Value of Climate Forecasts for the Management of Lake Lanier

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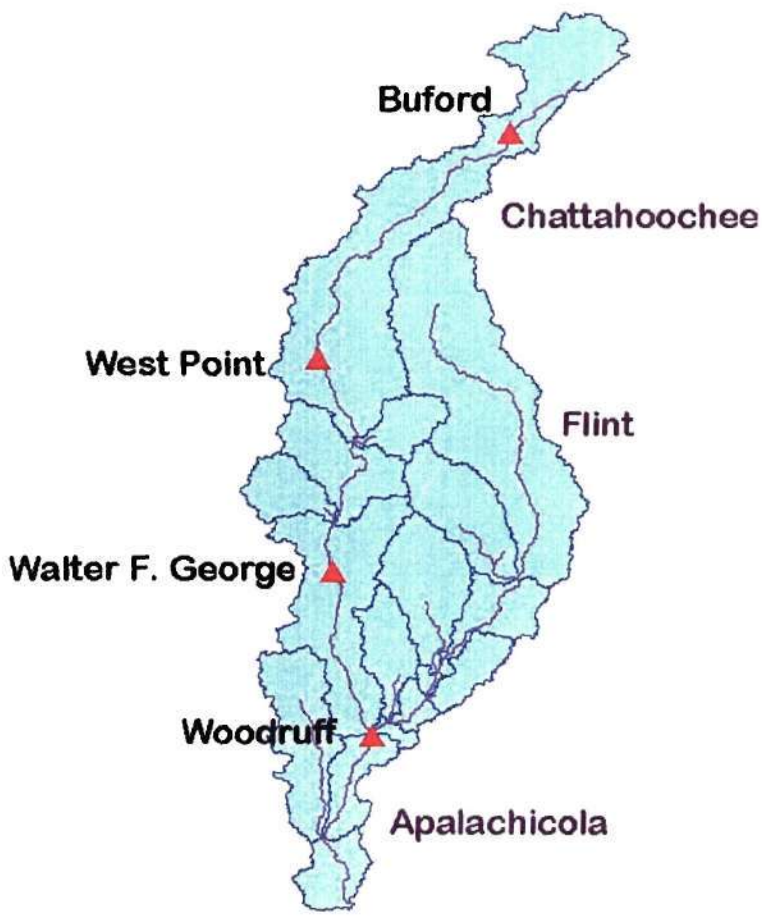

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1. Introduction and Overview

Are climate model predictions potentially useful for reservoir management? Can adaptive forecast-decision systems improve reservoir performance? These questions addressed in this report using Lake Lanier (Buford Dam) on the Chattahoochee River (Georgia) as a case study.

Figure 1 depicts the modeling framework used in this assessment. The principal modules pertain to (a) inflow forecasting, (b) reservoir management, and (c) scenario assessment. The inflow forecasting model to be used is an adaptation of the Sacramento model that has been developed by the Hydrologic Research Center (HRC). The model can generate 16-week inflow forecast ensembles (baseline forecasts) that can be conditioned on forecast information provided by the General Circulation Model of the Canadian Climate Analysis Center (CGCM). The hydrologic model and the conditioning process are described in the first part of this report. Reservoir management is based on a decision system that includes three coupled models pertinent to turbine load dispatching, short-range energy generation scheduling (hourly time steps), and long/mid-range reservoir management (weekly time steps). The decision model has been developed for the Apalachicola-Chattahoochee-Flint (ACF) river basin (of which Lake Lanier is a part) and is briefly described in the following section. The assessment process quantifies the response of the system over a long time horizon, assuming that reservoir releases are made based on the use of the forecast-control scheme. The assessment is performed for a historical inflow realization from 1950 to 1993.

In the following sections, we first describe the features of the ACF-DSS and then discuss the results of the assessment.

2. General Description of ACF-DSS Components

Water resources planning and management for the ACF River basin is a complex undertaking involving inter-dependent physical processes and water users. Thus, a comprehensive decision support system would have to represent the interaction of hydrologic (surface and groundwater) and land use processes, the demands of the various water users (water supply for municipal, industrial, and agricultural purposes; navigation; hydropower; water quality; river ecology; and recreation), and the integrative response of the river system. It should also have the ability to assess the benefits and consequences of different planning and operational policies and present this information to basin planners and decision makers in meaningful ways.

This section discusses the components of a decision support system that the Georgia Water Resources Institute (GWRI) has been developing for the ACF River basin. The system already includes hydrologic, river simulation, reservoir control, uncertainty analysis, and policy assessment modules, and is being used to support the tri-state (Georgia-Alabama-Florida) negotiation process for the development of a water allocation compact. Current work aims to expand the scope of the DSS by including remote sensing, groundwater simulation, water quality, and agricultural planning modules. A short description of the existing components follows. Figure 2 provides a schematic of the modeled ACF elements and water uses.

Streamflow Forecasting

The purpose of the streamflow forecasting component is to forecast the upcoming reservoir inflows and provide an appreciation of the forecast uncertainty through multiple forecast traces. These traces represent equally likely inflow realizations reflecting characteristics of the historical inflow sequences. Their tendency is to spread out as the forecast lead time increases and the hydrology of the basin moves away from its present condition. In this particular application

Lake Lanier inflows are forecasted by the HRC modeling system; forecasts for the other 22 inflow nodes are generated based on historical analog methods.

Reservoir Control

Due to the several times scales over which water uses are relevant, the reservoir control component includes three modules. The purpose of the turbine commitment and load dispatching module is to optimize hydro plant efficiency by determining the power load of each turbine such that the total plant outflow is equal to a given discharge level and total power is maximized. The inputs to this module include

- beginning-of-the-period reservoir elevations,
- various turbine and reservoir characteristics (e.g., elevation vs. storage and tailwater vs. discharge relationships, power vs. net hydraulic head vs. discharge curves, and operational turbine ranges, among others), and
- minimum and maximum discharge requirements.

This module utilizes Dynamic Programming as the optimization procedure and has a dual role: First to provide the feedback information needed by the other reservoir control (dynamic) modules in the form of an optimal relationship among total system outflow, total plant load, and reservoir elevation, and, second, in an operational mode, to determine the actual turbine loads which realize the discharge assigned to a particular plant while maximizing power generation. The first output is the connecting link between this and the other two decision modules.

The second reservoir control module is concerned with determining the best hourly power sequences for each hydropower station in the system over a period of one week. The objective it to maximize energy generation (given that all other stated objectives are met) with or without dependable capacity constraints. The inputs to this module include

- physical reservoir layout and characteristics (e.g., storage vs. elevation curves, storage and release constraints, etc.),
- the relationships between minimum discharge, reservoir elevation, and plant load, determined by the turbine load allocation module,
- other operational requirements (such as those of the service units) and dependable capacity commitments.

The optimization methodology of this module is also based on Dynamic Programming. In addition to the best hourly generation schedules for the system reservoirs, the mid/short range control module also derives the optimal weekly energy generation functions. These functions are passed on to the third control module.

Lastly, the purpose of the long range control module is **(1)** to quantify long term system performance and tradeoffs and **(2)** develop optimal, system-wide release schedules for each system reservoir over a period of several weeks. Such tradeoffs are usual between water uses (e.g., between water withdrawals and instream flows, upstream and downstream water uses, energy generation and drought management, and navigation and lake fluctuation, to mention but a few). The tradeoff curves are important information that decision makers and basin planners must review before selecting a water allocation and operational policy. For these determinations, this module requires input on weekly inflow forecasts, urban and agricultural water demands, reservoir characteristics, instream flow and navigation requirements, and energy generation targets. The optimization operations are carried out by the Extended Linear Quadratic Gaussian (ELQG) control method (developed by *A.P. Georgakakos and associates)*, a trajectory iteration control algorithm suitable for multidimensional uncertain systems.

The three modules constitute a multilevel control structure with an operational flow that follows two directions: The lower level modules are activated first and generate information that is used by the upper levels regarding performance functions and bounds. In the course of this upward flow, the decision system generates appropriate operational tradeoffs evaluating the consequences of various long- and mid/short-term policies. At these key points, the model halts and requests the input of the management authorities regarding their most preferred policy selections. Once these decisions are taken, the control levels are activated in the reverse order to generate the best turbine hourly sequences and loads implementing these decisions consistently across all relevant time scales.

Among, the unique features of this decision system are the explicit treatment of uncertainty at all operational levels, the detailed modeling of all water uses, the high computational efficiency and the design philosophy which incorporates the preferences of the decision authority through the evaluation of tradeoffs.

Policy Assessment

The purpose of the policy assessment component is to replicate the actual weekly operation of the ACF system under various water allocation policies, management strategies, and climate scenarios. Namely, at the beginning of each week of the simulation horizon, this component invokes the inflow forecasting and reservoir control components, determines the most appropriate reservoir releases, simulates the response of the system for the upcoming week, and repeats this process at the beginning of the following decision time. At the completion of the forecast-control-simulation process, the program generates sequences of all system performance measures. These sequences can be used to compare the benefits and consequences of alternative water allocation and operation policies.

ACF-DSS Advantages over Traditional Simulation Models

The decision to develop the ACF decision support system was prompted by the limitations exhibited by traditional simulation models (i.e., HEC-5 and STELLA) that were initially developed for the tri-state water negotiation process. The advantages include:

- better representation of important water uses, such as hydropower and ecological flow requirements;
- ability to forecast, assess the severity of, and manage droughts;
- ability to assess the benefits of *basin-wide* reservoir coordination strategies and the tradeoffs among the water uses;
- ability to more exhaustively identify the water allocation scenarios that could be of interest to the tri-state negotiation process, namely, scenarios that could potentially compromise better among the demands and lead to the negotiation of shared-vision water use agreements.

The ACF decision support system represents a modern river basin planning and management tool that effectively addresses the limitations of traditional river simulation models. It is developed to establish a uniform basis for evaluating various water allocation and river management scenarios and a common communication language among the technical staff of the negotiation teams.

ACF-DSS Software Package

The ACF-DSS computer software is a graphical user-friendly package, and runs on personal computers under the Windows operating systems (95, 98, 00, and NT). ACF-DSS can assess the ACF system response to water withdrawals, minimum flow targets, lake fluctuation ranges, navigation requirements, flow regimes sensitive to river ecology, hydropower objectives, and drought management plans, among others. The user can access and modify all input parameters through a graphical user interface. Once a particular simulation run finishes, ACF-DSS displays all important sequences and statistics pertaining to system conditions and uses. Such information is essential for understanding the capacity of the basin to meet the various water uses and for developing the information base for technically feasible and equitable water use agreements. ACF-DSS has been provided to the tri-state technical teams complete with technical reports, user manuals, and hands-on training.

3. Assessments

The coupled forecast-control scheme was used to assess the performance of Lake Lanier over a 34-year historical horizon from 1950 to 1993. The assessment was conducted for baseline forecasts as well as for GCM-conditioned forecasts (CGCM). The ACF-DSS management objectives are as follows:

- Meet municipal, industrial, and agricultural water supply withdrawals (projected for 2030);
- Meet instream flow requirements (pollution abatement);
- Meet 2-hrs peak power generation per week day;
- Maintain as high lake levels as possible (for hydropower optimization and drought management);
- Avoid spillage at least 95% of the time.

Figures 3 and 4 show the Lake Lanier levels and releases for the two assessment runs (baseline and CGCM forecasts). The figures show that the sequences do not exhibit marked differences. However, the lake levels for the GCM-conditioned forecasts are somewhat lower than for baseline forecasts. This happens because the ensemble bands of the GCM-conditioned forecasts are somewhat wider than those of the baseline, causing the decision system to make slightly higher releases to maintain the same spillage reliability. This effect is also seen on Figure 5, depicting the frequency curve form of the time sequences shown on Figures 3 and 4. The top graph of Figure 5 clearly shows that the CGCM lake levels are slightly, yet consistently, lower than the baseline levels. The explanation for this is provided by the bottom graph of Figure 5, showing that GCM releases are higher than baseline releases for high releases (high lake levels), and lower for low releases (low lake levels).

Table 1 summarizes the results of the two runs with respect to energy generation and minimum flow violations. The results indicate that the differences are not appreciable, but they are consistent with the previous comments. Namely, the baseline run produces slightly more energy generation (primary as well as secondary) and causes fewer violations of the instream flow targets.

4. Conclusions

This assessment shows that the climate forecasts provided by the Canadian General Circulation Model do not improve the management of Lake Lanier. Namely, the use of CGCM information does not improve forecast skill compared to the skill of hydrology-based forecasts. Additional reasons contributing to this result are that (1) lake storage and turbine outflow capacity are large in relation to inflows, (2) management decisions are primarily driven by demands and reservoir levels, and (3) forecast skill differences are mitigated by the adaptive features of the ACF-DSS.

However, the previous conclusion is strictly associated with the Canadian GCM. Further work should be undertaken to assess the forecast skill of other GCMs for the Southeastern US.

Acknowledgments

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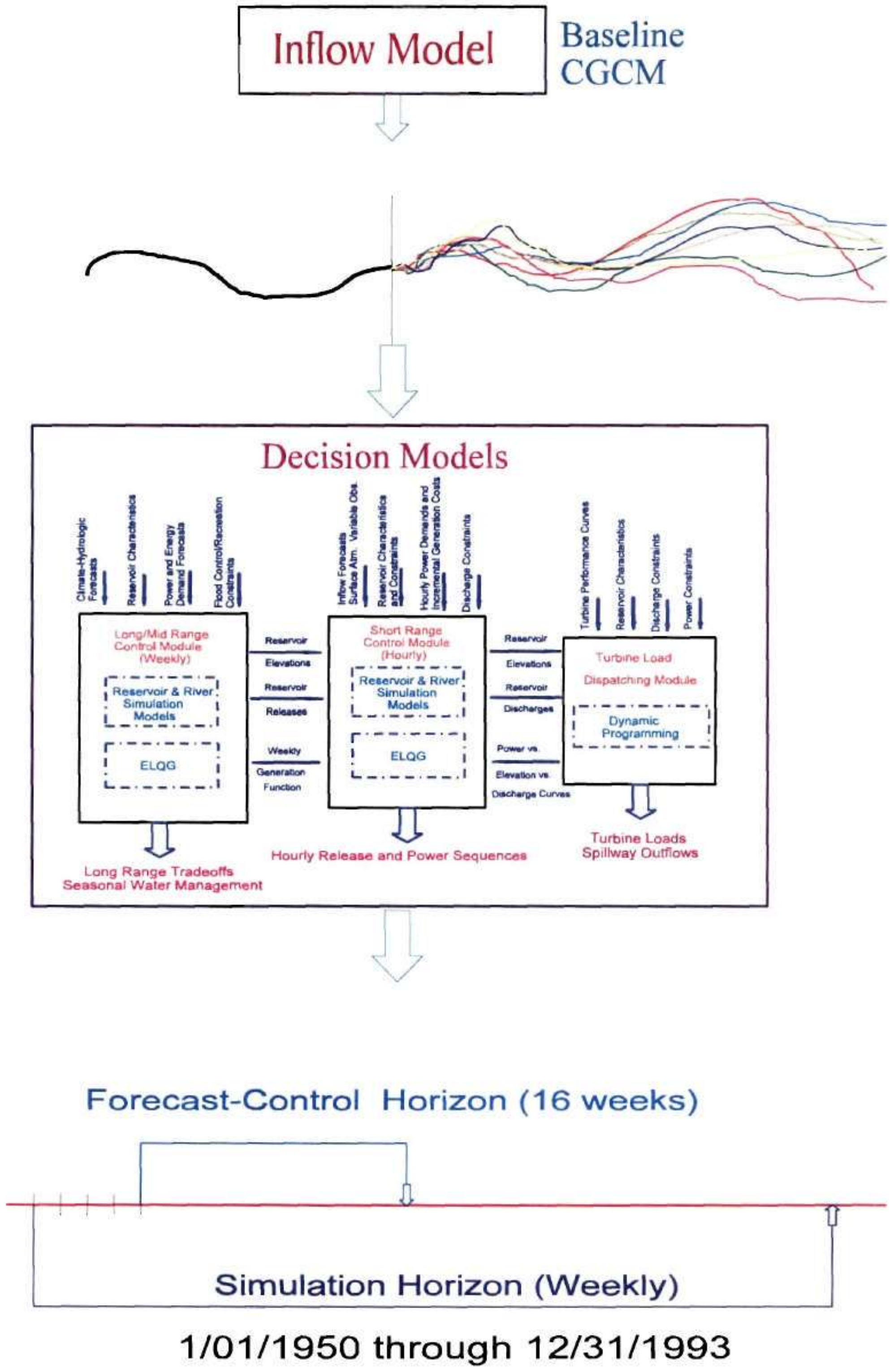


Figure 1: Elements of the ACF Decision Support System (ACF-DSS)

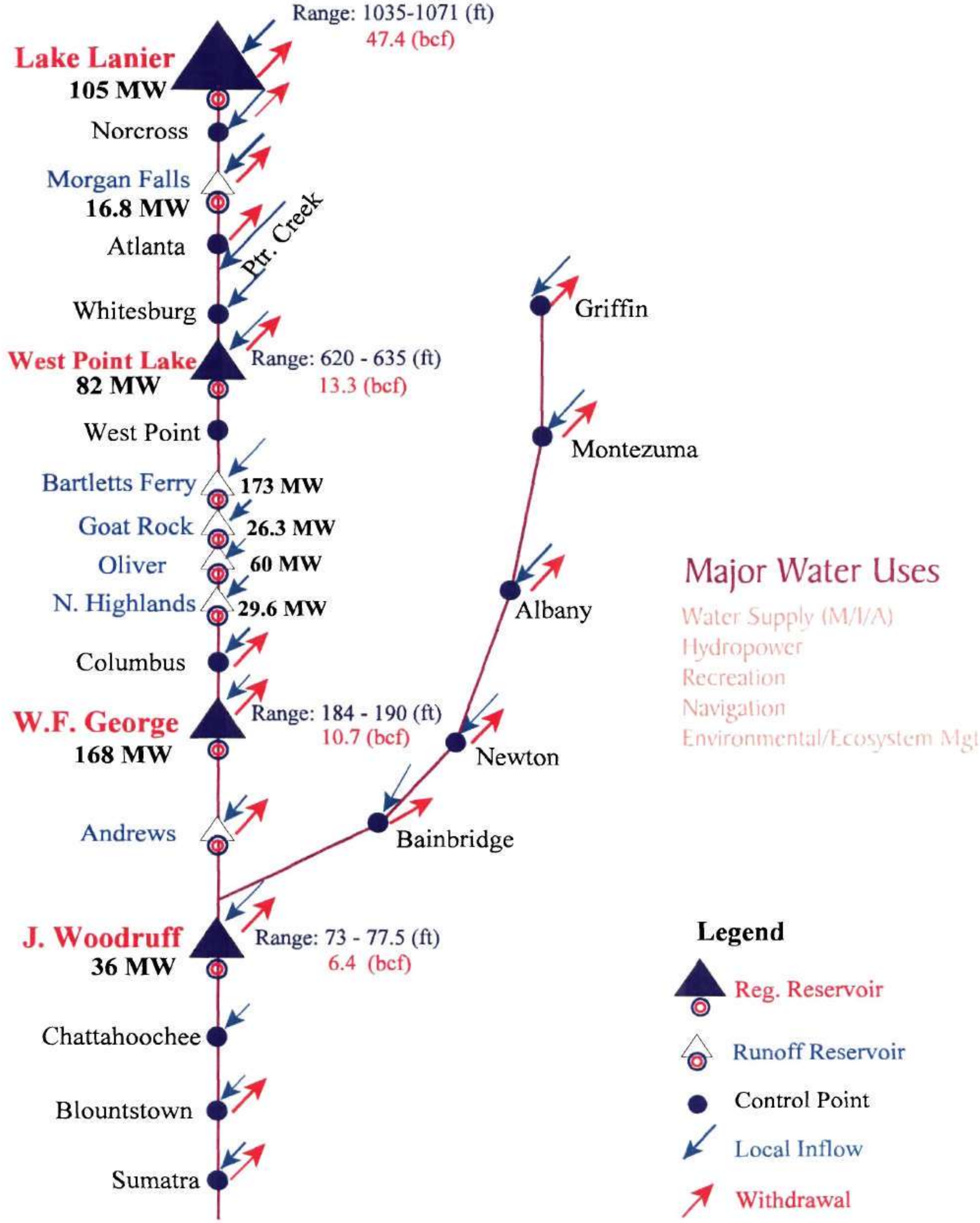


Figure 2: ACF System Schematic

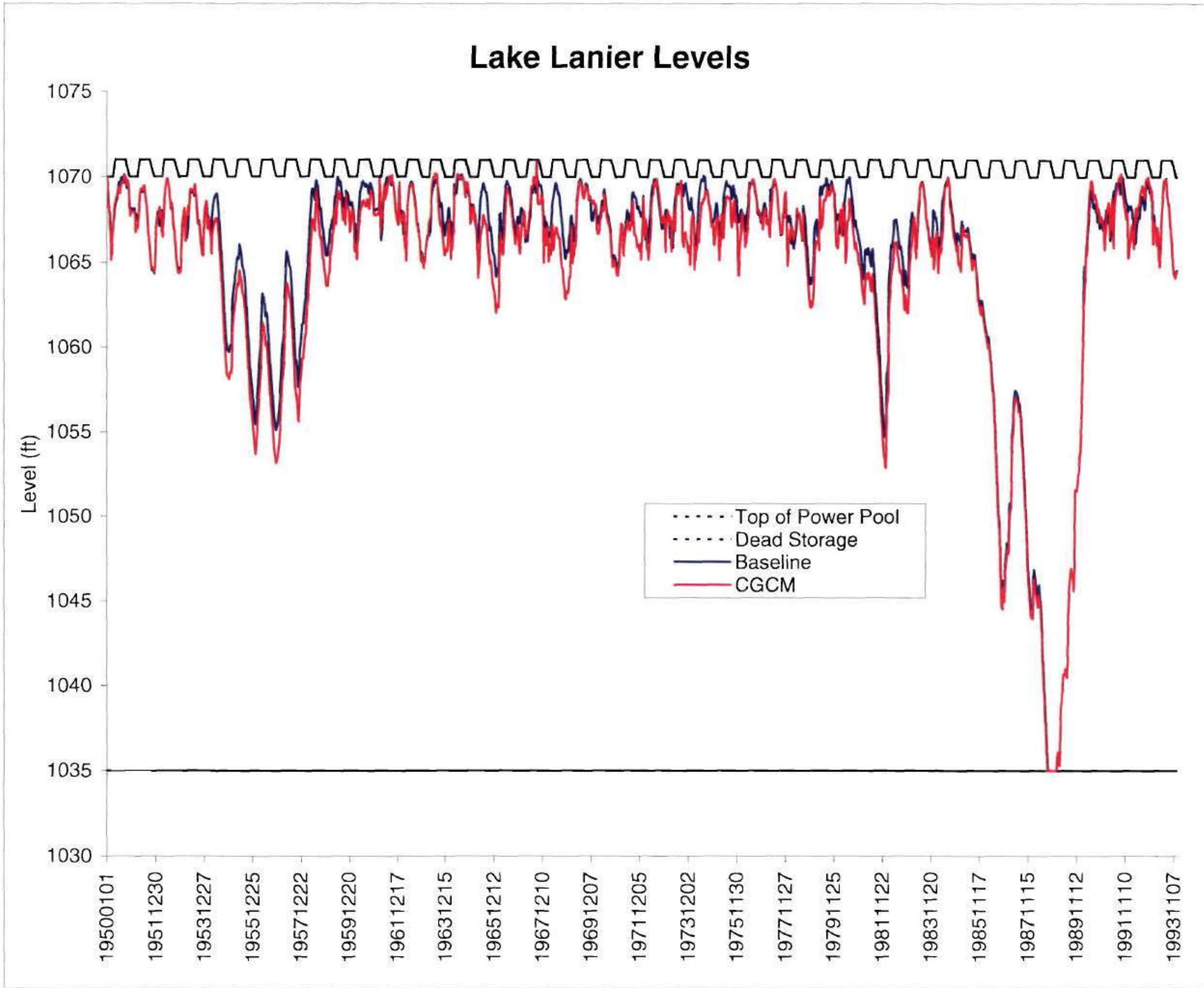


Figure 3: Lake Level Comparison

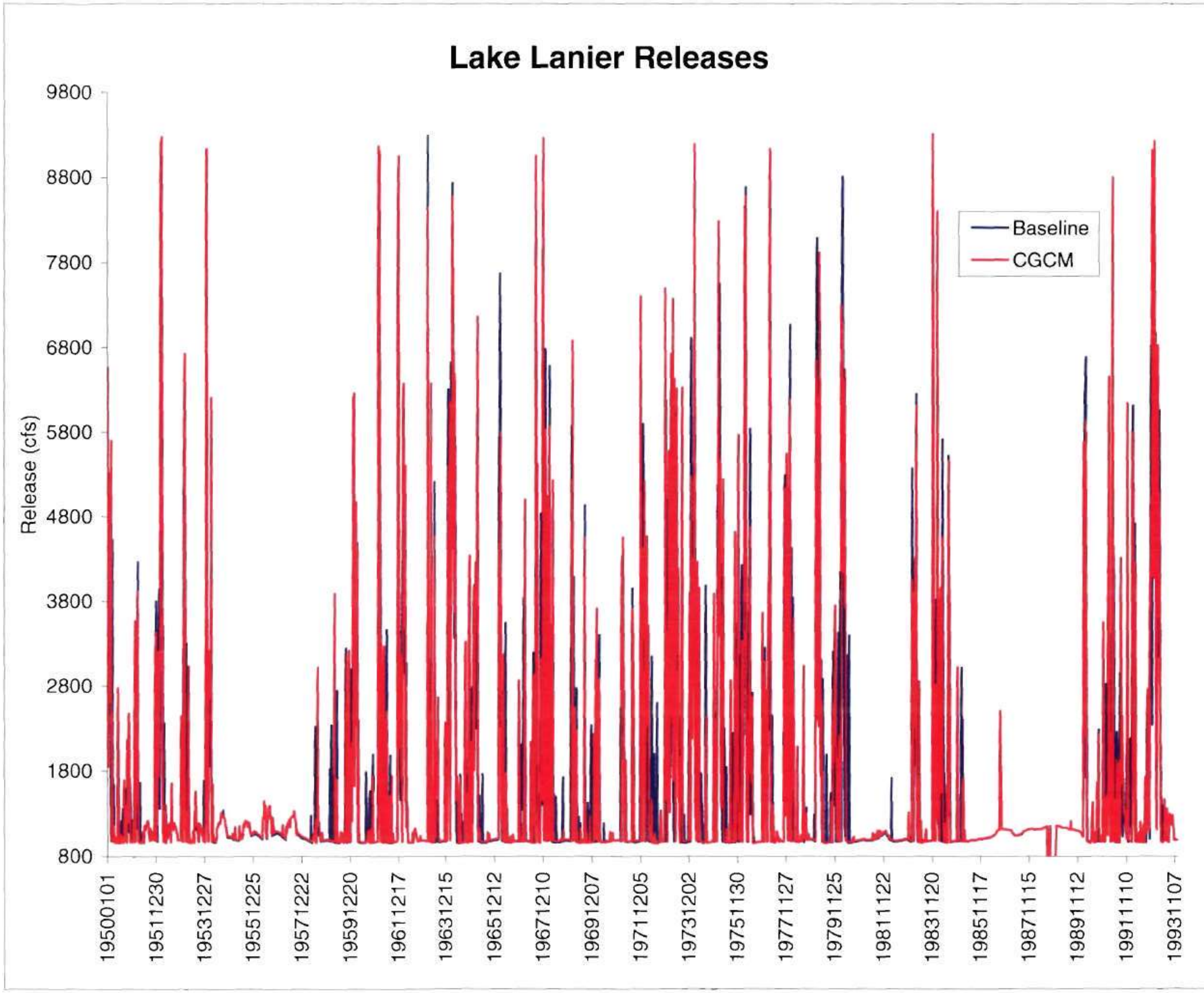
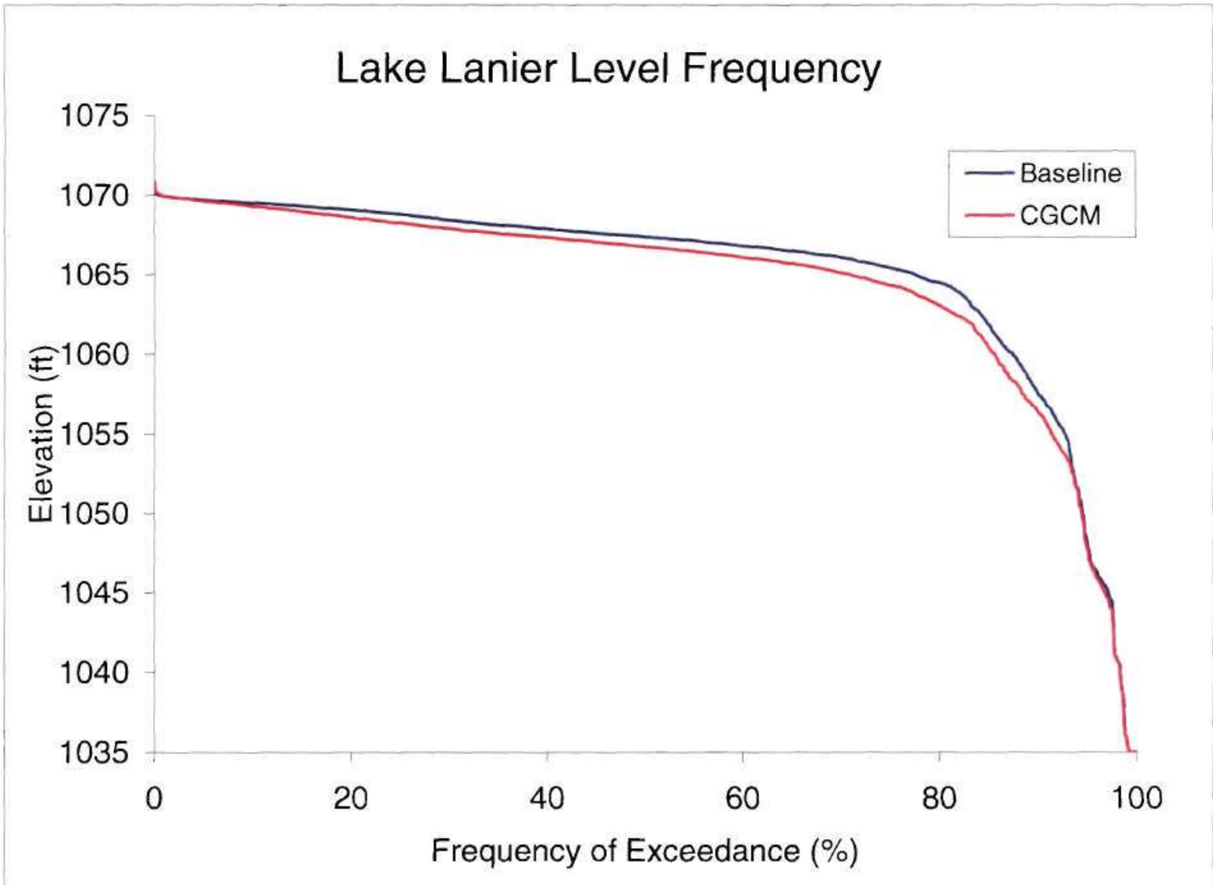


Figure 4: Lake Release Comparison



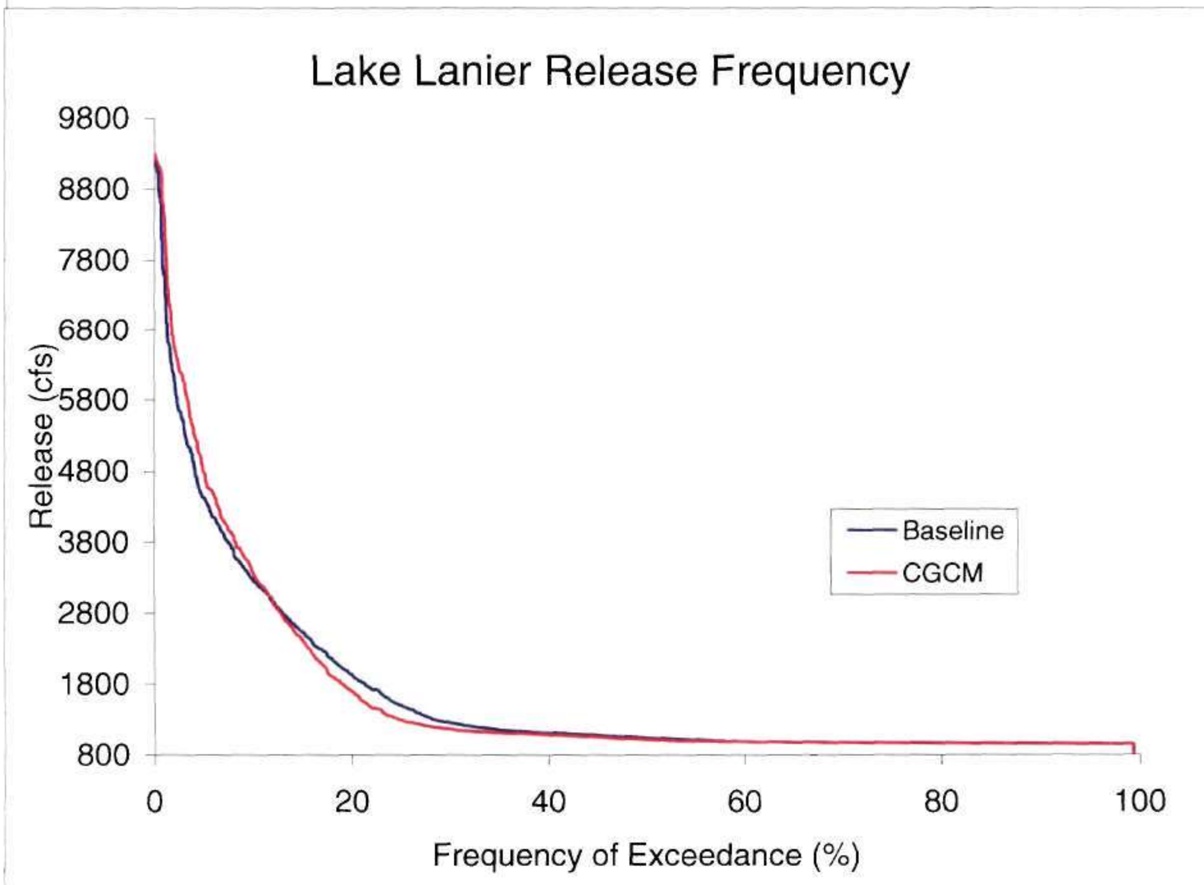


Figure 5: Lake Level and Release Frequency Comparison

Table 1: Energy Comparison

Energy Generation Comparison

Forecast	Energy (GWH)	Lake Lanier	West Point	George	Woodruff	System
Baseline	Primary	54.09	43.07	75.52	16.13	188.81
	Secondary	105.8	162.93	362.65	201.27	832.65
	Sum	159.89	206	438.17	217.4	1021.46
	Reliability (%)	99.61	100	100	100	99.61
CGCM	Primary	54.06	43.07	75.52	16.14	188.79
	Secondary	105.07	162.89	362.82	201.53	832.31
	Sum	159.13	205.96	438.34	217.67	1021.1
	Reliability (%)	99.56	100	100	100	99.56

Energy Generation from Private Reservoirs

Forecast	M. Falls	B. Ferry	G. Rock	Oliver	N. Hlands	System
Baseline	61.59	451.82	228.45	309.66	154.64	1206.16
CGCM	60.54	451.95	228.43	310.14	154.92	1205.98

Minimum Flow Violation Time Frequency (%)

Forecast	Atlanta	Columbus	Chattahoochee
Baseline	0.56	0.00	0.07
CGCM	0.63	0.00	0.07