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A Centennial Tribute, 1906-2006: History of U.S. Geological Survey Streamgaging Activities for the Suwannee River at White Springs, Florida

By Richard Jay Verdi and Stewart A. Tomlinson

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Preface

Besides outlining the history of the first continuous record streamgage in Florida, this report is a tribute to advances in the technology, creativity, and dedication that generations of public servants have provided within the Federal Government. Their contributions have enabled the general public to obtain a better understanding of stream hydrology. One group of these public servants is the hydrographer, a role composed of many job titles such as engineers, engineering technicians, hydrologists, hydrologic technicians, and hydrologic aids. At the turn of the 20th century, hydrographers made flow measurements at selected streams across the United States using a mechanical current meter. These measurements were often made under conditions now deemed unsafe, as the hydrographer sat over the stream suspended in a cable car with no sides from a cable anchored only by purportedly sturdy trees on each side of the riverbank, while using a weight and current meter over the stream. These flow measurements were snapshots in time and were published in annual reports of the U.S. Geological Survey (USGS). Although these data were useful, the public needed information that would provide a more indepth story as to the rise and fall of streams.

In the early 1900s, hydrographers began collecting water-level data in the form of daily observations at staff gages set by the river. From the 1910s to the 1950s, different types of graphical-recording devices were connected to a float and tape set in stilling wells to continuously monitor the level of the river; these became the primary method of collecting water-level data into the 1970s. Pressure-level sensors of various types began use in the 1960s and continue today. Digital punch-tape recorders began use in the 1960s and were a primary data-collection device into the 1990s. Hydrographers dealt with the challenges that this new technology presented—paper jams of all types, accidental spills of thousands of bits of paper from the punch-drive activity, corrections for time in processing the data, and entering those data into the computer. In the late 1970s and into the 1980s, first-generation Data Collection Platforms (DCPs) began use by the USGS, and this equipment provided some of the first real-time data for the country. Hydrographers had to develop computer programming skills to get the DCPs to collect the needed data. Despite these significant changes in technology for collecting stage record, hydrographers continued to use mechanical current meters as the primary method of making discharge measurements throughout the 20th century.

In the 1990s, as the use of real-time data transmitters expanded exponentially, the USGS took the lead in developing software to store and archive those data, making them more widely available to the public. Additionally, devices using acoustic Doppler technology were developed by manufacturers and tested by the USGS. The hydrographer's role changed significantly—from a job where mechanical skills were paramount to a position where computer programming and analytical skills are essential. Today, hydrographers use a variety of acoustic devices to make measurements during low and routine flow, as well as floods, in minutes instead of hours, and, in an environment where safety is of greatest importance. Right now, thousands of DCPs are sending data to USGS computers around the world which is subsequently released to the public on the Internet almost immediately after collection. Thus, critical information needed by the public to manage floods, droughts, reservoir levels, water quality, and water use, as well as long-term studies and recreational use are available in real time. And, at the helm of every one of these DCPs is the hydrographer, needed then just as now, to provide valuable water-resources information to the public.

Stewart A. Tomlinson, Hydrologic Data Chief
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Archival photograph of the Boat Ride attraction on the Suwannee River (photograph courtesy of the Florida Archive).

Conversion Factors, Datum, and Acronyms

Multiply	By	To obtain
Length		
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
Area		
square miles (m^2)	2.590	square kilometer (km^2)
Flow rate		
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

Vertical coordinate information is referenced to the North American Vertical Datum of 1929 (NGVD 29).

ADCP	Acoustic Doppler Current Profilers
DCP	Data Collection Platforms
GOES	Geostationary Operational Environmental Satellite
HDR	High Data Rate
NOAA	National Oceanic and Atmospheric Administration
NSIP	National Streamflow Information Program
NWIS	National Water Information System
NWIS Web	National Water Information System Webpage
SRWMD	Suwannee River Water Management District
USGS	U.S. Geological Survey

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Leroy Pearman (U.S. Geological Survey, Florida Integrated Science Center—Orlando, Florida) provided technical review of the history and methods. Enterprise Publishing Network specialists Teresa Embry, Rhonda Howard, Ron Spencer, and Jim Tomberlin are recognized for their assistance with editorial review, graphic design, and layout.

A Centennial Tribute, 1906-2006: History of U.S. Geological Survey Streamgaging Activities for the Suwannee River at White Springs, Florida

By Richard Jay Verdi and Stewart A. Tomlinson

Abstract

For centuries, the banks of the Suwannee River at White Springs were considered a sacred ground where people sought refuge in its “healing waters.” Many believed that the mineral-enriched waters cured illnesses. The U.S. Geological Survey began continuous streamgaging activities at White Springs, Florida, in 1906 after an increase in congressional appropriations and rapid town development due to growing tourism and residential population. In 1906, streamgage data was a once-per-day gage reading that were handwritten in a water-level booklet by a local observer with discharge measurements taken every 6 to 8 weeks by a hydrographer. In 2006, real-time data were recorded at 1-hour increments and transmitted to U.S. Geological Survey computer networks using the Geostationary Operational Environmental Satellite, thus enabling the general public to access readings within minutes of the actual measurement. Additional data and measurements are taken and made available for high or low flows that occur during significant floods and droughts.

The gage at White Springs has recorded several historic hydrologic events that affected the Suwannee River and surrounding areas. Major droughts include those during 1931-35, 1949-57, and 1998-2002. Severe floods occurred in 1948, 1973, and 2004. On April 10, 1973, the discharge was 38,100 cubic feet per second, which is the highest recorded discharge for the period of record. A flood of this magnitude is expected at a recurrence interval of about once every 200 to 500 years.

Introduction

The “healing waters” from Florida’s White Sulphur Springs have drawn people to the banks of the Suwannee River at White Springs for many centuries. Visitors and residents believed that drinking and bathing with the spring-water cured illnesses. In the early to mid-1800s, White Springs was the first tourist attraction in Florida, established when Mr. and Mrs. Sheffield built a log hotel beside the spring that flowed to the Suwannee River. The popularity of this natural resource led to the incorporation of White Springs in 1885. The town became a flourishing tourist destination that included several lavish hotels, boarding houses, and other local attractions.

The U.S. Geological Survey (USGS) began streamgaging activities on the Suwannee River at White Springs in 1906 when the town population and property developments increased around the spring area. Appropriations from the U.S. Congress for streamgaging activities across the Nation from 1903 to 1906 enabled the USGS to pay a local observer to read the non-recording gage once a day. The data were handwritten in an observer’s book that was examined by a USGS hydrographer on a regular basis. Water-level elevation data were subsequently published by the USGS using the observer’s daily reading as the mean for the day. USGS data collection and computation techniques for the Suwannee River at the White Springs streamgage have evolved dramatically since 1906, advancing from non-recording gages to graphical recorders to Data Collection Platforms.

Currently (2009), the Suwannee River at White Springs streamgage (fig. 1) is part of a network of more than

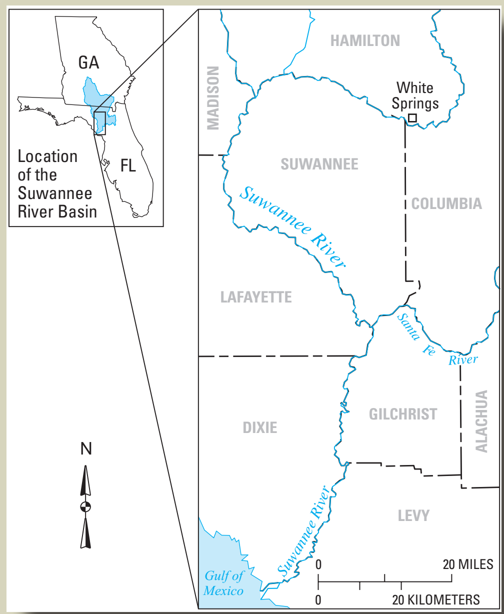


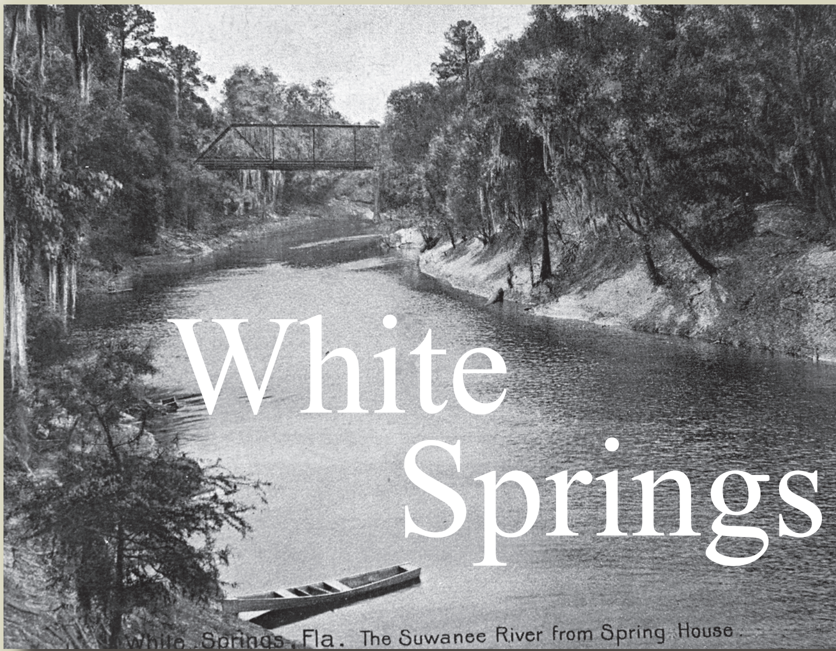
Figure 1. Site location of the Suwannee River at White Springs, Florida.

500 streamgages in Florida where streamflow data are published by the U.S. Geological Survey (USGS) as daily mean, periodic, or annual peak. The USGS uses a Data Collection Platform (DCP) to collect and transmit real-time data using the Geostationary Operational Environmental Satellite (GOES), thus providing immediate availability of these data to the public on the Internet. Water-level elevation data are published by the USGS as the arithmetic mean of all data recorded in a 24-hour period. Periodic streamflow measurements every 6 to 8 weeks help to sustain a correlation between water-level elevation and streamflow on a regular basis. These measurements allow the computation of mean daily discharges.

Purpose and Scope

This report commemorates the 100th anniversary of continuous USGS streamgaging activities in Florida beginning with daily measurements in 1906 from the gage on Suwannee River at White Springs. The scientific history of this streamgage is recorded using narrative descriptions and images of data collection instruments, methods of data analyses, and explanations of data distribution. The chronological history of this streamgage is presented using a timeline and descriptions of significant hydrologic events that necessitated documentation of site locations and equipment status, water-level elevations and streamflow computations, and operational cost comparisons. Brief discussions and archival photographs portray most of the major floods and droughts that occurred in the vicinity of Suwannee River at White Springs from 1906 to 2006.

Above: Bridge Street in White Springs circa 1905 (photograph courtesy of the Florida State Archive).



History of White Springs

The banks of the Suwannee River at White Springs have been considered “sacred ground” for many centuries, a place where people sought refuge and partook of the “healing waters.” Many believed that the mineral-enriched waters cured illnesses. During the 1700s, people of the Timucuan Nation inhabited the area around White Springs and the Suwannee River, which formed the western border with the Apalachee Nation. The Timucuans and Apalachees were known to drink and bathe together in the “healing waters” of the spring, while postponing any disagreements they had with each other (Tracy Woodard, White Springs Librarian, 2007, oral commun.; *http://www.whitesprings.org*, accessed March 19, 2008).

Spanish expeditions began in northern Florida in the early 1500s with explorer Ponce De Leon, and later, by explorers Panfilo Narvaez and Hernando De Soto. The Spanish established missions across northern Florida with the intent of “civilizing” and converting the native populations to Christianity. British, French, and Spanish explorers fought over the area for the next 200 years. The native inhabitants had little immunity against the European diseases introduced by these explorers. Tragically, 90 percent of the native population died within a century of these explorers coming to the area. In the 1700s, Europeans migrated into present-day North and South Carolina, Georgia, and Alabama. Native Americans from many of these areas moved west, but some separated from the main groups and moved south into Florida. They displaced or merged with the remaining indigenous Tribes in Florida, and became collectively known as the “Seminoles” (possibly from the Creek word “ishi semoli” which was used to refer to people who had separated, seceded, or run away) at the same time as the European immigrants were being collectively referred to as “Americans” (*http://www.keyhistory.org/seminolespage1.html*, accessed April 7, 2008).

The Spanish assumed control of Florida in 1783 as part of the treaty that ended the American Revolution. Clashes between the native Tribes and Spanish and American settlers occurred during the early 1800s. Florida became a U.S. territory in 1821 when Andrew Jackson served as Governor, and Tallahassee was established as the territorial capital in 1823 (Florida Memory Project, 2007).

In 1835, Bryant and Elizabeth Sheffield purchased most of the town of White Springs, including the spring itself, for use as a large plantation. White Springs became the first tourist destination in Florida when Mr. and Mrs. Sheffield constructed a log hotel adjacent to the spring for visitors (fig. 2). The town continued to grow through the mid-1800s with the attraction of the spring, the wealth of forest lands that provided lumber and naval stores, and the fertile soil which was excellent for growing cotton. The continued growth of White Springs, as well as Florida, led to statehood in 1845. During the Civil War, Southerners used White Springs as a retreat to escape the ravages of battle and to restore their health by swimming in the water. Boosted by riverboat travel on the Florida coast and rail travel from the north, many visitors came in the late 1800s to enjoy what White Springs had to offer—the Suwannee River, the spring, and the warm climate. Residents and visitors could enjoy 14 luxury hotels, several boarding houses, a store, cotton gin, gristmill, bowling alley, skating rink, moving picture shows, and boutiques. White Springs was incorporated in 1885 and was soon able to provide its residents with public drinking water, sidewalks, and a night watchman. Minnie Mosher Jackson upgraded the original log hotel at the spring to a spa in 1903 that included treatment rooms, a concession area, and an elevator (fig. 3) (Florida State Archive, 2008).

The USGS installed the first streamgage in Florida on the Suwannee River at White Springs in May 1906. There is no archival documentation that explains why the first streamgage was activated at White Springs; however, a plausible theory can be developed based upon available facts. Firstly, single miscellaneous discharge measurements were made at White Springs, Blue Spring, Green Cove Spring, Orange Spring, and Salt Springs in 1892-93. The measured discharge at White Springs was 44.56 ft^3/s (Powell, 1894). Secondly, daily water-level data began to be collected almost simultaneously at Silver Springs near Ocala, Florida, another popular tourist destination. Miscellaneous discharge measurements had been made at Silver Springs and at Dunnellon Springs in 1898 (Mycyk and Heath, 1988, p. 2). The USGS made flow measurements at several locations in northern Florida in December 1904, including three on the Suwannee River near White Springs (Hall and Hoyt, 1905, p. 181). More frequent requests from the general public for flow data from this reach of the Suwannee River were received during these early years. Thirdly, the U.S. Congress increased appropriations for streamgaging from $100,000 annually in 1902 to $200,000 annually from 1903-06 (Hall and Bolster, 1909, p. 7). Fourthly, F.H. Newell, who was in charge of the newly formed Hydrographic Branch of the USGS, wanted to use the increased appropriation to foster publicity and seek nationwide expansion for the program (Follansbee, 1994, p. 87). Therefore, it is probable that the White Springs location was selected because of available funds and popularity as a tourist destination on a major river in a State that had no gages. The White Springs and Silver Springs gages could have increased public support for the gaging program at a time when increased program expansion was a goal. Unfortunately, subsequent Congressional appropriations for the streamgaging program were reduced. The appropriation was reduced to $150,000 in 1907, then down to $100,000 in 1908-10. This would explain discontinuance of the gage in December 1908.

Top: Archival image of White Springs with a view of the Suwannee River from the Spring House (image courtesy of the Florida State Archive).

Figure 2. The original log hotel at White Springs constructed by Mr. and Mrs. Sheffield (lower left; 1906, photograph courtesy of Tracy Woodard).

Figure 3. The new Spring House at White Springs constructed by Minnie Mosher Jackson (lower right; 1907, photograph courtesy of the Florida State Archive).

Historic Data-Collection Operations and Computations

This section describes the data-collection operations at White Springs from 1906-2006. Additionally, computations of daily water-level elevation and daily streamflow are described herein.

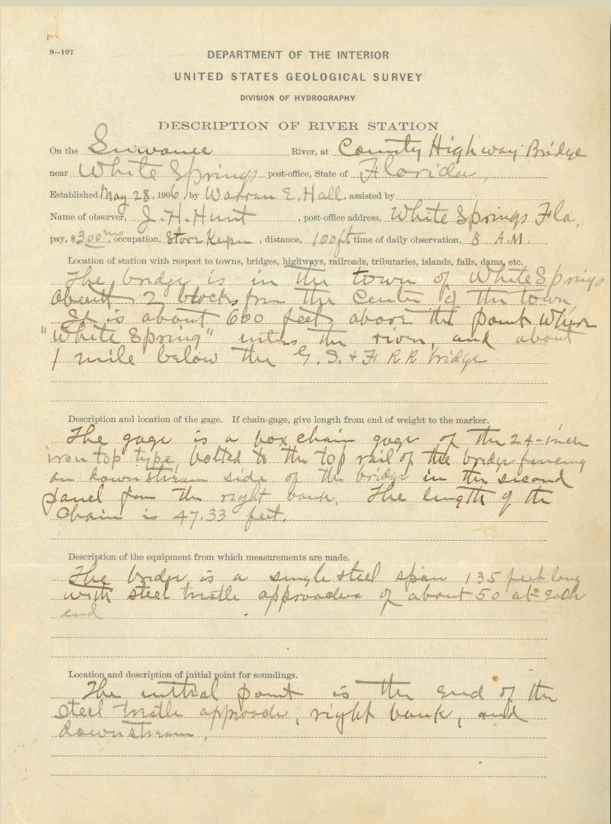
Historic Data-Collection Operations

Historically, the streamgage at White Springs has been operated at one of two locations: (1) at the county highway bridge (Highway 136), or (2) the bridge at U.S. Highway 41. During the early years of data collection (1906-08 and 1927-32), the streamgage was located at Highway 136 and then relocated to the newly constructed bridge on U.S. Highway 41 in 1932. With the exception of a short period from 1979 to 1983 (when the streamgage was relocated to Highway 136), data collection took place at the U.S. Highway 41 location during the remainder of the period of record. This section describes the data-collection operations since 1906.

Operations during 1906-08

Daily operation of the White Springs gage began May 28, 1906, when the non-recording chain gage was installed on the county highway bridge (fig. 4) in White Springs by Warren E. Hall. However, a streamflow measurement was made 12 days earlier on May 16 (Hall and Bolster, 1909) using a Price current meter (fig. 5). Price current meters feature a rotating-cup wheel that sends electronic signals in the form of audible clicks. The person making the measurement counted and timed the audible clicks, then converted these to velocity and streamflow. Measurements were made by wading across the stream during low flow. During medium and higher flows, measurements were made from the bridge at the streamgage location.

A local observer read the chain gage (fig. 6) once a day to determine the elevation of the water surface. A chain gage is a sash chain and weight gage mounted to a cantilevered arm with ruler-like gage sections and index marker that extends over the stream. The water level is measured by lowering the weight until it barely touches the water surface. The water level is read from the ruler-like gage sections and index marker (Rantz and others, 1982). The observer for the early years of streamgage operation was local storekeeper J.H. Hunt (Hall and Bolster, 1909). Mr. Hunt read the chain gage once each day at 7:00 a.m. local time and was paid $3 per month for his services.


9—197

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
DIVISION OF HYDROGRAPHY

DESCRIPTION OF RIVER STATION

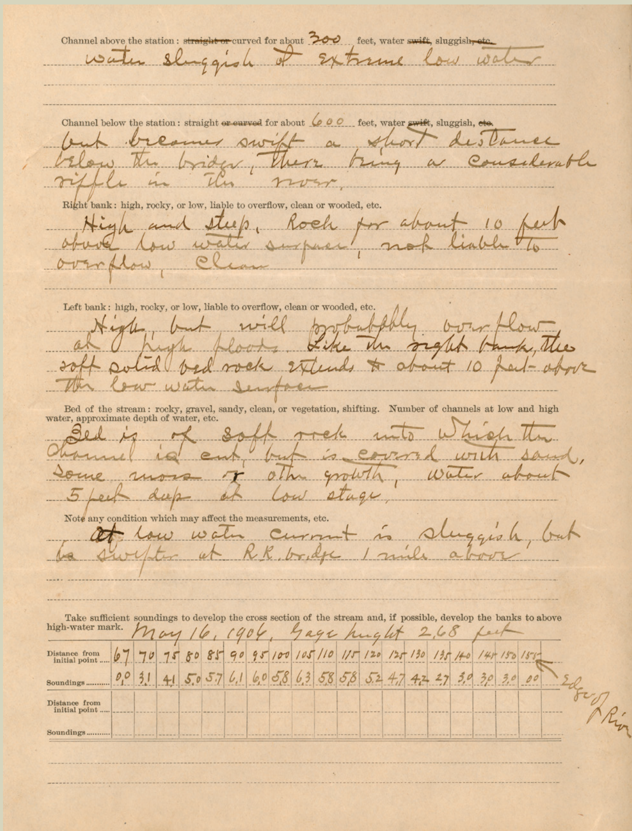
On the Suwannee River, at County Highway Bridge
near White Springs post-office, State of Florida,
Established May 28, 1906, by Warren E. Hall, assisted by
Name of observer, J. H. Hunt, post-office address, White Springs Fla.
pay, $3.00 mo, occupation, Store Keeper, distance, 100 ft. time of daily observation, 8 A.M.

Location of station with respect to towns, bridges, highways, railroads, tributaries, islands, falls, dams, etc.
The bridge is in the town of White Springs about 2 blocks from the Center of the town. It is about 600 feet above the point where "White Spring" enters the river, and about 1 mile below the G. S. & F. R.R. bridge

Description and location of the gage. If chain-gage, give length from end of weight to the marker.
The gage is a box chain gage of the 24-inch iron top type, bolted to the top rail of the bridge fencing on downstream side of the bridge in the second panel from the right bank. The length of the chain is 47.33 feet.

Description of the equipment from which measurements are made.
The bridge is a single steel span 135 feet long with steel trestle approaches of about 50 at each end

Location and description of initial point for soundings.
The initial point is the end of the steel trestle approach, right bank, and downstream,


Channel above the station: ~~straight or~~ curved for about 300 feet, water ~~swift~~, sluggish, ~~etc.~~
water sluggish at extreme low water

Channel below the station: straight ~~or curved~~ for about 600 feet, water ~~swift~~, sluggish, ~~etc.~~
but becomes swift a short distance below the bridge, there being a considerable riffle in the river.

Right bank: high, rocky, or low, liable to overflow, clean or wooded, etc.
High and steep. Rock for about 10 feet above low water surface, not liable to overflow, Clean

Left bank: high, rocky, or low, liable to overflow, clean or wooded, etc.
High, but will probably overflow at high floods. Like the right bank, the soft solid bed rock extends to about 10 feet above the low water surface

Bed of the stream: rocky, gravel, sandy, clean, or vegetation, shifting. Number of channels at low and high water, approximate depth of water, etc.
Bed is of soft rock into which the channel is cut, but is covered with sand, some moss or other growth, water about 5 feet deep at low stage,

Note any condition which may affect the measurements, etc.
~~At~~ low water current is sluggish, but is swifter at R.R. bridge 1 mile above

Take sufficient soundings to develop the cross section of the stream and, if possible, develop the banks to above high-water mark.
May 16, 1906, Gage height 2.68 feet

Distance from initial point	67	70	75	80	85	90	95	100	105	110	115	120	125	130	135	140	145	150	155
Soundings	0.0	3.1	4.1	5.0	5.7	6.1	6.0	5.8	6.3	5.8	5.8	5.2	4.7	4.2	2.7	3.0	3.0	3.0	0.0
Distance from initial point																			
Soundings																			

Edge of River

Warren E. Hall made five discharge measurements from May 16, 1906, to November 16, 1907, of streamflow ranging from 93 to 5,350 ft^3/s, which were used to develop a water-level elevation and streamflow correlation for the gage. Mr. Hall wrote a station description for the White Springs streamgage (fig. 7), which included information about the streamgage location with respect to nearby towns, highways, bridges, and railroads. The station description also included details about the equipment located at the streamgage, of the river above and below the streamgage, the condition of the river banks, the river bed, and information about conditions that may affect streamflow measurements. The streamgage was discontinued December 31, 1908, probably due to reductions in the USGS appropriations for the streamgaging program (Hall and Bolster, 1909; Follansbee, 1994). A major fire on February 24, 1911 (Jasper News, 1911; Hamilton County Bicentennial Committee, 1976), destroyed or damaged 35 buildings, including mercantile establishments and hotels. Nearly $200,000 in losses was estimated (Jasper News, 1911; Hamilton County Bicentennial Committee, 1976). The fire, and the decline of the riverboat era, had significant impact on the economy of the town and northern Florida.

Figure 4. The original streamgage location at Highway 136 (above; 2007, photograph by Richard Jay Verdi, USGS).

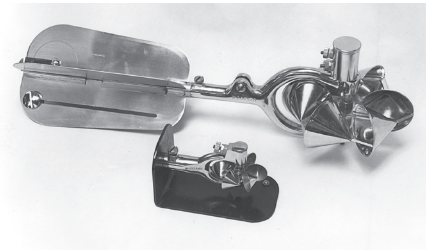


Figure 5. Current meters that are used to make streamflow measurements at Suwannee River at White Springs. These meters have been used to measure streamflow since before the installation of the streamgage at White Springs (top left; Rantz and others, 1982).

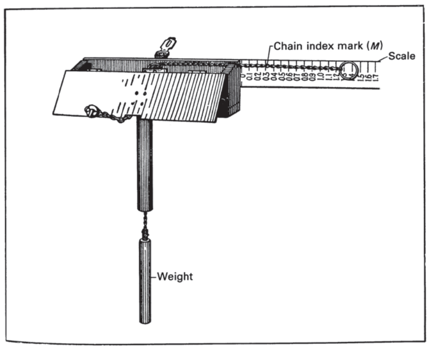
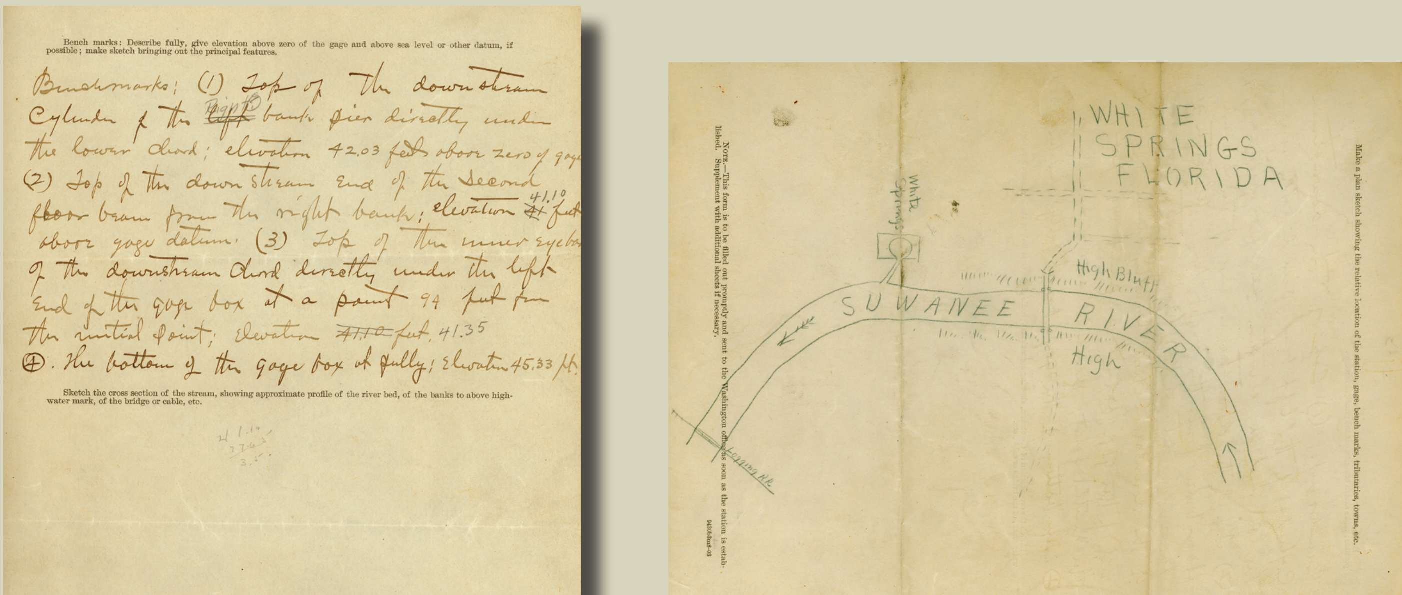


Figure 6. Schematic of what a chain gage would look like in 1906. The chain gage was used by the observer from 1906-1908 (bottom left; Rantz and others, 1982).



Bench marks: Describe fully, give elevation above zero of the gage and above sea level or other datum, if possible; make sketch bringing out the principal features.

Benchmarks; (1) Top of the downstream Cylinder of the ~~left~~ Right bank pier directly under the lower chord; elevation 42.03 feet above zero of gage (2) Top of the downstream end of the second floor beam from the right bank; elevation 41.10 feet above gage datum. (3) Top of the inner eyebar of the downstream chord directly under the left end of the gage box at a point 94 feet from the initial point; elevation ~~41.10~~ feet. 41.35 (4). The bottom of the gage box of pulley; Elevation 45.33 ft.

Sketch the cross section of the stream, showing approximate profile of the river bed, of the banks to above high-water mark, of the bridge or cable, etc.

NOTE.—This form is to be filled out promptly and sent to the Washington office as soon as the station is established. Supplement with additional sheets if necessary.

Make a plan sketch showing the relative location of the station, gage, bench marks, tributaries, towns, etc.

Figure 7. Original station description as written by Warren E. Hall. Mr. Hall wrote a station description for the White Springs streamgage which included information about the streamgage's location with respect to nearby towns, highways, bridges, and railroads. The station description also included descriptions of equipment located at the streamgage, of the river above and below the streamgage, of the condition of the river banks, the river bed, and information about conditions that may affect streamflow measurements.

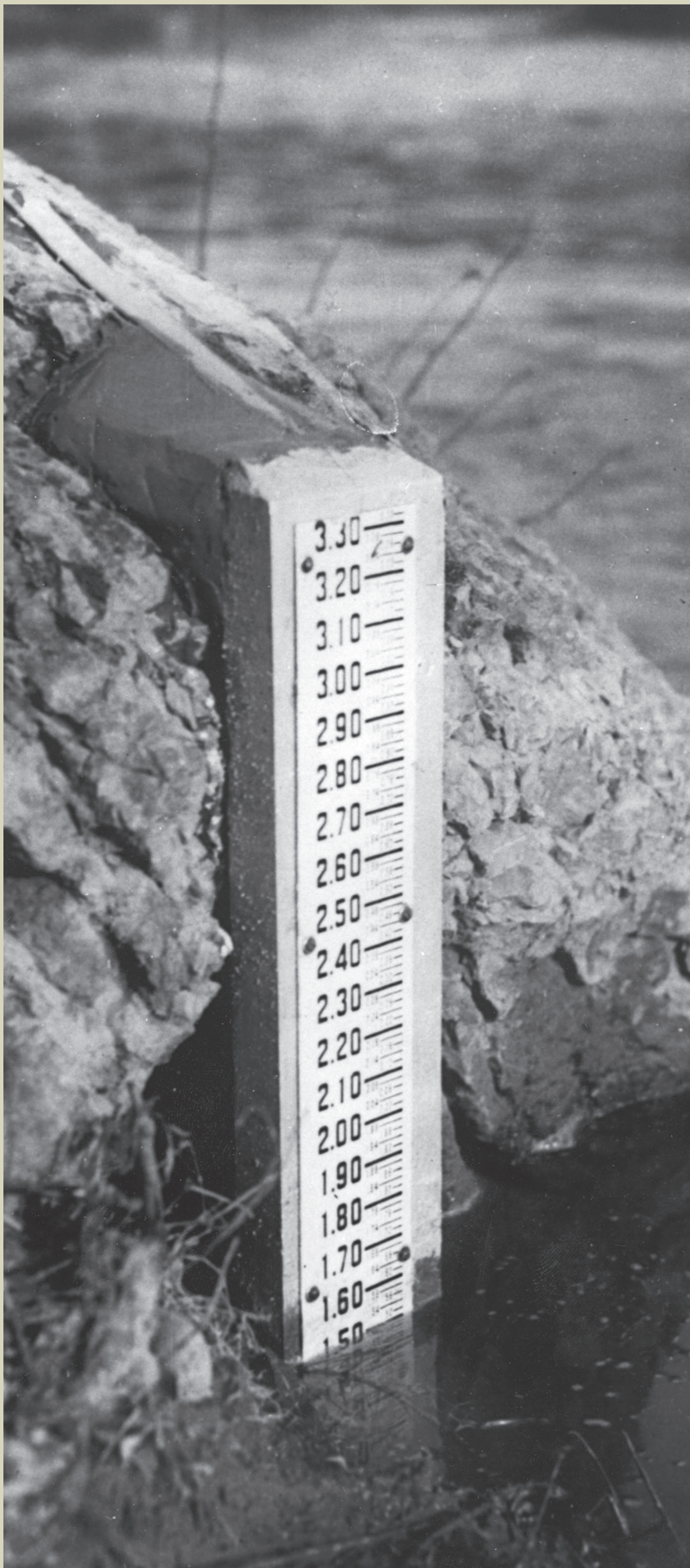


Figure 8. Picture of what the staff gage would have looked like at the Suwannee River at White Springs streamgage (above; Rantz and others, 1982).

Operations during 1927-32

The streamgage was reactivated on February 8, 1927, at the same location on the county highway bridge by P.E. Hanson. It is not known why, after nearly 20 years, the streamgage was reactivated, but several fiscal and environmental events occurred that may have been contributing factors. Firstly, there was a large increase in State contributions to the streamgaging program from 1919 to 1928 (R. Follansbee, unpub. data, undated, p. 1). This occurred partly as a result of decreased Federal appropriations for the streamgaging program, and partly because of an increased interest in power production for a growing population after World War I (R. Follansbee, unpub. data, undated, p. 1). Hydropower was a primary source of electric energy during this era, and streamflow records were necessary to assess the feasibility of water-power development. Perhaps not coincidentally, three other gages were installed in 1927 in the Suwannee River basin—on the Suwannee River at Ellaville and at Luraville, and on the Santa Fe River near Ft. White. A steam-electric powerplant began operation in 1953 using water from the Suwannee River below the Ellaville gage. Secondly, two gages were established on the Ochlocknee River in 1926—one at Havana and one at Bloxham—probably to gather data for management of the Lake Talquin dam and hydroelectric powerplant (now the C.H. Corn hydroelectric plant) built in 1929. An environmental factor for reactivation of the White Springs gage in 1927 was that the 1926 hurricane season produced eight hurricanes, one of which caused severe flooding and damage to summer crops in north-central Florida in July (Barnes, 1998). The July hurricane made landfall on the east coast of Florida and continued northwest, moving through the Suwannee River basin and into Georgia and Alabama (Barnes, 1998). Thus, it seems probable that the White Springs gage was reactivated because of the need for water data to assess the feasibility of using the Suwannee River to produce hydroelectric power, and the need for peak stage and flow information to assess the potential for flooding.

The streamgage was reactivated as a nonrecording staff gage. Essentially, this was a ruler attached to a permanent structure in the stream pool where the water level was being measured (fig. 8). A new, more detailed, station description which included a better site sketch was hand drawn in 1927 by P.E. Hanson and is shown in figure 9. The site sketch shows the location of the Edgewood Hotel (fig. 10), as a landmark and one of the luxury hotels in White Springs at the time. The Edgewood Hotel was destroyed by a fire and the former location remains a vacant lot. Two local observers read the non-recording staff gage twice each day, usually around 8:00 a.m. and 6:00 p.m. local time. The first observer was D.H. Williams, who operated a pressing shop in White Springs. He was paid $5 per month to read the staff gage from February 8, 1927, to February 16, 1929. The second observer was M.L. Scarborough, who operated a store and blacksmith shop at the left end of the highway bridge. He read the staff gage from February 16, 1929, to August 8, 1932, and was paid $7 per month for his services. During this period, the Great Florida Land Boom brought prosperity to the State and a highway system was initiated with the increased use of the automobile. By 1930, Suwannee River at White Springs was one of nine streamgages in Florida and a USGS office opened in Ocala with D.S. Wallace as the Florida District Engineer (Follansbee, unpub. data, p. 29).

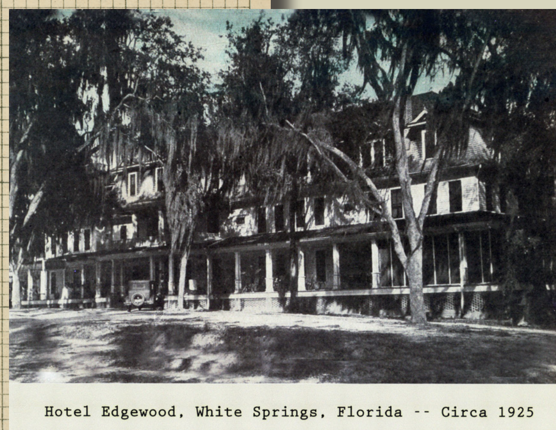


Figure 10. The Edgewood Hotel circa 1925 (above; picture courtesy of Tracy Woodard).

Figure 9. Updated site sketch showing the streamgage location, the Edgewood Hotel landmark, and White Springs drawn by P.E. Hanson on March 24, 1927 (above).

Operations during 1932-41

The White Springs gage remained funded and active during the 1932-41 period despite declining tourism due to the economic impacts of the Great Depression and the southern expansion of the railroads, thus, taking the tourist business away from the northern areas of Florida. Increased demand for hydrologic data and studies throughout Florida in response to drought, irrigation use, and population growth allowed for two hydrologic investigations offices to be established in 1939—one in Tallahassee and one in Miami (R. Follansbee, unpub. data, p. 261-267). For the first time, a continuous record of gage heights was obtained at the White Springs site using the newest technology, a graphical recorder. R.P. Mangold installed a continuous water-level graphical recorder on June 20, 1932, with attached float tape mechanism in a wooden shelter over a corrugated iron pipe stilling well at the new bridge location on U.S. Highway 41 (figs. 11 and 12). The non-recording staff gage was discontinued as the primary gage on July 31, 1932. Beginning on August 1, 1932, continuous water-level data from the recorder were used to compute daily mean water-level elevations. The hydrographer verified the water level recorded by the graphical recorder with the non-recording staff gage during each site visit. This procedure became one of the first efforts to ensure quality assurance of water data by the USGS. However, the technology of a continuous-record gage with associated quality-assurance practices presented some challenges. R.P. Mangold wrote a memo to the Washington Office (USGS headquarters) on January 3, 1934, which states:

> "The recorder at this station has caused more trouble than any other in the district. The clock has stopped repeatedly in spite of frequent replacements, cleaning, and adjusting, additional driving weight, etc. The float cable hung on several occasions, especially on a rapid rise or fall, when one of the solder balls failed to discharge from the float wheel, and quite a bit of record was lost from this cause."

Thus, observers were still a critical part of the streamgaging program and enabled the USGS to fill gaps in the record.

Figure 11. The new streamgage and location at Highway 41 in 1932 (above; photograph by USGS).

The recorder at this station has caused more trouble than any other in the district. The clock has stopped repeatedly in spite of frequent replacements, cleaning, and adjusting, additional driving weight, etc. The float cable hung on several occasions, especially on a rapid rise or fall, when one of the solder balls failed to discharge from the float wheel, and quite a bit of record was lost from this cause.

—R.P. Mangold, January 3, 1934

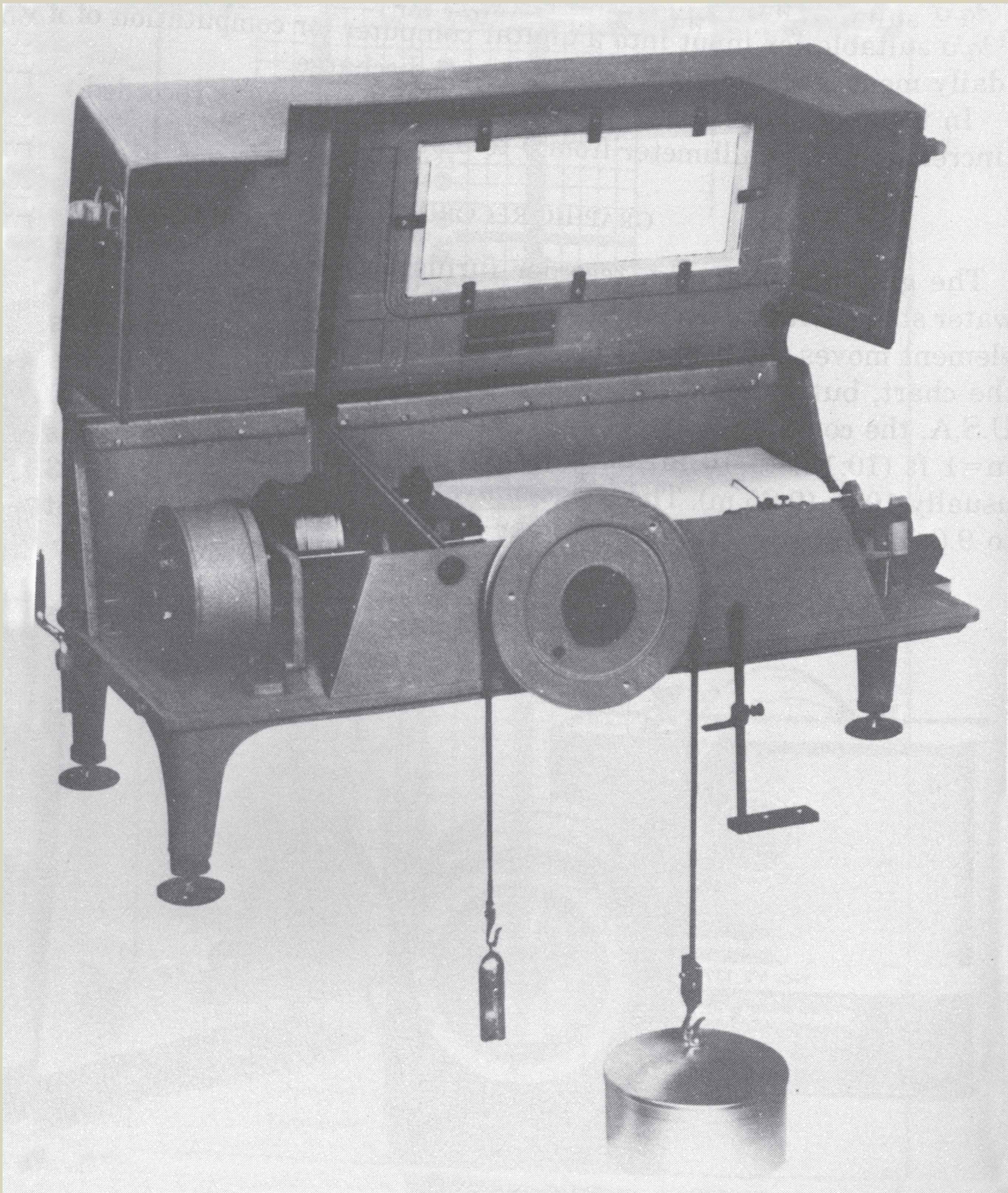


Figure 12. A graphical recorder similar to one that would have been used to collect continuous water-level elevation data from 1932-63 (above; Rantz and others, 1982).

Operations during 1941-63

During the 1941-63 period, the White Springs gage structure was modified to withstand floods. The sturdier construction made it easier and safer for hydrographers to complete measurements from the bridge. On June 10, 1941, the continuous water-level graphical recorder was relocated to a new concrete gage house and stilling well at the same location as the wooden shelter and well (fig. 13). A cableway was erected at the gage in 1941 to assure employee safety. In a letter dated May 5, 1941, from USGS Acting District Engineer G.E. Ferguson to C.W. Marsh in Lake City (a private citizen who owned the property on the south side of the river where the cableway anchors needed to be set), Mr. Ferguson requested permission to build the cableway on Mr. Marsh's land, stating that his engineers "are in constant danger of being struck by fast-moving trucks and automobiles" on the highway bridge. Permission was granted, and the cableway was constructed in June 1941, about 250 ft downstream from the gage. This location facilitated making streamflow measurements when the water level was too high to wade across the stream. Mr. J.A. McCabe made the first flow measurement from the cableway on July 9, 1941. The person making the streamflow measurement was able to move across the stream by sitting inside a metal "cable car" (fig. 14) that could be maneuvered back and forth on a cable across the stream (fig. 15). The cable was anchored to concrete blocks built into the banks on both sides of the river using an A-frame for support (fig. 15). Measurements were made from this car using a sounding reel and Price current meter. A site sketch (fig. 16) developed in the planning stages of the new gage on October 17, 1940, showed the location of the new gage house and cableway. During World War II, personnel servicing the White Springs gage, along with other streamgages in Florida, were called for military duty (R. Follansbee, unpub. data, undated, p. 5 and p. 125). At least four of the hydrographers for the White Springs gage—T.G. Johnson, G.B. Harrell Jr., J.A. McCabe, and M.S. Gardner—served in the military during the war for various periods between 1942 and 1946 (R. Follansbee, unpub. data, p. 125).

The USGS intermittently used observers from 1941 to 1963. These observers, as in the past, filled in data gaps caused by malfunctions of the continuous data recorder. Clock stoppage was the most persistent cause of missing record during this period. When the continuous data recorder failed or was being repaired, the observers inspected the streamgage once a day. When the continuous data recorder was installed and operational, observers inspected the recorder weekly to ensure it was in good working order. If the recorder malfunctioned, the observer would read the staff gage each day to obtain a water-level elevation. These observers were either private citizens who were paid for their efforts, or personnel from State agencies, such as the Florida Game and Freshwater Fish Commission.

Figure 13. The newly constructed streamgage house at Highway 41 circa 1941 (upper left; photograph by USGS).

Figure 14. The cable car that was used to maneuver back and forth across the stream on April 25, 1969 (below; photograph by USGS).

Figure 15. The cableway circa 1941 (lower left; photograph by USGS).

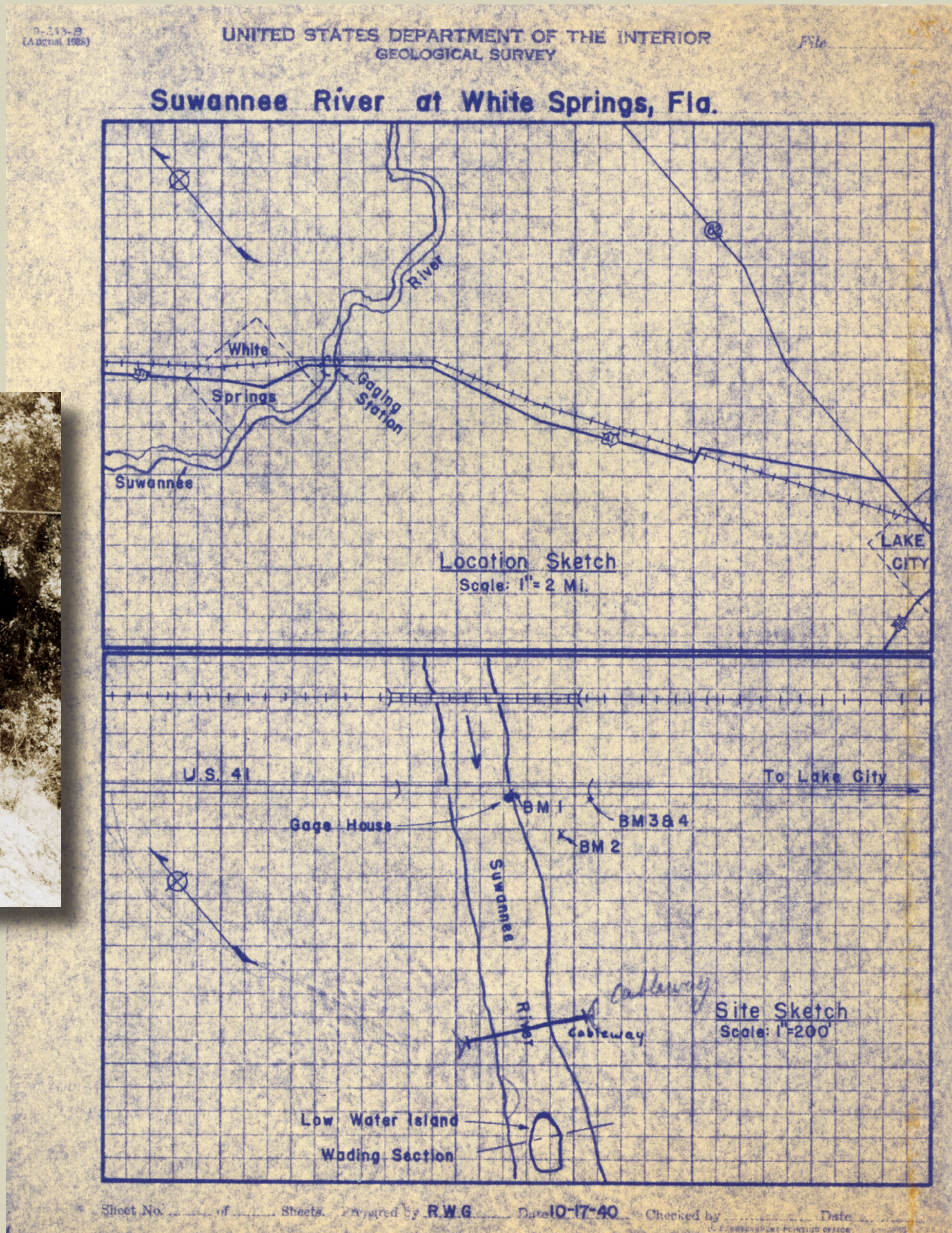


Figure 16. New site sketch from October 17, 1940, illustrating the location of the streamgage and cableway (above).

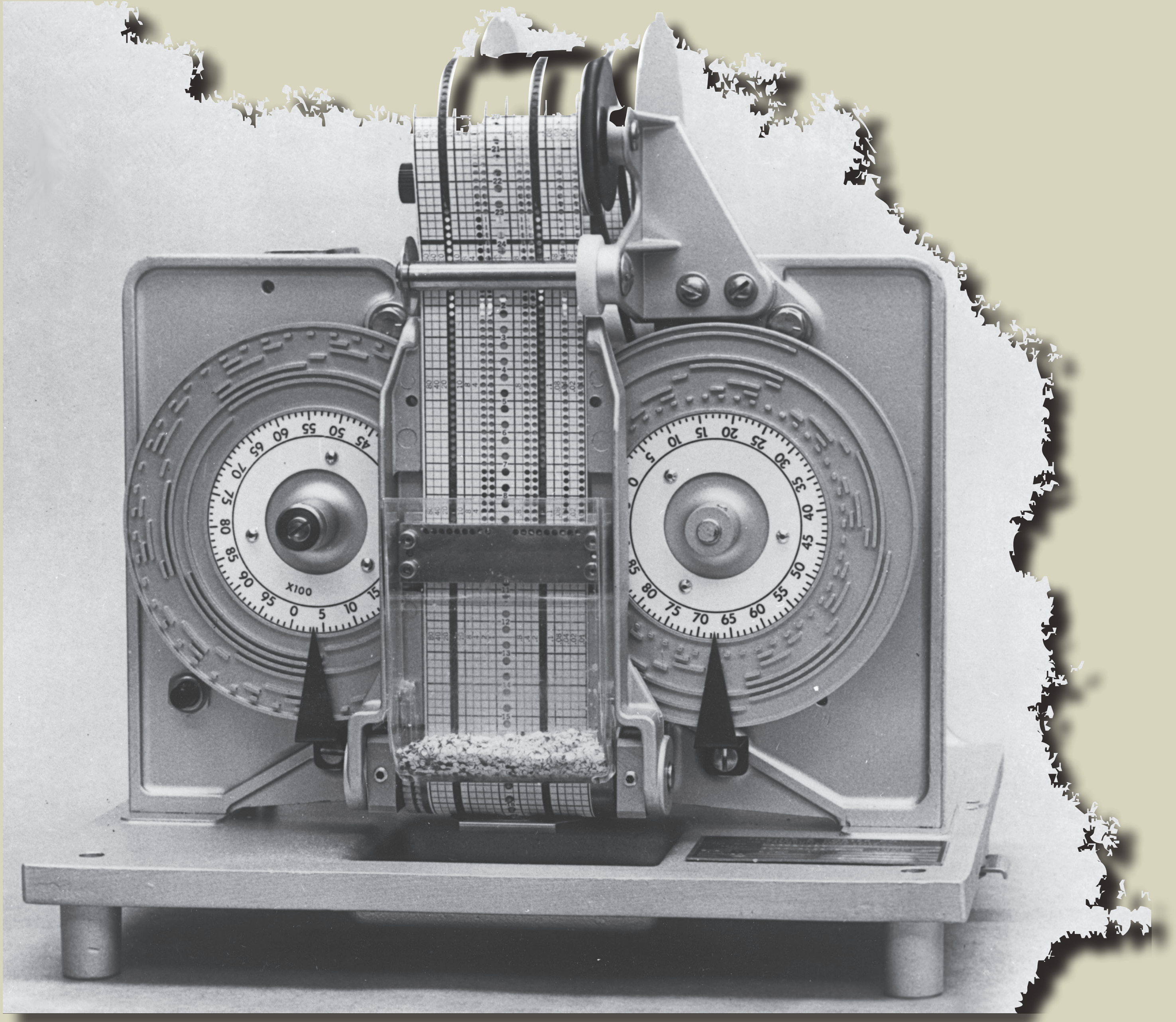


Figure 17. A digital punch recorder similar to one that would have been used to collect continuous water-level elevation data at Suwannee River at White Springs from 1963-79 and 1987-96 (above; Rantz and others, 1982).

Operations during 1963-79

The technologically advanced digital recorders were installed at the White Springs gage in 1963. On August 1, 1963, the USGS replaced the graphical recorder with a digital punch recorder (fig. 17) with attached float tape mechanism and a backup graphical recorder at the same location. Digital recorders are battery operated paper-tape punch machines that record a four-digit number on a paper tape at a pre-selected time increment, such as 1-hour intervals (Rantz and others, 1982). At the White Springs gage, the digital recorder initially collected data every 15 minutes. The backup graphical recorder was removed May 17, 1966. The programming was modified in 1968 for the digital recorder to record every hour, rather than every 15 minutes. Intermittent observer readings continued to be made at the site, with regular observations made by the Suwannee River Water Management District (SRWMD) beginning in 1973 when the main office was established in White Springs (Tom Mirti, Suwannee River Water Management District, oral commun., August 30, 2007). In addition to the observer readings, hydrographs from adjacent streamgages at Suwannee Springs and Benton were used to quality assure water data collected at the White Springs gage. Data collection at U.S. Highway 41 continued until September 26, 1979, when the Florida Department of Transportation began construction of a new bridge.

Above: Highway 41 Bridge crossing the Suwannee River in April 1973 (photograph by USGS).

Operations during 1979-87

A wire-weight gage became the primary instrument for obtaining water levels at White Springs during this period. While bridge construction on U.S. Highway 41 progressed from October 11, 1979, to December 1, 1983, the USGS relocated the streamgage downstream to the original location at Highway 136 and operated a non-recording wire-weight gage. The non-recording wire-weight gage was read each day by an observer to obtain water-level elevation. A wire-weight gage (fig. 18) consists of a drum wound with a layer of cable with a bronze weight attached to the end. To read the water-level elevation, a hydrographer lowers the weight to the top of the water surface and reads the elevation on the attached graduated disc and Veeder counter (Rantz and others, 1982). Observer gage-height readings were plotted and compared to hydrographs at the Suwannee Springs and Benton gages for quality assurance. The SRWMD made numerous flow measurements at the White Springs gage from 1980 to 1983, reflective of an enhanced cooperative effort with the USGS and the need for additional flow measurements during a period of drought. The SRWMD office moved to Live Oak in 1983, and the USGS assumed responsibility for most of the flow measurements at the site.

Because of safety concerns, the cableway, car, and A-frame support structure were dismantled. The last measurement made from the cableway was on January 6, 1982, by C.W. Calhoun. Completion of the new highway bridge provided a wider easement and high-water streamflow measurements could be made safely on its downstream side using a bridge crane and Price current meter. The wire-weight gage was moved to the U.S. Highway 41 location on December 2, 1983, and continued to be the primary gage until May 1, 1987.

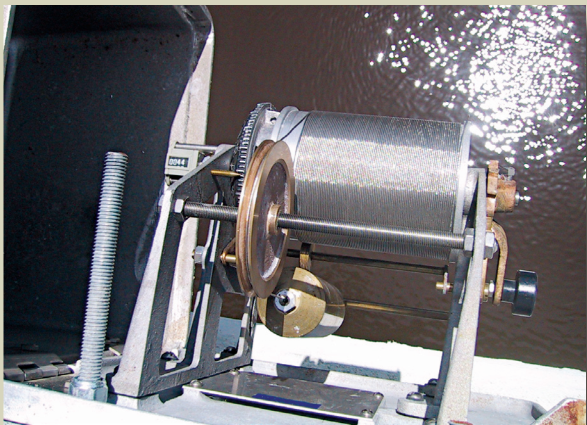
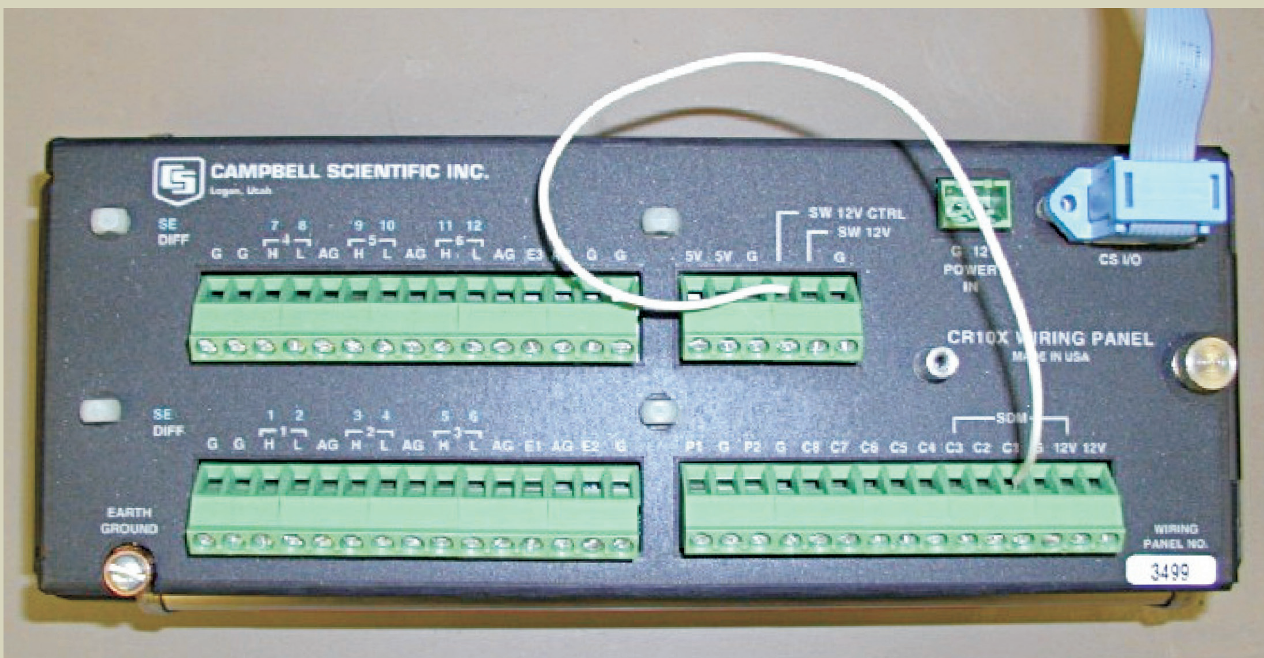


Figure 18. A wire-weight gage similar to one that was used at Suwannee River at White Springs from 1979-2006 (left; photograph by Stewart Tomlinson, USGS).

Figure 19. An electronic data recorder. One similar to this was used to collect continuous data at Suwannee River at White Springs from 1996-2003 (below; photograph by USGS).



Operations during 1987-96

The USGS installed another digital punch recorder at the U.S. Highway 41 location on May 1, 1987, and set the instrument to collect data at hourly intervals. Water-level elevations were measured using a fluidgage orifice. A fluidgage uses compressed nitrogen gas to measure the water pressure above the sensor and then converts the water pressure to water-level elevation using an internal mathematical equation. The observer continued reading the non-recording wire-weight gage throughout this period because of frequent equipment malfunction and damage from vandalism. Data from the fluidgage fluctuated by about 0.04 ft in stage due to the hysteresis lag in the recorder. This required numerous tape corrections to make it conform to the observer readings. Over a period of years (1987-96), USGS personnel attempted to modify the equipment at the streamgage to improve the quality of the continuous data. However, because of continued instrument problems and vandalism at the site, good quality continuous data were unattainable except for intermittent periods. Thus, the observer readings from the wire-weight gage were typically used to compute the final record. In the 1990 station analysis, hydrographer G.T. Losey wrote: “When you consider the effort that goes into entering the observer data, you feel you might as well use it solely.”

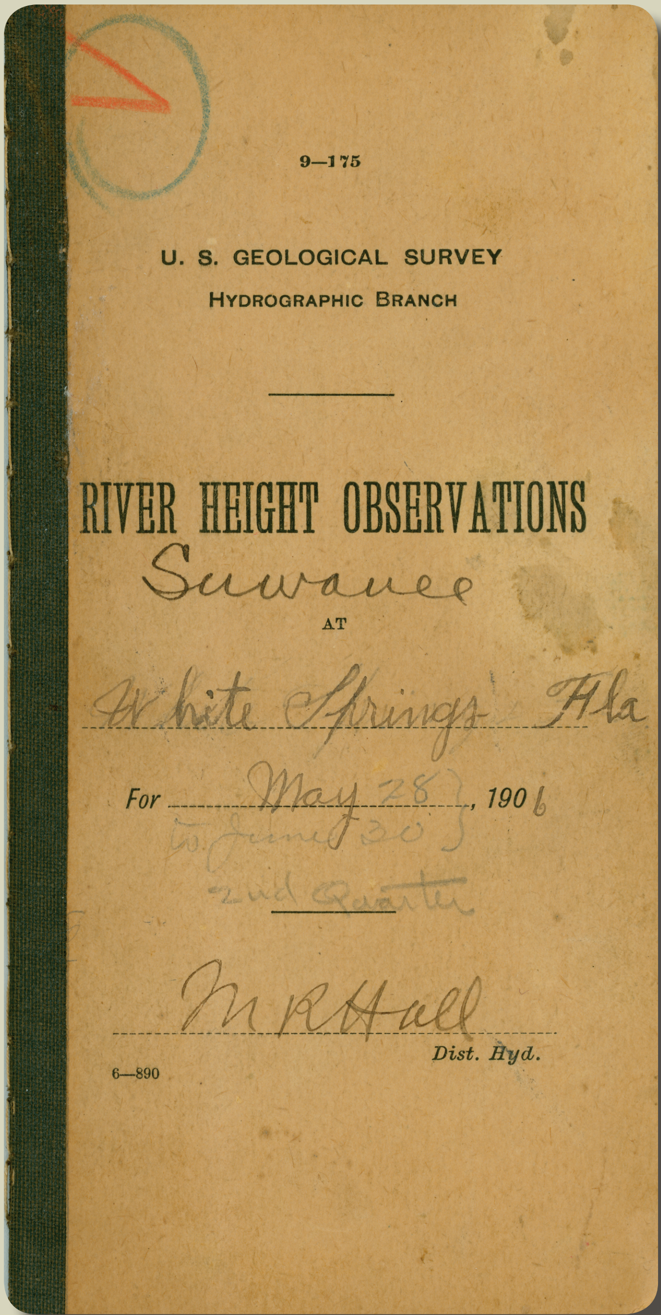
Operations during 1996-2003

The USGS replaced the digital recorder and fluidgage with an electronic basic data recorder (fig. 19) with a vented submersible pressure transducer on July 1, 1996, to resume continuous data collection at 1-hour intervals. A pressure transducer is an instrument that measures the pressure above the sensor and converts it to water-level elevation. The wire-weight gage continued to be read and those data were used to fill gaps in the electronic data, or make gage-height corrections to those data. A SRWMD-owned electronic data logger and phone line were installed on September 18, 1997, so that data could be retrieved using telephone modems. This new communication method provided collection, analysis, and quality assurance of continuous data at a more frequent interval, such as daily or weekly. Previously, a hydrographer had to visit the site every 6 to 8 weeks to download data to a personal laptop computer. These data were retrieved by computer programs using the telephone line and transferring data into the USGS National Water Information System (NWIS). The SRWMD also retrieved the same data for input to their hydrologic database. Later, the data were displayed on the public Internet, thus allowing users from across the world to view near real-time data at the White Springs gage and hundreds of other USGS gages across the country. Canoers, kayakers, and fishermen began to use the streamgage data for indications of optimal recreational conditions in the upper Suwannee River basin.

Figure 20. A Data Collection Platform. One similar to this was used at the Suwannee River at White Springs to collect and transmit by satellite continuous water-level elevation from 2003-06 (below; photograph by USGS).

Operations during 2003-06

The USGS personnel made regularly scheduled site visits to the White Springs gage to inspect the instruments and make streamflow measurements. Hydrographers removed the SRWMD-owned electronic data logger from service on August 7, 2003, and replaced it with a DCP (fig. 20) set to record data once every hour. The DCP consisted of an electronic data logger coupled with a satellite transmitter. The phone line and modem were maintained by the SRWMD to retrieve data for their database and public web site. A submersible pressure transducer continued to measure water-level elevation. The DCP transmitted data every 4 hours using GOES satellite telemetry and updated the National Water Information System Webpage (NWISWeb) within a few minutes for public viewing. The non-recording wire-weight gage continued to be periodically used to set the gage height on the DCP and to quality assure the electronic data set.



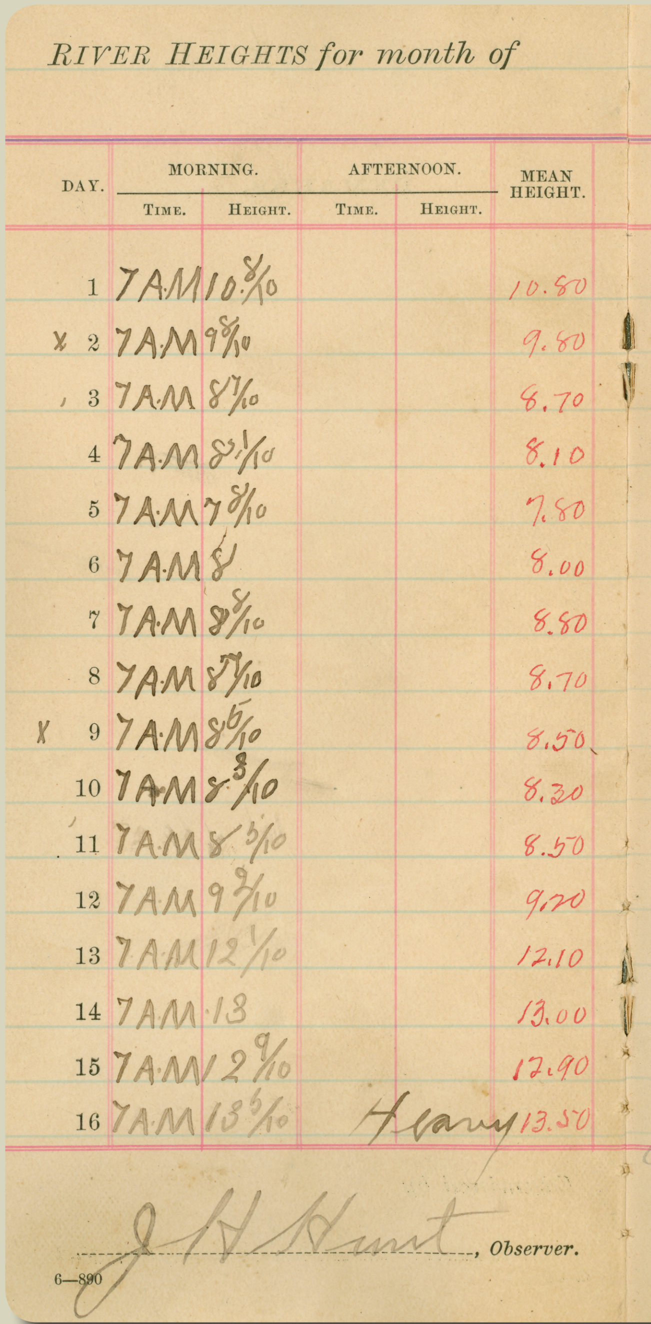
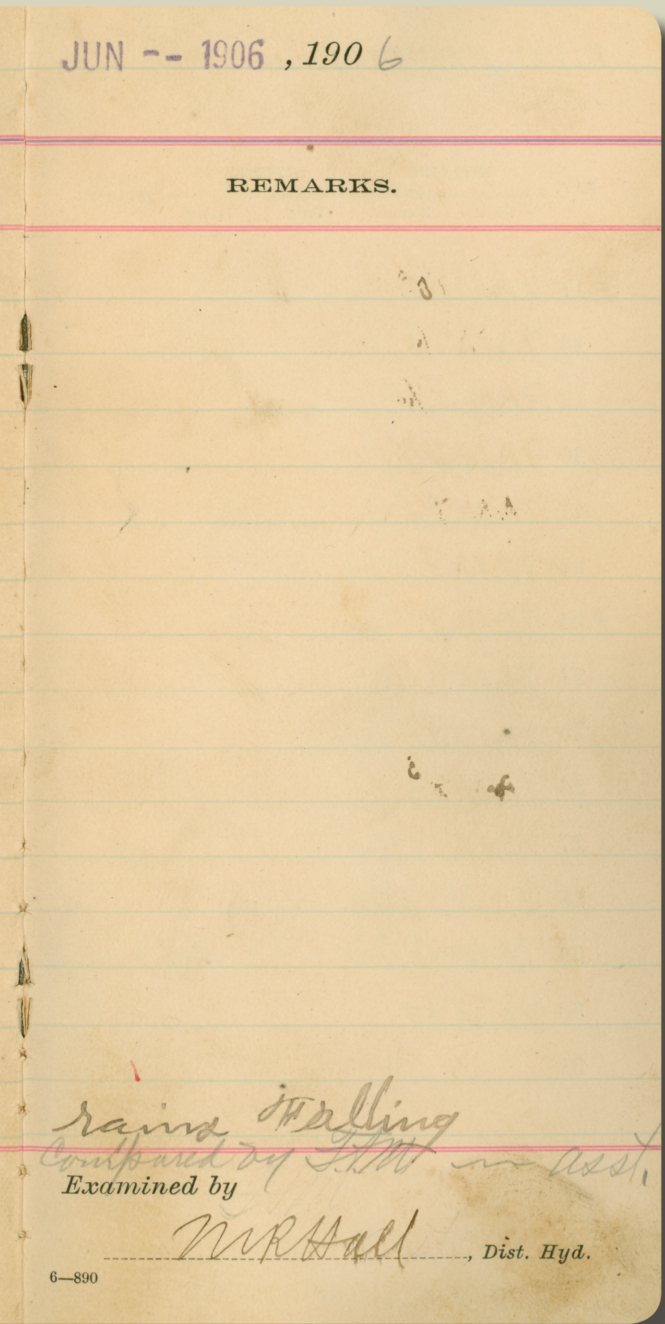


Figure 21. Example of the original observer's booklet used in 1906 to compute daily water-level elevation data.



Computations of Daily Water-Level Elevation

During the periods when observer readings were the primary source of reliable record at the gage (1906-08, 1927-32, 1979-83, and 1983-96), the USGS published daily water-level elevations computed from the single observation of the day, or, if two observations were made, as the arithmetic average. Readings by the observer were logged in a River Height Observations booklet or a field measurement sheet supplied by the USGS. At the end of each quarterly observation period, a USGS hydrographer would collect the booklet or note sheets from the observer and provide new ones for the next quarter. Figure 21 shows a sample of the original observation book used by Mr. Hunt from May 28, to June 30, 1906. Remarks were made in the observation book on June 16, stating that heavy rain fell that day. The water-level elevation was 13.50 ft, which equates to 62.04 ft above the National Geodetic Vertical Datum of 1929 (NGVD 29) after the gage datum of 48.54 ft is applied. The letter X next to a date signifies that the day was a Saturday. The observations were used as daily water-level elevations and are shown in the figure in the column labeled MEAN HEIGHT. Figure 22 shows a sample from the original observation book used by Mr. Scarborough from October 1 to December 31, 1929. Two observations were recorded each day, and the daily water-level elevation was computed as the arithmetic mean of the two observations. Similar to the climate notes in Mr. Hunt's booklets, the weather conditions were noted in Mr. Scarborough's booklets. A hydrographer would compute the daily water-level elevations, and a second hydrographer would check and verify the data for publication.

A graphical recorder furnished a continuous ink trace of water-level elevation with respect to time on a paper strip chart from 1932 to 1963 (Rantz and others, 1982). USGS hydrographers conducted periodic streamgage inspections. During these inspections, hydrographers performed the following activities:

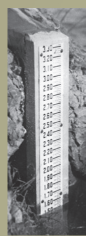
- Made streamflow measurements;
- Read the recorder and outside reference gages (the non-recording wire-weight gage or staff gage), and noted any differences;
- Collected the paper strip chart and replaced the chart (if needed); and
- Adjusted the recorder to the outside reference gages (if needed).

History of the Suwannee River at White Springs Streamgage in Florida

Pre-1875
Timucuan Nation inhabits White Springs area
Spanish and English exploration and settlement
White Springs area settled in 1835 by the Sheffield family
Florida becomes as State in 1845

1885
Town of White Springs Incorporated

1894
USGS lists White Springs as a major spring in 1892-93 Annual Report to the Director



1898
USGS makes miscellaneous flow measurements at Silver and Dunnelon Springs

1903
Minnie Mosher Jackson upgrades hotel to a spa

1904
USGS makes flow measurements at several locations in north Florida near White Springs

1906
May 28, 1906
Suwannee River at White Springs gage established
Streamflow measurements made with Price current meter.

1908
White Springs gage discontinued

USGS Streamgaging Budget

1902	$100,000
1903-06	$200,000
1907	$150,000
1908	$100,000

1911
Fire destroys 35 structures in White Springs

USGS Streamgaging Budget
1919-28 Increase in State contributions to streamgaging program

1926-27
Five streamgages established in north Florida

1927
White Springs gage re-established as a non-recording staff gage
Local observers used to record staff gage 1932-83

1928-29
Floods

1931-35
Drought

1932
Continuous geographical recorder installed
Readings compared to outside staff gage

1937-41
Drought

1939
Tallahassee and Miami USGS offices established

1941
Gage relocated to Highway 41 in a concrete gagehouse
Cableway for flow measurements completed

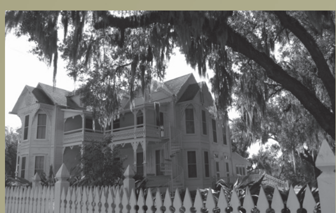
1941-46
U.S. involvement in WWII pulls four hydrographers from duty

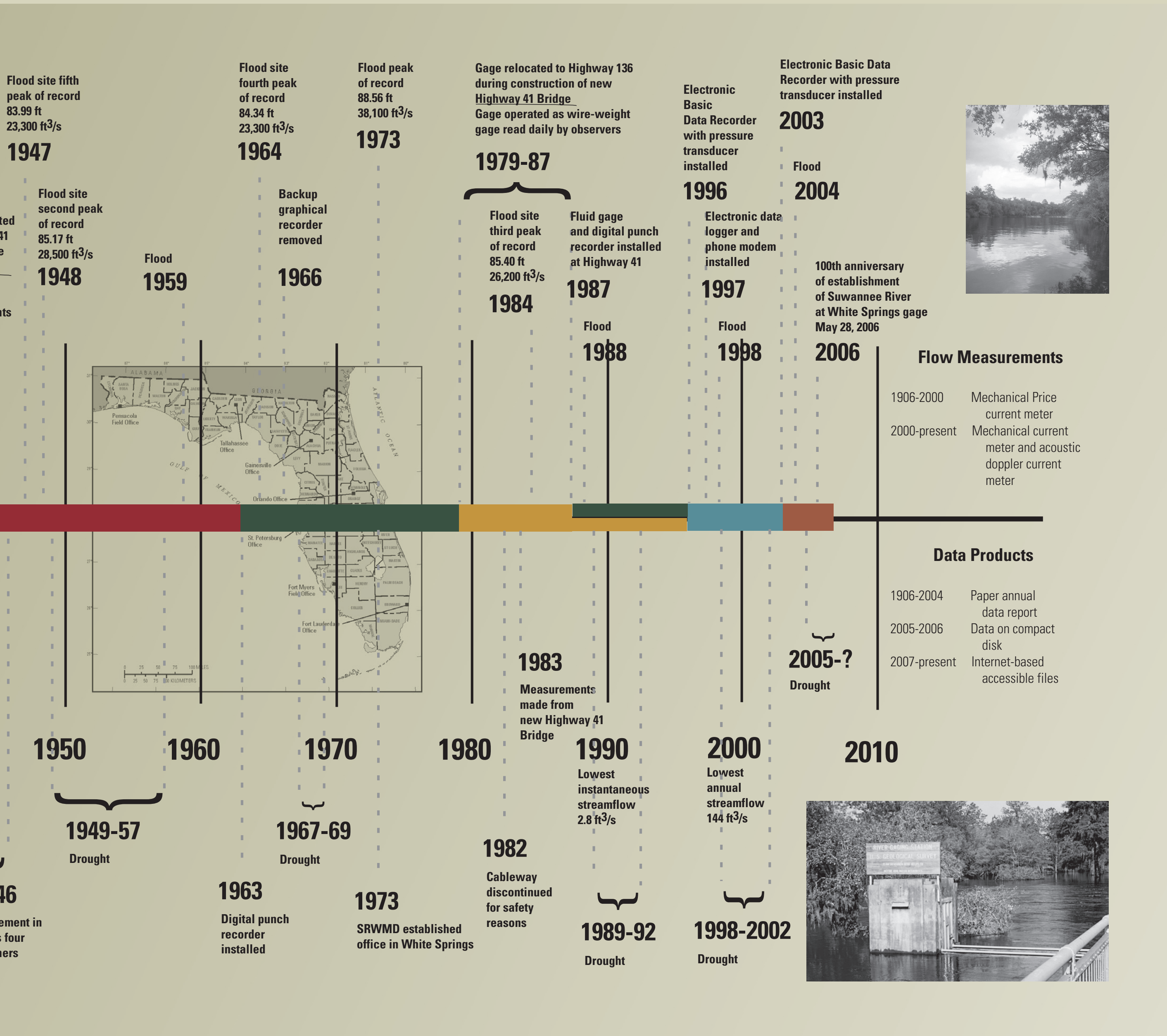
194
Flood s
peak o
83.99 f
23,300

1880 1890 1900 1910 1920 1930 1940

Primary sources of record

- Observer readings; mean daily flow computed from single or multiple daily observer readings
- Graphical recorder
- Digital punch recorder
- Electronic data logger
- Data collection platform (satellite real-time data)





Composite photograph of the Suwannee River at White Springs looking upstream from cable car (photograph by USGS).

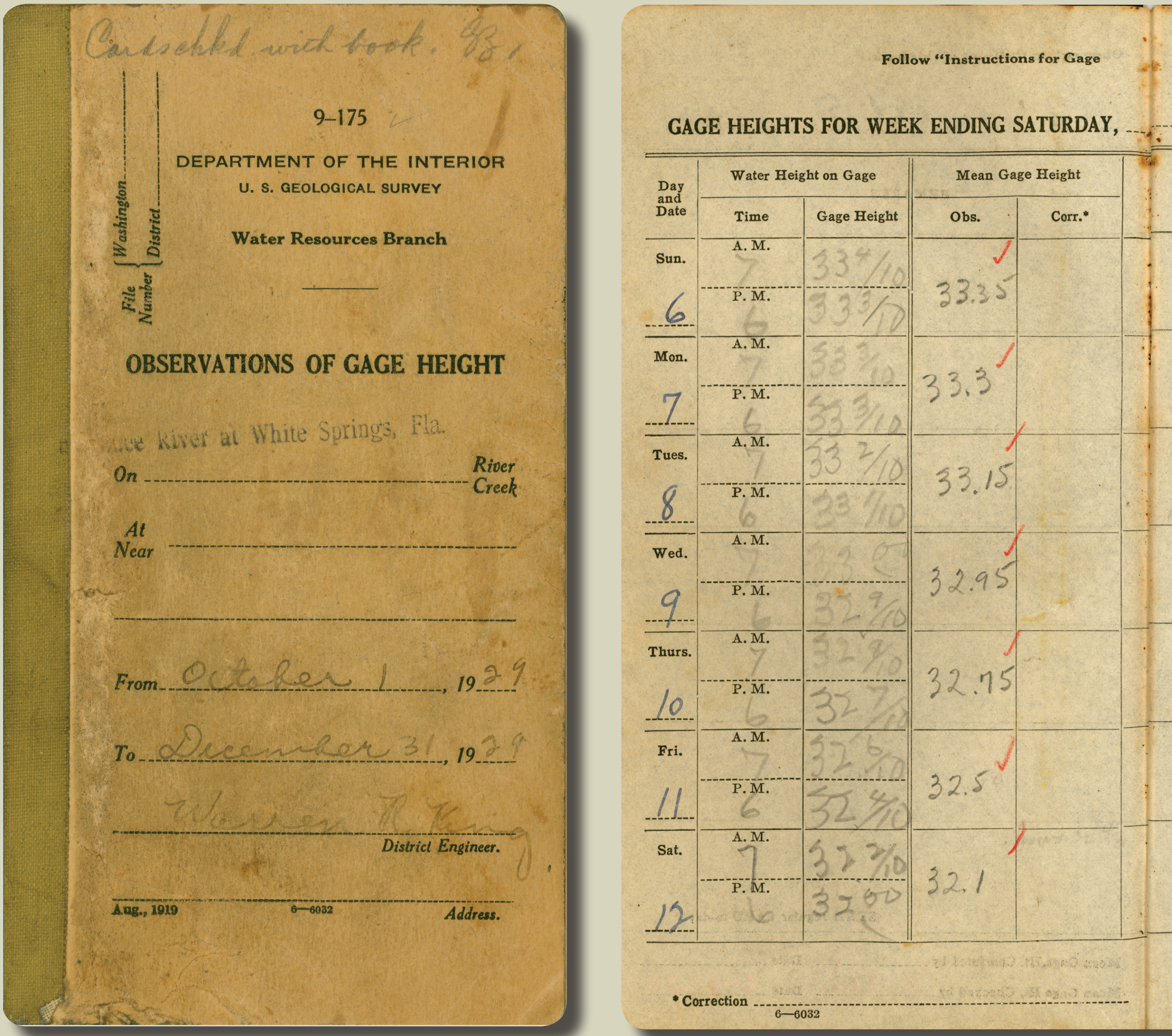
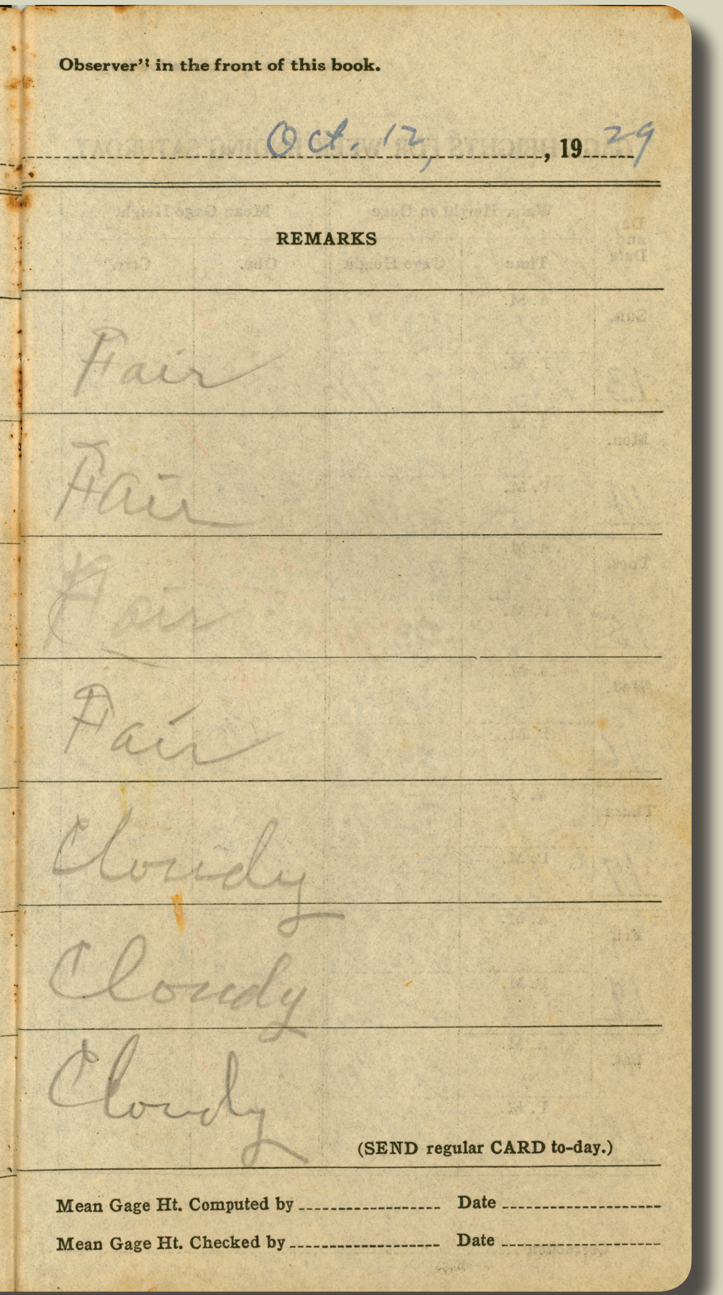


Figure 22. Example of the original observer's booklet used in 1929 to compute daily water-level elevation data.


Observer" in the front of this book.

Oct. 12, 1929

REMARKS

Fair

Fair

Fair

Fair

Cloudy

Cloudy

Cloudy

(SEND regular CARD to-day.)

Mean Gage Ht. Computed by ________ Date ________

Mean Gage Ht. Checked by ________ Date ________

The hydrographer computed daily water-level elevations by determining the point on the strip chart that most represented the mean of the continuous water level traced by the pen for a specific day. If an inspection showed that the outside reference gage and strip chart values did not match, the hydrographer would make corrections to the strip-chart data to reflect what the outside reference gage read. If the recorder malfunctioned and resulted in missing data, the hydrographer estimated water-level elevations from the observer's gage readings, or by comparing the station record with upstream or downstream gages.

Digital recorders provided a time series of mechanical punches representing the gage height on paper-tape during 1963-79 and 1987-96. Hydrographers computed the mean daily water-level elevation as the arithmetic mean of individual punched readings of water-level elevation during a given day. For example, if the continuous data recorder recorded data every hour (60 minutes), then the arithmetic mean would be the sum of the recorded values divided by 24 (number of data points punched in a single day). When the recorder failed, observer readings were used as daily means, or estimates were made from hydrographic comparison at gages upstream such as Suwannee River near Benton, or downstream such as Suwannee River at Suwannee Springs.

Hydrographers have used electronic data loggers and DCPs at the White Springs gage since 1996. These pieces of equipment store large amounts of data in a buffer within the data logger. Hydrographers program the recorders directly or with laptop computers to record data at specified intervals, such as 15 or 60 minutes, depending upon the rate at which gage height changes could occur. The recorder was programmed to take a water-level elevation every 60 minutes for the streamgage at White Springs. During site visits, hydrographers transfer these data to a laptop computer or other electronic storage device, and then upload to the USGS computers for entry into the NWIS database. Additionally, data are transmitted to USGS computers through telephone or satellite telemetry. Similar to digital recorders, the computer calculates the daily water-level elevations as the arithmetic mean of individual measurements of water-level elevation for a specific day.

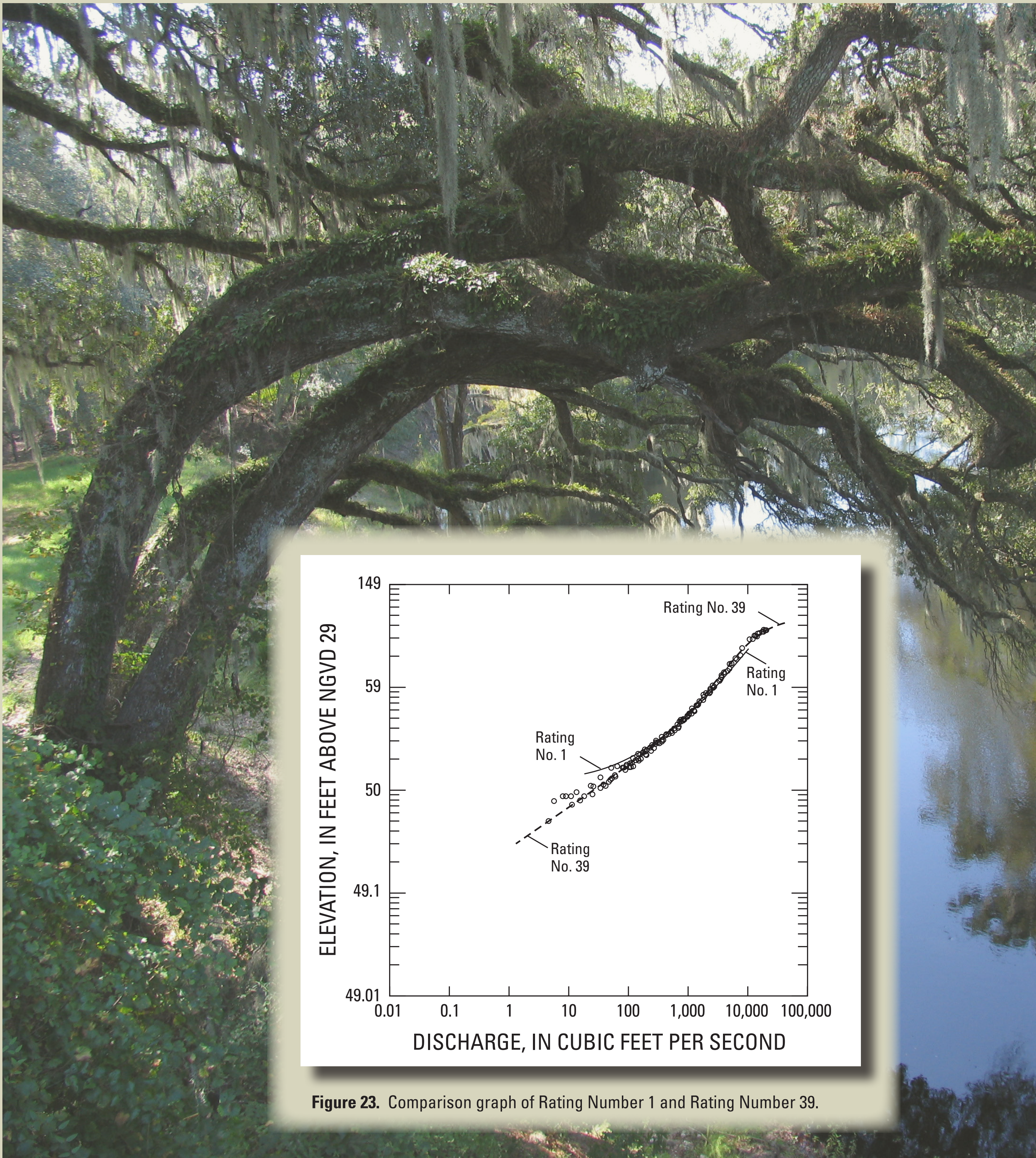


Figure 23. Comparison graph of Rating Number 1 and Rating Number 39.

Computations of Daily Streamflow

Continuous records of streamflow at Suwannee River at White Springs are computed by applying a streamflow rating for the stream to records of water-level elevation. Streamflow ratings are determined empirically by means of periodic water-level elevation and streamflow measurements (Rantz and others, 1982). Streamflow measurements are plotted on a graph with concurrent water-level elevation measurements to define the streamflow rating curve. This curve is typically the best-fit line through these plotted points, although there could be breaks where the slope of the curve changes due to the geometry of the stream channel. After a rating has been developed, hydrographers make periodic measurements every 6 to 8 weeks to assess any changes in the relation between water-level elevation and streamflow (Rantz and others, 1982). Additional measurements are also made at high and low flows to ensure that the measurements encompass most of the range of stage observed during the year.

Streamflow ratings are not permanent because physical changes, either permanent or temporary, in the reach of the river or channel downstream from the streamgage location can occur gradually or abruptly. Physical changes in the river system, such as vegetative growth during spring and summer, can cause a temporary change in the streamflow rating to the left of the defined rating curve as the vegetation causes the same discharge, but at a gradually higher water level. Therefore, a "shift" or adjustment to the rating may be developed to use during these seasons. If there is an abrupt change in the river system which affects the control for the gage and alters the connection between water-level elevation and streamflow, a new rating may be required. An example would be a major flood or storm, where flood waters deposit trees on the control, or, strong winds knock trees down into the stream causing them to act as a control.

During 1906-2006, the gage at Suwannee River at White Springs had 39 streamflow ratings. Rating Number 1 was used during the infancy of the streamgage from 1906 to 1908. Rating Number 39 has been used since October 10, 2006. Figure 23 shows Rating Number 1 compared to Rating Number 39 and streamflow measurements used for those ratings. The comparison of the two ratings demonstrates the stability of the stage-discharge connection and the consistency of the discharge measurement techniques used by USGS personnel throughout the 100-year history of the gage.

Summary of Major Drought and Flood Events

Florida has experienced several major droughts and floods since 1906. These significant hydrologic events are summarized in this section. The major droughts discussed in this section are those that (1) have 7-day low flow recurrence intervals of 10 years or greater, or (2) those having annual mean streamflow percent of average less than 20 percent. Some less severe droughts also occurred during the periods of record in 1960-64, 1970-77, and 1980-82, but are not discussed herein as they did not substantially impact the White Springs area. The floods discussed in this section are those ranking in the top 10 highest with regards to high flow recurrence intervals.

Major Droughts

Several major droughts that have occurred in Florida during the last century have had a dramatic impact on the White Springs area. Table 1 summarizes these droughts and states their effects on the Suwannee River at White Springs for the period of record for the streamgage (1906-08 and 1927-2006). The photograph shown in figure 24 is a view of the Suwannee River at White Springs looking upstream from Highway 41 taken September 13, 1999, during the statewide drought of 1998-2002. The most severe documented drought occurred from 1989-92. The lowest recorded instantaneous flow at the White Springs gage was 2.8 ft^3/s on September 26, 1990, which was also the lowest daily mean. The lowest annual 7-day low flow was 3.4 ft^3/s, which occurred on September 14, 1990. The subsequent discussions summarize the major droughts with comparisons of annual streamflow at White Springs to annual streamflow at nearby streamgages at Withlacoochee River near Pinetta and Suwannee River at Ellaville.

Drought of 1931-35

The drought of 1931-35 affected the panhandle and south-central peninsula of Florida with less than normal runoff for most streams in the area for 1 to 2.5 years (Bridges and Franklin, 1991). The lowest annual streamflow at the White Springs streamgage during this 5-year drought was 238 ft^3/s in 1934. This was 13 percent of the period of record average of 1,790 ft^3/s (table 1). This percentage is much lower when compared to nearby streamgages for the same period. In 1934, the Withlacoochee River near Pinetta reported 419 ft^3/s, 24 percent of its period of record average of 1,730 ft^3/s. The Suwannee River at Ellaville recorded streamflow at 2,340 ft^3/s during 1934, or about 37 percent of its period of record average of 6,380 ft^3/s. Statistics from the data show the 7-day low flow was 5.20 ft^3/s during the drought in 1932, which has a recurrence interval of once every 20 to 50 years (table 1).

Drought of 1937-41

The 5-year drought during 1937-41 was about as severe as the 5-year drought during 1931-35. This drought affected primarily northern and northwestern Florida with up to 4.5 consecutive years of lower than normal runoff for most streams (Bridges and Franklin, 1991). In 1941, the gage at Suwannee River at White Springs recorded its lowest annual streamflow during this drought of 299 ft^3/s, about 17 percent of its period of record average (table 1). Withlacoochee River near Pinetta and Suwannee River at Ellaville also recorded their lowest annual streamflow of this drought in 1941 with

Table 1. Chronology of droughts in Florida (1906-2006) and impacts at the White Springs streamgage location.

[ft^3/s, cubic feet per second. Major droughts featured in this report are shaded]

Date range	Lowest annual streamflow at White Springs (ft^3/s)	Year occurred	Percent of average	7-day low flow (ft^3/s)	Year occurred	Recurrence interval (years)
1931-1935	238	1934	13	5.20	1932	>20
1937-1941	299	1941	17	12.40	1941	10
1949-1957	155	1955	8	8.70	1955	>10
1960-1964	1,020	1963	57	40.30	1964	>2
1967-1969	208	1968	12	37.60	1968	>2
1970-1977	845	1974	47	20.10	1977	>5
1980-1982	634	1981	35	21.90	1981	>5
1989-1992	306	1989	17	3.40	1990	>50
1998-2002	144	2000	8	8.90	2000	>10

452 ft^3/s or about 26 percent of average, and 2,190 ft^3/s or 34 percent of average, respectively. The lowest 7-day low flow was 12.40 ft^3/s during the drought in 1941, which has a recurrence interval of about 10 years (table 1).

Drought of 1949-57

The severe drought during the 9-year period from 1949-57 affected the entire State of Florida. Most streams in northern Florida experienced less than normal runoff for 3 to 9 consecutive years (Bridges and Franklin, 1991). The drought was less severe in southern Florida, but most streams were affected with below normal runoff for 2 to 5 consecutive years (Bridges and Franklin, 1991). The lowest annual streamflow of this drought was recorded in 1955 at the White Springs, Ellaville, and Pinetta gages. Streamflow averaged 9 percent of the long-term average at White Springs with 156 ft^3/s (table 1). Streamflow at Pinetta was 236 ft^3/s or 14 percent of the average, whereas Ellaville was 1,300 ft^3/s or 20 percent of the average. The lowest 7-day low flow was 8.70 ft^3/s during the drought in 1955, which has a recurrence interval of 10 to 20 years (table 1).

Drought of 1967-69

The 3-year drought during 1967-69 affected the panhandle and northern part of Florida with below normal runoff in most streams for 2 to 4 consecutive years (Bridges and Franklin, 1991). The lowest annual streamflow at all three streamgages during this drought occurred in 1968. The annual streamflow at White Springs during this drought was 208 ft^3/s for 1968, approximately 12 percent of the period of record average (table 1). Pinetta recorded 247 ft^3/s, or 14 percent of its period of record average. Ellaville reported 1,810 ft^3/s, about 28 percent of the period of record average. The lowest 7-day low flow was 37.60 ft^3/s during the drought in 1968, which has a recurrence interval of greater than 2 years and less than 5 years (table 1).

Drought of 1989-92

The 1989-92 drought had a dramatic affect on streamflow at Suwannee River at White Springs, although the drought was statewide and affected most streams with less than normal runoff (Bridges and Franklin, 1991). The lowest instantaneous flow (2.8 ft^3/s on September 26, 1990) and lowest annual 7-day low flow (3.4 ft^3/s beginning September 24, 1990) during the 100-year period of record of the White Springs gage were recorded during this drought. The lowest annual streamflow recorded during the drought at White Springs was 306 ft^3/s in 1989, about 17 percent of the period of record average (table 1). The gages at Pinetta and Ellaville also recorded their lowest annual streamflow during 1989, with 739 ft^3/s, about 43 percent of its period of record average; and 2,600 ft^3/s, or about 41 percent of its period of record average, respectively. The 7-day low flow was 3.40 ft^3/s during the drought in 1990, which has a recurrence interval of greater than every 50 years (table 1).

Drought of 1998-2002

The 1998-2002 drought affected the entire State for 5 years and is considered the most severe drought to affect Florida since the 1949-57 drought (Verdi and others, 2006). Most streams in Florida suffered from less than normal runoff during this period. The Suwannee River at White Springs recorded its lowest annual flow during its 100-year period of record in 2000 at 144 ft^3/s, or 8 percent of the period of record average for the gage (table 1). The lowest annual streamflow at the gage at Pinetta during the drought was 333 ft^3/s in 2002, about 20 percent of its period of record average. Ellaville recorded 1,550 ft^3/s, approximately 24 percent of its period of record average in 2000. The lowest 7-day low flow was 8.90 ft^3/s during the drought of 2000, which has a recurrence interval of 10 to 20 years (table 1).

Figure 24. The Suwannee River at White Springs at Highway 41 on September 13, 1999, during the drought of 1998-2002 (left; photograph courtesy of Malcolm Greene).

Figure 25. The Spring House at White Springs during the flood of September-October 1928 (above; photograph courtesy of the Florida State Archive).

Major Floods

The Suwannee River at White Springs gage has experienced several major floods since streamgage monitoring began in 1906. Severe floods in the Suwannee River are usually caused by single storm systems or sequences of storms that have the ability to impact a widespread area for several days (U.S. Army Corps of Engineers, 1974). Atmospheric conditions are ideal during late winter or early spring for development of frontal-type rainfall systems that can stall for several days, causing large amounts of rainfall. An example was the flood of 1948, which was caused by a sequence of storms producing above normal rainfall during March and April. During the period of heaviest rainfall (March 31 to April 2), some locations within the Suwannee River basin recorded more than 10 in. of rain.

During the summer and fall seasons, low pressure tropical disturbances can develop in the Gulf of Mexico or Atlantic Ocean. These events can deliver intense rainfall across the path of the system, especially on the eastern or northeastern side of the center of low pressure. One example was the flood of September 1964, which resulted from the landfall of Hurricane Dora. Heavy rainfall occurred during the 3-day period of September 10 to 12 in the Suwannee River basin. For example, 18.47 in. of rain was recorded in Live Oak (Butson, 1964) and inundated the town with almost 5 ft of water (Bridges and Franklin, 1991).

The 10 major floods on the Suwannee River at White Springs are summarized in table 2 with information on peak streamflow, peak water-level elevation, date of occurrence, and recurrence intervals of each flood. A photographic example of damage from a major flood in 1929 shows that the Spring House recreational facility at White Springs had water rise halfway up the building during the peak period (fig. 25).

Table 2. Major floods and their impacts on the Suwannee River at White Springs streamgage location.

[ft^3/s, cubic feet per second; NGVD 1929, National Geodetic Vertical Datum of 1929]

Rank	Date	Peak streamflow (ft^3/s)	Peak water-level elevation (feet above NGVD 1929)	Recurrence interval (years)[1]
1	April 10, 1973	38,100	88.56	>350
2	April 5, 1948	28,500	85.17	>50
3	April 10, 1984	26,200	85.40	40
4	September 17, 1964	23,300	84.34	25
5	October 29, 1947	23,300	83.99	25
6	October 1, 1928	20,600	82.44	>10
7	March 22, 1959	20,100	83.14	>10
8	October 5, 1929	19,600	82.04	>10
9	February 26, 1998	19,300	84.73	>10
10	October 3, 2004	17,600	84.03	10

[1]Computed based on period-of-record peaks to water year 2006.

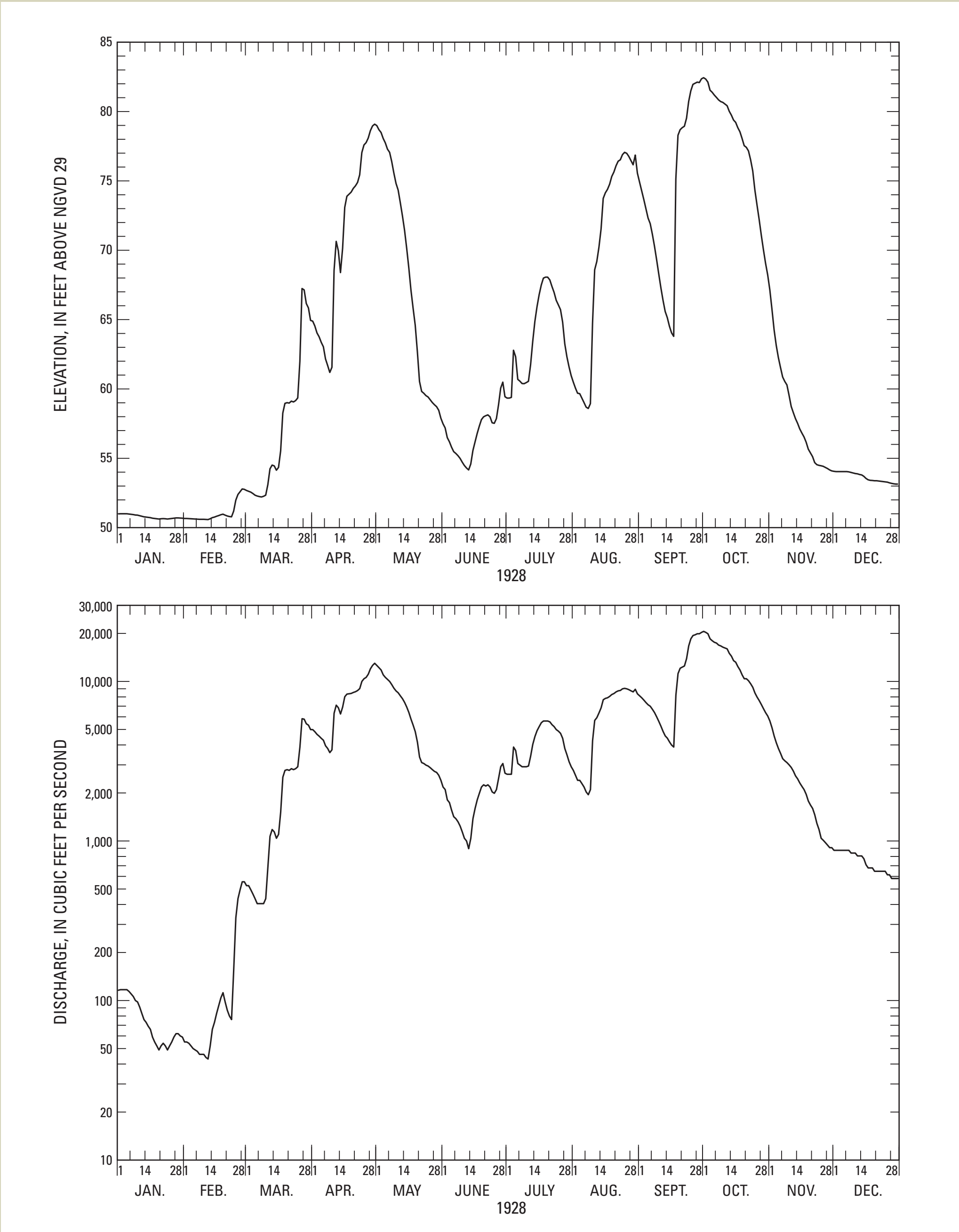


Figure 26. Water-level elevation and streamflow hydrographs of the three floods on the Suwannee River at White Springs during 1928.

Flood of 1928

The upper and middle Suwannee River basin received above-average rainfall in 1928 with 68.21 in. recorded at Lake City and 70.95 in. recorded at Madison in Florida (Mitchell, 1929), and 62.26 in. recorded at Alapaha in Georgia (von Herrmann, 1929a). The White Springs gage experienced three peaks in 1928 (fig. 26), due to runoff from the rainfall, which exceeded the flood stage of 77.00 ft above NGVD 29 as determined by the National Oceanic and Atmospheric Administration (NOAA). The first of these episodes occurred from March to May and was caused by the compounded effects of a series of frontal systems moving through the area in late February, March and April. Rainfall during the 3-day period of February 23-25 totaled 3.21 in. at Madison and 4.38 in. at Lake City, Florida (Mitchell, 1928a). This rainfall event caused a small rise in river levels (fig. 26).

In March, three additional storm systems produced heavy rainfall that caused even higher river levels, with the most significant rise occurring during the 3-day period of March 25-27 (fig. 26). Rainfall amounts for the month of March totaled 7.98 in. at Lake City, 8.58 in. at Live Oak, and 8.72 in. at Madison in Florida (Mitchell, 1928b), and 5.61 in. at Fargo and 7.12 in. at Alapaha in Georgia (von Herrmann, 1928a).

River levels started receding in April; however, four more storm systems moved across the area producing rainfall that ultimately led to the peak of 79.09 ft above NGVD 29 and a flow of 13,000 ft^3/s on April 30. Rainfall amounts were above normal for the month, totaling 10.40 in. at Lake City, 12.16 in. at Live Oak, and 12.34 in. at Madison, Florida (Mitchell, 1928c). Rainfall amounts totaled 10.96 in. at Fargo and 8.96 in. at Alapaha in Georgia (von Herrmann, 1928b).

The next two flood events in August and another in September 1928 were each caused by a combination of typical summertime thunderstorms and two hurricanes. Rainfall amounts in August were above average and totaled 8.71 in. at Lake City and 14.97 in. at Madison, Florida (Mitchell, 1928d), and 8.12 in. at Fargo and 14.43 in. at Alapaha, Georgia (von Herrmann, 1928c). The first hurricane made landfall just north of Fort Pierce on August 7 and traveled northwest through central Florida, through the Suwannee River basin in northern Florida, and into south-western Georgia on August 9 and 10. The storm then curved to the northeast and moved throughout the southeastern United States, exiting into the Atlantic Ocean near the Virginia Capes on August 12 (Young, 1928; Barnes, 1998). The storm lost hurricane strength and became a tropical storm soon after its landfall in Florida. This storm produced an average of 5.10 in. of rainfall in the Suwannee River basin. However, subsequent summertime thunderstorms produced additional rainfall in the basin, with runoff eventually causing a peak of 77.06 ft above NGVD 29 and flow of 9,050 ft^3/s on August 25 (fig. 26).

A second hurricane struck Florida on September 16, 1928, as a category 4 storm and caused what is referred to as “The Great Okeechobee Flood.” This same storm caused flooding on the Suwannee River at White Springs, thus producing the third flood event during 1928. This hurricane made landfall near West Palm Beach and moved northwest across Lake Okeechobee and the peninsula, with the center passing between Ocala and Cedar Key. The storm then turned north-northeast and moved into southeastern Georgia (Mitchell, 1928). The hurricane produced 5.10 in. of rain upstream from White Springs at Fargo, Georgia (von Herrmann, 1928d). Prior to and subsequent to the September 1928 hurricane, the White Springs area received several localized rainfall events. September 1928 rainfall totals were 8.27 in. at Lake City and 6.70 in. at Madison in Florida (Mitchell, 1928e) and totals were 13.16 in. at Fargo and 9.25 in. at Alapaha in Georgia (von Herrmann, 1928d). Runoff from these storms ultimately led to a flood peak of 82.44 ft above NGVD 29 and flow of 20,600 ft^3/s on October 1 (fig. 26; table 2). The recurrence interval on this flood was estimated to be between 10 and 25 years (table 2). This 1928 flood ranks sixth of the major 10 floods impacting the Suwannee River at White Springs from 1906 to 2006.

Above: Photographs of the Suwannee River in April 1924 (left) and April 1925 (right; photographs by USGS).

Flood of 1929

The second hurricane of 1929 was from September 28 to October 4. The storm moved through the Florida Straits, with the eye of the storm due south of Miami on the morning of September 28 (Mitchell, 1929). By 8:00 p.m., the center of the hurricane was located between Key West and Fort Myers traveling northwest into the Gulf of Mexico (Mitchell, 1929). Near midnight, the storm moved inland near Panama City. The storm made a turn toward the northeast on October 1 and moved through southern Georgia (Mitchell, 1929).

Before the hurricane made landfall in northern Florida, the Suwannee River at White Springs had experienced several days of rainfall, according to Mr. Scarborough, the USGS observer at the time. Mr. Scarborough's comments indicated that it rained each day during September 23-25. On September 27, heavy rain had fallen all day. September 28 was cloudy with no rain, but rainfall commenced on September 29 and continued through October 1. Rainfall at the weather gage at Fargo in Georgia totaled 11.00 in. during September 23-30, of which 7.88 in. was from the 2-day period of September 26-27 (von Herrmann, 1929b).

The flood peaked on October 5, 1929, at a water-level elevation of 82.04 ft above NGVD 29 and streamflow of 19,600 ft^3/s (table 2). The recurrence interval on this flood was computed to be between 10 and 25 years (table 2). This 1929 flood ranks eighth of the major 10 floods impacting the Suwannee River at White Springs from 1906 to 2006.

Flood of 1947

The flood of 1947 resulted from a combination of three tropical disturbances, two of which reached tropical storm strength and the other reached hurricane strength. The first tropical storm made landfall between Tampa and Cedar Key in the evening on September 23 and produced heavy rain throughout the peninsula and northern Florida as it traveled northeast. The storm then moved west of Jacksonville and up through southeastern Georgia, exiting into the Atlantic Ocean between North Carolina and the Virginia Capes on September 25 (Sumner, 1947). The rainfall total was 7.16 in., which was 2.75 in. above normal for Jasper, Florida, during September 1947 (Bennett, 1947a). The rainfall total was 12.94 in., which was 8.12 in. above normal for Lake City, Florida (Bennett, 1947a).

Another tropical storm hit in early October, just as the waters in the Suwannee River at White Springs were receding. This storm made landfall near Brunswick, Georgia, about midnight on October 6-7 (Sumner, 1947) and continued to move west across the Suwannee River basin. The tropical disturbance made a circular loop around the Florida Big Bend area on October 7, then tracked north through the Suwannee River basin and into southern Georgia.

The third tropical disturbance was a hurricane that made landfall on October 11 in southwest Florida near Cape Sable, then moved northeast, exiting between Miami and West Palm Beach on October 12 (Sumner, 1947). As the storm tracked through the Atlantic Ocean, it gained strength and turned west, moving into southern Georgia on October 15 (Sumner, 1947). The storm produced heavy rain with runoff that produced the peak of the flood of 1947. The rainfall totals for both storms were 9.58 in, which was 7.10 in. above normal (Bennett, 1947b). In Lake City, rainfall was 14.45 in., which was 11.72 in. above normal (Bennett, 1947b).

The flood peaked October 29, 1947, at a water-level elevation of 83.99 ft above NGVD 29 and streamflow of 23,300 ft^3/s. The recurrence interval on this flood was computed to be between 25 and 50 years (table 2). This 1947 flood ranks fifth of the major 10 floods impacting the Suwannee River at White Springs from 1906 to 2006.

Flood of 1948

The flood of 1948 resulted from a sequence of storms that produced prolonged, heavy, and above normal rainfall throughout most of the basin during March and April 1948. The heaviest rainfall occurred from March 31 to April 2 (U.S. Army Corps of Engineers, 1974). Rainfall amounts for the 3-day period totaled 5.40 in. at Lake City and 10.73 in. at Madison in Florida (Bennett, 1948a,b), and 9.52 in. at Alapaha and 10.22 in. at Moultrie in Georgia (Cornelius, 1948a,b). The Suwannee River at White Springs, including the basin from the coast north to the Florida-Georgia border, was out of its banks during the period of peak streamflow and water-level elevations (U.S. Army Corps of Engineers, 1974). Several towns along the river were inundated with flood waters. For example, parts of Ellaville, Dowling Park, and Old Town were flooded with up to 8 ft of water (U.S. Army Corps of Engineers, 1974). Throughout the basin, the flood damaged bridges, highways, and railroads. Transportation had to be rerouted for as long as 3 weeks while flood waters receded and damaged roadways were repaired (U.S. Army Corps of Engineers, 1974).

The flood peaked on April 5, 1948, at 85.17 ft above NGVD 29 and streamflow of 28,500 ft^3/s. The recurrence interval on this flood was computed to be between 50 and 100 years (table 2). This 1948 flood ranks second of the major 10 floods impacting the Suwannee River at White Springs from 1906 to 2006.

Flood of 1959

Two frontal-type systems brought 6 to 8 in. of rainfall to the Suwannee River basin during the first and third weeks of March 1959. The Suwannee River basin was already saturated because of higher than normal rainfall during the preceding 3 months, but the two frontal systems produced flooding along nearly 350 mi^2 of the river (U.S. Army Corps of Engineers, 1974). Some recreational facilities, such as the Spring House in White Springs, were affected by the flood waters (fig. 27). Highway 41 in White Springs was also flooded when the Suwannee River overflowed its banks (fig. 28).

The peak water-level elevation and streamflow occurred on March 22, 1959 at 83.14 ft above NGVD 29, about 2 ft less than the flood of 1948, with streamflow of 20,100 ft^3/s. The recurrence interval of this flood was computed to be between 10 and 25 years (table 2). This 1959 flood ranks seventh of the major 10 floods impacting Suwannee River at White Springs from 1906 to 2006.

Figure 27. The Spring House partially submerged during the flood of 1959 (upper right; photograph courtesy of Marlene Shaw).

Figure 28. Highway 41 in White Springs. The road is submerged in water due to flooding of the Suwannee River in 1959 (right center; photograph courtesy of Marlene Shaw).

Right: Downtown White Springs in 1928 (photograph courtesy of the Florida State Archive).

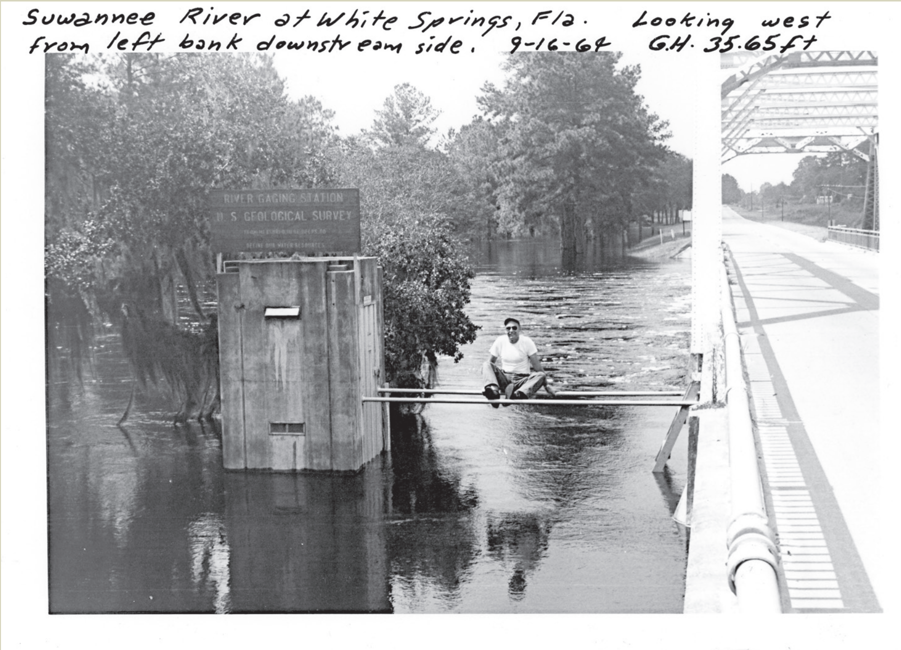


Figure 29. The streamgage at Highway 41 during the flood on September 16, 1964. The walkway to the gage was submerged in water. (left; photograph by USGS).

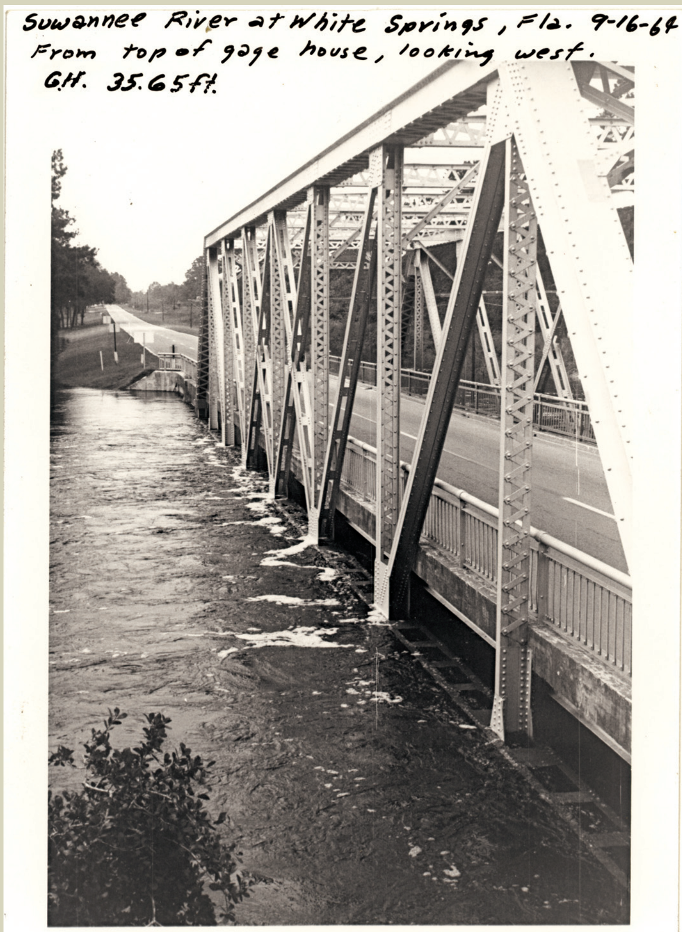


Figure 30. Looking west at Highway 41 at White Springs during the flood on September 16, 1964 (left; photograph by USGS).

Figure 31. Looking upstream of the Highway 41 Bridge at White Springs during the flood on September 16, 1964 (left; photograph by USGS).

Left: The main channel of the Suwannee River from the right bank at I-75 on September 17, 1964 (left; photograph by USGS).

Flood of 1964

The flood of 1964 resulted from rainfall due to Hurricane Dora, which came ashore at St. Augustine about midnight on September 10 (Dunn and others, 1965). Dora maintained movement to the west while pouring heavy amounts of rain over many northern Florida and southern Georgia river basins, including the Suwannee River (Dunn and others, 1965). As the storm approached the panhandle of Florida on September 11, Dora began curving to the northwest. By the morning of September 12, Dora made a U-turn and traveled east through southern Georgia. During the 3-day period from September 10-12, Dora's rainfall totals were 9.64 in. at Jasper, 11.69 in. at Lake City, and 18.47 in. at Live Oak in Florida (Butson, 1964). Figures 29 to 31 show photographs of the Suwannee River at White Springs at the Highway 41 Bridge on September 16, 1964 (the day before the river crested). Flood waters were just short of submerging the bridge, but covered the walkway that USGS personnel used to access the streamgage located at the Highway 41 Bridge.

The flood peaked on September 17, 1964, at a water-level elevation of 84.34 ft above NGVD 29 and streamflow of 23,300 ft^3/s. This flood has a recurrence interval of between 25 and 50 years (table 2). This 1964 flood ranks fourth of the major 10 floods impacting the Suwannee River at White Springs from 1906 to 2006.

Flood of 1973

A sequence of frontal storms with above normal rainfall moved through the basin during February, March, and April 1973 (U.S. Army Corps of Engineers, 1974), producing the record flood at the Suwannee River at White Springs gage. Rainfall was heaviest during the first week of April. Rainfall totals on April 1 were 4.95 in at Jasper, 1.63 in. at Lake City, and 3.40 in. at Live Oak in Florida (Environmental Data Service, 1973). Rainfall totals on April 4 were 8.45 in. at Jasper, 3.15 in. at Lake City, and 4.09 in. at Live Oak in Florida (Environmental Data Service, 1973). The flood closed highways and railroads, and damaged recreational facilities along the river (fig. 32). The Suwannee River submerged the Highway 41 Bridge and flooded the Spring House in White Springs up to its roof during the peak of this flood (fig. 33).

The hydrograph of water-level elevation and streamflow (fig. 34) for the Suwannee River at White Springs shows the flood peak occurred on April 10, 1973. The peak water-level elevation was 88.56 ft above NGVD 29 and streamflow was 38,100 ft^3/s. The recurrence interval of this flood was computed to be between 200 and 500 years (table 2). This 1973 flood ranks first of the major 10 floods impacting the Suwannee River at White Springs from 1906 to 2006.

Flood of 1984

In March 1984, two storms (March 5-6 and March 27-28) moved through southern Georgia and northern Florida producing above normal rainfall (Perry and others, 2001). The storms on March 27-28 produced high winds as well as intense rain (Perry and others, 2001). Rainfall totals were 12.01 in., which was 7.58 in. above normal at Jasper, Florida, during March 1984 (National Climatic Data Center, 1984a). March rainfall totaled 10.11 in. at Lake City, Florida, which was 5.87 in. above normal (National Climatic Data Center, 1984a). Additional rainfall recorded on April 4 totaled 3.18 in. at Jasper and 2.82 in. at Lake City in Florida (National Climatic Data Center, 1984b).

The flood peaked on April 10 at a water-level elevation of 85.40 ft above NGVD 29 and streamflow of 26,200 ft^3/s. This flood has a recurrence interval between 25 and 50 years (table 2). This 1984 flood ranks third of the major 10 floods impacting the Suwannee River at White Springs from 1906 to 2006.

Figure 32. Highway 41 Bridge at Suwannee River at White Springs on April 10, 1973. View is north toward the submerged bridge and highway and the Seaboard Coastline railroad bridge (above; photograph by Richard C. Heath, USGS).

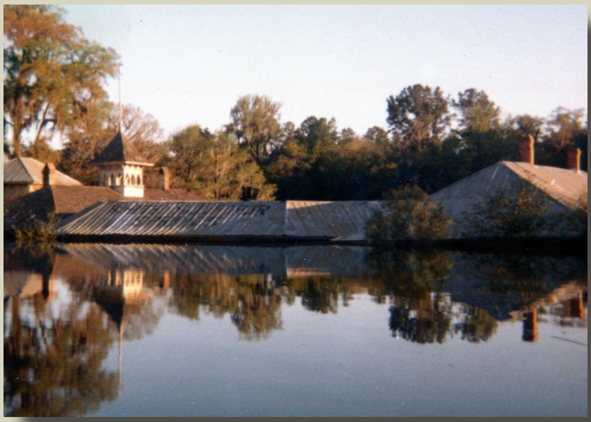


Figure 33. The Spring House in White Springs in April 1973 (above; photograph courtesy of Marlene Shaw).

Above: Water flowing over Highway 41 during the flood of 1973 (photograph by USGS).

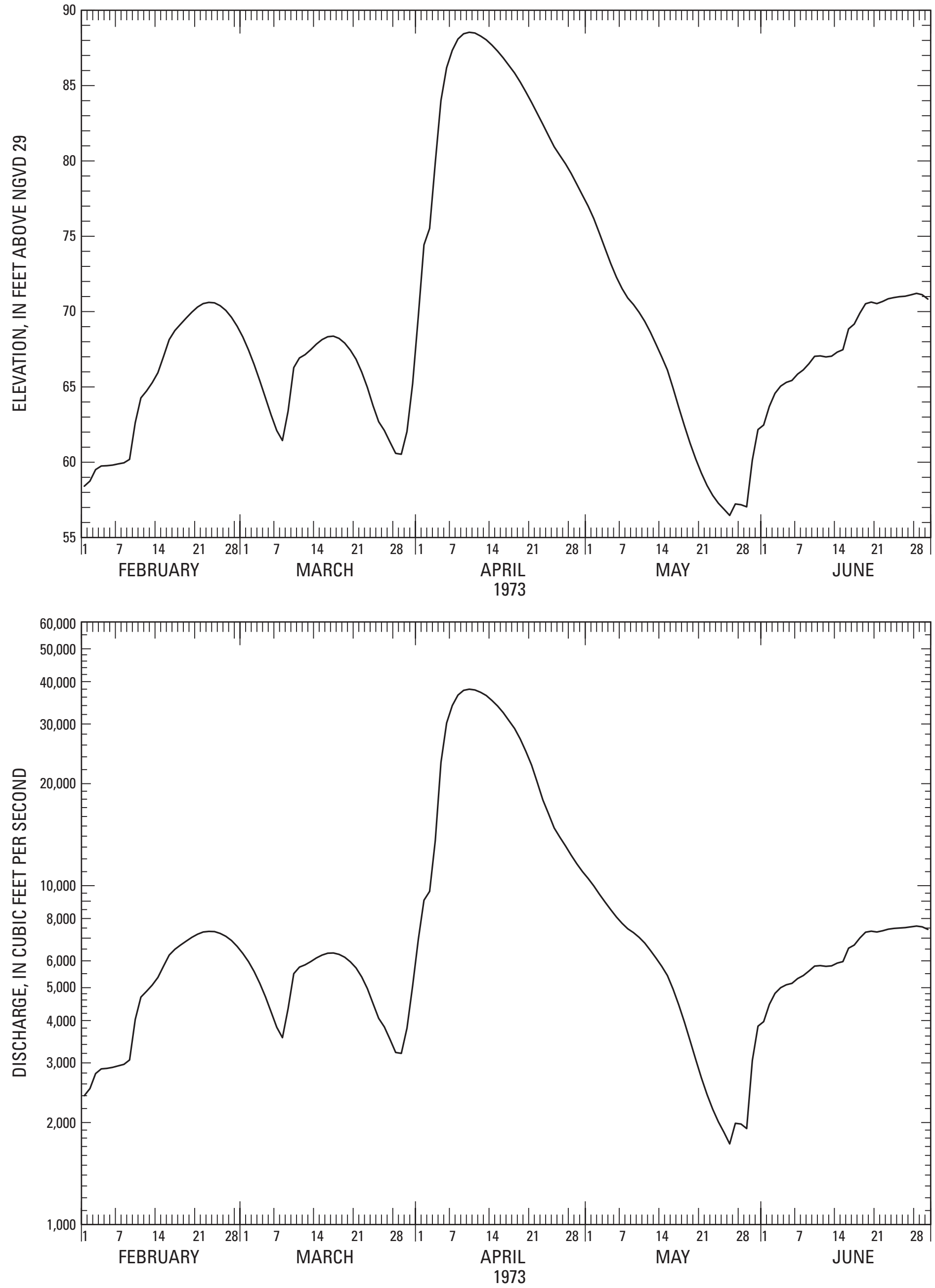


Figure 34. Hydrograph of water-level elevation and streamflow for the Suwannee River at White Springs during the flood of 1973.

Flood of 1998

A strong El Niño phenomenon in the fall and winter of 1997-98 produced heavy rainfall which ultimately led to the flood on the Suwannee River at White Springs in February 1998. Rainfall from October 1997 to February 1998 was well above normal and totaled 29.23 in. (11.44 in. above normal) at Jasper, Florida, during the 5-month period (National Climatic Data Center, 1998; 1999). Rainfall totaled 28.12 in. (11.47 in. above normal) during the same period at Lake City, Florida (National Climatic Data Center, 1998; 1999). The remnants of the Spring House at White Springs were flooded (fig. 35). The Suwannee River overflowed its banks and washed out or submerged roads along the river (fig. 36).

The flood peak occurred February 26, 1998, at a water-level elevation of 84.73 ft above NGVD 29 and streamflow of 19,300 ft^3/s. A flood of this magnitude is expected to occur once every 10 to 25 years (table 2). This 1998 flood ranks ninth of the major 10 floods recorded at Suwannee River at White Springs from 1906 to 2006.

Flood of 2004

Florida endured one tropical storm (Bonnie) and four hurricanes (Charley, Frances, Ivan, and Jeanne) in 2004 (Verdi, 2005). The impact of three of these storms—Bonnie, Frances, and Jeanne—led to the flood of 2004 on the Suwannee River at White Springs.

Tropical Storm Bonnie made landfall on August 12, 2004, in the panhandle just south of Apalachicola and quickly weakened to a tropical depression. Bonnie continued to move northeast through the Suwannee River basin and into southeastern Georgia. At White Springs, 1.38 in. of precipitation fell from August 12-13 as a result of the storm (National Weather Service, 2004a). This precipitation led to a very slight rise in the water level and streamflow (fig. 37).

Hurricane Frances made landfall near Fort Pierce on September 5, 2004. The slow-moving hurricane weakened to a tropical storm as it moved through Florida on a north-westward track, exiting to the Gulf of Mexico near New Port Richey (National Weather Service, 2004b). Continuing to move toward the northwest, Frances made the second Florida landfall near the mouth of the Aucilla River. The center of the storm did not travel through the Suwannee River basin; however, the storm was so large in diameter that it produced significant rainfall in the area. Rainfall totaled 9.11 in. at White Springs during September 4-8 (National Climatic Data Center, 2004); this event produced a sharp second peak in the September hydrograph (fig. 37).

Hurricane Jeanne made landfall at nearly the same location as Hurricane Frances near Fort Pierce on September 26. Shortly after landfall, Jeanne curved to the northwest and was downgraded to a tropical storm as it moved through the Florida peninsula (National Weather Service, 2004c). The center of the storm traveled directly over the Suwannee River basin before entering southern Georgia. Hurricane Jeanne produced an additional 6.40 in. of rain at White Springs during September 25-27, thus adding to the rainfall produced by Hurricane Frances 3 weeks earlier (National Climatic Data Center, 2004).

This last storm produced the third and highest flood peak in 2004 (fig. 37). On October 3, the flood peaked at 84.03 ft above NGVD 29 with a flow of 17,600 ft^3/s. This flood has a recurrence interval of 10 years (table 2). This 2004 flood ranks tenth of the major 10 floods impacting the Suwannee River at White Springs gage from 1906 to 2006.

Figure 35. The remnants of the Spring House in White Springs during the flood of 1998 (above; photograph courtesy of Malcolm Greene).

Figure 36. The Suwannee River at White Springs looking upstream from the Highway 41 Bridge during the flood of 1998 (above; photograph courtesy of Malcolm Greene).

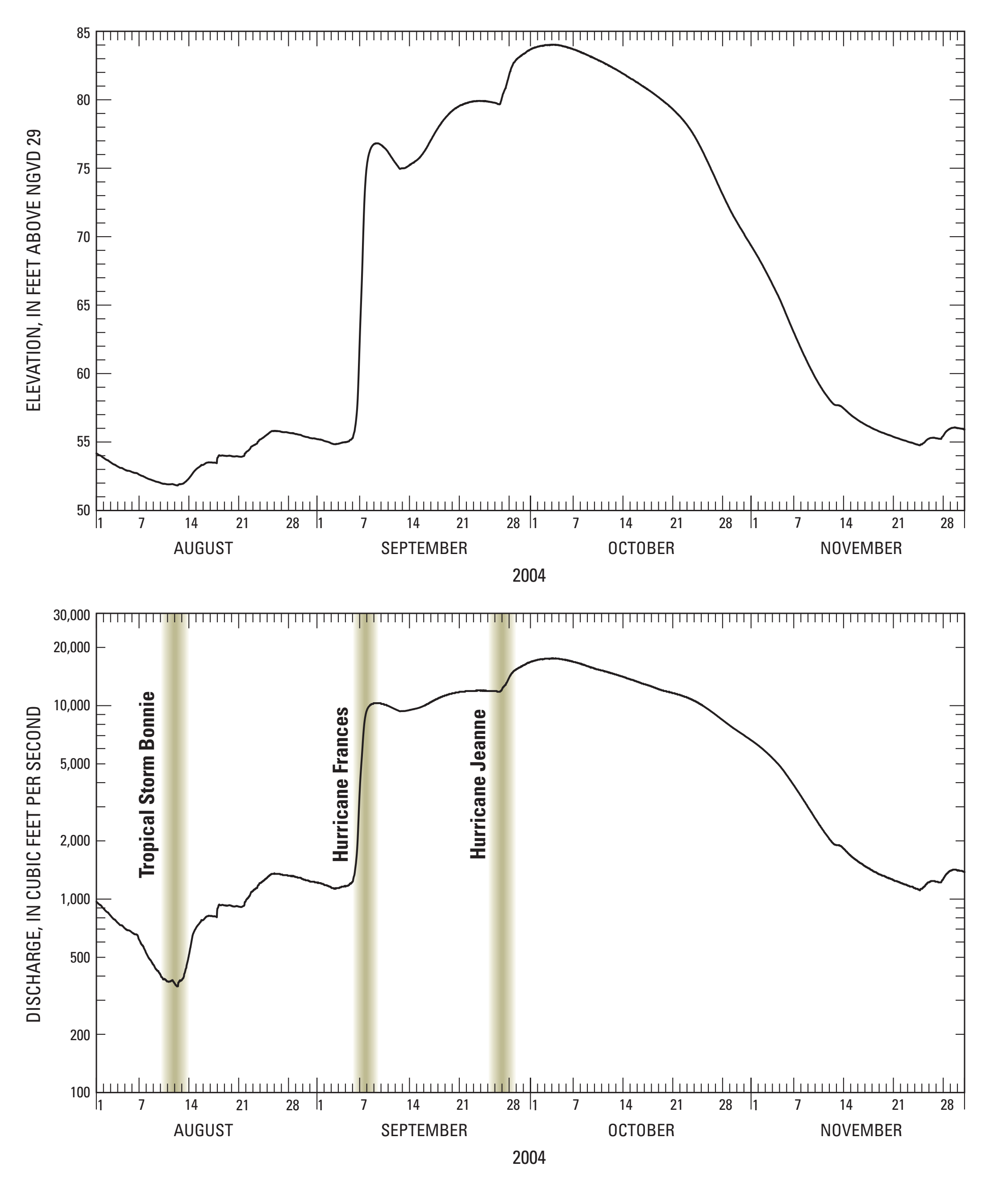


Figure 37. Water-level elevation and streamflow hydrographs of the floods on the Suwannee River at White Springs during 2004.

Progress of Streamgaging Activities and Costs

New technology and methodology for streamgaging allows for more reliable data sets and safer, more efficient measuring techniques. These tools can be used to assist local, State and Federal agencies in making sound decisions when dealing with severe drought, floods, and water-management issues. This section discusses the newest technologies and methodologies used at the streamgage for the Suwannee River at White Springs.

New Technology and Instrument Upgrades

Hurricanes during the record-breaking 2005 hurricane season, which included Hurricanes Katrina and Rita, destroyed or damaged many USGS hydrological monitoring stations along the Gulf coast from Texas to Florida. In 2006, the U.S. Congress approved a supplemental funding appropriation of $5,300,000 to facilitate repair, replacement, and gage hardening at USGS streamgages that are part of the National Streamflow Information Program (NSIP). The White Springs streamgage is included in the NSIP, which is discussed later in this report.

A part of the appropriation was designated for streamgages to be hardened to withstand the 200-year flood level. An analysis of peak streamflow data from the Suwannee River at White Springs determined that the 200-year flood level was 89.76 ft above NGVD 29. For streamflow, the 200-year flood level is 35,100 ft^3/s. A recent survey of elevation at the streamgage location determined the shelf that the DCP and associated power supply was situated on within the gage house was approximately 3 ft below the 200-year flood level. Work was performed to raise the shelf inside the gage house to an elevation of about 90.00 ft NGVD 29, which is slightly above the 200-year flood level. Additionally, equipment upgrades were made to provide more timelier and reliable data using state-of-the-art instrumentation.

The original DCP was replaced with a High Data Rate (HDR) DCP which is able to perform routine data transmissions every hour. Prior to the HDR, the transmission interval from the unit to the GOES satellite was every 3 or 4 hours at a rate of 100 baud using an assigned transmit time and 1-minute window on a routine-transmission channel. These data can be transmitted during emergency situations, such as floods or droughts, at intervals equal to the update interval of the data (for example, hourly) on a separate non-routine channel. The emergency transmissions provide the most up-to-date information for water managers and emergency management officials. A high-water threshold or rate of rise threshold during a flood would trigger the alarm within the DCP, thus prompting the unit to begin transmitting at the more frequent intervals. The same transmission can be accomplished by setting a low-water threshold during extreme drought conditions. The new HDR DCPs have the capability to transmit three times the amount of data compared to the traditional DCP's capability to transmit in a window of 10 to 15 seconds. This improvement is advantageous as more previously recorded readings can be sent along with the current data, so that a more complete data set can be obtained. Older style units were less reliable. If the DCP missed more than two consecutive transmissions, previous readings were missed and created a "gap" in the data set that had to be filled in manually after downloading the data from the DCP several weeks afterward.

An additional stage sensor, a radar, was installed on the Highway 41 Bridge at the White Springs gage to provide backup water-level readings if the primary stage sensor, a pressure transducer, malfunctioned. Additional equipment is necessary during floods when the data are used to forecast water levels downstream. The radar unit measures the distance to the water level in the stream using an electronic signal and converts it to a water-level elevation using an offset equation programmed within the radar unit.

Streamflow Measurements

The USGS and SRWMD personnel have made 636 streamflow measurements from 1906 to 2006. All have been used to relate the water-level elevation to streamflow in the Suwannee River at White Springs. Until recently, streamflow measurements have usually been taken using Price current meters similar to measurements taken 100 years ago. However, the advent of acoustics technology and the rapid advancement and use of acoustic Doppler current profilers (ADCP) (fig. 38) during the 21st century are revolutionizing how flow measurements are made.

An ADCP is a device that transmits acoustic pulses along four beams in a downward direction of the water column (Simpson and Oltmann, 1993). Parts of the acoustic pulses are reflected to the transmitter by particle movement within the water column being measured (Simpson and Oltmann, 1993). Frequency shifts of the reflected pulses are caused by Doppler effects; the frequency shifts are a function of the speed of the moving particles in the water column being measured (Simpson and Oltmann, 1993). The ADCP converts the frequency of these shifts into water velocity by using mathematical equations programmed within the ADCP (Simpson and Oltmann, 1993).

An ADCP measurement can be made more quickly and safely than a traditional flow measurement. For low and medium flows, the ADCP can be mounted on a small catamaran-type flotation device and tethered across the stream channel on the bridge. It takes about 3 to 5 minutes per pass across the channel; four passes are required for the measurement. For comparison, a current meter measurement made by wading or by bridge crane typically takes about 1 hour. An ADCP measurement permits the hydrographer making the flow measurement to spend less time on the bridge, which can be a safety risk. For higher flows, the ADCP can be mounted on a boat and the measurement can be obtained by making the passes across the stream channel. Newer acoustic devices exist that can be mounted on a wading rod, if tethering a catamaran is impractical. All of these acoustics methods require some manual note taking, but far less is required than with traditional measurements. The data are stored electronically on computers and can be downloaded and calculated along with inputs made by the hydrographer making the flow measurement.

Streamgaging Costs Then and Now

The streamgage for Suwannee River at White Springs is one of approximately 7,300 streamgages maintained by the USGS across the Nation. Through cooperative partnerships, these streamgages are funded by local, State, Federal, and Tribal agencies. Streamflow data from the streamgage for Suwannee River at White Springs, as well as other surface-water, groundwater, and water-quality data in Florida, can be accessed through the NWISWeb at *http://waterdata.usgs.gov/fl/nwis/*.

Funding during the 1906 fiscal year for the South Atlantic States District (North Carolina, South Carolina, Tennessee, Mississippi, Georgia, Alabama, and Florida) was set at $10,000 (Follansbee, 1994). This is the same year that the streamgage for Suwannee River at White Springs was established. An equal dispersion of this funding amongst all 96 streamgages in 1906 would indicate that the cost to operate the White Springs gage was about $104. This dollar amount inflates to $2,260 in 2007 dollars. The 1906 allocation was reduced to $6,850 in 1907 and to $4,900 in 1908 (Follansbee, 1994). These budget reductions probably caused the discontinuance of the streamgage on December 31, 1908. The end product from the work during 1906-08 was the publication of mean daily flow values in USGS reports. These volumes are known as the USGS water data annual reports, which became the standard information product for long-term hydrologic data collection for about 100 years.

The cost to maintain the continuous record streamgage in the Suwannee River at White Springs during fiscal year 2007 was $16,300 per year. This amount includes the cost of the DCP, water-level sensor, satellite air time, streamflow measurement equipment, gage repairs or refurbishment, field personnel labor, vehicles and boats, field supplies, travel, quality assurance, and computation, review, and publication of the data. Also included are costs associated with program administration as well as the development and distribution of

Figure 38. Acoustic Doppler current profilers (ADCP) used to make streamflow measurements (right; photographs by USGS).

the data to conveyances like NWISWeb. For the first time in USGS history, all finalized data from the White Springs gage for the 2006 water year, as well as every other continuous-record or periodic gage in USGS data programs, were publicly accessible on the Internet. Supporting gage information and statistics, such as station drainage area, contributing drainage area, gage datum, hydrologic unit, latitude and longitude, and daily, monthly, and annual statistics, are also available on the Internet either at NWISWeb or as part of the new annual data report products. Thus, while costs today are higher than in 1906, the end product has enhanced scientific value and increased public accessibility of streamflow and gage operations data.

National Streamflow Information Program

The White Springs streamgage was federally funded in fiscal year 2006, through NSIP, which was designed to meet local, State, regional, and national streamflow information needs. The program is also designed for collecting critical information during floods and droughts, evaluating streamflow characteristics to assess the implications of climate and land-use changes, developing a highly reliable system for delivering data to users, and implementing a program of research to build better data collection, delivery, and interpretation capabilities for the future.

The USGS identified five main goals to be achieved by the core set of streamgages in NSIP (*http://water.usgs.gov/nsip/federalgoals.html*, accessed September 9, 2007), which are funded by the USGS. The goals determined to have the highest priorities are:

- Interstate and International Waters - Interstate compacts, court decrees, and international treaties mandate long-term, accurate, and unbiased streamgaging by the USGS at State-line crossings, compact points, and international boundaries.

- Streamflow Forecasts - Real-time stage and discharge data are required to support flood forecasting by the National Weather Service across the country.

Above: Archival images (left and right) of White Springs, Florida, depicting views looking down the Suwannee River from the bridge and an outlet on the Suwannee River (images courtesy of the Florida State Archive).

- River Basin Outflows - Resource managers need to account for the contribution of water from each of the Nation's 350 major river basins to the next downstream basin, estuary, ocean or the Great Lakes.
- Sentinel Watersheds - A network of streamgaging stations is necessary to accurately respond to changes in climate, land use, and water use in 800 watersheds across the country that are relatively unaffected by flow regulation or diversion and typify major ecoregions and river basins.
- Water Quality - Streamgaging stations are critical in providing streamflow information for three national USGS water-quality networks (1) the Nation's largest rivers; (2) intermediate-sized rivers; and (3) small, pristine watersheds.

The White Springs gage serves as a streamflow flood forecast point. Because of the length of record, this gage can also serve as a sentinel for the Suwannee River watershed. Additional information about the NSIP program can be obtained at *http://water.usgs.gov/nsip/,* accessed September 9, 2007.

Conclusions

The USGS streamflow records from 1906 to 2006 have provided accurate data for various interpretive studies regarding climatology, hydrology, ecology, and biology. For example, the peak flow data are used to determine flood-frequency relations (2-, 5-, 10-, 25-, 50-, 100-, 200-, and 500-year recurrence intervals of floods) at White Springs. Real-time data from Florida gage sites are proving to be valuable resources that will improve statistical analyses for future interpretive studies with longer periods of record. Continued availability of real-time data and successful USGS operation of the streamgage at White Springs are crucial as this site serves as a flood forecast point for the National Weather Service.

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