APPENDIX I

RESSIM VERIFICATION SUMMARY

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ResSim Verification Summary

The United States Army Corps of Engineers (USACE) has developed a computer model to characterize current conditions and operations of six reservoirs within the Savannah River Basin. The model includes the Bad Creek, Jocassee, Keowee, Hartwell, Richard B. Russell (RBR), and J. Strom Thurmond (JST) reservoirs. The model has since been updated by HDR Engineering, Inc. of the Carolinas (HDR) and the USACE to include detailed operations of the Duke Energy Carolinas, LLC (Duke Energy) facilities (Bad Creek, Jocassee, and Keowee) and updated operational rules for the USACE facilities (Hartwell, RBR, and JST). The model has been tested and verified using version 3.1 RC3 revision 3.1.7.157 build 3.1.7.157R June 2011 of the USACE's Hydrologic Engineering Center's Reservoir System Simulation (HEC-ResSim) software (build 157).

The purpose of this operations and verification summary is to document inputs and assumptions used in the development of the model, demonstrate that the model reasonably characterizes operations of the six facilities modeled, and demonstrate that the model is an appropriate tool to be used in evaluating the effects of the operating scenarios.

Using average daily inflow as input, the model simulates operations to maximize peak period energy and budgets water to ensure that all operational constraints (physical, environmental, and operational) are met. The hydrologic dataset applied in the model is the product of a regional water availability study that was provided by ARCADIS (database submitted to HDR January 31, 2013) and developed for Duke Energy, the Savannah District of the USACE, and the Georgia Environmental Protection Division (GAEPD). The development of the basin-wide surface water time series is outlined in the Savannah River Unimpaired Flow 1939 – 2008 Time Series Extension Study Report. The model uses this historic inflow water series that has basin-wide spatial variability and each scenario that was run for the verification uses the same inflow series (unless noted otherwise).

The USACE Savannah River ResSim model was originally based on version 3.1 Beta III revisions 3.1.4.36 build 3.1.4.36R October 2008 of the USACE's HEC-ResSim software. It contained minimal logic for the operations of Jocassee and Keowee and it did not include Bad Creek. As previously stated, the Savannah River ResSim model has been updated to support the Comprehensive Environmental, Engineering, and Economic Impact Analysis Study (Comprehensive Study). The updated model includes a definition of the physical pumping and generation capabilities at Jocassee Pumped Storage Station, physical generation capabilities at Keowee Hydro Station, and operational logic to reflect actual reservoir operations at both facilities. The updated model also includes Bad Creek reservoir operations and physical pumping and generation capabilities. The 3.1 RC3 June 2011 version of the ResSim software provides additional logic support for the system storage balance rule which is an operational constraint in this system. The system storage balance logic allows the user to define the storage relationship between the reservoirs so that the Duke Energy storage (Jocassee and Keowee) will follow the USACE storage (Hartwell and JST) drawdown in accordance with the 1968 Operating Agreement between Duke Energy and the USACE. As part of the model updates, HDR revised the reservoir storage-volume relationships to reflect 2010 sedimentation estimates for Jocassee, Keowee, Hartwell, RBR, and JST. The Duke Energy storage-volume relationships at Jocassee Pumped Storage Station and Keowee Hydro Station were also revised based on bathymetric data collected in 2010 (see Figures I-1 and I-2). No new bathymetric data was available for the USACE facilities. The storage-volume relationships were updated based on published Environmental Protection Agency sedimentation rates for the Savannah River Basin, converted to sediment volume using methods outlined in the USACE EM 1110-2-4000, and estimated compressed density of the sediment (see Figures I-3 through I-5).

Figure I-1 Lake Jocassee Volume Comparison

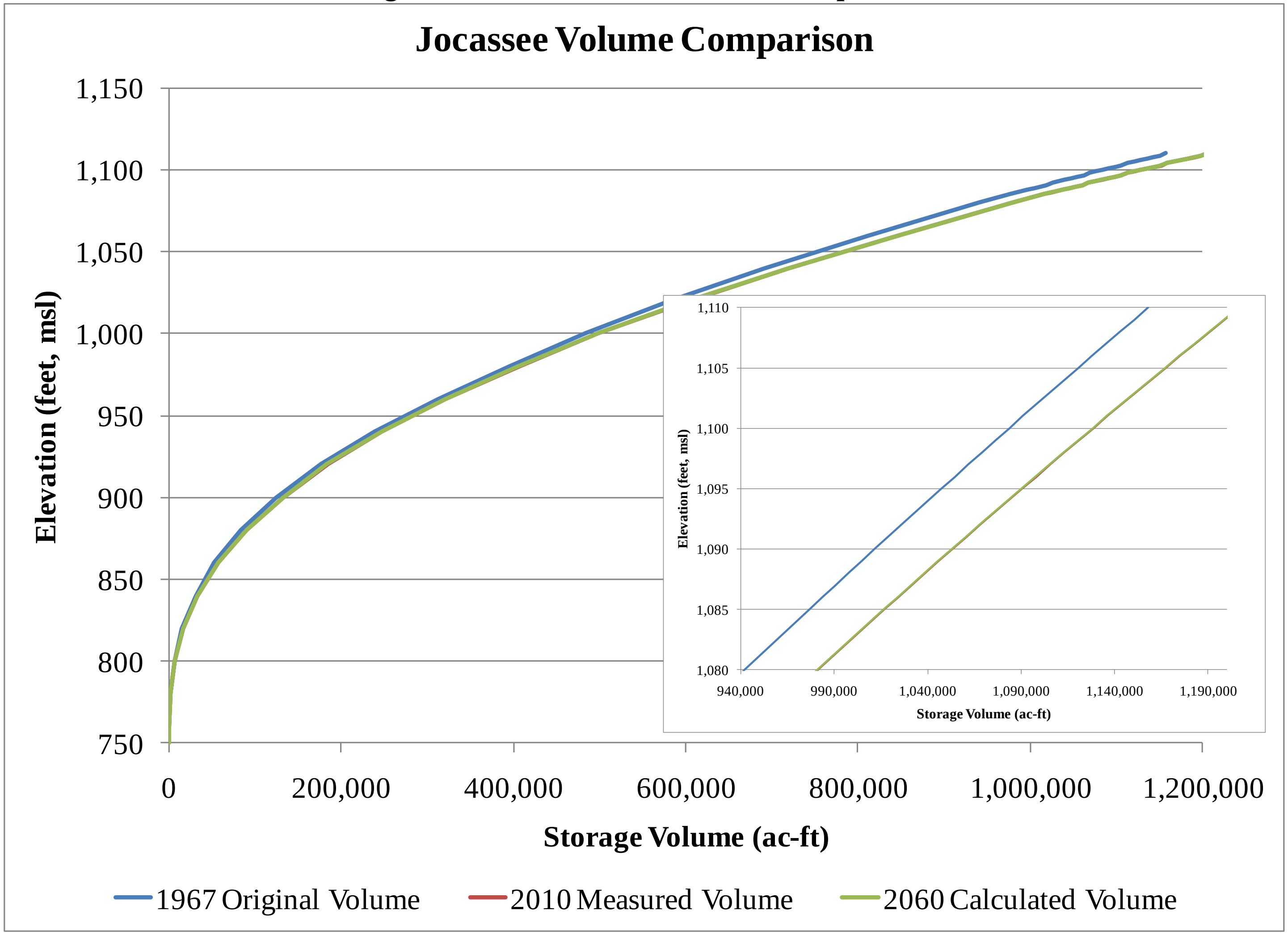


Figure I-2 Lake Keowee Volume Comparison

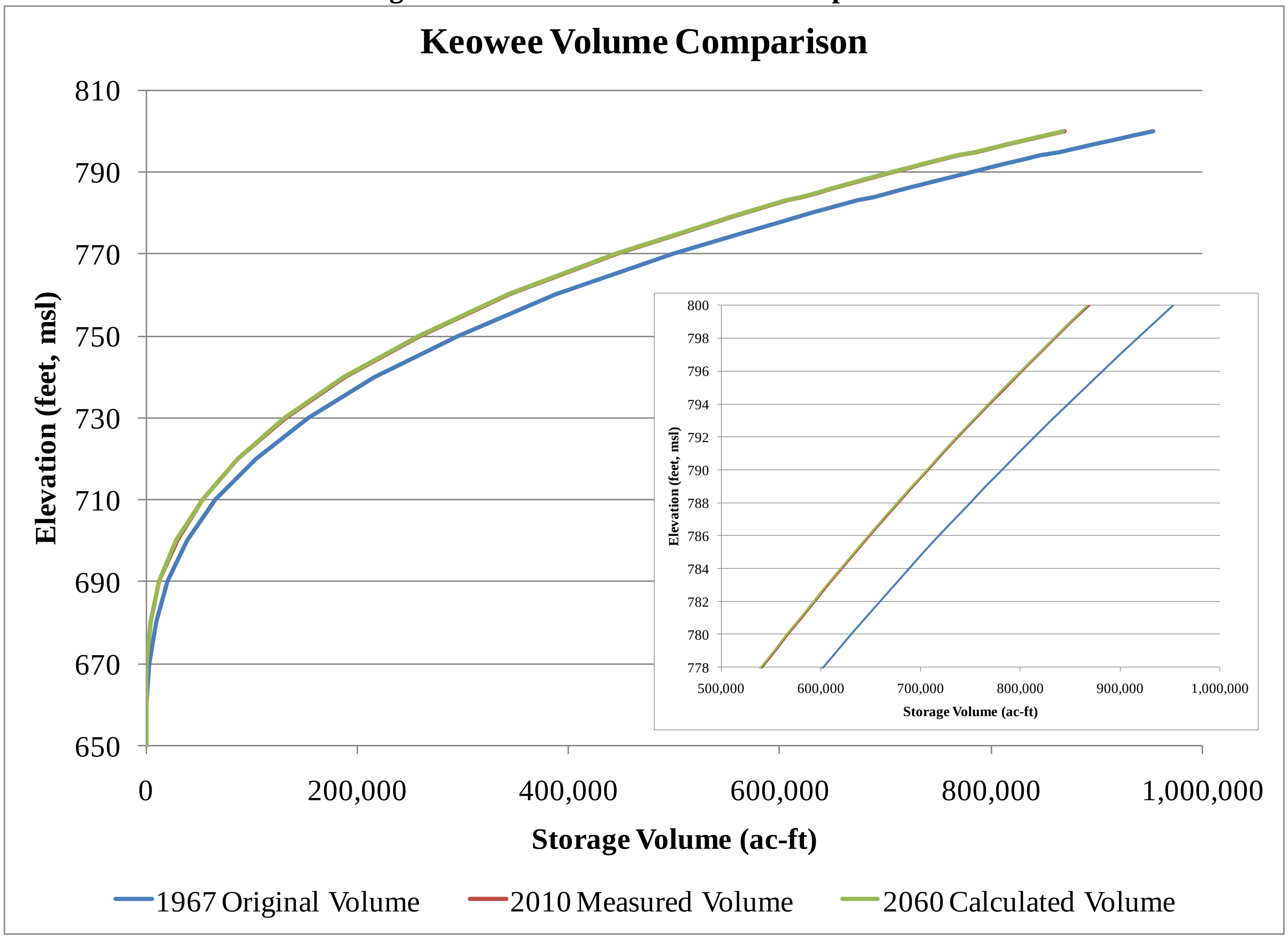


Figure I-3 Hartwell Lake Volume Comparison

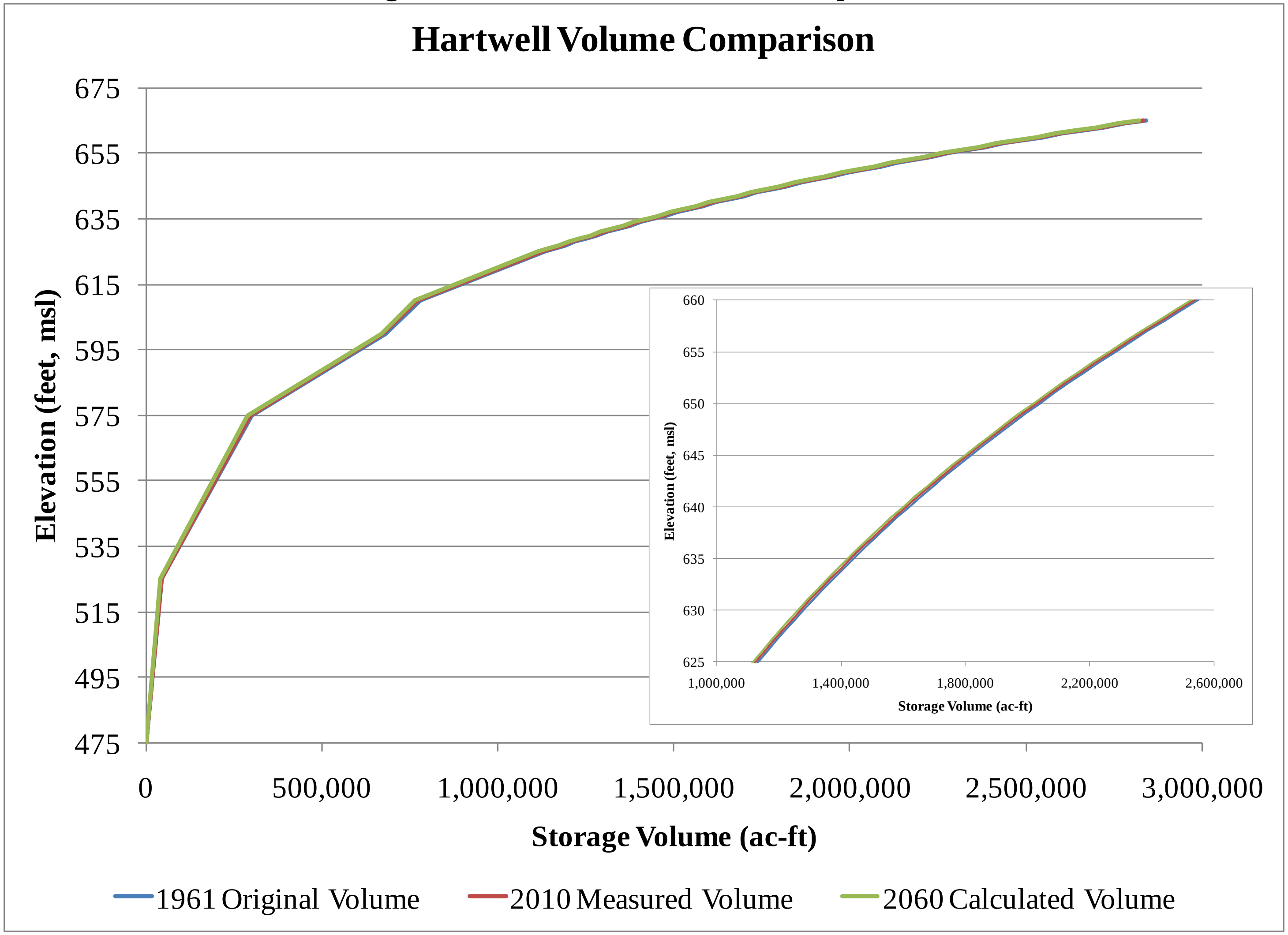


Figure I-4 RBR Lake Volume Comparison

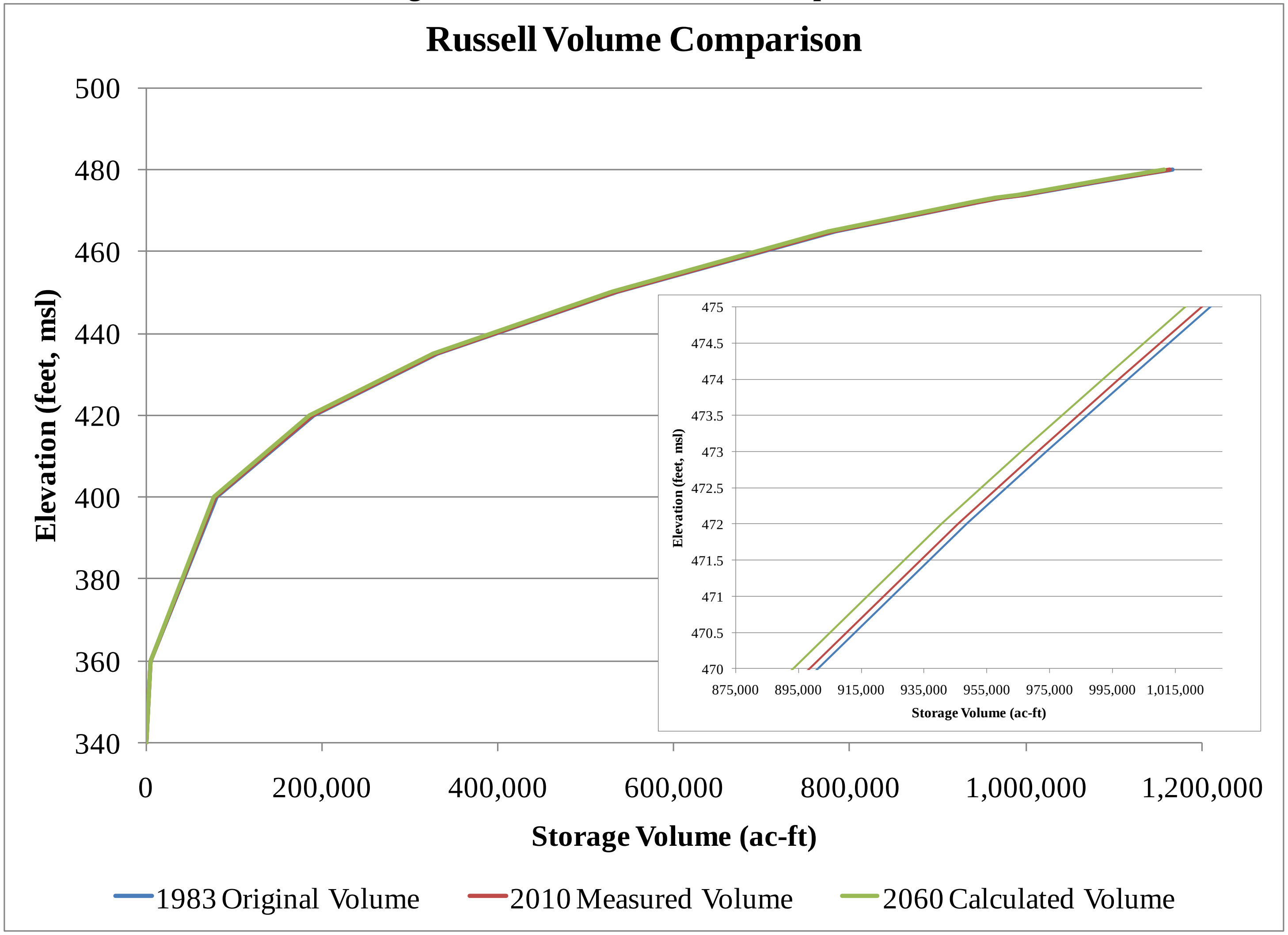
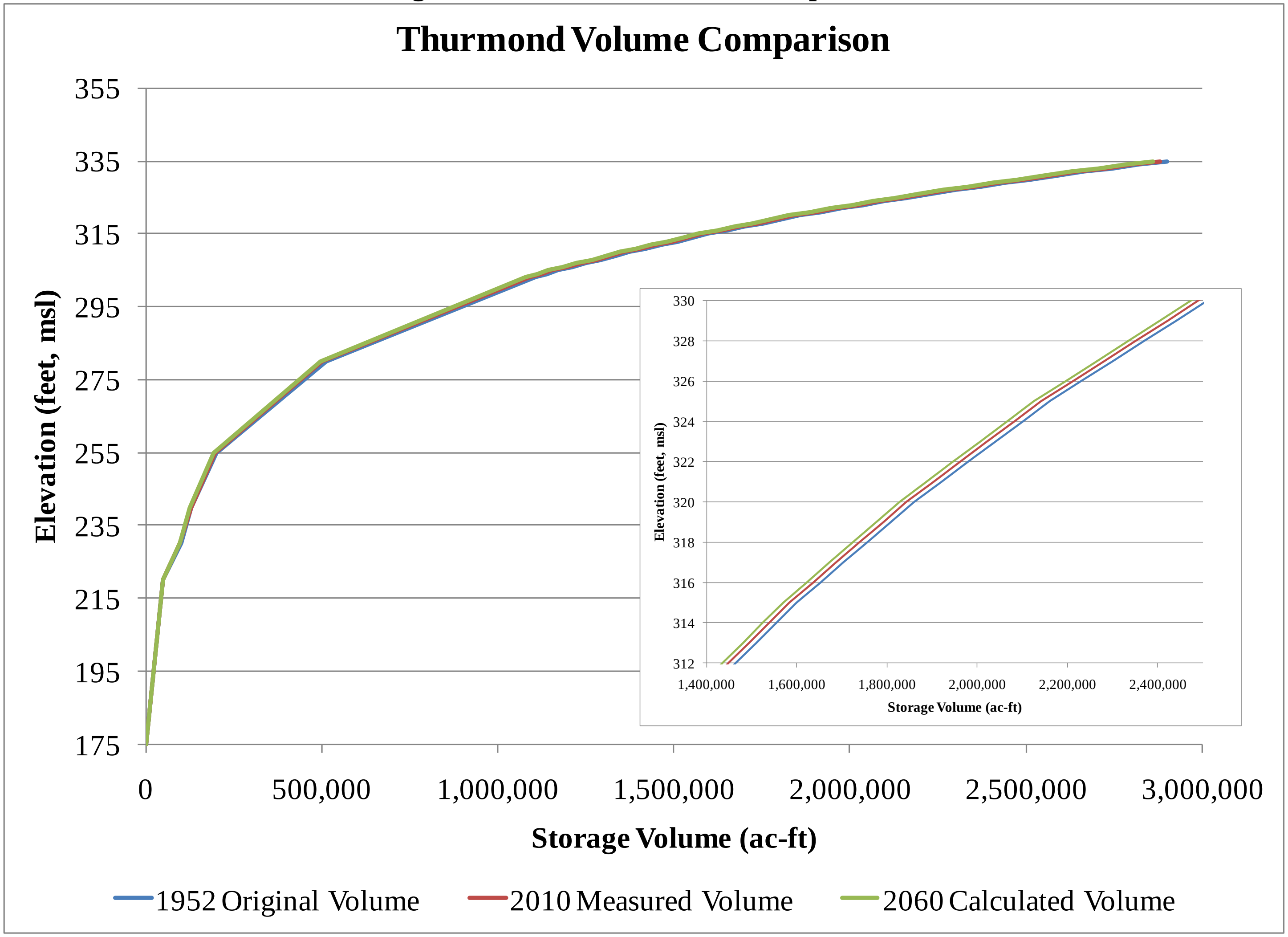


Figure I-5 JST Lake Volume Comparison



Verification is intended to validate the model input data and logic so the future water withdrawals with historical hydrology model setup may be used as the baseline for comparison of all subsequent analysis results. HDR performed model verification using comparisons of actual and modeled generation and total discharge. For hydropower reservoirs, the comparison of power generation is a well documented source of available data that reflects the overall water balance between the reservoirs on a daily basis. The comparison of historical and modeled generation is considered a good verification tool to measure volume and flow distribution between reservoirs and a good test of the model's logic and custom coded constraints. The verification simulation was performed using recent hydrologic years (1998-2008) with the available historical reservoir operations records and water use. Monthly varying water use was simulated based on the 2003 through 2008 median monthly historical water use provided, as part of the unimpaired flow databases, by ARCADIS (database submitted to HDR January 31, 2013). The database partitions used to extract the water use from the ARCADIS database files are outlined in Table 1.

Table I-1 Database Partitions

Part: A	Part: B	Part: C	Part: F
SO-BRIRCR	MILLHAVN	FLOW-DIV NET	COMP-REACH TOTAL
SO-SAVNAH	AUGUSTA	FLOW-DIV NET	COMP-REACH TOTAL
SO-SAVNAH	CLYO	FLOW-DIV NET	COMP-REACH TOTAL
SO-SAVNAH	HARTWL_R	FLOW-DIV NET	COMP-REACH TOTAL
SO-SAVNAH	RBR_R	FLOW-DIV NET	COMP-REACH TOTAL
SO-SAVNAH	SAVANNAH	FLOW-DIV NET	COMP-REACH TOTAL
SO-SAVNAH	THRMND_R	FLOW-DIV NET	COMP-REACH TOTAL
SO-SENECA	KEOWEE_R	FLOW-DIV NET	COMP-REACH TOTAL

The Savannah River ResSim Model is coded to run day-to-day operations based on general operating conditions or rules. The model follows these rules strictly, 24-hours per day and 365-days per year, similar to an automated operation. No day-to-day operations changes or learning-knowledge are used in the model. Actual project operations generally follow a set of operating rules but human intervention periodically deviates from the general operating rules to accommodate day-to-day realities such as equipment failure and maintenance, changing hydrologic conditions, power demands, grid support, etc. In addition to differences between modeled operations versus actual operations that include human interventions, there are also inherent discrepancies as a result of input data inaccuracies (e.g., differences in hydrology data, turbine or generator efficiencies, reservoir storage curves, etc.) that can not be economically recreated or captured through an engineering review of available data. It is important to understand that, due to these differences between actual operating conditions and modeled conditions, model results will never completely match historical operations.

The verification was performed using historical operations data provided by Duke Energy and the USACE. A verification scenario was established following the typical operating requirements of the system (same logic as the A2 scenario, Current Operating Conditions) with elevation rules applied such that the model will attempt to operate the reservoir pools as they were historically operated. This scenario, A2 operations with historical elevations, was run for the hydrologic period of 1998-2008. Figures I-6 through I-10 show comparisons of the modeled reservoir elevation compared to the historical reported elevations for the same period. Older data was not used due to less reliable data being available for each reservoir and changes in operating conditions that do not reflect current operating practices. Figures I-6 through I-10 show good modeled responses for seasonal changes in hydrology and good overall timing, verifying that the model logic and constraints (operation rules) are generally performing as expected.

Figure I-6 Lake Jocassee Modeled and Historical Elevation Comparison

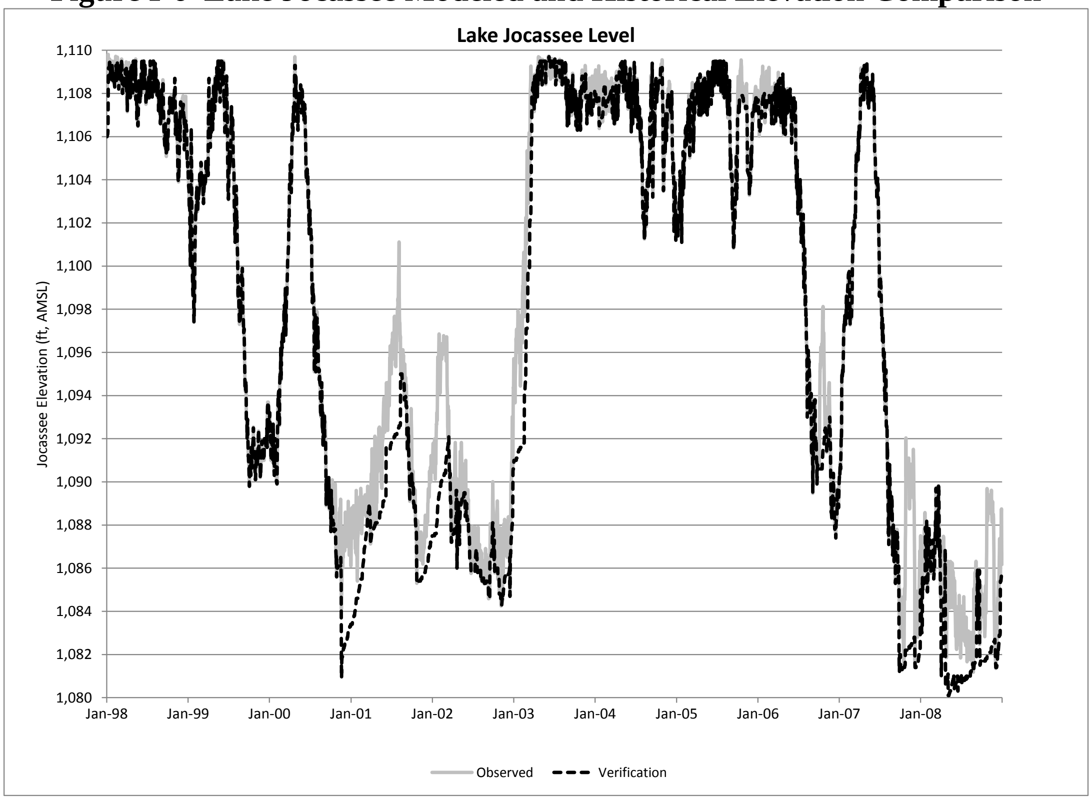


Figure I-7 Lake Keowee Modeled and Historical Elevation Comparison

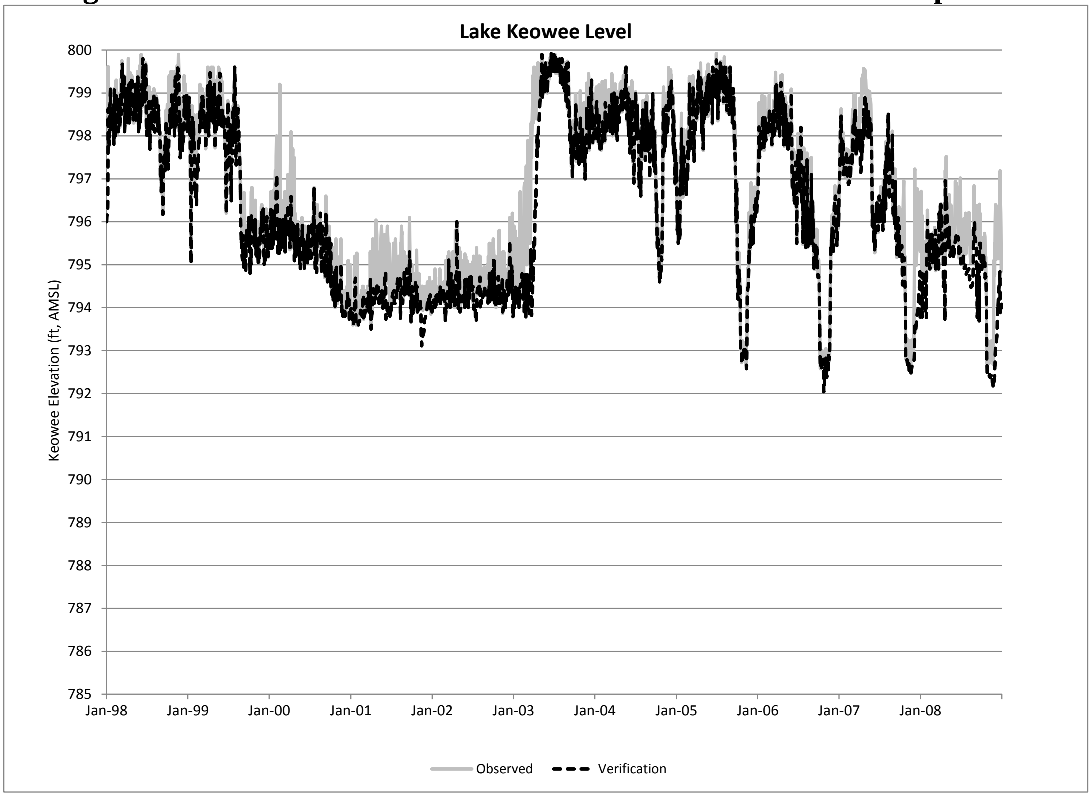


Figure I-8 Hartwell Lake Modeled and Historical Elevation Comparison

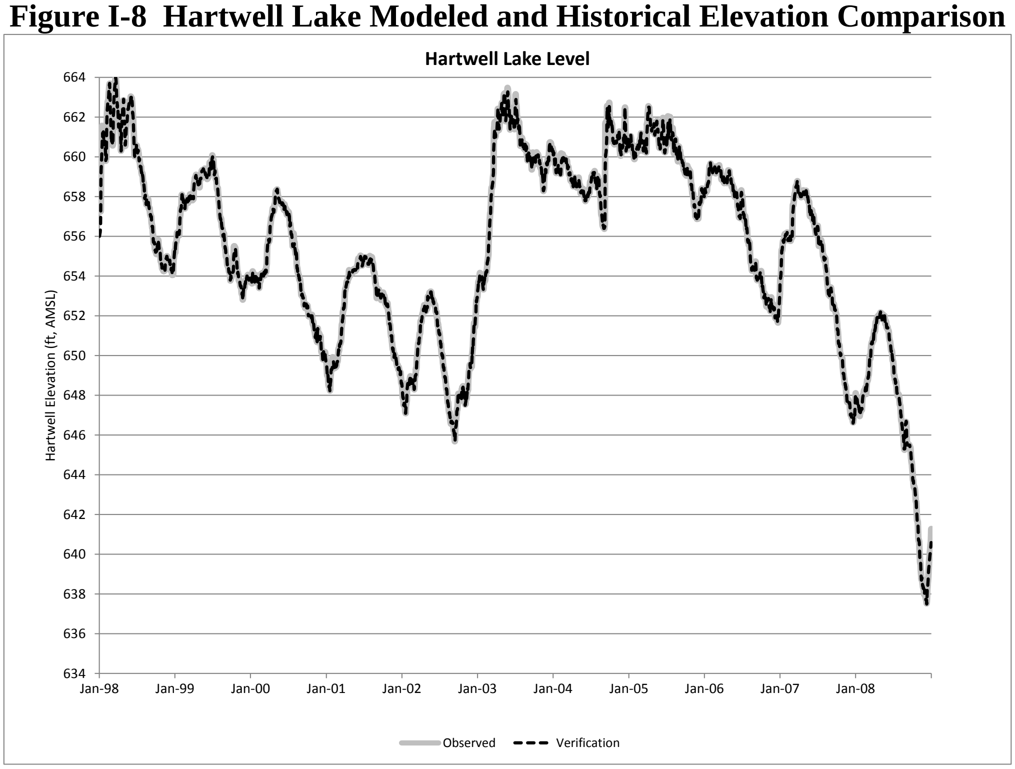


Figure I-9 RBR Lake Modeled and Historical Elevation Comparison

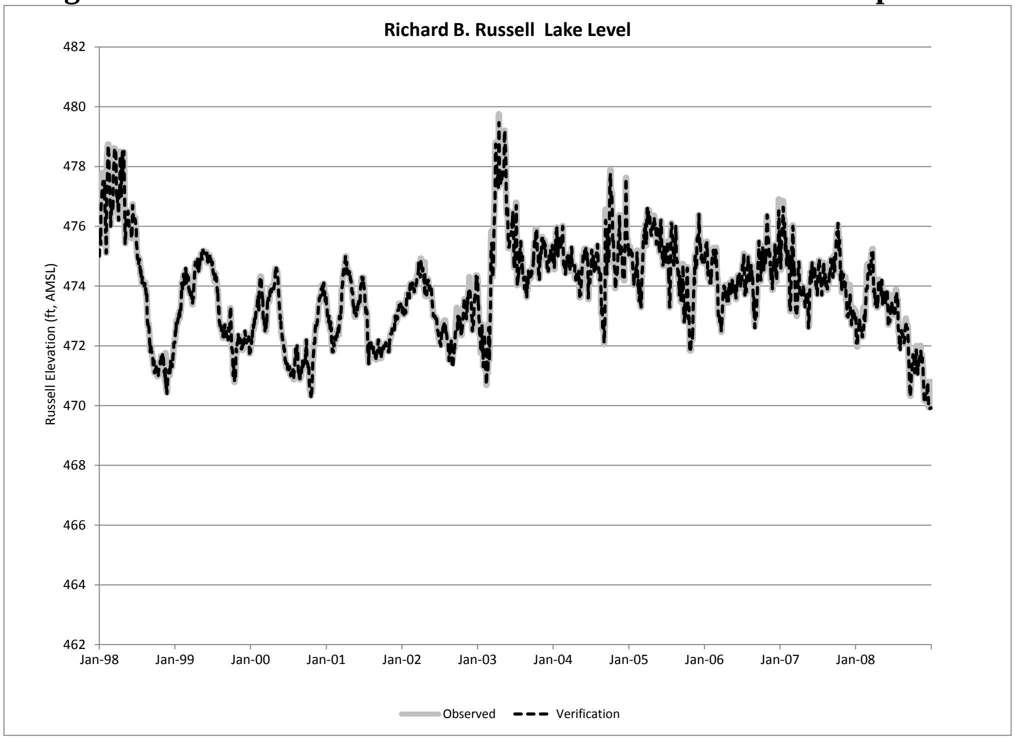
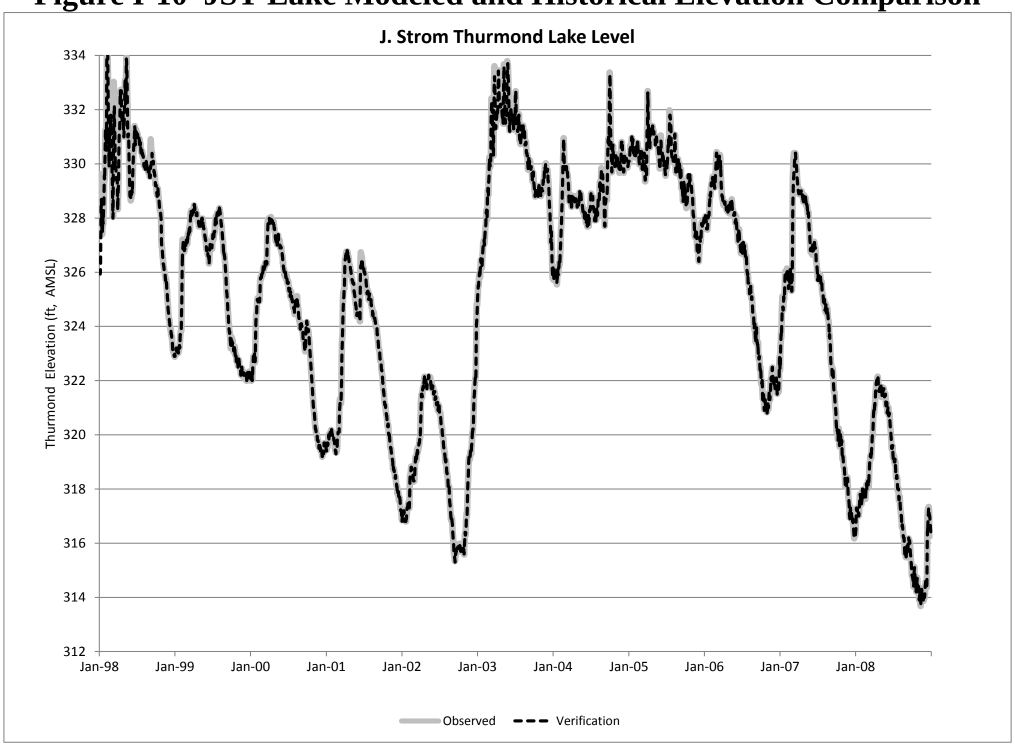


Figure I-10 JST Lake Modeled and Historical Elevation Comparison



The simulation of the historical scenario resulted in a modeled average annual energy output that was 2 percent lower than historical generation for the same period (see Table I-1). Based on available historical generation records, modeled and historical generation were compared for the period of 1998 – 2008 at all facilities except for RBR which was only evaluated for 2006 – 2008. Prior to 2006, the RBR pumping units were rarely operated.

Table I-1 Modeled and Historical Generation Comparison

Percent Difference between Modeled and Historical Generation ((modeled - historical)/historical)							
	Bad Creek	**Jocassee**	**Keowee**	**Hartwell**	**Richard B. Russell**	**J. Strom Thurmond**	**System Total**
1998	3%	34%	-3%	-2%		-7%	6%
1999	4%	174%	11%	5%		2%	34%
2000	-3%	102%	24%	8%		2%	17%
2001	11%	-93%	18%	5%		0%	-14%
2002	1%	-89%	13%	4%		-3%	-21%
2003	-11%	-24%	-4%	0%		-4%	-11%
2004	9%	24%	20%	-1%		-6%	9%
2005	-4%	23%	3%	2%		-7%	2%
2006	2%	28%	13%	5%	-6%	-5%	6%
2007	-13%	41%	33%	10%	-8%	0%	1%
2008	-37%	-67%	19%	6%	-34%	-1%	-39%
Average	-4%	6%	10%	3%	-15%	-4%	-2%

Table I-1 illustrates that there is generation variability between stations and between years, with the results for the USACE facilities generally being tighter than the Duke Energy facilities. These results are expected due to the way in which each operator dispatches each facility. The USACE dispatches Hartwell and JST using a more constant operating plan because they do not have other sources of generation to count on to make up the daily generation demand. Duke Energy has a diversified fleet of power stations that it uses to meet customer power demands which change on a daily basis. As a result, Jocassee and Keowee do not follow a constant set of operating rules as defined in the ResSim model. The system average results are considered to be good based on the overall performance of the model compared to historical operation.

For the period of 1998-2008 the model estimated a cumulative discharge from both Hartwell and JST that was 2 percent higher than historically reported from the two facilities for the same period, see Figures I-11 and I-12. These flow discharge comparisons are considered to be very good results and verify the model logic and constraints perform well for a diverse set of hydrologic conditions and the inflow data series is a reasonable representation of historical basin-wide water availability.

Figure I-11 Modeled and Historical Hartwell Discharge Comparison

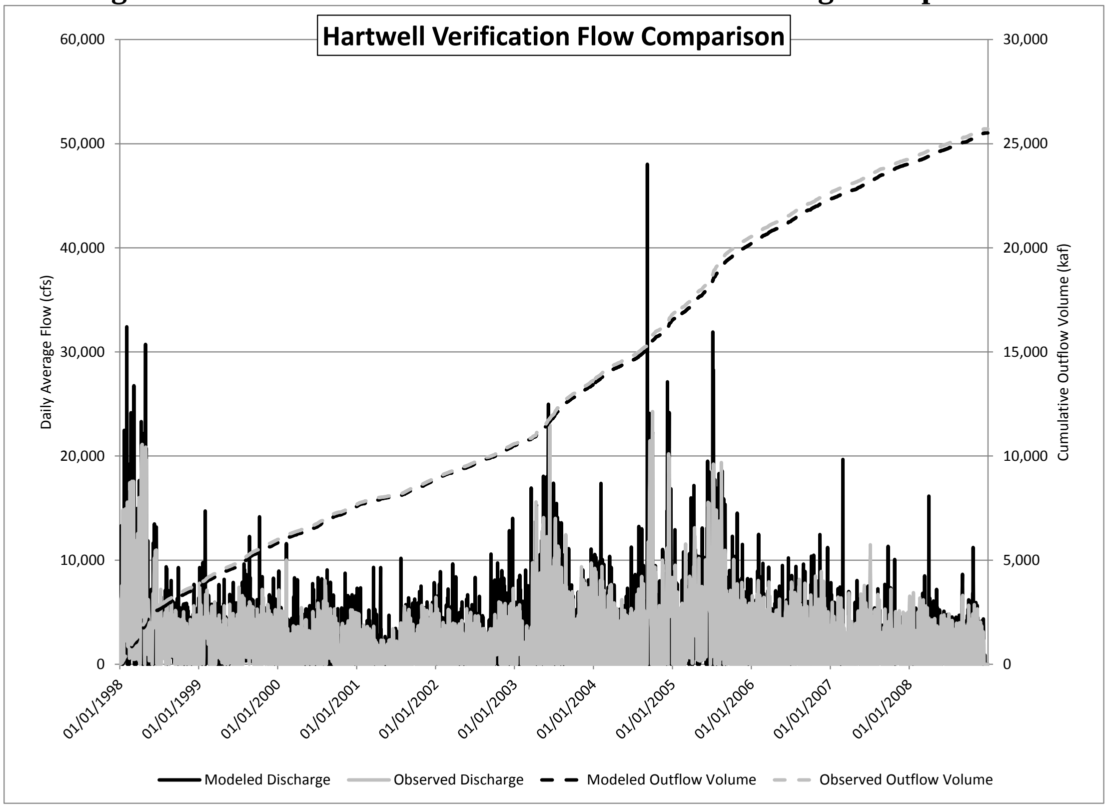


Figure I-12 Modeled and Historical JST Lake Discharge Comparison

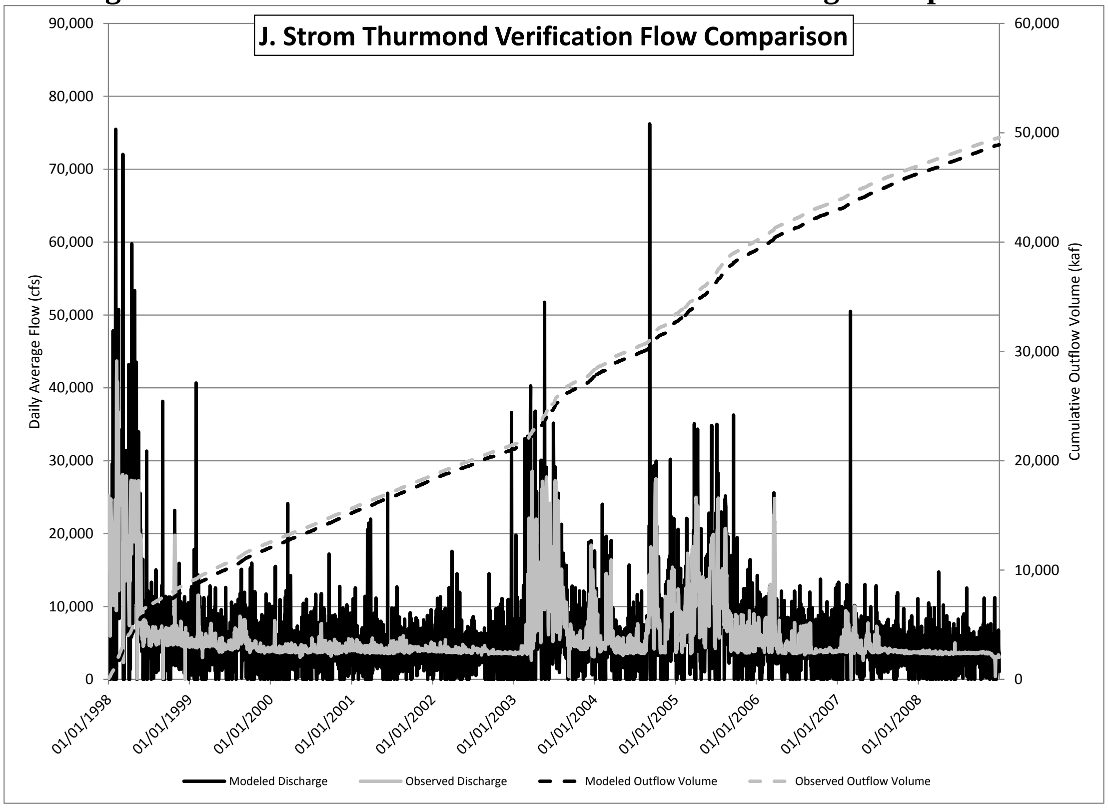


Table I-1 demonstrates there are swings between the modeled and historical generation. However, there are many factors that are inherent in the model data and setup that can contribute to output discrepancies (i.e., differences) when compared to historical data. In many cases, several of these factors may be involved simultaneously which makes it difficult to isolate individual sources of discrepancies. Two examples of potential sources of differences from historical generation are the standardized pumping rules and the hydrology:

- Pumping Operations – The model follows a set of defined rules for pumping and the historical records show that pumping operations vary greatly from year to year, month to month, and even day to day. This is considered the greatest source of modeled differences and swings in the generation comparison, and the reason why the goal of the modeling verification is to compare long term trends rather than monthly or annual values.
- Hydrology – The model uses unimpaired flow data as the input for daily inflow water to the system. The unimpaired hydrology was synthesized based on gage data and plant records, both of which have a certain amount of inherent error, especially when multiple locations and data sources are involved.

In the opinion of HDR, verification results demonstrate the operations model compares favorably to historical data; reasonably characterizes operations of the six facilities; and is an appropriate tool for use in evaluating the effects of operating scenarios on generation, reservoir levels, and outflows.