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HYDROLOGIC IMPLICATIONS OF REDUCTIONS IN STREAMFLOW AT HAINES CREEK AT LISBON AND AT OCKLAWAHA RIVER AT MOSS BLUFF, FLORIDA

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ILLUSTRATIONS

ILLUSTRATIONS (cont.)

EXECUTIVE SUMMARY

Since the early 1960's, there has been an approximate 50% decline in aggregate surface outflow from the Ocklawaha Chain of Lakes, as measured at Haines Creek at Lisbon, and at the Ocklawaha River near Moss Bluff. However, the decline in surface outflow during that period has not been accompanied by significant overall reductions in the mean annual levels of the lakes that make up the Ocklawaha Chain.

It is believed the reduction in flow of Haines Creek and of the Ocklawaha River is approximately coincident with the installation of both Burrell Lock and Dam (Haines Creek) and Moss Bluff Lock and Dam (Ocklawaha River) control structures and with the implementation of flow- and lake-level regulation schedules at those control structures.

Possible reasons for the reduction in outflow from the Ocklawaha Chain are (1) lowered potentiometric levels in the Floridan aquifer system (due to pumping and to drought), (2) maintenance of stabilized and, perhaps, artificially high lake levels in the Ocklawaha Chain, or (3) some combination of (1) and (2).

It is believed that maintained (or regulated) high lake levels in the Ocklawaha Chain in spite of lower Floridan aquifer levels cause increased downward leakage to the Floridan in some lakes and reduced upward leakage to other lakes. Intuitively, and at first reading this seems contradictory. It is not. Further, the resultant increased losses from some lakes and reduced gains in others do not offset each other and, in fact, work together in aggravating the problem.

The authors recommend that the SJRWMD contract with the U. S. Geological Survey to do an in-depth analysis of just what might have happened, or is happening, at Haines Creek and Moss Bluff.

It is further recommended that "scenario" ground-water flow modeling be conducted to determine what impact higher or lower lake stages might have on the St. Johns River Water Management District's Water 2020 optimization studies. This modeling could be accomplished by SJRWMD using Brian McGurk's East-Central Florida model.

INTRODUCTION

The Ocklawaha Chain of Lakes, hereinafter referred to as the Ocklawaha Lakes, are comprised of Lakes Apopka, Carlton, Beauclair, Dora, Harris, Little Lake Harris, Eustis, Griffin, and Yale and are located in the upper Ocklawaha River Basin and contribute to flow in Haines Creek and the upper Ocklawaha River. The Ocklawaha Lakes are used primarily for recreation, including boating, fishing, and water skiing. Water quality, water levels, and other aesthetic issues have generated concern among the residents in the area. Recent analyses of streamflows in the upper Ocklawaha River Basin indicate there have been reductions in streamflow in Haines Creek at Lisbon and in the Ocklawaha River at Moss Bluff since the early 1960's.

Many of the natural connections between lakes and streams in the Ocklawaha River basin in central Florida have been improved for navigation. Channelization and dredging occurred between the major upstream lakes of the Ocklawaha Chain (Apopka, Beauclair, Dora, Eustis, Harris, Little Lake Harris, and Griffin) except for Lake Yale. Channelization of the creeks and overflow areas between large lakes brought problems as well as navigable access. Floods and droughts were more pronounced because of the shortened time periods when flow through the creeks transported too much water through the system, either flooding areas downstream or causing the lakes upstream to lose valuable water during a drought. Control structures in the form of locks and dams were installed to help maintain more constant lake levels and to allow for better navigation.

Two major water control structures in the system are the Burrell Lock and Dam on Haines Creek at Lisbon and a lock and dam on the Ocklawaha River at Moss Bluff (Figure 1). The dam at Haines Creek helps regulate levels in Lake Eustis and other lakes upstream including Harris, Little Lake Harris, Dora, and Beauclair. The Moss Bluff dam helps regulate levels in Lake Griffin. Levels in Lake Yale are not directly affected by either of the dams discussed in this report. A third water control structure is on the Apopka-Beauclair Canal. It regulates the water level of and outflow from Lake Apopka.

PURPOSE AND SCOPE

The purpose of this report is to examine the historical records of water levels in the Ocklawaha Lakes; streamflow at Haines Creek at Lisbon and Ocklawaha River at Moss Bluff; and to investigate possible causes of reduction of streamflow in the upper Ocklawaha River (Figure 1).

DISCUSSION

Residents in the Lake Griffin area have, for some time, expressed concern about perceived low lake levels even during periods of average, or above-average, rainfall. To investigate this issue, Rolland Fulton, St. Johns River Water Management District (SJRWMD), prepared hydrographs for lake levels in Lakes Griffin and Eustis (Figures 2 and 3) and of discharge of Haines Creek at Lisbon and at Ocklawaha River near Moss Bluff (Figures 4 and 5). Fulton also used double-mass techniques (Figures 6 and 7) to analyze historical lake levels and stream discharges with regard to rainfall. The period of record for discharge data at Apopka-Beauclair Canal is not sufficient to allow similar analyses for that location.

Fulton noted no large-scale trends in the levels of Lakes Griffin and Eustis over the overall period of record. Even so, in the last 40 years, there were slight declining trends in Lake Griffin (Figure 2) and in Lake Eustis (Figure 3), although prior to a recent drought (1999-2002), the declining trends were on the order of only 2 to 3 inches -- not particularly noteworthy. However, during the drought conditions of the last few years, water levels in both lakes decreased by more than 1 foot.

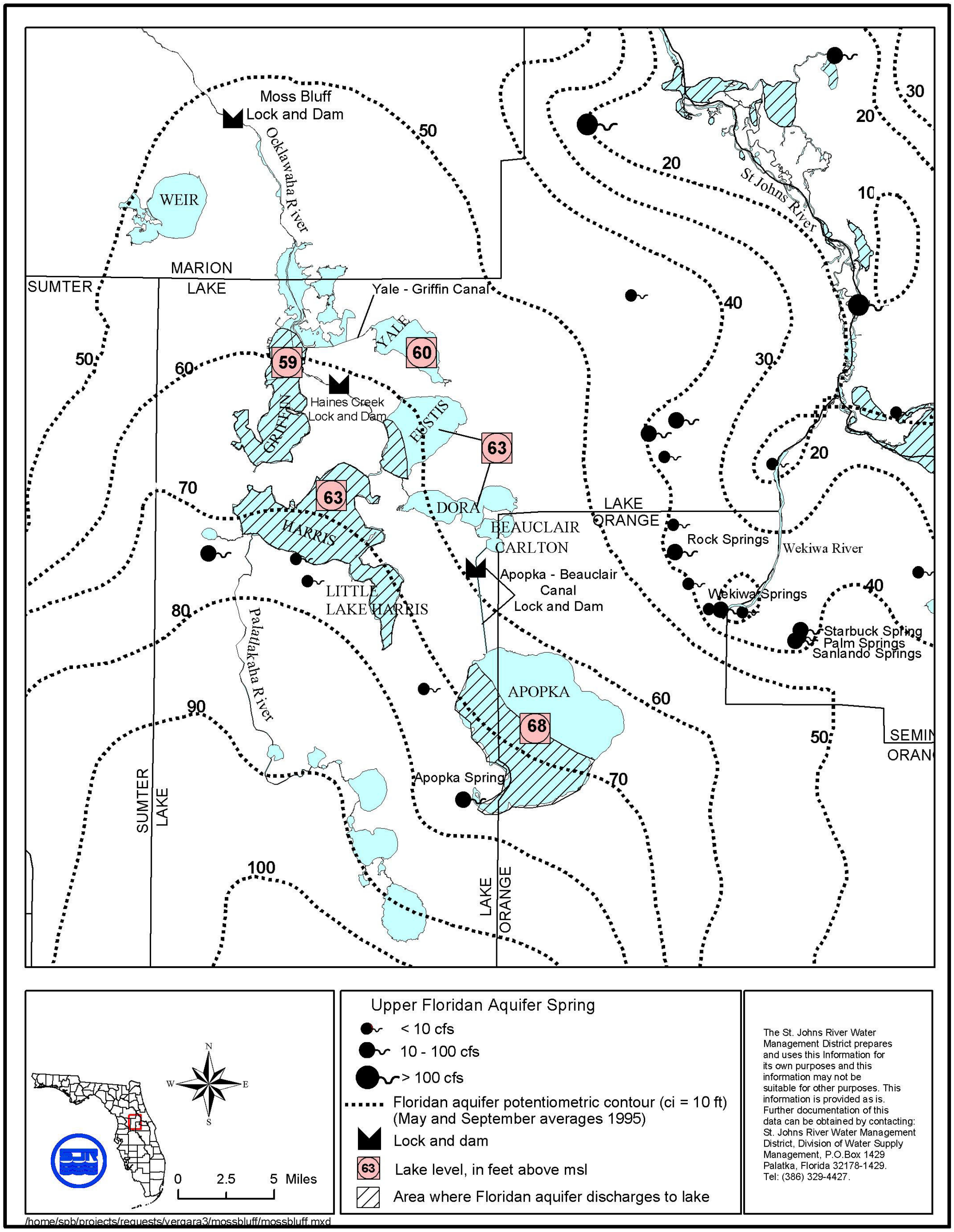

Figure 1. Ocklawaha basin lakes area with pertinent hydrologic features.

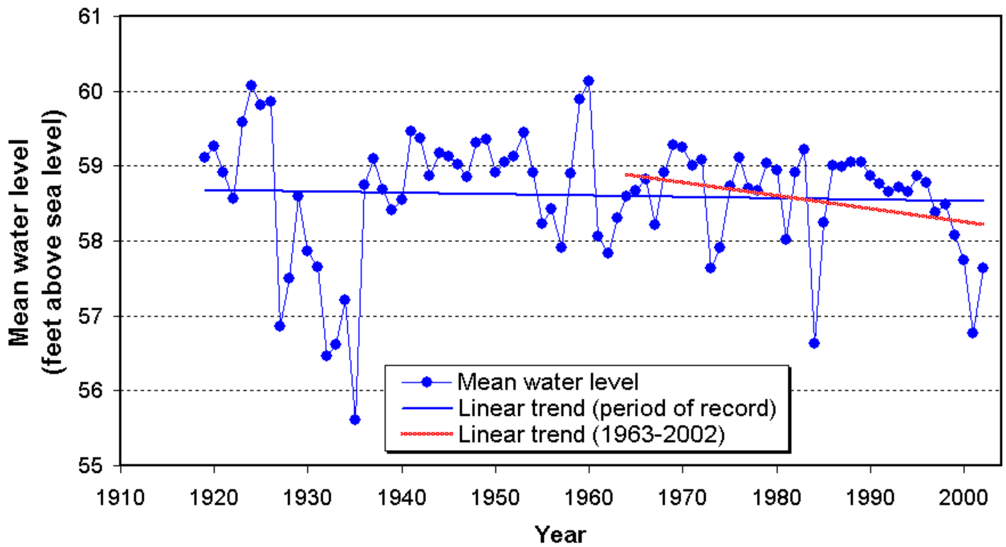

Figure 2. Lake Griffin annual mean water level (1919-2002)

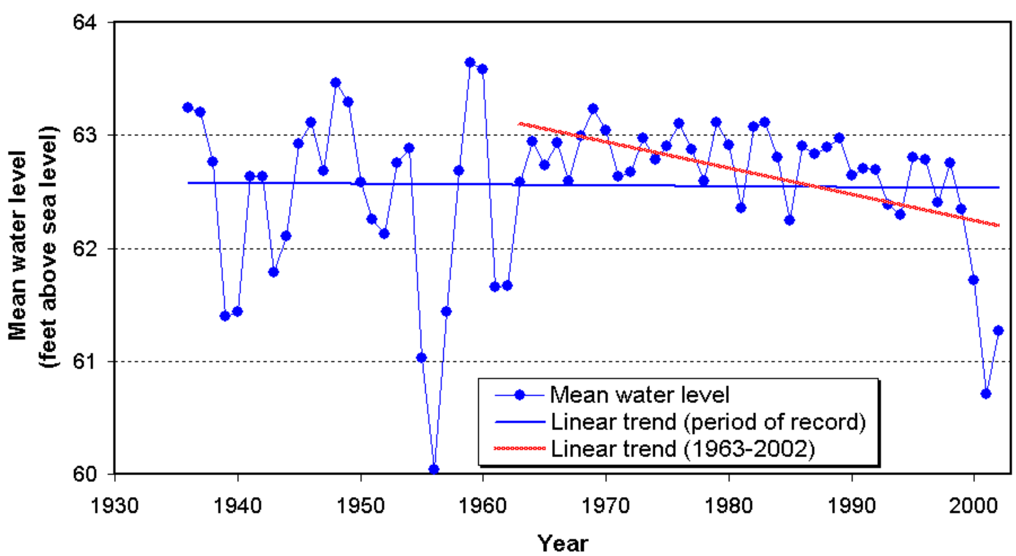

Figure 3. Lake Eustis annual mean water level (1936-2002)

However, there have been substantial declining trends in discharges in both the Ocklawaha River at Moss Bluff (Figure 4) and in Haines Creek at Lisbon (Figure 5). Mean discharges are shown only for years with complete records.

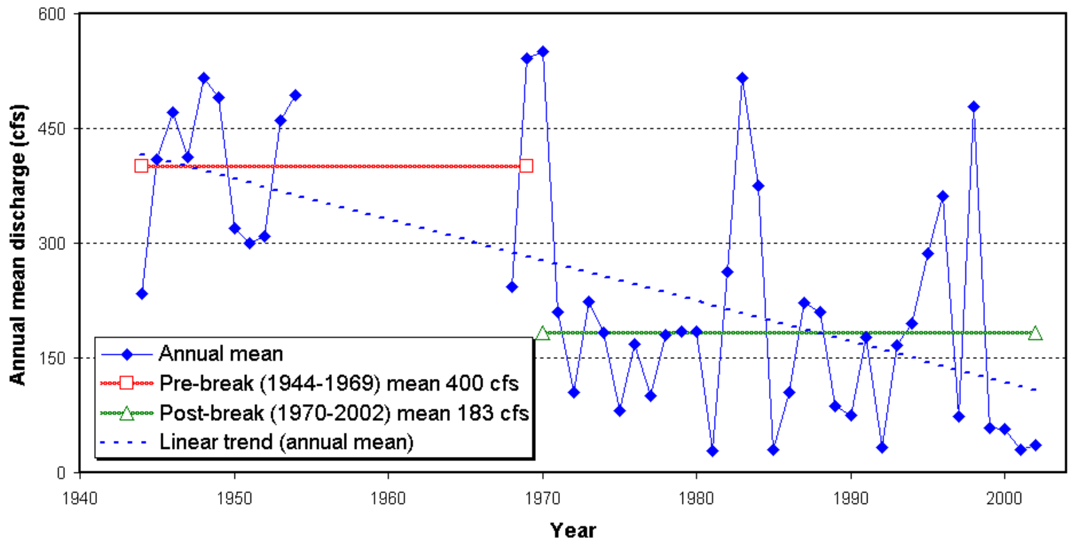

Figure 4. Ocklawaha River at Moss Bluff annual mean discharge (1944-2002)

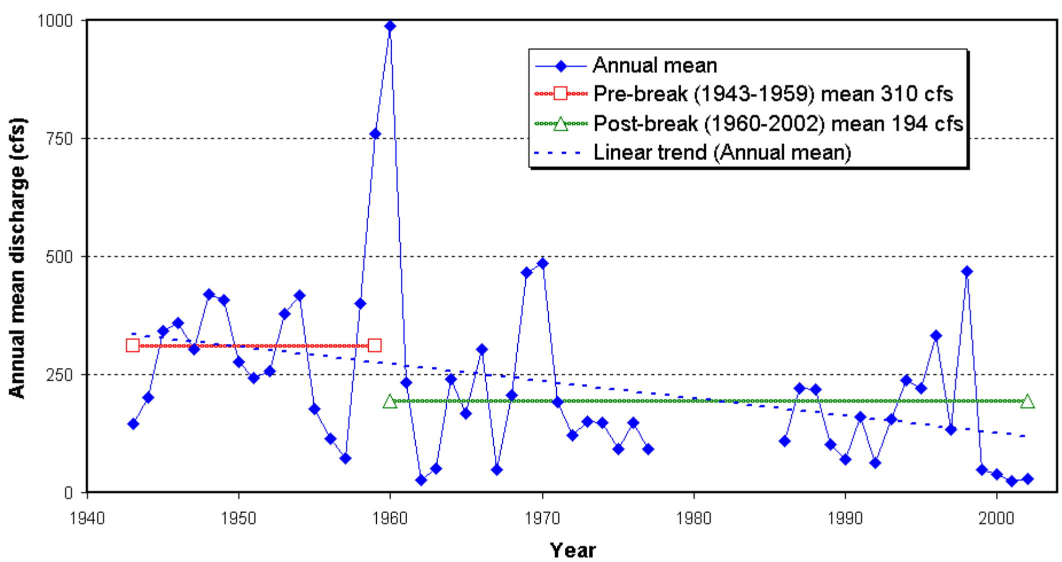

Figure 5. Haines Creek annual mean discharge (1943-2002)

To further evaluate the trends in discharges, Fulton conducted a double-mass analysis of streamflow against rainfall at the NOAA Lisbon weather station, which is centrally located in the Ocklawaha River basin near Haines Creek. Data used in the analysis were average annual discharges for years with complete discharge records and annual total rainfall. The double-mass analysis plotted cumulative average annual discharge against cumulative annual rainfall. For example, in Figure 6, the first point plots the average discharge in 1944 against rainfall in that year, the second point plots the sum of the average discharges in 1994 and 1945 against the sum of the rainfall in those two years, and so on. If there is no change over time in the relationship between rainfall and discharge, then the double-mass plot should result in a straight line. A change in the slope or a deviation from linearity would indicate a change in the rainfall-discharge relationship. The double-mass plots were visually inspected for changes in slope, and linear regression trend lines were fit to the data.

The double-mass analyses of streamflow of the Ocklawaha River at Moss Bluff against Lisbon rainfall and streamflow at Haines Creek against Lisbon rainfall (and Clermont rainfall) (Figures 6, 7) showed very significant changes over time. The changes in slope of the regression lines indicate that prior to the late 1950's, annual stream discharges per inch of annual rainfall were about **twice** what they were after that time. From the shapes of the graphs, it appears as if the changes were sudden and constant. Hereinafter, these changes are referred to as the "breaks." After the breaks, the reduction in annual average discharge at Haines Creek is about 120 cfs (Figure 5) and further downstream at Moss Bluff, the reduction is about 220 cfs (Figure 4).

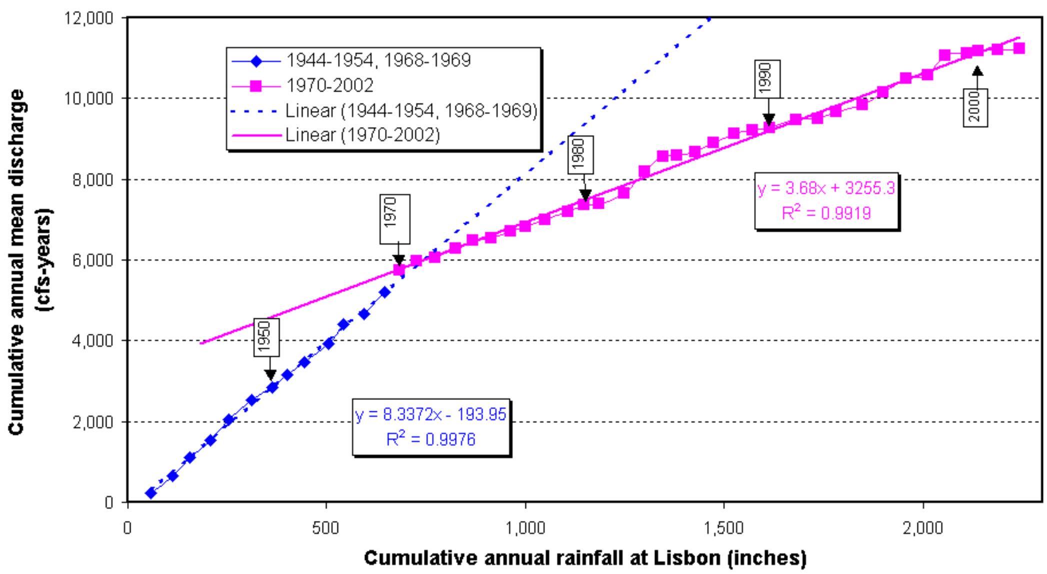

Figure 6. Double-mass curves for Ocklawaha River discharge at Moss Bluff vs. Lisbon rainfall *(Only years with complete discharge records are plotted)*

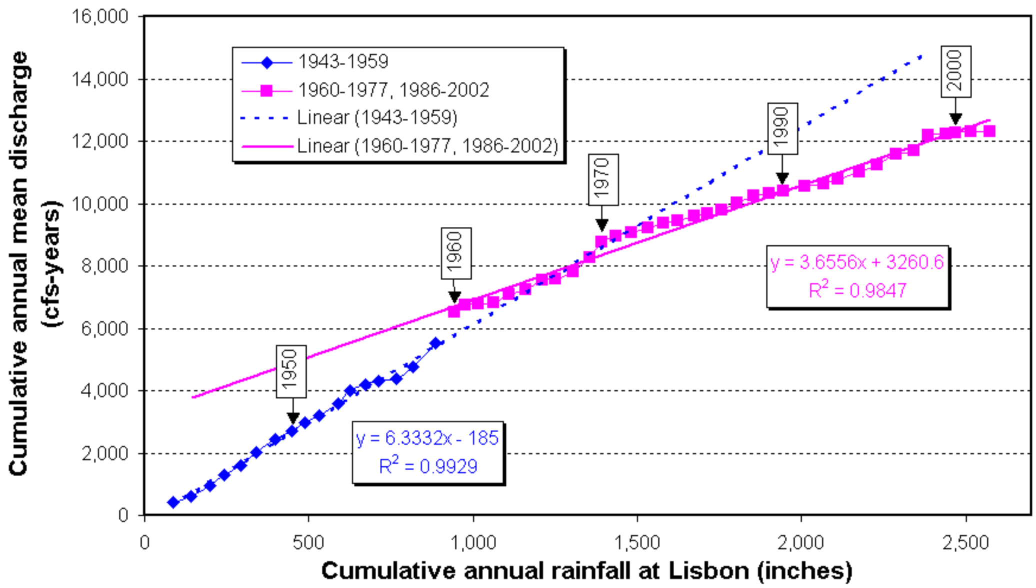

Figure 7. Double-mass curves for Haines Creek discharge vs. Lisbon rainfall
(Only years with complete discharge records are plotted)

Charles Tibbals (U.S. Geological Survey, retired) was hired by the St. Johns River Water Management District (SJRWMD) to coordinate an investigation of the cause of the change in discharge. Tibbals met with Jerry Salsano (project management consultant to SJRWMD), Ron Wycoff (CH2M Hill, Inc.), and Rolland Fulton (SJRWMD) to review Fulton's analysis. The group first thought that perhaps the historical Lisbon rainfall data could be in error, but when Clermont rainfall data were substituted for that of Lisbon, Fulton's original analyses remained essentially unchanged. The group next suspected that some sort of basin diversion had occurred, but quickly concluded that a surface diversion of that magnitude could not have occurred over a period of some 40 years without being noticed. And where might such a diversion have occurred? The upper Palatlakaha River (tributary to the Ocklawaha River), even if totally diverted, could not account for a reduction of basin yield that would be of the magnitude observed.

A decrease in ground-water levels due to ground-water pumping or drought can potentially cause a decline in basin runoff, but the upper Ocklawaha River basin appears to be in an area of relatively little ground-water use, especially in the early 1960's and early 1970's when the breaks occurred. Floridan aquifer pumping effects in the Orlando and west Orange County areas extend into the upper Ocklawaha basin, but during the time period in which the breaks began, Orlando pumping and agricultural irrigation pumping is not known to have been particularly large. Even as Orlando/west Orange County pumping increased, the graphical breaks do not worsen. The breaks appear to be "step-changes" in rainfall/runoff relations. However, data for Well OR-47 (Figure 8), located in the Orlando

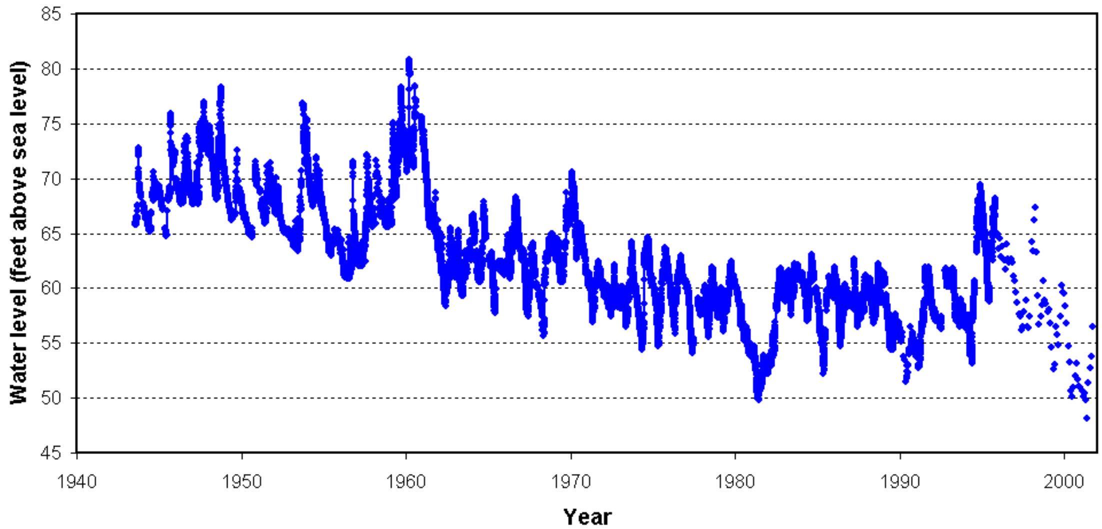

Figure 8. Water levels in Well OR-47, near Orlando

area, show a substantial decrease in the Floridan aquifer potentiometric level during the early 1960s, which is consistent with this explanation. The average water-level elevation during 1943-1961 was 68.01 ft above sea level vs. 59.81 ft above sea level for 1962-2000, a decrease of 8.2 feet. Three other wells in the basin also appear to show a decrease in the potentiometric surface during the 1960s (Figures 9-11) but there does not appear to be a decrease in discharge from Silver Springs (Figure 12). The cause for the decrease in Floridan aquifer potentiometric levels in the vicinity of Well O-47 has not been specifically identified, although it coincided with a severe drought in 1961-1962. Other than Floridan aquifer pumping, an aggravating circumstance regarding the potentiometric decline since about 1960, is the possibility of increased Floridan aquifer springflow in the Wekiva, Rock, Sanlando, Palm, and Starbuck springs groundwater basin. That phenomenon, though beyond the scope of this report, is thoroughly discussed in Tibbals (1990, p. 69-73).

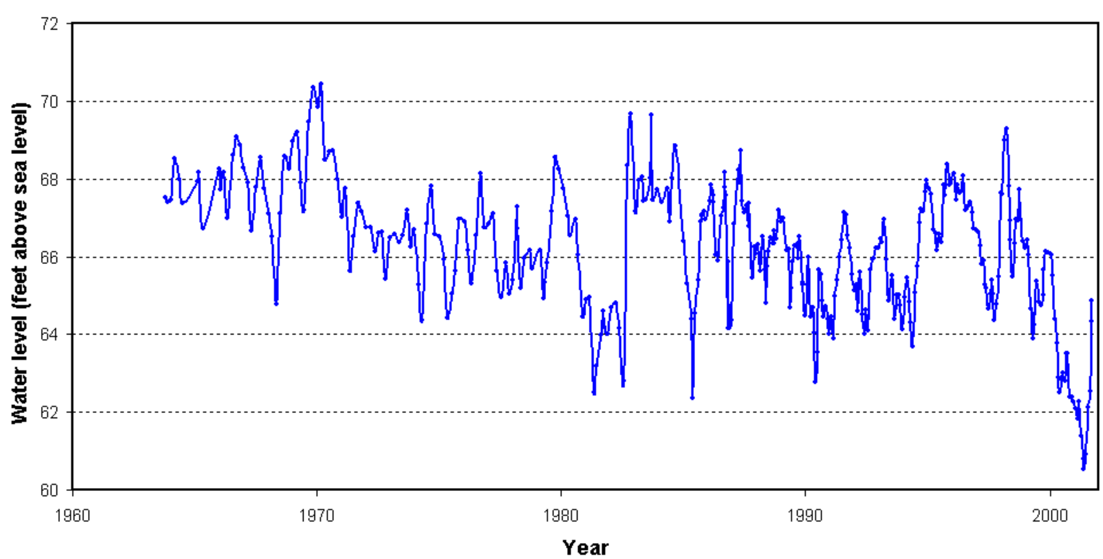

Figure 9. Water levels in Lake Yale Groves well

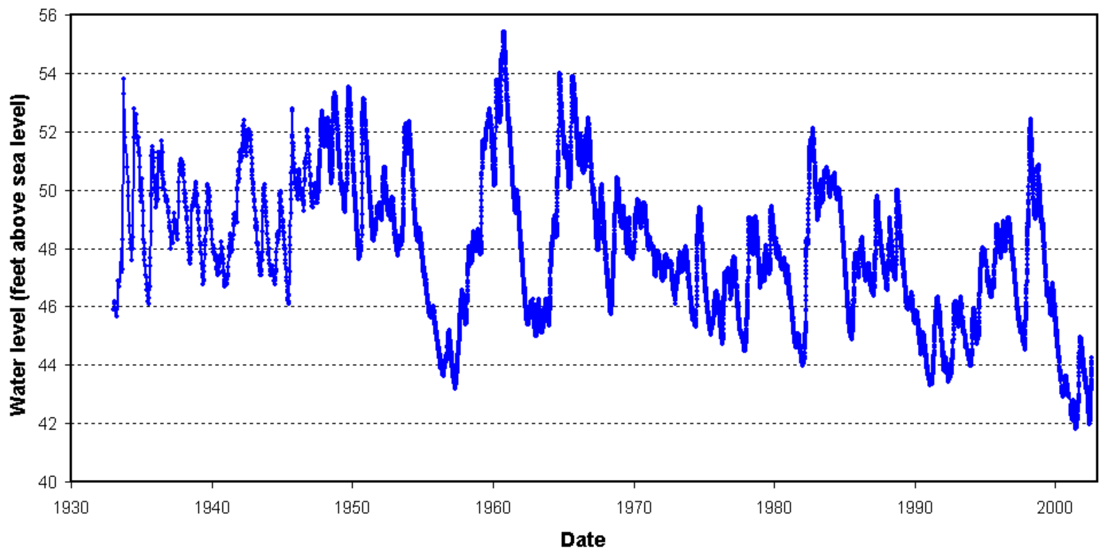

Figure 10. Water levels in Marion 5 (Sharpes Ferry) well

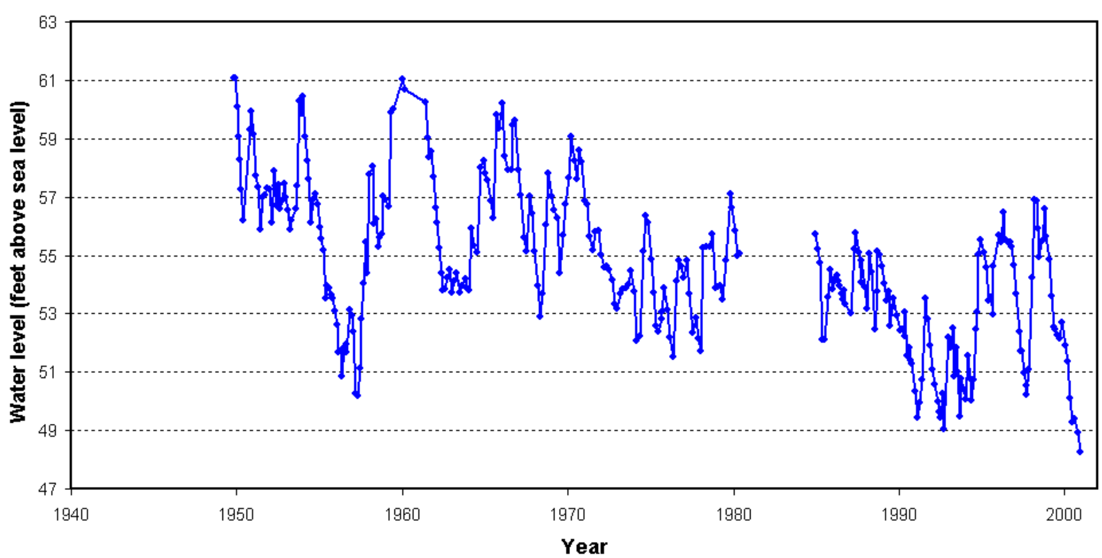

Figure 11. Water levels in Marion 48 Well

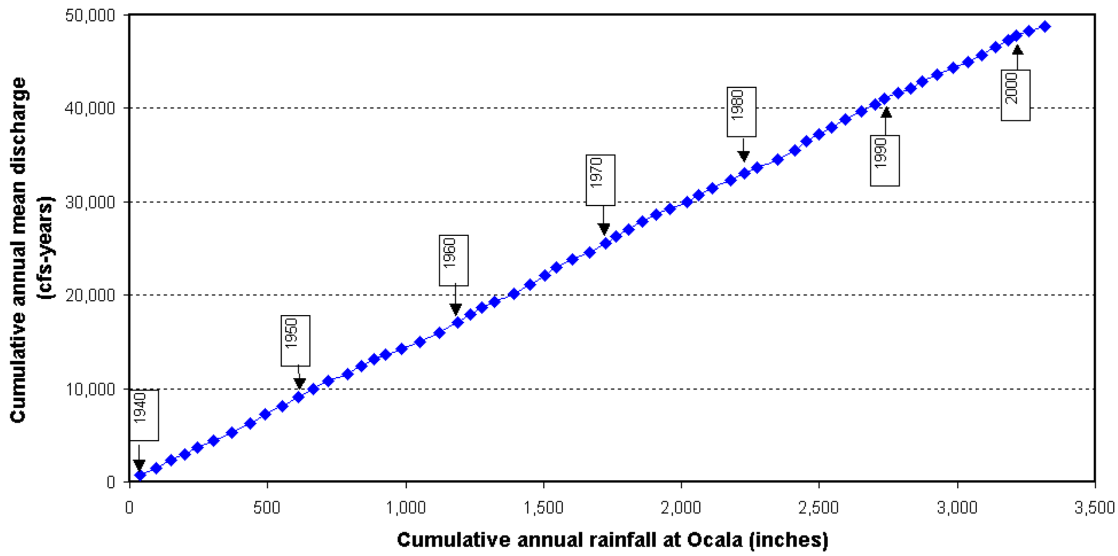

Figure 12. Double-mass curves for Silver Springs discharge vs. Ocala rainfall

Could a series of sinkholes have opened and drained water from the Ocklawaha Chain of Lakes? That is not an impossibility as far as sinkhole formation is concerned, but the potentiometric surface of the Floridan typically is at or above the Ocklawaha Lakes' levels and the Ocklawaha River level along much of its reach. Lakes Dora, Beauclair, and Carlton appear to be slightly above the Floridan; Lakes Harris, Little Harris, and Griffin are slightly below the Floridan; and Lakes Apopka and Eustis are partly above and partly below the Floridan, depending on location (Figure 1). Thus, some parts of the Ocklawaha Lakes and the Ocklawaha River are, for the most part, potential discharge areas for the Floridan and other parts are potential recharge areas to the Floridan. In discharge areas, Floridan ground water would tend to leak into the lakes rather than lake water leaking out into the Floridan. In recharge areas, the lakes would tend to leak water downward into the Floridan.

Year-in-year out, evaporation losses from the lakes are large but there is no reason why such losses would have suddenly increased in the mid-1960's. The total lake area exposed to evaporation increases at higher lake stages and decreases at lower stages but, even at lower lake stages the wetted soil area around the lakes at low lake stages represents the capillary fringe of the shallow water table and that capillary fringe functions much like an exposed water surface, thus causing the effective lake surface area to remain about the same. Therefore, the authors do not believe that changes in lake evaporation are the reasons for the breaks.

Discussed below are some of the remaining factors that could possibly account for some of the apparent missing streamflow.

In the early 1940's, the U.S. Geological Survey (USGS) began making streamflow discharge measurements on Apopka-Beauclair Canal, Haines Creek at Lisbon and at the Ocklawaha River at Moss Bluff. There are errors involved in all discharge measurements but the USGS has been measuring stream discharge since the early 1880's and their techniques constantly seek to minimize random errors and to eliminate bias error. Random errors tend to cancel each other over time, whereas bias error tends to persistently skew results in one direction. Even though the authors are confident that bias error is not a significant factor in USGS data integrity, they felt that several possibilities needed to be at least considered. Those possibilities are discussed below.

(1) In the years before the breaks, could the USGS have been measuring too much water and how might this happen? The "factor-of-two" changes (approximate 50% reductions) in discharges suggest that low-velocity current meters could have been used with the wrong current-meter rating table, thus doubling the apparent velocities (and doubling the computed discharge). This doesn't seem probable given the fact that numerous field men using numerous flowmeters measured these streams over a period of many years. The likelihood of every measurement being made with the wrong meter is extremely small.

Another possibility is that, somehow, the USGS could have been measuring the same water twice -- it can happen in eddy currents near the stream banks. This is not likely, and certainly not in the quantities of water that would have been involved in causing such breaks in the discharge-rainfall relations.

(2) In the years after the breaks, could the USGS have been measuring too little water? That could occur if:

a. Somehow, a very substantial portion of the flow was bypassing the measuring sections at both the Haines Creek and the Ocklawaha River stations and coming back into the channels below the measuring sections: The breaks in rainfall-runoff relations occurred at about the same time as installation of the Apopka-Beauclair, Haines Creek and Moss Bluff control structures. During such construction, temporary flow rerouting typically occurs. Could there be some residual rerouting at all three structures? Probably not, but Bradner conducted special field inspections at Haines Creek and Moss Bluff (see Appendix). Bradner found no residual flow rerouting at those locations. Also, no residual flow rerouting was observed at the Apopka-Beauclair structure when, several years ago, the SJRWMD constructed a temporary cofferdam restrictor in the Apopka-Beauclair Canal.

In the Appendix, Bradner cites a newspaper article from 1957, where it is indicated that dragline and dredging operations occurred both upstream and downstream of the Haines Creek dam. The downstream channel was said to be difficult to dredge because of dense clay encountered in the bottom of the channel and because of the occurrence of limestone below the clay. Possibly such dredging could have breached the confining layer above the

Upper Floridan aquifer and increased the likelihood of exchange of water to or from the aquifer.

The limestones referred to in the article may or may not have been the limestones of the Upper Floridan aquifer and they may or may not have been in intimate hydraulic connection with the Upper Floridan aquifer but, for the purposes of the following discussion, assume the limestones were in intimate hydraulic connection with the Upper Floridan.

The potentiometric surface of the Upper Floridan aquifer is above the water level of Haines Creek in the vicinity of the Haines Creek dam and along the entire downstream thread of the creek. What this means is that, if dredging breached the confining beds, and continued to breach the confining beds even after construction of Haines Creek dam, Floridan aquifer water would tend to leak upward into the creek and cause the creek flow to <u>increase</u> rather than to decrease.

More detailed mapping would have to be done to detail the exact positioning of the potentiometric surface in the localized areas of the Haines Creek and Moss Bluff dams.

It might be possible for water to leak under the Haines Creek dam and discharge upward into the river immediately downstream of the dam. However, the flow discharge measurements are made some distance downstream from the dam and likely would be measured anyway. If, for some reason, the “underflow” was discharging downstream of the measuring section, it would likely be measured even further downstream in the aggregate flow of the Ocklawaha River at Moss Bluff.

Further, an under-flow of some 120 cfs (the post-1960 flow deficit at the Haines Creek dam) should be noticeable in the creek in the form of a large, first-order magnitude spring boil (or boils) in the river.

This same discussion would apply to the Moss Bluff dam area except the unmeasured under-flow would have to be about 220 cfs.

b. <u>Could the USGS have been measuring too close to the structures?</u> If water is released from the bottom of the lift gates and the measuring sections are too close to the structure, the normal flow distribution in the vertical section could be so distorted that the simple 0.2 depth measured velocities averaged with the 0.8 depth measured velocities would not give enough weight to the 0.8 depth velocities. Bradner’s inspection of the measuring sites indicated that the measuring sections were sufficiently far downstream of the structures to eliminate such an error.

(3) <u>Is it possible the rainfall - runoff analysis was incorrect ?</u> Some error is always possible, especially when dealing with periods of missing data (see Appendix). However, those errors are not obvious and certainly not on the order of magnitude necessary to generate the breaks in the graphs. Also, the simple time-series flow hydrographs for both

stations (Figures 4 and 5) showed essentially 2 separate flow regimes -- before and then after the early-to-mid 1960's.

(4) Finally, the authors believe the primary causative factors are a combination of lower potentiometric aquifer levels and implementation of new regulation schedules for the Ocklawaha Chain-of-Lakes, both of which occurred during the early 1960s. Although the new regulation schedules did not substantially change the long-term trends in water levels, they did tend to stabilize water levels (Figures 2 and 3), limiting the natural declines in water levels that would have occurred during drought periods, or would have resulted from lowering of aquifer potentiometric levels. In areas of lakes where the lake level is typically higher than the Floridan potentiometric surface, higher maintained lake levels can increase the amount of lake water that leaks down into the Floridan aquifer. In areas of lakes where the lake level is typically lower than the Floridan potentiometric surface, higher maintained lake levels can decrease the amount of Floridan aquifer water that leaks upward into the lakes. In both cases, the result of higher maintained lake levels reduces the amount of water that is available to flow downstream.

A case in point is Lake Apopka. Lake levels in the north half of Lake Apopka are above the potentiometric surface of the Floridan, hence that area of the lake is a Floridan recharge area – water leaks downward out of the lake to the Floridan aquifer. Lake levels in the south half of the lake are below the potentiometric surface of the Floridan aquifer and, hence, the south half of the lake is a Floridan aquifer discharge area which leaks water from the Floridan aquifer into the lake (although the lake level is the same from north to south, the potentiometric surface of the Floridan slopes downward from south to north). Lake Apopka has its own control structure on Apopka-Beauclair Canal. If the Floridan aquifer levels have decreased but the current regulation schedule has attempted to maintain Lake Apopka water levels at elevations similar to the period prior to the breaks, increased losses caused by downward leakage to the Floridan could occur under the north half of the lake. Also, upward leakage of Floridan water under the south side of the lake would be reduced, plus the outflow of Lake Apopka spring on the south side of the lake would tend to be reduced. The combined effects of maintaining levels in Lake Apopka would be to decrease downstream flow in the Apopka-Beauclair Canal and, thus, to Haines Creek and at Moss Bluff. The authors do not believe that such reductions of flow in the Apopka-Beauclair Canal are responsible for all of the reductions in streamflow at Haines Creek and at Moss Bluff but they believe those possible reductions are contributory to the problem.

The authors recommend that the SJRWMD contract with the USGS to do an in-depth analysis of what might have happened, or is happening, at Haines Creek and Moss Bluff. This will not be a small chore. It will require recovering and examining every historical discharge field sheet, revisiting the discharge computations; field reconnaissance; additional discharge measurements at various locations below the structures; an examination of the discharge data at other discharge stations upstream and downstream of the 2 stations in question; analyzing lake levels and Floridan aquifer levels in the entire upper Ocklawaha basin area; and, possibly, the drilling of Floridan observation wells in the lakes to confirm head differences. A phased approach would be most cost-effective, especially if the solution were to be found in an early phase.

The authors also recommend that "scenario" ground-water flow modeling be conducted to see what impact higher and lower lake stages might have on the St. Johns River Water Management District's Water 2020 optimization studies. This modeling could be accomplished by SJRWMD using Brian McGurk's East-Central Florida model.

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APPENDIX

by

Laura Anne Bradner

A review by personnel of the St. Johns River Water Management District (SJRWMD) indicated that the U.S. Geological Survey (USGS) has measured a substantial reduction in flow at Haines Creek at Lisbon and at Ocklawaha River at Moss Bluff after control structures were installed at those locations. Lake levels in Lakes Eustis and Griffin have been managed by use of the control structures to maintain a narrower range of fluctuation.

In order to verify that the USGS data are correct, a review of the original records and files of the USGS was conducted in order to document the historical construction and management information on the dams and to review the actual discharge measurements made from 1942 to present and the calculations used to compute daily discharge.

Information in this report was derived from notes on the individual discharge measurements, copies of letters, and newspaper articles in the files of the USGS. Many dates used to establish timelines were taken from newspaper articles and were not further verified.

Moss Bluff Lock and Dam: The U.S. Army Corps of Engineers installed a power dam at Moss Bluff in 1925. The Moss Bluff location also had a boat-lock in order to maintain navigability. The power dam held the Ocklawaha River and Lake Griffin at levels sufficient to run the turbines at the power plant and to supply gravity irrigation flow to the Ocklawaha Muck Farms located on Lake Griffin. The difference between upstream and downstream levels at the dam was sometimes as much as 15 feet. According to notes in the USGS files, the power dam needed a flow of 235 cubic feet per second (cfs) to operate at maximum efficiency.

Newspaper articles referenced the Labor Day storm of 1933, noting that the dam at Moss Bluff was overflowing, even with all structures open. Floods have also occurred in 1958, 1959, and 1960 and during some wet periods in 1970 and in 1996-1998. The extreme high water periods in 1960 presented major problems because the structure at Moss Bluff could not be opened for a period of time due to flooding that was already occurring downstream on the Ocklawaha River. During that period, the boat-lock was reinforced with sandbags because water was flowing over the top of the structure.

Extraordinarily dry, low-water conditions occurred in 1954-1956, 1961-1962, 1981, 1985, 1990, 1999, 2000, and 2001.

Although no specific reference regarding the power dam's condition was in the USGS notes, the operation of the power turbines was apparently discontinued at the Moss Bluff dam sometime in the 1950s and the site continued to deteriorate. In 1958, the dam was repaired because of high-water damage and the dikes had to be strengthened and raised so flows could be increased through the Moss Bluff boat-lock. In 1969, the Corps of Engineers built a new boat-lock and dam at the Moss Bluff site, apparently because of the deteriorated condition of the existing structures. In 1973, the dike holding the channel upstream broke and Lake Griffin water levels dropped rapidly until the channel was stabilized. The dike was repaired and has since been stable.

TIMELINE: OCKLAWAHA RIVER AT MOSS BLUFF LOCK AND DAM

1925 – Power Dam and lock constructed
1933 – Flooding
1943 – USGS gaging began
1954-55 Extreme dry period – low lake levels occurred
1956 –USGS daily discharge records discontinued
1958 – Dam and dikes repaired after damage from
high flows from upstream
1960 – Flooding upstream and downstream – no releases until April
1962 – Drought- no flow through structures and no lockages due to low river levels
1968 – USGS daily discharge records reestablished
1969 – New lock and dam constructed
1973 – Break in upstream dike
1975 – Dredging work in canal to remove old lock and spillway

Haines Creek at Lisbon -- Burrell Lock and Dam: Haines Creek was dredged for navigation prior the 1940s, before the USGS began discharge measurements on the creek. During the dry seasons of 1953-56, lakefront homeowners on Lake Eustis were alarmed by the low water levels. Their concerns moved the Lake County Water Authority (LCWA) to install a lock and dam in Haines Creek in order to maintain higher water levels for navigation through Lake Eustis. Construction of the lock and dam occurred during an approximately 6-month period in 1956. The dam consisted of three radial arm gates and a lock that had two lock-filling tubes. A newspaper article in 1957, indicated that dragline and dredging operations occurred both upstream and downstream of the Haines Creek dam. The downstream channel was said to be difficult to dredge because of dense clay encountered in the bottom of the channel and because of the occurrence of limestone below the clay.

Notes in USGS files indicate that the Apopka-Beauclair canal structure was probably installed about the same time as the Haines Creek structure.

A new dam was installed at Haines Creek in 1978. That control structure, which is currently in operation, has 4 drop gates and 2 lift gates. The lock's two fill tubes can also allow water to flow through the structure. According to recent conversations with Will Davis, former Executive Director of the LCWA, it was determined that the lock was reconditioned and not replaced.

TIMELINE: HAINES CREEK AT LISBON (BURRELL LOCK AND DAM)

1942 – USGS gaging began
1954-55 - Extreme dry period – low lake levels occurred
1956 – Lock and Dam installed
1958 - High flows occurred
1960 – Flooding downstream and upstream
1978 – New control structure installed
1978-85 – USGS conducts periodic discharge measurements but no daily record computed
1985 -2000– USGS daily discharge computed

USGS DISCHARGE DATA

The U.S. Geological Survey began gaging the flow at Haines Creek at Lisbon in 1942, and at the Ocklawaha River Moss Bluff site in 1943. Although periodic (6-10 per year) discharge measurements were made throughout the periods of record, daily discharge calculations at Moss Bluff were discontinued from 1955-1968, and, at Haines Creek, daily discharge calculations were discontinued from 1978-85. In computing daily discharges, different stage/discharge/gate-opening ratings were used depending on the configurations of the dams.

For the purposes of this study and as a check on the earlier computations, time-weighted average annual discharges were calculated for the periods of record by using the actual discharge measurements and extrapolating the data between the dates of the measurements. This method appears to be fairly accurate when the measurements were fairly frequent and evenly spaced in time. In some of the later years, as in 1989 and 1996-97 at Haines Creek and 1989, 1992, 1996, and 1997 at Moss Bluff, the measurements were spaced too far apart for accurate averaging. The latter years may have time-weighted discharges that are too high. The visits by the field personnel during those years generally coincided with extremely low discharges through the structures and accurate measurements could not be made. Measurements were made only when the flow velocities were high enough for accurate determinations.

Individual discharge measurements at Moss Bluff and at Haines Creek appear to be accurate in most cases. Field technicians rated most measurements as good-to-fair because of the conditions of the channel. A good-to-fair rating means there is error in the range of 5 to 8 percent. A few measurements plotted far from the stage/discharge/gate-opening current ratings used at the time and weren't used, but the vast majority of the measurements were probably as accurate as reasonably possible. The errors within the measurements were most likely due to weeds in the channel or hard-to-determine accurate channel depths caused by the silty soft bottoms in the creeks.

At Haines Creek, high flows are measured from the bridge and low flows are measured in a large culvert just downstream of the structure and upstream of the bridge. Moss Bluff discharge measurements were about evenly divided between bridge and boat. There appears to be no bias toward any particular type of measurement method. Beginning

February 20, 1998, boat measurements at Moss Bluff have employed relatively new Doppler technology. Prior to that time conventional current meters were used, as they continue to be at most other USGS flow-measuring sites.