Water Supply Reallocation Workshop

Determining Yield and Storage Requirement

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Tulsa, OK

James Hathorn, Jr

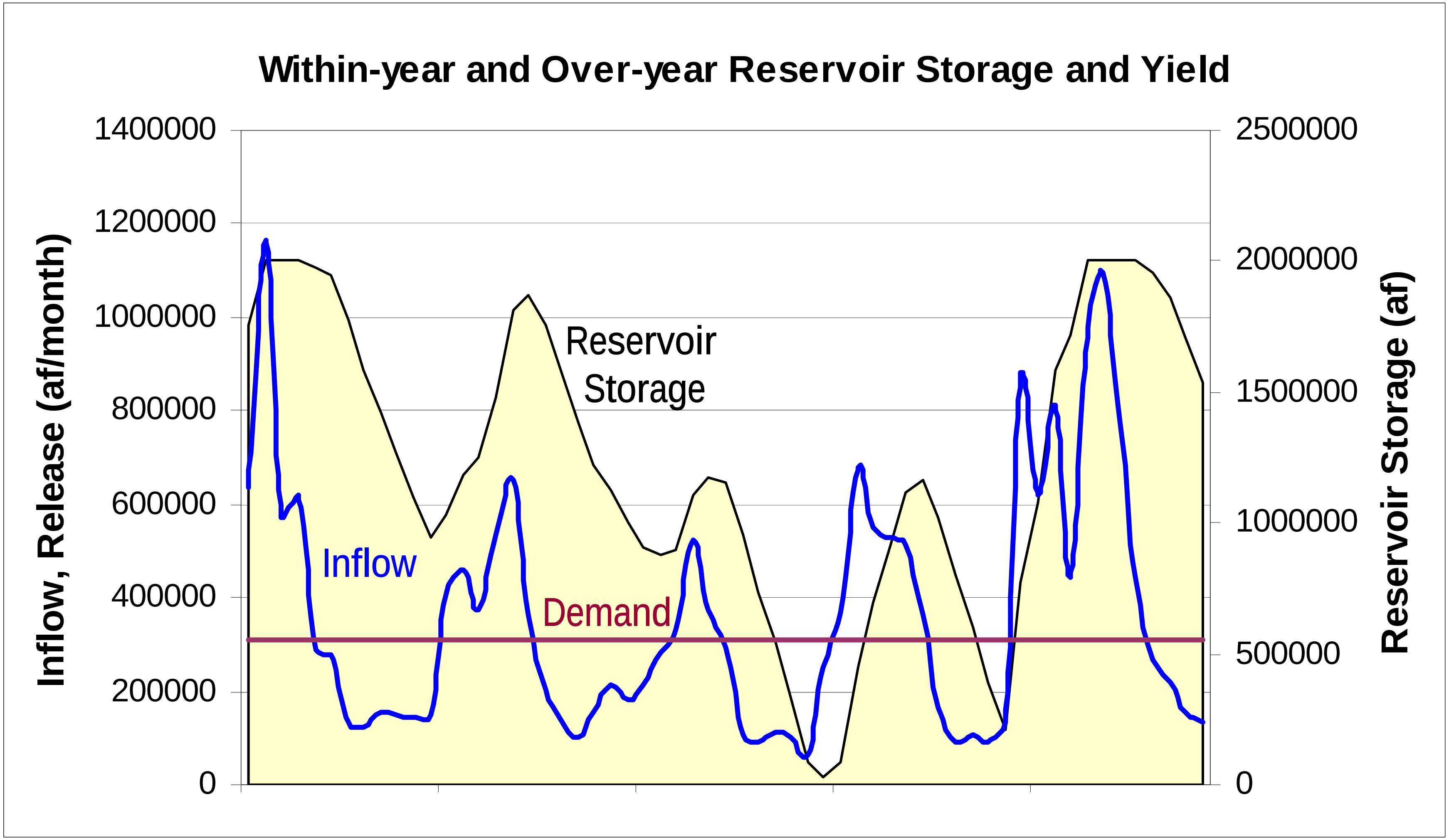
Redistribution of Water

The function of a reservoir system is to redistribute the natural occurrence of water in time and place.

- Formerly, people settled near rivers and used water when it arrived.
- Then we built reservoirs to accumulate and release water to improve the distribution in time
    - **flood control, water supply storage**
- And conveyance to improve the distribution in space

Distribution of Water in Time

- **Within-year Reservoir Storage**
  - Reservoir stores wet season water for use in dry season
- **Over-year Reservoir Storage**
  - Reservoir stores wet year water for use in dry years or extended drought
- Evaluation of current and future demand and local hydrology will determine if within- or over-year is needed, and the required size of reservoir.


Within-year and Over-year Reservoir Storage and Yield
Inflow, Release (af/month)
Reservoir Storage (af)
1400000
1200000
1000000
800000
600000
400000
200000
0
2500000
2000000
1500000
1000000
500000
0
Reservoir Storage
Inflow
Demand

Corp Guidelines

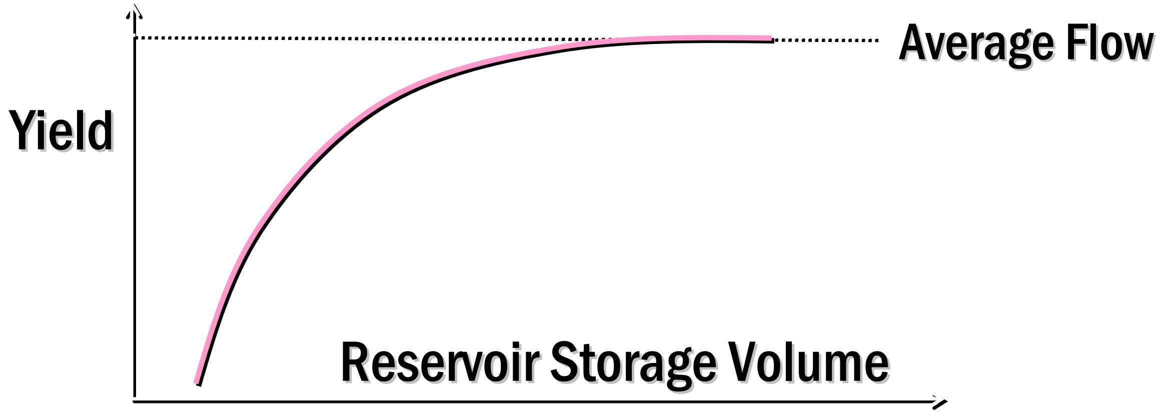
- EM 1110-2-1420
  - "Hydrologic Engineering Requirements for Reservoirs" (Oct 1997)
- EM 1110-2-1417
  - "Flood Runoff Analysis" (Aug 1994)
- EM 1110-2-1701
  - "Engineering and Design Hydropower" (Dec 1985)

Terms

- Yield – also know as firm yield and critical yield is the maximum sustainable flow at some point in time during the most adverse sequence of streamflow (critical period).
- Storage – water impounded in surface or underground reservoirs for future use.

Storage / Yield of a Reservoir

- YIELD = amount of water provided on a regular basis (yield ≤ average flow)
- The most basic evaluation is the Storage / Yield relationship.



Storage / Yield Relationship

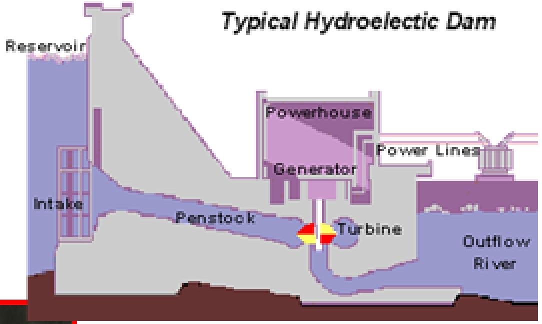
- In a study, there are 2 ways define the relationship:
  - Planning: For a given demand, how large must the reservoir at that location be?
  - Reassessment/Operations: For a given reservoir, what is the annual yield?

Fix one variable, vary the other

Storage / Yield Relationship

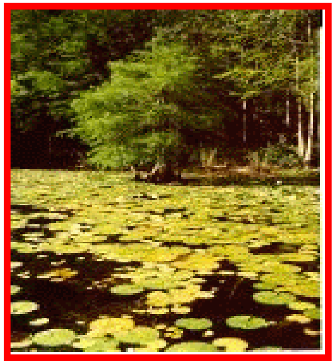
- There are various methods for determining the relationship between reservoir storage and yield
  - Simplified Methods (Planning)
    - Rippl Mass Diagram
    - Sequent Peak Algorithm
  - Sequential Reservoir Routing (Operations)
    - simulation of realistic reservoir operation over a multiple year period
    - more complex demand patterns and sources can be evaluated, as well as losses

Purpose



- Storage requirements for
  - Water supply
  - Water quality
  - Hydroelectric power
  - Navigation
  - Irrigation
  - Other conservation purpose


Water Supply


Water Quality


Irrigation


Navigation

Yield Objectives

- Determine yield given a storage allocation
- Find storage required given a desired yield
- Determination of complementary or competitive aspects of multi project development
- Analysis of alternative operation rules for a project or group of projects

Input Data Needed...

- The **supply** data used can be either
  - the historical record, or a critical dry period within the record
  - a synthetic event or data series
- The **demand** requirements can be either
  - 100% of actual or forecasted demand

    constant or varied, depending on the method
  - or met with some frequency or reliability

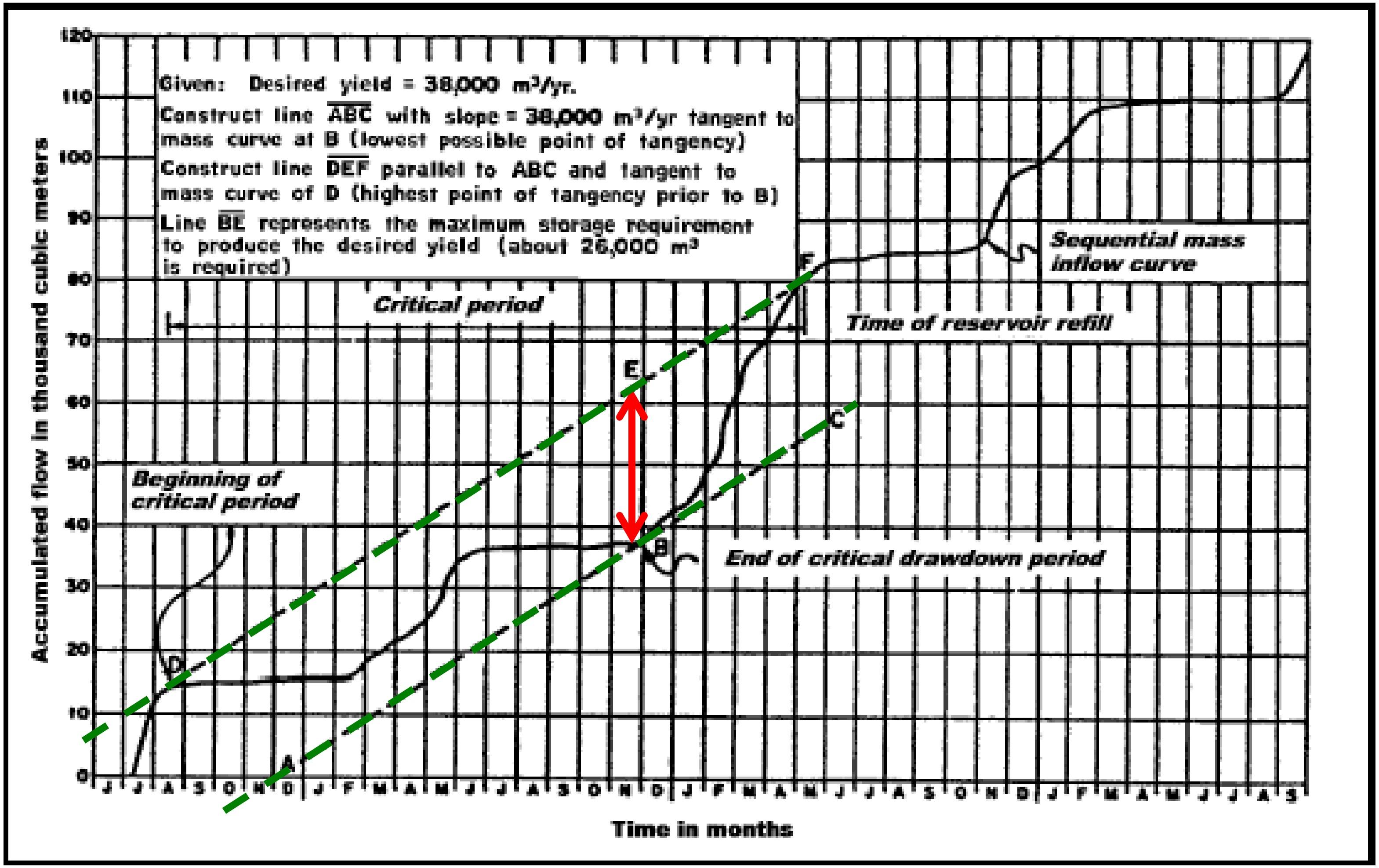
Simplified

- Sequential Mass Curve
  - Constructed by accumulating inflows to a reservoir site throughout the period of record & plotting the accumulated inflows versus the sequential time period
- Depth Duration
  - Relationship of storage yield vs shortage frequency

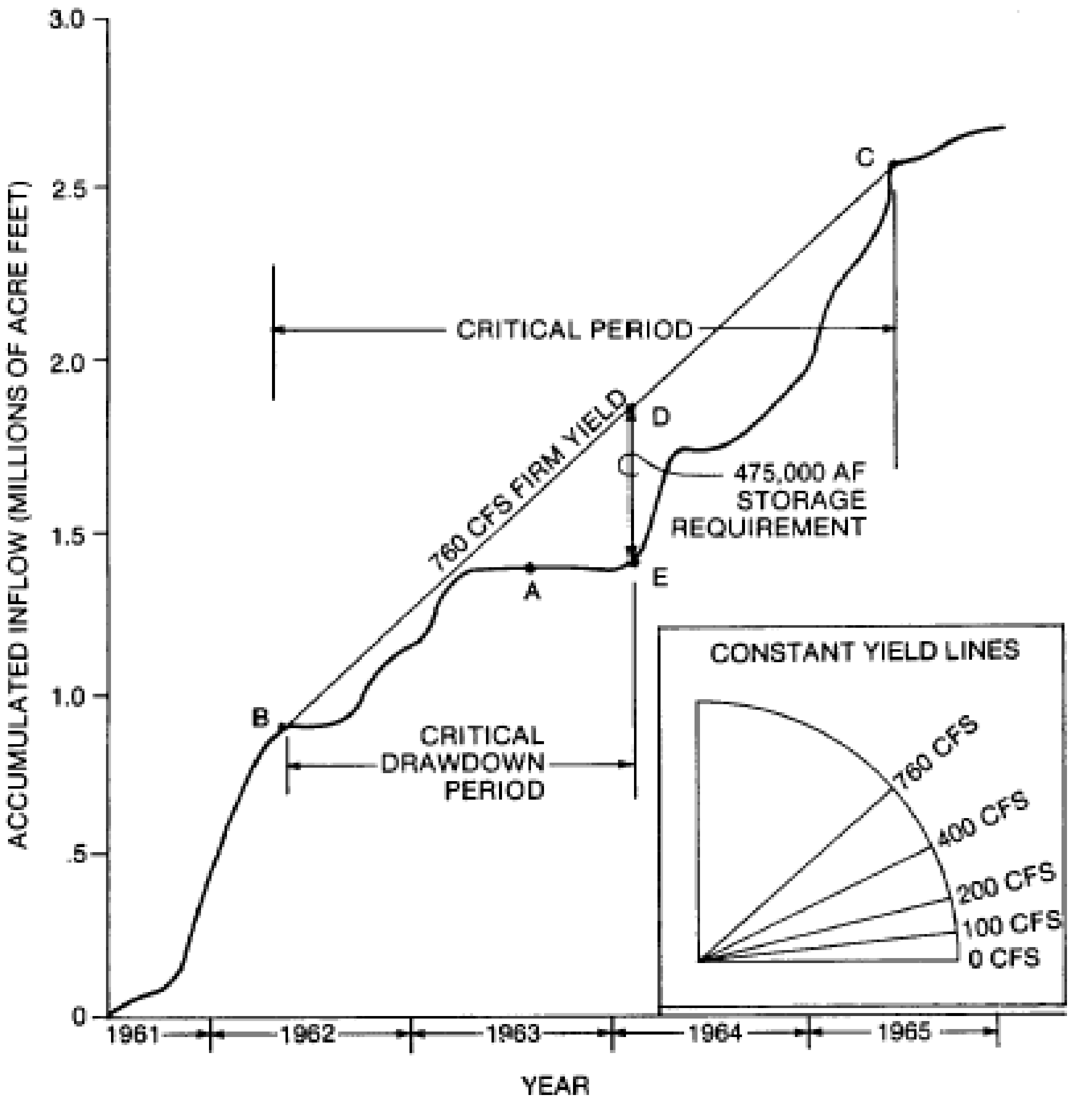
Sequential Mass Curve

- Manual graphical procedure used to identify the critical period and firm yield
- Firm yield is maximized by fully drafting available storage to supplement natural streamflow
- Mass curve is cumulative plotting of reservoir inflow
- The slope of the mass curve at any point in time represents the inflow at that time.

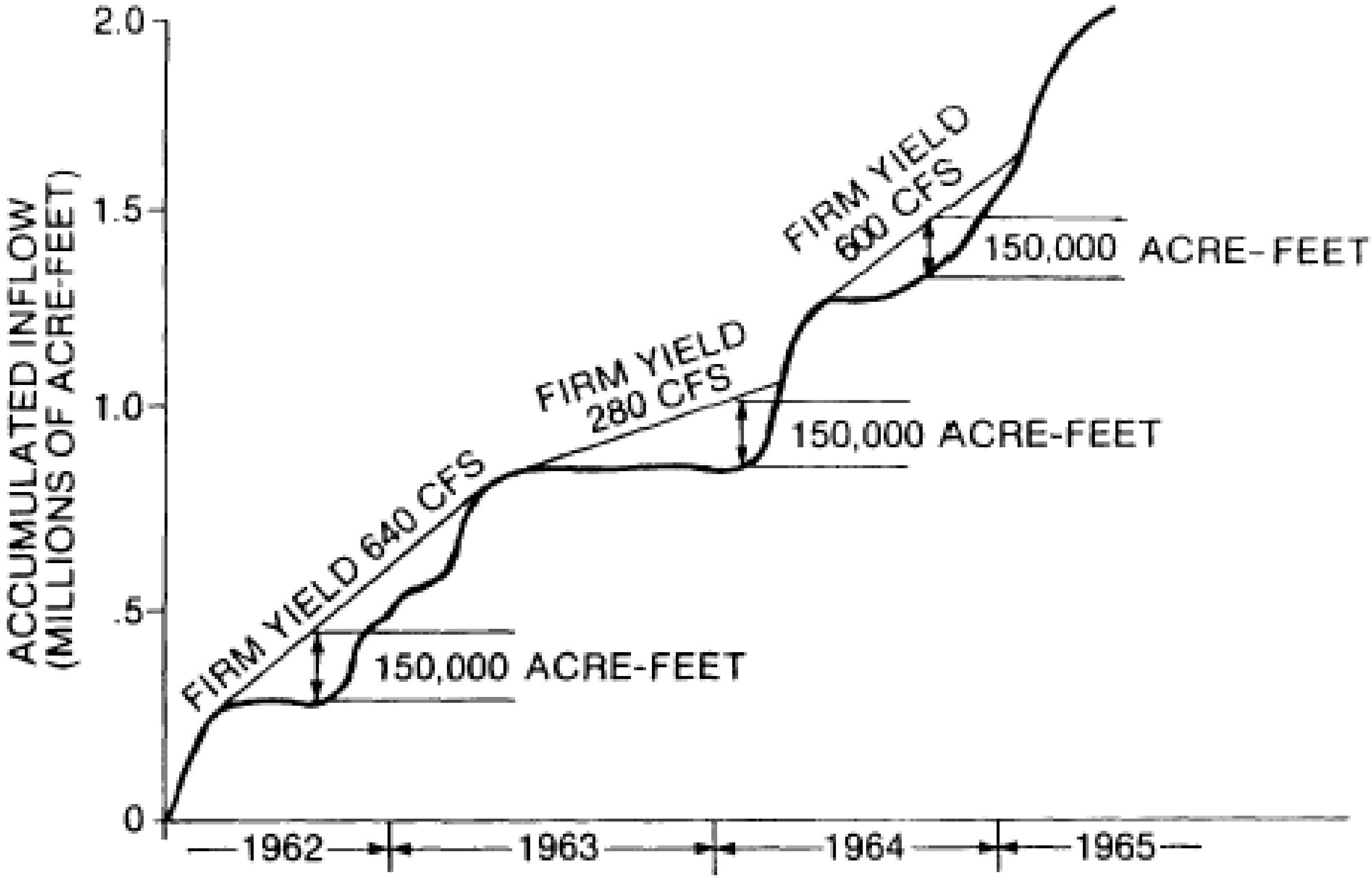
Sequential Mass Curve



Mass Curve & Constant Yield Lines



Yield Given Storage



Simplified Limitations

- Does not reflect seasonal variations in demand
- Inability to accurately evaluate evaporation losses

Detailed Sequential Analysis

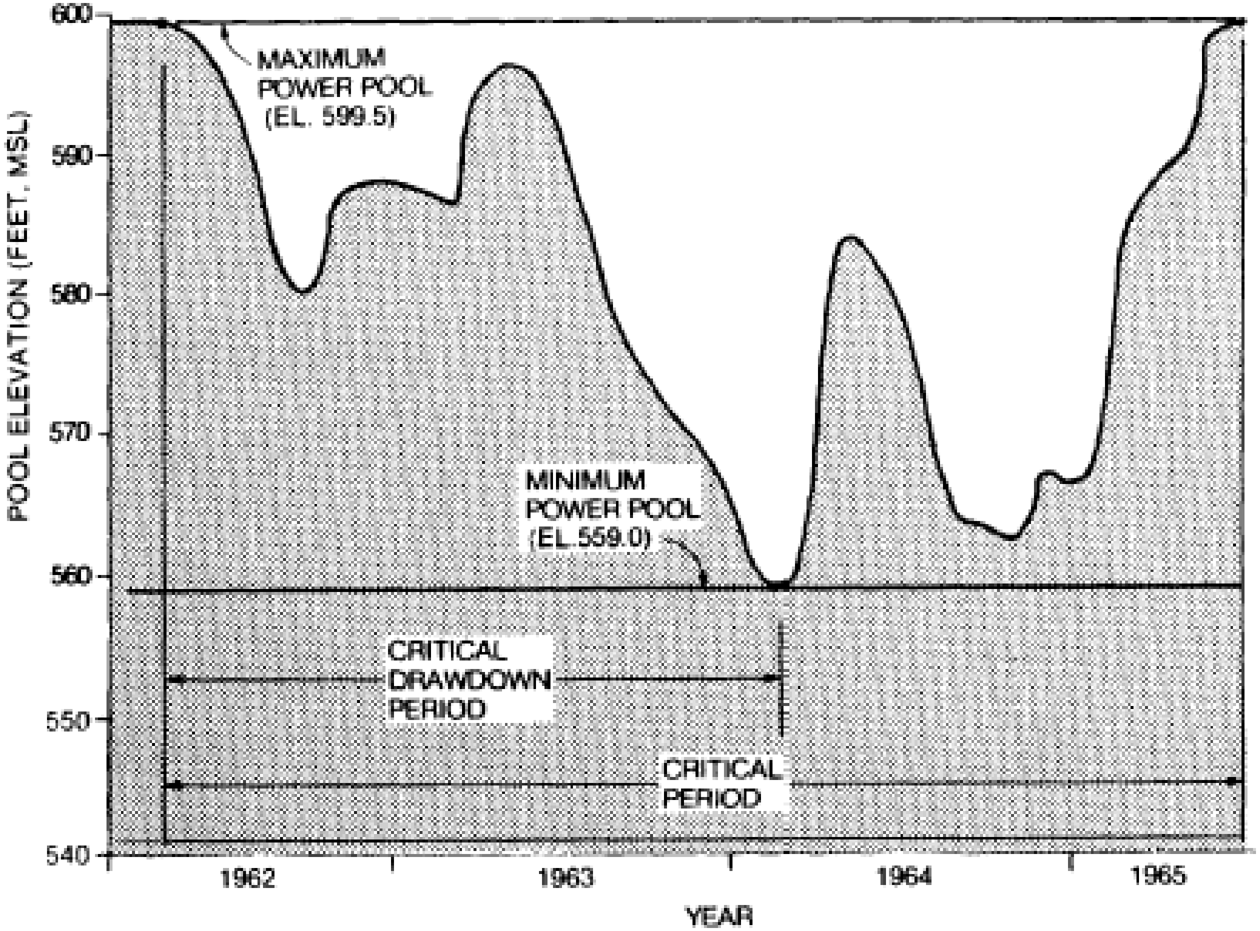
- Conservation of mass

  $I – O = \Delta S$

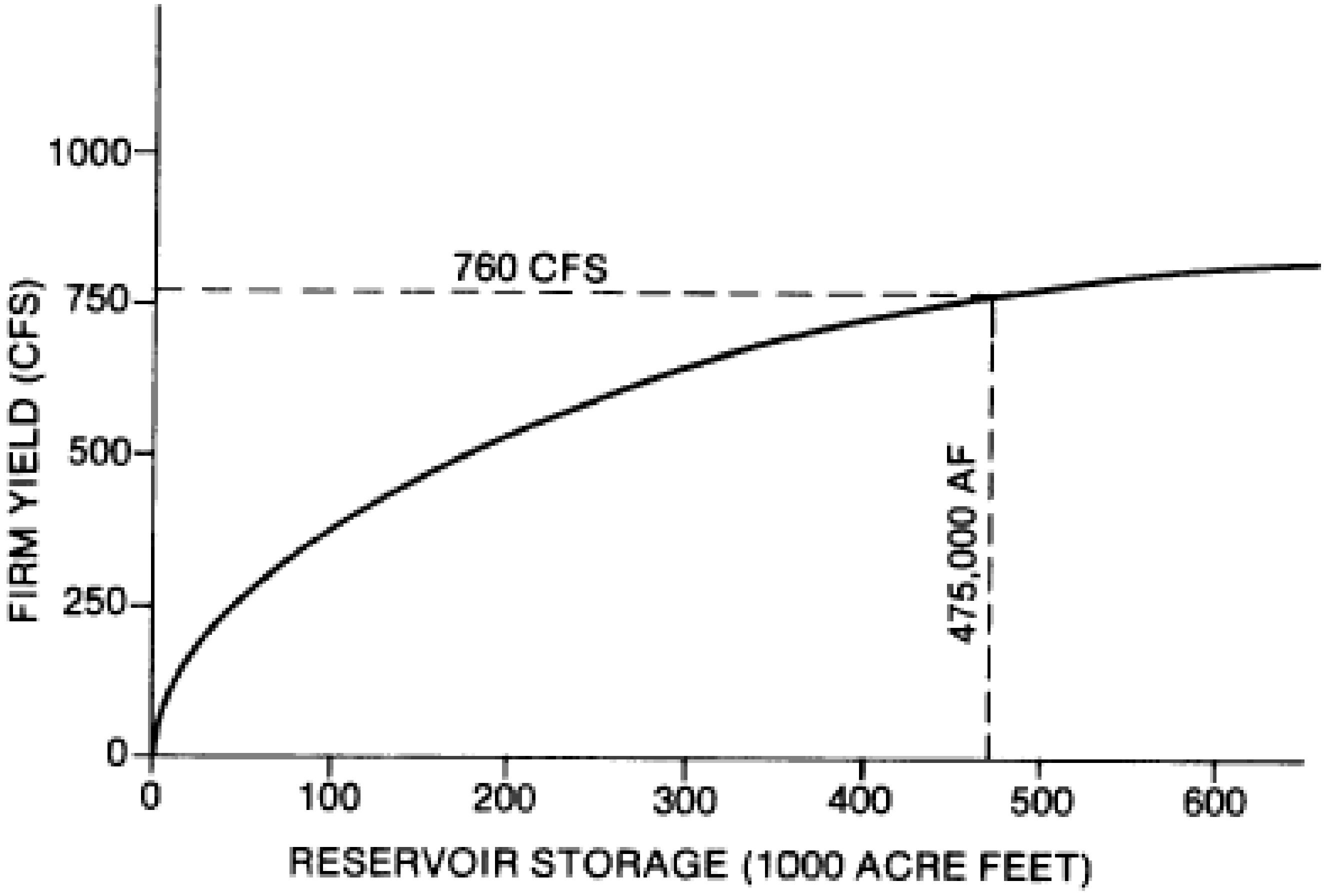
  I = inflow, O= outflow, ΔS=change in storage

- Computer Simulation (HEC-5, ResSim)
  - Multipurpose reservoir
  - Varying demand
  - Evaporation evaluation
  - Firm yield optimization

Maximize Firm Yield



Firm Yield Curve

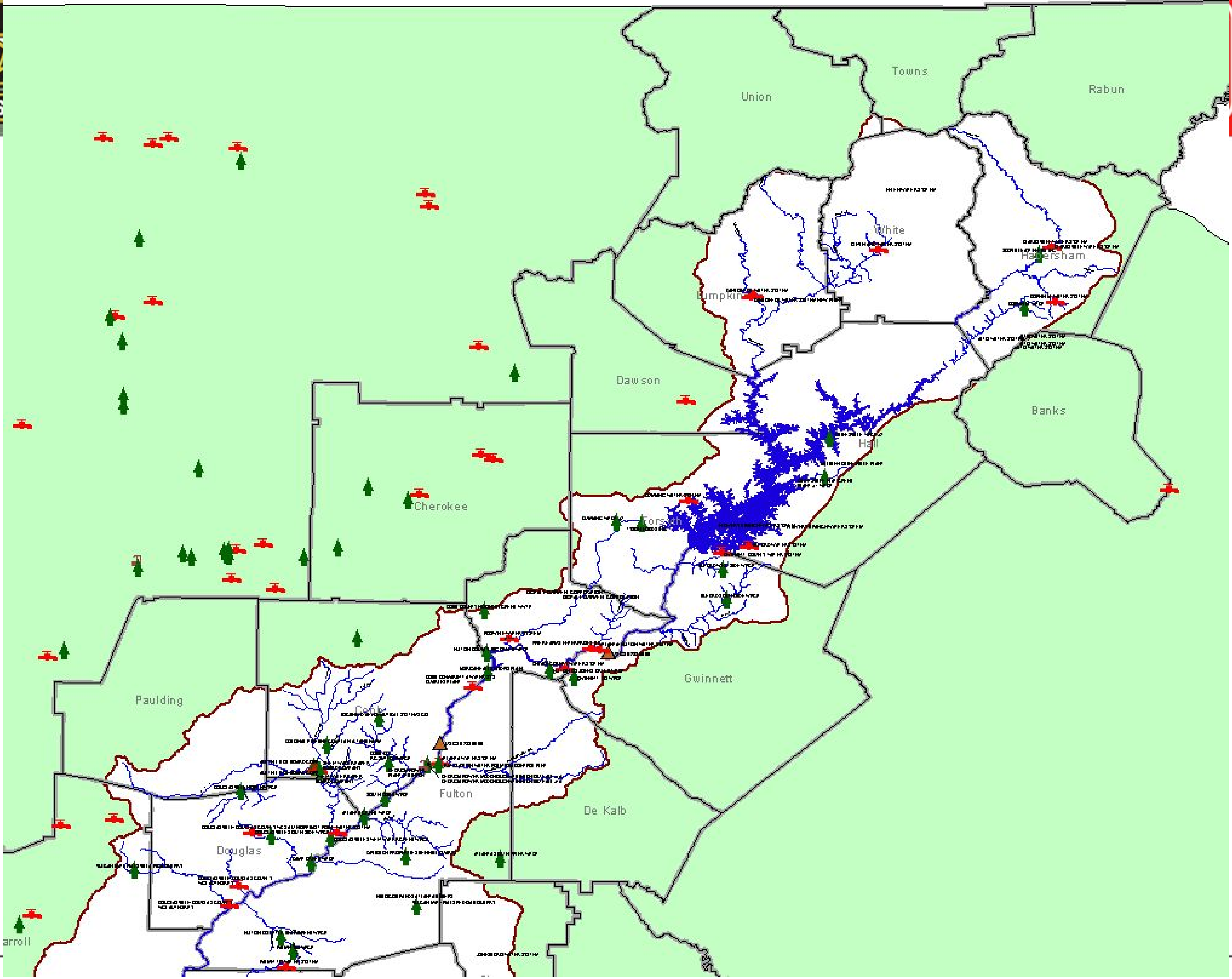


Critical Period Analysis

- These methods looked at historical critical periods of low streamflow and determined demand that could be met without failure (worst case analysis)
  - only one particular duration and magnitude -- many other options are possible
  - can be subject to sampling error with a short data set
  - also leads to false confidence about reliability
- Alternatives to critical period are probabilistic descriptions...

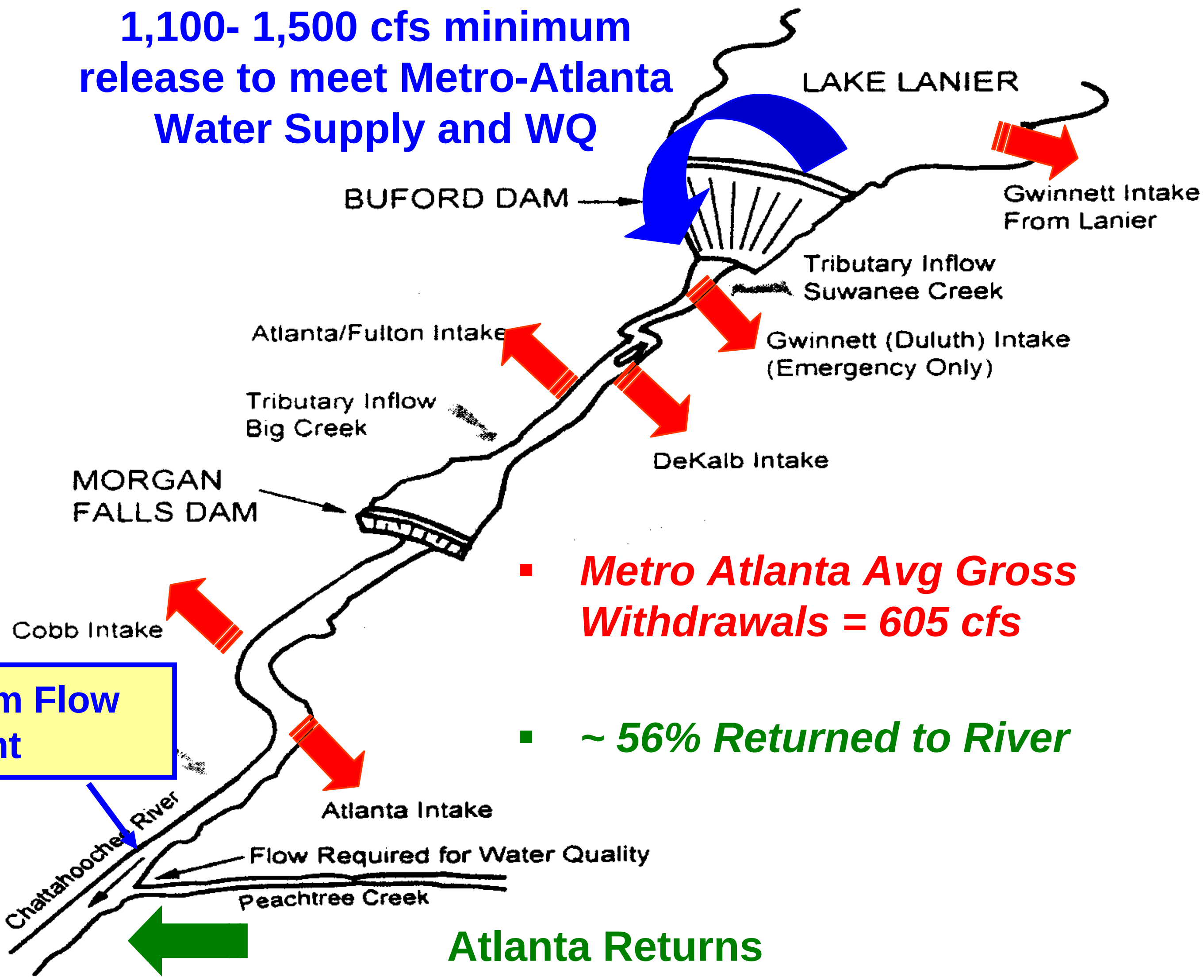
Case Study #1

- ACF Litigation
  - Buford Dam forms Lake Lanier
  - Currently no water storage contracts exist
  - What percent of yield / storage currently provided to metro Atlanta area?



Towns
Union
Rabun
White
Habersham
Lumpkin
Dawson
Banks
Hall
Cherokee
Forsyth
Gwinnett
Paulding
Fulton
De Kalb
Douglas
arroll

1,100- 1,500 cfs minimum release to meet Metro-Atlanta Water Supply and WQ



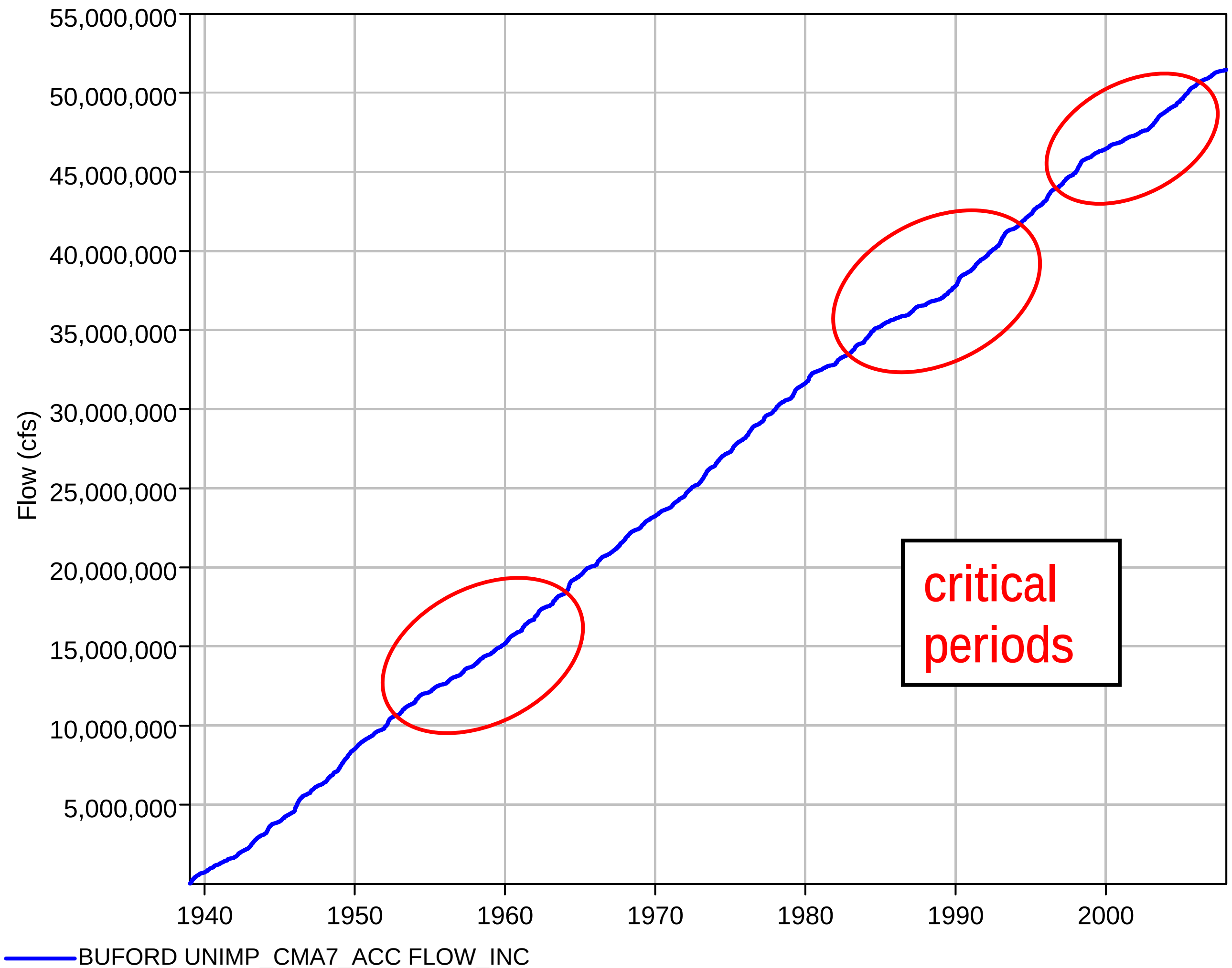
750 cfs Instream Flow Requirement

- *Metro Atlanta Avg Gross Withdrawals = 605 cfs*
- *~ 56% Returned to River*

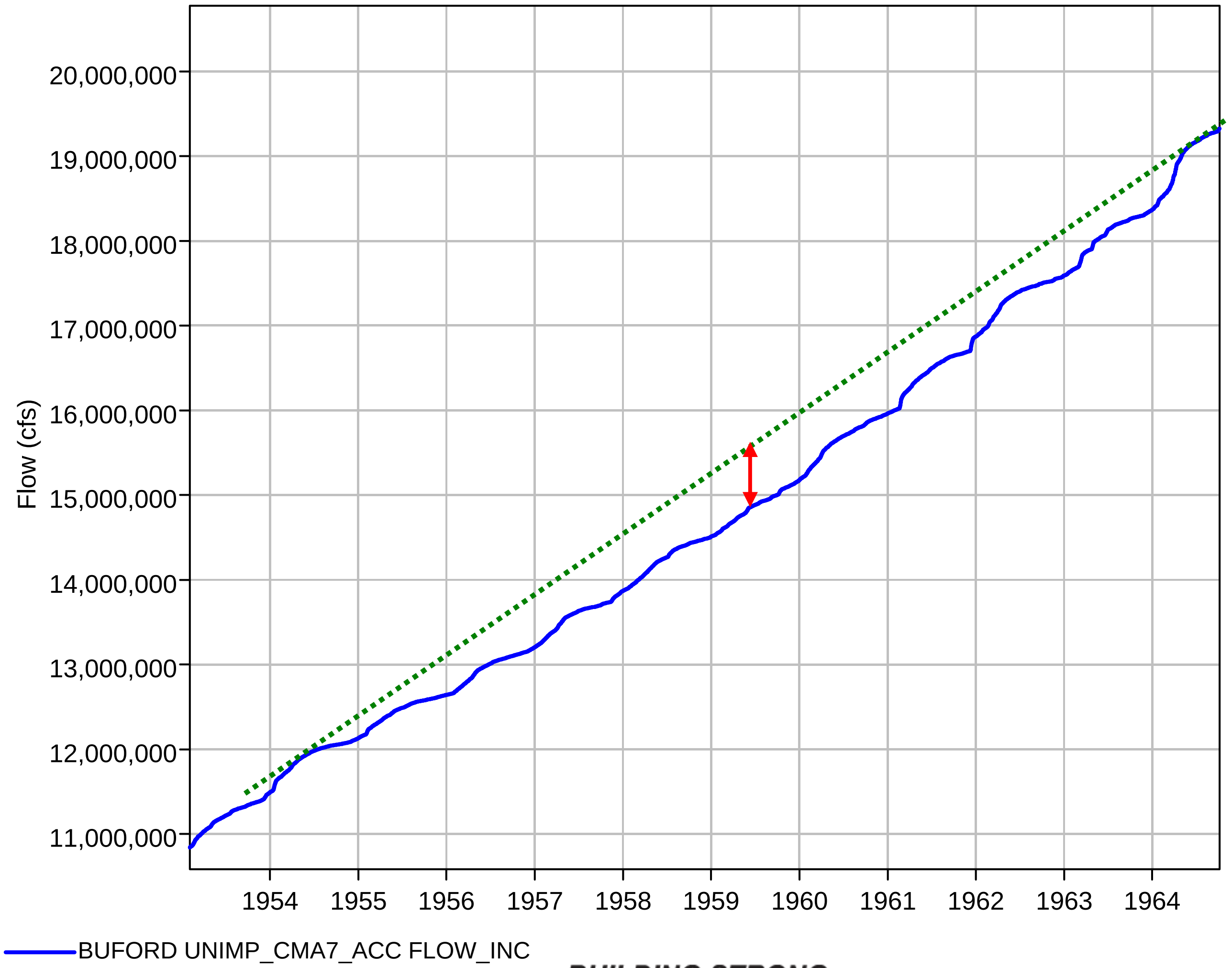
Atlanta Returns

Water Quality Requirement

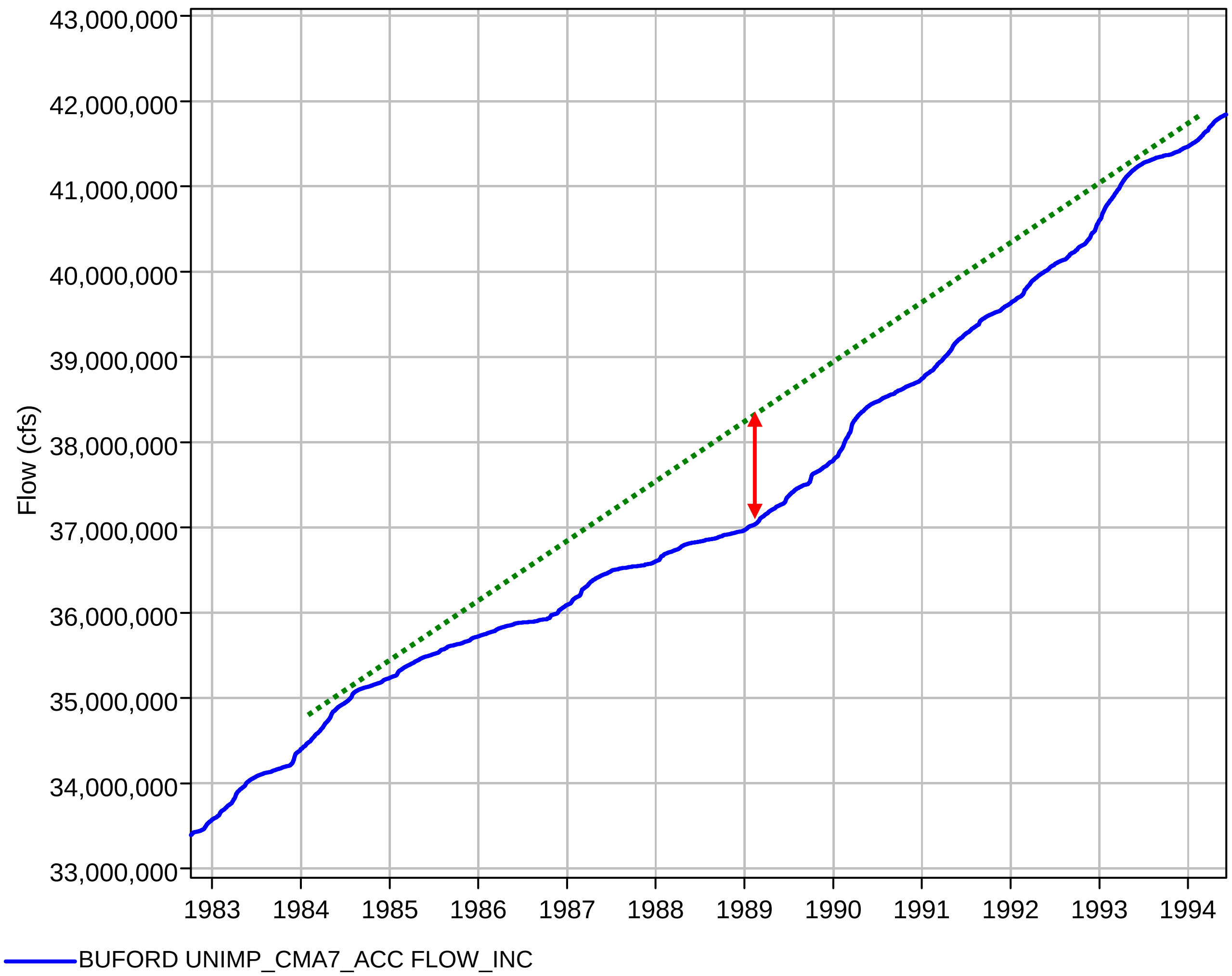
Rippl Mass Diagram Analysis



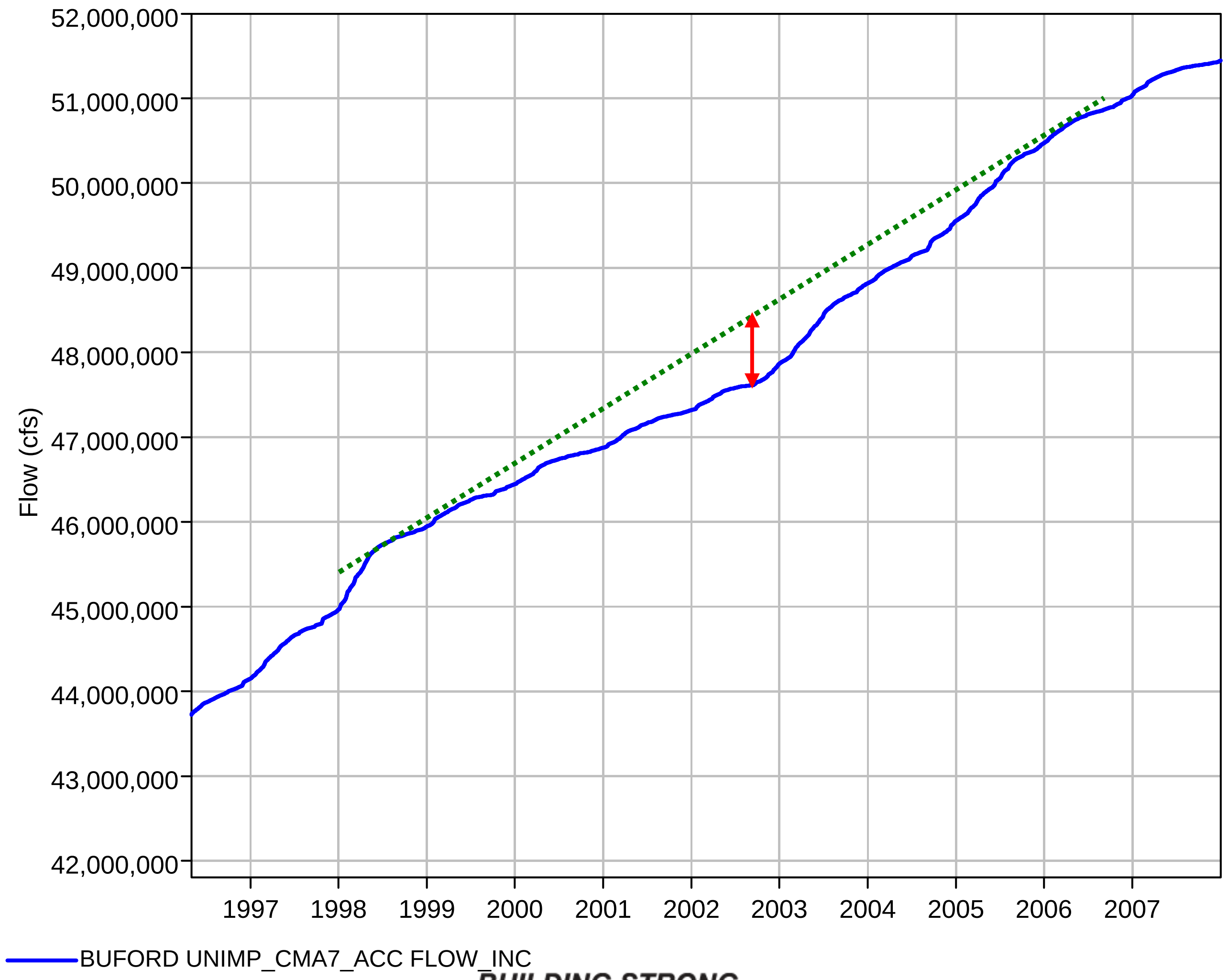
1954-1964 Critical Period



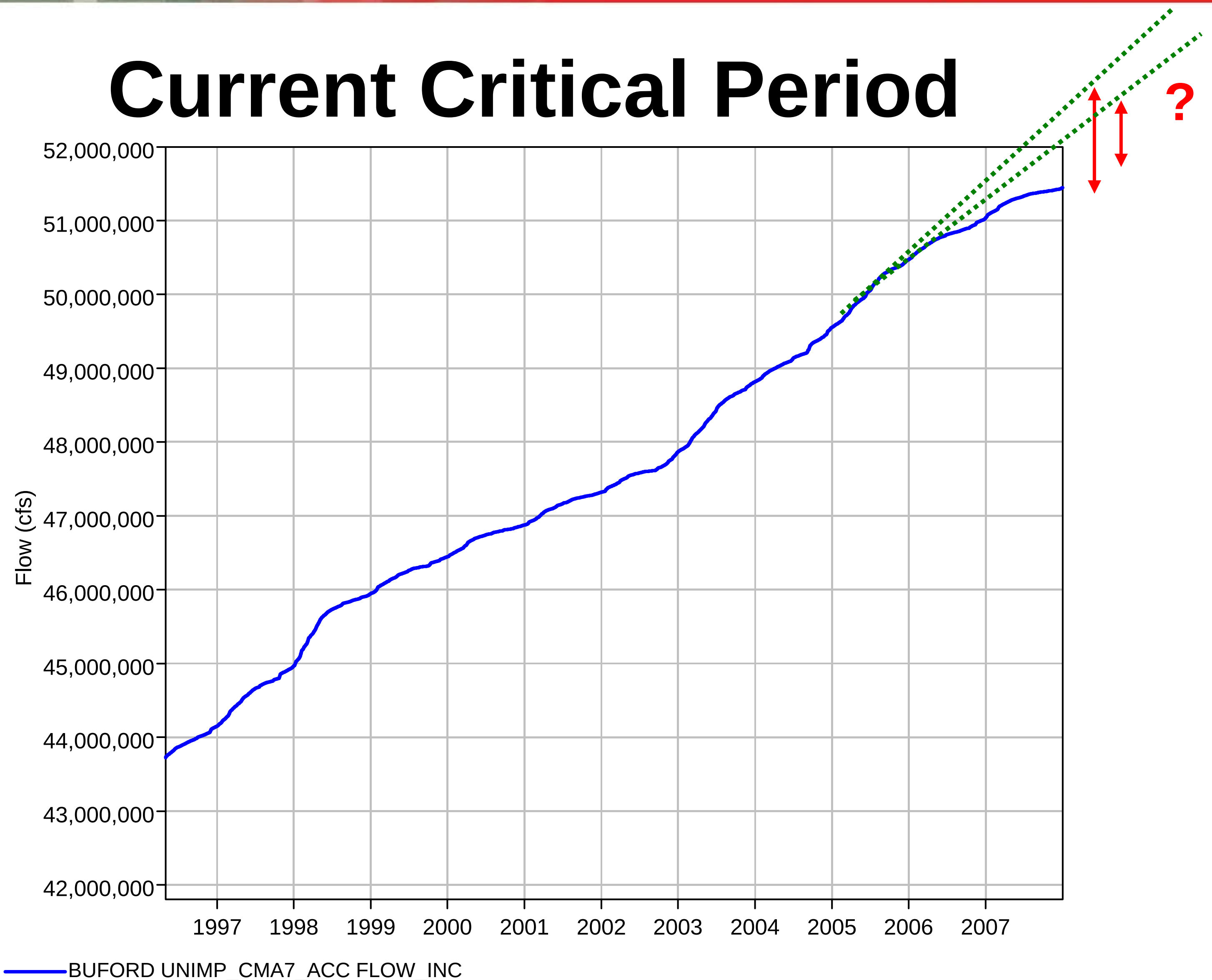
1985-1993 Critical Period



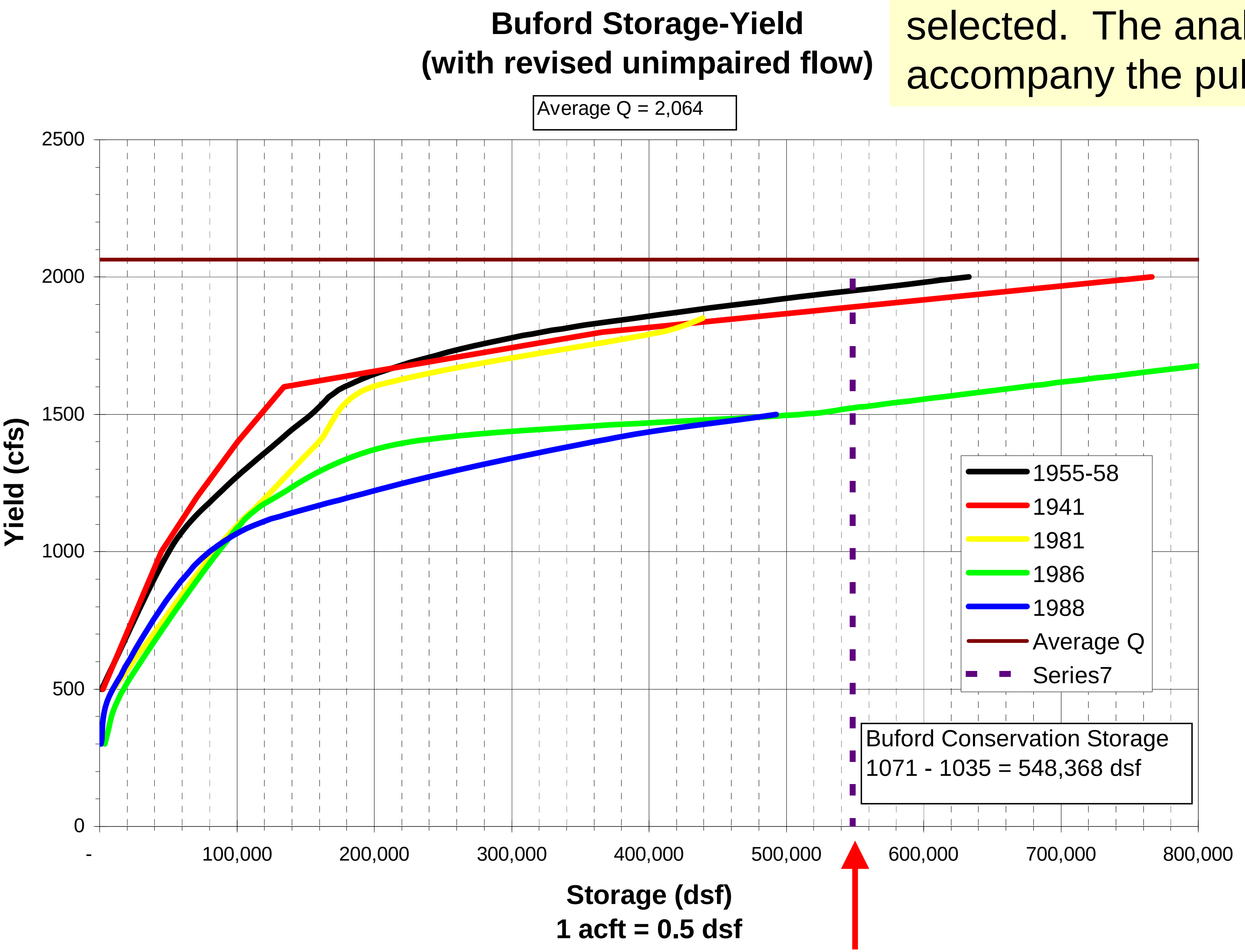
1999-2005 Critical Period



Current Critical Period

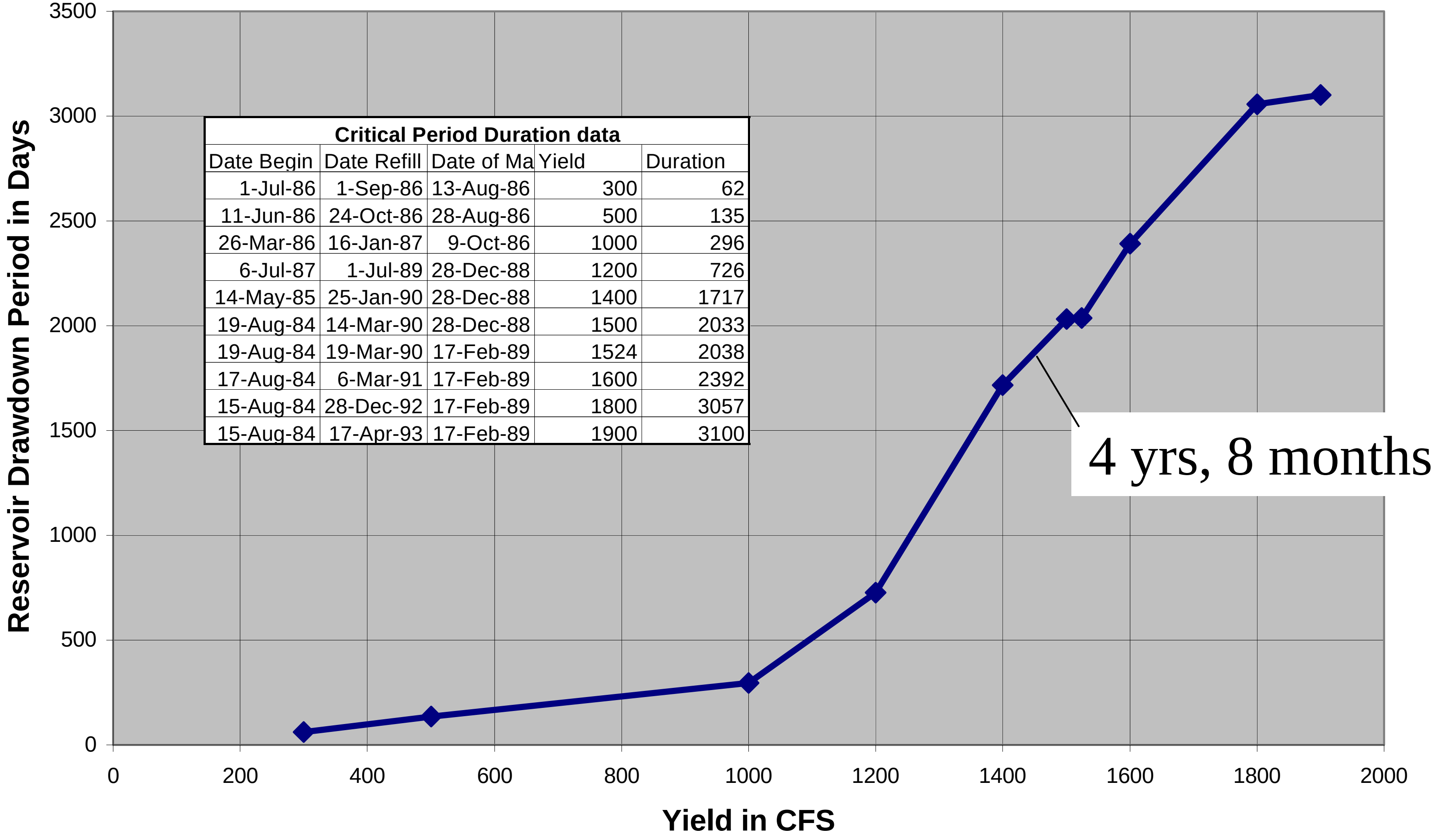


Yield is dependent on critical period selected. The analysis period should accompany the published value.



Year	Yield (cfs)
1941	1,890
1954	1,950
1986	1,524

Lanier Critical Period Duration



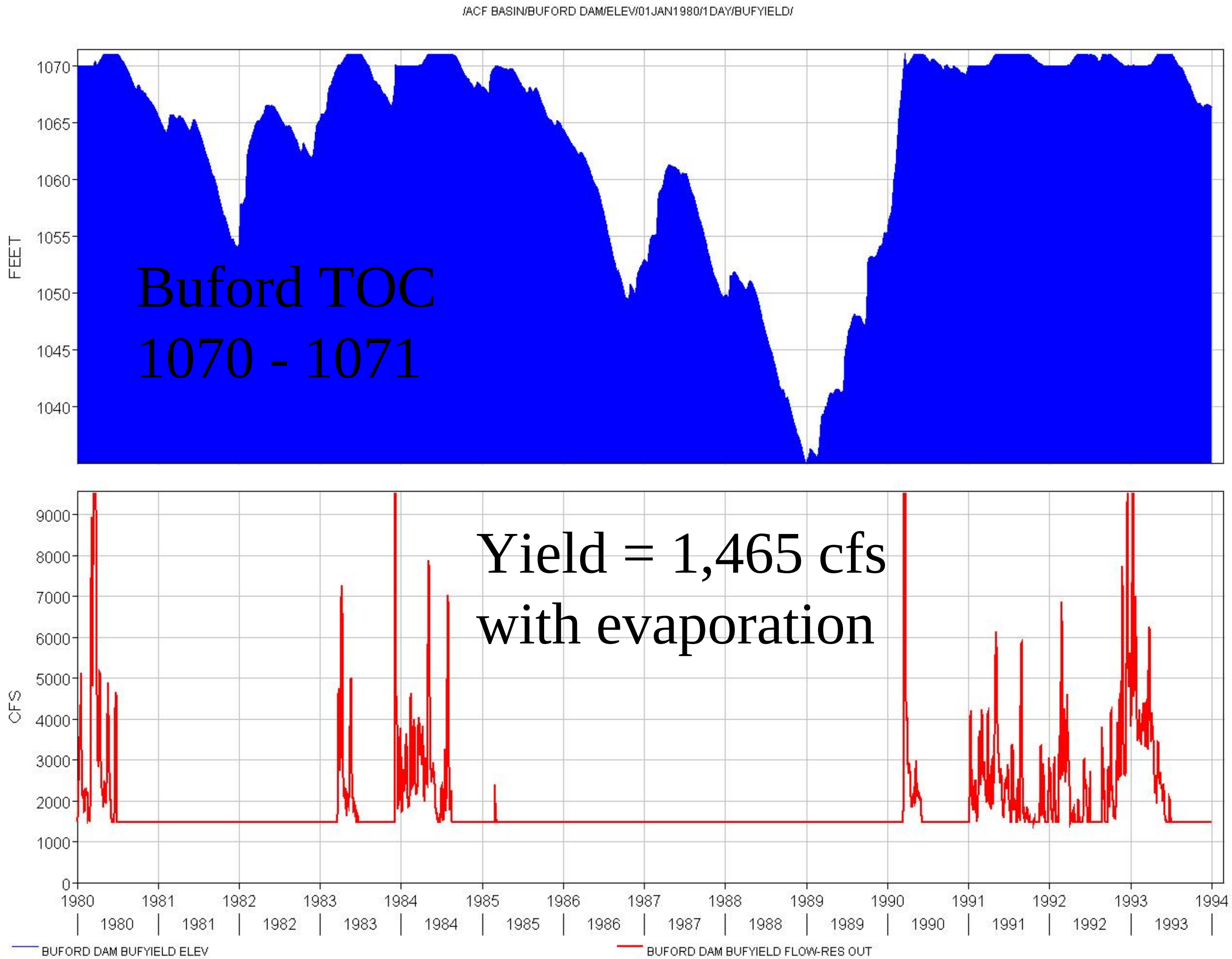
Critical Period Duration data

Date Begin	Date Refill	Date of Ma	Yield	Duration
1-Jul-86	1-Sep-86	13-Aug-86	300	62
11-Jun-86	24-Oct-86	28-Aug-86	500	135
26-Mar-86	16-Jan-87	9-Oct-86	1000	296
6-Jul-87	1-Jul-89	28-Dec-88	1200	726
14-May-85	25-Jan-90	28-Dec-88	1400	1717
19-Aug-84	14-Mar-90	28-Dec-88	1500	2033
19-Aug-84	19-Mar-90	17-Feb-89	1524	2038
17-Aug-84	6-Mar-91	17-Feb-89	1600	2392
15-Aug-84	28-Dec-92	17-Feb-89	1800	3057
15-Aug-84	17-Apr-93	17-Feb-89	1900	3100

Buford Dam Critical Yield

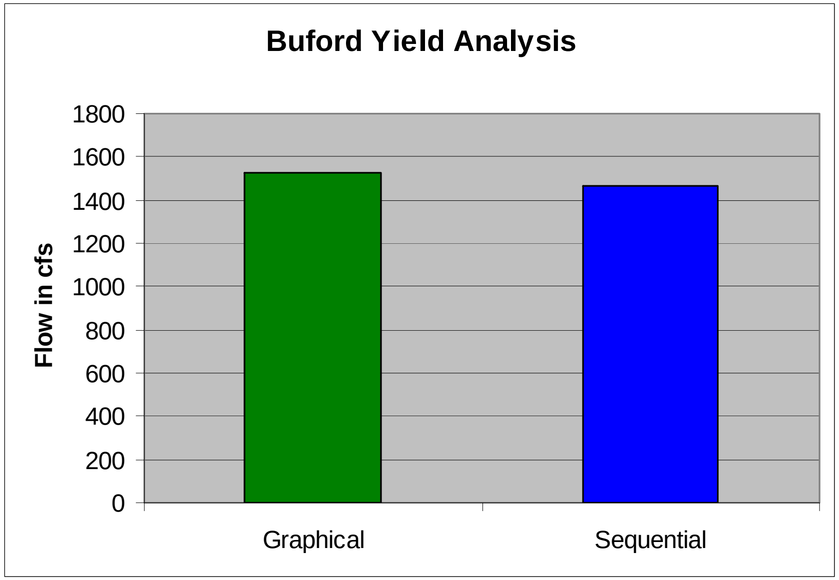
- Graphical Method
- Unimpaired Flow 1939-1993
- Critical Period 1980's
- Buford Conservation Storage 549,000 dsf
  (1071-1035)
- Critical Yield = 1,524 cfs (w/o evap)

Buford Yield – Sequential Analysis



Buford Yield

- Graphical
  - 1,524 cfs (w/o evap)
- Sequential
  - 1,465 cfs
- Current critical period may be the worst, awaiting additional data



Case Study #2

- Okatibbee Reservoir, Meridian MS
  - US Department of Energy, emergency water supply agreement
  - Development and operations of the planned Strategic Petroleum Reserve storage
  - Dependable water source during drought conditions

Background

- The U.S. Department of Energy (DOE) is interested in establishing an emergency water supply agreement with the US Army Corps of Engineers (USACE) for water from the Okatibbee Reservoir to support the development and operations of the planned Strategic Petroleum Reserve storage site at Richton, MS. DOE is currently looking at the construction of a raw water intake facility on the Pascagoula River near the Merrill gage to support the development and operations of the Richton storage site. This water intake facility will be used to supply fresh water to the Richton site for the solution mining of storage caverns and oil drawdown operations.

I - Yazoo River Basin

II - Tombigbee River Basin

III - North Independent Streams

IV - Tennessee River Basin

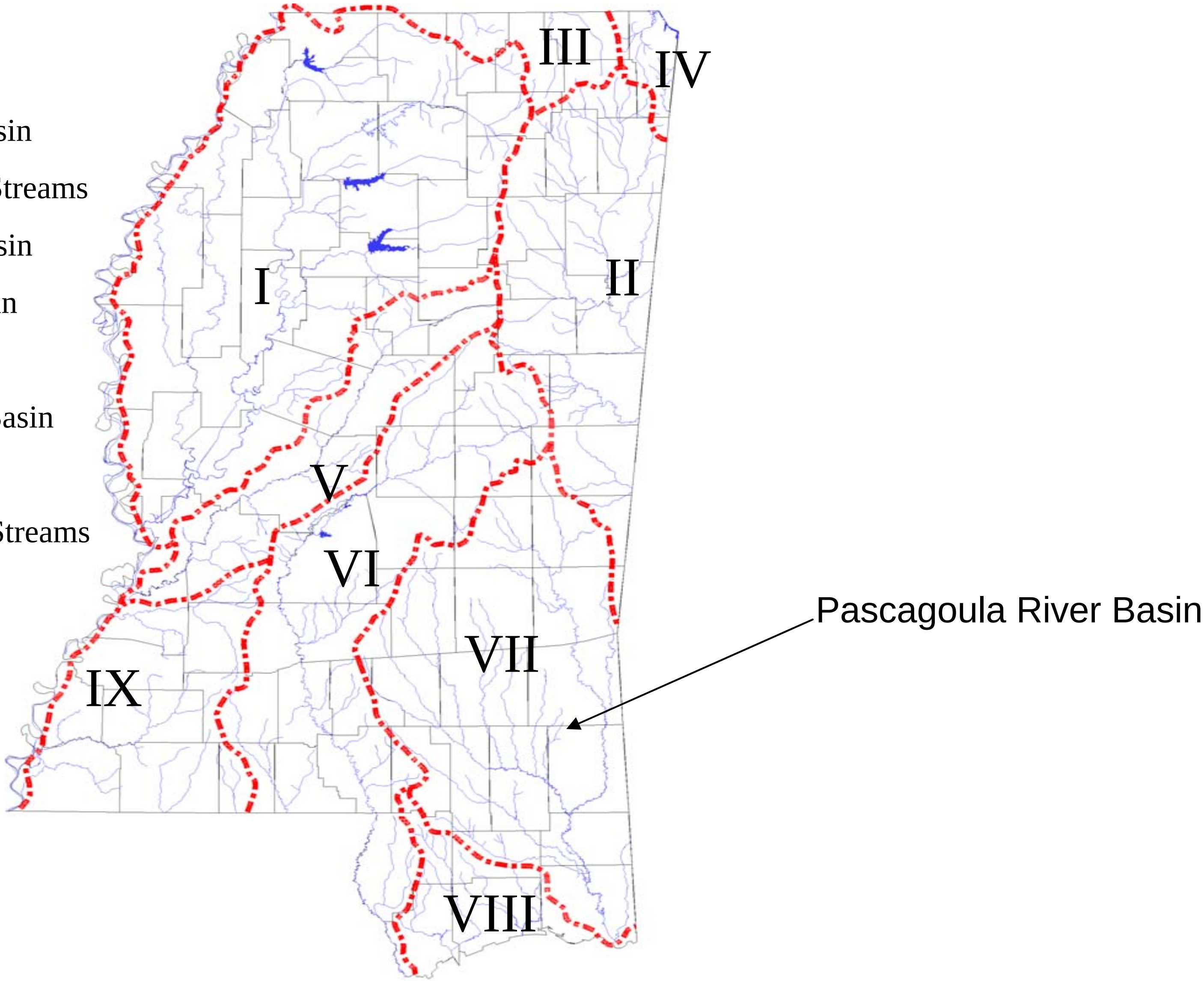
V - Big Black River Basin

VI - Pearl River Basin

VII - Pascagoula River Basin

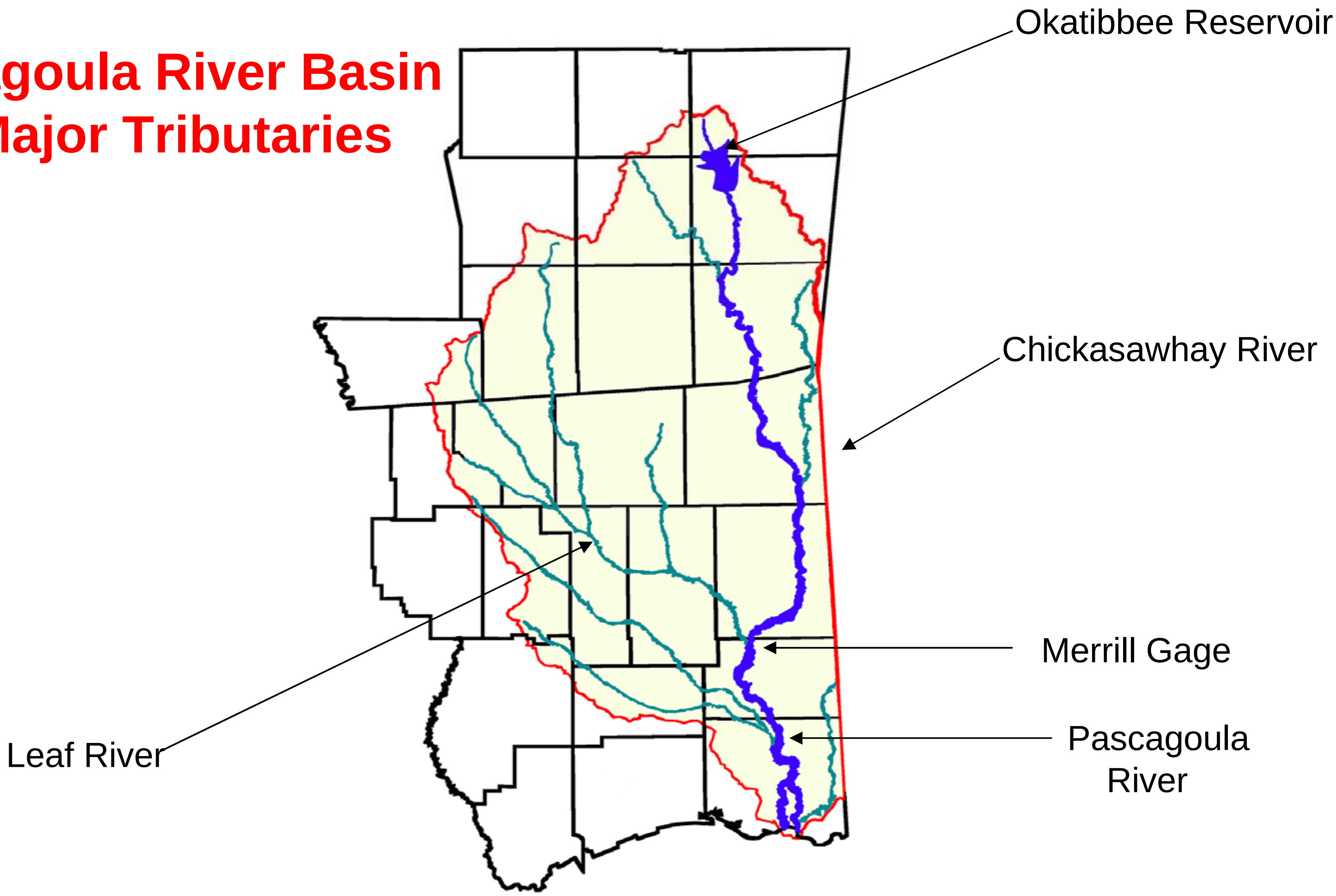
VIII - Coastal Streams

IX - South Independent Streams



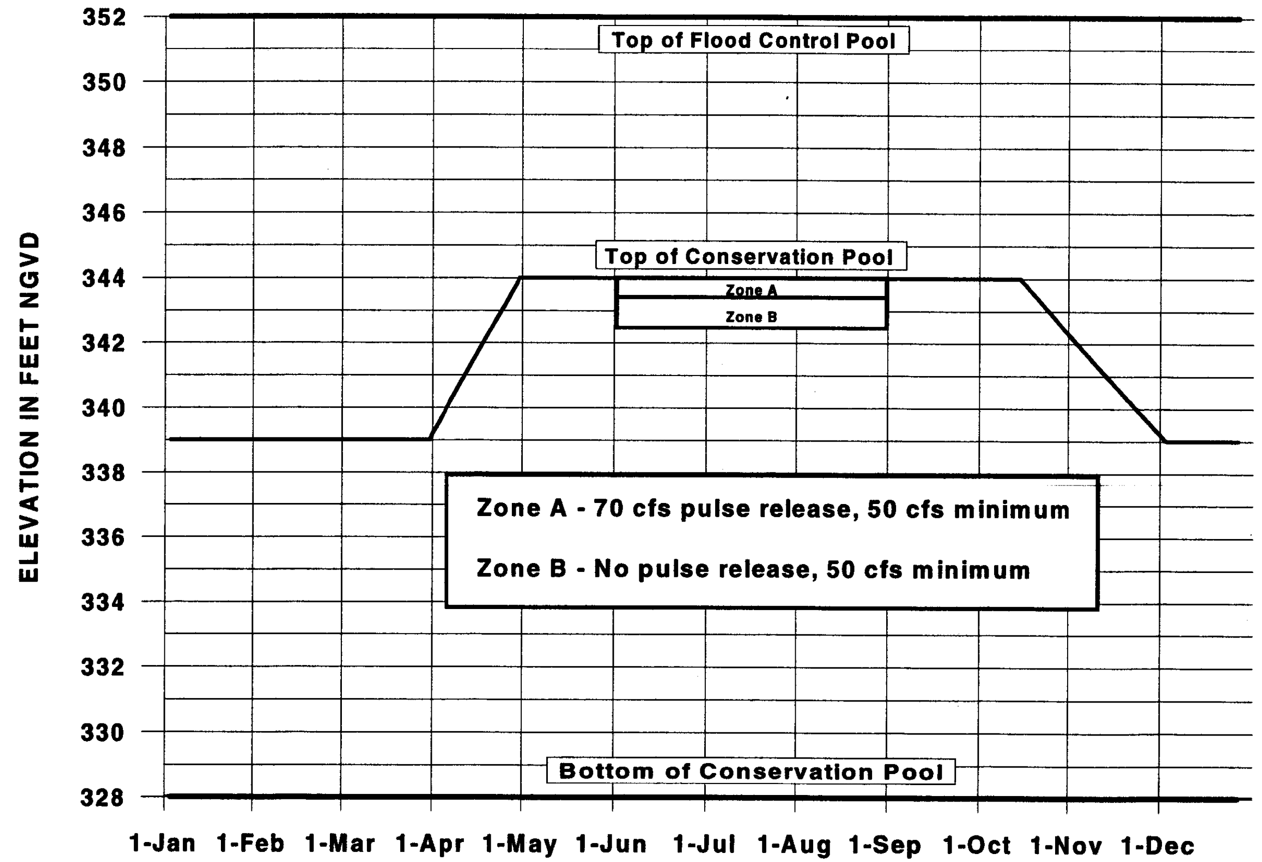
MAJOR RIVER BASINS

Pascagoula River Basin with Major Tributaries



Okatibbee Lake

	Elevation (msl)	Total Storage (acre-feet)
Top of Flood Control	350	88,6500
Top of Conservation (May thru 15 Oct)	344	46,060
Top of Conservation (Dec thru Mar)	339	29,160
Maximum Drawdown for Water Quality and Water Supply	328	7,760



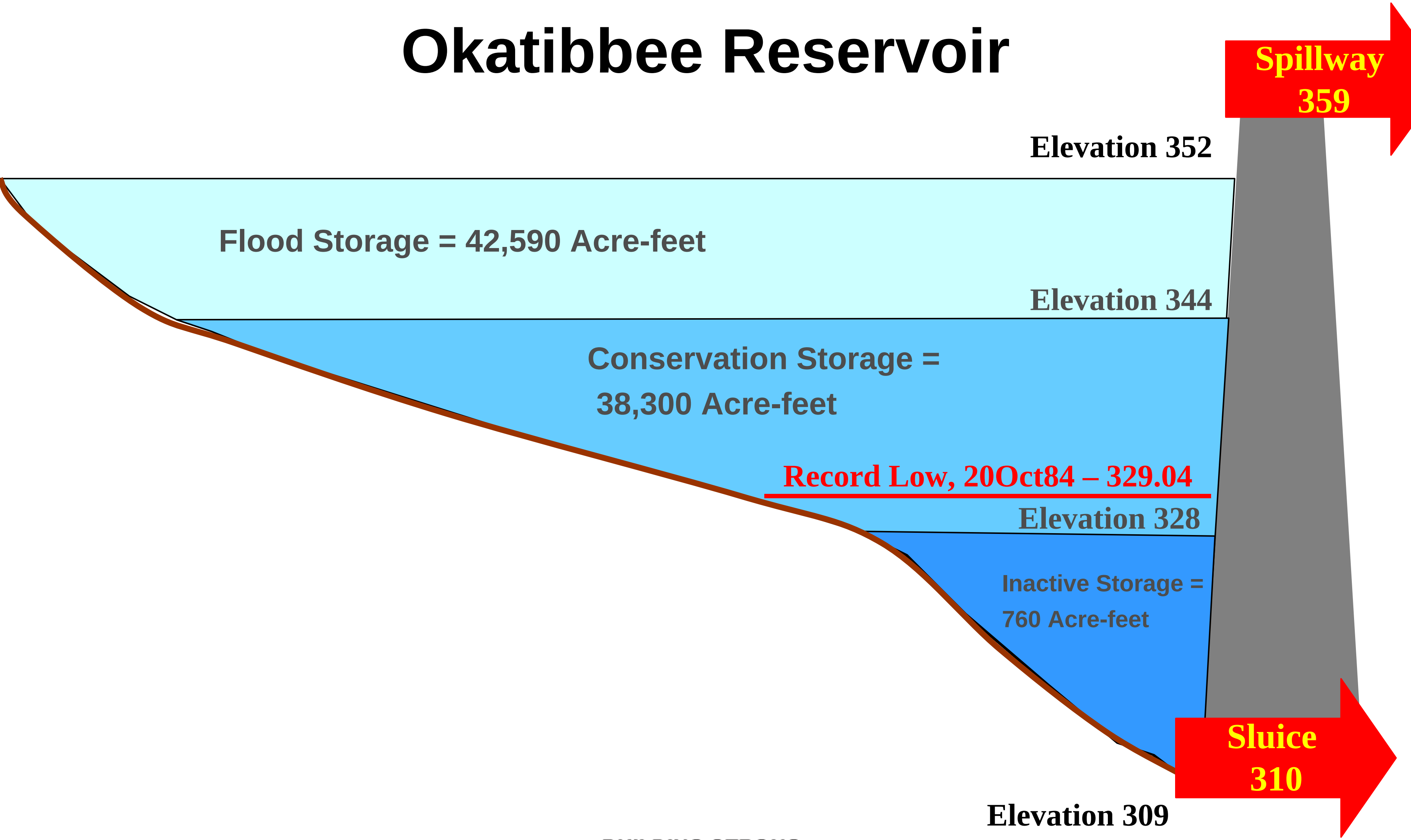
CORPS OF ENGINEERS

PASCAGOULA RIVER BASIN
WATER CONTROL MANUAL

OKATIBBEE LAKE
OKATIBBEE CREEK, MISSISSIPPI
OPERATING LEVELS
AND ACTION ZONES

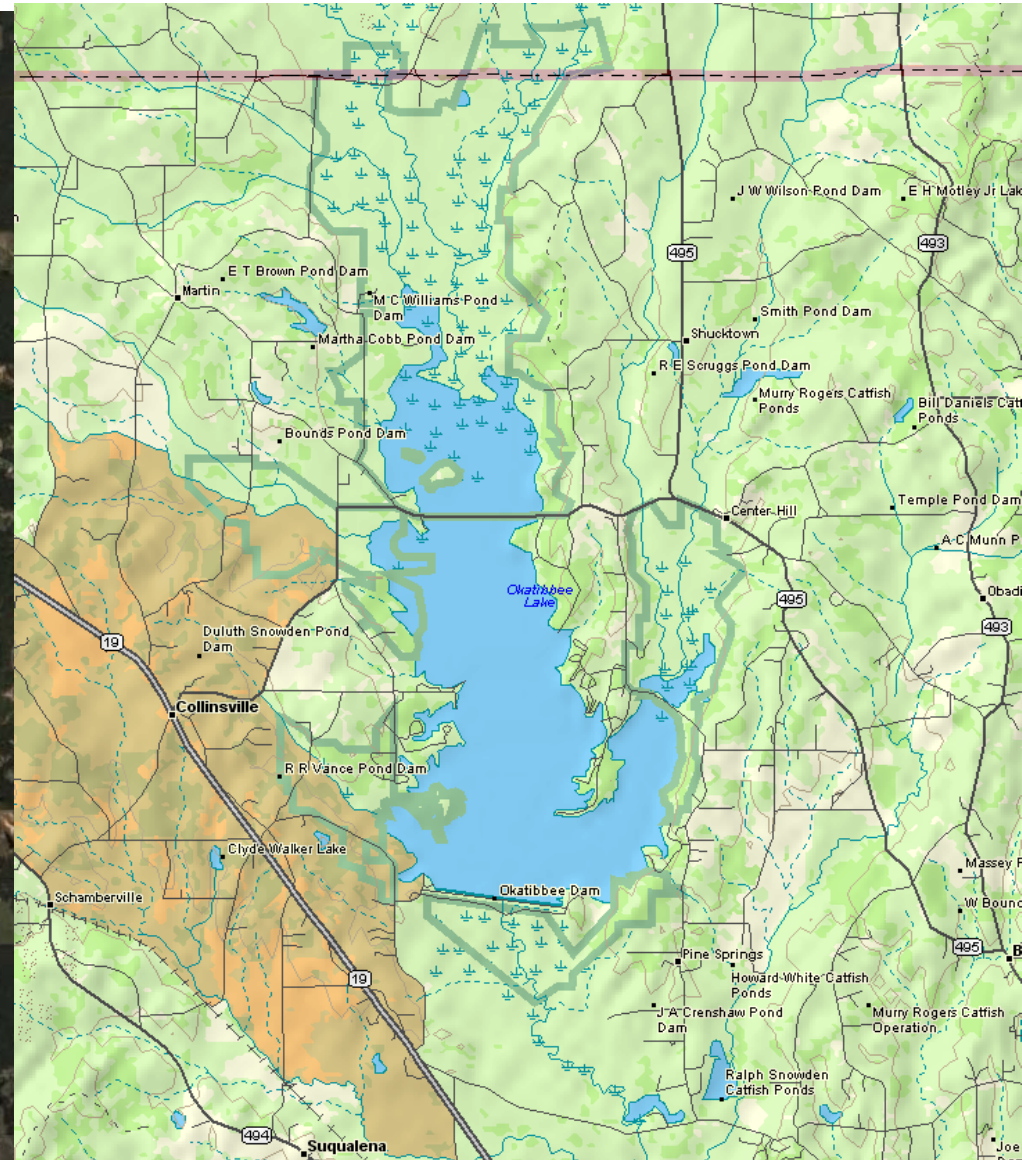
U.S. ARMY

Okatibbee Reservoir



US Army Corps of Engineers

Mobile District

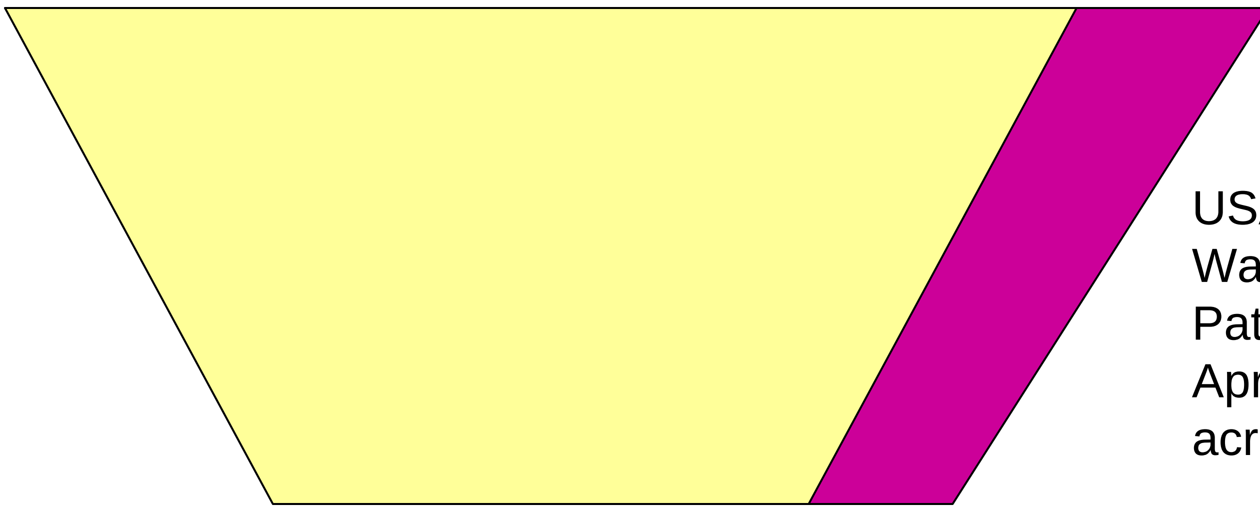


Okatibbee Outlet


Record Low Flow Recorded
2007
Stream Gauge Station At Merrill
Pascagoula River
George County

Existing Storage Account

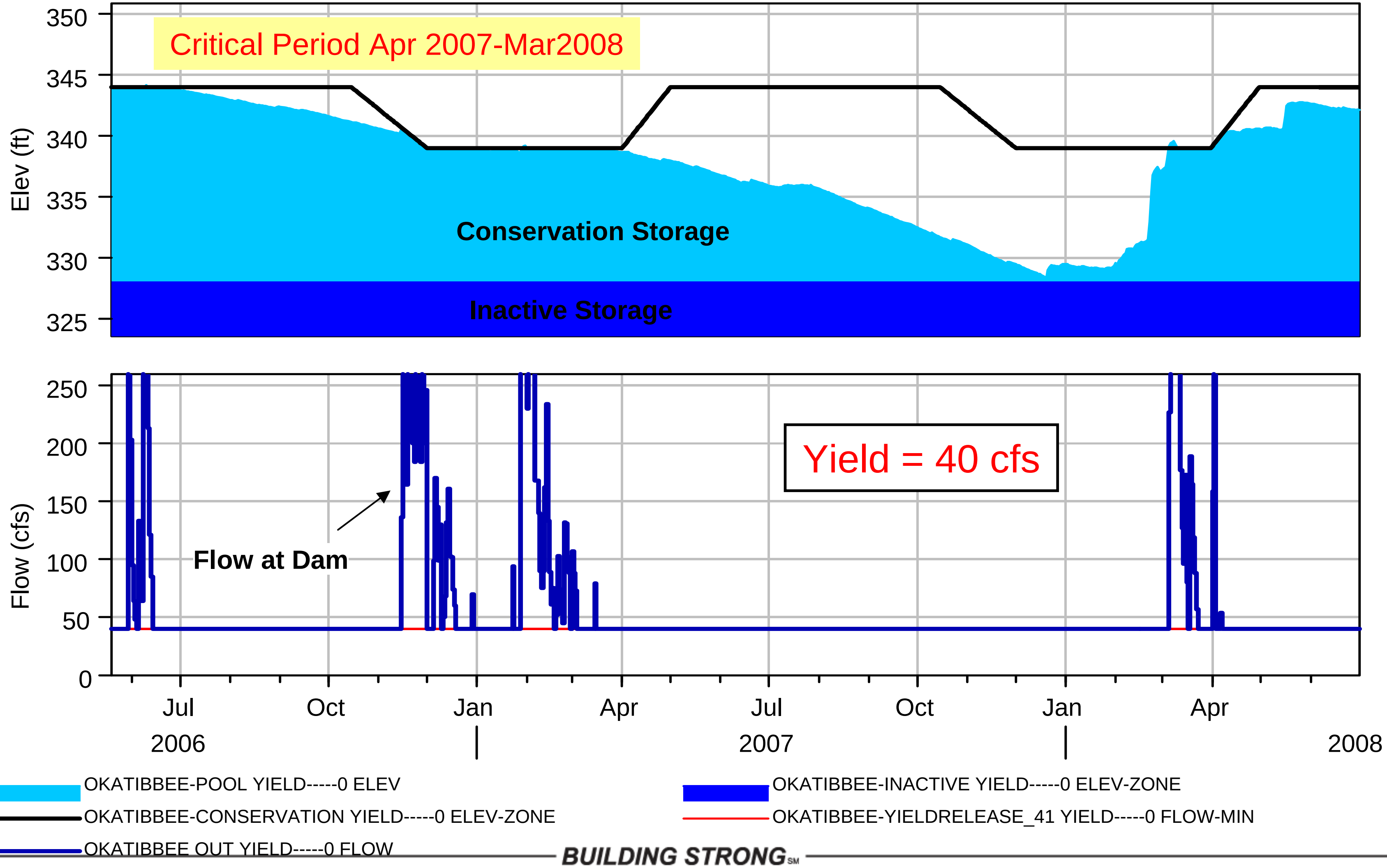
Okatibbee Conservation Storage



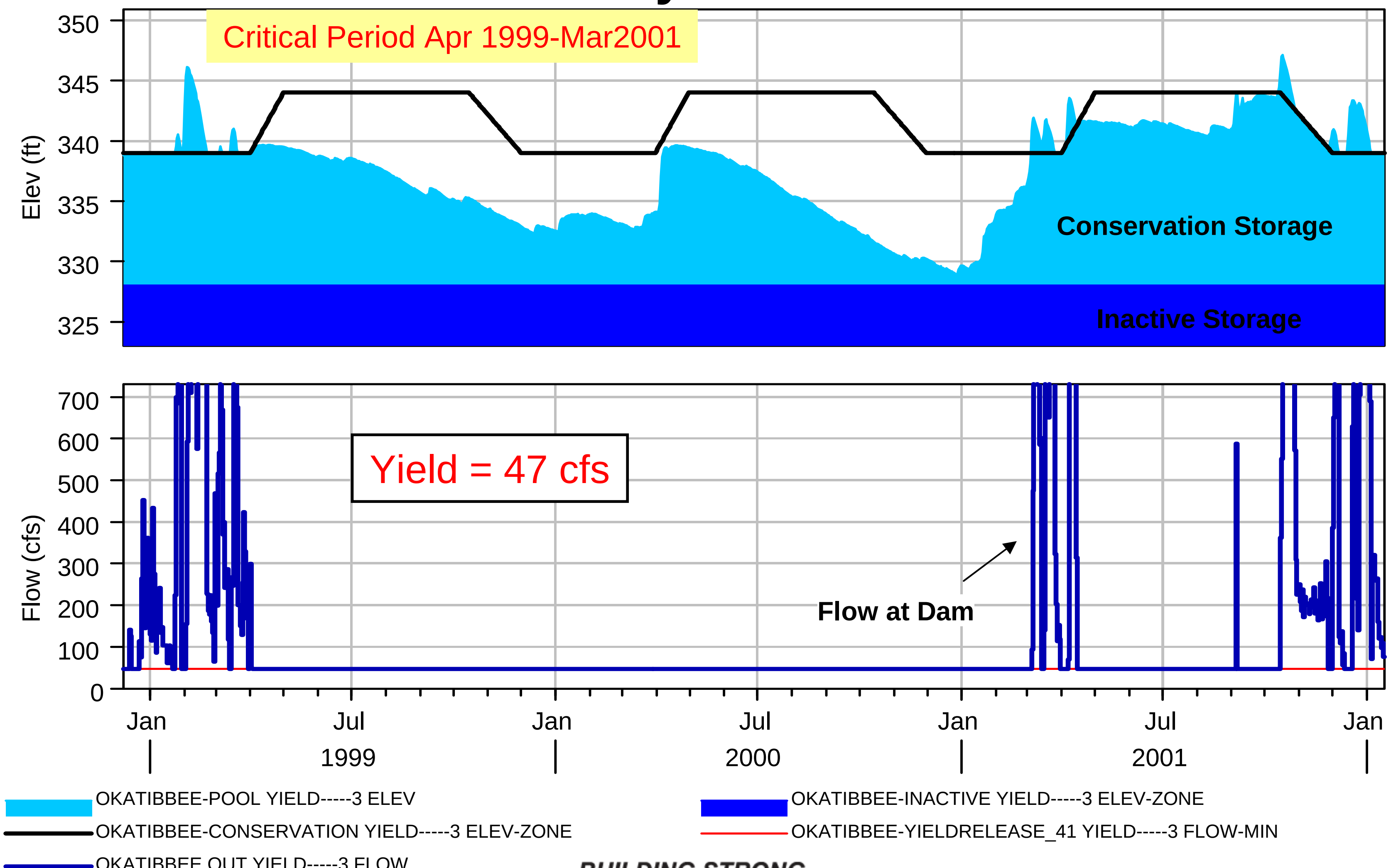
USACE entered into a Water Storage contract with Pat Harrison Waterway District April 23, 1965 for 13,100 acre-feet of storage (25 mgd)

- Pat Harrison (PHWD) 13,100 ac-ft (34.2 %)
- Remaining Conservation Storage 25,200 ac-ft (65.8 %)

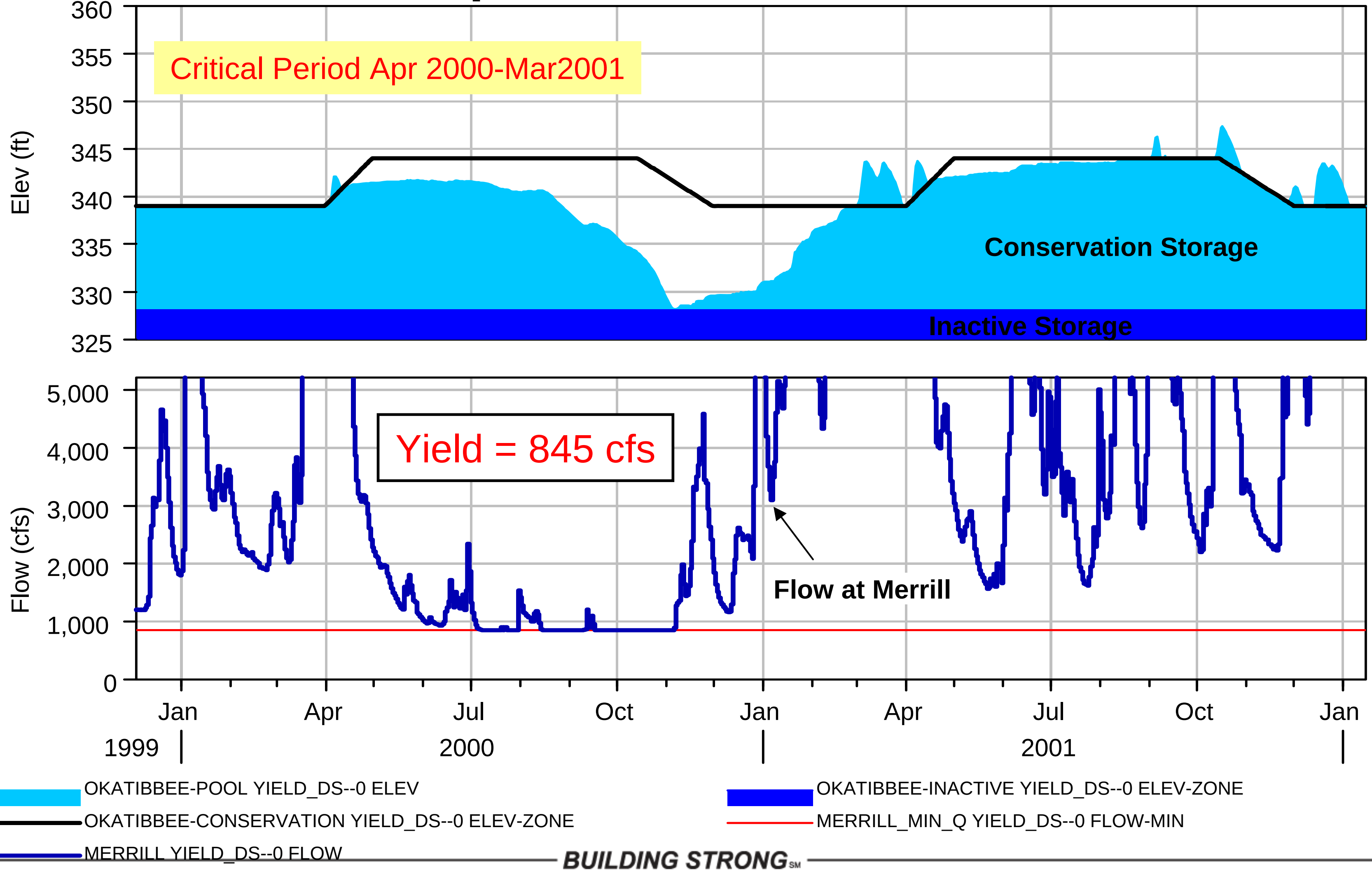
Okatibbee Yield Analysis Immediately Downstream



Okatibbee Yield Analysis Immediately Downstream



Okatibbee Yield Analysis
Operation for Merrill



Yield Analysis Summary

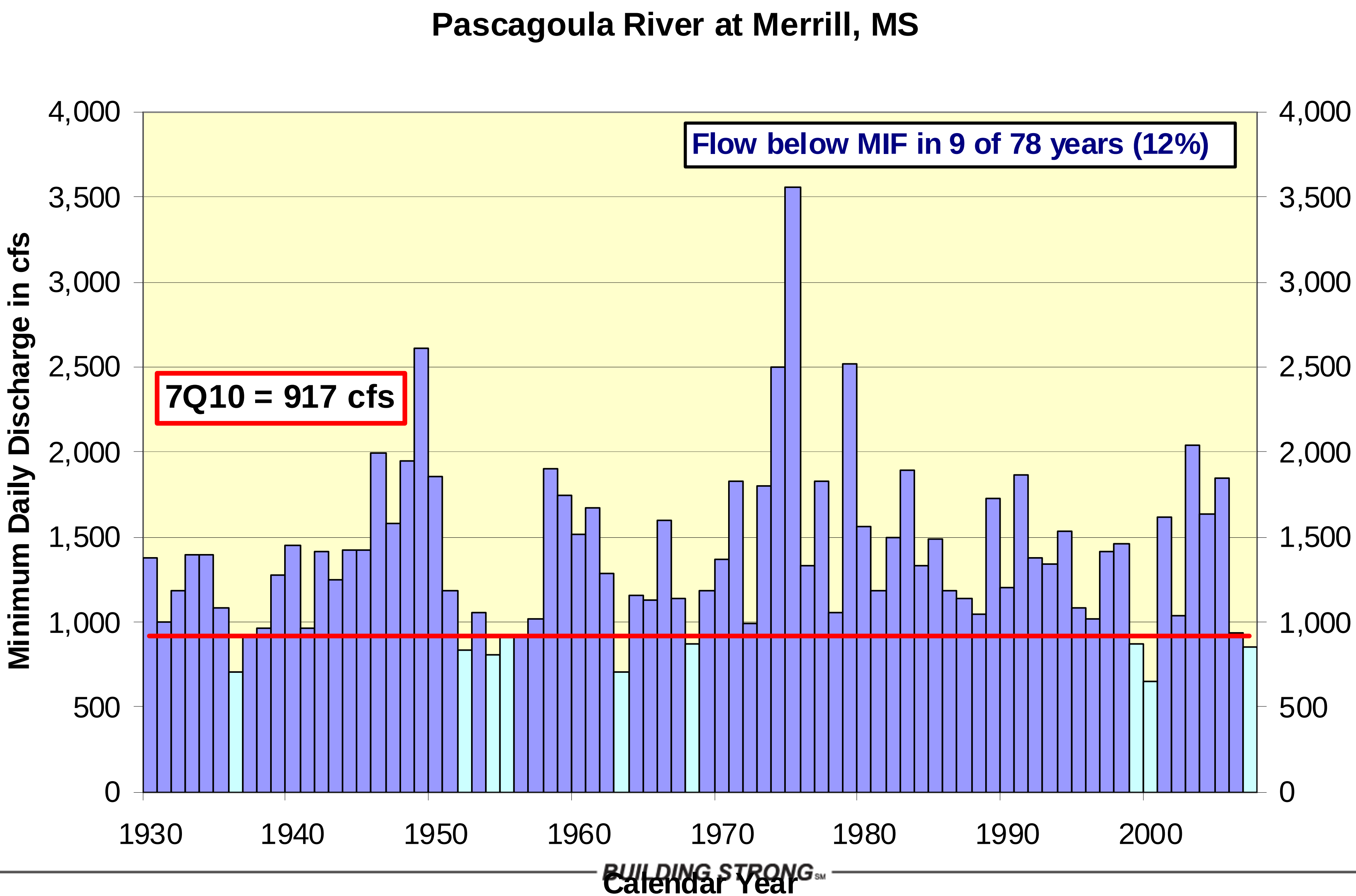
Okatibbee Conservation Storage = 38,300 ac-ft

Storage Yield from the most severe critical periods

Critical Period	Yield
Apr 1999- Mar2001	47 cfs
Apr 2007- Mar2008	40 cfs

Distribution of Yield

Storage Account	Critical Period Apr 1999- Mar2001	Critical Period Apr 2007- Mar2008
Pat Harrison	16.07 cfs	13.68 cfs
Remaining Storage	30.93 cfs	26.32 cfs

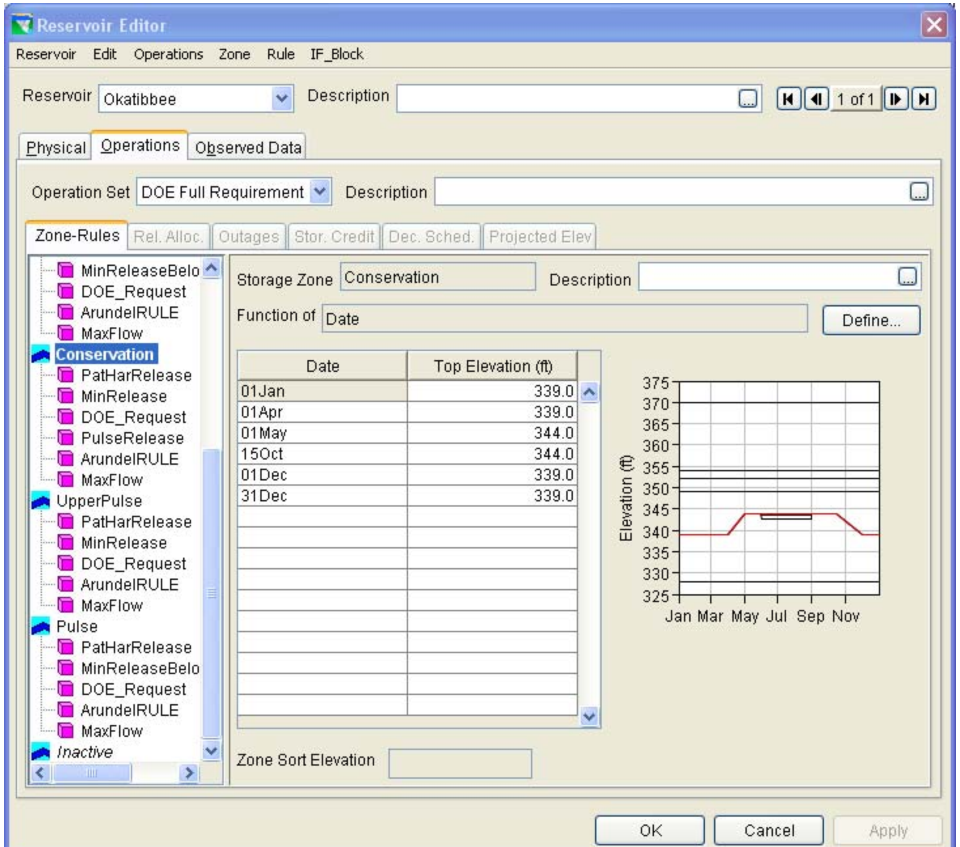

Pascagoula River at Merrill, MS
Flow below MIF in 9 of 78 years (12%)
7Q10 = 917 cfs
Minimum Daily Discharge in cfs
0
500
1,000
1,500
2,000
2,500
3,000
3,500
4,000
1930
1940
1950
1960
1970
1980
1990
2000
Calendar Year

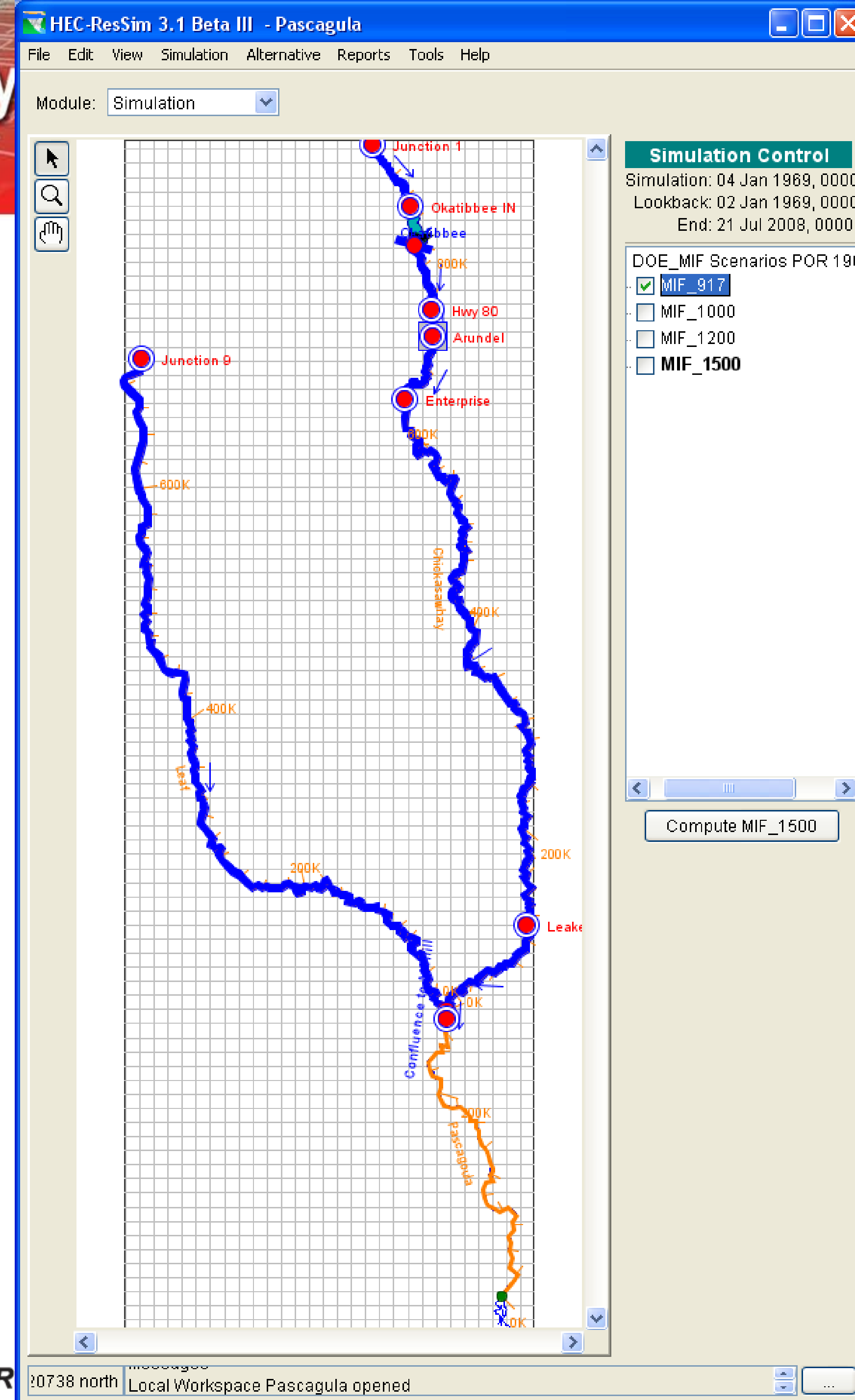
Model Results

- Number of days each year that releases from Okatibbee not available
- Percent of Time Okatibbee releases made to meet DOE requirement

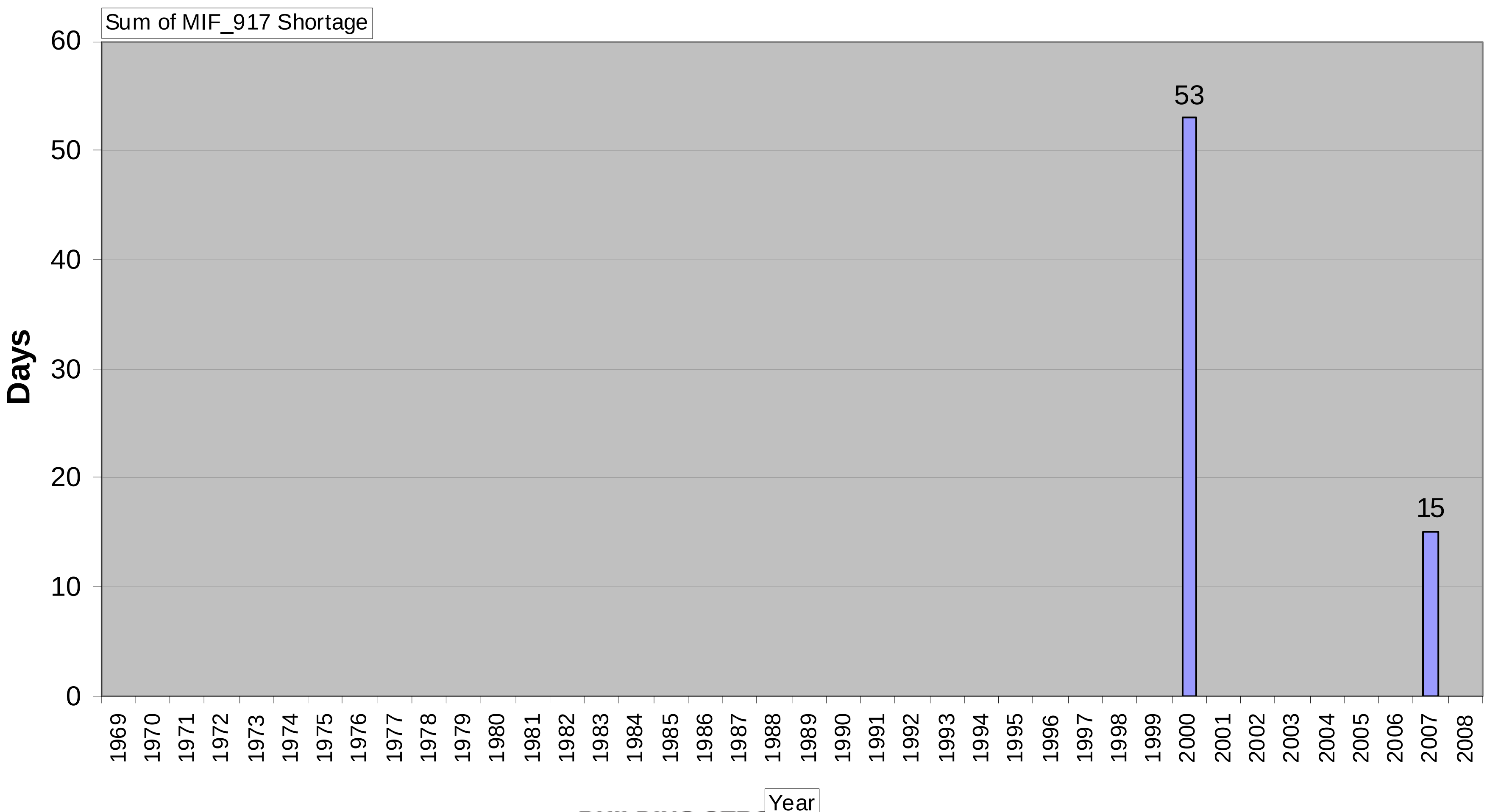
US Army

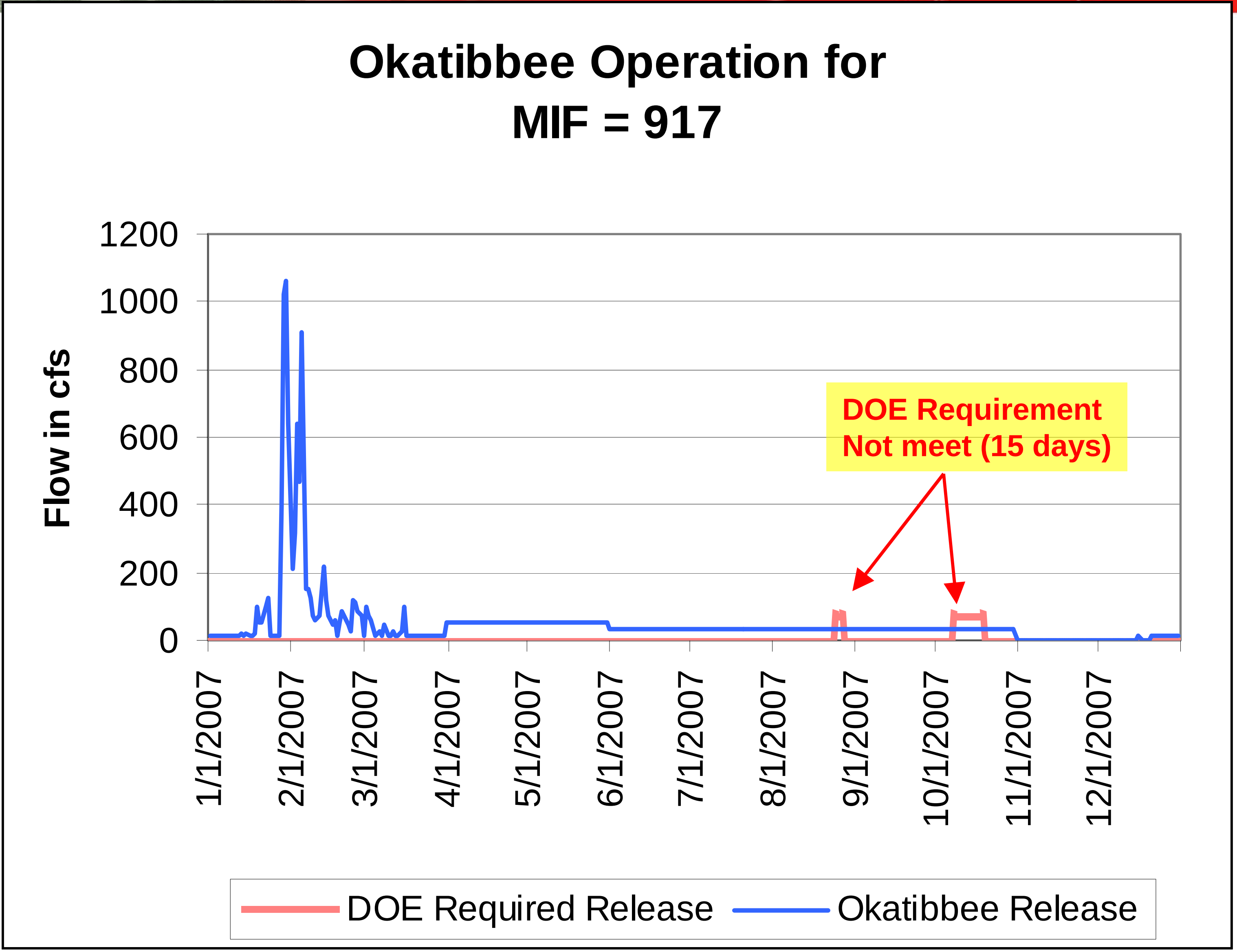
ResSim Model





Days Okatibbee Release Not Available
MIF = 917 cfs




Okatibbee Operation for
MIF = 917
Flow in cfs
1200
1000
800
600
400
200
0
1/1/2007
2/1/2007
3/1/2007
4/1/2007
5/1/2007
6/1/2007
7/1/2007
8/1/2007
9/1/2007
10/1/2007
11/1/2007
12/1/2007
DOE Requirement
Not meet (15 days)
DOE Required Release
Okatibbee Release

Modeling Results

- The results indicate that the DOE release requirements can be meet during the non-critical periods. As a reminder the critical periods are
  - Apr 1999- Mar2001
  - Apr 2007- Mar2008
- The 2007 drought period is the most severe recorded since the construction of Okatibbee Dam. In fact it's so severe **no** DOE releases can be made for any of the 4 scenarios. During this period all available storage is allocated to existing project purposes.
- The following charts indicate the periods DOE releases requirement is not meet.