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DETERMINATION OF POTENTIAL WATER SUPPLY YIELD OF THE UPPER ST. JOHNS RIVER AT STATE ROAD 50, FLORIDA, USING MINIMUM FLOWS AND LEVELS COMPLIANCE AS A CONSTRAINT

ST. JOHNS RIVER WATER MANAGEMENT DISTRICT

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by

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EXECUTIVE SUMMARY

The Upper St. Johns River (USJR), located in east-central Florida in the St. Johns River Water Management District (SJRWMD), is a major source of water supply for irrigation and drinking water. Thousands of acres of agricultural lands in the upper reaches of the USJR draw water from the river for irrigation and Lake Washington has been the primary municipal water supply source for the City of Melbourne for decades. The USJR is a potential source for additional water supplies. A number of water supply development projects are currently under consideration.

The primary purpose of this report is to present an estimate of the potential additional water supply yield, in addition to existing withdrawals, available from the St. Johns River (SJR) at or above State Road (SR) 50. The analyses described in this report considered additional water supply withdrawal at SR 50 for various selected withdrawal scenarios. It is recognized that water supply development within the USJR basin is likely to occur at multiple locations and design of any proposed additional water supply facility will require a Minimum Flows and Levels (MFLs) compliance analysis similar to the analysis presented herein.

The primary consideration in determining the water supply potential of the USJR is meeting MFLs established for different locations on the river. SJRWMD established MFLs for the SJR at SR 50 in the year 2007. If the current discharge conditions in the river are disturbed by actions such as diverting additional water for irrigation and/or drinking water supplies, water levels and discharges in the river will decline, and the established MFLs may not be met. Water supply potential of a river is the maximum quantity that could be diverted from the river without causing water levels or flows to fall below one or more of the established MFLs.

The investigation described in this report resulted in the determination of the potential additional water supply yield of the SJR at SR 50 using MFLs compliance as a constraint. Two data series were used in the analyses: 1) The United States Geological Survey (USGS) historic discharge data for 1933-2006, and 2) simulated data from the SJRWMD USJR Basin (USJRB) watershed model for Project Conditions 2004 (Rao 2004 and 2009, Appendix A). The SJRWMD USJRB model was essentially a simplified version of the well-known Stanford Watershed model (Crawford and Linsley 1966), with the runoff simulation procedure based on a watershed model introduced in 1976 by the Agricultural Research Service, U.S. Department of Agriculture (Williams and LaSeur 1976). The USGS historic data are primarily pre-project conditions data and thus do not reflect the USJRB project benefits that include augmentation of low flows and increased discharge volumes that result from curtailing discharge diversion to the Indian River Lagoon. The historic record includes historic water supply withdrawals including agricultural irrigation withdrawals and public water supply withdrawals.

The model, on the other hand, fully incorporates the project conditions as completed by 2004. The watershed model also includes existing (2004) water supply withdrawals; agricultural irrigation and withdrawals from Lake Washington (15.5 mgd) for the City of Melbourne's public supply system. Currently, SJRWMD is developing an HSPF model (Hydrologic Simulation Program FORTRAN) for the USJRB, with the project in its ultimate (2010) configuration, but the model development was not complete at the time this report was prepared.

Discharge diversions (DD) for water supply (at SR 50) are considered only when discharges in the river exceed certain minimum values (Minimum River Flow, MRF). Four MRFs are assumed for evaluation: MRF = 300, 200, 100, and 50 cfs. The range of MRFs assumed in this evaluation represents reasonable low flows to support ecologic preservation (HSW Engineering, Inc. 2006). Further, each MRF was evaluated for five DD values: DD = up to 30, 50, 70, 90, 110 cfs. The four MRF and the five DD values assumed for the evaluation gave rise to 20 scenarios. A few additional (special) scenarios were also evaluated and are described in the Methods I and II sections of this document. For a given MRF, the DD values given in the foregoing are maximum values. For example, if MRF = 300 cfs and DD = 90 cfs, but the actual river flow is 310 cfs, then the diverted discharge is only 10 cfs; a DD of 90 cfs would occur only when the actual river flow is equal to or greater than 390 cfs. Time series of discharge data reflecting a given MRF and a given DD (i.e., for a given scenario) were developed from the original (i.e., no diversion) USGS or model data by a FORTRAN program.

Four MFLs (discharges and stages) are set for SJR at SR 50: 1) Minimum frequent high (MFH); 2) Minimum average (MA); 3) Minimum frequent low (MFL), and; 4) Minimum infrequent low (MIL). Compliance with these MFLs is evaluated by standard statistical procedures only for discharges. MFLs compliance for stages is not evaluated because there is no satisfactory methodology to compute the time series of stage data that would reflect MRFs and DDs. Based on evaluations performed by SJRWMD (HSW Engineering, Inc. 2006, Mace 2006), withdrawals within the range of the MRFs considered in the evaluations described in this document would provide for adequate environmental protection during low-flow periods, meet recommended MFLs for the SJR at SR 50, and allow for development of water supplies from the river.

Potential water supply yield evaluation methods and results

Potential additional water supply yield of the SJR at SR 50 was determined by three methods.

Method I and Results: USGS 1933-2006 historic data were used in this method. Diversion of discharges was assumed to occur when river flows are above MRF, up to a maximum value of the DD for the scenario. Twenty scenarios were evaluated by this method and the results of MFLs compliance and the potential water supply yield are as follows:

Table A. SJR at SR 50: Summary of MFLs compliance (Method I)

MRF (cfs)	Discharge for Diversion (cfs) 30	50	70	90	110
300	Y	Y	Y	Y	N(MA)
200	Y	Y	Y	N(MA)	N(MA)
100	Y	Y	Y	N(MA)	N(MA, MFL)
50	Y	Y	Y	N(MA)	N(MA, MFL)

Y = All MFLs met; N = MFLs in the parentheses not met

Table B. SJR at SR 50: Potential water supply yield, mgd
(Mean of diversion discharges for the period analyzed)

MRF (cfs)	Discharge Diversion (cfs) 30	50	70	90	110
300	14.2	23.8	33.0	42.1	**51.1**
200	15.7	26.0	36.0	**45.9**	**55.6**
100	17.4	28.6	39.7	**50.5**	**61.2**
50	18.5	30.4	42.0	**53.4**	**64.6**

The water supply yields shown in bold are infeasible because MFLs are not met for these scenarios.

Maximum yield by this method was 42.1 mgd (from the scenario with MRF = 300 cfs and DD = 90 cfs).

Method II and results: USGS 1933-2006 historic data were also used in this method, but discharge diversions were assumed to occur at two levels (tiers) of MRFs, that is, additional diversion was made assuming a second higher MRF. This method was applied to two scenarios, as described below.

Scenario II-1
Tier 1 discharge: If MRF > 300 cfs, DD = up to 90 cfs
Tier 2 Discharge: If MRF > 600 cfs, DD = 90 + up to 40 cfs
Example: If the river flow, Q = 610 cfs, DD = 90 + 10 = 100 cfs
If the river flow, Q = 650 cfs, DD = 90 + 40 = 130 cfs
Scenario II-2
Tier 1 discharge: If MRF > 50 cfs, DD = up to 70 cfs
Tier 2 Discharge: If MRF > 400 cfs, DD = 70 + up to 40 cfs (additional)

All of the MFLs were met for Scenario II-1, and the potential water supply yield for this scenario was 57.3 mgd. One of the MFLs, MA, was not met for Scenario II-2.

Method III and results: This method used the 1942-2001 simulated data for the USJRB Project Conditions 2004. The four borderline scenarios for which MFLs were not met by Method I (e.g., MRF = 300 cfs and DD = 110 cfs, Tables A) were re-evaluated by Method III. The MA was not met by Method I for these scenarios. With the project conditions simulated data, the MFLs were met for all of the four scenarios re-evaluated. The potential average yields for the four scenarios by Method III were as follows.

Scenario III-1: 56.2 mgd (MRF = 300 cfs; DD = 110 cfs)
Scenario III-2: 49.8 mgd (MRF = 200 cfs; DD = 90 cfs)
Scenario III-3: 54.0 mgd (MRF = 100 cfs; DD = 90 cfs)
Scenario III-4: 56.1 mgd (MRF = 50 cfs; DD = 90 cfs)

Scenario III-1 produced the highest potential average yield of the four scenarios, and it also had some ‘free-board’ (i.e., MA would actually not be met at a higher DD). By an iterative process, DD was gradually increased, and it was determined that the limiting higher value of DD at which MA would be just met was 150 cfs. The potential additional average yield for this scenario (MRF = 300 cfs and DD = 150 cfs) was 75.5 mgd.

Maximum average yields by the three methods: Maximum additional average water yields obtained by the three methods were:

Method I:	42.1 mgd
Method II:	57.3 mgd
Method III:	75.5 mgd

The maximum of these three methods (Method III) resulted in about an 80% increased yield over Method I (from 42.1 mgd to 75.5 mgd), and about a 30% increased yield over Method II (from 57.3 mgd to 75.5 mgd). This result clearly demonstrated that the USJRB Project greatly enhances the water supply potential by its creation of water management and marsh conservation areas and the flow regulation through the project area. By applying a two-tier withdrawal method to discharges under project conditions (Method II with USGS data), water supply withdrawals under Method III can be further increased.

Discharge diversions during drought periods

Potential water supply yields of the SJR at SR 50 for different scenarios presented in the foregoing were the average yields for the periods of evaluation; 72 years for the USGS data and 60 years for the model data. Actual yields for individual years varied. For the periods of analysis, the annual yields varied from 2.4 to 58.1 mgd for Method I, 2.4 to 83.9 mgd for Method II, and 8.0 to 96.9 mgd for Method III. Because of the MRF constraint, water for diversion would not be available for several continuous days during low flow periods. The present analyses showed, if a drought similar to the extreme historic drought of 1980-1982 occurred, water for diversion would not be available for a continuous period of almost 23 months depending upon the magnitude of the MRF selected for design. There were 12 other drought years during which no water diversion would be possible for continuous periods of 4 to 8 months. Thus, even though the USJRB project greatly enhances the water supply potential of the SJR at SR 50, the increase was only in average volumes, but does not provide higher discharges during the drought conditions.

The drought characteristics of the river and the need to meet MFLs at SR 50 have important implications for water supply facilities design. Because the proposed withdrawals would be made only when river flows exceed certain minimum discharges (i.e., MRFs), water available for diversion would be limited during some drought periods and the SJR becomes an unreliable source under these conditions. Reliability must be provided by raw water or treated water storage, or by integrated development with other more reliable sources of supply including groundwater.

Conclusions

The following conclusions were reached based on data evaluations presented in this report.

1. Average additional potential water supply yields of the SJR at SR 50 based on MFLs compliance as a constraint are: a) 42.1 mgd based on the historic USGS discharge data (1933-2006), with diversion discharges up to a maximum of 90 cfs when river flows exceed 300 cfs; b) 57.3 mgd based on the historic USGS discharge data (1933-2006), with diversion discharges up to a maximum of 90 cfs when river flows exceed 300 cfs, and additional diversion discharges up to a maximum of 40 cfs when river flows exceed 600 cfs, and; c) 75.5 mgd based on the 1942-2001 simulated data for the USRB Project Conditions 2004, with diversion discharges up to a maximum of 150 cfs when river flows exceed 300 cfs. This yield could be further increased by additional diversion when river flows exceed 600 cfs.
2. Yearly water supply yield of the SJR at SR 50 can vary widely due to variation of annual/seasonal rainfall. Typically, the annual yield ranges for the three average yields given in the foregoing (i.e., Cases a, b, and c) are, 2.4 to 58.1 mgd, 2.4 to 83.9 mgd, and 8.0 to 96.9 mgd, respectively.
3. No water for diversion would be available for prolonged periods (several months to years) during severe droughts. This condition occurs because water supply discharges are diverted from the SJR only when river flows exceed certain minimum discharge (e.g., 300 cfs), and the river flow is below this minimum during severe droughts for prolonged periods. Therefore, the MRF will be an important water supply facilities design parameter. If the MRF is not maintained, three of the MFLs, MA, MFL, and MIL might not be met.
4. It appears, the USJRB project would increase the potential water supply yield of the SJR at SR 50 by about 80% over the pre-project conditions (42.1 to 75.5 mgd) because of low flow augmentation and other water management practices

currently in place as a result of USJRB project. However, because of the MRF requirements to support ecological preservation, no increase in water supply withdrawals is possible during some drought conditions (i.e., water available for diversion would be limited during some drought periods because the proposed withdrawals would be made only when river flows exceed certain minimum discharges).

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INTRODUCTION

The Upper St. Johns River (USJR), located in East Central Florida in the St. Johns River Water Management District (SJRWMD) (Figures 1 and 2), is a major source of water supply for irrigation and drinking water. Thousands of acres of agricultural lands in the upper reaches of the USJR (Planning Units 6A, 6B, 6C, and 6F, Figure 2) draw water from the river for irrigation and Lake Washington has been the primary municipal water supply source for the City of Melbourne for decades. The USJR is a potential source for additional water supplies. A number of water supply development projects are currently under consideration in Planning Units 6G and 6H (Figure 2).

The primary consideration in determining water supply potential of the USJR is meeting Minimum Flows and Levels (MFLs) established for different locations on the river. SJRWMD established MFLs for four locations on the St. Johns River (SJR) (Chapter 40C-8, Florida Administrative Code, [*F.A.C.*]). These locations are: 1) Lake Washington; 2) SJR 1.5 miles downstream of Lake Washington weir, 3) SJR at State Road (SR) 50 (Figure 2); and 4) SJR at SR 44 near DeLand, Volusia County (Figure 1). If the current discharge conditions in the river are disturbed, like diverting additional water for irrigation and/or drinking water supplies, water levels and discharges in the river decline, and the established MFLs may not be met. Water supply potential of a river is the maximum quantity that could be diverted from the river without causing water levels or flows to fall below one or more of the established MFLs.

This document reports on data analysis that was performed to estimate the potential additional water supply yield, in addition to existing withdrawals, available from the St. Johns River (SJR) at or above State Road (SR) 50. Two data series are used in the analyses: 1) The United States Geological Survey (USGS) historic discharge data for 1933-2006, and 2) 1942- 2001 model simulated data. This report presents:

- A brief description of MFLs evaluation procedures
- Potential water supply yield methods and MFLs evaluations for a number of scenarios considered
- Summary of results and conclusions

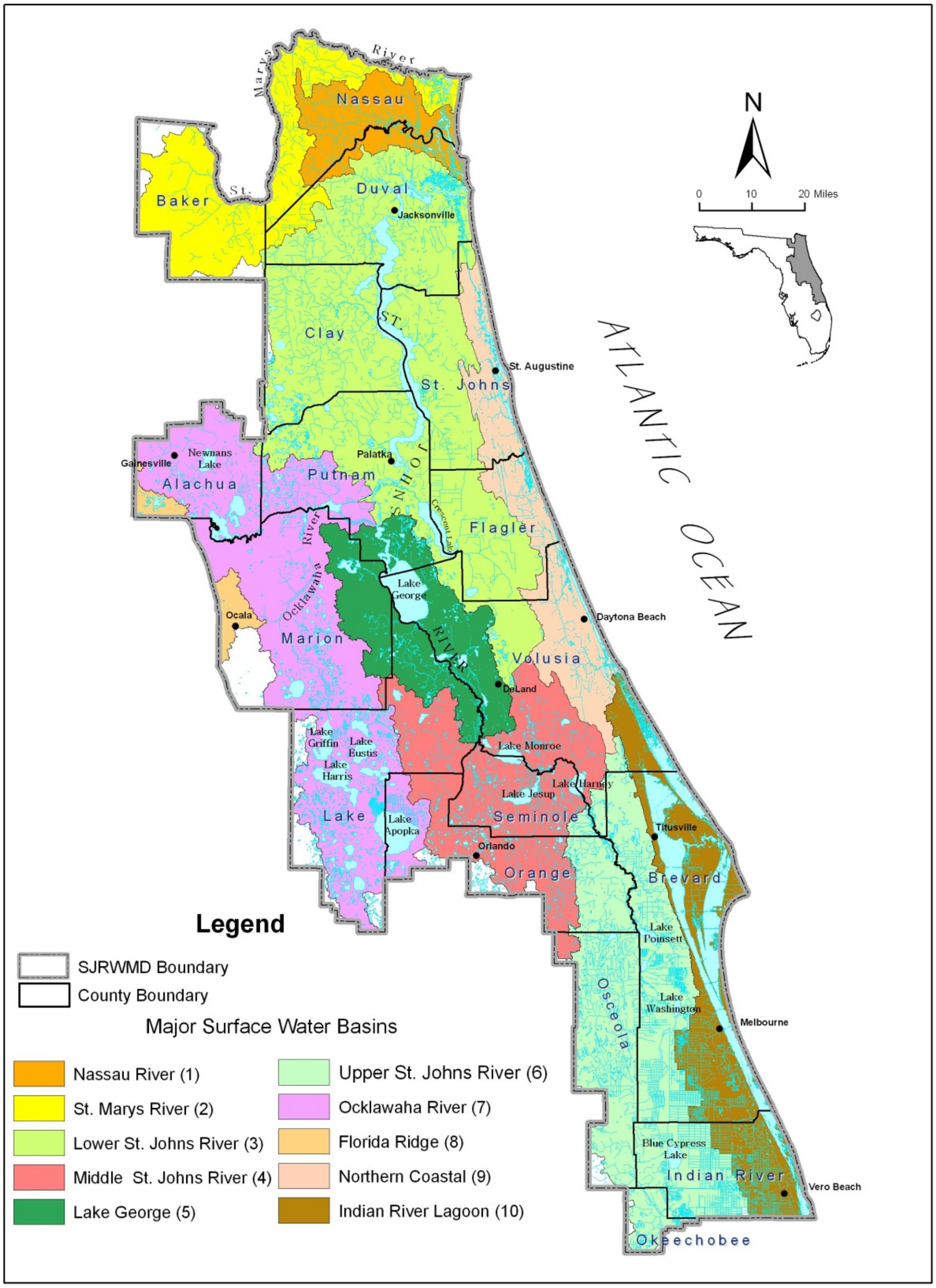

Figure 1. Major surface water basins in the St. Johns River Water Management District

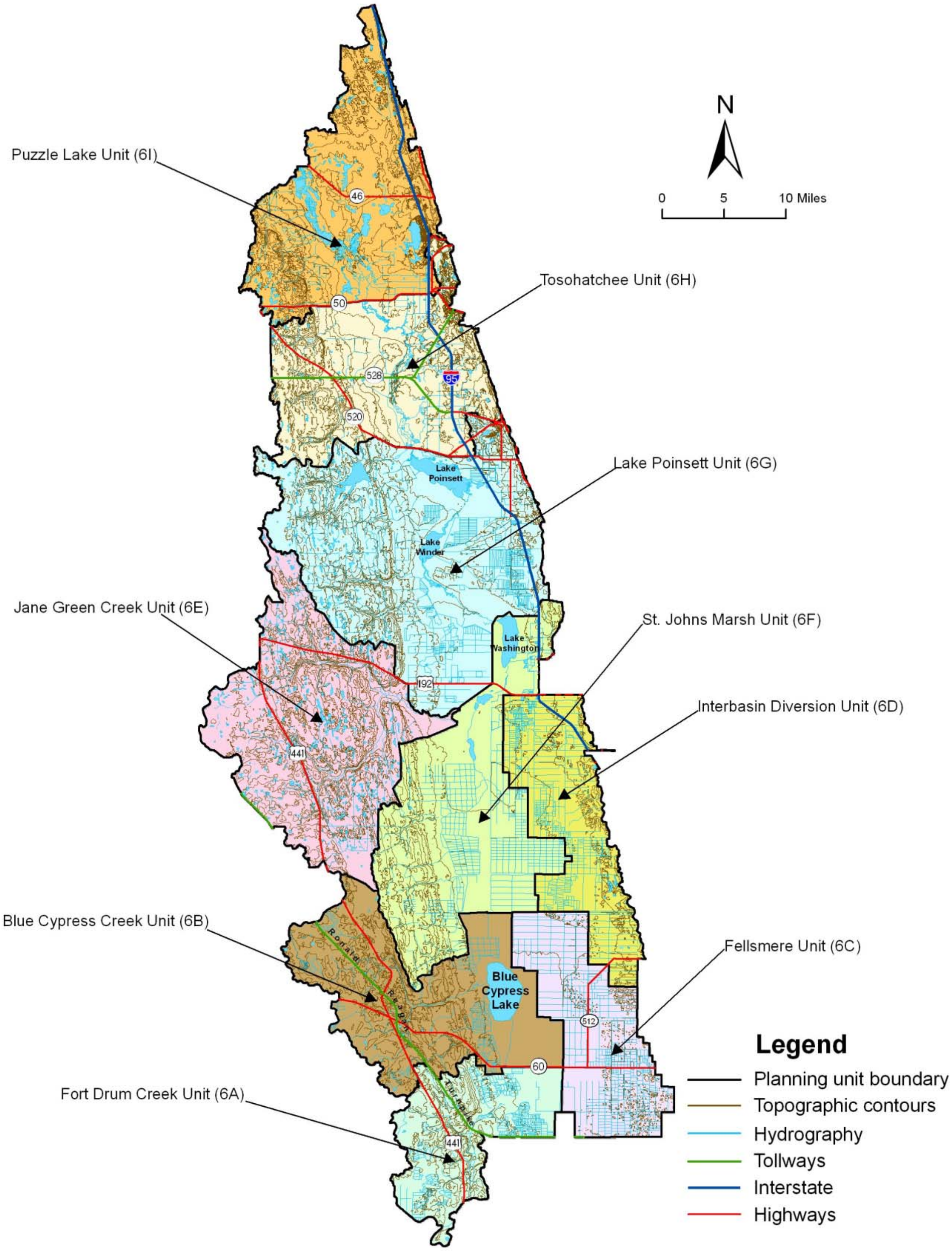

Figure 2. The Upper St. Johns River Basin and its surface water planning units

MFLs FOR THE ST. JOHNS RIVER AT SR 50

Chapter 40C-8, *F.A.C.*, 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 (MIH), minimum frequent high (MFH), minimum average (MA), minimum frequent low (MFL), and minimum infrequent low (MIL)* flows and/or water levels. Four MFLs have been established for the St. Johns River at SR 50 (Table 1; Mace 2007). Detailed definitions for MFLs and further explanation of the MFLs can be found in Chapter 40C-8, *F.A.C*.

Table 1. MFLs for the St. Johns River at SR 50

MFL Category	Level (ft NGVD)	Flow (cfs)	Duration (days)	Return interval (T) (years)
Minimum Frequent High	8.1	1,950	≥30	≤2
Minimum Average	5.9	580	≤180	≥1.5
Minimum Frequent Low	4.2	140	≤120	≥5
Minimum Infrequent Low	2.7	43	≤60	≥50

The details of the procedures used in determining the foregoing MFLs are described in Mace (2007).

The terms “Duration” and “Return interval” appearing in Table 1 are defined as follows for the purpose of this report.

“Duration” means the amount of time in consecutive days.

“Return interval” means the average length of time, in years, between two inundation events or dewatering events of equal or greater magnitude, over the long term.

EVALUATION OF MFLS FOR THE ST. JOHNS RIVER AT SR 50 – THE PROCEDURES

To verify 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. 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 MFLs. The stage and discharge data gauged by the USGS since October 1933 (i.e., Water Year, WY 1934), and model simulated data were used in this report for computing various hydrologic statistics and comparing them with the MFLs for the St. Johns River at SR 50. This section describes and illustrates the MFLs evaluation procedures using the current USGS data, that is, without discharge diversions.

The MFLs evaluation procedures

The MFLs compliance was evaluated graphically and the evaluation procedures consisted 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. The following sections illustrate these procedures through analysis of the 1934-2005 USGS WY data without considering discharge diversions for water supply.

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 3-6). The long-term hydrographs (Figures 3 and 5) indicate the MFLs compliance during different time periods, and the duration curves (Figures 4 and 6) indicate the overall MFLs compliance.

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 return period (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 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). 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.

Tables I-1 through I-4 (Appendix I) illustrate the steps involved in developing data for probability plots. Tables I-1 through I-3 are generated first (by FORTRAN programs); these are the data series for different durations. Then the data in Table I-4, the Weibull plotting positions and the required data for MFLs plotting, are generated (also by FORTRAN programs). Further details of these tables are as follows.

Table I-1 gives the highest discharges exceeded continuously for different durations for the 72 years of data used in the evaluation. A reference year June 1 through May 31 was used in evaluating these data series because this reference year includes the wet period, generally June through November. The 30-day duration data were used from this table for the MFH evaluation.

Table I-2 gives the lowest discharges not exceeded continuously for different durations for the 72 years of data used in the evaluation. A reference year October 1 through September 30 was used in evaluating these data series because this reference year includes the dry period, generally November/December through May. The 60-day and 120-day duration data were used from this table for MIL, and MFL evaluations, respectively.

Table I-3 gives the lowest mean discharges for different durations for the 72 years of data used in the evaluation. A reference year October 1 through September 30 was used in evaluating these data series because this reference year includes the dry period, generally November/December through May. The 183-day duration data were used from this table for MA evaluation.

Table I-4 gives data for various MFLs arranged in descending order, and the Weibull plotting positions.

Appendixes I and II present the MFLs graphs for discharges and stages, respectively. These graphs were generated by Grapher 6 software (Golden Software, Inc. 2005). 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 band 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 (see Page 4) gives durations and return intervals for the MFLs for the SJR at SR 50, which should be met to preserve the current ecological conditions of the system. The durations that are to be met are limiting durations (data for other durations also can be found in Tables I-1 through I-3, Appendix I); lower limit for 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 Table I-4 (Appendix I). Data for the limiting durations are plotted in developing MFLs graphs (Appendixes I and II).

The probability band: The probability plots in Appendixes I and II show a probability band running upward from the horizontal line of the minimum level/discharge. Like durations, the Ts shown in Table 1 also are limiting values; upper limit for MFH, and lower limits for the MA, MFL, and MIL. One side of the vertical bands shown in the figures corresponds to the limiting Ts shown in Table 1 and a desirable range. If data plot through the vertical band, it is an indication that the data have a T satisfying the set limit for T, and thus the MFLs would be 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 minimum stage/discharge, and b) actual duration of data with the set T. For example, in the figure for the MFH (Figure I - 2, Appendix I), a line drawn through the plotted data points (30-day duration time series) intersects the MFH line of 1,950 cfs at about 73% exceedance probability level, or T = 1.37 years, which is the actual T; this T is less than the set T of 2 years for the MFH (Table 1). Further, the data intersect the vertical probability band at about 2,100 cfs, which means there is some ‘free board,’ that is, the MFH could be met even at lower discharges.

Data adequacy

The MFL evaluations in this report were based on 72 years of streamflow data covering the period October 1933 – May 2006. This is a sufficiently long period of data for performing generalized evaluations. However, for satisfactory evaluation of MFLs, it is necessary to ensure that the data are well balanced in terms of prolonged wet and dry periods. This can be done by a plot of smoothed data (i.e., 5 or 10-year moving averages, by detrending data, if necessary), which could reveal the wet and dry cycles of discharges. In addition, cycles in sea surface temperatures (SSTs) also might be useful for this evaluation, which is briefly discussed here.

During the last two decades, research has indicated a possible relation between the SSTs and rainfall/streamflow occurrences in various parts of the world. Enfield et al. (2001) showed that the warm and cool phases of the North Atlantic Multidecadal Oscillation (AMO) influence the rainfall occurrences in the United States. For south Florida, they showed that the warm and cool phases of the AMO coincided with higher and lower rainfall/streamflow phases, respectively.

AMO is a graph of the10-year moving averages of detrended SST data averaged over the entire north Atlantic; the north Atlantic region lying between the Americas and Europe/west Africa, from the equator to 70º N Latitude (Figure 7). However, two of the required conditions for formation of tropical storms and hurricanes over the ocean are: 1) maximum SSTs should exceed 26.5º C, and 2) the oceanic region should be away from the equator at least by 300 miles. By analyzing the 1854-2005 north Atlantic SST data, Rao delineated the region satisfying these conditions and named it the North Atlantic Warm Region (NAWR, Figure 7; Rao 2009); NAWR is found to be much less than 50% of the entire north Atlantic. Whether a Multidecadal Oscillation (MO) developed specifically for NAWR would have a better correlation with rainfall/streamflow occurrences in northeast Florida has been investigated by Rao (2009). MOs for both North Atlantic and NAWR are developed using the currently available SST data (i.e., 1854-2005) and compared to the North East Florida

Index Rainfall (NEFIR). AMO data are available directly from a NOAA website (updated monthly), but the NAWR data were 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) are used.

Rainfall records in northeast Florida began in 1867 for 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 it included 24 stations by 1942. The NAWR MO and AMO differed during the first warm and cool phases of MO, and NEFIR better agreed with the NAWR MO (Figure 8). 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 higher rainfall phase did not exactly coincide with second warm MO. Figure 9 is developed for the wet season (June-November), and the high and low rainfall phases appear to be better defined for the wet season.

Figure 10 compares the SR 50 discharge data with MO. The 10-year moving averages of discharges for the SJR at SR 50 reveal rather prolonged wet and dry phases during its record period. When the records began, the discharges were low and they are now in a recovering phase after a low discharge phase. Furthermore, in general, the high and low discharge phases matched with the MO warm and cool phases, respectively.

The 10-year moving averages graph of the USJR discharges at SR 50, as seen in Figure 10, is quite well balanced in terms of wet and dry phases, and thus the record may be deemed adequate for the MFLs analyses. Figures 8-10 can play an important role in choosing a simulation period when the streamflow data are to be generated by models. If proper balance is not given to the wet and dry phases of rainfall, the data generated may be inadvertently biased. In the case of SR 50 MFLs, a sensitivity analysis may be performed choosing different periods for analysis, and the effect of the wet and dry cycles noticed in Figure 10 may be determined.

POTENTIAL WATER SUPPLY YIELD DETERMINATION: DISCHARGE DIVERSION SCENARIOS AND MFLs EVALUATIONS

Two data series were available to perform the various analyses for determining the potential water supply yield of the St. Johns River at SR 50: 1) USGS historic discharge data for 1933-2006, and 2) model simulated data for 1942-2001. In the late 1970s, the SJRWMD and the U.S. Army Corps of Engineers (USACE) commenced a massive flood control and environmental restoration project for the USJR Basin (USJRB). Construction of the project, which began in 1988, was mostly completed by the end of 2001 at a cost of about $200 million. The project is designed to reduce peak flows and augment low flows in the river, and also partially recover the discharge diversions that have been taking place to the Indian River Lagoon from the USJRB. The USGS long-term data does not reflect the project conditions and project benefits (i.e., the modified discharges resulting from the project operation). Long-term data reflecting the project conditions were only available through model simulation. In the late 1970s, SJRWMD developed a continuous hydrologic simulation model for the USJRB for project planning, design, and other evaluations. It was essentially a simplified version of the well-known Stanford Watershed model (Crawford and Linsley 1966), with the runoff simulation procedure based on a watershed model introduced in 1976 by the Agricultural Research Service (Williams and LaSeur 1976). Dr. C. Charles Tai, the then Director of the Division Engineering, SJRWMD, developed an initial version of the model for the pre-project conditions (Tai 1978; Suphunvorranop and Tai. 1982). The task of developing the full model was assigned to Rao (the author of this report). Rao made further improvements to the pre-project conditions model by introducing additional model concepts, developing detailed input data, and by detailed model calibration; Rao also developed a model for the USJRB Project conditions. The USACE completed a general design memorandum (GDM) for the project in 1984 using the SJRWMD model results for developing the project environmental impact statement (EIS).

The SJRWMD model was used for several basin evaluations during 1985-2000: environmental, flood control, MFLs development and water supply (Rao 1985; Rao and Tai 1987; Rao, Borah, and Miller 1995, Miller et al. 1996a; Miller et al. 1996b, and; Hall and Borah 1998). The 1980s pre-project and project conditions models were fully updated during 2000-2005 to incorporate the latest watershed data available from the highly sophisticated SJRWMD GIS database, and to include the project as completed by 2004 (Rao 2004 and 2009). Both updated models were thoroughly calibrated. The 1980s project conditions model was only a design model and was not calibrated because the prototype data with the project in place was not yet available. The model was calibrated only in 2002 using the1994-2001 basin data (Rao 2004). SJRWMD used the updated model for two major studies in 2003: 1) Development of an environmental water management plan for the USJRB Project (Miller, Tremwel and Minno 2003), and 2) Development of an EIS for the Three Forks Marsh Conservation Area in the USJRB by the USACE (USACE 2003). This model, with some additional updates (Rao 2009), was used for the present study. Appendix A presents a brief description of the model with model results for the SJR at SR 50. The model results showed that the USJRB project would increase low discharges at SR 50 (below 1,250 cfs) by up to 150 cfs, and stages below 7.50 ft NGVD by up to 0.6 ft.

Currently, SJRWMD is developing an HSPF model (Hydrological Simulation Program – FORTRAN, Bicknell et al. 2001) for the USJRB that incorporates the project in its ultimate (2010) configuration, but the model development was not complete at the time of preparation of this report.

Discharge diversion scenarios

The MFLs for SJR at SR50 were used as environmental constraints to evaluate water supply yield in this reach of the USJRB. Four ‘minimum river flows (MRF)’ and five discharge diversions (DD) were assumed. The four MRFs were: 300, 200, 100, and 50 cfs. The five DDs were: 30, 50, 70, 90, and 110 cfs. The range of MRFs assumed represents reasonable low flows to support ecologic preservation (HSW Engineering, Inc. 2006). The four MRFs and the five DDs give rise to 20 scenarios for evaluation (Table 2). A special case, designated as Scenario A6, was also considered and it was evaluated only for the project conditions data.

The historic gauged USGS data and the USJRB model simulated data represent existing hydrologic conditions, with no water supply diversions at SR 50. Both data sets, however, do include existing upstream discharge withdrawals. A FORTRAN program was developed to derive the time series of modified discharge data for each scenario reflecting the corresponding MRF and DD, and for producing some DD statistics. This MFLs evaluation only analyzed discharge data because there was no satisfactory methodology to compute the time series of stage data that reflects the MRFs and DDs.

Table 2. SJR at SR 50: Scenarios for MFLs evaluation

MRF (cfs)	Discharge Diversion (cfs)					
	30	50	70	90	110	150
300	A1	A2	A3	A4	A5	A6
200	B1	B2	B3	B4	B5	
100	C1	C2	C3	C4	C5	
50	D1	D2	D3	D4	D5	

The following criterion was used to evaluate MFLs for different scenarios. For a given MRF, the scenario with the highest DD was evaluated first (e.g., Scenario A5 for MRF = 300 cfs). If any of the MFLs were not met, then the scenario with the next lower DD was evaluated (i.e., A4, etc.). MFLs evaluations were stopped at the scenario where all of the MFLs were met, because other scenarios with lower DDs would also be met.

Potential water supply yield evaluation methods

Potential water supply yield of the St. Johns River at SR 50 was determined by three methods. These are:

> **Method I:** Evaluation with the USGS 1933-2006 historic data - Diversion after meeting the MRF. In this method, diversion of discharge was assumed to occur after meeting the MRF, up to a maximum of the DD for the scenario.
>
> **Method II:** Evaluation with the USGS 1933-2006 historic data - Two-tier diversion. In this method, discharge diversions were assumed to occur at two levels of MRFs.
>
> **Method III:** Evaluation with the 1942-2001 simulated data - Diversion after meeting the MRF. These data reflect the minimum flow augmentation and the other benefits from the USJRB project.

Assumptions

MRF. MRF is the quantity of discharge that should always be maintained in the river, unless the river flow (Q) naturally declines due to drought conditions. For a given scenario, on a given day:

1. Full diversion occurs only if Q was greater than or equal to (MRF + DD).
2. No diversion occurs if Q was less than or equal to MRF.
3. If Q was less than (MRF + DD), the discharge available for diversion equals Q minus MRF.

The foregoing assumptions were incorporated into the FORTRAN program that developed time series data for each scenario.

Data series for MA, MFL, and MIL evaluations. The USGS water years comprised the reference years for developing these time series. Thus, Oct 1933 to Sept 2005 data (72 years) were used in these analyses by Methods I and II. For Method III, the October-December 1941 data were composed from the nearest daily data (i.e., January-March 1942), and Water Years 1942-2001 (60 years) data were used.

Data series for MFH evaluations. The reference year for these time series was June – May. Thus, June 1934 – May 2006 data (72 years) were used in these analyses by Methods I and II. For Method III, June 1942-May 2001 (59 years) data were used.

Data series for developing discharge-duration graphs. 1934-2005 calendar years data (72 years) were used in Methods I and II. For Method III, the 1942-2001 calendar years data (60 years) were used.

Upstream diversions. The discharges gauged by the USGS at SR 50 on the St. Johns River reflect flows after meeting the historic upstream diversions (i.e., agricultural and municipal withdrawals discussed earlier). Therefore, the present analyses by Methods I and II would not reflect any future revisions in the upstream withdrawals. The project conditions model assumed various withdrawals for agricultural irrigation upstream, and a 15.5 mgd withdrawal from Lake Washington.

Data homogeneity. During the 1933-2006 USGS data period, land use changes including urban development and additional agricultural developments occurred in the USJRB. Further, construction of the Upper St. Johns River Basin Project that began in the late 1980s, affected the basin boundary and flow conditions in Planning Units 6A through 6F (Figure 2). The later few years of the USGS discharge data may have been affected somewhat by the currently completed project. To examine whether the historic land use changes and the USJRB project as thus far completed have significantly affected the flow conditions of the SJR at SR 50, a mass curve of discharges was plotted (Figure 11). The mass curve did not show any continuous shifts, and the fluctuations about the trendline drawn through the mass curve generally conformed to the fluctuations in the10-year moving discharge averages (Figure 10). The hydrographs of annual discharges (calendar year and the USGS Water Years) did not show a major trend shift in the overall flow condition (i.e., the discharges neither increased nor decreased with time; Figures 11 – 13). The historic land use changes did not significantly affect the St. Johns River discharge volumes at SR 50; the post-project conditions data is too short to exhibit project effects (Figures 11 – 13). From these results, it was concluded that the USGS data were homogeneous for the present analyses. The simulated data used in Method III, reflecting the project conditions, was homogeneous because the model assumed the same basin conditions (i.e., 2004 conditions) for the entire simulation period (i.e., 1942-2001).

Determination of absolute minimum MRF

The DD values assumed for developing various withdrawal scenarios were arbitrary (but appeared to be reasonable). An initial MFLs evaluation was performed to determine the absolute MRF that should be maintained to meet MFLs. For this purpose, the MRF was assumed to be zero as a starting value, and DD was assumed to be 70 cfs, a consensus value for DD. An evaluation with these assumptions showed that the MIL would not be met (Figure III – 5, Appendix III). Then additional evaluations were performed by gradually increasing the MRF. An MRF value of 45 cfs was found to be satisfactory to meet the MIL (Figure III – 6, Appendix III). On this basis, the absolute minimum MRF was determined as 45 cfs, which is below the six DDs assumed in developing the DD scenarios, but exceeds the established MIL discharge of 43 cfs.

Method I: The scenarios evaluated and results

Twenty DD scenarios, A1 through D5 (Table 2) were evaluated by Method I. MFLs graphs similar to those presented in Appendix I were generated for each DD scenario under each MRF as per the criterion described in the foregoing. The analyses for each scenario are presented in the Appendixes named by scenario number (e.g., Appendix A5 for Scenario A5). With DD = 110 cfs, one or more MFLs were not met for all MRFs. With DD = 90 cfs, the MA was not met for all MRFs except MRF = 300 cfs. With DD = 70 cfs, all MFLs were met for all of the MRFs considered. Since all MFLs were met for all of the MRFs with DD = 70 cfs, the MFLs for other scenarios with lower DDs were not evaluated, but it was assumed that the MFLs would be met for those scenarios (Table 3). Based on these results, it may be concluded that the optimal DD by Method I lies between 90 and 110 cfs, and the exact value may be determined by running additional scenarios, gradually increasing DD from 90 cfs. Otherwise, 90 cfs may be regarded as the optimal DD tentatively.

Potential water supply yield by Method I. The mean of the discharges diverted for the period of analysis (1934-2005 Water Years) was regarded as the potential additional water supply yield of the SJR at SR 50. The potential water supply yields for the 20 scenarios analyzed are summarized in Table 4. However, as shown by Table 3, MFLs were not met for some of the scenarios, and these scenarios may be regarded as infeasible. The infeasible yields are shown in bold text in Table 4. Scenario A4 gave a maximum yield of 42.1 mgd by Method I (Table 4).

Table 3. SJR at SR 50: Summary of MFLs compliance (Method I)

MRF (cfs)	Discharge for Diversion (cfs)				
	30	50	70	90	110
300	Y	Y	Y	Y	N(MA)
200	Y	Y	Y	N(MA)	N(MA)
100	Y	Y	Y	N(MA)	N(MA, MFL)
50	Y	Y	Y	N(MA)	N(MA, MFL)

Y = All MFLs met; N = MFLs in the parentheses not met

Table 4. SJR at SR 50: Potential water supply yield, mgd (Method I)
(Mean of diversion discharges for the period analyzed)

MRF (cfs)	Discharge Diversion (cfs)				
	30	50	70	90	110
300	14.2	23.8	33.0	42.1	**51.1**
200	15.7	26.0	36.0	**45.9**	**55.6**
100	17.4	28.6	39.7	**50.5**	**61.2**
50	18.5	30.4	42.0	**53.4**	**64.6**

The water supply yields shown in bold are infeasible because MFLs are not met for these scenarios.

Other diversion statistics

In addition to the graphical evaluations of the MFLs, the following diversion statistics were produced:

1. Number of days diversion occurred each year (Table 5)
2. Number of days diversion occurred each month (Table 6)
3. Monthly and annual discharge diversions (Table 7)

Tables 5 – 7 are the results for Scenario A4. Table 5 gives the total number of days diversion occurred each year with a break-up of days as follows: a) full diversion; b) diversion quantity less than 50% DD; c) diversion quantity equals 50% DD to less than full DD; and d) no diversion. Under Scenario A4, diversion occurred for all days in a year only for 11 of the 72 years (15%). Diversion occurred only for 16 days in 1981.

Table 6 is a monthly break-up of diversion days for each year. This table shows that no water would be available for diversion continuously for several months during dry periods. The most severe drought occurred during 1980–1982, and no diversion would have been allowed for nearly a continuous 24-month period.

Table 7 gives monthly and annual diversion quantities. Annual values also are given as averages in acre-ft and mgd. For this scenario, the diversion discharge was determined to be 72% of the maximum possible diversion (42.1 mgd / 58.1 mgd).

Tables similar to Tables 5 – 7 were generated for all of the 20 scenarios, but they are not presented in this report. They are available in the output files of the FORTRAN program, and can be retrieved, if necessary.

Method II: The scenarios evaluated and results

Two scenarios, designated as Scenario A4A and D3A were evaluated by this method. Discharges occur in two stages (tiers) as follows.

Scenario A4A:
Tier 1 discharge: If MRF > 300 cfs, DD = up to 90 cfs
Tier 2 Discharge: If MRF > 600 cfs, DD = 90 + up to 40 cfs
Example: If the river flow, Q = 610 cfs, DD = 90 + 10 = 100 cfs
If the river flow, Q = 650 cfs, DD = 90 + 40 = 130 cfs

Scenario D3A:
Tier 1 discharge: If MRF > 50 cfs, DD = up to 70 cfs
Tier 2 Discharge: If MRF > 400 cfs, DD = 70 + up to 40 cfs

Potential water supply yield by Method II. All of the MFLs were met for Scenario A4A (Appendix A4A), and the potential water supply yield was 57.3 mgd. One of the MFLs, the MA, was not met for Scenario D3A (Appendix D3A). Thus, the maximum potential water supply yield by Method II was 57.3 mgd.

Method III: The scenarios evaluated and results

Scenarios A5, B4, C4, and D4, for which MFLs are not met by Method I (Tables 2 – 3), were evaluated by Method III (i.e., model data for the 2004 Project Conditions). The MA was not met by Method I for these scenarios. With the simulated data, the MFLs were met for all of the above four scenarios. The potential average yield for each scenario and the Appendixes that present the respective MFLs graphs, are as follows.

Scenario A5A: 56.2 mgd (MRF = 300 cfs; DD = 110 cfs) (Appendix A5A)
Scenario B4A: 49.8 mgd (MRF = 200 cfs; DD = 90 cfs) (Appendix B4A)
Scenario C4A: 54.0 mgd (MRF = 100 cfs; DD = 90 cfs) (Appendix C4A)
Scenario D4A: 56.1 mgd (MRF = 50 cfs; DD = 90 cfs) (Appendix D4A)

Scenario A5A produced the highest potential average yield, and it also has some 'free-board' (i.e., MA would not be met at a higher DD; see Figure A5A – 3 in Appendix A5A). By an iterative process, DD was gradually increased and it was found that the MA was just met at DD = 150 cfs; this case is designated as Scenario A6. The potential average yield for this scenario was 75.5 mgd. Tables 8-10 present various diversion statistics for Scenario A6.

Potential water supply yield by Method III. MFLs were met for all of the five scenarios evaluated by Method III. Potential water supply yield for the five scenarios ranged from 49.8 to 75.5 mgd. The maximum of these scenarios reflects about 80% increased yield over the Method I evaluations (from 42.1 mgd for Scenario A4 to 75.5 mgd for Scenario A6), and about 30% increased yield over the Method II evaluations (from 57.3 mgd for Scenario A4A to 75.5 mgd for Scenario A6). This result clearly demonstrated that the USJRB Project greatly enhances the water supply potential by its creation of water management and marsh conservation areas (Figure 14) and flow regulation through the project area.

Even though the USJRB project greatly enhances the water supply potential of the SJR at SR 50, the MRF requirements to support ecological preservation will not allow diversions for several days during many low rainfall years, and the full DD would only be possible for a limited number of days in any year (Tables 8 – 9). The statistics showed that diversion for the entire year would be possible only for 14 out 60 years or 23% of years (Table 8). Therefore, water supply developers should recognize this constraint (i.e., MRF) and plan for alternative sources for drought periods. A quantitative analysis of the anticipated deficits can be performed from the results given in Table 10.

Table 5. SJR near Christmas: Diversion statistics - # of days Diversion occurs

```
       Minimum River Flow = 300. cfs Diversion up to  90. cfs (Scenario A4 Annual)

   WtrYr   Total FullDiv <50%Div 50to<Ful  NoDiv   check

    1934     365     363       0       2       0     365
    1935     220     209       5       6     145     365
    1936     366     366       0       0       0     366
    1937     294     242      36      16      71     365
    1938     289     262       8      19      76     365
    1939     176     146      15      15     189     365
    1940     327     312       9       6      39     366
    1941     350     336       7       7      15     365
    1942     365     365       0       0       0     365
    1943     135     125       6       4     230     365
    1944     229     207      15       7     137     366
    1945     261     255       3       3     104     365
    1946     264     235       8      21     101     365
    1947     311     292      11       8      54     365
    1948     271     258       6       7      95     366
    1949     253     241       5       7     112     365
    1950     189     151      27      11     176     365
    1951     293     223      42      28      72     365
    1952     274     254       8      12      92     366
    1953     304     296       5       3      61     365
    1954     323     305      14       4      42     365
    1955     302     287       4      11      63     365
    1956     169     136      19      14     197     366
    1957     365     365       0       0       0     365
    1958     344     297      15      32      21     365
    1959     348     328       6      14      17     365
    1960     366     366       0       0       0     366
    1961     257     205      26      26     108     365
    1962      99      84      11       4     266     365
    1963     291     272      11       8      74     365
    1964     282     255      12      15      84     366
    1965     300     271      15      14      65     365
    1966     365     365       0       0       0     365
    1967     277     257      10      10      88     365
    1968     172     165       3       4     194     366
    1969     365     354       7       4       0     365
    1970     333     292      18      23      32     365
    1971     140      74      28      38     225     365
    1972     314     296      13       5      52     366
    1973     365     351       6       8       0     365
    1974     234     226       6       2     131     365
    1975     203     191       5       7     162     365
    1976     232     225       5       2     134     366
    1977     201     194       4       3     164     365
    1978     365     354       6       5       0     365
    1979     330     315       6       9      35     365
    1980     211     197      11       3     155     366
    1981      16      11       1       4     349     365
    1982     150     147       2       1     215     365
    1983     363     353       3       7       2     365
    1984     366     366       0       0       0     366
    1985     242     217      16       9     123     365
    1986     232     207      13      12     133     365
    1987     281     269       8       4      84     365
    1988     317     297       9      11      49     366
    1989     161      85      52      24     204     365
    1990     221     183      26      12     144     365
    1991     365     365       0       0       0     365
    1992     333     301      19      13      33     366
    1993     362     350       9       3       3     365
    1994     235     191      29      15     130     365
    1995     357     344       7       6       8     365
    1996     366     366       0       0       0     366
    1997     209     198       4       7     156     365
```

Table 5 -Continued

```
WtrYr   Total FullDiv <50%Div 50to<Ful  NoDiv   check

1998     335     318      14       3      30     365
1999     228     199      13      16     137     365
2000     184     167       7      10     182     366
2001     140     133       2       5     225     365
2002     279     258       4      17      86     365
2003     324     306      14       4      41     365
2004     266     214      20      32     100     366
2005     365     365       0       0       0     365
2006     166     159       2       5     199     365
```

Table 6. SJR near Christmas: Diversion statistics - # of days Diversion occurs
Minimum River Flow = 300. cfs Diversion up to 90. cfs (Scenario A4 Monthly)

WtrYr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1934	31	30	31	31	28	31	30	31	30	31	31	30	365
1935	31	30	31	29	0	0	0	0	7	31	31	30	220
1936	31	30	31	31	29	31	30	31	30	31	31	30	366
1937	31	30	31	31	28	31	30	31	14	0	18	19	294
1938	31	30	31	31	28	31	23	0	0	23	31	30	289
1939	31	30	13	0	0	0	0	8	2	31	31	30	176
1940	31	30	31	31	29	31	30	15	14	24	31	30	327
1941	31	30	16	31	28	31	30	31	30	31	31	30	350
1942	31	30	31	31	28	31	30	31	30	31	31	30	365
1943	31	22	0	0	0	0	0	0	0	21	31	30	135
1944	31	30	31	29	0	0	5	0	11	31	31	30	229
1945	31	30	31	31	28	11	0	0	7	31	31	30	261
1946	31	30	31	31	28	31	6	0	0	15	31	30	264
1947	31	30	31	12	16	31	30	21	17	31	31	30	311
1948	31	30	31	31	29	31	20	0	0	7	31	30	271
1949	31	30	31	31	28	4	0	0	6	31	31	30	253
1950	31	30	31	31	28	19	14	0	0	0	0	5	189
1951	15	30	31	31	28	24	1	31	18	23	31	30	293
1952	31	30	31	31	29	31	30	17	2	0	12	30	274
1953	31	30	31	31	28	31	30	25	0	6	31	30	304
1954	31	30	31	31	28	31	17	2	30	31	31	30	323
1955	31	30	31	31	28	31	23	0	5	31	31	30	302
1956	31	30	31	31	19	0	0	0	0	0	0	27	169
1957	31	30	31	31	28	31	30	31	30	31	31	30	365
1958	31	30	31	31	28	31	30	31	30	17	24	30	344
1959	31	30	14	31	28	31	30	31	30	31	31	30	348
1960	31	30	31	31	29	31	30	31	30	31	31	30	366
1961	31	30	31	31	28	31	5	0	0	22	18	30	257
1962	23	0	0	0	0	0	0	0	0	17	29	30	99
1963	31	30	31	31	28	31	30	15	0	17	31	16	291
1964	31	30	31	31	29	31	30	23	0	0	16	30	282
1965	31	30	31	31	23	31	19	0	12	31	31	30	300
1966	31	30	31	31	28	31	30	31	30	31	31	30	365
1967	31	30	31	31	25	30	0	0	7	31	31	30	277
1968	31	22	0	0	0	0	0	0	27	31	31	30	172
1969	31	30	31	31	28	31	30	31	30	31	31	30	365
1970	31	30	31	31	28	31	30	31	11	18	31	30	333
1971	31	6	0	0	18	0	0	0	0	24	31	30	140
1972	25	30	31	31	29	31	16	9	20	31	31	30	314
1973	31	30	31	31	28	31	30	31	30	31	31	30	365
1974	31	30	31	31	15	0	0	0	4	31	31	30	234
1975	31	30	31	5	0	0	0	0	14	31	31	30	203
1976	31	30	31	16	0	0	0	2	30	31	31	30	232
1977	31	30	31	31	28	18	0	0	0	0	5	27	201
1978	31	30	31	31	28	31	30	31	30	31	31	30	365
1979	31	30	15	31	28	31	18	24	30	31	31	30	330
1980	31	30	31	31	29	31	23	0	0	0	3	2	211
1981	0	0	0	0	0	0	0	0	0	0	0	16	16
1982	0	0	0	0	0	0	22	6	30	31	31	30	150
1983	31	30	31	31	28	31	30	31	28	31	31	30	363
1984	31	30	31	31	29	31	30	31	30	31	31	30	366
1985	31	30	31	31	28	17	18	0	5	3	18	30	242
1986	31	30	31	31	28	23	0	0	0	0	28	30	232
1987	31	30	31	31	28	31	30	31	13	0	0	25	281
1988	31	30	31	31	29	31	30	31	6	6	31	30	317
1989	30	8	18	10	28	28	0	0	0	4	18	17	161
1990	31	30	31	31	28	31	7	0	0	0	6	26	221
1991	31	30	31	31	28	31	30	31	30	31	31	30	365
1992	31	30	31	31	29	31	30	11	17	31	31	30	333
1993	31	30	31	31	28	31	30	31	30	31	28	30	362
1994	31	20	0	3	18	31	4	10	26	31	31	30	235

Table 6. -Continued

WtrYr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1995	31	30	31	31	28	31	30	31	22	31	31	30	357
1996	31	30	31	31	29	31	30	31	30	31	31	30	366
1997	31	30	31	8	0	0	0	0	17	31	31	30	209
1998	31	30	31	31	28	31	30	31	23	12	27	30	335
1999	31	30	30	9	16	0	0	0	20	31	31	30	228
2000	31	30	31	31	29	3	0	0	0	4	0	25	184
2001	31	30	0	0	0	0	0	0	0	18	31	30	140
2002	31	30	31	31	28	24	0	0	12	31	31	30	279
2003	31	30	31	31	28	31	30	4	16	31	31	30	324
2004	31	30	31	18	29	22	0	2	13	29	31	30	266
2005	31	30	31	31	28	31	30	31	30	31	31	30	365
2006	31	30	31	31	28	15	0	0	0	0	0	0	166

Table 7. SJR near Christmas: Diversion statistics - Diversion in cfs-days
Minimum River Flow = 300. cfs Diversion up to 90. cfs (Scenario A4 Discharges)

WtrYr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annl	acrft	mgd
1934	2790.	2700.	2790.	2790.	2520.	2790.	2657.	2790.	2700.	2790.	2790.	2700.	32807.	178.2	58.1
1935	2790.	2700.	2790.	2109.	0.	0.	0.	0.	630.	2790.	2790.	2700.	19299.	104.8	34.2
1936	2790.	2700.	2790.	2790.	2610.	2790.	2700.	2790.	2700.	2790.	2790.	2700.	32940.	178.5	58.1
1937	2790.	2700.	2790.	2790.	2520.	2790.	2700.	2470.	174.	0.	356.	1379.	23459.	127.4	41.5
1938	2790.	2700.	2790.	2790.	2520.	2790.	1517.	0.	0.	2004.	2790.	2297.	24988.	135.8	44.2
1939	2194.	2700.	642.	0.	0.	0.	0.	680.	28.	2790.	2790.	2700.	14524.	78.9	25.7
1940	2790.	2700.	2790.	2790.	2610.	2790.	2700.	1105.	996.	1943.	2790.	2700.	28704.	155.5	50.7
1941	2790.	2500.	999.	2790.	2520.	2790.	2700.	2790.	2700.	2790.	2790.	2700.	30859.	167.7	54.6
1942	2790.	2700.	2790.	2790.	2520.	2790.	2700.	2790.	2700.	2790.	2790.	2700.	32850.	178.5	58.1
1943	2790.	1518.	0.	0.	0.	0.	0.	0.	0.	1850.	2790.	2700.	11648.	63.3	20.6
1944	2790.	2700.	2790.	1962.	0.	0.	147.	0.	739.	2790.	2790.	2700.	19408.	105.2	34.3
1945	2790.	2700.	2790.	2790.	2520.	706.	0.	0.	630.	2790.	2790.	2700.	23206.	126.1	41.1
1946	2790.	2700.	2790.	2790.	2377.	2593.	126.	0.	0.	1241.	2790.	2700.	22897.	124.4	40.5
1947	2790.	2700.	2790.	655.	1352.	2790.	2700.	1438.	1530.	2790.	2790.	2700.	27025.	146.8	47.8
1948	2790.	2700.	2790.	2790.	2610.	2790.	1381.	0.	0.	465.	2790.	2700.	23806.	129.0	42.0
1949	2790.	2700.	2790.	2790.	2387.	84.	0.	0.	482.	2790.	2790.	2700.	22303.	121.2	39.5
1950	2790.	2700.	2790.	2790.	2520.	674.	456.	0.	0.	0.	0.	55.	14775.	80.3	26.1
1951	1350.	2700.	2790.	2790.	2520.	1632.	4.	1246.	715.	1346.	2790.	2700.	22583.	122.7	40.0
1952	2790.	2700.	2790.	2790.	2610.	2790.	2700.	1355.	39.	0.	856.	2573.	23993.	130.0	42.3
1953	2790.	2700.	2790.	2790.	2520.	2790.	2700.	1831.	0.	540.	2790.	2700.	26941.	146.4	47.7
1954	2790.	2700.	2790.	2790.	2520.	2790.	462.	152.	2700.	2790.	2790.	2700.	27974.	152.0	49.5
1955	2790.	2700.	2790.	2790.	2520.	2790.	1542.	0.	450.	2790.	2790.	2700.	26652.	144.8	47.2
1956	2790.	2700.	2790.	1963.	1076.	0.	0.	0.	0.	0.	0.	2322.	13641.	73.9	24.1
1957	2790.	2700.	2790.	2790.	2520.	2790.	2700.	2790.	2700.	2790.	2790.	2700.	32850.	178.5	58.1
1958	2790.	2700.	2790.	2790.	2520.	2790.	2700.	2790.	2505.	1088.	1210.	2433.	29106.	158.1	51.5
1959	2603.	2680.	784.	2790.	2520.	2790.	2700.	2790.	2700.	2790.	2790.	2700.	30637.	166.4	54.2
1960	2790.	2700.	2790.	2790.	2610.	2790.	2700.	2790.	2700.	2790.	2790.	2700.	32940.	178.5	58.1
1961	2790.	2700.	2790.	2790.	2520.	2225.	168.	0.	0.	989.	1025.	2629.	20626.	112.1	36.5
1962	1819.	0.	0.	0.	0.	0.	0.	0.	0.	1152.	2364.	2700.	8035.	43.7	14.2
1963	2790.	2700.	2790.	2790.	2520.	2790.	2700.	957.	0.	1417.	2790.	1021.	25265.	137.3	44.7
1964	2790.	2700.	2790.	2790.	2610.	2790.	2596.	1062.	0.	0.	1360.	2700.	24188.	131.1	42.7
1965	2790.	2700.	2790.	2520.	1589.	2790.	1418.	0.	809.	2790.	2790.	2700.	25686.	139.5	45.5
1966	2790.	2700.	2790.	2790.	2520.	2790.	2700.	2790.	2700.	2790.	2790.	2700.	32850.	178.5	58.1
1967	2790.	2700.	2790.	2640.	1834.	2429.	0.	0.	554.	2790.	2790.	2700.	24017.	130.5	42.5
1968	2790.	1696.	0.	0.	0.	0.	0.	0.	2430.	2790.	2790.	2700.	15196.	82.3	26.8
1969	2790.	2700.	2790.	2790.	2488.	2264.	2700.	2790.	2700.	2790.	2790.	2700.	32292.	175.4	57.2
1970	2790.	2700.	2790.	2790.	2520.	2790.	2700.	2286.	610.	1470.	2460.	2504.	28410.	154.3	50.3
1971	2386.	302.	0.	0.	998.	0.	0.	0.	0.	1520.	2790.	1838.	9834.	53.4	17.4
1972	2204.	2700.	2790.	2788.	2610.	2790.	1176.	382.	1568.	2790.	2790.	2700.	27288.	147.8	48.2
1973	2790.	2700.	2790.	2790.	2520.	2790.	2700.	2790.	2122.	2790.	2790.	2700.	32272.	175.3	57.1
1974	2790.	2700.	2790.	2790.	949.	0.	0.	0.	306.	2790.	2790.	2700.	20605.	111.9	36.5
1975	2790.	2700.	2763.	167.	0.	0.	0.	0.	1260.	2592.	2790.	2700.	17762.	96.5	31.4
1976	2790.	2700.	2790.	1067.	0.	0.	0.	180.	2700.	2790.	2790.	2700.	20507.	111.1	36.2
1977	2790.	2700.	2790.	2790.	2520.	1396.	0.	0.	0.	0.	373.	2430.	17789.	96.6	31.5
1978	2790.	2700.	2790.	2790.	2520.	2790.	2700.	2549.	2429.	2790.	2790.	2700.	32338.	175.7	57.2
1979	2790.	2700.	950.	2790.	2520.	2790.	1422.	2160.	2700.	2790.	2790.	2700.	29102.	158.1	51.5
1980	2790.	2700.	2790.	2790.	2610.	2790.	1615.	0.	0.	0.	39.	9.	18133.	98.2	32.0
1981	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	1330.	1330.	7.2	2.4
1982	0.	0.	0.	0.	0.	0.	1957.	409.	2700.	2790.	2790.	2700.	13346.	72.5	23.6
1983	2790.	2700.	2790.	2790.	2520.	2790.	2700.	2782.	2213.	2764.	2790.	2700.	32329.	175.6	57.2
1984	2790.	2700.	2790.	2790.	2610.	2790.	2700.	2790.	2700.	2790.	2790.	2700.	32940.	178.5	58.1
1985	2790.	2700.	2790.	2790.	2512.	1028.	1352.	0.	59.	48.	1620.	2700.	20389.	110.8	36.1
1986	2790.	2700.	2790.	2790.	2520.	1525.	0.	0.	0.	0.	1937.	2700.	19752.	107.3	35.0
1987	2790.	2700.	2790.	2790.	2520.	2790.	2700.	2790.	593.	0.	0.	2202.	24665.	134.0	43.7
1988	2790.	2700.	2790.	2790.	2610.	2790.	2700.	2732.	136.	280.	2745.	2700.	27763.	150.4	49.0
1989	2400.	720.	1014.	900.	2133.	838.	0.	0.	0.	67.	1513.	897.	10482.	56.9	18.6
1990	2154.	2700.	2790.	2790.	2520.	2543.	268.	0.	0.	0.	75.	1875.	17715.	96.2	31.4
1991	2790.	2700.	2790.	2790.	2520.	2790.	2700.	2790.	2700.	2790.	2790.	2700.	32850.	178.5	58.1
1992	2790.	2700.	2790.	2790.	2610.	2599.	2280.	646.	922.	2790.	2790.	2700.	28407.	153.9	50.1
1993	2790.	2700.	2790.	2790.	2520.	2790.	2700.	2790.	2700.	2790.	1774.	2700.	31834.	173.0	56.3
1994	2790.	1335.	0.	78.	1412.	2404.	58.	229.	2193.	2790.	2790.	2700.	18779.	102.0	33.2
1995	2790.	2700.	2790.	2790.	2520.	2790.	2700.	2790.	1365.	2790.	2790.	2700.	31515.	171.2	55.8
1996	2790.	2700.	2790.	2790.	2610.	2790.	2700.	2790.	2700.	2790.	2790.	2700.	32940.	178.5	58.1

Table 7. –Continued

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WtrYr   Oct    Nov    Dec    Jan    Feb    Mar    Apr    May    Jun    Jul    Aug    Sep   Annl  acrft   mgd

  1997 2790. 2700. 2776.  371.    0.    0.    0.    0. 1485. 2790. 2790. 2700. 18402. 100.0  32.6
  1998 2790. 2700. 2790. 2790. 2520. 2790. 2700. 2790. 1747.  288. 2430. 2700. 29035. 157.7  51.4
  1999 2790. 2700. 2337.  360. 1012.    0.    0.    0. 1800. 2790. 2755. 2700. 19244. 104.6  34.1
  2000 2790. 2700. 2790. 2790. 2439.   66.    0.    0.    0.  181.    0. 2130. 15886.  86.1  28.0
  2001 2790. 2513.    0.    0.    0.    0.    0.    0.    0. 1616. 2790. 2700. 12409.  67.4  22.0
  2002 2790. 2700. 2790. 2790. 2197. 1807.    0.    0. 1080. 2790. 2790. 2700. 24434. 132.7  43.2
  2003 2790. 2700. 2790. 2790. 2520. 2790. 2366.   78. 1019. 2790. 2790. 2700. 28123. 152.8  49.8
  2004 2790. 2700. 2766.  697. 2515. 1703.    0.   90.  814. 2471. 2790. 2700. 22036. 119.4  38.9
  2005 2790. 2700. 2790. 2790. 2520. 2790. 2700. 2790. 2700. 2790. 2790. 2700. 32850. 178.5  58.1
  2006 2790. 2700. 2790. 2790. 2520. 1104.    0.    0.    0.    0.    0.    0. 14694.  79.8  26.0

                                                                        mean  23812. 129.3  42.1
                                                                         max  32940. 178.5  58.1
                                                                         min   1330.   7.2   2.4
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Table 8. SJR near Christmas: Diversion statistics - # of days Diversion occurs
Minimum River Flow = 300. cfs Diversion up to 150. cfs (Scenario A6 Annual)
1942-2001 SIMULATED DISCHARGES BY RAO'S MODEL: PROJECT CONDITIONS 2004

WtrYr	Total	FullDiv	<50%Div	50to<Ful	NoDiv	check
1942	364	364	0	0	1	365
1943	255	212	21	22	110	365
1944	307	262	31	14	59	366
1945	270	260	7	3	95	365
1946	277	244	24	9	88	365
1947	358	337	16	5	7	365
1948	335	312	17	6	31	366
1949	264	245	6	13	101	365
1950	299	197	38	64	66	365
1951	343	319	11	13	22	365
1952	366	361	0	5	0	366
1953	365	346	12	7	0	365
1954	340	317	17	6	25	365
1955	264	231	17	16	101	365
1956	234	201	12	21	132	366
1957	365	364	0	1	0	365
1958	365	364	0	1	0	365
1959	365	361	0	4	0	365
1960	366	366	0	0	0	366
1961	258	230	17	11	107	365
1962	160	134	16	10	205	365
1963	335	295	21	19	30	365
1964	366	346	12	8	0	366
1965	293	227	28	38	72	365
1966	365	365	0	0	0	365
1967	219	192	13	14	146	365
1968	185	167	12	6	181	366
1969	353	339	8	6	12	365
1970	363	327	14	22	2	365
1971	198	161	23	14	167	365
1972	268	187	38	43	98	366
1973	365	337	8	20	0	365
1974	253	225	23	5	112	365
1975	261	232	20	9	104	365
1976	238	224	7	7	128	366
1977	212	152	23	37	153	365
1978	340	317	15	8	25	365
1979	350	322	14	14	15	365
1980	323	246	39	38	43	366
1981	66	2	37	27	299	365
1982	242	200	10	32	123	365
1983	361	347	8	6	4	365
1984	359	344	9	6	7	366
1985	280	231	25	24	85	365
1986	255	241	6	8	110	365
1987	329	275	28	26	36	365
1988	366	337	3	26	0	366
1989	232	168	47	17	133	365
1990	303	248	17	38	62	365
1991	354	323	23	8	11	365
1992	246	215	14	17	120	366
1993	365	350	3	12	0	365
1994	283	211	49	23	82	365
1995	365	365	0	0	0	365
1996	366	364	0	2	0	366
1997	240	205	21	14	125	365
1998	365	365	0	0	0	365
1999	266	250	6	10	99	365
2000	235	214	12	9	131	366
2001	206	188	9	9	159	365

Table 9. SJR near Christmas: Diversion statistics - # of days Diversion occurs
Minimum River Flow = 300. cfs Diversion up to 150. cfs (Scenario A6 Monthly)
1942-2001 SIMULATED DISCHARGES BY RAO'S MODEL: PROJECT CONDITIONS 2004

WtrYr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1942	31	30	30	31	28	31	30	31	30	31	31	30	364
1943	31	30	31	20	0	7	6	8	30	31	31	30	255
1944	31	30	31	31	26	14	25	5	22	31	31	30	307
1945	31	30	31	31	28	18	0	0	9	31	31	30	270
1946	31	30	31	31	28	9	0	0	25	31	31	30	277
1947	31	30	31	29	23	31	30	31	30	31	31	30	358
1948	31	30	31	31	29	31	29	1	30	31	31	30	335
1949	31	30	31	31	28	2	0	0	19	31	31	30	264
1950	31	30	31	31	24	8	30	10	12	31	31	30	299
1951	31	30	31	31	28	16	23	31	30	31	31	30	343
1952	31	30	31	31	29	31	30	31	30	31	31	30	366
1953	31	30	31	31	28	31	30	31	30	31	31	30	365
1954	31	30	31	31	28	31	30	6	30	31	31	30	340
1955	31	30	31	31	28	1	4	6	10	31	31	30	264
1956	31	30	31	31	15	0	0	0	4	31	31	30	234
1957	31	30	31	31	28	31	30	31	30	31	31	30	365
1958	31	30	31	31	28	31	30	31	30	31	31	30	365
1959	31	30	31	31	28	31	30	31	30	31	31	30	365
1960	31	30	31	31	29	31	30	31	30	31	31	30	366
1961	31	30	31	31	28	12	0	0	3	31	31	30	258
1962	31	19	0	0	0	10	0	0	8	31	31	30	160
1963	31	30	31	31	28	31	23	10	28	31	31	30	335
1964	31	30	31	31	29	31	30	31	30	31	31	30	366
1965	31	30	31	27	17	30	16	0	19	31	31	30	293
1966	31	30	31	31	28	31	30	31	30	31	31	30	365
1967	31	30	31	2	16	6	0	0	11	31	31	30	219
1968	31	21	9	0	4	0	0	2	26	31	31	30	185
1969	31	30	31	31	25	22	30	31	30	31	31	30	353
1970	31	30	31	31	28	31	30	29	30	31	31	30	363
1971	31	30	10	0	13	16	5	0	1	31	31	30	198
1972	31	30	25	0	20	11	19	16	24	31	31	30	268
1973	31	30	31	31	28	31	30	31	30	31	31	30	365
1974	31	30	31	31	14	4	0	0	20	31	31	30	253
1975	31	30	31	31	7	0	5	7	27	31	31	30	261
1976	31	30	31	1	0	0	6	17	30	31	31	30	238
1977	31	30	31	22	9	0	0	0	0	28	31	30	212
1978	31	30	31	31	28	31	17	24	25	31	31	30	340
1979	31	30	25	31	28	31	23	29	30	31	31	30	350
1980	31	30	31	31	29	31	6	18	24	31	31	30	323
1981	19	11	13	0	0	0	0	0	0	0	0	23	66
1982	31	25	0	0	0	3	30	31	30	31	31	30	242
1983	31	30	31	27	28	31	30	31	30	31	31	30	361
1984	31	30	31	31	29	27	27	31	30	31	31	30	359
1985	31	30	31	27	0	10	21	11	27	31	31	30	280
1986	31	30	31	31	22	0	0	0	18	31	31	30	255
1987	31	30	31	30	0	24	30	31	30	31	31	30	329
1988	31	30	31	31	29	31	30	31	30	31	31	30	366
1989	31	27	17	10	28	15	0	0	12	31	31	30	232
1990	31	30	31	31	23	31	21	0	13	31	31	30	303
1991	31	30	31	31	20	28	30	31	30	31	31	30	354
1992	31	30	31	27	0	0	7	0	28	31	31	30	246
1993	31	30	31	31	28	31	30	31	30	31	31	30	365
1994	31	29	0	8	26	31	10	27	29	31	31	30	283
1995	31	30	31	31	28	31	30	31	30	31	31	30	365
1996	31	30	31	31	29	31	30	31	30	31	31	30	366
1997	31	30	30	0	0	0	7	20	30	31	31	30	240
1998	31	30	31	31	28	31	30	31	30	31	31	30	365
1999	31	30	31	31	28	3	0	0	20	31	31	30	266
2000	31	30	31	31	29	8	0	0	0	14	31	30	235
2001	31	23	0	0	0	2	9	19	30	31	31	30	206

Table 10. SJR near Christmas: Diversion statistics - Diversion in cfs-days
Minimum River Flow = 300. cfs Diversion up to 150. cfs (Scenario A6 Discharges)
1942-2001 SIMULATED DISCHARGES BY RAO’S MODEL: PROJECT CONDITIONS 2004

WtrYr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annl	acrft	mgd
1942	4650.	4500.	4500.	4650.	4200.	4650.	4500.	4650.	4500.	4650.	4650.	4500.	54600.	296.6	96.6
1943	4650.	4500.	4650.	2030.	0.	387.	318.	571.	4128.	4650.	4650.	4500.	35034.	190.3	62.0
1944	4650.	4500.	4650.	4650.	3238.	1629.	1243.	300.	3286.	4650.	4650.	4500.	41946.	227.3	74.0
1945	4650.	4500.	4650.	4650.	4200.	2028.	0.	0.	1070.	4650.	4650.	4500.	39548.	214.9	70.0
1946	4650.	4500.	4650.	4650.	3331.	412.	0.	0.	2619.	4650.	4650.	4500.	38612.	209.8	68.3
1947	4650.	4500.	4650.	3314.	2241.	4650.	4500.	4650.	4500.	4650.	4650.	4500.	51455.	279.5	91.1
1948	4650.	4500.	4650.	4650.	4350.	4650.	3426.	6.	3081.	4650.	4650.	4500.	47763.	258.8	84.3
1949	4650.	4500.	4650.	4650.	3569.	18.	0.	0.	2604.	4650.	4650.	4500.	38441.	208.8	68.0
1950	4650.	4500.	4650.	4650.	2623.	394.	4477.	875.	1073.	3631.	2470.	4437.	38430.	208.8	68.0
1951	4650.	4500.	4650.	4650.	4200.	1462.	2704.	4650.	4500.	4650.	4650.	4500.	49766.	270.4	88.1
1952	4650.	4500.	4650.	4650.	4350.	4472.	4500.	4650.	4500.	4650.	4650.	4500.	54722.	296.5	96.6
1953	4650.	4500.	4650.	4650.	4200.	3066.	4500.	4650.	4500.	4650.	4650.	4500.	53166.	288.8	94.1
1954	4650.	4500.	4650.	4650.	4200.	4650.	2987.	388.	4500.	4650.	4650.	4500.	48975.	266.1	86.7
1955	4650.	4500.	4650.	4650.	2963.	7.	99.	561.	942.	4650.	4650.	4500.	36822.	200.0	65.2
1956	4650.	4500.	4650.	4207.	1441.	0.	0.	0.	176.	4293.	4650.	4500.	33067.	179.2	58.4
1957	4650.	4500.	4650.	4650.	4200.	4637.	4500.	4650.	4500.	4650.	4650.	4500.	54737.	297.4	96.9
1958	4650.	4500.	4640.	4650.	4200.	4650.	4500.	4650.	4500.	4650.	4650.	4500.	54740.	297.4	96.9
1959	4650.	4500.	4604.	4627.	4200.	4650.	4500.	4650.	4500.	4650.	4650.	4500.	54681.	297.1	96.8
1960	4650.	4500.	4650.	4650.	4350.	4650.	4500.	4650.	4500.	4650.	4650.	4500.	54900.	297.5	96.9
1961	4650.	4500.	4650.	4650.	4081.	375.	0.	0.	80.	4281.	4650.	4500.	36417.	197.8	64.5
1962	4650.	1637.	0.	0.	0.	457.	0.	0.	1200.	4650.	4650.	4500.	21744.	118.1	38.5
1963	4650.	4500.	4650.	4535.	4186.	4650.	2827.	653.	2432.	4650.	4650.	4500.	46883.	254.7	83.0
1964	4650.	4500.	4650.	4650.	4350.	4650.	4500.	3767.	3902.	4650.	4650.	4500.	53419.	289.4	94.3
1965	4650.	4500.	4650.	3228.	2244.	3519.	1366.	0.	2137.	4093.	4650.	4500.	39537.	214.8	70.0
1966	4650.	4500.	4650.	4650.	4200.	4650.	4500.	4650.	4500.	4650.	4650.	4500.	54750.	297.5	96.9
1967	4650.	4500.	4262.	31.	2123.	238.	0.	0.	1269.	4650.	4650.	4500.	30873.	167.7	54.6
1968	4650.	2518.	1023.	0.	17.	0.	0.	11.	3900.	4650.	4650.	4500.	25919.	140.4	45.7
1969	4650.	4500.	4650.	4650.	2762.	3191.	4500.	4650.	4500.	4650.	4650.	4500.	51853.	281.7	91.8
1970	4650.	4500.	4650.	4650.	4200.	4650.	4500.	2840.	3836.	4650.	4650.	4500.	52276.	284.0	92.5
1971	4650.	4500.	783.	0.	1539.	944.	114.	0.	29.	4646.	4650.	4500.	26355.	143.2	46.6
1972	4433.	4458.	2463.	0.	1794.	512.	2622.	2091.	2190.	4650.	4650.	4500.	34363.	186.2	60.7
1973	4650.	4449.	3788.	4650.	4200.	4367.	4397.	4650.	4500.	4650.	4650.	4500.	53451.	290.4	94.6
1974	4650.	4500.	4650.	4650.	1368.	84.	0.	0.	1471.	4650.	4650.	4500.	35173.	191.1	62.3
1975	4650.	4500.	4650.	4596.	320.	0.	179.	817.	3104.	4650.	4650.	4500.	36616.	198.9	64.8
1976	4650.	4500.	3993.	3.	0.	0.	680.	2446.	4500.	4650.	4650.	4500.	34572.	187.3	61.0
1977	4650.	4500.	4334.	1804.	622.	0.	0.	0.	0.	2672.	4650.	4500.	27732.	150.7	49.1
1978	4650.	4500.	4650.	4650.	4200.	4650.	1547.	2513.	3750.	4650.	4650.	4500.	48910.	265.7	86.6
1979	4650.	4500.	3092.	4650.	4200.	4650.	2615.	3806.	4500.	4650.	4650.	4500.	50463.	274.2	89.3
1980	4650.	4500.	4650.	4650.	4350.	3582.	44.	1462.	1822.	3757.	4650.	4386.	42503.	230.3	75.0
1981	1190.	924.	680.	0.	0.	0.	0.	0.	0.	0.	0.	1749.	4543.	24.7	8.0
1982	4214.	2701.	0.	0.	0.	305.	4433.	4402.	4500.	4650.	4650.	4500.	34355.	186.6	60.8
1983	4650.	4500.	4650.	2841.	4200.	4650.	4500.	4650.	4500.	4650.	4650.	4500.	52941.	287.6	93.7
1984	4650.	4500.	4650.	4650.	4350.	2938.	3903.	4635.	4500.	4650.	4650.	4500.	52576.	284.9	92.8
1985	4650.	3964.	4650.	3108.	0.	1483.	2096.	1378.	3124.	4650.	4650.	4500.	38253.	207.8	67.7
1986	4650.	4500.	4650.	4650.	2600.	0.	0.	0.	2545.	4650.	4650.	4500.	37395.	203.2	66.2
1987	4650.	4500.	3676.	3073.	0.	1968.	4500.	4509.	4500.	4650.	4650.	4500.	45176.	245.4	80.0
1988	4650.	4500.	4650.	4650.	4349.	4186.	4500.	4630.	4121.	4263.	4650.	4500.	53649.	290.7	94.7
1989	4650.	3076.	1150.	1500.	3675.	696.	0.	0.	351.	4650.	4650.	4500.	28898.	157.0	51.1
1990	4650.	4500.	4650.	4522.	2177.	3839.	2008.	0.	1945.	4650.	4650.	4500.	42091.	228.7	74.5
1991	4650.	4500.	4650.	4650.	1823.	2846.	4444.	4650.	4500.	4650.	4650.	4500.	50513.	274.4	89.4
1992	4650.	4500.	4650.	3303.	0.	0.	488.	0.	3250.	4650.	4650.	4500.	34641.	187.7	61.1
1993	4650.	4500.	4650.	4650.	4200.	4650.	4500.	4650.	4500.	4650.	3803.	4500.	53903.	292.8	95.4
1994	4650.	2793.	0.	663.	2929.	4201.	1352.	1772.	3684.	4650.	4650.	4500.	35844.	194.7	63.4
1995	4650.	4500.	4650.	4650.	4200.	4650.	4500.	4650.	4500.	4650.	4650.	4500.	54750.	297.5	96.9
1996	4650.	4500.	4650.	4650.	4350.	4650.	4500.	4638.	4500.	4650.	4650.	4500.	54888.	297.4	96.9
1997	4650.	4500.	3675.	0.	0.	0.	134.	1825.	4454.	4650.	4650.	4500.	33038.	179.5	58.5
1998	4650.	4500.	4650.	4650.	4200.	4650.	4500.	4650.	4500.	4650.	4650.	4500.	54750.	297.5	96.9
1999	4650.	4500.	4650.	4546.	3700.	48.	0.	0.	3000.	4650.	4650.	4500.	38894.	211.3	68.8
2000	4650.	4500.	4650.	4650.	4344.	488.	0.	0.	0.	1073.	4640.	4500.	33495.	181.5	59.1
2001	4650.	2891.	0.	0.	0.	300.	985.	2411.	4500.	4650.	4650.	4500.	29537.	160.5	52.3
												mean	42709.	231.9	75.5
												max	54900.	297.5	96.9
												min	4543.	24.7	8.0

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The investigations described in this report determined the potential additional water supply yield, in addition to existing withdrawals, of the SJR at SR 50 based on MFLs compliance as a constraint. Two data series were analyzed in the evaluations: 1) USGS historic discharge data for 1933-2006, and 2) simulated data from the SJRWMD USJRB watershed model (Rao 2004 and 2009) for project conditions 2004. Because the construction of the USJRB Project has just recently been completed (with the exception of a few components), the USGS historic data do not reflect the project benefits that include augmentation of low flows and increased discharge volumes that result from curtailing discharge diversion to the Indian River Lagoon. Therefore, the results based on the USGS data are considered conservative. SJRWMD is developing an HSPF model for the USJRB for the ultimate (2010) configuration of the project. However, model results are not currently available.

Discharge diversions (DD) for water supply (at SR 50) were considered only when discharges in the river exceed certain minimum values (Minimum River Flow, MRF). Four MRF values were assumed for the evaluations: MRF = 300, 200, 100, and 50 cfs. Further, each MRF was evaluated for five DD values: DD = up to 30, 50, 70, 90, 110 cfs. The four MRF and the five DD values assumed for the evaluations resulted in 20 scenarios. A few additional (special case) scenarios were also evaluated. For a given MRF, the DD values given in the foregoing are maximum values. For example, if MRF = 300 cfs and DD = 90 cfs, but the actual river flow is 310 cfs, then the diverted discharge was only 10 cfs; a DD of 90 cfs would occur only when the river flow was equal to or greater than 390 cfs. Time series of discharge data for a given MRF and DD (i.e., for a given scenario) were developed from the original (i.e., no diversion) USGS or model data by a FORTRAN program.

Four MFLs (discharges and stages) are recommended for SJR at SR 50: 1) Minimum frequent high (MFH); 2) Minimum average (MA); 3) Minimum frequent low (MFL), and; 4) Minimum infrequent low (MIL). Compliance with these MFLs was evaluated by standard statistical procedures only for discharges. MFLs compliance for stages was not evaluated because there is no satisfactory method to compute the time series of stage data that would reflect MRFs and DDs. Based on evaluations performed by SJRWMD (HSW Engineering, Inc. 2006, Mace 2007), withdrawals within the range of the MRFs considered in the evaluation described in this document would provide for adequate environmental protection during low-flow periods, meet recommended MFLs for the St. Johns River at SR 50, and allow for development of water supplies from the river.

Potential water supply yield evaluation methods and results

Potential additional water supply yield of the St. Johns River at SR 50 was determined by three approaches or methods.

Method I and Results: USGS 1933-2006 historic data were analyzed in this method. Diversion of discharges was assumed to occur when river flows are above MRF, up to a maximum value of the DD for the scenario. Twenty scenarios were evaluated by this method, and the results of MFLs compliance and the potential water supply yield are as follows:

Table A. SJR at SR 50: Summary of MFLs compliance (Method I)

MRF (cfs)	Discharge for Diversion (cfs)				
	30	50	70	90	110
300	Y	Y	Y	Y	N(MA)
200	Y	Y	Y	N(MA)	N(MA)
100	Y	Y	Y	N(MA)	N(MA, MFL)
50	Y	Y	Y	N(MA)	N(MA, MFL)

Y = All MFLs met; N = MFLs in the parentheses not met

Table B. SJR at SR 50: Potential water supply yield, mgd
(Mean of diversion discharges for the period analyzed)

MRF (cfs)	Discharge Diversion (cfs)				
	30	50	70	90	110
300	14.2	23.8	33.0	42.1	**51.1**
200	15.7	26.0	36.0	**45.9**	**55.6**
100	17.4	28.6	39.7	**50.5**	**61.2**
50	18.5	30.4	42.0	**53.4**	**64.6**

The water supply yields shown in bold are infeasible because MFLs are not met for these scenarios.

Maximum yield by this method was 42.1 mgd (from the scenario with MRF = 300 cfs and DD = 90 cfs).

Method II and results: USGS 1933 – 2006 historic data were also analyzed in this method, but discharge diversions were assumed to occur at two levels (tiers) of MRFs, that is, additional diversion was made assuming a second higher MRF. This method was applied to two scenarios, as described below.

Scenario II-1
Tier 1 discharge: If MRF > 300 cfs, DD = up to 90 cfs
Tier 2 Discharge: If MRF > 600 cfs, DD = 90 + up to 40 cfs
Example: If the river flow, Q = 610 cfs, DD = 90 + 10 = 100 cfs
If the river flow, Q = 650 cfs, DD = 90 + 40 = 130 cfs

Scenario II-2
Tier 1 discharge: If MRF > 50 cfs, DD = up to 70 cfs
Tier 2 Discharge: If MRF > 400 cfs, DD = 70 + up to 40 cfs (additional)

All of the MFLs were met for Scenario II-1, and the potential water supply yield for this scenario was 57.3 mgd. One of the MFLs, the MA, was not met for Scenario II-2.

Method III and results: This method analyzed the 1942 – 2001 simulated data for the USJRB Project Conditions 2004. The four borderline scenarios for which MFLs were not met by Method I (e.g., MRF = 300 cfs and DD = 110 cfs, Table A) were re-evaluated by Method III. The MA was not met by Method I for these scenarios. With the project conditions simulated data, the MFLs were met for all of the four scenarios re-evaluated. The potential average yields for the four scenarios by Method III were as follows.

Scenario III-1: 56.2 mgd (MRF = 300 cfs; DD = 110 cfs)
Scenario III-2: 49.8 mgd (MRF = 200 cfs; DD = 90 cfs)
Scenario III-3: 54.0 mgd (MRF = 100 cfs; DD = 90 cfs)
Scenario III-4: 56.1 mgd (MRF = 50 cfs; DD = 90 cfs)

Scenario III-1 produced the highest potential average yield of the four scenarios, and also indicated some MFLs ‘free-board’ (i.e., MA would actually not be met at a higher DD). By an iterative process, DD was gradually increased, and it was determined that the limiting higher value of DD at which the MA would be just met was 150 cfs. The potential additional average yield for this scenario (MRF = 300 cfs and DD = 150 cfs) was 75.5 mgd.

Maximum average yields by the three methods: Maximum additional average water supply yields that may be obtained by the three methods were:

Method I: 42.1 mgd
Method II: 57.3 mgd
Method III: 75.5 mgd

The maximum of these three methods (Method III) showed about an 80% increased yield over Method I (from 42.1 mgd to 75.5 mgd), and about a 30% increased yield over Method II (from 57.3 mgd to 75.5 mgd). This result clearly demonstrated that the USJRB Project greatly enhances the water supply potential by its creation of water management and marsh conservation areas and flow regulation through the project area. By applying a two-tier withdrawal method to discharges under project conditions (similar to Method II with USGS data), water supply withdrawals under Method III can be further increased.

Discharge diversions during drought periods

Potential water supply yields of the SJR at SR 50 for different scenarios presented in the foregoing were the average yields for the periods of evaluation; 72 years for the USGS data and 60 years for the model data. Actual yields for individual years varied. For the periods of analysis, the annual yields varied from 2.4 to 58.1 mgd for Method I, 2.4 to 83.9 mgd for Method II, and 8.0 to 96.9 mgd for Method III. Because of the MRF constraint, water for diversion would not be available for several continuous days during low flow periods. The present analyses showed that, if a drought similar to the extreme historic drought of 1980-1982 occurred, water for diversion would not be available for a continuous period of almost 23 months depending upon the magnitude of the MRF selected for design. There were 12 other drought years during which no water diversion would be possible for continuous periods of 4 to 8 months. Thus, even though the USJRB project greatly enhances the water supply potential of the SJR at SR 50, this increase is only in average volumes, but does not provide higher discharges during the drought conditions.

The drought characteristics of the river and the need to meet MFLs at SR 50 have important implications for water supply facilities design. Because the proposed withdrawals would be made only when river flows exceed certain minimum discharges (i.e., MRFs), water available for diversion would be limited during some drought periods; thus, the St. Johns River becomes an unreliable source under these conditions. Reliability must be provided by raw water or treated water storage or by integrated development with other more reliable sources of supply including groundwater.

Conclusions

The following conclusions are reached based on data evaluations presented in this report.

1. Average additional potential water supply yield of the SJR at SR 50 based on MFLs compliance as a constraint was: a) 42.1 mgd based on the historic USGS discharge data (1933-2006), with diversion discharges up to a maximum of 90 cfs when river flows exceed 300 cfs; b) 57.3 mgd based on the historic USGS discharge data (1933-2006), with diversion discharges up to a maximum of 90 cfs when river flows exceed 300 cfs, and additional diversion discharges up to a maximum of 40 cfs when river flows exceed 600 cfs, and; c) 75.5 mgd based on the 1942-2001 simulated data for the USRB Project Conditions 2004, with diversion discharges up to a maximum of 150 cfs when river flows exceed 300 cfs. This yield could be further increased by additional diversion when river flows exceed 600 cfs.
2. Yearly water supply yield of the SJR at SR 50 can vary widely due to variation of annual/seasonal rainfall. Typically, the annual yield ranges for the three average yields given in the foregoing (i.e., Cases a, b, and c) are, 2.4 to 58.1 mgd, 2.4 to 83.9 mgd, and 8.0 to 96.9 mgd, respectively.

3. No water for diversion would be available for prolonged periods (several months to years) during severe droughts. This condition occurred because water supply discharges were diverted from the SJR only when river flows exceeded certain minimum discharge (e.g., 300 cfs), and the river flow was below this minimum during severe droughts for prolonged periods. Therefore, the MRF will be an important water supply facilities design parameter. If the MRF is not maintained, three MFLs, the MA, the MFL, and the MIL, might not be met.
4. It appears, the USJRB project would increase the potential water supply yield of the SJR at SR 50 by about 80% over the pre-project conditions (42.1 to 75.5 mgd) because of low flow augmentation and other water management practices as a result of the USJRB project. However, because of the MRF requirements to support ecological preservation, no increase in water supply withdrawals is possible during some drought conditions (i.e., water available for diversion would be limited during some drought periods because the proposed withdrawals would be made only when river flows exceed certain minimum discharges).

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**Figure 3. St. Johns River near Christmas (at S.R. 50)
Discharge hydrograph (USGS daily discharge data: 1934-2006)**

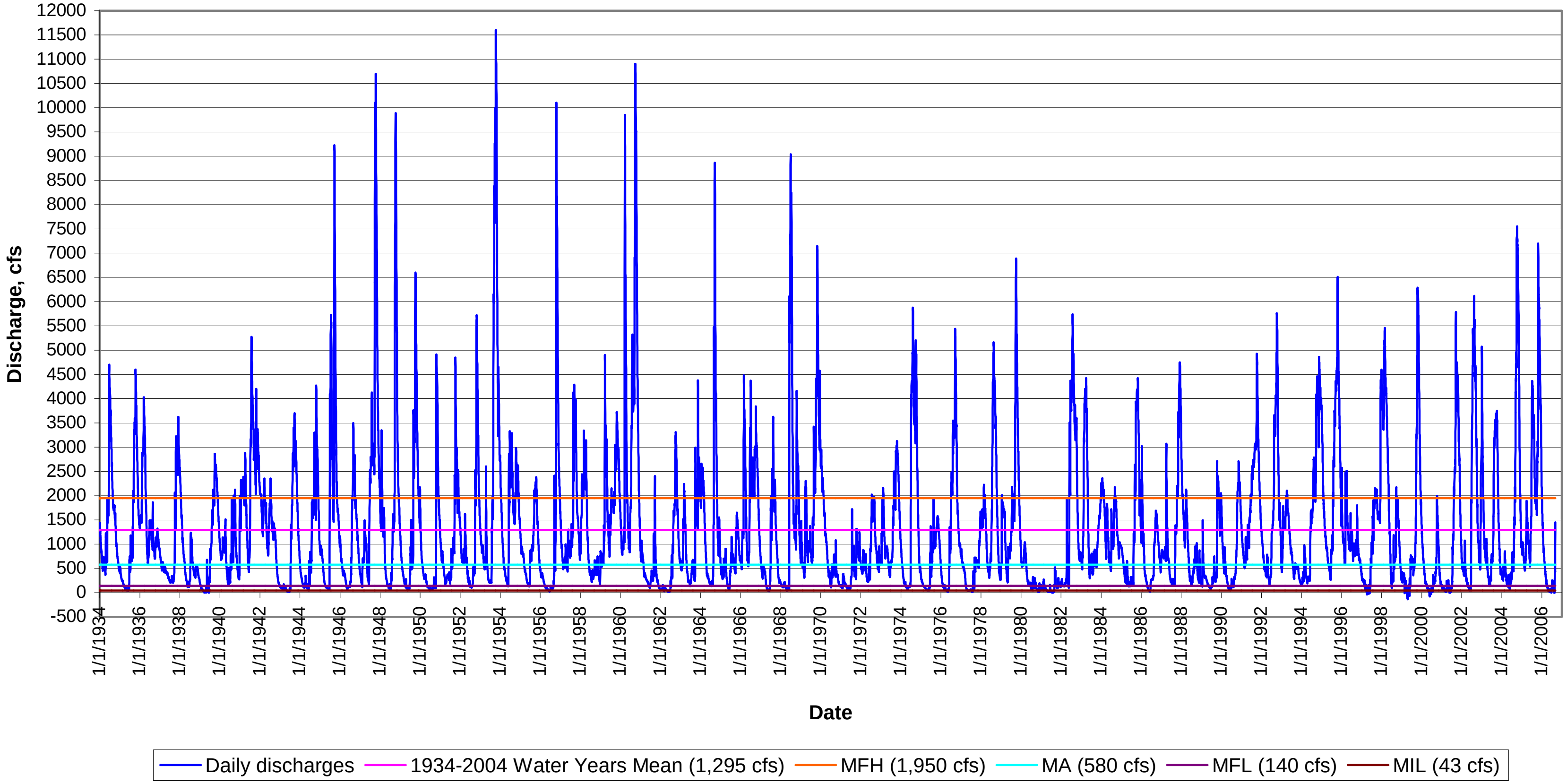


Figure 4. St. Johns River near Christmas (at S.R. 50)
Discharge-duration curve (USGS 1934-2005 daily discharge data)

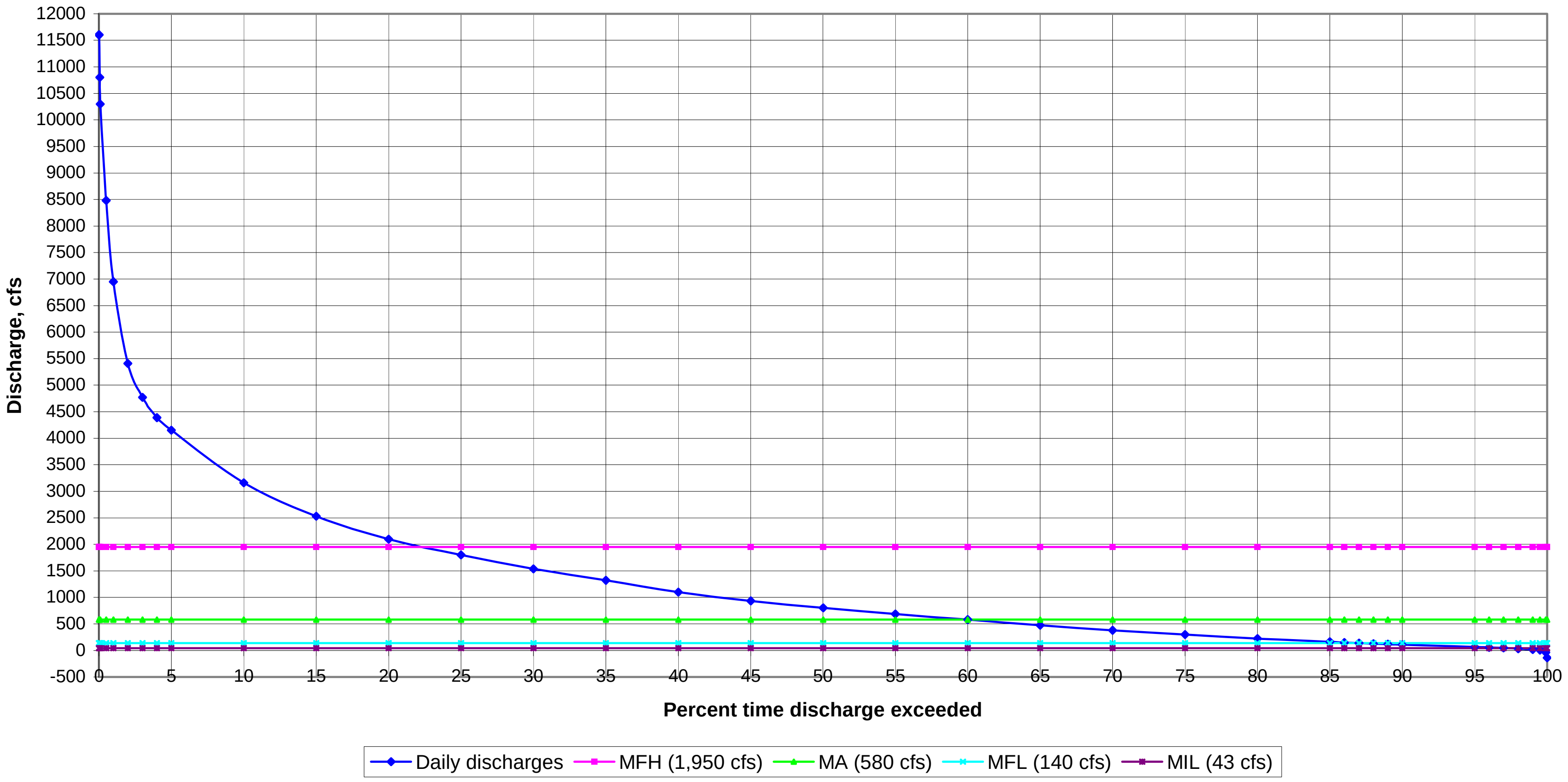


Figure 5. St. Johns River near Christmas (at S.R. 50)
Stage hydrograph (USGS daily stage data: 1934-2005)

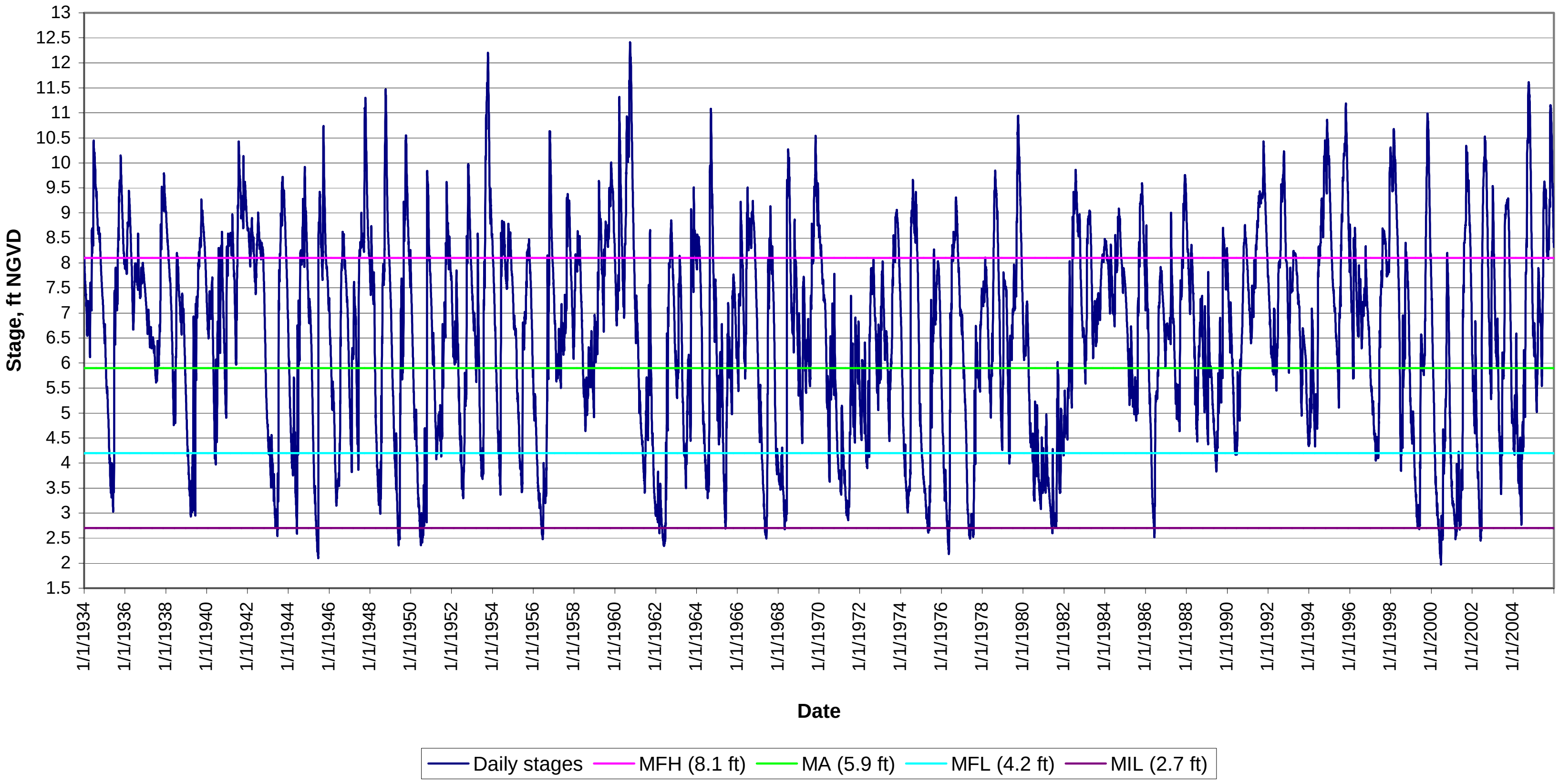
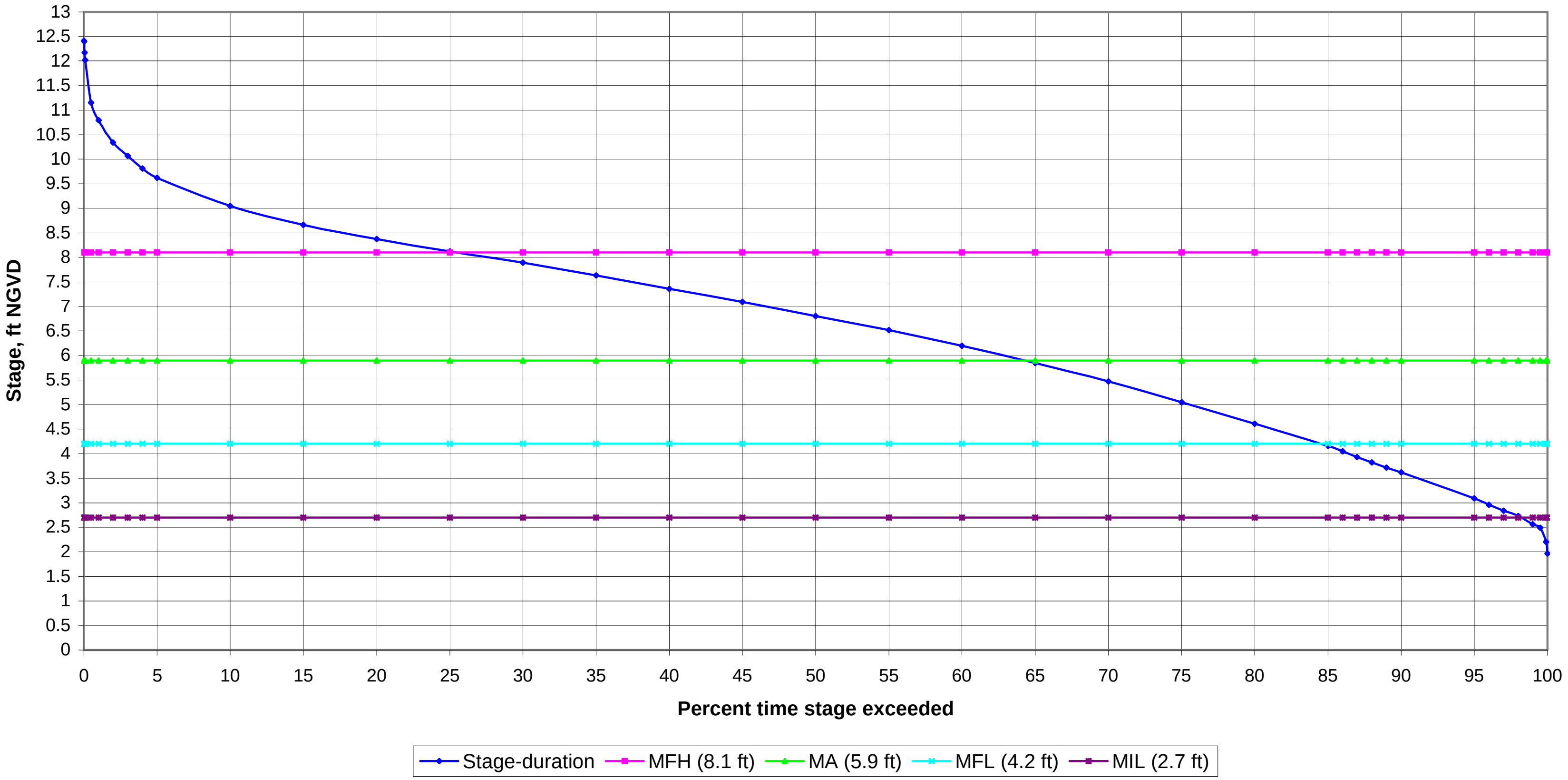


Figure 6. St. Johns River near Christmas (at S.R. 50)
Stage-duration curve (USGS 1934-2005 daily stage data)



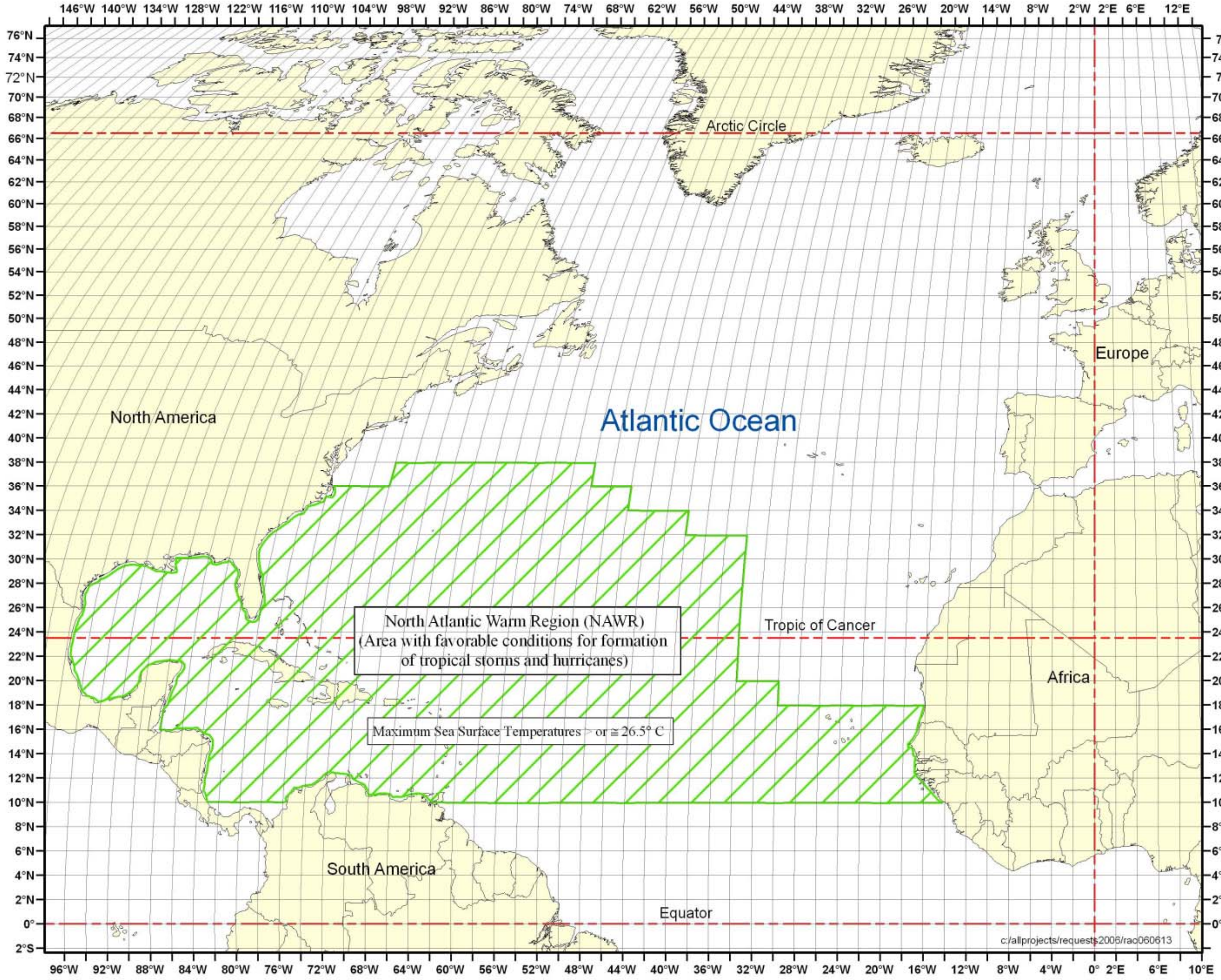


Figure 7. The North Atlantic Ocean

Figure 8. North Atlantic Sea Surface Temperatures and NE Florida Index Rainfall 10-year moving averages (Detrended data)

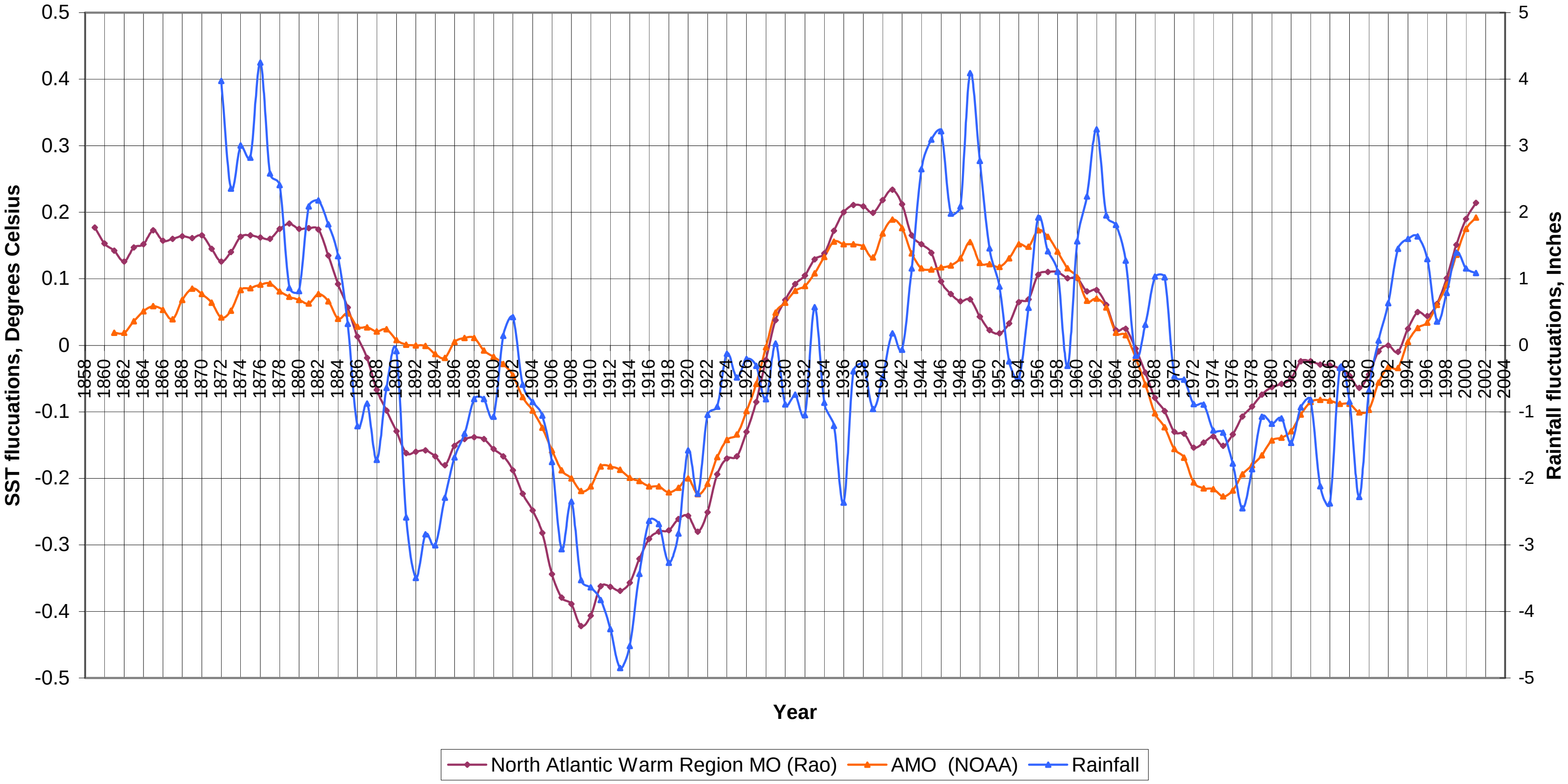


Figure 9. North Atlantic Sea Surface Temperatures and NE Florida Index Rainfall Wet Season (June - November): 10-year moving averages (Detrended data)

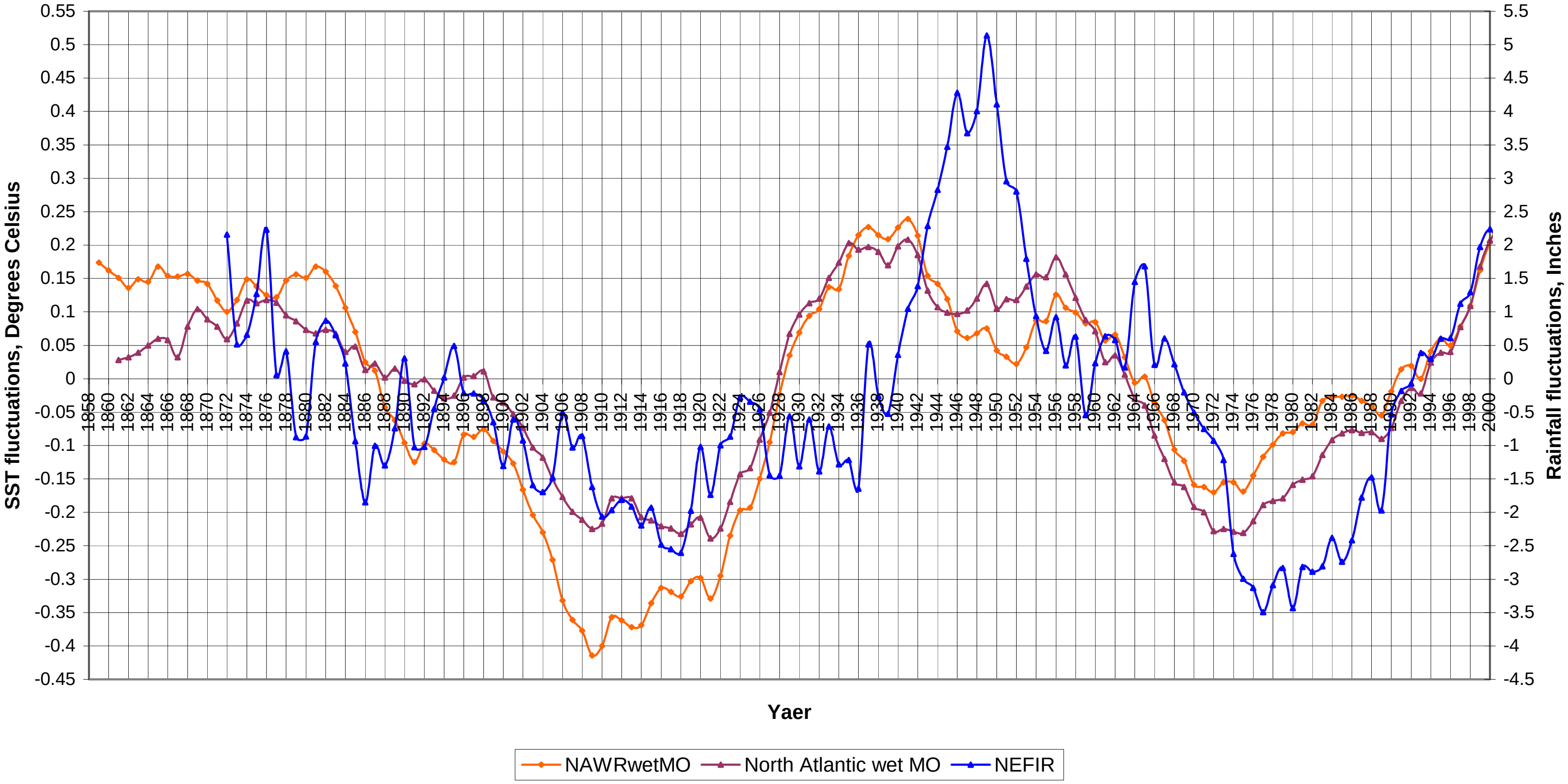


Figure 10. North Atlantic SSTs and discharges for the St. Johns River near Christmas
10-year moving averages

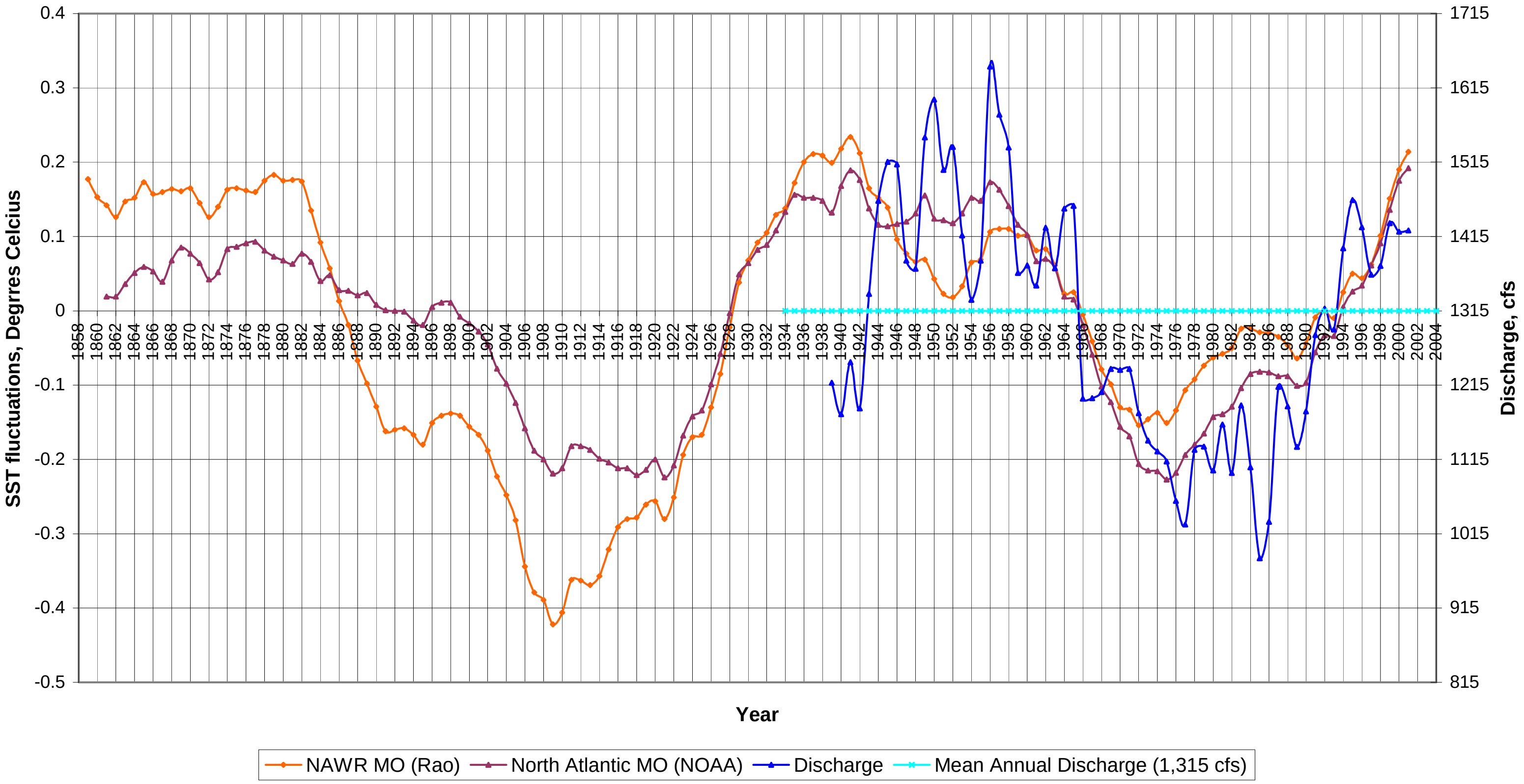


**Figure 11. St. Johns River near Christmas (at S.R. 50)
Mass curve of discharges (1934-2005 USGS Water Years)**

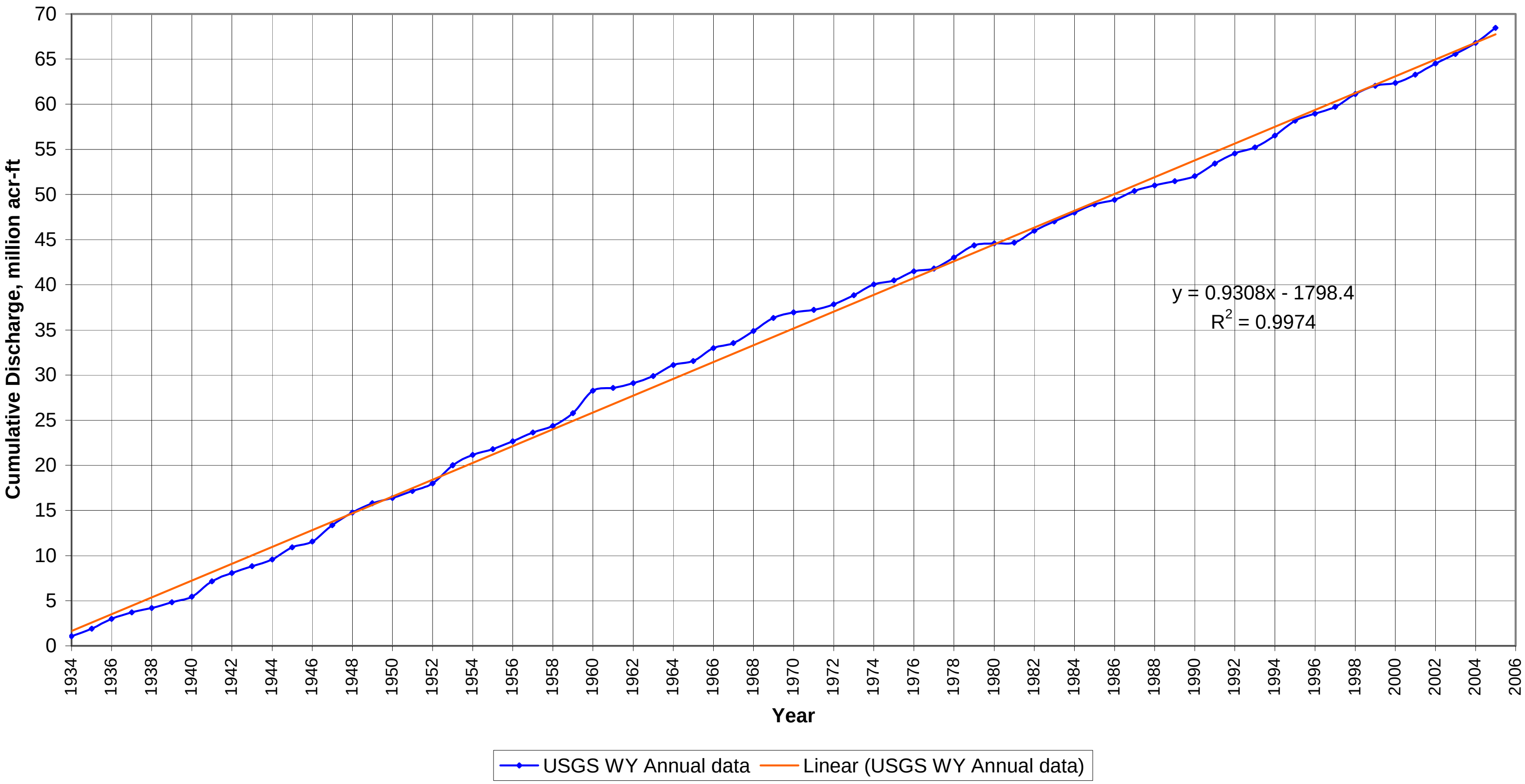


Figure 12. St. Johns River near Christmas (at S.R. 50)
Hydrograph of annual mean discharges (USGS Data: 1934-2005 Calendar Years)

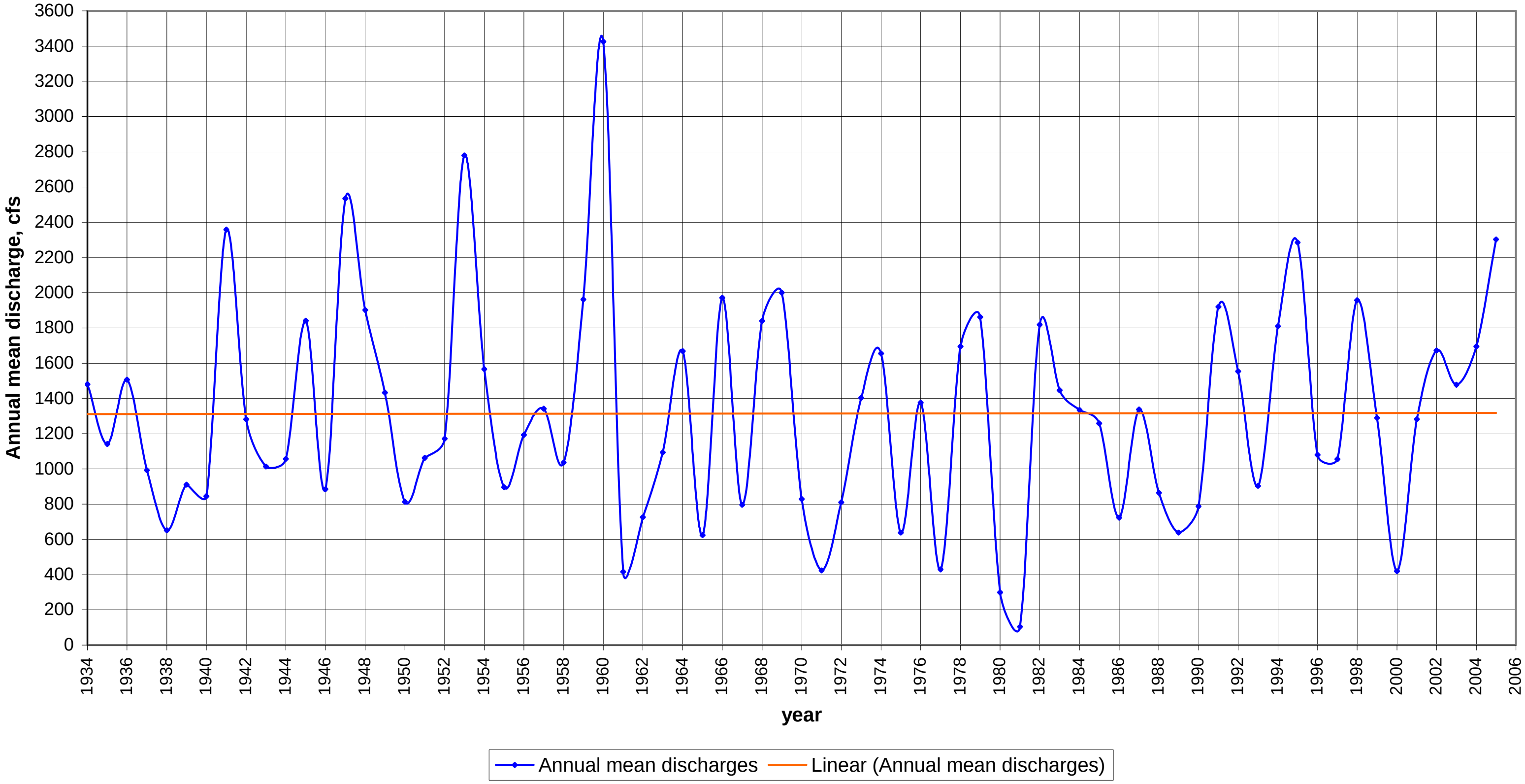
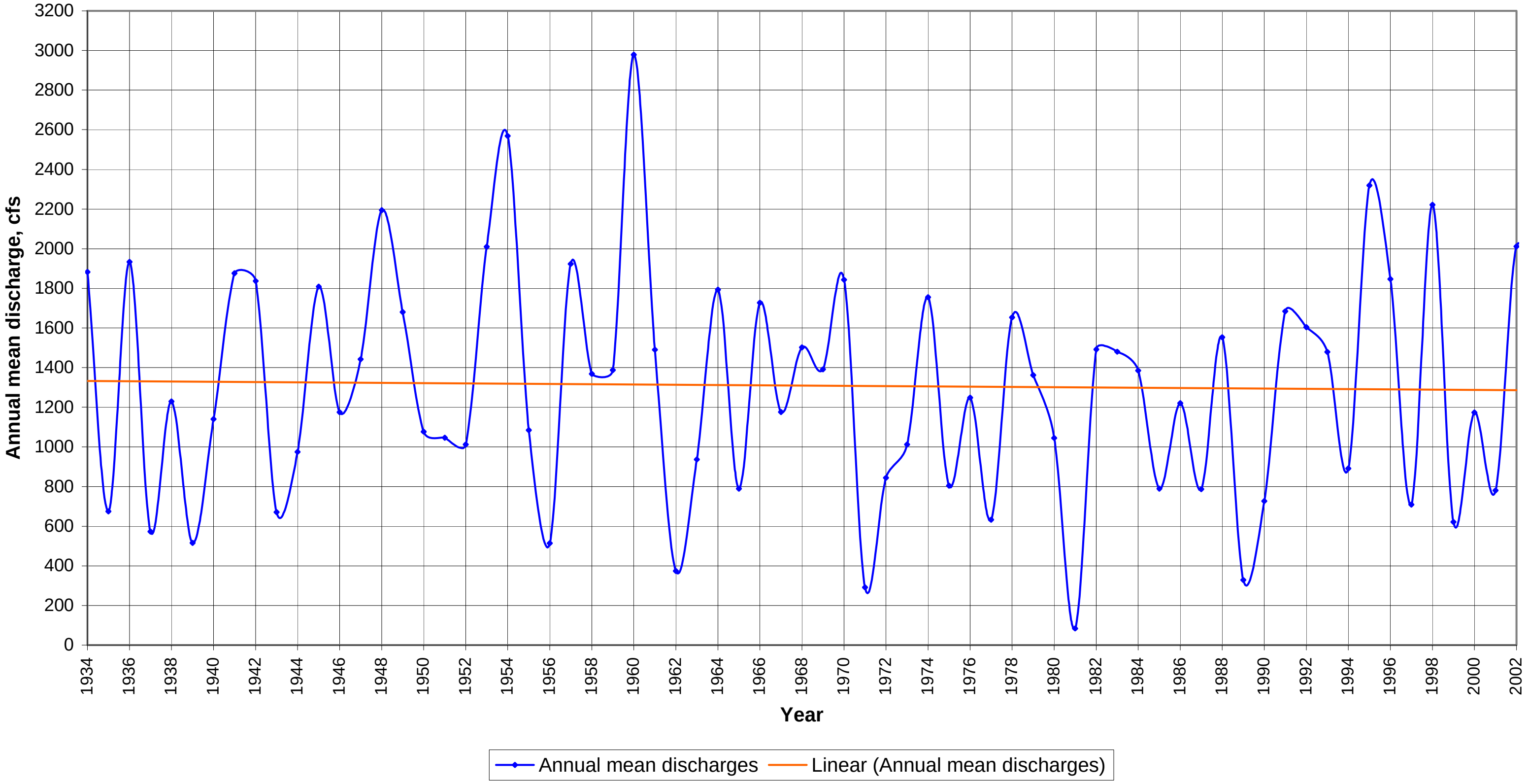


**Figure 13. St. Johns River near Christmas (at S.R. 50)
Hydrograph of annual mean discharges (USGS Data: 1934-2005 Water Years)**



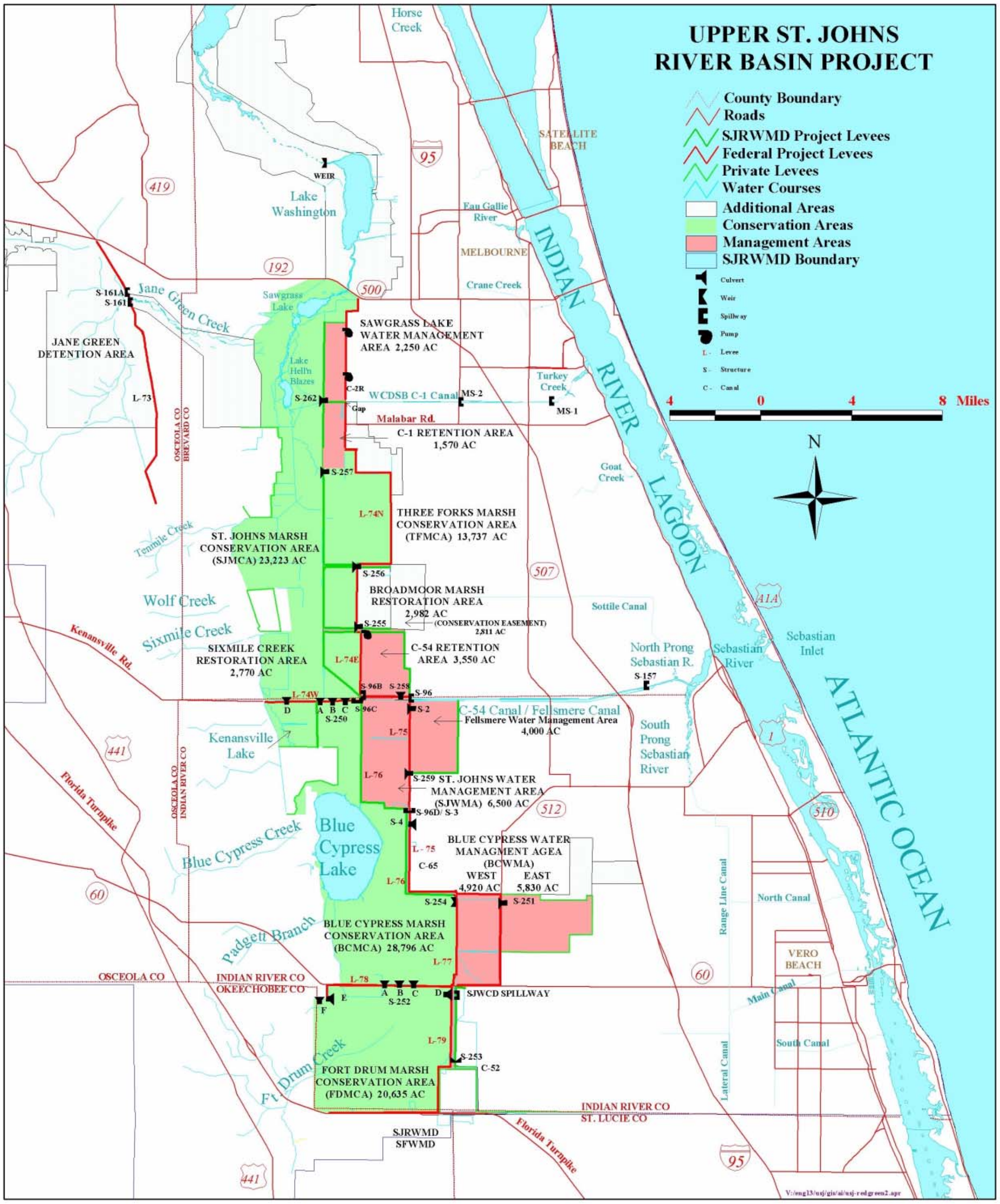


Figure 14. The Upper St. Johns River Basin Project Area

APPENDIX A

Rao's USJRB Watershed Model: A brief description

The USJRB Hydrologic Simulation Model

The Upper St. Johns River Basin hydrologic simulation model (denoted as USJHM, Upper St. Johns Hydrologic Model, henceforth), developed in the late 1970s/early 1980s, was essentially a simplified version of the well-known Stanford Watershed model (Crawford and Linsley 1966), with the runoff simulation procedure based on a watershed model introduced in 1976 by the Agricultural Research Service (ARS), U.S. Department of Agriculture. The ARS model was a simplified continuous simulation model to predict daily, monthly, and annual runoff with reasonable accuracy for watersheds throughout the United States (Williams and LaSeur 1976). It has a one-day time step, and was based on the SCS runoff curve number procedure and a soil moisture accounting technique for computing daily runoff and infiltration. The model developers asserted that 'it was designed to have general applicability, computational efficiency, simple inputs, and good prediction accuracy.' Practicing engineers throughout the US extensively use the SCS method because of its simplicity and the ready availability of input data. Williams and LaSeur (1976) stress the virtues of the SCS runoff curve number method by stating: (1) It is a reliable procedure that has been used for many years in the United States; (2) it is computationally efficient; (3) the required inputs are generally available; and (4) it relates runoff to soil type, land use, and management practices.

The ARS originally developed the model as a surface water model, but later expanded it into a water quality model. Its current version is known as SWAT (Soil and Water Assessment Tool, Neitsch et al. 2005). EPA recognizes SWAT and HSPF equally for developing TMDLs (Total Maximum Daily Loads), and applications of SWAT, and HSPF, are now available through the EPA's BASINS program (Better Assessment Science Integrating point and Non-point Sources, Version 3.0, Environmental Protection Agency 2001).

In the late 1970s, Dr. C. Charles Tai, the then Director of the Division Engineering, SJRWMD, developed an initial version of the USJHM for the pre-project conditions (Tai 1978; Suphunvorranop and Tai. 1982). The task of developing the full model, however, was assigned to Rao (the author of this report). Rao made further improvements to the pre-project conditions (then called existing conditions) model originally developed by Tai by detailed calibration and parameter optimization and introducing additional modeling concepts/procedures. Two versions of the model were developed: 1) Pre-development conditions; and 2) the USJRB project conditions. The pre-development conditions model represented approximately Year 1900 conditions by eliminating roads, levees, and other developments in the floodplain and extending the floodplain to its maximum limits based on the USGS contour information. This model produced information, such as floodplain acreages, stages, and storages for the mean annual, and other floods of different recurrence intervals (e.g., 100-years), for comparison with the developed basin conditions. The project conditions version of the model was used extensively during 1977-1984 to evaluate innumerable USJRB plan alternatives while developing a Basic Design Concept and also while finalizing the Project with the USACE. During 1980-2000, the model was used for several other basin evaluations: environmental, flood control, MFLs development and water supply (Rao 1985; Rao and Tai 1987; Rao, Borah, and Miller 1995; Miller et al. 1996a; Miller et al. 1996b, and; Hall and Borah 1998).

During 2000-2005, Rao fully updated both the pre-project and project conditions versions of the model by incorporating the latest model input data available through the highly sophisticated GIS database of the SJRWMD (Rao 2004 and 2009). The updated input data included land use and soils data and revised sub-basin boundaries. The models were re-calibrated and validated, including writing additional model code to incorporate other modeling concepts. Input data files were developed for long-term simulations covering a 60-year period (1942-2001).

While the basic runoff and infiltration methodologies were drawn from the ARS model, the complex USJRB processes that included specific agricultural practices, the maze of water management and marsh conservation areas and the controlled movement of flow through these areas, the simulation of vast floodplain with the embedded lakes like Lakes Washington, Winder and Poinsett, and the simulation of tributary flows, were all modeled by specific code writing. That is the greatest challenge posed to modelers when generalized models such as HSPF or SWAT are applied to basins like the USJRB. The modeler must determine how to model certain hydrologic processes specific to the basin. This process was more direct in the case of USJHM because the necessary code could be readily written. If the selected model (e.g., HSPF) has no provision for modeling certain hydrologic processes specific to the basin, they are either to be approximated, or omitted, which might result in unsatisfactory simulation. The USJHM was peer reviewed by SJRWMD in-house staff and a consultant, Camp, Dresser, and McKee, Inc. Some of the comments from the Camp, Dresser, and McKee peer reviewer were as follows.

- A key feature of the USJRB models is that the developers were able to develop special computer code to explicitly (simulate) the complex special water regulation conditions that exist in the basin. If other models were used, it may have been necessary to use rules that are more approximate.
- CDM has found that the USJRB model has been developed with a sufficient level of detail for its intended purpose. There are custom routines built into the model that simulate the unique agricultural practices of the USJRB and the model has been sufficiently calibrated.
- The procedures used to simulate the basin hydrology are similar to those used in other nationally recognized models and appear to be conceptually accurate for the modeling of the hydrologic processes in the USJRB. It would be difficult to find a model that explicitly simulates processes included in the USJRB models (e.g., irrigation withdrawals and simulation of runoff from storage areas that are partially inundated).
- It is clear that with the construction of the improvements in the USJRB, the hydrologic conditions are quite complex. It would likely be difficult to simulate the control structures and control strategy explicitly in other models (e.g., HSPF).

(Underlining in the above bullets is done for emphasis by the author of this report)

The modeling approach used to arrive at a satisfactory simulation for the USJRB was as follows:

1. Set up and calibrate the pre-project conditions model first, choosing an appropriate calibration period. Period 1978-1985 was chosen to calibrate the pre-project conditions model.
2. Validate the pre-project conditions model as follows. Since long-term observed discharge and/or stage data are available for a number of locations in the basin, and it is generally ascertained that the historic land use changes did not significantly affect the basin hydrology (i.e., volumes of discharge, see Figure 11), optimize any model parameters as appropriate, to obtain a good match of simulated and observed data duration curves (stage and discharge) for the available period of data for pre-project conditions. It is assumed that pre-project conditions end in 1993.
3. Use the pre-project conditions model to develop the project conditions model by incorporating the basin changes and other water control procedures that took place as a result of the project. Retain the applicable model parameters and the hydrologic concepts/procedures determined for the pre-project conditions model. Calibrate project conditions model (The period 1994-2001 was used for model calibration).

This approach yielded quite satisfactory simulations for the USJRB, and a comparison of pre-project and project conditions results also illustrated the benefits derived from the project. An example of model performance is presented in the model simulation results for the SJR near Christmas (Figures A1 – A20). This is the downstream most station for calibration, and the basin has a drainage area of 1,539 square miles at this station; thus, the results for this station reflect the model performance practically for the entire USJRB. The upstream stations for which model calibration for pre-project conditions was performed are (refer to Figures 2 and 14):

1. SJR at SR 60 (Stages)
2. Blue Cypress Lake (Stages)
3. SJR near Melbourne (Discharges)
4. SJR near Cocoa (Discharges and stages)

Simulation of duration curves. The stage and discharge duration curves for pre-project conditions (1942-1993 period) were optimized interactively, that is, making sure that both stage and discharge duration curves have a good match, simultaneously, with the duration curves from the observed data. The overall stage and discharge duration curves show a good match between the simulated and observed conditions (Figures A-1 and A-5). The lower values in the 60-100% exceedance range (which greatly influence the MFLs and the water supply potential) were further examined in Figures A-2 and A-6. The low stages in the 60-100% exceedance range matched with an error typically less than 0.2 ft (Figure A-2). The discharges below 400 cfs matched with an error of 0 to 40 cfs (Figure A-6). Project conditions duration curves showed that both the project conditions stages and discharges would be higher than the pre-project/USGS values in the 35-100% exceedance range (Figures A-3, A-4, A-7 and A-8); the improvement occurs for stages below 7.5 ft NGVD and discharges below 1,250 cfs. The stages increased by about 0.6 ft, and discharges by about 150 cfs.

Simulation of hydrographs. A good match of simulated and observed data duration curves also led to a highly satisfactory simulation of discharge hydrographs (Figures A-9 through A-14) and a good simulation of stage hydrographs (Figures A-15 through A-20). Satisfactory simulation of historic hydrographs plays a crucial role in accurate evaluation of MFLs, because MFLs are duration-based events (Table 1).

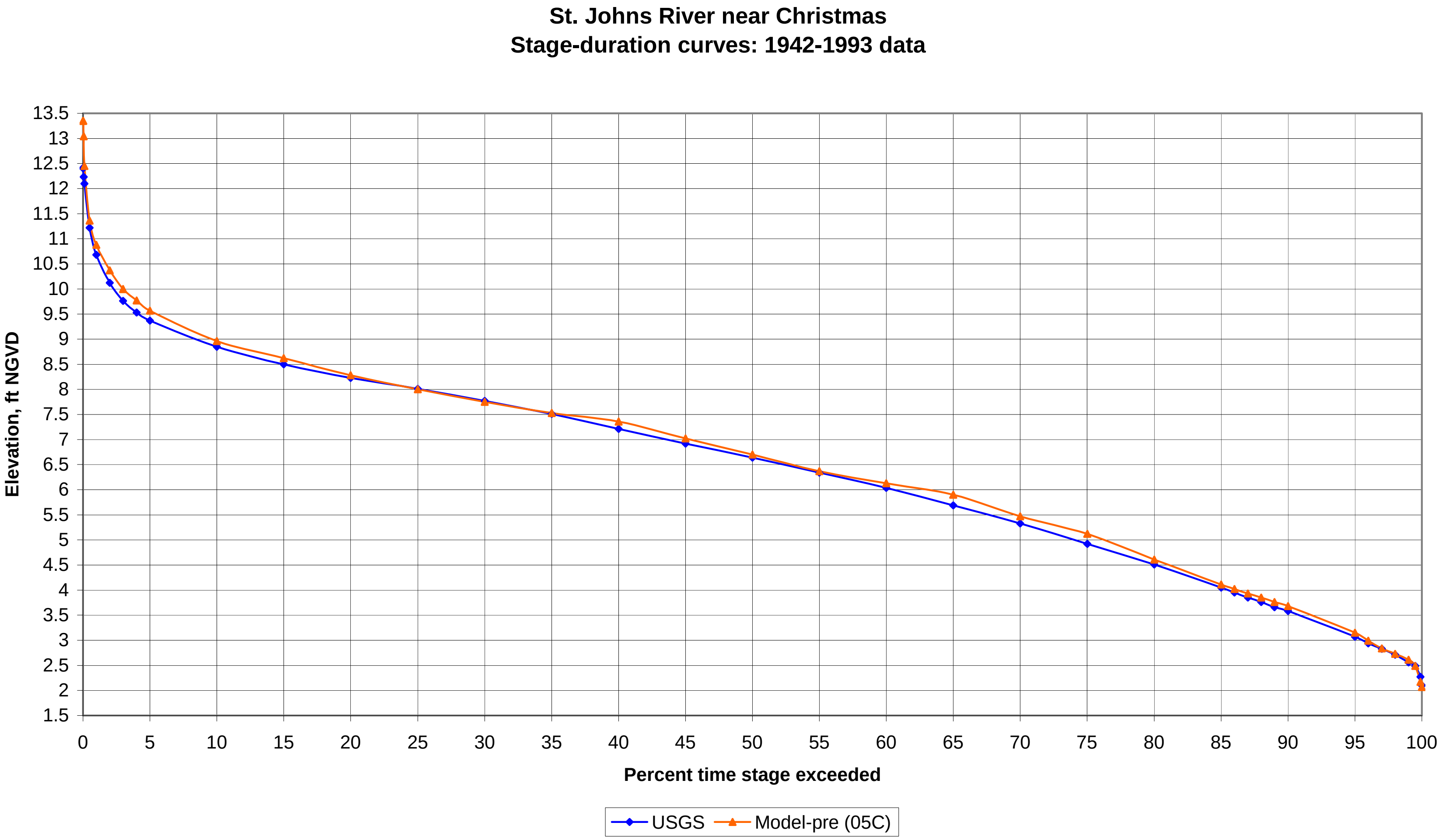


Figure A-1: Comparison of stage-duration curves: Pre-project conditions vs. USGS

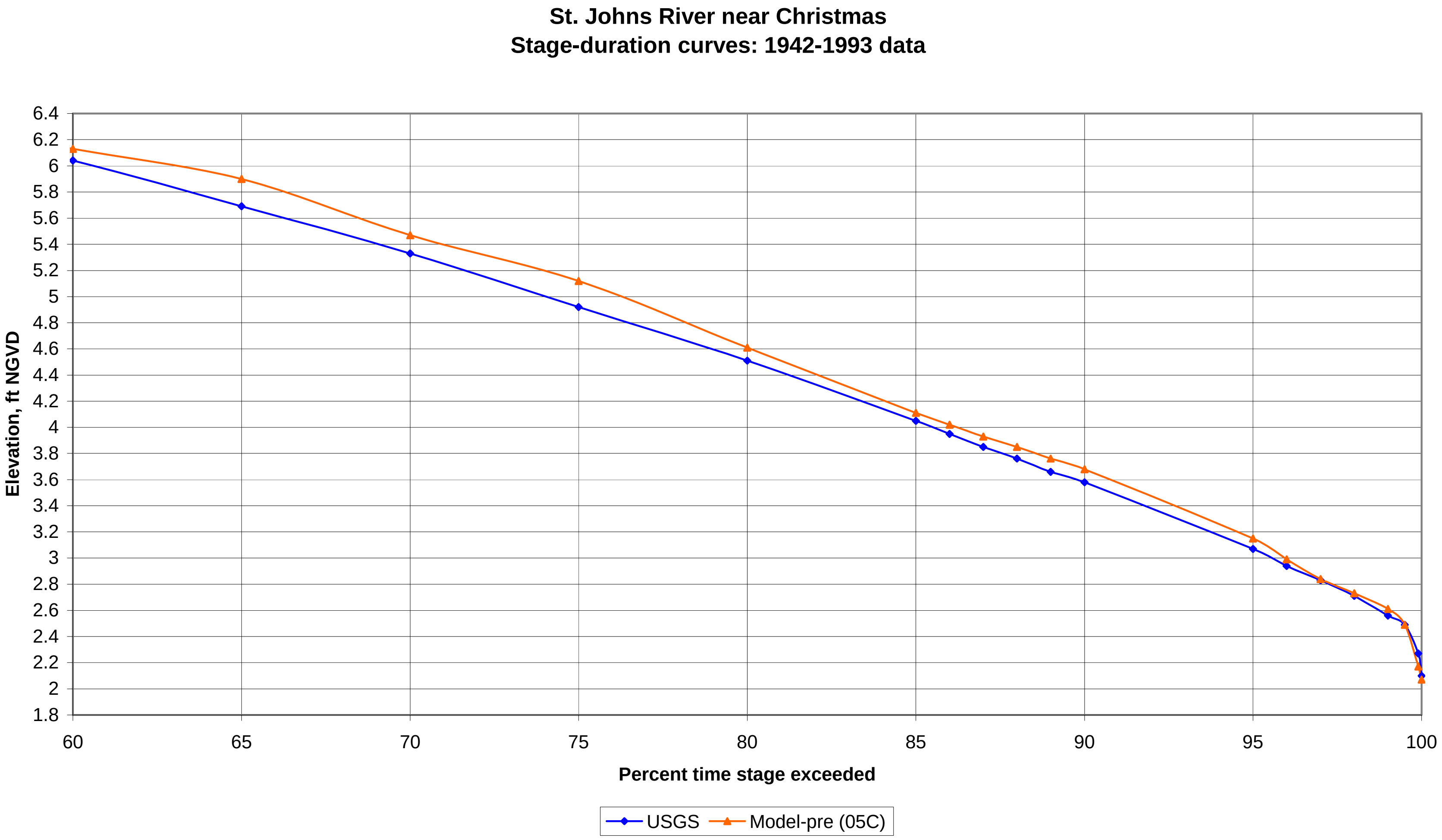


Figure A-2: Comparison of stage-duration curves: Pre-project conditions vs. USGS (60 to 100% range)

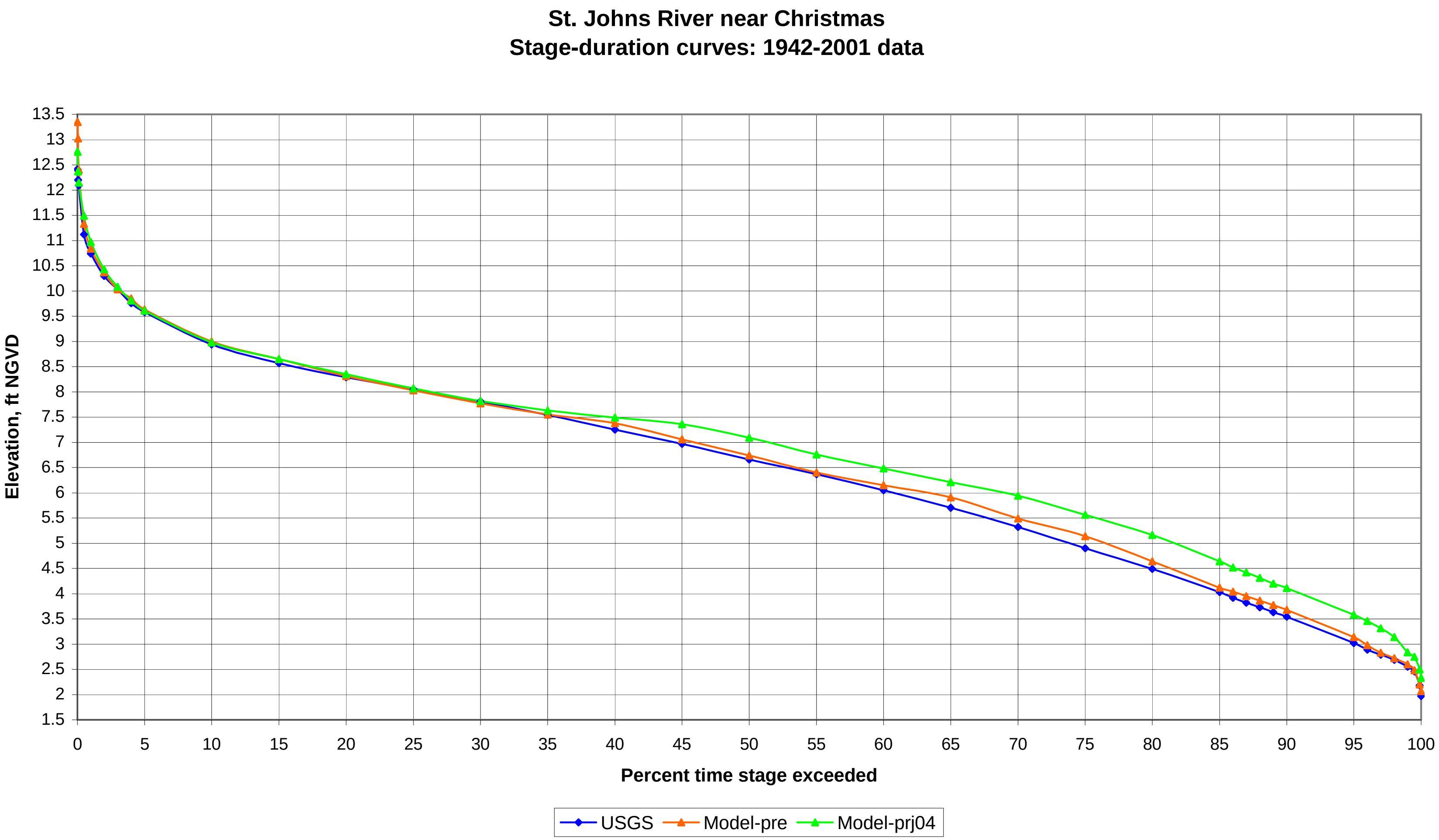


Figure A-3: Comparison of stage-duration curves: USGS, Pre-project and Project conditions

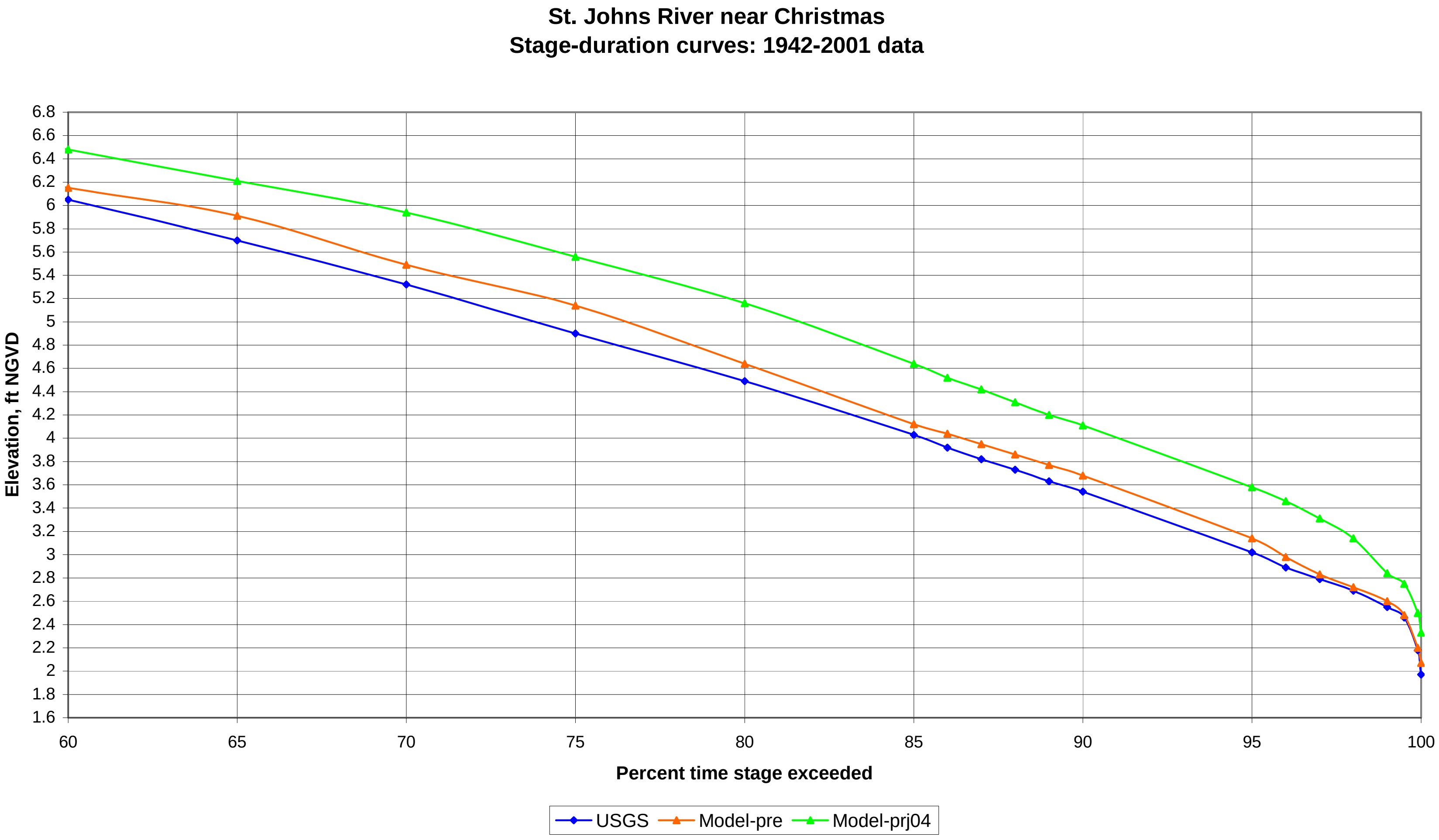


Figure A-4: Comparison of stage-duration curves: USGS, Pre-project and Project conditions (60-100% range)

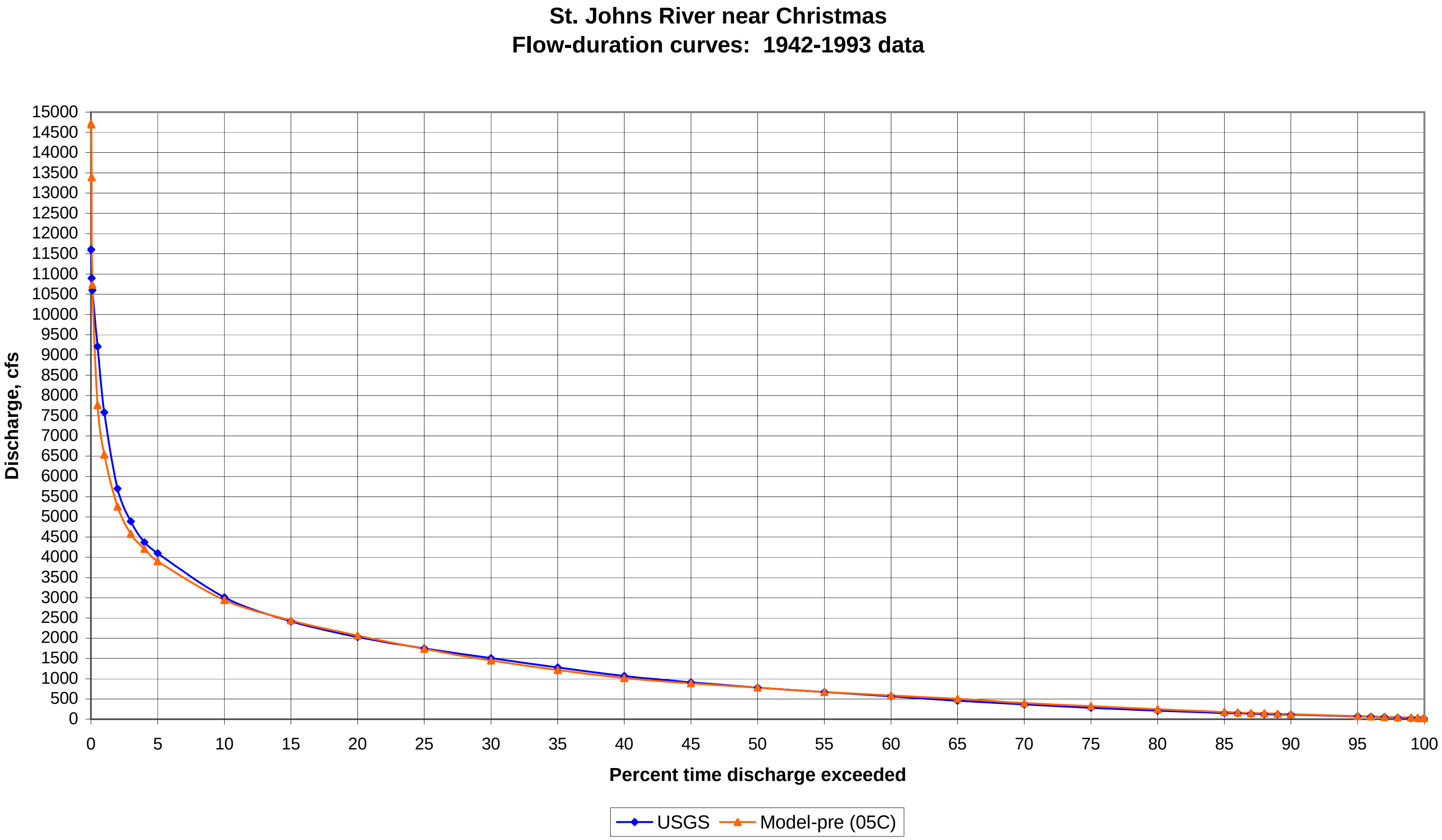


Figure A-5: Comparison of discharge-duration curves: Pre-project conditions vs. USGS

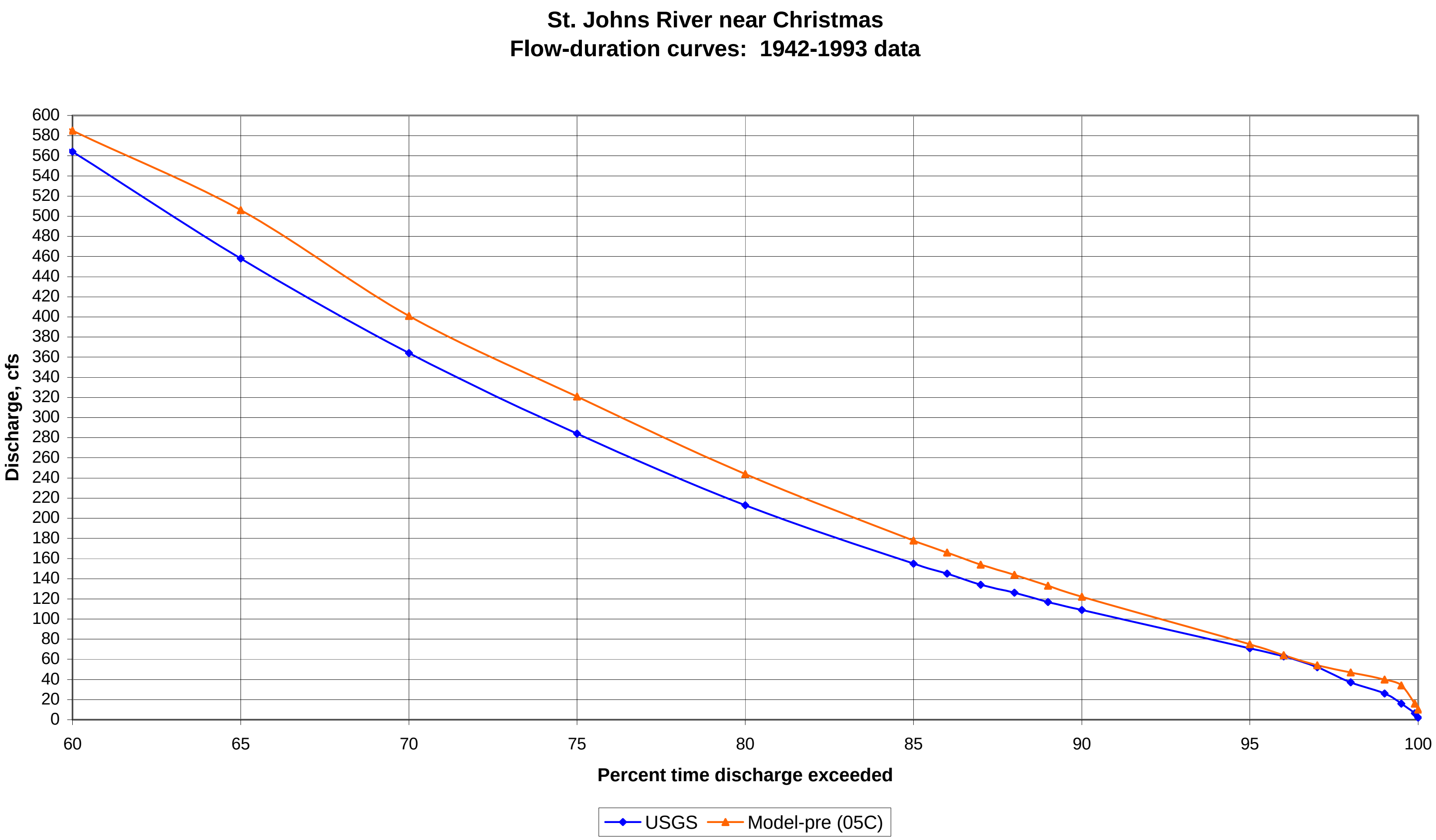


Figure A-6: Comparison of discharge-duration curves: Pre-project conditions vs. USGS (60 to 100% range)

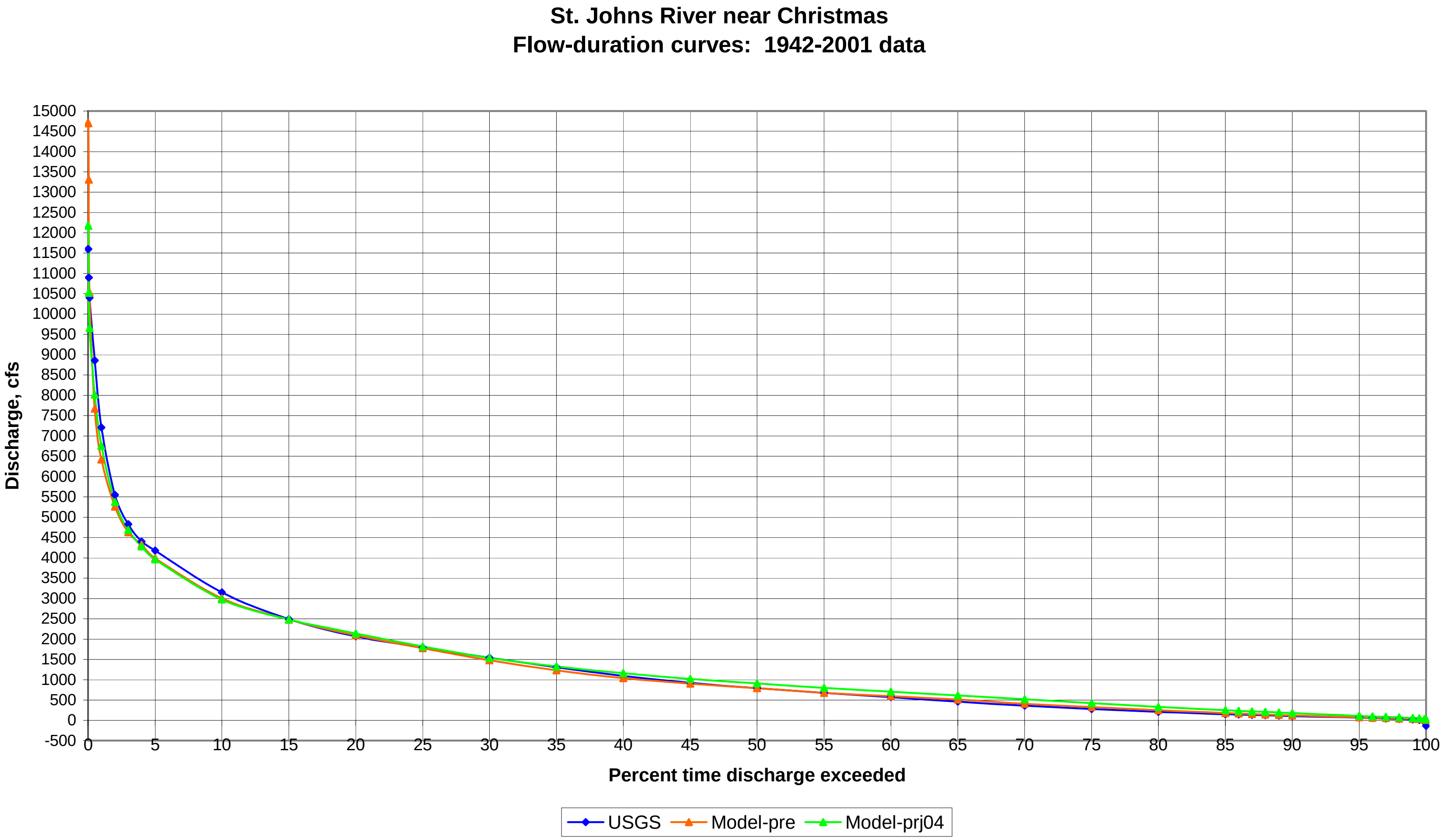


Figure A-7: Comparison of discharge-duration curves: USGS, Pre-project and Project conditions

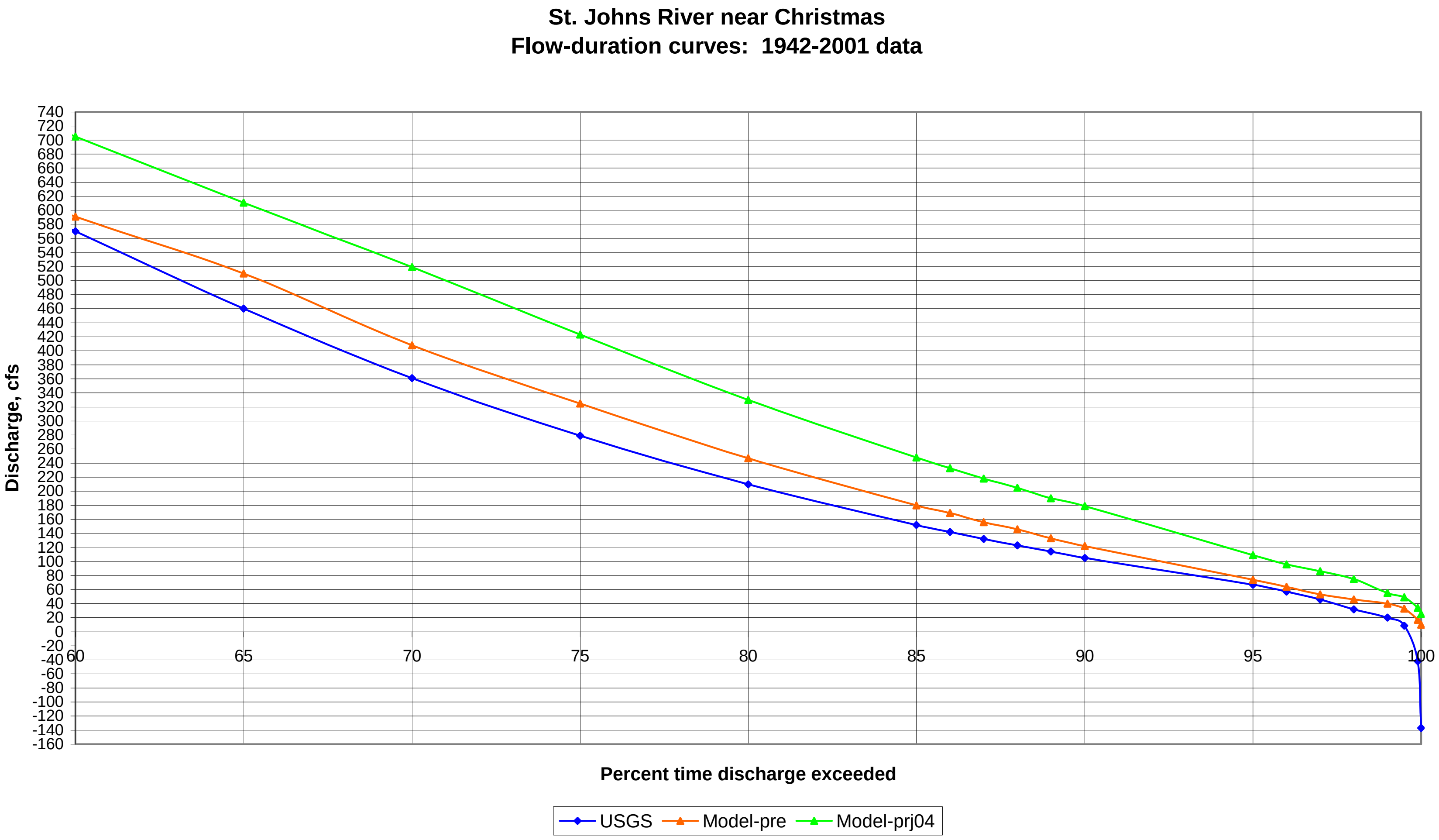


Figure A-8: Comparison of discharge-duration curves: USGS, Pre-project and Project conditions (60-100% range)

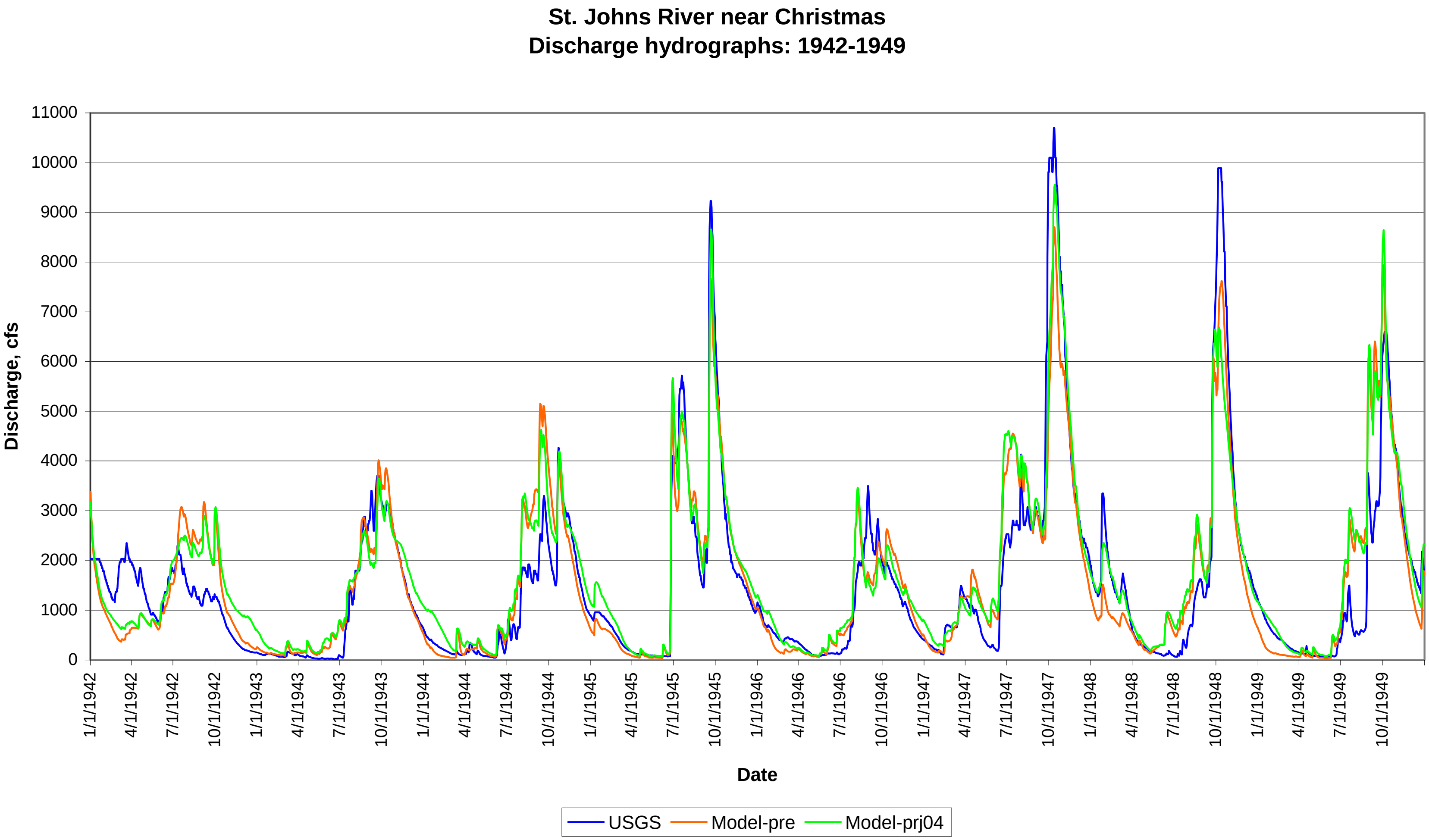


Figure A-9: Comparison of discharge hydrographs: USGS, Pre-project and Project conditions (1942-1949)

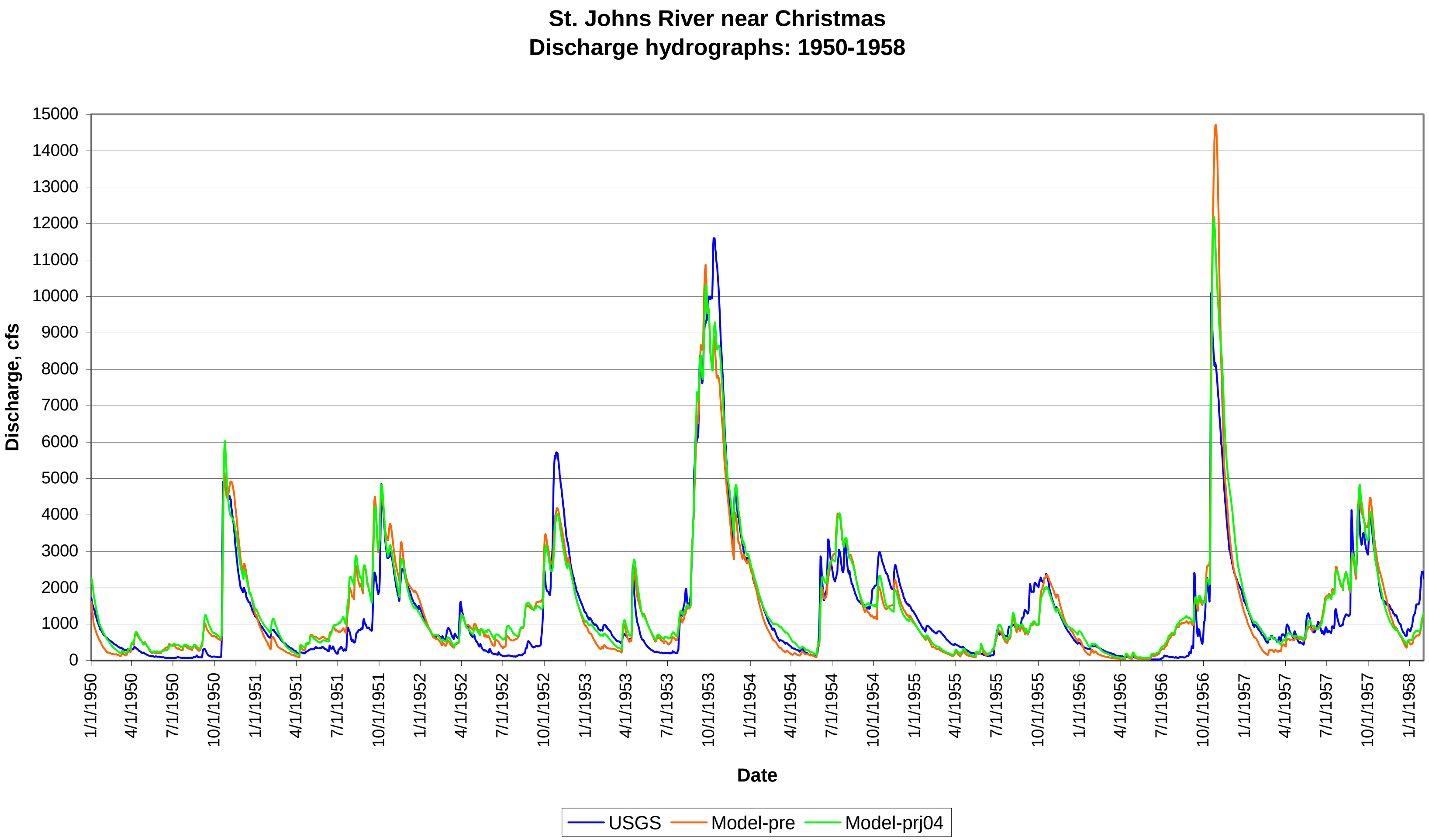


Figure A-10: Comparison of discharge hydrographs: USGS, Pre-project and Project conditions (1950-1958)

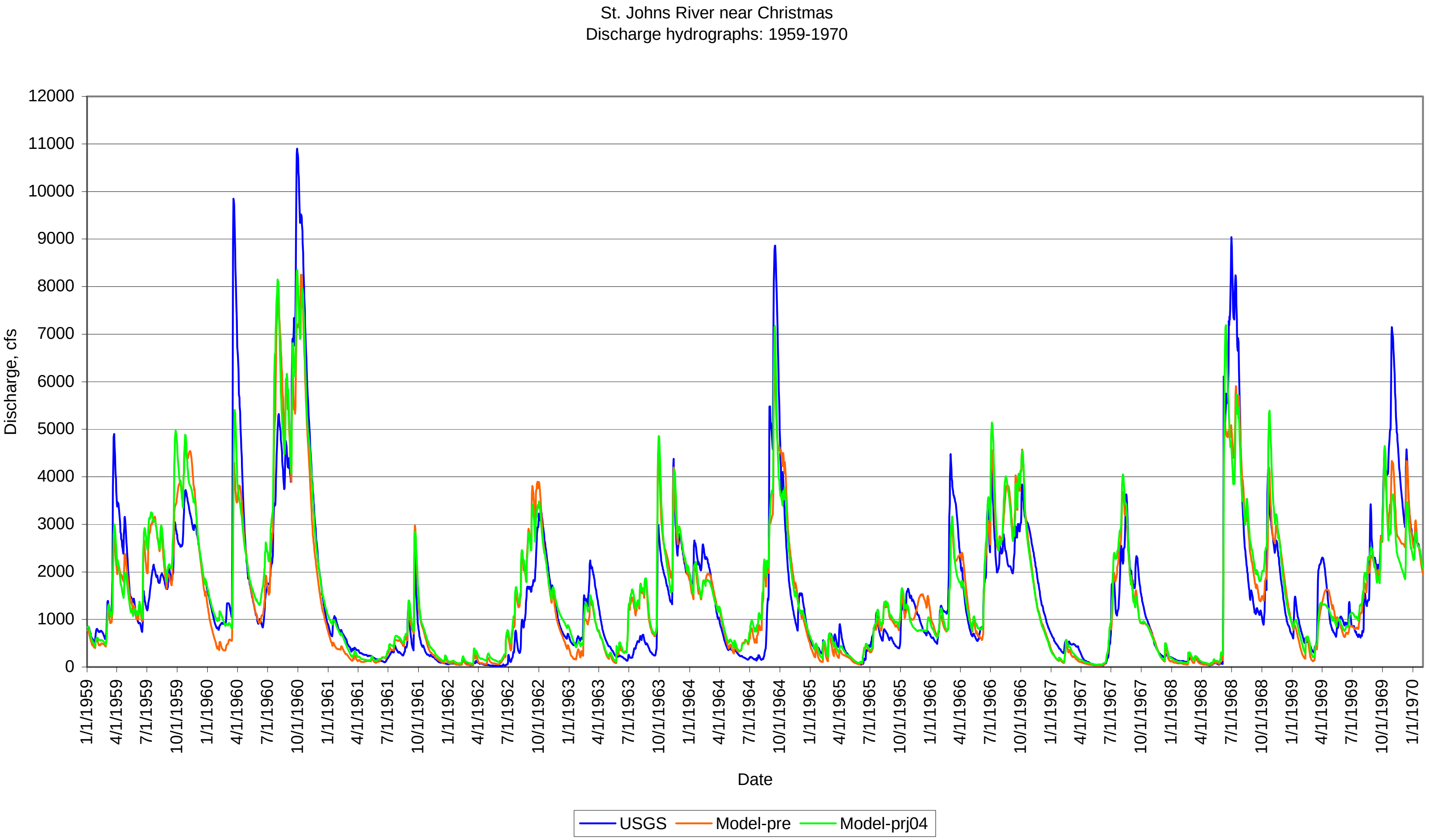


Figure A-11: Comparison of discharge hydrographs: USGS, Pre-project and Project conditions (1959-1970)

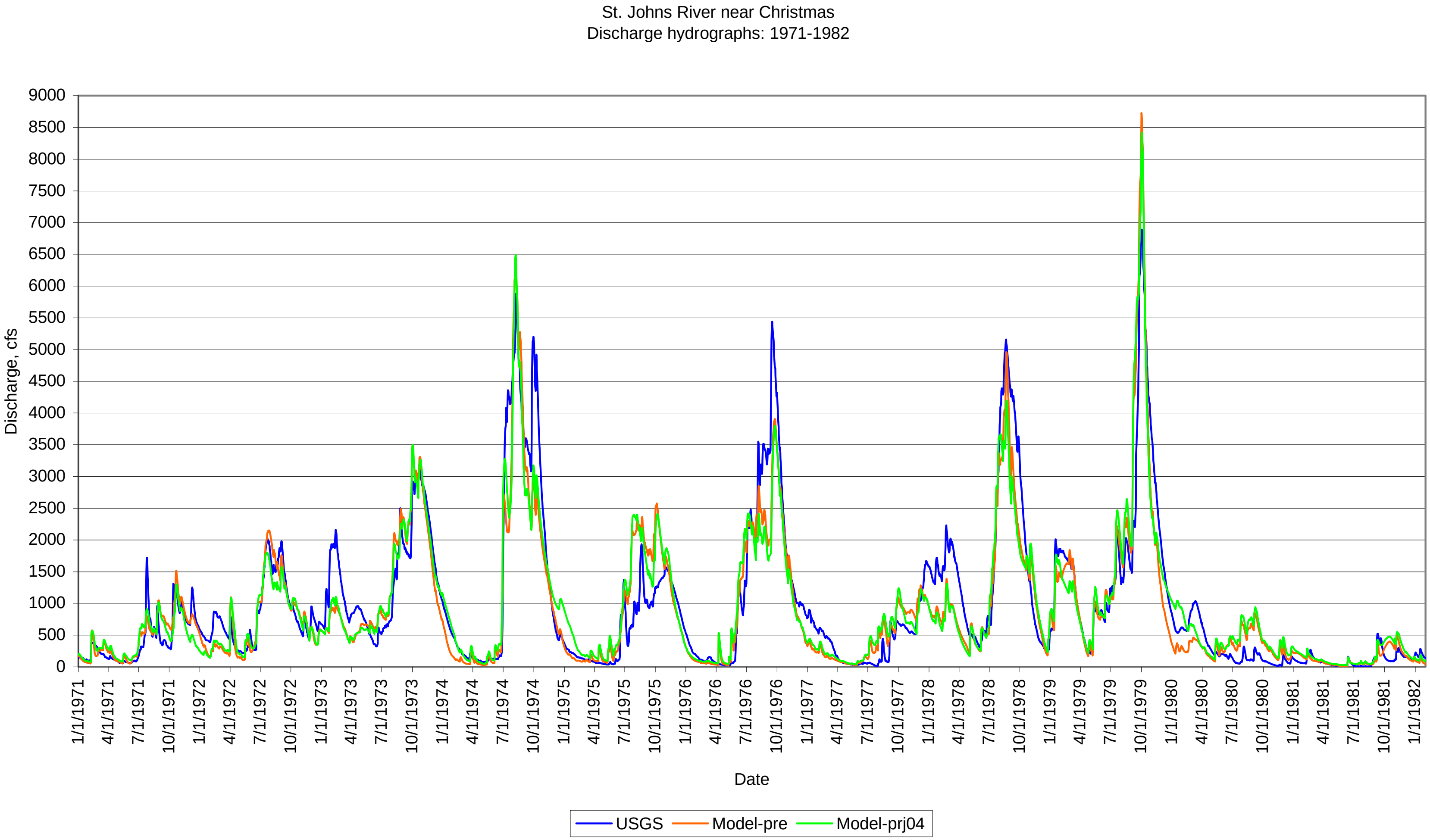


Figure A-12: Comparison of discharge hydrographs: USGS, Pre-project and Project conditions (1971-1982)

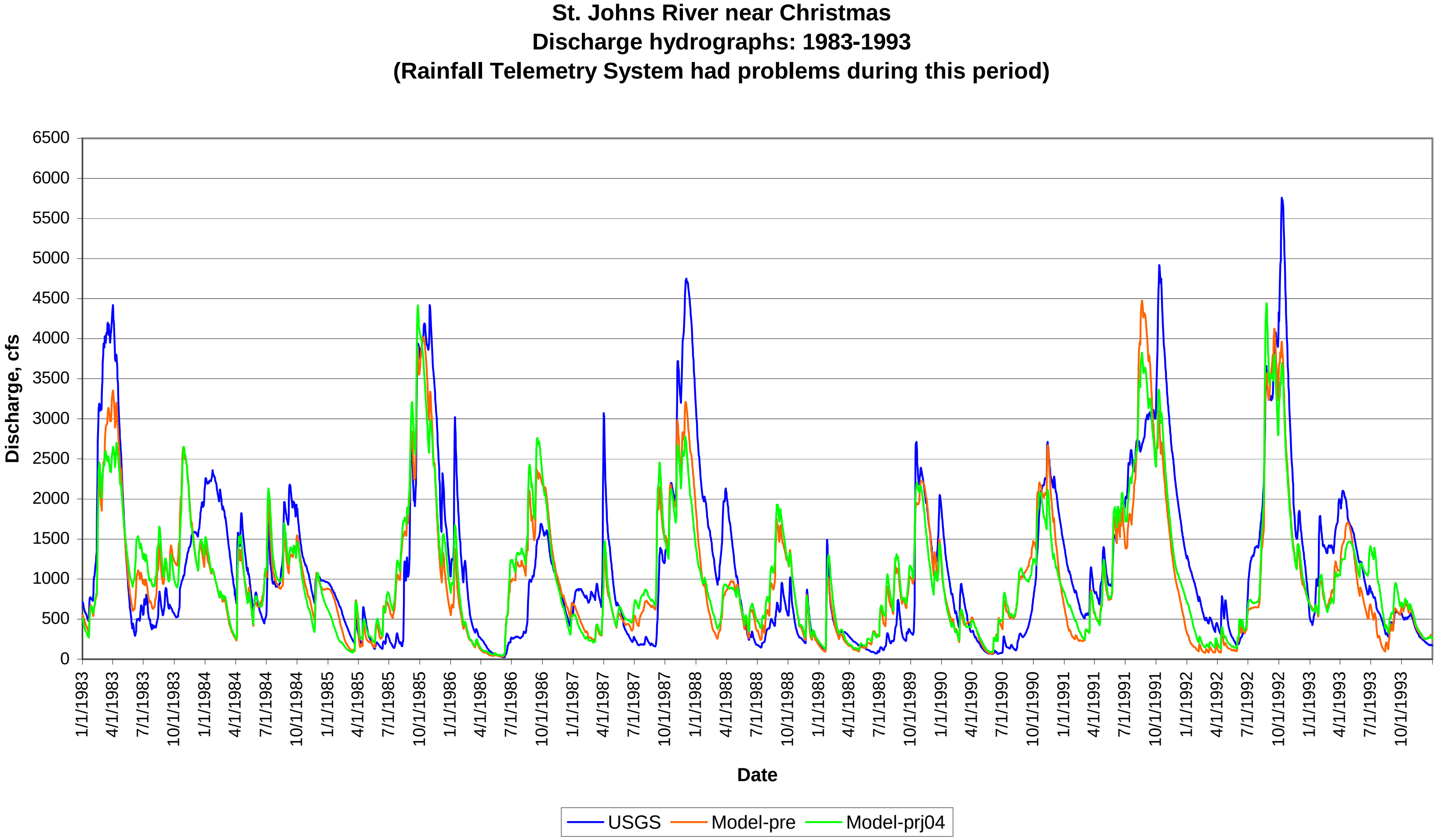


Figure A-13: Comparison of discharge hydrographs: USGS, Pre-project and Project conditions (1983-1993)

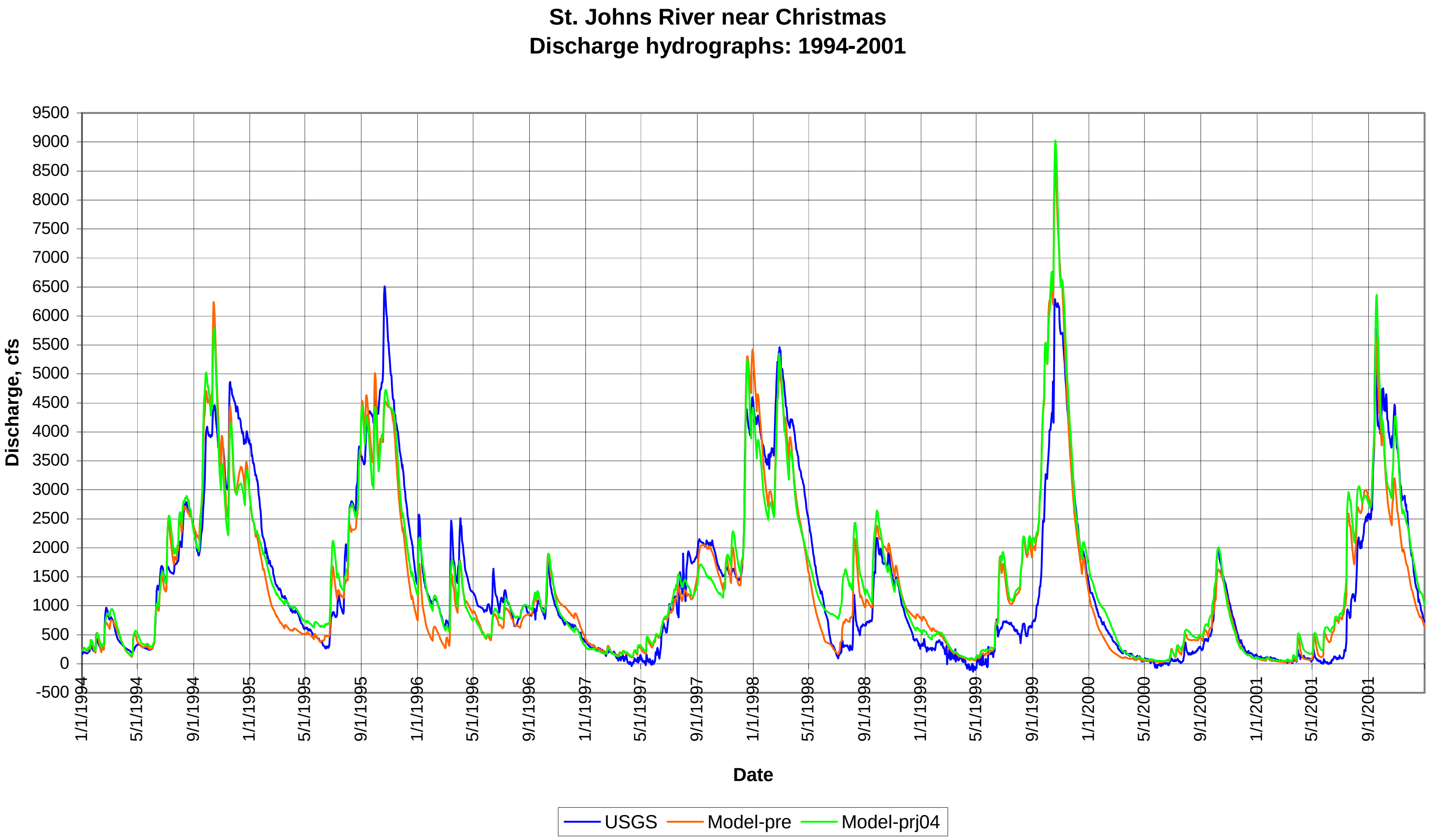


Figure A-14: Comparison of discharge hydrographs: USGS, Pre-project and Project conditions (1994-2001)

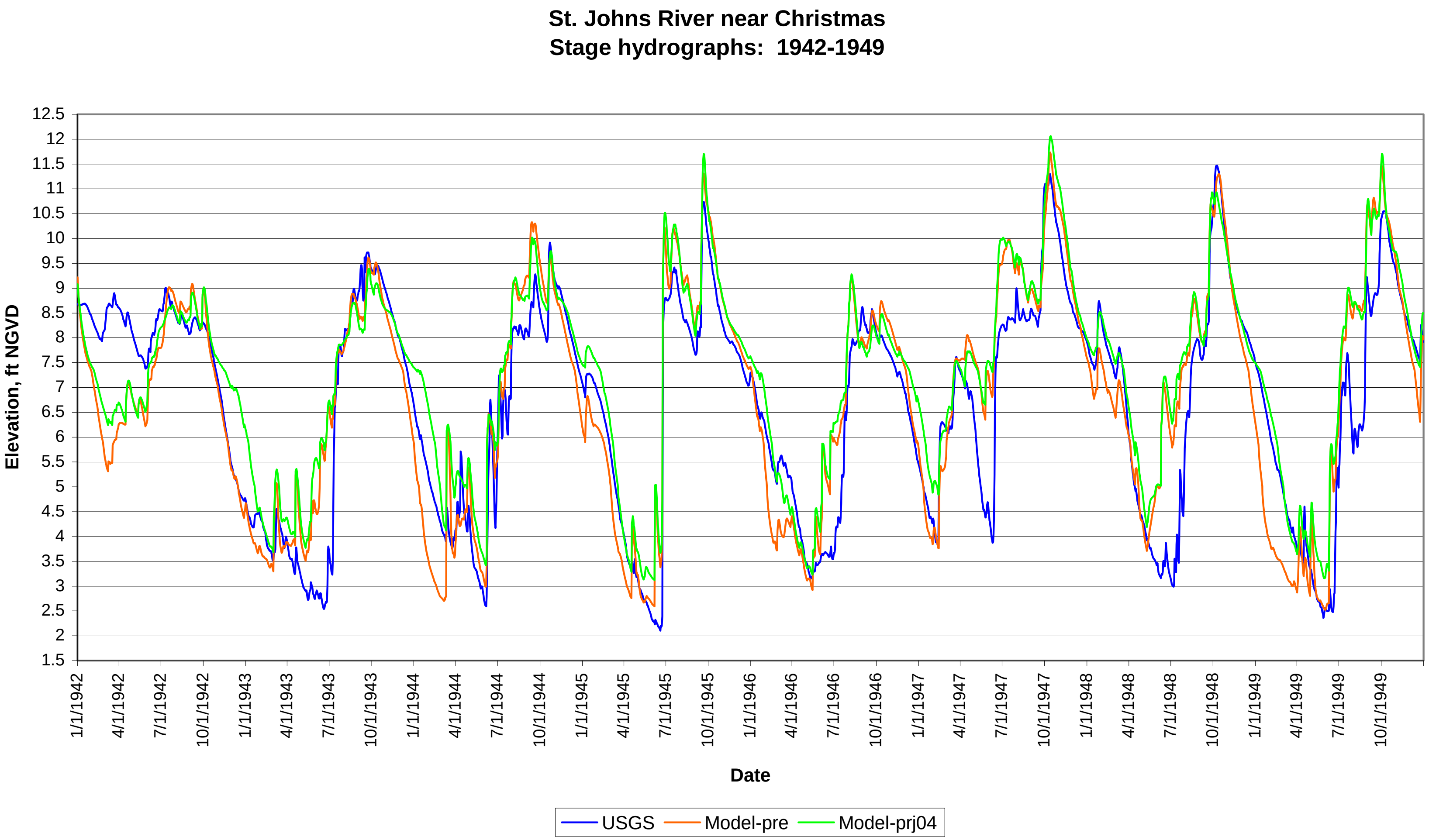


Figure A-15: Comparison of stage hydrographs: USGS, Pre-project and Project conditions (1942-1949)

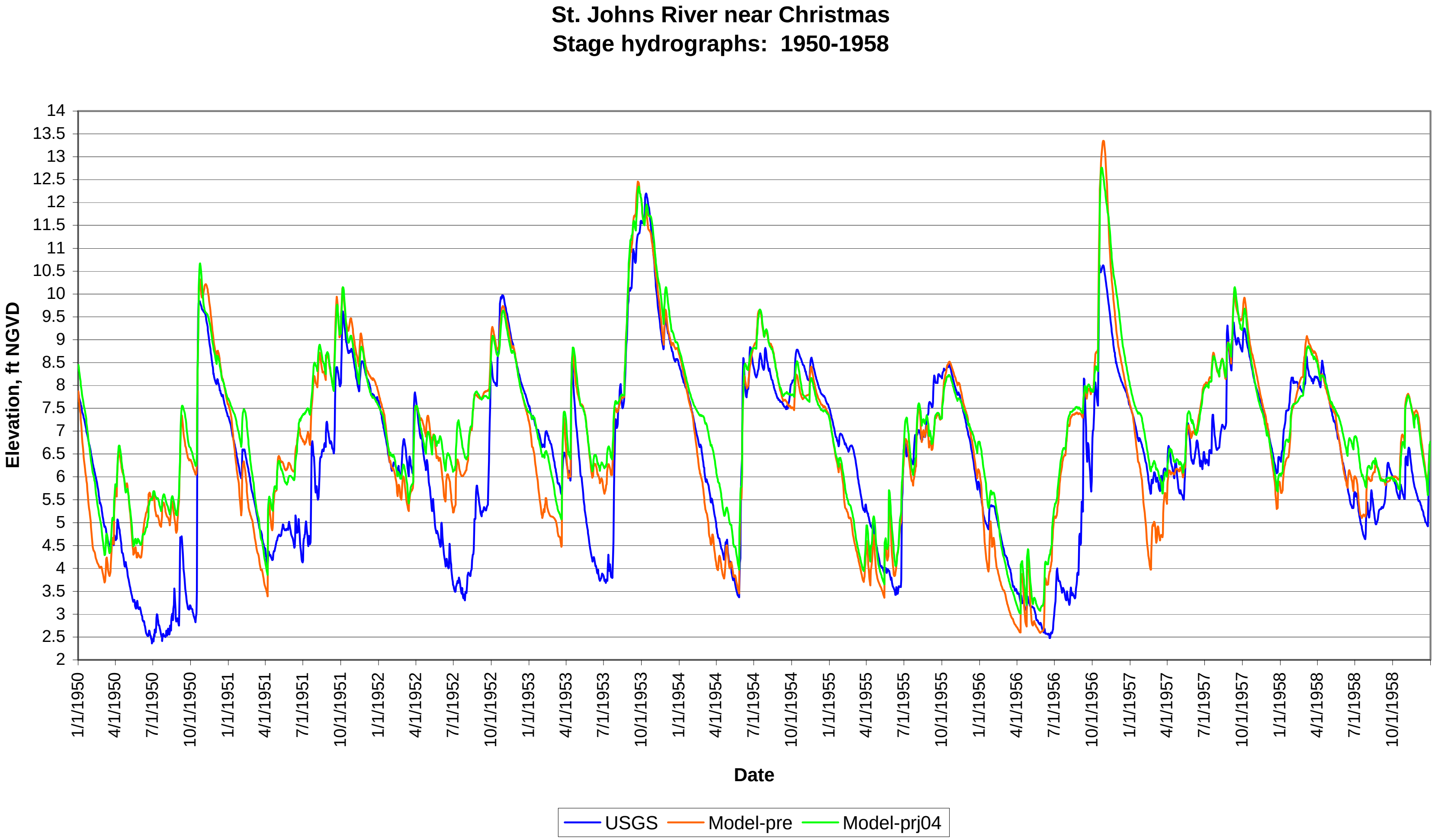


Figure A-16: Comparison of stage hydrographs: USGS, Pre-project and Project conditions (1950-1958)

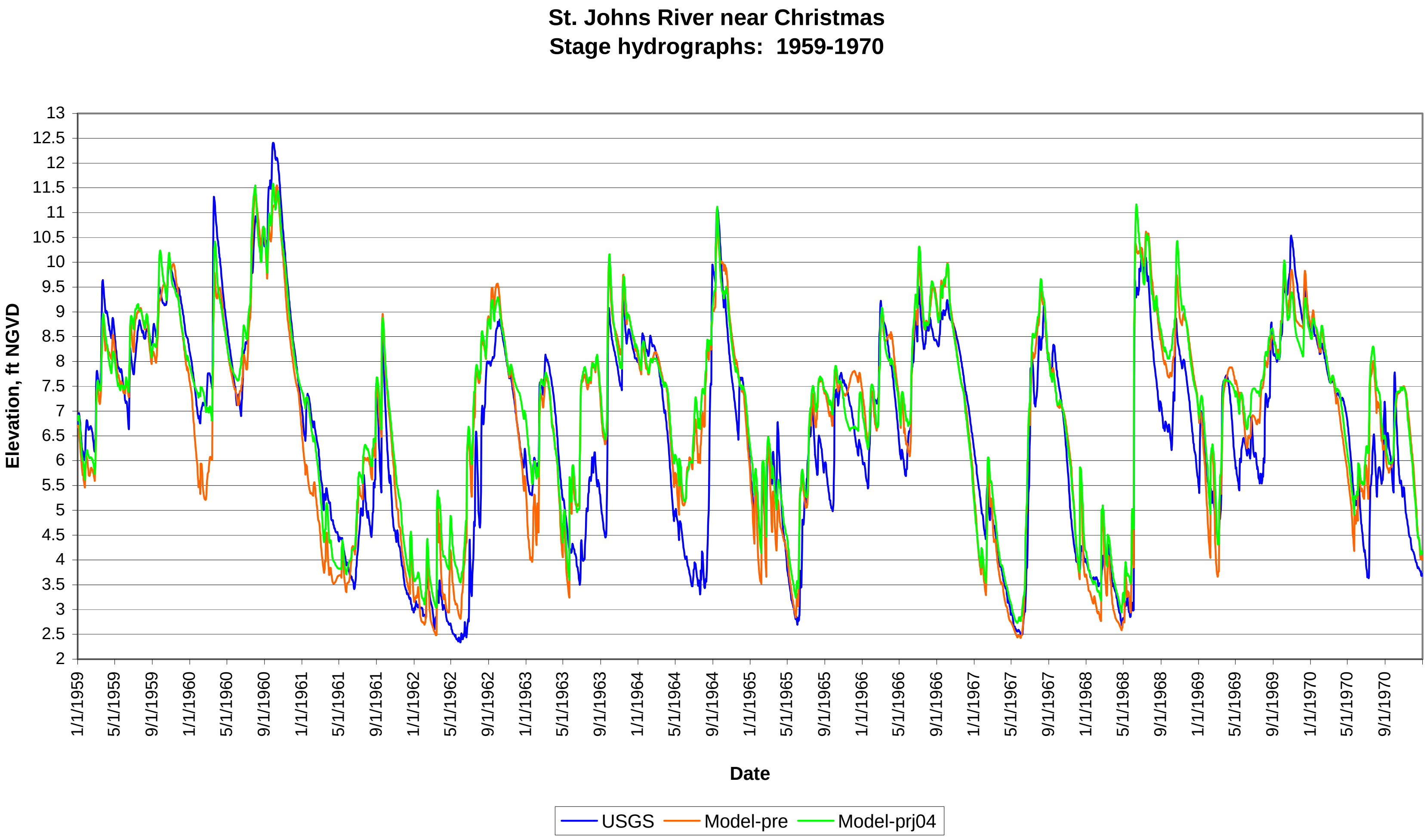


Figure A-17: Comparison of stage hydrographs: USGS, Pre-project and Project conditions (1959-1970)

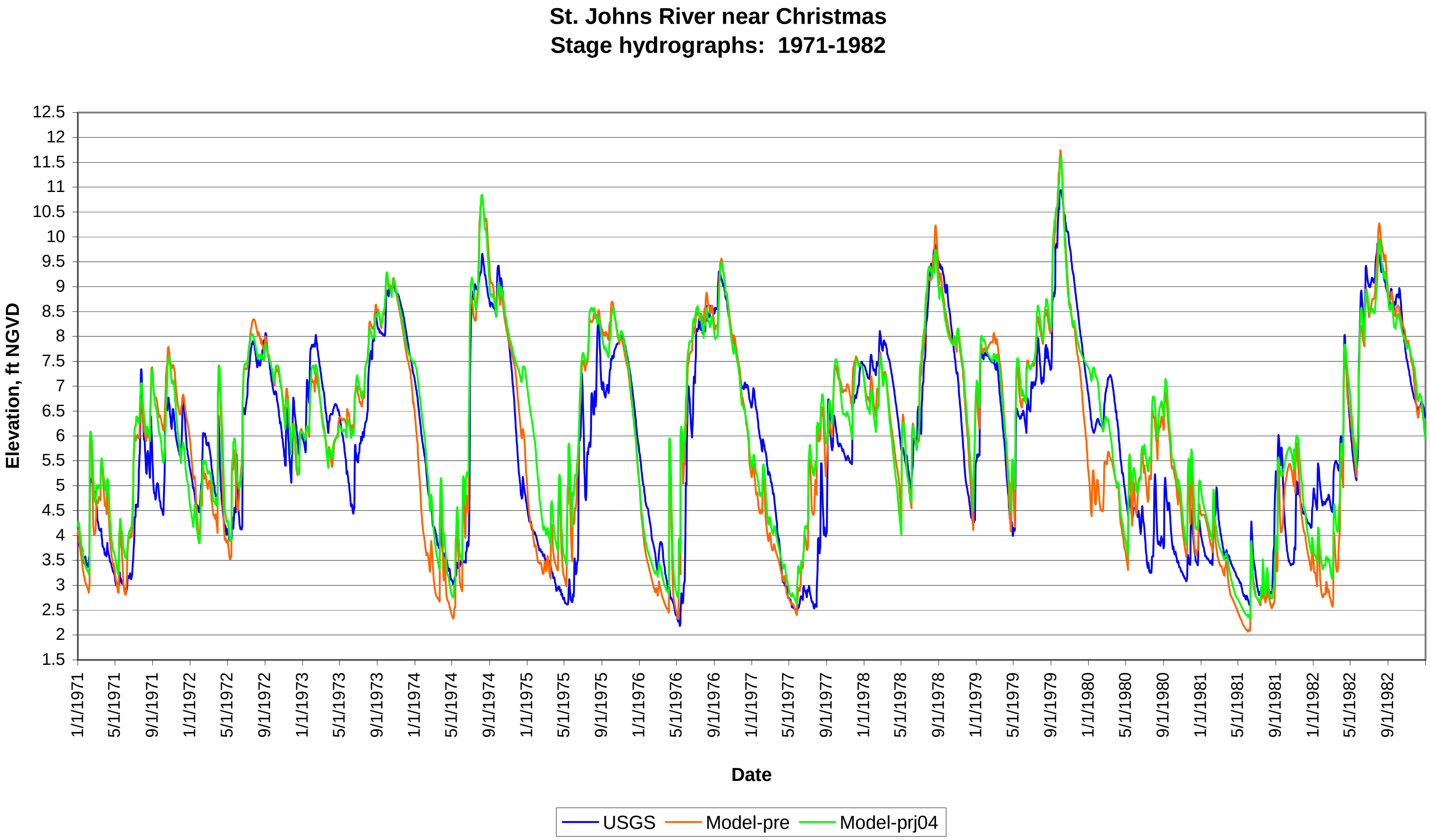


Figure A-18: Comparison of stage hydrographs: USGS, Pre-project and Project conditions (1971-1982)

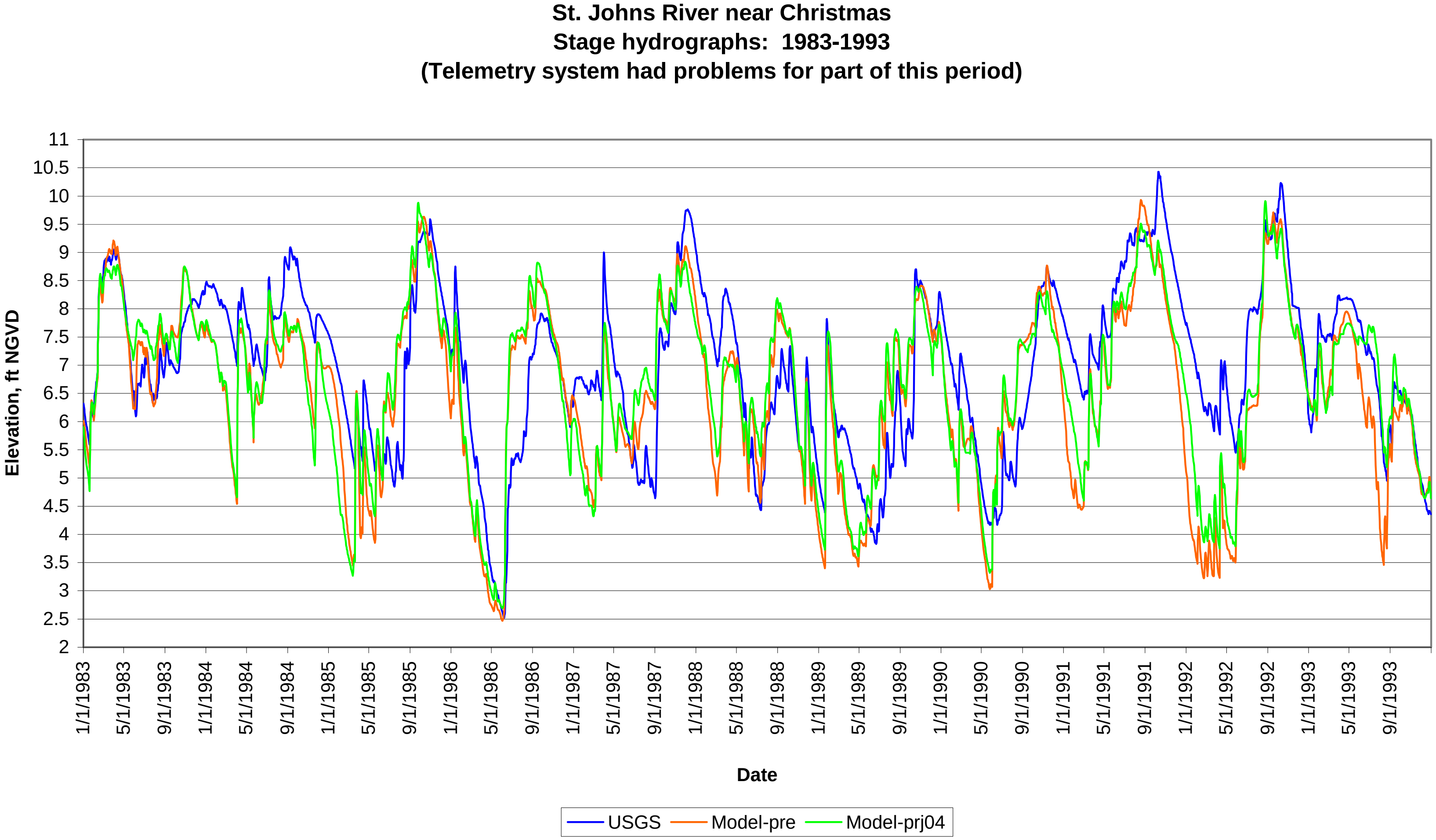


Figure A-19: Comparison of stage hydrographs: USGS, Pre-project and Project conditions (1983-1993)

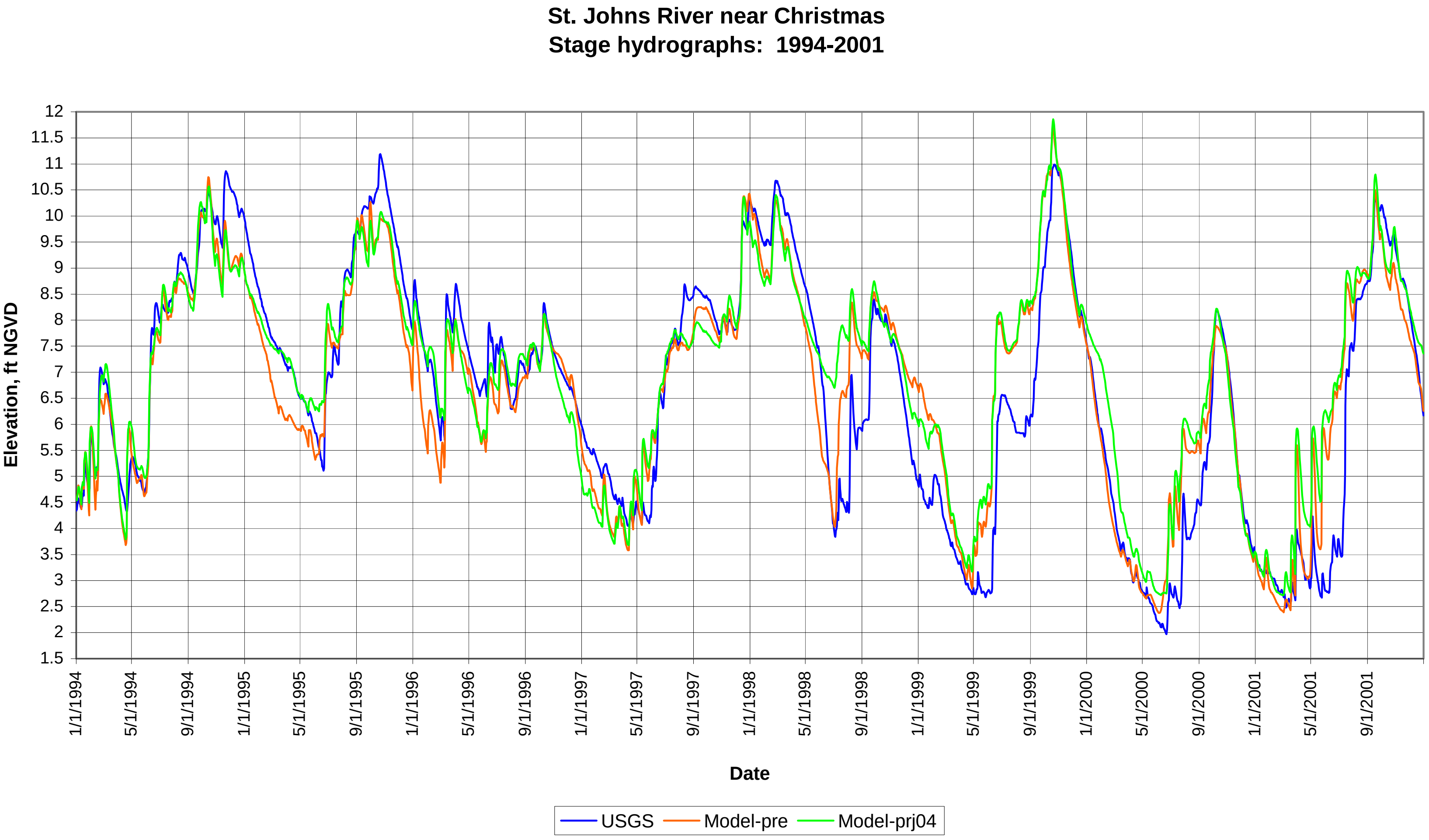


Figure A-20: Comparison of stage hydrographs: USGS, Pre-project and Project conditions (1994-2001)

APPENDIX I

MFLs evaluations for the St. Johns River at the SR 50 Bridge
1933-2005 USGS Discharges

Table I-1. SJR near Christmas: Highest Discharges, cfs (USGS)

Highest values exceeded continuously for the following number of days in year ending May 31

year	1	7	14	30	60	90	120	183	1 year
1934	4700.00	4400.00	3850.00	3650.00	2420.00	1750.00	1590.00	654.00	36.00
1935	4600.00	4300.00	3940.00	3270.00	2820.00	1860.00	1400.00	1300.00	31.00
1936	1860.00	1440.00	1300.00	1220.00	985.00	883.00	698.00	698.00	0.00
1937	3620.00	3380.00	3060.00	2820.00	2430.00	2070.00	1320.00	615.00	118.00
1938	1240.00	940.00	816.00	768.00	475.00	352.00	308.00	235.00	0.00
1939	2860.00	2690.00	2490.00	2400.00	1950.00	1800.00	1400.00	768.00	0.00
1940	2880.00	2600.00	2180.00	1990.00	1600.00	648.00	475.00	272.00	0.00
1941	5270.00	5050.00	4640.00	3720.00	3020.00	2480.00	2030.00	2030.00	430.00
1942	2350.00	2120.00	1910.00	1720.00	1270.00	1090.00	1090.00	226.00	22.00
1943	3700.00	3600.00	3200.00	2900.00	2550.00	1910.00	1260.00	448.00	15.00
1944	4270.00	3790.00	3160.00	2670.00	1540.00	1500.00	1500.00	786.00	0.00
1945	9230.00	8520.00	6540.00	3960.00	2080.00	1460.00	1460.00	985.00	70.00
1946	3500.00	2840.00	2450.00	2120.00	1740.00	1460.00	991.00	289.00	110.00
1947	10700.00	10100.00	9810.00	7820.00	3850.00	2440.00	2440.00	2260.00	119.00
1948	9890.00	9890.00	8770.00	6440.00	2550.00	1740.00	1260.00	589.00	0.00
1949	6600.00	6500.00	6100.00	4330.00	3000.00	2240.00	1340.00	554.00	70.00
1950	4910.00	4820.00	4530.00	3100.00	1600.00	888.00	622.00	176.00	66.00
1951	4850.00	3920.00	3030.00	2590.00	1640.00	1600.00	1020.00	629.00	186.00
1952	5720.00	5550.00	5100.00	3510.00	1870.00	1420.00	961.00	356.00	0.00
1953	11600.00	11200.00	10200.00	9340.00	6170.00	3230.00	2740.00	1290.00	130.00
1954	3330.00	2850.00	2600.00	2380.00	1990.00	1600.00	1410.00	1410.00	167.00
1955	2380.00	2270.00	2150.00	2010.00	1420.00	1130.00	861.00	479.00	39.00
1956	10100.00	8410.00	7840.00	4900.00	2200.00	1530.00	901.00	200.00	0.00
1957	4290.00	3620.00	3180.00	2910.00	2310.00	1950.00	1220.00	715.00	652.00
1958	4900.00	4240.00	3370.00	2540.00	1420.00	1020.00	585.00	218.00	170.00
1959	9850.00	8780.00	6730.00	4060.00	2530.00	1990.00	1650.00	1450.00	738.00
1960	10900.00	10300.00	9340.00	7260.00	4370.00	3740.00	3390.00	1180.00	0.00
1961	2400.00	1560.00	858.00	423.00	350.00	239.00	239.00	98.00	15.00
1962	3310.00	3080.00	2960.00	2420.00	1600.00	1300.00	809.00	454.00	15.00
1963	4380.00	3310.00	2470.00	2340.00	1780.00	1750.00	1730.00	1060.00	132.00
1964	8860.00	8210.00	6740.00	4580.00	1970.00	875.00	762.00	280.00	0.00
1965	4480.00	3900.00	3550.00	2690.00	1130.00	881.00	553.00	486.00	50.00
1966	4370.00	3600.00	3100.00	2870.00	2360.00	1970.00	1970.00	1190.00	30.00
1967	3630.00	3070.00	2520.00	2120.00	1660.00	1080.00	800.00	199.00	28.00
1968	9040.00	7850.00	7310.00	6650.00	3190.00	1410.00	980.00	888.00	0.00
1969	7150.00	6700.00	5600.00	4500.00	3450.00	2800.00	2470.00	1920.00	326.00
1970	1080.00	764.00	503.00	394.00	330.00	330.00	280.00	124.00	59.00
1971	1720.00	1120.00	1040.00	848.00	661.00	525.00	388.00	388.00	57.00
1972	2160.00	1960.00	1870.00	1570.00	1460.00	944.00	742.00	427.00	0.00
1973	3130.00	3030.00	2850.00	2790.00	2100.00	1710.00	1390.00	661.00	69.00
1974	5880.00	5350.00	4930.00	4160.00	3470.00	3080.00	2400.00	417.00	37.00
1975	1930.00	1730.00	1510.00	1380.00	1180.00	925.00	925.00	359.00	21.00
1976	5440.00	5130.00	4580.00	3380.00	3040.00	2020.00	1740.00	904.00	0.00
1977	2230.00	1940.00	1810.00	1700.00	1350.00	1300.00	1140.00	510.00	9.50
1978	5160.00	4970.00	4720.00	4260.00	3390.00	1950.00	1070.00	368.00	211.00
1979	6890.00	6600.00	6150.00	4320.00	2850.00	1770.00	1480.00	941.00	165.00
1980	322.00	235.00	194.00	127.00	95.00	56.00	52.00	15.00	0.00
1981	1920.00	1240.00	618.00	218.00	181.00	129.00	129.00	109.00	2.20
1982	5740.00	5330.00	5140.00	4340.00	3750.00	3350.00	2690.00	689.00	385.00
1983	2360.00	2280.00	2220.00	2190.00	1900.00	1530.00	1370.00	697.00	292.00
1984	2180.00	2050.00	1890.00	1710.00	1280.00	957.00	902.00	702.00	0.00
1985	4420.00	4080.00	3930.00	3860.00	3040.00	1910.00	1180.00	957.00	32.00
1986	3070.00	2260.00	1660.00	1510.00	1100.00	899.00	651.00	415.00	24.00
1987	4750.00	4700.00	4510.00	3960.00	2950.00	1980.00	1620.00	930.00	158.00
1988	1490.00	993.00	698.00	589.00	445.00	356.00	213.00	147.00	0.00
1989	2710.00	2420.00	2180.00	2060.00	1170.00	1170.00	626.00	304.00	67.00
1990	2710.00	2520.00	2270.00	2170.00	1810.00	1210.00	839.00	507.00	65.00
1991	4920.00	4700.00	4280.00	3440.00	2950.00	2650.00	2340.00	1700.00	173.00
1992	5760.00	5490.00	4920.00	3900.00	3230.00	2080.00	1500.00	725.00	0.00
1993	1210.00	1120.00	952.00	807.00	539.00	306.00	281.00	252.00	171.00
1994	4860.00	4620.00	4460.00	3970.00	3250.00	3000.00	2910.00	1870.00	251.00
1995	6510.00	5970.00	5290.00	4580.00	4160.00	3440.00	2600.00	1210.00	260.00
1996	1800.00	1440.00	1170.00	881.00	760.00	760.00	656.00	643.00	0.00

Table I-1 -Continued

Highest values exceeded continuously for the following number of days in year ending May 31

year	1	7	14	30	60	90	120	183	1 year
1997	5460.00	5110.00	4950.00	4150.00	3580.00	3360.00	3340.00	1440.00	61.00
1998	2170.00	1920.00	1850.00	1670.00	1190.00	710.00	491.00	228.00	0.00
1999	6290.00	6150.00	5730.00	4400.00	3190.00	1810.00	1150.00	475.00	0.00
2000	1990.00	1780.00	1560.00	1140.00	503.00	272.00	181.00	72.00	0.00
2001	5790.00	4380.00	4210.00	3970.00	3120.00	2460.00	1860.00	481.00	0.00
2002	6120.00	5440.00	5120.00	4820.00	4230.00	2950.00	1230.00	479.00	45.00
2003	3750.00	3600.00	3430.00	3390.00	2990.00	1620.00	851.00	380.00	71.00
2004	7550.00	7240.00	7150.00	6630.00	4350.00	1980.00	1350.00	716.00	0.00
2005	7200.00	6290.00	6040.00	5150.00	2820.00	1940.00	1600.00	1600.00	11.00
mean	4672.11	4241.00	3802.49	3130.90	2190.33	1604.51	1255.58	697.62	89.75
max	11600.00	11200.00	10200.00	9340.00	6170.00	3740.00	3390.00	2260.00	738.00
min	322.00	235.00	194.00	127.00	95.00	56.00	52.00	15.00	0.00

Table I-2. SJR near Christmas: Lowest discharges, cfs (USGS)

Lowest values not exceeded continuously for the following number of days in year ending Sep 30

Year	1	7	14	30	60	90	120	183	1 Year
1934	367.00	444.00	570.00	640.00	735.00	985.00	1220.00	1980.00	4700.00
1935	31.00	43.00	64.00	84.00	99.00	129.00	221.00	528.00	3600.00
1936	596.00	634.00	698.00	823.00	1490.00	1490.00	1700.00	3350.00	4600.00
1937	208.00	214.00	221.00	228.00	320.00	339.00	381.00	528.00	1320.00
1938	118.00	126.00	165.00	195.00	250.00	407.00	746.00	1240.00	3620.00
1939	0.00	2.00	9.00	34.00	49.00	87.00	160.00	535.00	2860.00
1940	150.00	168.00	222.00	315.00	513.00	793.00	1420.00	1510.00	2740.00
1941	272.00	292.00	292.00	400.00	790.00	1990.00	2320.00	2390.00	5270.00
1942	765.00	790.00	912.00	1030.00	1480.00	1850.00	2350.00	2350.00	4200.00
1943	15.00	19.00	27.00	30.00	51.00	99.00	154.00	170.00	3700.00
1944	46.00	56.00	65.00	84.00	224.00	348.00	348.00	648.00	3300.00
1945	73.00	75.00	76.00	82.00	116.00	192.00	534.00	1000.00	9230.00
1946	70.00	77.00	86.00	107.00	152.00	240.00	387.00	701.00	6380.00
1947	111.00	128.00	206.00	298.00	550.00	711.00	1170.00	1490.00	9810.00
1948	62.00	74.00	114.00	149.00	180.00	294.00	550.00	1620.00	10700.00
1949	69.00	72.00	74.00	78.00	127.00	280.00	368.00	944.00	9890.00
1950	66.00	72.00	76.00	86.00	99.00	116.00	142.00	376.00	6600.00
1951	88.00	96.00	105.00	267.00	370.00	381.00	414.00	850.00	4910.00
1952	106.00	116.00	124.00	143.00	235.00	324.00	532.00	1570.00	4850.00
1953	198.00	203.00	213.00	227.00	292.00	861.00	1790.00	2600.00	10000.00
1954	130.00	139.00	165.00	242.00	375.00	604.00	1290.00	2860.00	11600.00
1955	126.00	145.00	147.00	194.00	276.00	465.00	726.00	934.00	2980.00
1956	25.00	30.00	31.00	45.00	81.00	108.00	139.00	230.00	2410.00
1957	434.00	480.00	532.00	680.00	832.00	996.00	1050.00	1300.00	10100.00
1958	218.00	239.00	298.00	393.00	466.00	466.00	666.00	3140.00	3990.00
1959	170.00	198.00	269.00	409.00	742.00	745.00	851.00	3460.00	4900.00
1960	780.00	830.00	872.00	932.00	1340.00	1990.00	2990.00	8150.00	10900.00
1961	98.00	111.00	127.00	160.00	236.00	292.00	402.00	533.00	10700.00
1962	15.00	22.00	24.00	32.00	53.00	87.00	129.00	158.00	3060.00
1963	132.00	154.00	180.00	247.00	288.00	490.00	678.00	1470.00	3310.00
1964	135.00	167.00	187.00	215.00	250.00	342.00	444.00	2160.00	8860.00
1965	50.00	66.00	71.00	124.00	293.00	572.00	904.00	904.00	4680.00
1966	486.00	528.00	612.00	721.00	979.00	1290.00	1550.00	4370.00	4480.00
1967	28.00	29.00	36.00	43.00	104.00	350.00	488.00	715.00	3840.00
1968	32.00	43.00	50.00	88.00	98.00	223.00	223.00	266.00	9040.00
1969	306.00	336.00	434.00	598.00	1060.00	1370.00	1550.00	2300.00	4160.00
1970	103.00	115.00	160.00	280.00	454.00	583.00	739.00	1200.00	7150.00
1971	57.00	64.00	73.00	95.00	103.00	171.00	226.00	384.00	1720.00
1972	217.00	223.00	247.00	288.00	586.00	796.00	832.00	876.00	2020.00
1973	320.00	350.00	386.00	586.00	670.00	828.00	956.00	1790.00	2900.00
1974	69.00	77.00	83.00	107.00	126.00	183.00	222.00	1060.00	5880.00
1975	37.00	39.00	46.00	63.00	80.00	118.00	144.00	558.00	5100.00
1976	21.00	26.00	27.00	39.00	80.00	156.00	190.00	1060.00	5440.00
1977	9.50	22.00	34.00	44.00	66.00	69.00	106.00	449.00	4270.00
1978	308.00	351.00	402.00	483.00	668.00	1070.00	1690.00	2230.00	5160.00
1979	211.00	240.00	264.00	406.00	757.00	1010.00	1310.00	2010.00	6700.00
1980	52.00	55.00	67.00	130.00	206.00	242.00	322.00	630.00	6890.00
1981	2.20	6.40	8.60	14.00	44.00	90.00	160.00	160.00	522.00
1982	88.00	88.00	92.00	124.00	200.00	285.00	285.00	299.00	5740.00
1983	292.00	351.00	432.00	553.00	808.00	808.00	891.00	4420.00	4420.00
1984	445.00	496.00	537.00	778.00	1140.00	1720.00	1720.00	1910.00	2360.00
1985	129.00	147.00	187.00	211.00	320.00	324.00	648.00	648.00	3940.00
1986	24.00	28.00	36.00	61.00	134.00	257.00	283.00	883.00	4420.00
1987	158.00	168.00	187.00	245.00	281.00	334.00	687.00	3070.00	3070.00
1988	146.00	163.00	180.00	224.00	356.00	503.00	716.00	2040.00	4750.00
1989	70.00	77.00	90.00	108.00	150.00	201.00	315.00	416.00	1490.00
1990	65.00	70.00	70.00	101.00	124.00	286.00	286.00	460.00	2710.00
1991	507.00	540.00	565.00	655.00	1050.00	1150.00	1400.00	1800.00	3110.00
1992	173.00	190.00	214.00	279.00	570.00	785.00	785.00	1200.00	4920.00
1993	281.00	328.00	353.00	460.00	604.00	838.00	1210.00	2100.00	5760.00
1994	171.00	180.00	182.00	203.00	306.00	428.00	570.00	970.00	4090.00
1995	260.00	301.00	320.00	466.00	631.00	914.00	1170.00	2090.00	4860.00
1996	574.00	686.00	751.00	995.00	1010.00	1270.00	1640.00	2510.00	6510.00

Table I-2 -Continued

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Lowest values not exceeded continuously for the following number of days in year ending
Sep 30

 Year        1         7        14        30        60        90       120       183    1 Year

 1997   -40.00     25.00     36.00    139.00    163.00    197.00    260.00    555.00   2150.00
 1998    92.00    164.00    242.00    403.00    840.00   1190.00   1370.00   3940.00   5460.00
 1999  -137.00    -44.00     -3.70     89.00    167.00    248.00    381.00    552.00   3270.00
 2000   -76.00    -17.00      2.50     19.00     97.00     99.00    174.00    368.00   6290.00
 2001    -2.70     28.00     36.00     62.00    112.00    161.00    241.00    255.00   5790.00
 2002    43.00     65.00     67.00    103.00    195.00    354.00   1070.00   1070.00   6120.00
 2003   132.00    154.00    187.00    267.00    403.00    792.00    990.00   1650.00   5070.00
 2004    71.00     92.00     94.00    190.00    363.00    393.00    475.00    848.00   7240.00
 2005   454.00    514.00    554.00    658.00   1020.00   1080.00   1890.00   1890.00   7550.00

 mean   165.31    188.62    216.14    282.65    423.32    586.65    796.40   1495.57   5224.06
  max   780.00    830.00    912.00   1030.00   1490.00   1990.00   2990.00   8150.00  11600.00
  min  -137.00    -44.00     -3.70     14.00     44.00     69.00    106.00    158.00    522.00
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Table I-3. SJR near Christmas: Lowest mean discharges, cfs (USGS)

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
1934	367.00	406.14	461.86	522.77	570.78	654.19	707.93	1007.50	1882.85
1935	31.00	35.71	45.71	55.23	59.32	71.28	97.47	185.75	674.97
1936	596.00	609.57	632.29	695.90	928.87	1062.58	1090.34	1267.15	1933.71
1937	208.00	210.57	213.29	218.57	250.13	254.67	275.01	329.43	572.93
1938	118.00	120.29	132.14	150.57	172.88	216.89	308.56	432.78	1229.92
1939	0.00	0.71	3.00	10.30	18.98	33.50	51.36	95.66	515.65
1940	150.00	159.00	174.86	210.43	275.10	368.14	536.92	672.81	1140.71
1941	272.00	280.29	283.14	316.03	462.30	751.34	1020.51	1390.93	1876.10
1942	765.00	782.86	822.21	897.13	1116.90	1320.60	1390.37	1417.45	1836.86
1943	15.00	16.71	19.43	22.93	27.75	41.43	58.33	72.38	671.07
1944	46.00	49.14	55.43	66.63	118.40	126.72	133.90	210.60	974.55
1945	73.00	73.86	74.50	76.37	85.32	102.93	161.62	393.27	1808.52
1946	70.00	73.57	78.57	90.33	109.23	132.68	179.08	282.42	1174.91
1947	111.00	120.14	150.93	199.33	306.78	420.34	531.63	583.54	1442.79
1948	62.00	66.43	79.86	103.47	113.75	149.08	206.14	520.66	2194.10
1949	69.00	70.29	71.07	72.70	80.80	106.90	145.09	301.45	1679.90
1950	66.00	70.29	72.79	75.93	77.03	83.09	90.48	137.05	1076.56
1951	88.00	91.86	97.36	225.23	272.73	291.63	292.51	390.27	1046.82
1952	106.00	110.43	113.86	122.43	139.73	169.17	223.96	398.04	1011.80
1953	198.00	200.86	204.50	208.20	224.28	319.44	515.92	593.26	2010.08
1954	130.00	133.00	142.79	171.37	239.17	325.96	474.53	1036.03	2569.22
1955	126.00	133.29	136.71	150.67	181.90	247.00	324.38	484.15	1084.01
1956	25.00	27.86	29.00	32.37	47.40	61.34	70.97	94.10	514.29
1957	434.00	458.14	482.79	579.30	630.98	632.58	685.74	763.99	1922.85
1958	218.00	228.14	248.79	296.47	322.70	348.58	402.62	824.12	1367.95
1959	170.00	184.29	209.36	279.57	423.47	433.88	495.68	882.52	1387.57
1960	780.00	803.14	826.14	868.77	1004.55	1201.59	1560.36	2249.72	2978.36
1961	98.00	104.43	112.36	127.20	163.13	194.03	229.05	275.41	1491.05
1962	15.00	17.71	18.64	22.17	29.35	40.24	49.07	58.83	373.94
1963	132.00	141.14	157.21	185.03	209.83	273.14	340.63	446.02	936.63
1964	135.00	152.71	162.07	175.07	180.48	206.16	246.52	572.68	1793.61
1965	50.00	57.71	61.79	79.67	138.73	232.02	327.73	369.60	789.14
1966	486.00	508.71	540.36	601.90	694.53	848.02	972.02	1389.39	1727.47
1967	28.00	28.14	30.86	34.33	55.97	105.07	191.66	290.84	1175.56
1968	32.00	37.00	42.43	56.43	65.37	92.59	105.14	131.16	1501.94
1969	306.00	320.57	356.00	433.47	579.30	704.13	906.95	975.17	1391.47
1970	103.00	107.43	124.43	173.87	264.07	322.93	370.05	503.53	1842.65
1971	57.00	61.00	64.71	72.50	77.68	93.33	115.25	145.69	291.64
1972	217.00	220.43	226.50	243.03	291.28	351.76	435.97	483.58	844.09
1973	320.00	332.29	348.71	423.37	508.02	580.69	661.15	844.07	1011.65
1974	69.00	73.57	76.21	86.37	101.77	116.19	130.09	281.03	1755.81
1975	37.00	38.00	39.86	46.50	52.25	66.98	81.03	150.48	804.82
1976	21.00	23.71	24.07	27.50	43.47	66.98	81.68	243.38	1248.84
1977	9.50	15.07	20.46	35.83	44.55	42.85	48.60	107.67	633.12
1978	308.00	328.14	355.21	403.07	475.10	584.20	789.32	1099.33	1653.18
1979	211.00	229.00	238.43	304.73	443.87	648.07	768.78	920.44	1361.79
1980	52.00	53.43	57.07	74.47	113.93	129.67	146.88	199.43	1045.64
1981	2.20	4.13	5.63	6.71	11.06	23.06	22.00	40.81	84.36
1982	88.00	88.00	89.00	98.73	155.72	148.73	161.23	162.18	1492.25
1983	292.00	319.00	366.14	440.77	528.68	521.63	567.55	1106.95	1480.53
1984	445.00	471.57	494.86	576.03	712.02	837.50	927.44	1090.88	1385.05
1985	129.00	137.29	153.79	162.70	197.38	201.59	240.69	279.50	788.65
1986	24.00	25.86	29.14	39.20	64.15	110.71	150.27	244.30	1220.81
1987	158.00	163.86	174.71	194.43	197.28	219.58	295.20	627.78	786.57
1988	146.00	152.14	161.86	182.60	236.90	302.47	376.48	638.34	1552.49
1989	70.00	72.71	79.00	87.67	107.82	128.39	155.78	212.24	327.77
1990	65.00	67.57	68.00	75.30	81.42	111.49	124.06	193.78	726.29
1991	507.00	524.57	540.64	562.80	711.23	760.19	839.69	1040.91	1684.56
1992	173.00	181.14	190.07	223.83	297.43	375.20	392.73	544.04	1603.50
1993	281.00	305.57	316.57	374.03	458.58	533.00	637.20	990.84	1479.22
1994	171.00	175.86	177.29	183.67	208.18	236.96	291.10	332.33	891.24
1995	260.00	280.57	291.43	352.70	458.25	576.04	672.88	961.17	2319.44
1996	574.00	657.14	671.64	800.30	854.02	925.39	963.93	1096.93	1846.83

Table I-3. –Continued

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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

 1997   -40.00     -3.19      6.86     39.27     42.69     63.92     95.96    176.00    709.51
 1998    92.00    131.29    163.86    240.97    336.05    455.89    593.02   1258.64   2221.27
 1999  -137.00    -82.29    -72.40    -36.97      3.23     42.22     92.26    177.52    621.19
 2000   -76.00    -47.86    -33.54    -16.25     13.71     27.88     51.00    108.24   1174.18
 2001    -2.70      8.74     17.01     27.71     55.50     72.37     65.17     76.12    780.20
 2002    43.00     51.71     56.00     68.40     99.22    142.86    256.67    362.78   2011.53
 2003   132.00    141.86    153.71    182.17    248.93    370.59    468.93    651.98   1471.22
 2004    71.00     79.00     81.71    105.83    138.85    178.59    225.16    297.95   1031.25
 2005   454.00    486.57    510.86    565.53    700.13    778.58    953.43    958.52   2299.12

 MEAN   165.31    177.22    189.08    220.33    273.78    330.16    397.90    557.44   1308.92
  MAX   780.00    803.14    826.14    897.13   1116.90   1320.60   1560.36   2249.72   2978.36
  MIN  -137.00    -82.29    -72.40    -36.97      3.23     23.06     22.00     40.81     84.36
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Table I-4. SJR near Christmas: Discharge data for MFLs plots, cfs (USGS)

	MFH		MIL	MFL	MA
weib	**30**	**weib**	**60**	**120**	**183**
1.37	9340.00	98.63	1490.00	2990.00	2249.72
2.74	7820.00	97.26	1480.00	2350.00	1417.45
4.11	7260.00	95.89	1340.00	2320.00	1390.93
5.48	6650.00	94.52	1140.00	1890.00	1389.39
6.85	6630.00	93.15	1060.00	1790.00	1267.15
8.22	6440.00	91.78	1050.00	1720.00	1258.64
9.59	5150.00	90.41	1020.00	1700.00	1106.95
10.96	4900.00	89.04	1010.00	1690.00	1099.33
12.33	4820.00	87.67	979.00	1640.00	1096.93
13.70	4580.00	86.30	840.00	1550.00	1090.88
15.07	4580.00	84.93	832.00	1550.00	1040.91
16.44	4500.00	83.56	808.00	1420.00	1036.03
17.81	4400.00	82.19	790.00	1400.00	1007.50
19.18	4340.00	80.82	757.00	1370.00	990.84
20.55	4330.00	79.45	742.00	1310.00	975.17
21.92	4320.00	78.08	735.00	1290.00	961.17
23.29	4260.00	76.71	670.00	1220.00	958.52
24.66	4160.00	75.34	668.00	1210.00	920.44
26.03	4150.00	73.97	631.00	1170.00	882.52
27.40	4060.00	72.60	604.00	1170.00	844.07
28.77	3970.00	71.23	586.00	1070.00	824.12
30.14	3970.00	69.86	570.00	1050.00	763.99
31.51	3960.00	68.49	550.00	990.00	672.81
32.88	3960.00	67.12	513.00	956.00	651.98
34.25	3900.00	65.75	466.00	904.00	638.34
35.62	3860.00	64.38	454.00	891.00	627.78
36.99	3720.00	63.01	403.00	851.00	593.26
38.36	3650.00	61.64	375.00	832.00	583.54
39.73	3510.00	60.27	370.00	785.00	572.68
41.10	3440.00	58.90	363.00	746.00	544.04
42.47	3390.00	57.53	356.00	739.00	520.66
43.84	3380.00	56.16	320.00	726.00	503.53
45.21	3270.00	54.79	320.00	716.00	484.15
46.58	3100.00	53.42	306.00	687.00	483.58
47.95	2910.00	52.05	293.00	678.00	446.02
49.32	2900.00	50.68	292.00	666.00	432.78
50.68	2870.00	49.32	288.00	648.00	398.04
52.05	2820.00	47.95	281.00	570.00	393.27
53.42	2790.00	46.58	276.00	550.00	390.27
54.79	2690.00	45.21	250.00	534.00	369.60
56.16	2670.00	43.84	250.00	532.00	362.78
57.53	2590.00	42.47	236.00	488.00	332.33
58.90	2540.00	41.10	235.00	475.00	329.43
60.27	2420.00	39.73	224.00	444.00	301.45
61.64	2400.00	38.36	206.00	414.00	297.95
63.01	2380.00	36.99	200.00	402.00	290.84
64.38	2340.00	35.62	195.00	387.00	282.42
65.75	2190.00	34.25	180.00	381.00	281.03
67.12	2170.00	32.88	167.00	381.00	279.50
68.49	2120.00	31.51	163.00	368.00	275.41

Table I-4. -Continued

	MFH		MIL	MFL	MA
weib	30	weib	60	120	183
69.86	2120.00	30.14	152.00	348.00	244.30
71.23	2060.00	28.77	150.00	322.00	243.38
72.60	2010.00	27.40	134.00	315.00	212.24
73.97	1990.00	26.03	127.00	286.00	210.60
75.34	1720.00	24.66	126.00	285.00	199.43
76.71	1710.00	23.29	124.00	283.00	193.78
78.08	1700.00	21.92	116.00	260.00	185.75
79.45	1670.00	20.55	112.00	241.00	177.52
80.82	1570.00	19.18	104.00	226.00	176.00
82.19	1510.00	17.81	103.00	223.00	162.18
83.56	1380.00	16.44	99.00	222.00	150.48
84.93	1220.00	15.07	99.00	221.00	145.69
86.30	1140.00	13.70	98.00	190.00	137.05
87.67	881.00	12.33	97.00	174.00	131.16
89.04	848.00	10.96	81.00	160.00	108.24
90.41	807.00	9.59	80.00	160.00	107.67
91.78	768.00	8.22	80.00	154.00	95.66
93.15	589.00	6.85	66.00	144.00	94.10
94.52	423.00	5.48	53.00	142.00	76.12
95.89	394.00	4.11	51.00	139.00	72.38
97.26	218.00	2.74	49.00	129.00	58.83
98.63	127.00	1.37	44.00	106.00	40.81

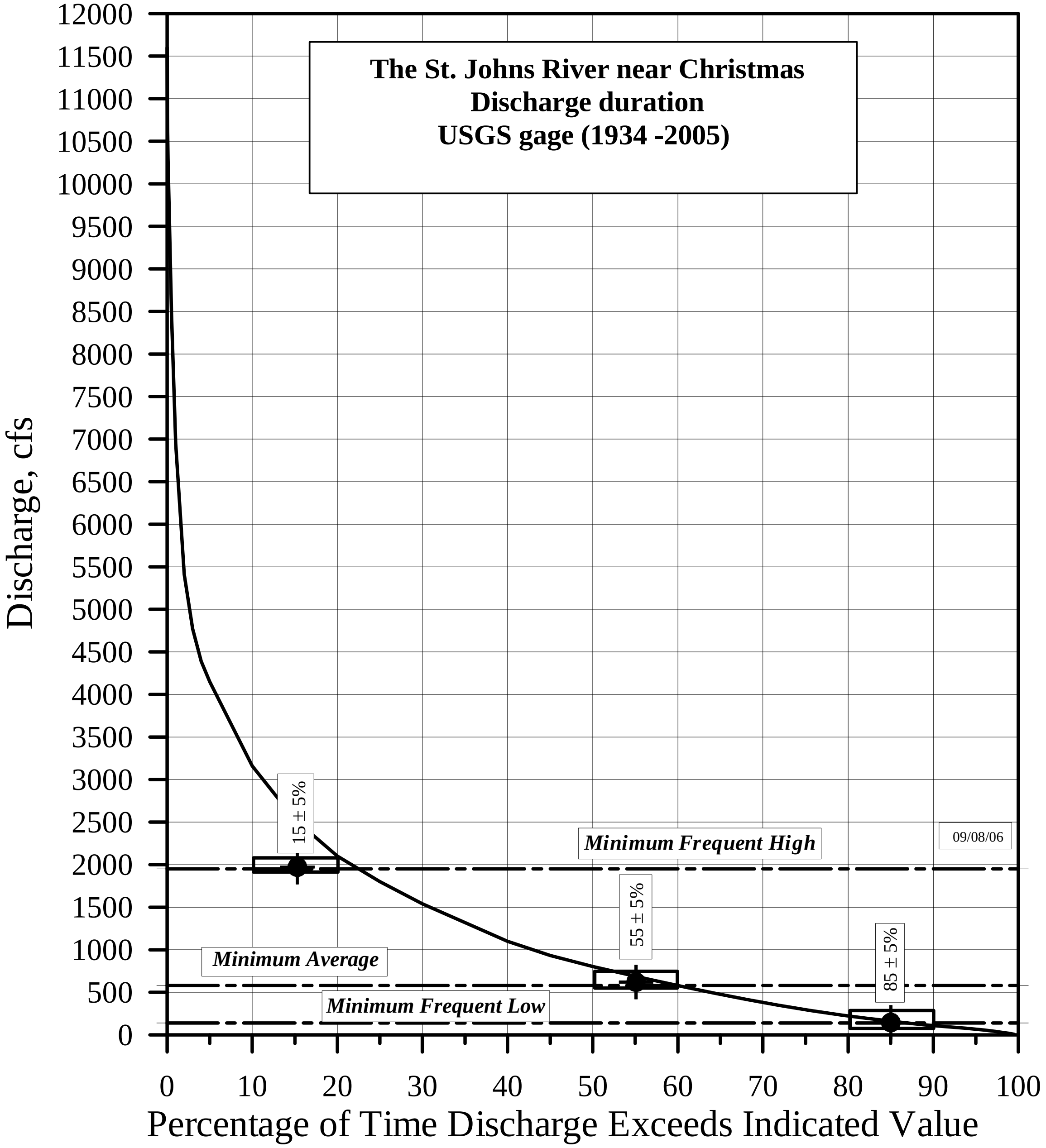

Figure I – 1. Flow duration

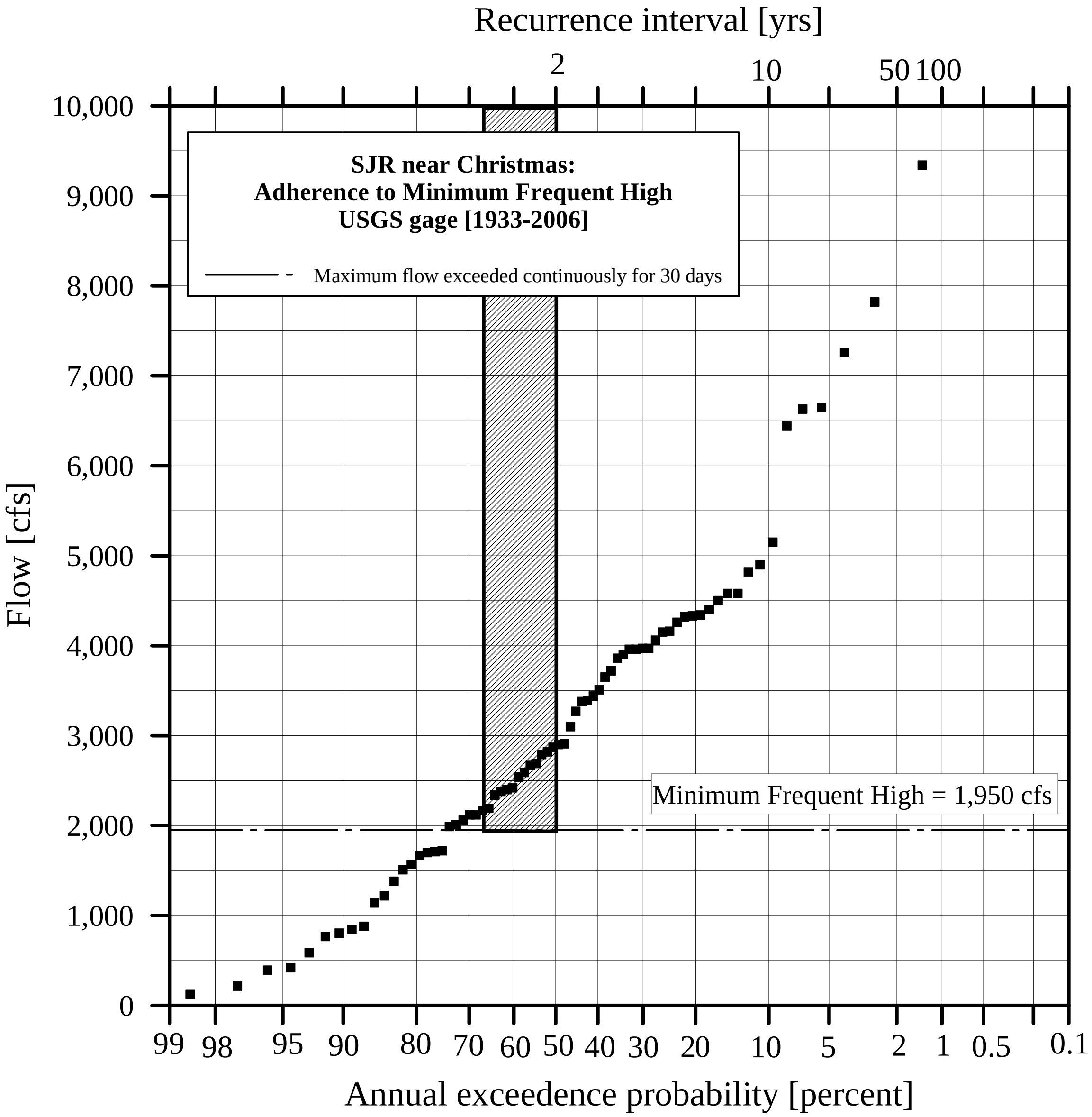

Figure I – 2. MFLs evaluation for the Minimum Frequent High discharge

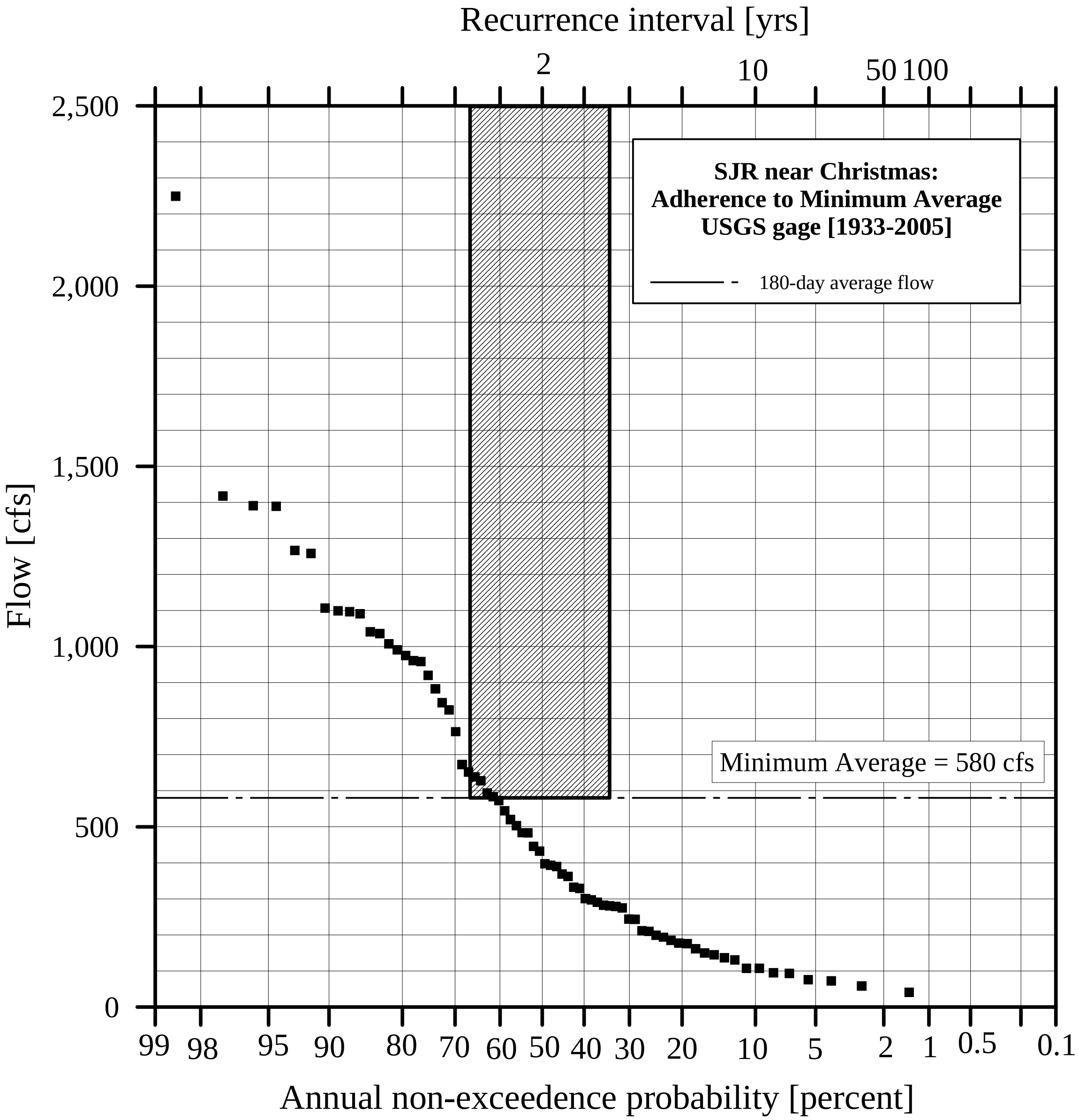

Figure I – 3. MFLs evaluation for the Minimum Average discharge

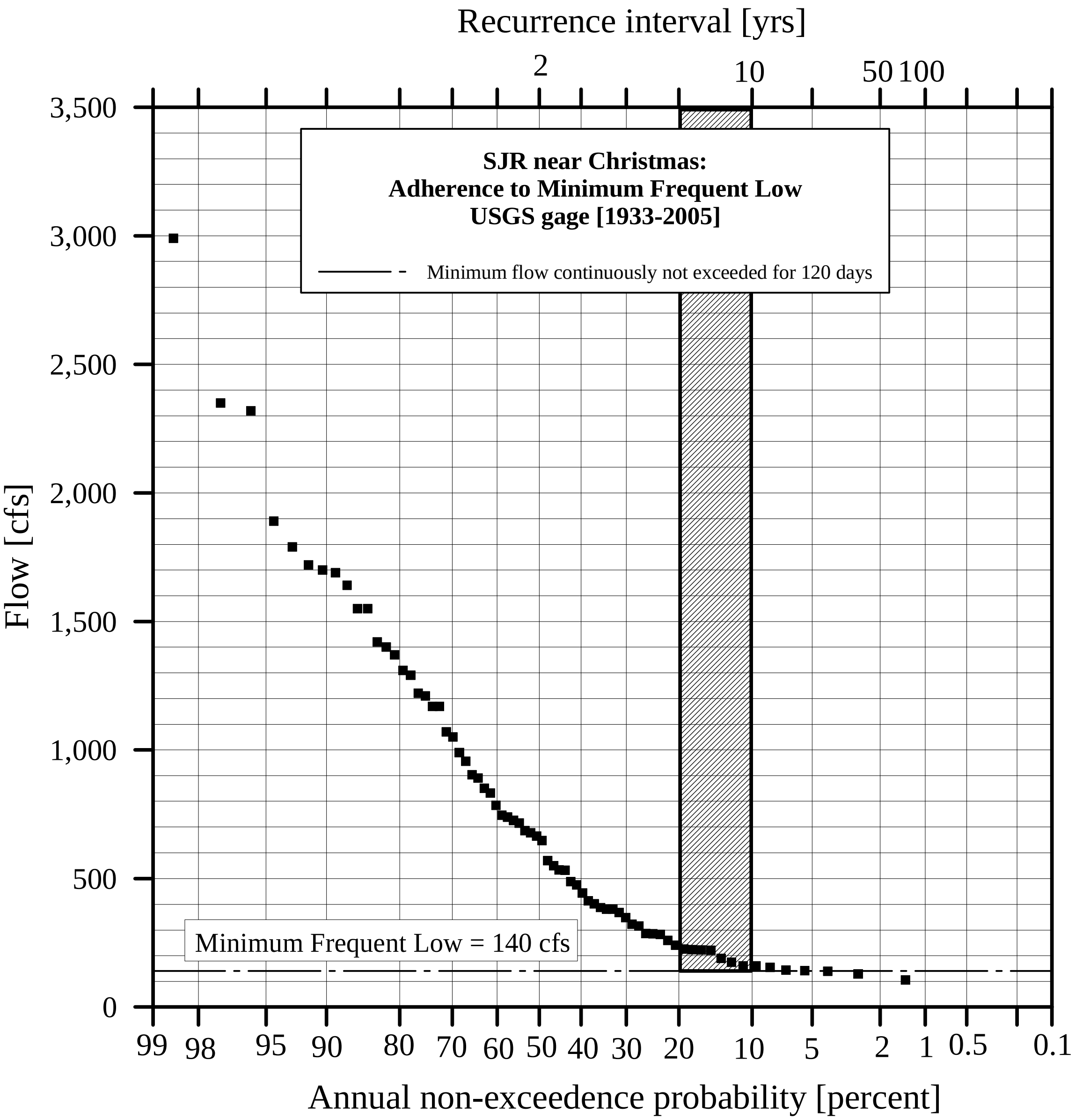

Figure I – 4. MFLs evaluation for the Minimum Frequent Low discharge

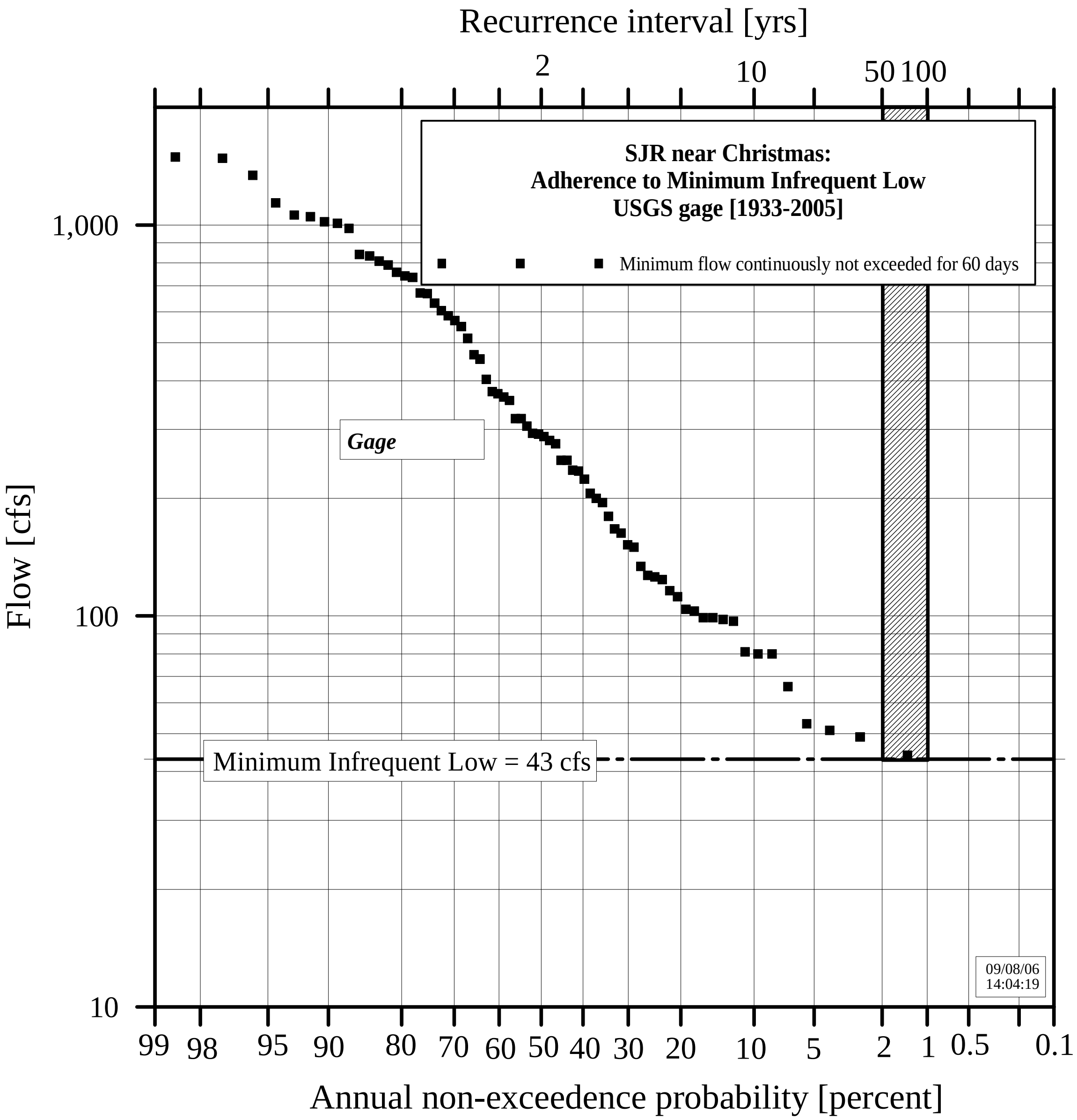

Figure I – 5. MFLs evaluation for the Minimum Infrequent Low discharge

APPENDIX II

MFLs graphs for the St. Johns River at the SR 50 Bridge
1933-2005 USGS Stages

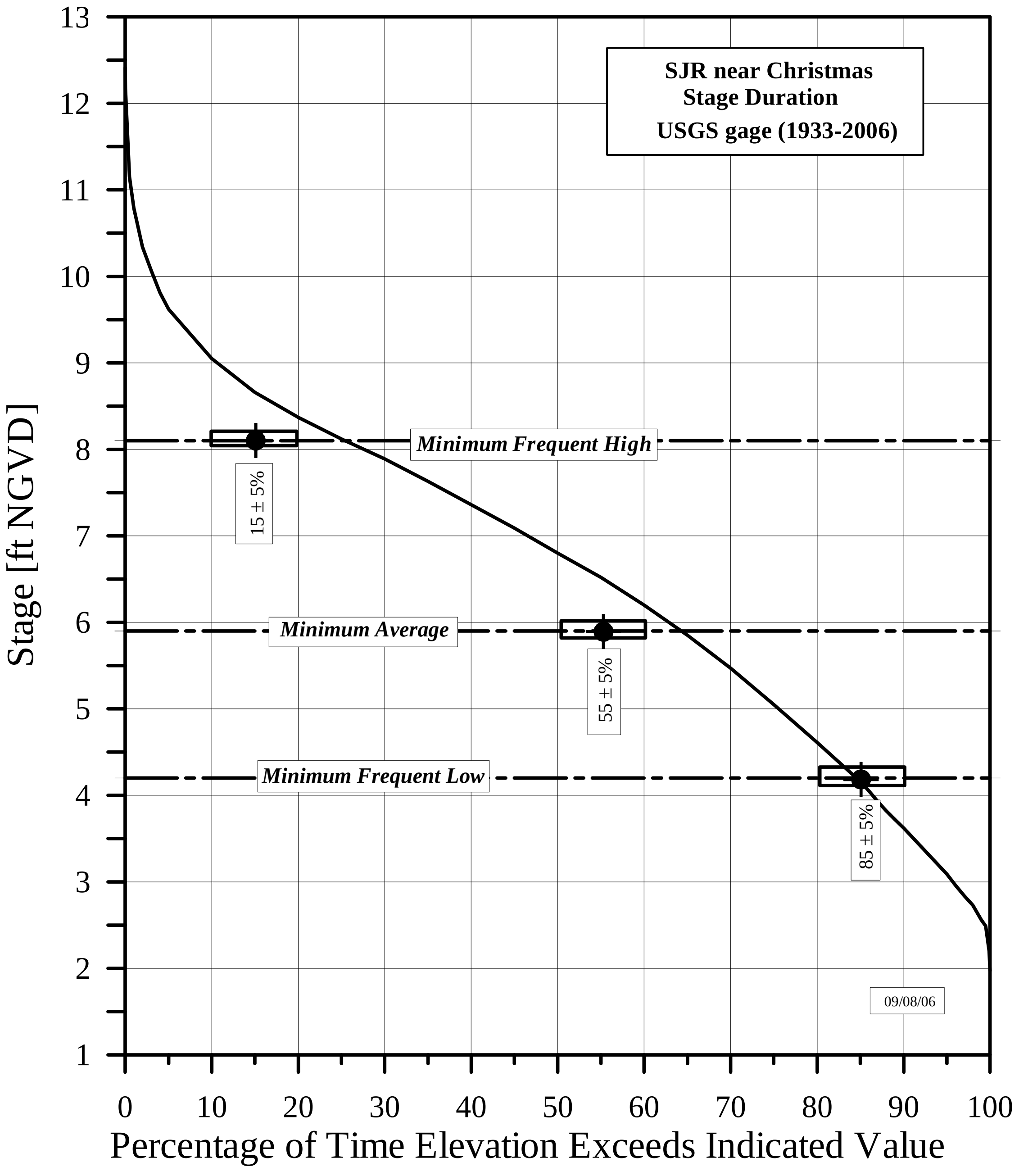

Figure II – 1. Stage duration

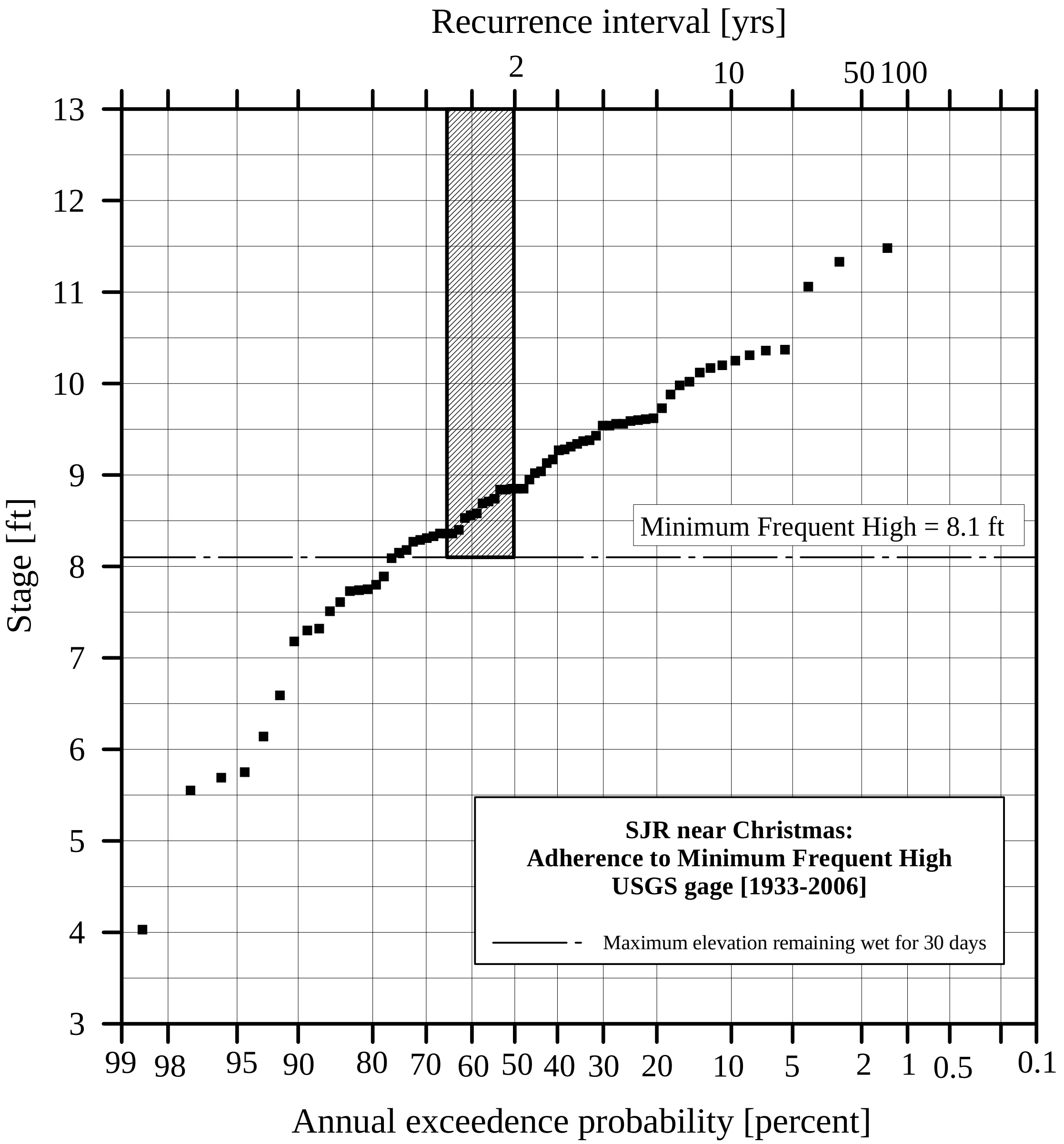

Figure II – 2. MFLs evaluation for the Minimum Frequent High level

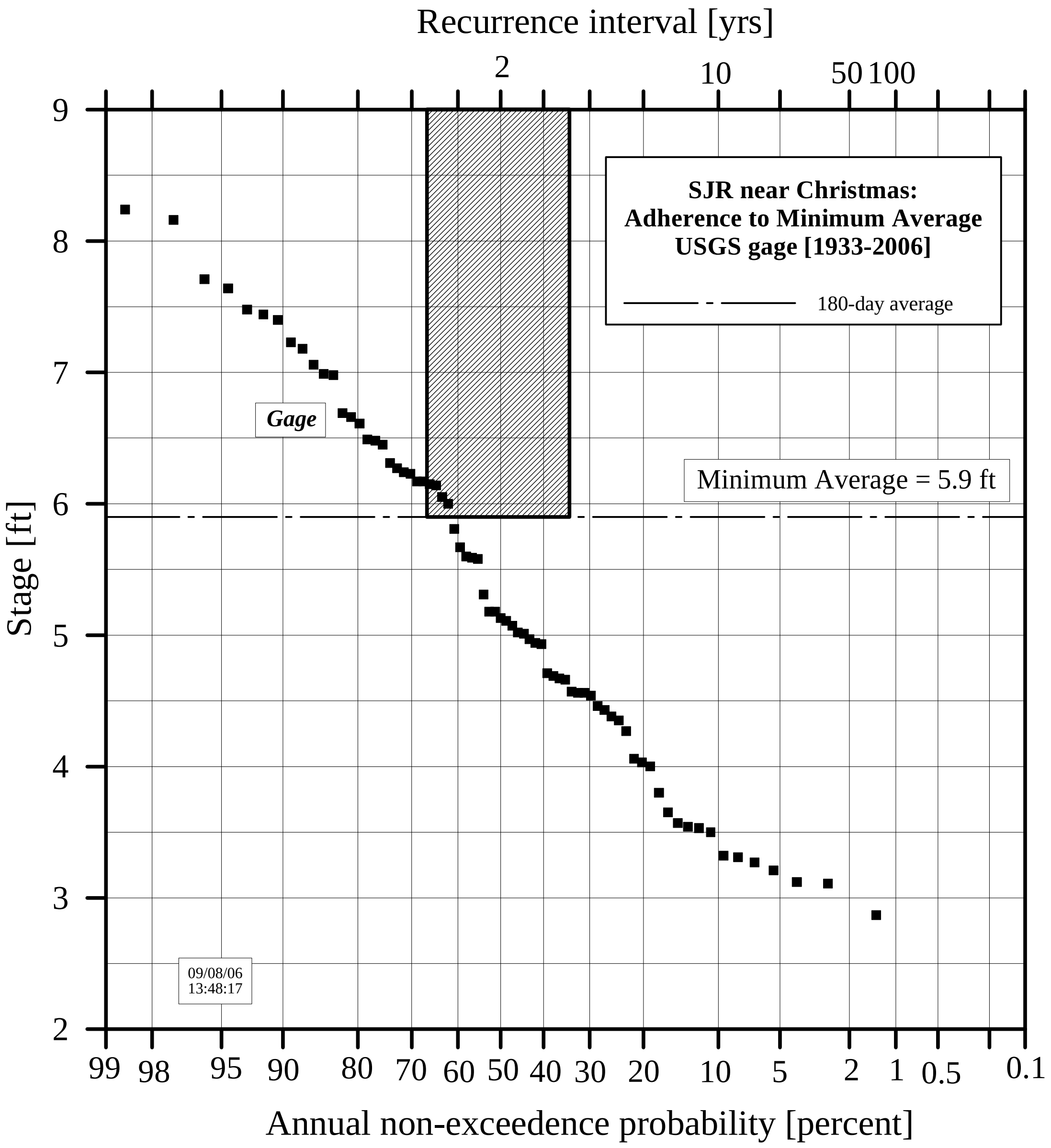

Figure II – 3. MFLs evaluation for the Minimum Average level

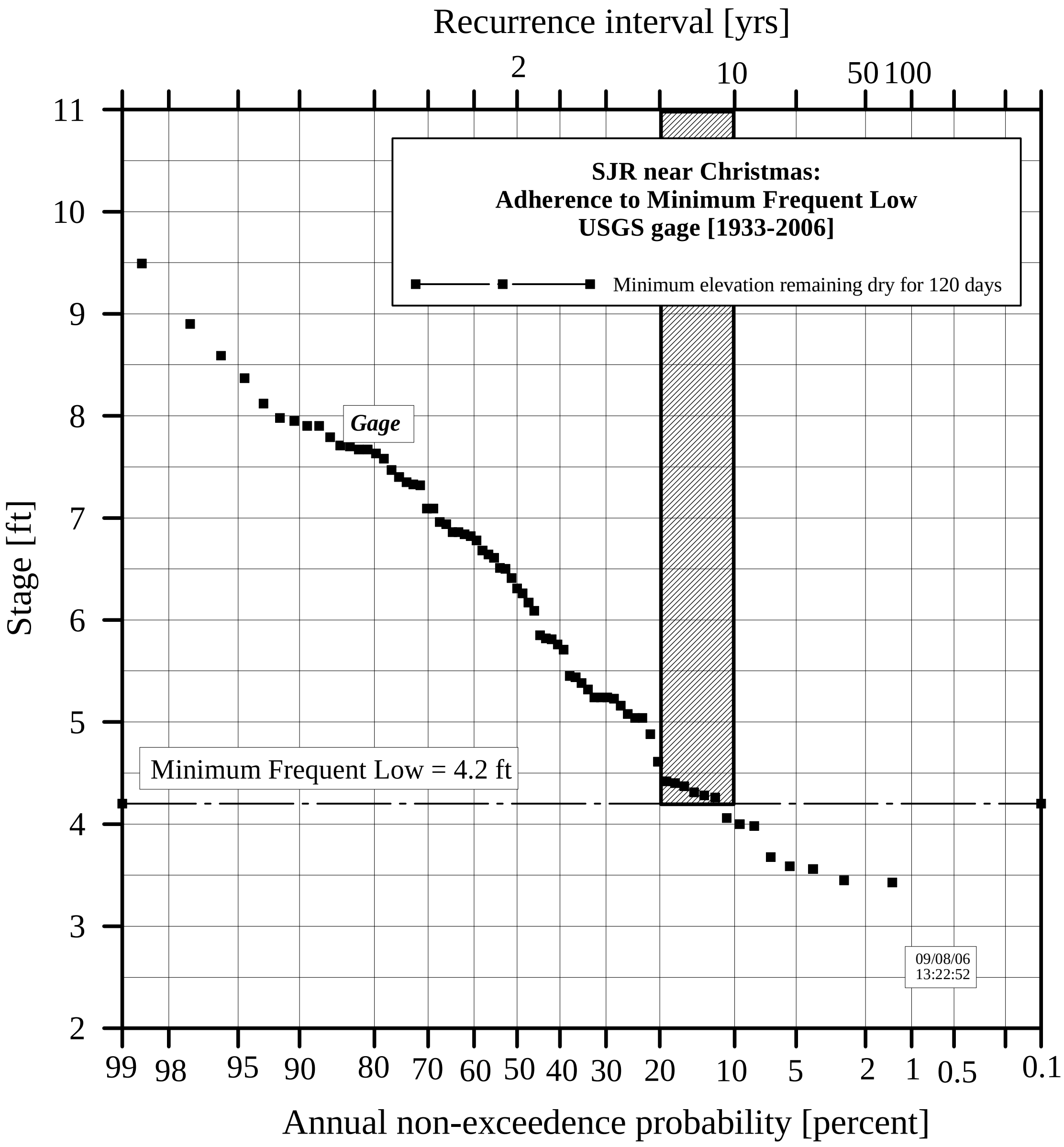

Figure II – 4. MFLs evaluation for the Minimum Frequent Low level

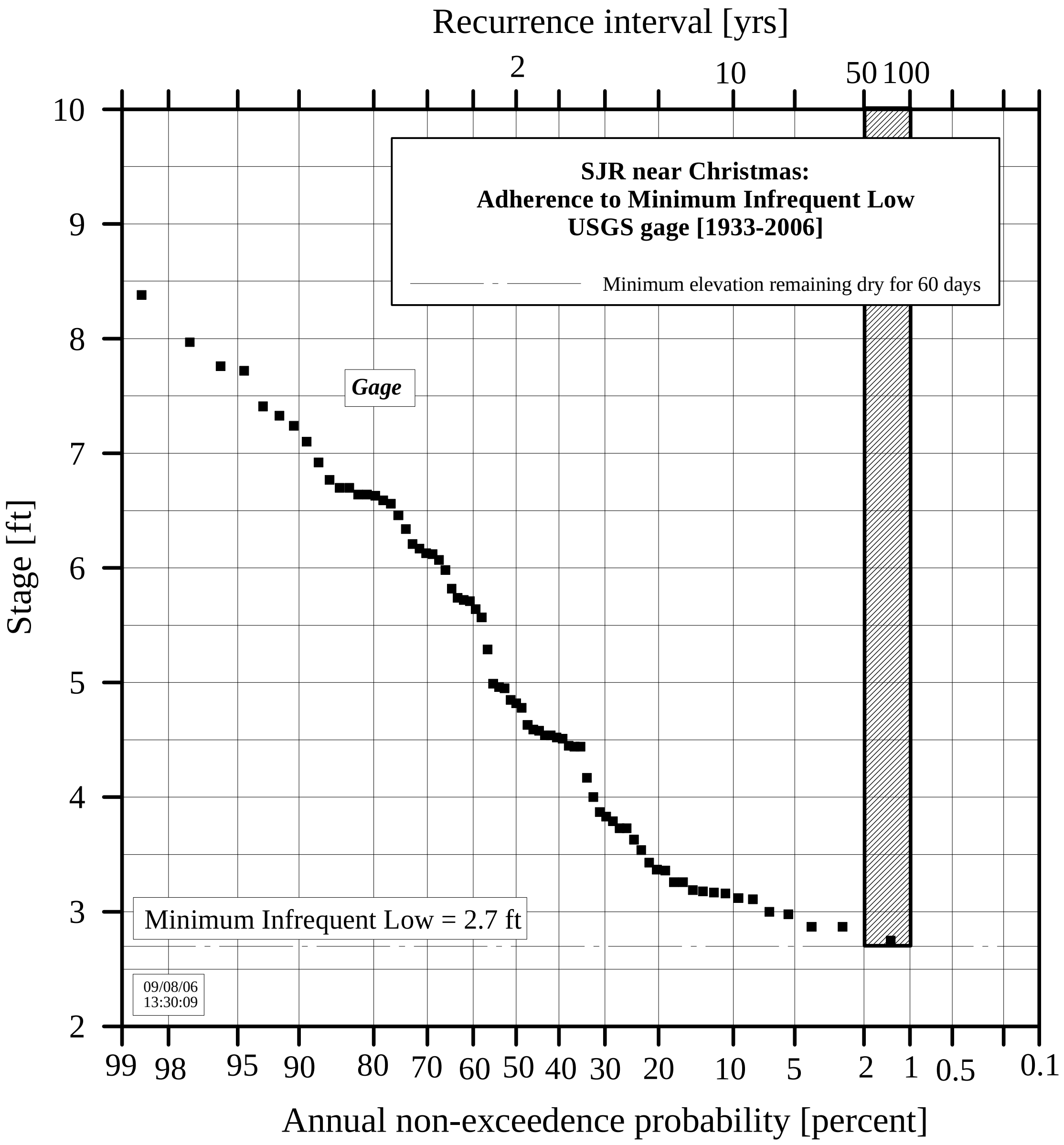

Figure II – 5. MFLs evaluation for the Minimum Infrequent Low level

APPENDIX III

MFLs analysis to determine absolute Minimum River Flow
1933-2006 USGS Discharges

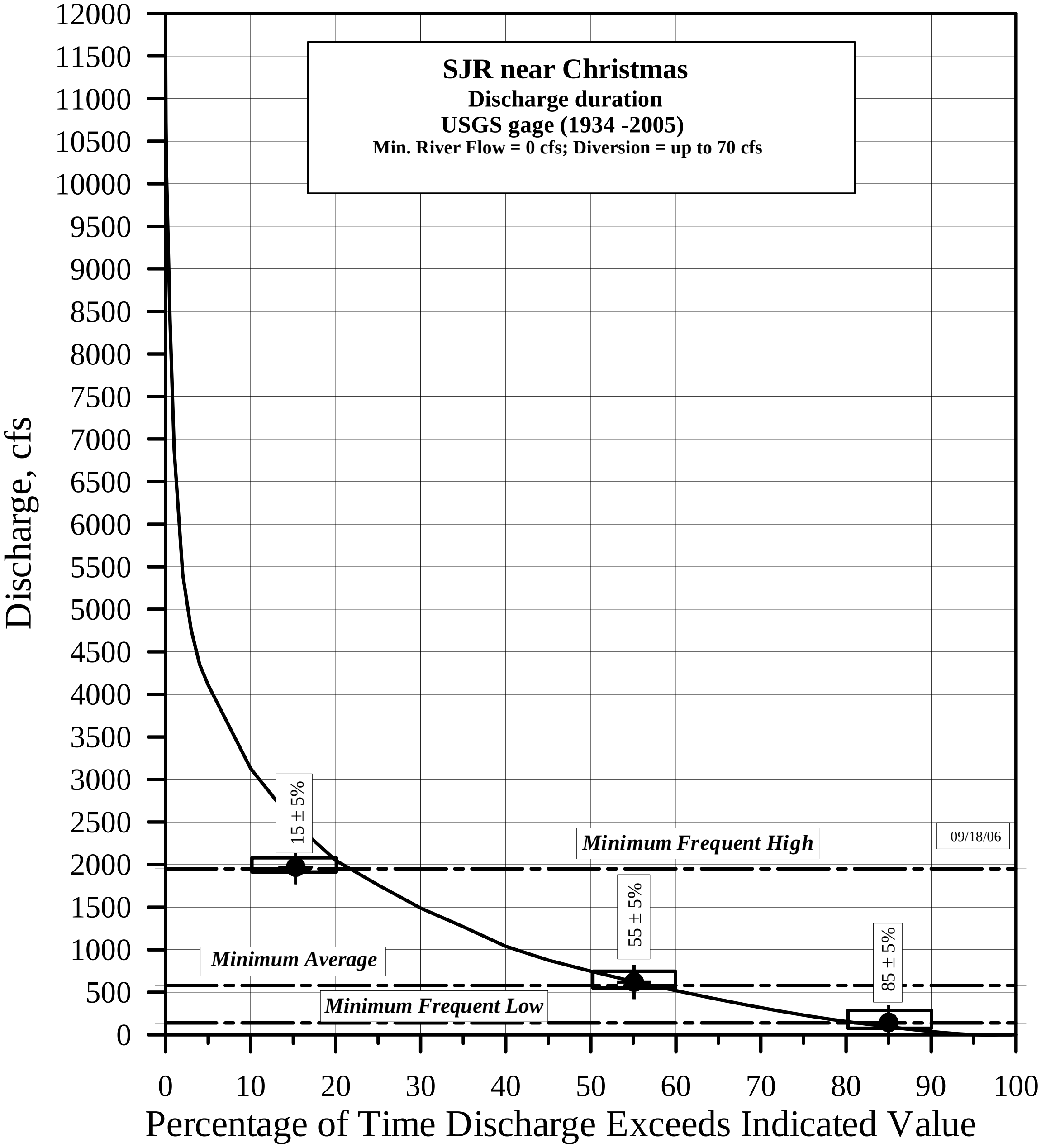

Figure III – 1. Flow duration

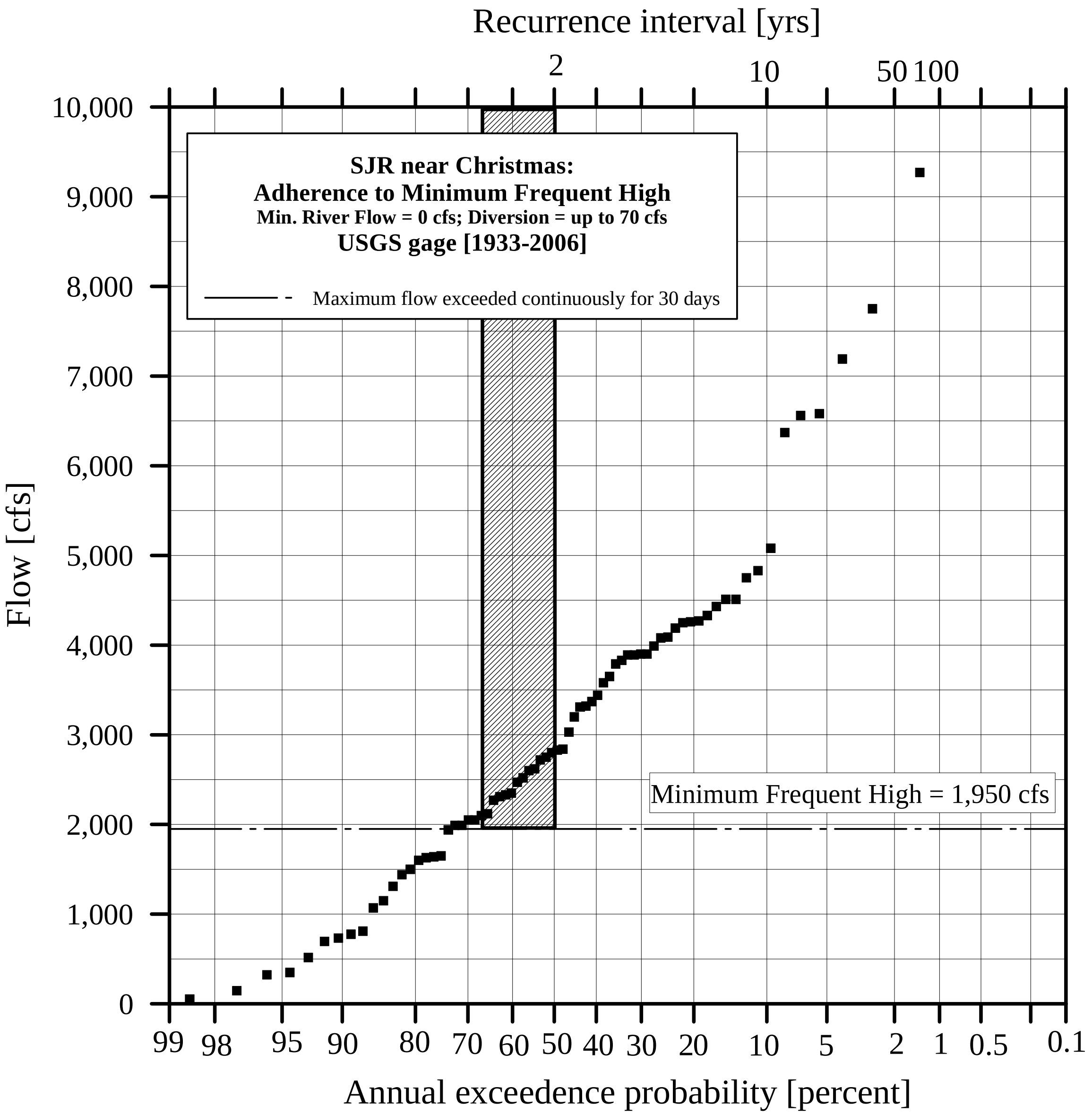

Figure III – 2. MFLs evaluation for the Minimum Frequent High discharge

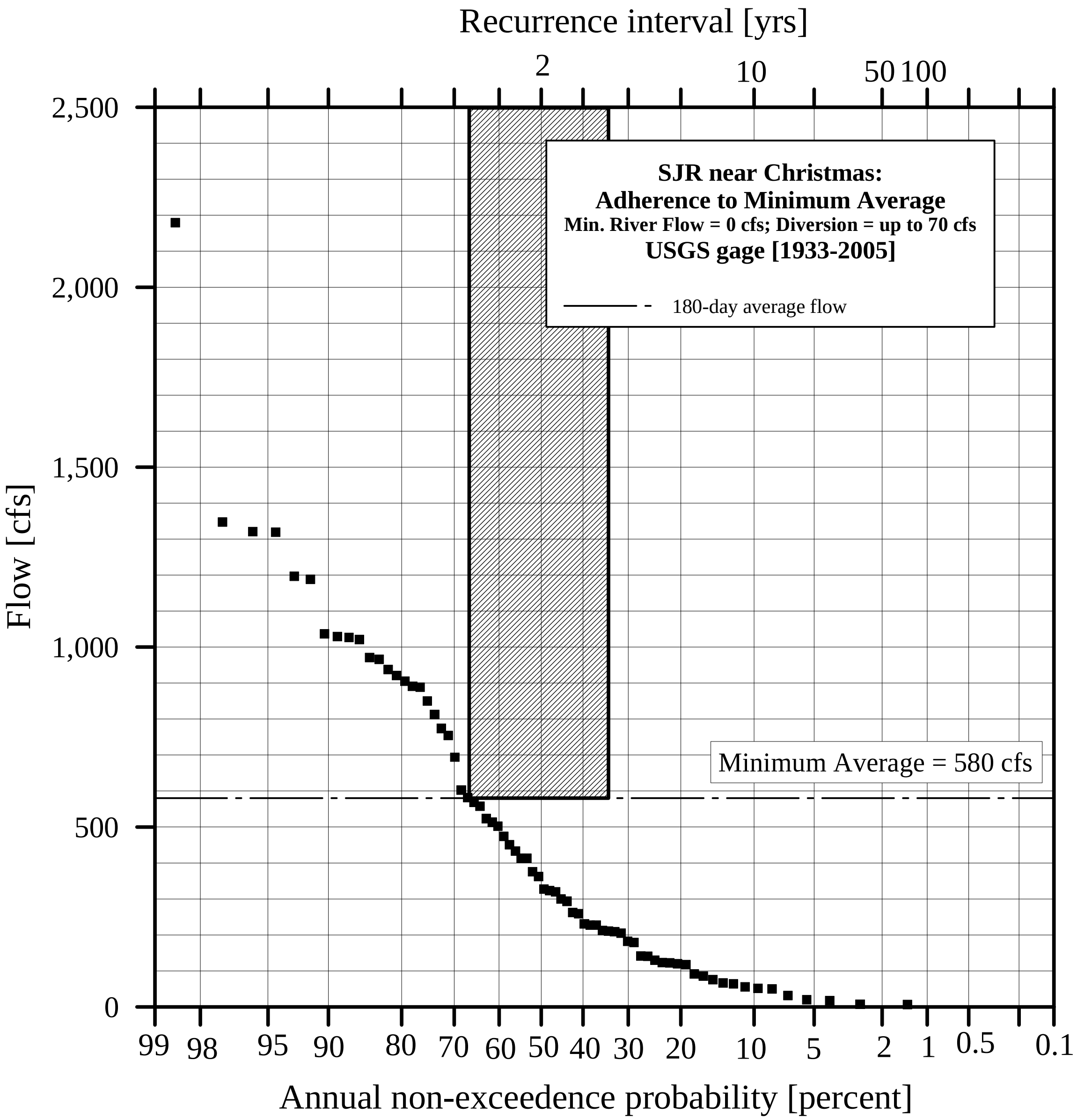

Figure III – 3. MFLs evaluation for the Minimum Average discharge

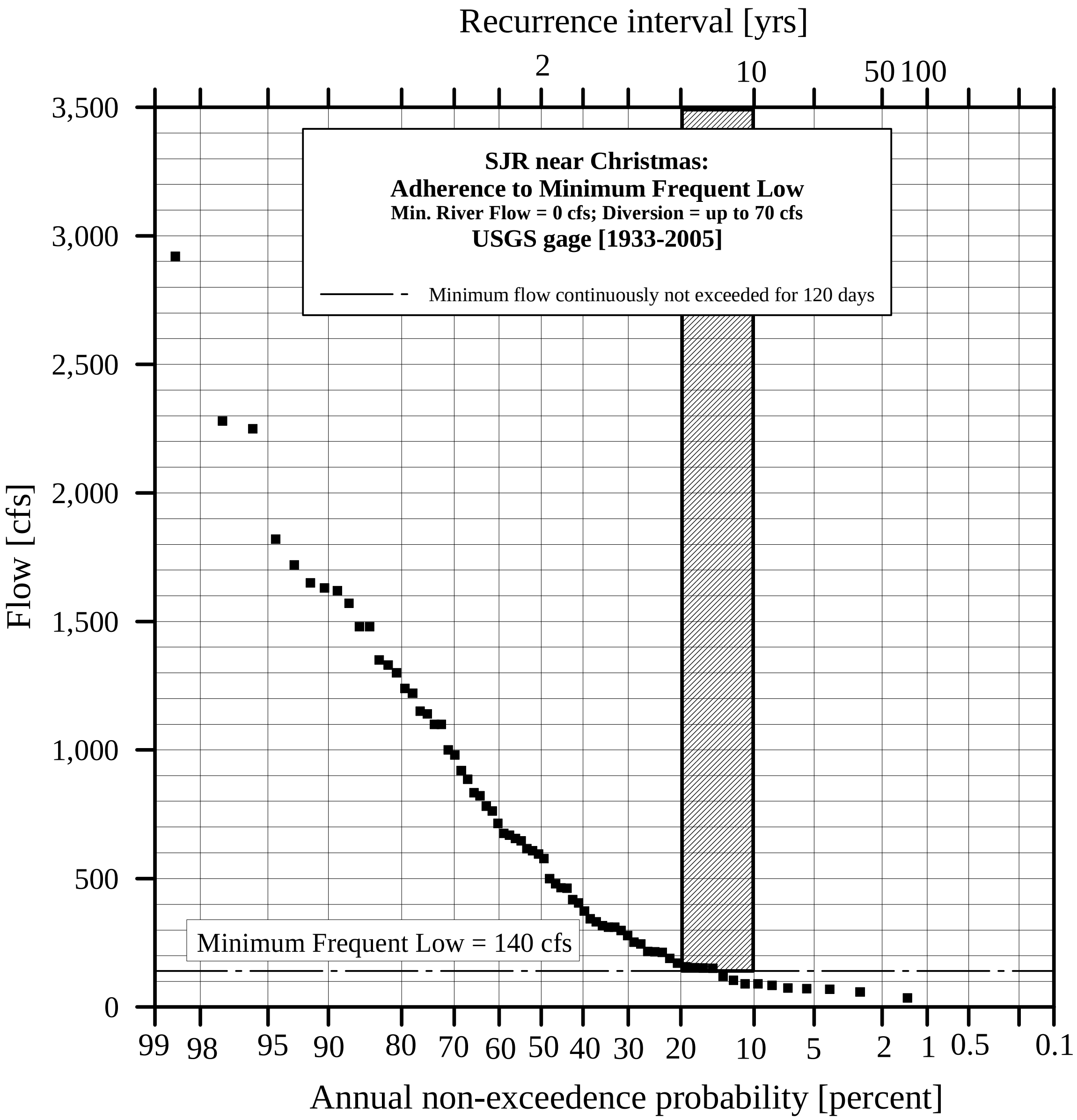

Figure III – 4. MFLs evaluation for the Minimum Frequent Low discharge

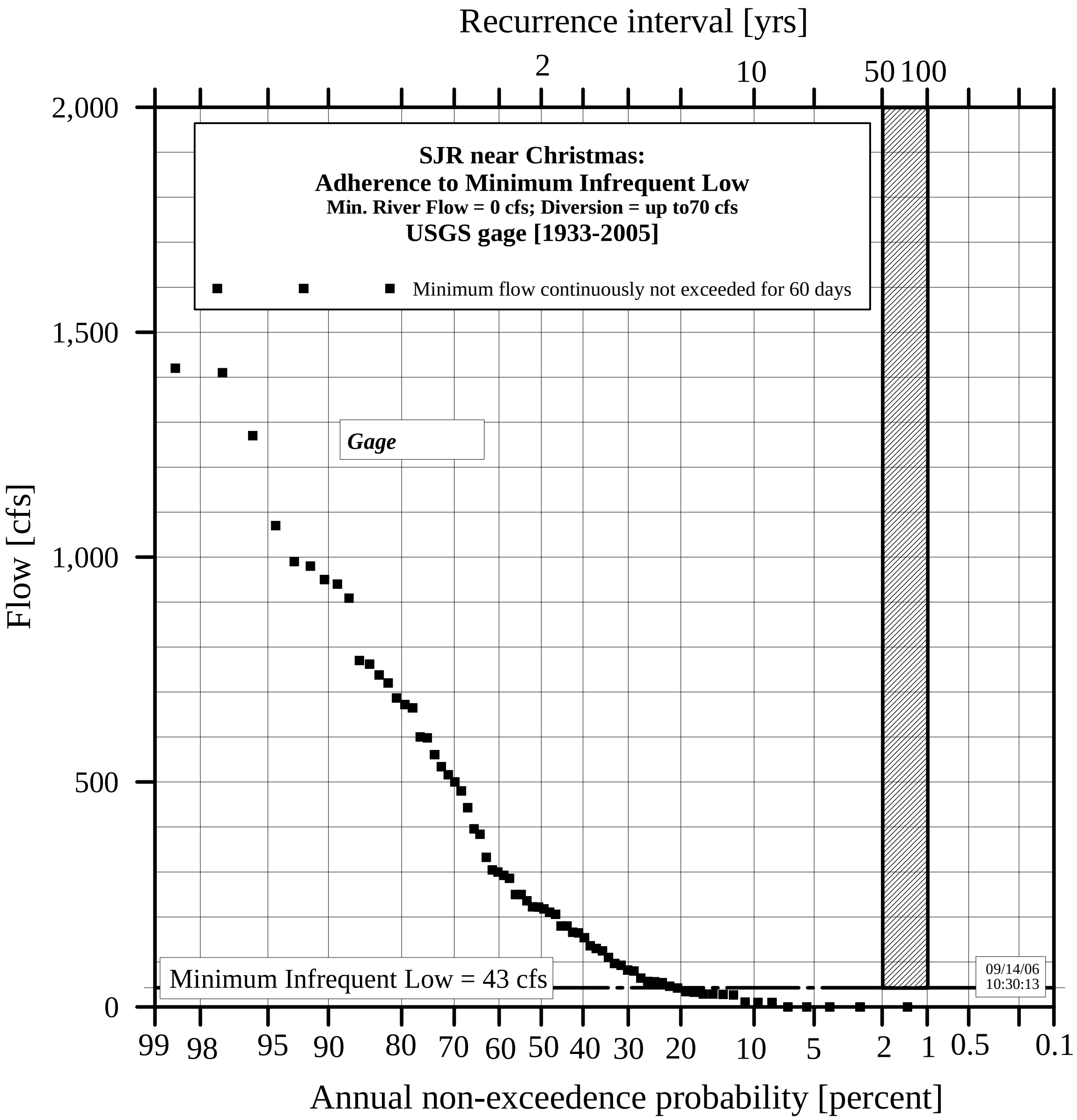

Figure III – 5. MFLs evaluation for the Minimum Infrequent Low discharge (MRF = 0 cfs)

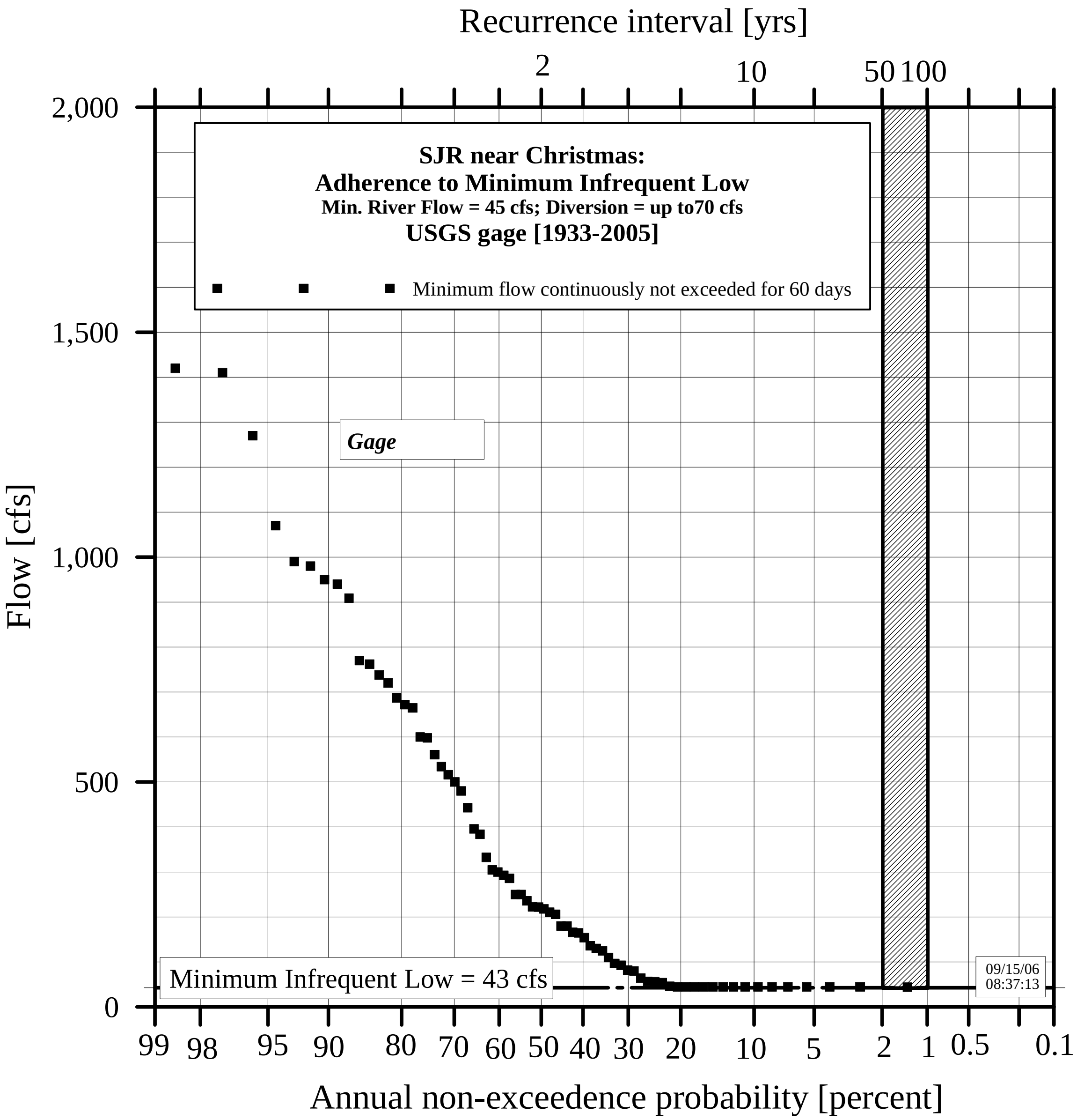

Figure III – 6. MFLs evaluation for the Minimum Infrequent Low discharge (MRF = 45 cfs)

APPENDIX A5

MFLs analysis for Scenario A5
1933-2006 USGS Discharges

MRF = 300 cfs; DD = 110 cfs

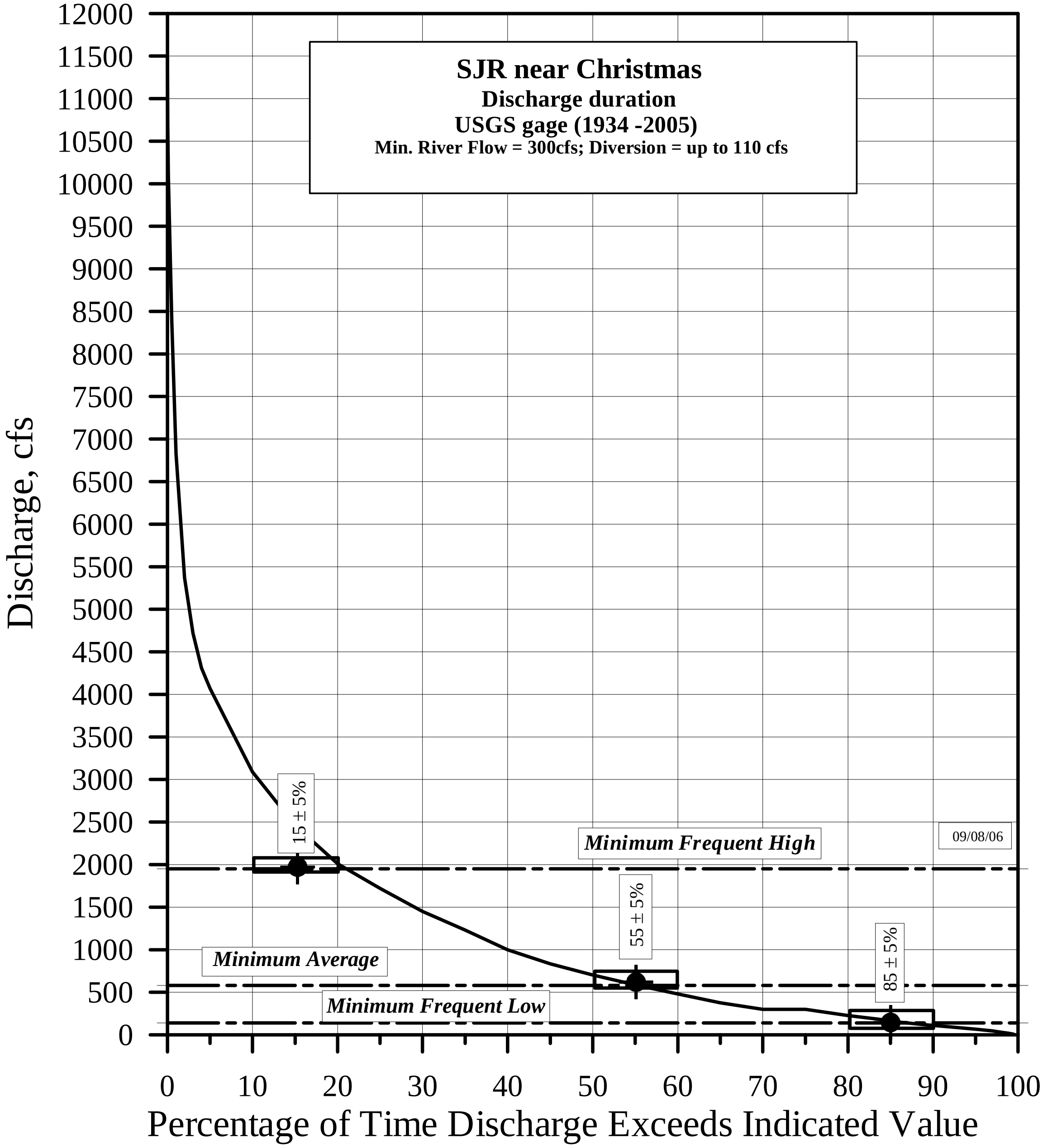

Figure A5 – 1. Flow duration

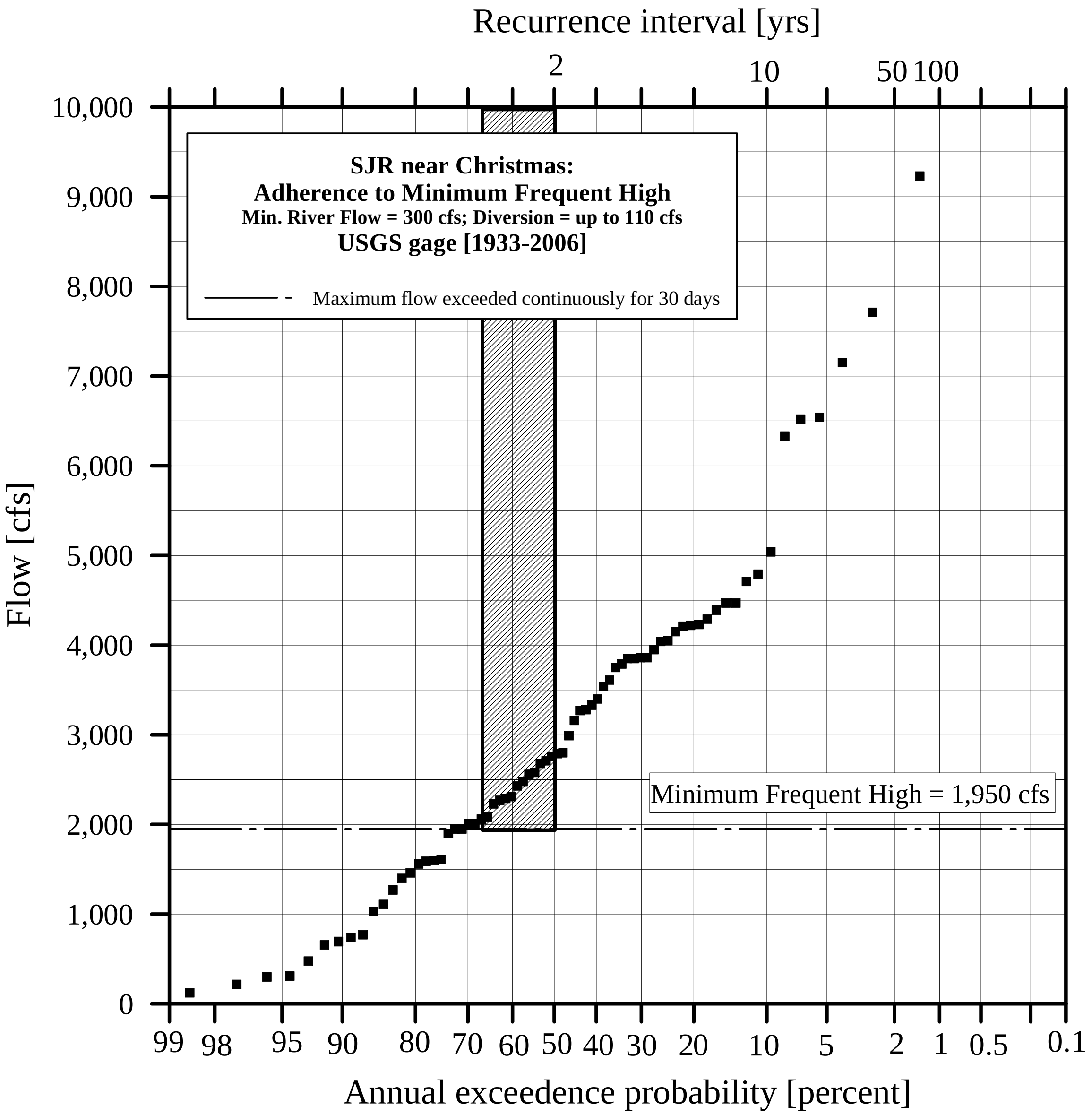

Figure A5 – 2. MFLs evaluation for the Minimum Frequent High discharge

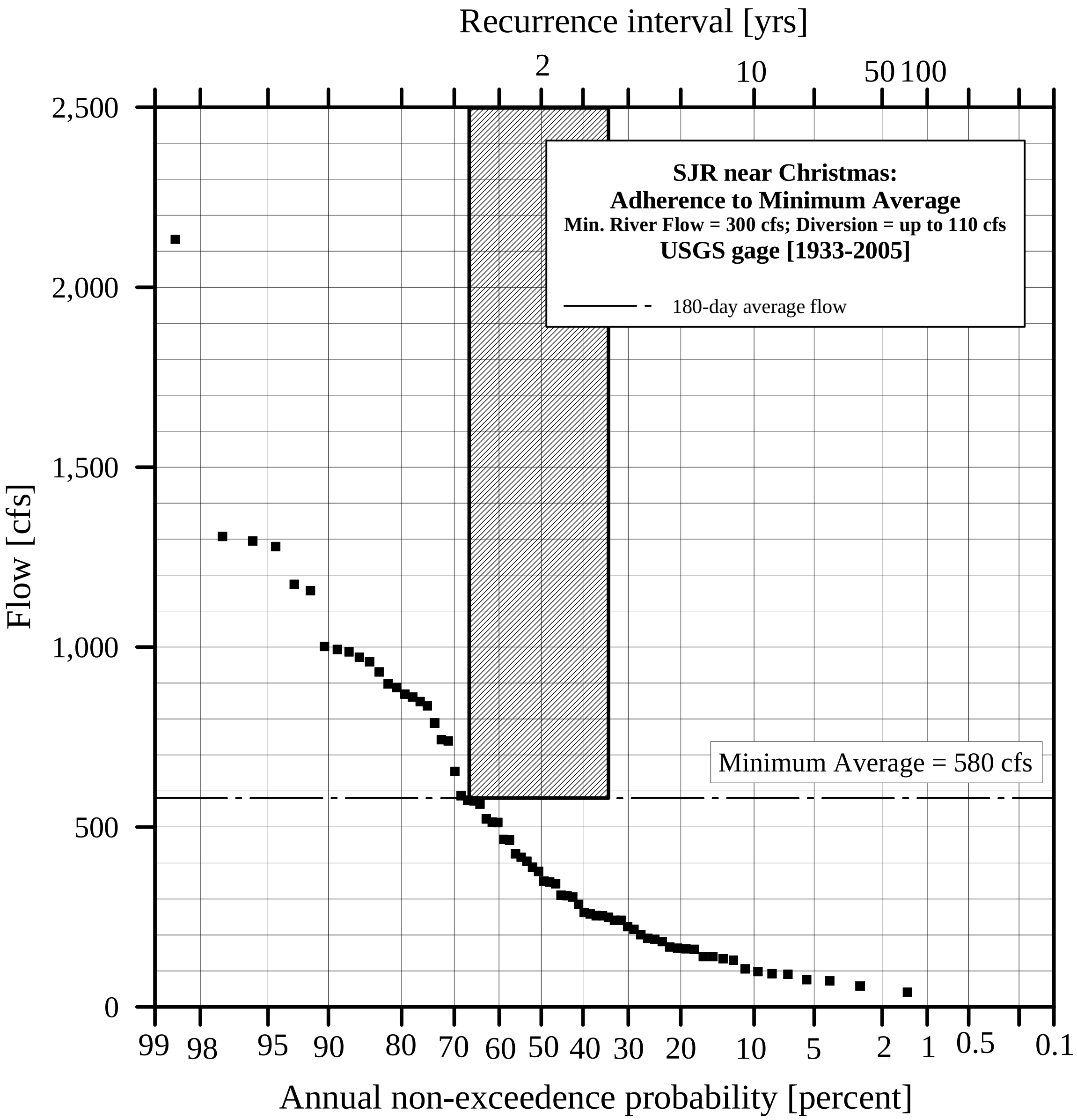

Figure A5 – 3. MFLs evaluation for the Minimum Average discharge

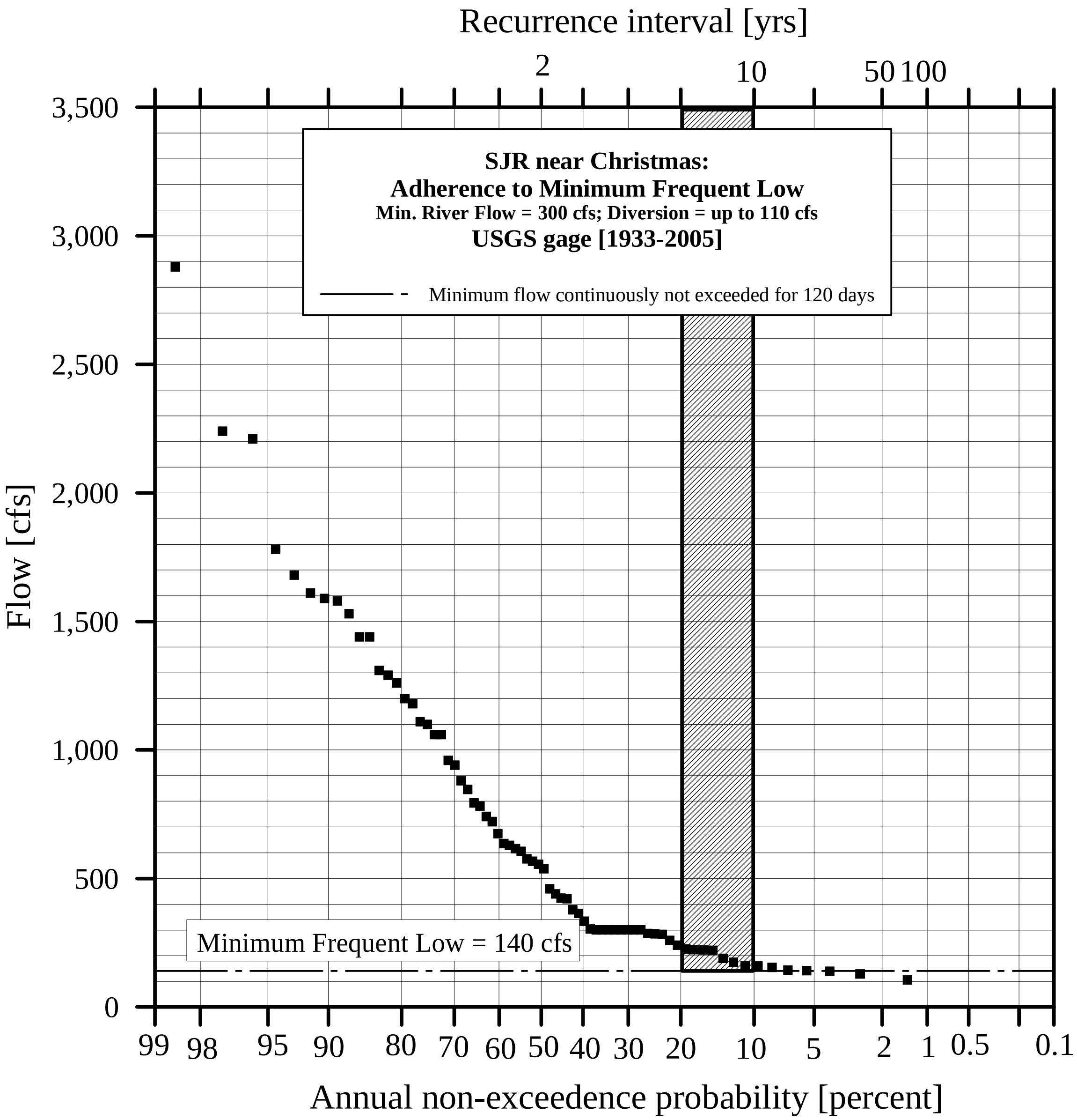

Figure A5 – 4. MFLs evaluation for the Minimum Frequent Low discharge

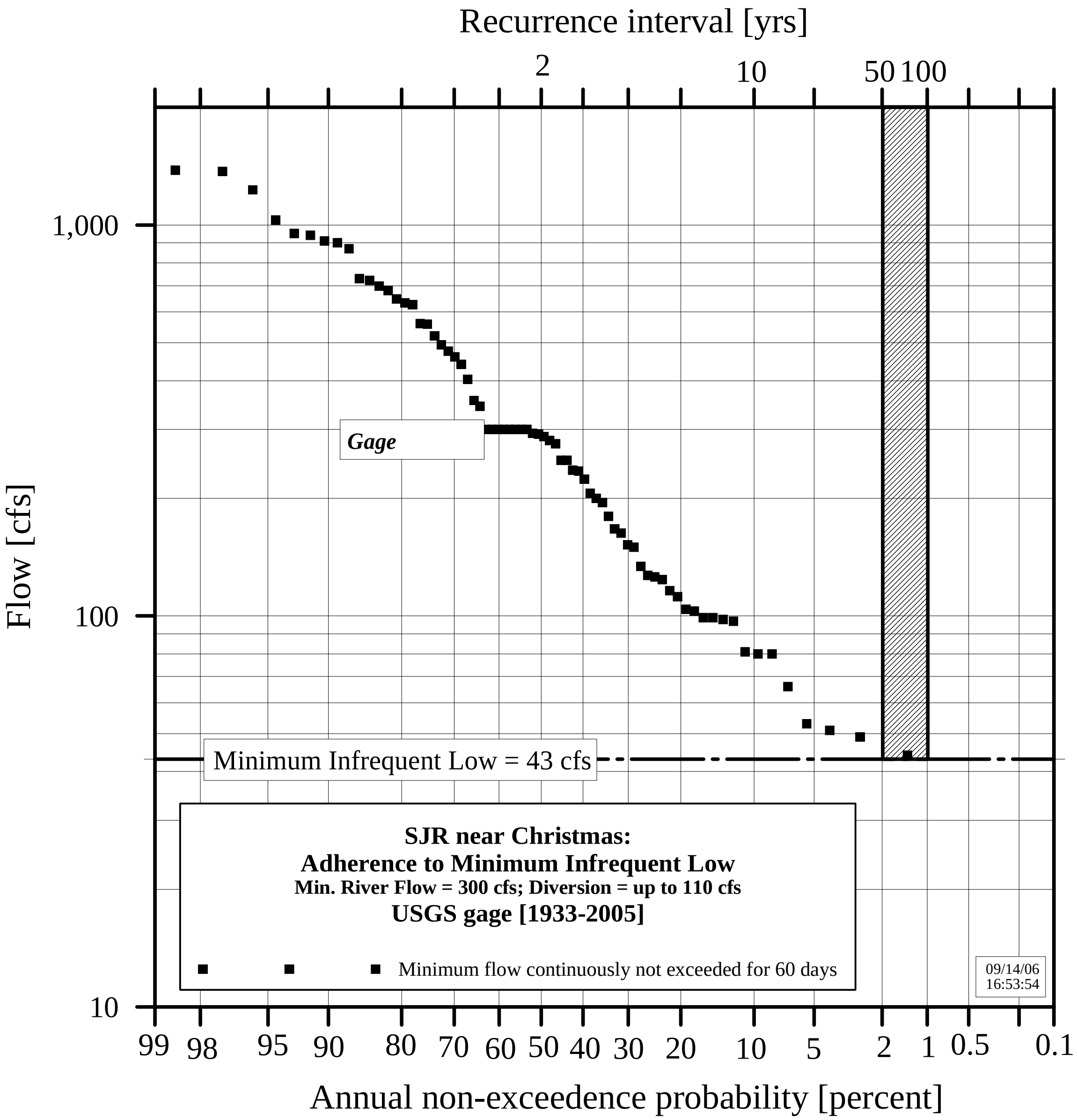

Figure A5 – 5. MFLs evaluation for the Minimum Infrequent Low discharge

APPENDIX A4

MFLs analysis for Scenario A4
1933-2006 USGS Discharges

MRF = 300 cfs; DD = 90 cfs

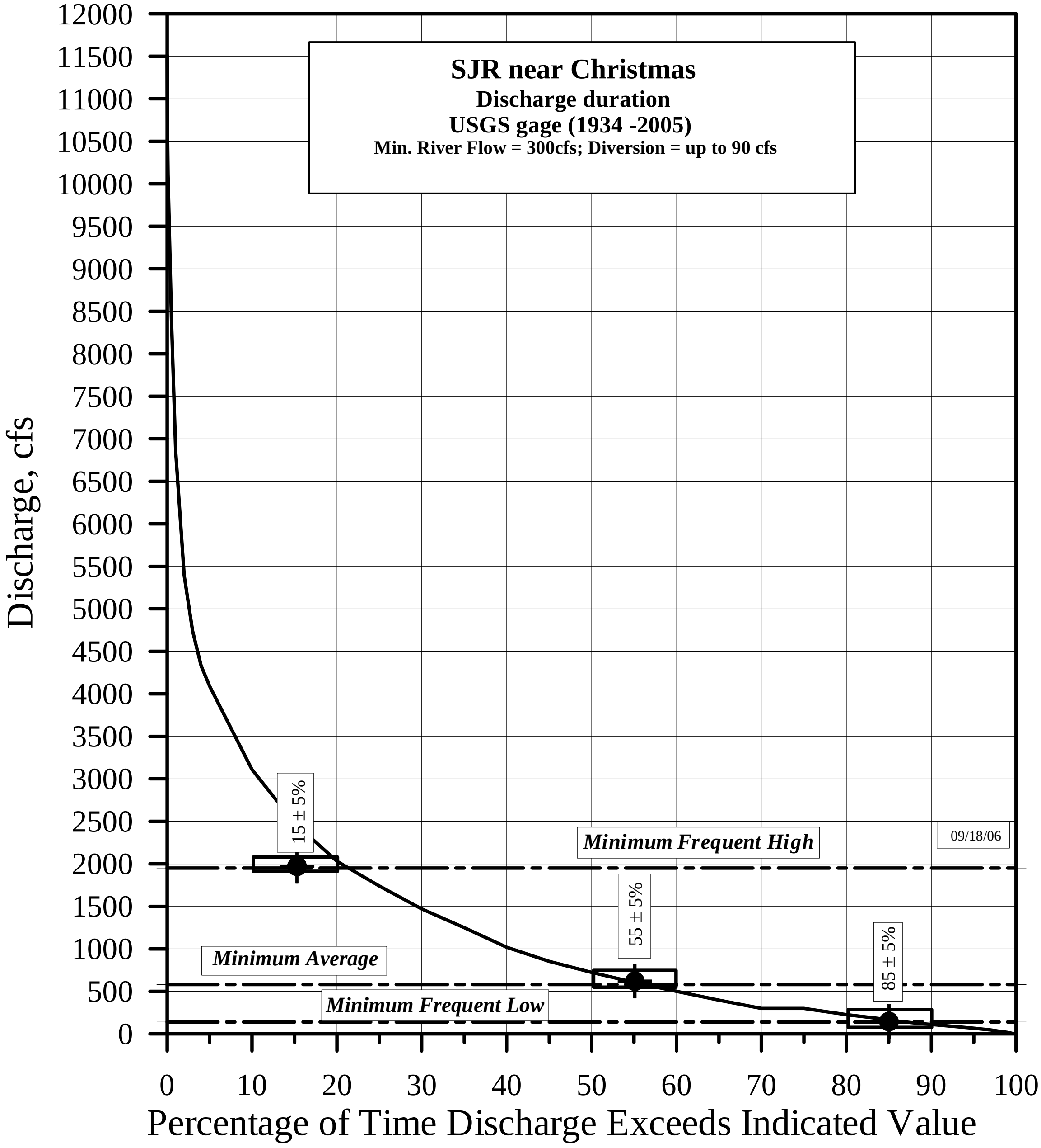

Figure A4 – 1. Flow duration

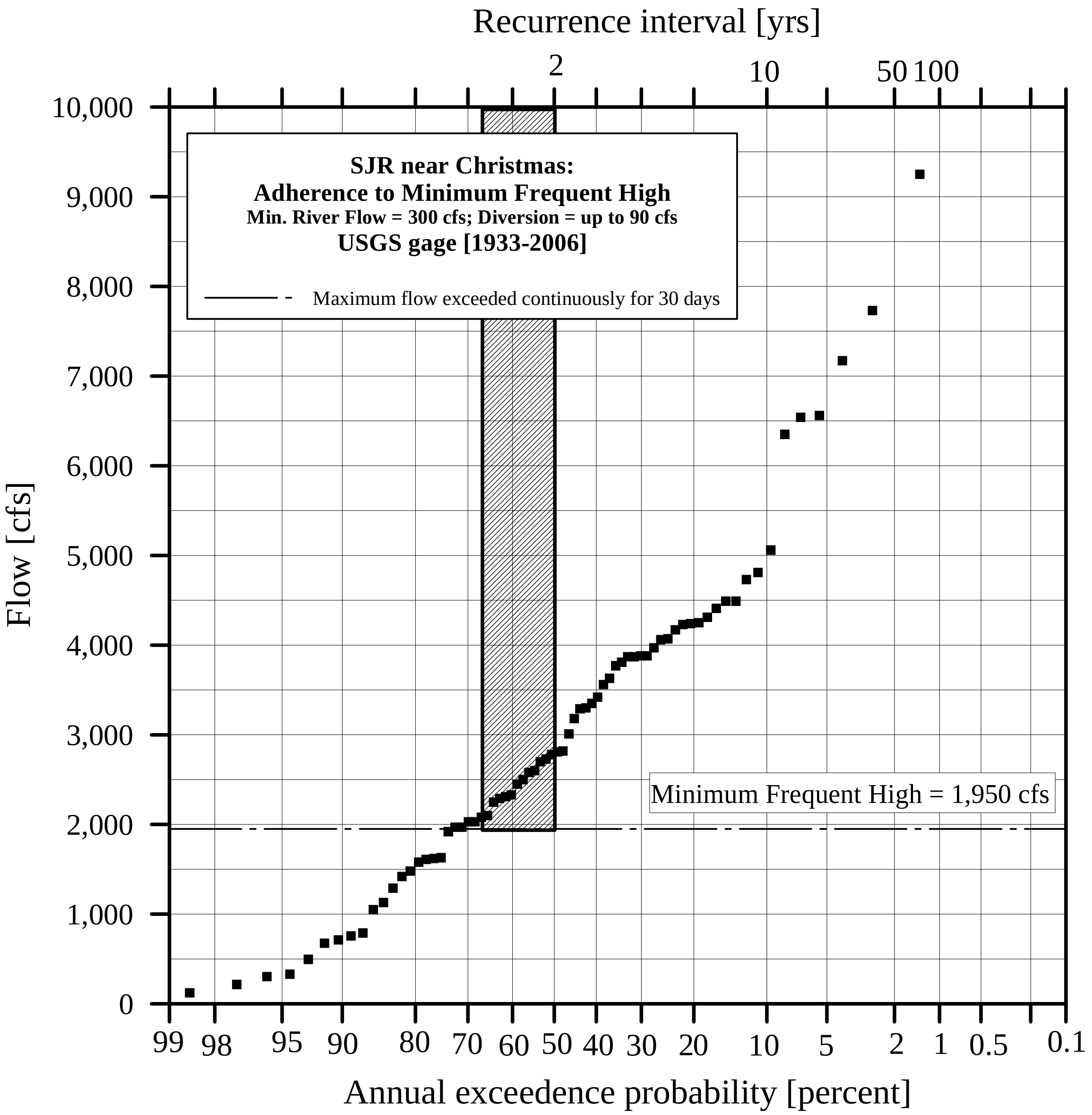

Figure A4 – 2. MFLs evaluation for the Minimum Frequent High discharge

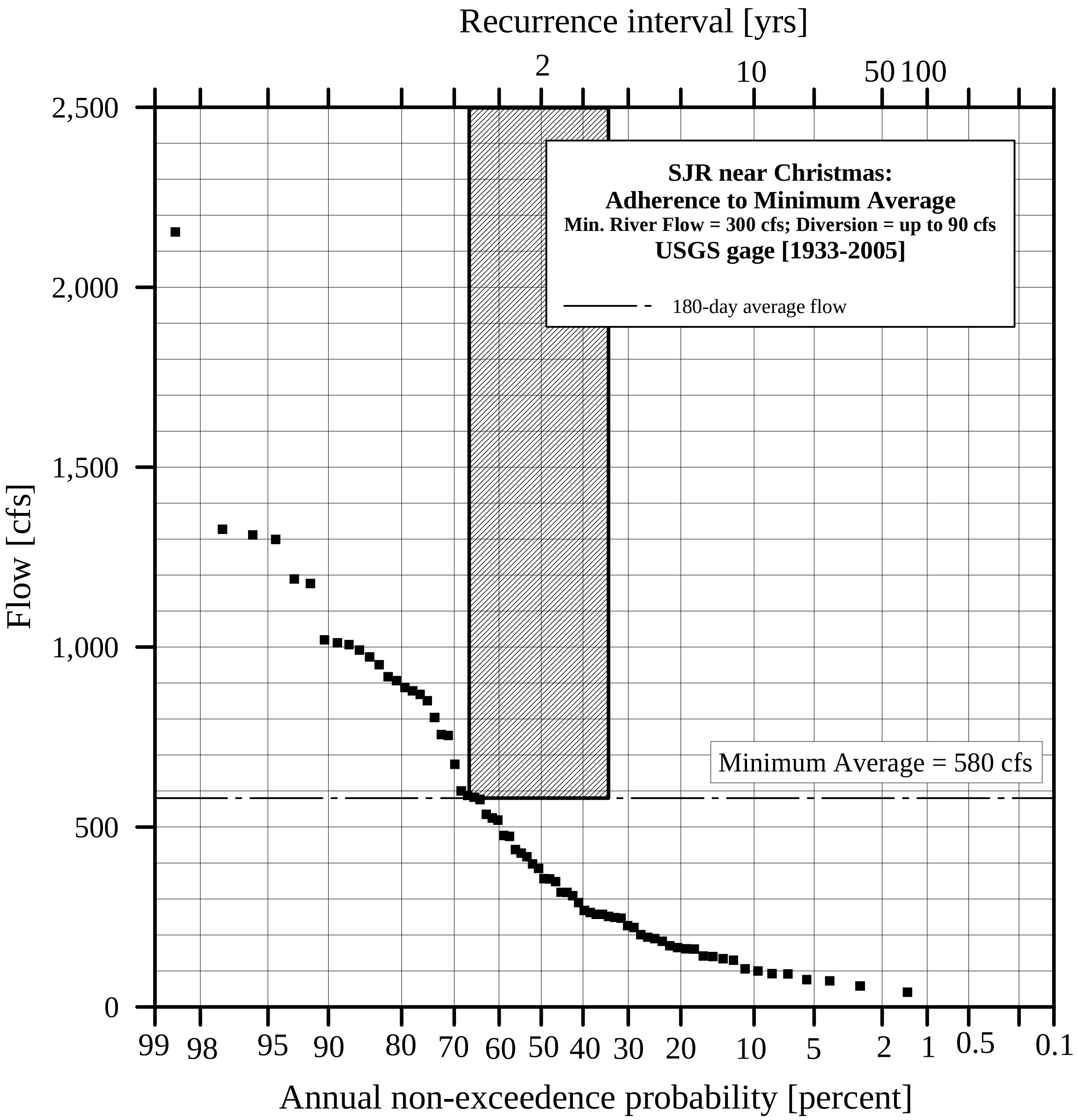

Figure A4 – 3. MFLs evaluation for the Minimum Average discharge

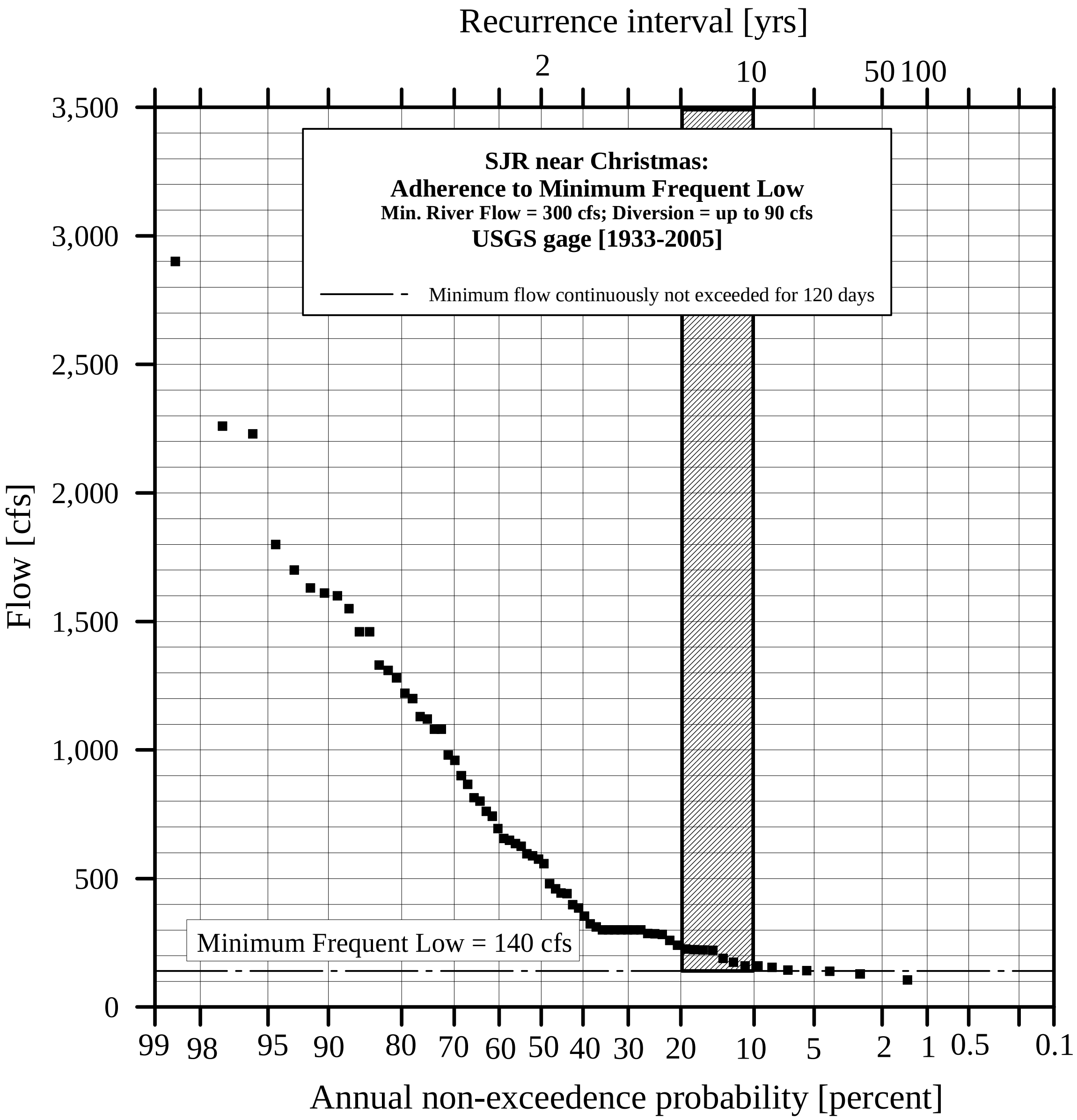

Figure A4 – 4. MFLs evaluation for the Minimum Frequent Low discharge

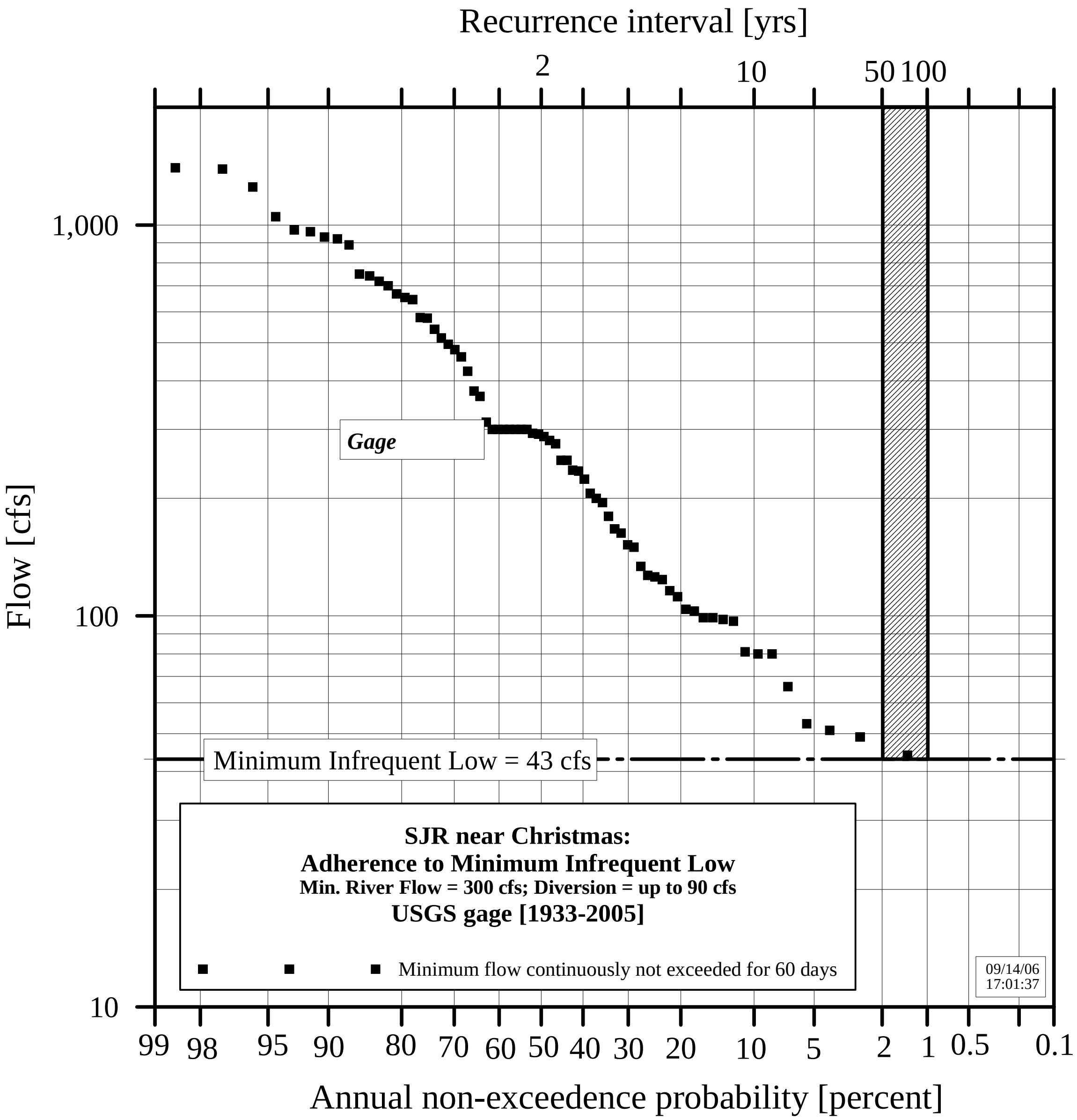

Figure A4 – 5. MFLs evaluation for the Minimum Infrequent Low discharge

APPENDIX B5

MFLs analysis for Scenario B5
1933-2006USGS Discharges

MRF = 200 cfs; DD = 100 cfs

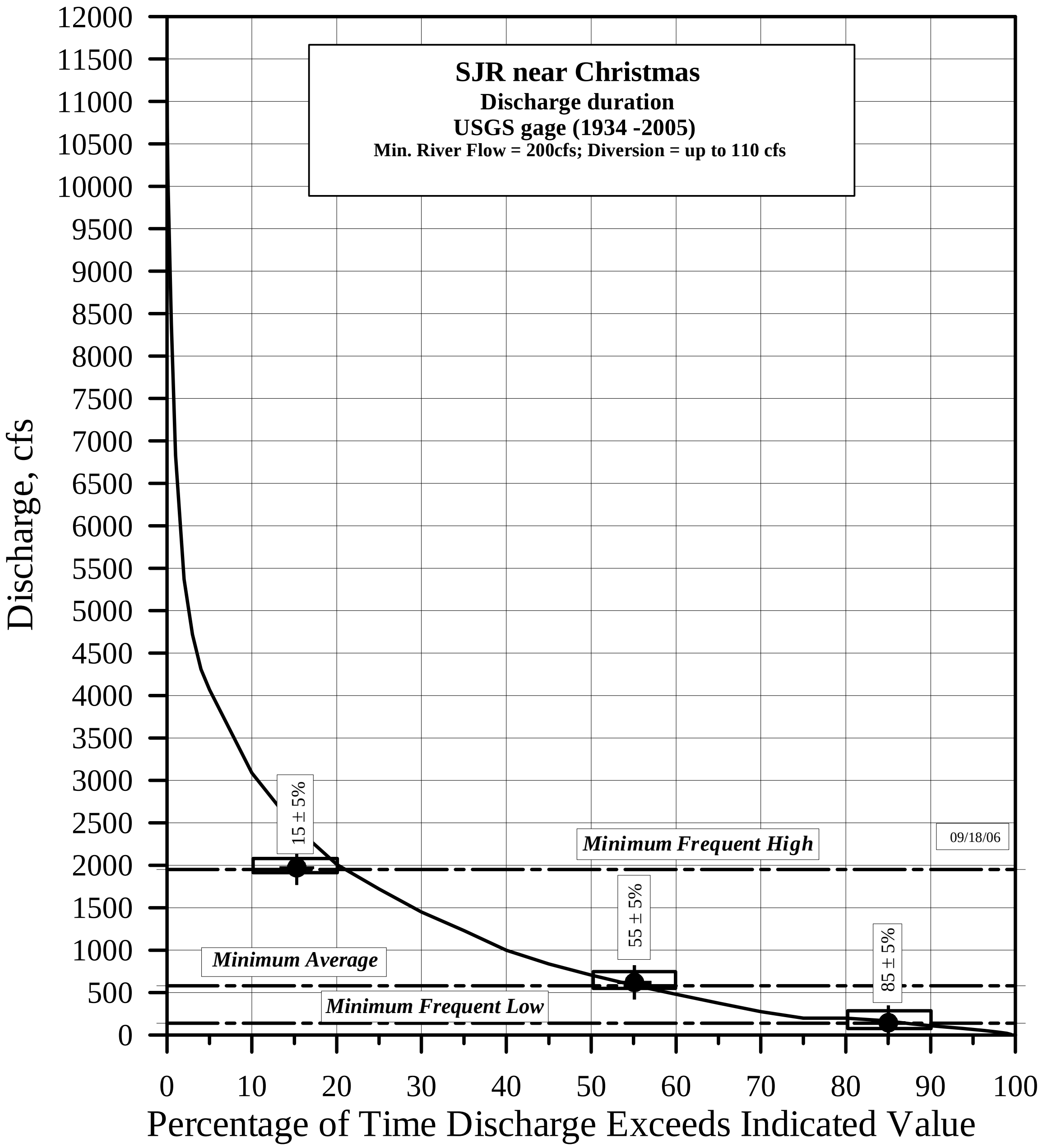

Figure B5 – 1. Flow duration

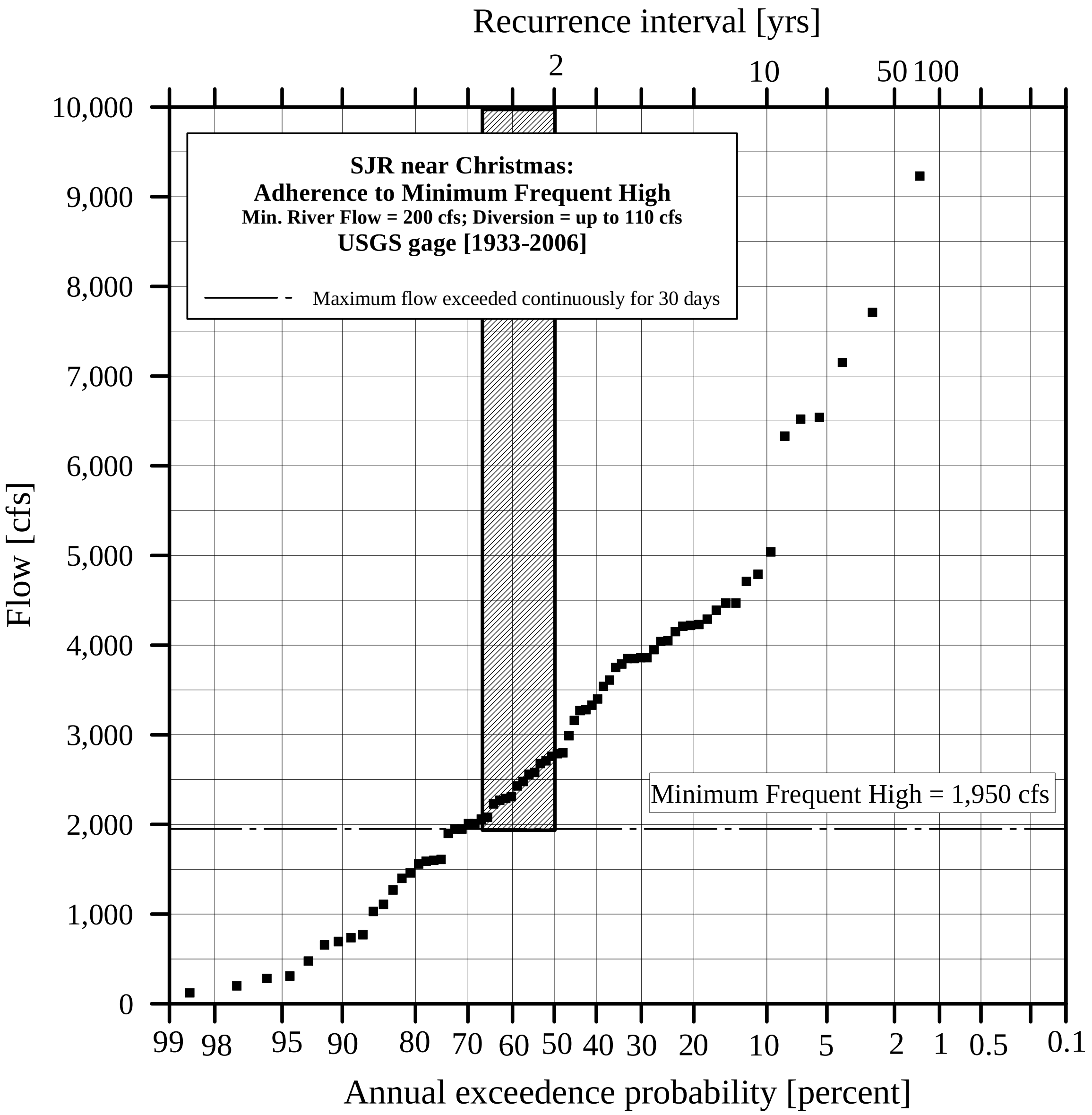

Figure B5 – 2. MFLs evaluation for the Minimum Frequent High discharge

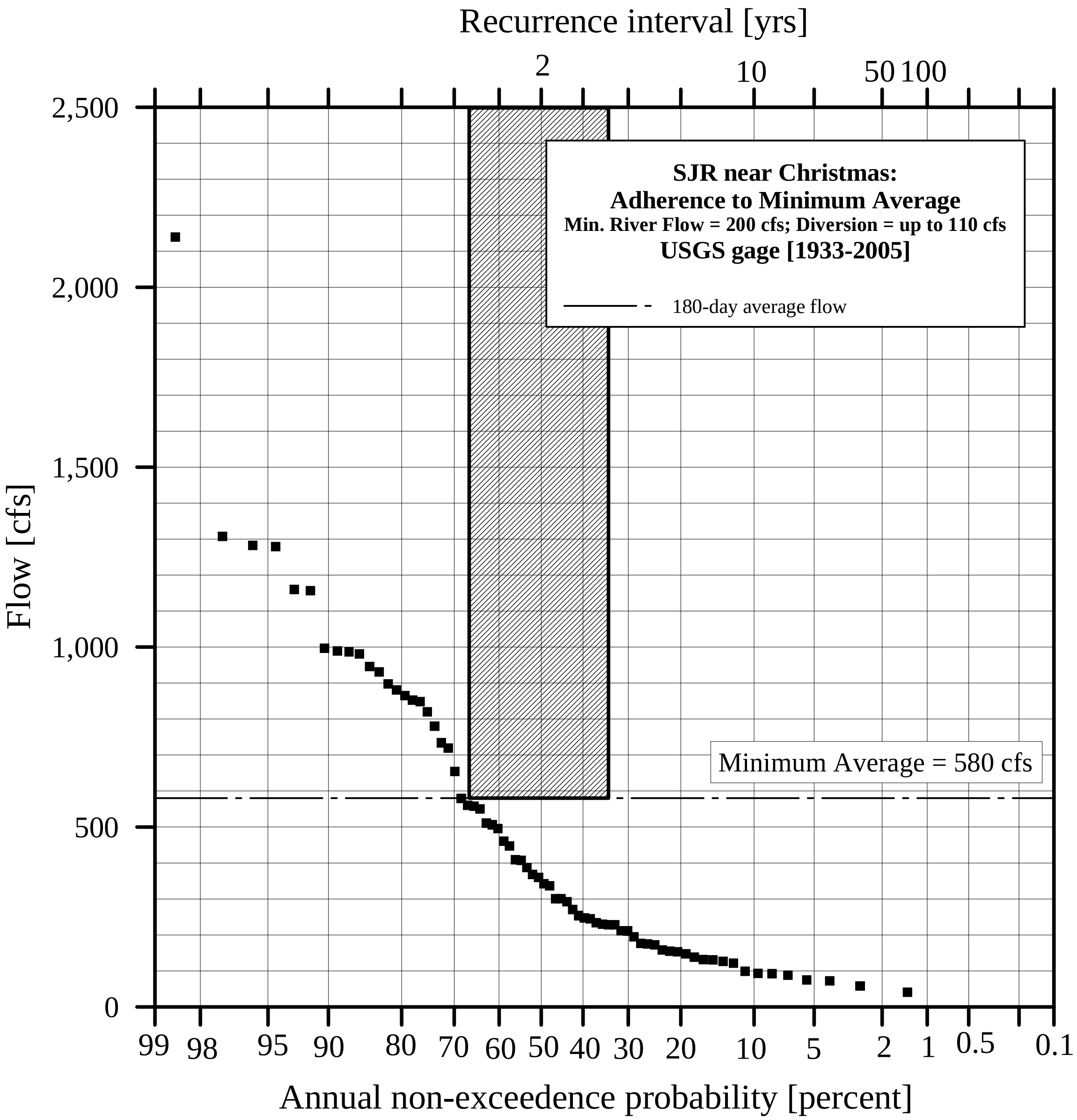

Figure B5 – 3. MFLs evaluation for the Minimum Average discharge

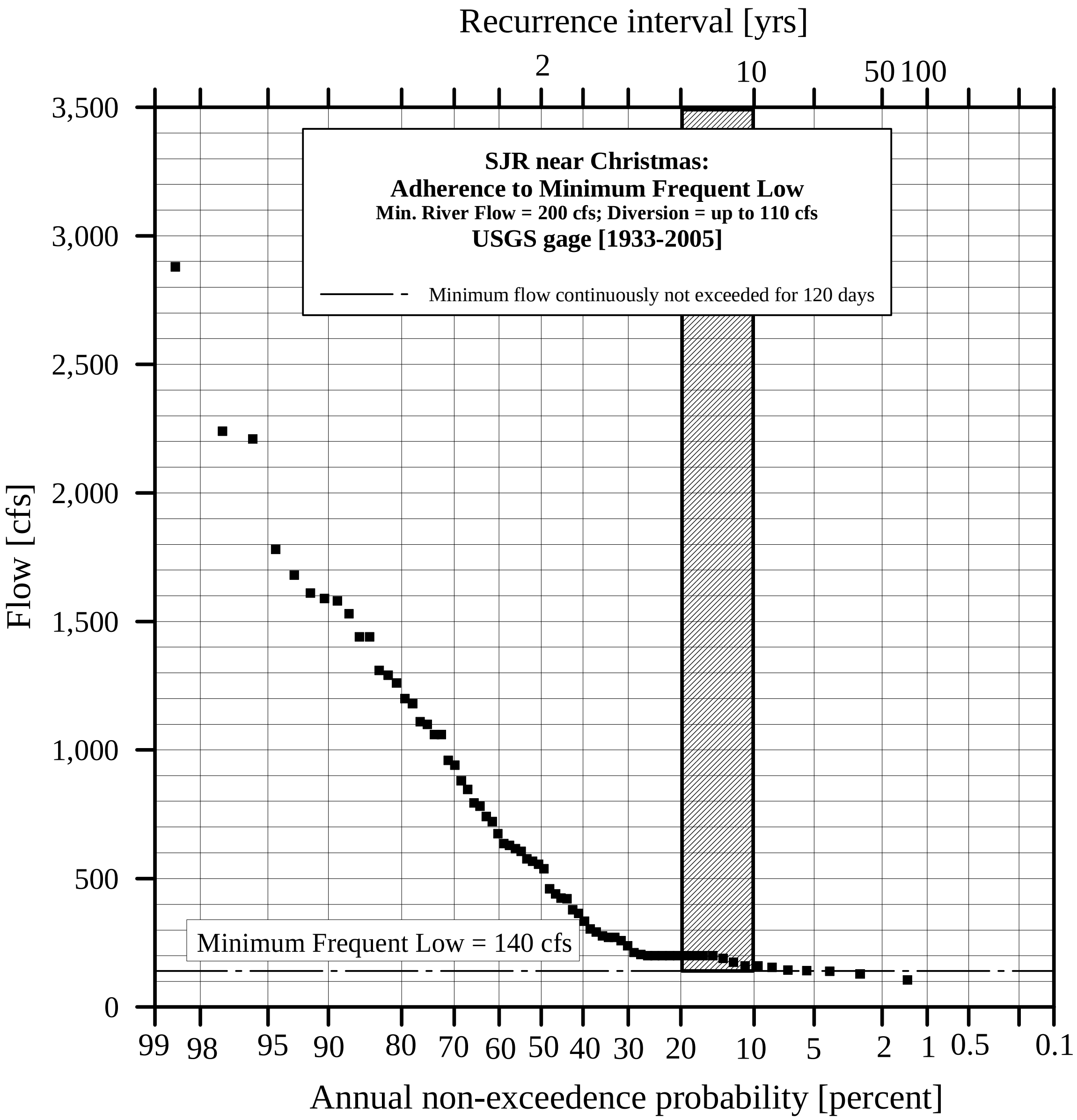

Figure B5 – 4. MFLs evaluation for the Minimum Frequent Low discharge

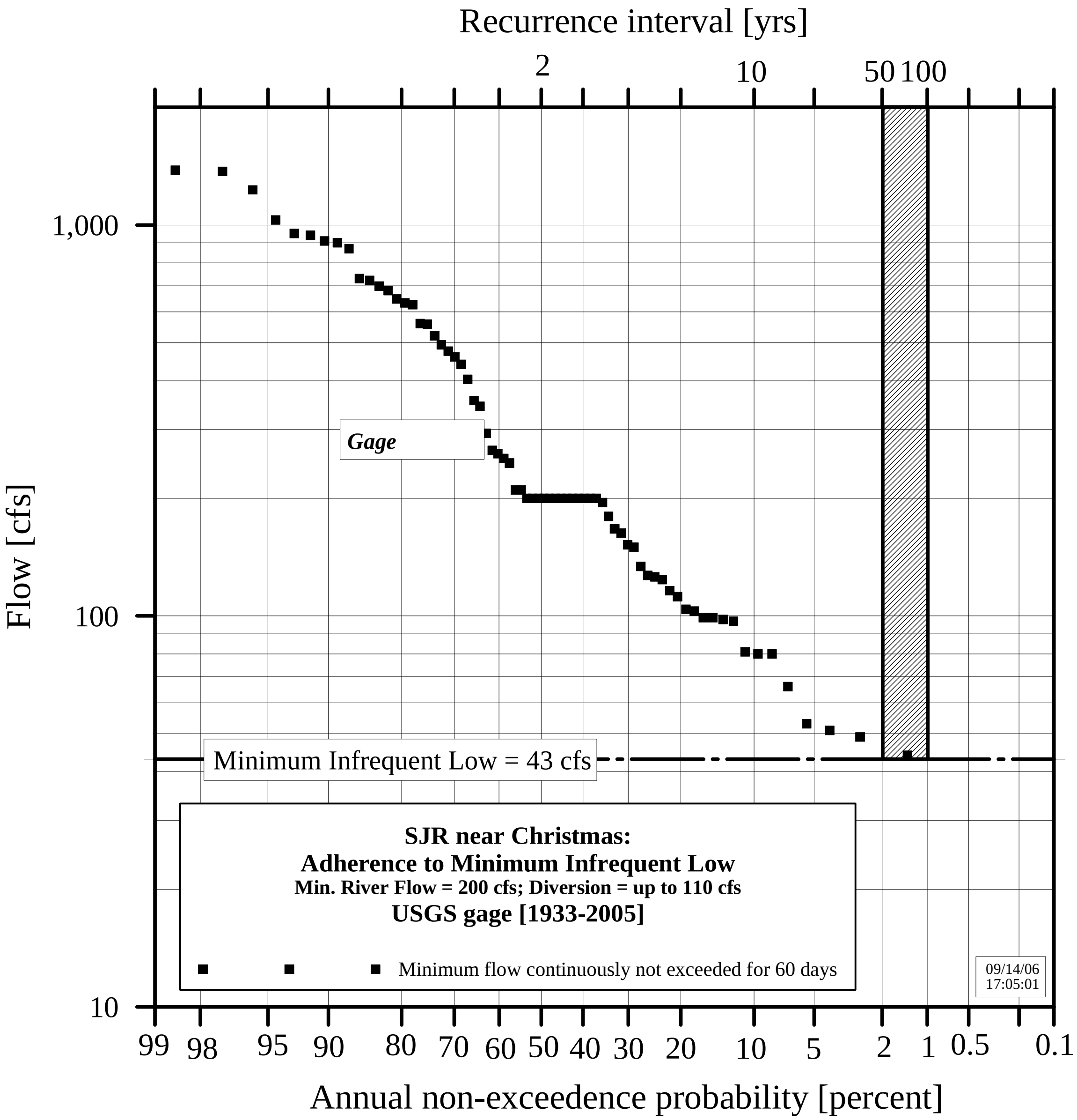

Figure B5 – 5. MFLs evaluation for the Minimum Infrequent Low discharge

APPENDIX B4

MFLs analysis for Scenario B4
1933-2006 USGS Discharges

MRF = 200 cfs; DD = 90 cfs

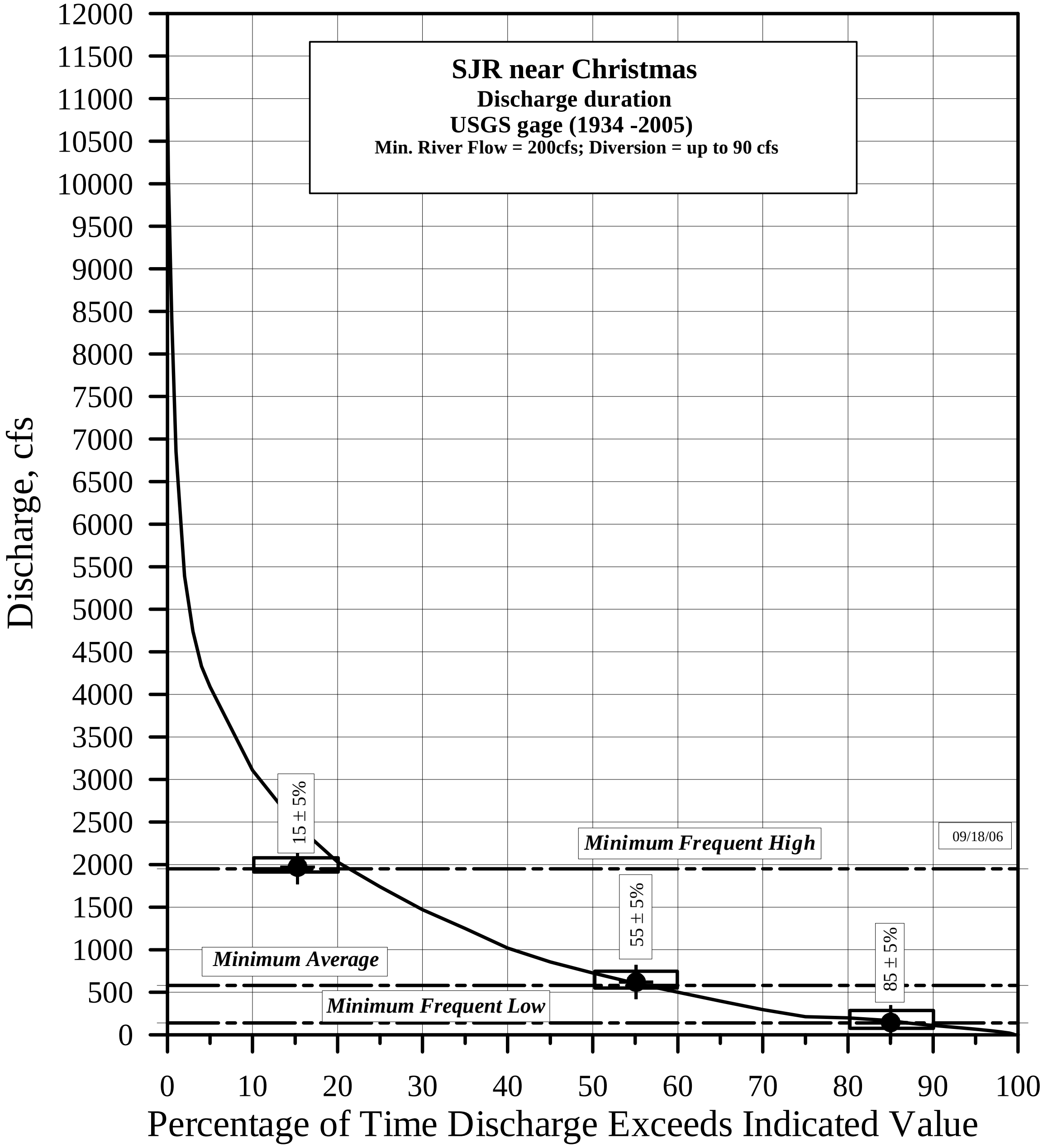

Figure B4 – 1. Flow duration

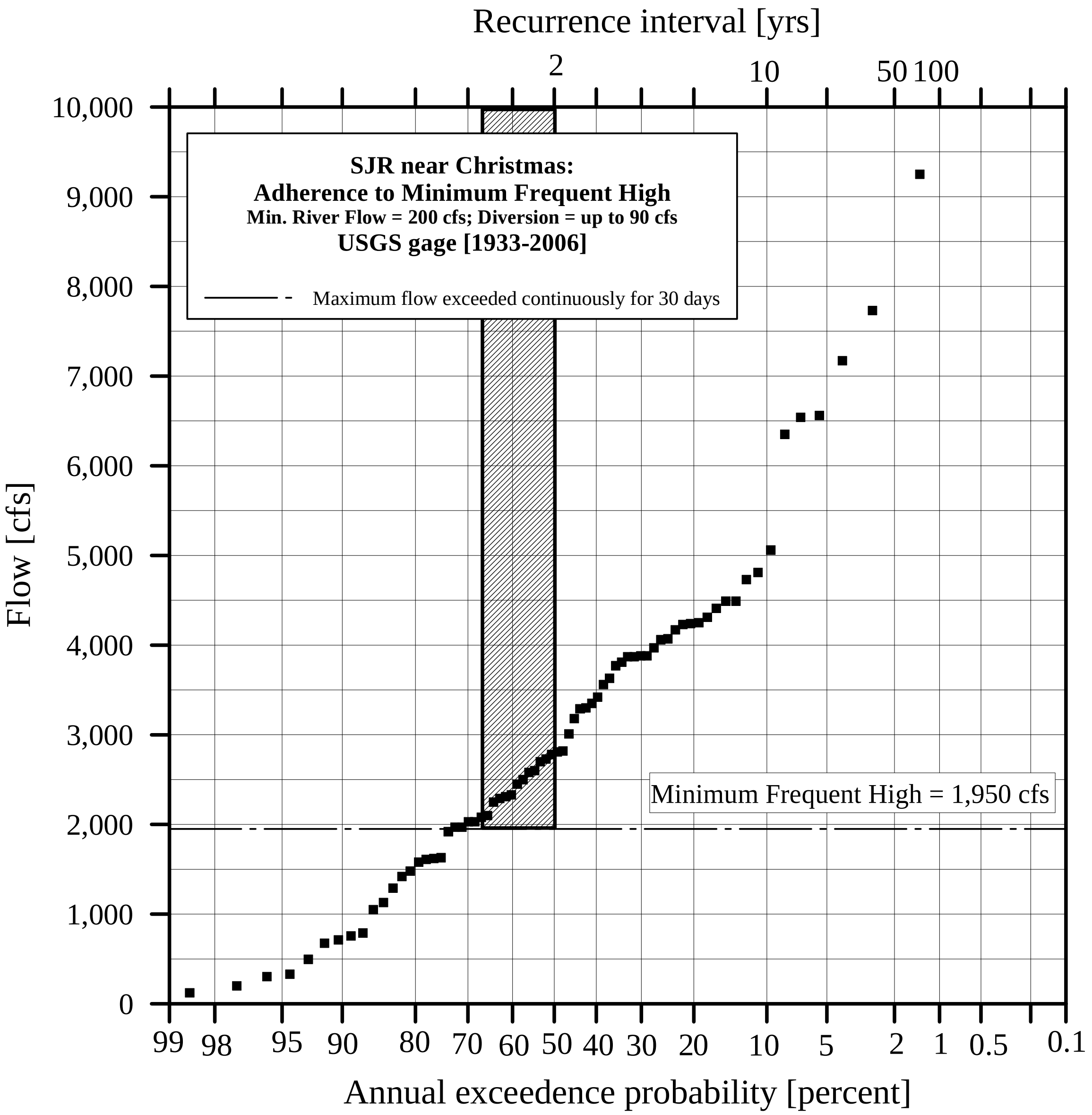

Figure B4 – 2. MFLs evaluation for the Minimum Frequent High discharge

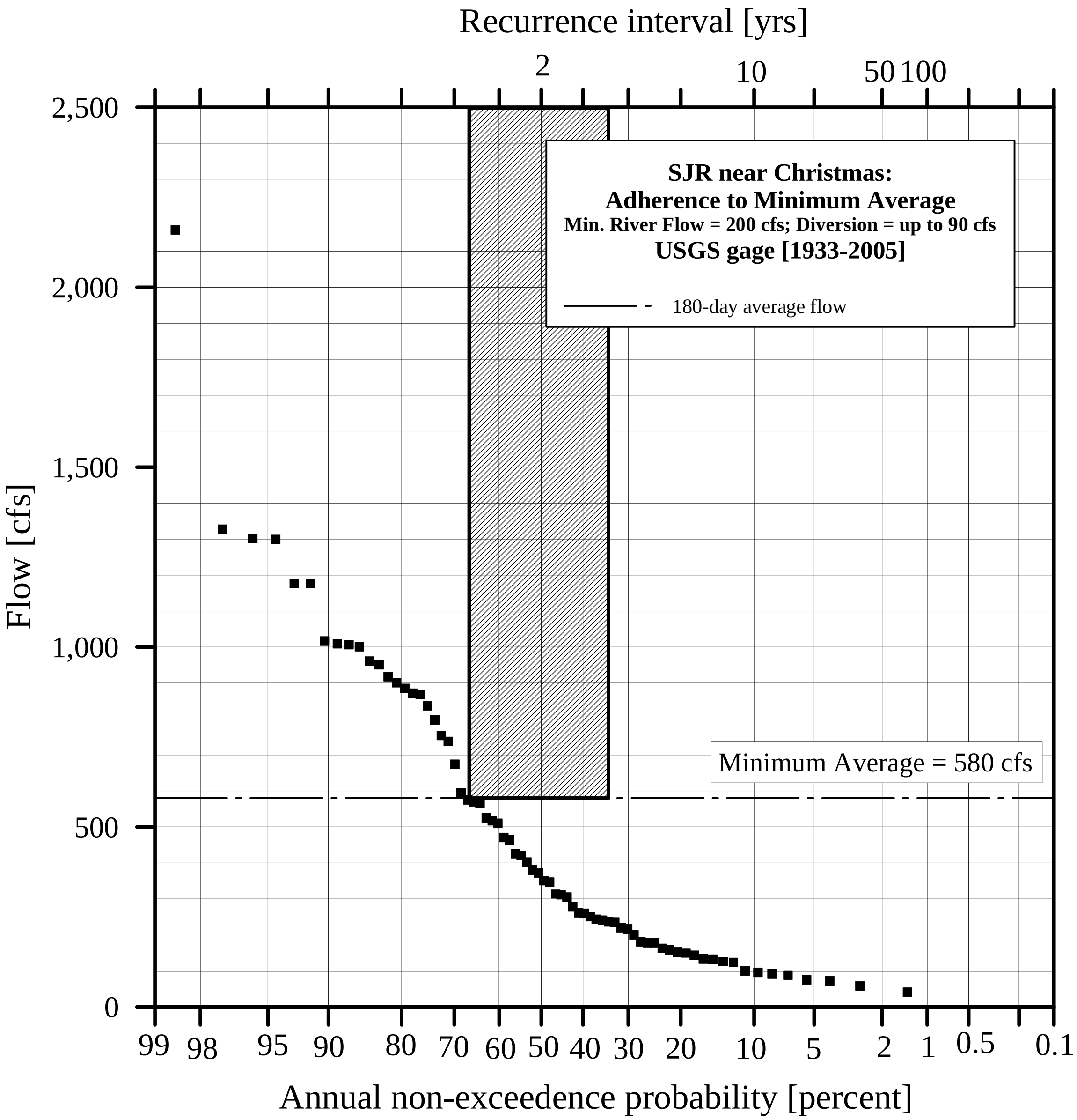

Figure B4 – 3. MFLs evaluation for the Minimum Average discharge

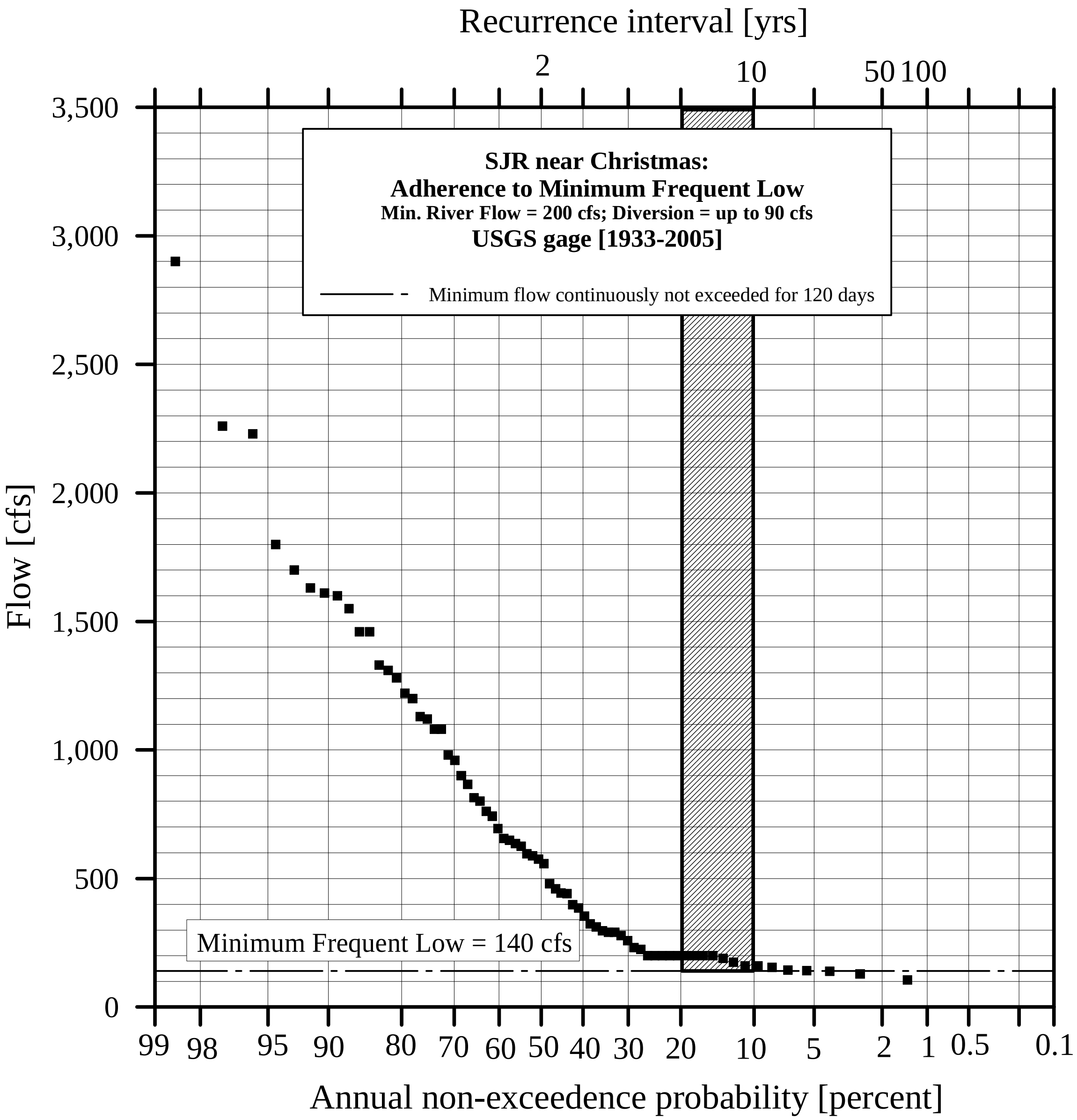

Figure B4 – 4. MFLs evaluation for the Minimum Frequent Low discharge

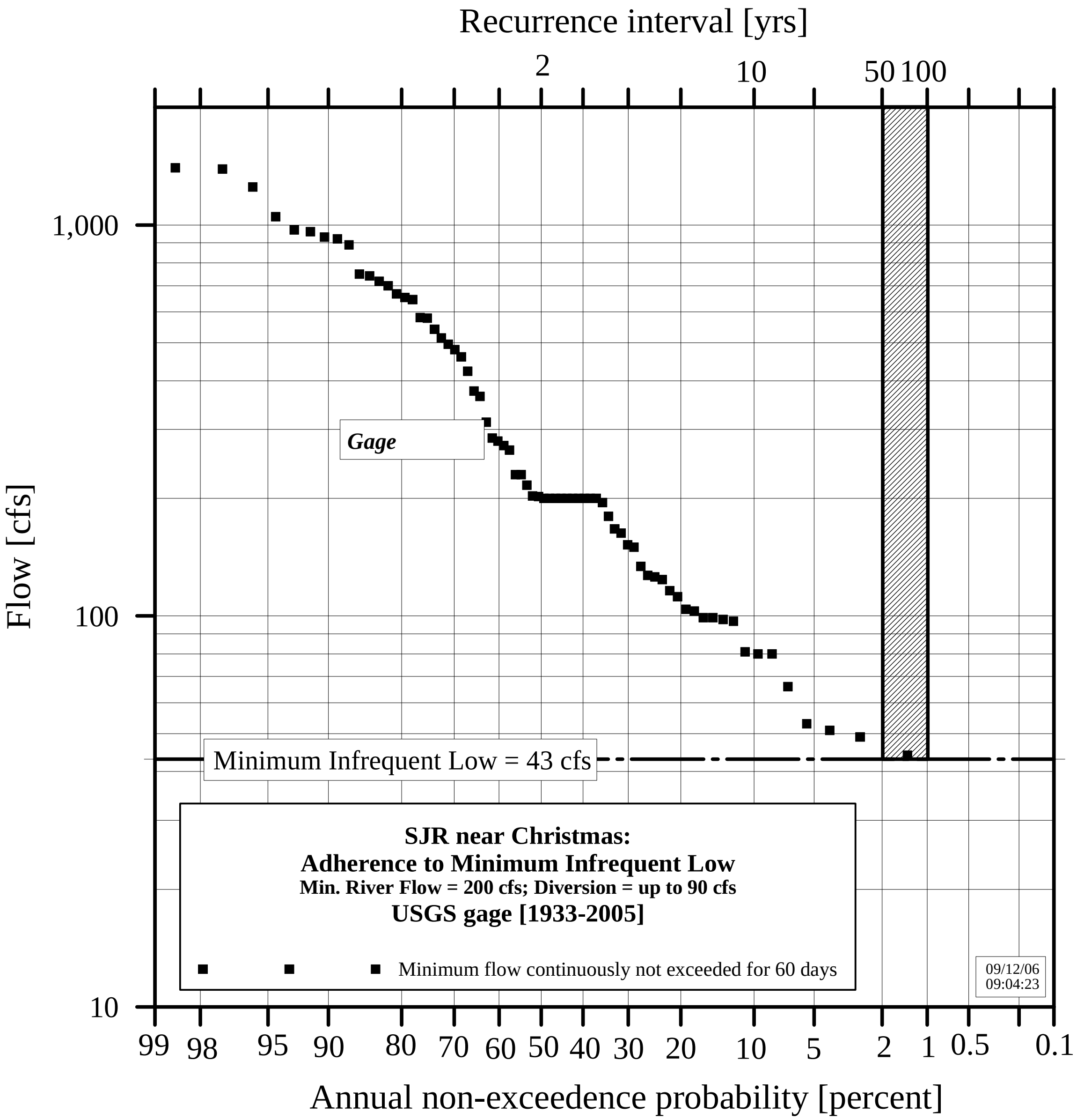

Figure B4 – 5. MFLs evaluation for the Minimum Infrequent Low discharge

APPENDIX B3

MFLs analysis for Scenario B3
1933-2006 USGS Discharges

MRF = 200 cfs; DD = 70 cfs

Only MA evaluated

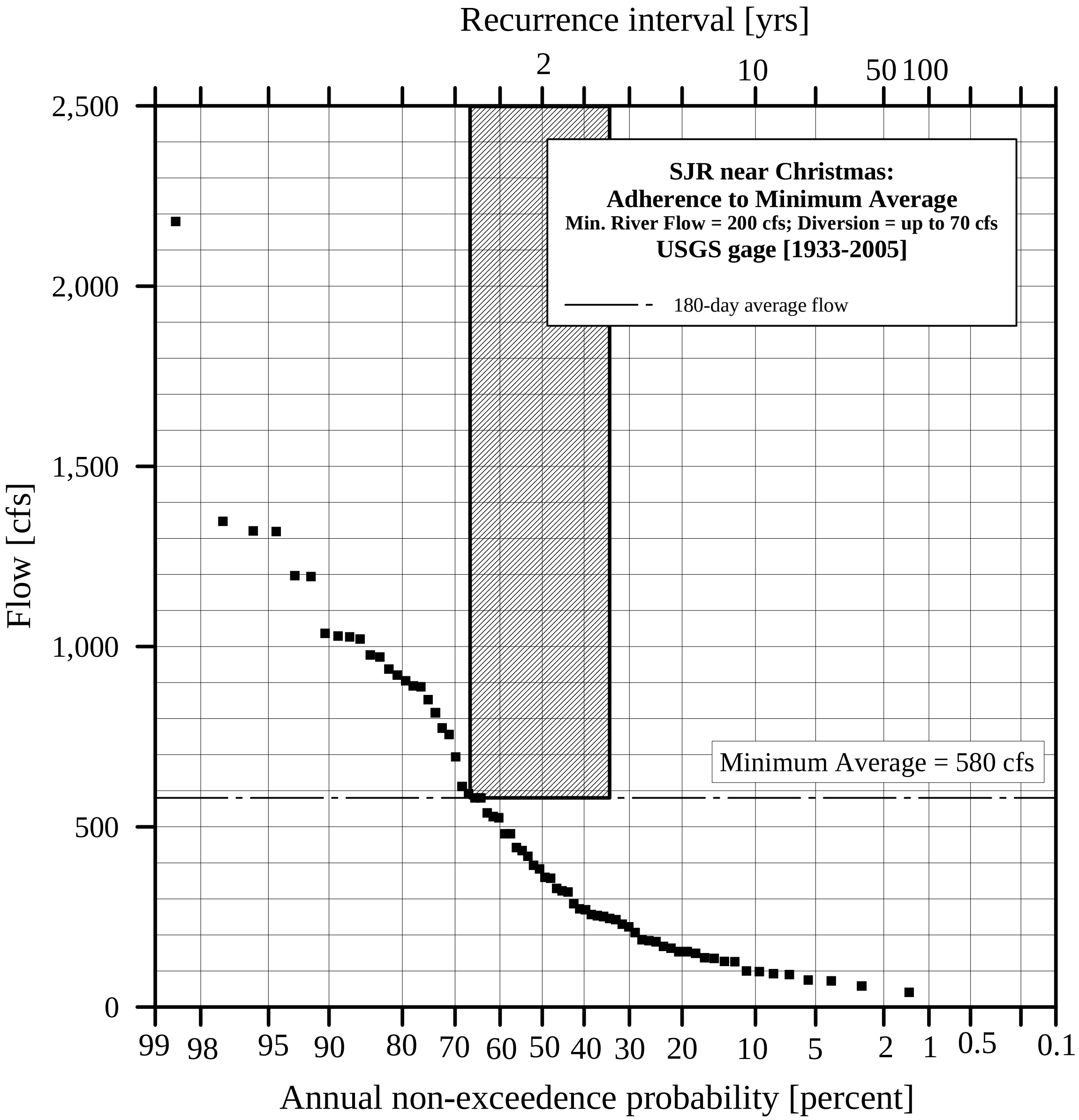

Figure B3 – 1. MFLs evaluation for the Minimum Average discharge

APPENDIX C5

MFLs analysis for Scenario C5
1933-2006 USGS Discharges

MRF = 100 cfs; DD = 110 cfs

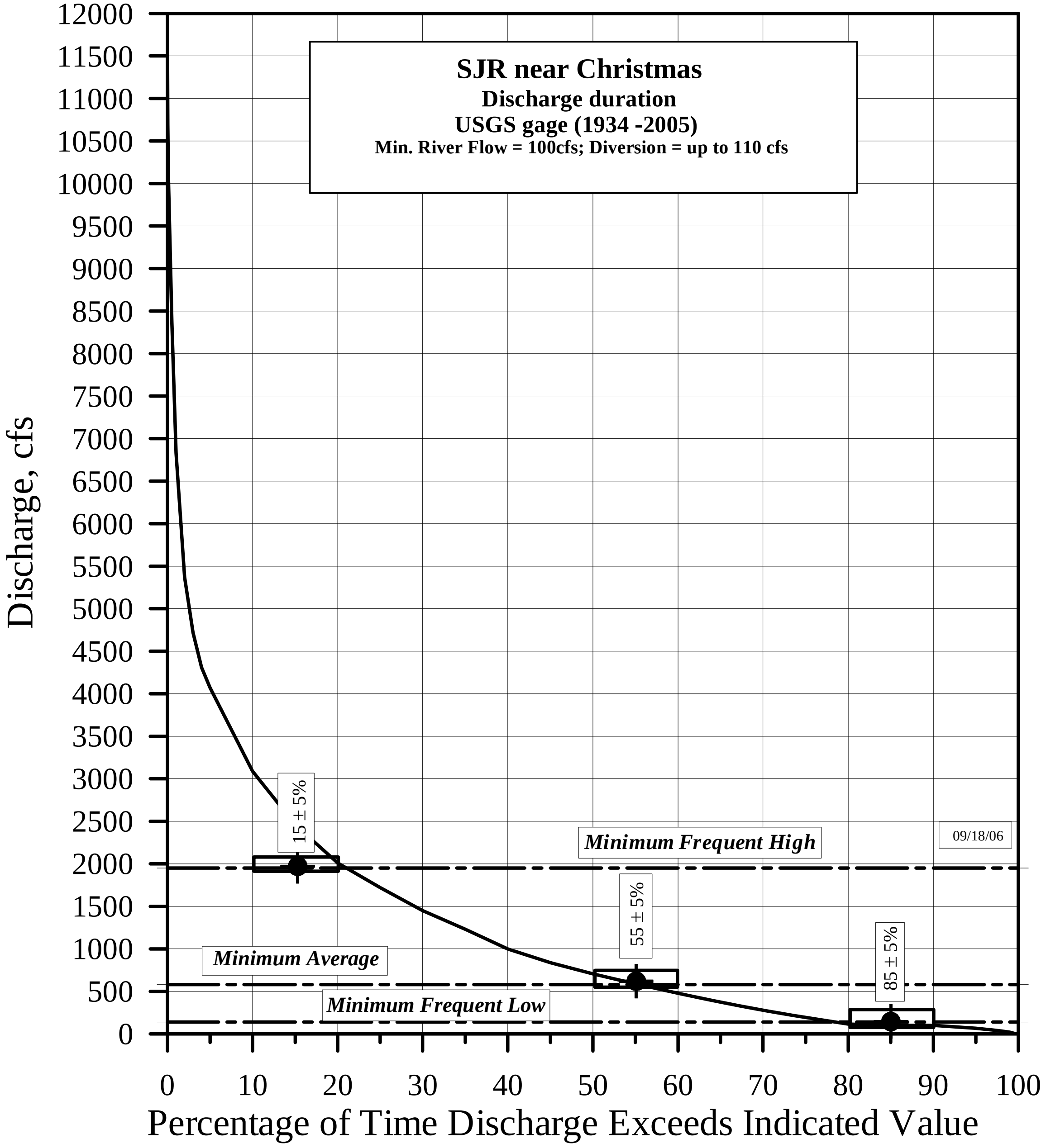

Figure C5 – 1. Flow duration

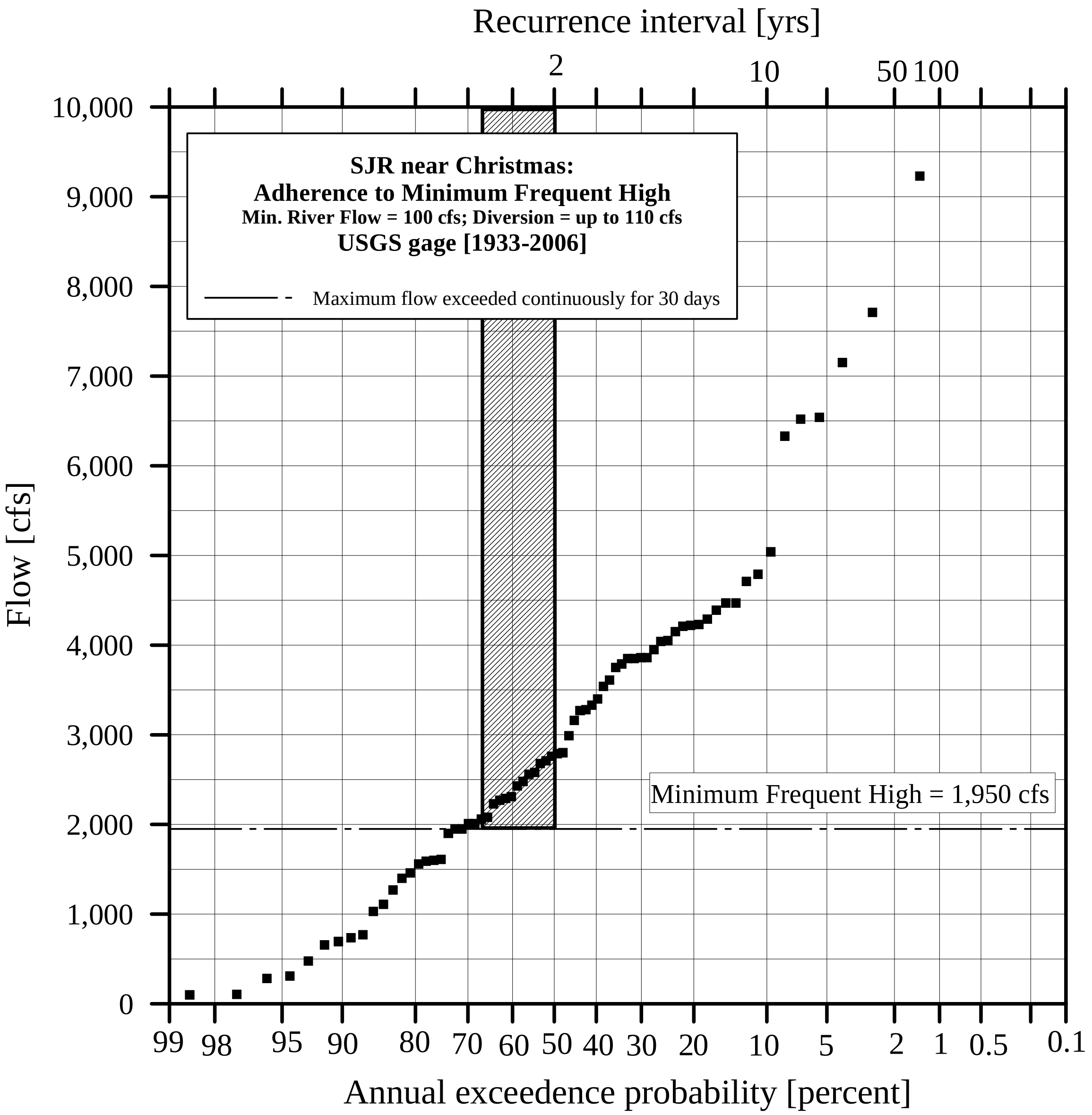

Figure C5 – 2. MFLs evaluation for the Minimum Frequent High discharge

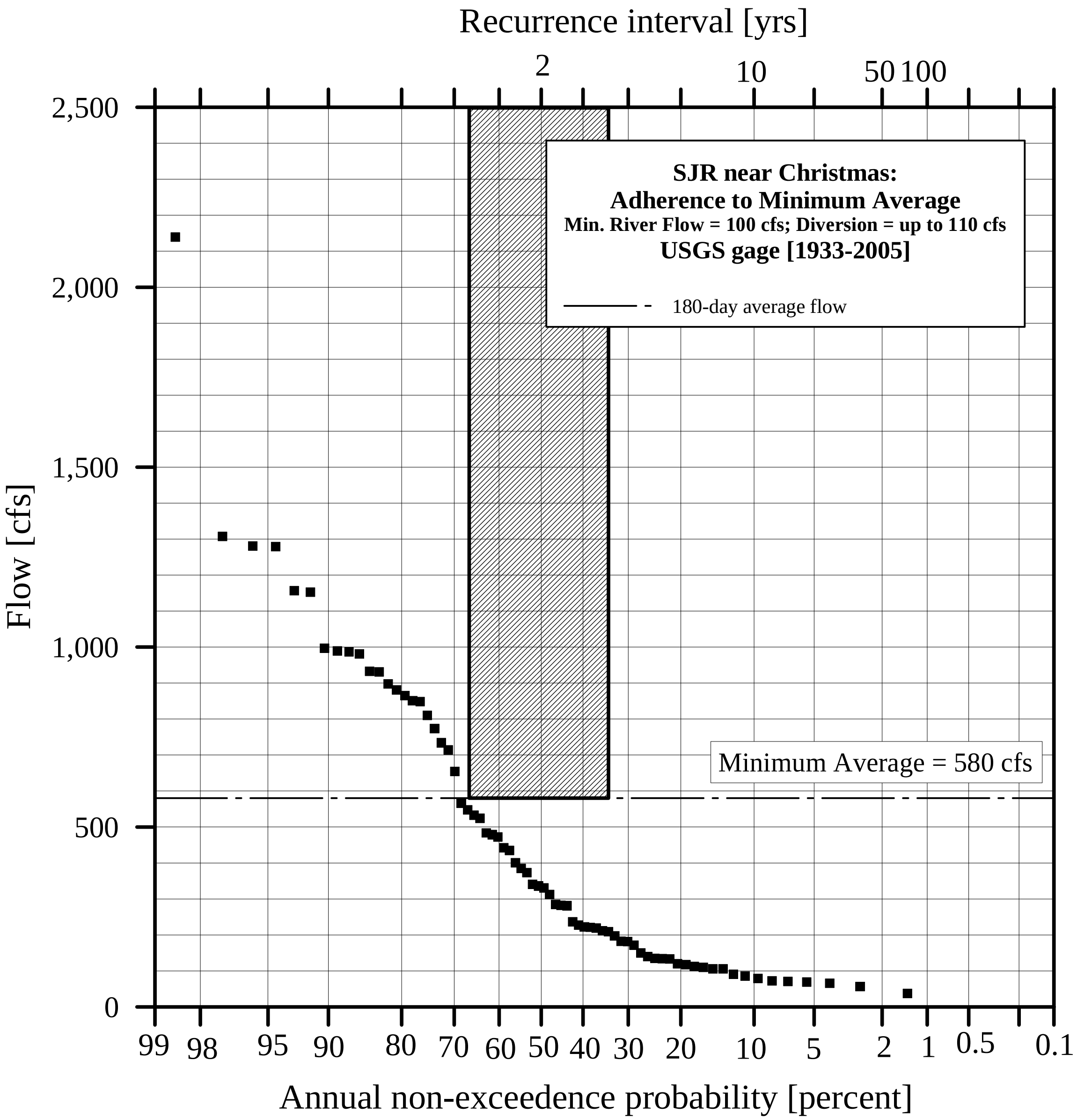

Figure C5 – 3. MFLs evaluation for the Minimum Average discharge

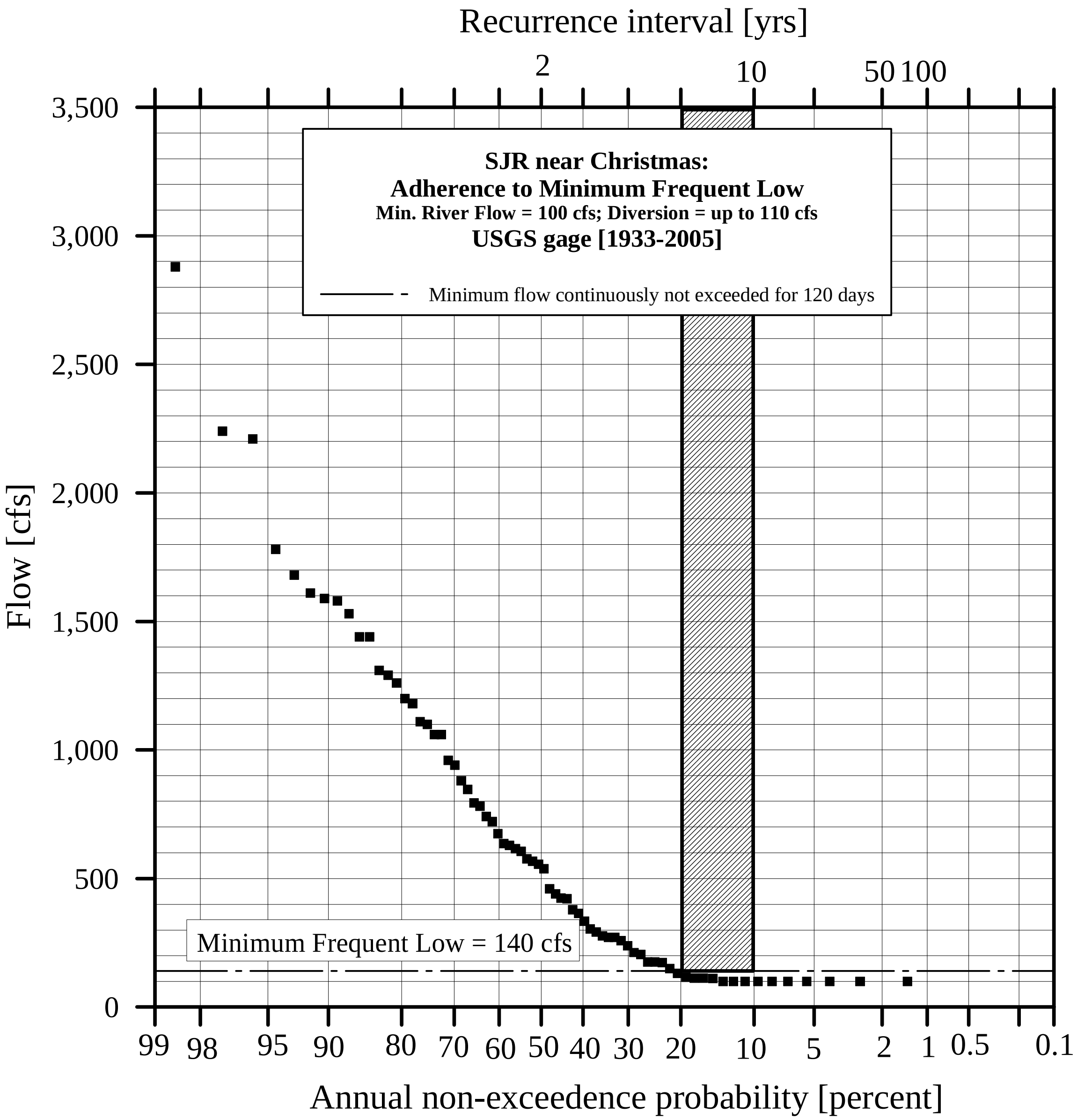

Figure C5 – 4. MFLs evaluation for the Minimum Frequent Low discharge

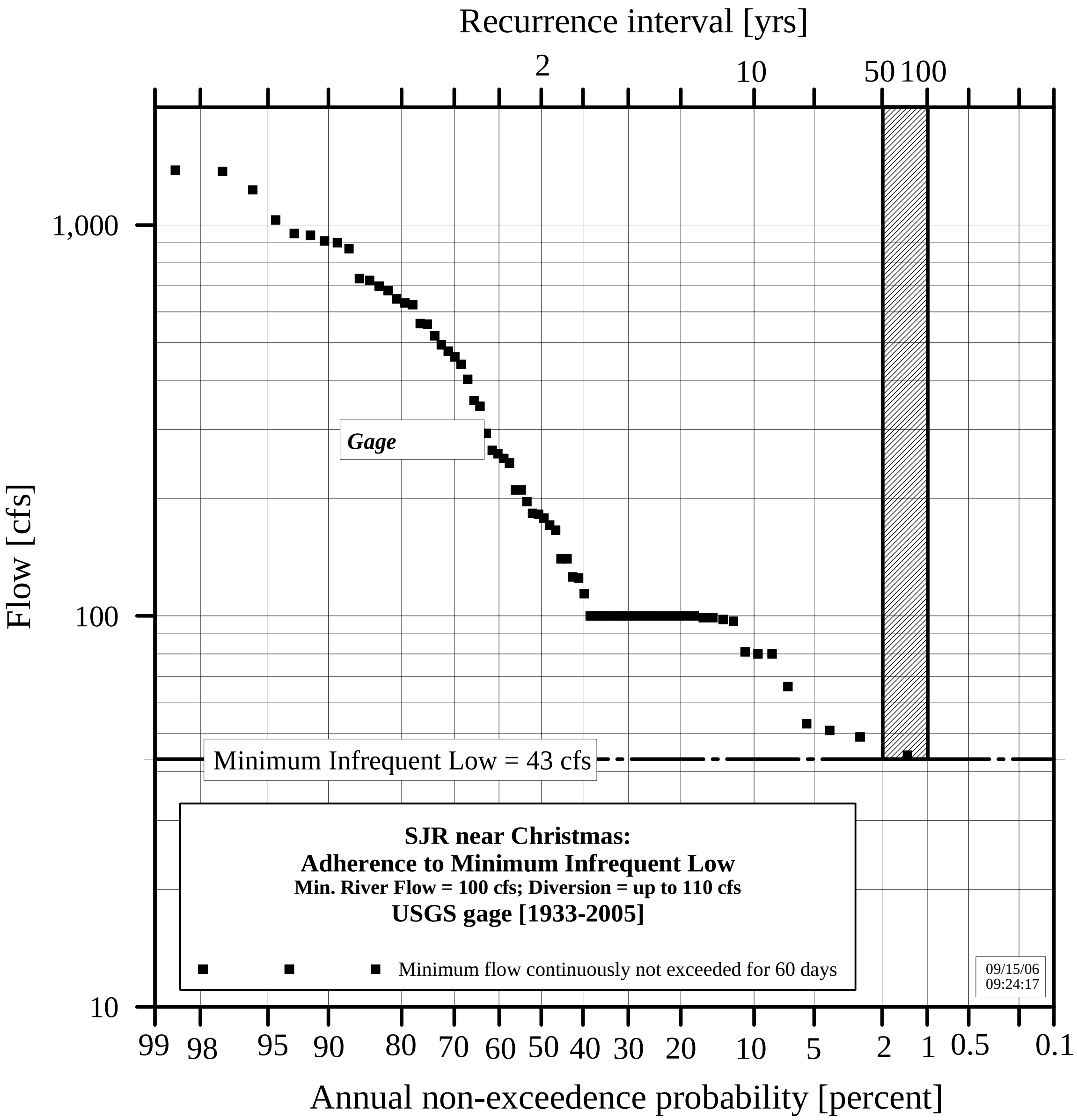

Figure C5 – 5. MFLs evaluation for the Minimum Infrequent Low discharge

APPENDIX C4

MFLs analysis for Scenario C4
1933-2006 USGS Discharges

MRF = 100 cfs; DD = 90 cfs

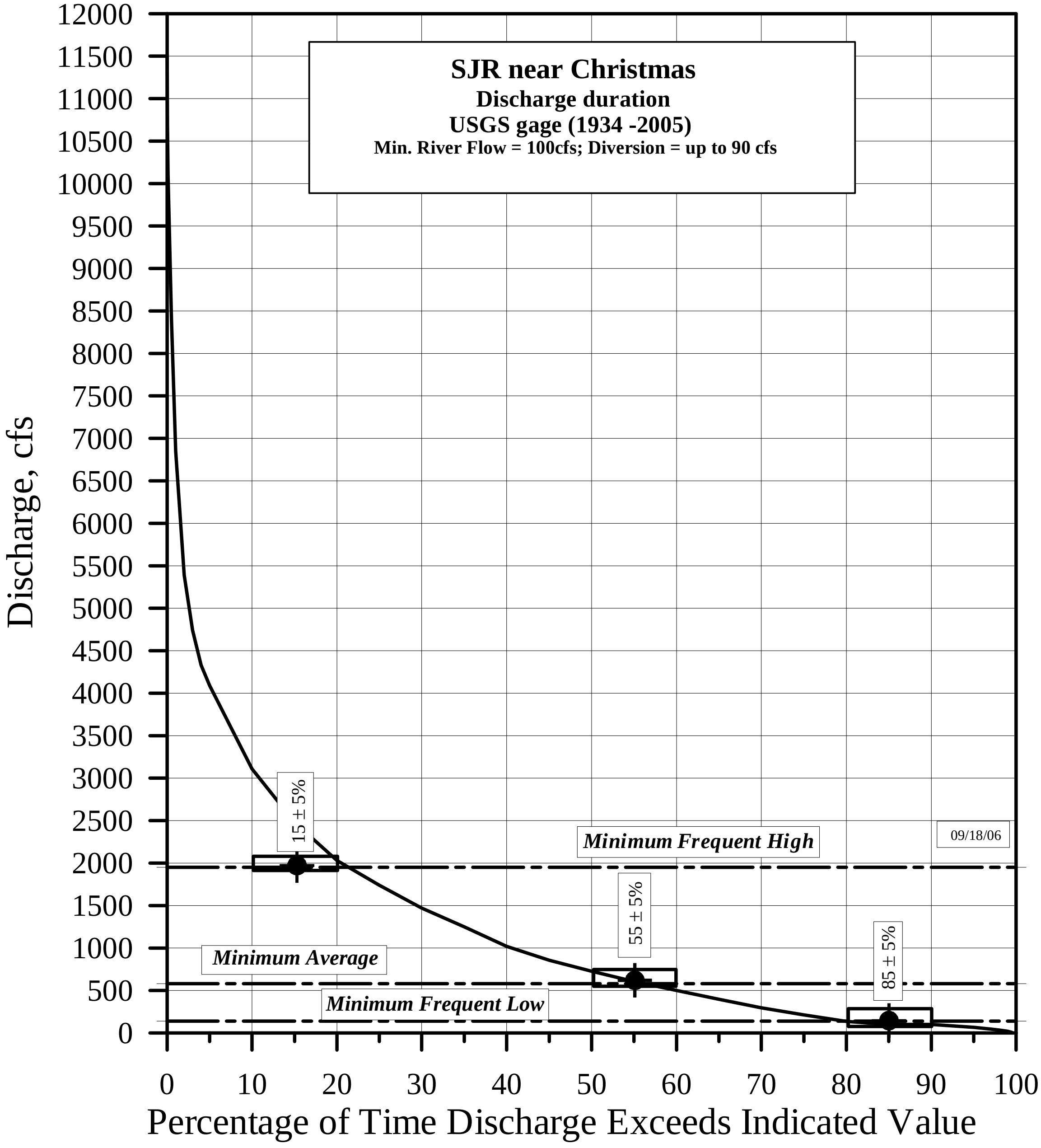

Figure C4 – 1. Flow duration

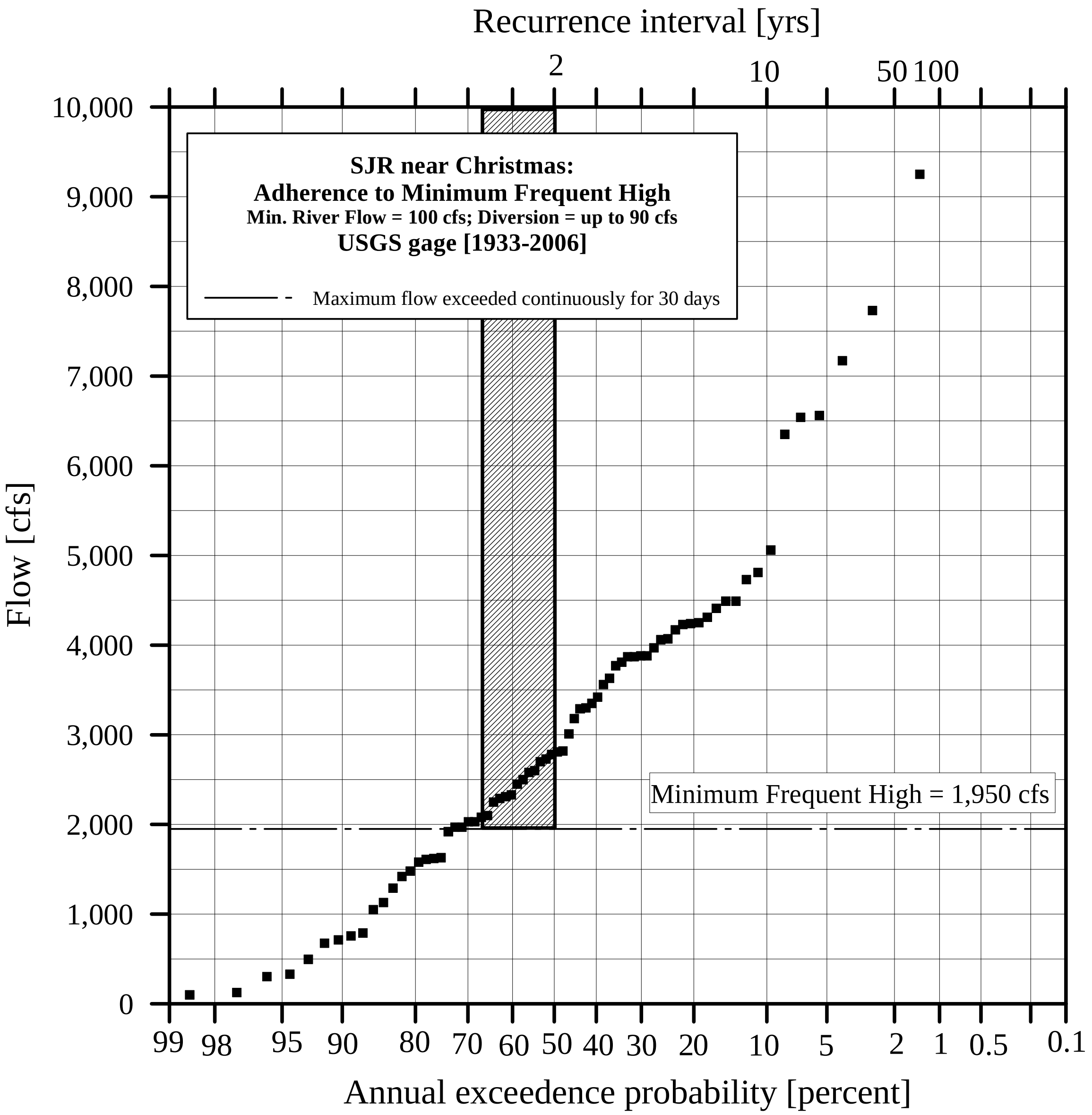

Figure C4 – 2. MFLs evaluation for the Minimum Frequent High discharge

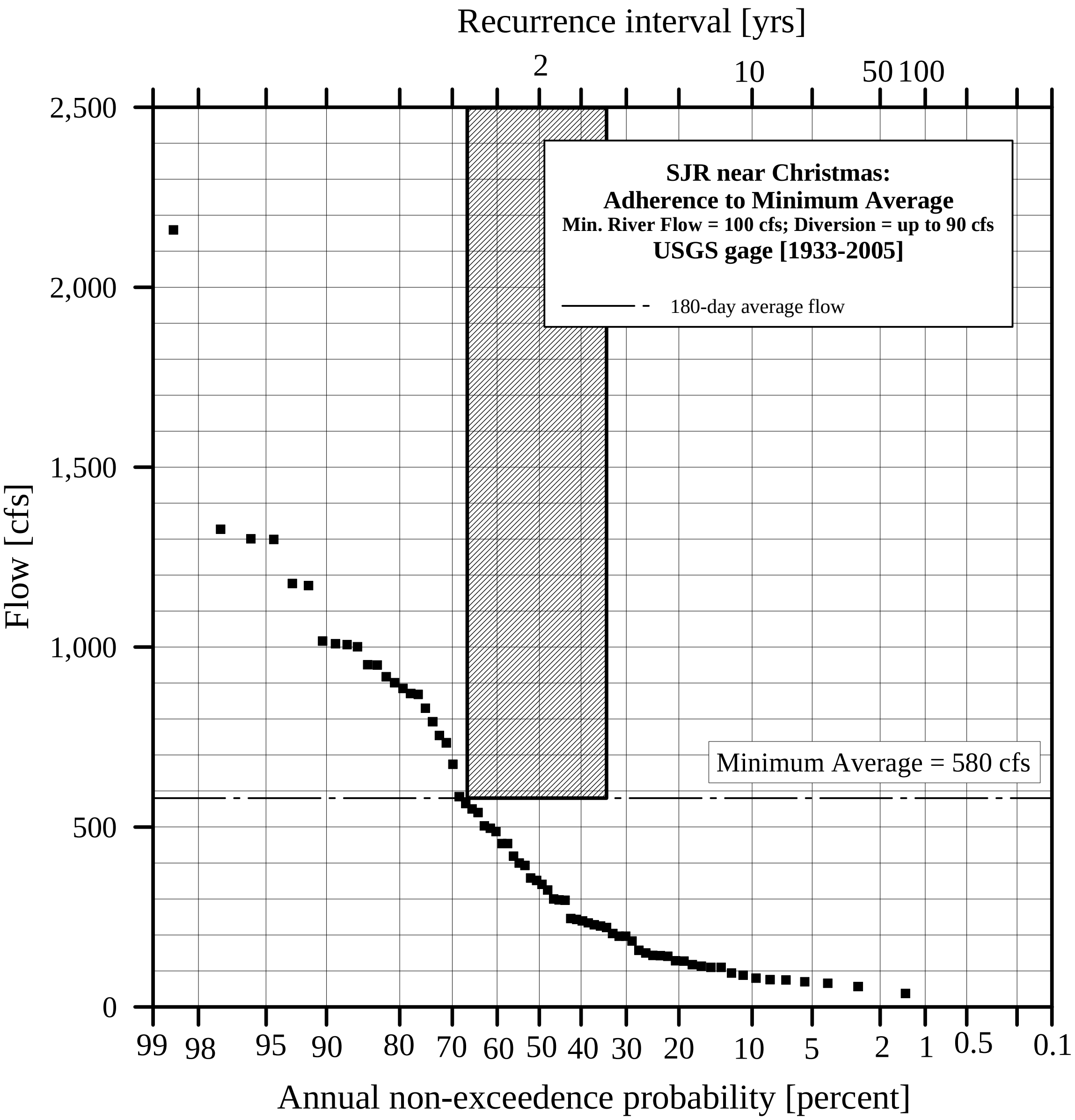

Figure C4 – 3. MFLs evaluation for the Minimum Average discharge

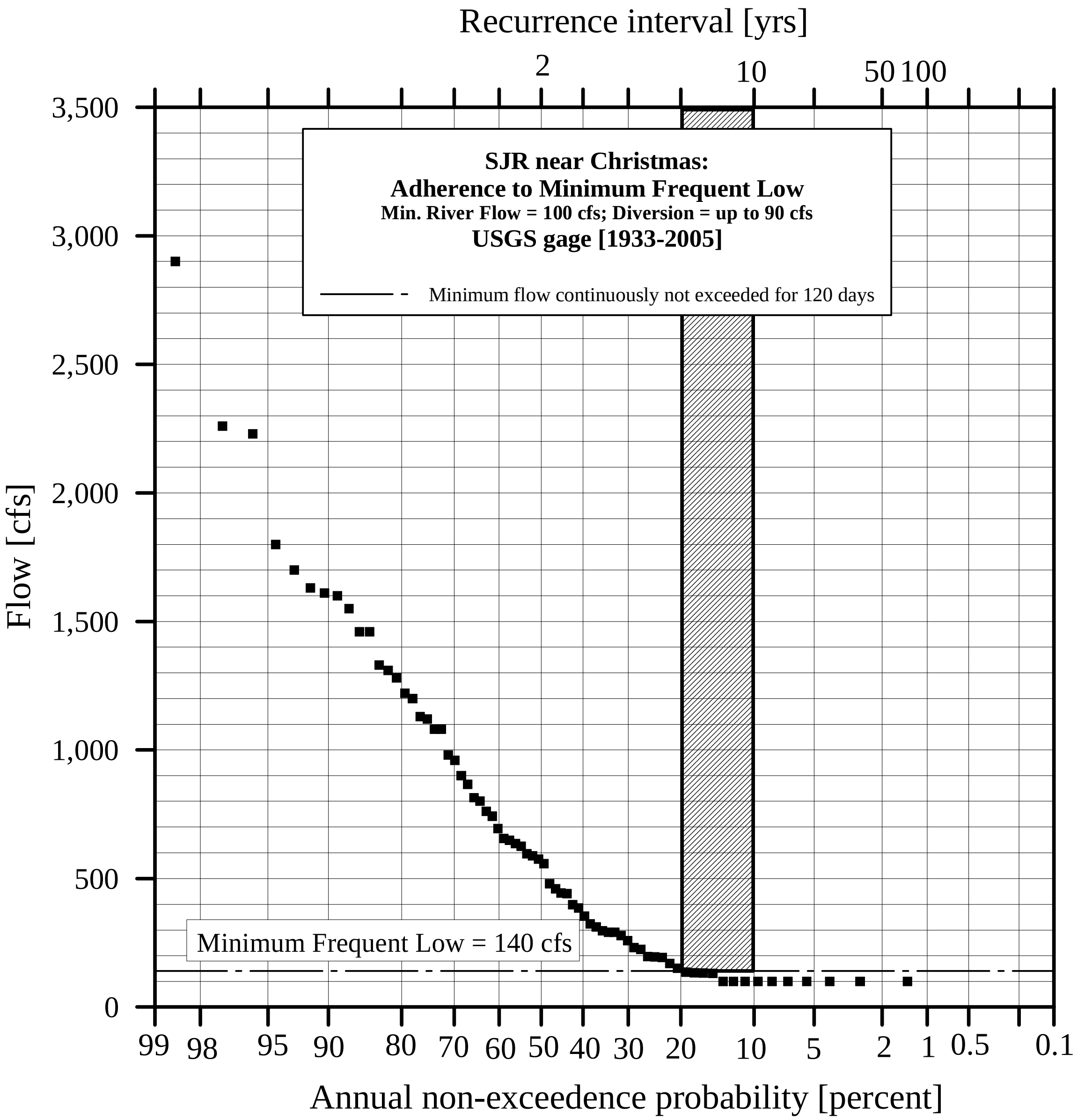

Figure C4 – 4. MFLs evaluation for the Minimum Frequent Low discharge

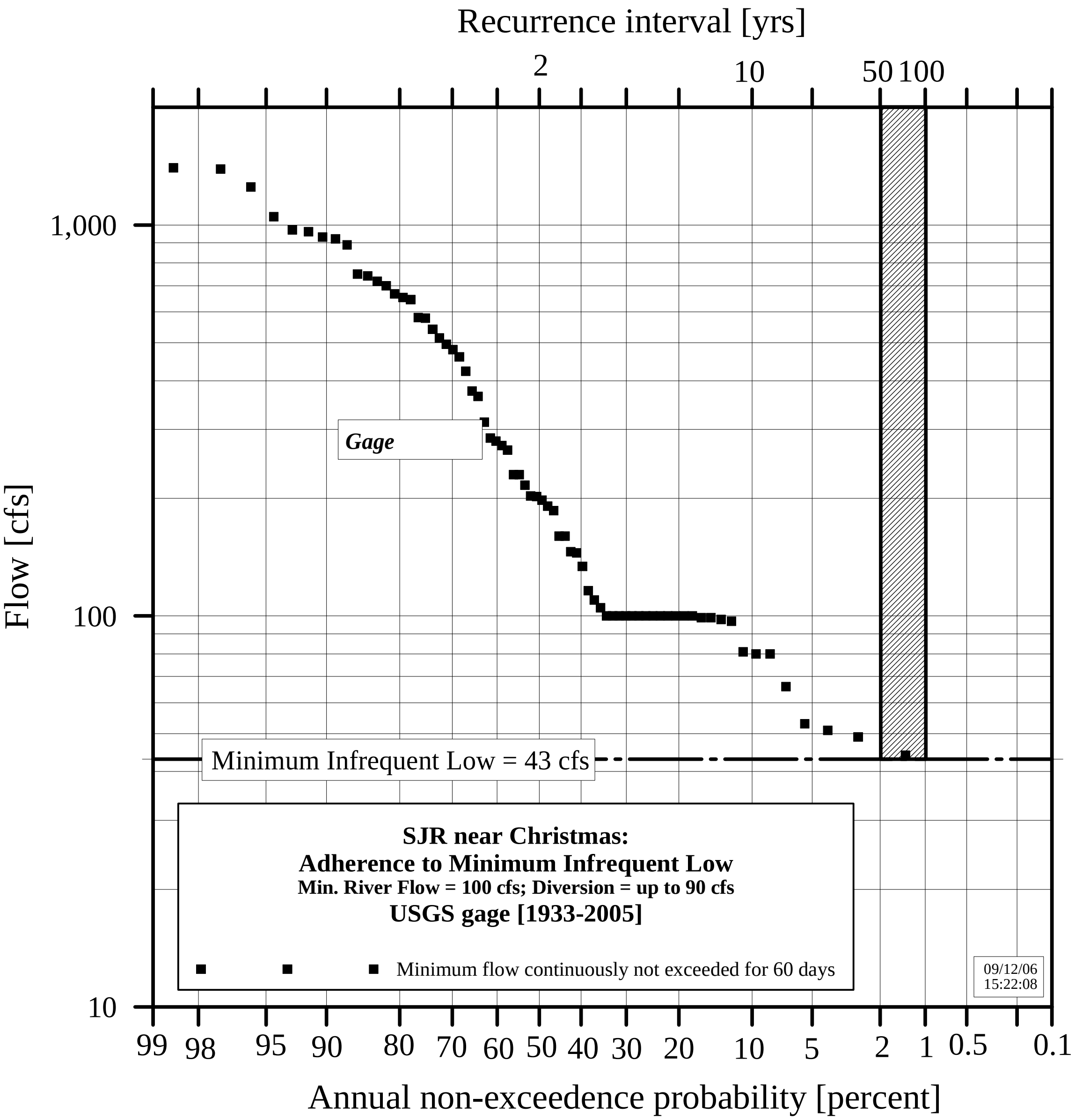

Figure C4 – 5. MFLs evaluation for the Minimum Infrequent Low discharge

APPENDIX C3

MFLs analysis for Scenario C3
1933-2006 USGS Discharges

MRF = 100 cfs; DD = 70 cfs

Only MA evaluated

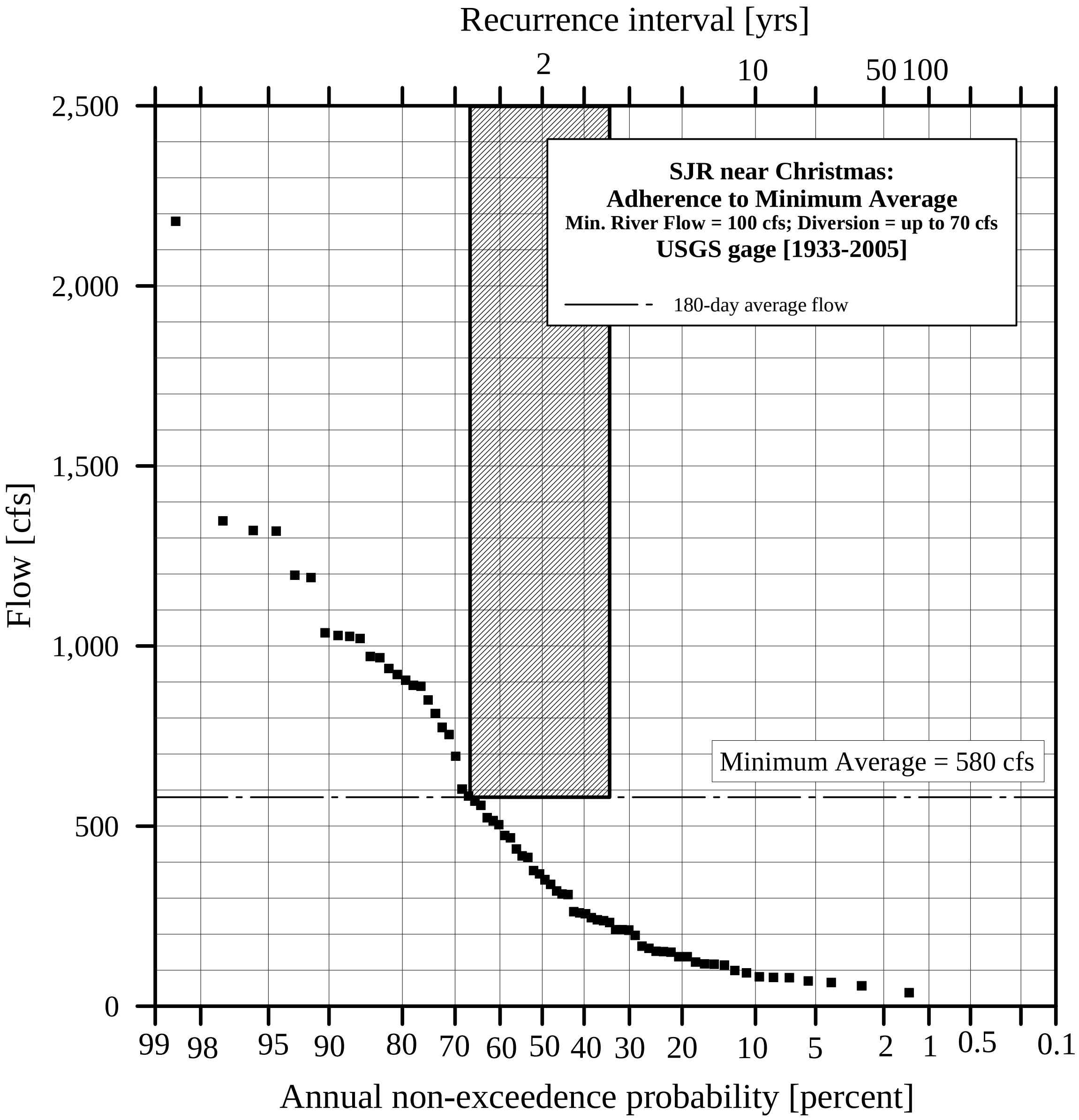

Figure C3 – 1. MFLs evaluation for the Minimum Average discharge

APPENDIX D5

MFLs analysis for Scenario D5
1933-2006 USGS Discharges

MRF = 50 cfs; DD = 50 cfs

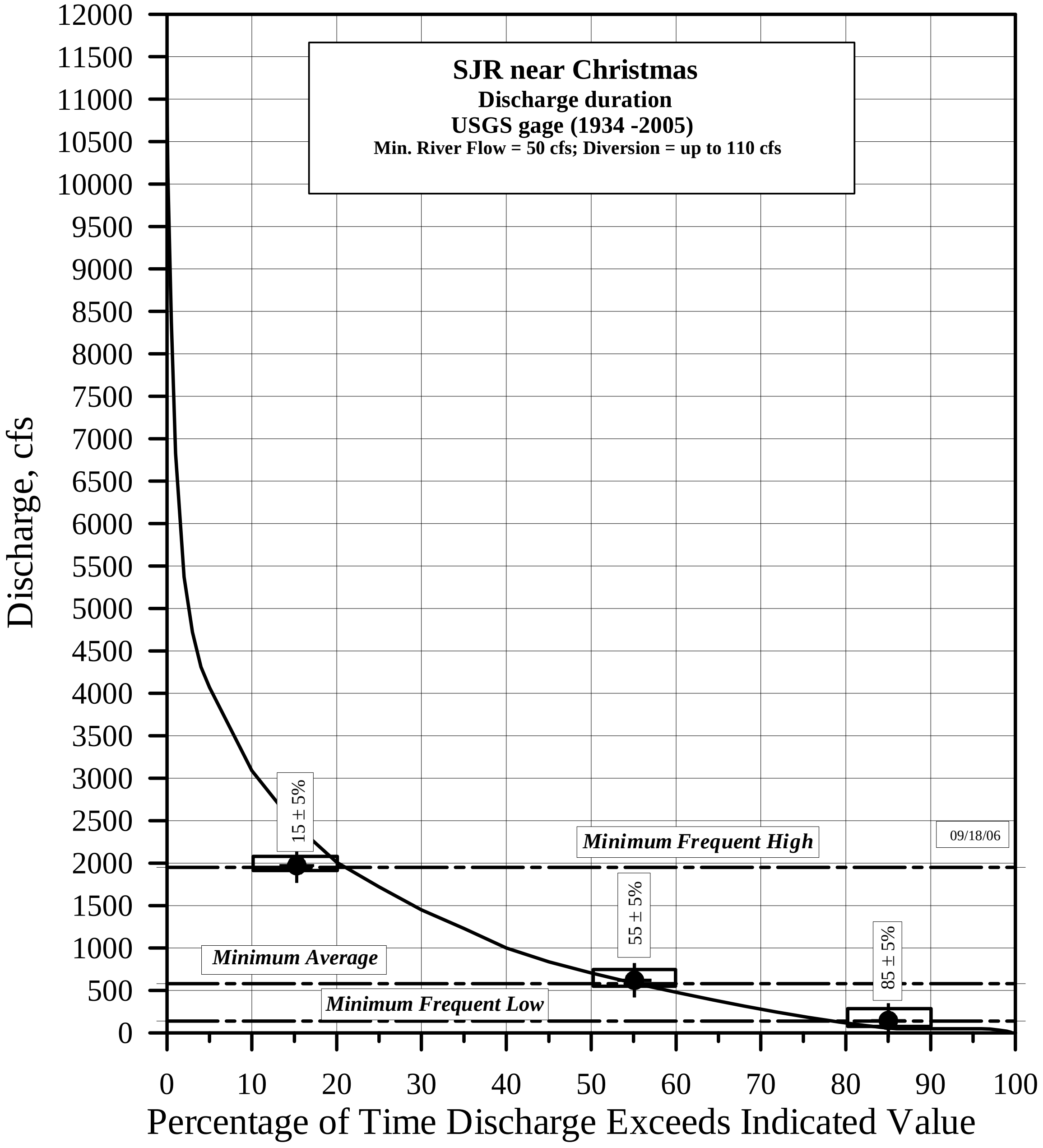
SJR near Christmas
Discharge duration
USGS gage (1934 -2005)
Min. River Flow = 50 cfs; Diversion = up to 110 cfs
Discharge, cfs
12000
11500
11000
10500
10000
9500
9000
8500
8000
7500
7000
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
15 ± 5%
55 ± 5%
85 ± 5%
Minimum Frequent High
Minimum Average
Minimum Frequent Low
09/18/06
0
10
20
30
40
50
60
70
80
90
100
Percentage of Time Discharge Exceeds Indicated Value

Figure D5 – 1. Flow duration

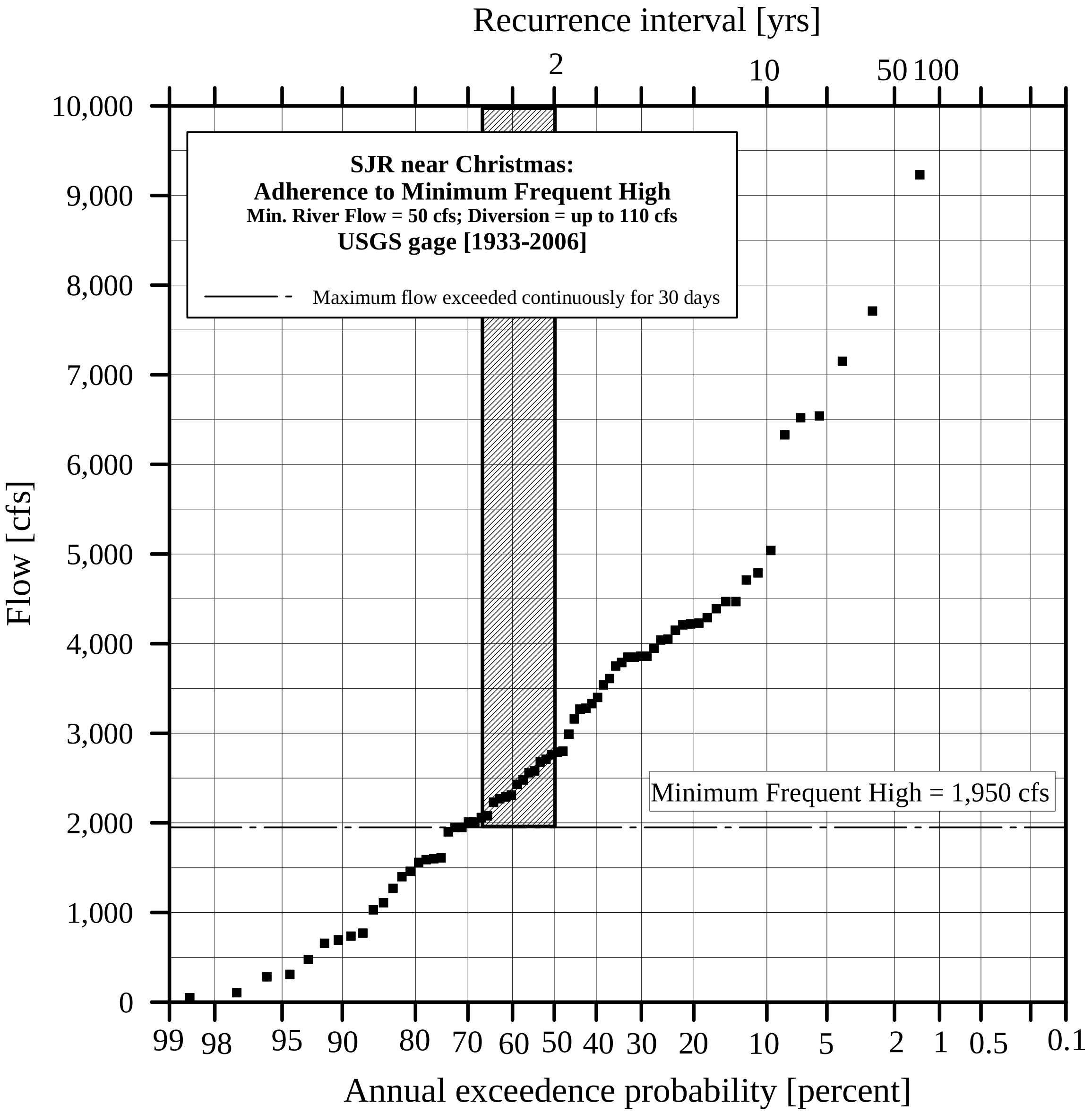

Figure D5 – 2. MFLs evaluation for the Minimum Frequent High discharge

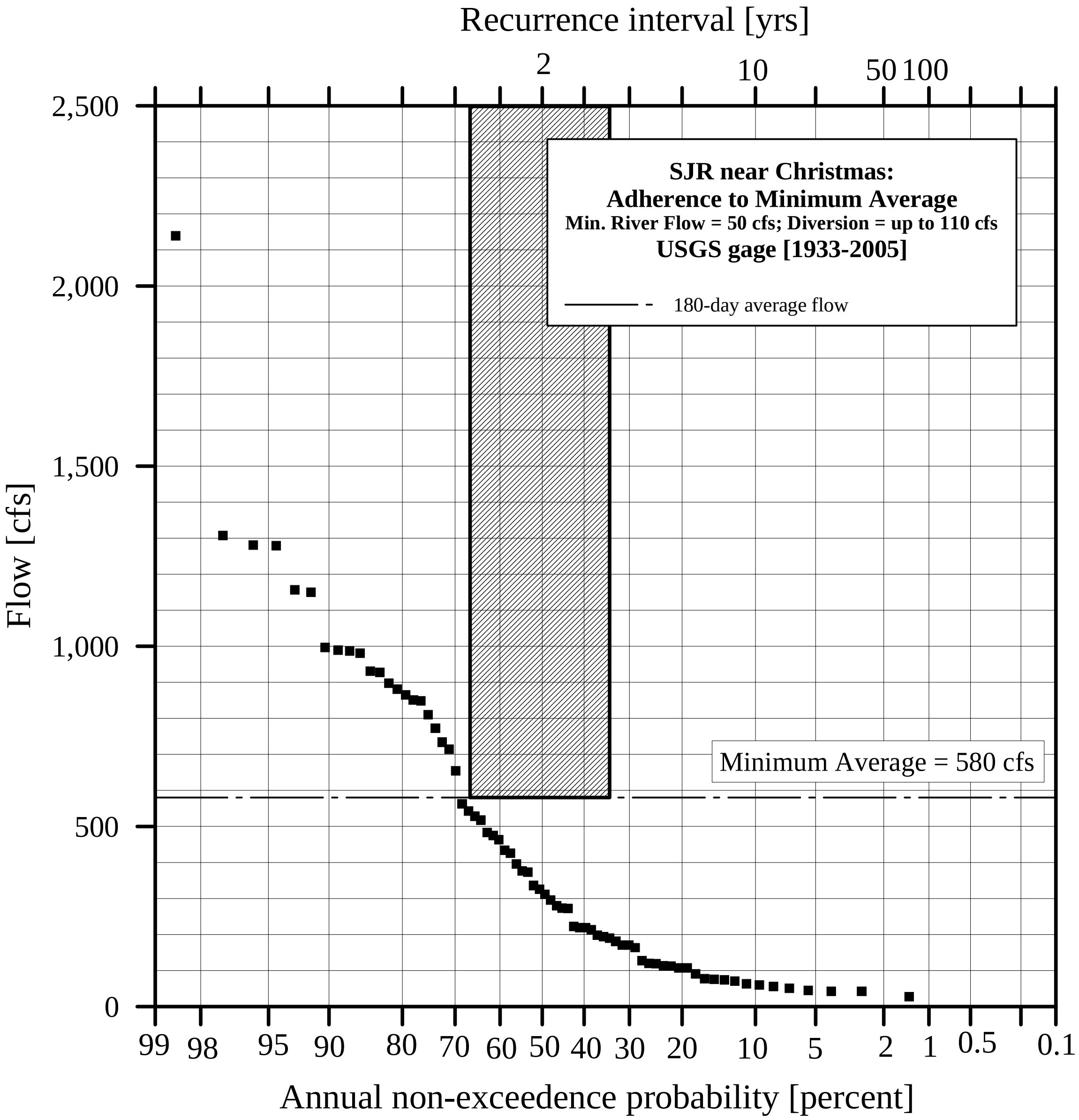

Figure D5 – 3. MFLs evaluation for the Minimum Average discharge

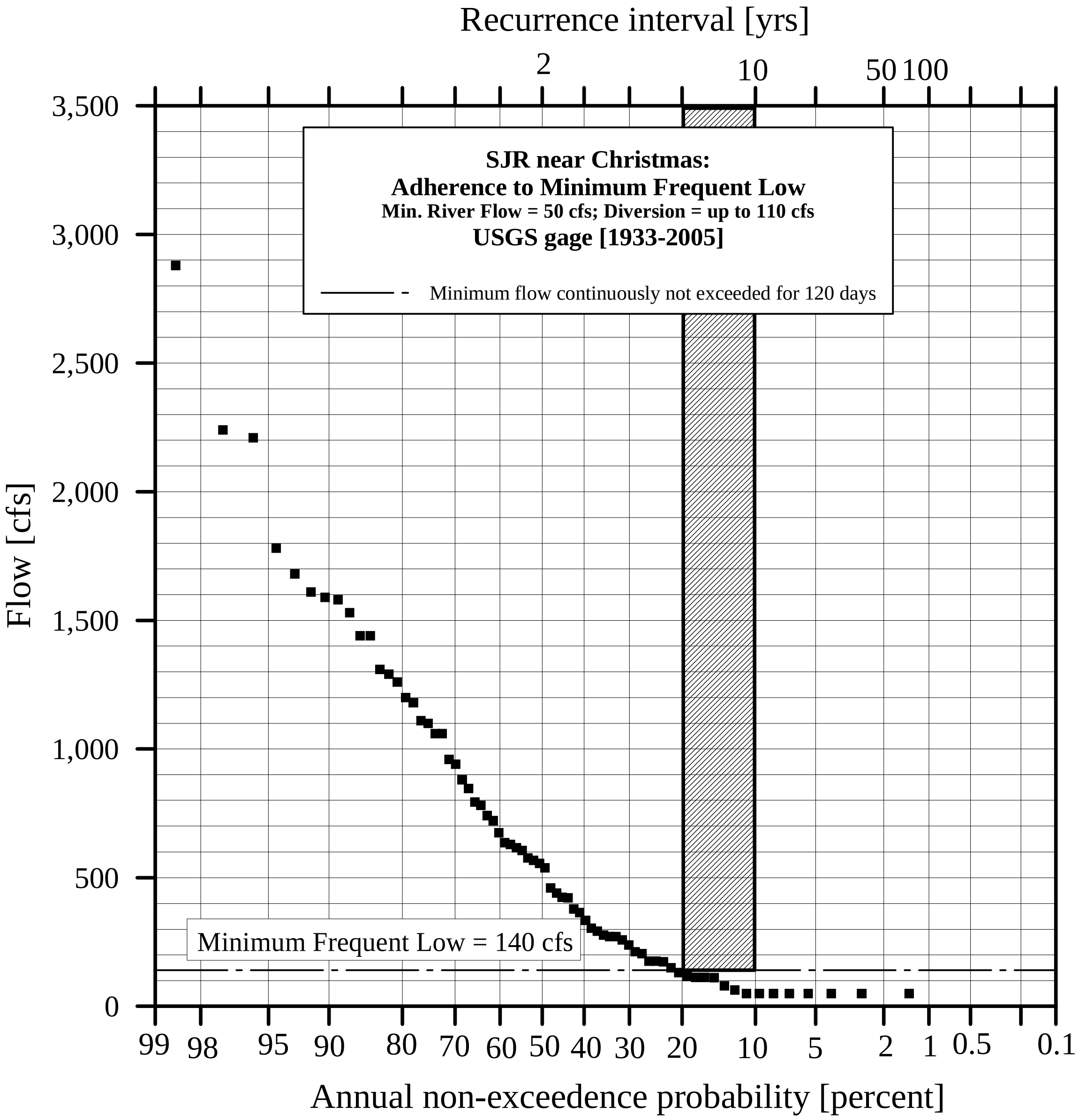

Figure D5 – 4. MFLs evaluation for the Minimum Frequent Low discharge

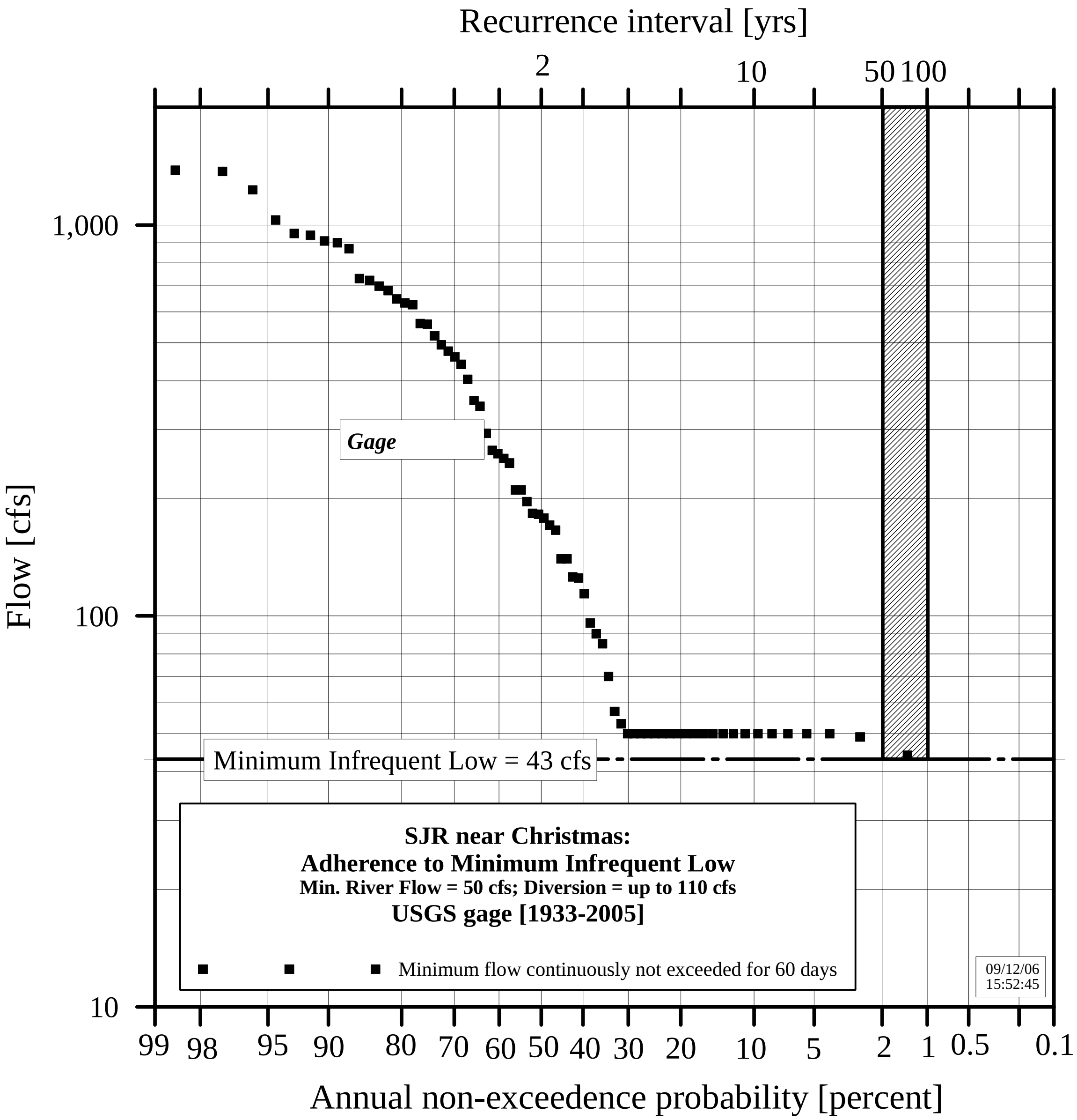

Figure D5 – 5. MFLs evaluation for the Minimum Infrequent Low discharge

APPENDIX D4

MFLs analysis for Scenario D4
1933-2006 USGS Discharges

MRF = 50 cfs; DD = 90 cfs

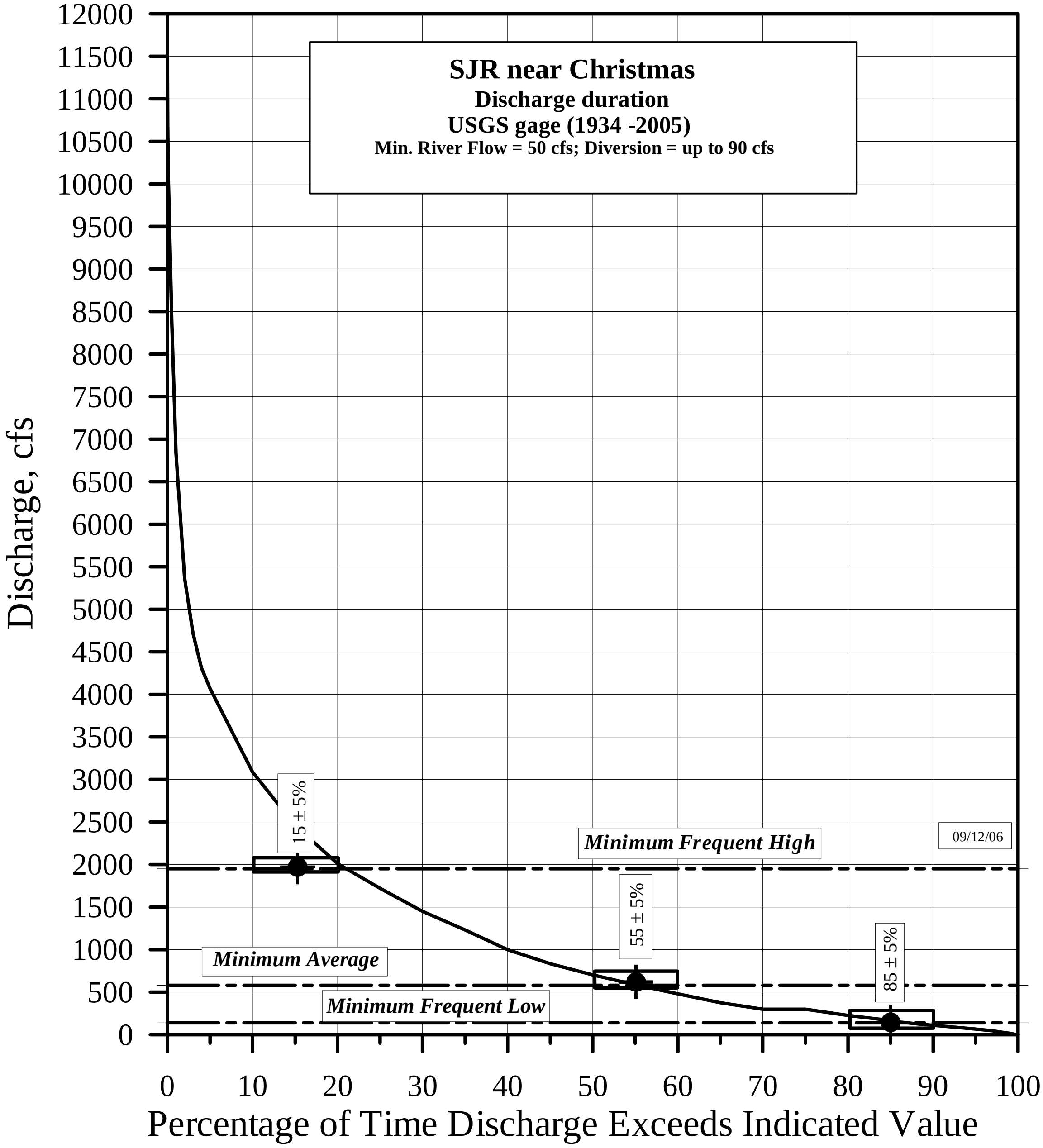

Figure D4 – 1. Flow duration

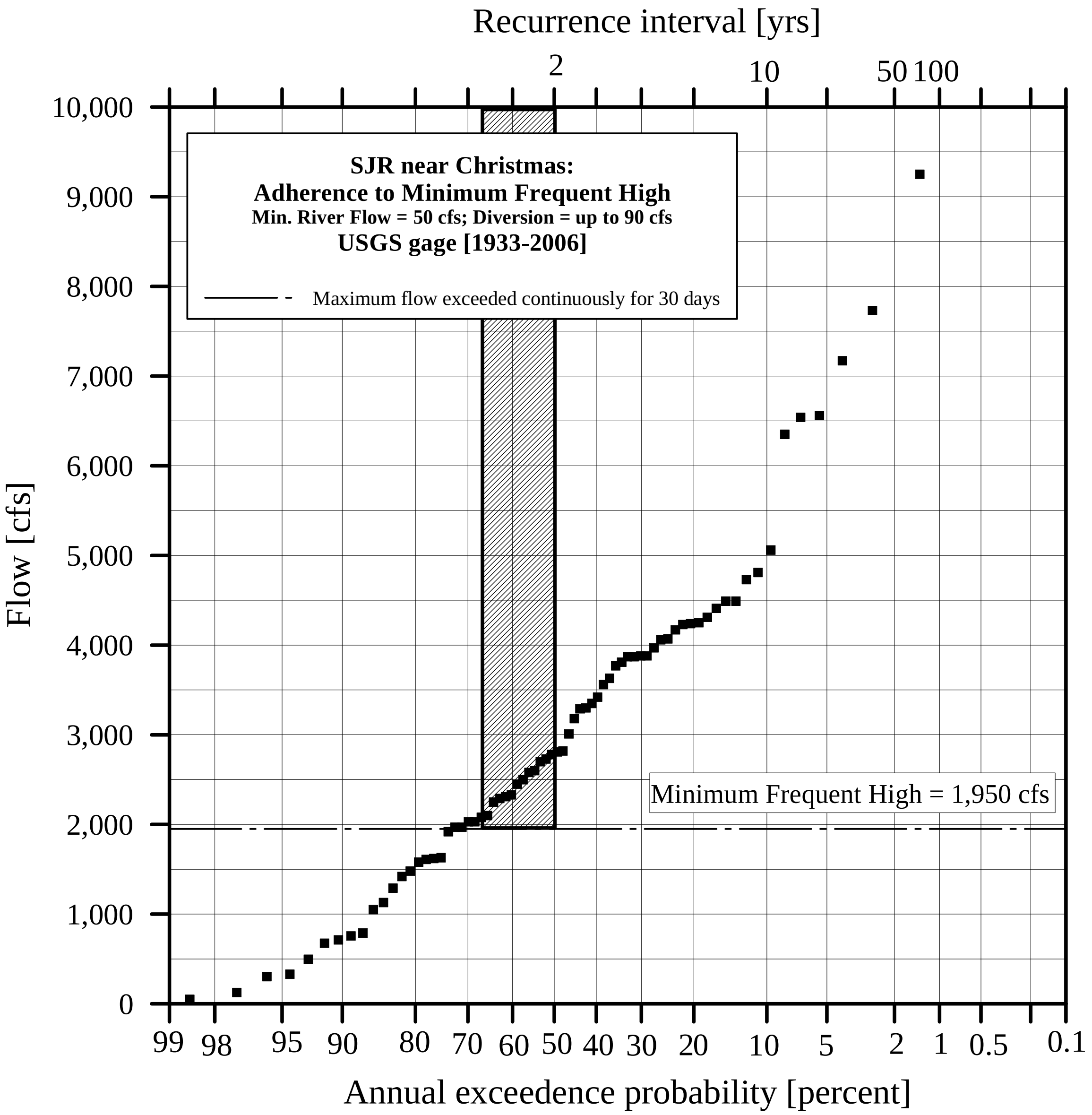

Figure D4 – 2. MFLs evaluation for the Minimum Frequent High discharge

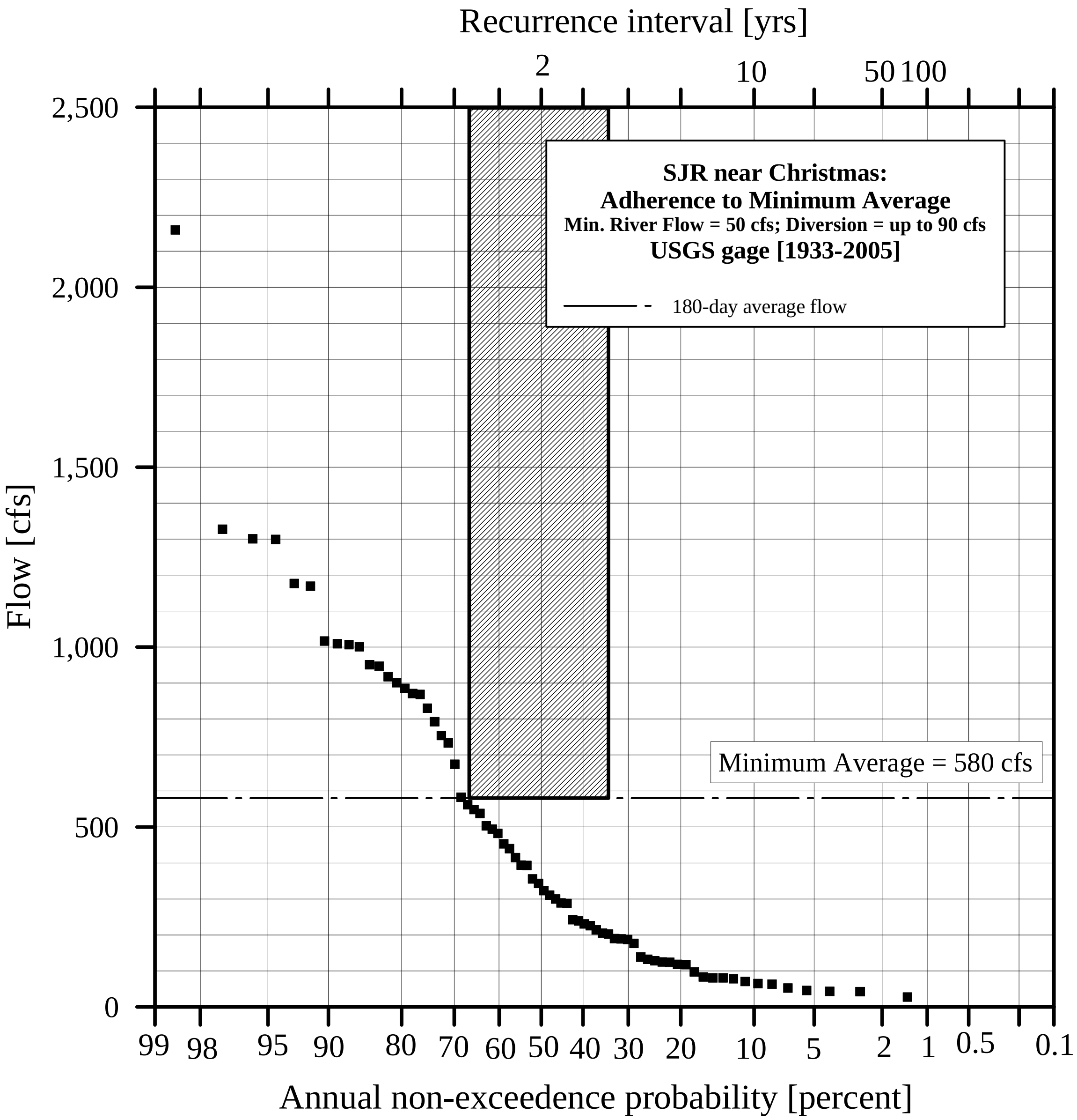

Figure D4 – 3. MFLs evaluation for the Minimum Average discharge

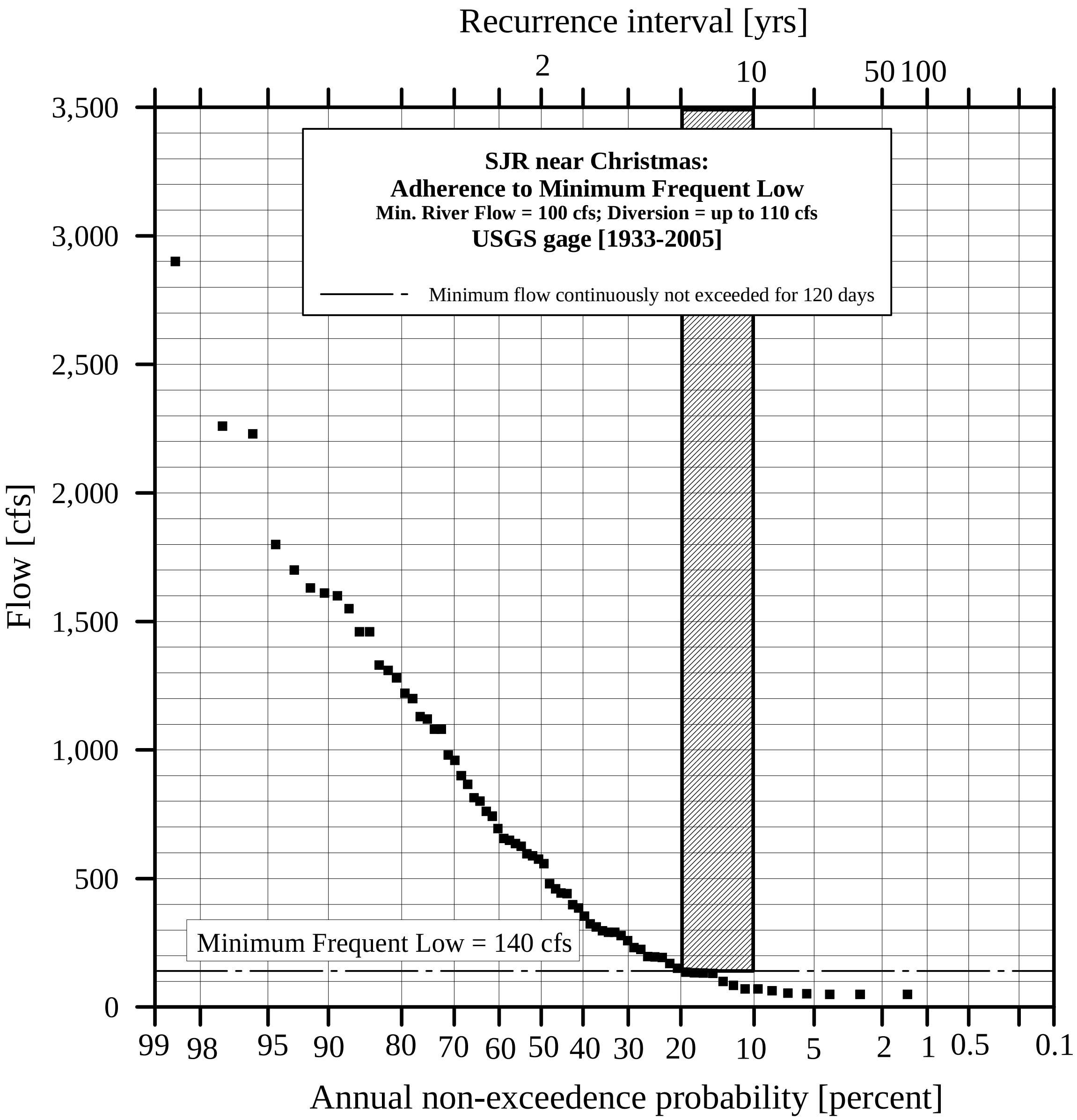

Figure D4 – 4. MFLs evaluation for the Minimum Frequent Low discharge

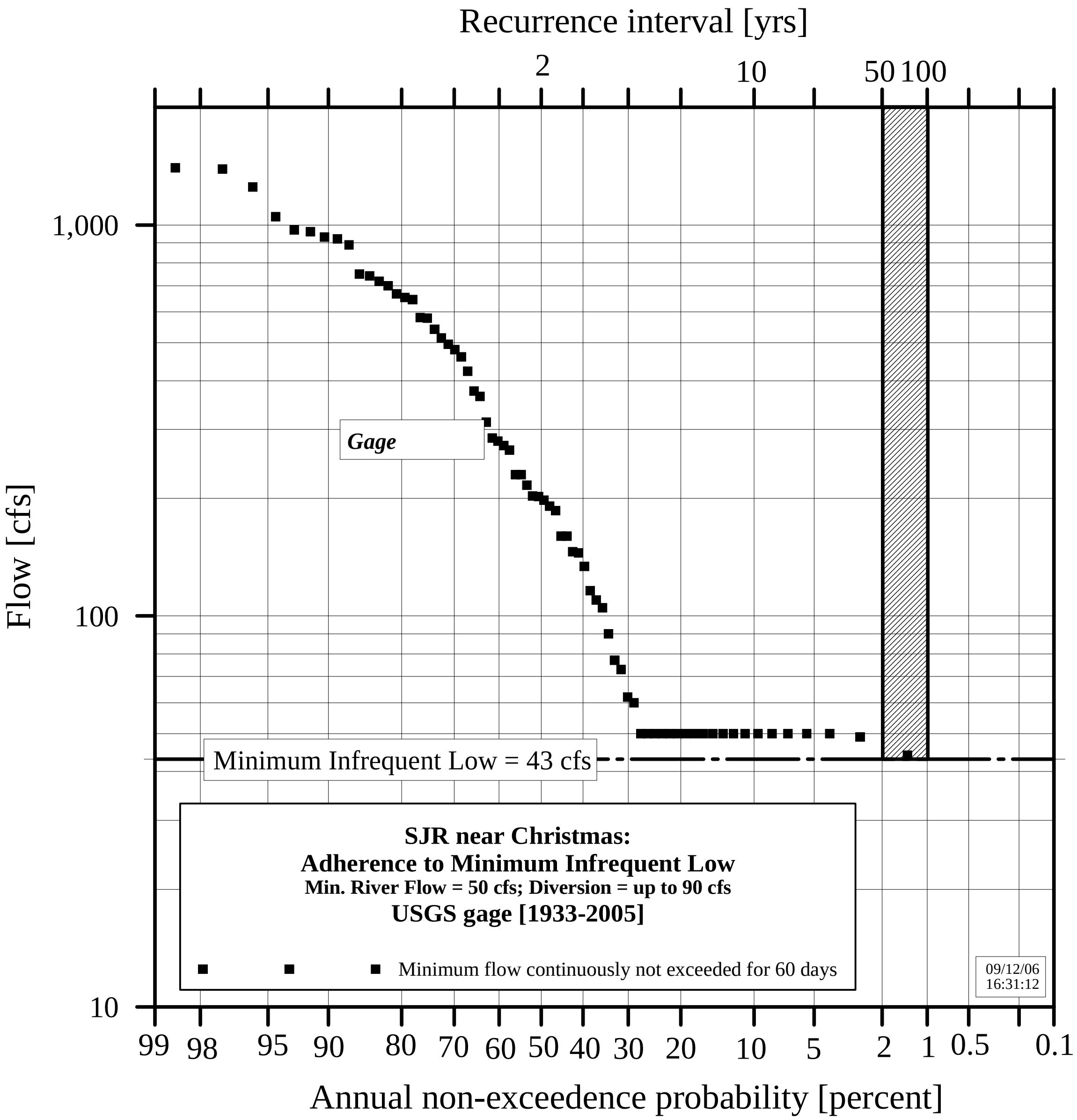

Figure D4 – 5. MFLs evaluation for the Minimum Infrequent Low discharge

APPENDIX D3

MFLs analysis for Scenario D3
1933-2006 USGS Discharges

MRF = 50 cfs; DD = 70 cfs

Only MA evaluated

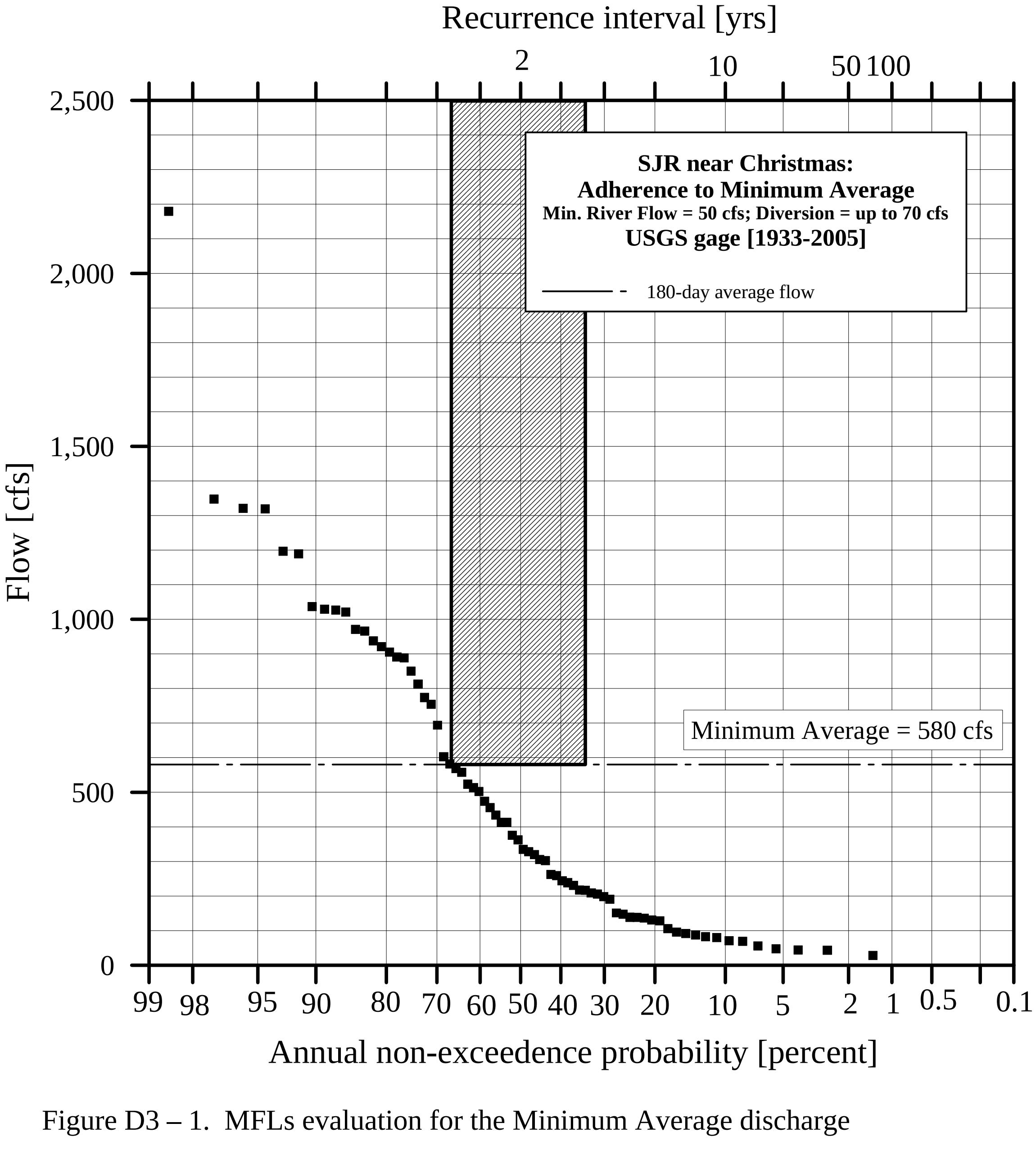

Figure D3 – 1. MFLs evaluation for the Minimum Average discharge

APPENDIX A4A

MFLs analysis for Scenario A4A
1933-2006 USGS Discharges

MRF = 300/600 cfs; DD = up to 90/130 cfs

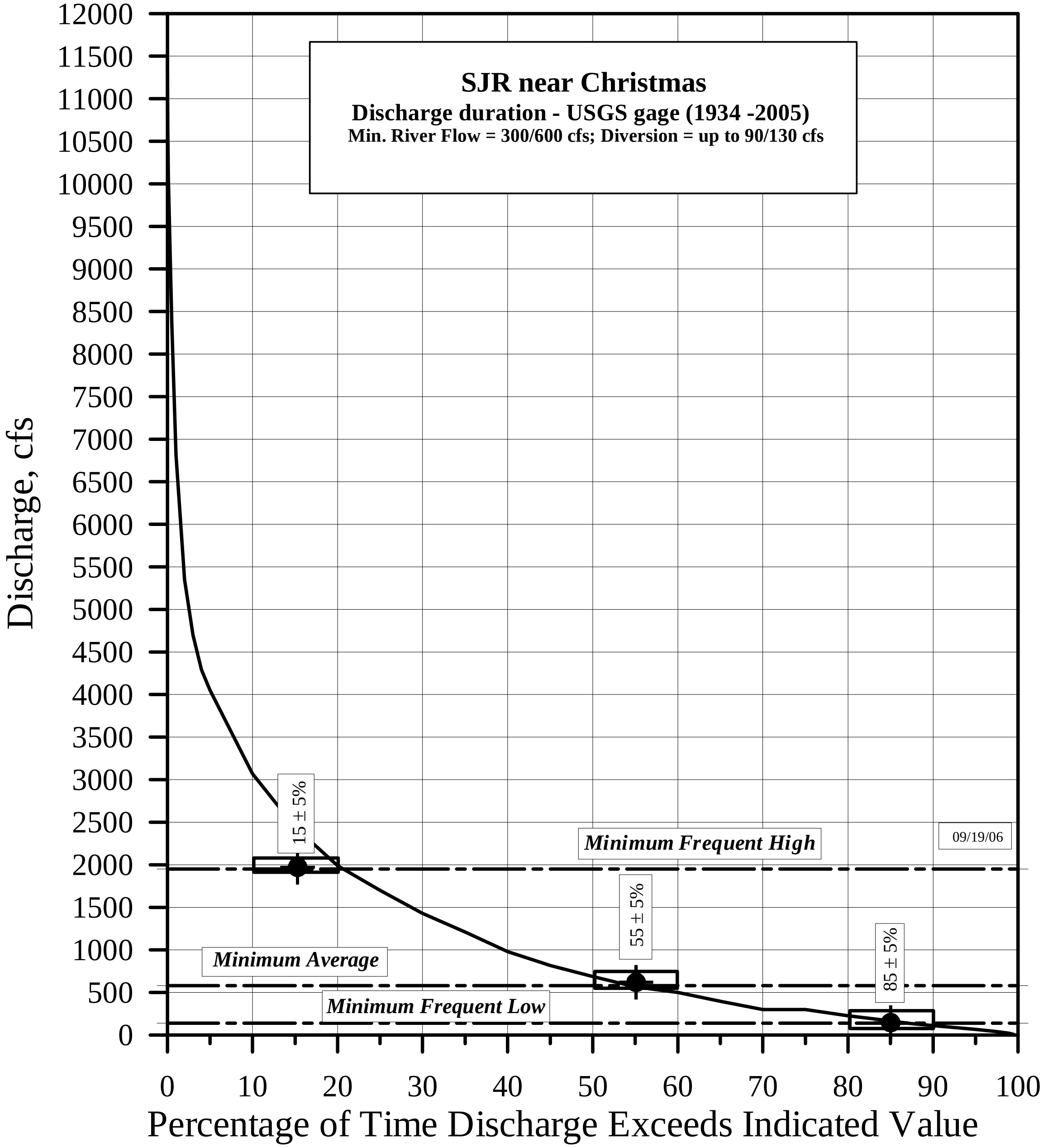

Figure A4A – 1. Flow duration

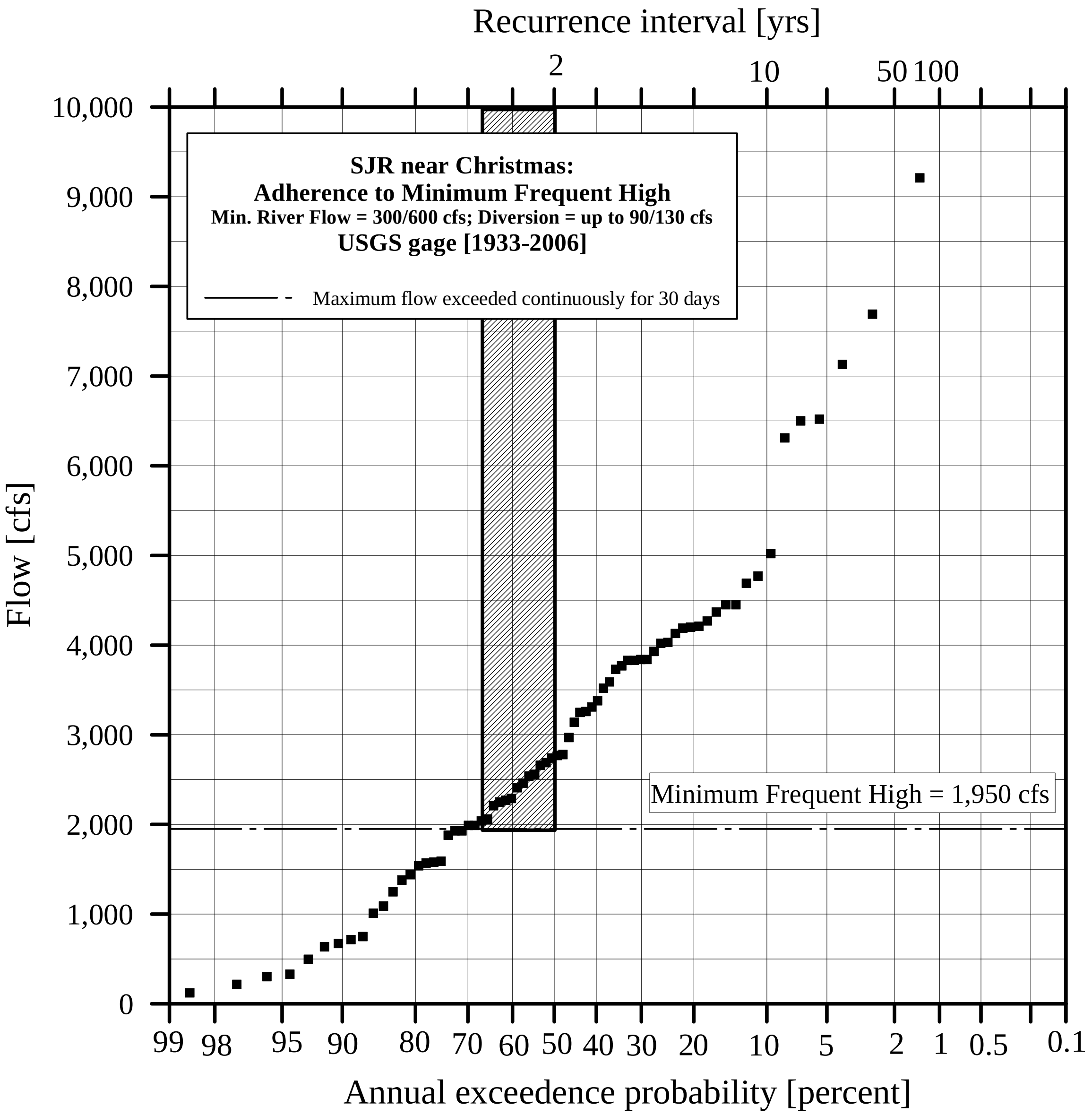

Figure A4A – 2. MFLs evaluation for the Minimum Frequent High discharge

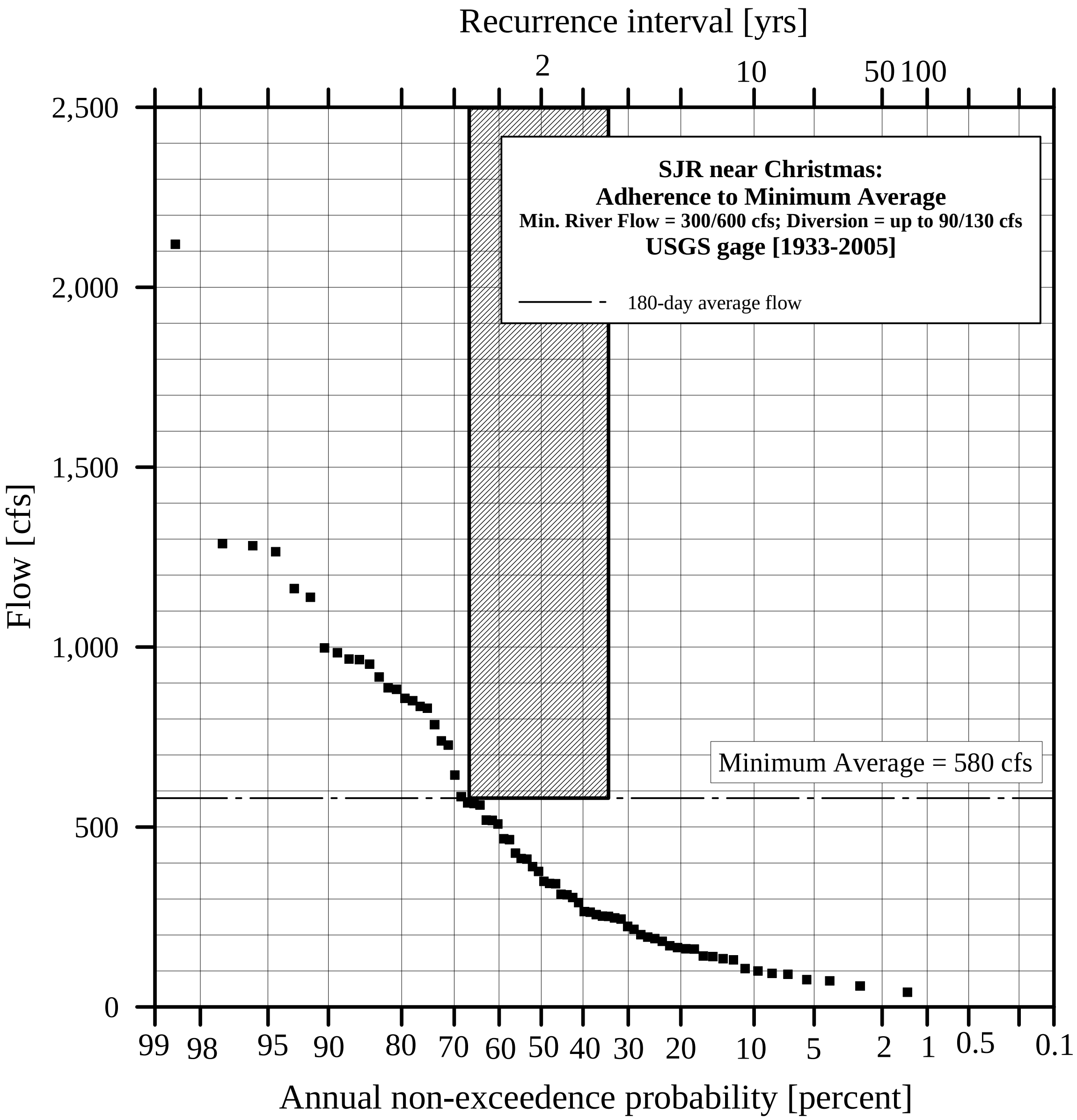

Figure A4A – 3. MFLs evaluation for the Minimum Average discharge

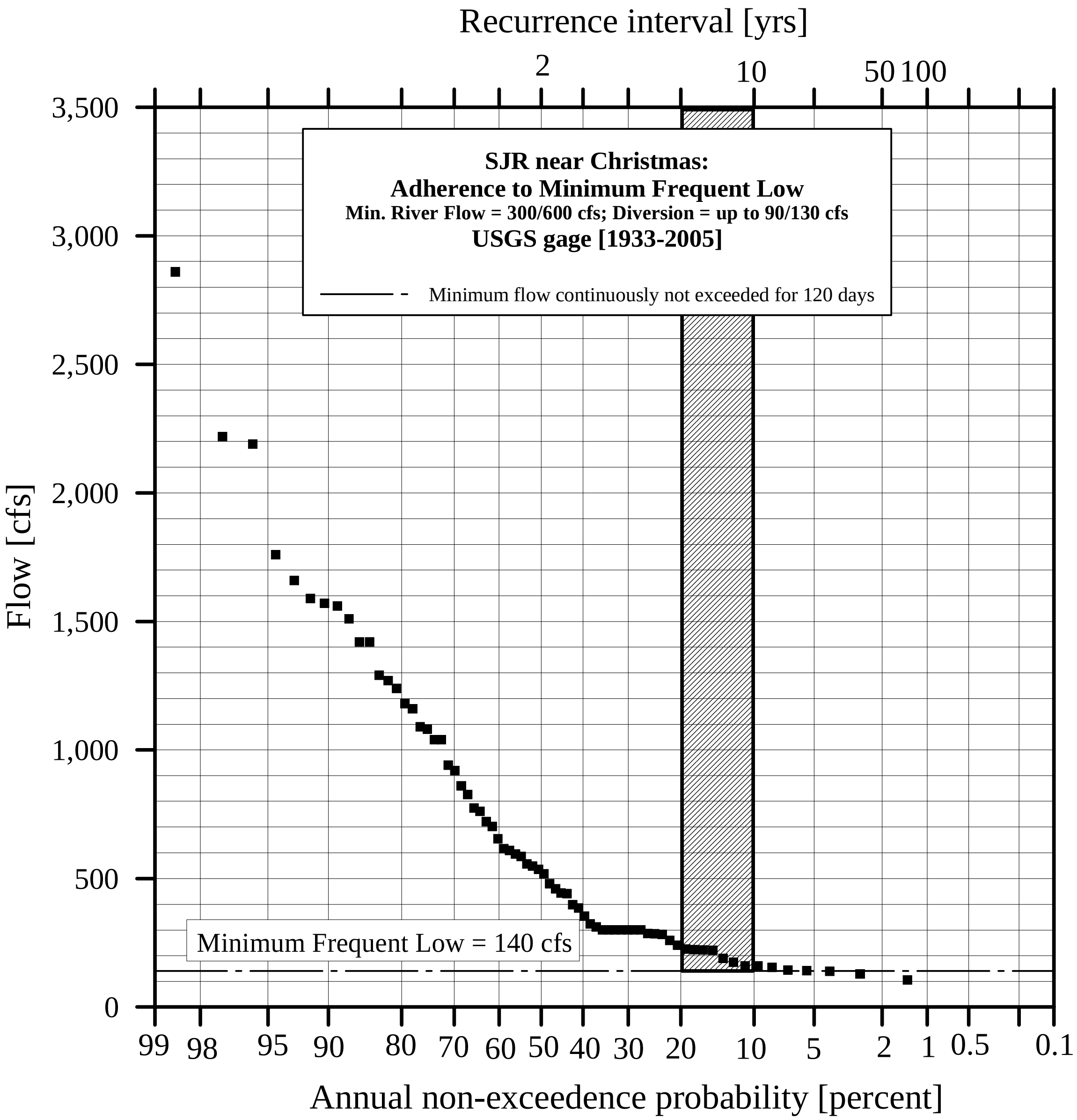

Figure A4A – 4. MFLs evaluation for the Minimum Frequent Low discharge

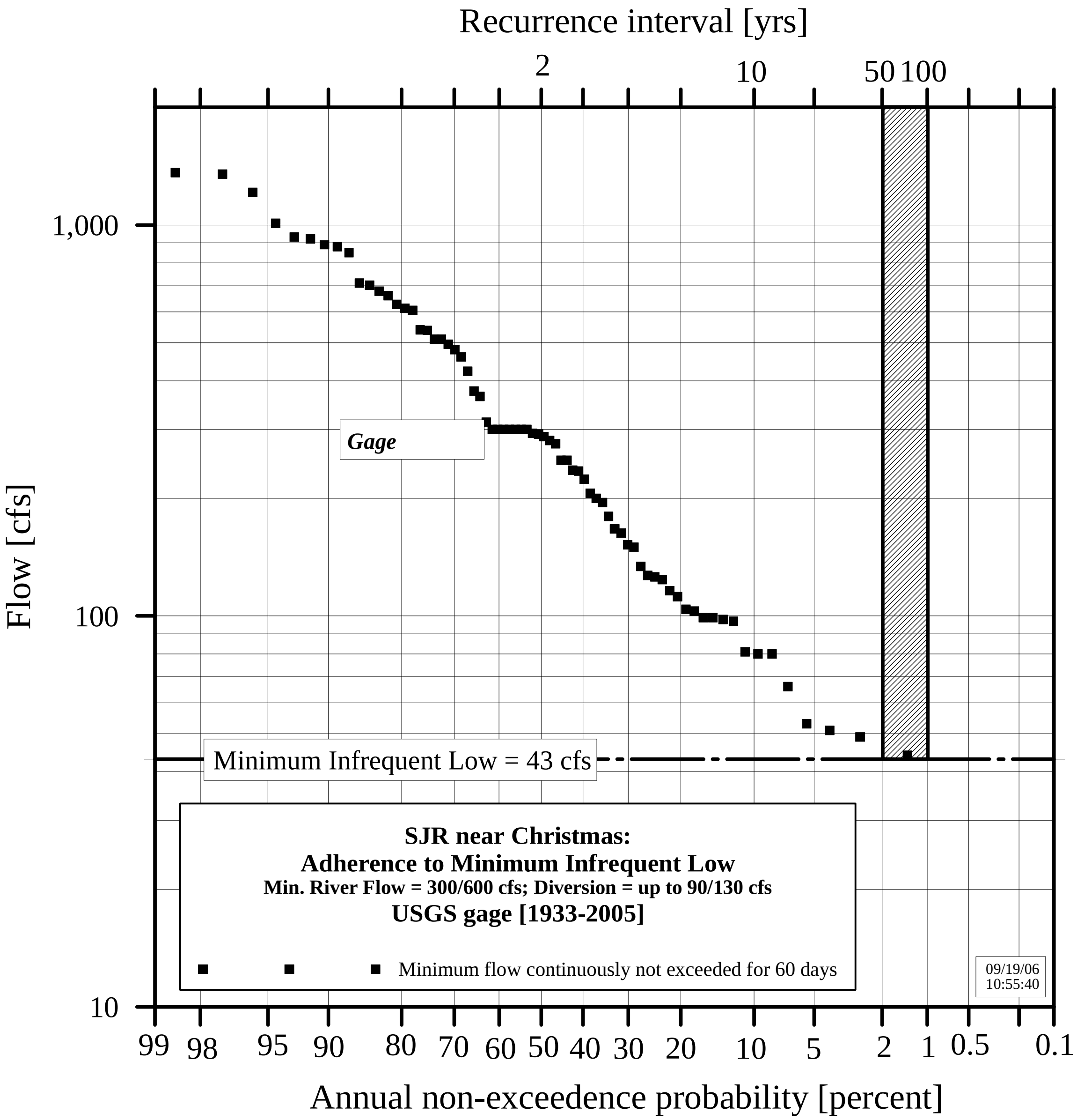

Figure A4A – 5. MFLs evaluation for the Minimum Infrequent Low discharge

APPENDIX D3A

MFLs analysis for Scenario D3A
1933-2006 USGS Discharges

MRF = 50/400 cfs; DD = 70/100 cfs

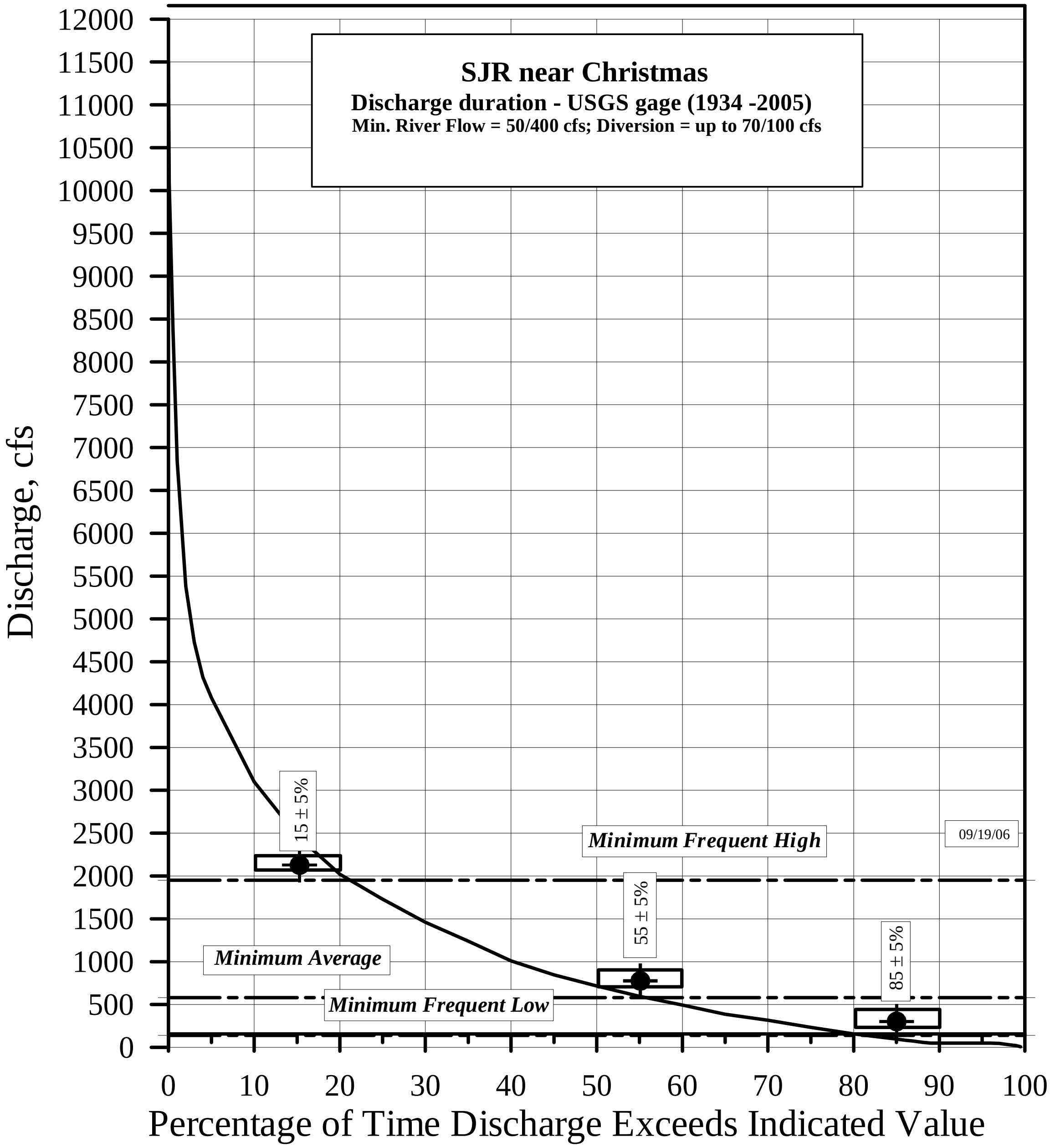

Figure D3A – 1. Flow duration

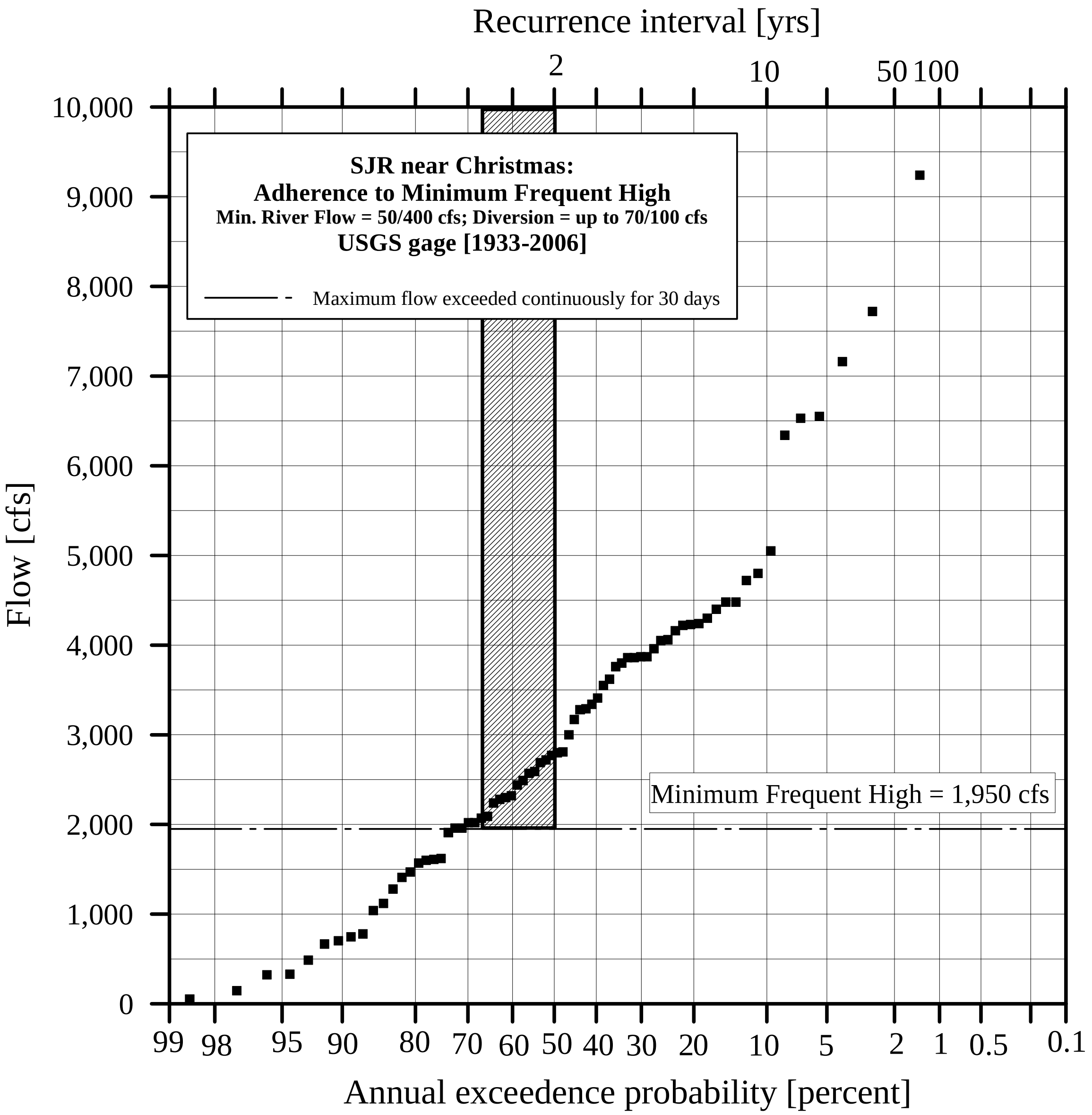

Figure D3A – 2. MFLs evaluation for the Minimum Frequent High discharge

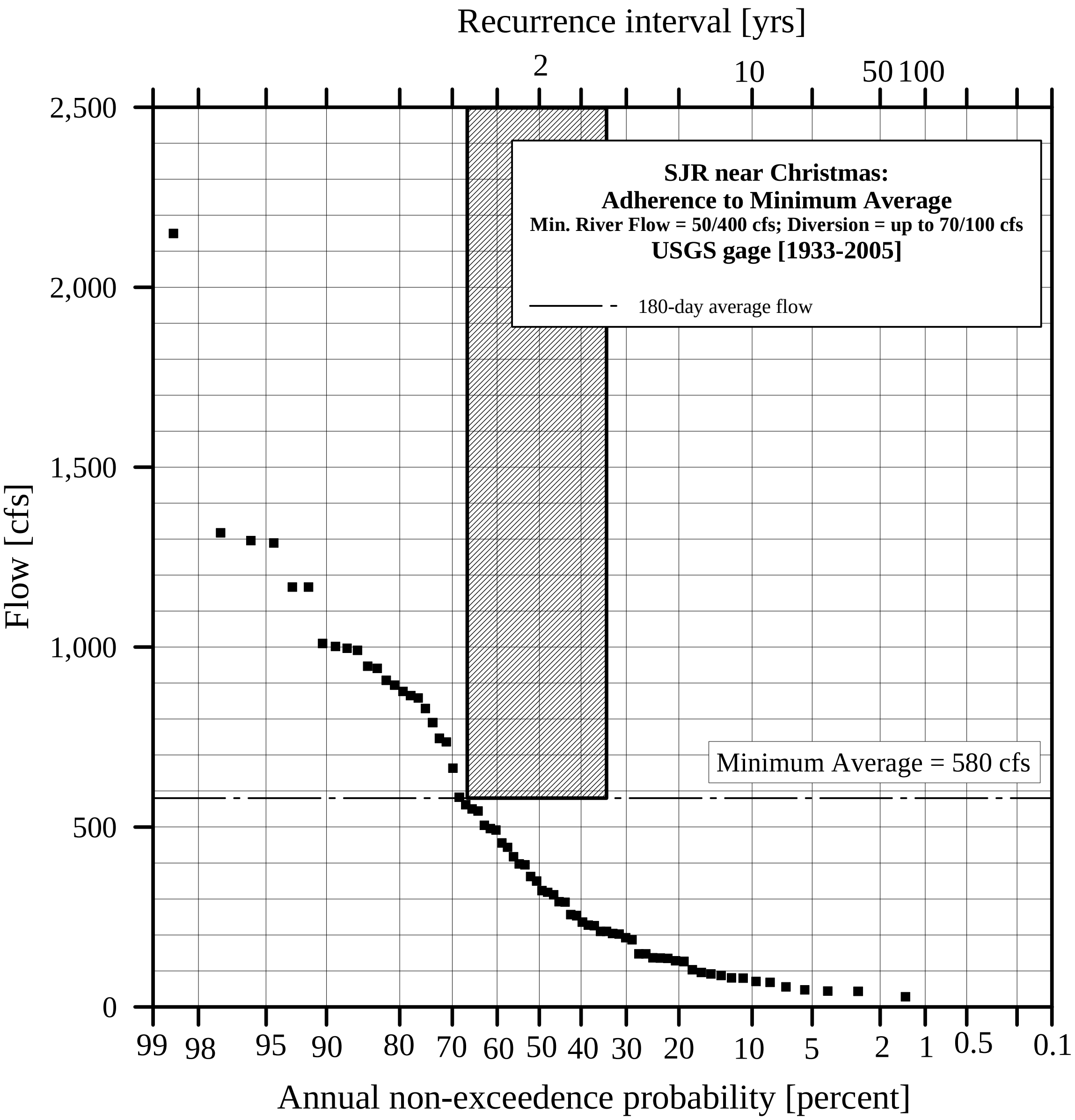

Figure D3A – 3. MFLs evaluation for the Minimum Average discharge

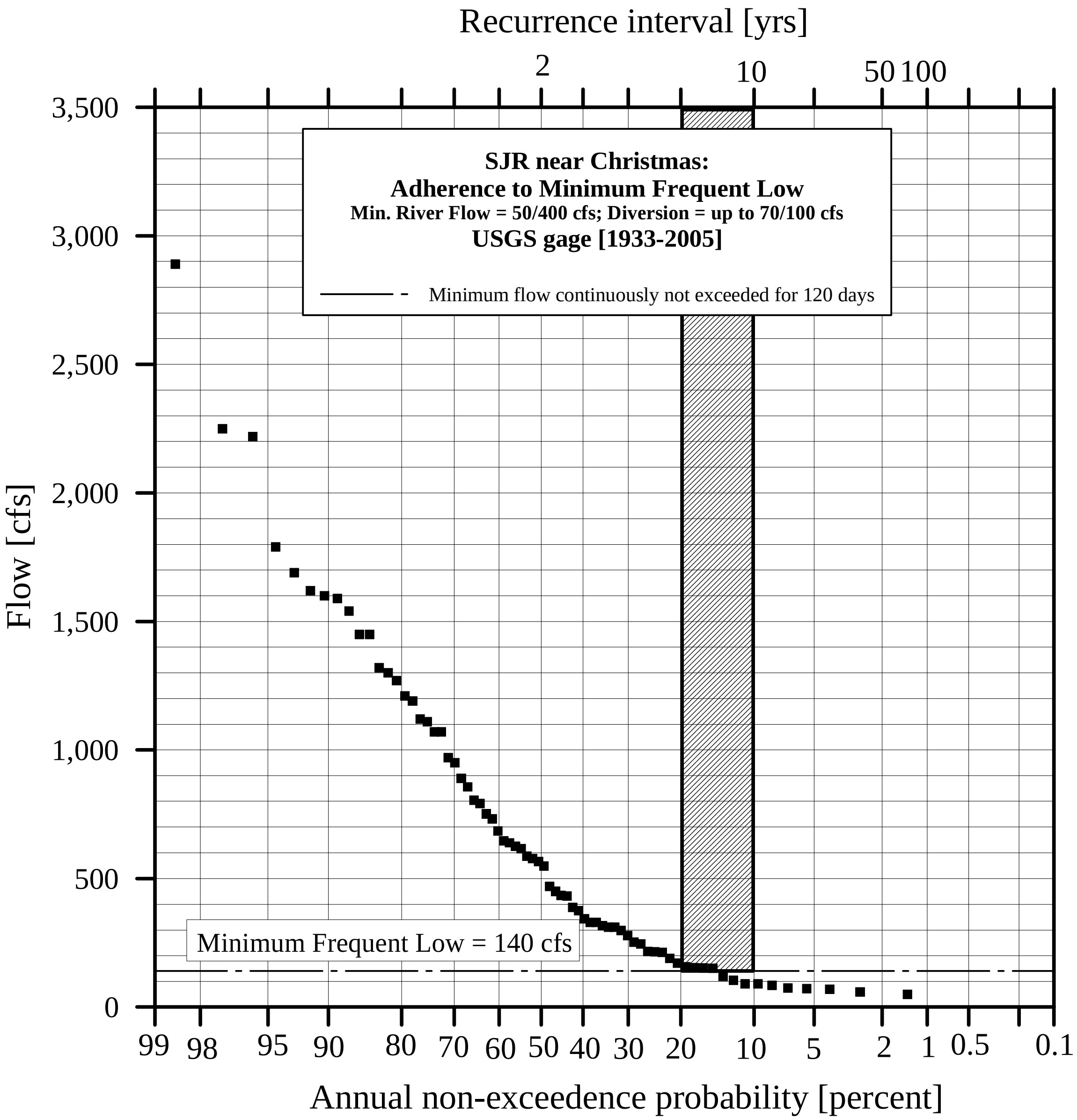

Figure D3A – 4. MFLs evaluation for the Minimum Frequent Low discharge

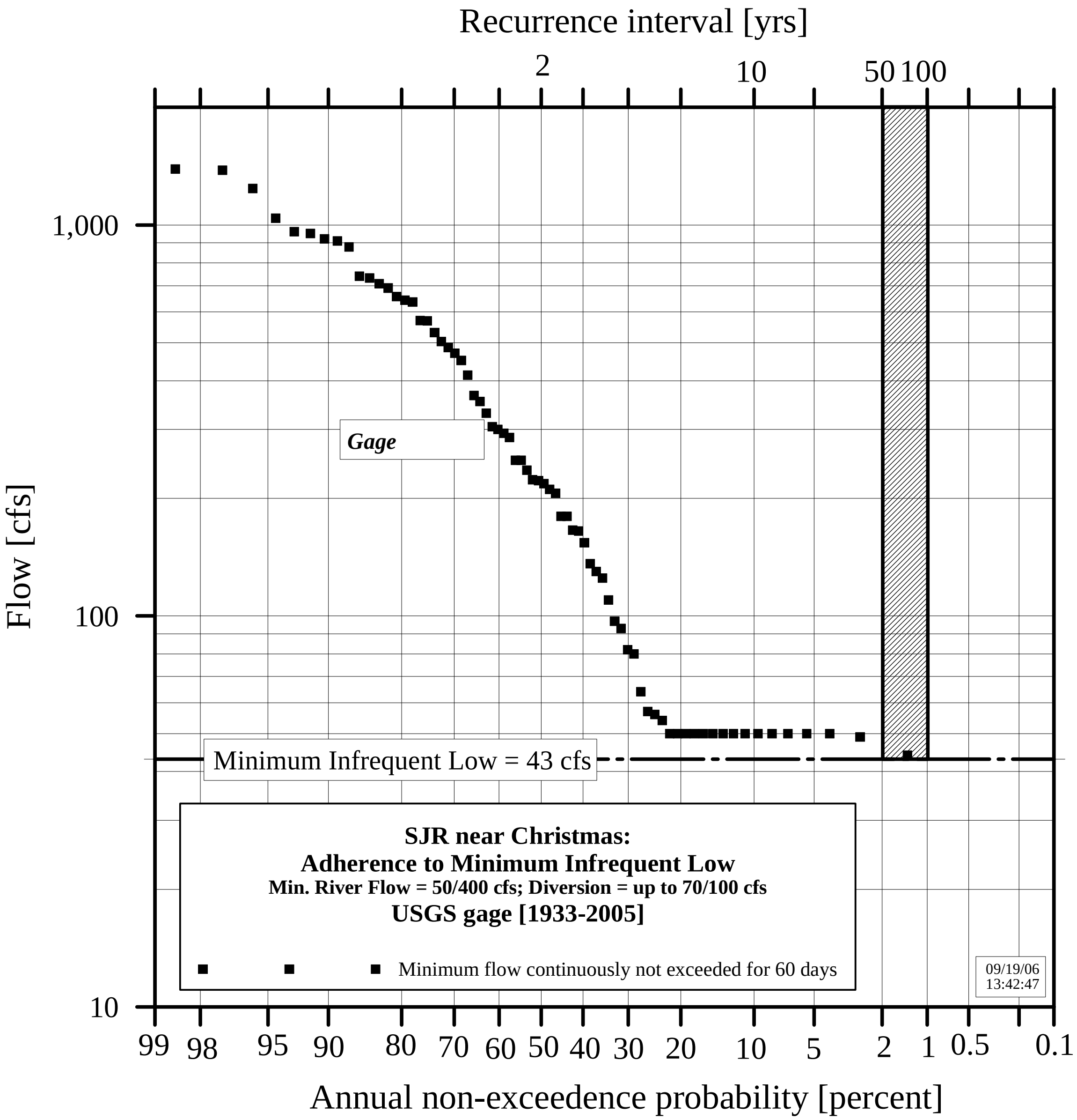

Figure D3A – 5. MFLs evaluation for the Minimum Infrequent Low discharge

APPENDIX A5A

Rao’ Upper St. Johns Model: Project conditions 2004

MFLs analysis for Scenario A5A
1942-2001 Simulated discharges

MRF = 300 cfs; DD = 110 cfs

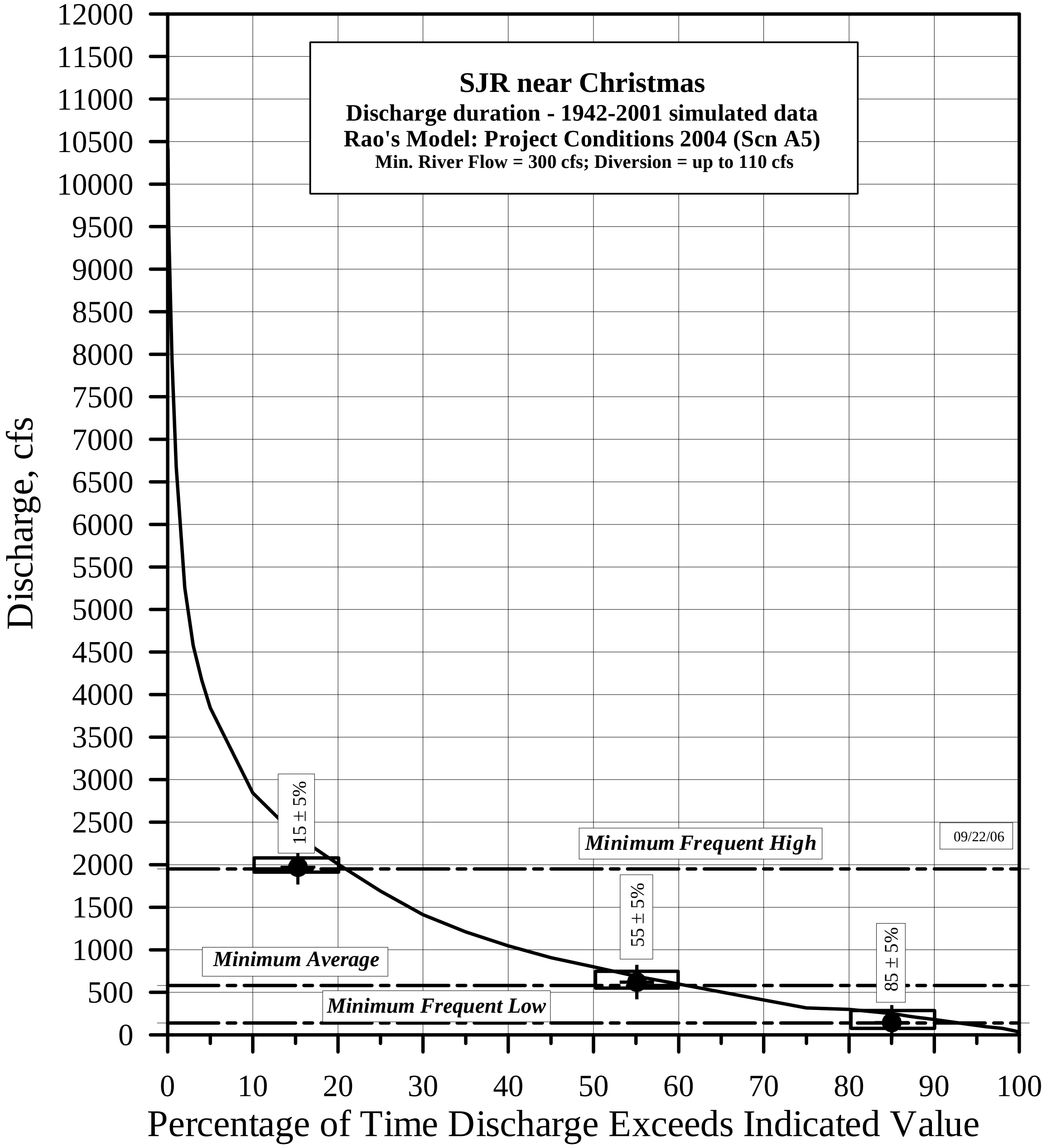

Figure A5A – 1. Flow duration

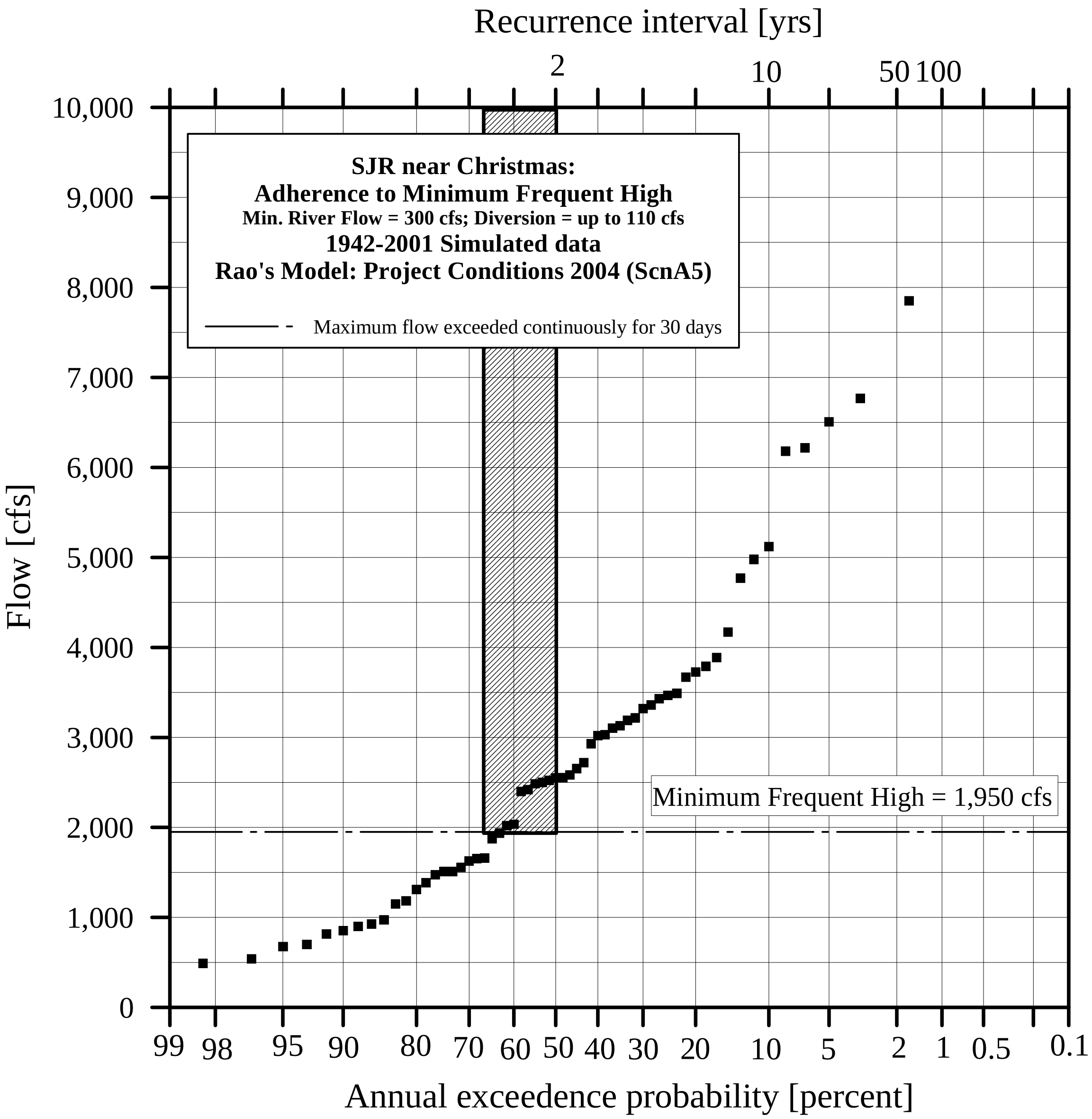

Figure A5A – 2. MFLs evaluation for the Minimum Frequent High discharge

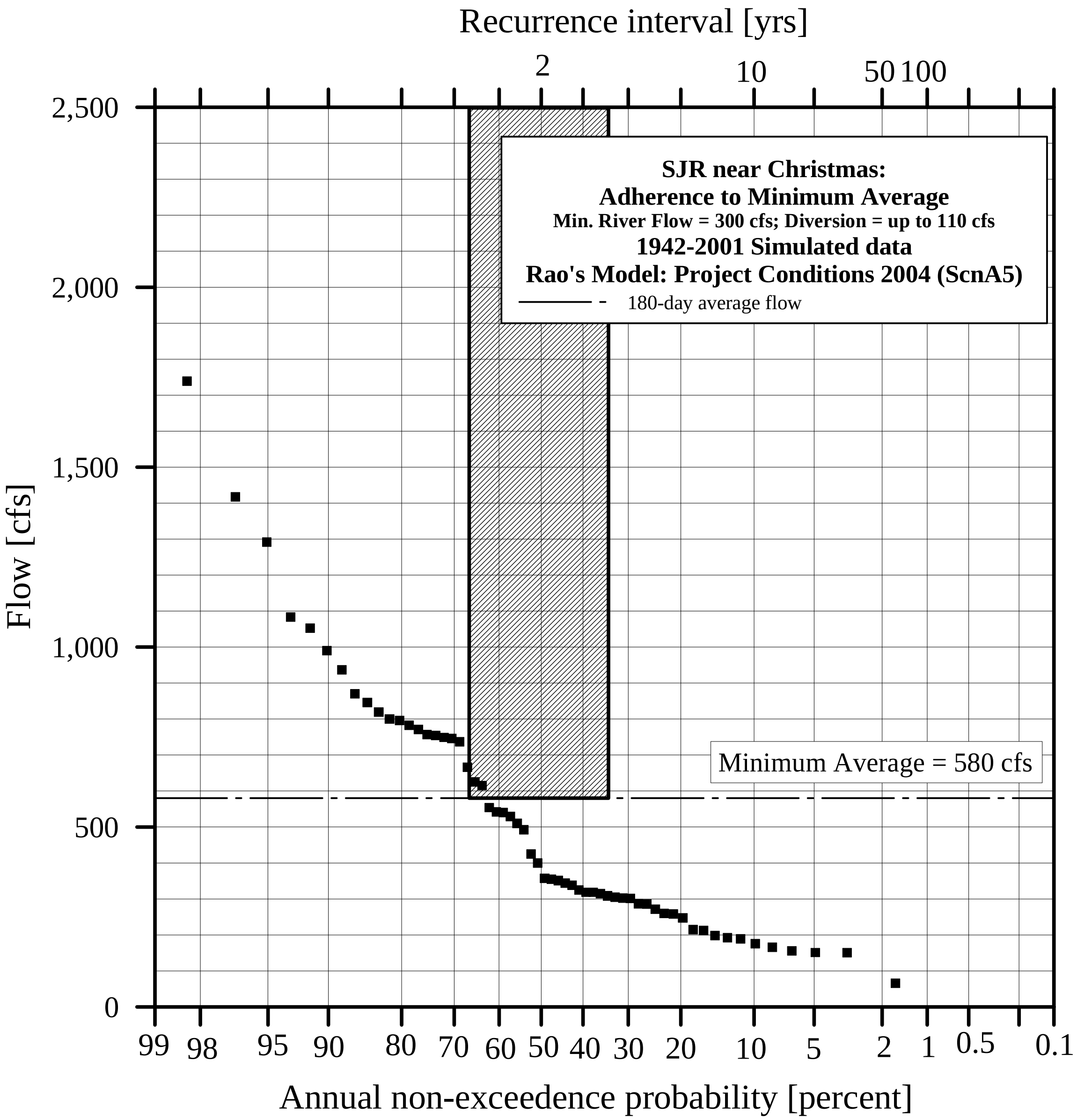

Figure A5A – 3. MFLs evaluation for the Minimum Average discharge

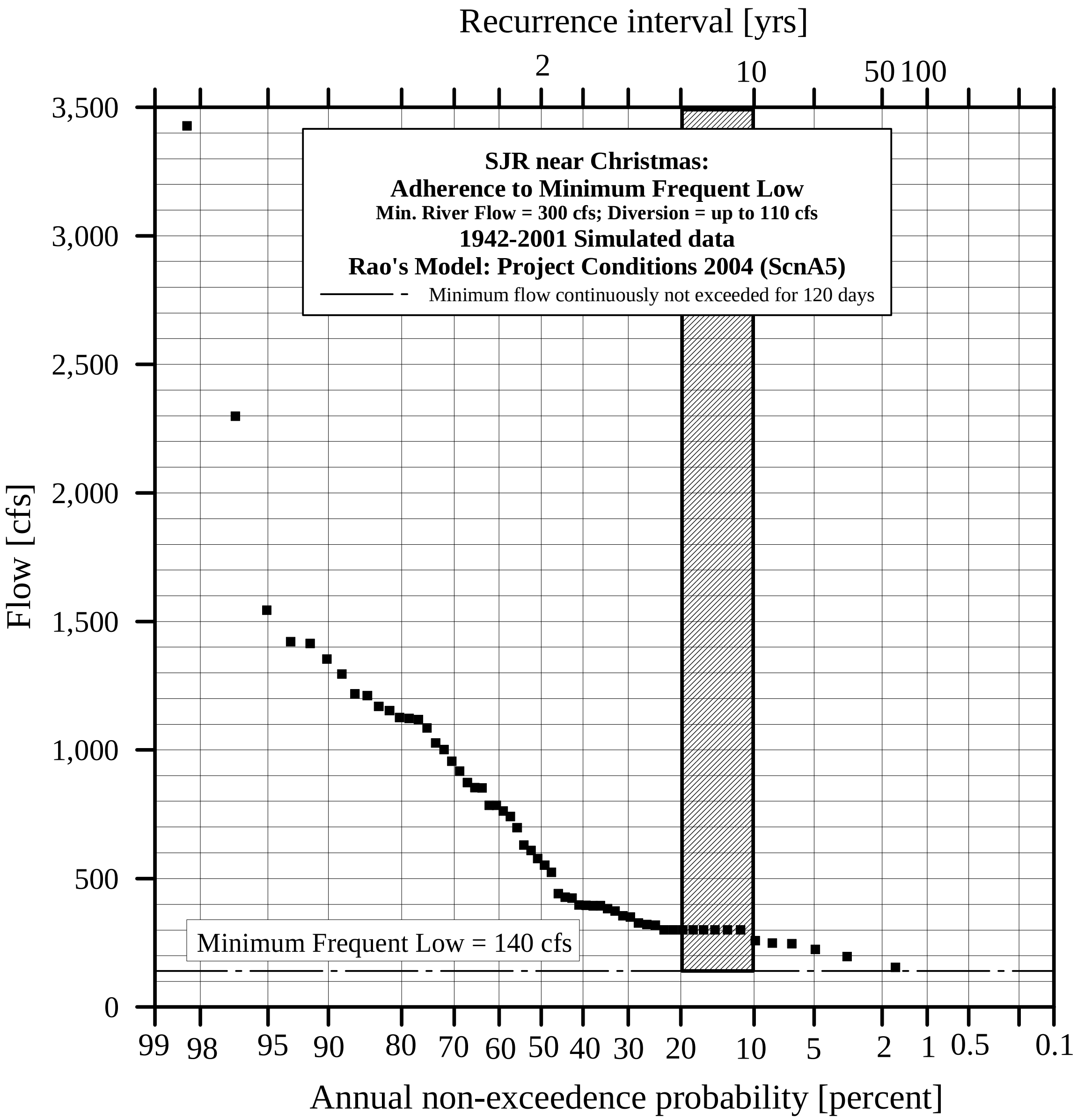

Figure A5A – 4. MFLs evaluation for the Minimum Frequent Low discharge

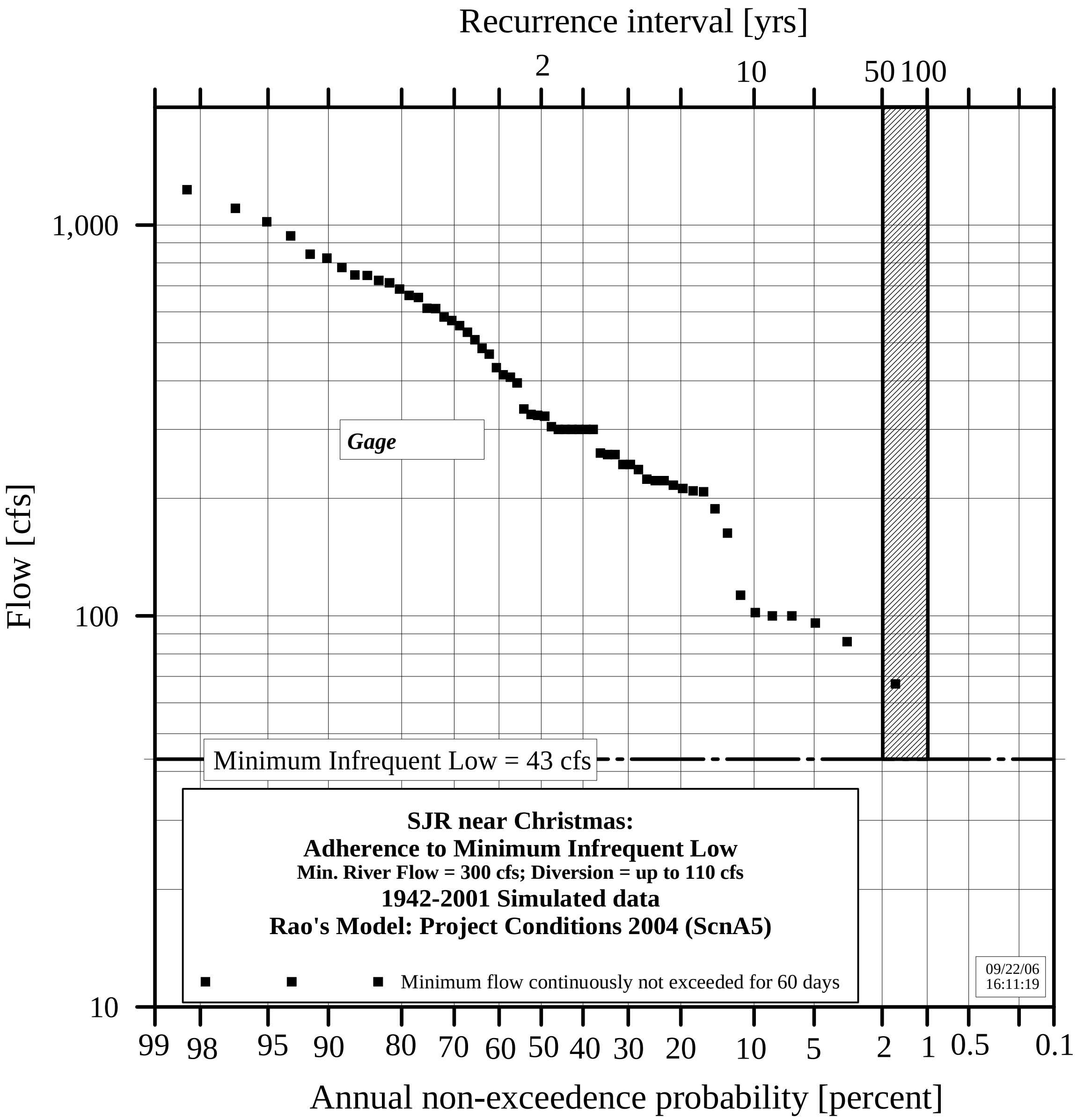

Figure A5A – 5. MFLs evaluation for the Minimum Infrequent Low discharge

APPENDIX B4A

Rao' Upper St. Johns Model: Project conditions 2004

MFLs analysis for Scenario B4A
1942-2001 Simulated discharges

MRF = 200 cfs; DD = 90 cfs

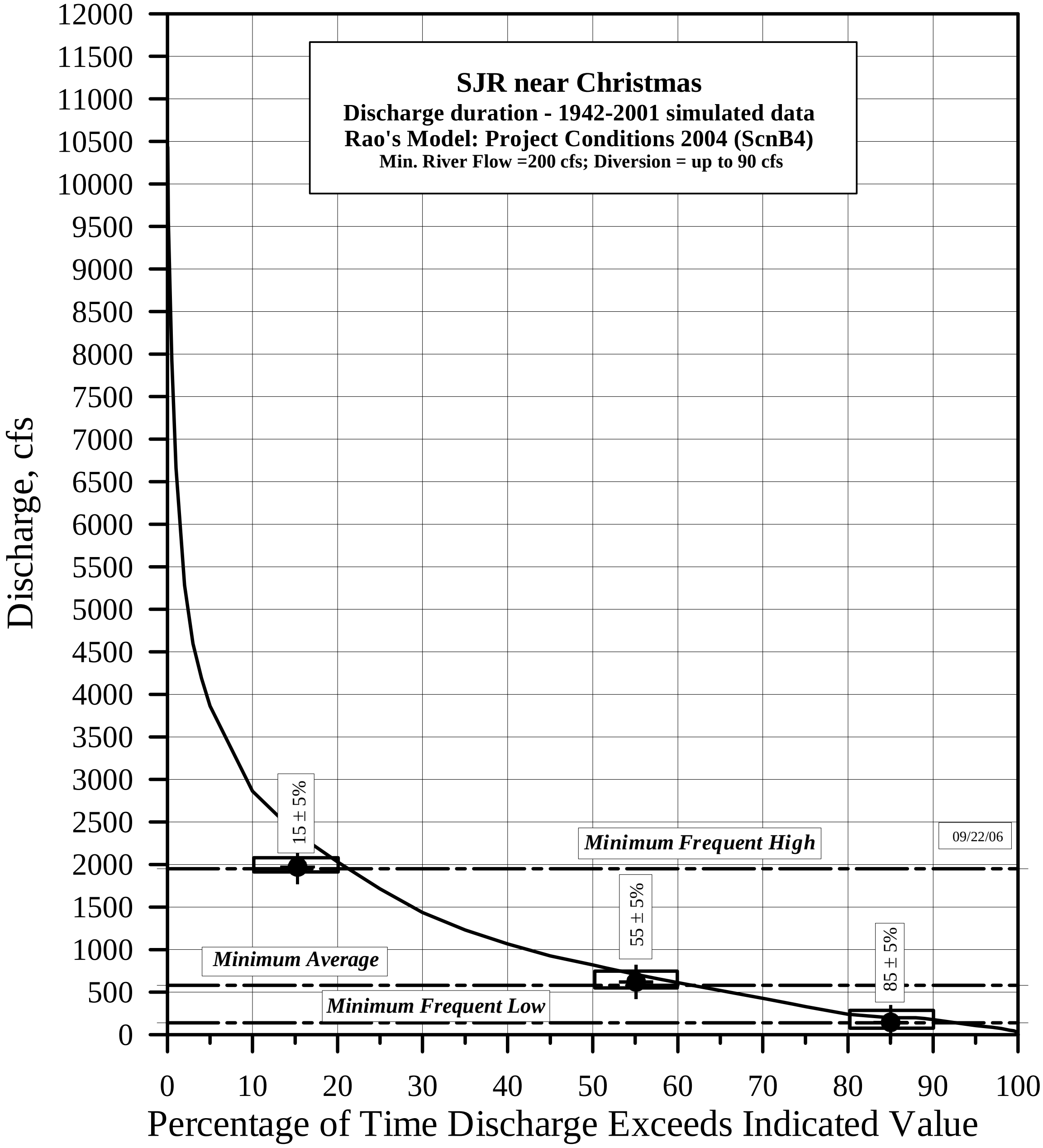

Figure B4A – 1. Flow duration

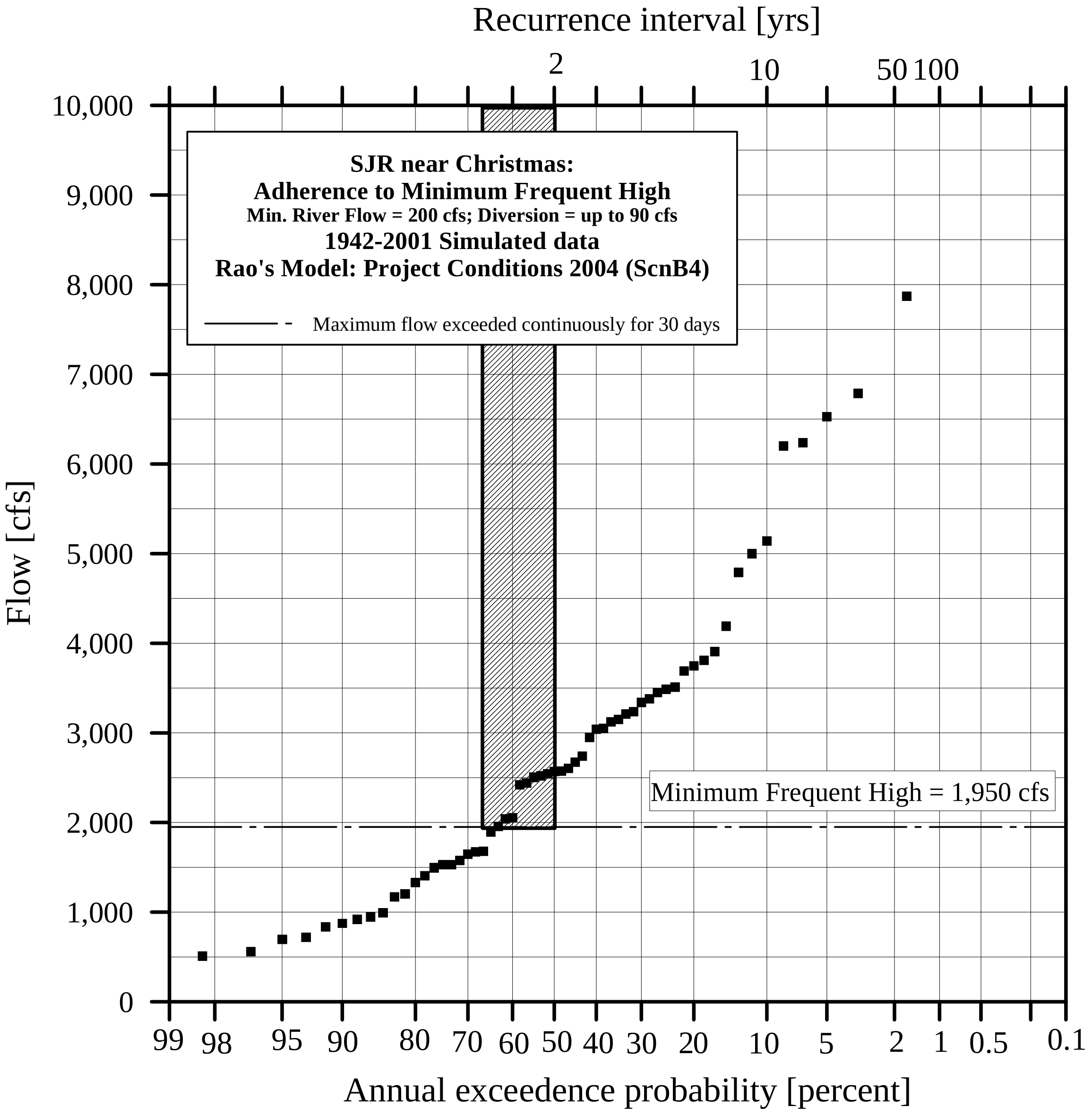

Figure B4A – 2. MFLs evaluation for the Minimum Frequent High discharge

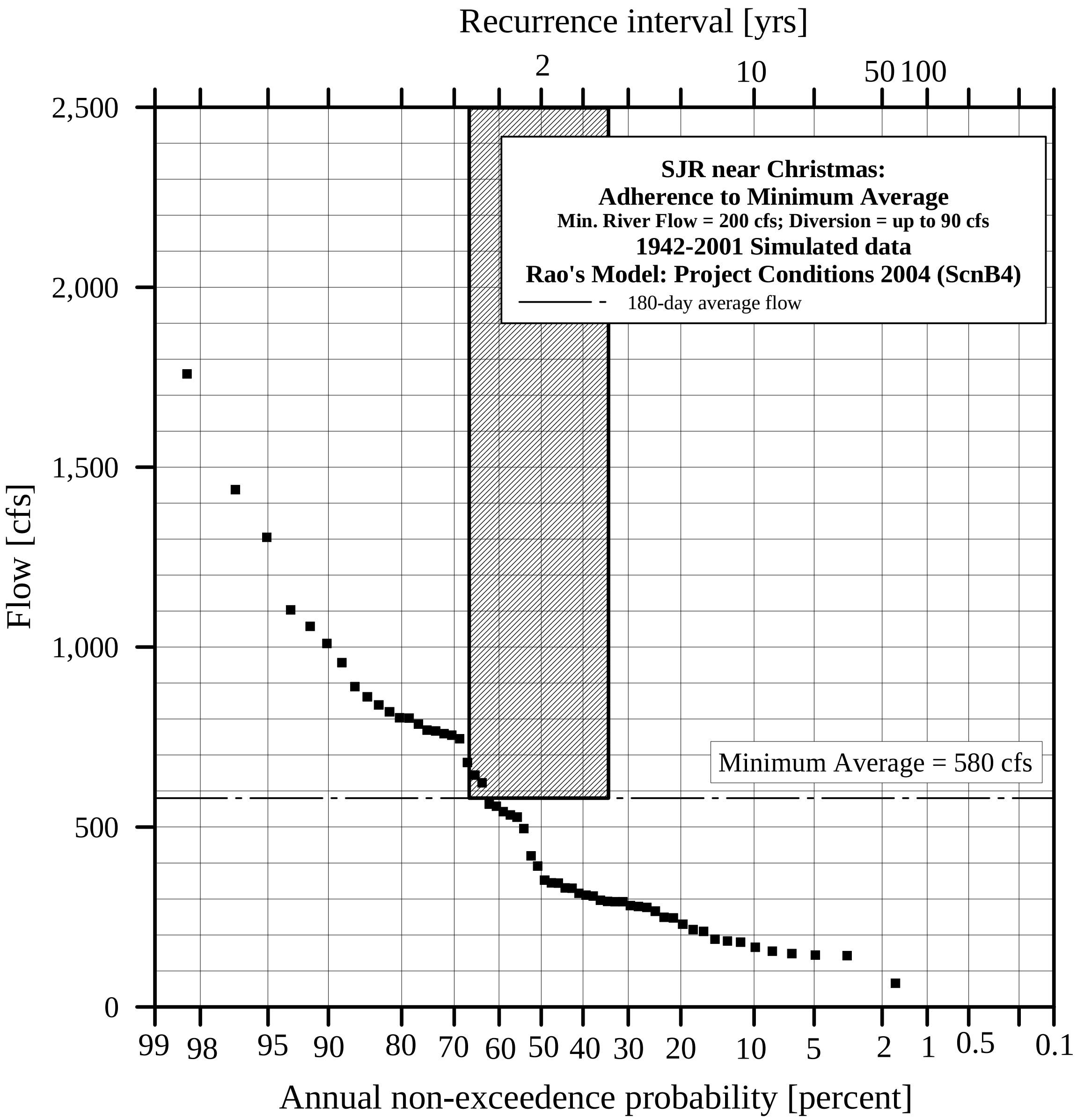

Figure B4A – 3. MFLs evaluation for the Minimum Average discharge

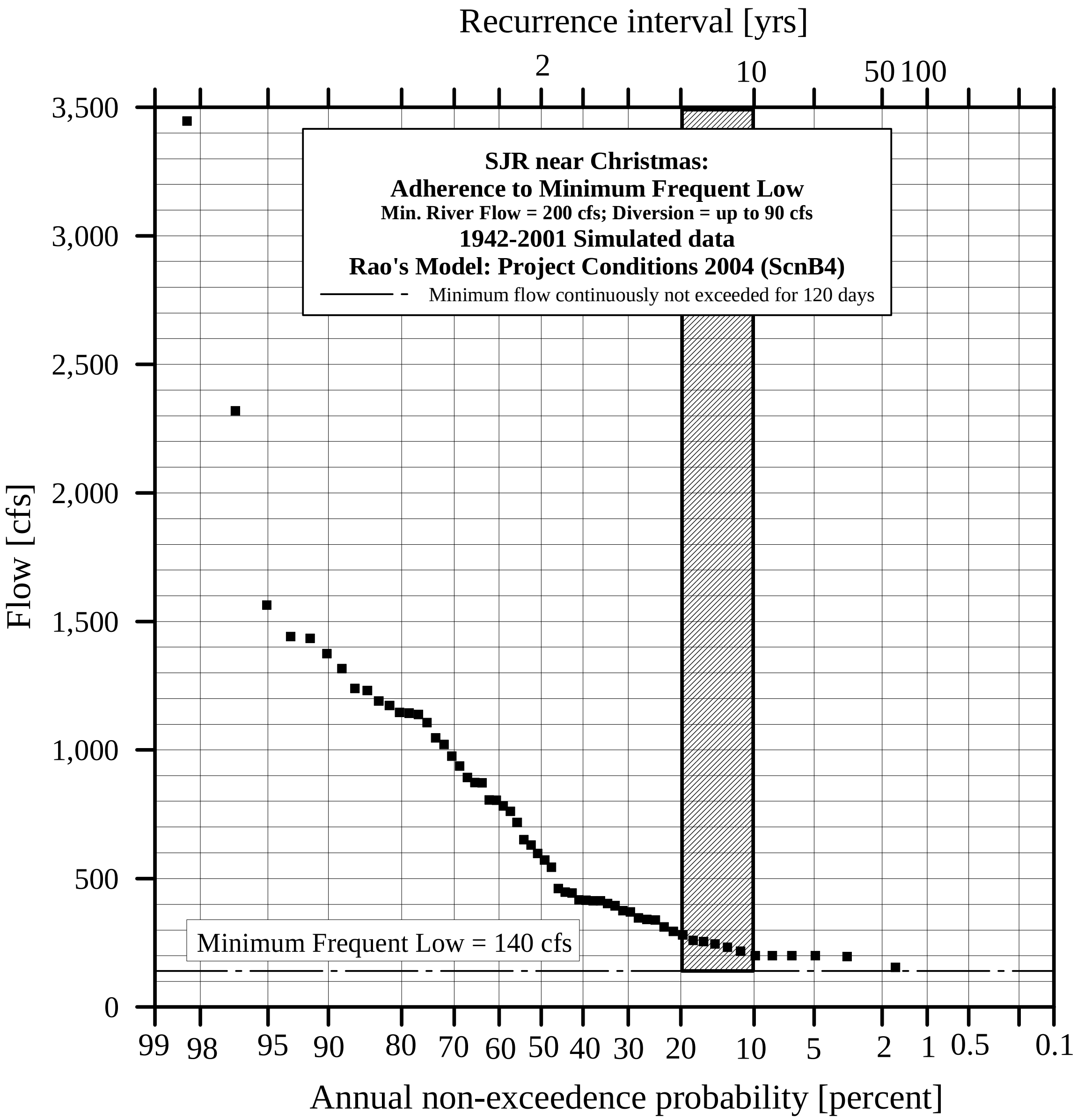

Figure B4A – 4. MFLs evaluation for the Minimum Frequent Low discharge

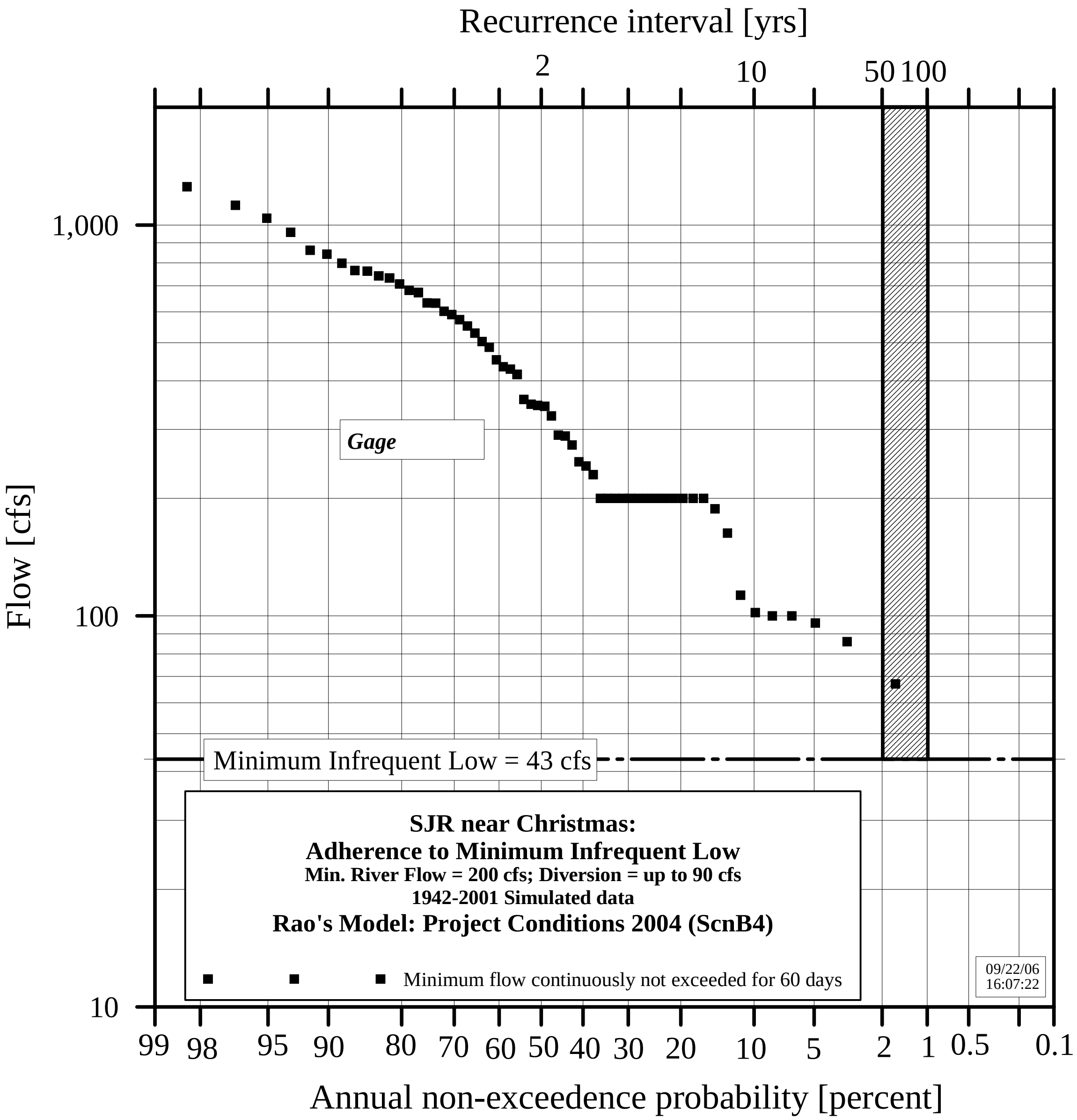

Figure B4A – 5. MFLs evaluation for the Minimum Infrequent Low discharge

APPENDIX C4A

Rao’ Upper St. Johns Model: Project conditions 2004

MFLs analysis for Scenario C4A
1942-2001 Simulated discharges

MRF = 100 cfs; DD = 90 cfs

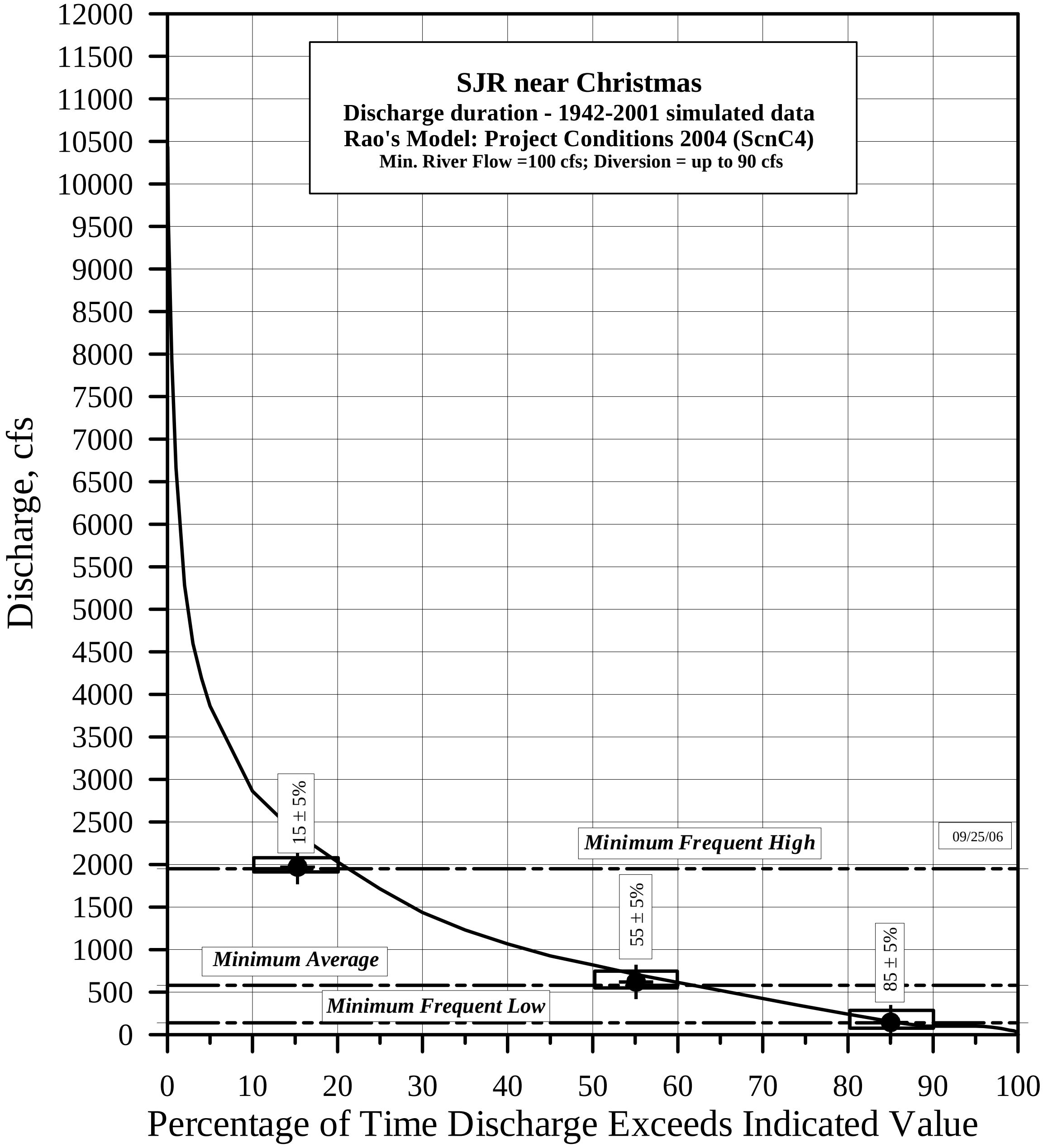

Figure C4A – 1. Flow duration

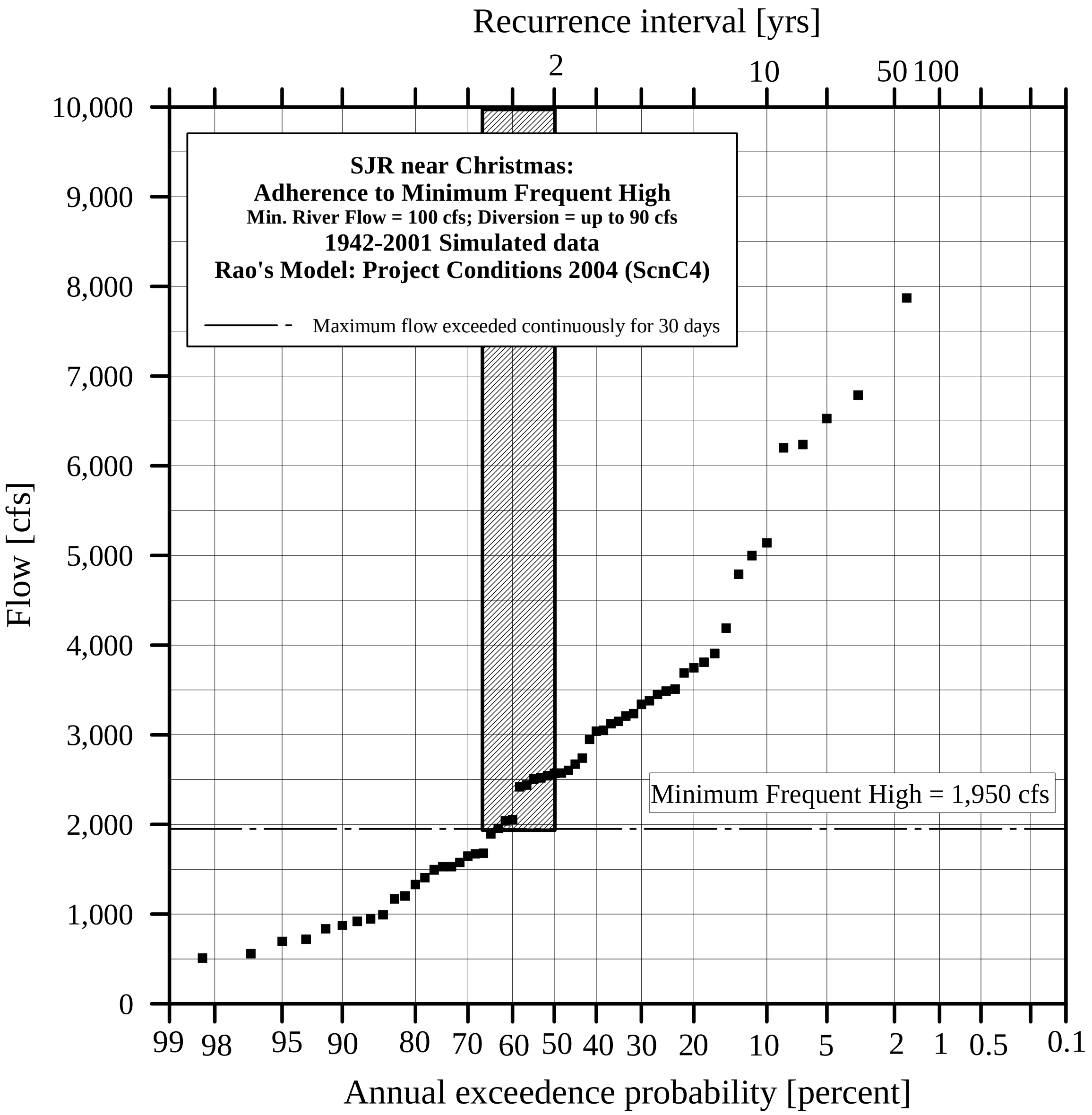

Figure C4A – 2. MFLs evaluation for the Minimum Frequent High discharge

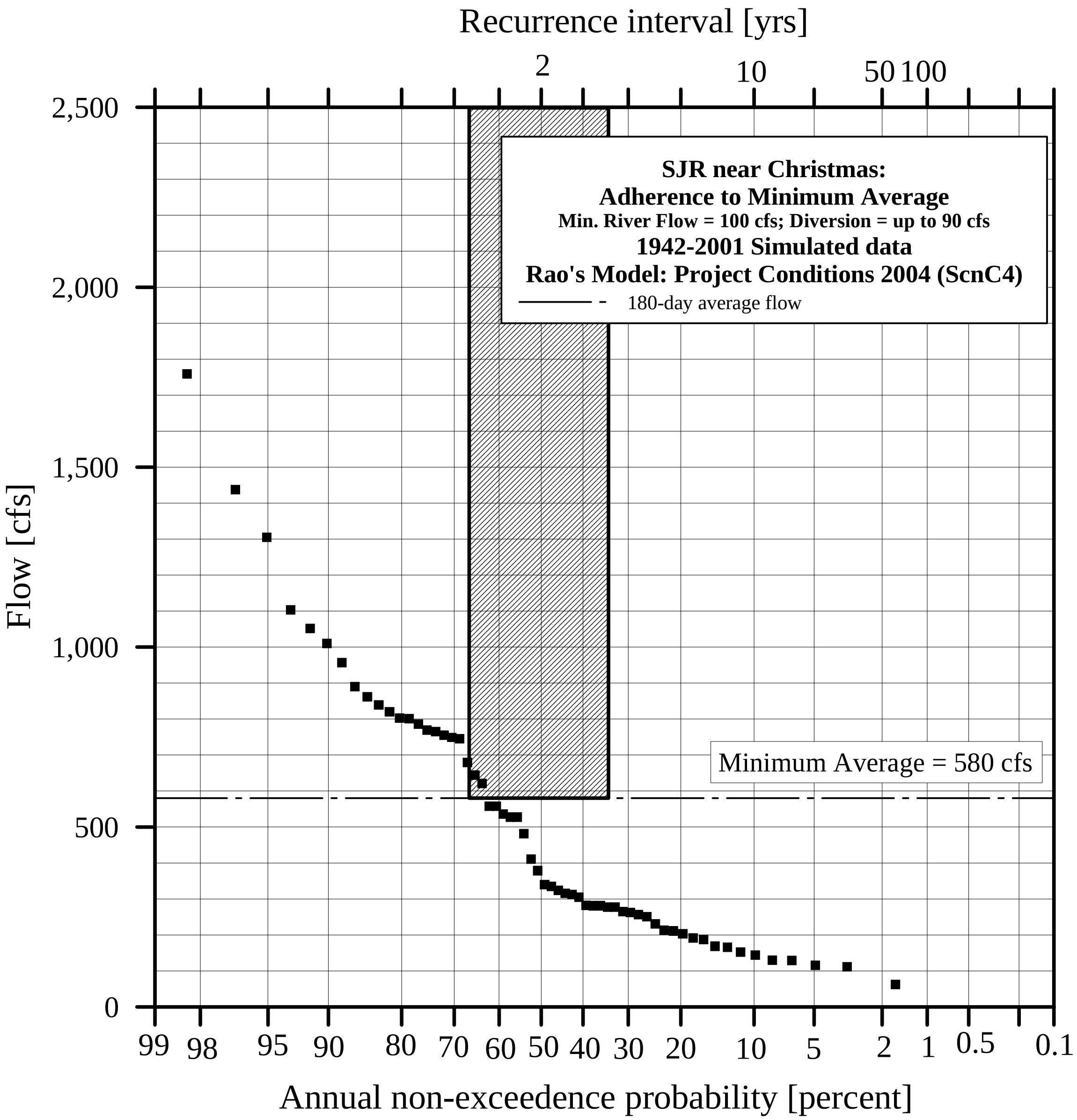

Figure C4A – 3. MFLs evaluation for the Minimum Average discharge

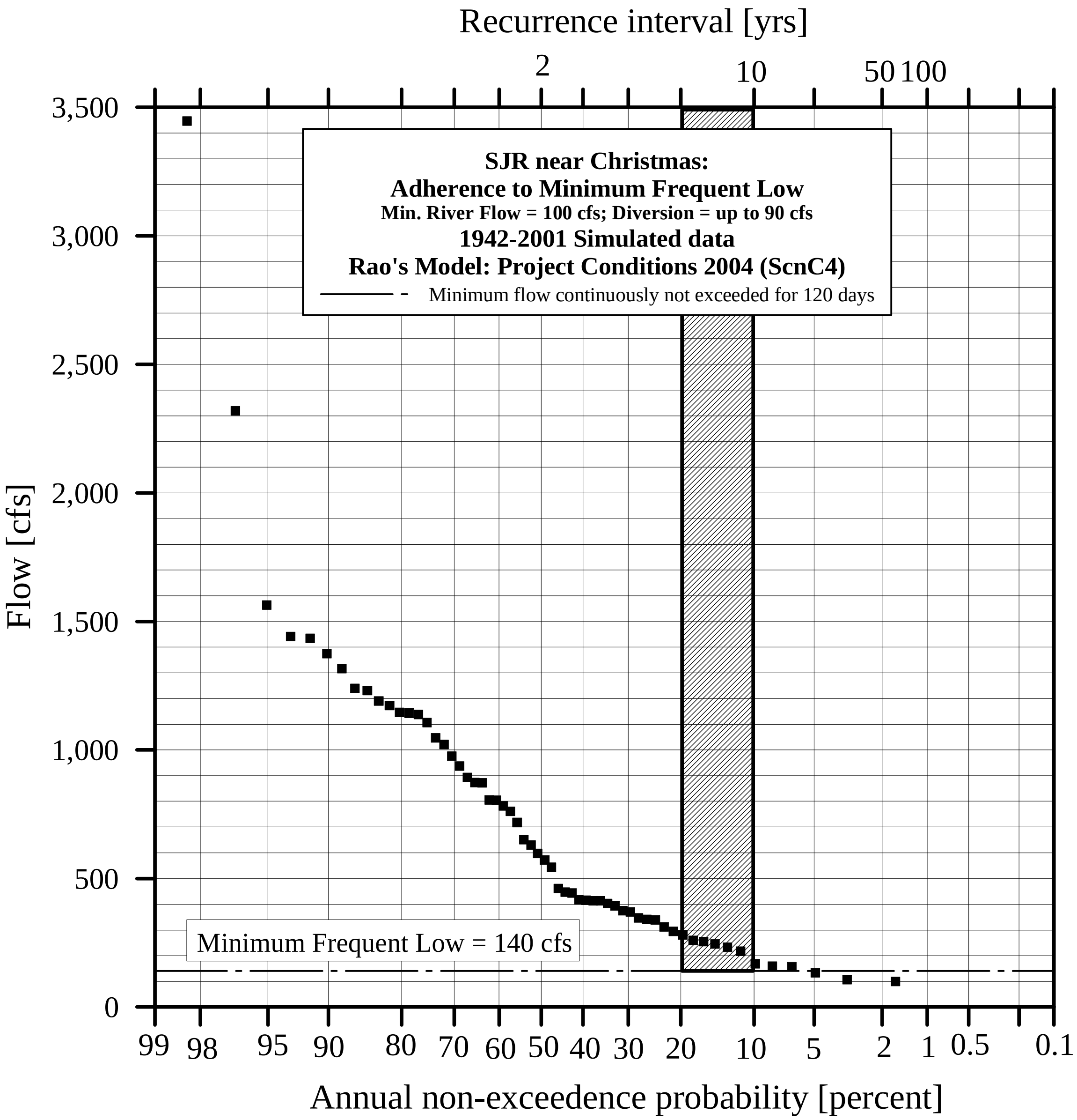

Figure C4A – 4. MFLs evaluation for the Minimum Frequent Low discharge

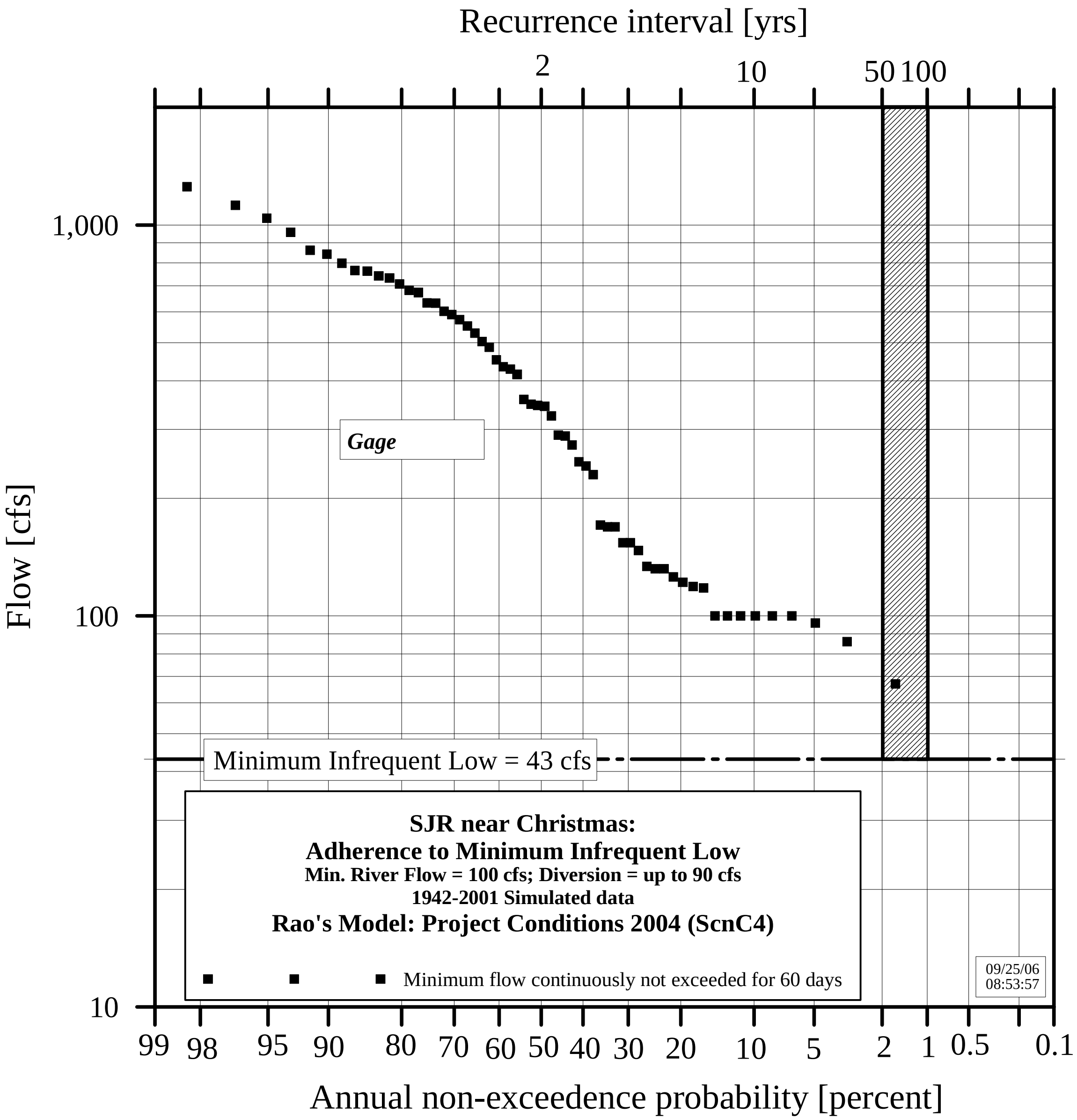

Figure C4A – 5. MFLs evaluation for the Minimum Infrequent Low discharge

APPENDIX D4A

Rao' Upper St. Johns Model: Project conditions 2004

MFLs analysis for Scenario D4A
1942-2001 Simulated discharges

MRF = 50 cfs; DD = 90 cfs

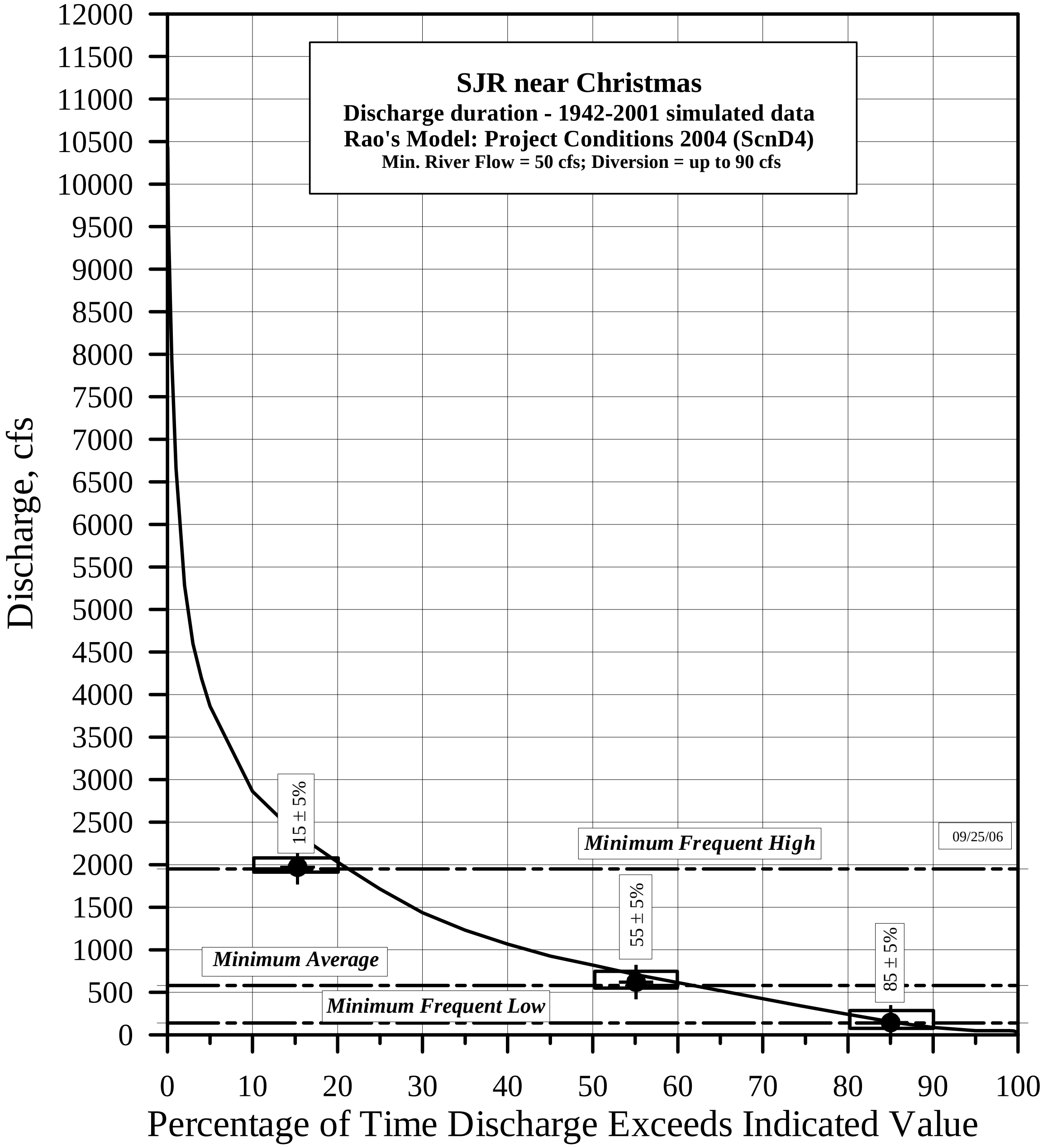

Figure D4A – 1. Flow duration

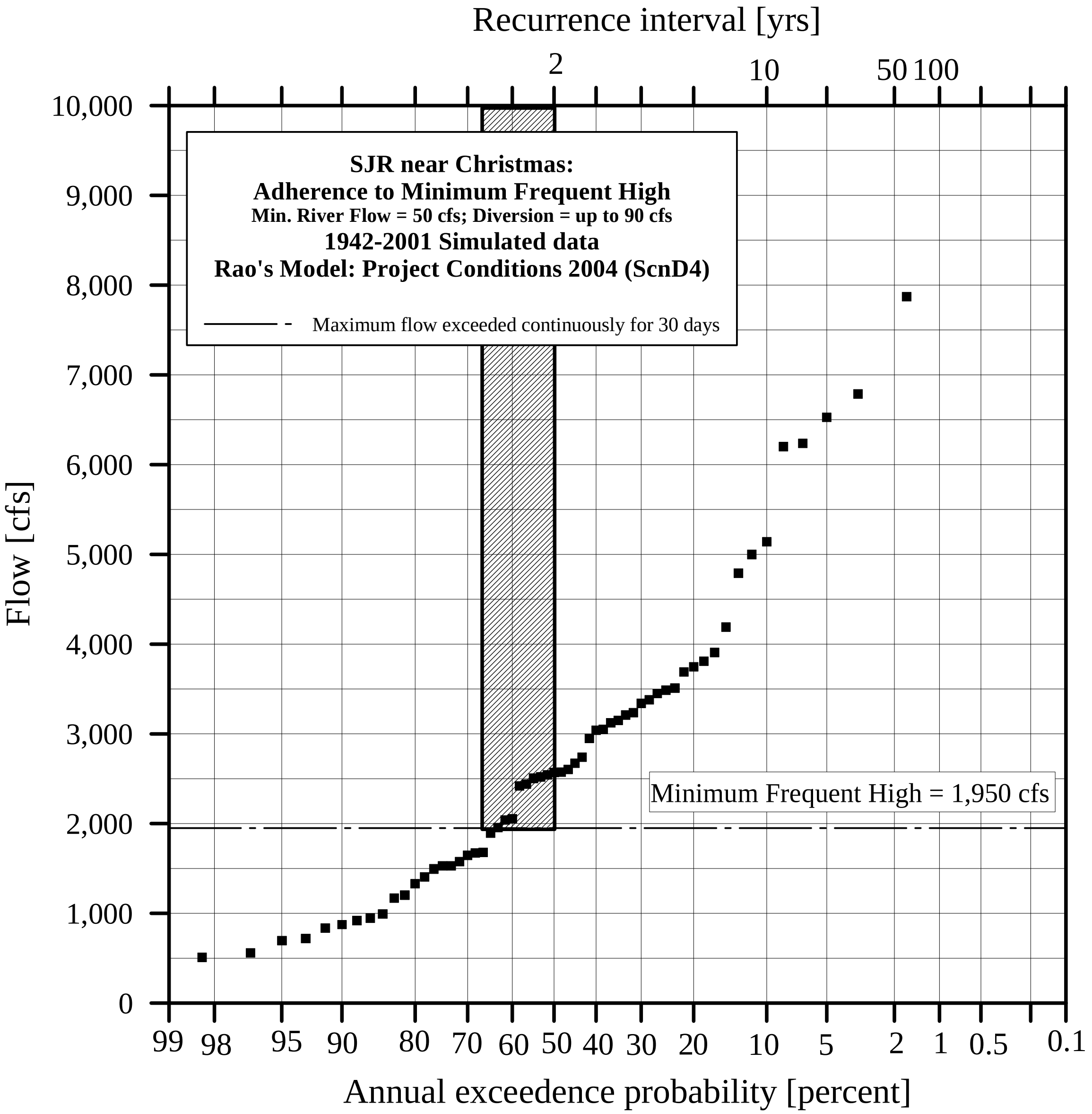

Figure D4A – 2. MFLs evaluation for the Minimum Frequent High discharge

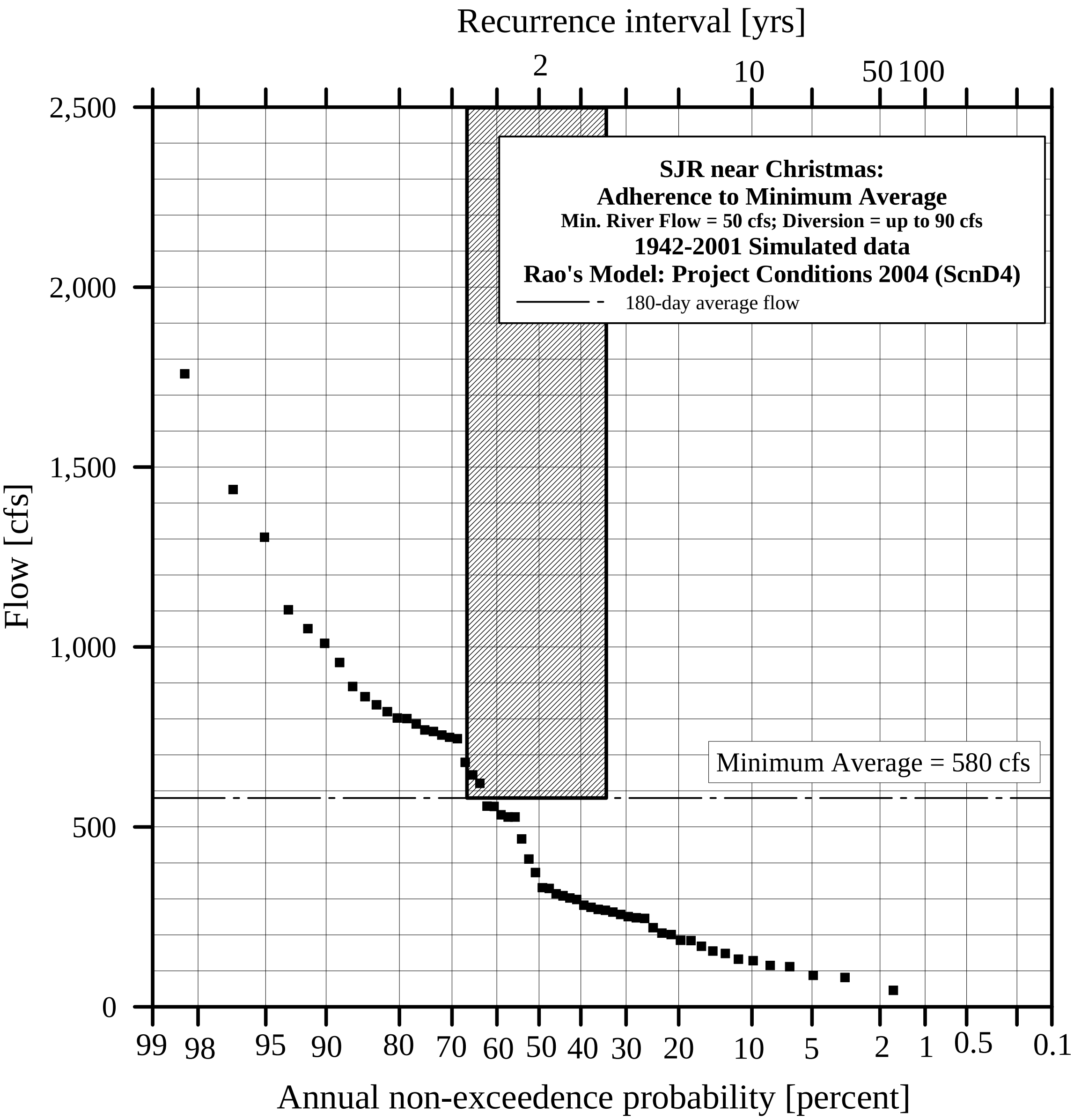

Figure D4A – 3. MFLs evaluation for the Minimum Average discharge

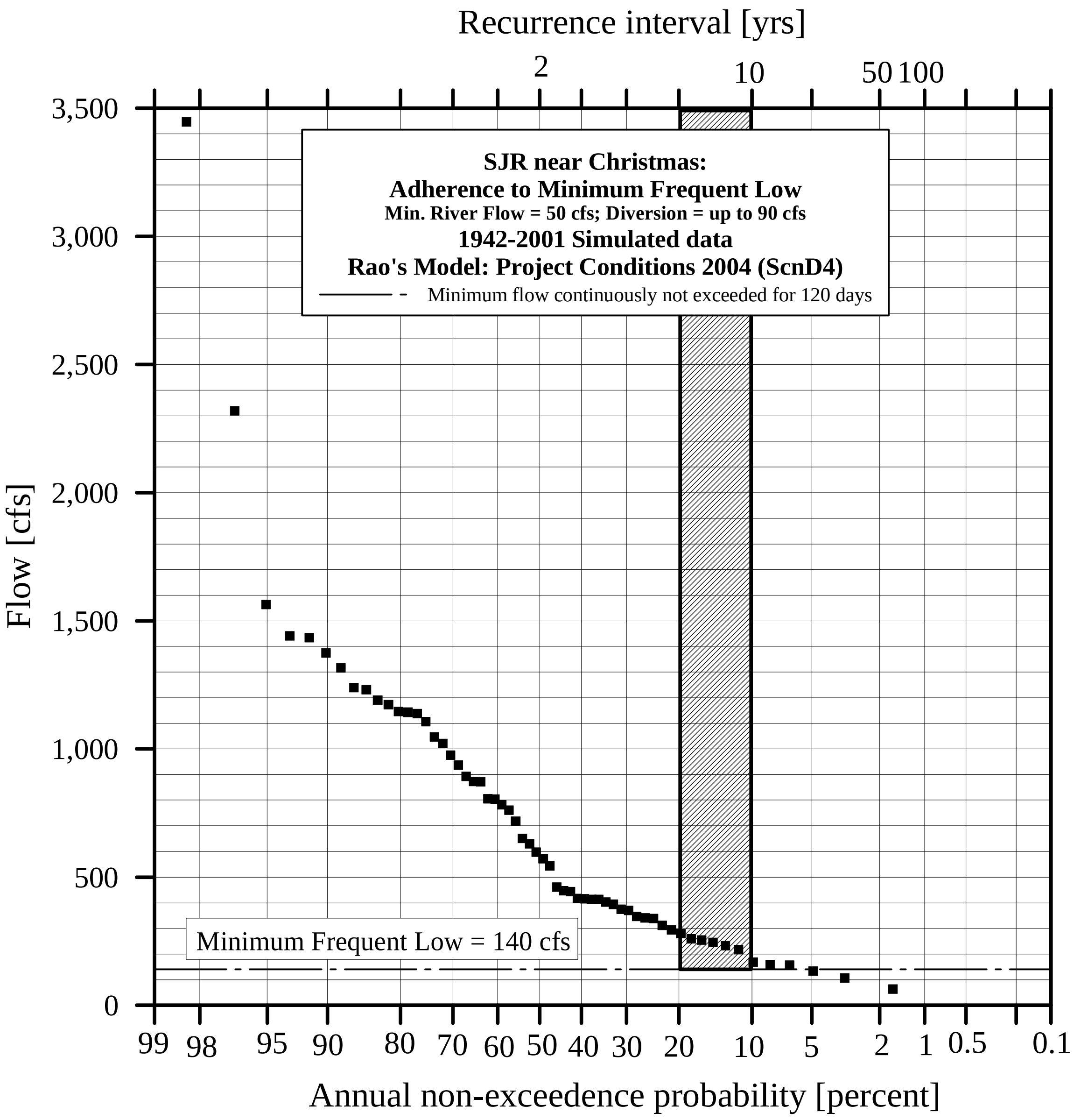

Figure D4A – 4. MFLs evaluation for the Minimum Frequent Low discharge

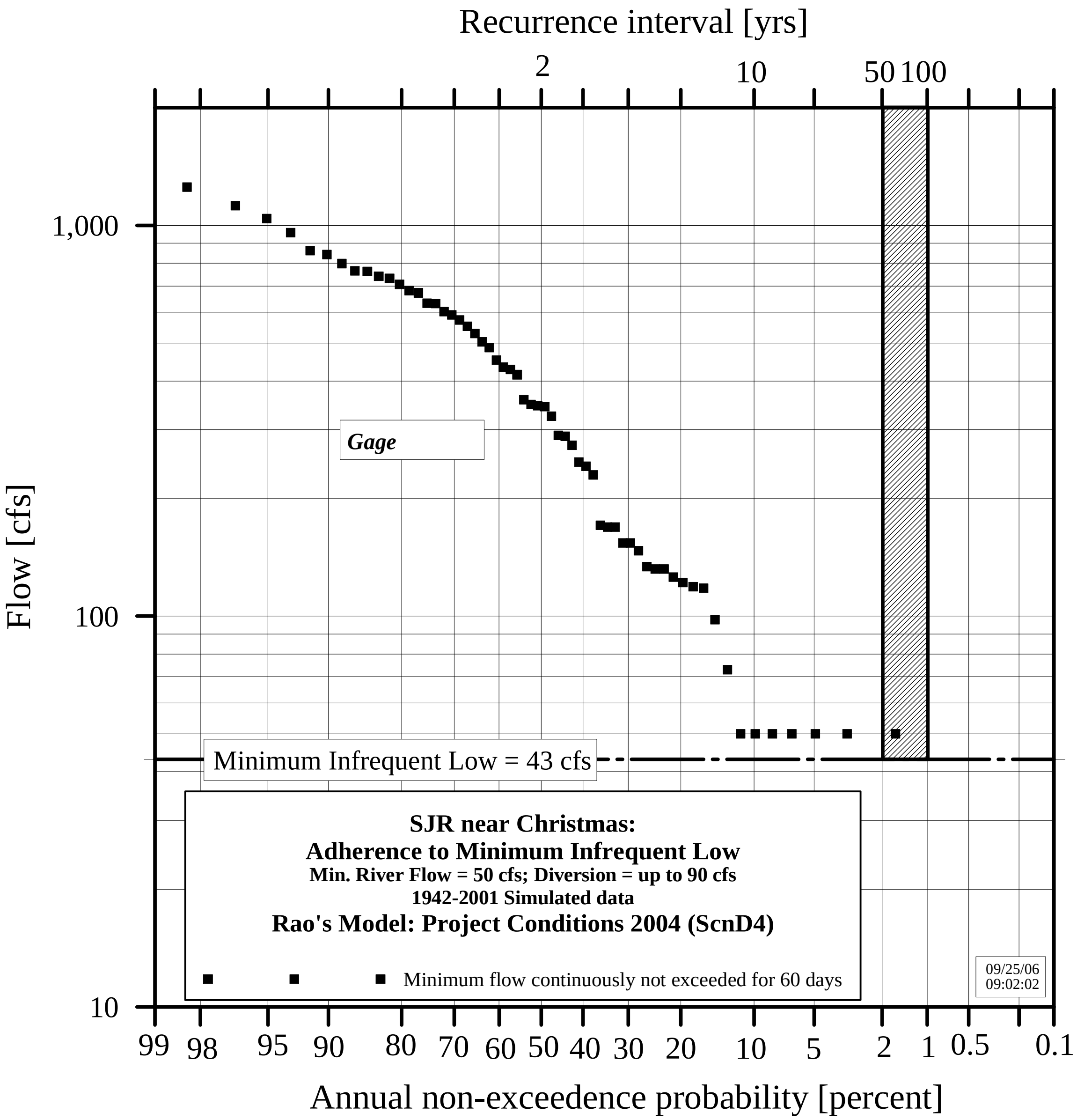

Figure D4A – 5. MFLs evaluation for the Minimum Infrequent Low discharge

APPENDIX A6

Rao’ Upper St. Johns Model: Project conditions 2004

MFLs analysis for Scenario A6
1942-2001 Simulated discharges

MRF = 300 cfs; DD = 150 cfs

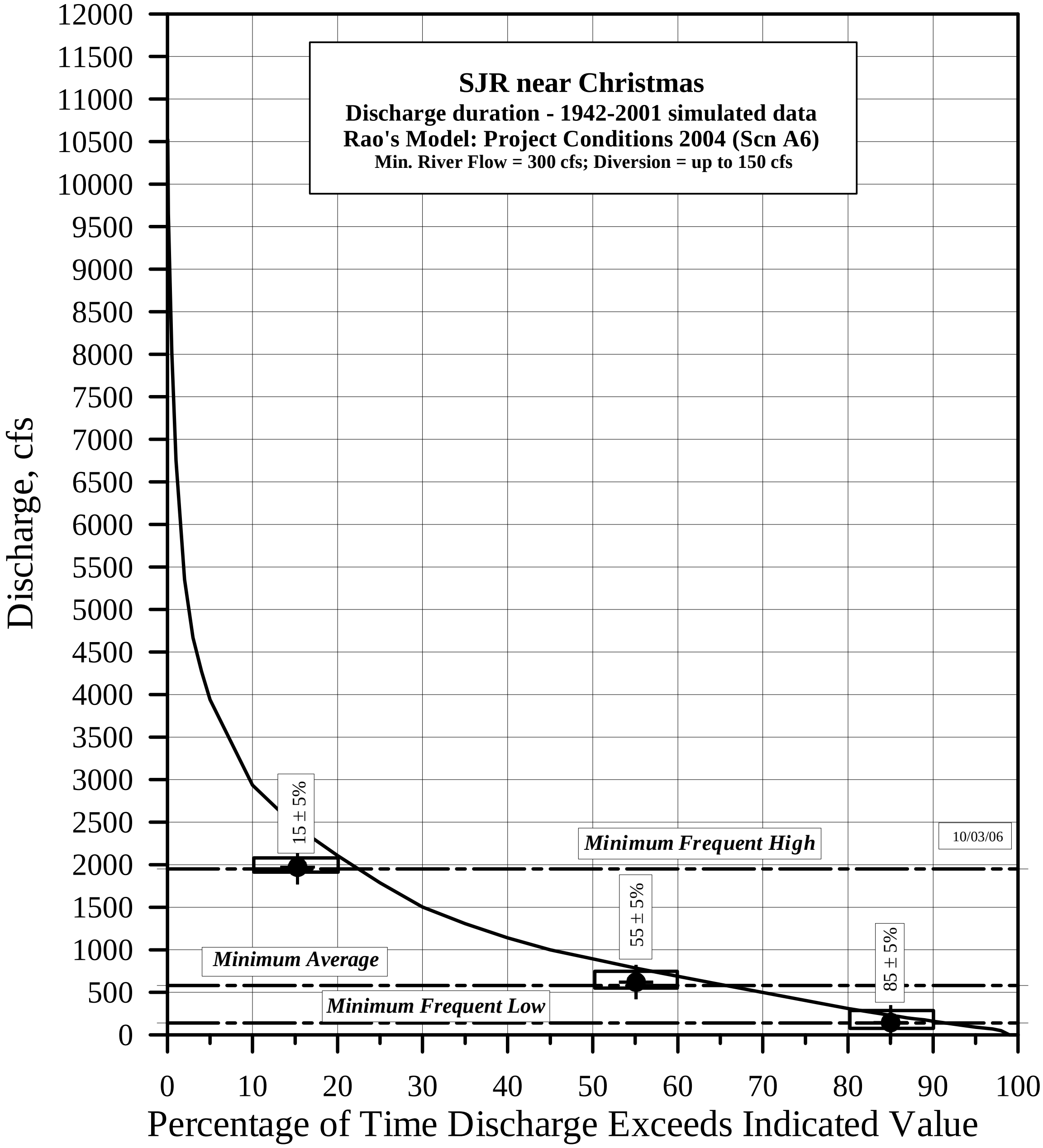

Figure A6 – 1. Flow duration

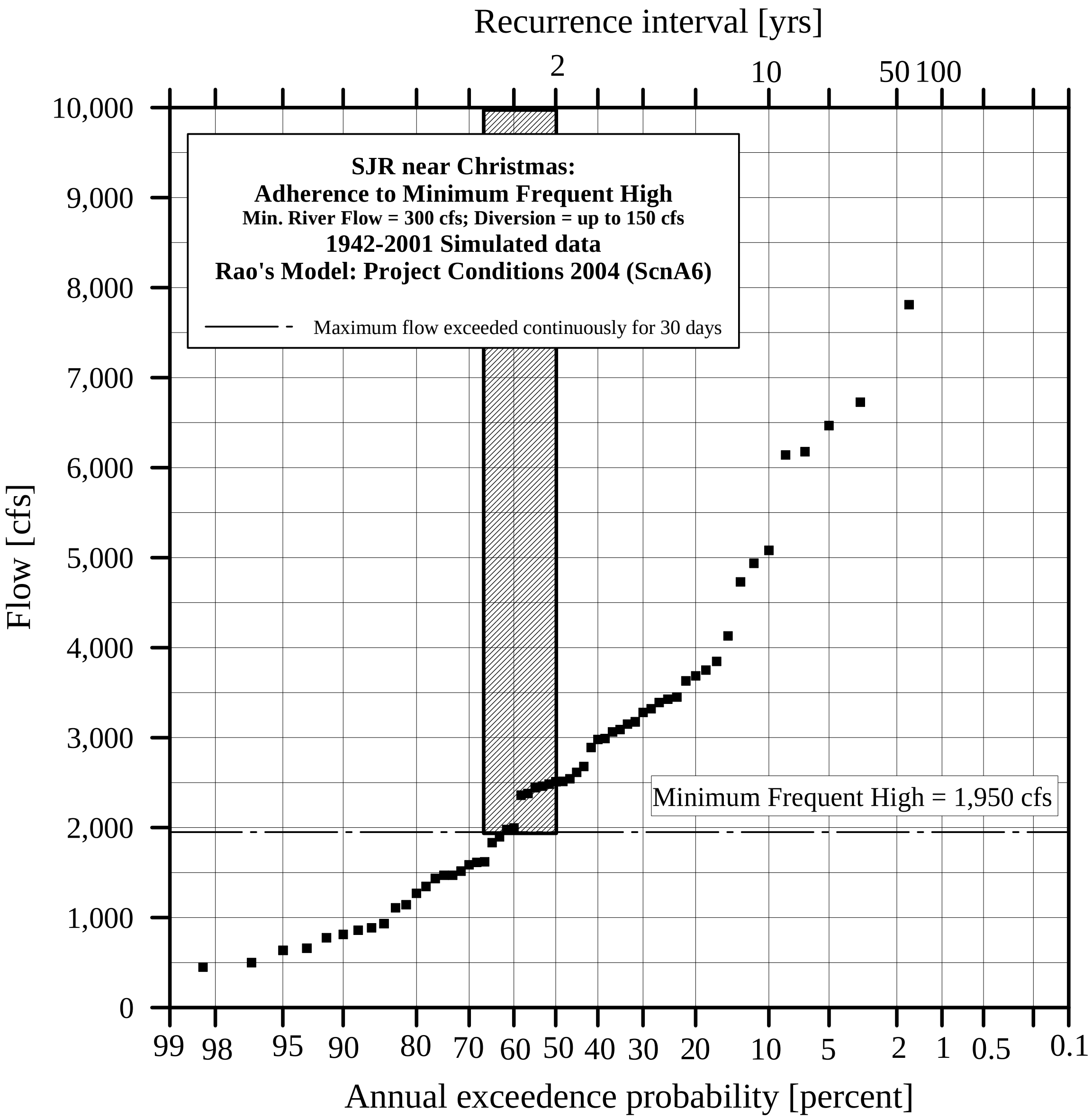

Figure A6 – 2. MFLs evaluation for the Minimum Frequent High discharge

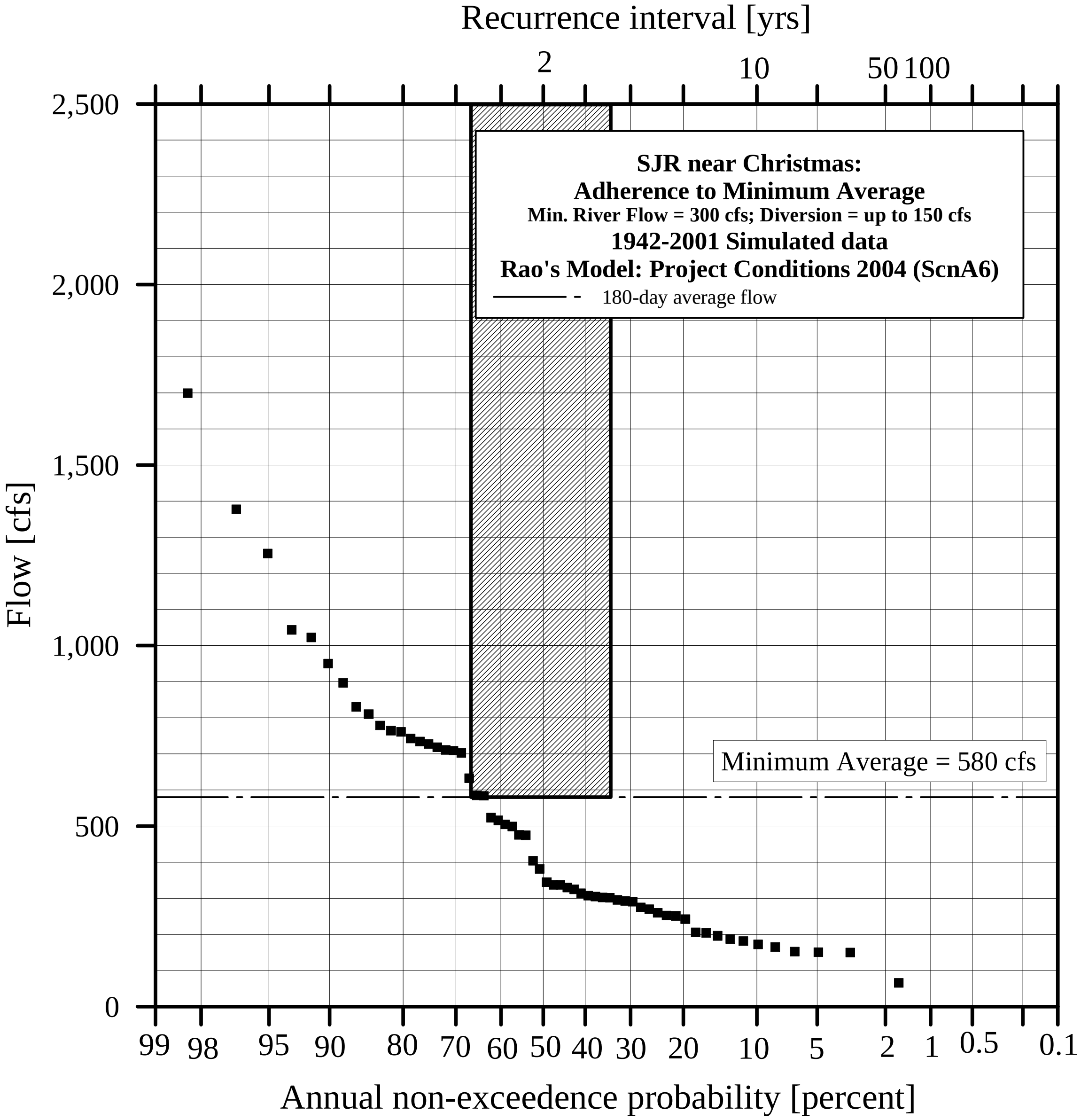

Figure A6 – 3. MFLs evaluation for the Minimum Average discharge

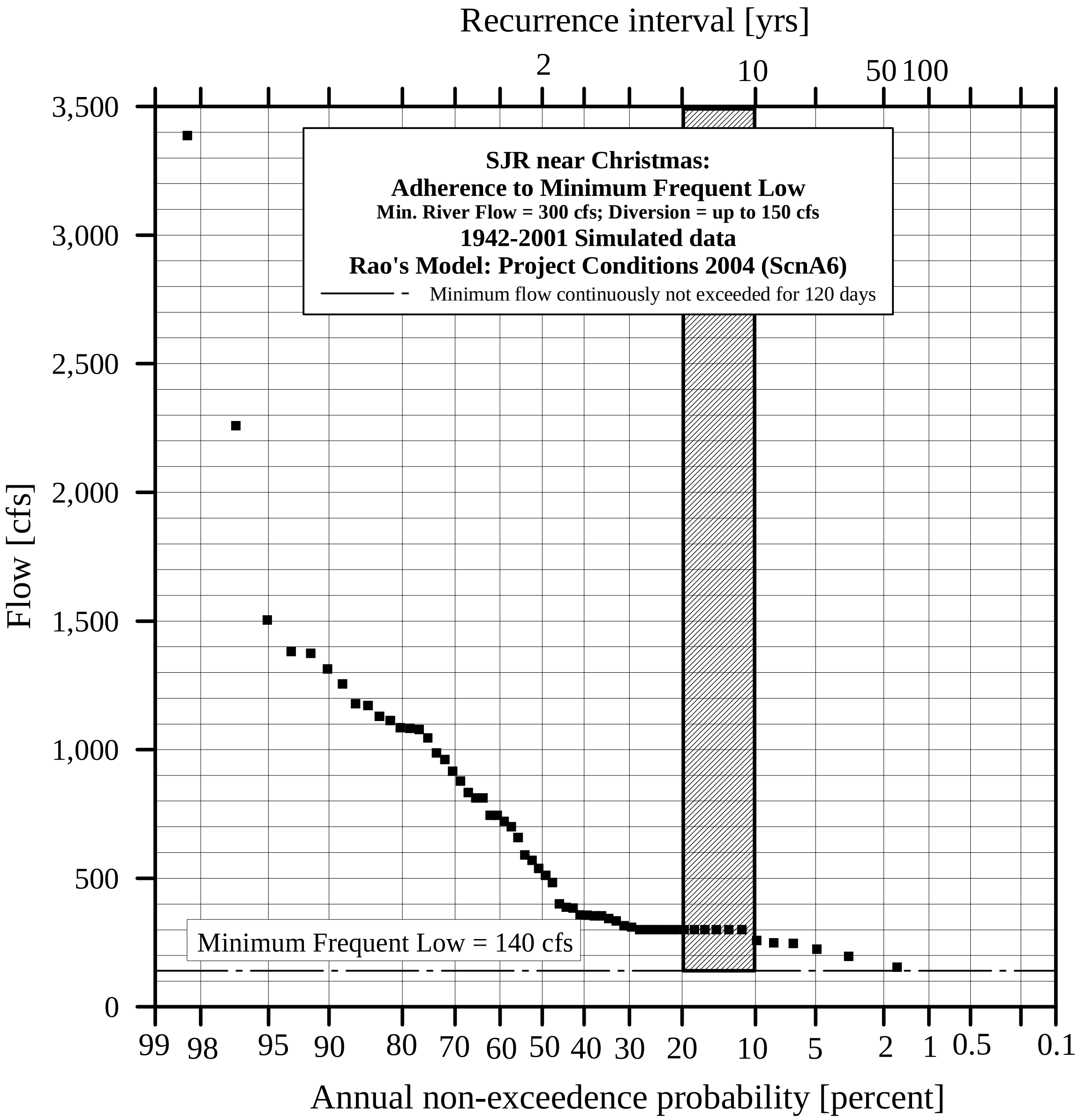

Figure A6 – 4. MFLs evaluation for the Minimum Frequent Low discharge

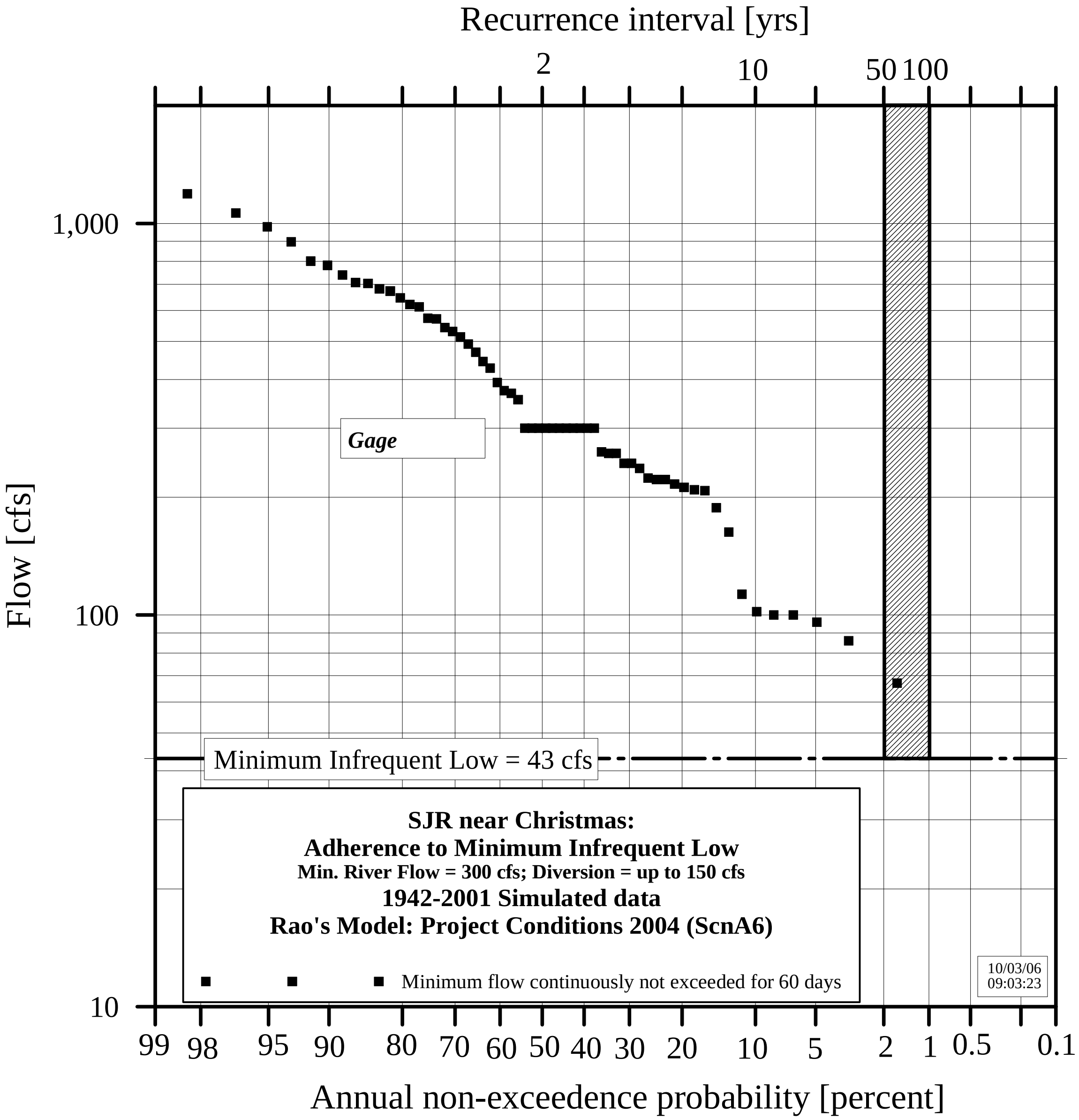

Figure A6 – 5. MFLs evaluation for the Minimum Infrequent Low discharge