Model Certification

Tar River Basin Hydrologic Model

OVERVIEW

The Tar River Basin Hydrologic Model is based on the most practical geographic resolution and calculation time step appropriate for modeling the impacts to the quantities of surface waters in the basin. It is a decision support tool that can be used for multipurpose decision making for surface water resource management and, with additional information, drought management. In order for the model to be useful as a decision support tool, it must be capable of approximating real water conditions. How well the model accomplishes this task is determined by comparing the model results to known characteristics and examining the variation. While the ideal situation would be a perfect match, this is highly unusual because of the various time frames and geographic scales over which data are collected, and the need to certain assumptions and to fill in missing data using approximations from known data. The ultimate goal of any model is to make it useful in the sense that the model produces data to answer the questions it was designed for, and provides accurate information about the system being modeled.

DWR's certification process evaluates each hydrologic model's calibration and validates the models performance using qualitative and quantitative measures. Graphical and statistical comparisons are used to determine if the model can adequately characterize conditions in the river system being modeled. Certification is intended to put a "seal" of the credibility on a model. Documentation of the certification process is included with the model development documentation on the division's website.

Scope of the Certification

The Tar River model uses a set of estimated daily natural inflows to characterize the water entering the river system. This inflow dataset was developed using 80 years of flow records and gage extension techniques to fill-in data gaps in monthly USGS data adjusted for known historic withdrawals, discharges, and reservoir operations to simulate flow conditions without anthropocentric modifications. Since the hydrologic models are intended to be planning tools to support water resource management and develop evaluations reliable reproduction of daily data is less critical than monthly and annual data. The modeling effort focuses on analyzing the effects of withdrawals of 100,000 gallons per day or more and the surface waters that can support those withdrawals. The certification process analyzes the models ability to reproduce streamflows at USGS stream gage sites and reservoirs where water operation records are available.

For all model simulation data sets, it is important to keep in mind that the model is essentially a long mathematical equation that calculates results strictly based on how the equation is set up. Each model run produces results that are based on the numbers processed at each node given the parameters set in the model scenario with no ability to make compromise decisions, like those that can be made by the human operators of water withdrawal and water control facilities. For the model to function as intended, decision criteria have to be mathematically defined based on characteristics that can be linked to water quantity, such as changes in water levels. However,

facility operators are not necessarily constrained to take the same action at the same water level as the model. Therefore, we expect real-time management decisions to result in variations between actual and simulated conditions.

Certification Scenarios

The Tar River Basin Hydrologic Model is based on historic flow data that captures the range of flows experienced in the basin from January 1930 to September 2009. The 80 years of reconstructed data constitute the period of record of flow data for this model. In this certification process current condition operation or base case simulation scenario run, which is also called as "Simbase" scenario here in the document, is compared with the available historic observed USGS gage flows at various model nodes or essentially the gage nodes and reservoir nodes.

During development each model is adjusted to reproduce as well as possible a specific set of conditions. This set of conditions constitutes the "base case" for the model and provides the starting point against which other scenarios are compared. For the Tar River model the base case scenario reflects the effect of withdrawing the 2010 water demands under the 2010 management protocols during the flow conditions experienced in each year in the flow data period of record. This provides the ability to answer questions like; What would flow conditions look like if 2010 demands were withdrawn using current management regimes during a repeat of the flows experienced in 1955? Since the base case focuses on current withdrawal capacities and management regimes the certification focuses on evaluating the model's ability to reproduce conditions in the recent past when reliable use and flow data are available to test the model performance. The last five years of Simbase scenario values are compared along with the available period of records for individual USGS gages or Reservoir operation. Additional review will be done to further characterize the model for other limitations or biases of the data, as necessary. The results are part of the overall analysis but only included to highlight any data interpretation issues.

Hydrologic model certification is evaluated through qualitative and quantitative measures, involving both graphical comparisons and statistical tests. Daily, monthly and annual values are compared as appropriate for the type of flow and evaluation criteria set for Simbase and USGS flows in this regard as follows:

Table 1: Model Data Certification /Characterization Analyses

Scenario Data Sets	Data Type	Period of Record	Recent Records	Statistical Correlation	Graphical Measures	Data Format
USGS Flow	Gage Flow	Gage Period of Records	Last 5 Year Records	Goodness of Fit - Nash Sutcliffe Efficiency - Percent BIAS - RMSE Standard Ratio	- Hydrograph - Frequency Plots - Mass Curve - Low Flow	- Monthly
Simulated Basecase for 2010 Demand and Operation	Model Output	Common Gage periods	Common Last 5 Year Records			

Certification Results

The results of both statistical and graphical model evaluation techniques are discussed in this section. The model has seven gage nodes and one reservoir node and these eight nodes flow values are used for the statistical tests and graphical evaluations. Table 2 presents the pertaining information and descriptions of the nodes used for the certification datasets for the listed important locations in the Tar River basin. The last model gage node is Greenville Gage. This gage is near tidally influenced section in the lower Tar basin, where flow is influenced by diurnal tidal waves and wind. Therefore this gage node is not included in this evaluation purposes.

Table 2: Model Data Certification Stations / Model Nodes

No	USGS Gage Location	USGS Gage Number	Data Type	Drainage Area, Sq-miles	Model Node	Model Node Name
1	Tar River near Tar River	02081500	Flow	167	010	Tar River Gage
2	Tar River at US 401 at Louisburg	02081747	Flow	427	050	Louisburg Gage
3	Cedar Creek near Louisburg	02081800	Flow	47.8	070	Cedar Creek Gage
4	Tar River Reservoir near Rocky Mount	NA	Elevation	777	120	Tar River Reservoir
5	Fishing Creek Near Enfield	02083000	Flow	526	200	Enfield Gage
6	Swift Creek at Hillardston	02082770	Flow	166	280	Swift Creek Gage
7	Tar River at Tarboro	02083500	Flow	2183	300	Tarboro Gage
8	Conetoe Creek near Bethel	02083800	Flow	78.1	380	Conetoe Creek Gage

As presented in Table 1, the quantitative evaluations are divided into groups of standard statistical tests such as Nash-Sutcliffe Efficiency (NSE), Observations Standard Deviation Ratio (RSR), and Percent Bias (PBIAS). Several graphics are also provided for visual comparison of simulated and historic data. Table 3 summarizes the statistical test results for the flows and reservoir elevations at the eight mentioned nodes in the model along with the limits and performance ratings. The table also provides the drought period comparison for the USGS and Simbase flow values. Total numbers of days in drought condition for the flow values of US Drought Monitor flow categories are summarized here. Only one node shows the percent difference in days are outside the acceptance limit of ≤ ± 25% and that node has poor data.

Table 3: Statistical Summary – Goodness of Fit for the last Five years of Data

Gages	Goodness of Fit Results			Drought Period Comparison		
	Data Format: Monthly			Data Source	Total Days	% Difference ≤ ± 25%
	NSE > 0.5	RSR ≤ 0.70	PBIAS ≤ ± 25%			
010 Tar River Gage Flow	0.9999	0.0077	0.7	USGS	527	
	Satisfactory	Satisfactory	Satisfactory	Simbase	509	-3.4%
050 Louisburg Gage Flow	0.9999	0.0102	0.2	USGS	536	
	Satisfactory	Satisfactory	Satisfactory	Simbase	496	-7.5%
070 Cedar Creek near Louisburg Gage Flow	-0.7936	1.3282	-90.1	USGS	617	
	Poor	Poor	Poor	Simbase	1707	176.7%
200 Fishing Creek Near Enfield Gage Flow	1	0.0042	-0.3	USGS	617	
	Satisfactory	Satisfactory	Satisfactory	Simbase	627	1.6%
120 Tar River Reservoir Elevation	-0.2057	1.0905	-0.3	N/A		
	Poor	Poor	Satisfactory			
240 Swift Creek Gage Flow	0.9999	0.0073	-0.4	USGS	532	
	Satisfactory	Satisfactory	Satisfactory	Simbase	536	0.8%
300 Tarboro Gage Flow	0.9995	0.0227	-0.3	USGS	581	
	Satisfactory	Satisfactory	Satisfactory	Simbase	597	2.8%
380 Conetoe Gage Flow	0.9999	0.0114	-1.8	USGS	497	
		Satisfactory	Satisfactory	Simbase	564	13.5%

NOTE : Cedar Creek statistical correlation is poor partly due to:

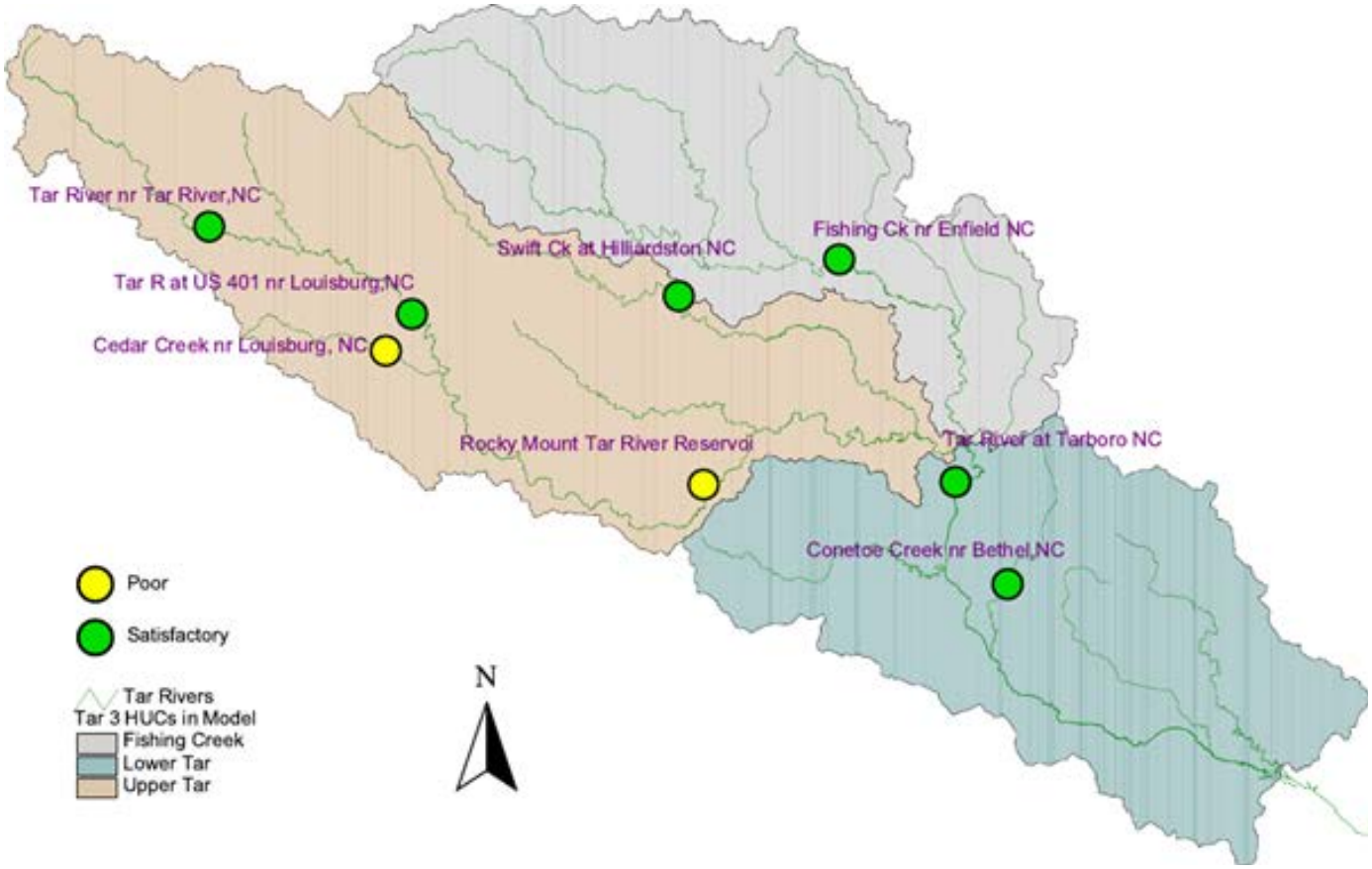
* Cedar Creek gage has only 19 years of flow records; therefore model inflow was generated based on nearby gage flows as synthetic flow data. Other gages have up to 80 years of records.
* Cedar Creek has very small drainage area – only 47.8 sq-miles, and in impaired segment in the headwater part.
* The gage is in a tributary below two very small lakes known as Franklinton reservoirs operated by Franklinton in Franklin County. These two lakes are not modeled as reservoirs with operating rules.

This summary table shows the overall model credibility. Out of the eight nodes, only one node is showing poor correlation. Cedar Creek near Louisburg gage performed poor for all instances. This gage has only 19 years of flow records; therefore model inflow was generated based on nearby gage flows as synthetic flow data. Other gages have up to 80 years of records. Cedar Creek has very small drainage area of 47.8 sq-miles and is in impaired segment in the headwater part. The gage is in a tributary below two very small lakes known as Franklinton Reservoirs operated by Franklinton in Franklin County; these two lakes are not modeled as reservoirs with operating rules. The flow values below the lakes are not close to the historic operation values, and thus giving poor correlations for all the tests in all temporal formats.

Similarly, Tar River Reservoir elevation values also showing poor correlation for two of the three tests. Only PBIAS is satisfactory. Tar River Reservoir is in operation by City of Rocky Mount since 1979 having sufficient data points for the statistical tests. However a malfunctioning gage below the reservoir recorded much lower flows and forced to release more water from the reservoir to

maintain downstream flow in 2007; thus lake elevation was observed to a significant low level. Therefore, elevation correlations are measured poor.

Figure 1: Map of Model Gage Nodes- GOF Result at a Glance



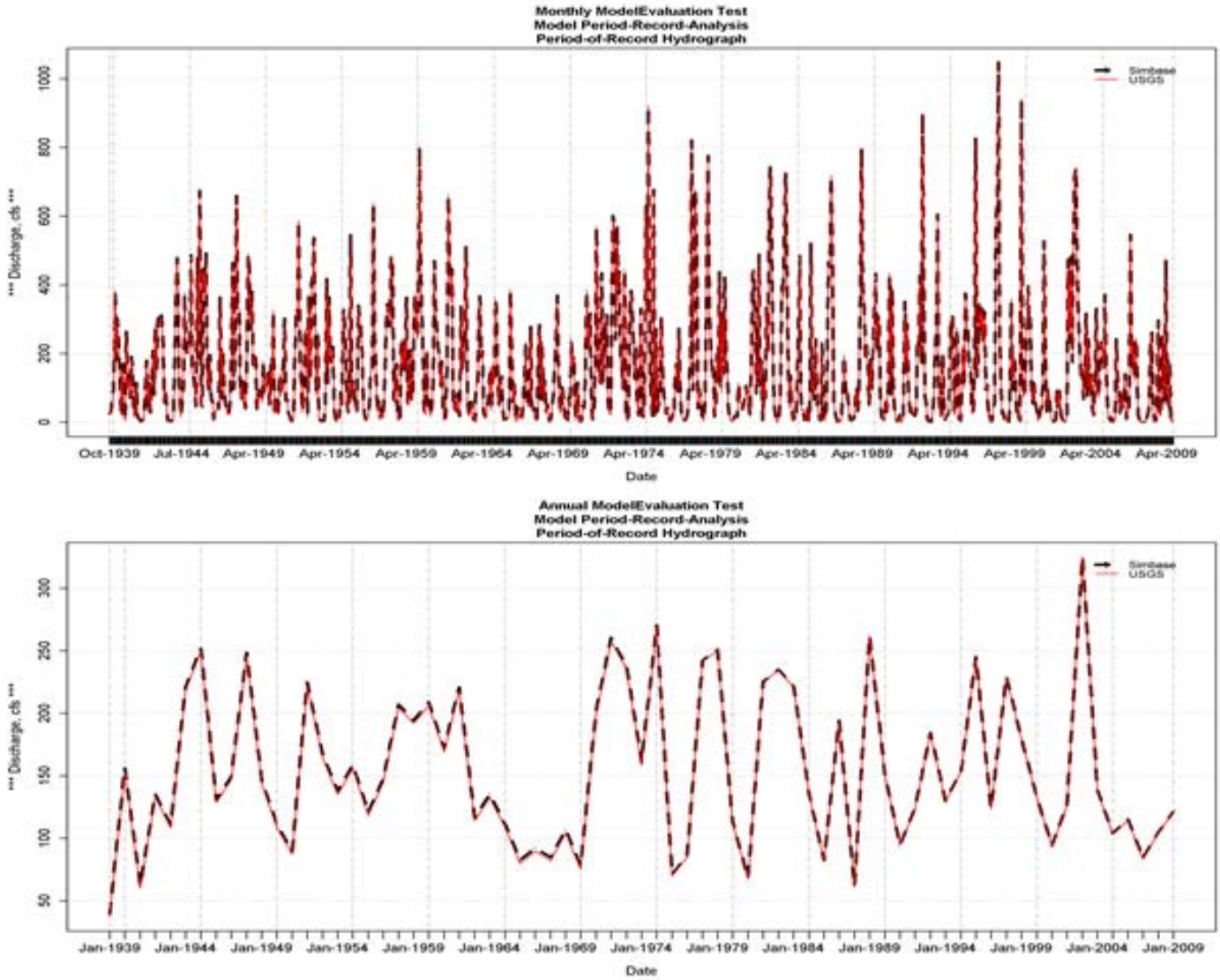
The other six gages exhibited satisfactory test results indicating overall good model simulation performance. GOG results are exhibited in a map in Figure 1 above. The green nodes have satisfactory and yellow nodes have poor correlations. Note the model map is limited to the three HUCs in upper portion of the entire Tar basin.

Example Node: Tar River near Tar River Gage Graphical Evaluation Measures

Standard Flow Evaluation:

A. Hydrograph – Time Series Monthly and Annual Plots for Daily Flows

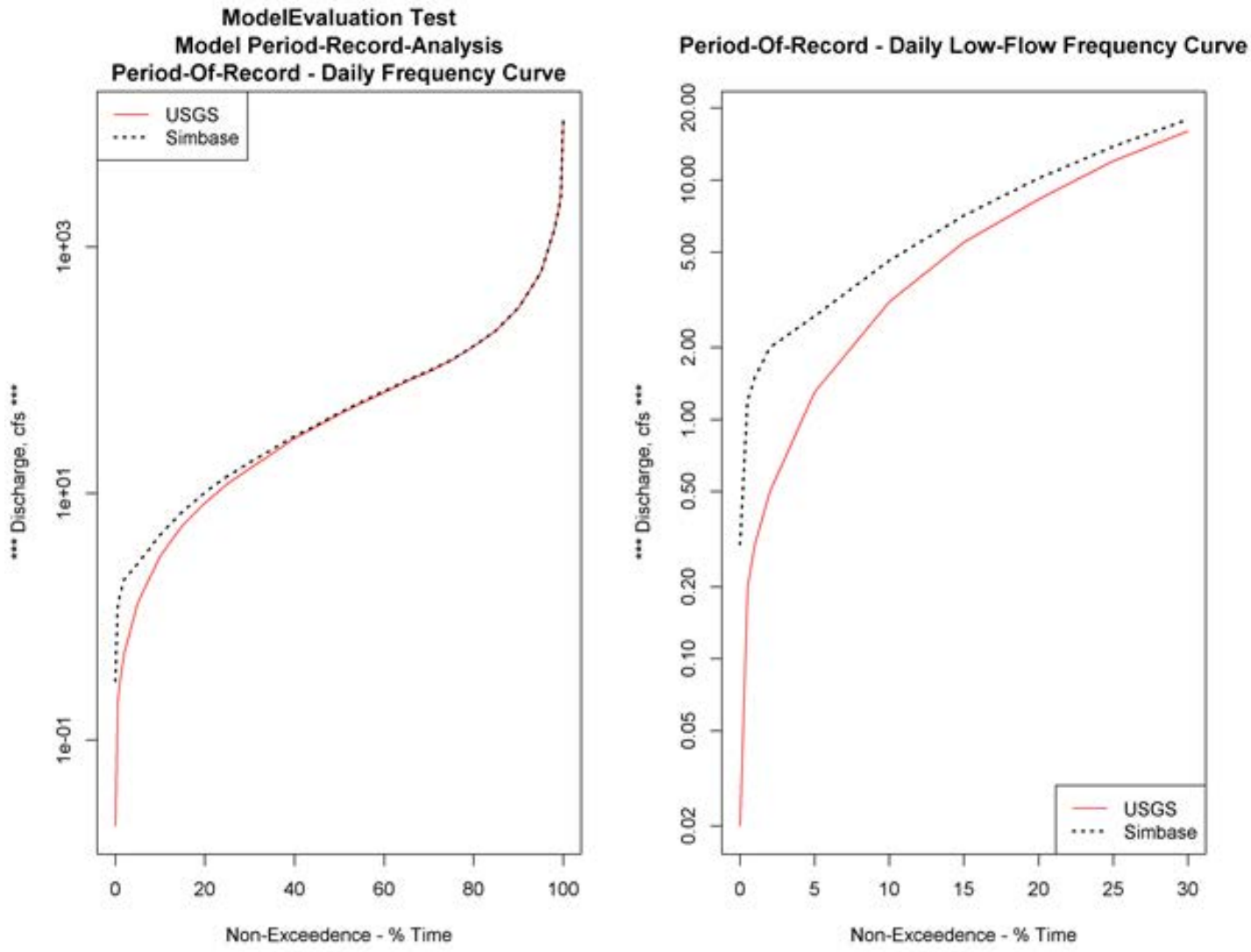
Figure 2: Tar River Gage Period of Record Daily, Monthly and Annual Flow Hydrograph



Hydrograph in Figure 2 provides time series flow plots for monthly and annual flows for Tar River at Tar River gage. This gage is the first gage used in the upper tar watershed and is considered as one of the unregulated gage location without any major human created disturbances other than wastewater return flows from Kerr Lake watershed and irrigation withdrawals. The flow values match quite well with the USGS flows except for few high flows, and gives very good correlation as shown in Table 2 and Table 3.

B. Frequency Curve- Daily Flows

FIGURE 3: TAR RIVER GAGE PERIOD OF RECORD DAILY FLOW FREQUENCY CURVE



The curves in the above Figure 3 provide a better visualization of the flow duration of the two sets of data for full range and low flows. About 40 percent to 100 percent of the times the flow frequencies were very close. However, at the very low range of less frequent occurrences, Simbase flows are little higher than USGS gage flows.

Intake Yield Evaluation

C. Yield Curve – Daily Mass Curve

Yield curve is a daily mass curve of cumulative demand vs. cumulative source flow. It provides the range of sustainable demand for the flow condition as specified here as daily storage value in Figure 4. USGS storage and Simbase storage mass curve is plotted against the systematic demand draft or withdrawal. The plot reveals a good matching similar trend of yield values.

Table 4 provides daily storage values of USGS and Simbase model run from this analysis. Increased demands in cfs with USGS daily cfs values indicate there are always sufficient remaining flows available in the stream at that location after the withdrawal at the rate of the corresponding demands.

Figure 4: Tar River Gage Period of Record Yield Daily Mass Curve

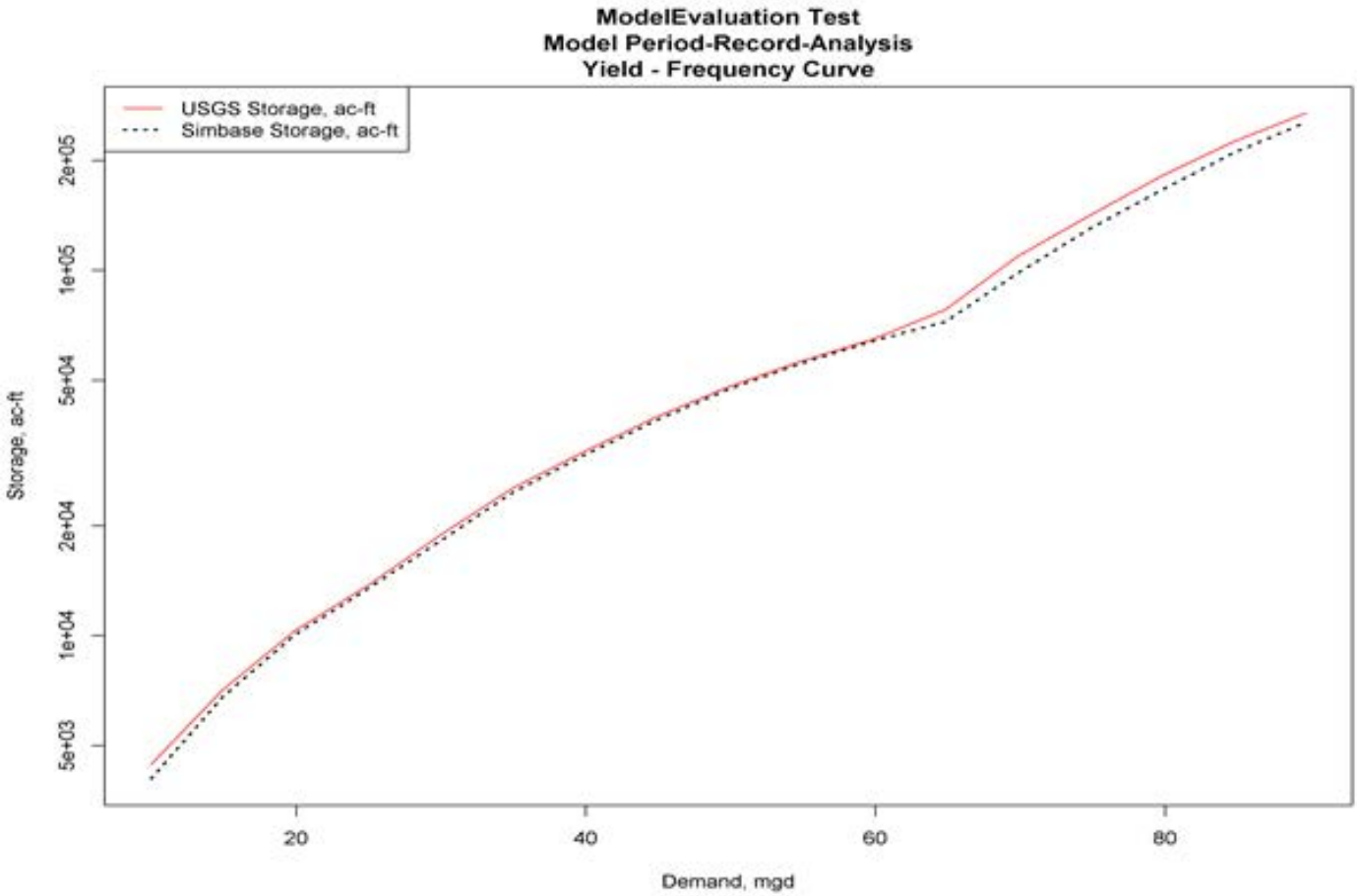


Table 4: Tar River Gage Period of Record Yield Analysis

Demand CFS	USGS Storage CFSD	Simbase Storage CFSD	Remaining Flow CFS
15	2,233	2,042	2,217
23	3,592	3,429	3,569
31	5,211	5,075	5,181
39	6,896	6,759	6,857
46	9,480	9,130	9,434
54	12,728	12,378	12,674
62	16,061	15,722	15,999
69	20,002	19,592	19,933
77	24,207	23,795	24,129
85	28,423	28,010	28,338
93	32,647	32,233	32,554
100	39,321	36,461	39,221
108	55,031	49,436	54,923
116	71,125	65,444	71,009
123	91,432	83,685	91,308
131	113,575	105,827	113,444
139	135,752	127,991	135,613

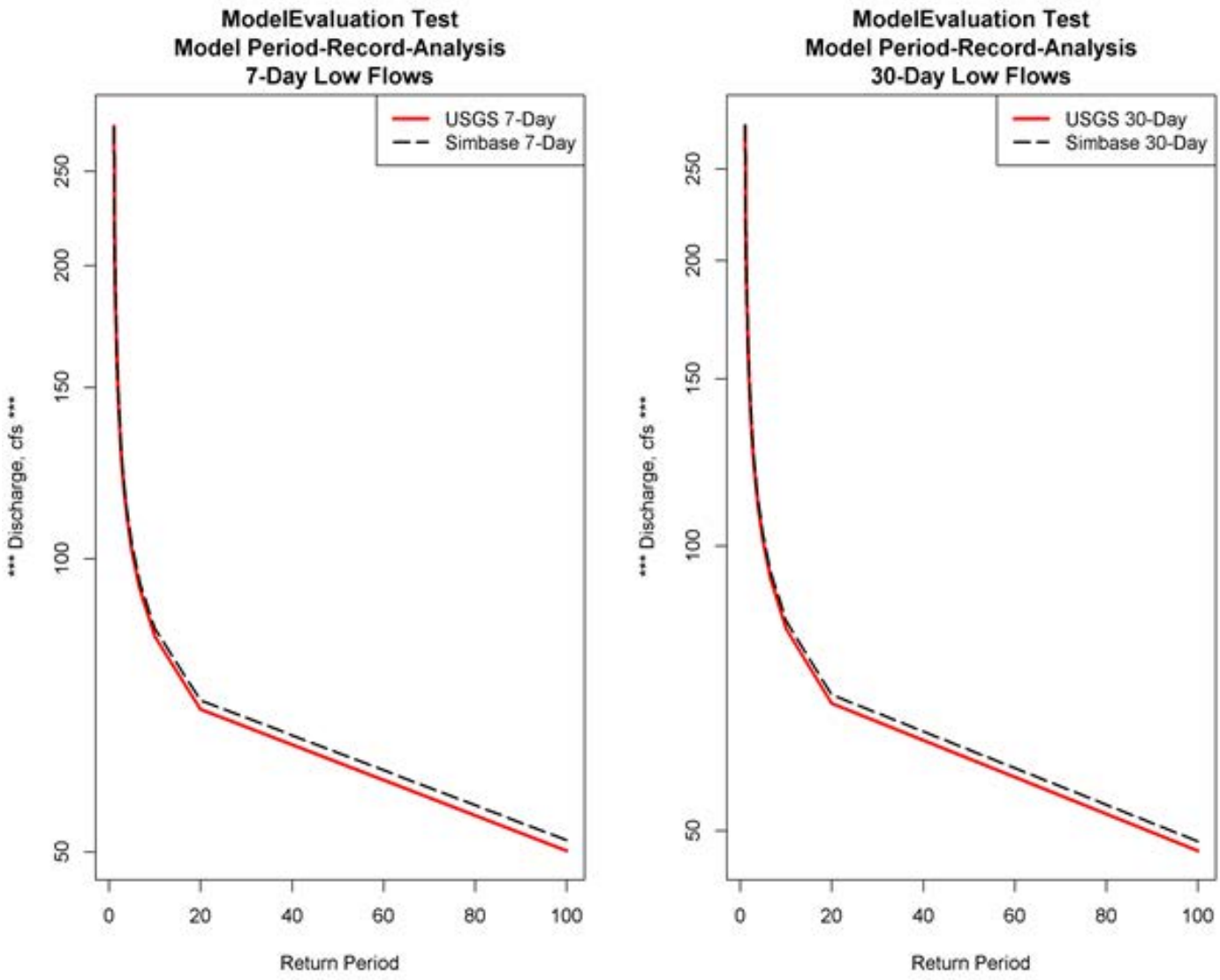
Low Flow Evaluation

D. Low Flow Curve – Log-Pearson III 7 Day and 30 day

Log Pearson statistical technique is used to analyze distribution of 7 day and 30 day low flow values. 7 day low flow with 10 year return period also known as 7Q10 is used in hydrologic low flow analyses; whereas 30 day low flow with two year return period or 30Q2 is used for drought planning purposes. 7Q10 values are also used for regulating water withdrawals and discharges into streams. Daily streamflows in the 30Q2 range are general indicators of initial drought conditions which may cover large areas, and may be used by regulators in determining water-use restrictions.

Figure 5 shows the two plots for 7 day and 30 day low flows. 7Q10 values and 30Q2 values are in the same magnitude, only higher return periods have slightly different values but the difference is not much.

Figure 5: Modeled 7 day and 30 day low flows



Drought Planning

A. Low Flow – Log-Pearson II 30 Day

As was discussed under Low Flow Evaluation and shown in Figure 5.

B. Drought Condition Evaluation – Daily Flows

USGS gage flow is one of the indicators used to evaluate the drought conditions. USGS historic flow percentiles are used to categorize the drought classifications from D0 – as abnormally dry to D4 as exceptional Drought as shown in the following Table 5. Tar gage flow is estimated based on the category classifications, and USGS gage flows and Simbase gage flows are evaluated for number of days within that drought category, and later percent difference of the days are estimated. From extreme (D3) to exceptional drought (D4), the model underestimated the number of days shown as negative percent difference in high order. In overall total number of days in drought is also underestimated with the order of little less than 15% of the days. The reason to have lower severe category drought is that the model drought plan was active, and that triggered the drought in advance and prevented it from triggering further extreme conditions later on.

Table 5: Tar River Gage Period Summary of Drought Periods

Drought Category / Flow Percentile Range	USGS cfs	USGS Days	Simbase Days	% Difference Days
D0 Abnormally Dry 20% - 30%	16	2,793	2,864	2.54
D1 Moderate Drought 10% - 20%	8	2,521	2,735	8.49
D2 Severe Drought 5% - 10%	2.9	1,180	1,344	13.90
D3 Extreme Drought 2% - 5%	1.3	762	134	-82.41
D4 Exceptional Drought Less Than 2%	0.5	516	25	-95.16
D1-D4 Total time in drought conditions		4,979	4,238	-14.88