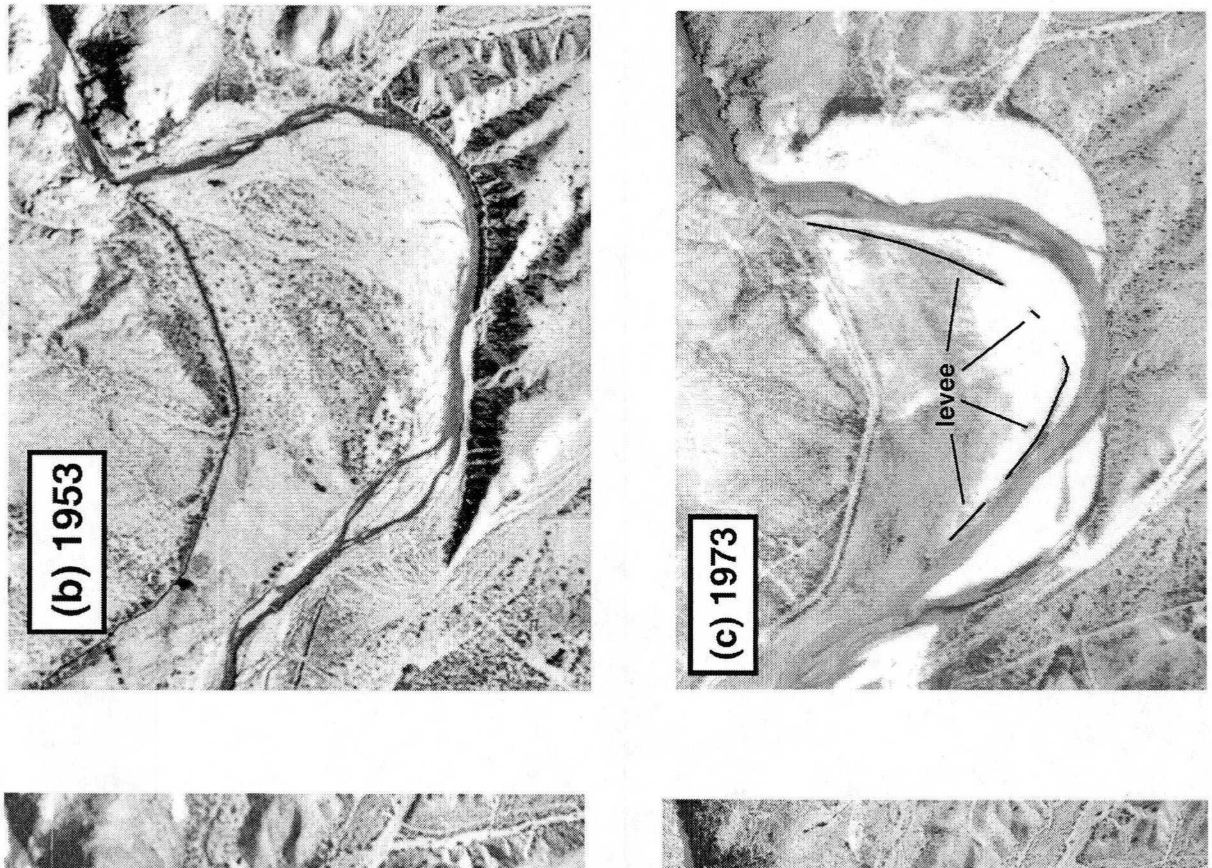
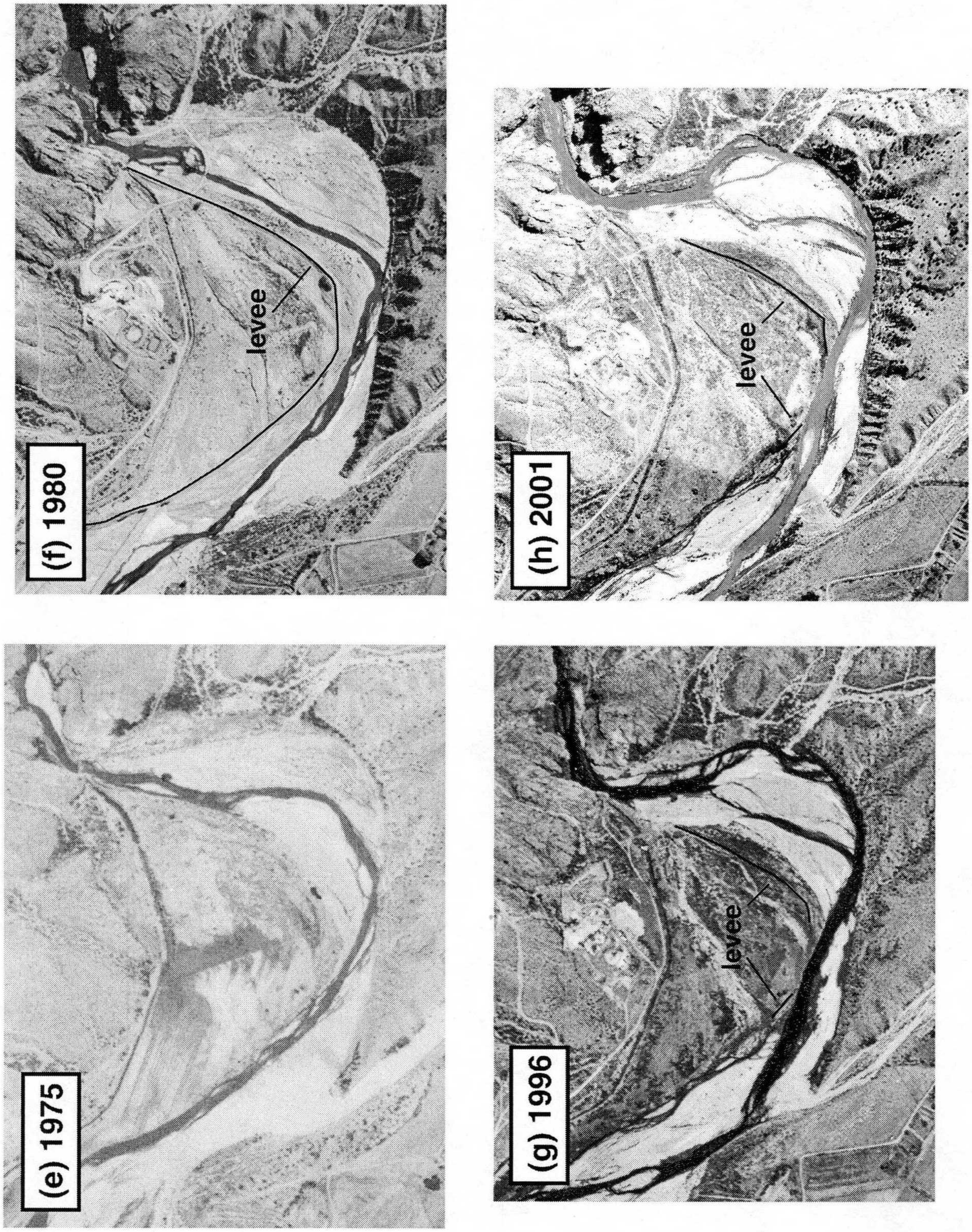

(e) 1980
A
B
C
(f) 1984
A
B
C
(g) 1996
A
B
C
(h) 2001
A
B
C

Figure 12. Case Study (4): Upstream of Ash Creek. *(a) 1935. Relatively wide flood channel; active channel is positioned along right bank; (b) 1953. Active channel migration to left bank; multiple threads evident in point bar; (c) 1965. Channel narrowing due in part to levee construction along the right bank. The levee was breached by a flow between 1953 and 1965; (d) 1973. Channel widened; extensive sedimentation behind levee. Similar channel position to 1935; (e) 1975. Similar channel position and width to 1973; (f) 1980. Right bank point bar was modified by flood flows. Levees were repaired and reduced the flood channel width; (g) 1996. Damage to levee on right bank. Channel position is similar to 1953; (h) 2001. Similar channel position to 1996. Flow is from right to left in the aerial photos.*



(a) 1935
(b) 1953
(c) 1965
levee
(c) 1973
levee


(e) 1975
(f) 1980
levee
(g) 1996
levee
(h) 2001
levee

Cliff-Gila Valley

Reaches of high variability occur near Gila Bird Area, Bill Evans Lake, Riverside, Route 211 Bridge and Seeds of Change (Figures 13 & 14).

Case Study (5): Gila Bird Area

This reach is located in the southernmost portion of the Cliff-Gila valley (Figure 14). In 1935, the channel was variable in width and appears to have been leveed along the left bank (Figure 15). Between 1935 and 1956, the channel widened at the upstream end and narrowed at the downstream end of the reach. By 1965, the channel had narrowed along the entire length of the reach. Major channel widening is evident in the 1973, 1980 and 1995 photographs, all of which follow large floods occurring in 1972, 1978, and 1984, respectively. Lateral erosion between 1984 and 1995 was the most dramatic, creating a channel that was approximately 100 m wider than the 1935 channel. The most dramatic changes occurred at point A, where lateral erosion on the right bank increased the channel width nearly equal the valley width by 1980, and in the downstream portion of the reach (indicated by a black frame), where lateral erosion on the left bank increased channel width. By 1996, continued lateral erosion downstream from point A and in the box such increased the channel width to encompass the majority of the former floodplain. Although the new parts of the channel had formed on surfaces that had weak bar and swale morphology in previous photography, these surfaces had not historically been a part of the main channel. 2001 aerial photographs show a narrowed channel on the left bank due to berms built by the U.S. Forest Service.

Case Study (6): Bill Evans Lake

Changes in channel width near Bill Evans Lake mostly occurred from 1965 to 1973 and from 1984 to 1995 in response to large floods in the Cliff-Gila Valley (Figure 16). From 1935 to 1965, the channel narrowed and was straightened by levees in the 1950's and 60's, forcing the abandonment of channel bends. At least one tributary in the reach was also straightened during this time period (point A on Figure 16). By 1973, the channel had widened and multiple banks and levees had been eroded. By 1975, a new diversion and canal had been constructed on the left bank. By 1980, the channel was significantly wider than 1975 and remained similar in position and width until 1984. The active flow channel also increased in sinuosity. From 1984 to 1995, lateral erosion upstream of Mangas Creek fan and Davis Canyon fan increased the width of the flood channel. The line of vegetation marking the former bank can still be seen upstream of Mangas Creek fan (shown by arrow). Lateral erosion in other locations also increased channel width from 1984 to 1996.

Case Study (7): Riverside

The Riverside reach is located between the old Route 180 Bridge and Greenwood Canyon. From 1935 to 1956, channel position in the Riverside reach remained very similar (Figure 17). By 1965, the channel had narrowed considerably. Some channel bends were cutoff by levees (indicated by arrows) and developed into farmland. Between 1965 and 1975, the active channel widened slightly. More extensive widening occurred by 1980. Most of the channel changes in the 1980 aerial photography were generally within the historical flood channel width of 1935. The exceptions to this occurred on the left bank near Riverside, and the right bank at point A. The bend in the latter example was cutoff by a levee following the 1978 flood. By 1996, the channel had widened further and the majority of levees present in the 1980 aerial photography had been destroyed. Areas where the channel position was new in the historical period include the reach between Riverside and point A and the left bank downstream of Pope Canyon. The channel in 2001 was very similar to that of 1996.

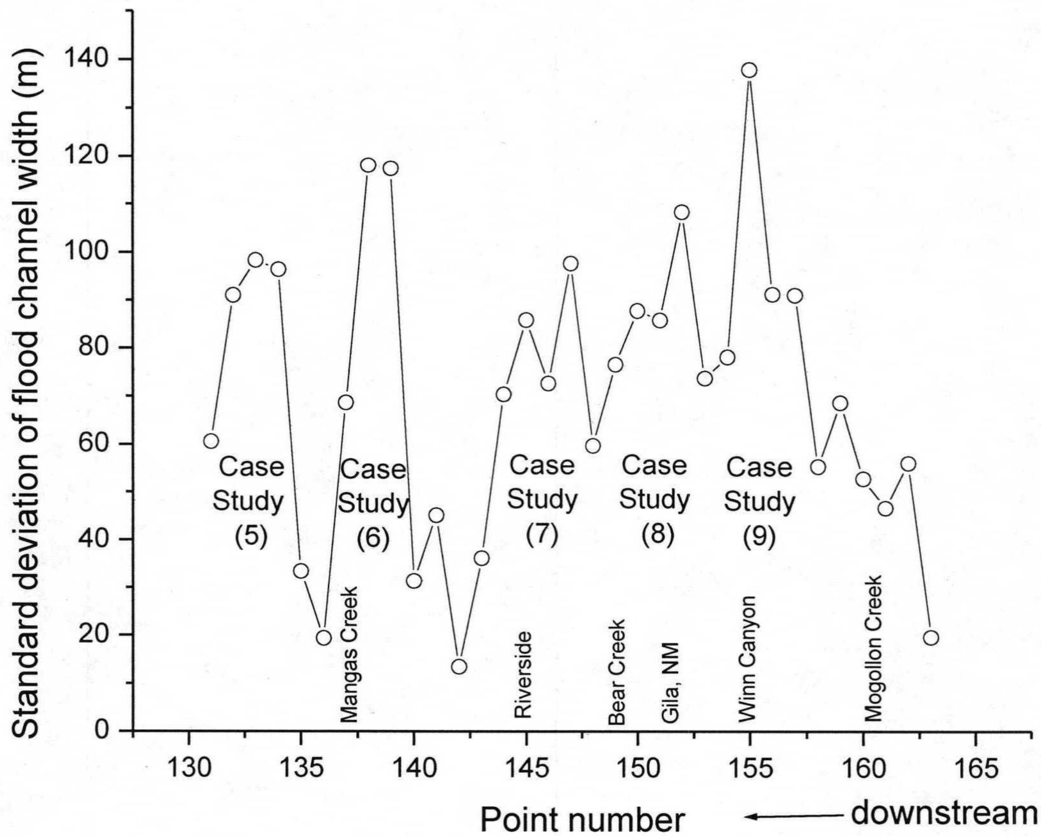


Figure 13. Variability in channel width measurements, Cliff-Gila Valley.

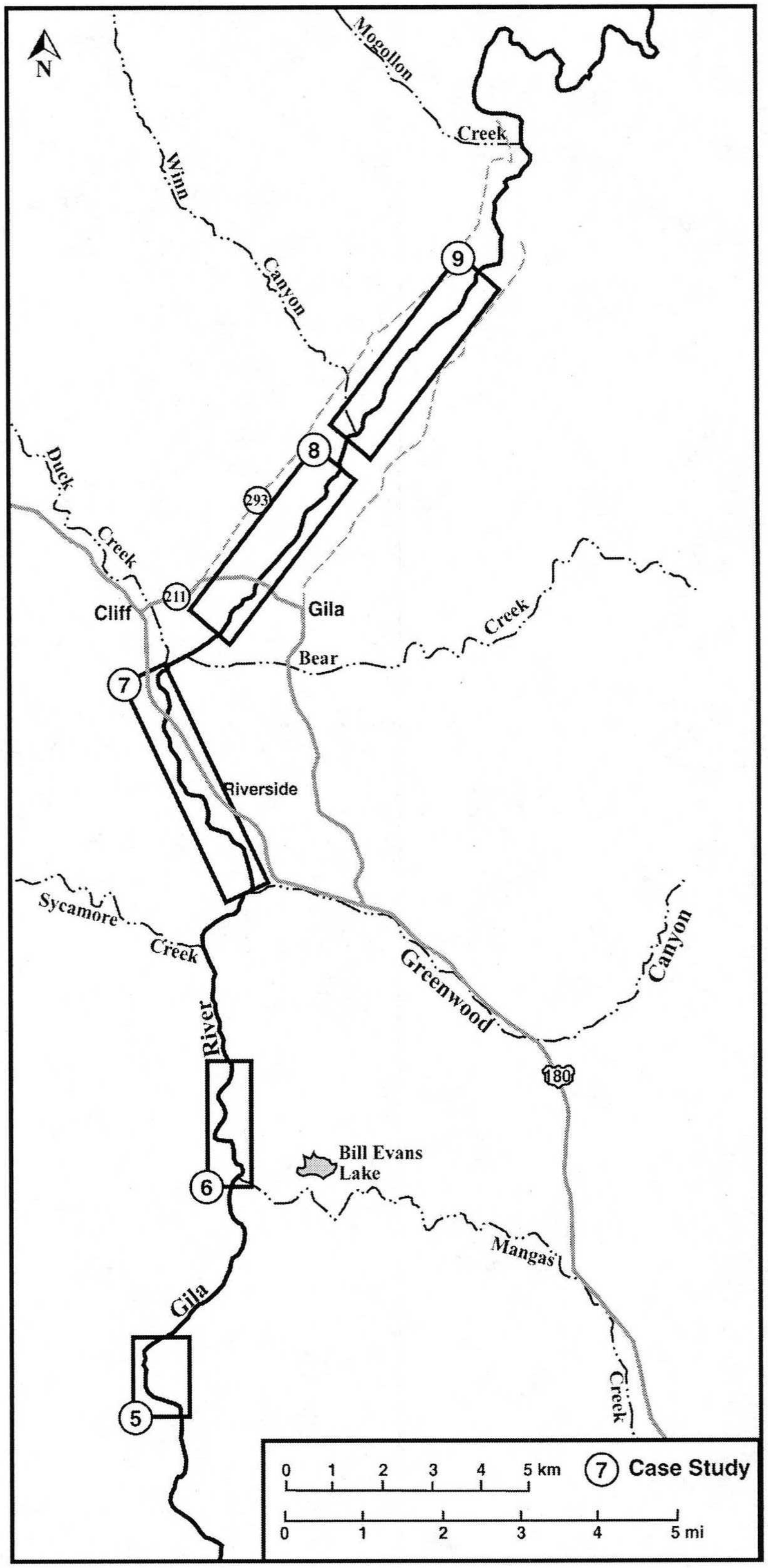
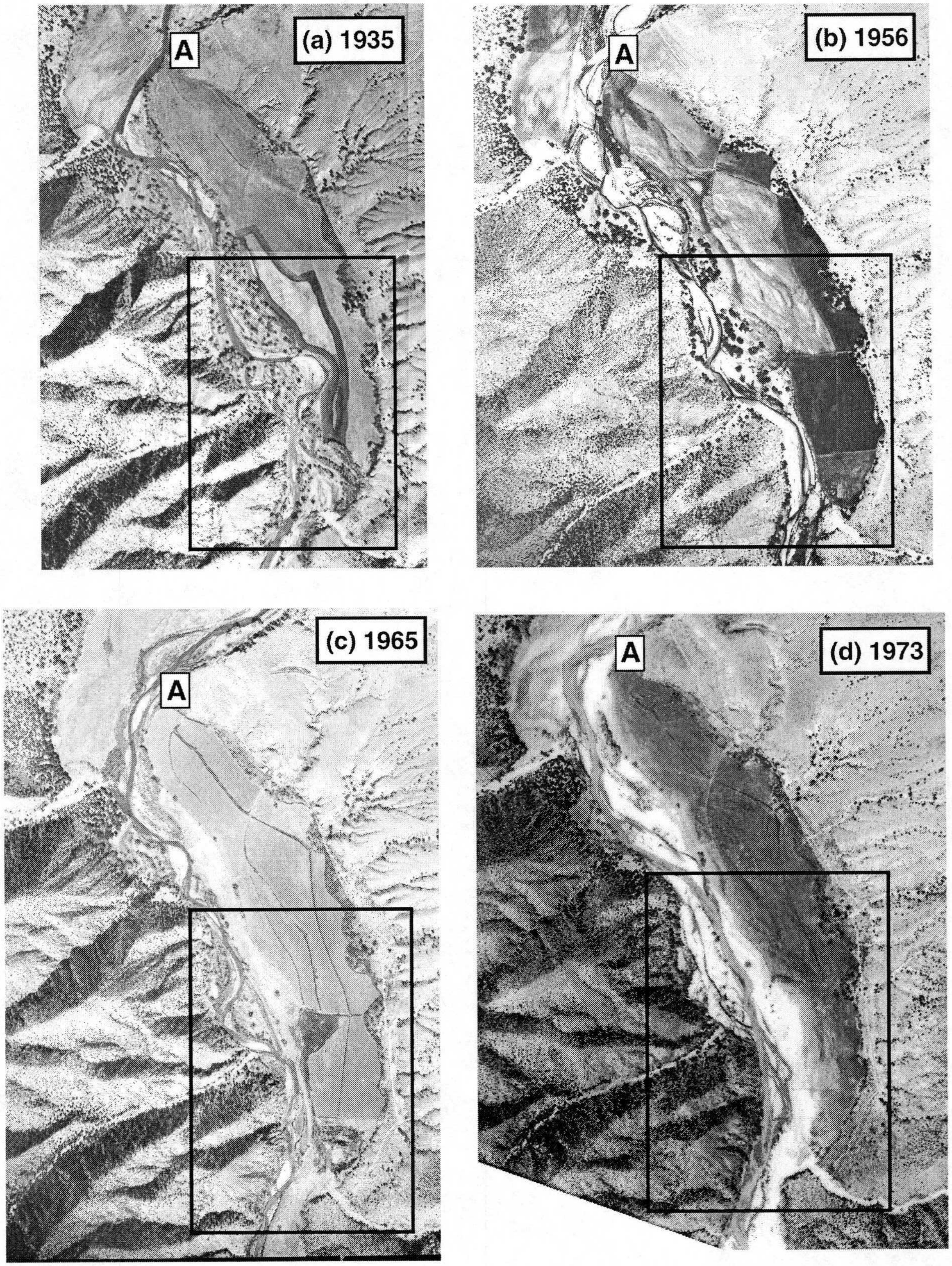
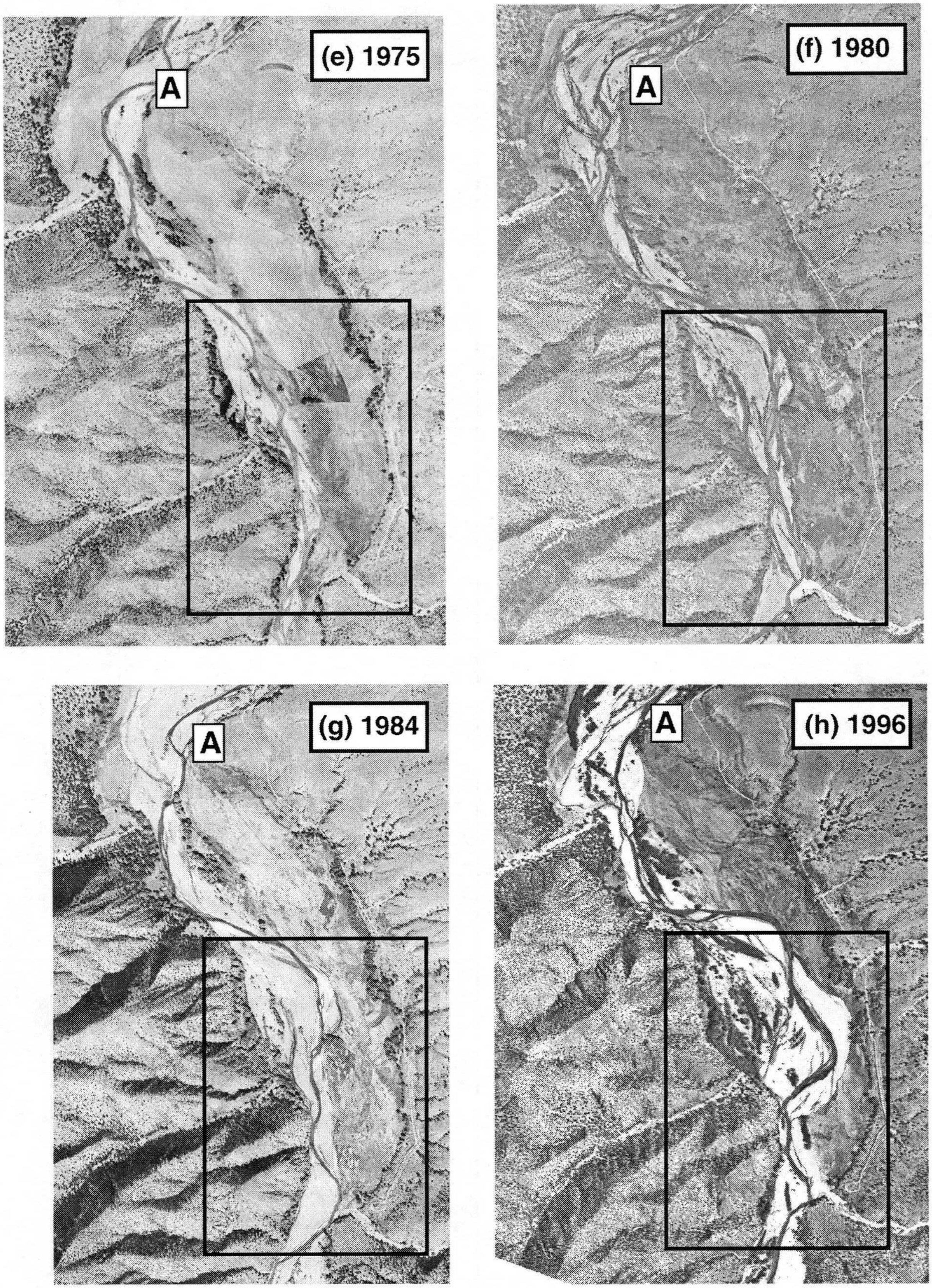


Figure 14. Location of case studies in Cliff-Gila Valley. *The following reaches in the Cliff-Gila valley were identified for case studies: Gila Bird Area (Case Study 5), Bill Evans Lake (Case Study 6), Riverside (Case Study 7), Route 211 Bridge (Case Study 8), and Seeds of Change (Case Study 9).*

Figure 15. Case Study (5): Gila Bird Area. *(a) 1935. Note point A and the black frame; (b) 1956. Channel widening at Point A and narrowing in the frame; (c) 1965. Main channel narrowed along entire length; (d) 1973. Over the entire reach, the channel widened and decreased in sinuosity; (e) 1975. Similar channel position to 1973; (f) 1980. Channel widened along entire length. At point A, lateral erosion on the right bank increased the channel width to nearly equal the valley width. Lateral erosion on the left bank increased channel width (black frame); (g) 1984. Similar channel position to 1980; (h) 1996. Continued lateral erosion downstream from point A and in the black frame; (i) 2001. Minor channel narrowing. Flow is from top to bottom in the aerial photos.*


A
(a) 1935
A
(b) 1956
(c) 1965
A
A
(d) 1973


(e) 1975
A
(f) 1980
A
(g) 1984
A
(h) 1996
A

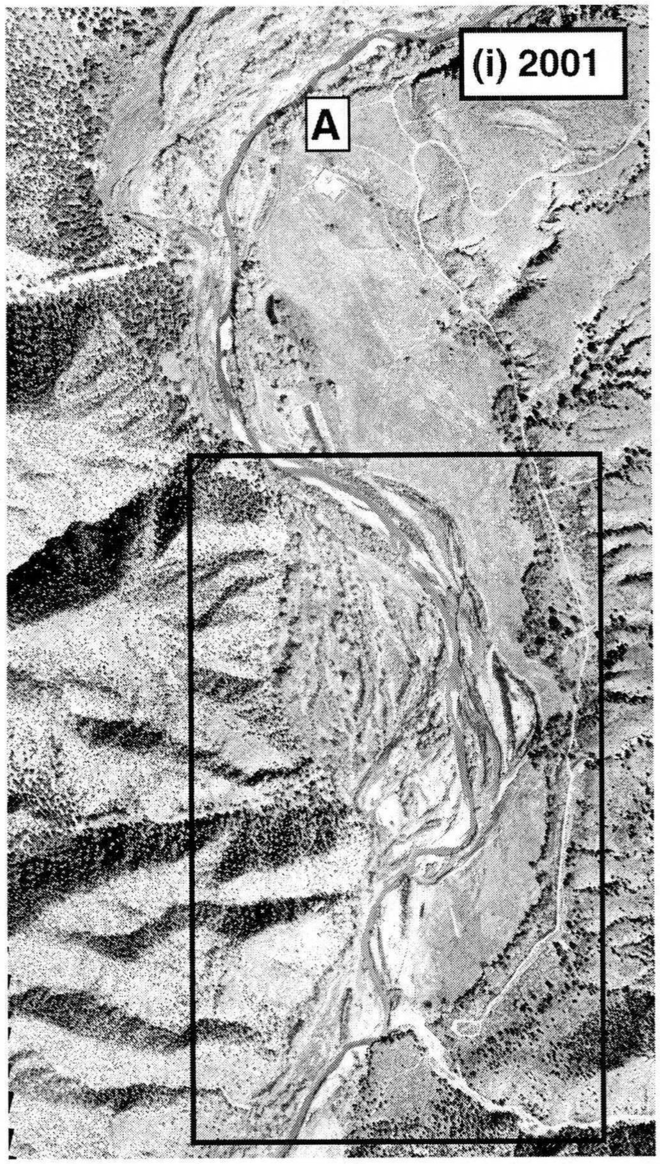
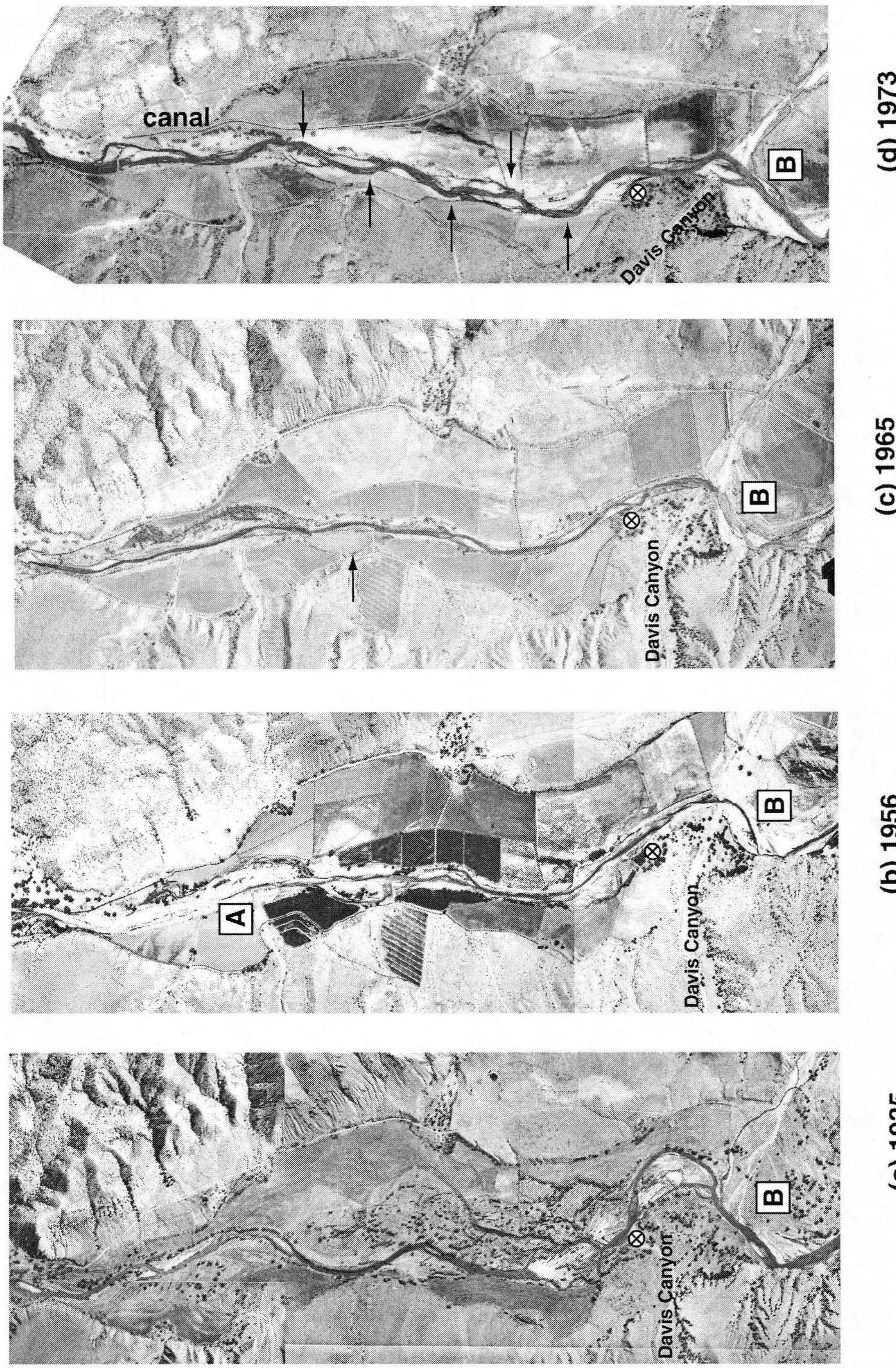
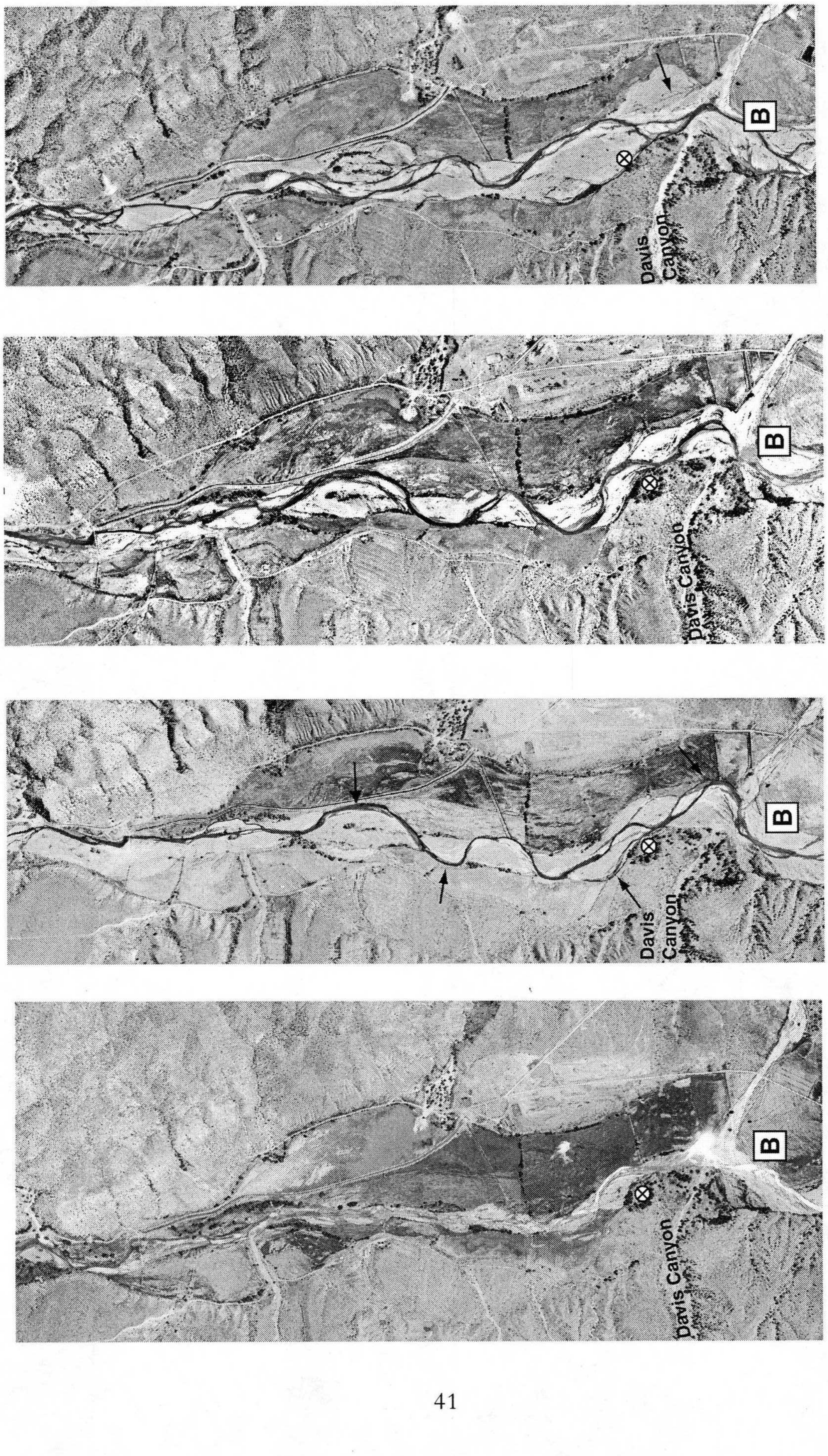

(i) 2001
A

Figure 16. Case Study (6): Bill Evans Lake. *(a) 1935. Wide channel with multiple sinuous threads; (b) 1956. Channel and tributary (point A) were straightened and leveed; (c) 1965. Channel narrowed further; note the abandoned meander on the right bank (indicated by the arrow); (d) 1973. A new canal was built; overbank sedimentation and erosion of the levees occurred at multiple locations (shown by arrows); (e) 1975. Similar configuration to 1973 with minor erosion on the left bank upstream from Mangas Creek fan (point B); (f) 1980. Flood channel widened significantly from 1975 as indicated by arrows; the active channel increased in sinuosity; (g) 1984. Similar channel position and width to 1980; increase in active channel sinuosity; (h) 1996. Lateral erosion upstream of Mangas Creek fan and Davis Canyon fan (indicated by X in circle) increased the width of the flood channel. Arrow indicates former bank; (i) 2001. Similar channel position to 1996 with minor lateral erosion (indicated by arrow). Flow is from top to bottom in the aerial photos.*


(a) 1935
Davis Canyon
B
(b) 1956
A
Davis Canyon
B
(c) 1965
Davis Canyon
B
(d) 1973
canal
Davis Canyon
B

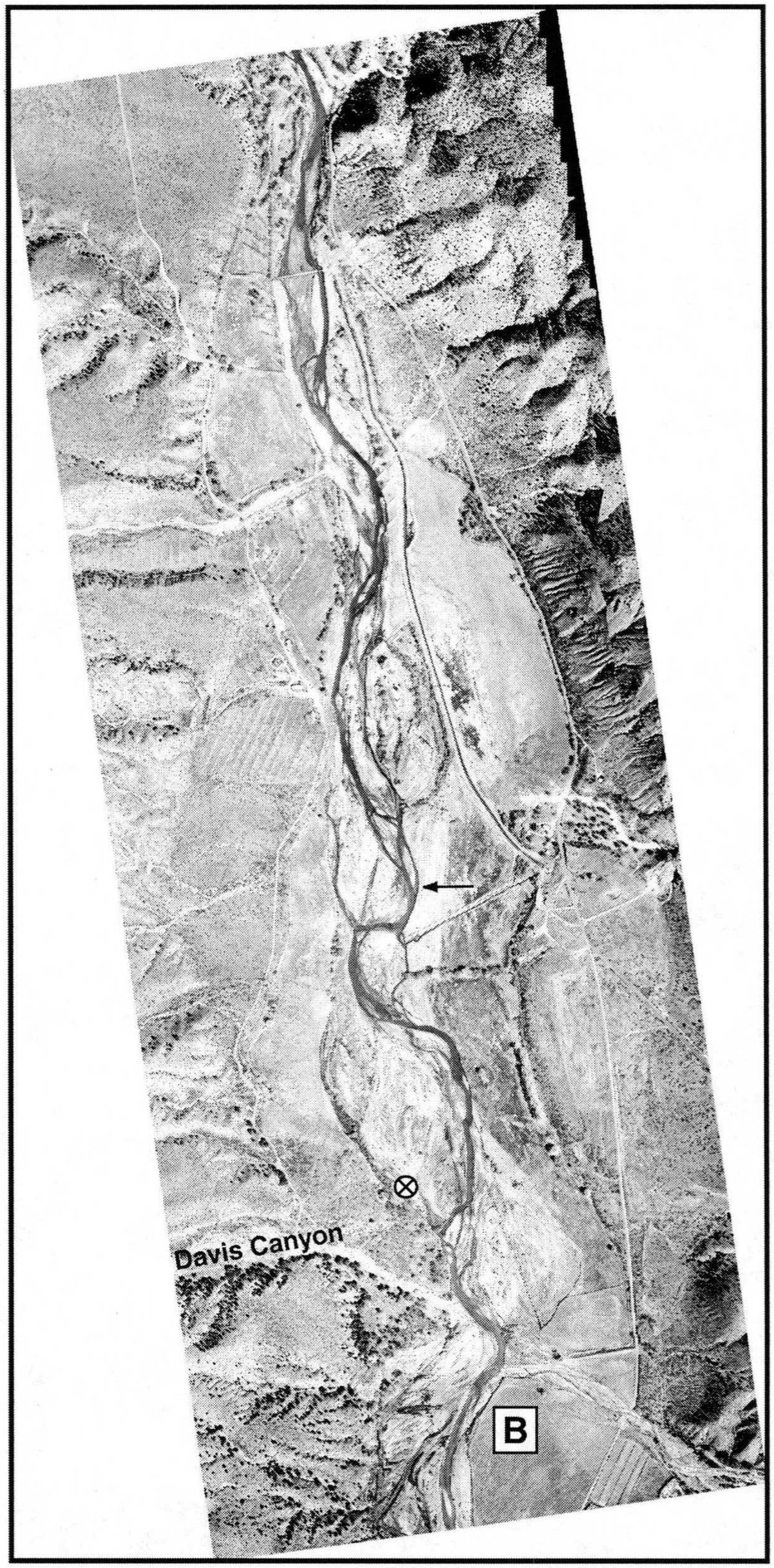


(e) 1975

(f) 1980

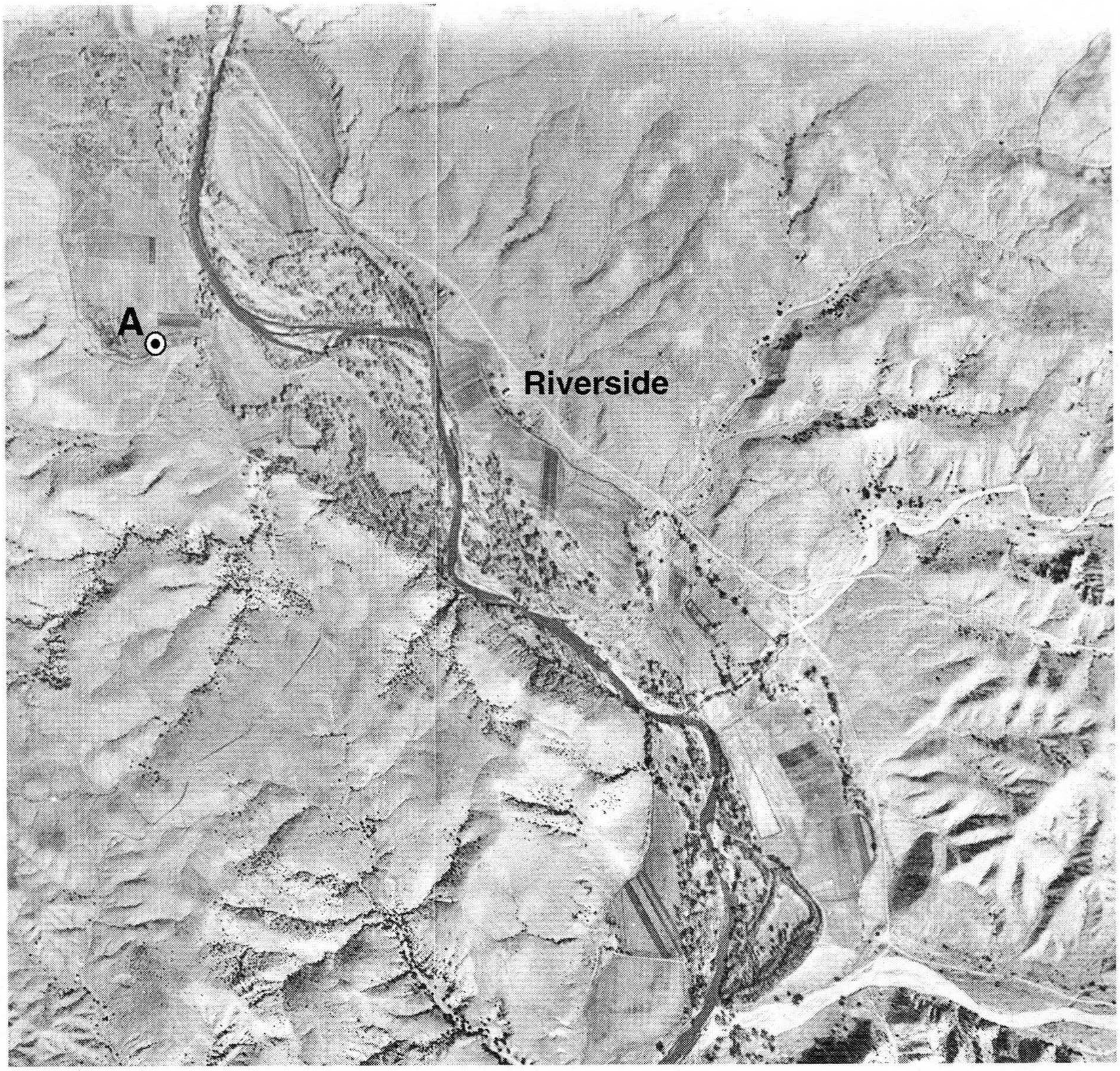
(g) 1984

(h) 1996

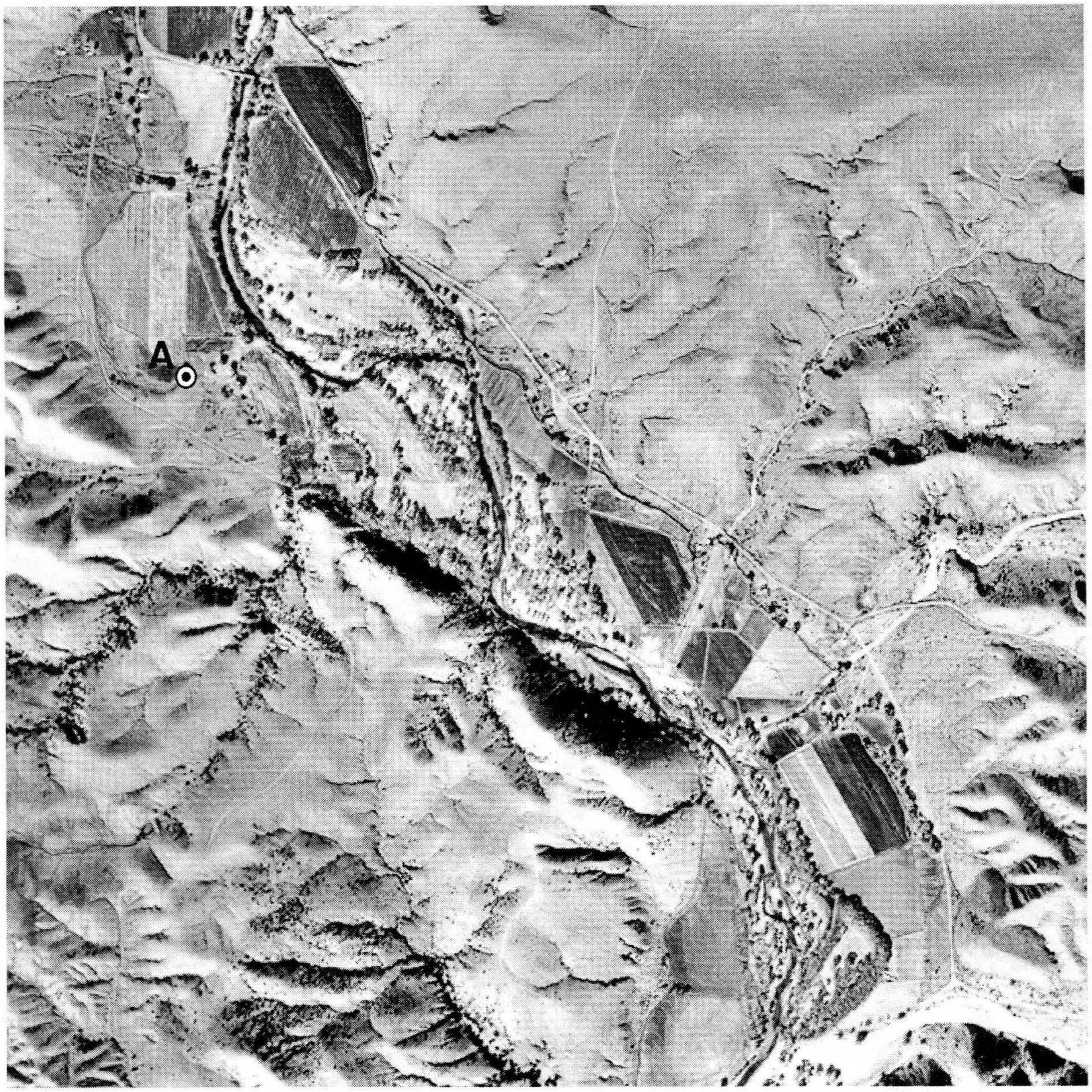


(i) 2001

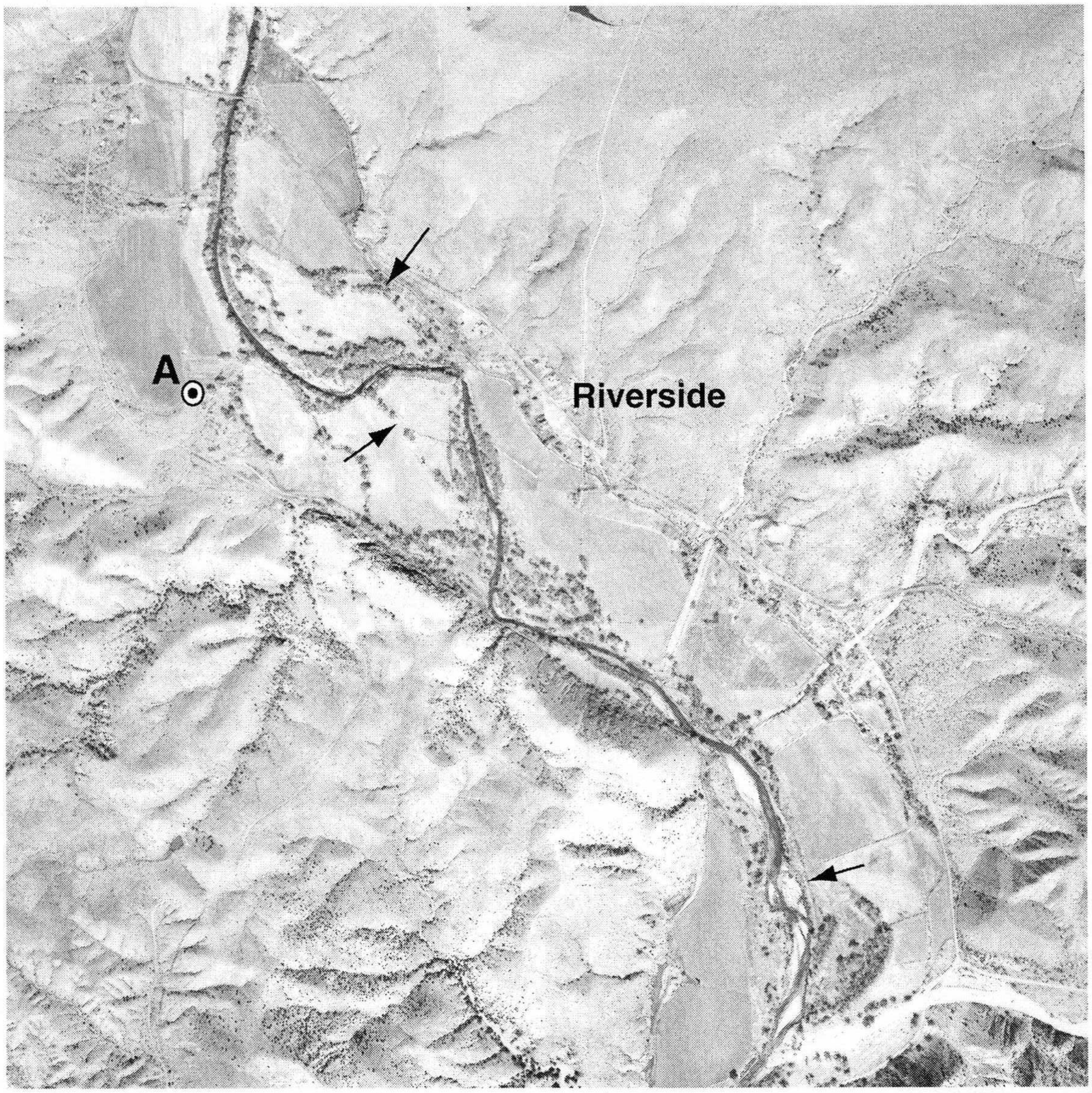
Figure 17. Case Study (7): Riverside. *(a) 1935; (b) 1953. Similar channel position to 1935; (c) 1965. Channel narrowed considerably. Some channel bends were cut off by levees (indicated by arrows) and developed into farmland; (d) 1975. The active channel widened downstream from point A; (e) 1980. Further and more extensive widening along the left bank near Riverside (indicated by an arrow), and the right bank at point A; (f) 1996. The channel widened further (arrow indicates example), destroying the majority of levees in the 1980 aerial photography; (g) 2001. Similar channel position to 1996. Flow is from top to bottom in the aerial photos.*



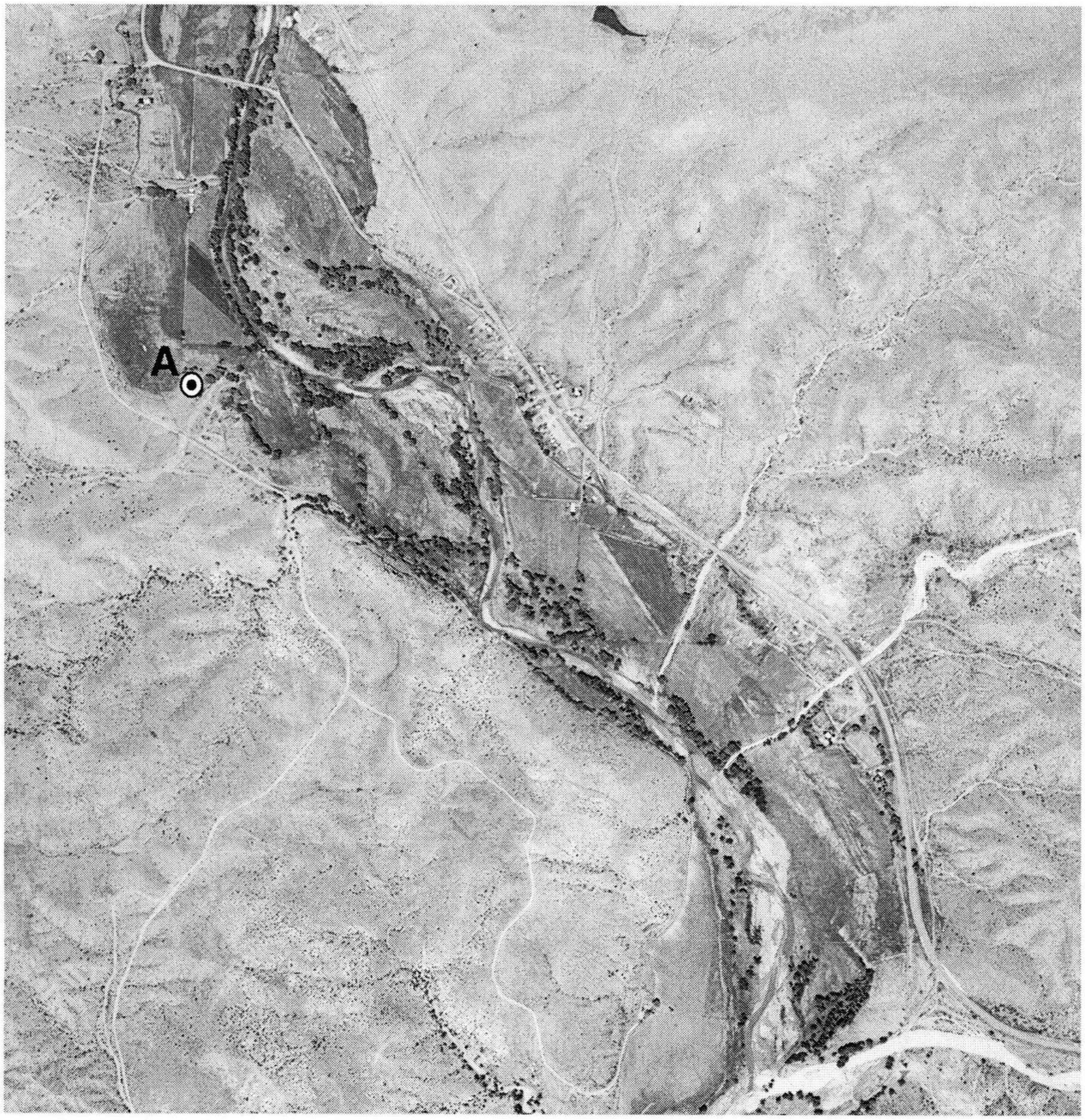
(a) 1935



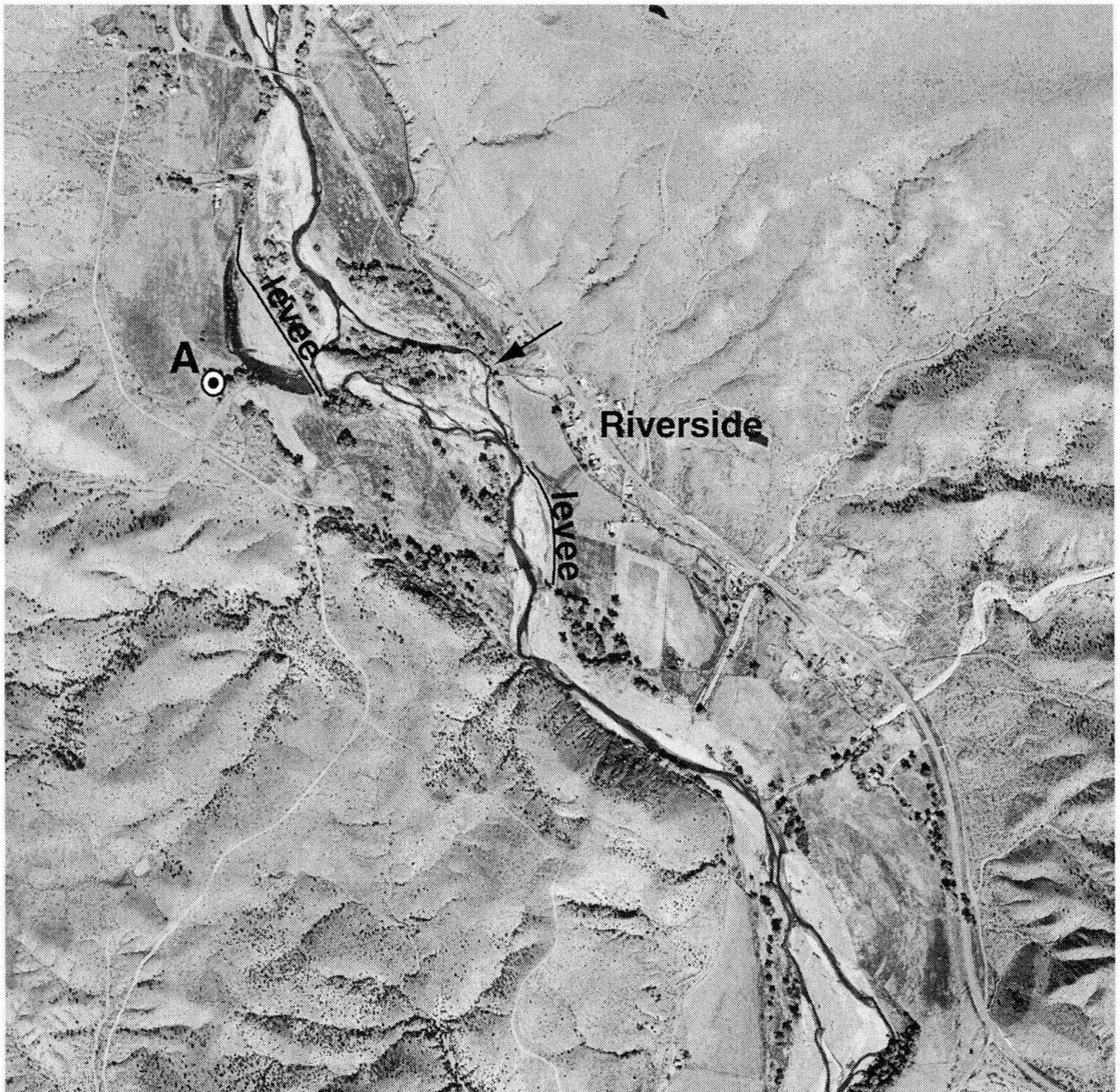
(b) 1953



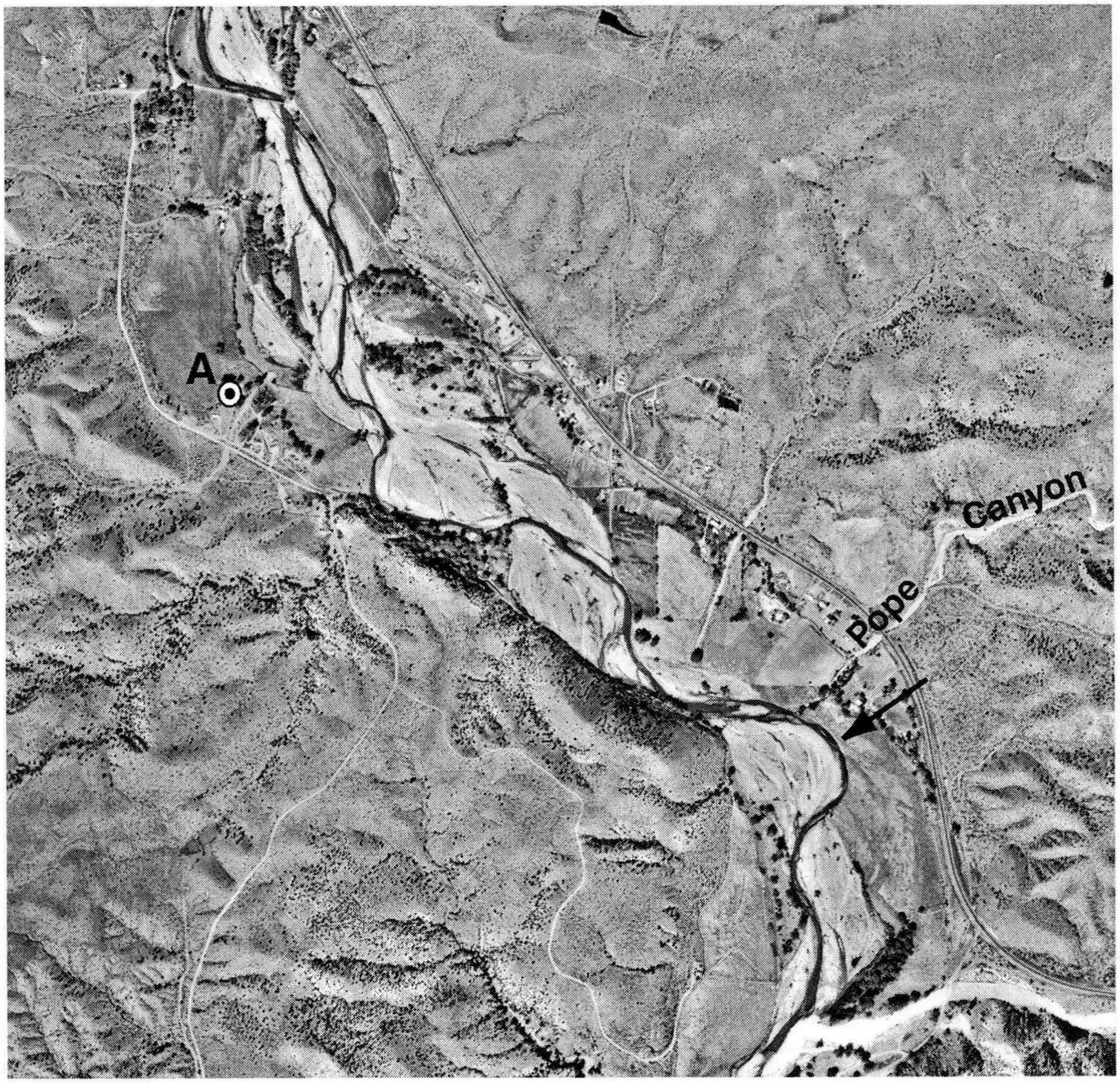
(c) 1965



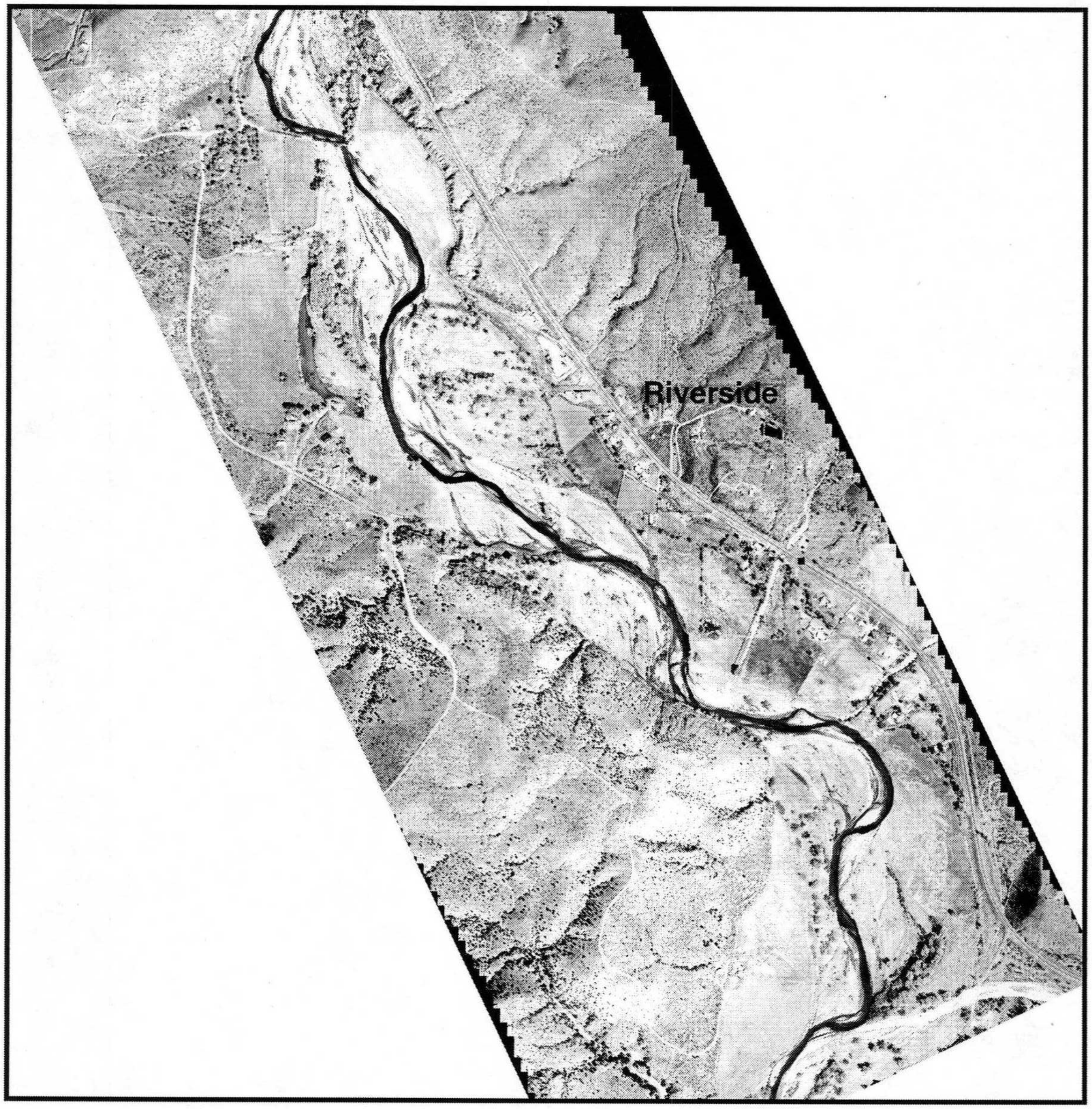
(d) 1975



(e) 1980



(f) 1996



(g) 2001

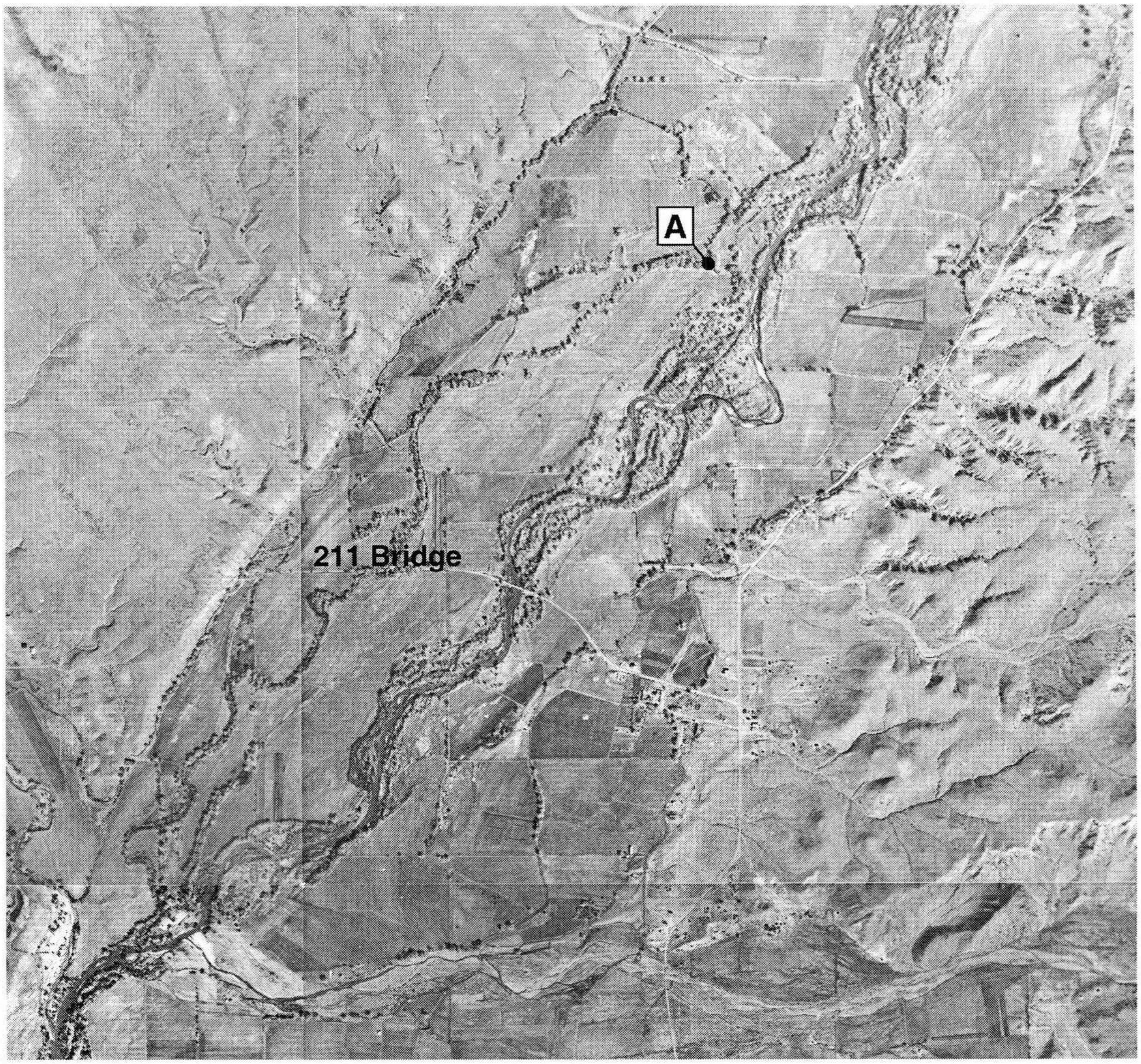
Case Study (8): Route 211 Bridge

The majority of channel changes in this reach occurred upstream of the Route 211 Bridge (Figure 18). The 1935 channel was relatively wide with a sinuous active channel and some small levees setback from the river along farmlands. The active channel, in contrast, was narrow. From 1935 to 1965, the channel was artificially straightened by levees, cutting off many previous channel bends. Major tributaries, such as Bear Creek, were also leveed during this period. 1975 photographs show eroded levees and a wider active channel. These effects are presumably from the 1972 flood. By 1980, new levees had been built following the 1978 flood; impacts from this flood can be seen in places where the post-1978 channel was cut off by the new levees. By 1996, a major change in channel width had occurred, eroding levees along the entire reach and forming new channel positions that were unprecedented in the historical record. The present (2001) channel is very similar compared to the 1996 channel.

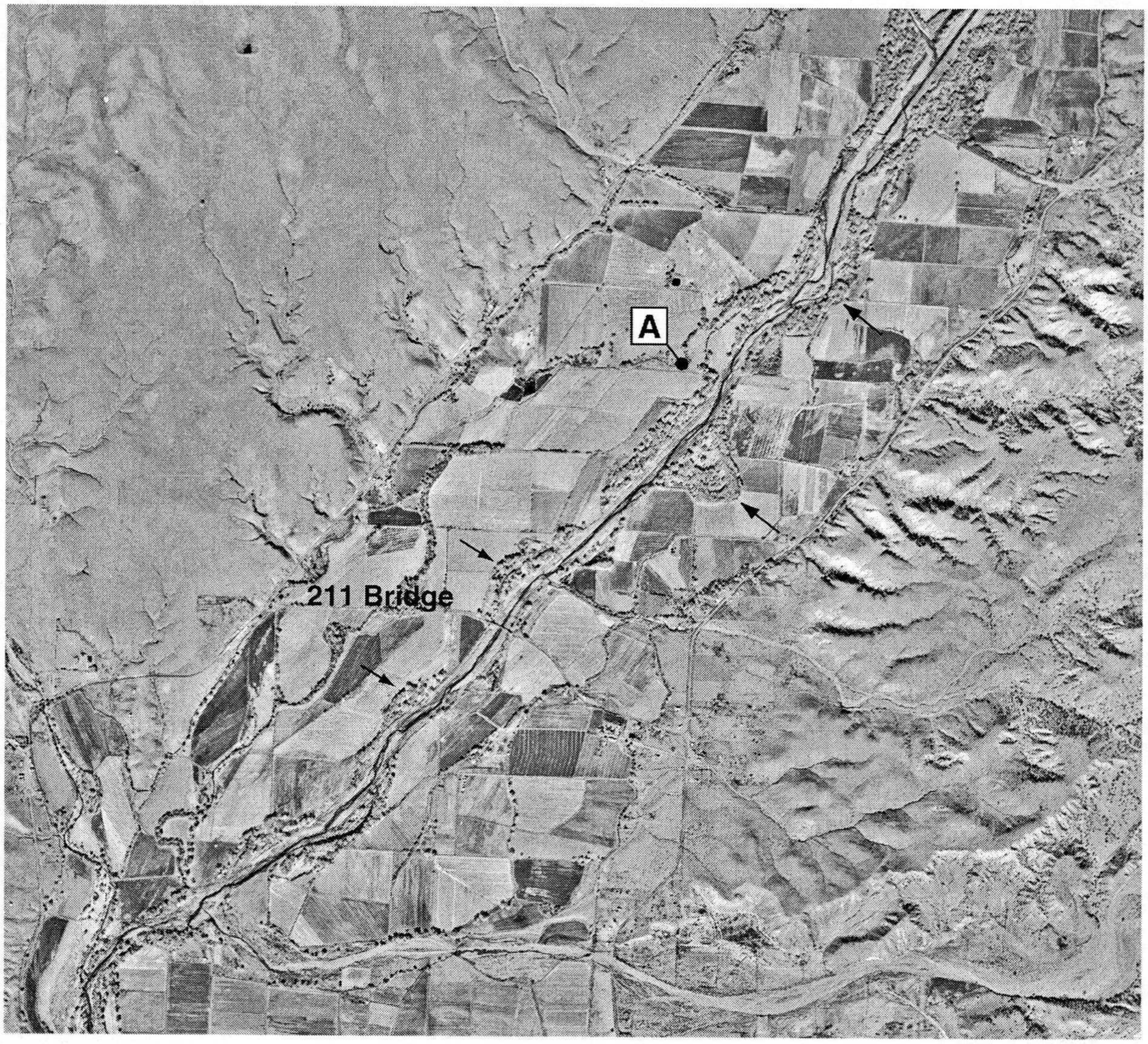
Case Study (9): Seeds of Change

The Seeds of Change reach extends from the upstream end of the Shelley diversion canal downstream to Winn Canyon (Figure 14). From 1935 to 1950, agricultural encroachment and levee building narrowed the channel (Figure 19); the most prominent levee was built at the upstream end of the reach near point A and reduced the flood channel width by approximately one third to one half. Channel straightening and levee construction further narrowed the channel and cutoff meanders from 1950 to 1953. The channel widened by 1975, eroding some of the levees constructed prior to 1965. The 1978 flood further widened the channel; levees were replaced or repaired in the same locations, which cut off some new sections of channel formed by the 1978 flood. Levees built following the 1978 flood were mostly destroyed by 1996; in some cases the channel positions were unprecedented in the historical aerial photography. New levees were built in some locations, such as near point B near the old Bennett farm, to direct channel flow. In this case, berms, a pilot channel, and backwater area were created in an attempt to stabilize the reach. The present (2001) channel is very similar compared to the 1996 channel.

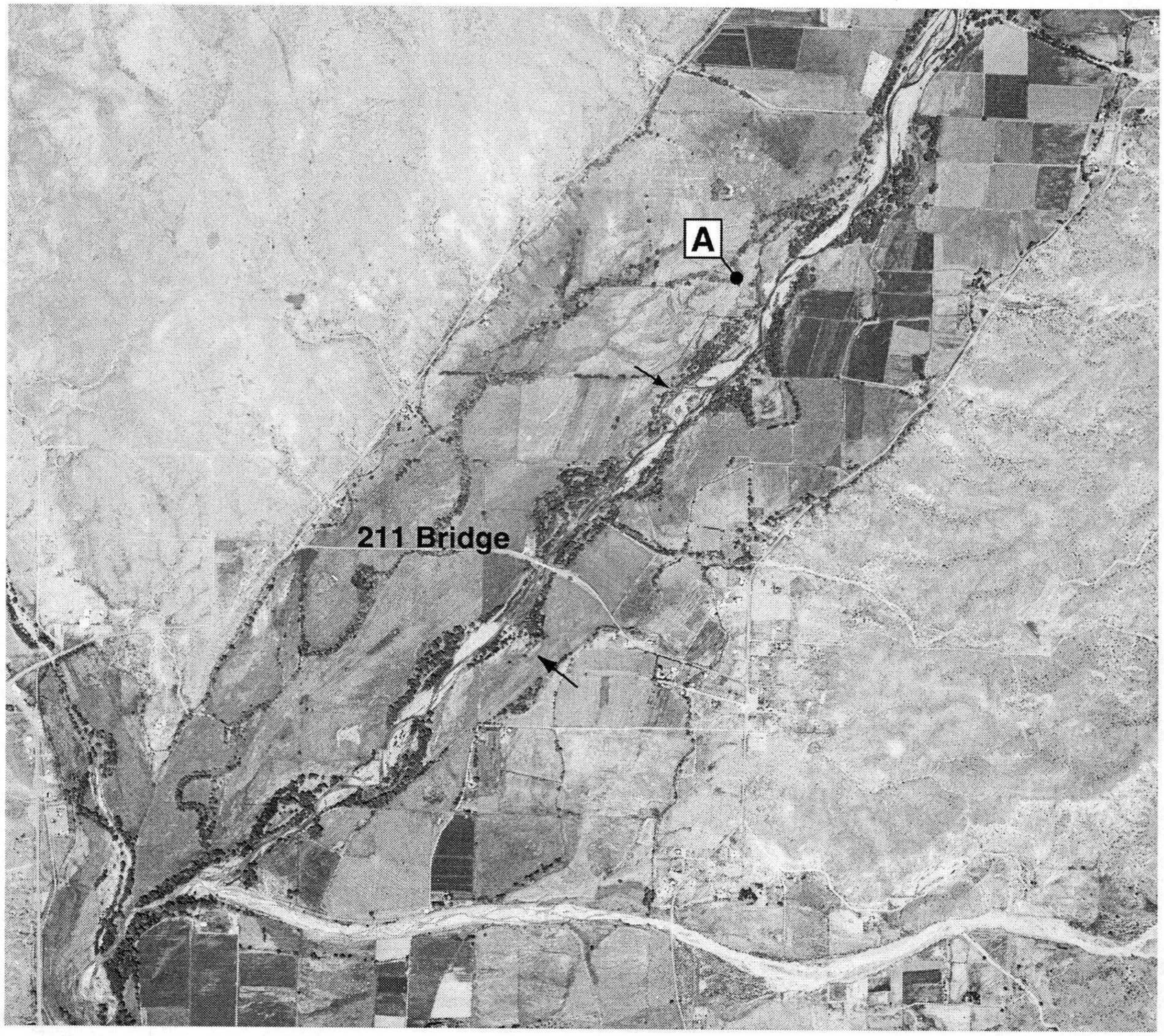
Figure 18. Case Study (8): Route 211 Bridge. *(a) 1935. Channel was wide with a sinuous active channel; (b) 1953. Channel was straightened and leveed, cutting off previous 1935 meanders (shown by arrows); (c) 1975. Channel widened through lateral erosion of some levees (shown by arrows); (d) 1980. Widened channel; levees had been replaced or repaired, cutting off some new sections of channel (arrow indicates an example of this scenario). Note the location of point A; (e) 1996. Eroded levees along the entire reach; new unprecedented channel positions had formed. Refer to point A and arrows for locations of major channel change; (f) 2001. Similar channel position to 1996. Flow is from top to bottom in the aerial photos.*



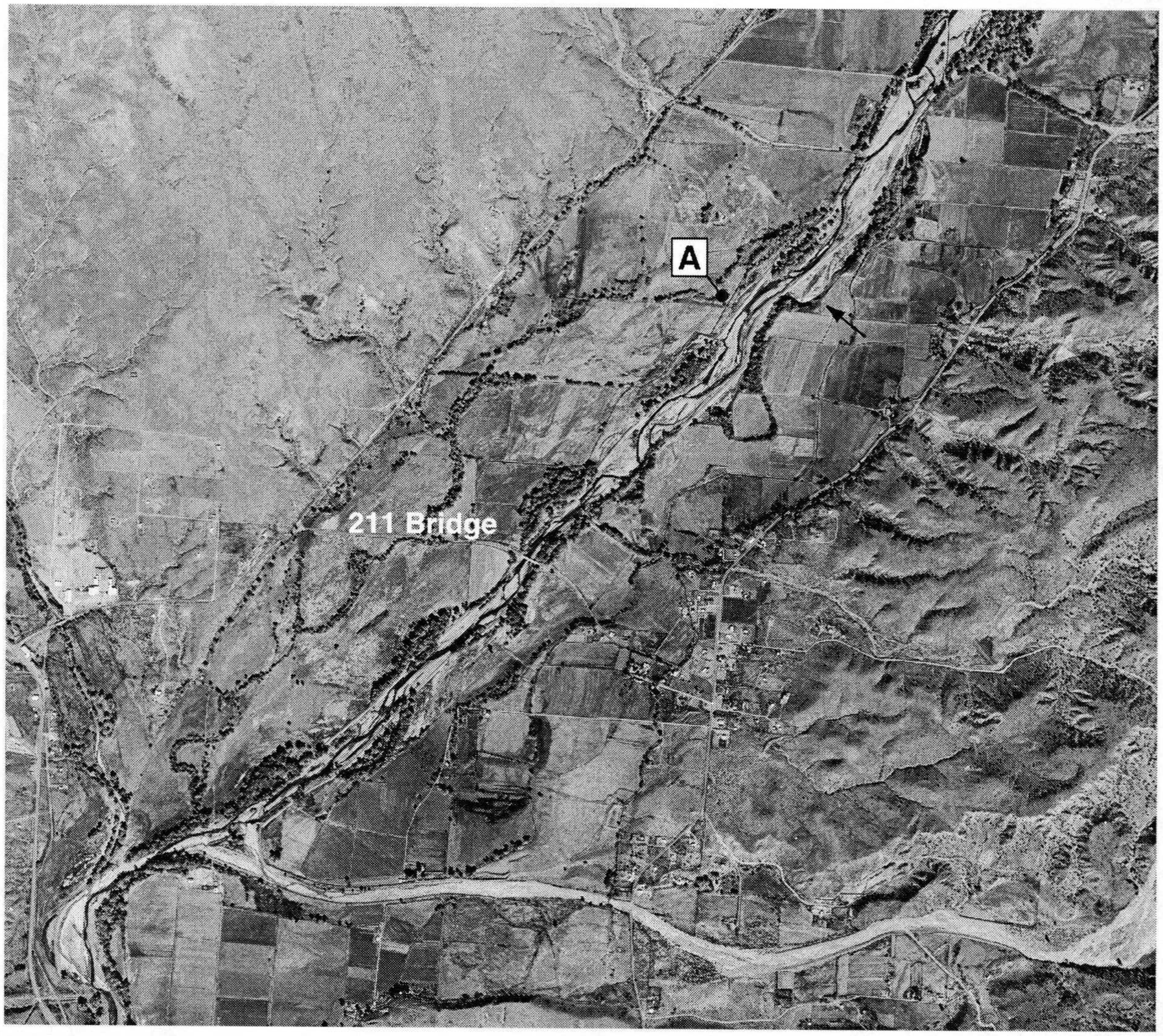
(a) 1935



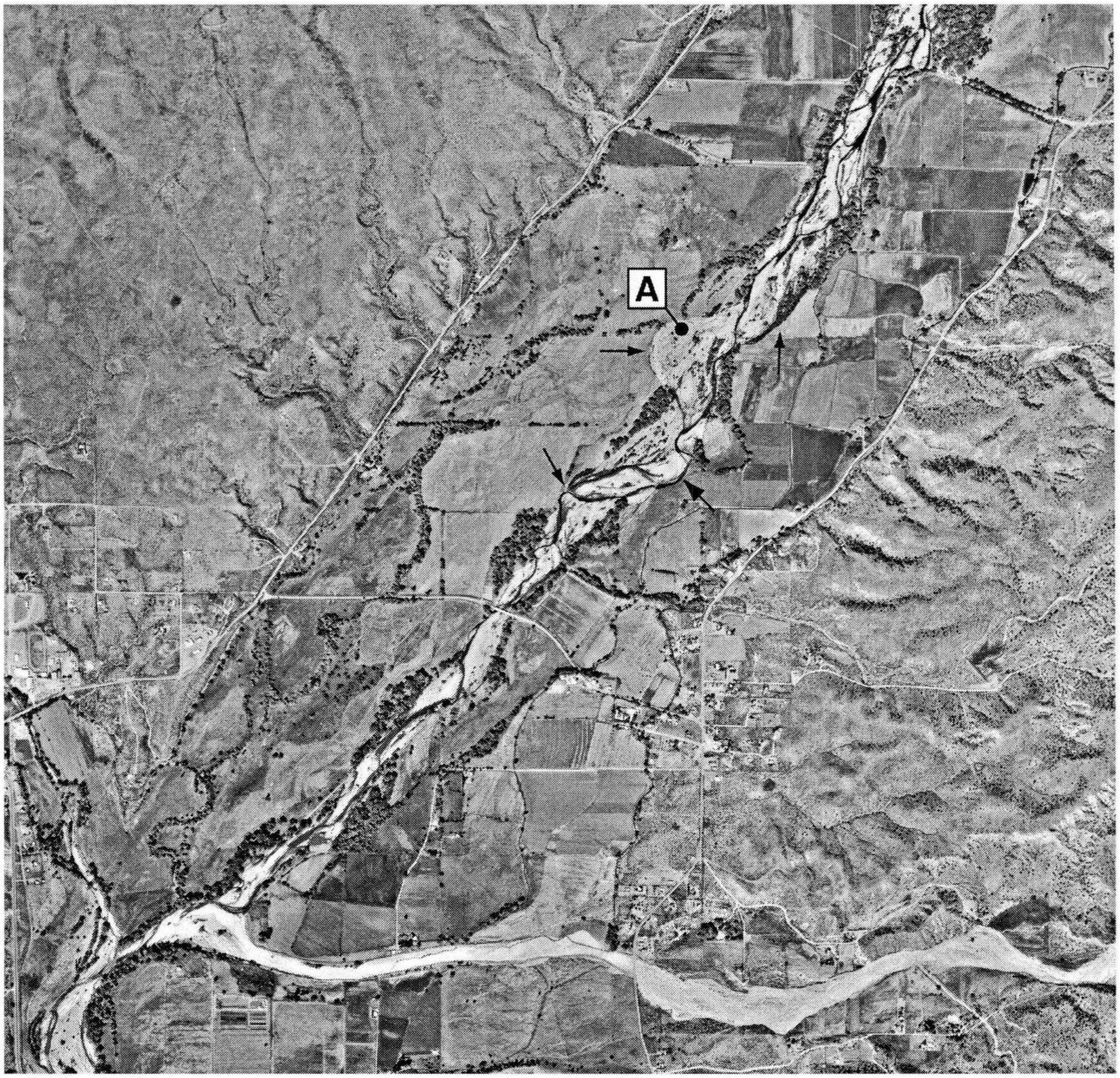
(b) 1953



(c) 1975



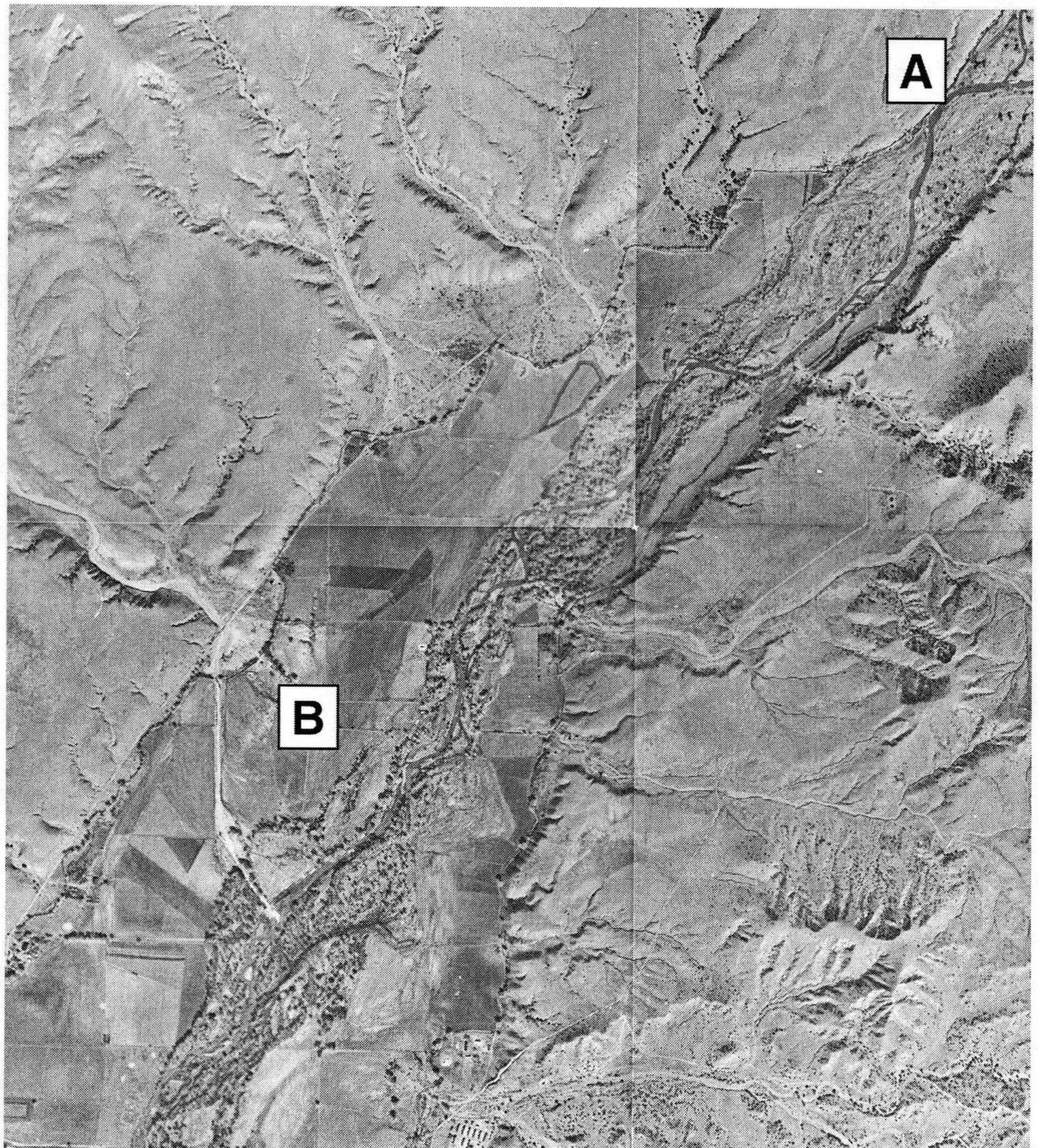
(d) 1980



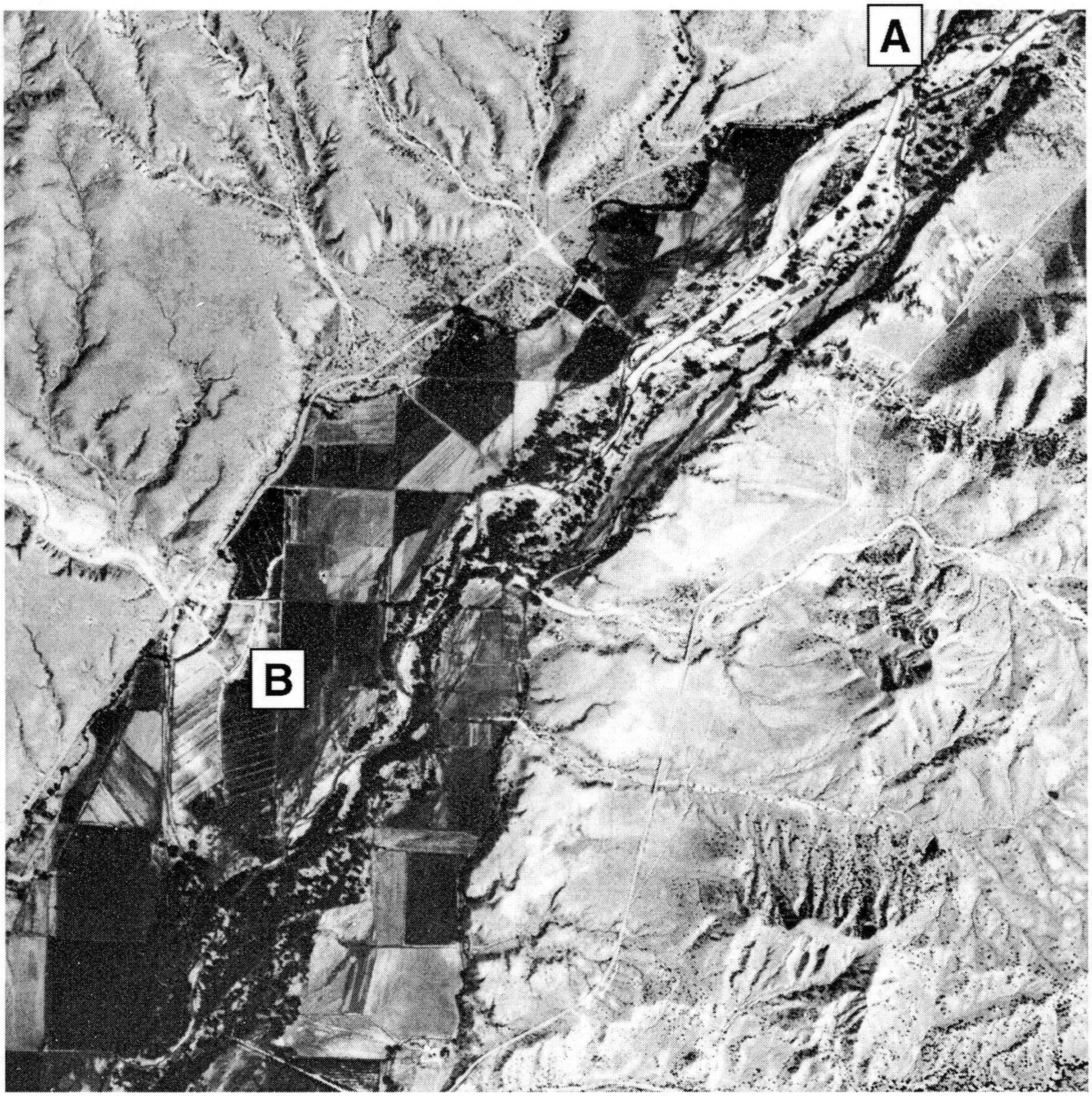
(e) 1996

(f) 2001

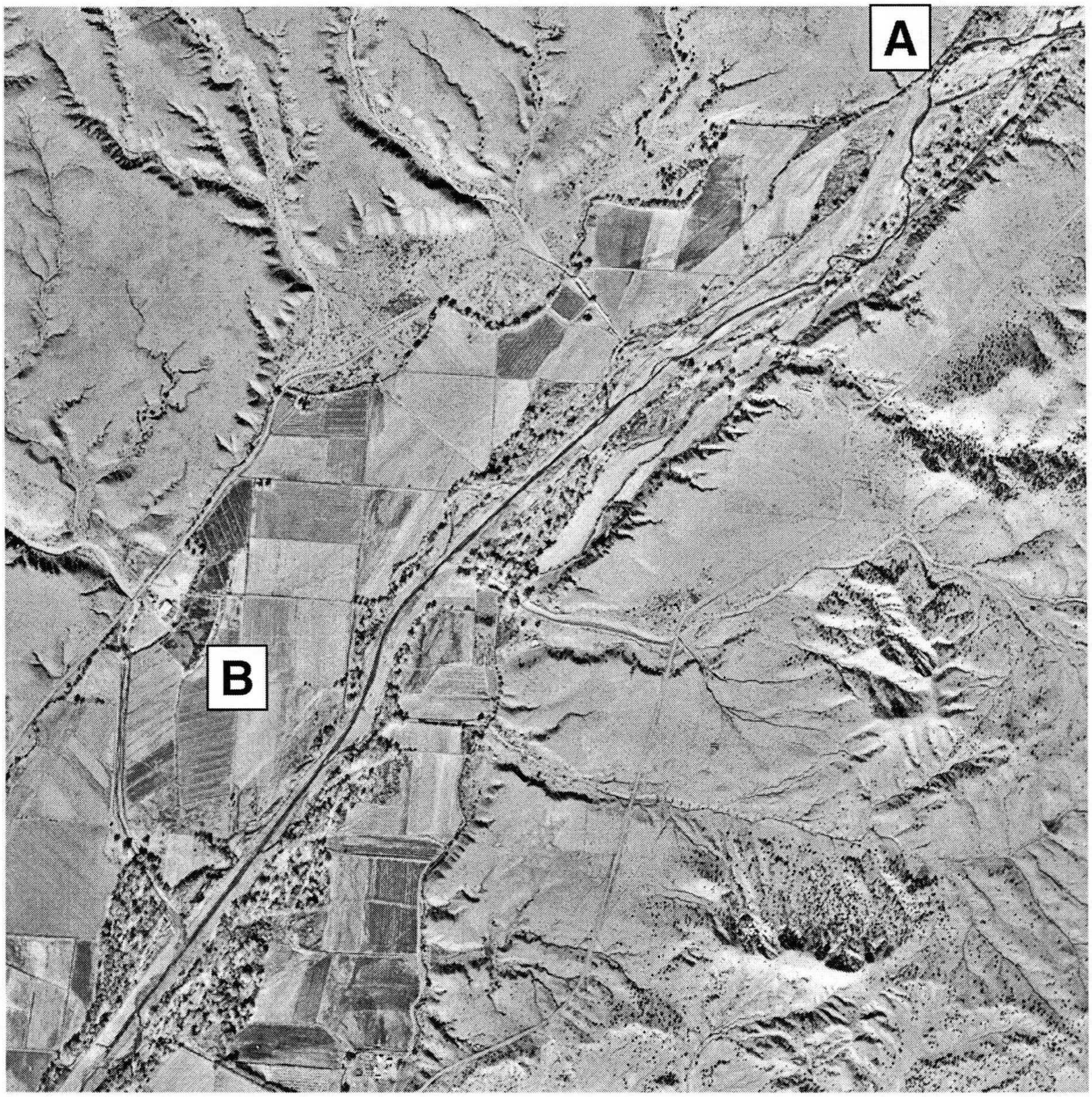
Figure 19. Case Study (9): Seeds of Change. *(a) 1935; (b) 1950. From 1935 to 1950, the channel narrowed by agricultural encroachment and levee building; the most prominent levee was built at the upstream end of the reach near point A; (c) 1953. Channel straightening and levee construction further narrowed the channel and cutoff 1950 meanders; (d) 1965. Similar channel position to 1953; (e) 1975. The channel widened, eroding some of the levees constructed prior to 1965; (f) 1980. Further channel widening, eroding levees; levees were replaced or repaired in the same locations, which cut off new channel formed by the 1978 flood (point A); (g) 1984. Similar channel configuration to 1980; (h) 1996. Levees were mostly destroyed. Unprecedented channel positions on the right bank downstream of point A and at point B. New levees were built in some locations, such as point B; (i) 2001. Similar channel position to 1996. Flow is from top to bottom in the aerial photos.*



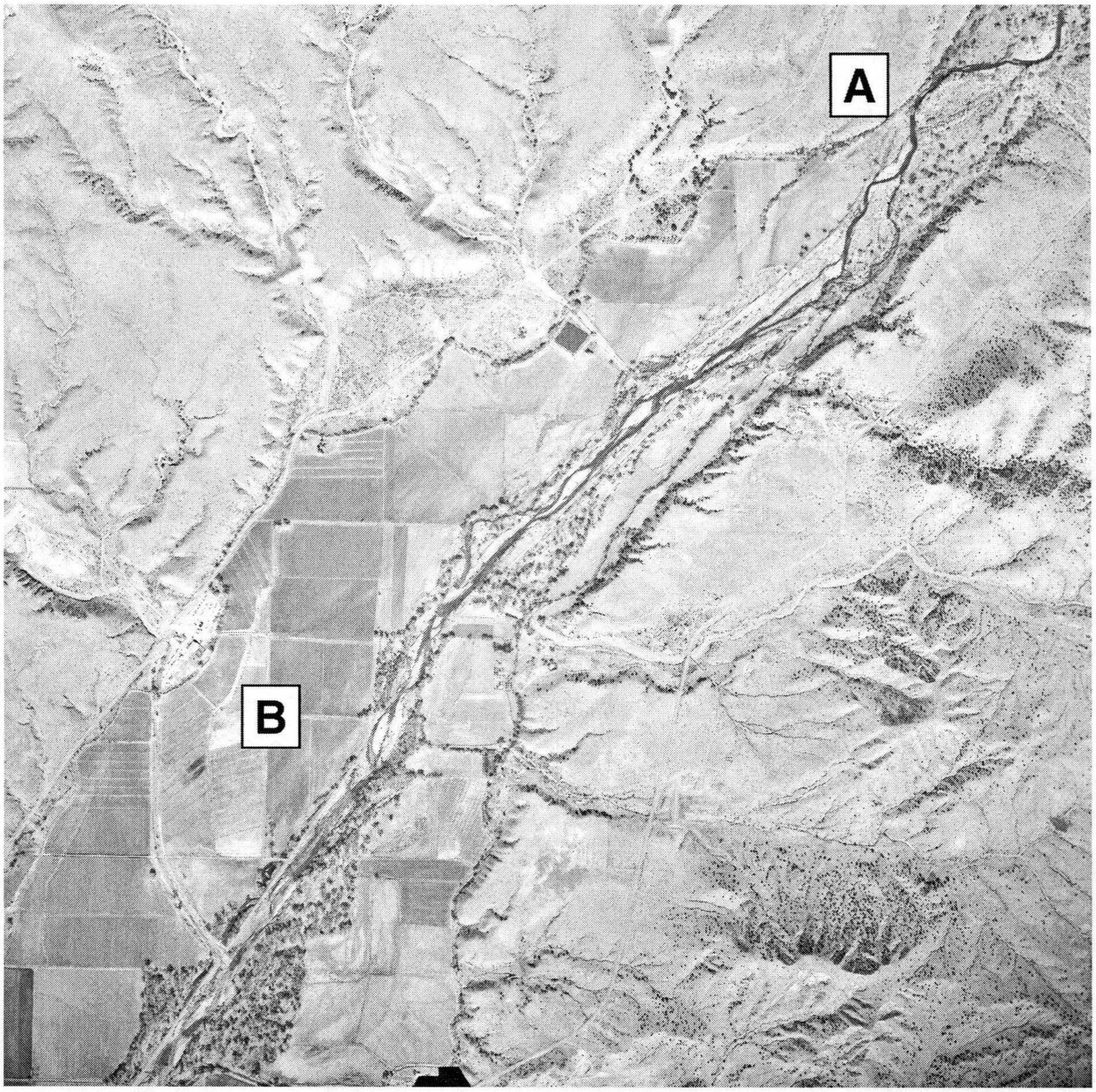
(a) 1935



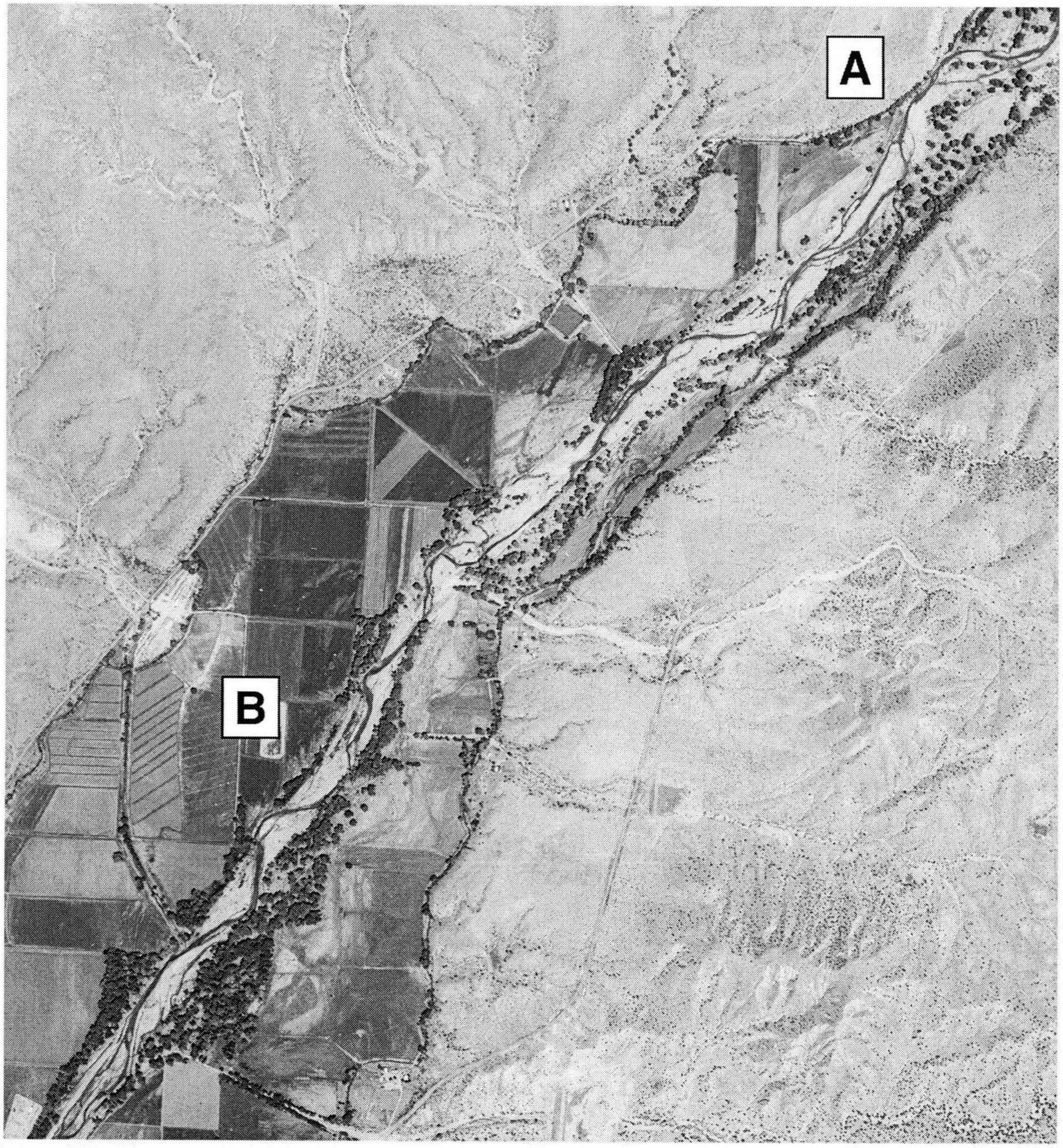
(b) 1950



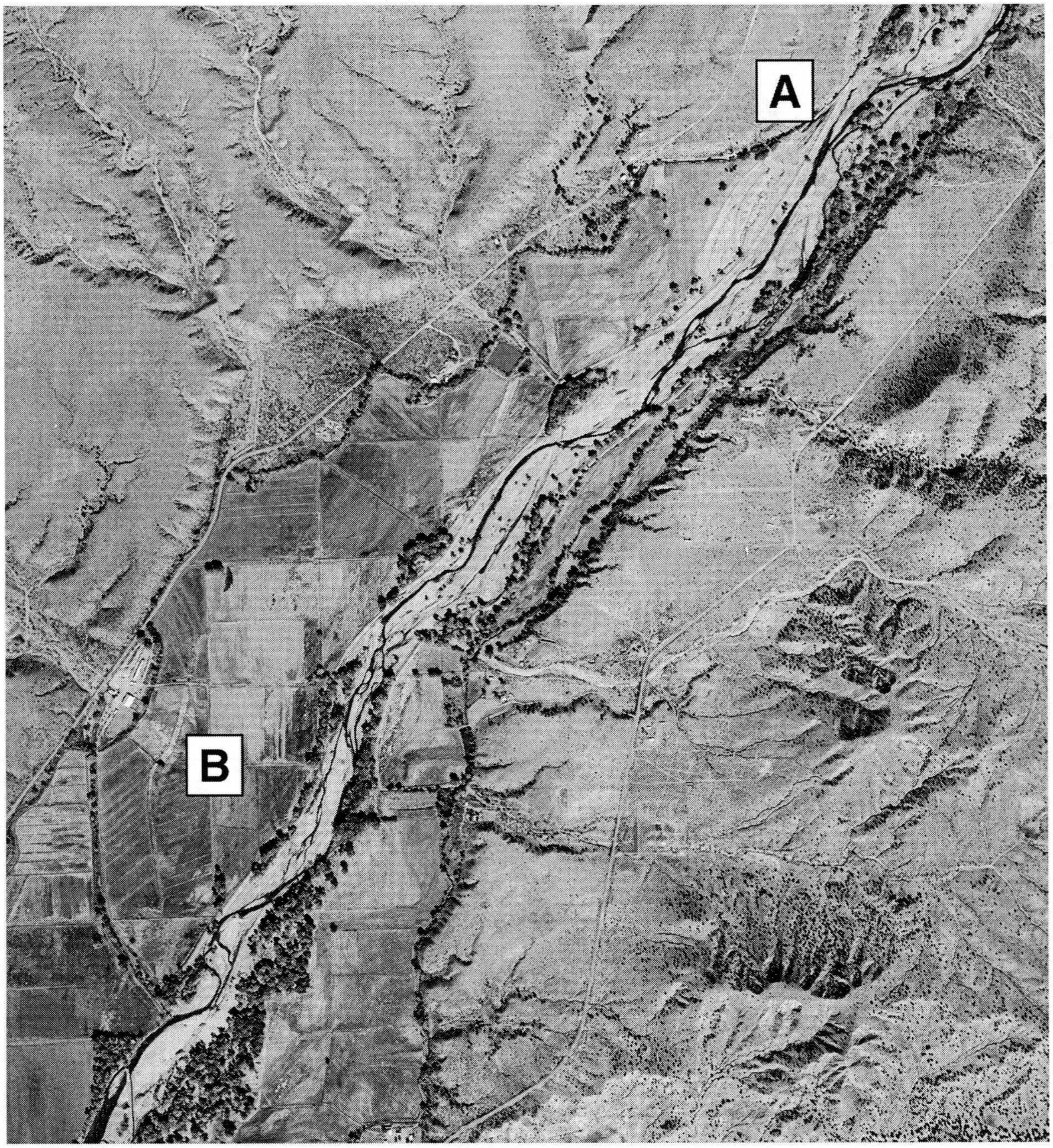
(c) 1953



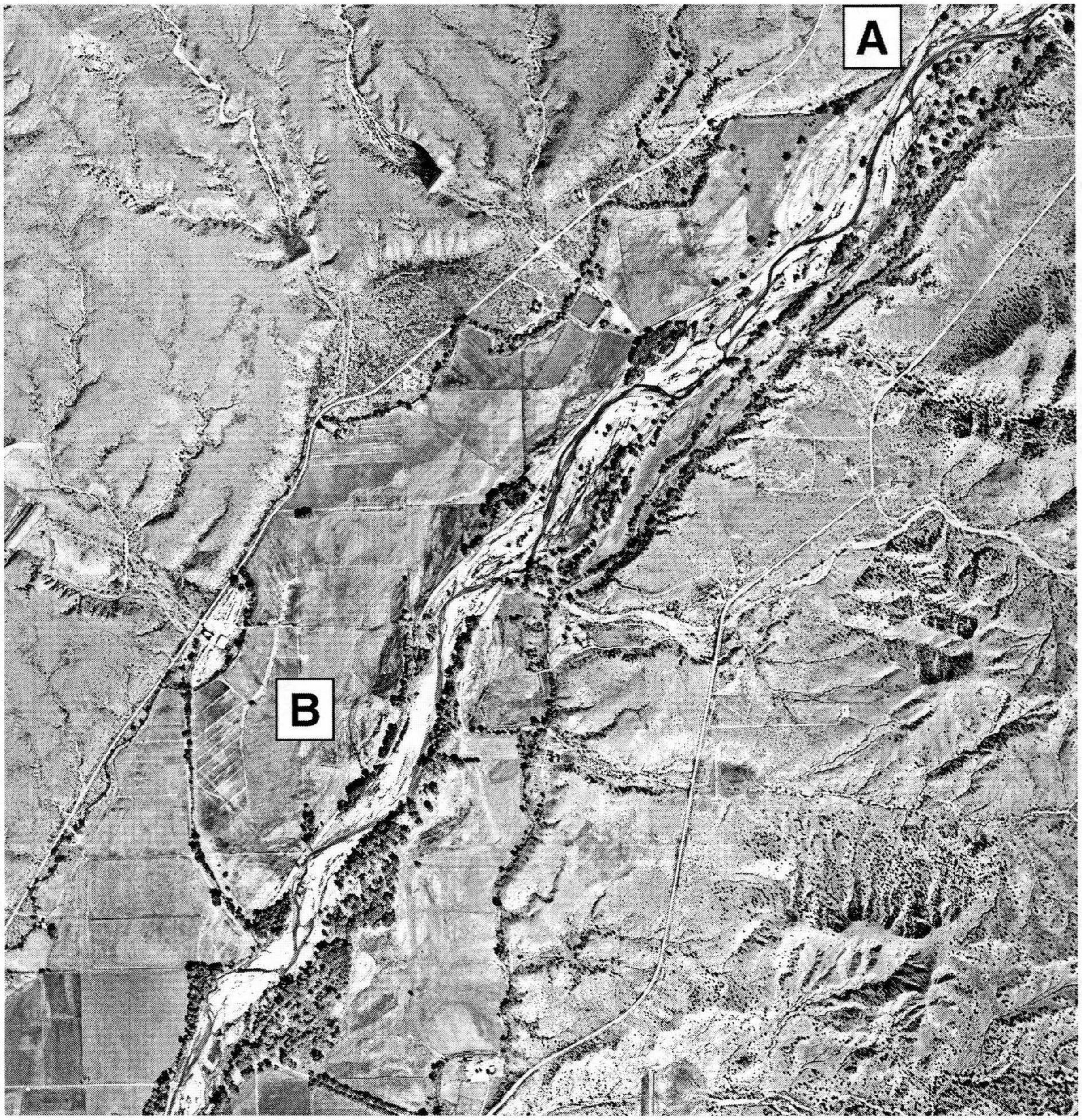
(d) 1965



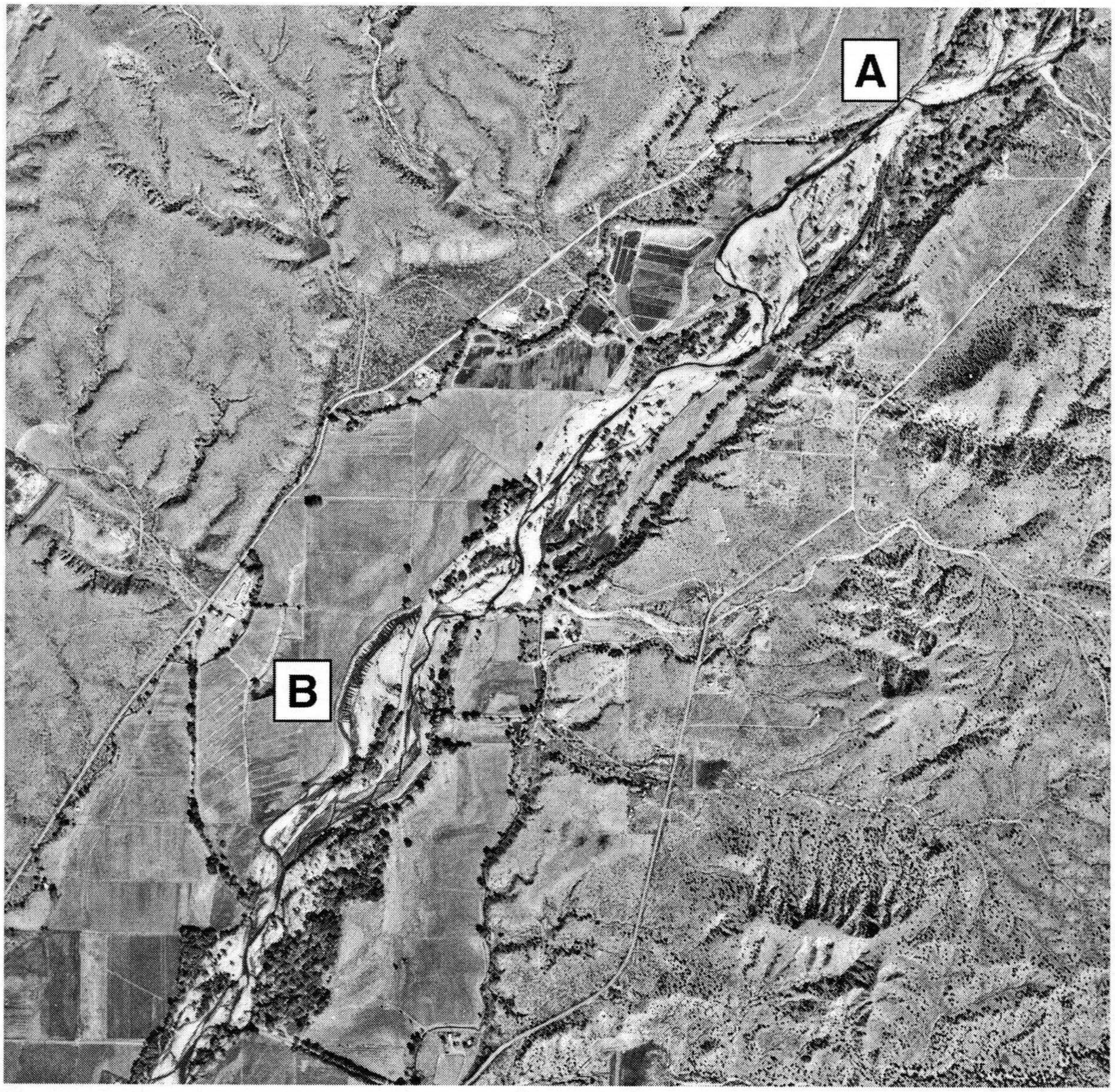
(e) 1975



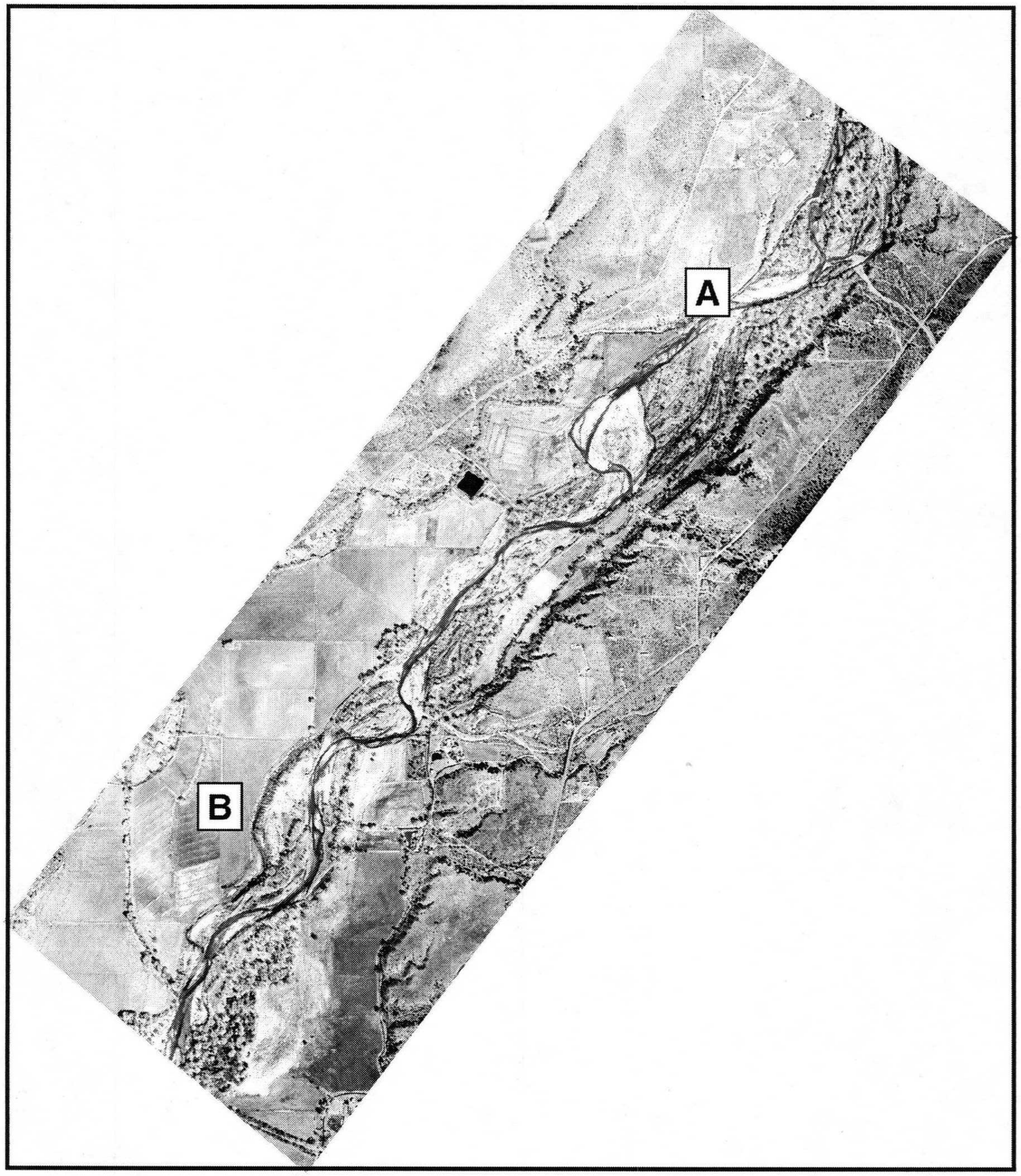
(f) 1980



(g) 1984



(h) 1996



(i) 2001

DISCUSSION

NATURE OF CHANNEL CHANGES, VIRDEN, REDROCK AND CLIFF-GILA VALLEYS

This study has shown that high variability exists in channel width and position in the alluvial valleys of the Gila River in south-central New Mexico. Although many channel positions that are documented are not new, there are several cases where they are unprecedented in the historical record. It is also apparent that more unprecedented channel positions were formed between 1980 and 1996 than in any other time interval in the historical period. Examples of such cases include both Case studies in Virden Valley, the Lower Box to Road Canyon reach in Redrock Valley, and Bill Evans Lake, Route 211 Bridge, and Seeds of Change reaches in Cliff-Gila Valley. Flood channel widths in recent decades (1980's to present) are similar to or slightly larger than 1935 flood channel widths for the Gila River during the period of study. 2001 flood channel widths are similar to the 1935 flood channel widths, varying by ± 25 m.

Trends in flood channel width data appear to coincide in general with the hydrologic record of stream flow on the Gila River. Decreases in average flood channel width occur during periods of few large floods (1950's to 1960's) and increases occur during periods of multiple large floods. Although the largest increases in flood channel width have followed large floods, such as the 1972 and 1983 flood, other data show no change even following the largest flood in 1978. The most probable cause for this discrepancy is the placement of levees following large floods and prior to aerial photography. The levees that were constructed or repaired following the 1978 flood, for example, were in place prior to 1980 aerial photography. This is supported by Donegan (1997), who states that the levees were repaired or replaced rapidly following the flood in anticipation of further flooding. The aerial photography show that levees cut off many of the new channels formed during the 1978 flood. In these locations, the channel width was measured between the levees, as this was the allowable flood width. The combined 1996 measurements from Redrock and Cliff-Gila Valleys and 1998 measurements from Virden Valley seem to be large compared to 1995 Cliff-Gila data. Although there is minimal change in Cliff-Gila Valley between 1995 and 1996 and channel width is actually smaller in Virden Valley, channel widths in Redrock Valley are much larger and skew the result. Stream flow records from 1984 to 1998 show that Redrock Valley experienced larger peak flows than Cliff-Gila Valley for many of the largest floods. This may account for the large increase in flood channel width in the 1996/98 data. It is also possible that while damaged levees were repaired in other valleys, constricting the width of the channel, they were not repaired in Redrock Valley.

Active channel width data, in contrast to flood channel width data, show a general increase in width from 1935 to the 1990's. Although no statistical tests were performed, these data appear to correspond to trends in precipitation and stream flow documented by England (2002). For example, he indicates that positive trends, or increases, in winter precipitation at the Cliff, Redrock, and Glenwood station, were found for the 1941-2000 and 1951-2000 periods of record, while positive trends in the maximum 1-day precipitation at the Gila Hot Springs station and Mimbres Ranger Station, were found for the 1951-2000 and 1961-2000 periods of record. Positive trends were also noted in stream flow records for the 10, 30, 50, 70, and 90th percentiles at the Gila and Virden gages for the 1941-2000 and 1951-2000 periods of record. See England (2002) for additional information. The general increase in precipitation as well as stream flow is thus associated with a wider active channel historically, despite the similarity in flood channel widths over time.

Similar patterns in active channel width have been documented on the upper Gila River in east-central Arizona (Burkham, 1972; Hooke, 1996; Klawon, 2001). In Safford Valley, mean active channel widths were generally small in the late 1800's. This was followed by an increase in channel width in the early 1900's, which corresponds to a period of frequent large floods. Channel narrowing occurred from the

1920's through the 1960's, a period of few large floods. Other factors such as vegetation growth, levee construction and agricultural development also promoted channel narrowing during this period. In the 1960's, a period of more frequent large floods began and channel widths again increased. Flood channel widths documented by Klawon (2001) also show a similar pattern with 1935 mean flood channel widths being very similar to mean widths in 2000.

Comparisons between Virden, Redrock and Cliff-Gila valleys show that reaches of high variability (standard deviation >60m) are approximately 10-15% more common in the Cliff-Gila Valley than in Redrock or Virden valleys when reach length is taken into account. The Geomorphic Map, Task 8 of this project, will be an important component that will complement this study by showing the long-term behavior of the Gila River system in conjunction with this study's examination of fluctuating channel widths in the short term.

UNCERTAINTY IN WIDTH MEASUREMENTS

Width measurements developed in this study are based on non-rectified aerial photographs and have uncertainty associated with them. The conversion factors were used to analyze error that may be incurred from using non-rectified aerial photographs. Approximately nine measurement segments on 7.5-minute USGS topographic maps were made in the three valleys; the same segments were then measured on each aerial photograph set. The criteria for choosing segments was based on the ability to locate the segment on all aerial photograph sets as well as the topographic maps. Straight-line segments such as roads or canals with well-defined intersections were preferred; however, due to the range of photograph years and limited geographic detail on topographic maps, physiographic features were also used. These included sharp bends or peaks in bedrock outcrops as well as intersection points between bedrock and roads. Ratios of the two lengths were then compared among points to determine the error involved in measuring widths. As would be expected in the data sets for Virden, Redrock, and Cliff-Gila valleys, uncertainty was larger for small-scale photograph sets and smaller for large-scale photograph sets (Figure 20). The 1950 data set was one exception, where its scale was relatively small and uncertainty small. The number of measurements was limited for this data set due to its coverage and may not be representative if all of the segments could have been measured.

The largest errors occurred in the 1953 and 1975 data sets, which were two of the smallest scale photographs used in the study, on the order of 1:57,000 and 1:40,000, respectively. The largest error values for these sets are ± 2.4 m and ± 2.3 m. These values are small compared to average channel widths of 60 to 280 m.

Another source of measurement error is associated with the repeatability in the measurement and the error associated with the measurement device. Measurements were made multiple times on random points to determine the precision associated with the data set. Error measurements were on the order of ± 2 m (Table 3). Measurements of channel width for the Gila River were made on the aerial photographs with a digital caliper and measured to a hundredth of a millimeter (0.01 mm), which corresponds to an computed ground distance of 0.12 to 0.56 m depending on the scale of the photographs. On the 2001 photograph set, widths were measured on a digital orthophoto, whose uncertainty is related to the survey ground control data. The uncertainty associated with the survey data is typically a few centimeters or less, which is minimal compared to measurement error introduced by the user.

Table 3. Test of precision

Measurement (mm)	Measurement (m)
13.55	403.8
13.47	401.4
13.38	398.7
13.44	400.5
13.39	399.0
13.46	401.1
13.37	398.4
13.45	400.8
13.48	401.7
13.52	402.9
13.55	403.8
13.42	399.9
13.45	400.8
13.48	401.7
13.50	402.3
13.47	401.4
13.53	403.2
13.53	403.2
13.55	403.8
13.51	402.5
Average=	401.5 ± 1.7

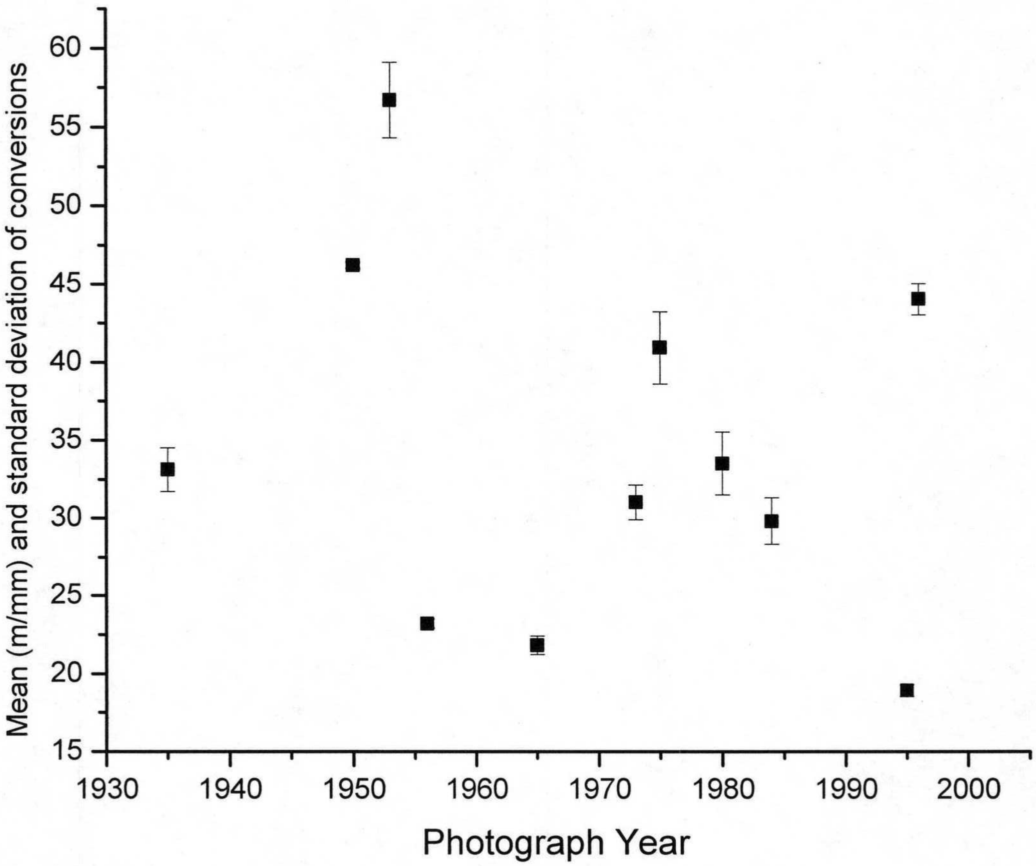


Figure 20. Uncertainty in channel width measurements. *Mean and standard deviation of the calculated conversion are plotted against photograph year.*

CONCLUSIONS

From 1935 to the early 1960's, the channel generally narrowed by vegetation growth, and levee and agricultural development. From the 1970's to 2001, the channel generally widened and in 2001 was approximately the same width on average as it was in 1935. Results from this study show that channel changes are related to large floods on the Gila River. During periods of large floods, channel widths increase, while in periods of few large floods channel widths decrease. This pattern appears to be accentuated by the building of levees, bridges, and other structures as well as agricultural development of land that was previously part of the channel. In most cases, flood channel widths at specific channel locations are variable, but not unprecedented in the historical record. Reaches of high variability, however, show that there are multiple locations where recent channel changes are unique in historical aerial photography. These types of channel changes are present in all three valleys.

The analysis of change using flood channel widths for Virden, Redrock, and Cliff-Gila Valley show that Cliff-Gila Valley has experienced more perturbations in the period of study than either Virden or Redrock Valley and that more unprecedented channel positions were formed between 1980 and 1996 than at any other time in the historic period. Major channel changes generally occurred following large floods. This highlights the important point that the largest floods in the Gila River system have lasting effects that can be observed in channel morphology for decades following their occurrence.

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Appendix A

SOURCE OF AERIAL PHOTOGRAPHY: LIST OF CONTACTS

Table A1. List of Contacts

Gary Garrison Natural Resources Conservation Service 2610 North Silver Silver City, NM 88061 (505) 388-1569
James Hollen Pacific Western Technologies, Ltd. Mapping and Information Division 8338-A Comanche Road NE Albuquerque, NM 87110 (505) 294-5051
Horizons, Inc. 3600 Jet Drive P.O. Box 3134 Rapid City, SD 57709-3134 (605) 343-0280 email: sales@horizonsinc.com
Michelle Pointon National Air Survey Center Corp. 4321 Baltimore Avenue Bladensburg, MD 20710 (301) 927-7180 email: nascc.com
Steve Reiter U.S. Geological Survey Bldg 810, Denver Federal Center Denver, CO 80225 (303) 202-4168
Connie Slusser Bureau of Land Management Bldg. 50, Denver Federal Center Denver, CO 80225 (303) 236-7991
USDA Aerial Photography Field Office Farm Service Agency 2222 West 2300 South Salt Lake City, UT 84119-2020
U.S. Geological Survey EROS Data Center Sioux Falls, SD 57198-0001 Internet: edc.www.cr.usgs.gov/webglis
Whittier College Fairchild Aerial Photography Collection Whittier, CA 90608 (562) 907-4220 email: fairchild@whittier.edu

Appendix B

SOURCE DATA

Table B1. List of Aerial Photographs

Year	Date(s)	Agency/Vendor[1]	Scale	Film type[2]	Coverage
1935	unknown	NARA (Fairchild)	1:31680	B/W	All
1950	9/1950	NARA (Unical)	1:39996	B/W	Cliff-Gila
1953	11/23-25/1953	AMS	1:54000	B/W	
1956	7/03/1956	Whittier (Fairchild)	1:24000	B/W	Cliff-Gila
1965	11/30/1964 2/19/1965 2/20/1965	ASCS	1:20000	B/W	Virden Redrock Cliff-Gila
1973	4/06/1973	NASAAM	1:30000	B/W	All
1975	8/30-31/1975	BLM	1:31680	CLR	All
1980	11/2-3/1980 11/5-7/1980 8/21/1981	BLM	1:31680	CLR	All
1984	10/08-10/1984	USGS	1:26887	CLR	All
1995	5/18/1995	PWT	1:18000	B/W	Cliff-Gila
1996	9/28/1996 10/10-11/1996	USGS	1:40000	CIR	Redrock Cliff-Gila
1998	5/23-25/1998	USGS	1:40000	B/W	Virden
2001	3/04/2001	USBR	1:10000	B/W	All

[1]Agency/Vendor information:

AMS Army Map Service (USGS)
ASCS Agricultural Stabilization and Conservation Service
BLM Bureau of Land Management, Denver
NARA National Archives and Records Administration
NASAAM National Aeronautics and Space Administration, Ames (USGS)
PWT Pacific Western Technologies
UNICAL National Archives and Records Administration
USBR Bureau of Reclamation (Horizons Aerial Photography)
USGS Geological Survey
WhittierWhittier College Fairchild Collection

[2]Aerial Photograph Film Type:

B/W black and white
CIR color infrared
CLR color

Appendix C

CHANNEL WIDTH MEASUREMENT POINT LOCATIONS

CHANNEL WIDTH MEASUREMENT POINT LOCATIONS

Sixty-two channel width measurement points were established along the Gila River. The measurement point locations represent an endpoint that could be easily recognized on all photograph sets as well as topographic maps and from which a straight-line segment could be extended across the river channel. See the Methodology discussion in the text for a more complete explanation of this procedure. UTM coordinates for each point were measured from USGS 7.5 minute quadrangles to six digits, listing the easting first and the northing second. All points are located in UTM zone 12 and reflect the northings and eastings for a 10-meter square.

Table C1. UTM Coordinates for channel width measurement points

Point No.	UTM Coordinates	Point No.	UTM Coordinates
102	068324 361890	133	072378 363504
103	068526 361771	134	072426 363551
104	068552 361772	135	072488 363513
105	068727 361810	136	072541 363690
106	068718 361654	137	072578 363798
107	068891 361722	138	072484 363900
108	068906 361588	139	072570 363939
109	069071 361622	140	072453 364126
110	069178 361541	141	072510 364221
111	069261 361526	142	072474 364326
112	069338 361476	143	072506 364398
113	070602 361668	144	072602 364457
114	070648 361718	145	072494 364598
115	070712 361801	146	072372 364612
116	070826 361816	147	072356 364704
117	070938 361778	148	072426 364846
118	071036 361825	149	072362 364922
119	071146 361729	150	072448 375030
120	071142 361882	151	072618 365038

Point No.	UTM Coordinates	Point No.	UTM Coordinates
121	071095 361985	152	072690 365092
122	071198 361945	153	072606 365262
123	071281 361926	154	072832 365290
124	071316 361982	155	072726 365442
125	071428 362012	156	072818 365546
126	071434 362180	157	072900 365588
127	071545 3632236	158	072931 365660
128	071654 362356	159	073011 365744
129	071691 362254	160	073055 365846
130	071785 362258	161	073024 365924
131	072463 363299	162	072949 365960
132	072456 363434	163	072993 366070

Appendix D

CHANNEL WIDTH MEASUREMENTS

CHANNEL WIDTH MEASUREMENTS

Channel width measurements are listed from year 1935 to 2001 for the Gila River, New Mexico. Rows that are left completely blank in the tables indicate that data were not available for the measurement point. Measurements were recorded to one-hundredth of a millimeter. Following conversion to ground distance, measurements were rounded to the nearest meter.

Table D1. Channel width measurement data

1935

Point number	Measured active channel width (mm)	Computed active channel width (m)	Measured flood channel width (mm)	Computed flood channel width (m)
102	0.77	25	8.14	269
103	0.95	31	3.19	106
104	0.84	28	11.91	394
105	1.12	37	7.61	252
106	1.81	60	9.22	305
107	1.18	39	4.43	147
108	2.01	67	4.99	165
109	3.59	119	8.93	296
110	3.25	108	5.18	171
111	1.9	63	12.7	420
112	5.3	175	9.14	303
113	1.65	55	3.8	126
114	1.17	39	4.77	158
115	1.79	59	9.3	308
116	1.75	58	4.25	141
117	3.42	113	8.95	296
118	0.74	24	11.6	384
119	2.21	73	5.55	184
120	2.59	86	7.55	250
121	1.09	36	3.4	113
122	3.13	104	10.04	332
123	1.19	39	2.47	82
124	2.24	74	4.72	156
125	1.1	36	7.34	243
126	3.66	121	10.6	351
127	1.53	51	6.48	214
128	0.98	32	9.37	310
129	1.46	48	2.39	79
130	7.17	237	8.89	294
131	1.47	49	10.82	358
132	1.1	36	5.87	194
133	1.65	55	10.29	341
134	1.89	63	10.99	364
135	1.84	61	2.11	70
136	1.29	43	4.06	134
137	3.17	105	3.7	122
138	5.89	195	6.85	227

Point number	Measured active channel width (mm)	Computed active channel width (m)	Measured flood channel width (mm)	Computed flood channel width (m)
139	2.09	69	15.57	515
140	2.28	75	7.12	236
141	0.96	32	5.82	193
142	2.65	88	4.5	149
143	2.31	76	7.63	253
144	1.05	35	12.79	423
145	1	33	11.75	389
146	1.17	39	9.53	315
147	1.08	36	3.78	125
148	2.42	80	5.8	192
149	1.73	57	9.53	315
150	1.78	59	6.66	220
151	0.93	31	6.36	211
152	1.05	35	14.51	480
153	1.23	41	9.35	309
154	1.39	46	17.06	565
155	1.54	51	17.45	578
156	1.26	42	10.26	340
157	0.95	31	9.57	317
158	0.9	30	9.44	312
159	0.87	29	7.6	252
160	2.59	86	7.88	261
161	1	33	6.03	200
162	0.62	21	5.14	170
163	3.53	117	3.53	117

1950

Point number	Measured active channel width (mm)	Computed active channel width (m)	Measured flood channel width (mm)	Computed flood channel width (m)
102				
103				
104				
105				
106				
107				
108				
109				
110				
111				
112				
113				
114				
115				
116				
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127				
128				
129				
130				
131				
132				
133				
134				
135				
136	2.07	96	3.27	151
137	3.15	146	4.64	214
138	1.89	87	3.36	155
139	2.61	121	6.59	304
140	1.33	61	4.54	210
141	2.55	118	5.87	271
142	0.76	35	2.72	126
143	3.78	175	6.13	283
144	2.01	93	5.74	265
145	0.87	40	5.51	255
146	4.21	195	7.03	325
147	1.35	62	4.73	219
148	1.09	50	4.09	189
149	1.41	65	6.6	305

Point number	Measured active channel width (mm)	Computed active channel width (m)	Measured flood channel width (mm)	Computed flood channel width (m)
150	1.42	66	5.04	233
151	1.18	55	5.17	239
152	1.11	51	6.49	300
153	1.8	83	6.72	310
154	1.41	65	7.95	367
155	1.12	52	8.63	399
156	0.67	31	9.24	427
157	0.8	37	4.16	192
158	3.39	157	8.94	413
159	0.98	45	5.76	266
160	1.05	49	5.49	254
161	1.15	53	3.75	173
162	1.61	74	5.8	268
163	2.14	99	2.14	99

1953

Point number	Measured active channel width (mm)	Computed active channel width (m)	Measured flood channel width (mm)	Computed flood channel width (m)
102	1.14	65	3.15	179
103	1.01	57	3.77	214
104	0.98	56	4.74	269
105	0.96	54	4.45	252
106	1.15	65	3.23	183
107	0.66	37	1.64	93
108	1.6	91	2.48	141
109	1.27	72	4.69	266
110	2.49	141	3.54	201
111	1.35	77	4.16	236
112	5.68	322	5.91	335
113	1.21	69	2.37	134
114	1.09	62	2.12	120
115	0.86	49	4.28	243
116	0.72	41	3.45	196
117	1.04	59	6.09	345
118	0.79	45	6.77	384
119	0.82	46	1.96	111
120	1.91	108	4.68	265
121	1.21	69	3.45	196
122	1.01	57	5.75	326
123	0.46	26	1.91	108
124	0.37	21	3.67	208
125	0.27	15	2.52	143
126	0.97	55	4.61	261
127	2.35	133	5.46	310
128	0.77	44	4.13	234
129	1.94	110	6.99	396
130	2.98	169	9.25	524
131	1.48	84	3.24	184
132	1.39	79	3.66	208
133	1.22	69	3.12	177
134	1.98	112	4.61	261
135	1.56	88	3.33	189
136	2.54	144	2.54	144
137	1.57	89	3.21	182
138	1.5	85	1.63	92
139	1.95	111	3.78	214
140	3.57	202	3.57	202
141	1.47	83	3.1	176
142	0.74	42	2.62	149
143	1.18	67	3.8	215
144	1.16	66	7.45	422
145	0.96	54	5.21	295
146	0.81	46	6.01	341
147	1.06	60	2.15	122
148	0.75	43	3.44	195
149	1.29	73	4.34	246

Point number	Measured active channel width (mm)	Computed active channel width (m)	Measured flood channel width (mm)	Computed flood channel width (m)
150	1.88	107	3.98	226
151	1.67	95	5.97	338
152	1.44	82	9.9	561
153	2.24	127	5.93	336
154	1.74	99	6.2	352
155	1.88	107	6.23	353
156	1.71	97	6.76	383
157	1.27	72	3.22	183
158	1.76	100	4.86	276
159	3.13	177	4.56	259
160	2.02	115	3.62	205
161	2.95	167	3.77	214
162	1.91	108	2.34	133
163	1.66	94	1.66	94

1956

Point number	Measured active channel width (mm)	Computed active channel width (m)	Measured flood channel width (mm)	Computed flood channel width (m)
102				
103				
104				
105				
106				
107				
108				
109				
110				
111				
112				
113				
114				
115				
116				
117				
118				
119				
120				
121				
122				
123				
124				
125				
126				
127				
128				
129				
130				
131	1.82	42	7.97	185
132	2.33	54	8.46	196
133	2.29	53	8.31	193
134	2.29	53	8.6	200
135	2.63	61	6.41	149
136	4.24	98	6.28	146
137	2.18	51	5.1	118
138	2.4	56	2.8	65
139	5.23	121	5.23	121
140	4.37	101	9.58	222
141	3.67	85	8.56	199
142	3	70	6.3	146
143	2.49	58	10.63	247
144	2.68	62	12.29	285
145	1.22	28	11.85	275
146	0.93	22	14.02	325
147	2.02	47	4.41	102
148	0.95	22	8.86	206
149	1.8	42	9.88	229

Point number	Measured active channel width (mm)	Computed active channel width (m)	Measured flood channel width (mm)	Computed flood channel width (m)
150	2.44	57	3.59	83
151	1.65	38	4	93
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153				
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156				
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158				
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161				
162				
163				

1965

Point number	Measured active channel width (mm)	Computed active channel width (m)	Measured flood channel width (mm)	Computed flood channel width (m)
102	2.53	55	7.73	169
103	0.5	11	1.86	41
104	1	22	5.92	129
105	0.83	18	3.27	71
106	1.92	42	2.89	63
107	0.85	19	4.37	95
108	5.17	113	6.83	149
109	10.51	229	11.1	242
110	5.36	117	8.5	185
111	3.35	73	13.91	303
112	7.64	167	17.64	385
113	1.94	42	6.1	133
114	1.63	36	5.16	112
115	2.01	44	4.45	97
116	1.18	26	3.81	83
117	1.29	28	14.25	311
118	1.86	41	3.53	77
119	2.97	65	8.79	192
120	1.74	38	10.53	230
121	1	22	8.55	186
122	0.77	17	12.45	271
123	2.31	50	4.05	88
124	1.3	28	5.84	127
125	1	22	6.02	131
126	2.56	56	17.11	373
127	2.62	57	14.85	324
128	3.76	82	15.47	337
129	3.2	70	7.86	171
130	6.72	146	11.75	256
131	2.39	52	5.96	130
132	2.02	44	7.04	153
133	2.74	60	8.57	187
134	3.81	83	5.25	114
135	1.96	43	5.13	112
136	1.69	37	6.06	132
137	3.1	68	4.91	107
138	2.02	44	3.58	78
139	1.89	41	5.86	128
140	2.33	51	11.63	254
141	2.24	49	11.77	257
142	2	44	7.09	155
143	4.05	88	11.05	241
144	3.04	66	17.68	385
145	1.71	37	10.52	229
146	0.97	21	5.86	128
147	2.41	53	4.56	99
148	0.93	20	6.55	143
149	6.67	145	11.67	254

Point number	Measured active channel width (mm)	Computed active channel width (m)	Measured flood channel width (mm)	Computed flood channel width (m)
150	2.96	65	9.43	206
151	2.39	52	11.29	246
152	3.96	86	10.66	232
153	3.5	76	14.13	308
154	3.12	68	11.12	242
155	3.62	79	7.45	162
156	3.36	73	5.62	123
157	4.95	108	4.95	108
158	6.31	138	14.25	311
159	2.02	44	11.82	258
160	1.74	38	12.41	271
161	3.07	67	5.82	127
162	1.64	36	9.06	198
163	4.63	101	4.63	101

1973

Point number	Measured active channel width (mm)	Computed active channel width (m)	Measured flood channel width (mm)	Computed flood channel width (m)
102	2.33	72	4.73	147
103	0.92	29	9.26	287
104	0.76	24	8.44	262
105	2	62	11.35	352
106	2.56	79	4.8	149
107	1.49	46	2.6	81
108	1.12	35	5.82	180
109	7	217	8.8	273
110	3.32	103	5.86	182
111	8.33	258	10.24	317
112	9.61	298	12.04	373
113	1.69	52	4.09	127
114	1.28	40	5.32	165
115	1.02	32	2.73	85
116	1.36	42	9.02	280
117	3.05	95	10.29	319
118	1.83	57	12.12	376
119	2.33	72	5.83	181
120	2.1	65	8.66	268
121	2.65	82	11.31	351
122	1.23	38	9.9	307
123	1.21	38	2.96	92
124	1.61	50	8.36	259
125	0.82	25	5.52	171
126	1.86	58	12.23	379
127	0.92	29	9.86	306
128	5.43	168	11.87	368
129	5.25	163	6.71	208
130	8.27	256	9.69	300
131	2.32	72	6.44	200
132	5.92	184	6.57	204
133	4.95	153	6.99	217
134	6.42	199	8.81	273
135	2.34	73	4.92	153
136	2.67	83	3.68	114
137	3.03	94	5.31	165
138	2.97	92	2.97	92
139	2.25	70	6.43	199
140	2.39	74	8.14	252
141	3.26	101	4.92	153
142	1.81	56	5.03	156
143	2.96	92	6.93	215
144	3.33	103	8.43	261
145	2.98	92	8.36	259
146	1.05	33	8.8	273
147	1.39	43	3.51	109
148	1.23	38	5.87	182
149	1.19	37	5.45	169

Point number	Measured active channel width (mm)	Computed active channel width (m)	Measured flood channel width (mm)	Computed flood channel width (m)
150	2.58	80	11.6	360
151	1.75	54	6.87	213
152	4.37	135	13.58	421
153	2.86	89	10.83	336
154	3.07	95	10.53	326
155				
156				
157				
158				
159				
160				
161				
162				
163				

1975

Point number	Measured active channel width (mm)	Computed active channel width (m)	Measured flood channel width (mm)	Computed flood channel width (m)
102	1.07	44	3.22	132
103	0.52	21	2.25	92
104	0.54	22	3.33	136
105	1	41	2.95	121
106	1.79	73	1.79	73
107	1.19	49	2.9	119
108	0.74	30	4.03	165
109	3.79	155	6.85	280
110	2.26	92	4.36	178
111	1.2	49	6.82	279
112	3.81	156	7.68	314
113	1.19	49	2.99	122
114	1.3	53	4.56	187
115	1.03	42	5.39	220
116	0.95	39	4.94	202
117	1.37	56	8.55	350
118	1.31	54	7.69	315
119	1.06	43	4.25	174
120	1.96	80	6.71	274
121	0.94	38	6.72	275
122	1.23	50	6.57	269
123	1.1	45	1.62	66
124	1.34	55	3.61	148
125	0.86	35	3.93	161
126	1.96	80	9.63	394
127	0.99	40	8.06	330
128	0.83	34	9.61	393
129	0.95	39	7.04	288
130	4.73	193	14.36	587
131	1.77	72	5.99	245
132	3.51	144	5.47	224
133	2.52	103	6.12	250
134	3.12	128	7.95	325
135	1.71	70	3.71	152
136	2	82	2.57	105
137	2.52	103	4.99	204
138	1.65	67	4.99	204
139	2.26	92	4.88	200
140	1.68	69	6.54	267
141	1.64	67	5.46	223
142	1.94	79	3.83	157
143	1.52	62	6.39	261
144	2.4	98	6.07	248
145	0.69	28	2.54	104
146	0.61	25	6.61	270
147	1.16	47	2.34	96
148	0.61	25	3.49	143
149	1.79	73	3.81	156

Point number	Measured active channel width (mm)	Computed active channel width (m)	Measured flood channel width (mm)	Computed flood channel width (m)
150	1.62	66	6.52	267
151	1.69	69	7.08	290
152	2.85	117	7.95	325
153	2.22	91	7.56	309
154	2.4	98	10.01	409
155	1.7	70	8.26	338
156	2.91	119	9.22	377
157	2.41	99	9.29	380
158	2.29	94	9.89	405
159	2.4	98	6.46	264
160	1.41	58	8.25	337
161	1.87	76	4.49	184
162	3.89	159	4.48	183
163	2.2	90	2.2	90

1980

Point number	Measured active channel width (mm)	Computed active channel width (m)	Measured flood channel width (mm)	Computed flood channel width (m)
102	3.48	117	5.76	193
103	2.3	77	3.47	116
104	2.75	92	4.78	160
105	4	134	6.53	219
106	1.95	65	3.72	125
107	1.61	54	2.23	75
108	1.43	48	4.53	152
109	7.14	239	8.04	269
110	4.18	140	5.55	186
111	5.51	185	6.35	213
112	3.96	133	10.91	365
113	2.43	81	3.62	121
114	1.44	48	6.47	217
115	3.16	106	5.71	191
116	1.69	57	9.74	326
117	2.92	98	11.08	371
118	3.68	123	10.65	357
119	4.93	165	7.19	241
120	3.9	131	7.83	262
121	3.12	105	7.6	255
122	3.22	108	7.56	253
123	1.24	42	2.1	70
124	3	101	3.75	126
125	2.22	74	4.43	148
126	5.86	196	11.41	382
127	1.63	55	7.39	248
128	3.94	132	4.67	156
129	3.78	127	5.27	177
130	2.11	71	8.13	272
131	5.44	182	7.1	238
132	7.37	247	8.82	295
133	10.15	340	11.86	397
134	6.08	204	12.25	410
135	2.42	81	5.27	177
136	2.99	100	4.44	149
137	4.87	163	7.04	236
138	5.68	190	5.68	190
139	4.92	165	12.23	410
140	4.34	145	7.22	242
141	2.03	68	6.72	225
142	3.56	119	4.46	149
143	6.17	207	9.58	321
144	6.01	201	10.14	340
145	3.48	117	8.46	283
146	2.08	70	8.97	300
147	4.85	162	4.85	162
148	3.21	108	5.8	194
149	6.8	228	11.44	383

Point number	Measured active channel width (mm)	Computed active channel width (m)	Measured flood channel width (mm)	Computed flood channel width (m)
150	2.77	93	2.77	93
151	3.85	129	3.98	133
152	3.75	126	6.09	204
153	2.13	71	4.57	153
154	4.52	151	10.26	344
155	3.77	126	7.44	249
156	6.98	234	6.98	234
157	5.84	196	5.84	196
158	4.54	152	9.1	305
159	6.08	204	12.83	430
160	5.63	189	9.47	317
161	3.9	131	6.63	222
162	5.73	192	8.92	299
163	3.77	126	3.77	126

1984

Point number	Measured active channel width (mm)	Computed active channel width (m)	Measured flood channel width (mm)	Computed flood channel width (m)
102				
103	1.65	49	7.76	231
104	1.41	42	5.24	156
105	2.2	66	7.46	222
106	2.31	69	4.71	140
107	1.6	48	2.61	78
108	1.46	44	4.41	131
109	1.42	42	8.43	251
110	1.66	49	5.84	174
111	2.35	70	6.84	204
112	2.45	73	11.82	352
113	2	60	4.37	130
114	2.09	62	6.07	181
115	3.66	109	6.83	204
116	1.85	55	10.53	314
117	2.7	80	12.8	381
118	3.62	108	13.5	402
119	6.04	180	8.76	261
120	4.17	124	6.78	202
121	5.21	155	7.46	222
122	6.7	200	9.52	284
123	1.53	46	2.68	80
124	2.88	86	5.65	168
125	3.16	94	5.38	160
126	6.91	206	14.01	417
127	4.25	127	11.13	332
128	6.71	200	12.9	384
129	4.62	138	6.44	192
130	2.73	81	9.71	289
131	6.28	187	8.95	267
132	9.71	289	10.55	314
133	11.25	335	14.7	438
134	7.75	231	14.28	426
135	2.91	87	5.25	156
136	2.88	86	2.88	86
137	7.46	222	9.07	270
138	6.88	205	8.6	256
139	5.97	178	8.24	246
140	6.42	191	8.55	255
141	2.69	80	8.25	246
142	3.52	105	5	149
143	5.46	163	9.69	289
144	7.87	235	15.39	459
145	4.47	133	13.35	398
146	3.14	94	14.45	431
147	5.05	150	12.51	373
148	3.92	117	12.62	376
149	2.81	84	8.97	267

Point number	Measured active channel width (mm)	Computed active channel width (m)	Measured flood channel width (mm)	Computed flood channel width (m)
150	3.01	90	12.76	380
151	4.46	133	12.21	364
152	4.31	128	9.37	279
153	2.33	69	4.72	141
154	4.93	147	11.52	343
155	3.55	106	7.53	224
156	6.33	189	7.84	234
157	5	149	6.94	207
158	4.18	125	8.08	241
159	4.37	130	13.79	411
160	3.38	101	6.96	207
161	5.25	156	10.07	300
162	6.26	187	10.13	302
163	1.83	55	1.83	55

1995

Point number	Measured active channel width (mm)	Computed active channel width (m)	Measured flood channel width (mm)	Computed flood channel width (m)
102				
103				
104				
105				
106				
107				
108				
109				
110				
111				
112				
113				
114				
115				
116				
117				
118				
119				
120				
121				
122				
123				
124				
125				
126				
127				
128				
129				
130				
131	9.04	171	10.57	200
132	14.68	277	22.47	425
133	7.47	141	20.3	384
134	5.65	107	20.34	384
135	4.56	86	7.43	140
136	3.52	67	6.58	124
137	11.52	218	11.52	218
138	11.78	223	17.24	326
139	13.39	253	17.14	324
140	4.11	78	9.26	175
141	4.78	90	7.64	144
142	2.39	45	7.37	139
143	10	189	11.75	222
144	6.05	114	20.01	378
145	14.73	278	16.31	308
146	11.35	215	17.35	328
147	8.51	161	12.85	243
148	5.64	107	9.5	180
149	4.48	85	18.82	356

Point number	Measured active channel width (mm)	Computed active channel width (m)	Measured flood channel width (mm)	Computed flood channel width (m)
150	4.94	93	12.06	228
151	8.47	160	16	302
152	8.87	168	17.46	330
153	4.27	81	17.26	326
154	6.61	125	19.34	366
155	2.97	56	8.06	152
156	8.03	152	16.34	309
157	7.73	146	14.08	266
158	4.77	90	15.72	297
159	6.16	116	19.39	366
160	6.52	123	10.67	202
161	4.33	82	10.78	204
162	3.59	68	10.82	204
163	4.82	91	4.82	91

1996/98

Point number	Measured active channel width (mm)	Computed active channel width (m)	Measured flood channel width (mm)	Computed flood channel width (m)
102	2.21	96	5.59	243
103	2.34	102	4.65	202
104	2.39	104	6.43	280
105	3.4	148	8.59	374
106	0.61	27	3.21	140
107	0.96	42	2.49	108
108	1.9	83	3.78	164
109	2.1	91	6.3	274
110	1.11	48	4.15	181
111	2.54	110	6.48	282
112	5.3	231	9.14	398
113	1.13	50	2.64	117
114	4.79	212	6.18	274
115	3.56	158	7.44	330
116	1.45	64	7.36	326
117	4.7	208	8.53	378
118	4.58	203	9.18	407
119	2.56	113	10.07	446
120	2.06	91	5.18	229
121	1.76	78	6.55	290
122	3.47	154	6.02	267
123	0.87	39	0.87	39
124	1.66	74	7.58	336
125	2.73	121	3.52	156
126	4.64	206	10.52	466
127	2.42	107	8.63	382
128	5.45	241	9.37	415
129	3.04	135	5.07	225
130	4.53	201	9.82	435
131	3.52	156	4.46	198
132	3.21	142	8.49	376
133	5.02	222	8.86	392
134	6.17	273	8.38	371
135	1.99	88	3.03	134
136	1.75	78	2.88	128
137	4.88	216	5.78	256
138	5.21	231	8.13	360
139	5.71	253	8.55	379
140	2.18	97	4.03	179
141	2.09	93	5.64	250
142	1.41	62	3.19	141
143	3.11	138	5.05	224
144	2.61	116	7.48	331
145	6.38	283	8.77	389
146	4.88	216	8.28	367
147	4.33	192	7.47	331
148	2.58	114	4.74	210
149	6.15	272	8.61	381

Point number	Measured active channel width (mm)	Computed active channel width (m)	Measured flood channel width (mm)	Computed flood channel width (m)
150	1.74	77	4.33	192
151	4.08	181	8.31	368
152	4.02	178	8.27	366
153	3.59	159	7.82	346
154	5.46	242	9.02	400
155	2.96	131	2.78	123
156	4.2	186	8.13	360
157	2.79	124	8.75	388
158	1.48	66	6.09	270
159	2.33	103	8	354
160	2.16	96	3.94	175
161	0.93	41	3.62	160
162	1.25	55	4.93	218
163	1.81	80	2.36	105

2001

Point number	Measured active channel width (m)	Measured flood channel width (m)
102	83	284
103	79	285
104	74	232
105	149	522
106	82	152
107	76	90
108	64	153
109	97	267
110	48	157
111	203	324
112	212	367
113		
114		
115		
116	52	93
117	192	204
118	173	378
119	230	421
120	162	238
121	187	285
122	177	260
123	44	65
124	63	139
125	81	151
126	238	420
127	99	318
128	212	295
129	120	192
130	209	234
131	83	171
132	49	368
133	103	341
134	114	261
135	38	111
136	45	122
137	166	337
138	188	422
139	138	272
140	147	193
141	79	143
142	66	110
143	127	198
144	165	358
145	132	384
146	99	349
147	176	273
148	91	183
149	150	340

Point number	Measured active channel width (m)	Measured flood channel width (m)
150	64	186
151	112	241
152	144	280
153	101	231
154	63	373
155	66	303
156	187	302
157	116	276
158	49	294
159	151	319
160	87	219
161	56	172
162	59	192
163	91	114