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AN EVALUATION OF MINIMUM FLOWS AND LEVELS FOR THE WEKIVA RIVER AT THE STATE ROAD 46 BRIDGE, FLORIDA, USING THE 1935–2004 USGS STREAMFLOW DATA

ST. JOHNS RIVER WATER MANAGEMENT DISTRICT

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by

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EXECUTIVE SUMMARY

The Wekiva River is located in Lake, Seminole, and Orange counties in east-central Florida. In 1988, the Florida Legislature enacted the Wekiva River Protection Act and directed the St. Johns River Water Management District (SJRWMD or the District) to establish minimum flows and levels (MFLs) for surface watercourses in the Wekiva River System no later than March 1, 1991. In June 1992, the SJRWMD Governing Board approved adopting five MFLs for the Wekiva River at State Road (S.R.) 46. After a public hearing in August 1992, the rule was filed with the Department of State and became effective on September 16, 1992. The five MFLs are: minimum infrequent high (MIH), minimum frequent high (MFH), minimum average (MA), minimum frequent low MFL), and minimum infrequent low (MIL). These five MFLs define the minimum hydrologic regime needed to protect the Wekiva River from significant harm to its water resources and ecology. The following table presents the established/adopted MFLs for the Wekiva River at the S.R. 46 Bridge.

Wekiva River at the S.R. 46 Bridge: Minimum flows and levels

MFL Category (1)	Level (ft NGVD) (2)	Flow (cfs) (3)	Duration (days) (4)	Return period (years) (5)
Minimum Infrequent High	9.0	880	≥7	≤5
Minimum Frequent High	8.0	410	≥30	≤2
Minimum Average	7.6	240	≤180	≥1.7
Minimum Frequent Low	7.2	200	≤90	≥3
Minimum Infrequent Low	6.1	120	≤7	≥100

The MFLs for the Wekiva River were determined based on evaluations of topographic, soils, and vegetation data collected within plant communities associated with the river near S.R. 46. Each MFL is tied to hydrologic statistics (i.e., a suitable duration and a recurrence interval) that are calculated from the observed long-term water level/discharge data at S.R. 46. The calculated statistics are used as indicators to determine whether or not consumptive uses of water caused water levels to fall below the established MFLs.

In 1994, SJRWMD determined that the adopted MFLs for the Wekiva River were being met based on an analysis of the U.S. Geological Survey (USGS) 1936-1990 Water Year (WY) streamflow data for the Wekiva River at the S.R. 46 Bridge. Increased groundwater and surface water uses in the Wekiva River basin, however, could potentially reduce discharges and water levels; therefore, it is necessary to periodically evaluate the observed stage/discharge data to verify that the established MFLs are being met. The evaluation procedure consists of re-computing various hydrologic statistics with the updated hydrologic data, and comparing the statistics with the established MFLs.

The objective of this report is a re-evaluation of the MFLs for the Wekiva River at the S.R. 46 Bridge based on the 1936-2004 WY USGS data (i.e., the updated data as available at the time of this report) and to determine whether the MFLs are still being met. For consistency in data evaluations, various statistical procedures used for MFLs analysis in this report are same as those that were used by SJRWMD in 1994 for verification of the Wekiva River MFLs. Data evaluations, however, are also performed by graphical procedures, which have been developed by the SJRWMD staff subsequent to the 1994 evaluations; currently, SJRWMD uses the graphical procedures as a standard for evaluating MFLs. Data for a recently (1995) established upstream gauging station, the Wekiva River at Old RR Crossing, are also analyzed to determine the suitability of this location as an alternative MFLs monitoring site.

Conclusions

The following conclusions are reached based on the MFLs analysis and other data evaluations performed in this report.

1. The Wekiva River at the S.R. 46 Bridge location appears to have experienced periodic re-adjustments in the channel geometry and channel morphology during the USGS gauging period (i.e., October 1935 to the present). These re-adjustments have caused a decline in stages. Stage declines of about 0.5 ft, especially in low stages, appear to have occurred specifically around 1957 and 1973, with a minor decline of 0.25 ft around 1990. The channel appears to have more-or-less stabilized since 1973. For these reasons, the stage data collected for the period of record may not be considered homogeneous (i.e., data representing the same or constant channel conditions), but nearly homogeneous for specific periods (specifically for 1935-1956, 1957-1972, 1973-1989, and 1990-2004).
2. The channel re-adjustments do not appear to have affected the discharge data gauged by the USGS at the S.R. 46 Bridge because based on periodic measurements of discharges, USGS constantly updates/revises its stage-discharge relation (which is used to compute daily discharges from observed stages) to obtain accurate discharge for a given stage at a given time.
3. An evaluation of MFLs based on the 1936-1990 USGS (Water Year) streamflow data (i.e., the period of data available when MFLs for the Wekiva River at the S.R. 46 Bridge location were established) showed that all of the MFLs (stages and discharges) were being met.
4. An evaluation of MFLs based on the 1936-2004 USGS streamflow data (i.e., the period of data available currently) shows that all of the MFLs for discharges are being met; in the case of stages, however, the evaluations by the original methodology (i.e., 1990s methodology) showed that two of the MFLs, Minimum Average (MA) and the Minimum Frequent Low (MFL) are marginally not being met. The graphical method showed that only MFL is not being met. Since the MFLs for stages were met with the 1936-1990 data, but not with the 1936-2004

data, it seems obvious that the lower low water levels that occurred during the additional data period (i.e., 1991-2004) were responsible for the latter result.

5. A sensitivity analysis performed on the 1936 – 2004 observed stage data indicates that the MFLs for stages were being met through the year 2000, but were exceeded later on.
6. Hypothetical stage data developed for the period 1936 – 2004 that represented the stage regime of the period 1957 – 1972 (the stable regime intermediate between the higher and the lower stages) gave the following results: a) the hypothetical stage data are compatible to the observed discharge data and likely to provide the MFLs results representing those of a stable Wekiva River channel bed, and; b) the MA level would be met by a slight free-board, and the MFL level would be met with quite a large free-board of about 0.3 ft. From these results it is concluded that had the Wekiva River channel bed at SR 46 been stable, the MFLs for stages would have been met.
7. Based on data collected by SJRWMD, water use in the Wekiva River basin increased after 1995. This increase, however, based on the evaluation presented in this report, has not caused flows to fall below the established MFLs. Water use, as reported by public supply utilities and other major water users in the basin, increased from 69.3 to 100.7 mgd between 1995 and 2000. Water use leveled off to about 80 mgd during 2001-2005. Despite this conclusion, the phase restrictions included in Section 40C-8.031, *FAC,* have not been continuously met. These phase restrictions are established by rule and are to become effective when the flows and levels in the Wekiva River at the SR 46 Bridge fall below the flows and levels established for each phase.
8. It appears, regulation of the Ocklawaha chain of lakes maintaining higher lake levels since about 1960 increased the groundwater contribution to the Wekiva River basin. This report estimates this increase as about 27.5 cfs for the Wekiva River at the S.R. 46 Bridge. However, how this increased groundwater contribution benefited MFLs is not specifically analyzed in this report.
9. An analysis of the 1995-2004 streamflow data for the upstream gauging station, the Wekiva River at Old RR Crossing, gave the following results: a) The average difference in discharges between the gauges at the S.R. 46 Bridge and Old RR Crossing is about 50 cfs for 95% of the time, the S.R. 46 Bridge discharges being higher, b) on the average, the stages at Old RR Crossing are higher by about 2.3 ft, c) similar to the S.R. 46 location, Old RR Crossing also seems to have been experiencing periodic re-adjustments in the channel geometry/morphology. It appears, stages have experienced an upward shift of 0.2 ft during 1997/1998, and; d) the discharge data may be considered unaffected by the disturbances in the channel geometry/morphology because USGS constantly updates/revises its stage-discharge relationship.

Recommendations

The following recommendations are made based on various findings of this report.

1. Stage data analyses performed in this study indicate that the Wekiva River near the gauging station does not have a stable channel. A re-adjustment of channel geometry/morphology occurred periodically both at the S.R. 46 Bridge and the Old RR Crossing locations, giving rise to different stages for the same magnitude in discharges. The implication of this occurrence with respect to the MFLs determination is that the plant communities and soils along the Wekiva River were subjected to long-term water stages that had non-uniform fluctuating characteristics. In light of this information, SJRWMD staff should re-assess the methodologies used in establishing the Wekiva River MFLs in the early 1990s. Specifically, if the characteristic features of various plant communities and soils that lead to the determination of various minimum levels are the result of a varying stage hydrology rather than a constant stage hydrology, the procedures that may be applicable to establishing minimum levels under such conditions should be investigated, and developed. The Wekiva River MFLs should be re-established using the revised procedures.

2. From the point of view of data availability, there appears to be no particular advantage in choosing the Old RR Crossing as a future MFLs station. While the stages suffered a downward shift at the S.R. 46 Bridge, stages appear to have experienced an upward shift at the old RR Crossing. Choosing an alternate site for MFLs should come more from the available plant communities at either site that would provide robust criteria (i.e., very satisfactory and strong criteria) for determining minimum levels. At present, 71 years of observed stage and discharge data are available at the S.R. 46 Bridge, which is a desirable long-term data sample; furthermore, these data could be either adjusted for the present stage hydrology (i.e., to conform to the present channel geometry and morphology), or simply the earlier data up to 1972 could be discarded and still have a sufficiently long-term observed data sample. Only a 10-year period of hydrologic records is available at the Old RR Crossing site.

3. Because the long-term water stage data (October 1935 to present) collected for the Wekiva River at the S.R. 46 Bridge lost its homogeneity as a result of channel instability at the gauged location, but the discharge data for the same period at the same location appears to be unaffected (due to revisions in USGS gauging procedures to insure accurate streamflow data), SJRWMD should consider using just discharge data for MFLs evaluations, at least until a stable cross section is found or MFLs are established at a more stable segment of the river.

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INTRODUCTION

The Wekiva River, located in Lake, Seminole, and Orange counties in east-central Florida, is a tributary to the St. Johns River (Figure 1). It has a drainage area of about 396 sq. mi., and the Little Wekiva River and Black Water Creek are its primary tributaries. Additionally, three minor watercourses (Rock Springs Run, Sulphur Run, and Seminole Creek) drain into the Wekiva River. The Wekiva River and the five watercourses draining into it are referred to as "The Wekiva River System" [Paragraph 369.303(10), *Florida Statutes (F.S.)*].

In 1988, the Florida Legislature enacted the Wekiva River Protection Act (Part III of Chapter 369, *F.S.*) and directed the St. Johns River Water Management District (SJRWMD or the District) to establish minimum flows and levels (MFLs) for surface watercourses in the Wekiva River System no later than March 1, 1991 [Paragraph 373.415(3), *F.S.*]. Section 373.042, *F.S.*, directed the state water management districts to use the best available information to calculate MFLs.

Establishing MFLs for the Wekiva River was a pioneering work for SJRWMD. Following the Wekiva River Protection Act, SJRWMD worked diligently for over two years finalizing a methodology for establishing MFLs, and applying the methods to the Wekiva River System. In January 1991, the SJRWMD staff determined an initial set of five MFLs for the Wekiva River at State Road (S.R.) 46 (Figure 1) (Neubauer 1991). The results went through an iterative review process, and the five MFLs were further revised. Finally, in June 1992, the SJRWMD Governing Board approved adopting the five MFLs for the Wekiva River at S.R. 46. After a public hearing in August 1992, the rule was filed with the Department of State and it became effective on September 16, 1992. The five MFLs are: minimum infrequent high (MIH), minimum frequent high (MFH), minimum average (MA), minimum frequent low MFL), and minimum infrequent low (MIL). These five MFLs define the minimum hydrologic regime needed to protect the Wekiva River from significant harm to its water resources and ecology.

The MFLs for the Wekiva River were determined based on evaluations of topographic, soils, and vegetation data collected within plant communities associated with the river near S.R. 46. Each MFL is tied to hydrologic statistics (i.e., a suitable duration and a recurrence interval) that are calculated from the observed long-term water level/discharge data at S.R. 46. The calculated statistics are used as indicators to determine whether or not consumptive uses of water caused water levels to fall below the established MFLs. A detailed description of how these MFLs were established is given in Hupalo et al. (1994).

The U.S. Geological Survey (USGS) has collected stage and discharge data since October 1935 (i.e., Water Year, WY, 1936) for the Wekiva River at the S.R. 46 Bridge. Based on an analysis of the 1936-1990 USGS WY data, Hupalo et al. (1994) determined that the adopted MFLs for the Wekiva River were being met. Increased groundwater and surface water uses in the Wekiva River basin, however, could potentially reduce discharges and water levels; therefore, it is necessary to periodically evaluate the observed stage/discharge data to verify that the established MFLs are being met. The evaluation procedure consists of re-computing various hydrologic statistics with the updated hydrologic data, and comparing the statistics with the established MFLs.

The objective of this report is a re-evaluation of the MFLs for the Wekiva River at the S.R. 46 Bridge based on the 1936-2004 WY USGS data (i.e., the updated data as available at the time of this report) and to verify whether the MFLs are still being met. For consistency in data evaluations, various statistical procedures used for this report are the same as those that were used for verification of the Wekiva River MFLs in the 1990s (i.e., by Hupalo et al. 1994). These statistical procedures were originally compiled/developed by the author of this report and were not fully reported in Hupalo et al. (1994); they are comprehensively described herein. Data evaluations also are performed by graphical procedures, which have been developed by the staff of the Division of Water Supply Management (DWSM), SJRWMD, subsequent to the work by Hupalo et al. (1994); these procedures are currently used as a standard for evaluating MFLs by SJRWMD.

Data for a recently (1995) established upstream gauging station, the Wekiva River at Old RR Crossing, are also analyzed to determine the suitability of this location as an alternative MFLs monitoring site. Recommendations are made for further work.

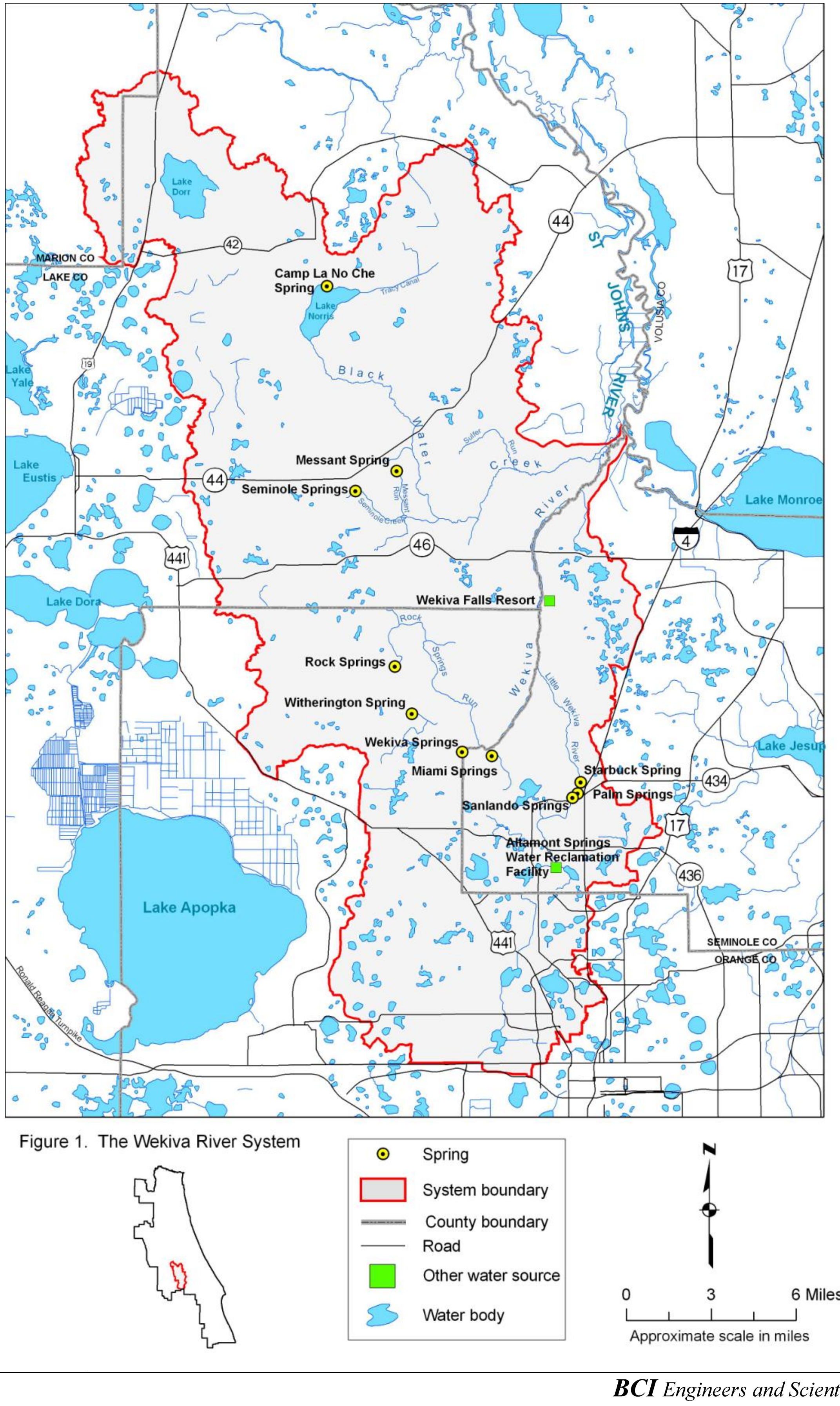

Figure 1. The Wekiva River System

ESTABLISHED MFLs FOR THE WEKIVA RIVER AT THE S.R. 46 BRIDGE

Chapter 40C-8, *Florida Administrative Code* (SJRWMD 2004), establishes minimum flows and/or levels for surface watercourses and minimum levels for groundwater at specific locations within SJRWMD. The District implemented the MFLs program in the 1980s and it typically defines three to five MFLs for each system: *minimum infrequent high, minimum frequent high, minimum average, minimum frequent low, and minimum infrequent low* flows and/or water levels. Five MFLs were established for the Wekiva River at S.R. 46 Bridge (Table 1; Hupalo et al. 1994). Detailed definitions for MFLs and further explanation of the MFLs can be found in Chapter 40C-8 (SJRWMD 2004).

Table 1. Wekiva River at the S.R. 46 Bridge: Minimum flows and levels

MFL Category	Level (ft NGVD)	Flow (cfs)	Duration (days)	Return period (years)
Minimum Infrequent High	9.0	880	≥7	≤5
Minimum Frequent High	8.0	410	≥30	≤2
Minimum Average	7.6	240	≤180	≥1.7
Minimum Frequent Low	7.2	200	≤90	≥3
Minimum Infrequent Low	6.1	120	≤7	≥100

The work completed by Hupalo et al. (1994) at SJRWMD was a pioneering work in establishing MFLs, with one of the study objectives being, "To develop a conceptual model for determining minimum flows and levels based on ecological criteria—a model that can be applied to other surface waters in SJRWMD." Development of MFLs by Hupalo et al. (1994) for the Wekiva River at the S.R. 46 Bridge consisted of three steps.

1) The stage values ("Level" in Table 1) for each MFLs category as defined above were determined based on the ecologic characteristics of the plant communities and soils observed in vegetation sampling plots. The sampling plots were typically "5-meter x 20-meter" in size, and the long axis was perpendicular to the stream. The data were collected along two transects on the Wekiva River, one upstream and one downstream of the S.R. 46 Bridge. For the MA, however, the report states that the minimum stage could not be determined precisely from the vegetation characteristics, and was based on the 60th percentile of the stage-duration curve at the bridge.
2) For each stage shown in Table 1, durations and return periods (T) were conceptually assigned based on the definition and interpretation of each minimum level, and a

consensus among the study authors. Then, the return periods for the established stages were verified by performing a hydrologic frequency analysis (by log-Pearson Type 3 distribution) on the USGS stage data for 1936-1990 Water Years; the computed hydrologic statistics included the conceptually determined return periods as shown in Table 2. In this case, the annual series of data used in frequency analysis are mean stages for the respective durations. For example, for the MIH, the data consists of the highest mean stages that occurred over a seven-day continuous period in each year. Similarly, for the MFL, the data consists of the lowest mean stages that occurred over a 90-day continuous period in each year. In developing annual series of data, the highest mean stage/discharge for a given duration for a given year is evaluated by computing the mean values for all available durations (i.e., consecutive days) in the year, and selecting the highest value from the computed values. For example, a 365-day year has 359 '7- consecutive day' periods, and the mean values for each of these 359 periods are computed, and the maximum value selected. Likewise, the lowest mean stage/discharge for a given duration for a given year is evaluated by computing the mean values for all available durations (i.e., consecutive days) in the year, and selecting the lowest value from the computed values. High and low stages/discharges are determined for years ending May 31 and September 30, respectively; use of these reference years is determined based on the climatic and hydrologic conditions of SJRWMD and are designed to capture most extreme events possible. Tables 3-6 present these data for selected durations for the USGS data through Water Year 2004. For high stages/discharges (Tables 3 and 5), however, data for the Reference Year 2005 are also included so that the high stages/discharges that occurred during the 2004 hurricane events could be included in the present analyses. The reader should note that the study of Hupalo et al. (1994) included data for only 1936-1990, while the complete data shown in Tables 3-6 are used in the further analyses performed in this report.

3) The minimum flows shown in Table 1 were derived assuming that recurrence intervals of stages correspond to the recurrence intervals of flows. For example, a 5-year stage would also correspond to a 5-year discharge. For this purpose, frequency analysis was performed on annual series of discharge data, using mean discharges for various durations similar to mean stages explained in the foregoing (see Tables 5 and 6 for the duration of interest). The daily streamflow data used in the analysis, however, was not that gauged by the USGS, but derived by a hydrologic simulation model (i.e., SSARR, The Streamflow Synthesis and Reservoir Regulation model developed by the U.S. Army Corps of Engineers, North Pacific Division, 1986). The model was used because of the importance of spring flows in the Wekiva River Basin and the need to set MFLs for them; also, flow data were required at other locations where USGS did not monitor data. Tables 5 and 6, however, are derived from the USGS daily data.

Subsequent to the 1994 work by Hupalo et al., SJRWMD staff developed graphical procedures for the evaluation of MFLs, which will be described in the next section of this document.

Table 2. Comparison of the "conceptual" and "computed" return intervals for the Wekiva River Minimum Levels at the S.R. 46 Bridge

MFL Category	Level (ft NGVD)	Duration (days)	Return period (years)	
			Conceptual	Computed [1]
Minimum Infrequent High	9.0	≥7	≤5	4
Minimum Frequent High	8.0	≥30	≤2	1.7
Minimum Average	7.6	≤180	≥1.7	2
Minimum Frequent Low	7.2	≤90	≥3	5
Minimum Infrequent Low	6.1	≤7	≥100	> 500

[1] Computed = obtained from a hydrologic frequency analysis on the 1936-1990 USGS Water-Year stage data

Table 3. The Wekiva River at the S.R. 46 Bridge: Annual series of mean high stages derived from the USGS daily stage data (The stages are in feet NGVD)

Highest mean stages for the following number of consecutive days in year ending May 31

YEAR	1	7	14	30	60	90	120	183	1 YEAR
1937	9.30	9.07	8.89	8.69	8.65	8.61	8.58	8.56	8.48
1938	9.11	8.89	8.77	8.61	8.51	8.48	8.46	8.43	8.34
1939	8.71	8.68	8.62	8.53	8.43	8.40	8.38	8.38	8.33
1940	8.84	8.56	8.36	8.31	8.19	8.13	8.12	8.10	8.05
1941	8.32	8.22	8.13	8.09	8.04	8.01	7.96	7.86	7.80
1942	8.80	8.63	8.43	8.39	8.30	8.25	8.25	8.23	8.14
1943	8.68	8.57	8.50	8.37	8.29	8.30	8.28	8.23	8.22
1944	9.23	8.83	8.64	8.46	8.43	8.38	8.34	8.23	8.09
1945	10.04	9.30	8.74	8.35	8.16	8.08	8.06	7.99	7.86
1946	10.56	9.89	9.43	8.98	8.73	8.63	8.57	8.53	8.41
1947	9.48	9.33	9.22	8.95	8.73	8.68	8.63	8.54	8.50
1948	9.66	9.27	8.99	8.76	8.71	8.64	8.61	8.53	8.36
1949	8.74	8.66	8.61	8.44	8.25	8.21	8.16	8.10	7.99
1950	9.50	9.16	8.73	8.35	8.30	8.18	8.12	8.04	7.97
1951	10.33	9.52	8.96	8.44	8.38	8.28	8.23	8.13	8.03
1952	8.94	8.78	8.60	8.41	8.30	8.28	8.25	8.24	8.20
1953	9.11	8.89	8.82	8.57	8.34	8.26	8.23	8.17	8.14
1954	9.65	9.45	9.28	8.94	8.80	8.71	8.62	8.47	8.19
1955	9.43	8.97	8.57	8.32	8.13	8.09	8.09	8.06	8.01
1956	8.56	8.48	8.44	8.38	8.28	8.25	8.23	8.19	8.16
1957	9.16	8.94	8.58	8.33	8.25	8.23	8.24	8.18	8.03
1958	8.50	8.27	8.05	7.92	7.76	7.68	7.65	7.59	7.56
1959	9.04	8.79	8.41	8.08	7.92	7.82	7.75	7.67	7.56
1960	10.41	9.85	9.21	8.62	8.31	8.19	8.10	7.96	7.88
1961	11.05	10.65	10.22	9.89	9.19	9.15	8.95	8.60	8.41
1962	7.95	7.91	7.87	7.79	7.71	7.67	7.63	7.56	7.47
1963	8.60	8.30	8.07	8.00	7.88	7.80	7.78	7.77	7.71
1964	9.50	9.24	8.93	8.66	8.57	8.47	8.46	8.28	7.94
1965	10.10	9.62	9.05	8.42	8.06	8.01	8.04	7.77	7.68
1966	8.97	8.88	8.77	8.51	8.34	8.30	8.23	8.01	7.89
1967	9.39	9.24	9.17	8.92	8.60	8.41	8.29	8.00	7.68
1968	8.72	8.48	8.31	8.18	8.13	8.07	8.01	7.90	7.68
1969	9.30	9.13	8.98	8.75	8.57	8.36	8.29	8.13	7.96
1970	9.05	8.83	8.42	8.08	7.98	7.90	7.89	7.82	7.74
1971	8.94	8.65	8.21	8.06	7.88	7.80	7.75	7.73	7.66
1972	9.21	9.03	8.83	8.66	8.46	8.30	8.19	8.05	7.82
1973	8.07	7.89	7.83	7.74	7.66	7.68	7.65	7.55	7.51
1974	8.46	8.35	8.25	8.11	7.97	7.93	7.87	7.61	7.21
1975	9.13	9.00	8.87	8.28	7.82	7.71	7.64	7.48	7.34
1976	8.61	8.47	8.36	8.17	8.03	8.04	7.97	7.79	7.56
1977	8.13	8.04	7.91	7.81	7.75	7.70	7.66	7.54	7.36
1978	8.32	8.21	8.08	8.01	7.77	7.62	7.53	7.42	7.33
1979	8.67	8.38	8.16	7.96	7.71	7.58	7.46	7.33	7.33
1980	8.35	8.22	8.05	7.95	7.67	7.59	7.53	7.37	7.26
1981	7.16	7.07	7.04	7.03	7.03	7.02	7.00	6.95	6.92
1982	8.31	8.09	7.79	7.55	7.40	7.32	7.26	7.19	7.06
1983	8.33	7.99	7.74	7.69	7.56	7.54	7.54	7.42	7.30
1984	7.91	7.61	7.52	7.35	7.30	7.27	7.25	7.21	7.16
1985	7.97	7.87	7.77	7.50	7.43	7.35	7.29	7.19	7.04
1986	8.59	8.24	7.83	7.65	7.54	7.44	7.37	7.33	7.18
1987	8.97	8.68	8.17	7.55	7.29	7.18	7.15	7.10	7.07
1988	7.93	7.73	7.64	7.47	7.36	7.31	7.28	7.23	7.21
1989	8.32	8.13	7.88	7.64	7.48	7.42	7.38	7.30	7.21
1990	7.39	7.30	7.29	7.25	7.24	7.20	7.18	7.16	7.10
1991	8.04	7.76	7.39	7.17	7.11	7.00	6.98	6.94	6.90
1992	8.13	8.05	7.90	7.80	7.59	7.49	7.40	7.30	7.08
1993	8.39	8.18	7.88	7.62	7.55	7.44	7.41	7.37	7.23
1994	7.27	7.18	7.17	7.11	7.07	7.05	7.04	7.02	6.97
1995	9.81	9.36	8.75	8.16	7.75	7.61	7.61	7.51	7.29
1996	8.83	8.51	8.14	7.80	7.55	7.47	7.39	7.32	7.23
1997	8.45	8.21	7.86	7.45	7.32	7.24	7.25	7.20	7.06
1998	8.96	8.88	8.69	8.44	8.15	8.11	8.04	7.84	7.48

Table 3—Continued

Highest mean stages for the following number of consecutive days in year ending May 31									
YEAR	**1**	**7**	**14**	**30**	**60**	**90**	**120**	**183**	**1 YEAR**
1999	7.93	7.82	7.68	7.49	7.37	7.37	7.35	7.28	7.08
2000	8.63	8.45	8.36	8.11	7.86	7.66	7.57	7.42	7.20
2001	7.50	7.36	7.30	7.26	7.21	7.18	7.16	7.10	6.93
2002	9.25	8.74	8.24	7.80	7.46	7.35	7.28	7.18	6.95
2003	8.56	8.31	8.05	7.92	7.68	7.60	7.48	7.42	7.27
2004	8.57	8.21	7.91	7.82	7.69	7.63	7.56	7.45	7.25
2005	9.57	9.35	8.91	8.57	8.21	7.83	7.62	7.41	6.96
MEAN	8.83	8.59	8.35	8.12	7.96	7.88	7.83	7.74	7.61
MAX	11.05	10.65	10.22	9.89	9.19	9.15	8.95	8.60	8.50
MIN	7.16	7.07	7.04	7.03	7.03	7.00	6.98	6.94	6.90

MEAN = Mean value of the series

MAX = Maximum value of the series

MIN = Minimum value of the series

Table 4. The Wekiva River at the S.R. 46 Bridge: Annual series of mean low stages derived from the USGS daily stage data (The stages are in feet NGVD)

Lowest mean stages for the following number of consecutive days in year ending Sept 30									
YEAR	1	7	14	30	60	90	120	183	1 YEAR
1936	7.98	7.99	7.99	8.00	8.03	8.04	8.08	8.15	8.21
1937	8.22	8.25	8.28	8.32	8.41	8.44	8.43	8.46	8.50
1938	8.08	8.10	8.14	8.15	8.16	8.18	8.19	8.24	8.31
1939	7.94	7.94	7.96	7.99	8.00	8.06	8.11	8.16	8.25
1940	7.72	7.74	7.75	7.78	7.79	7.88	7.90	7.93	7.99
1941	7.47	7.48	7.49	7.50	7.53	7.61	7.67	7.72	7.83
1942	7.90	7.91	7.94	8.08	8.13	8.16	8.18	8.20	8.22
1943	7.97	8.04	8.10	8.12	8.13	8.15	8.16	8.18	8.23
1944	7.65	7.73	7.80	7.83	7.84	7.88	7.90	7.92	7.98
1945	7.60	7.61	7.62	7.66	7.67	7.69	7.71	7.73	7.98
1946	8.26	8.29	8.31	8.31	8.34	8.38	8.40	8.41	8.49
1947	8.30	8.32	8.33	8.34	8.35	8.36	8.36	8.40	8.49
1948	7.88	7.91	7.93	7.94	7.95	7.96	7.97	8.01	8.19
1949	7.78	7.80	7.80	7.83	7.84	7.86	7.86	7.87	7.99
1950	7.82	7.82	7.82	7.83	7.86	7.87	7.87	7.89	8.00
1951	7.78	7.78	7.79	7.83	7.86	7.87	7.91	7.92	8.04
1952	8.04	8.05	8.06	8.08	8.10	8.12	8.13	8.15	8.19
1953	7.92	7.92	7.92	7.93	7.95	7.98	8.02	8.08	8.27
1954	7.72	7.72	7.73	7.74	7.76	7.77	7.78	7.80	7.97
1955	7.84	7.84	7.85	7.93	7.95	7.96	7.99	8.02	8.12
1956	8.06	8.06	8.06	8.06	8.07	8.10	8.12	8.12	8.16
1957	7.36	7.39	7.41	7.45	7.52	7.54	7.62	7.68	7.84
1958	7.24	7.25	7.25	7.28	7.40	7.44	7.46	7.46	7.50
1959	7.24	7.25	7.30	7.32	7.41	7.42	7.48	7.57	7.68
1960	7.64	7.64	7.65	7.66	7.68	7.69	7.73	7.91	8.17
1961	7.44	7.45	7.48	7.50	7.54	7.57	7.62	7.84	8.06
1962	7.31	7.31	7.32	7.33	7.34	7.35	7.35	7.37	7.50
1963	7.43	7.45	7.45	7.49	7.51	7.55	7.54	7.56	7.67
1964	7.42	7.43	7.43	7.44	7.56	7.60	7.77	7.98	8.08
1965	7.16	7.16	7.16	7.17	7.22	7.27	7.31	7.44	7.62
1966	7.45	7.47	7.48	7.50	7.54	7.56	7.61	7.81	8.04
1967	7.27	7.27	7.28	7.28	7.29	7.31	7.32	7.35	7.55
1968	7.33	7.34	7.35	7.38	7.43	7.43	7.44	7.49	7.82
1969	7.27	7.31	7.33	7.37	7.51	7.61	7.65	7.75	7.76
1970	7.21	7.22	7.24	7.31	7.48	7.58	7.60	7.68	7.75
1971	7.46	7.46	7.47	7.48	7.51	7.56	7.61	7.62	7.81
1972	7.36	7.37	7.39	7.41	7.50	7.51	7.54	7.58	7.64
1973	7.19	7.22	7.24	7.30	7.32	7.33	7.36	7.41	7.59
1974	6.71	6.71	6.72	6.74	6.76	6.77	6.78	6.82	7.12
1975	7.13	7.13	7.13	7.15	7.16	7.18	7.19	7.20	7.42
1976	7.22	7.23	7.24	7.26	7.29	7.31	7.34	7.33	7.51
1977	7.02	7.03	7.03	7.04	7.05	7.07	7.09	7.14	7.25
1978	6.99	6.99	7.01	7.05	7.08	7.11	7.15	7.35	7.38
1979	6.94	6.96	6.96	6.98	7.04	7.07	7.13	7.23	7.35
1980	6.88	6.91	6.91	6.93	6.98	6.99	7.00	7.07	7.09
1981	6.78	6.79	6.79	6.79	6.80	6.81	6.82	6.86	6.88
1982	6.96	6.96	6.97	6.99	7.01	7.02	7.03	7.06	7.27
1983	6.97	6.98	7.00	7.01	7.04	7.06	7.10	7.17	7.21
1984	6.96	6.96	6.98	7.02	7.05	7.06	7.07	7.10	7.18
1985	6.84	6.84	6.85	6.85	6.85	6.86	6.87	6.88	7.03
1986	6.91	6.92	6.94	6.96	7.01	7.03	7.03	7.04	7.14
1987	6.84	6.85	6.86	6.89	6.91	6.93	6.94	7.01	7.09
1988	7.03	7.04	7.06	7.07	7.11	7.14	7.17	7.22	7.27
1989	7.01	7.02	7.04	7.05	7.07	7.07	7.08	7.09	7.14
1990	6.87	6.89	6.91	6.91	6.92	6.94	6.95	6.97	7.03
1991	6.66	6.67	6.68	6.68	6.70	6.71	6.73	6.78	7.04
1992	6.82	6.83	6.83	6.84	6.84	6.85	6.86	6.87	7.02
1993	6.86	6.87	6.88	6.90	6.93	6.96	6.98	7.03	7.16
1994	6.73	6.74	6.74	6.77	6.80	6.84	6.90	6.94	7.10
1995	6.67	6.67	6.70	6.76	6.79	6.83	6.89	6.94	7.21
1996	6.93	6.93	6.94	6.95	7.00	7.15	7.14	7.22	7.24
1997	6.63	6.64	6.65	6.66	6.69	6.72	6.76	6.84	7.01

Table 4—Continued

Lowest mean stages for the following number of consecutive days in year ending Sept 30									
YEAR	1	7	14	30	60	90	120	183	1 YEAR
1998	7.17	7.18	7.20	7.22	7.28	7.30	7.31	7.39	7.59
1999	6.73	6.74	6.75	6.78	6.79	6.80	6.81	6.86	7.01
2000	6.72	6.73	6.74	6.75	6.76	6.80	6.83	6.89	7.14
2001	6.52	6.52	6.54	6.55	6.59	6.60	6.65	6.74	6.97
2002	6.61	6.61	6.62	6.62	6.65	6.67	6.72	6.78	7.07
2003	6.83	6.85	6.88	6.92	6.95	7.06	7.15	7.19	7.30
2004	6.71	6.71	6.72	6.74	6.79	6.83	6.86	6.94	7.23
MEAN	7.30	7.31	7.32	7.34	7.38	7.41	7.44	7.49	7.62
MAX	8.30	8.32	8.33	8.34	8.41	8.44	8.43	8.46	8.50
MIN	6.52	6.52	6.54	6.55	6.59	6.60	6.65	6.74	6.88

MEAN = Mean value of the series

MAX = Maximum value of the series

MIN = Minimum value of the series

Table 5. The Wekiva River at the S.R. 46 Bridge: Annual series of mean high discharges derived from the USGS daily discharge data (The discharges are in cfs)

Highest mean discharges for the following number of consecutive days in year ending May 31									
YEAR	1	7	14	30	60	90	120	183	1 YEAR
1937	912.00	676.71	541.71	464.17	353.33	319.97	295.48	292.97	277.50
1938	673.00	583.29	478.57	376.07	320.55	323.89	313.35	296.24	241.34
1939	490.00	466.14	431.50	372.50	301.33	264.13	253.28	238.27	212.45
1940	711.00	517.00	420.79	369.90	295.48	288.73	294.00	264.08	241.10
1941	658.00	513.14	403.36	340.33	331.83	326.70	305.30	266.87	251.94
1942	927.00	790.71	642.36	500.07	423.67	396.99	374.80	359.55	313.67
1943	511.00	431.43	389.79	314.43	275.78	272.90	267.72	244.32	229.82
1944	844.00	574.86	462.86	374.53	365.53	341.99	318.22	274.46	242.37
1945	1580.00	940.14	617.57	406.00	344.67	361.04	332.98	301.68	254.29
1946	2060.00	1394.86	964.86	667.67	555.25	505.64	471.70	395.20	323.89
1947	890.00	784.00	714.57	541.97	414.32	395.68	362.38	323.49	294.14
1948	1050.00	765.14	591.29	462.23	428.40	392.97	374.23	338.97	303.06
1949	594.00	563.14	540.00	459.93	420.63	377.71	340.67	292.88	240.19
1950	929.00	779.43	611.00	449.10	405.48	361.59	337.38	312.70	260.21
1951	1570.00	980.14	703.93	489.70	407.37	362.66	337.70	308.30	246.94
1952	541.00	469.71	399.29	329.50	282.25	283.94	273.71	265.16	247.38
1953	670.00	549.86	514.71	425.70	330.87	293.82	280.85	276.62	248.65
1954	1100.00	944.86	811.29	625.77	541.70	490.84	444.31	418.13	330.60
1955	870.00	601.29	452.29	381.10	308.30	286.02	270.00	254.30	233.25
1956	380.00	326.14	317.86	297.93	260.97	252.42	244.86	233.52	221.56
1957	717.00	587.14	435.14	331.20	281.72	258.22	243.52	234.73	227.76
1958	871.00	731.43	609.00	500.70	411.37	378.88	357.39	320.13	311.72
1959	1210.00	1045.00	816.29	605.60	499.27	433.86	405.19	365.32	315.11
1960	1920.00	1512.86	1096.86	734.50	569.28	495.16	448.82	400.48	371.77
1961	1860.00	1650.00	1399.29	1212.10	877.83	823.77	741.65	626.33	485.63
1962	338.00	313.00	306.86	295.93	283.20	269.50	267.16	254.67	237.89
1963	689.00	523.86	434.86	413.90	366.27	333.09	313.38	306.25	271.31
1964	1090.00	897.43	731.93	578.30	479.27	468.41	428.94	381.82	330.85
1965	1570.00	1244.29	1007.79	708.13	522.62	433.37	395.54	354.15	299.83
1966	884.00	845.57	786.64	604.57	453.83	398.67	364.33	323.40	308.52
1967	1130.00	835.29	724.00	564.63	496.40	468.06	476.08	400.77	319.02
1968	707.00	571.86	473.79	405.57	366.22	348.47	331.19	301.84	266.39
1969	978.00	844.00	745.29	621.13	545.68	469.53	459.39	452.89	382.28
1970	1140.00	978.00	780.07	634.90	599.57	559.62	531.63	524.21	432.28
1971	960.00	799.00	587.57	467.43	391.37	356.71	337.88	340.57	308.70
1972	792.00	687.14	596.29	535.90	458.62	408.61	376.00	340.85	312.27
1973	482.00	446.00	407.07	368.40	344.25	324.28	310.03	293.61	272.00
1974	745.00	631.00	537.29	522.83	469.62	453.11	412.42	354.40	288.34
1975	1140.00	1075.71	1012.86	755.87	567.03	514.83	474.67	395.25	308.96
1976	657.00	598.29	556.36	474.47	399.95	377.28	367.72	330.99	276.51
1977	467.00	436.29	391.21	356.27	338.08	325.49	311.17	300.26	275.84
1978	592.00	542.86	464.79	443.87	380.98	343.34	322.63	301.55	278.95
1979	915.00	773.14	683.43	598.80	475.23	417.18	389.63	354.67	338.37
1980	756.00	702.14	633.07	592.80	477.12	424.72	390.91	352.44	317.74
1981	275.00	248.57	240.43	233.60	227.27	225.17	225.63	216.37	211.00
1982	722.00	616.00	473.57	352.37	286.17	257.09	239.08	219.75	209.71
1983	740.00	559.71	485.86	428.73	408.83	390.13	363.13	319.26	313.40
1984	609.00	511.57	493.57	425.43	389.83	372.51	355.03	337.09	315.17
1985	570.00	536.86	504.86	449.17	423.05	378.51	350.31	315.93	271.07
1986	942.00	805.71	642.36	481.07	408.98	373.27	347.46	348.51	304.68
1987	1220.00	1058.86	806.07	544.17	459.63	436.06	397.02	342.20	303.32
1988	549.00	471.43	422.57	359.57	342.67	313.18	297.42	288.95	268.55
1989	724.00	631.29	520.21	414.60	340.55	319.77	312.55	296.87	257.47
1990	321.00	283.57	281.57	269.27	264.98	255.47	249.29	243.96	229.97
1991	641.00	526.00	399.36	323.87	298.98	263.26	238.28	218.63	217.29
1992	699.00	659.71	596.21	556.73	474.30	433.81	398.53	353.21	292.00
1993	758.00	663.57	540.29	439.70	408.95	371.50	359.12	345.46	303.98
1994	336.00	300.14	283.93	273.03	266.02	258.23	253.43	251.44	239.58
1995	1830.00	1525.71	1150.64	822.40	615.12	553.47	551.71	502.99	400.44
1996	1160.00	988.86	803.21	637.53	536.65	501.17	465.05	438.66	396.13
1997	886.00	769.14	613.71	450.40	398.33	362.98	370.04	345.77	296.29

Table 5—Continued

Highest mean discharges for the following number of consecutive days in year ending May 31

YEAR	1	7	14	30	60	90	120	183	1 YEAR
1998	1040.00	990.00	876.07	727.60	582.80	581.97	549.50	458.44	358.02
1999	550.00	502.71	445.57	381.03	321.60	305.64	305.52	288.55	251.00
2000	879.00	791.29	748.50	639.63	527.50	440.46	396.83	355.77	281.73
2001	315.00	264.14	241.50	232.80	217.18	208.43	204.13	198.61	189.90
2002	1040.00	836.00	646.64	487.27	387.48	355.06	334.58	302.46	258.95
2003	902.00	798.00	689.57	638.53	492.02	465.97	456.93	426.34	384.04
2004	909.00	756.00	633.29	597.30	549.27	526.27	495.08	447.95	364.58
2005	1410.00	1281.43	1027.71	845.93	670.42	539.50	460.22	409.11	315.34
MEAN	878.22	728.98	605.72	492.58	416.25	383.66	361.25	331.04	289.65
MAX	2060.00	1650.00	1399.29	1212.10	877.83	823.77	741.65	626.33	485.63
MIN	275.00	248.57	240.43	232.80	217.18	208.43	204.13	198.61	189.90

MEAN = Mean value of the series

MAX = Maximum value of the series

MIN = Minimum value of the series

Table 6. The Wekiva River at the S.R. 46 Bridge: Annual series of mean low discharges derived from the USGS daily discharge data (The discharges are in cfs)

Lowest mean discharges for the following number of consecutive days in year ending Sept 30

YEAR	1	7	14	30	60	90	120	183	1 YEAR
1936	156.00	168.29	173.07	182.10	192.02	210.13	226.05	274.05	275.18
1937	145.00	161.43	171.43	182.63	191.12	207.24	225.00	239.60	258.38
1938	129.00	152.14	161.57	165.17	166.50	172.88	180.05	201.99	245.54
1939	105.00	105.00	108.86	125.63	157.58	159.98	166.48	180.00	222.35
1940	169.00	175.86	182.00	185.03	191.12	200.03	204.74	218.85	233.07
1941	172.00	173.14	174.79	179.57	187.87	199.37	223.38	250.19	287.54
1942	174.00	184.14	187.14	192.20	222.48	239.28	236.84	252.79	281.81
1943	171.00	183.57	186.36	190.40	195.55	201.80	205.48	208.25	240.53
1944	166.00	169.14	171.50	175.67	181.72	194.12	203.94	209.86	236.98
1945	167.00	169.86	174.29	176.40	184.12	191.44	196.73	214.30	308.55
1946	208.00	213.86	215.71	216.47	222.68	235.52	241.48	251.50	292.23
1947	185.00	190.29	195.50	201.10	227.25	236.68	238.95	257.42	296.77
1948	195.00	206.14	210.50	215.57	217.18	219.86	223.39	247.48	285.14
1949	162.00	167.71	169.86	170.67	171.35	175.24	177.38	184.66	240.08
1950	141.00	152.57	153.43	158.20	166.85	174.90	180.02	189.04	234.79
1951	172.00	173.57	178.29	180.80	182.73	186.42	191.57	212.12	253.05
1952	196.00	197.71	200.29	204.17	208.68	213.24	212.70	216.72	236.18
1953	196.00	206.43	212.21	213.57	224.82	232.40	239.79	246.09	307.24
1954	188.00	190.00	195.14	195.93	203.73	209.43	215.50	222.35	278.46
1955	185.00	191.43	192.57	196.47	201.18	206.24	205.39	215.33	235.57
1956	177.00	182.86	187.00	189.33	193.87	194.00	195.03	201.88	210.86
1957	179.00	182.29	184.86	188.47	193.30	199.78	207.23	215.16	267.43
1958	196.00	197.71	199.71	208.17	226.02	240.44	259.35	268.21	289.33
1959	192.00	195.29	203.14	214.30	282.35	276.67	292.06	342.55	350.77
1960	202.00	210.57	218.07	229.37	255.23	278.66	311.62	380.95	454.11
1961	212.00	220.29	226.29	234.77	250.95	258.47	266.28	278.40	370.15
1962	194.00	199.14	207.00	210.20	213.37	215.07	217.02	219.69	233.84
1963	212.00	213.71	218.14	227.67	230.62	234.27	249.48	256.30	289.33
1964	186.00	188.29	191.71	195.10	244.73	246.81	255.34	295.60	350.39
1965	174.00	178.57	180.57	183.07	193.27	206.66	225.99	247.50	281.33
1966	170.00	181.43	194.29	221.10	234.65	241.72	256.57	313.89	357.40
1967	198.00	202.00	204.00	205.67	206.80	210.28	220.29	235.73	272.98
1968	178.00	183.71	188.29	193.33	203.80	221.08	234.88	231.60	310.71
1969	236.00	238.43	243.07	255.63	272.23	273.72	277.60	300.83	362.53
1970	249.00	251.57	254.57	266.80	275.57	280.61	287.77	323.67	412.80
1971	228.00	230.00	231.86	236.73	243.33	248.13	257.04	295.67	321.20
1972	216.00	216.00	216.86	222.43	239.25	247.24	254.47	273.56	278.69
1973	191.00	193.86	195.14	197.80	202.40	220.14	233.09	266.80	306.62
1974	198.00	199.71	200.36	202.50	207.80	211.02	216.51	228.04	317.16
1975	196.00	196.86	198.29	201.60	208.05	210.83	213.27	220.87	256.93
1976	193.00	194.71	195.43	200.50	211.92	222.06	220.12	224.49	277.52
1977	173.00	175.29	176.79	180.80	186.97	193.78	202.18	227.63	266.85
1978	210.00	210.86	212.14	214.73	224.00	234.21	247.18	288.20	309.26
1979	255.00	256.86	258.36	259.30	275.12	284.32	284.09	311.02	336.76
1980	212.00	212.71	214.64	219.33	220.13	222.59	225.29	248.88	270.00
1981	185.00	186.14	186.71	187.80	188.68	190.68	192.70	201.03	203.22
1982	165.00	165.71	167.21	170.30	178.33	182.51	184.07	192.34	252.41
1983	223.00	227.14	229.79	230.33	233.83	235.22	242.75	290.87	321.09
1984	232.00	234.29	236.93	241.20	264.68	269.31	268.47	278.49	313.14
1985	216.00	216.86	217.07	218.43	219.30	220.83	222.15	225.73	264.62
1986	201.00	203.43	206.57	208.90	216.77	230.87	233.07	250.95	287.57
1987	217.00	219.00	220.43	223.83	228.87	237.40	247.37	289.65	300.06
1988	191.00	194.71	199.36	201.23	207.45	210.44	214.73	245.93	271.99
1989	199.00	200.14	204.21	206.47	210.32	211.69	213.02	218.56	245.61
1990	180.00	184.29	188.00	190.00	192.13	195.10	198.97	208.93	224.98
1991	158.00	158.86	160.07	161.90	164.73	166.93	170.75	183.62	274.12
1992	190.00	191.00	200.71	206.00	206.93	209.72	214.88	230.43	259.83
1993	203.00	206.86	208.50	214.70	221.37	230.84	234.73	247.15	284.84
1994	188.00	190.14	193.86	196.87	204.67	215.63	229.43	234.62	310.08
1995	206.00	208.86	209.29	217.47	228.33	235.69	245.83	259.58	376.47
1996	241.00	252.00	260.43	286.53	297.75	330.64	325.78	361.42	381.86

Table 6—Continued

Lowest mean discharges for the following number of consecutive days in year ending Sept 30

YEAR	1	7	14	30	60	90	120	183	1 YEAR
1997	210.00	212.14	213.29	224.40	232.00	234.70	235.67	240.27	270.98
1998	223.00	224.57	226.36	235.23	255.95	264.46	273.33	281.47	367.58
1999	173.00	175.14	178.21	183.87	187.58	194.80	200.33	211.08	253.90
2000	164.00	170.29	171.79	176.23	176.75	179.76	181.08	184.27	245.57
2001	150.00	152.43	153.86	158.53	171.88	182.11	182.48	185.31	227.96
2002	186.00	187.43	188.14	190.63	195.07	197.53	210.23	221.14	293.71
2003	250.00	253.29	259.43	263.23	278.80	323.82	351.98	368.02	405.80
2004	139.00	140.43	141.64	148.33	158.58	173.32	186.25	222.22	336.38
MEAN	189.84	194.20	197.64	203.03	213.23	221.20	228.47	246.71	289.54
MAX	255.00	256.86	260.43	286.53	297.75	330.64	351.98	380.95	454.11
MIN	105.00	105.00	108.86	125.63	157.58	159.98	166.48	180.00	203.22

MEAN = Mean value of the series

MAX = Maximum value of the series

MIN = Minimum value of the series

EVALUATION OF MFLS FOR THE WEKIVA RIVER AT THE S.R. 46 BRIDGE

To determine whether the established MFLs are being met, the observed (i.e., gauged) or simulated long-term stage and discharge data for water bodies are analyzed by statistical procedures. The statistical procedure used in the 1990s evaluations (Hupalo et al. 1994) consisted of hydrologic frequency analysis by a standard probability distribution, the log Pearson type 3 distribution. Subsequently, SJRWMD staff developed graphical procedures for the evaluation of MFLs. The results of these procedures indicate whether or not water levels or flows will fall below the established MFLs. The stage and discharge data gauged by the USGS since October 1935 (i.e., WY 1936), are used in this report for computing various hydrologic statistics and comparing them with the established MFLs for the Wekiva River at the S.R. 46 Bridge. This section describes the MFLs evaluation procedures and the evaluation results.

The MFLs evaluation procedures: Log Pearson type 3 distribution

Log Pearson type 3 distribution (LP) is one of the commonly used distributions in hydrologic frequency analysis. The U.S. Water Resources Council recommended its use for flood flow frequency analysis using the logarithmic moments method (1976). Rao evaluated general properties of LP (1980a), and developed alternative fitting methods for LP (1980b, 1983) in association with SJRWMD's MFLs Program. A comprehensive description of LP and its fitting methods can be found in Appendix A of SJRWMD Technical Publication, SJ86-2, 'Magnitude and frequency of flood discharges in North East Florida,' (Rao 1986, available online at www.sjrwmd.com) and elsewhere (Rao 1988).

Each column of data presented in Tables 3-6 constitutes a data sample for frequency analysis by LP or any other probability distribution. Table 7 illustrates results of LP analysis for the 7-day highest mean discharges (the duration chosen for MIH, Table 1) from Table 5 by five alternative fitting methods. Return period T is given by $T = 1/(1 - F)$ for maximum values and $T = 1/F$ for minimum values, in which F = exceedance probability. For large data samples, the discharge estimates for different Ts by the five methods do not differ widely. For smaller samples, and for data with anomalies like outliers, the estimates by different fitting methods, and also by different probability distributions might differ widely. It is beyond the scope of this report to discuss the remedial methods, but some suggestions are given in Rao (1986, 1988). By Monte Carlo analysis, Rao found that mxm1 method has generally superior statistical properties. For flood flow frequency analysis, Bulletin #17B of the Hydrology Subcommittee (USGS 1982) offers several procedures for improving Log-Pearson fit.

Table 7. Log Pearson estimates of 7-day maximum discharges for the Wekiva River at the S.R. 46 Bridge

F	T	by rlmo	by mxm1	by mxlk	by lgmo	by mxm2
0.500	2.	680.92	678.40	681.02	681.60	686.27
0.800	5.	953.37	948.82	950.87	953.47	954.63
0.900	10.	1127.51	1124.81	1123.84	1127.50	1121.45
0.960	25.	1340.33	1343.35	1335.86	1340.50	1320.37
0.980	50.	1493.81	1503.43	1489.24	1494.34	1460.61
0.990	100.	1643.24	1661.33	1638.95	1644.30	1594.61
0.995	200.	1789.91	1818.21	1786.29	1791.67	1723.79
0.998	500.	1980.72	2025.29	1978.54	1983.66	1888.60
0.999	1000.	2123.54	2182.35	2122.86	2127.57	2009.53

F = Cumulative distribution function or Exceedance probability; T = Return period in years; rlmo = real data moments method; mxm1 = mixed moments 1 method (uses mean and variance of real data and the mean of logarithmic data); mxlk = maximum likelihood method; lgmo = logarithmic data moments method, and mxm2 = mixed moments 2 method (uses the means of real and logarithmic data and variance of real data)

For the present sample, sample size 69 years, the differences in the estimates are found to be minor. For the Wekiva River at S.R. 46, the MFLs requirement for MIH is that a 7-day maximum discharge of 880 cfs should have a T ≤ 5 years (Table 1). Table 7 gives a T value between 2 and 5 years for this discharge; by interpolation using a probability paper T is found to be 3.8 years, hence the MFLs requirement is met. Hupalo et al. (1994) determined the "computed" T values shown in Table 2 using the 1936-1990 WY USGS data by the procedure illustrated in Table 7.

The MFLs evaluation procedures: Graphical

The MFLs graphical evaluation procedures consist broadly of two steps: a) a visual comparison of data (daily stages and discharges, and duration curves) with the established MFLs, and; b) by probability (frequency) plots of annual series of data for specified durations. These procedures are illustrated using the 1936-1990 USGS WY data, the data used in 1994 in verifying MFLs for the Wekiva River at the S.R. 46 Bridge. The SJRWMD staff standardized the procedures being described herein after the Hupalo et al. (1994) report was completed, and these procedures are applied for the first time to the Wekiva River data in this report.

Visual comparison of stage/discharge data with MFLs. This comparison is made by plotting the established MFLs values on stage/discharge hydrographs and the graphs of duration curves (Figures 2-5). The 1936-1990 stage hydrograph for the Wekiva River at S.R. 46 Bridge (Figure 2) shows that the MIH level of 9.0 ft NGVD was exceeded during several years up to 1974, but not exceeded afterwards (i.e., during 1975-1990). Also, during the 22-year period of 1936-1956, water levels were practically continuously above the MA and MFL levels of 7.6 and 7.2 ft NGVD, respectively. Thus, during the 25-year period of 1975-1990, the condition that MIH should have a return period (T) of 5 years or less is not met. Likewise, the return periods for MA and MFL levels are not met during 1936-1956. The discharges (Figure 3), nevertheless, appear to be meeting the established MFLs, overall.

Further, the stage hydrograph (Figure 2) shows that minimum stages were relatively high during 1936-1956, and there was a downward shift around 1957, and a further downward shift around 1973. The discharge hydrograph (Figure 3), however, does not indicate a corresponding decline in low flows in these time periods. In general, the discharge hydrograph does not exhibit any long-term trend; the peaks appear to be the result of major storm events, and the prolonged low flows, as occurred during 1980-1982, are the result of hydrologic droughts. Since only the stage hydrograph exhibited an anomaly, it is an indication that the channel geometry near S.R. 46 underwent some transformation, specifically some time around 1957 and again around 1973; it might have included channel improvements, erosion, and possibly vegetation changes affecting the channel roughness. The USGS constantly updates/revises its stage-discharge relation (which is used to compute daily discharges from the observed stages) by periodic measurements of discharges, so that stages represent discharges relatively accurately at a given time. Thus, discharge records may be considered to be independent of the anomalies in stage data and accurate within the margin of error rated by the USGS. The USGS rates the Wekiva River discharge data as “fair,” which means that about 95% of daily discharges reported are within 15% of their true values. Because the long-term discharge hydrograph (Figure 3) did not exhibit any obvious trend, it may be generally concluded that no major changes occurred in the surface water hydrology, or in the groundwater hydrology of the basin. Due largely to upstream springs, the Wekiva River discharge gauged at the S.R. 46 Bridge includes considerable groundwater inflows. The long-term stage data, however, may be regarded as non-homogeneous because the stages observed were a function of the channel geometry, which, it appears, varied with time. These aspects of the USGS stage and discharge data will be further addressed later in this report, under ‘MFLs evaluation with 1936-2004 USGS WY data.’

The duration curves (Figures 4 and 5) give the percentage of time stages/discharges exceeded a chosen value for the analyzed period (e.g., 1936-1990). Because the stage data were not homogeneous for 1936-1990, in general, no correspondence was found in percentages for a given MFLs value. For example, during 1936-1990, the MFH level of 8.0 ft NGVD was exceeded for about 34% of time, while the MFH flow of 410 cfs was exceeded only for about 10% of time.

Probability plots of annual series of data. To evaluate whether MFLs meet the established return intervals, the annual series of data for the desired duration are plotted on probability paper and the plotted data are examined at the T of interest. The procedure consists of: i) arranging data in descending order of magnitude, ii) assigning a plotting position for each data value, and iii) plotting the data on probability paper. The 1936-1990 annual series of stage and discharge data from Tables 3-6 are shown in descending order of magnitude in Tables 8-11, with their ranking. Since the data were gauged from October 1935, the month in which the reference year for low stages/discharges starts, the low stages/discharges have an extra year for plotting compared to the high

Table 8. The Wekiva River at the S.R. 46 Bridge: The Weibull plotting positions for the annual series of high stage data for different durations (Stages are in ft NGVD)

		Duration (days)								
m	PP	1	7	14	30	60	90	120	183	1 year
1	1.82	11.05	10.65	10.22	9.89	9.19	9.15	8.95	8.60	8.50
2	3.64	10.56	9.89	9.43	8.98	8.80	8.71	8.63	8.56	8.48
3	5.45	10.41	9.85	9.28	8.95	8.73	8.68	8.62	8.54	8.41
4	7.27	10.33	9.62	9.22	8.94	8.73	8.64	8.61	8.53	8.41
5	9.09	10.10	9.52	9.21	8.92	8.71	8.63	8.58	8.53	8.36
6	10.91	10.04	9.45	9.17	8.76	8.65	8.61	8.57	8.47	8.34
7	12.73	9.66	9.33	9.05	8.75	8.60	8.48	8.46	8.43	8.33
8	14.55	9.65	9.30	8.99	8.69	8.57	8.47	8.46	8.38	8.22
9	16.36	9.50	9.27	8.98	8.66	8.57	8.41	8.38	8.28	8.20
10	18.18	9.50	9.24	8.96	8.66	8.51	8.40	8.34	8.24	8.19
11	20.00	9.48	9.24	8.93	8.62	8.46	8.38	8.29	8.23	8.16
12	21.82	9.43	9.16	8.89	8.61	8.43	8.36	8.29	8.23	8.14
13	23.64	9.39	9.13	8.87	8.57	8.43	8.30	8.28	8.23	8.14
14	25.45	9.30	9.07	8.83	8.53	8.38	8.30	8.25	8.19	8.09
15	27.27	9.30	9.03	8.82	8.51	8.34	8.30	8.25	8.18	8.05
16	29.09	9.23	9.00	8.77	8.46	8.34	8.28	8.24	8.17	8.03
17	30.91	9.21	8.97	8.77	8.44	8.31	8.28	8.23	8.13	8.03
18	32.73	9.16	8.94	8.74	8.44	8.30	8.26	8.23	8.13	8.01
19	34.55	9.13	8.89	8.73	8.42	8.30	8.25	8.23	8.10	7.99
20	36.36	9.11	8.89	8.64	8.41	8.30	8.25	8.23	8.10	7.97
21	38.18	9.11	8.88	8.62	8.39	8.29	8.23	8.19	8.06	7.96
22	40.00	9.05	8.83	8.61	8.38	8.28	8.21	8.16	8.05	7.94
23	41.82	9.04	8.83	8.60	8.37	8.25	8.19	8.12	8.04	7.89
24	43.64	8.97	8.79	8.58	8.35	8.25	8.18	8.12	8.01	7.88
25	45.45	8.97	8.78	8.57	8.35	8.19	8.13	8.10	8.00	7.86
26	47.27	8.94	8.68	8.50	8.33	8.16	8.09	8.09	7.99	7.82
27	49.09	8.94	8.68	8.44	8.32	8.13	8.08	8.06	7.96	7.80
28	50.91	8.84	8.66	8.43	8.31	8.13	8.07	8.04	7.90	7.74
29	52.73	8.80	8.65	8.42	8.28	8.06	8.04	8.01	7.86	7.71
30	54.55	8.74	8.63	8.41	8.18	8.04	8.01	7.97	7.82	7.68
31	56.36	8.72	8.57	8.36	8.17	8.03	8.01	7.96	7.79	7.68
32	58.18	8.71	8.56	8.36	8.11	7.98	7.93	7.89	7.77	7.68
33	60.00	8.68	8.48	8.31	8.09	7.97	7.90	7.87	7.77	7.66
34	61.82	8.67	8.48	8.25	8.08	7.92	7.82	7.78	7.73	7.56
35	63.64	8.61	8.47	8.21	8.08	7.88	7.80	7.75	7.67	7.56
36	65.45	8.60	8.38	8.17	8.06	7.88	7.80	7.75	7.61	7.56
37	67.27	8.59	8.35	8.16	8.01	7.82	7.71	7.66	7.59	7.51
38	69.09	8.56	8.30	8.13	8.00	7.77	7.70	7.65	7.56	7.47
39	70.91	8.50	8.27	8.08	7.96	7.76	7.68	7.65	7.55	7.36
40	72.73	8.46	8.24	8.07	7.95	7.75	7.68	7.64	7.54	7.34
41	74.55	8.35	8.22	8.05	7.92	7.71	7.67	7.63	7.48	7.33
42	76.36	8.33	8.22	8.05	7.81	7.71	7.62	7.54	7.42	7.33
43	78.18	8.32	8.21	7.91	7.79	7.67	7.59	7.53	7.42	7.30
44	80.00	8.32	8.13	7.88	7.74	7.66	7.58	7.53	7.37	7.26
45	81.82	8.32	8.09	7.87	7.69	7.56	7.54	7.46	7.33	7.21
46	83.64	8.31	8.04	7.83	7.65	7.54	7.44	7.38	7.33	7.21
47	85.45	8.13	7.99	7.83	7.64	7.48	7.42	7.37	7.30	7.21
48	87.27	8.07	7.91	7.79	7.55	7.43	7.35	7.29	7.23	7.18
49	89.09	7.97	7.89	7.77	7.55	7.40	7.32	7.28	7.21	7.16
50	90.91	7.95	7.87	7.74	7.50	7.36	7.31	7.26	7.19	7.10
51	92.73	7.93	7.73	7.64	7.47	7.30	7.27	7.25	7.19	7.07
52	94.55	7.91	7.61	7.52	7.35	7.29	7.20	7.18	7.16	7.06
53	96.36	7.39	7.30	7.29	7.25	7.24	7.18	7.15	7.10	7.04
54	98.18	7.16	7.07	7.04	7.03	7.03	7.02	7.00	6.95	6.92

m = Rank; PP = m/(N + 1), where N = sample size (N = 54 for this sample, reference years 1937-1990)

Table 9. The Wekiva River at the S.R. 46 Bridge: The Weibull plotting positions for the annual series of low stage data for different durations (Stages are in ft NGVD)

		Duration (days)								
m	PP	1	7	14	30	60	90	120	183	1 year
1	98.21	8.30	8.32	8.33	8.34	8.41	8.44	8.43	8.46	8.50
2	96.43	8.26	8.29	8.31	8.32	8.35	8.38	8.40	8.41	8.49
3	94.64	8.22	8.25	8.28	8.31	8.34	8.36	8.36	8.40	8.49
4	92.86	8.08	8.10	8.14	8.15	8.16	8.18	8.19	8.24	8.31
5	91.07	8.06	8.06	8.10	8.12	8.13	8.16	8.18	8.20	8.27
6	89.29	8.04	8.05	8.06	8.08	8.13	8.15	8.16	8.18	8.25
7	87.50	7.98	8.04	8.06	8.08	8.10	8.12	8.13	8.16	8.23
8	85.71	7.97	7.99	7.99	8.06	8.07	8.10	8.12	8.15	8.22
9	83.93	7.94	7.94	7.96	8.00	8.03	8.06	8.11	8.15	8.21
10	82.14	7.92	7.92	7.94	7.99	8.00	8.04	8.08	8.12	8.19
11	80.36	7.90	7.91	7.93	7.94	7.95	7.98	8.02	8.08	8.19
12	78.57	7.88	7.91	7.92	7.93	7.95	7.96	7.99	8.02	8.17
13	76.79	7.84	7.84	7.85	7.93	7.95	7.96	7.97	8.01	8.16
14	75.00	7.82	7.82	7.82	7.83	7.86	7.88	7.91	7.98	8.12
15	73.21	7.78	7.80	7.80	7.83	7.86	7.88	7.90	7.93	8.08
16	71.43	7.78	7.78	7.80	7.83	7.84	7.87	7.90	7.92	8.06
17	69.64	7.72	7.74	7.79	7.83	7.84	7.87	7.87	7.92	8.04
18	67.86	7.72	7.73	7.75	7.78	7.79	7.86	7.86	7.91	8.04
19	66.07	7.65	7.72	7.73	7.74	7.76	7.77	7.78	7.89	8.00
20	64.29	7.64	7.64	7.65	7.66	7.68	7.69	7.77	7.87	7.99
21	62.50	7.60	7.61	7.62	7.66	7.67	7.69	7.73	7.84	7.99
22	60.71	7.47	7.48	7.49	7.50	7.56	7.61	7.71	7.81	7.98
23	58.93	7.46	7.47	7.48	7.50	7.54	7.61	7.67	7.80	7.98
24	57.14	7.45	7.46	7.48	7.50	7.54	7.60	7.65	7.75	7.97
25	55.36	7.44	7.45	7.47	7.49	7.53	7.58	7.62	7.73	7.84
26	53.57	7.43	7.45	7.45	7.48	7.52	7.57	7.62	7.72	7.83
27	51.79	7.42	7.43	7.43	7.45	7.51	7.56	7.61	7.68	7.82
28	50.00	7.36	7.39	7.41	7.44	7.51	7.56	7.61	7.68	7.81
29	48.21	7.36	7.37	7.39	7.41	7.51	7.55	7.60	7.62	7.76
30	46.43	7.33	7.34	7.35	7.38	7.50	7.54	7.54	7.58	7.75
31	44.64	7.31	7.31	7.33	7.37	7.48	7.51	7.54	7.57	7.68
32	42.86	7.27	7.31	7.32	7.33	7.43	7.44	7.48	7.56	7.67
33	41.07	7.27	7.27	7.30	7.32	7.41	7.43	7.46	7.49	7.64
34	39.29	7.24	7.25	7.28	7.31	7.40	7.42	7.44	7.46	7.62
35	37.50	7.24	7.25	7.25	7.30	7.34	7.35	7.36	7.44	7.59
36	35.71	7.22	7.23	7.24	7.28	7.32	7.33	7.35	7.41	7.55
37	33.93	7.21	7.22	7.24	7.28	7.29	7.31	7.34	7.37	7.51
38	32.14	7.19	7.22	7.24	7.26	7.29	7.31	7.32	7.35	7.50
39	30.36	7.16	7.16	7.16	7.17	7.22	7.27	7.31	7.35	7.50
40	28.57	7.13	7.13	7.13	7.15	7.16	7.18	7.19	7.33	7.42
41	26.79	7.03	7.04	7.06	7.07	7.11	7.14	7.17	7.23	7.38
42	25.00	7.02	7.03	7.04	7.05	7.08	7.11	7.15	7.22	7.35
43	23.21	7.01	7.02	7.03	7.05	7.07	7.07	7.13	7.20	7.27
44	21.43	6.99	6.99	7.01	7.04	7.05	7.07	7.10	7.17	7.27
45	19.64	6.97	6.98	7.00	7.02	7.05	7.07	7.09	7.14	7.25
46	17.86	6.96	6.96	6.98	7.01	7.04	7.06	7.08	7.10	7.21
47	16.07	6.96	6.96	6.97	6.99	7.04	7.06	7.07	7.09	7.18
48	14.29	6.94	6.96	6.96	6.98	7.01	7.03	7.03	7.07	7.14
49	12.50	6.91	6.92	6.94	6.96	7.01	7.02	7.03	7.06	7.14
50	10.71	6.88	6.91	6.91	6.93	6.98	6.99	7.00	7.04	7.12
51	8.93	6.87	6.89	6.91	6.91	6.92	6.94	6.95	7.01	7.09
52	7.14	6.84	6.85	6.86	6.89	6.91	6.93	6.94	6.97	7.09
53	5.36	6.84	6.84	6.85	6.85	6.85	6.86	6.87	6.88	7.03
54	3.57	6.78	6.79	6.79	6.79	6.80	6.81	6.82	6.86	7.03
55	1.79	6.71	6.71	6.72	6.74	6.76	6.77	6.78	6.82	6.88

m = Rank; PP = (N – m + 1)/(N + 1), where N = sample size (N = 55 for this sample, reference years 1936-1990)

Table 10. The Wekiva River at the S.R. 46 Bridge: The Weibull plotting positions for the annual series of high discharge data for different durations (Discharges are in cfs)

		Duration (days)								
m	PP	1	7	14	30	60	90	120	183	1 year
1	1.82	2060.00	1650.00	1399.29	1212.10	877.83	823.77	741.65	626.33	485.63
2	3.64	1920.00	1512.86	1096.86	755.87	599.57	559.62	531.63	524.21	432.28
3	5.45	1860.00	1394.86	1012.86	734.50	569.28	514.83	476.08	452.89	382.28
4	7.27	1580.00	1244.29	1007.79	708.13	567.03	505.64	474.67	418.13	371.77
5	9.09	1570.00	1075.71	964.86	667.67	555.25	495.16	471.70	400.77	338.37
6	10.91	1570.00	1058.86	816.29	634.90	545.68	490.84	459.39	400.48	330.85
7	12.73	1220.00	1045.00	811.29	625.77	541.70	469.53	448.82	395.25	330.60
8	14.55	1210.00	980.14	806.07	621.13	522.62	468.41	444.31	395.20	323.89
9	16.36	1140.00	978.00	786.64	605.60	499.27	468.06	428.94	381.82	319.02
10	18.18	1140.00	944.86	780.07	604.57	496.40	453.11	412.42	365.32	317.74
11	20.00	1130.00	940.14	745.29	598.80	479.27	436.06	405.19	359.55	315.17
12	21.82	1100.00	897.43	731.93	592.80	477.12	433.86	397.02	354.67	315.11
13	23.64	1090.00	845.57	724.00	578.30	475.23	433.37	395.54	354.40	313.67
14	25.45	1050.00	844.00	714.57	564.63	469.62	424.72	390.91	354.15	313.40
15	27.27	978.00	835.29	703.93	544.17	459.63	417.18	389.63	352.44	312.27
16	29.09	960.00	805.71	683.43	541.97	458.62	408.61	376.00	348.51	311.72
17	30.91	942.00	799.00	642.36	535.90	453.83	398.67	374.80	342.20	308.96
18	32.73	929.00	790.71	642.36	522.83	428.40	396.99	374.23	340.85	308.70
19	34.55	927.00	784.00	633.07	500.70	423.67	395.68	367.72	340.57	308.52
20	36.36	915.00	779.43	617.57	500.07	423.05	392.97	364.33	338.97	304.68
21	38.18	912.00	773.14	611.00	489.70	420.63	390.13	363.13	337.09	303.32
22	40.00	890.00	765.14	609.00	481.07	414.32	378.88	362.38	330.99	303.06
23	41.82	884.00	731.43	596.29	474.47	411.37	378.51	357.39	323.49	299.83
24	43.64	871.00	702.14	591.29	467.43	408.98	377.71	355.03	323.40	294.14
25	45.45	870.00	687.14	587.57	464.17	408.83	377.28	350.31	320.13	288.34
26	47.27	844.00	676.71	556.36	462.23	407.37	373.27	347.46	319.26	278.95
27	49.09	792.00	631.29	541.71	459.93	405.48	372.51	340.67	315.93	277.50
28	50.91	756.00	631.00	540.00	449.17	399.95	362.66	337.88	312.70	276.51
29	52.73	745.00	616.00	537.29	449.10	391.37	361.59	337.70	308.30	275.84
30	54.55	740.00	601.29	520.21	443.87	389.83	361.04	337.38	306.25	272.00
31	56.36	724.00	598.29	514.71	428.73	380.98	356.71	332.98	301.84	271.31
32	58.18	722.00	587.14	504.86	425.70	366.27	348.47	331.19	301.68	271.07
33	60.00	717.00	583.29	493.57	425.43	366.22	343.34	322.63	301.55	268.55
34	61.82	711.00	574.86	485.86	414.60	365.53	341.99	318.22	300.26	266.39
35	63.64	707.00	571.86	478.57	413.90	353.33	333.09	313.38	296.87	260.21
36	65.45	689.00	563.14	473.79	406.00	344.67	326.70	313.35	296.24	257.47
37	67.27	673.00	559.71	473.57	405.57	344.25	325.49	312.55	293.61	254.29
38	69.09	670.00	549.86	464.79	381.10	342.67	324.28	311.17	292.97	251.94
39	70.91	658.00	542.86	462.86	376.07	340.55	323.89	310.03	292.88	248.65
40	72.73	657.00	536.86	452.29	374.53	338.08	319.97	305.30	288.95	247.38
41	74.55	609.00	523.86	435.14	372.50	331.83	319.77	297.42	276.62	246.94
42	76.36	594.00	517.00	434.86	369.90	330.87	313.18	295.48	274.46	242.37
43	78.18	592.00	513.14	431.50	368.40	320.55	293.82	294.00	266.87	241.34
44	80.00	570.00	511.57	422.57	359.57	308.30	288.73	280.85	265.16	241.10
45	81.82	549.00	471.43	420.79	356.27	301.33	286.02	273.71	264.08	240.19
46	83.64	541.00	469.71	407.07	352.37	295.48	283.94	270.00	254.67	237.89
47	85.45	511.00	466.14	403.36	340.33	286.17	272.90	267.72	254.30	233.25
48	87.27	490.00	446.00	399.29	331.20	283.20	269.50	267.16	244.32	229.97
49	89.09	482.00	436.29	391.21	329.50	282.25	264.13	253.28	243.96	229.82
50	90.91	467.00	431.43	389.79	314.43	281.72	258.22	249.29	238.27	227.76
51	92.73	380.00	326.14	317.86	297.93	275.78	257.09	244.86	234.73	221.56
52	94.55	338.00	313.00	306.86	295.93	264.98	255.47	243.52	233.52	212.45
53	96.36	321.00	283.57	281.57	269.27	260.97	252.42	239.08	219.75	211.00
54	98.18	275.00	248.57	240.43	233.60	227.27	225.17	225.63	216.37	209.71

m = Rank; PP = m/(N + 1), where N = sample size (N = 54 for this sample, reference years 1937-1990)

Table 11. The Wekiva River at the S.R. 46 Bridge: The Weibull plotting positions for the annual series of low discharge data for different durations (Discharges are in cfs)

		Duration (days)								
m	PP	1	7	14	30	60	90	120	183	1 year
1	98.21	255.00	256.86	258.36	266.80	282.35	284.32	311.62	380.95	454.11
2	96.43	249.00	251.57	254.57	259.30	275.57	280.61	292.06	342.55	412.80
3	94.64	236.00	238.43	243.07	255.63	275.12	278.66	287.77	323.67	370.15
4	92.86	232.00	234.29	236.93	241.20	272.23	276.67	284.09	313.89	362.53
5	91.07	228.00	230.00	231.86	236.73	264.68	273.72	277.60	311.02	357.40
6	89.29	223.00	227.14	229.79	234.77	255.23	269.31	268.47	300.83	350.77
7	87.50	217.00	220.29	226.29	230.33	250.95	258.47	266.28	295.67	350.39
8	85.71	216.00	219.00	220.43	229.37	244.73	248.13	259.35	295.60	336.76
9	83.93	216.00	216.86	218.14	227.67	243.33	247.24	257.04	290.87	321.20
10	82.14	212.00	216.00	218.07	223.83	239.25	246.81	256.57	289.65	321.09
11	80.36	212.00	213.86	217.07	222.43	234.65	241.72	255.34	288.20	317.16
12	78.57	212.00	213.71	216.86	221.10	233.83	240.44	254.47	278.49	313.14
13	76.79	210.00	212.71	215.71	219.33	230.62	239.28	249.48	278.40	310.71
14	75.00	208.00	210.86	214.64	218.43	228.87	237.40	247.37	274.05	309.26
15	73.21	202.00	210.57	212.21	216.47	227.25	236.68	247.18	273.56	308.55
16	71.43	201.00	206.43	212.14	215.57	226.02	235.52	242.75	268.21	307.24
17	69.64	199.00	206.14	210.50	214.73	224.82	235.22	241.48	266.80	306.62
18	67.86	198.00	203.43	207.00	214.30	224.00	234.27	239.79	257.42	300.06
19	66.07	198.00	202.00	206.57	213.57	222.68	234.21	238.95	256.30	296.77
20	64.29	196.00	200.14	204.21	210.20	222.48	232.40	236.84	252.79	292.23
21	62.50	196.00	199.71	204.00	208.90	220.13	230.87	234.88	251.50	289.33
22	60.71	196.00	199.14	203.14	208.17	219.30	222.59	233.09	250.95	289.33
23	58.93	196.00	197.71	200.36	206.47	217.18	222.06	233.07	250.19	287.57
24	57.14	195.00	197.71	200.29	205.67	216.77	221.08	226.05	248.88	287.54
25	55.36	194.00	196.86	199.71	204.17	213.37	220.83	225.99	247.50	285.14
26	53.57	193.00	195.29	199.36	202.50	211.92	220.14	225.29	247.48	281.81
27	51.79	192.00	194.71	198.29	201.60	210.32	219.86	225.00	246.09	281.33
28	50.00	191.00	194.71	195.50	201.23	208.68	215.07	223.39	245.93	278.69
29	48.21	191.00	193.86	195.43	201.10	208.05	213.24	223.38	239.60	278.46
30	46.43	188.00	191.43	195.14	200.50	207.80	211.69	222.15	235.73	277.52
31	44.64	186.00	190.29	195.14	197.80	207.45	211.02	220.29	231.60	275.18
32	42.86	185.00	190.00	194.29	196.47	206.80	210.83	220.12	228.04	272.98
33	41.07	185.00	188.29	192.57	195.93	203.80	210.44	217.02	227.63	271.99
34	39.29	185.00	186.14	191.71	195.10	203.73	210.28	216.51	225.73	270.00
35	37.50	180.00	184.29	188.29	193.33	202.40	210.13	215.50	224.49	267.43
36	35.71	179.00	184.14	188.00	192.20	201.18	209.43	214.73	222.35	266.85
37	33.93	178.00	183.71	187.14	190.40	195.55	207.24	213.27	220.87	264.62
38	32.14	177.00	183.57	187.00	190.00	193.87	206.66	213.02	219.69	258.38
39	30.36	174.00	182.86	186.71	189.33	193.30	206.24	212.70	218.85	256.93
40	28.57	174.00	182.29	186.36	188.47	193.27	201.80	207.23	218.56	253.05
41	26.79	173.00	181.43	184.86	187.80	192.13	200.03	205.48	216.72	252.41
42	25.00	172.00	178.57	182.00	185.03	192.02	199.78	205.39	215.33	245.61
43	23.21	172.00	175.86	180.57	183.07	191.12	199.37	204.74	215.16	245.54
44	21.43	171.00	175.29	178.29	182.63	191.12	195.10	203.94	214.30	240.53
45	19.64	170.00	173.57	176.79	182.10	188.68	194.12	202.18	212.12	240.08
46	17.86	169.00	173.14	174.79	180.80	187.87	194.00	198.97	209.86	236.98
47	16.07	167.00	169.86	174.29	180.80	186.97	193.78	196.73	208.93	236.18
48	14.29	166.00	169.14	173.07	179.57	184.12	191.44	195.03	208.25	235.57
49	12.50	165.00	168.29	171.50	176.40	182.73	190.68	192.70	201.99	234.79
50	10.71	162.00	167.71	171.43	175.67	181.72	186.42	191.57	201.88	233.84
51	8.93	156.00	165.71	169.86	170.67	178.33	182.51	184.07	201.03	233.07
52	7.14	145.00	161.43	167.21	170.30	171.35	175.24	180.05	192.34	224.98
53	5.36	141.00	152.57	161.57	165.17	166.85	174.90	180.02	189.04	222.35
54	3.57	129.00	152.14	153.43	158.20	166.50	172.88	177.38	184.66	210.86
55	1.79	105.00	105.00	108.86	125.63	157.58	159.98	166.48	180.00	203.22

m = Rank; PP = (N − m + 1)/(N + 1), where N = sample size (N = 55 for this sample, reference years 1936-1990) stages/discharges. The plotting position (PP) for each data value is computed by the Weibull formula, which is the most commonly used formula for these analyses. Chow (1964) discusses at length various PP formulas available, and comments on their merits. If N is the total number of values in a data sample, and m is the rank of the data value, then the Weibull formula can be written as, PP = m/(N + 1) for high stages/discharges; for low stages/discharges, the data would plot in an opposite order of high values and the plotting position formula would become, PP = (N – m + 1)/(N + 1). PP indicates annual exceedance probability for high stages/discharges, and annual non-exceedance probability for low stages/discharges. The PP values are shown as percents in Tables 8-11. Chow (1964) states that all methods of determining plotting positions give practically the same results in the middle of a distribution but produce different positions near the "tails" of the distribution. The return interval of 100 years or greater for the MIL level lies in the lower tail of a distribution, therefore, other PP formulas may be more appropriate for that particular level and will be evaluated.

Using the data presented in Tables 8-11, probability plots were produced for the five MFLs given in Table 1 by Grapher 6 software. Figures 6-10 are the five MFLs graphs for stages, and Figures 11-15 are for discharges. These figures have three basic graphical features that facilitate MFLs evaluation: i) a horizontal line indicating the established minimum level/discharge value, ii) data points representing the annual series of data, and iii) a vertical line that corresponds to the probability of the set T through which the data should plot to meet the established MFLs. The second and third features are further explained in the following.

The data series plotted. Table 1 gives durations and return intervals established for Wekiva River MFLs, which should be met to preserve the current ecological conditions of the system. The durations that are to be met are limiting durations; lower limits for the MIH and the MFH and upper limits for the MA, MFL, and MIL. Annual series of data (arranged in order) corresponding to these limiting durations can be found in Tables 8-11. Data for the limiting durations are plotted in developing MFLs graphs (Figures 6-15).

The probability line: Figures 6-15 show a probability line running upward from the horizontal line of the established minimum level/discharge. Like durations, the Ts shown in Table 1 also are limiting values; upper limits for MIH and MFH, and lower limits for MA, MFL, and MIL. The vertical lines shown in Figures 6-15 correspond to the limiting Ts shown in Table 1. If data plot through the vertical line, it is an indication that the data have a T satisfying the set limit for T, and thus the MFLs are met.

The probability plots provide additional information such as, a) the actual T of data for the set duration. This is the point where a line drawn through the plotted data intersects the horizontal line plot of the established minimum stage/discharge, and; b) actual duration of data with the set T. For example, in Figure 6 (for MIH), a line drawn through the plotted data points (7-day duration time series) intersects the MIH line of 9.0 ft at about 30% exceedance probability level, or T = 3.33 years, which is the actual T; this T is less than the set T of 5 years for MIH (Table 1). Further, the data intersect the vertical probability line at about 9.2 ft NGVD, which means there is some 'free board.'

Table 12. The Wekiva River at the S.R. 46 Bridge: The Hazen plotting positions for the annual series of low stage data for different durations (Stages are in ft NGVD)

		Duration (days)								
m	PP	1	7	14	30	60	90	120	183	1 year
1	99.09	8.30	8.32	8.33	8.34	8.41	8.44	8.43	8.46	8.50
2	97.27	8.26	8.29	8.31	8.32	8.35	8.38	8.40	8.41	8.49
3	95.45	8.22	8.25	8.28	8.31	8.34	8.36	8.36	8.40	8.49
4	93.64	8.08	8.10	8.14	8.15	8.16	8.18	8.19	8.24	8.31
5	91.82	8.06	8.06	8.10	8.12	8.13	8.16	8.18	8.20	8.27
6	90.00	8.04	8.05	8.06	8.08	8.13	8.15	8.16	8.18	8.25
7	88.18	7.98	8.04	8.06	8.08	8.10	8.12	8.13	8.16	8.23
8	86.36	7.97	7.99	7.99	8.06	8.07	8.10	8.12	8.15	8.22
9	84.55	7.94	7.94	7.96	8.00	8.03	8.06	8.11	8.15	8.21
10	82.73	7.92	7.92	7.94	7.99	8.00	8.04	8.08	8.12	8.19
11	80.91	7.90	7.91	7.93	7.94	7.95	7.98	8.02	8.08	8.19
12	79.09	7.88	7.91	7.92	7.93	7.95	7.96	7.99	8.02	8.17
13	77.27	7.84	7.84	7.85	7.93	7.95	7.96	7.97	8.01	8.16
14	75.45	7.82	7.82	7.82	7.83	7.86	7.88	7.91	7.98	8.12
15	73.64	7.78	7.80	7.80	7.83	7.86	7.88	7.90	7.93	8.08
16	71.82	7.78	7.78	7.80	7.83	7.84	7.87	7.90	7.92	8.06
17	70.00	7.72	7.74	7.79	7.83	7.84	7.87	7.87	7.92	8.04
18	68.18	7.72	7.73	7.75	7.78	7.79	7.86	7.86	7.91	8.04
19	66.36	7.65	7.72	7.73	7.74	7.76	7.77	7.78	7.89	8.00
20	64.55	7.64	7.64	7.65	7.66	7.68	7.69	7.77	7.87	7.99
21	62.73	7.60	7.61	7.62	7.66	7.67	7.69	7.73	7.84	7.99
22	60.91	7.47	7.48	7.49	7.50	7.56	7.61	7.71	7.81	7.98
23	59.09	7.46	7.47	7.48	7.50	7.54	7.61	7.67	7.80	7.98
24	57.27	7.45	7.46	7.48	7.50	7.54	7.60	7.65	7.75	7.97
25	55.45	7.44	7.45	7.47	7.49	7.53	7.58	7.62	7.73	7.84
26	53.64	7.43	7.45	7.45	7.48	7.52	7.57	7.62	7.72	7.83
27	51.82	7.42	7.43	7.43	7.45	7.51	7.56	7.61	7.68	7.82
28	50.00	7.36	7.39	7.41	7.44	7.51	7.56	7.61	7.68	7.81
29	48.18	7.36	7.37	7.39	7.41	7.51	7.55	7.60	7.62	7.76
30	46.36	7.33	7.34	7.35	7.38	7.50	7.54	7.54	7.58	7.75
31	44.55	7.31	7.31	7.33	7.37	7.48	7.51	7.54	7.57	7.68
32	42.73	7.27	7.31	7.32	7.33	7.43	7.44	7.48	7.56	7.67
33	40.91	7.27	7.27	7.30	7.32	7.41	7.43	7.46	7.49	7.64
34	39.09	7.24	7.25	7.28	7.31	7.40	7.42	7.44	7.46	7.62
35	37.27	7.24	7.25	7.25	7.30	7.34	7.35	7.36	7.44	7.59
36	35.45	7.22	7.23	7.24	7.28	7.32	7.33	7.35	7.41	7.55
37	33.64	7.21	7.22	7.24	7.28	7.29	7.31	7.34	7.37	7.51
38	31.82	7.19	7.22	7.24	7.26	7.29	7.31	7.32	7.35	7.50
39	30.00	7.16	7.16	7.16	7.17	7.22	7.27	7.31	7.35	7.50
40	28.18	7.13	7.13	7.13	7.15	7.16	7.18	7.19	7.33	7.42
41	26.36	7.03	7.04	7.06	7.07	7.11	7.14	7.17	7.23	7.38
42	24.55	7.02	7.03	7.04	7.05	7.08	7.11	7.15	7.22	7.35
43	22.73	7.01	7.02	7.03	7.05	7.07	7.07	7.13	7.20	7.27
44	20.91	6.99	6.99	7.01	7.04	7.05	7.07	7.10	7.17	7.27
45	19.09	6.97	6.98	7.00	7.02	7.05	7.07	7.09	7.14	7.25
46	17.27	6.96	6.96	6.98	7.01	7.04	7.06	7.08	7.10	7.21
47	15.45	6.96	6.96	6.97	6.99	7.04	7.06	7.07	7.09	7.18
48	13.64	6.94	6.96	6.96	6.98	7.01	7.03	7.03	7.07	7.14
49	11.82	6.91	6.92	6.94	6.96	7.01	7.02	7.03	7.06	7.14
50	10.00	6.88	6.91	6.91	6.93	6.98	6.99	7.00	7.04	7.12
51	8.18	6.87	6.89	6.91	6.91	6.92	6.94	6.95	7.01	7.09
52	6.36	6.84	6.85	6.86	6.89	6.91	6.93	6.94	6.97	7.09
53	4.55	6.84	6.84	6.85	6.85	6.85	6.86	6.87	6.88	7.03
54	2.73	6.78	6.79	6.79	6.79	6.80	6.81	6.82	6.86	7.03
55	0.91	6.71	6.71	6.72	6.74	6.76	6.77	6.78	6.82	6.88

m = Rank; PP = 1-(2m - 1)/2N, where N = sample size (N = 55 for this sample)

Table 13. The Wekiva River at the S.R. 46 Bridge: The Hazen plotting positions for the annual series of low discharge data for different durations (Discharges are in cfs)

		Duration (days)								
m	PP	1	7	14	30	60	90	120	183	1 year
1	99.09	255.00	256.86	258.36	266.80	282.35	284.32	311.62	380.95	454.11
2	97.27	249.00	251.57	254.57	259.30	275.57	280.61	292.06	342.55	412.80
3	95.45	236.00	238.43	243.07	255.63	275.12	278.66	287.77	323.67	370.15
4	93.64	232.00	234.29	236.93	241.20	272.23	276.67	284.09	313.89	362.53
5	91.82	228.00	230.00	231.86	236.73	264.68	273.72	277.60	311.02	357.40
6	90.00	223.00	227.14	229.79	234.77	255.23	269.31	268.47	300.83	350.77
7	88.18	217.00	220.29	226.29	230.33	250.95	258.47	266.28	295.67	350.39
8	86.36	216.00	219.00	220.43	229.37	244.73	248.13	259.35	295.60	336.76
9	84.55	216.00	216.86	218.14	227.67	243.33	247.24	257.04	290.87	321.20
10	82.73	212.00	216.00	218.07	223.83	239.25	246.81	256.57	289.65	321.09
11	80.91	212.00	213.86	217.07	222.43	234.65	241.72	255.34	288.20	317.16
12	79.09	212.00	213.71	216.86	221.10	233.83	240.44	254.47	278.49	313.14
13	77.27	210.00	212.71	215.71	219.33	230.62	239.28	249.48	278.40	310.71
14	75.45	208.00	210.86	214.64	218.43	228.87	237.40	247.37	274.05	309.26
15	73.64	202.00	210.57	212.21	216.47	227.25	236.68	247.18	273.56	308.55
16	71.82	201.00	206.43	212.14	215.57	226.02	235.52	242.75	268.21	307.24
17	70.00	199.00	206.14	210.50	214.73	224.82	235.22	241.48	266.80	306.62
18	68.18	198.00	203.43	207.00	214.30	224.00	234.27	239.79	257.42	300.06
19	66.36	198.00	202.00	206.57	213.57	222.68	234.21	238.95	256.30	296.77
20	64.55	196.00	200.14	204.21	210.20	222.48	232.40	236.84	252.79	292.23
21	62.73	196.00	199.71	204.00	208.90	220.13	230.87	234.88	251.50	289.33
22	60.91	196.00	199.14	203.14	208.17	219.30	222.59	233.09	250.95	289.33
23	59.09	196.00	197.71	200.36	206.47	217.18	222.06	233.07	250.19	287.57
24	57.27	195.00	197.71	200.29	205.67	216.77	221.08	226.05	248.88	287.54
25	55.45	194.00	196.86	199.71	204.17	213.37	220.83	225.99	247.50	285.14
26	53.64	193.00	195.29	199.36	202.50	211.92	220.14	225.29	247.48	281.81
27	51.82	192.00	194.71	198.29	201.60	210.32	219.86	225.00	246.09	281.33
28	50.00	191.00	194.71	195.50	201.23	208.68	215.07	223.39	245.93	278.69
29	48.18	191.00	193.86	195.43	201.10	208.05	213.24	223.38	239.60	278.46
30	46.36	188.00	191.43	195.14	200.50	207.80	211.69	222.15	235.73	277.52
31	44.55	186.00	190.29	195.14	197.80	207.45	211.02	220.29	231.60	275.18
32	42.73	185.00	190.00	194.29	196.47	206.80	210.83	220.12	228.04	272.98
33	40.91	185.00	188.29	192.57	195.93	203.80	210.44	217.02	227.63	271.99
34	39.09	185.00	186.14	191.71	195.10	203.73	210.28	216.51	225.73	270.00
35	37.27	180.00	184.29	188.29	193.33	202.40	210.13	215.50	224.49	267.43
36	35.45	179.00	184.14	188.00	192.20	201.18	209.43	214.73	222.35	266.85
37	33.64	178.00	183.71	187.14	190.40	195.55	207.24	213.27	220.87	264.62
38	31.82	177.00	183.57	187.00	190.00	193.87	206.66	213.02	219.69	258.38
39	30.00	174.00	182.86	186.71	189.33	193.30	206.24	212.70	218.85	256.93
40	28.18	174.00	182.29	186.36	188.47	193.27	201.80	207.23	218.56	253.05
41	26.36	173.00	181.43	184.86	187.80	192.13	200.03	205.48	216.72	252.41
42	24.55	172.00	178.57	182.00	185.03	192.02	199.78	205.39	215.33	245.61
43	22.73	172.00	175.86	180.57	183.07	191.12	199.37	204.74	215.16	245.54
44	20.91	171.00	175.29	178.29	182.63	191.12	195.10	203.94	214.30	240.53
45	19.09	170.00	173.57	176.79	182.10	188.68	194.12	202.18	212.12	240.08
46	17.27	169.00	173.14	174.79	180.80	187.87	194.00	198.97	209.86	236.98
47	15.45	167.00	169.86	174.29	180.80	186.97	193.78	196.73	208.93	236.18
48	13.64	166.00	169.14	173.07	179.57	184.12	191.44	195.03	208.25	235.57
49	11.82	165.00	168.29	171.50	176.40	182.73	190.68	192.70	201.99	234.79
50	10.00	162.00	167.71	171.43	175.67	181.72	186.42	191.57	201.88	233.84
51	8.18	156.00	165.71	169.86	170.67	178.33	182.51	184.07	201.03	233.07
52	6.36	145.00	161.43	167.21	170.30	171.35	175.24	180.05	192.34	224.98
53	4.55	141.00	152.57	161.57	165.17	166.85	174.90	180.02	189.04	222.35
54	2.73	129.00	152.14	153.43	158.20	166.50	172.88	177.38	184.66	210.86
55	0.91	105.00	105.00	108.86	125.63	157.58	159.98	166.48	180.00	203.22

m = Rank; PP = 1-(2m – 1)/2N, where N = sample size (N = 55 for this sample)

MFLs evaluation with the 1936-1990 USGS (WY) data

Stages. Figures 6-10 are the probability plots of annual series of stage data using the Weibull formula for the five MFLs (Table 1). The data plot through the vertical T line for the MIH, MFH, MA, and the MFL levels, and thus the required Ts are satisfied for these four MFLs. For the MIL level, the data do not plot deep into the lower tail level by the Weibull formula, because the sample size (N = 55) is much less than the established T of 100 years. The lowest stage is 6.71 ft NGVD, and the Weibull PP for this stage is 1.79% (Rank, m = 55). Chow (1964) presents eight PP formulas and reviewing these formulas showed that the Hazen formula would give the lowest PP for low stages/discharges, with a value of 0.91% (i.e., annual non-exceedance probability) for m = 55 (Tables 12-13). The Hazen formula has the form, PP = 1 – (2m – 1)/2N for low stages/discharges. A probability plot of stage data with the Hazen plotting positions takes the lowest stage value to the other side of the probability line (Figure16), thus meeting the MFLs requirement. Also, the Hazen lower tail plots smoothly compared to the Weibull plot (Figure 10). For the established MIL of 6.1 ft NGVD, Hupalo et al. (1994) determined T > 500 years by log Pearson analysis, which is supported by Figure 16.

Discharges. Figures 11-15 are the probability plots of annual series of discharge data using the Weibull formula for the five MFLs (Table 1). The data plot through the vertical T line for the MIH, MFH, MA, and the MFL discharges, and thus the required Ts are met for these four MFLs. For the MIL discharge, the data do not plot deep into the lower tail by the Weibull formula, as it occurred with the MIL level. A probability plot of data for the MIL with Hazen plotting positions did not plot the lower tail as smoothly as stages (Figure 17). The lowest data value of 105 cfs may be regarded as an outlier since it is far removed from the next higher 7-day low discharge of 152 cfs (Table 13). The data are re-plotted by assigning a value of T = 500 years for the lowest discharge, and keeping the Hazen PPs for the rest of the data (Figure 18). With this adjustment, the lower tail of the plotted data appears to be smoother, the lowest data point conforming more to the data trend. A line plotted through the lower tail of data points now passes through the probability line, thus meeting the MIL requirement.

Summary. All of the established MFLs (levels and discharges) for the Wekiva River at S.R. 46 Bridge are met based on a graphical evaluation of the USGS streamflow data for 1936-1990 WYs. Hupalo et al. (1994) previously showed that the MFLs were met by LP frequency analysis. The stage data for 1936-1990, however, appear to be non-homogeneous with permanent shifts occurring in the recorded stages during specific time periods (i.e., 1957, 1973, and 1990). It is likely that some of the MFLs may not have been met during these specific periods.

MFLs evaluation with the 1936-2004 USGS (WY) data

Stage/discharge hydrographs, and duration curves. Figures 19 and 20 present the daily stage and discharge hydrographs, respectively, for the 1935-2004 period. For 1935 Calendar year, data were available only from October 1st. In the previous section, mention has been made that shifts in low stages occurred around the years of 1957, 1973, and 1990.

Since these stage shifts occurred in specific years, they appear to be the result of some disturbances in channel geometry at about the period of these years rather than a gradual erosion of the channel bed. From Figure 19, one can observe four distinct periods that appear to have more-or-less uniform channel geometry: 1936-1956, 1957-1972, 1973-1989, and 1990-2004. The discharges (Figure 20), however, do not show any specific trend; therefore, the falling stages could be the result of only the riverbed/cross-section and vegetation (channel roughness) changes, as described earlier. The higher low stages that occurred in the earlier periods were never recovered, thus the shifts that occurred in the channel geometry and other conditions appear to be permanent.

Stage-duration curves for the aforementioned four periods (Figure 21) indicate that stages have fallen by about 0.5 ft between the periods 1936-1956 and 1957-1972, and again between 1957-1972 and 1973-1989. A minor downward shift of less than 0.25 ft occurred between the periods 1973-1989 and 1990-2004; based on these observations, it may be viewed that the stage data for the 1973-2004 is more-or-less homogeneous, while the prior data differs substantially from this period. Discharge-duration curves for the same four periods (Figures 22 and 23) give inconsistent results; that is, discharges that occurred in these periods were not commensurate with stages. For the period of 1936-1956, when the stages were higher, the discharges were the lowest of the four periods. The 1957-1972 duration curve has the highest of all discharges. For the period of 1990-2004, which has the lowest stages of the four periods in the 8 to 100-percentile range, the discharges were next to the highest for the discharges above 250 cfs, and then diminish, becoming similar to the 1936-1956 period for discharges below 200 cfs. From these results, it may be concluded that, in general, there was no correspondence between stages and discharges over the period of record, and this should be taken into consideration in evaluating MFLs.

The Ocklawaha River Chain of Lakes regulation and the Wekiva River basin spring flows. By analyzing the discharge data of the Ocklawaha River, Tibbals, Fulton, and Bradner (2004) showed that a substantial reduction in the surface water discharges of the Ocklawaha River occurred since the early 1960s coinciding with the higher lake levels maintained with the just then implemented lake regulation schedules. This flow reduction was attributed to the changes in the groundwater flow regime at the Ocklawaha chain of lakes: Where the Floridan potentiometric surface levels were higher than the lake levels, higher lake levels reduced the groundwater head differences, thus reducing the groundwater discharges to the lakes; where the Floridan potentiometric surface levels were lower than the lake levels, the higher lake levels increased the groundwater head differences, thus increasing discharges from the lakes into the Floridan aquifer. The net result was a loss of water to the chain of lakes. Furthermore, Tibbals believes, "Some of the 'missing' Ocklawaha River water that resulted from the maintaining of high lake stages in the Ocklawaha Chain exited Rock and Wekiva Springs (their flow increased also) and, perhaps, others that help feed the Wekiva River (Personal communication from Tibbals to Fulton, December 06, 2004, Appendix A).

To verify whether any changes occurred in the flow regime of the Wekiva River at the S.R. 46 Bridge around 1960, mass curve analyses are performed on the annual mean and annual low discharges in this study. Figure 24 is a comparison of the annual mean and annual low discharges for 1936-2004 water years. The annual low discharges comprised 40 to 90% of the annual mean discharges, indicating thereby that substantial groundwater contribution occurs. Both annual mean and annual low discharges exhibit an increasing trend of discharges. Figures 25 and 26 are the mass curves of the annual mean and annual low discharges, respectively. Both mass curves exhibited distinctly different flow regimes for the 1936-1960 and 1960-2004 periods. In both figures, the regression lines developed for the 1936-1959/1960 flow regimes are extended to 2004/2005 to indicate the deviation of the two regimes. Assuming that groundwater discharges comprise practically all of the annual low flows, the average increase in groundwater discharge for 1960-2004 is calculated as about 27.5 cfs from Figure 26 [The difference in discharge volumes of the two regimes at 2004 is 2,400 acre-ft days, which occurred over 44 years. This converts to 2400/(44x1.98) = 27.5 cfs]. By similar calculation from Figure 25, the overall mean discharge increase is obtained as about 37.5 cfs during 1960-2005, which may be the result of the increase in groundwater discharges and urbanization in the basin.

In summary, it appears indeed that the groundwater discharge contribution to the Wekiva River increased around 1960, coinciding with the implementation of the Ocklawaha Chain of Lakes regulation with higher water levels. For now, this conclusion is rather tentative, and it could only be verified by groundwater modeling. Also, how this increased groundwater contribution benefited MFLs is not specifically analyzed in this report.

An explanation that the increased post-1960 Wekiva River discharges could be due to increased groundwater discharges is also offered on the basis of the Atlantic Multidecadal Oscillation (AMO) in the following.

Atlantic Multidecadal Oscillation (AMO) and the Wekiva River discharges. During the last two decades, several studies showed a possible relation between Sea Surface Temperatures (SSTs) and rainfall occurrences in various parts of the world (The references are too many, and these are comprehensively discussed in Rao 2006, Draft). Enfield et al. (2000) showed that the warm and cool phases of the North Atlantic SSTs influence (or govern) the rainfall occurrences in the United States. For South Florida, they showed that the warm and cool phases of the SSTs coincided with higher and lower rainfall phases, respectively.

AMO is a graph of the10-year moving averages of SSTs averaged over the North Atlantic; the North Atlantic region lying between the Americas and Europe/West Africa, from the equator to 70° N Latitude (Figure 27). From literature search, Rao (2006 Draft), however, found that two of the required conditions for formation tropical storms and hurricanes are: 1) maximum SSTs should exceed 26.5° C, and 2) the oceanic region should be away from the equator at least by 300 miles. By analyzing the1854-2005 North Atlantic SST data, Rao delineated the region satisfying these conditions and named it the North Atlantic Warm Region (NAWR) (Figure 27). Rao developed Multidecadal Oscillations (MO) for both North Atlantic and NAWR using the currently available SST data (i.e., 1854-2005), and compared them to the North East Florida Index Rainfall (NEFIR) (Figure 28). AMO data are available directly from a NOAA website (updated monthly), but the NAWR data were fully developed by Rao by averaging SSTs specifically over the NAWR. For this purpose, global monthly SST data available at 2x2 Lat/Long grid from a NOAA website from 1854 to present (updated monthly) were used.

Rainfall records in North East Florida began in 1867 with Jacksonville, and the network grew to 18 stations by 1902. NEFIR is an arithmetic average of rainfall from these stations as the network grew, and NEFIR included 24 stations by 1942. The moving averages shown in Figure 28 were computed from detrended data, which are the SST and rainfall fluctuations about a trendline, similar to the trendlines shown on Figure 24. Full details of the procedures can be found in Rao (2006 Draft).

Figure 28 shows that the NAWR MO and AMO differed during the first warm and cool phases of MO, and NEFIR better agreed with the NAWR MO. The latter warm and cool phases of the AMO and NAWR MO are more-or-less concurrent. In general, the high and low rainfall phases of NEFIR broadly followed the MO, except that the second high rainfall phase did not exactly coincide with second warm MO. Figure 29 is developed for the wet season (June-November), and the high and low rainfall phases appear to be better defined for the wet season. Figures 30-31 are developed for a rainfall station closer to the Wekiva River basin, the Orlando station. In Figures 30-31, the rainfall data are the actual annual data, with the mean annual rainfall coinciding with zero line of the SST fluctuations. Orlando rainfall did not follow MO up to about the mid 1940s.

Figures 28-31 indicate that the period following 1960 is generally a low rainfall phase. The overall groundwater and surface water discharges of the Wekiva River (at the S.R. 46 Bridge), represented by the annual low flows and mean flows, respectively (Figure 24), however, do not appear to be affected by the low rainfall phase following 1960. The river exhibited a sustained increased discharge over the pre-1960 discharge. Since this contribution is not due to an increase in the post-1960 rainfall (i.e., a higher rainfall phase), it is likely that the groundwater contribution to the Wekiva River basin increased after 1960.

Probability plots and the MFLs evaluation results. Appendixes B and C present the probability plots of data, including Log Pearson (LP) fits, for stages and discharges, respectively. The return periods obtained by the LP analysis for various MFLs with the 1936-2004 USGS WY stage and discharge data are summarized in Table 14.

In Table 14, the return period to be satisfied for each MFL is shown in Column 2 (See Table 1 for the established stages, discharges, and durations for each MFL). The LP analysis with the 1936-2004 data shows that stages would not meet the required MFLs return periods for MA and MFL levels (Figures B-3 and B-4, Appendix B), marginally (In Table 14, the two values are shown in bold). Discharges comply with the established MFLs (Appendix C).

The graphical method (Appendixes B and C) shows that all of the MFLs are met except the MFL level of 7.2 ft NGVD. The MFL level misses the targeted level by about 0.15 ft. In the case of MA for stages (Figure B-3, Appendix B), the Log Pearson fit misses the

Table 14. Wekiva River at the S.R. 46 Bridge: Return periods for MFLs by LP

MFL Category (1)	Required Return Period (years) (2)	Return Period by LP for Stages (years) (3)	Return Period by LP for Discharges (years) (4)	
Minimum Infrequent High (MIH)	≤5	3.8	3.8	
Minimum Frequent High (MFH)	≤2	1.8	1.5	
Minimum Average (MA)	≥1.7	**1.6**	2.0	
Minimum Frequent Low (MFL)	≥3	**2.8**	3.8	
Minimum Infrequent Low (MIL)	≥100	> 1000	250.0	

required return period, but the plotted data satisfy the required return period. On the other hand, the Log Pearson fit passes close to the required return period than data in the case of MFL for stages (Figure B-4, Appendix B). In general, Riggs (1972) recommends considering graphical curve as the basic frequency curve for low flow analysis. Also, in the case low return periods (for all MFLs except MIL, Table 14), the graphical plot may be preferred because the distribution of data better describes the nature of flow occurrences at these return periods, and a theoretical fit like Log Pearson may not pass through the data satisfactorily.

Summary and additional comments. An evaluation of MFLs based on the1936-2004 USGS streamflow data for the Wekiva River at S.R. 46 Bridge shows that all of the MFLs for discharges are met, but two of the MFLs for stages (MA and MFL) are not met ***marginally***. Since the MFLs stages were met with the 1936-1990 data, but not met with the 1936-2004 data, it seems obvious that the lower low water levels that occurred during the additional data period (i.e., 1991-2004) were responsible for the latter result. Furthermore, because the higher low water levels that occurred during the early period of record (1936-1972) were not recovered, the future low water levels would tend to be similar to those that occurred during 1991-2004, and MFLs evaluations in the future would give results either similar to those with 1936-2004 data, or not meeting some of the additional MFLs.

The 1936-1990 data sample (N = 55) that was used by Hupalo et al. (1994) for various analyses in establishing MFLs for the Wekiva River at the S.R. 46 Bridge included 18 years (33%) of data with relatively lower low-stages (1973-1990), while the 1936-2004 data sample (N = 69) included 32 years (46%) of lower low-stages (1973-2004). Thus, the effect of relatively higher low stages is predominant on the hydrologic statistics derived from the 1936-1990 data sample, hence on the MFLs evaluation.

THE WEKIVA RIVER AT OLD R.R. CROSSING NEAR SANFORD

A new streamflow gauging station was established in July 1995 on the Wekiva River at about 1.6 miles upstream of the S.R. 46 Bridge at an abandoned Rail Road crossing. The USGS designates this station as "Wekiva River at Old R.R. Crossing near Sanford." It will be referred to as "Old RR Crossing" for brevity in this report. The USGS rates records at this station as "good," which means about 95% of the daily discharges reported are within 10% of their true values. The drainage area at this station is 185 sq. mi., about 4 sq. mi. less than the drainage area at the S.R. 46 Bridge gauging station. The following sections present some comparisons of the discharge and stage data for the S.R. 46 and the Old RR Crossing gauging stations, and comments on suitability of the Old RR Crossing station as a future MFLs location.

Discharge and stage data analyses

Figures 32 and 33 present discharge and stage hydrographs, respectively, and Figures 34 and 35 discharge-duration and stage-duration curves, respectively, comparing data for concurrent periods for the gauges at the Old RR Crossing and the S.R. 46 Bridge. In Figure 36, the differences in daily discharges between the two gauges are plotted against daily discharges at the Old RR Crossing; Figure 37 gives similar plot for stages. Tables 15-16 present the mean low and high discharges, respectively, and Tables 17-18 present the mean low and high stages, respectively, for the concurrent periods of the two gauges. The following is a discussion of these results.

Discharges. The daily discharges ranged from 120 to 1,070 cfs at the Old RR Crossing and 150 to 1,160 cfs at the S.R. 46 Bridge (Tables 15-16). The mean discharge at S.R. 46 Bridge for the eight-year period, 1996-2003, exceeds the mean discharge at the Old RR station by 43.44 cfs or 16.5% (Table 15; the one year values in this table are the water-year means). For individual water years, the differences in mean discharges are in the range of 29.41 (8%; 1996) to 64.86 (21%; 1998) cfs. On a daily basis, in general, the differences in discharges between the Old RR Crossing and the S.R. 46 Bridge are higher for peak events (Figure 32). There is no well-defined correlation, however, between the discharge differences and the Old RR Crossing discharges (Figure 36). Discharge-duration curves for the two gauges for the calendar years 1996-2003 (Figure 34) indicate an average difference of about 50 cfs between the two gauges for 95% of time, or when discharges at the Old RR Crossing are below 540 cfs.

Table 15. Mean low discharges for the Wekiva River at the Old RR Crossing and the S.R. 46 Bridge (1996-2003 Water Years)

The Wekiva River at the Old RR Crossing: Discharges (cfs)

LOWEST MEAN VALUES FOR THE FOLLOWING NUMBER OF CONSECUTIVE DAYS IN YEAR ENDING SEPT 30									
YEAR	1	7	14	30	60	90	120	183	1 YEAR
1996	235.00	240.43	247.71	262.73	275.15	300.81	299.82	328.80	352.45
1997	157.00	160.00	164.21	167.23	169.23	173.56	176.43	188.85	223.59
1998	170.00	171.14	172.93	181.47	198.45	209.53	216.57	234.39	302.72
1999	149.00	151.43	154.07	161.40	165.15	168.84	173.19	185.15	221.56
2000	131.00	135.14	135.36	136.83	141.40	146.29	151.10	155.63	204.04
2001	120.00	121.43	125.00	127.90	130.52	134.26	137.68	139.21	182.51
2002	136.06	138.65	142.83	147.46	152.96	153.21	165.36	176.05	259.16
2003	209.37	211.73	217.25	222.15	234.95	304.15	302.63	323.23	353.83
MEAN	163.43	166.24	169.92	175.90	183.48	198.83	202.85	216.41	262.48
MAX	235.00	240.43	247.71	262.73	275.15	304.15	302.63	328.80	353.83
MIN	120.00	121.43	125.00	127.90	130.52	134.26	137.68	139.21	182.51

The Wekiva River at the S.R. 46 Bridge: Discharges (cfs)

LOWEST MEAN VALUES FOR THE FOLLOWING NUMBER OF CONSECUTIVE DAYS IN YEAR ENDING SEPT 30									
YEAR	1	7	14	30	60	90	120	183	1 YEAR
1996	241.00	252.00	260.43	286.53	297.75	330.64	325.78	361.42	381.86
1997	210.00	212.14	213.29	224.40	232.00	234.70	235.67	240.27	270.98
1998	223.00	224.57	226.36	235.23	255.95	264.46	273.33	281.47	367.58
1999	173.00	175.14	178.21	183.87	187.58	194.80	200.33	211.08	253.90
2000	164.00	170.29	171.79	176.23	176.75	179.76	181.08	184.27	245.57
2001	150.00	152.43	153.86	158.53	171.88	182.11	182.48	185.31	227.96
2002	186.00	187.43	188.14	190.63	195.07	197.53	210.23	221.14	293.71
2003	250.00	253.29	259.43	263.23	278.80	323.82	351.98	368.02	405.80
MEAN	199.62	203.41	206.44	214.83	224.47	238.48	245.11	256.62	305.92
MAX	250.00	253.29	260.43	286.53	297.75	330.64	351.98	368.02	405.80
MIN	150.00	152.43	153.86	158.53	171.88	179.76	181.08	184.27	227.96

Table 16. Mean high discharges for the Wekiva River at the Old RR Crossing and the S.R. 46 Bridge (1996-2004 reference years)

The Wekiva River at the Old RR Crossing: Discharges (cfs)

HIGHEST MEAN VALUES FOR THE FOLLOWING NUMBER OF CONSECUTIVE DAYS IN YEAR ENDING MAY 31									
YEAR	**1**	**7**	**14**	**30**	**60**	**90**	**120**	**183**	**1 YEAR**
1996	1070.00	893.00	737.43	577.83	505.82	477.06	442.32	412.87	372.22
1997	779.00	667.43	534.50	402.70	356.77	325.98	334.40	310.31	253.04
1998	866.00	802.14	714.71	601.57	489.55	482.57	459.75	380.18	297.42
1999	519.00	465.00	403.57	341.33	296.23	272.93	264.33	246.10	216.37
2000	774.00	667.29	610.93	514.77	416.50	349.40	319.76	292.06	234.20
2001	293.00	241.86	221.00	204.63	185.45	179.53	172.35	163.54	150.97
2002	968.00	751.57	575.43	421.43	335.37	300.88	276.86	252.81	210.63
2003	728.52	683.14	612.61	575.49	489.47	466.63	421.66	396.09	347.79
2004	795.78	677.69	559.15	529.38	485.87	468.51	427.76	392.62	306.95
MEAN	754.81	649.90	552.15	463.24	395.67	369.28	346.58	316.29	265.51
MAX	1070.00	893.00	737.43	601.57	505.82	482.57	459.75	412.87	372.22
MIN	293.00	241.86	221.00	204.63	185.45	179.53	172.35	163.54	150.97

The Wekiva River at the S.R. 46 Bridge: Discharges (cfs)

HIGHEST MEAN VALUES FOR THE FOLLOWING NUMBER OF CONSECUTIVE DAYS IN YEAR ENDING MAY 31									
YEAR	**1**	**7**	**14**	**30**	**60**	**90**	**120**	**183**	**1 YEAR**
1996	1160.00	988.86	803.21	637.53	536.65	501.17	465.05	438.66	396.13
1997	886.00	769.14	613.71	450.40	398.33	362.98	370.04	345.77	296.29
1998	1040.00	990.00	876.07	727.60	582.80	581.97	549.50	458.44	358.02
1999	550.00	502.71	445.57	381.03	321.60	305.64	305.52	288.55	251.00
2000	879.00	791.29	748.50	639.63	527.50	440.46	396.83	355.77	281.73
2001	315.00	264.14	241.50	232.80	217.18	208.43	204.13	198.61	189.90
2002	1040.00	836.00	646.64	487.27	387.48	355.06	334.58	302.46	258.95
2003	902.00	798.00	689.57	638.53	492.02	465.97	456.93	426.34	384.04
2004	909.00	756.00	633.29	597.30	549.27	526.27	495.08	447.95	364.58
MEAN	853.44	744.02	633.12	532.46	445.87	416.44	397.52	362.50	308.96
MAX	1160.00	990.00	876.07	727.60	582.80	581.97	549.50	458.44	396.13
MIN	315.00	264.14	241.50	232.80	217.18	208.43	204.13	198.61	189.90

Table 17. Mean low stages for the Wekiva River at the Old RR Crossing and the S.R. 46 Bridge (1996-2003 Water Years)

The Wekiva River at the Old RR Crossing: Stages(ft NGVD)

LOWEST MEAN VALUES FOR THE FOLLOWING NUMBER OF CONSECUTIVE DAYS IN YEAR ENDING SEPT 30									
YEAR	1	7	14	30	60	90	120	183	1 YEAR
1996	8.97	9.00	9.04	9.05	9.12	9.25	9.27	9.37	9.41
1997	8.74	8.76	8.77	8.78	8.80	8.82	8.83	8.88	9.05
1998	9.19	9.22	9.23	9.26	9.31	9.34	9.38	9.45	9.61
1999	9.21	9.22	9.23	9.26	9.28	9.30	9.31	9.36	9.50
2000	9.05	9.07	9.08	9.10	9.12	9.17	9.20	9.26	9.54
2001	9.00	9.00	9.02	9.04	9.06	9.10	9.13	9.15	9.32
2002	8.83	8.84	8.86	8.88	8.93	8.98	9.05	9.16	9.38
2003	9.05	9.06	9.08	9.09	9.15	9.36	9.42	9.50	9.71
MEAN	9.01	9.02	9.04	9.06	9.10	9.17	9.20	9.27	9.44
MAX	9.21	9.22	9.23	9.26	9.31	9.36	9.42	9.50	9.71
MIN	8.74	8.76	8.77	8.78	8.80	8.82	8.83	8.88	9.05

The Wekiva River at the S.R. 46 Bridge: Stages(ft NGVD)

LOWEST MEAN VALUES FOR THE FOLLOWING NUMBER OF CONSECUTIVE DAYS IN YEAR ENDING SEPT 30									
YEAR	1	7	14	30	60	90	120	183	1 YEAR
1996	6.93	6.93	6.94	6.95	7.00	7.15	7.14	7.22	7.24
1997	6.63	6.64	6.65	6.66	6.69	6.72	6.76	6.84	7.01
1998	7.17	7.18	7.20	7.22	7.28	7.30	7.31	7.39	7.59
1999	6.73	6.74	6.75	6.78	6.79	6.80	6.81	6.86	7.01
2000	6.72	6.73	6.74	6.75	6.76	6.80	6.83	6.89	7.14
2001	6.52	6.52	6.54	6.55	6.59	6.60	6.65	6.74	6.97
2002	6.61	6.61	6.62	6.62	6.65	6.67	6.72	6.78	7.07
2003	6.83	6.85	6.88	6.92	6.95	7.06	7.15	7.19	7.30
MEAN	6.77	6.78	6.79	6.81	6.84	6.89	6.92	6.99	7.17
MAX	7.17	7.18	7.20	7.22	7.28	7.30	7.31	7.39	7.59
MIN	6.52	6.52	6.54	6.55	6.59	6.60	6.65	6.74	6.97

Table 18. Mean high stages for the Wekiva River at the Old RR Crossing and the S.R. 46 Bridge

The Wekiva River at the Old RR Crossing: Stages(ft NGVD)

HIGHEST MEAN VALUES FOR THE FOLLOWING NUMBER OF CONSECUTIVE DAYS IN YEAR ENDING MAY 31									
YEAR	1	7	14	30	60	90	120	183	1 YEAR
1996	11.27	10.89	10.52	10.11	9.83	9.76	9.65	9.55	9.23
1997	10.60	10.32	9.94	9.55	9.41	9.31	9.35	9.26	9.08
1998	11.07	10.93	10.72	10.42	10.10	10.07	10.02	9.79	9.51
1999	10.28	10.15	9.99	9.78	9.64	9.60	9.57	9.52	9.43
2000	11.13	10.96	10.86	10.62	10.35	10.14	10.07	9.93	9.69
2001	9.69	9.53	9.44	9.41	9.35	9.32	9.28	9.27	9.20
2002	11.67	11.16	10.68	10.23	9.92	9.80	9.73	9.63	9.39
2003	10.69	10.45	10.18	10.06	9.75	9.71	9.70	9.60	9.51
2004	11.01	10.86	10.78	10.65	10.44	10.32	10.20	10.04	9.81
MEAN	10.82	10.58	10.35	10.09	9.86	9.78	9.73	9.62	9.43
MAX	11.67	11.16	10.86	10.65	10.44	10.32	10.20	10.04	9.81
MIN	9.69	9.53	9.44	9.41	9.35	9.31	9.28	9.26	9.08

The Wekiva River at the S.R. 46 Bridge: Stages(ft NGVD)

HIGHEST MEAN VALUES FOR THE FOLLOWING NUMBER OF CONSECUTIVE DAYS IN YEAR ENDING MAY 31									
YEAR	1	7	14	30	60	90	120	183	1 YEAR
1996	8.83	8.51	8.14	7.80	7.55	7.47	7.39	7.32	7.23
1997	8.45	8.21	7.86	7.45	7.32	7.24	7.25	7.20	7.06
1998	8.96	8.88	8.69	8.44	8.15	8.11	8.04	7.84	7.48
1999	7.93	7.82	7.68	7.49	7.37	7.37	7.35	7.28	7.08
2000	8.63	8.45	8.36	8.11	7.86	7.66	7.57	7.42	7.20
2001	7.50	7.36	7.30	7.26	7.21	7.18	7.16	7.10	6.93
2002	9.25	8.74	8.24	7.80	7.46	7.35	7.28	7.18	6.95
2003	8.56	8.31	8.05	7.92	7.68	7.60	7.48	7.42	7.27
2004	8.57	8.21	7.91	7.82	7.69	7.63	7.56	7.45	7.25
MEAN	8.52	8.28	8.03	7.79	7.59	7.51	7.45	7.36	7.16
MAX	9.25	8.88	8.69	8.44	8.15	8.11	8.04	7.84	7.48
MIN	7.50	7.36	7.30	7.26	7.21	7.18	7.16	7.10	6.93

The drainage area of about 4 sq. mi. between the Old RR Crossing gauge and the S.R. 46 gauge is relatively small compared to the total drainage area of 189 sq. mi. at the S.R. 46 gauge. This area, however, contributed about 16.5% of the discharge gauged at the Old RR Crossing during the eight-year period of water years 1996-2003, which is not commensurate with the contributing drainage area. Much of this higher discharge can be attributed to about 19 cfs mean spring discharge from Wekiva Falls located upstream of S.R. 46 (e-mail communication from David Clapp, Division of Engineering, SJRWMD), and urbanization of the area.

Stages. The daily stages ranged from 9.69 to 11.67 ft NGVD at the Old RR Crossing and 6.52 to 9.25 ft NGVD at the S.R. 46 Bridge (Tables 17-18). The mean stage at S.R. 46 Bridge for the eight-year period, 1996-2003, is below the mean stage at the Old RR station by 2.27 ft (Table 17; the one year values in this table are the water-year means). The stage differences between the Old RR Crossing and the S.R. 46 Bridge are higher during the later five years compared to the first three years of the 1996-2003 period (Table 17 and Figure 33). The differences in annual mean stages ranged from 2.02 to 2.17 ft for 1996-1998, while they had a range of 2.31 to 2.49 ft for 1999-2003. Analysis of stage data to determine possible reasons for this shift in the annual mean stage differences are reported in a later section of this document. Unlike discharges, Figure 33 does not give a clear indication whether stage differences are higher during peak stages. The noise in the stage-differences around 7/1/2002, and around 7/1/2003 (Figure 33) was caused by the missing records at the S.R. 46 gauge; the missing records were estimated by linear interpolation, which can be seen from the straight-line portion of the S.R. 46 stage hydrograph at these dates.

No correlation could be found between the daily stage differences in the two gauges and the Old RR Crossing daily stages (Figure 37); stage differences had a range of about 1.9 to 2.7 ft with no particular (defined) association to stages at the Old RR Crossing gauge. The stage differences at the two gauges do not have much variation from the point of view of stage duration (Figure 35). The stage differences shown by the stage-duration curves had a range of only about 2.2 to 2.3 ft when the Old RR stages are below 9.5 ft NGVD, and 2.3 to 2.5 ft for stages above 9.5 ft NGVD.

Stage-discharge relationship. A plot of daily stage versus discharge data for the Old RR Crossing gauge shows that discharges for a given stage varied during the data period (Figure 38a). The reason for this variation may be the shifting geometry/morphology of the channel near the gauging station. Stage-discharge data plotted for shorter periods (Figures 38b-38c) show a better-defined stage-discharge relationship, indicating thereby that different stage-discharge relationships are valid (or used by the USGS) for different gauging periods. The USGS, as mentioned earlier, periodically revises its rating curve to obtain accurate discharges from the stage data. The current (2004) USGS rating curve (Figure 39), being used since October 1, 1997, is designated as Rating No. 3. Therefore, it appears the USGS used two other rating curves before October 1, 1997, and it is an indication that shifts in the channel geometry might have occurred. For lower discharges, however, it appears USGS uses some additional procedures to compute discharge for a given stage, as evident from Figures 38b and 38c (multiple discharges are seen for the same stage). These figures, in general indicate that the channel has a changing geometry/morphology, and therefore, the stage data may not be considered homogeneous. To get some idea of the effects of these changes, even though the recorded data are not of sufficient length, stage-duration and discharge-duration curves are compared for five periods (Figures 40-41). The five periods chosen are: 1) July 1995 – September 1997 (Period 1), 2) July 1995 – September 1998 (Period 2), 3) October 1997 – October 2004 (Period 3), 4) October 1998 – October 2004 (Period 4), and; 5) July 1995 – October 2004 (Period 5).

Periods 1 and 3 are the periods during which the USGS used different rating curves. During Period 2, the annual mean stage differences between the Old RR Crossing and the S.R. 46 Bridge gauges were lower, but they were higher during Period 4 (as discussed earlier, see the previous page, sub-heading **Stages;** also see Figure 33). Figures 40 and 41 show some anomalous results. These figures show that stages at the Old RR Crossing gauge were lower during Periods 1 and 2 compared to Periods 3 and 4, but discharges were higher during Periods 1 and 2 compared to Periods 3 and 4. This indicates that some transformation that occurred in the channel geometry/morphology around 1997/1998 caused stages at the Old RR Crossing gauge to shift higher. This explains why the stage differences between the Old RR Crossing and the S.R. 46 Bridge gauges were lower during Period 2, but higher during Period 4. The USGS appears to have suitably modified the stage-discharge relationship to compute discharges accurately during these periods. The duration curves for Period 5 reflect the average conditions for the period of record. The low stages that occurred in the early years (i.e., before the shift) influenced the stage duration curve more in the 85-100% percentile range by bringing the average curve down (Figure 40). The severe drought that occurred during water years 2000-2001 (Tables 15 and 17) generally lowered the average discharge-duration curve relative to Periods 1 and 2 (Figure 41).

Suitability of Old RR Crossing as a future MFLs location

Various stage data analyses performed in this study indicate that the Wekiva River does not have a stable channel. Data showed that the channel geometry/morphology experiences periodic shifts both at the S.R. 46 Bridge and the Old RR Crossing locations. It may be expected that these periodic shifts will continue to occur at both locations. Because the USGS periodically adjusts the stage-discharge relation it uses to compute discharges for a given stage (at a given time), the discharge data are free from the shifts in the channel geometry, and may be deemed accurate within the constraints of the USGS error margins. The stages recorded, however, are those that actually occurred, and because they are influenced by the shifts in the channel geometry/morphology, the data suffer from a lack of homogeneity.

From the available data point of view, there appears to be no particular advantage in choosing Old RR Crossing as a future MFLs station. While the stages suffered a downward shift at the S.R. 46 Bridge, stages appear to have experienced an upward shift at the old RR Crossing. Choosing an alternate site for MFLs should come more from the available plant communities at either site that would provide robust criteria for determining minimum levels. At present, 71 years of observed stage data are available at the S.R. 46 Bridge, which could be adjusted for the present stage hydrology. If the Old RR Crossing site is deemed to be more appropriate than the S.R. 46 Bridge site based upon plant communities, then long-term data for the Old RR Crossing site can be generated by some correlation with data from the S.R. 46 Bridge site. The following steps are suggested: 1) establish a correlation between discharges at Old RR Crossing and S.R. 46 Bridge, 2) using the correlation, convert S.R. 46 Bridge discharge data into discharge data for Old RR Crossing, and 3) using the current stage-discharge relationship, generate long-term stage data for Old RR Crossing from the discharge data obtained in Step 2.

CONSUMPTIVE WATER USE IN THE WEKIVA RIVER BASIN

SJRWMD issues consumptive use permits (CUPs) for all major water uses within its jurisdiction. One of the requirements of CUPs is that the permitted users report their actual water use by using a water meter or by an alternative method approved by SJRWMD (visit the website: www.sjrwmd.com/programs/cuppermitting.html). The goal of the Consumptive Use Permitting Program is to provide water for reasonable-beneficial uses while protecting the water resources of SJRWMD. In general, compliance with MFLs is a criterion for protecting the water resources of SJRWMD when issuing new CUPs or renewing existing permits.

Consumptive water use in the Wekiva River basin is primarily supplied by groundwater withdrawals by public water supply utilities and by irrigators of nurseries, golf courses, and urban landscape. Excessive groundwater withdrawals could lower the aquifer pressures leading to a reduction of spring and other groundwater discharges to the Wekiva River. This, in turn, might cause water levels/flows to fall below established Wekiva River MFLs.

The objective of this section is to review the reported water use data for the Wekiva River basin south of SR 46 since 1995 (i.e., when the Wekiva River MFLs were first evaluated for their compliance) and assess whether changes in water use have affected Wekiva River discharges at SR 46 (i.e., on the established MFLs).

Water use assessment

The permitted water users report their monthly water use data (i.e., groundwater withdrawal data) to SJRWMD and the Florida Department of Environmental Protection (DEP). Currently, the Division of Ground Water Programs (GWP), SJRWMD, is developing updated regional groundwater models for SJRWMD, and part of this effort involves a comprehensive compilation of groundwater withdrawal data using the SJRWMD and DEP databases (G. Robinson, personal communication 2007). These data, which include only major users (average withdrawal of 0.05 mgd or greater as of 2005), are used in this assessment. There are 21 permits in this category (Table 19), and some include well fields developed at multiple locations (Figure 42). Also, the bordering well fields within a distance of about 2.5 miles (4 Kilometers) from the basin line are included in this assessment because they might affect the groundwater flow contribution to the Wekiva River.

Orlando Utilities Commission (OUC) is the major user with a withdrawal of 25 mgd or above and there are 12 users that draw less than one mgd (Table 20). For the period assessed, 1995 had the lowest annual water use, and only one new major user was added after 1995. Additional groundwater withdrawals were permitted after 1995 following the establishment of the Wekiva River MFLs. The annual water use increased from about 69 to

100 mgd between 1995 and 2000 (Table 20 and Figure 43). There was a major reduction, however, from 2000 to 2001 (from 100.7 to 80.7 mgd), probably due to the severe drought that occurred in 2001 (Table 6).

The 2001-2005 average annual water use was about 80 mgd, an increase of about 11 mgd (17 cfs) over the 1995 use, representing an increase of 17%. Year 2000 was the maximum water consumption year with100.7 mgd, an increase of about 30 mgd (46.4 cfs) over the 1995 water use, representing an increase of 43%. The 2000 water use was substantially higher compared to the 1995 use both by percent (43%) and quantitatively (46.4 cfs). For the increased water use that occurred during 1995-2005 (Table 20), this study has shown that the established MFLs for discharges are still being met.

Table 19. Major water users south of SR 46 in the Wekiva River Basin and their consumptive use permit numbers

Permit No	Name of the water user
160	SANLANDO UTILITIES CORP.
2416	Oak Springs MHP
3159	ORLANDO UTILITIES COMMISSION
3203	Clarcona Resort
3216	Larry Horne WL Determinations
3217	City of Apopka Public Supply
3278	Zellwood Station
3317	Eastern & Western Water Utility
3383	Rock Springs MHP
8213	Seminole County Lynwood Well Field
8230	Seminole County Northwest Service Area
8346	Weathersfield
8347	Jansen
8348	BEAR LAKE
8356	Lake Harriet
8359	Meredith Manor
8372	City Water Supply
50258	City of Maitland
50281	Apple Valley
62724	Fairways at Mt. Plymouth
92244	Silver Star Village

Table 20. Average groundwater withdrawals (mgd) by major water users south of SR 46 in the Wekiva River basin

Permit No	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
160	8.801071	9.020974	9.129163	10.24304	10.08861	10.79133	8.211417	7.833333	7.651708	8.66271	7.635806
2416	0.17092	0.202542	0.212297	0.147467	0.138212	0.114648	0.111052	0.085958	0.073228	0.08183	0.05365
3159	24.74417	26.34283	25.3215	28.09408	32.51446	37.42333	28.28617	27.4895	25.2215	25.267	25.23352
3203	0.200167	0.222083	0.218955	0.227472	0.166386	0.16164	0.135934	0.130646	0.118338	0.138319	0.144284
3216	2.799159	4.484583	4.349208	4.880167	5.176167	6.302917	5.397917	5.113583	4.604583	4.236921	3.992262
3217	5.637617	6.943667	6.747917	7.374917	7.184917	7.861	6.66525	6.432311	6.56094	7.192749	7.463927
3278	0.571	0.613042	0.525368	0.576167	0.39075	0.467583	0.34825	0.324594	0.324245	0.360865	0.35325
3317	10.04501	10.95351	10.63385	11.58306	11.27728	13.67743	12.2258	13.59875	13.38408	15.3025	15.296
3383	0.230421	0.205839	0.248572	0.241472	0.273317	0.276809	0.23875	0.244188	0.211951	0.138265	0.148919
8213	3.873958	3.183708	3.40625	4.148667	4.986167	5.97525	4.983833	4.991083	4.357241	4.707832	4.491
8230	1.600251	1.880417	2.193083	3.159292	3.843333	4.504083	3.763333	4.290417	4.930944	5.119868	5.400917
8346	0.347	0.366083	0.3525	0.400167	0.368	0.355917	0.32075	0.324764	0.3045	0.3025	0.277047
8347	0.070333	0.074417	0.074417	0.084	0.0862	0.096225	0.078	0.076043	0.073583	0.081812	0.070198
8348	0.059333	0.062333	0.059833	0.0668	0.069583	0.071267	0.059833	0.063581	0.057167	0.053917	0.055553
8356	0.075086	0.083578	0.0763	0.08327	0.082935	0.085239	0.072525	0.075303	0.070977	0.075015	0.061385
8359	0.2704	0.27115	0.271501	0.349317	0.324435	0.326568	0.29319	0.228723	0.225795	0.22196	0.211195
8372	6.44975	6.39825	6.609183	7.609048	7.596946	7.830799	6.040024	5.836222	5.759044	6.338488	6.034353
50258	2.809417	3.0605	3.140125	3.572223	3.501667	3.666399	2.890717	2.83	2.758228	2.840912	2.799962
50281	0.454986	0.487332	0.461757	0.545491	0.52174	0.564235	0.482558	0.457835	0.435321	0.495505	0.441583
62724	0	0	0	0	0	0	0.011717	0.05088	0.065043	0.096638	0.119978
92244	0.089304	0.05325	0.101174	0.135854	0.100383	0.109571	0.073364	0.108179	0.067775	0.119186	0.125024
Annual Total	69.29935	74.91009	74.13296	83.52197	88.69148	100.6622	80.69038	80.58589	77.25619	81.83479	80.40981

SENSITIVITY ANALYSIS OF STAGE DATA FOR THE WEKIVA RIVER AT SR 46

Stage data for the Wekiva River at SR 46 for the period of record (i.e., 1935 to the present) indicated that downward shifts occurred in stages around 1957, 1973, and 1990 (Figure 19), rendering the data non-homogeneous. No literature indicating specific causes for this occurrence could be found. However, these downward shifts have been commonly attributed to some disturbance in channel geometry/morphology. The resulting data affected MFLs evaluations for stages. MFLs for stages were met based on an evaluation using the 1935-1990 data, the data available when the MFLs for the Wekiva River at SR 46 were established, but not met based on an evaluation of the 1935-2004 data. Specifically, the MA and MFL levels were exceeded based on an evaluation using the 1935-2004 data. The MFLs for discharges, however, were met based on the evaluations of data for both periods, indicating that the discharge characteristics were not significantly affected during the period of record, and the decline in stages was not due to a decline in discharges. The following questions have been raised by these results.

- How did the shifting channel conditions in the Wekiva River affect the MFLs with time?
- Would the MFLs for stages have been met had the shifts in the channel conditions not occurred?

To answer these questions, the following series of sensitivity analyses of stage data were performed.

- Identifying the specific year from which the MFLs of stages were not being met. This was determined by gradually increasing the stage data sample size from 1972 to 2004.
- Studying the stage-discharge relationships that existed for time periods for which the stage data appeared to be more-or-less homogeneous (i.e., the periods 1935-1956, 1957-1972, 1973-1989, and 1990-2004).
- Generating hypothetical data for the period 1935-2004 by the stage-discharge relationship from one of the foregoing periods, and performing MFLs analysis using the hypothetical data.

Determine the effect of declining stages at SR 46 on MFLs stages

The lower limits of return periods (T) for the MA and MFL levels are 1.7 and 3 years, respectively (Table 1). In this analysis, the Log Pearson type 3 frequency analysis was performed on the183- and 90-day mean low stage data by increasing the sample size from 1972 to 2004. Then, the stage values for T = 1.7 years from the 183-day data samples (i.e., MA), and T = 3 years from the 90-day data samples (i.e., MFL) were evaluated and summarized in Table 21. If the Log Pearson predicted stages for these return periods are higher than the MFLs stages, then the MFLs are met.

As indicated by Figure 19, stages at SR 46 were relatively higher until 1972, and then declined. For the period 1936-1972, the Log Pearson predicted stages are greater than the established MFLs stages by 0.37 and 0.45 ft, respectively, for the MA and MFL levels; these were the ‘free-boards’ available in 1972 for the MA and MFL levels (Table 21). As the period of record increased from 1972, there was a gradual decrease in the available free-boards, and the MA and MFL levels were just being met in the year 2000. After the year 2000, it may be regarded that the MFLs have been exceeded. It may be concluded from these results that the lower stages that occurred since the early 1970s gradually decreased the MFLs stages.

The period 1973-2004 had relatively lower stages, and it is also the most recent period exceeding 30 years of data, the desirable requirement for MFLs analysis. Log Pearson predictions from data for this period show that the MA and MFL levels miss the required stages by 0.53 and 0.35 ft, respectively (Table 21). When the Wekiva River MFLs were established (early 1990s), the length of the period with lower stages was about 18 years, but it is about 35 years now (2007).

Evaluate the stage-discharge relationships for different data periods

Figures 44 – 47 present plots of stage-discharge (H-Q) data for the periods 1936-1956, 1957-1972, 1973-1989, and 1990-2004, respectively. H-Q relationships are not single-valued for most rivers because of backwater effects. In general, at a given stage, higher discharges occur during rising stages and lower discharges during falling stages, and the USGS applies appropriate procedures to compute the discharges accurately for a given stage (Kennedy 1984). Even though the data appear rather dispersed in these figures, an average H-Q relationship is discernible for each data period. Figure 48 compares the H-Q regression relationships developed for the four periods; these regression-based relationships are denoted as the average H-Q relationships.

The average H-Q relationships for the periods 1973-1989 and 1990-2004 do not differ significantly from each other, while the average H-Q relationships for the periods 1936-1956 and 1957-1972 show higher stages for a given discharge compared to the 1973-1989 and 1990-2004 stages. In general, these H-Q relationships show that the period 1936-1972 had a higher stage regime and the period 1973-2004 a lower stage regime.

Perform MFLs analysis with hypothetical stage data

One of the questions that may be posed by this study is, if the Wekiva River at SR 46 had a stable channel, would the MFLs for stages be met? To answer this question, the stage-discharge relationship that occurred during the period 1957 – 1972 is chosen as a representative overall relationship, and hypothetical stage data were generated using this regime. Stages for the period 1936 – 1956 appear rather high (Figure 48), while the stages for the period 1957 – 1972 are intermediate between the 1936 – 1956 and 1973 – 2004 stages.

The hypothetical stage data for the period 1936 – 2004 were developed converting the discharge data for the period 1936 – 2004 using the quadratic regression equation shown on Figure 45. The stage-duration curve for the 1936 – 2004 hypothetical data shows a close resemblance to the 1936 – 2004 discharge-duration curve while the stage-duration curve for the 1936 – 2004 observed data had a marked deviation from it (Figure 49). This result shows that the hypothetical stage data are compatible to the observed discharge data and thus likely to provide the MFLs results representing those of a stable Wekiva River channel bed. The 1936-2004 hypothetical data stage-duration curve deviated from the 1957 – 1973 observed data stage-duration curve by up to 0.2 ft in the lower stages and by up to 0.3 ft in the higher stages; this result may have occurred because the period of the hypothetical data is much longer.

The MFLs frequency graphs developed for the 1936 – 2004 hypothetical stage data showed that the MA level would be met by a slight free-board, while the MFL level would be met with quite a large free-board of about 0.3 ft (Figures 50 – 51). This result leads to the conclusion that had the Wekiva River channel bed at SR 46 been stable, the MFLs for stages would have been met.

Table 21. The Wekiva River at SR 46: Summary of results of Log Pearson type 3 frequency analysis for different time periods (Stages are in ft NGVD)

Period	Sample size (Years)	Minimum Average 1.7-year low stage (183-day low stages) (Required: 7.6 ft NGVD)	Minimum Frequent Low 3-year low stage (90-day low stages) (Required: 7.2 ft NGVD)
1936-1972	37	7.97 (0.4)	7.65 (0.5)
1936-1980	45	7.83 (0.2)	7.47 (0.3)
1936-1985	50	7.76 (0.2)	7.39 (0.2)
1936-1990	55	7.72 (0.2)	7.33 (0.1)
1936-1995	60	7.65 (0.1)	7.25 (0.1)
1936-2000	65	7.61 (0)	7.21 (0)
1936-2004	69	7.57 (0)	7.15 (-0.1)
1973-2004	32	7.07 (-0.5)	6.85 (-0.4)

Values in parentheses are ‘free-boards,’ rounded to one decimal place. Free-board is the difference between the Log Pearson predicted stage and the established MFLs stage.

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Minimum Flows and Levels (MFLs) for the Wekiva River at the S.R. 46 Bridge were established in the early 1990s based on evaluations of topographic, soils, and vegetation data collected within plant communities associated with the river near S.R. 46. At the time these MFLs were established, an analysis of the 1936-1990 USGS stage and discharge data showed that the adopted MFLs for the Wekiva River were being met. Increased groundwater and surface water uses in the basin, however, could potentially reduce discharges and water levels in the river; therefore, it is necessary to periodically evaluate the observed stage/discharge data to verify that the established MFLs are being met. The primary objective of this report is a re-evaluation of the MFLs for the Wekiva River at the S.R. 46 Bridge based on the 1936-2004 USGS data (i.e., the updated data as available at the time of this report) and to verify whether the MFLs are still being met.

This report briefly reviewed the MFLs methodology, and evaluated the MFLs using the1936-2004 USGS streamflow data. For consistency with the original methodology, MFLs evaluations were performed by Log Pearson analysis (the 1990s method), and also by a graphical method developed later by the SJRWMD staff. Data for a recently (1995) established upstream gauging station, the Wekiva River at Old RR Crossing, were also analyzed to determine this location's suitability as an alternative MFLs site.

Conclusions

The following conclusions are reached based on MFLs analysis and other data evaluations performed in this report.

1. The Wekiva River at the S.R. 46 Bridge location appears to have experienced periodic re-adjustments in the channel geometry and channel morphology during the USGS gauging period (i.e., October 1935 to the present). These re-adjustments have caused a decline in stages. Stage declines of about 0.5 ft, especially in low stages, appear to have occurred specifically around 1957 and 1973, with a minor decline of 0.25 ft around 1990. The channel appears to have more-or-less stabilized since 1973. For these reasons, the stage data collected for the period of record may not be considered homogeneous (i.e., data representing the same or constant channel conditions), but nearly homogeneous for specific periods (specifically for 1935-1956, 1957-1972, 1973-1989, and 1990-2004).
2. The channel re-adjustments do not appear to have affected the discharge data gauged by the USGS at the S.R. 46 Bridge because based on periodic measurements of discharges, USGS constantly updates/revises its stage-discharge

relation (which is used to compute daily discharges from observed stages) to obtain accurate discharge for a given stage at a given time.

3. An evaluation of MFLs based on the 1936-1990 USGS (Water Year) streamflow data (i.e., the period of data available when MFLs for the Wekiva River at the S.R. 46 Bridge location were established) showed that all of the MFLs (stages and discharges) were being met.
4. An evaluation of MFLs based on the 1936-2004 USGS streamflow data (i.e., the period of data available currently) shows that all of the MFLs for discharges are being met; in the case of stages, however, the evaluations by the original methodology (i.e., 1990s methodology) showed that two of the MFLs, Minimum Average (MA) and the Minimum Frequent Low (MFL) are marginally not being met. The graphical method showed that only MFL is not being met. Since the MFLs for stages were met with the 1936-1990 data, but not with the 1936-2004 data, it seems obvious that the lower low water levels that occurred during the additional data period (i.e., 1991-2004) were responsible for the latter result.
5. A sensitivity analysis performed on the 1936 – 2004 observed stage data indicates that the MFLs stages were being met through the year 2000, but were exceeded later on.
6. Hypothetical stage data developed for the period 1936 – 2004 that represented the stage regime of the period 1957 – 1972 (the stable regime intermediate between the higher and the lower stages) gave the following results: a) the hypothetical stage data are compatible to the observed discharge data and likely to provide the MFLs results representing those of a stable Wekiva River channel bed, and; b) the MA level would be met by a slight free-board, and the MFL level would be met with quite a large free-board of about 0.3 ft. From these results it is concluded that had the Wekiva River channel bed at SR 46 been stable, the MFLs for stages would have been met.
7. Based on data collected by SJRWMD, water use in the Wekiva River basin increased after 1995. This increase, however, based on the evaluation presented in this document, has not caused flows to fall below the established MFLs. Water use, as reported by public supply utilities and other major water users in the basin, increased from 69.3 to 100.7 mgd between 1995 and 2000. Water use leveled off to about 80 mgd during 2001-2005. Despite this conclusion, the phase restrictions included in Section 40C-8.031, *FAC,* have not been continuously met. These phase restrictions are established by rule and are to become effective when the flows and levels in the Wekiva River at the SR 46 Bridge fall below the flows and levels established for each phase.
8. It appears, regulation of the Ocklawaha chain of lakes maintaining higher lake levels since about 1960 increased the groundwater contribution to the Wekiva River basin. This report estimates this increase as about 27.5 cfs for the Wekiva River at the S.R. 46 Bridge. However, how this increased groundwater contribution benefited MFLs is not specifically analyzed in this report.
9. An analysis of the 1995-2004 streamflow data for the upstream gauging station, the Wekiva River at Old RR Crossing, gave the following results: a) The average difference in discharges between the gauges at the S.R. 46 Bridge and Old RR Crossing is about 50 cfs for 95% of the time, the S.R. 46 Bridge discharges being

higher, b) on the average, the stages at Old RR Crossing are higher by about 2.3 ft, c) similar to the S.R. 46 location, Old RR Crossing also seems to have been experiencing periodic re-adjustments in the channel geometry/morphology. It appears, stages have experienced an upward shift of 0.2 ft during 1997/1998, and; d) the discharge data may be considered unaffected by the disturbances in the channel geometry/morphology because USGS constantly updates/revises its stage-discharge relationship.

Recommendations

The following recommendations are made based on various findings of this report.

1. Stage data analyses performed in this study indicate that the Wekiva River near the gauging station does not have a stable channel. A re-adjustment of channel geometry/morphology occurred periodically both at the S.R. 46 Bridge and the Old RR Crossing locations, giving rise to different stages for the same magnitude in discharges. The implication of this occurrence with respect to the MFLs determination is that the plant communities and soils along the Wekiva River were subjected to long-term water stages that had non-uniform fluctuating characteristics. In light of this information, SJRWMD staff should re-assess the methodologies used in establishing the Wekiva River MFLs in the early 1990s. Specifically, if the characteristic features of various plant communities and soils that lead to the determination of various minimum levels are the result of a varying stage hydrology rather than a constant stage hydrology, the procedures that may be applicable to establishing minimum levels under such conditions should be investigated, and developed. The Wekiva River MFLs should be re-established using the revised procedures.

2. From the point of view of data availability, there appears to be no particular advantage in choosing the Old RR Crossing as a future MFLs station. While the stages suffered a downward shift at the S.R. 46 Bridge, stages appear to have experienced an upward shift at the old RR Crossing. Choosing an alternate site for MFLs should come more from the available plant communities at either site that would provide robust criteria (i.e., very satisfactory and strong criteria) for determining minimum levels. At present, 71 years of observed stage and discharge data are available at the S.R. 46 Bridge, which is a desirable long-term data sample; furthermore, these data could be either adjusted for the present stage hydrology (i.e., to conform to the present channel geometry and morphology), or simply the earlier data up to 1972 could be discarded and still have a sufficiently long-term observed data sample. Only a 10-year period of hydrologic records is available at the Old RR Crossing site.

3. Because the long-term water stage data (October 1935 to present) collected for the Wekiva River at the S.R. 46 Bridge lost its homogeneity as a result of channel

instability at the gauged location, but the discharge data for the same period at the same location appears to be unaffected (due to revisions in USGS gauging procedures to insure accurate streamflow data), SJRWMD should consider using just discharge data for MFLs evaluations, at least until a stable cross section is found or MFLs are established at a more stable segment of the river.

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Figure 2. The Wekiva River at S.R. 46 Bridge
USGS daily stage data (1935-1990)
(Note: USGS data starts on 10/1/1935. Missing data are estimated by interpolation)

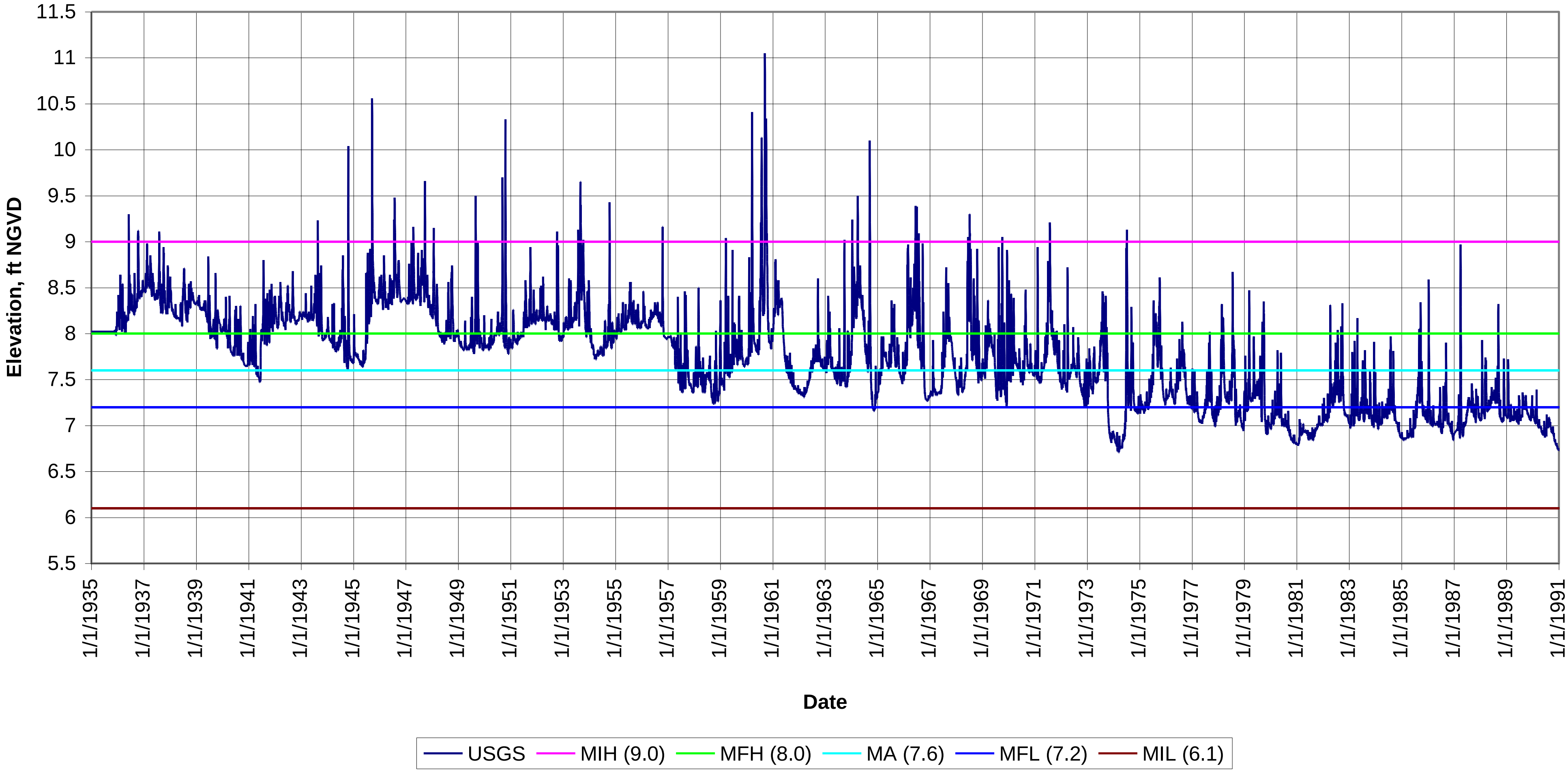


Figure 3. The Wekiva River at S.R. 46 Bridge
USGS Daily discharge data (1935-1990)

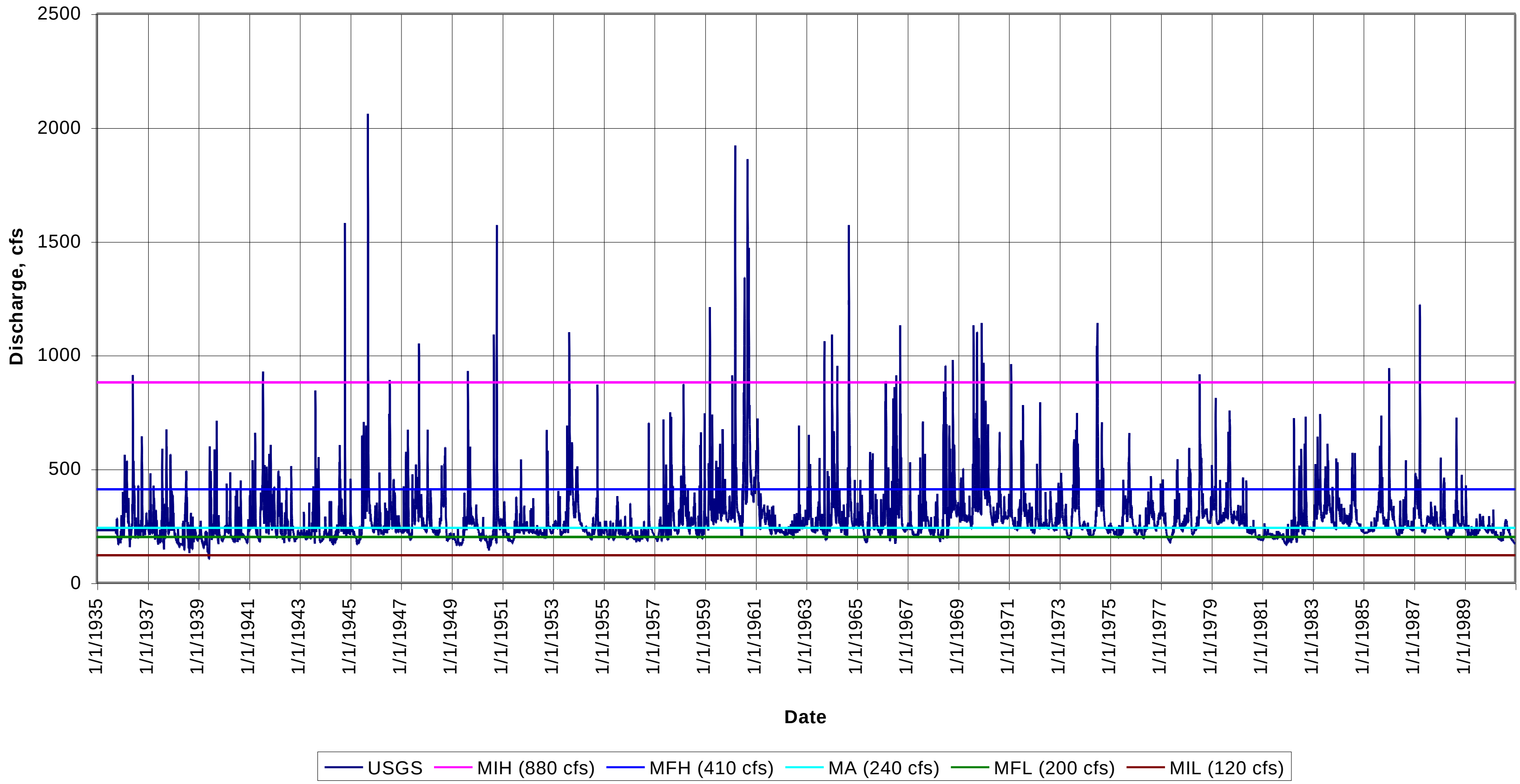


Figure 4. The Wekiva River at S.R. 46 Bridge
Stage-duration curve: 1936-1990 USGS data

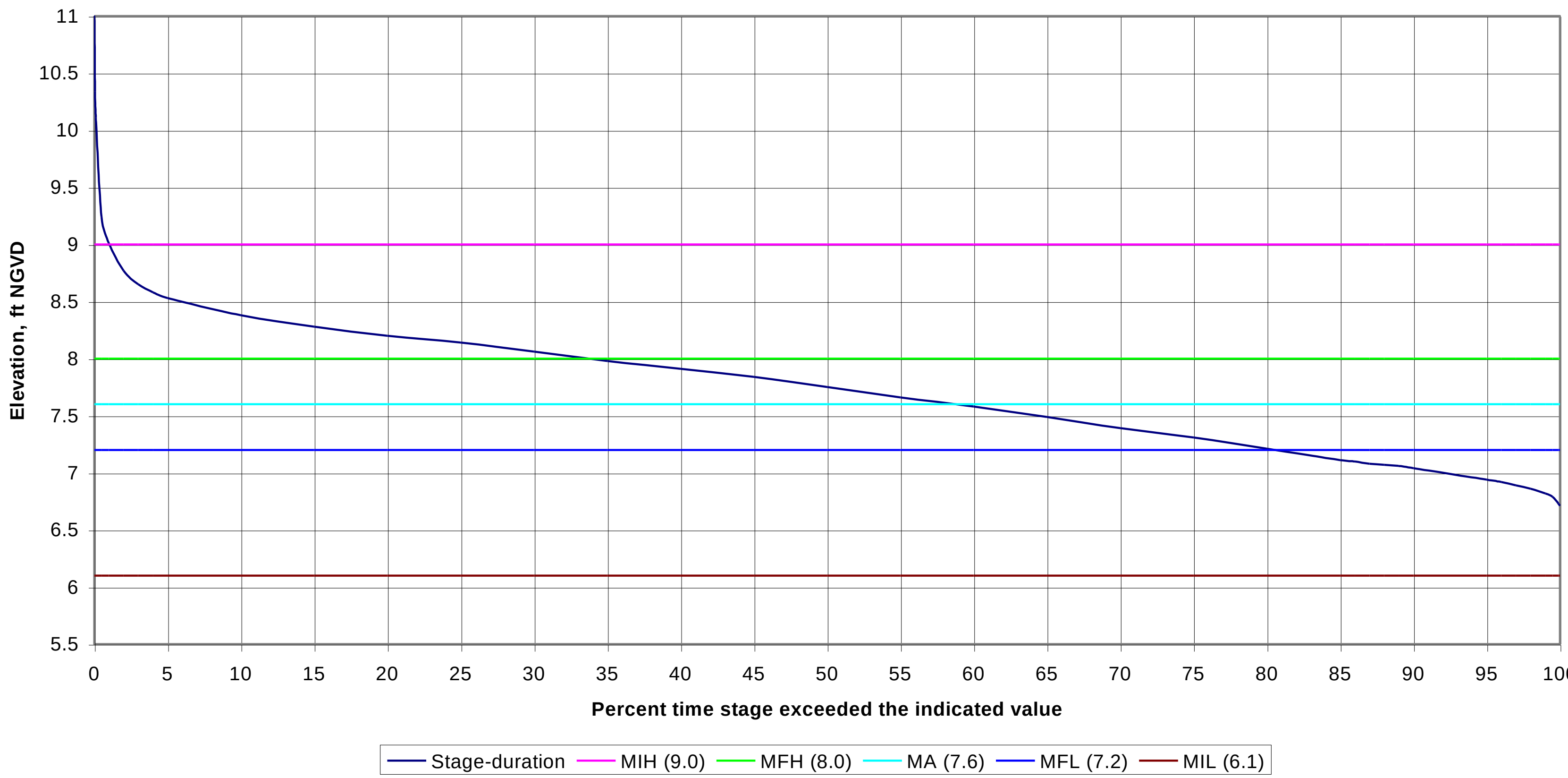
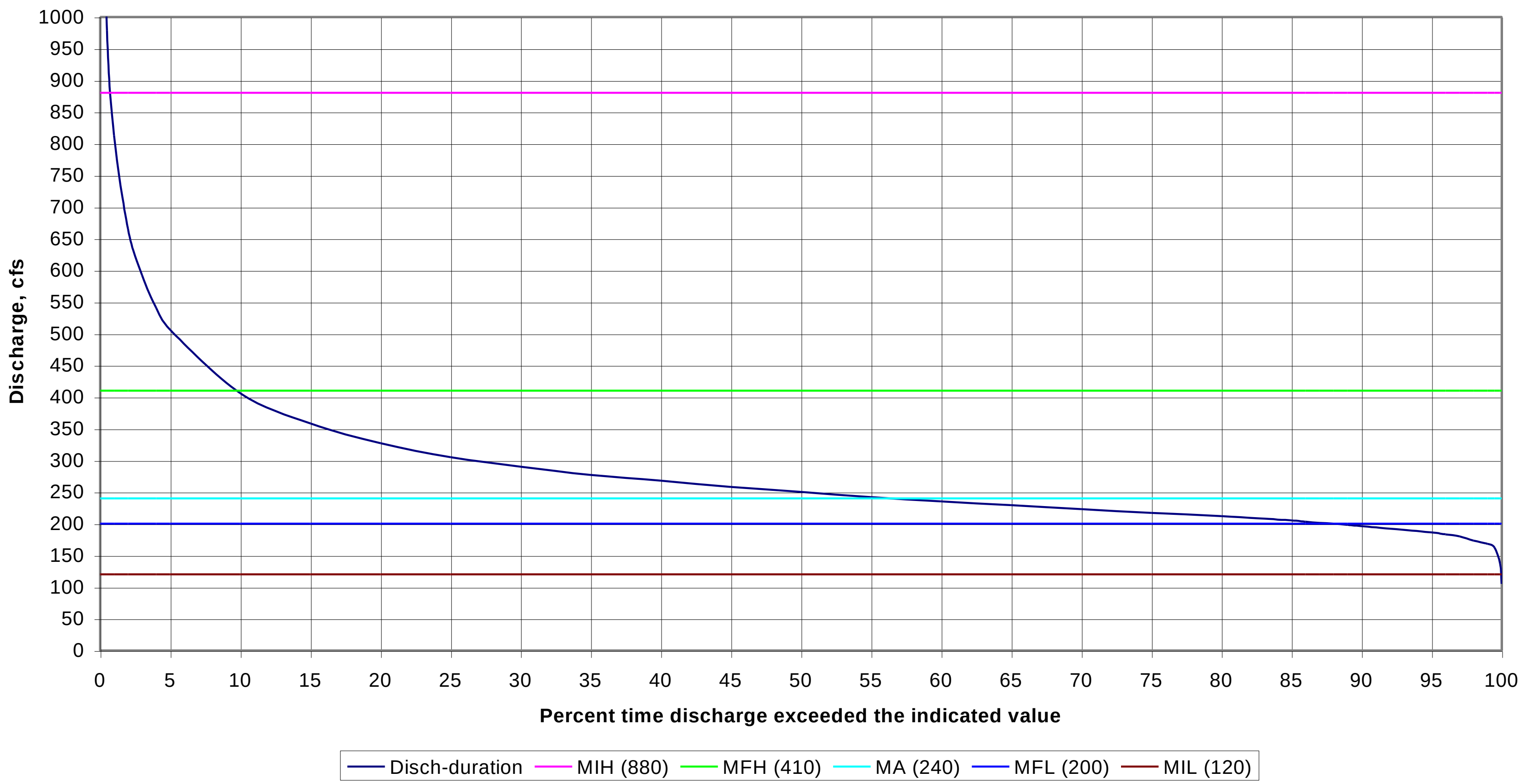


Figure 5. The Wekiva River at S.R. 46 Bridge
Discharge-duration curve: 1936-1990 USGS data
(Discharges are shown in the range of 0 - 1,000 cfs)



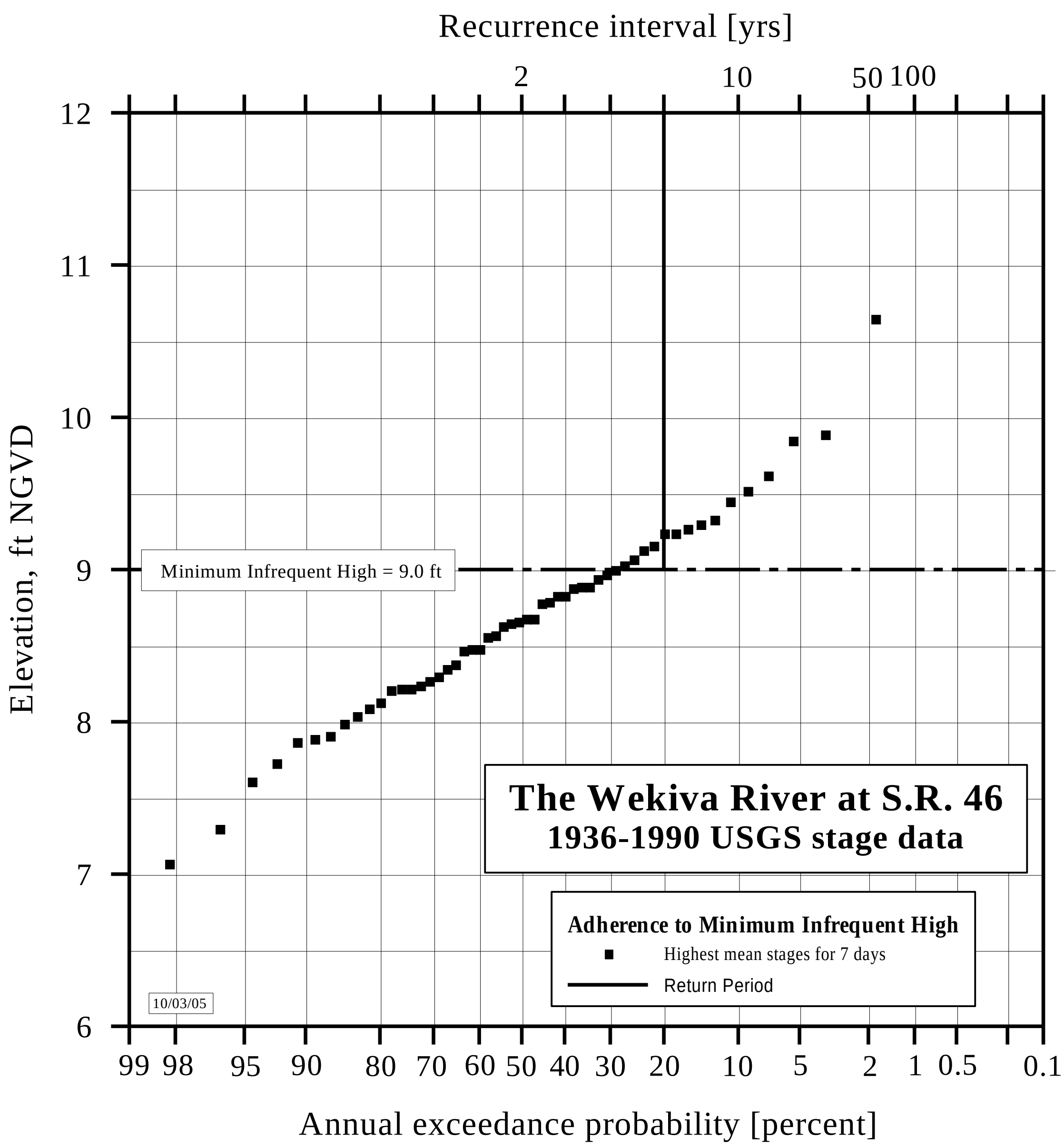


Figure 6. MFLs evaluation for the Minimum Infrequent High level

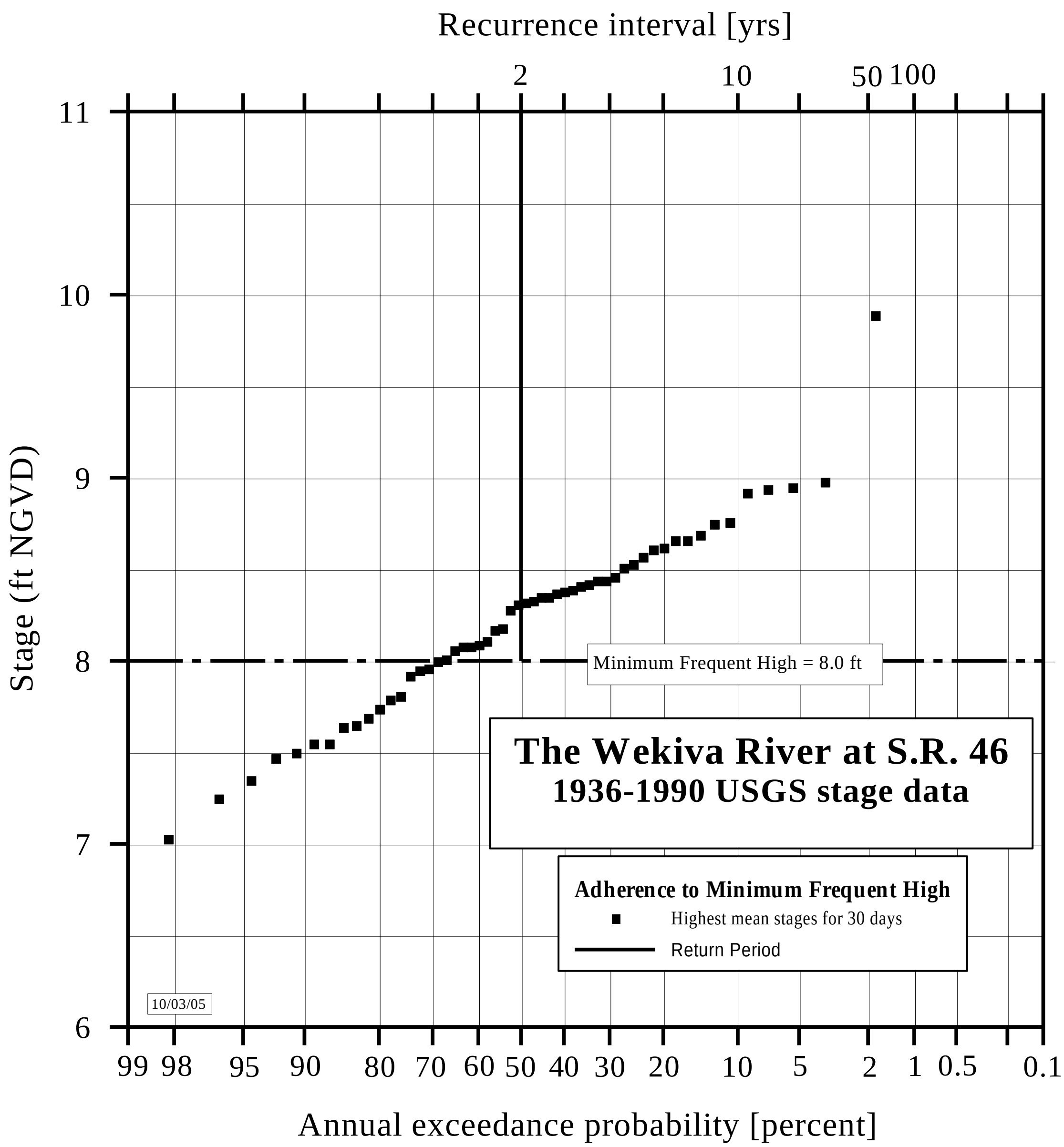


Figure 7. MFLs evaluation for the Minimum Frequent High level

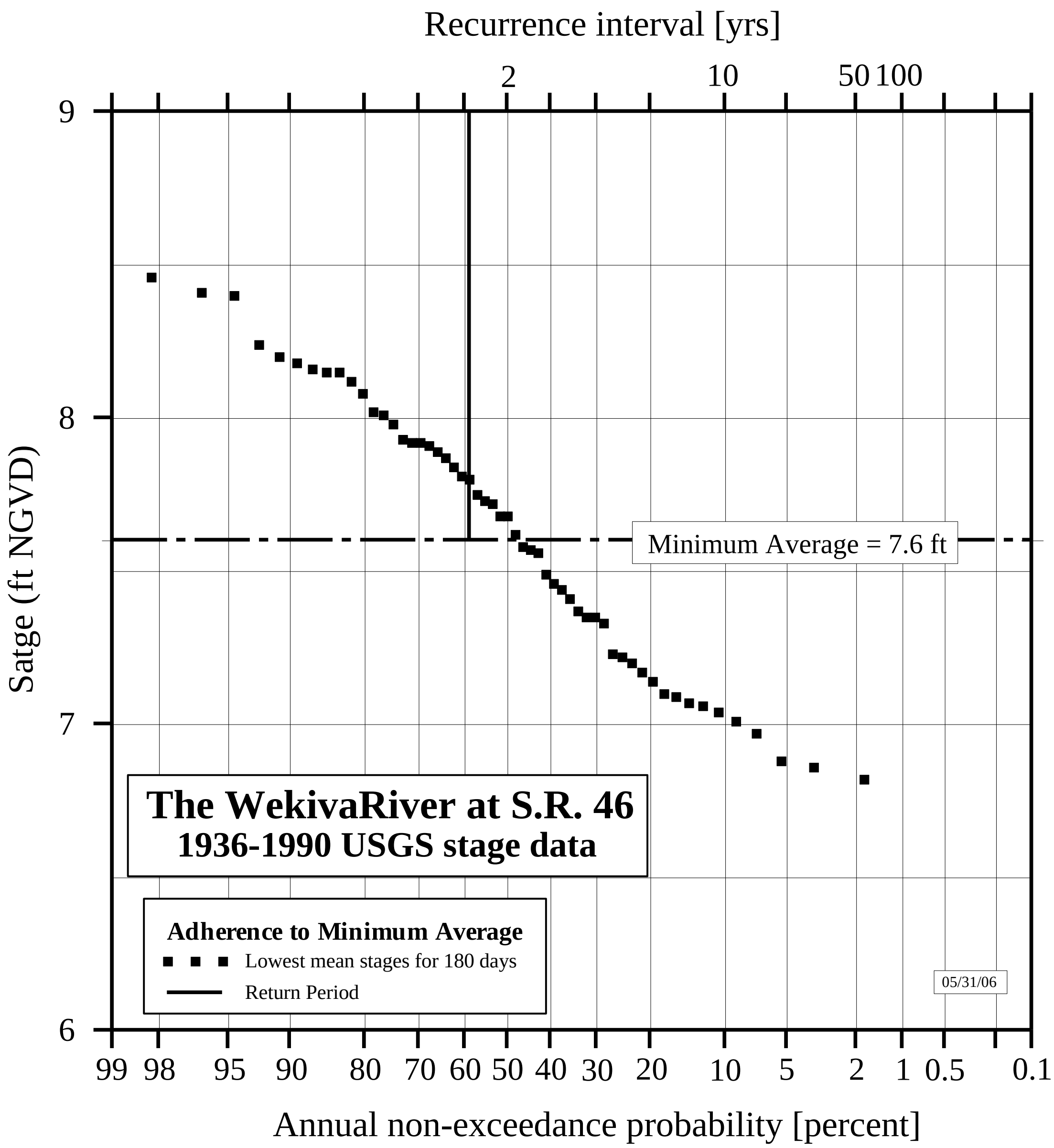


Figure 8. MFLs evaluation for the Minimum Average level

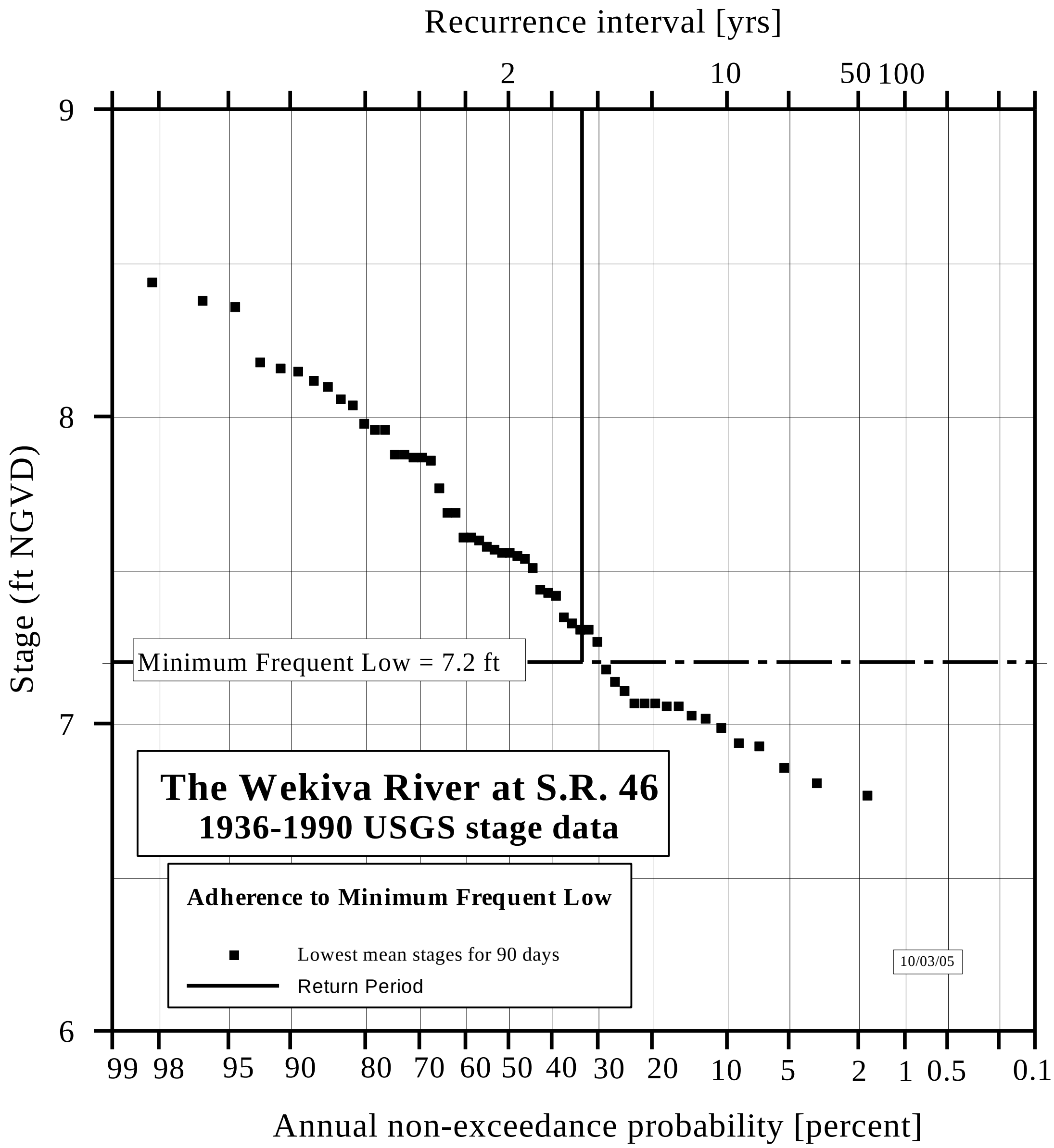


Figure 9. MFLs evaluation for the Minimum Frequent Low level

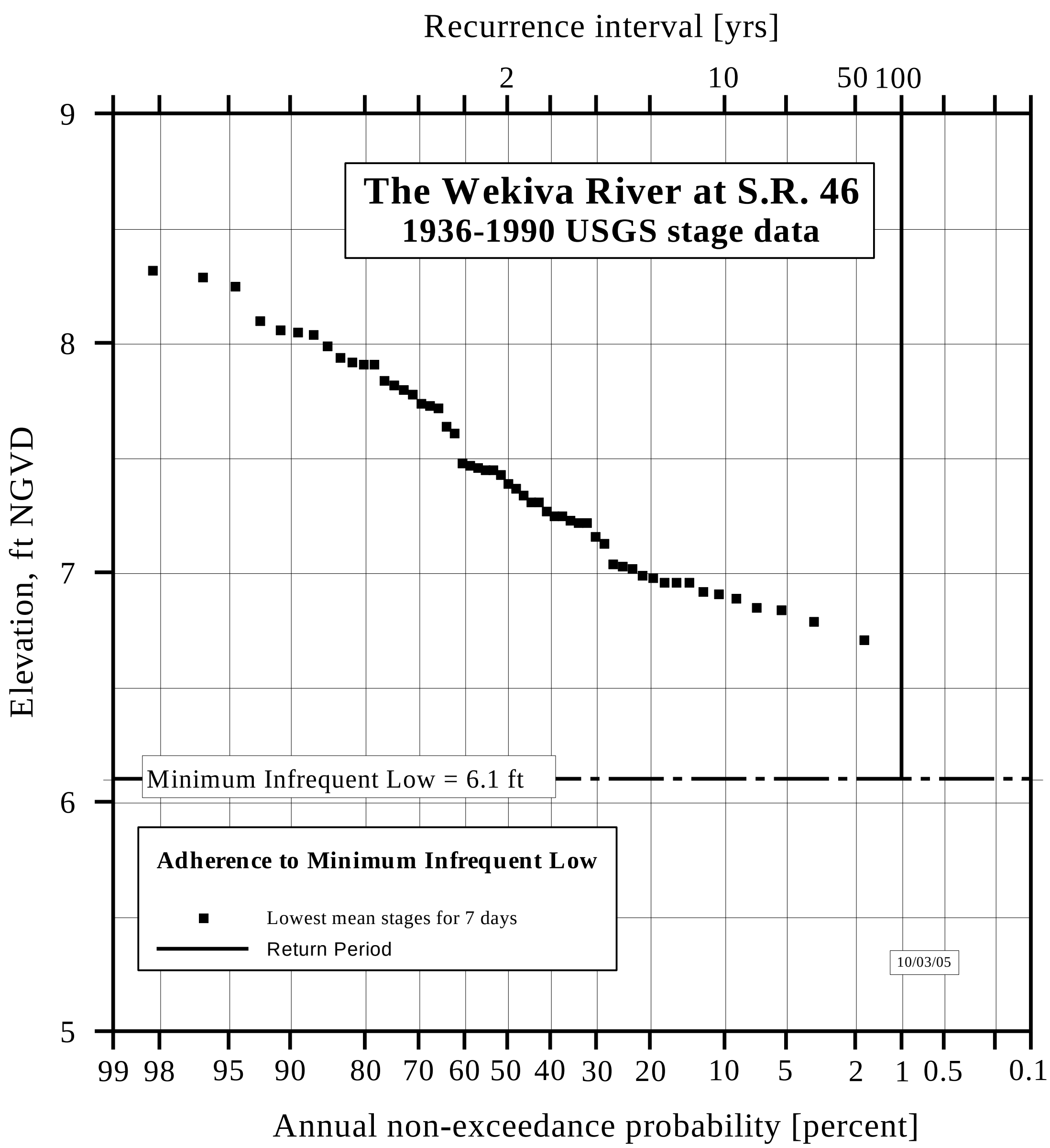


Figure 10. MFLs evaluation for the Minimum Infrequent Low level

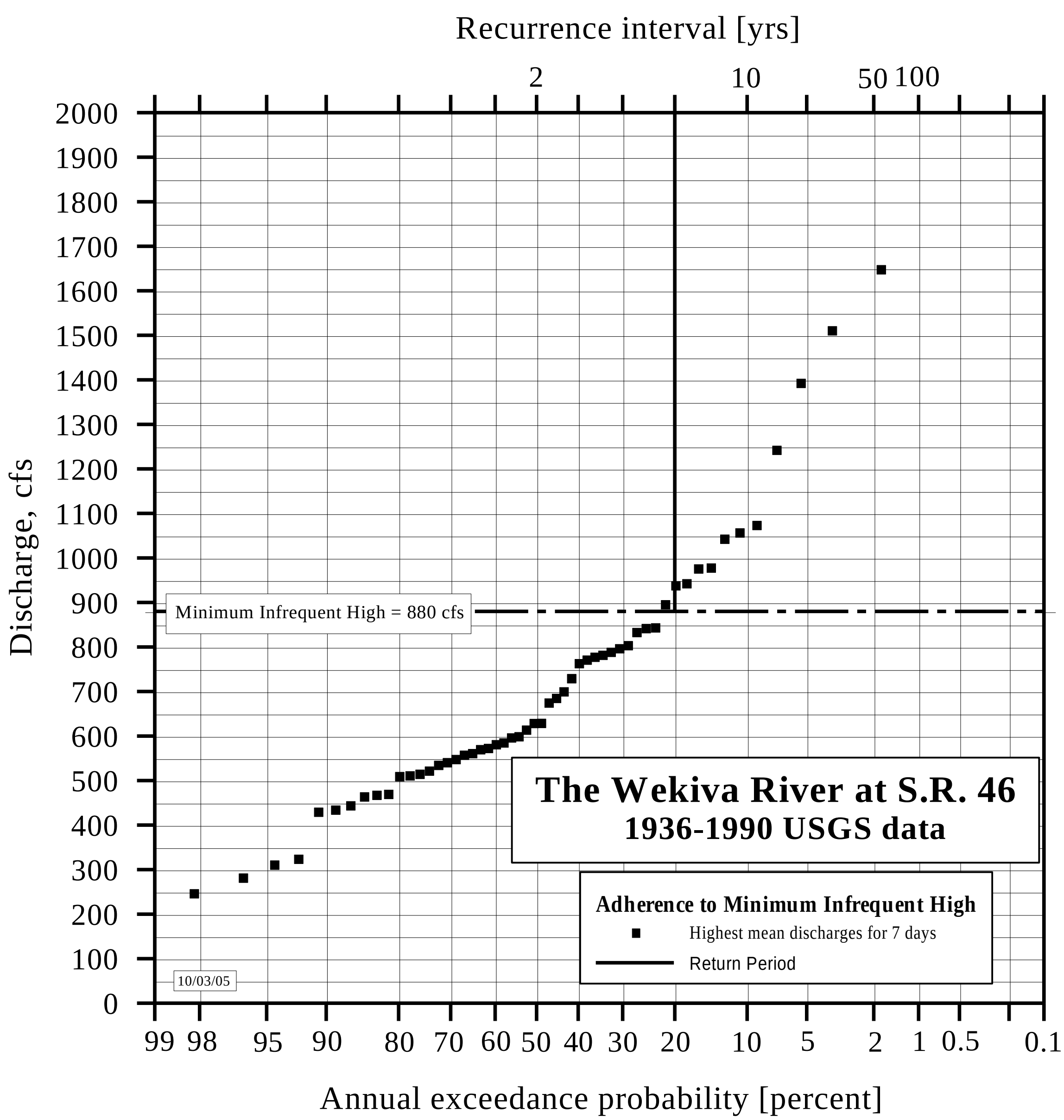


Figure 11. MFLs evaluation for the Minimum Infrequent High discharge

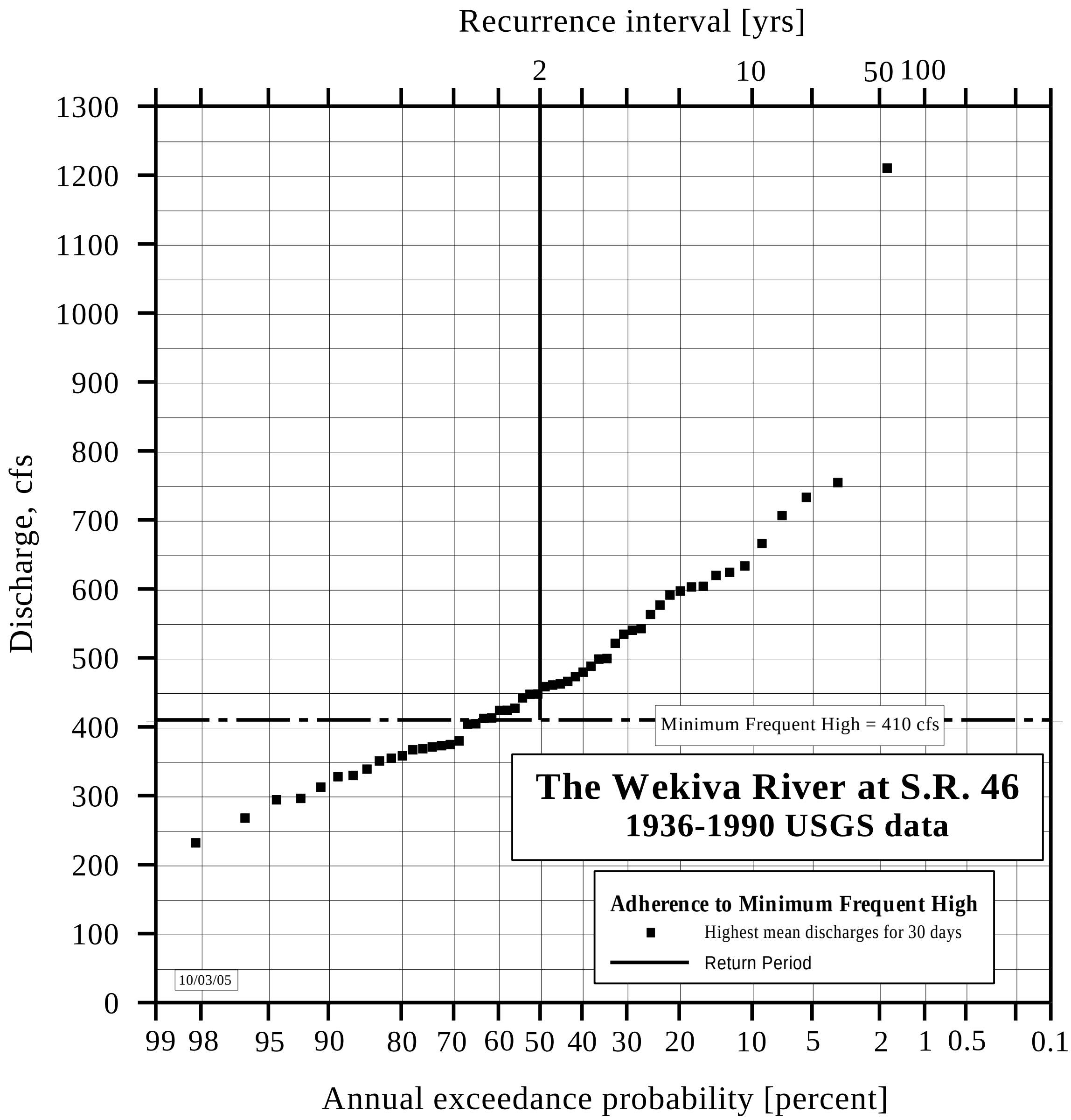


Figure 12. MFLs evaluation for the Minimum Frequent High discharge

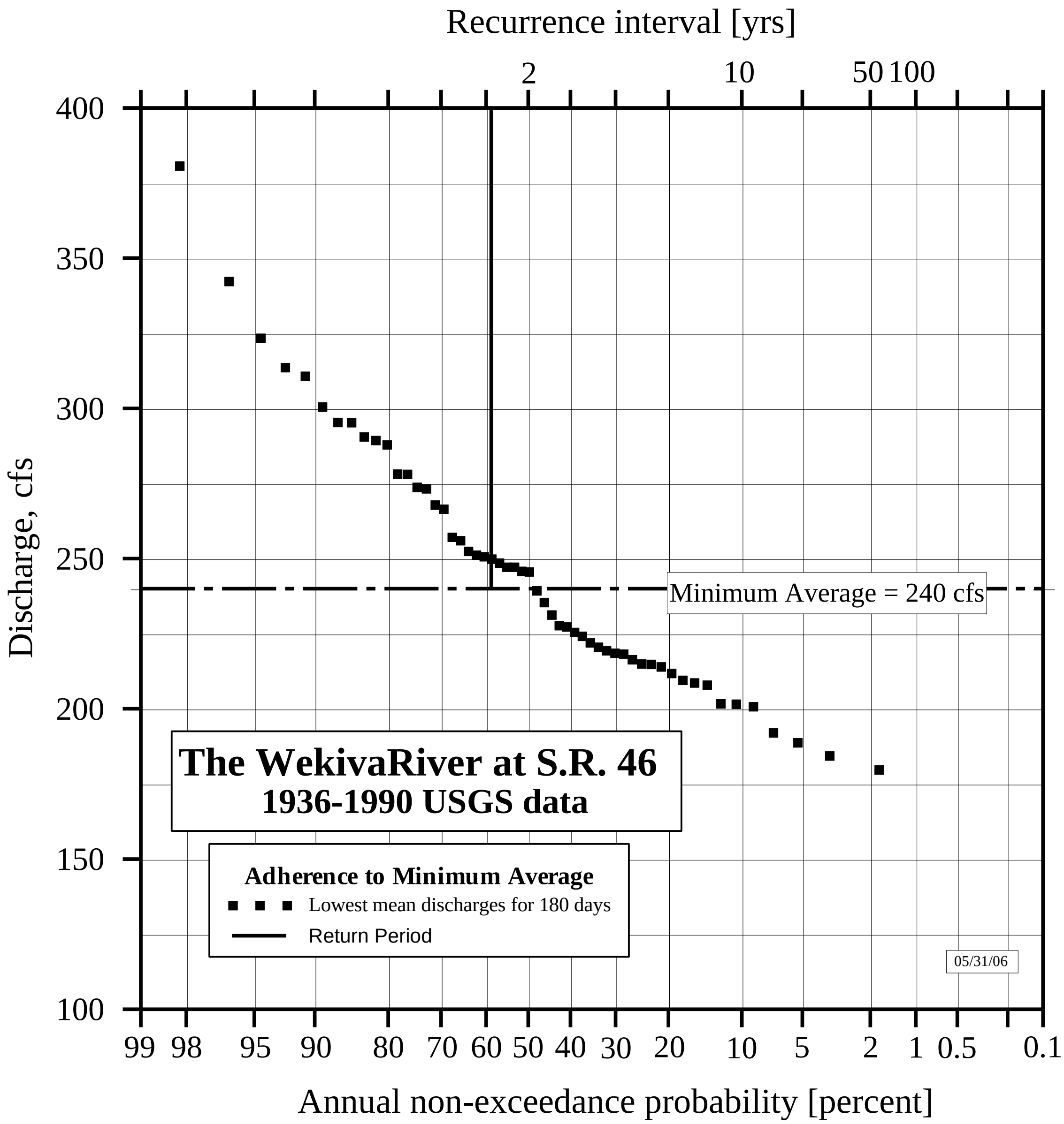


Figure 13. MFLs evaluation for the Minimum Average discharge

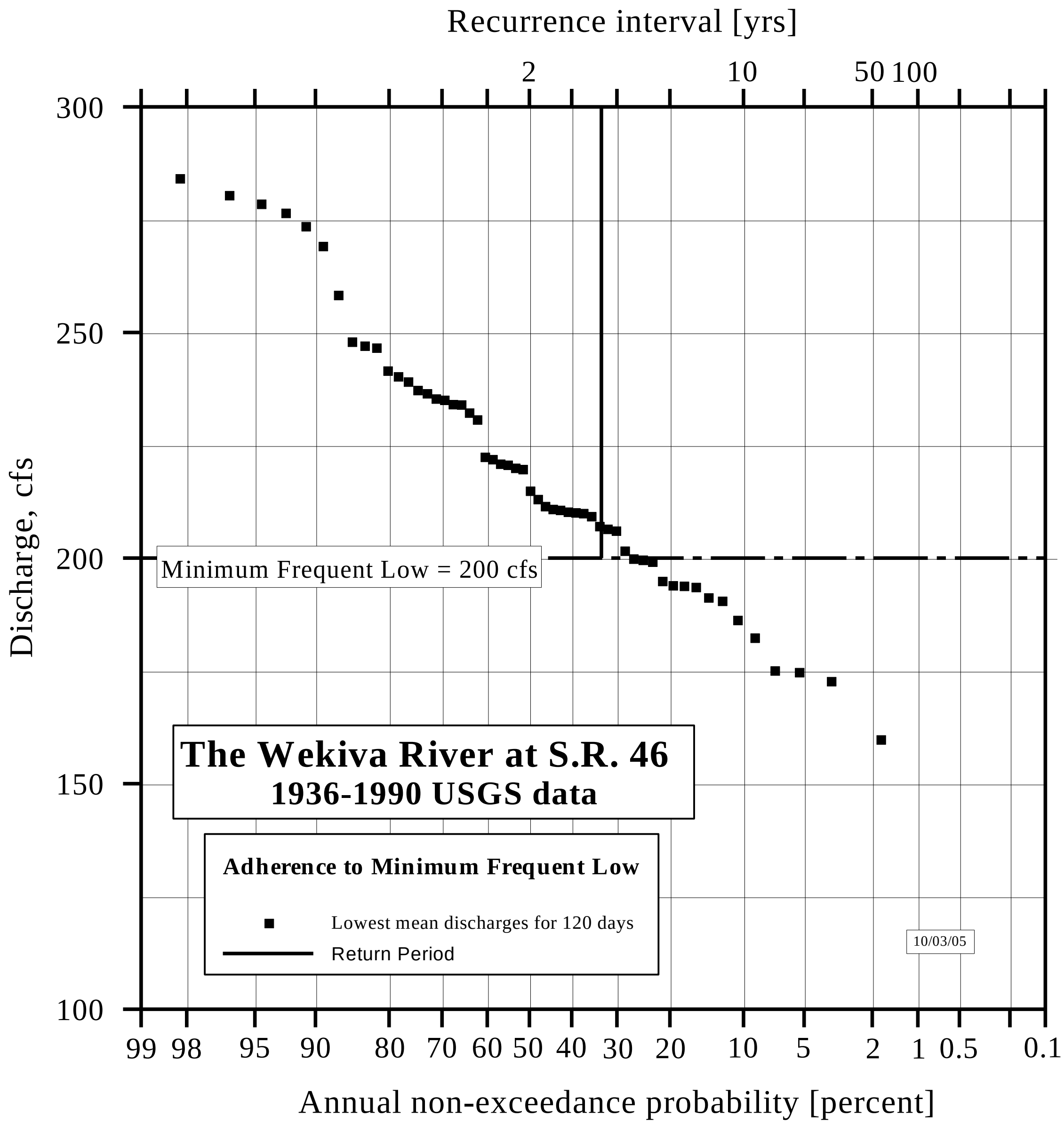


Figure 14. MFLs evaluation for the Minimum Frequent Low discharge

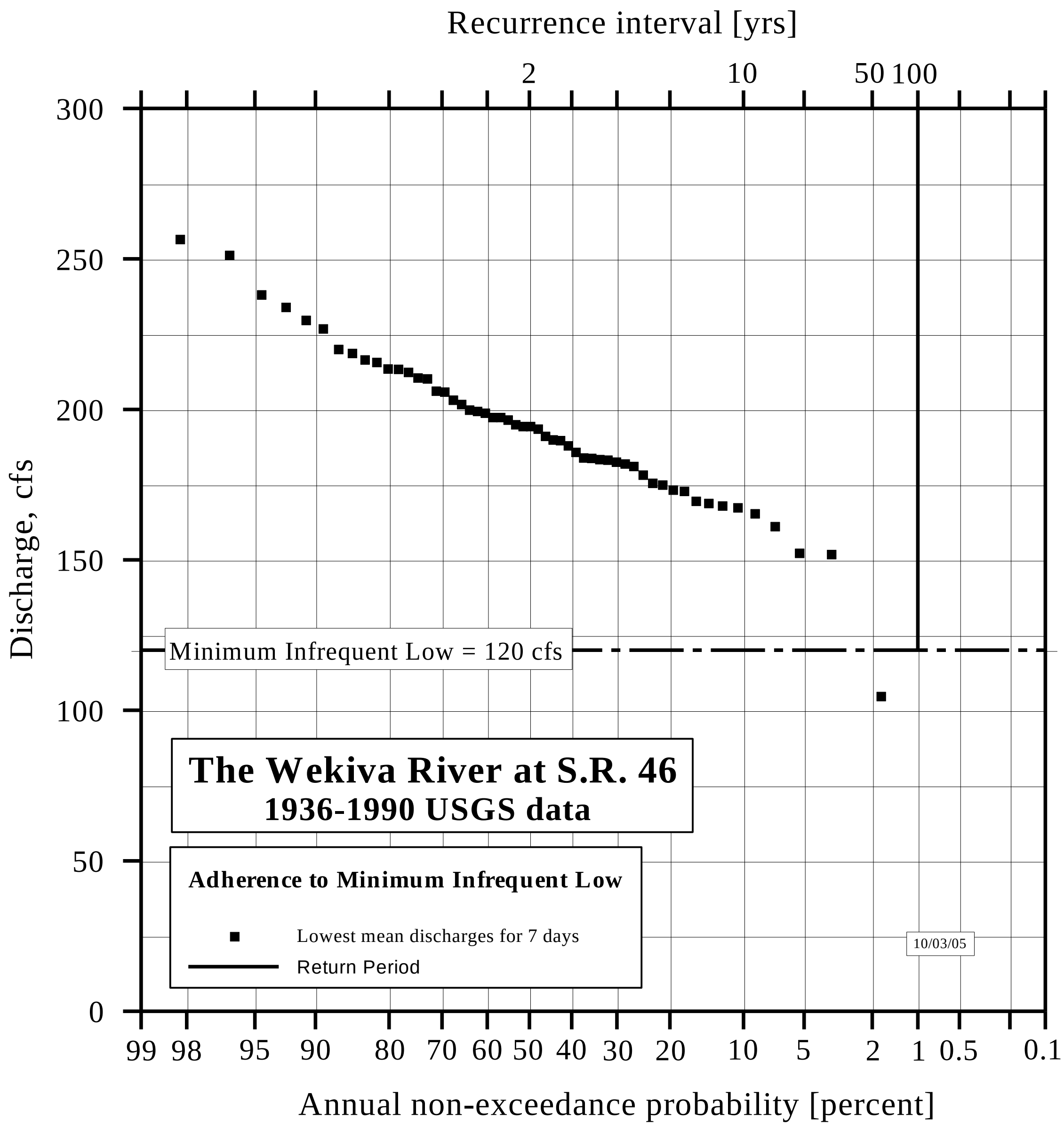


Figure 15. MFLs evaluation for the Minimum Infrequent Low discharge

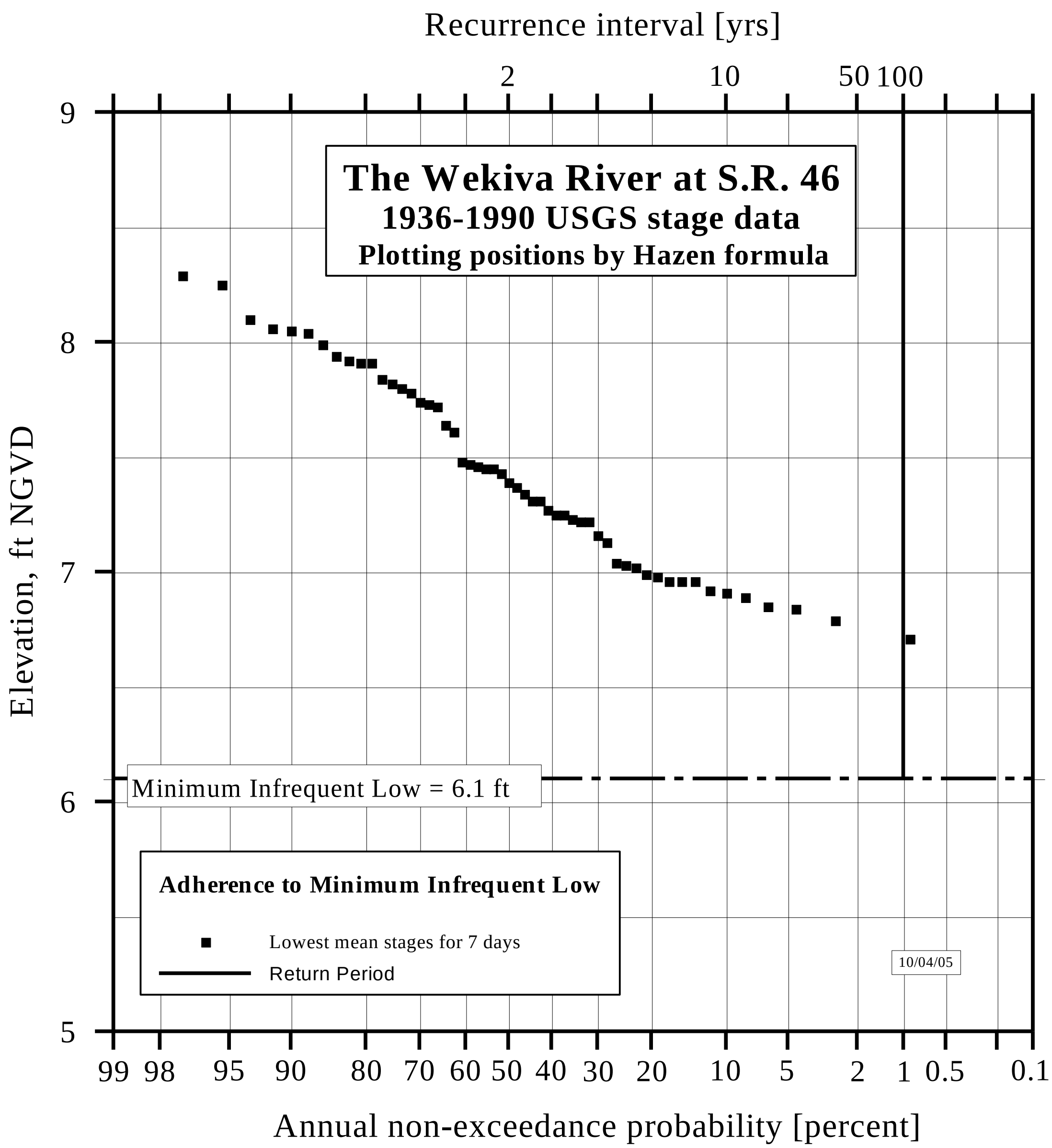


Figure 16. MFLs evaluation for the Minimum Infrequent Low stage
(Plotting positions are computed by Hazen formula)

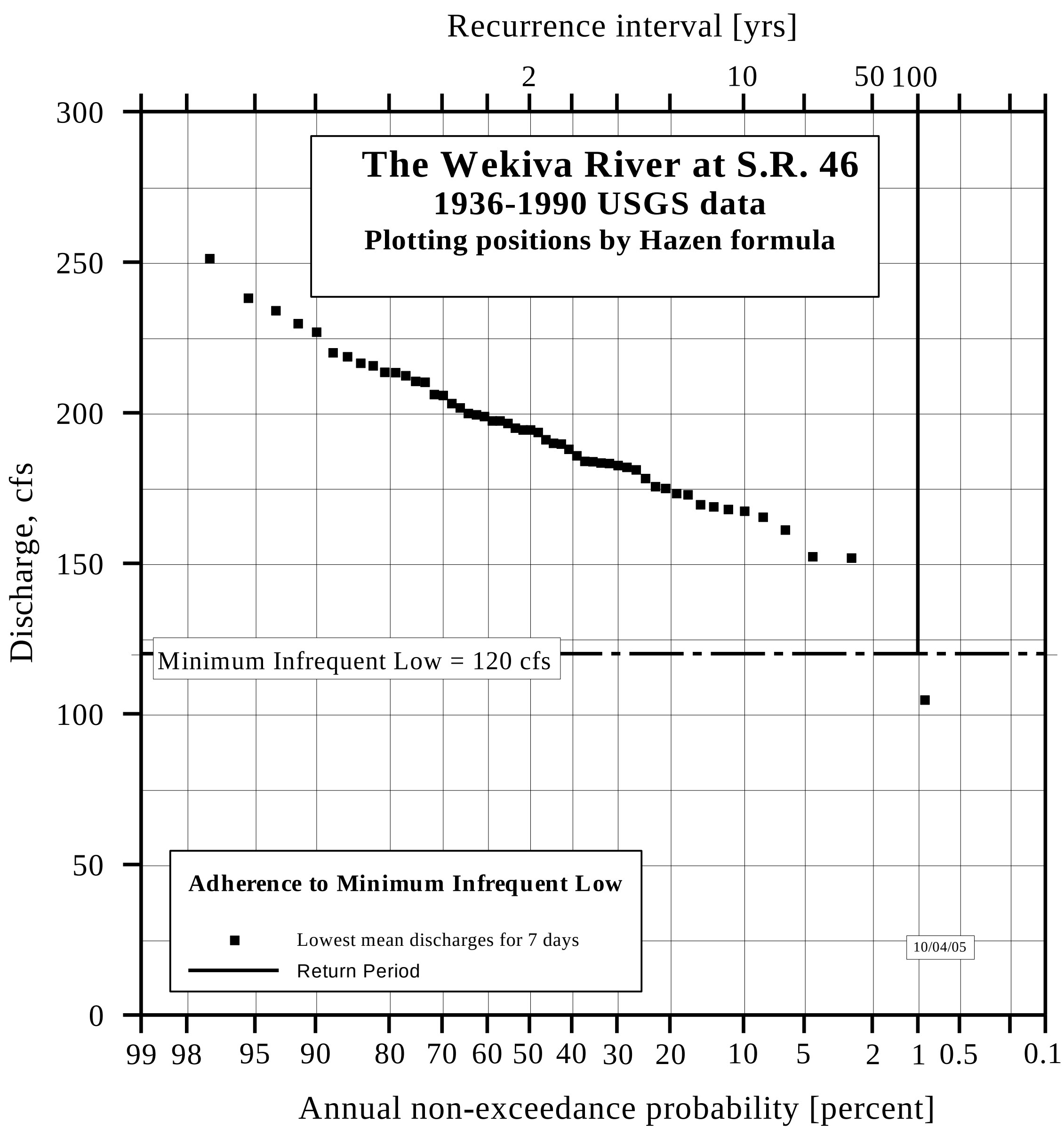


Figure 17. MFLs evaluation for the Minimum Infrequent Low discharge (Plotting positions are computed by Hazen formula)

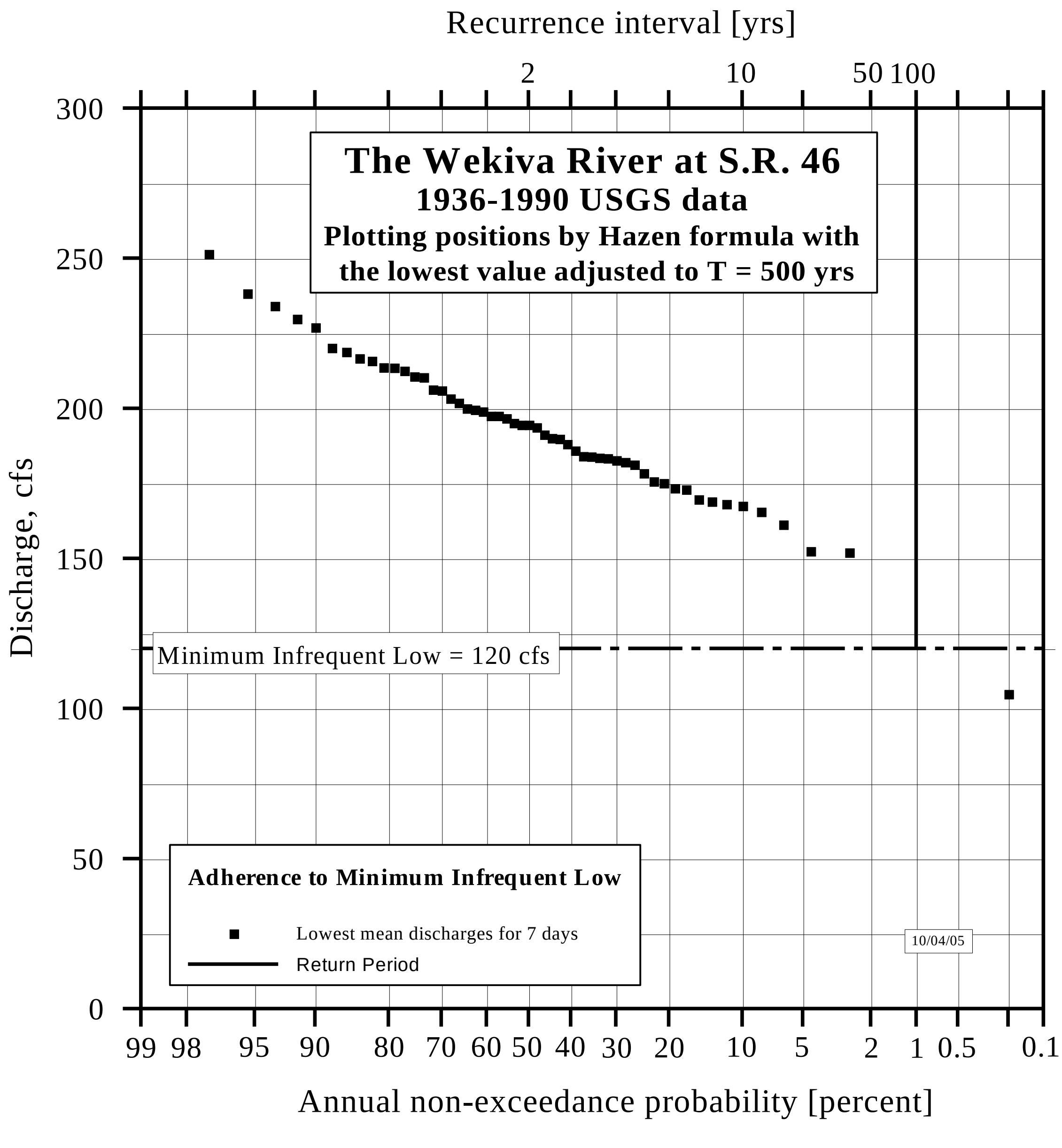


Figure 18. MFLs evaluation for the Minimum Infrequent Low discharge (Plotting positions are computed by Hazen formula, with the lowest value manually adjusted to T = 500 yrs)

Figure 19. The Wekiva River at S.R. 46 Bridge
USGS daily stage data (1935-2004)
(Note: USGS data starts on 10/1/1935. Missing data are estimated by interpolation)

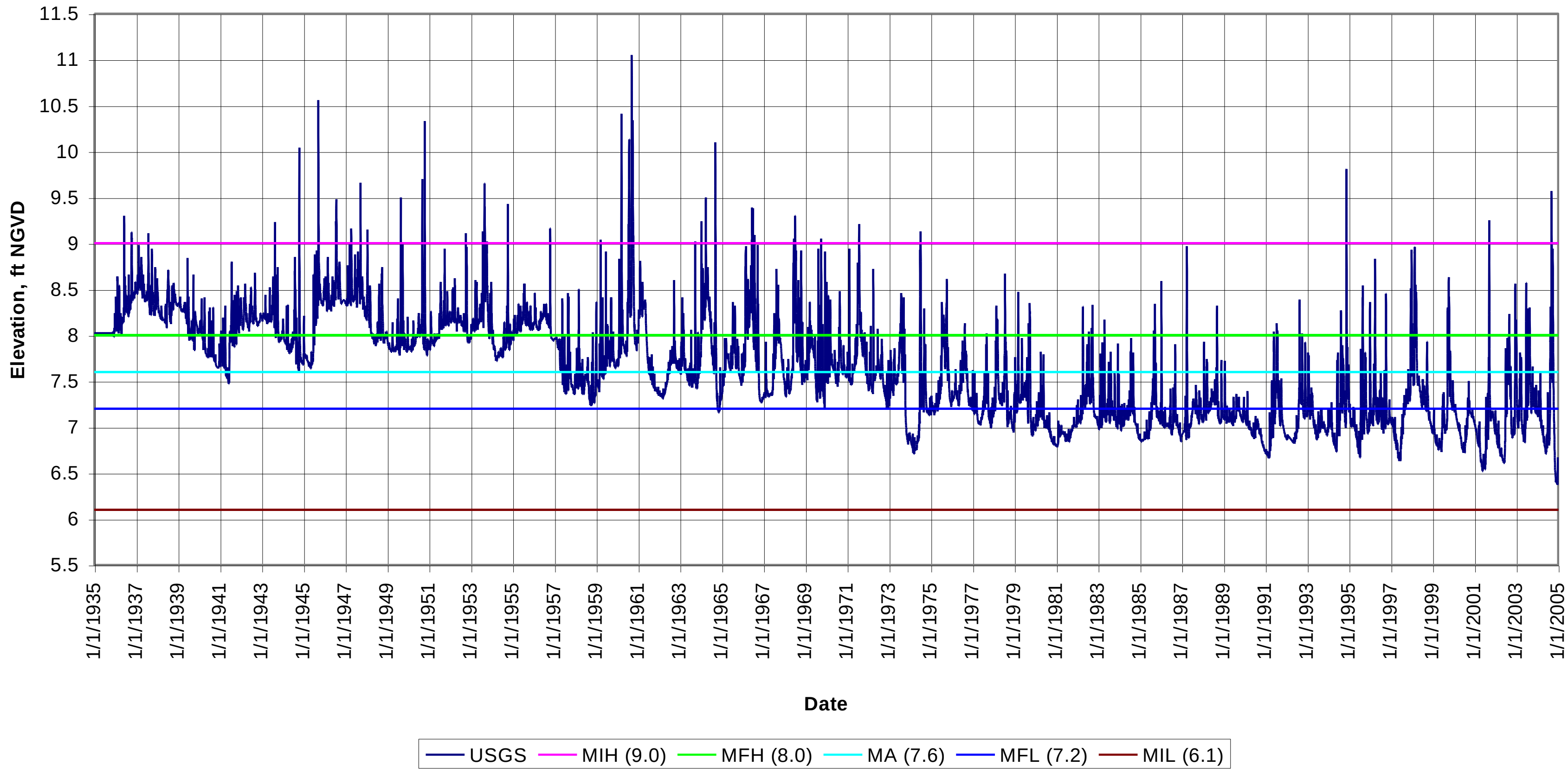


**Figure 20. The Wekiva River at S.R. 46 Bridge
USGS Daily discharge data (1935-2004)**

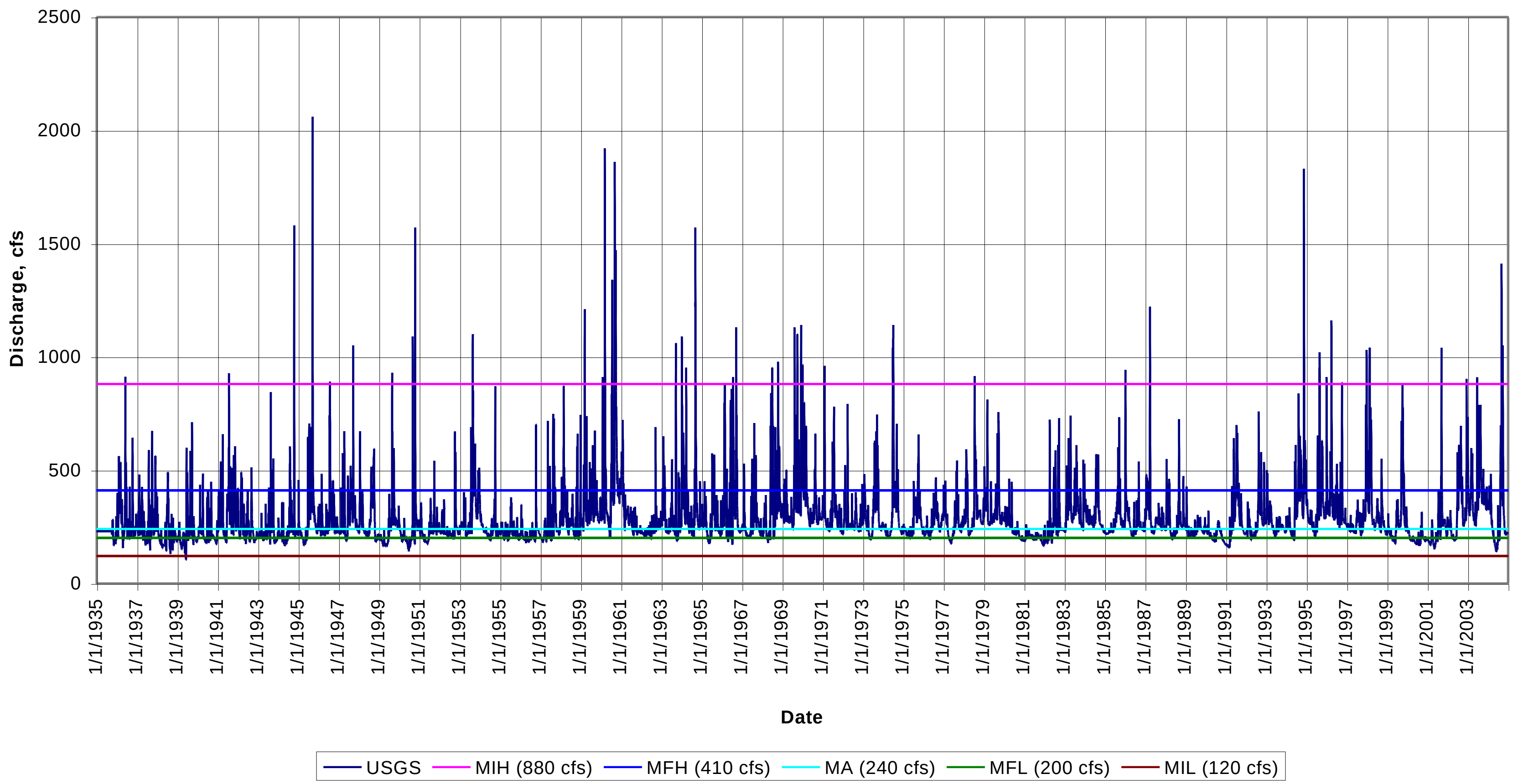


Figure 21. The Wekiva River at S.R. 46 Bridge
Stage-duration curves for different periods: USGS data

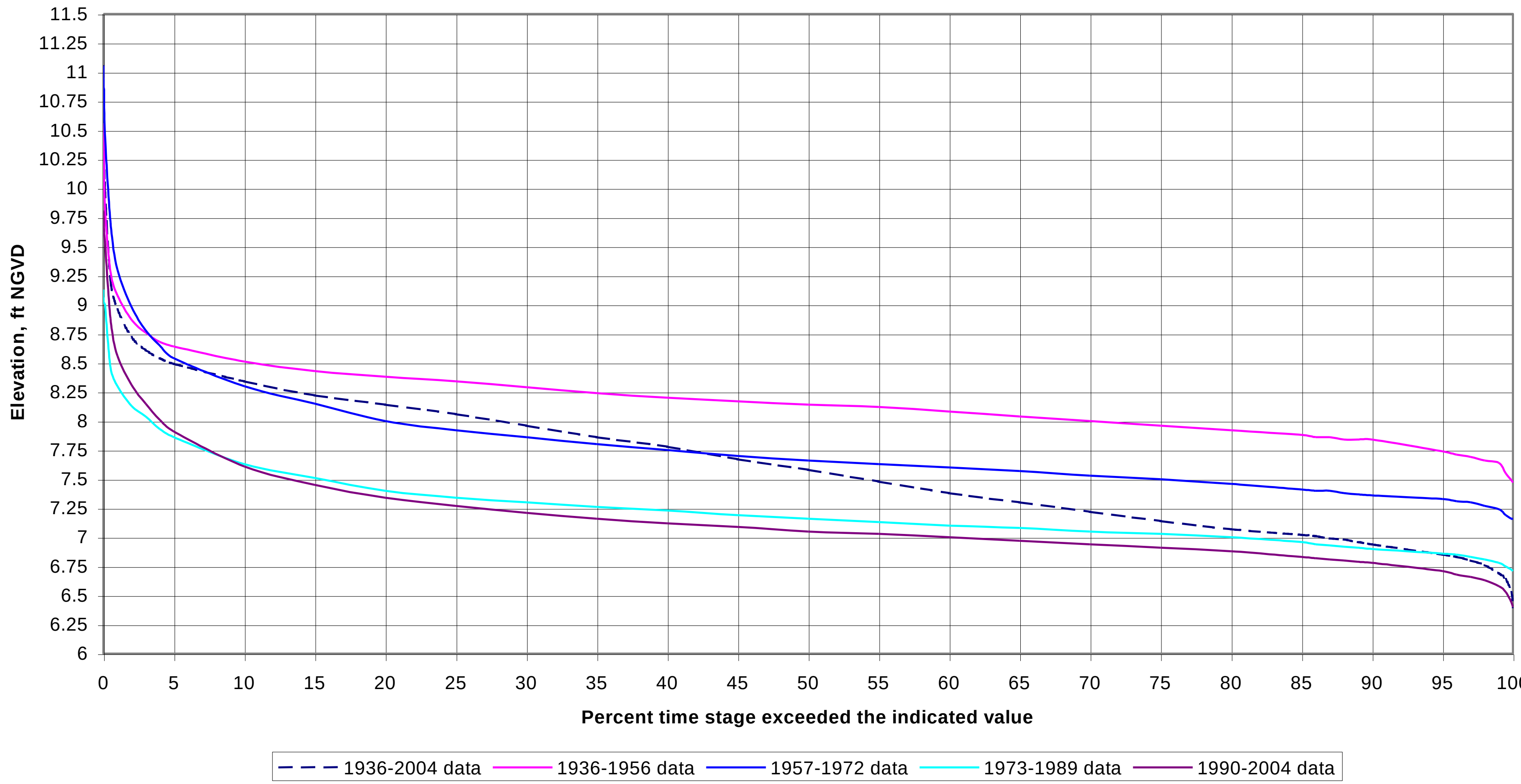


Figure 22. The Wekiva River at S.R. 46 Bridge
Discharge-duration curves for different periods: USGS data

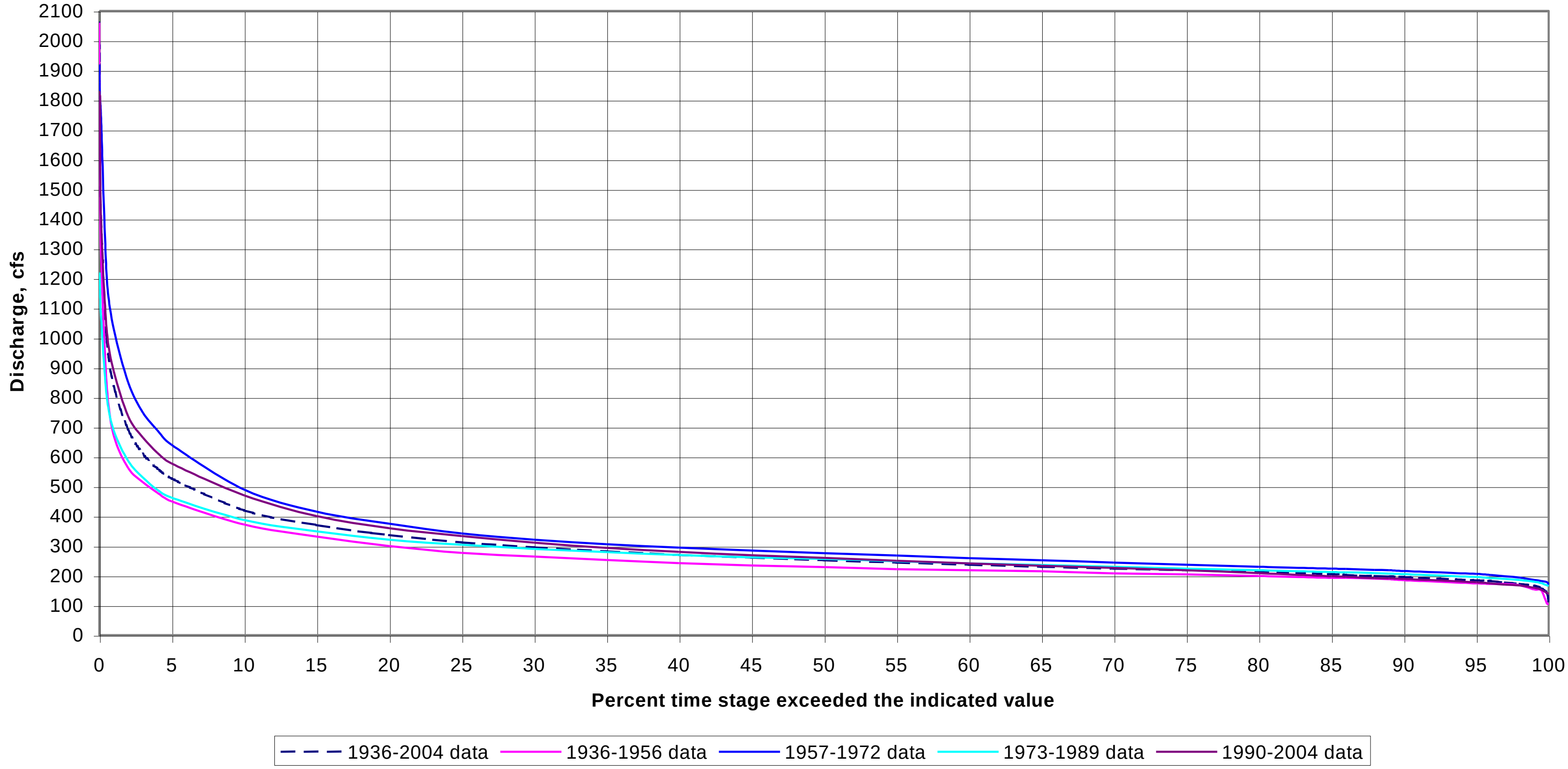


Figure 23. The Wekiva River at S.R. 46 Bridge
Discharge-duration curves for different periods: USGS data
Discharges in the range of 0 to 400 cfs

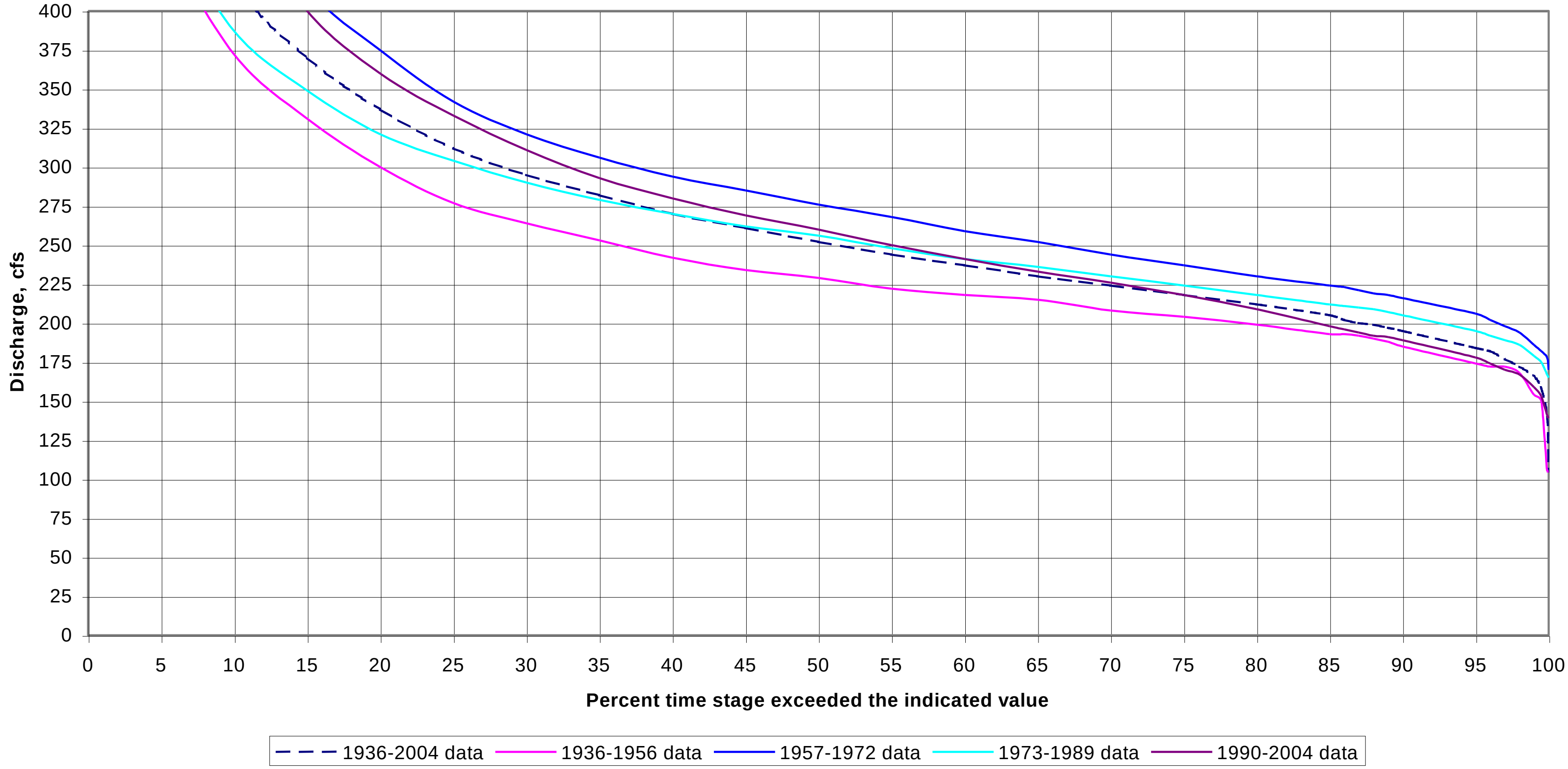


Figure 24. The Wekiva River at the S.R. 46 Bridge
Annual mean and low flow comparison

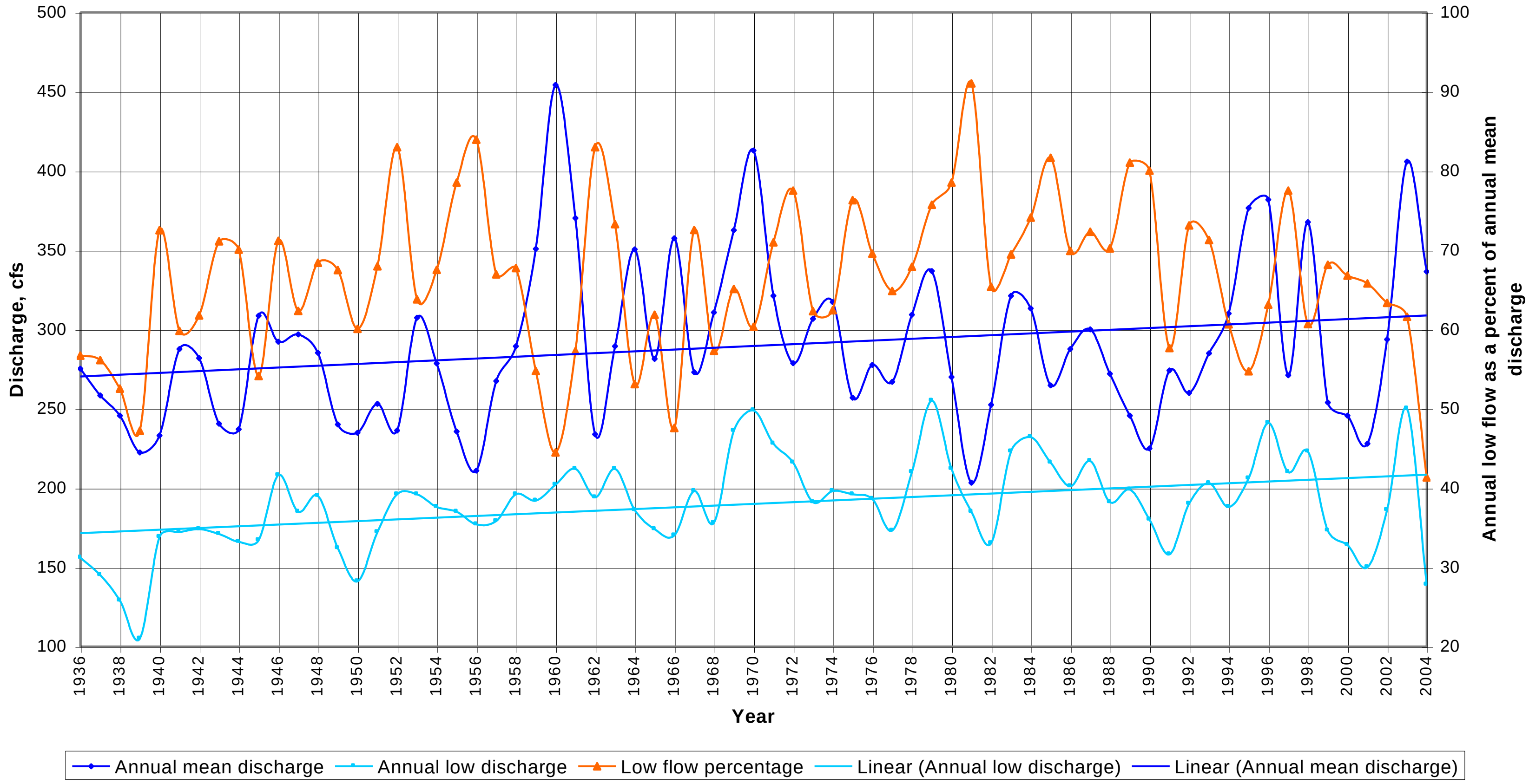


Figure 25. The Wekiva River at the S.R. 46 Bridge
Mass curve of annual discharges

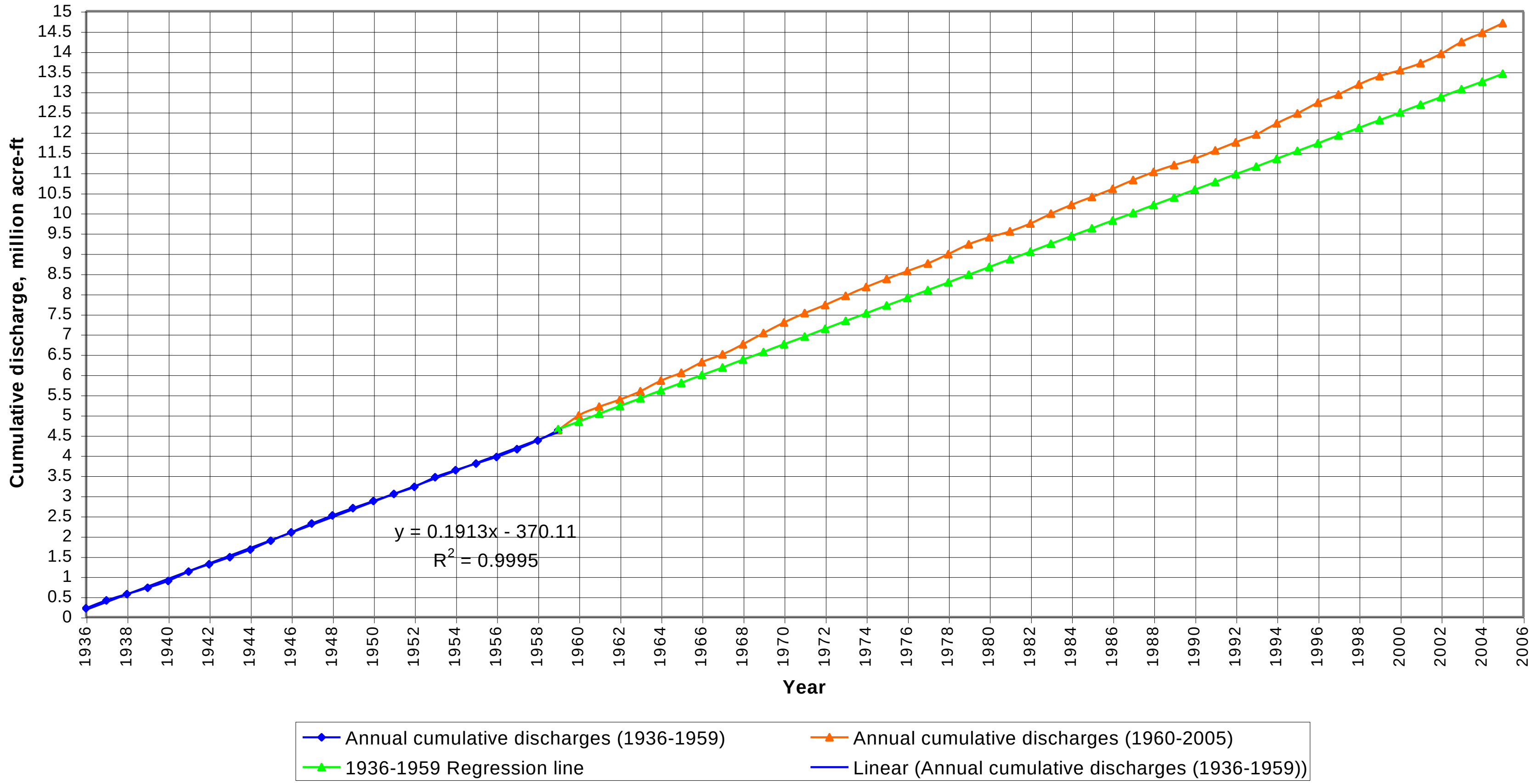
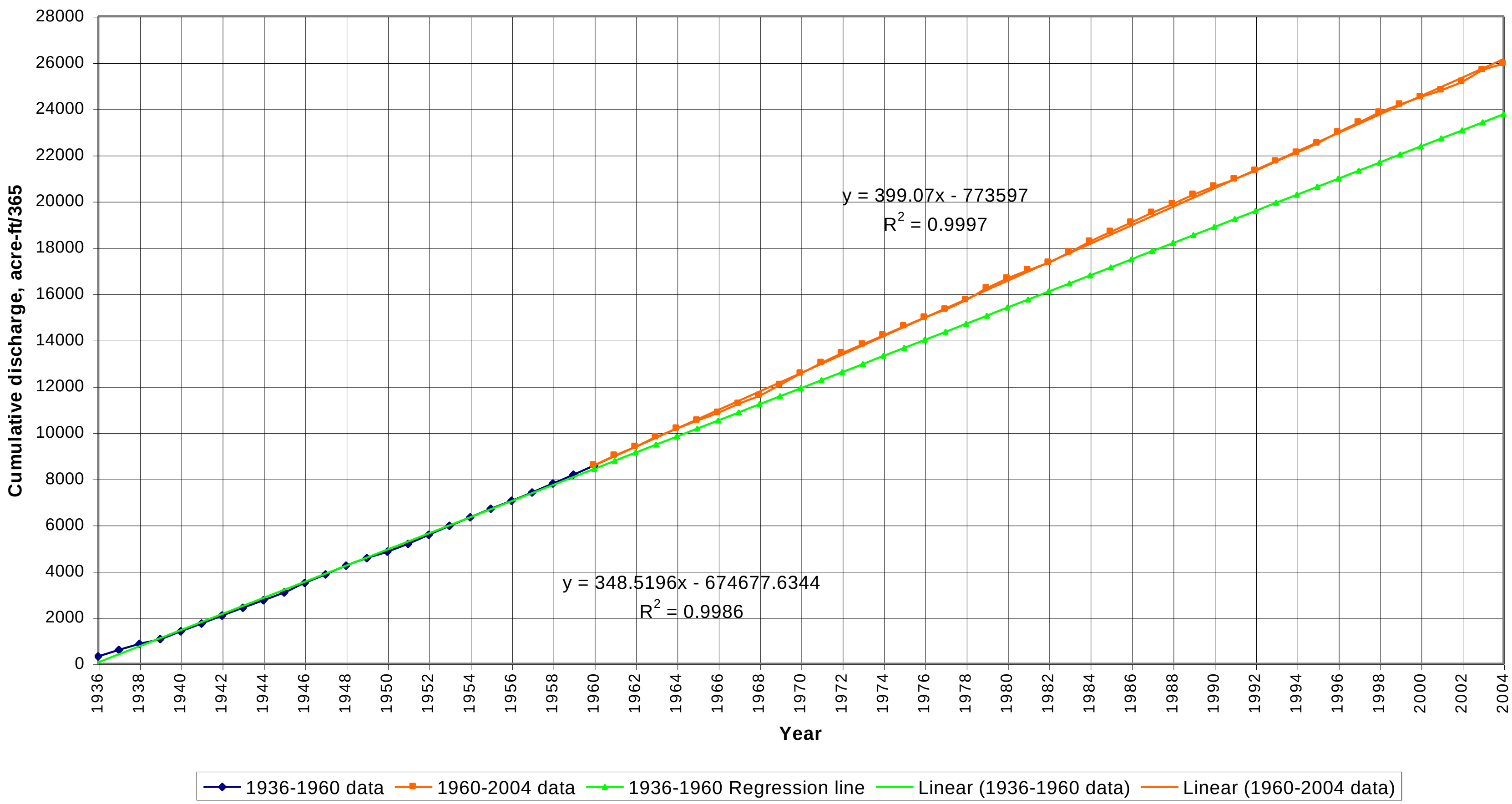


**Figure 26. The Wekiva River at the S.R. 46 Bridge
Mass curve of annual low flows**



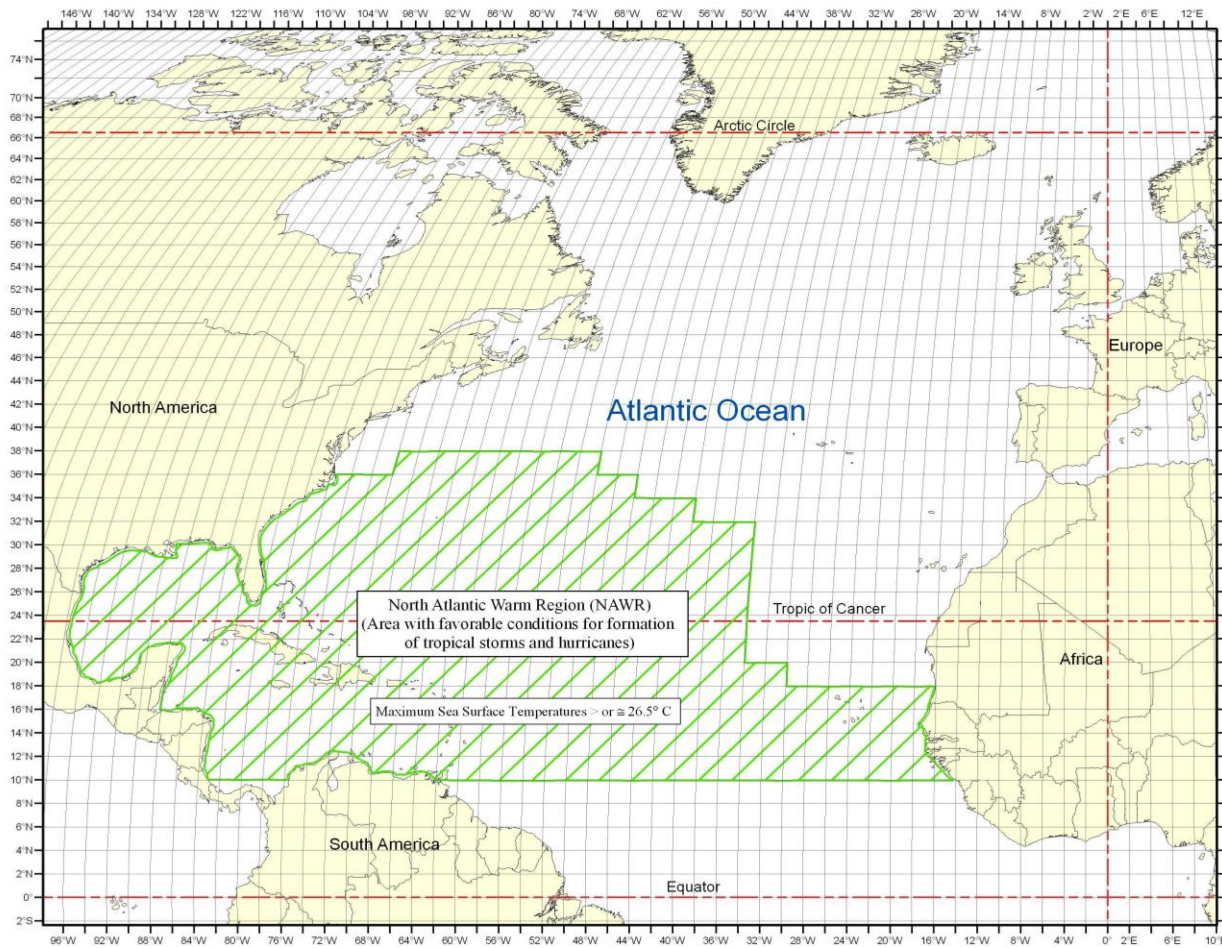


Figure 27. The North Atlantic Ocean

Figure 28. North Atlantic Sea Surface Temperatures and NE Florida Index Rainfall
10-year moving averages (Detrended data)

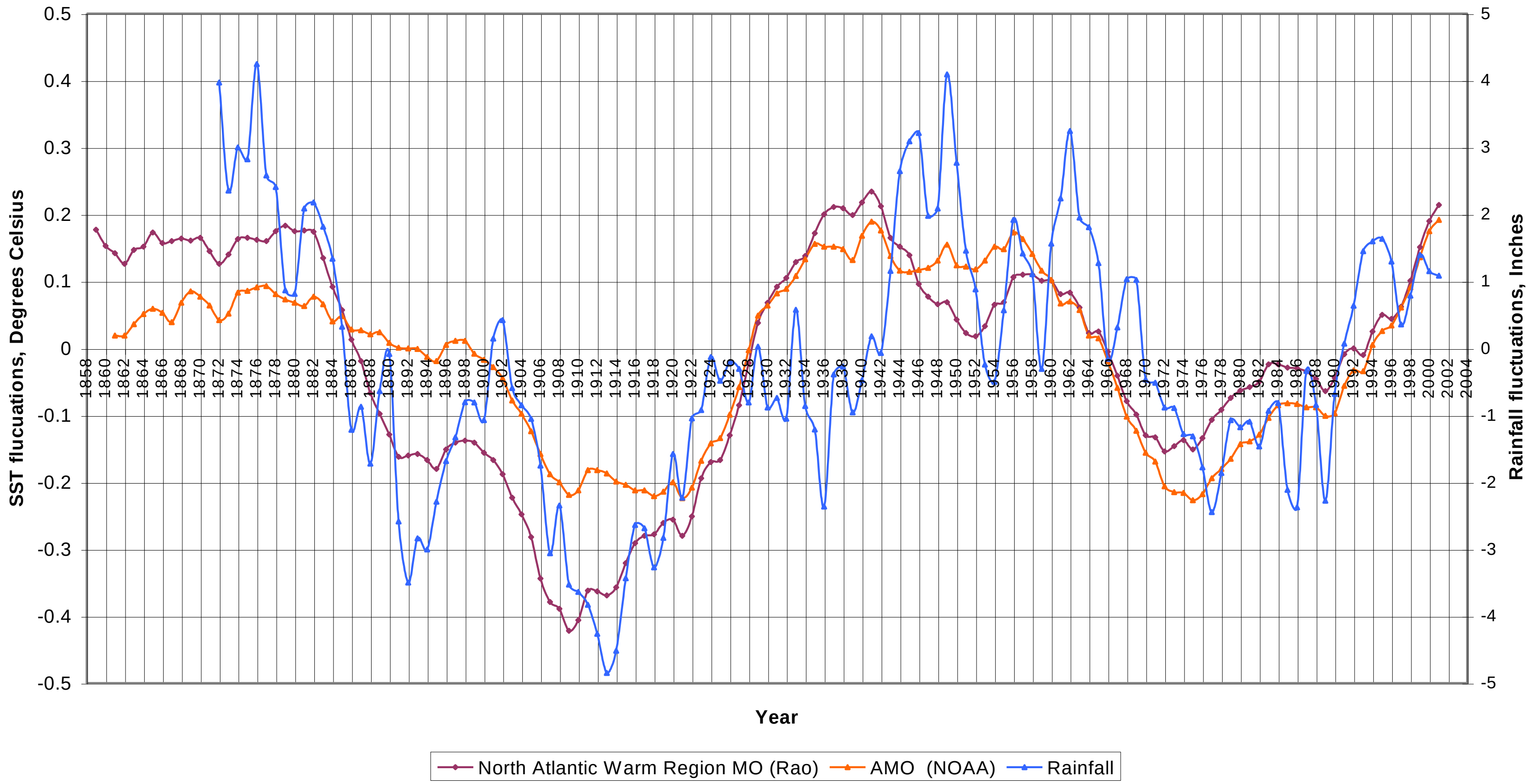


Figure 29. North Atlantic Sea Surface Temperatures and NE Florida Index Rainfall Wet Season (June - November): 10-year moving averages (Detrended data)

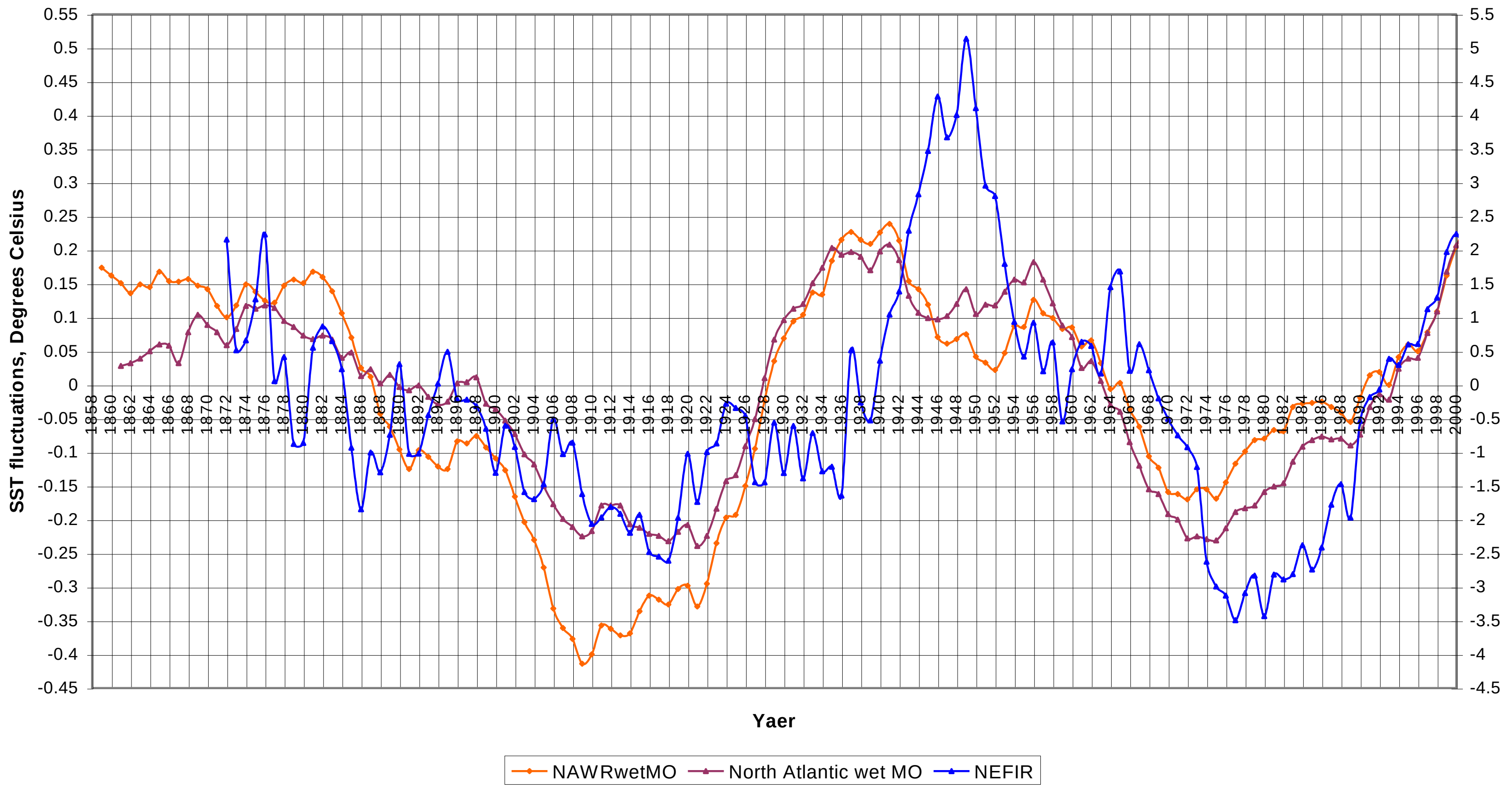


Figure 30. North Atlantic SSTs and Orlando Rainfall
Comparison of ten-year moving averages

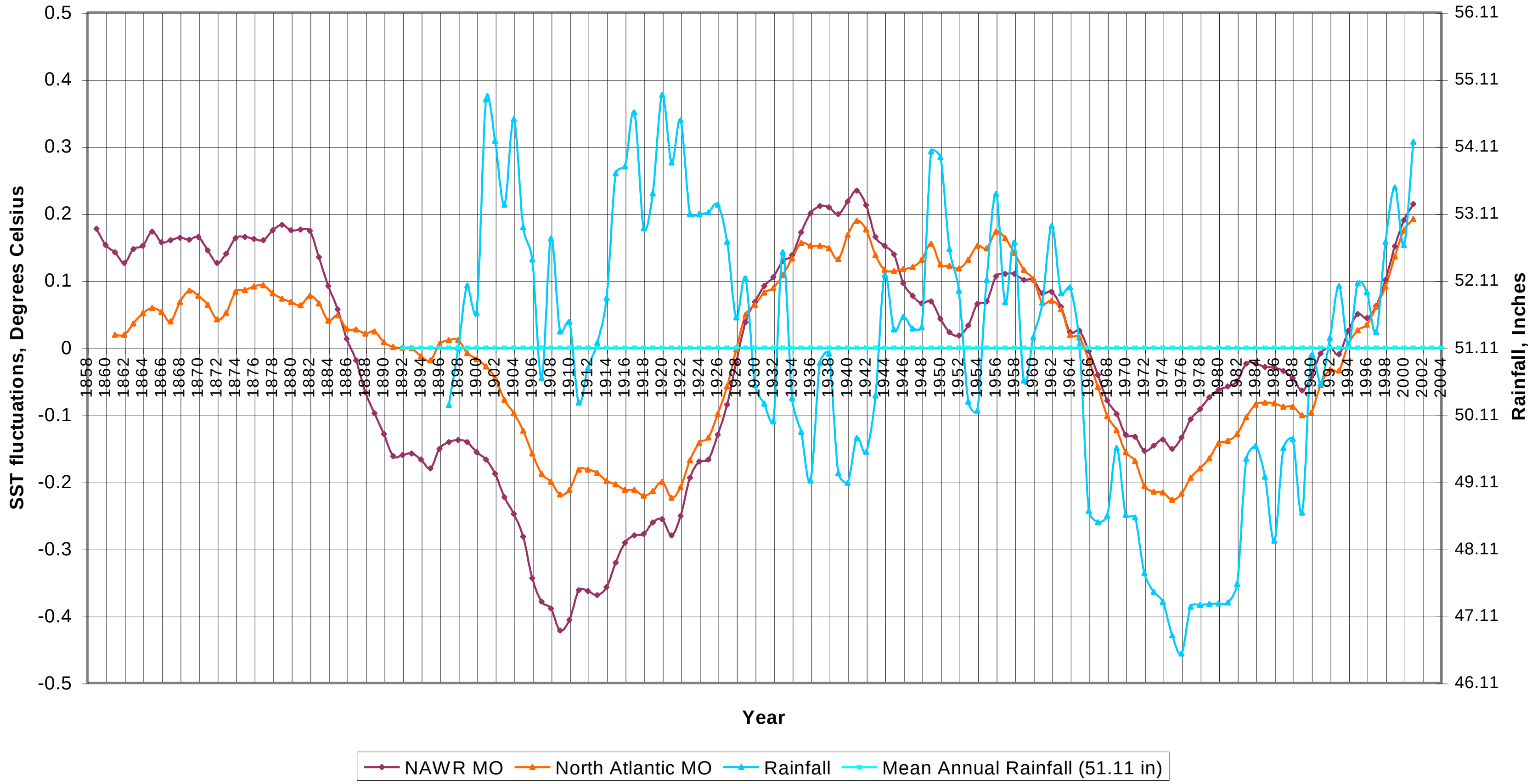


Figure 31. North Atlantic Sea Surface Temperatures and Orlando Rainfall Wet-Season (Jun-Nov): 10-year moving averages

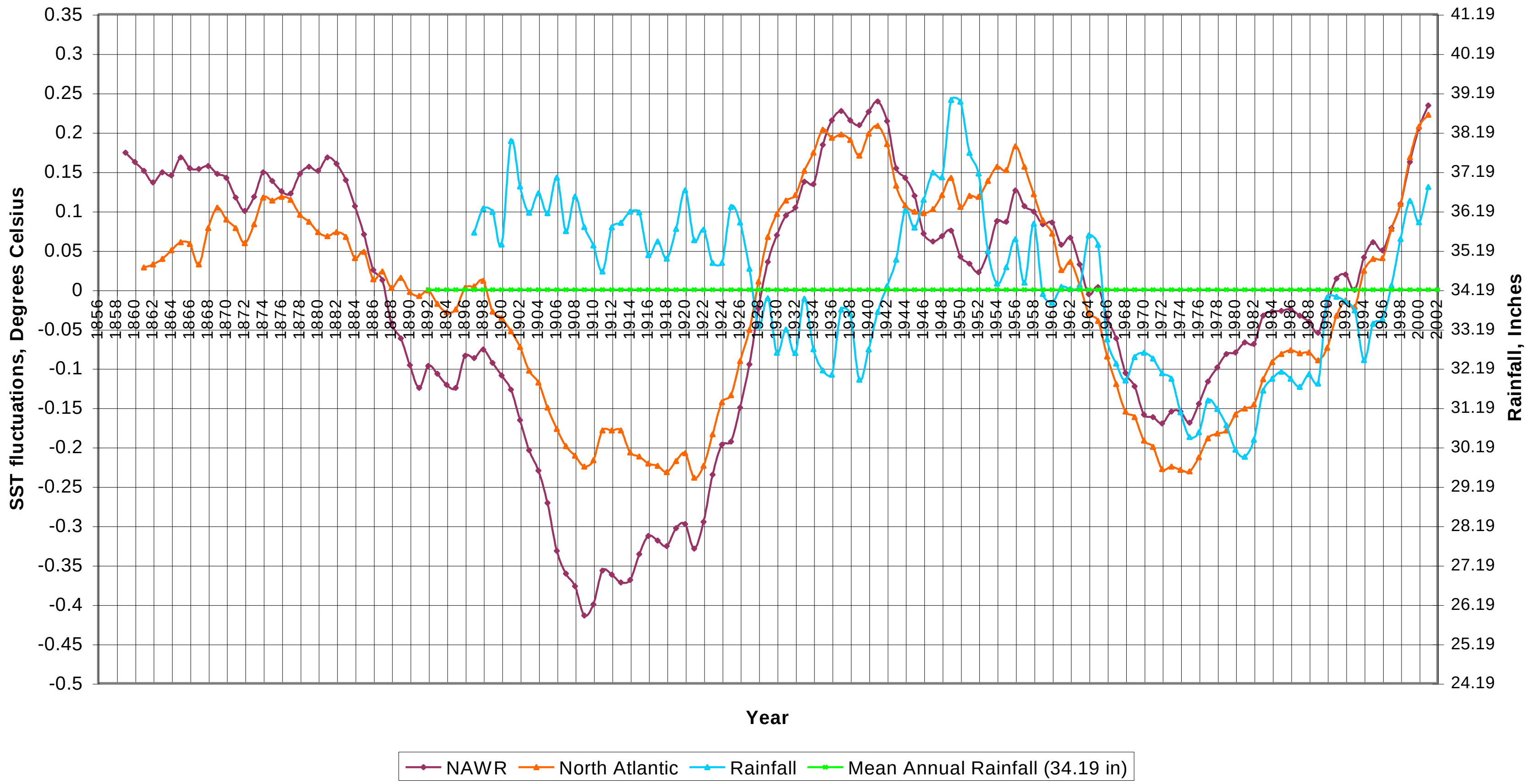


Figure 32. The Wekiva River at the Old RR Crossing and the S.R. 46 Bridge Discharge hydrographs and daily discharge differences

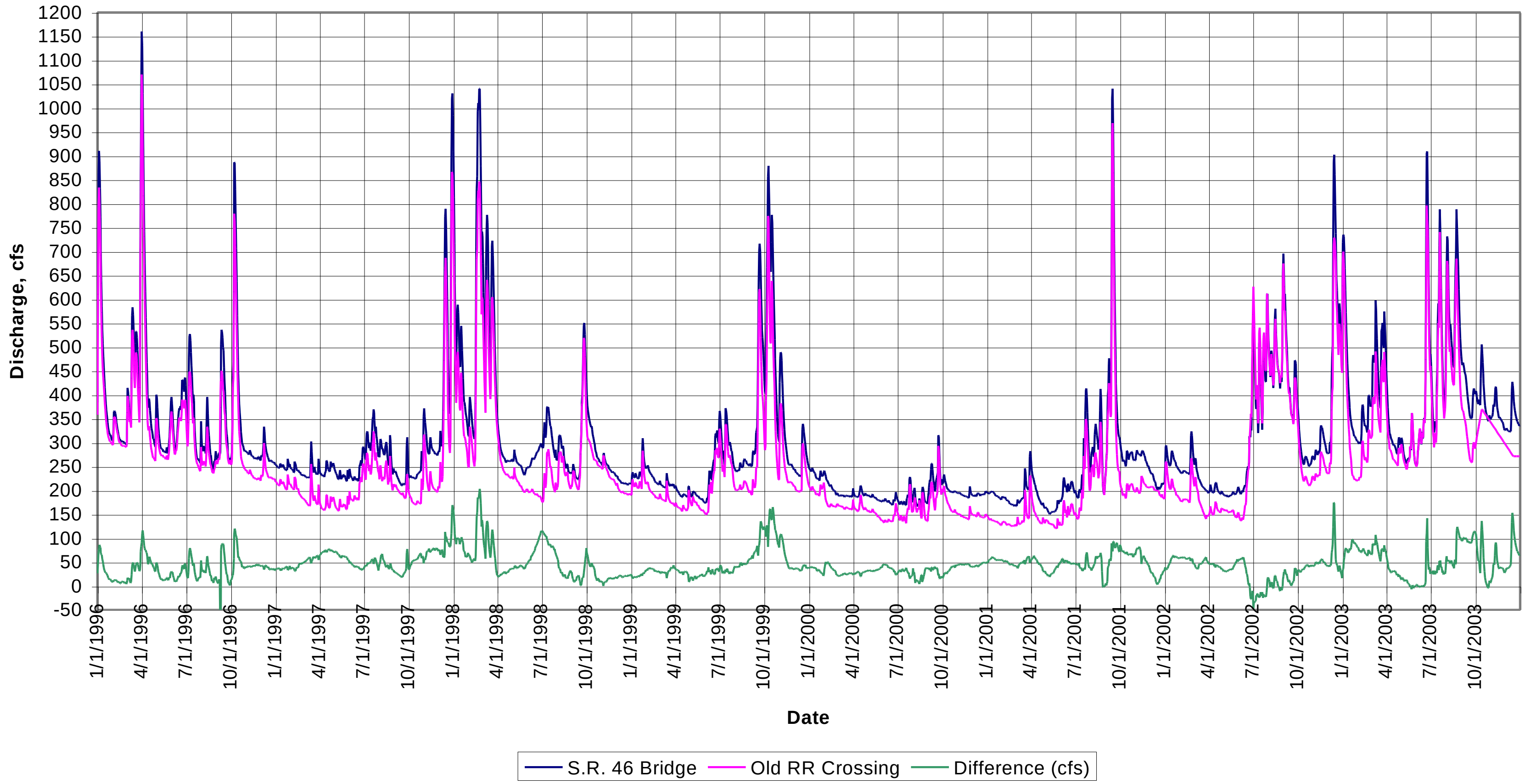


Figure 33. The Wekiva River at the Old RR Crossing and the S.R. 46 Bridge
Stage hydrographs and daily stage differences

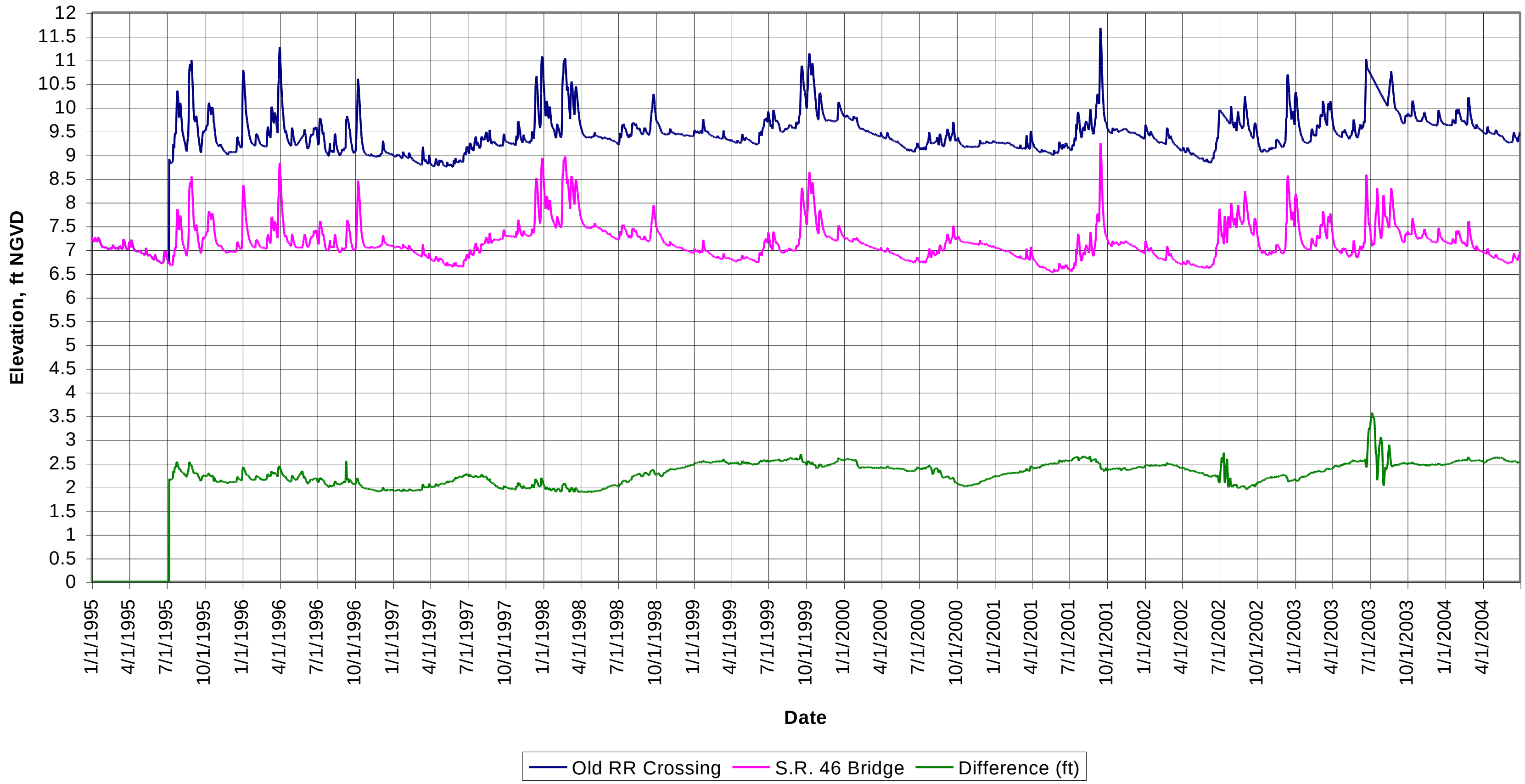


Figure 34. The Wekiva River at the Old RR Crossing and the S.R. 46 Bridge
Comparison of discharge-duration curves

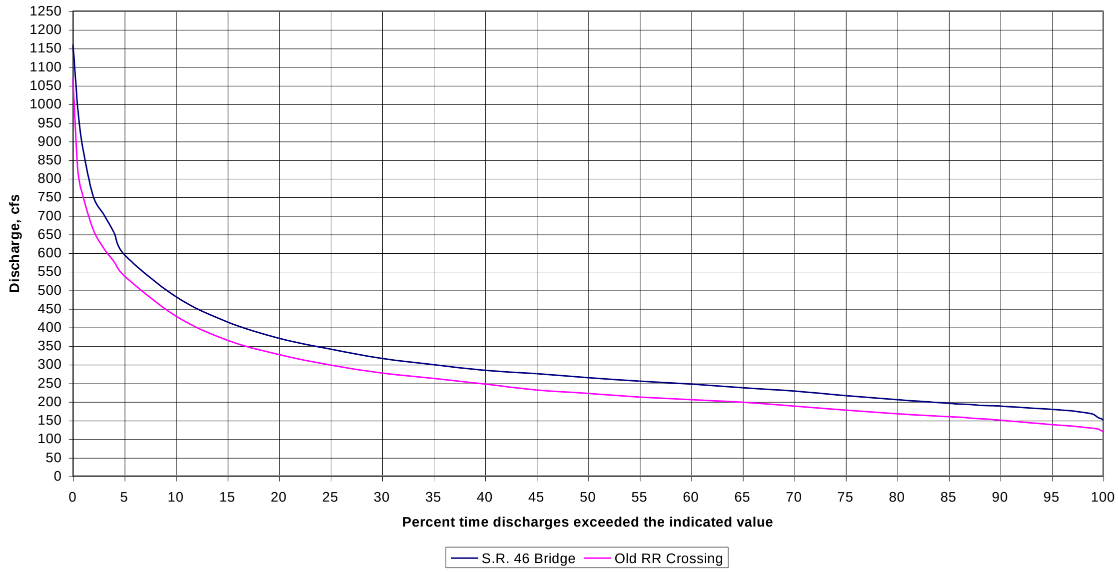


Figure 35. The Wekiva River at the Old RR Crossing and the S.R. 46 Bridge
Comparison of stage-duration curves

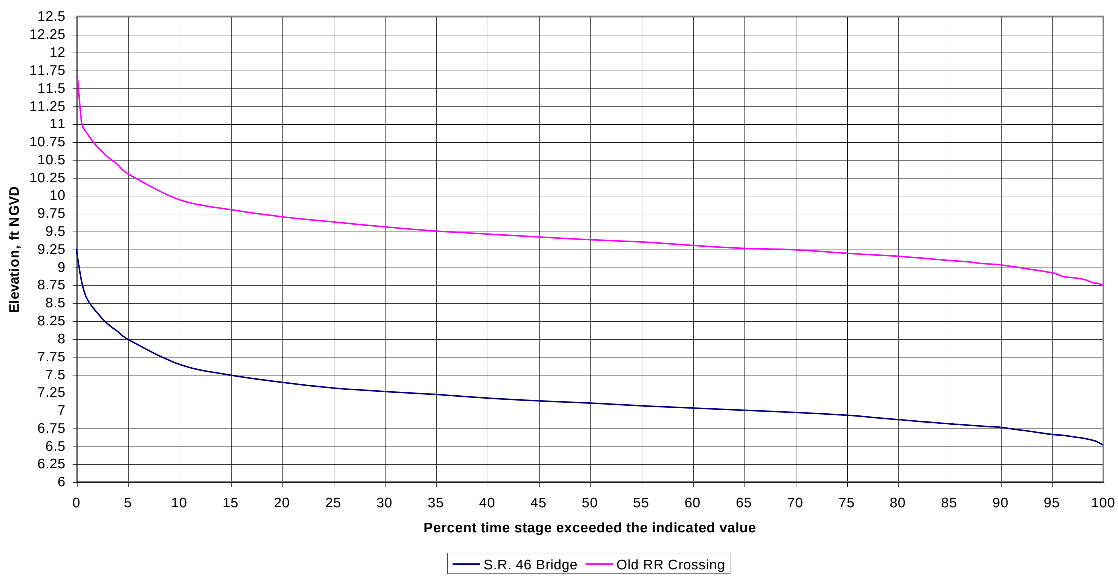


Figure 36. The Wekiva River at the Old RR Crossing
Daily discharges vs. discharge differences from the S.R. 46 gage

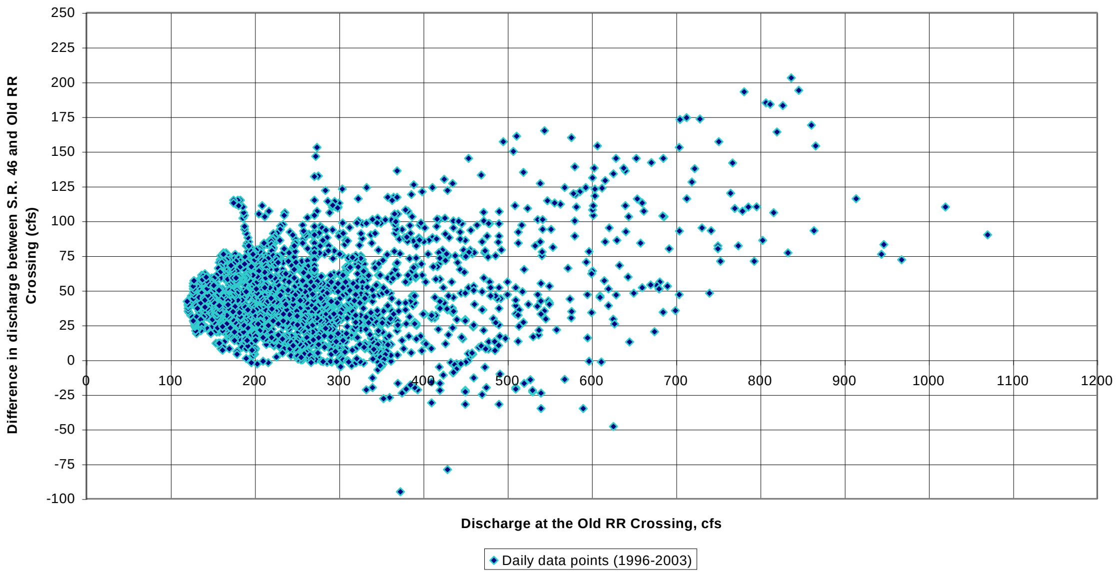


Figure 37. The Wekiva River at the Old RR Crossing
Daily stages vs. stage differences from the S.R. 46 gage

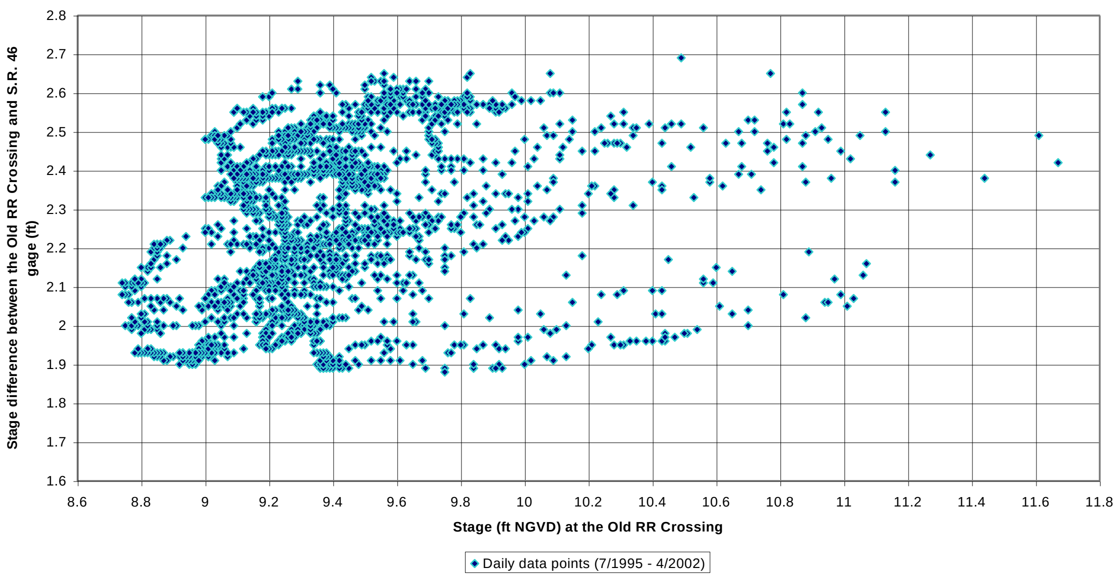


Figure 38a. The Wekiva River at Old RR Crossing
Stage vs. Discharge (7/8/1995 - 10/31/2004 USGS data)

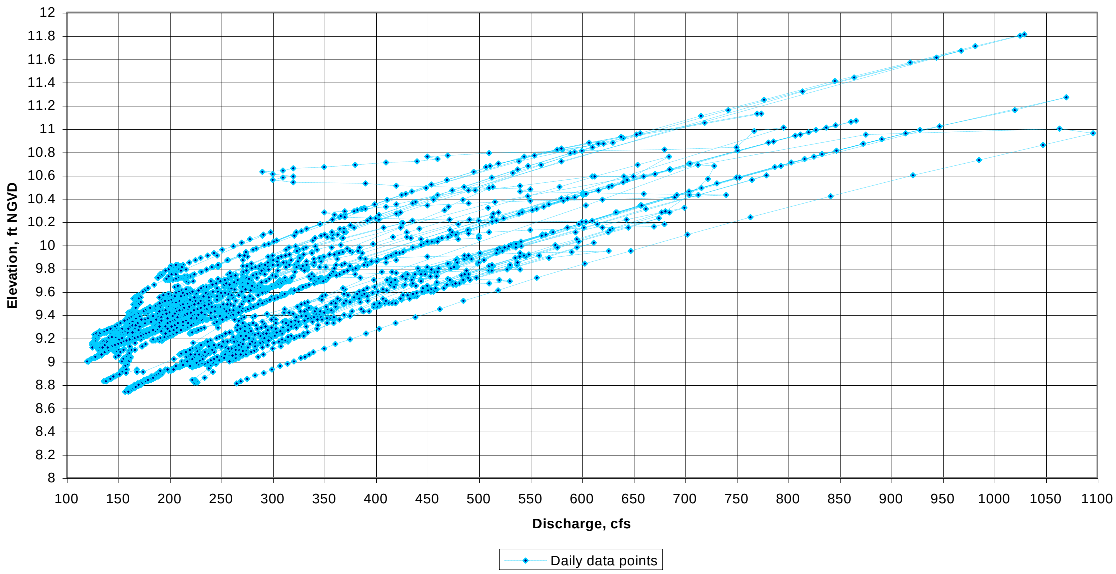
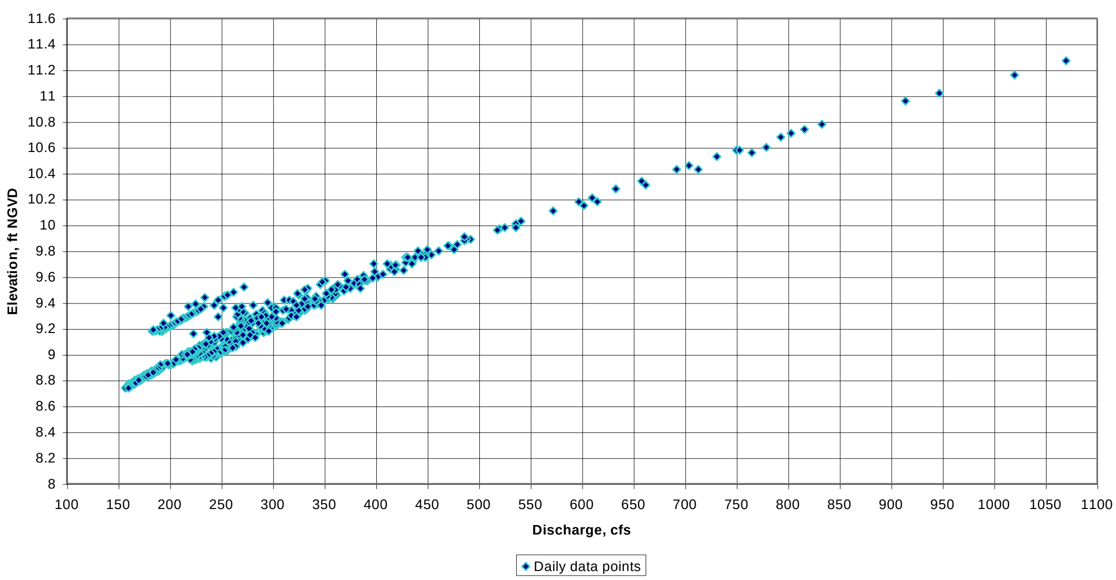
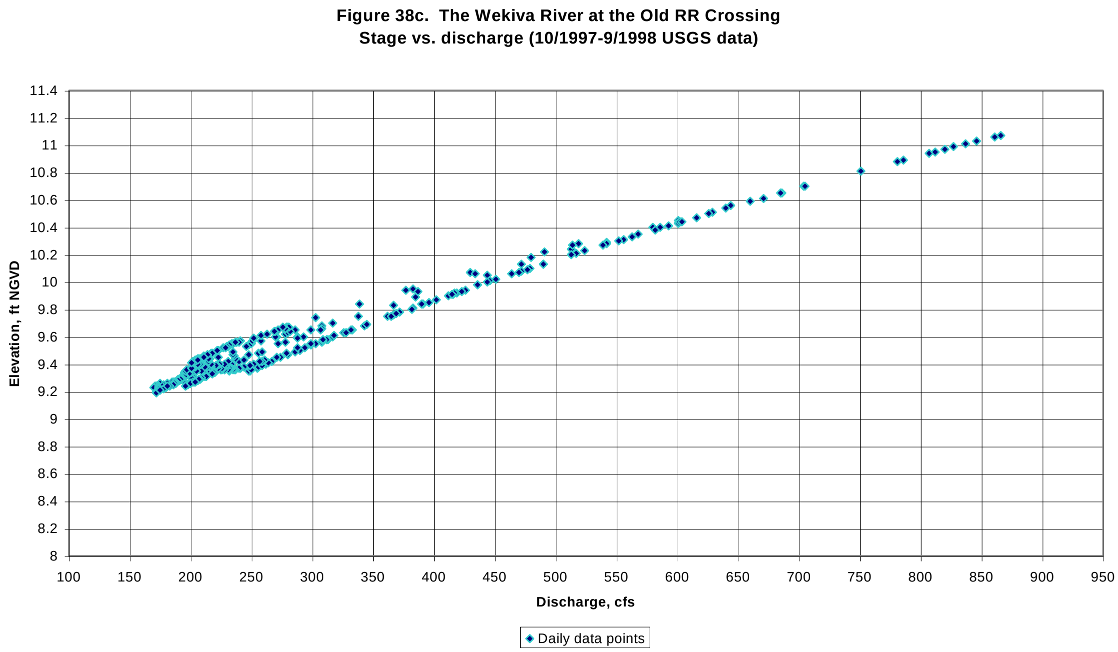


Figure 38b. The Wekiva River at the Old RR Crossing
Stage vs. discharge (1/1996 - 9/1997 USGS data)





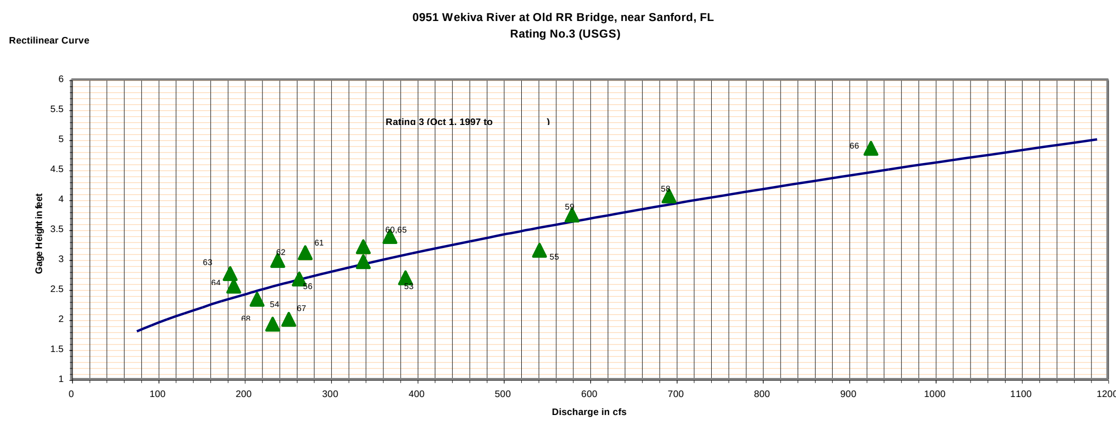


Figure 39. Current (2004) USGS rating curve for the Wekiva River at Old RR Crossing (Datum = 4.96 ft)

Figure 40. The Wekiva River at the Old RR Crossing
Stage-duration curves for different periods

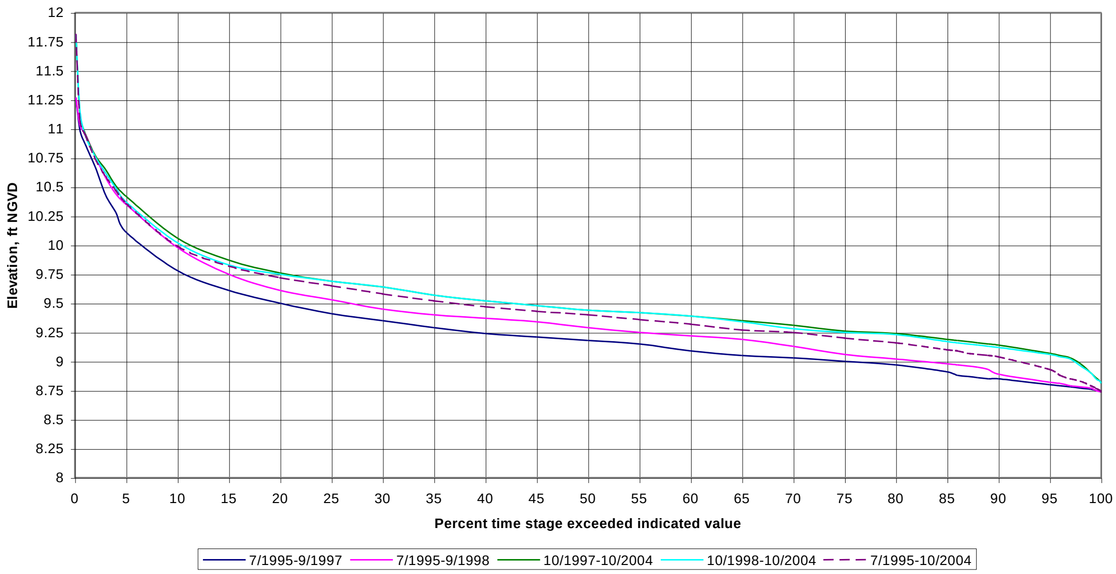
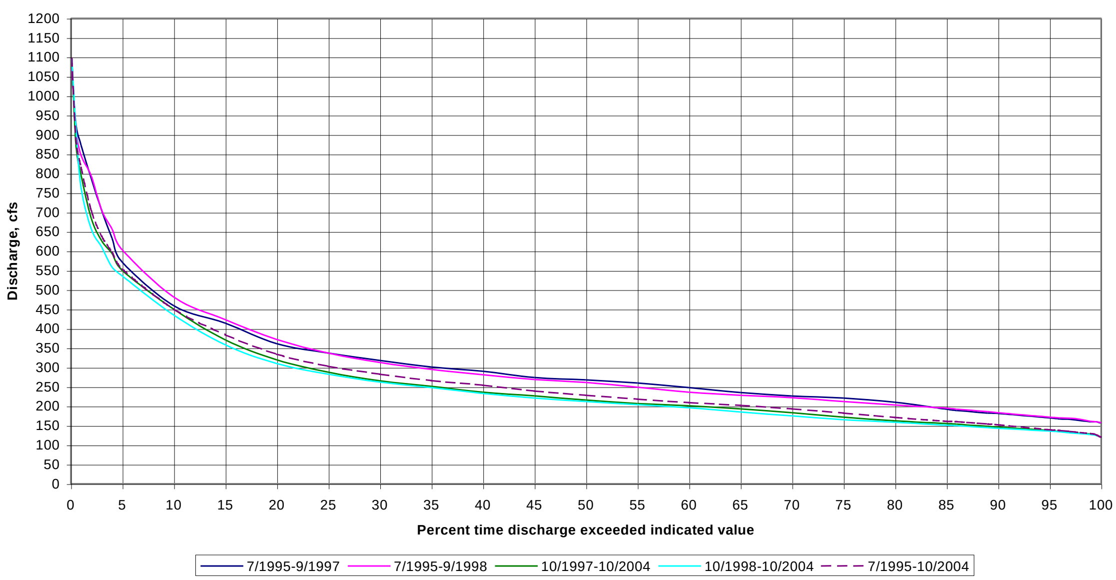


Figure 41. The Wekiva River at the Old RR Crossing
Discharge-duration curves for different periods



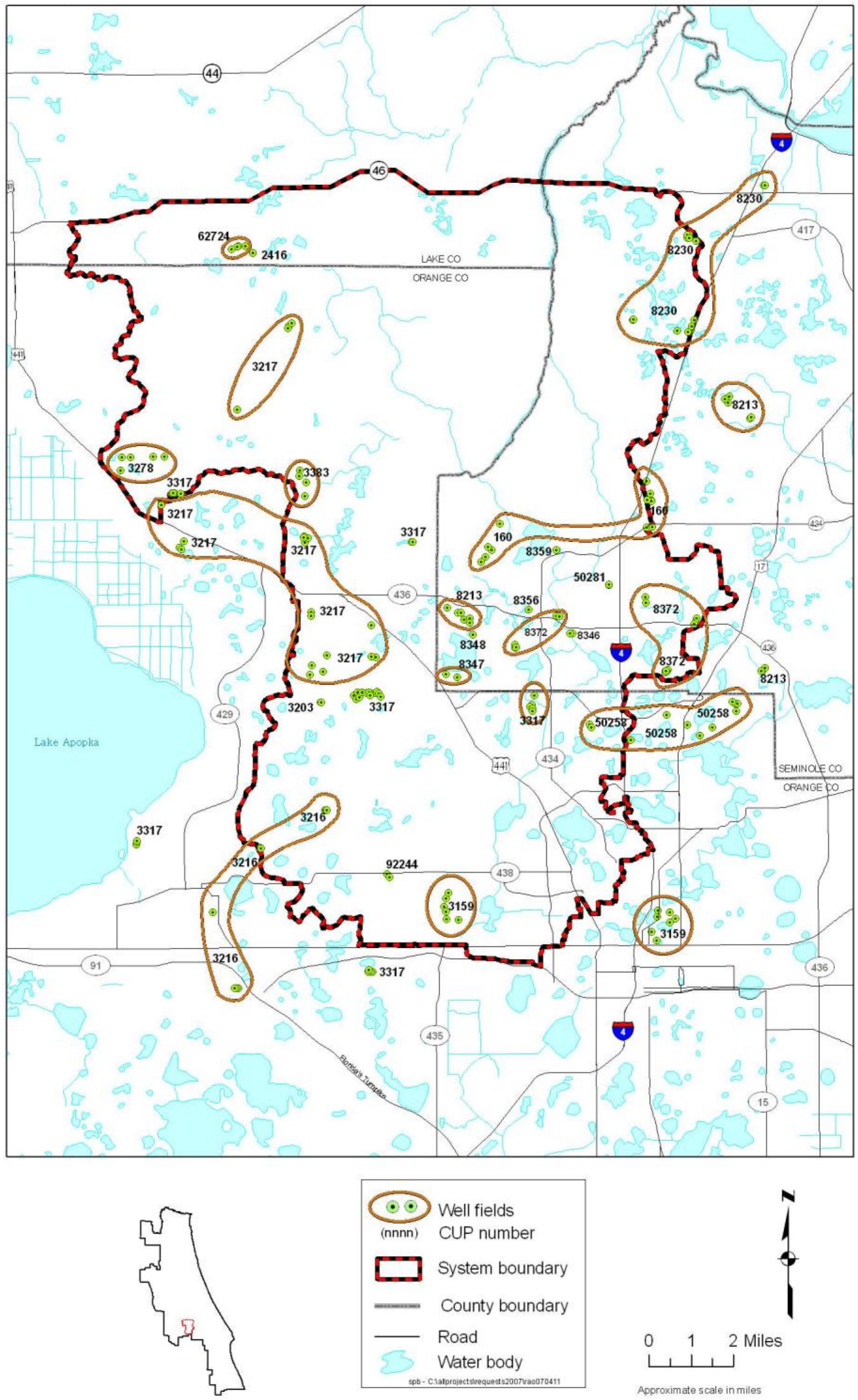


Figure 42. Major groundwater withdrawal locations in the Wekiva River basin south of SR 46: Well-fields and their Consumptive Use Permit numbers

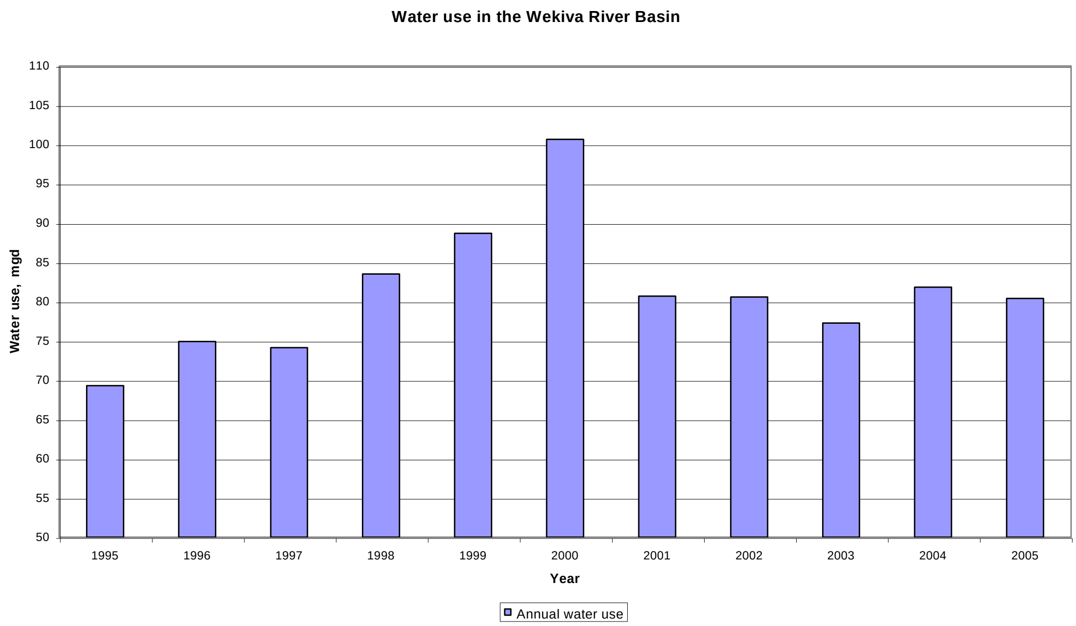


Figure 43. Water use variation during 1994-2005 in the Wekiva River basin

Figure 44. Wekiva River at SR 46
Stage-discharge data: 1936 - 1956

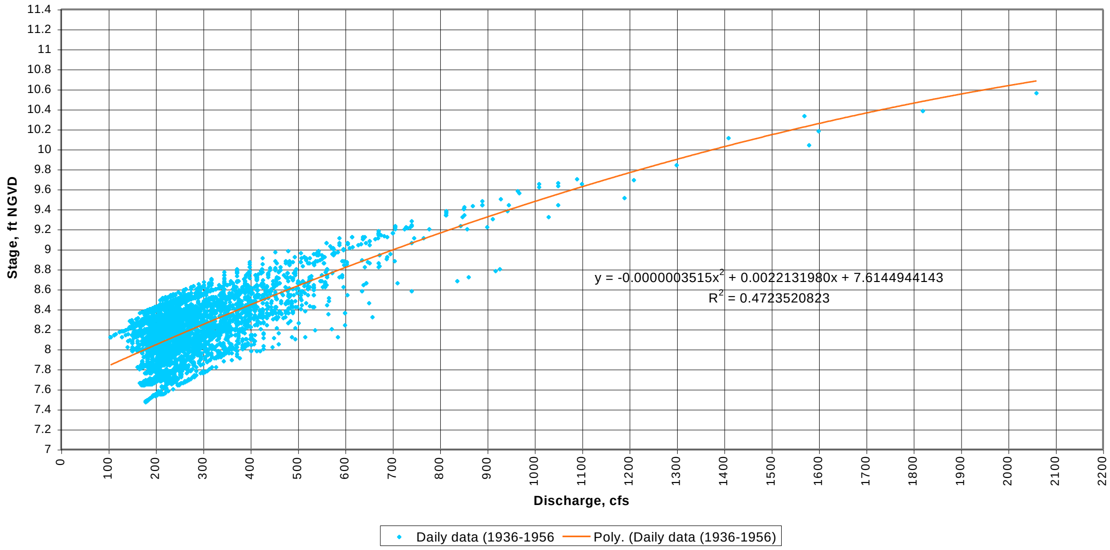


Figure 45. Wekiva River at SR 46
Stage-discharge data: 1957 - 1972

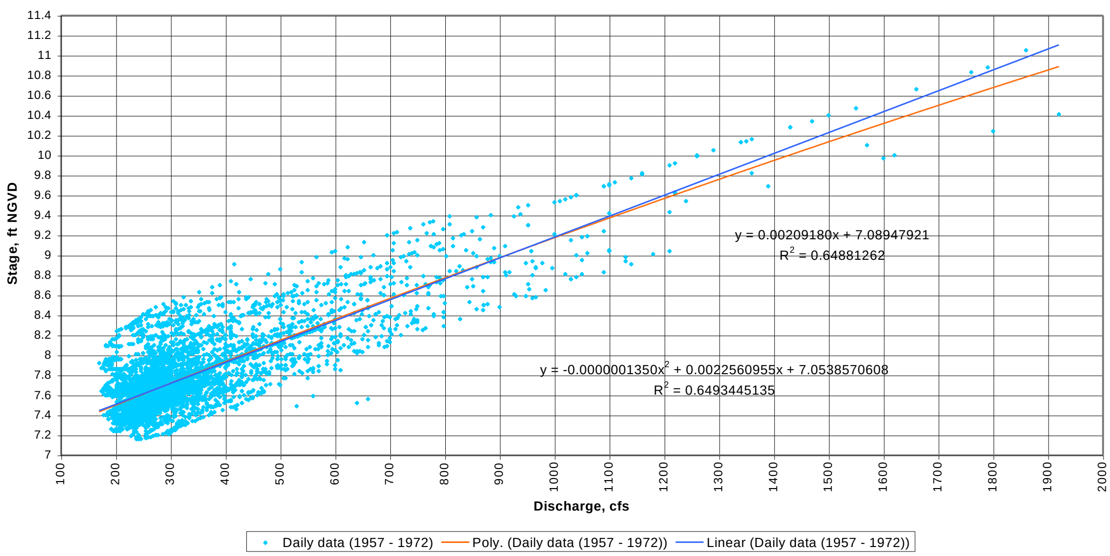


Figure 46. Wekiva River at SR 46
Stage-discharge data: 1973 - 1989

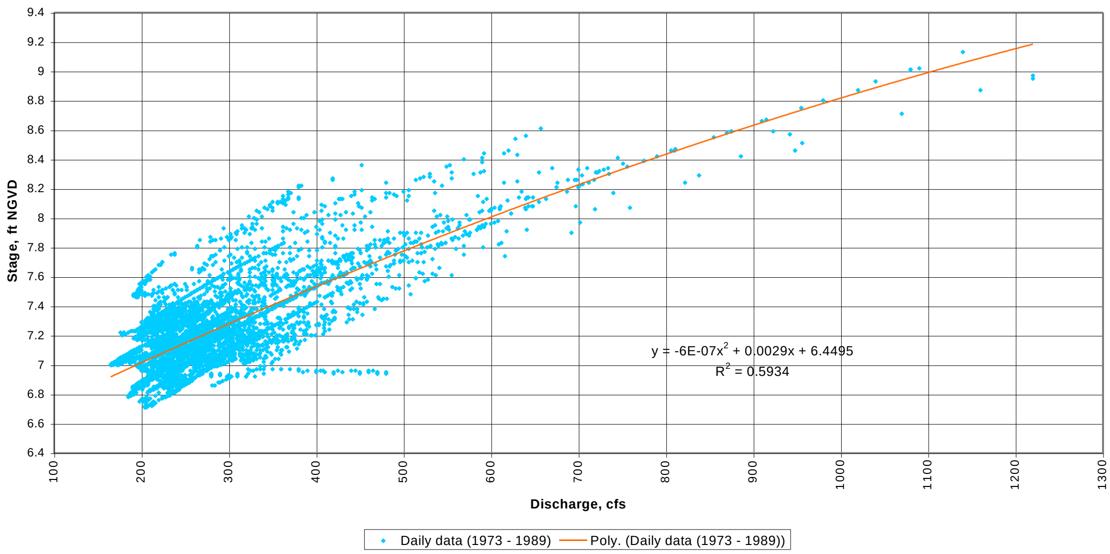


Figure 47. Wekiva River at SR 46
Stage-discharge data: 1990 - 2004

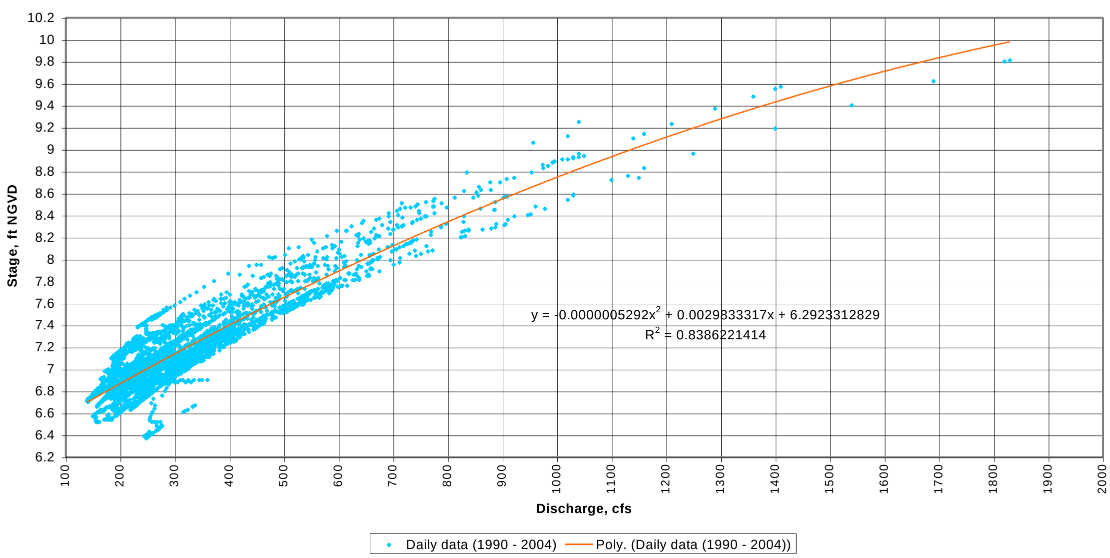


Figure 48. Wekiva River at SR 46: USGS stage-discharge data analysis
Average stage-discharge relationships for different time periods based on regression

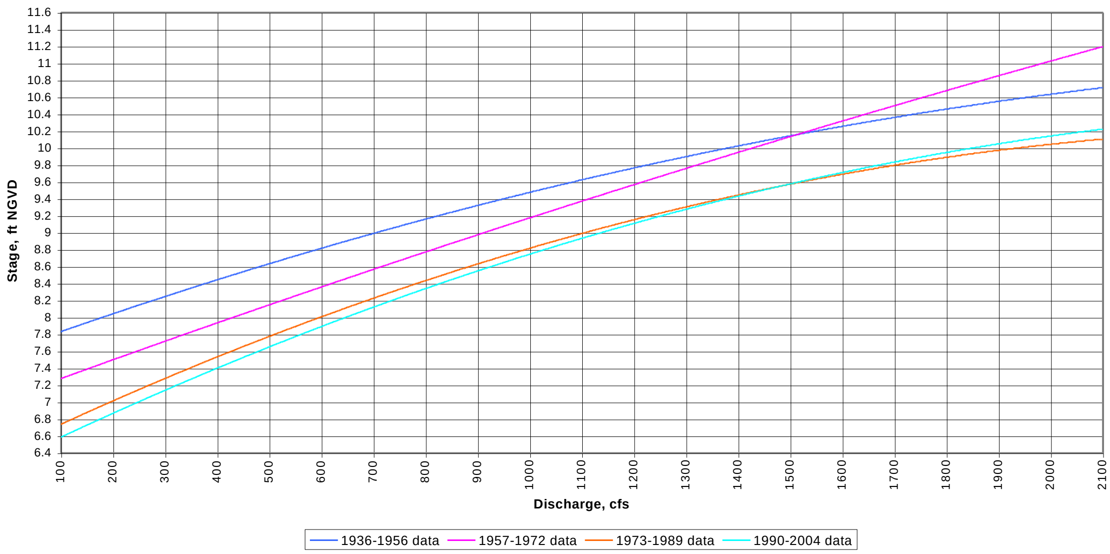
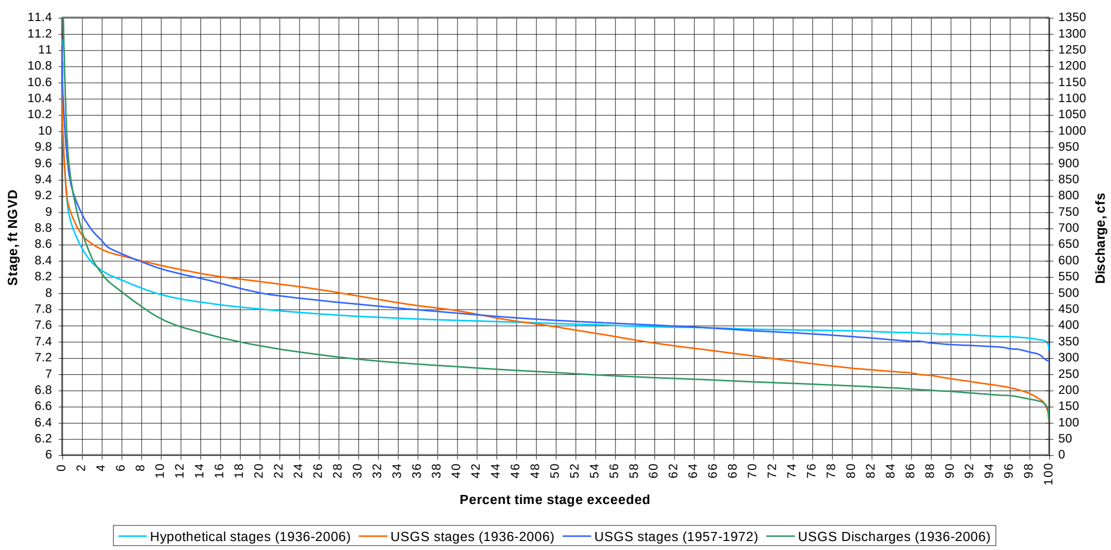


Figure 49. Wekiva River at SR 46: Stage/discharge duration curves
USGS data and the hypothetical data representing the 1957 - 1973 regime



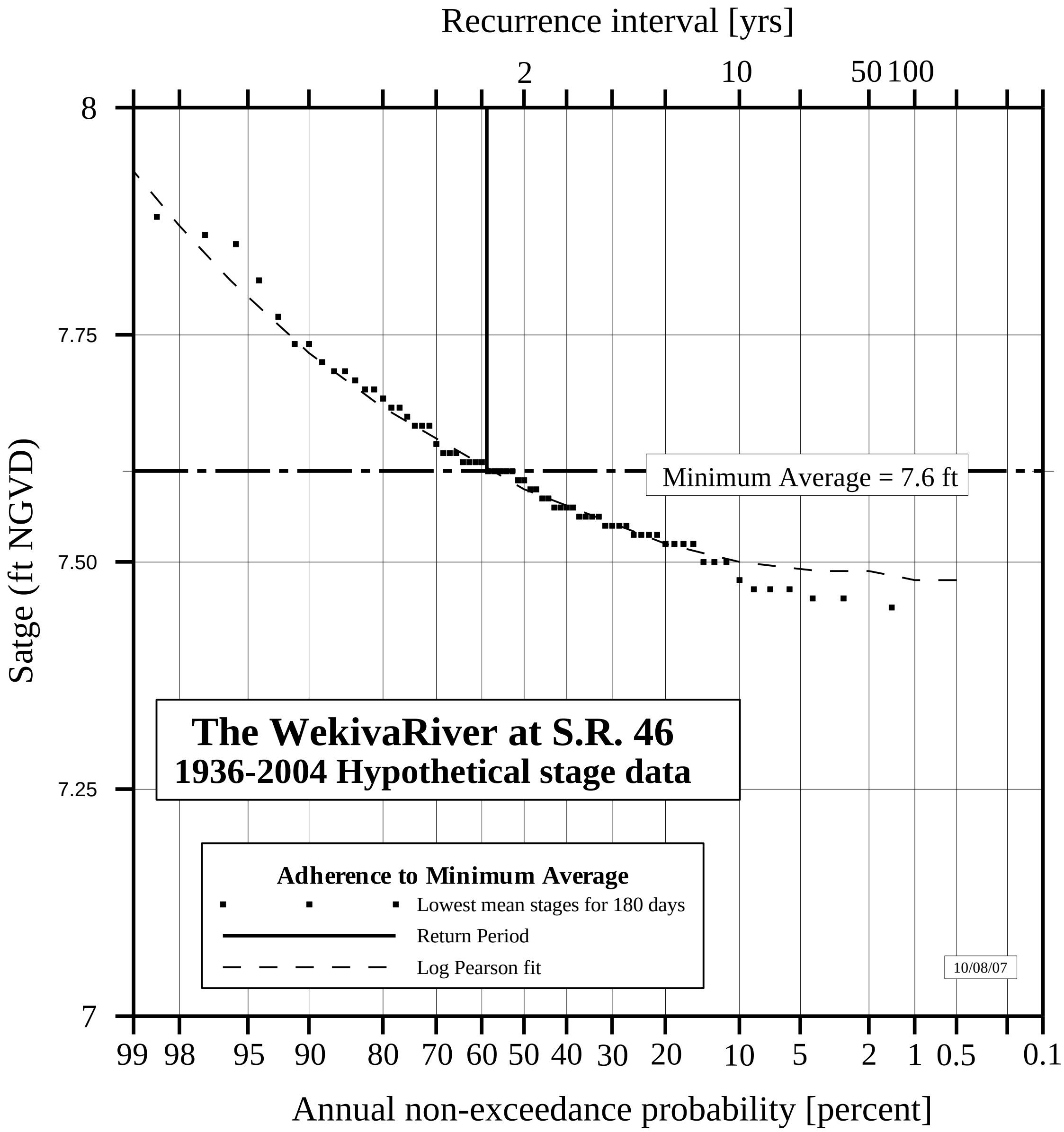


Figure 50. Stage – frequency graph for the Minimum Average level by the 1936 – 2004 WY hypothetical stage data

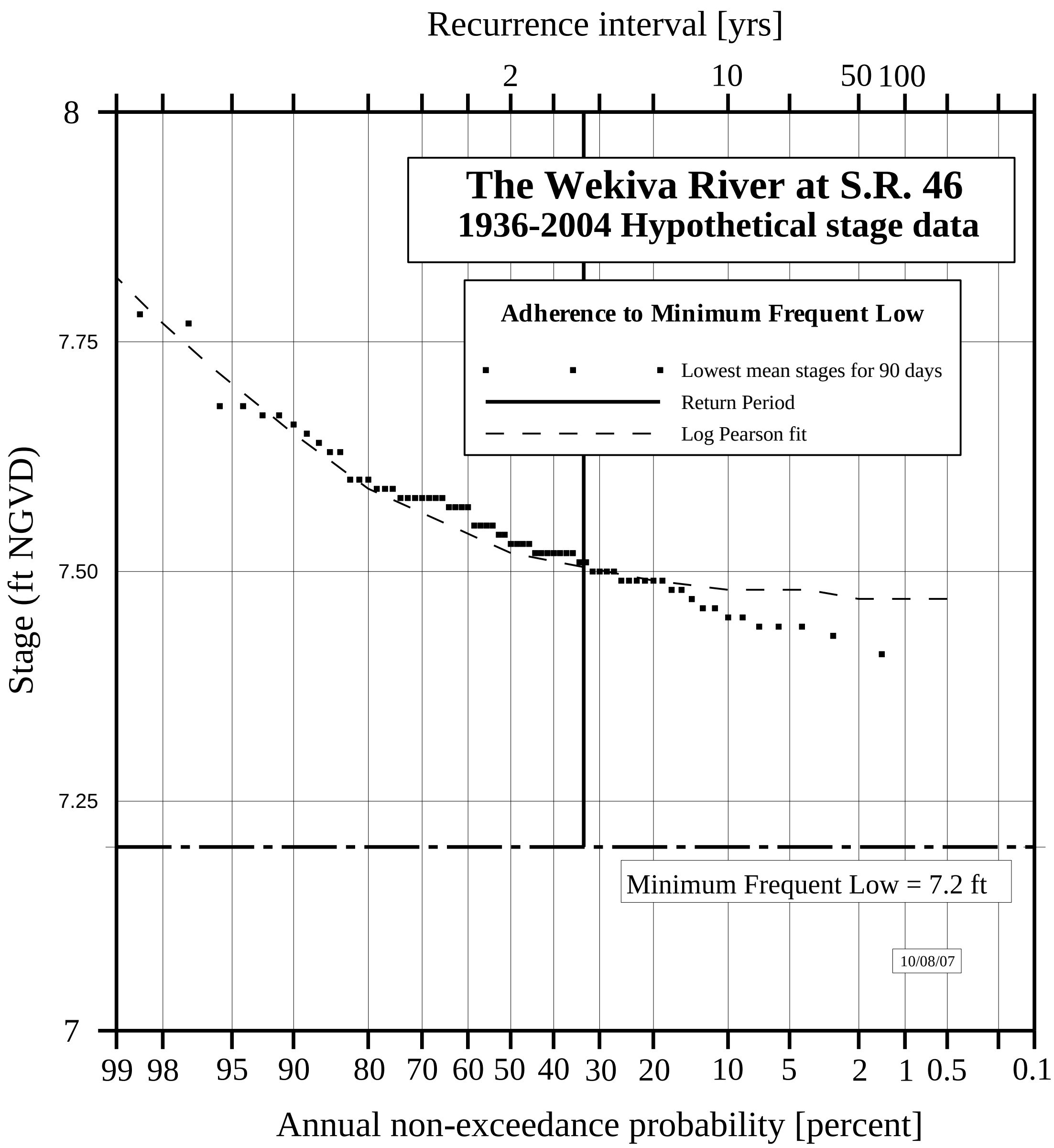


Figure 51. Stage – frequency graph for the Minimum Frequent Low level by the 1936 – 2004 WY hypothetical stage data

APPENDIX A

From: Charles Tibbals [mailto:ctibbals@tibbals.com]
Sent: Monday, December 06, 2004 2:27 PM
To: Rolland Fulton
Cc: Charles Tibbals; Barbara Vergara; Shahrokh Rouhani; Bill Osburn; Doug Munch; Sonny Hall
Subject: Sorry I missed talking to you; Ocklawaha & Wekiva Rivers

Rolly,

I'm sorry I didn't get a chance to talk to you last Friday. After the presentations I became sidetracked and overly engrossed in a conversation with Doug Munch and Shahrokh Rouhani and, by the time we broke up, you had already left.

I liked Martin Kelly's presentation. It definitely should give anyone pause before ascribing all flow changes to anthropomorphic activities.

I went to the SWFWMD publications web site and downloaded Martin's illustrations for the Ocklawaha River at Moss Bluff. Sure enough, just as Martin said, the change in that flow regime was far greater than in any of the other stations he analyzed -- greater (I believe) than could be explained solely by reduction in rainfall as a result of the Atlantic Multidecadal Oscillation.

And then there is the increase in flow of the Wekiva River near Sanford beginning at and during the same time period that the Ocklawaha flow decreased. (The flow of the Econlockhatchee River near Chuluota also increased but that, I think, is probably more the result of increased surface runoff from developed areas in its drainage basin)

The Wekiva River really doesn't get a lot of direct surface runoff except via inflow from the Little Wekiva River and that flow (and its increases) doesn't account for all of the increased flow of the Wekiva.

I believe that some of the "missing" Ocklawaha river water that resulted from the maintaining of high lake stages in the Ocklawaha Chain exited Rock and Wekiva Springs (their flow increased also) and, perhaps, others that help feed the Wekiva River. Also, I believe that some of the "missing" water flowed downgradient in the Floridan aquifer toward pumping centers in and around the Orlando/west Orange County areas.

Ah, Central Florida hydrology. Isn't it great?

Best regards,
Charles

APPENDIX B

MFLs graphs for the Wekiva River at the S.R. 46 Bridge

1936-2004 USGS WY stages

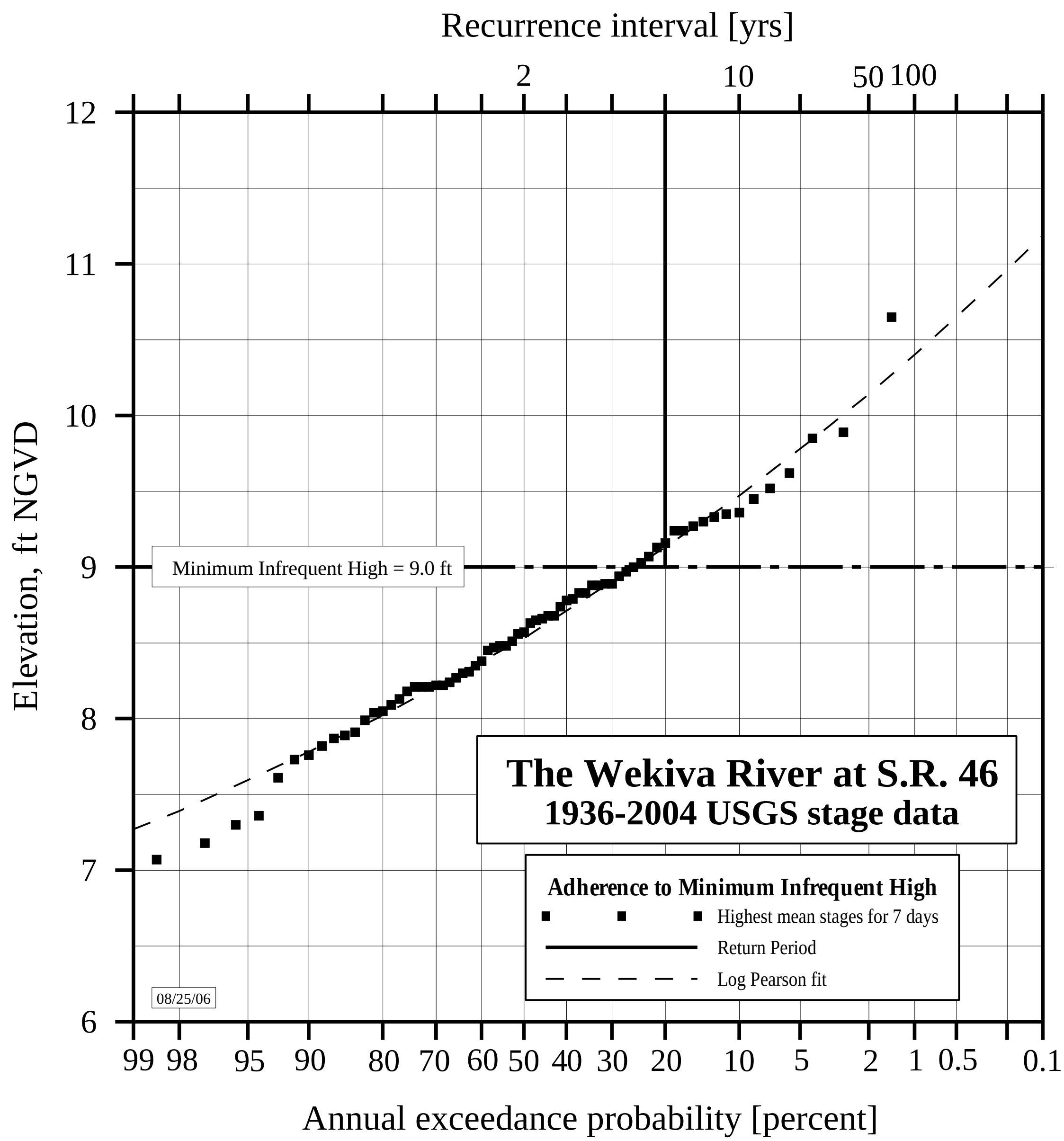


Figure B-1. MFLs evaluation for the Minimum Infrequent High level

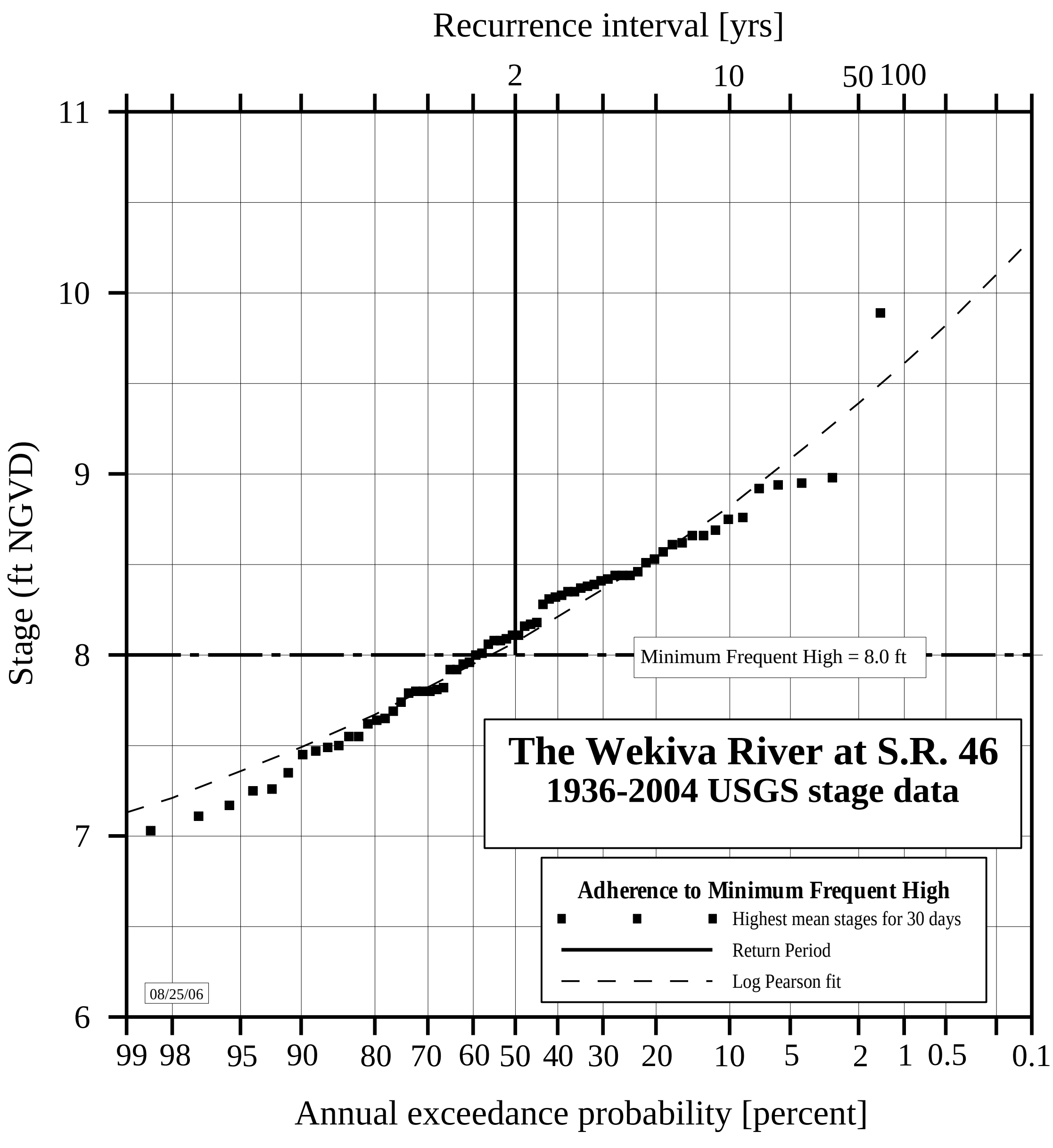


Figure B-2. MFLs evaluation for the Minimum Frequent High level

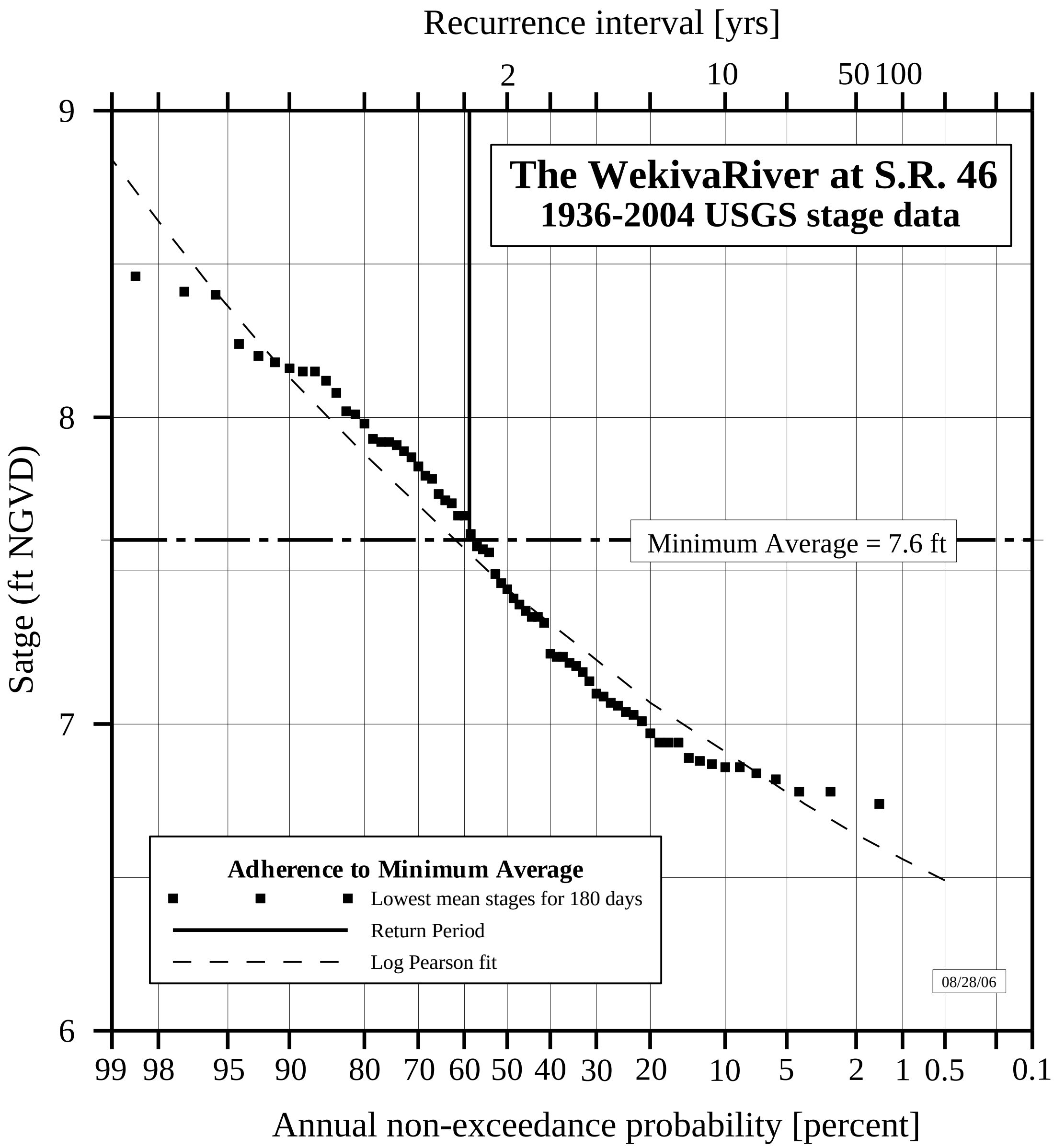


Figure B-3. MFLs evaluation for the Minimum Average level

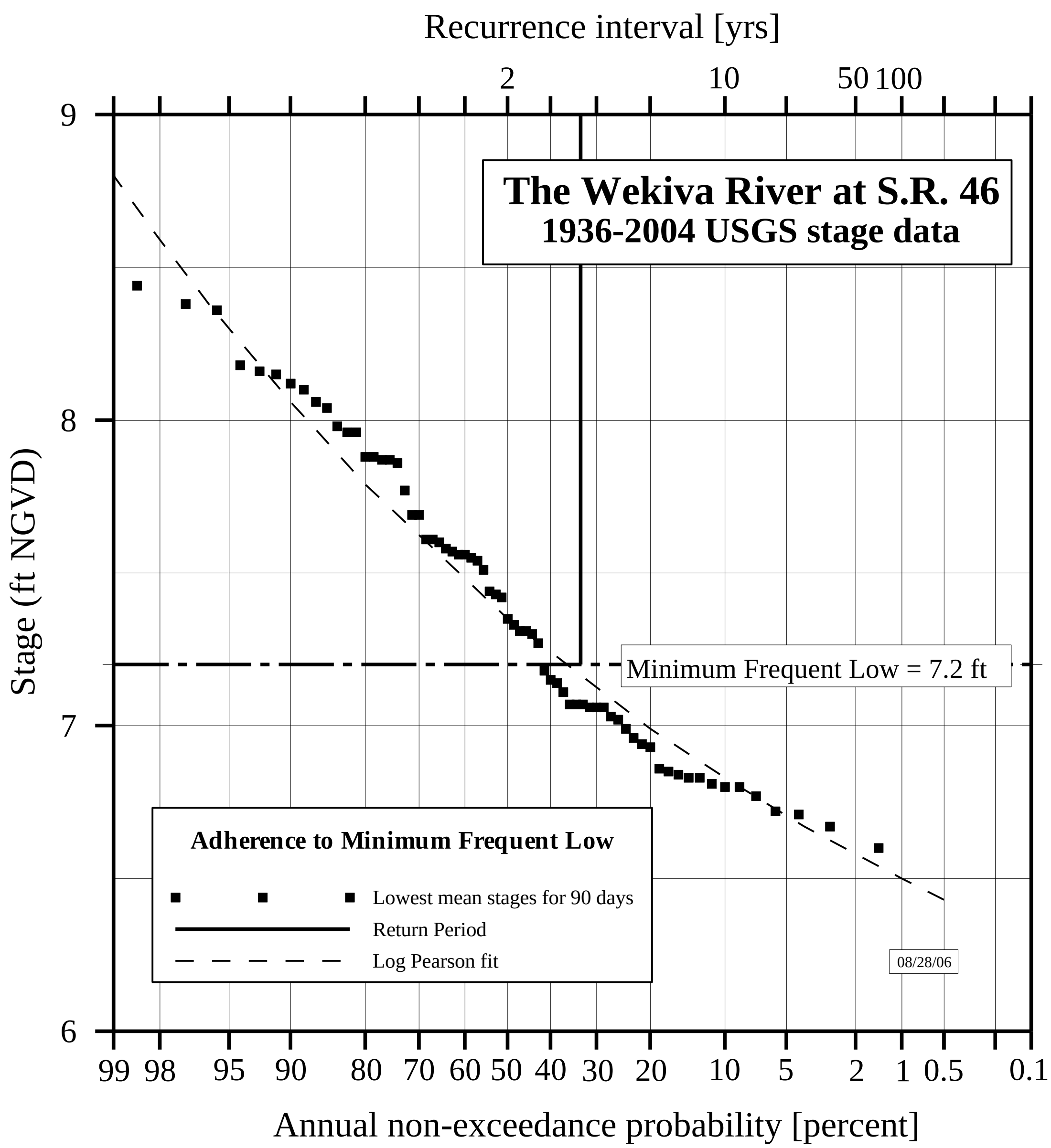


Figure B-4. MFLs evaluation for the Minimum Frequent Low level

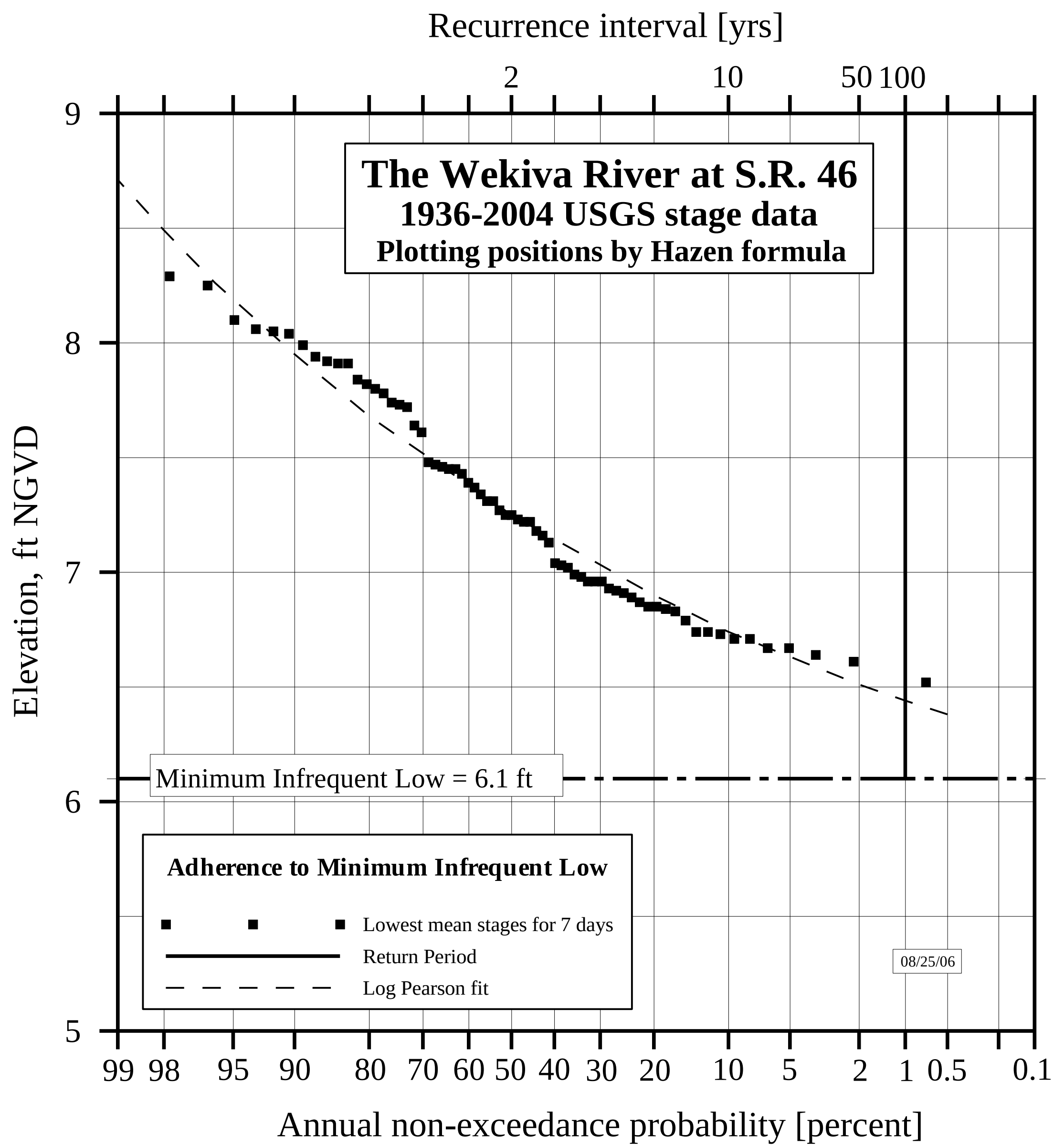


Figure B-5. MFLs evaluation for the Minimum Infrequent Low level

APPENDIX C

MFLs graphs for the Wekiva River at the S.R. 46 Bridge

1936-2004 USGS WY discharges

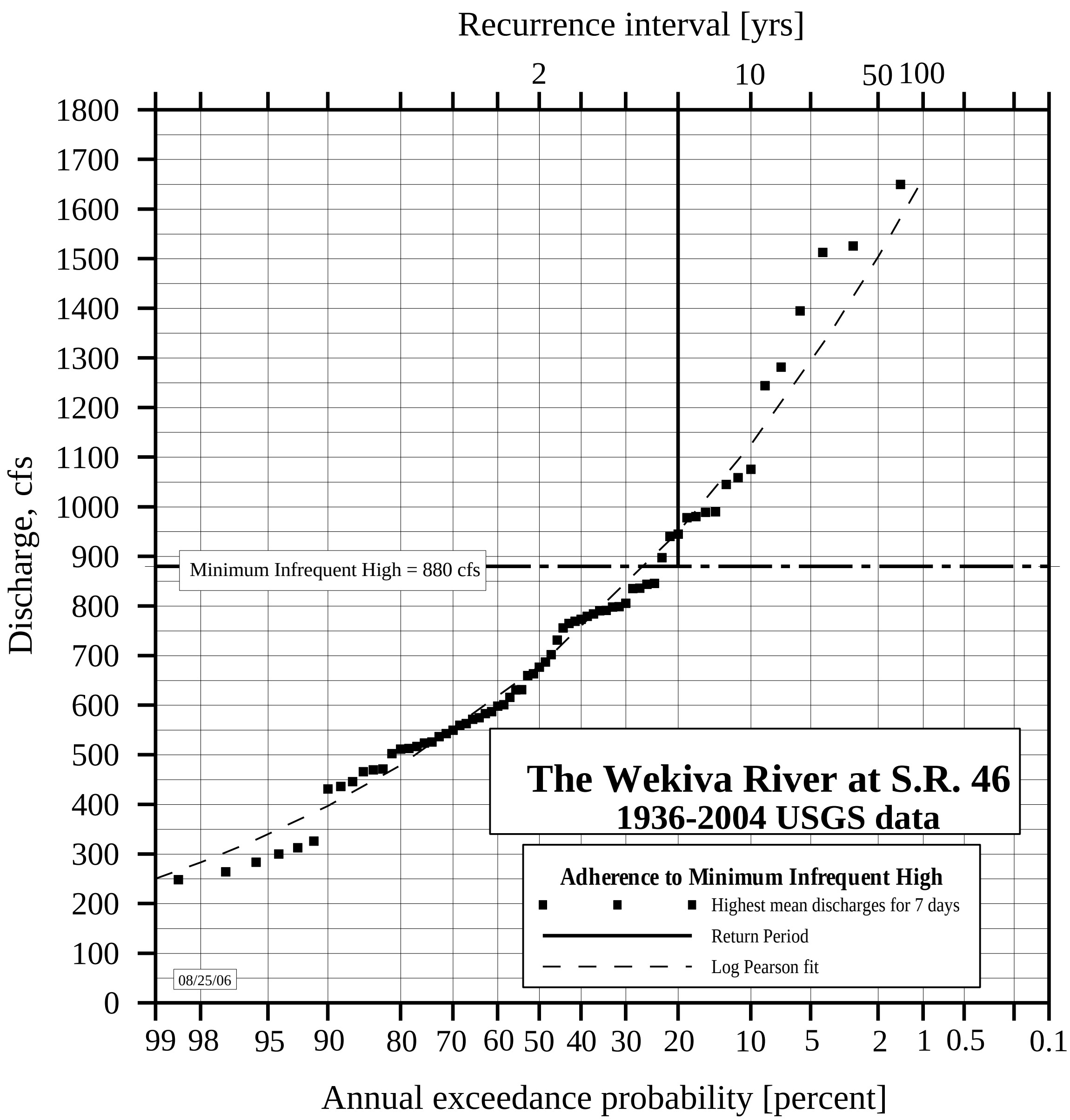


Figure C-1. MFLs evaluation for the Minimum Infrequent High discharge

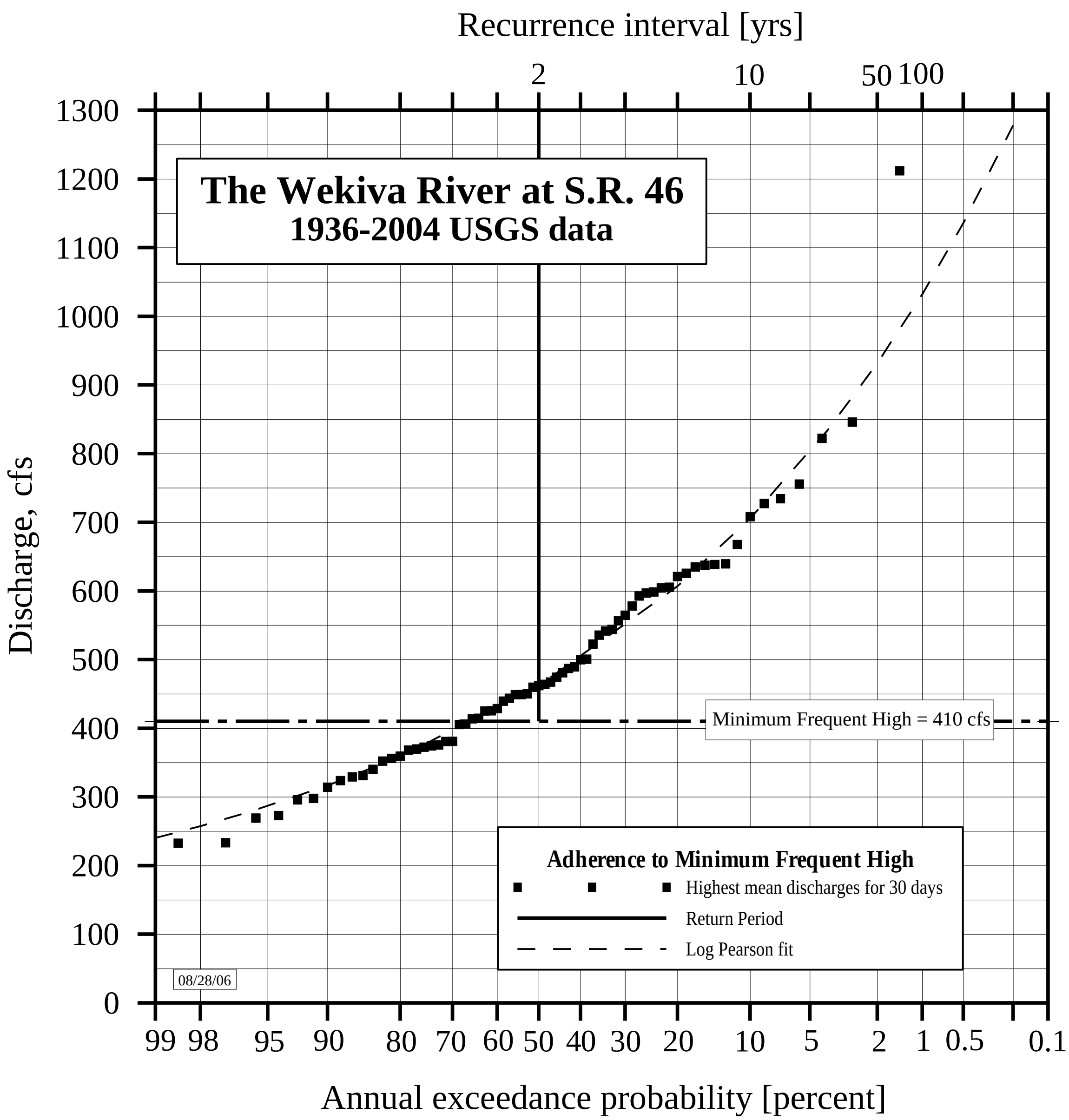


Figure C-2. MFLs evaluation for the Minimum Frequent High discharge

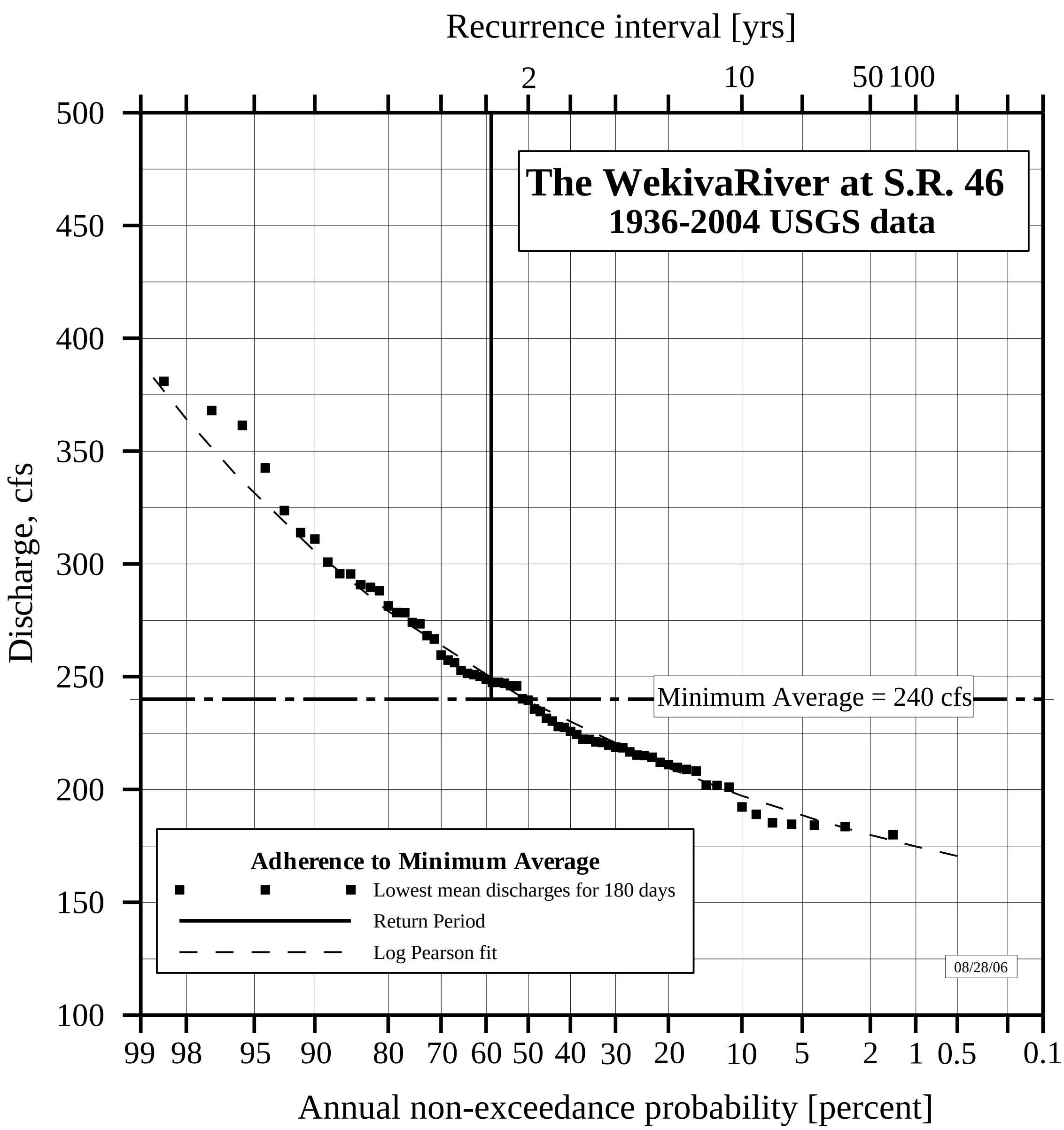


Figure C-3. MFLs evaluation for the Minimum Average discharge

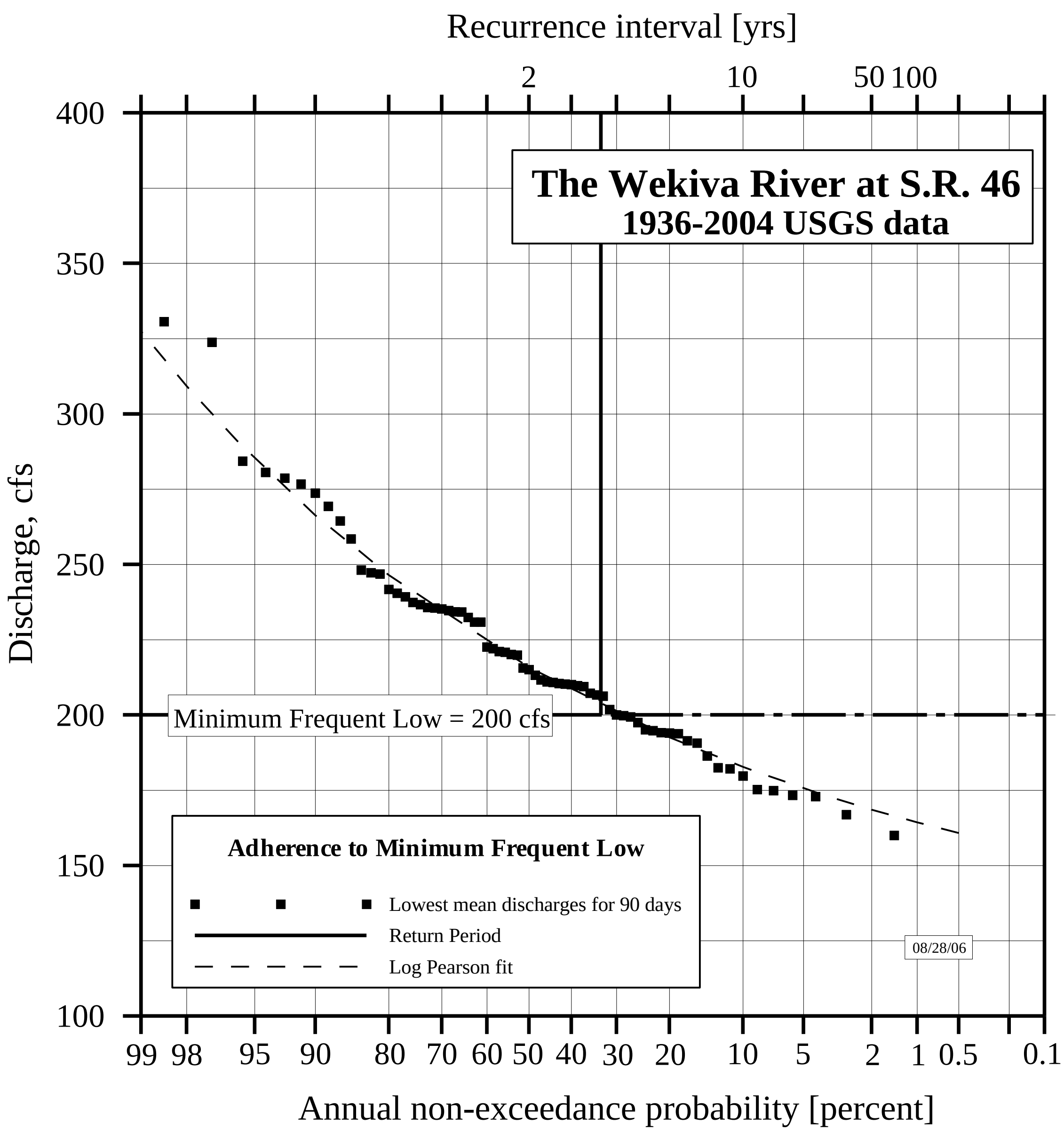


Figure C-4. MFLs evaluation for the Minimum Frequent Low discharge

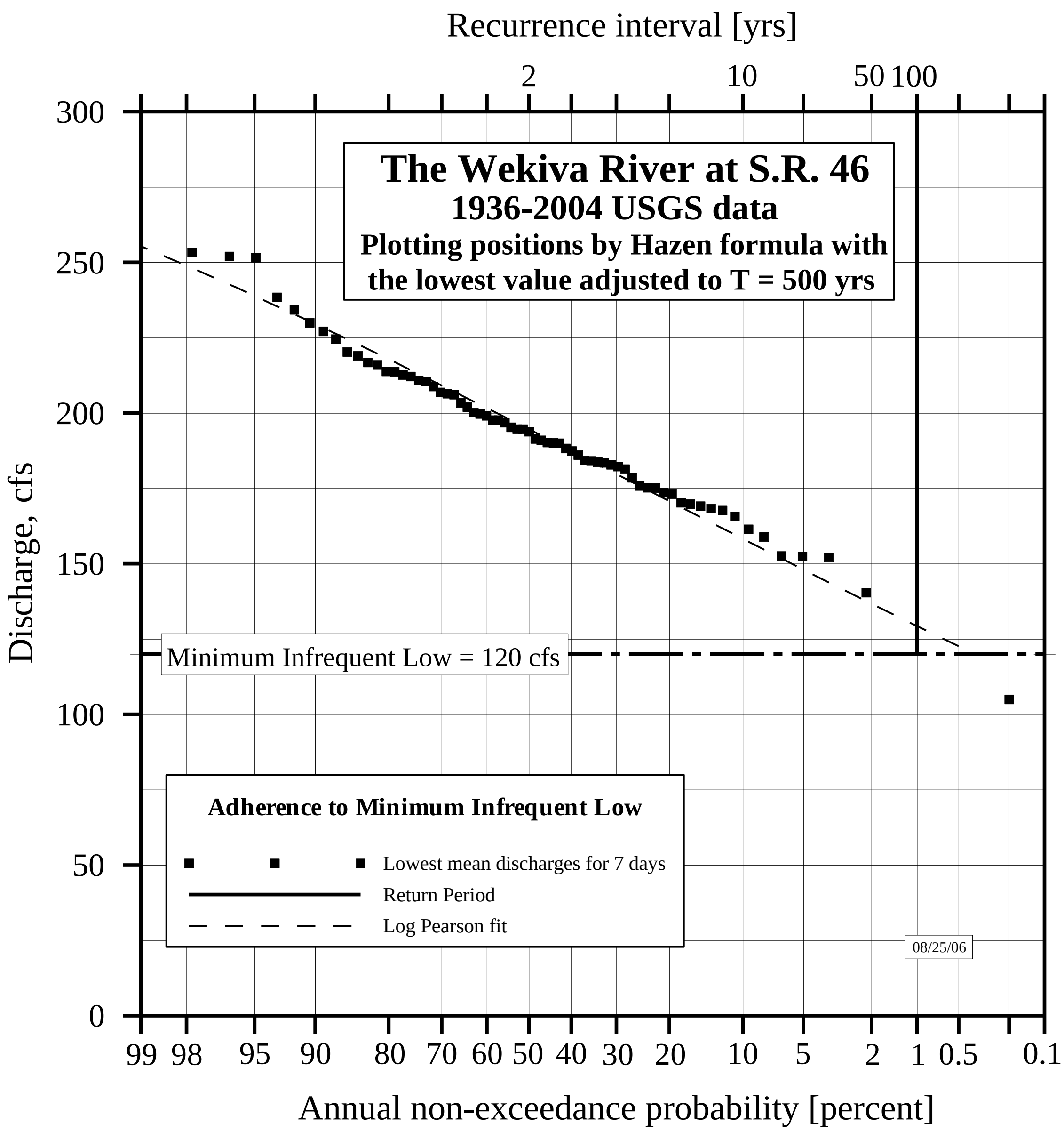


Figure C-5. MFLs evaluation for the Minimum Infrequent Low discharge