Appendix A - Critical Yield Methodology

1 INTRODUCTION

The methodology describing how the Corps determined critical yield and crucial datasets that significantly affect analyses results is detailed below.

1.1 RIVER DIVERSIONS

The difference between water withdrawn from a river and water returned to the river is defined as a diversion. Diversions are a net volume or quantity assumed to be permanently lost from the river.

1.1.1 Unimpaired Flow Data Set

The unimpaired flow data set is historically observed flows, adjusted for some of the human influence within the river basins. Man-made changes in the river basins influence water flow characteristics and are reflected in measured flow records. Determining critical yield requires removing identifiable and quantifiable man-made changes such as municipal and industrial water withdrawals and returns, agricultural water use, and increased evaporation and runoff due to the presence of surface water reservoirs, from the observed flow measurements.

The daily unimpaired flow data set is used as the input flow series for all yield model simulations and represents the Corps' best estimate of a pre-development flow series. By making these flow adjustments for man-made activities, any combination of water demands input to the ResSim model and modeled over the entire flow record (1939 – 2008), produces a consistent basis for comparing yield results. Yield simulations are computed for with no water diversion and with current water diversion scenarios using current river diversions to compute yield accounts for existing conditions.

The unimpaired flow dataset is not an exact replication of a flow dataset representing conditions that would exist without the influence of human activities or a precise measure of natural flow conditions. This is because all human influences, such as land use changes, cannot be accounted for, and many flow set adjustments are estimates based upon assumptions, not direct measurements of the human influences.

The original unimpaired flow data set developed as part of the Alabama-Coosa-Tallapoosa and Apalachicola Chattahoochee Flint (ACT/ACF) River Basins Comprehensive Water Resources Study, <u>ACT/ACF Comprehensive Water Resources Study, Surface Water Availability Volume I: Unimpaired Flow, July 8, 1997</u> . The Comprehensive Study was study conducted by the States of Alabama, Florida and Georgia and the Corps pursuant to a Memorandum of Understanding. One purpose of the study was to identify available water resources and water demands in the ACT and ACF Basins, and recommend a coordination mechanism for the equitable allocation of water resources between the States. Several technical modeling and assessment tools were developed to support this process, including the unimpaired flow dataset and the HEC-5 hydrological model.

The process accumulated data at over 50 locations for the 1939 to 1993 period of record. Because of the occurrence of negative flows in the daily values, the data has been smoothed using 3-, 5-, or 7-day averaging. This preserves the volume of the flow and eliminates most of the small negative flows in some of the daily flow data.

The Mobile District modeling team develops the unimpaired flow data sets every 1 - 3 years employing water use data provided by the States of Alabama, Florida and Georgia. The unimpaired flow datasets are reviewed by the states before finalizing. All supporting data and the final results of the analyses are provided to the states. This data set has recently been extended through 2008 and is available from the Corps of Engineers.

1.2 DROUGHT PERIOD UTILIZED IN CRITICAL YIELD

Several drought periods have been identified from the historic record and from previous yield analyses (reference Appendix D - References and Prior Reports). Drought periods were identified in 1940-41; 1954-58; 1984-89; 1999-2003, and 2006-2008. These are shown below in Table A-1 and described in more detail at Appendix E - Drought Descriptions.

Each period is referenced in accordance to the decade or most severe year of occurrence. Critical yield was computed for each of the drought periods and the lowest value selected as the critical yield value for this report.

Table A-1. Drought Periods

Drought Periods	Label
1940-1941	1940
1954-1958	1950
1984-1989	1980
1999-2003	2000
2006-2008	2007

The most recent drought and recovery period extend beyond 2008. Lake Lanier reached a historic low elevation of 1050.79 feet NGVD on December 28, 2007, and nearly again on December 8, 2008, when the pool reached elevation 1051 feet NGVD. A return to almost normal rainfall and conservative management allowed the reservoir to refill 20 feet over the next 10 months.

Lake Lanier recovery was marked by reaching full pool elevation of 1071 feet NGVD on October 14, 2009. Figure A-1 shows the most recent critical period for Lake Lanier and includes the drawdown and refill period through 2009.

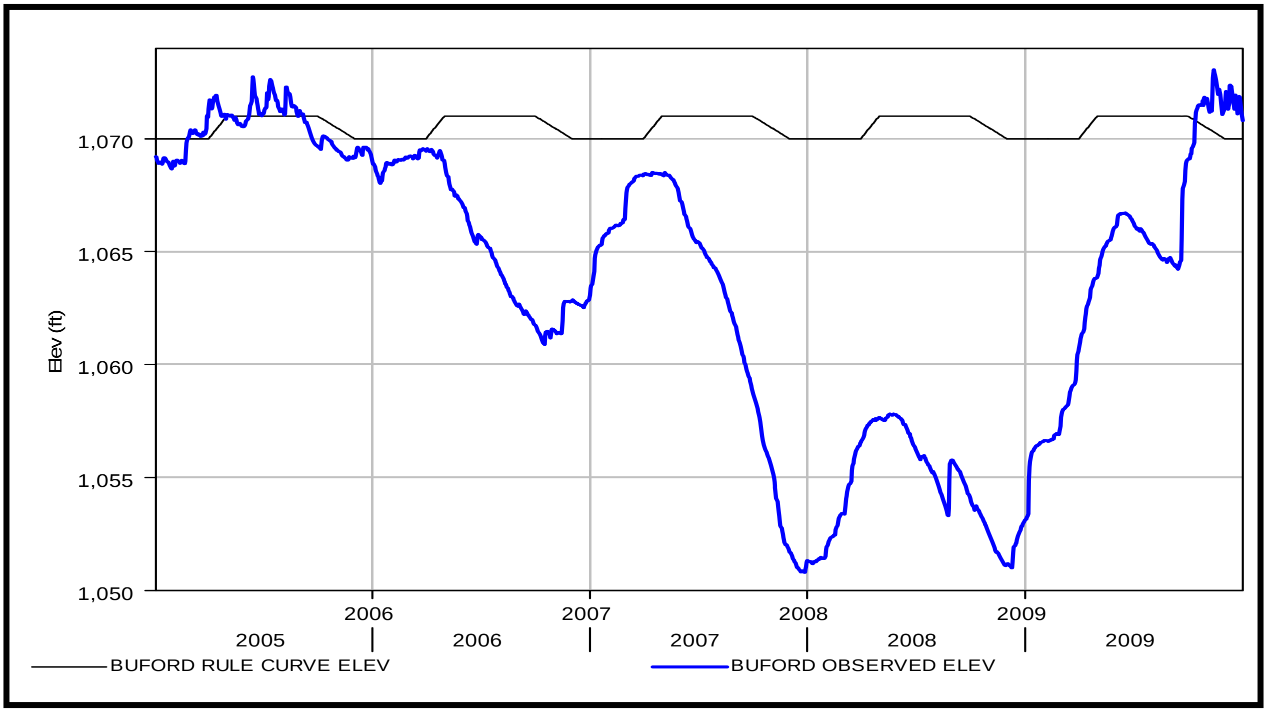

Figure A-1. Lake Lanier Pool Elevation 2005-2009

The data necessary to develop an unimpaired flow data set representing all of Calendar Year 2009 is not available. However, the Lake Lanier critical yield values from the partial 2007 drought are considered representative of actual critical yield because the lake steadily refilled from the low of December 8, 2008. Though the reservoir did refill in 2009, all yield values computed for the 2007 critical period will be recomputed when the unimpaired flow is extended to include Calendar Year 2009.

The remaining projects in the yield analysis, West Point Lake and Walter F. George Lake, refilled in 2008.

1.3 MODELS

A computer simulation model is a computer program that simulates a simplified model of a system. The U.S. Army Corps of Engineers' Hydrologic Engineering Center's (HEC) Reservoir System Simulation (HEC-ResSim) is a computer program comprised of a graphical user interface (GUI) and a computational engine to simulate reservoir operations. HEC-ResSim was developed to aid engineers and planners performing water resources studies by representing the behavior of reservoirs and to help reservoir operators plan releases in real-time during day-to-day and emergency operations.

The HEC-ResSim Firm Yield process calculates the release for a single minimum release operation rule that drains the reservoir's pool to empty once in the period of record. This figure can also be described as the largest release that can be supplied reliably throughout the record.

The process involves computing a simulation run with an estimate of the largest release, and recomputing iteratively with successive estimates until the correct release is found.

The user enters the maximum number of iterations that will be run and two tolerance values. The Storage Test Tolerance value shares the same units as the reservoir storage and is the value the reservoir must decrease in order to be considered empty. It will be used as the tolerance for all the zone storage values listed in the reservoir table. The Rule Test Tolerance value will share the same units as the minimum release rule and is used in the calculations as a test for violations of the minimum release rule.

The ResSim ACT and ACF yield models include a net precipitation-evaporation rate for each reservoir that utilizes evaporation values developed for National Oceanic and Atmospheric Administration (NOAA) Technical Reports, monthly pan evaporation rates and National Weather Service (NWS) reports of rainfall and flow rates. The net evaporation losses, evaporation minus precipitation, were computed in inches at the projects. The NOAA report was used because historic monthly evaporation data is not available at the projects. Historic monthly precipitation data was obtained from the NWS.

1.4 METHODS EMPLOYED IN CRITICAL YIELD ANALYSIS

There are several ways of computing critical yield. Sequential analysis is currently the most accepted method. This method uses the conservation of mass principles to account for the water in the reservoir inflows and releases. The fundamental equation is:

$$I - O = \Delta S$$

Where:

I = Total inflow during the time period, in volume units

O = Total outflow during the time period, in volume units

ΔS = Change in storage during the time period, in volume units

Sequential routing uses an iterative form of the above equation:

$$S_t = S_{t-1} + I_t - O_t$$

Where:

S_t = Storage at the end of time t, volume units

S_{t-1} = Storage at the end of time t-1, volume units

I_t = Average inflow during time step Δ, in volume units

O_t = Average outflow during time step Δ, in volume units

The HEC-ResSim computer application uses sequential analysis and the sequential routing method with the application's Firm Yield routine to maximize yield from a specified amount of storage.

It is important to be aware that the most severe drought event at one reservoir may not be the most severe drought event at another reservoir in the same river system. For the purposes of computing critical yield on the ACF System, the lowest critical yield value (typically associated with the most severe drought event) at an upstream reservoir will be used to calculate a downstream reservoir's critical yield. This is because on the ACF System, the amount of water exiting an upstream reservoir influences the amount of water available in a downstream reservoir. This is germane to Methods A and B described below.

1.4.1 Method A (Without Diversions)

Method A assumes that there are no withdrawals from or returns to the lake or the river as it flows between projects. This condition results in the maximum yield possible from the Federal projects. Critical yield from an upstream reservoir is assumed to be permanently removed from the system and does not contribute to the inflow at downstream reservoirs.

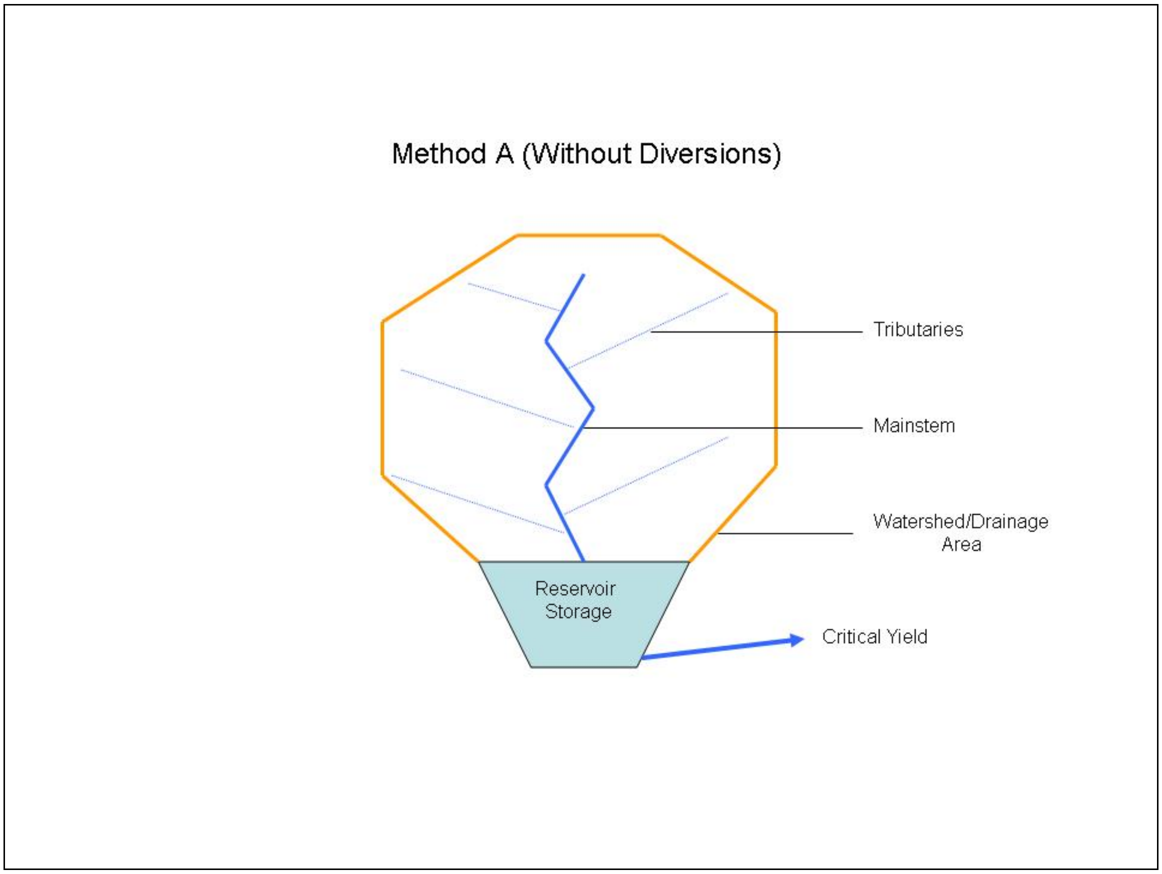

Figure A-2. Critical Yield Method A (Without Diversions)

1.4.2 Method B (With Diversions)

Method B assumes net river withdrawals and returns are occurring; this method does not include withdrawals from the Corps reservoirs. Critical yield from an upstream reservoir is assumed to be permanently diverted from the system and does not contribute to the inflow at downstream reservoirs. This condition results in the most severe downstream impact. The results of Method B represent a realistic assessment of the critical yield available from Federal projects controlled by the Corps. Method B used the most severe drought events documented during the hydrologic period of record and the year of maximum river withdrawals (2006 for the ACT; 2007 for the ACF) to make the calculations.

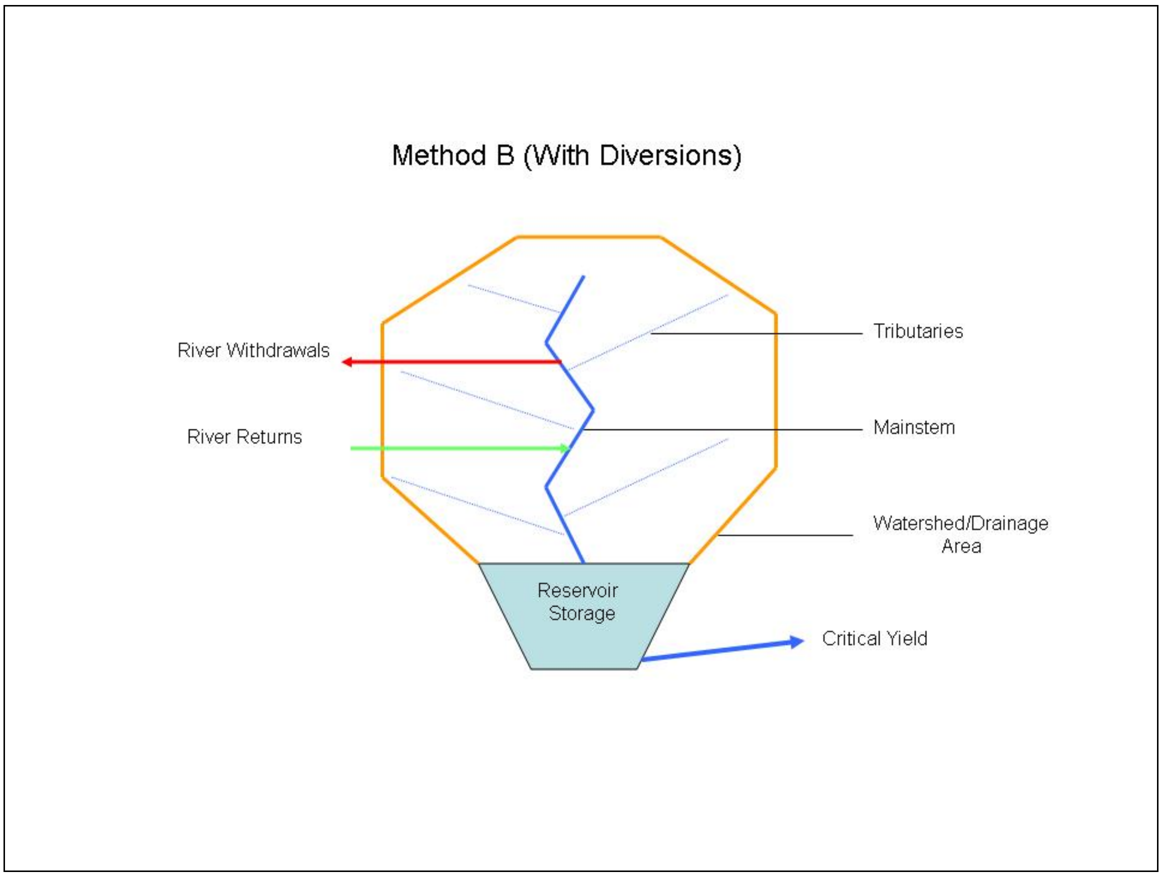

Figure A-3. Critical Yield Method B (With Diversions)

1.4.3 Method C (River System Yield)

Method C computes a system yield for diversion from the most downstream storage reservoir. It assumes upstream reservoirs operate in tandem to maximize the critical yield at the most downstream reservoir. Method C computes critical yield for the ACF River System with and without net river withdrawals. The with net river withdrawals condition results represent the Corps' yield. The without net river withdrawals condition results represent the system theoretical maximum yield.

ACT critical yields are computed using only Methods A and B. This is because both Carters Dam and Allatoona Dam operate independently and do not influence water availability at the other reservoir.

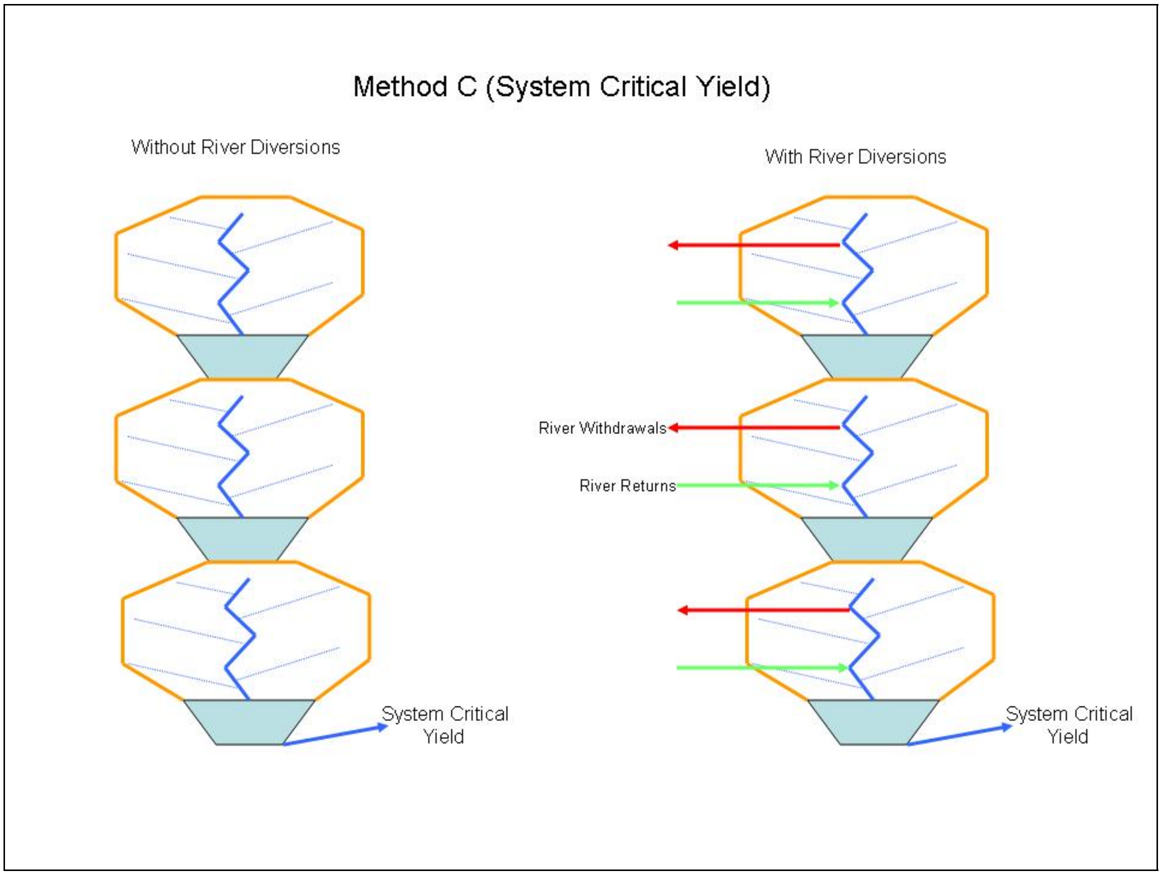

Figure A-4. Critical Yield Method C (System Critical Yield)

1.4.4 Seasonal Storage

The amount of conservation storage is seasonal at federal projects because of the seasonal drawdown to support flood reduction operations. Table A-2 lists the elevation difference in the guide curve and reduction in conservation storage for the federal projects.

Table A-2. Seasonal Conservation Storage Reduction

Project	Elevation Difference (feet)	Storage Difference (ac-ft)	Percent Reduction In Conservation Storage
Allatoona	17 = 840-823	164,702	58%
Carters	2 = 1074-1072	6,492	5%
Buford	1 = 1071 – 1070	38,200	4%
West Point	7 = 635 – 628	162,232	53%
Walter F. George	2 = 190 – 188	87,300	36%

For Allatoona, West Point and Walter F. George, the yield of these projects is highly dependent on the beginning of the critical dry period. In other words, does it begin during the winter level, summer level or transition level of the guide curve? Although all three projects have a high probability of refill to summer pool from a low winter level, extreme rare events will prevent the project from refilling. Consequently, if the critical period begins before the reservoir reaches full summer level the critical yield will be lower than when compared to starting at full summer level. For the determination of critical yields, the yield simulation begins approximately one year before the drought period begins. The analyses assume about one year of normal flows prior to the beginning of the drought period. Drawdown could start whenever flows were low enough for the lake to fall below a target level, be it winter, summer or transition. For the efficiency of computations, separate drought periods were run, always considering the prior year average flows and assuming the highest possible elevation on the guide curve as the target level.