CHANGES IN RIPARIAN VEGETATION IN THE SOUTHWESTERN UNITED STATES:

Floods and Riparian Vegetation on the San Juan River, Southeastern Utah

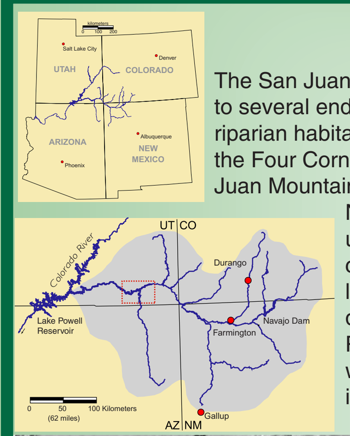
USGS GROUND WATER RESOURCES PROGRAM

ROBERT H. WEBB and DIANE E. BOYER
U.S. Geological Survey, 1675 W. Anklam Road, Tucson, AZ 85745

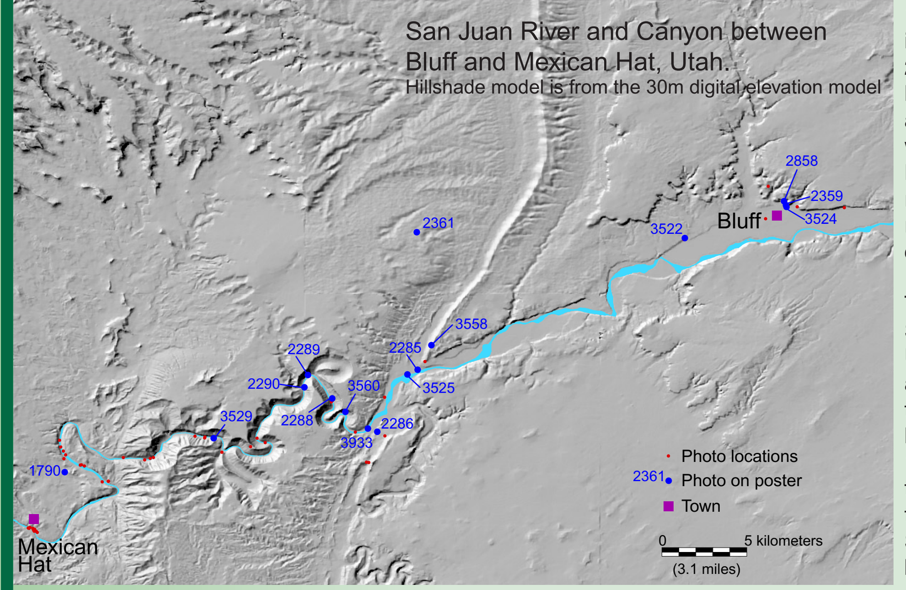
USGS OPEN FILE REPORT OF 01-314

LYNN ORCHARD and VICTOR R. BAKER
Department of Hydrology and Water Resources, University of Arizona, Tucson, AZ 85712

INTRODUCTION



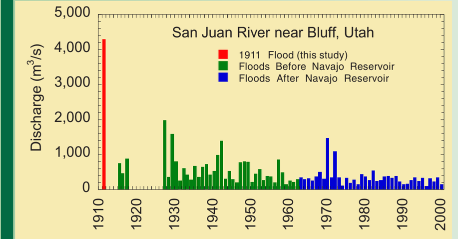
The San Juan River is an important source of water for agriculture and domestic use, is home to several endangered fish species, is a valued whitewater recreation area, and supports valued riparian habitat. This major tributary of the Colorado River drains 60,000 km^2 (23,000 mi^2) of the Four Corners Region upstream from Mexican Hat, Utah, and has its headwaters in the San Juan Mountains of southwestern Colorado. The river cuts a canyon through northern New Mexico and southern Utah until it enters Lake Powell reservoir. The river was unregulated before June 28,1962, when Navajo Dam was completed; the dam's flood-control operations reduce peak discharges downstream. Before flow regulation, a very large flood occurred on the San Juan River on October 6, 1911, causing severe damage; however, the discharge for this flood has only been roughly estimated. Photographs of the river corridor from the 19th and early 20th centuries show a wide floodplain with sparse riparian vegetation, and repeat photographs show a large increase in both native and non-native vegetation. The purpose of this poster is to evaluate whether the 1911 flood, or other floods in the late 19th and early 20th century, explain the lack of riparian vegetation along this river, and whether flood control by Navajo Reservoir has resulted in an influx of riparian vegetation and channel narrowing.

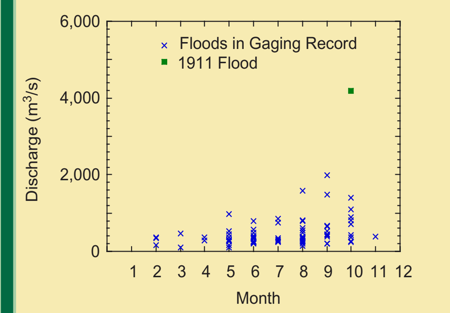


The gaging station of the San Juan River near Bluff, Utah (the gaging station actually is upstream from the bridge at Mexican Hat), has recorded floods from 1914 to 1916 and 1927 to the present. Historically, the largest floods on the San Juan River occurred between late summer and early fall (August-October).

The largest flood in the gaging record had a discharge of 1,980 m^3/s (70,000 ft^3/s) on September 10, 1927; the stage of this flood was about 10 m (31 ft). After 1962 and through 2001, the largest flood on the San Juan River was 1,090 m^3/s (38,500 ft^3/s) caused by Tropical Storm Norma on September 6, 1970 (Roeske et al., 1978). Most of the runoff generated by this storm was downstream from Navajo Reservoir.

Several floods before the start of the gaging record in 1914 were larger and more damaging than the 1927 flood. Published accounts document two extremely large floods in 1909 and 1911. The 1909 flood occurred in early September and was attributed to heavy and continuous rains in the San Juan's headwaters. Long-time residents of nearby Farmington, New Mexico, stated that the flood was the largest since the settlement of the area in 1880 (Freeman, 1909). A larger flood peaked on October 6, 1911, after a week of heavy rains (Brandenberg, 1911). This flood destroyed most of the bridges on the mainstem San Juan River, including the first Goodridge bridge at Mexican Hat. That bridge was 12 m (39 ft) above the river. LaRue (1925) reported that this flood had a discharge of 4,250 m^3/s (150,000 ft^3/s), but provided no supporting documentation.

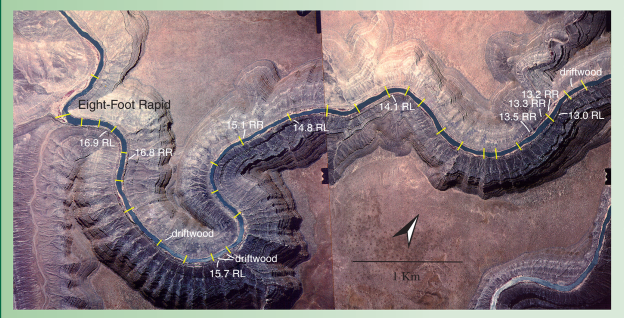




Seasonality of annual peak floods in the San Juan River. The largest floods result from rainfall in August-October.

EVIDENCE OF PAST FLOODS

Paleoflood hydrology involves the reconstruction of the dates and discharges of past floods, including historical events not recorded at gaging stations. The San Juan Canyon upstream from Mexican Hat contains an extraordinary amount of slackwater-deposit, paleostage-indicator (SWD-PSI) evidence that allows estimation of the discharges of past floods (Orchard, 2001). As the river flows west between Bluff and Mexican Hat, Utah, it cuts perpendicularly through a series of uplifted monoclines and anticlines in Paleozoic rocks and becomes entrenched deep in the limestones of the Honaker Trail and Paradox Formations. The resistant limestones form a narrow, deep canyon with numerous bedrock overhangs that preserve sediment deposited by large floods. A nearly continuous series of slackwater deposits and driftwood lines deposited 8-14 m (26-45 ft) above the channel are present within the 8 km (5 mi) reach (river mile 13 to 18). Stratigraphic sequences were described at 11 sites, and paleostage indicators such as driftwood lines have been described at several other sites (Orchard, 2001). Each stratigraphic section contains evidence of 3-5 floods, but as many as 10 flood deposits are present in some sections. The discovery of human-made structures and artifacts buried under flood deposits suggests that these floods are all historic. The presence of non-native plant materials in the sediments further underscores that all flood deposits are historic (Orchard, 2001).



Aerial photographs of the study reach, including the location of the surveyed cross sections (yellow bars), Eight-Foot Rapid, and the location of prominent slackwater and driftwood deposits (white text). Flow is from right to left.

Throughout the study reach, well-preserved driftwood lines are sometimes continuous for over 1 km (0.6 mi). These driftwood lines contain historic artifacts, such as sawn wood, metal cans, and nails. Some of the nails have round heads, suggesting they were manufactured after 1900. These high driftwood lines greatly exceed the expected elevations of any measured discharge recorded in the gaging record, and we attribute them to the October 1911 flood. The continuous driftwood lines provide a record of the water-surface profile during this large flood.

Slackwater deposits in this reach of the San Juan river are typically found under overhangs created by bedrock outcrops. Driftwood is found at higher elevations than slackwater deposits and typically lies on rocky talus slopes exposed to weathering.

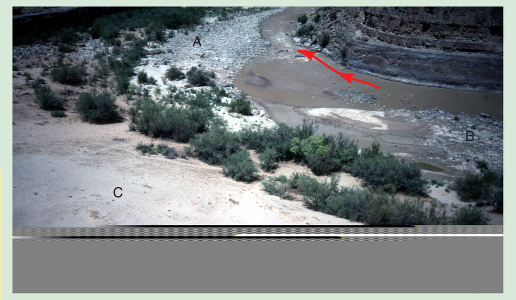
In this view, typical exposure of slackwater sediments is preserved underneath a bedrock overhang. This particular deposit is at river mile 15.1 on river right and contains 6 flood units.

DISCHARGE ESTIMATES

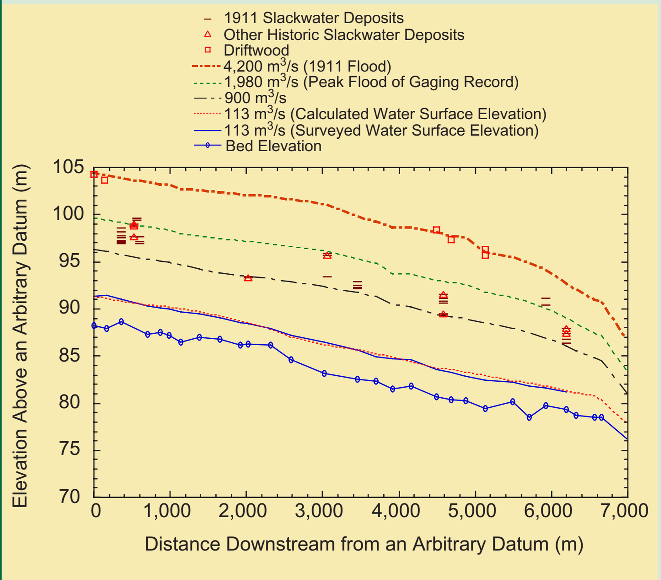
The abundant slackwater-deposit paleostage-indicators (SWD-PSI), particularly the driftwood lines, allow water-surface elevations of the 1911 flood to be known at many more points than are typically available in paleoflood studies on other rivers in the region. Paleoflood discharges typically are calculated using one-dimensional hydraulic models based on Manning-n roughness coefficients (Webb and Jarrett, in press). We measured 30 channel cross-sections spaced at 200-300 m (650-975 ft) intervals over a distance of 8 km (5 mi) that were designed to correspond to a surveyed water-surface profile from the SWD-PSI (Orchard, 2001). Low-water Manning-n coefficients were determined by calibrating a step-backwater model to a water-surface profile measured at a constant discharge of 113 m^3/s (4,000 ft^3/s). The Manning-n values were extended upwards to the SWD-PSI elevations by correlation with published photographs of channels with known roughness coefficients. Bedrock controls the entire cross section at the upstream end of the study reach, indicating that scour and fill is not significant, and an ancient debris fan and a severe constriction constrain hydraulic conditions to critical depth at the downstream end.

The abundance of SWD-PSI along the San Juan River allow the use of the slope-area method, which ordinarily is not appropriate for estimating discharges for paleofloods (Webb and Jarrett, in press). A particularly well-defined driftwood line near the center of the reach provided sufficient elevations to allow a slope-area estimate using 3 of the 30 cross sections. Using the slope-area method, the discharge of the 1911 flood was estimated to have a discharge of 4,350 m^3/s (154,000 ft^3/s). The step-backwater analysis used all 30 cross sections and estimated a discharge of approximately 4,200 m^3/s (148,000 ft^3/s) for the 1911 flood.

Driftwood is one of the primary paleostage indicators used to reconstruct the 1911 flood discharge. The highest-elevation flood deposits in the study area are driftwood lines that contain both sawn wood, nails, and metal cans. The hashed area shows the approximate cross-sectional area and stage of a 4,200 m^3/s (148,000 ft^3/s) discharge. Abundant driftwood in the foreground is piled on the upstream side of a rock, indicating flow was from upstream to downstream and the entire cross section was part of the effective flow area. The raft in the center right of the frame is 6 m (18 ft) long, and the discharge in the photo is 25 m^3/s (~900 ft^3/s).



This downstream view shows Eight-Foot Rapid, the downstream control section for the step-backwater model of the 1911 and other floods. Features preserved here include (A) an ancient debris fan, (B) a younger debris fan, and (C) slackwater deposits in the form of an extremely large reattachment bar.



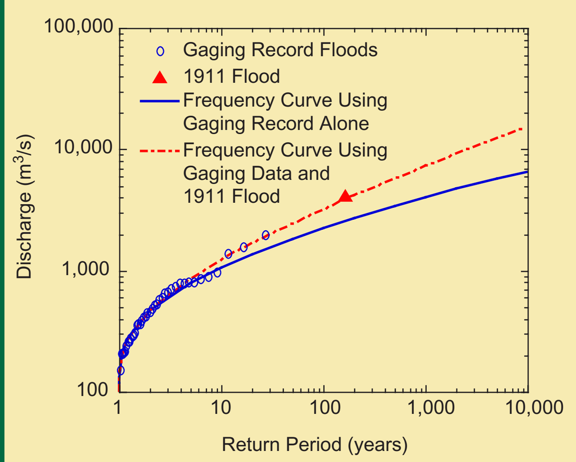
Surveyed and calculated water-surface profiles compared to elevations of slackwater and driftwood deposits.

This structure at mile 13.2 is buried by a flood deposit. The structure may be historic or related to Ancestral Puebloan use of San Juan Canyon. Other structures provide evidence that all the flood deposits in San Juan Canyon upstream from Mexican Hat are historic.

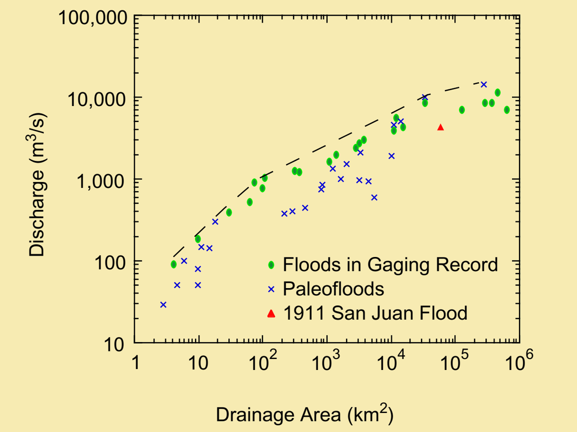
FLOOD FREQUENCY

To calculate flood frequency, we combined the discharge of the 1911 flood with the pre-dam gaging data using an efficient method of moments procedure based on type II censoring (Cohn et al., 1997). The 1911 flood was considered as the largest between 1880 and 2001. Based on our analysis, the 1911 flood has an estimated recurrence interval of about 150 years. Including the 1911 flood in the frequency analysis increased the estimate of the 100-year flood by 44% from 2,240 m^3/s (gaging data alone) to 3,210 m^3/s (79,100 to 113,000 ft^3/s respectively). To verify the reasonableness of the discharge of the 1911 flood, we plotted its value on the regional envelope curve for the Colorado River drainage (Enzel et al., 1993), with the result that the discharge plotted well below the enveloping curve.

The 1911 flood was not only the largest flood during the historic period, it is the largest flood that has left preserved evidence in the San Juan Canyon. No flood evidence was observed at elevations higher than the historic driftwood line deposited by the 1911 flood despite conditions ideal for the preservation of flood deposits. All flood deposits at elevations lower than the 1911 driftwood line contained evidence that indicated they were historic. This suggests that the 1911 flood may have been large enough to remove any flood deposits that were emplaced before 1911.



Flood-frequency curves calculated using gaging data alone and gaging data with the 1911 flood



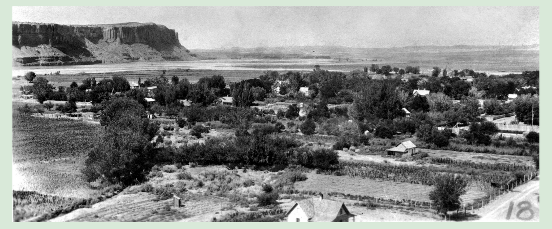
Regional envelope curve for the lower Colorado River drainage basin (modified from Enzel et al., 1993).

REPEAT PHOTOGRAPHY

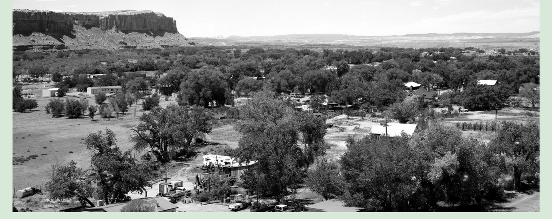
We matched a total of 74 historical photographs between Bluff and Mexican Hat. The main purpose of matching these photographs was to evaluate long-term changes in riparian vegetation in this reach. The following 15 sets of photographs illustrate the changes we observed in the riparian vegetation along the San Juan River.

(1890s). This downstream view, with the Navajo Twins rock formation at left, shows Bluff in the early 1890s and the wide and denuded channel of the San Juan River in the middle distance. Scattered groves of trees line the channel, which in places is about 400 m (1,300 ft) wide. Bluff was founded in 1880, more than a decade before this photograph (Charles Goodman 64, courtesy of the University of Utah Marriott Library).

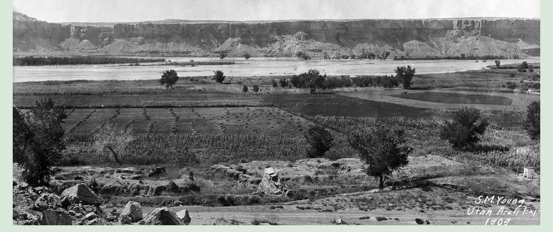
(July 2, 2000). The channel of the San Juan River is no longer visible from this vantage point. The floodplain is clogged with riparian vegetation, both native and non-native species. Cottonwoods (*Populus fremontii*) are locally abundant in this reach, but the most widespread species are coyote willow (*Salix exigua*) and non-native tamarisk (*Tamarix* sp.); Russian olive (*Elaeagnus angustifolia*) is locally abundant. Trees have grown in town also, blending with the riparian vegetation (Dominic Oldershaw, Stake 2858).



(July 15, 1921). This view, taken in approximately the same direction as the previous one but upstream from the Navajo Twins, shows the channel of the San Juan River was free of riparian vegetation in 1921. The trees in Bluff are taller than in 1890, and the town appears to be considerably larger (Robert N. Allen 18, courtesy of the USGS Photo Library).



(July 2, 2000). The San Juan River channel is completely obscured by riparian vegetation. Both native and non-native species densely cover the former floodplain (Dominic Oldershaw, Stake 3524).



(1909). This view, from approximately the same position as the previous photograph but angled across the San Juan River, shows the channel beyond cultivated agricultural fields. Broad islands vegetated with low-statured riparian vegetation appear in the channel at both the left and right sides of the view. Scattered trees, probably cottonwoods, are visible across the channel in the center. This photograph was taken just before the 1909 flood (Stuart Malcolm Young NAU.PH.643.1.2, courtesy of Northern Arizona University Cline Library).

(July 2, 2000). The main highway from Bluff to Blanding appears in the foreground, and agricultural fields continue to be tilled in this area. The channel of the San Juan is obscured in a sea of riparian plants, mostly tamarisk, willows, and scattered cottonwood trees. Note that the former islands appear to have denser riparian vegetation than the formerly barren areas (Dominic Oldershaw, Stake 2359a).

(1925). West of Bluff, the San Juan River flows beneath bluffs of Page Sandstone. This view, from the old road between Bluff and Mexican Hat, faces due south from a terrace above the right bank. Flow is from left to right. The channel is broad and almost entirely free of vegetation, with numerous secondary channels; the main channel is probably directly beneath the distant bluffs (Lee 3172, courtesy of the USGS Photo Library).

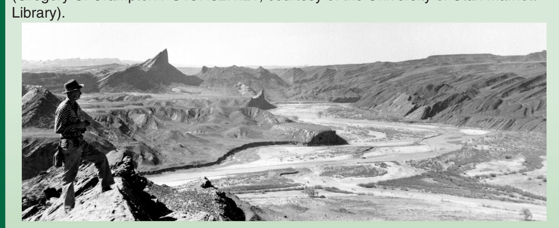
(March 22, 1998). The channel of the San Juan River has narrowed considerably, and all secondary channels have disappeared. Most of the vegetation is tamarisk and Russian olive, although coyote willows line the active channel (Robert H. Webb, Stake 3522a).

(ca. 1927) The original view was taken from the mouth of Comb Wash looking southwest toward the Mule's Ear diatreme (center). The flowing water is almost indistinguishable from the sandy channel, but the river is flowing beneath the cutbank in the middle distance. The channel here is wide and vegetation free except for small cottonwoods at right (Herbert E. Gregory 536, courtesy of the USGS Photo Library).

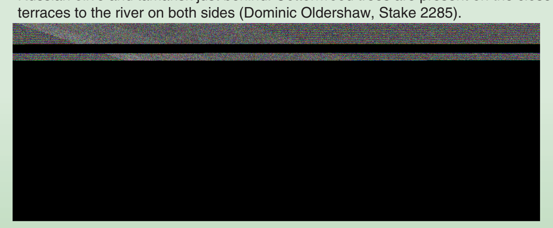
(March 23, 1998). The view is now blocked by riparian vegetation, including non-native tamarisk (taller trees) and native rabbitbrush (*Chrysothamnus nauseosus*; white flower heads). The cottonwood trees, leafless in March, appear in the right midground. The cottonwoods in the original view are no longer present, but new cottonwoods are in approximately same location (Robert H. Webb, Stake 3525).

(March 1953). This upstream view of the San Juan River shows the mouth of Comb Wash (left midground, just beyond the jeep). Short-statured riparian plants with the appearance of coyote willow line both the San Juan and the upstream side of Comb Wash. This photograph was taken 9 years before completion of Navajo Reservoir (Gregory C. Crampton PO197:52:1:21, courtesy of the University of Utah Marriott Library).

(August 26,1997). Considerable riparian vegetation is now present throughout this view, and Comb Wash drains into a shallow distributary channel north (river right) of the main river channel. Both native and non-native riparian vegetation have increased; coyote willow generally is the shrub closest to the river channel, with Russian olive and tamarisk just behind. Cottonwood trees are present on the closest terraces to the river on both sides (Dominic Oldershaw, Stake 2285).



(March 1953). The photographer is standing on "San Juan Hill," a promontory just upstream from the confluence of Comb Wash (right foreground), and the view of the San Juan River is downstream. The Mule's Ear diatreme is at left center, and the entrance to San Juan Canyon is at right center; Chinle Wash joins the San Juan River at about the point where the river disappears from view. The channel of the San Juan, which was obviously much wider, has narrowed recently; note the sharp cutbank across the river in the center of the photograph and low cutbanks and floodplains. Low-statured riparian vegetation is becoming established along both drainages; a lone cottonwood appears at lower center (Gregory C. Crampton PO197:52:1:36, courtesy of the University of Utah Marriott Library).



(March 23, 1998). The channel of both the San Juan River and Chinle Wash have narrowed considerably. In this reach, the channel of the San Juan is divided through a series of islands densely covered with riparian vegetation. Cottonwood trees are difficult to identify in this late-winter view, but they are present along most of the channel, particularly along river right (Dominic Oldershaw, Stake 3558).

(July 19, 1921). This downstream view, downstream from the confluence with Chinle Creek, shows the entrance to San Juan Canyon. The channel is wide with broad sand bars. A high terrace on river right is covered with dense, low vegetation that could be either coyote willows, young tamarisk, or native shrubs such as rabbitbrush; several young cottonwoods are present on the far bank (river right). This photograph was matched in 1973 (Baars, 1974, p. 67), and riparian vegetation had begun encroaching on the river channel at that time (Hugh D. Miser 415, courtesy of the USGS Photo Library).

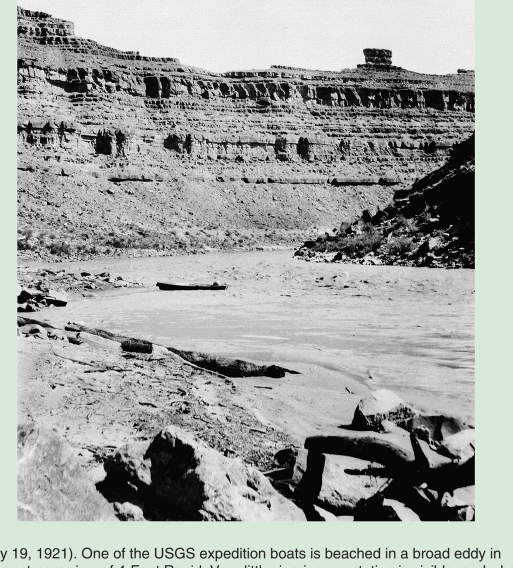
(August 26, 1997). The channel has narrowed significantly, both between 1921 and 1997 and especially between 1974 and 1997. The cottonwood trees present in 1921 have greatly increased in size, and tamarisk and Russian olive cover the floodplains. Russian olive is relatively sparse in the canyons downstream (Dominic Oldershaw, Stake 2286).

(1985). This upstream view, just downstream from the confluence of Chinle Wash and the San Juan River, shows the small boats of a commercial river trip. The river trip participants are likely hiking to the Mule's Ear diatreme, which is out of this view to the right. By 1985, riparian vegetation was relatively dense in this reach (Bill Belknap NAU.PH.96.4.318.8, courtesy of the Northern Arizona University Cline Library).

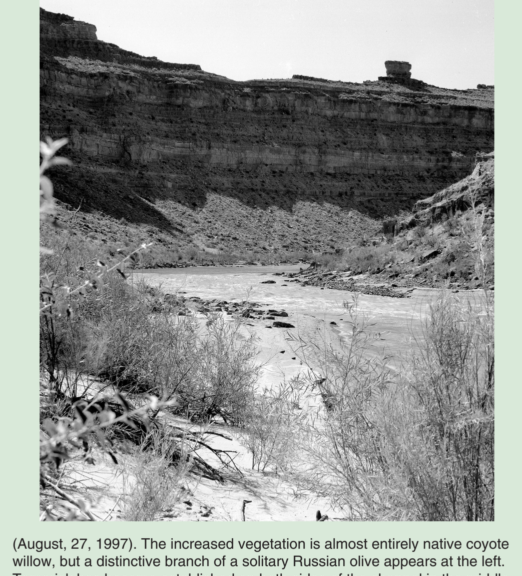
(October 28, 1999). Riparian vegetation has increased considerably in the 14 years since the 1985 photograph. Much of the increase is in non-native tamarisk, but cottonwood trees on both sides of the river have also increased in size. The gravel bar exposed on river left (right center) is not new but merely exposed in the low discharge of 23 m^3/s (822 ft^3/s) of this view (Dominic Oldershaw, Stake 3933).

(1921). Eugene C. LaRue, a USGS hydrologist, took this photograph of the San Juan River about 3 km (2 mi) downstream from the entrance to the canyon to document a potential damsite. This upstream view, which is the left center cropped from LaRue's wider view, shows the dam hand drawn on the photograph. Very little riparian vegetation is present in this reach, and the pointbar across the river appears scoured (Eugene C. LaRue 827, courtesy of the USGS Photo Library).

(March 24, 1998). At this low water level of less than 28 m^3/s (1,000 ft^3/s), a line of pourovers marks the first rapid of note in San Juan Canyon. The formerly denuded point bar is covered with riparian vegetation, much of which is non-native tamarisk (Dominic Oldershaw, Stake 3560a).



(July 19, 1921). One of the USGS expedition boats is beached in a broad eddy in this upstream view of 4-Foot Rapid. Very little riparian vegetation is visible, and what is present are low-statured shrubs. A clear high-water mark appears in the middle distance, probably as a result of the 1911 and other floods (Hugh D. Miser 418, courtesy of the USGS Photo Library).



(August, 27, 1997). The increased vegetation is almost entirely native coyote willow, but a distinctive branch of a solitary Russian olive appears at the left. Tamarisk has become established on both sides of the channel in the middle distance. Despite the substantial channel narrowing several miles upstream, the channel has not narrowed appreciably here, and the increase in riparian vegetation is not as large as in the alluvial reaches between Bluff and the entrance to the canyon. The light high-water mark has faded, obscured by desert vegetation (Dominic Oldershaw, Stake 2288).

(1941). A boat used by Norm Nevills on his pioneering river expeditions on the San Juan appears in this upstream view from the start of our study reach. Scattered stands of dense riparian vegetation are present on both banks, separated by scoured bedrock or barren sand. Some of the taller plants on the far bank (river left) likely are netleaf hackberry (*Celtis reticulata*), a small, native tree. This view does not show a significant change in density or cover of riparian vegetation in comparison with other photographs taken between 1875 and 1921 (Phillip W. Tompkins PO341:7:14:5, courtesy of the University of Utah Marriott Library).

(August 27, 1997). Riparian vegetation has increased greatly, particularly on the point bar at right center. Tamarisk has increased the most, although native species such as coyote willow are also present. A lone juniper appears under the cliff upslope from the point bar (Dominic Oldershaw, Stake 2289).

(1875). This upstream view, one of the first photographs of the San Juan River, shows high-elevation flood deposits on the far side of the river (left midground). These flood deposits were emplaced before the 1911 flood (William Henry Jackson 57-MS-538, courtesy of the National Archives).

(August 27, 1997). Most of the new vegetation is coyote willow, with scattered tamarisk trees on the far bank. The flood deposits are no longer prominent, being obscured by native grasses and desert shrubs. Driftwood, some of which was deposited by the 1911 flood, is about 13 m (42 ft) above the low-water channel on the slope leading to the background cliffs (Dominic Oldershaw, Stake 2290).

(1921) This downstream view shows the entrance to First Narrows and is just downstream from Eight-Foot Rapid. Our study reach ended at the entrance to First Narrows. The scattered riparian vegetation (left side) appears to be mostly netleaf hackberry trees (Robert N. Allen 27, courtesy of the Dan O'Laurie Museum).

(March 24, 1998). The original camera station is buried under a new sand bar; our camera station is about 1.2 m (4 ft) too high. Coyote willows line the river, with tamarisk just visible behind the willows. Beaver had culled some of the willows from the sandbar shortly before our visit (Robert H. Webb, Stake 3529).

(December 1894). This downstream view of the San Juan River is taken from a point on a cliff of Moenkopi Formation just upstream from the Mexican Hat. A gold dredge is visible in the center of the river in the midground. The channel is relatively wide and braided around sandbars in this reach. Other photographs taken at this time indicate that the riparian vegetation on the terraces (both sides of the river) are native coyote willow, leafless in winter (Charles Goodman PO068:78, courtesy of the University of Utah Marriott Library).

(July 3, 2000). Riparian vegetation has increased significantly on both sides of the river, resulting in significant channel narrowing. This reach is only partly bedrock controlled and has responded similarly to the reach from Bluff to the head of the canyon, both in terms of increases of riparian vegetation and channel narrowing. The vegetation consists of native coyote willow closest to the river channel and on the point bar in the middle distance where the dredge once was; a band of dense tamarisk occurs behind the willows. The floodplain consists of a mixture of native shrubs and smaller tamarisk (Dominic Oldershaw, Stake 1790).

CONCLUSIONS

The largest historic flood in the San Juan River occurred on October 6, 1911, with a discharge of 4,200 m^3/s (148,000 ft^3/s) and a recurrence interval of about 150 years. This flood appears to have removed all older flood evidence from San Juan Canyon below its peak stage. No flood evidence was found higher than the 1911 flood deposits despite ideal settings for preservation, suggesting that the 1911 flood may represent the largest flood on the San Juan River for a much longer time period than 1880-2001. Wide, vegetation-free channel conditions existed before the 1911 flood and afterwards until the last half of the 20th century, suggesting that this flood did not significantly affect the distribution of riparian communities. Channel narrowing occurred after 1941, as it has on other rivers in the region. Native and non-native riparian vegetation have encroached on the previously wide channel in the alluvial reach and in previously barren parts of the bedrock canyon. The increase in riparian vegetation has accelerated in recent decades. Changes in flood frequency and riparian vegetation are affected both by climatic fluctuations and flow regulation. The increase in riparian vegetation, particularly in the last 30 years, is associated with a regional increase in precipitation, particularly during winter. Unlike other rivers, winter floods have not increased, in part because of the operation of Navajo Reservoir. Construction of Navajo Dam and Reservoir has affected the San Juan River in complex ways that are not fully addressed in this study, including the attenuation of flood peaks caused by storms at higher elevations in the basin, storage of sediment generated in the Navajo Reservoir basin, and changes in seasonal flow patterns, all of which could have influenced the increase in riparian vegetation. Because flood waters mostly are generated at the higher elevations and sediment mostly is generated at lower elevations in the drainage, the channel narrowing is consistent with a river with decreased flow competence, or ability to transport sediment, but with a continued high sediment yield from its tributaries.

Acknowledgments. We offer special thanks to the River Office staff of the Monticello Field Office, Bureau of Land Management. Dominic Oldershaw matched many of the photographs. Peter Griffiths and Jessica Young helped with the illustrations. Additional thanks to the many field assistants who endured freezing rain, blistering heat, flash floods, and all of the other joys of working in such a beautiful canyon.

REFERENCES

Baars, D.L. (ed.), 1974, Geology of the canyons of the San Juan River: Durango, Colorado, Four Corners Geological Society, 94 p.

Brandenburg, F.H., 1911, Floods in southwestern Colorado and northwestern New Mexico: Monthly Weather Review, v. 39, p. 1570-1572.

Cohn, T.A., Lane, W.L., and Baier, W.G., 1997, An algorithm for computing moments-based flood quantile estimates when historical information is available: Water Resources Research, v. 33, p. 2089-2096.

Enzel, Yehouda, Ely, L.L., House, P.K., Baker, V.R., and Webb, R.H., 1993, Paleoflood evidence for a natural upper bound to flood magnitudes in the Colorado River basin: Water Resources Research, v. 29, p. 2287-2297.

Freeman, W.B., 1909, Flood on the San Juan River September, 1909: Monthly Weather Review, v. 37, p. 648-649.

LaRue, E.C., 1925, Water power and flood control of Colorado River below Green River, Utah: U.S. Geological Survey Water-Supply Paper 556, 176 p.

Orchard, K.L., 2001, Paleoflood hydrology of the San Juan River, southeastern Utah: Tucson, University of Arizona, unpubl. M.S. thesis, 138 p.

Roeske, R.H., Cooley, M.E., and Aldridge, B.N., 1978, Floods of September 1970 in Arizona, Utah, Colorado, and New Mexico: U.S. Geological Survey Water-Supply Paper 2052, 135 p.

Webb, R.H., and Jarrett, R.D., In press, One-dimensional estimation techniques for discharges of paleofloods and historical floods, in House, P.K., Webb, R.H., Baker, V.R., and Levish, D.R., Ancient floods and modern hazards, principles and applications of paleoflood hydrology: Washington, D.C., American Geophysical Union, Water Science and Application Series, v. 5, in press.