NEAR-TERM FORECASTING OF SURFACE WATER SUPPLIES FROM THE HILLSBOROUGH RIVER AND TAMPA BYPASS CANAL SYSTEM

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INTRODUCTION

Tampa Bay Water, the largest wholesale water supplier in Florida, serves more than two million residents in the Tampa Bay region through its member governments in Hillsborough, Pasco, and Pinellas Counties (the Tri-County Region), as well as the cities of New Port Richey, St. Petersburg, and Tampa. Wellfields historically have supplied approximately 60 percent of the Tampa Bay region's drinking water. Tampa Bay Water holds a Southwest Florida Water Management District (SWFWMD) Consolidated Water Use Permit (WUP 2011771.00, December 15, 1998) that governs the operation of 11 of its wellfields. Because this WUP includes a schedule that requires reductions in average annual wellfield pumping, Tampa Bay Water developed a Master Water Supply Plan to develop alternative source supplies including surface water.

This report describes the development of a suite of computer modeling tools to forecast daily flows at key locations along the Hillsborough River and Tampa Bypass Canal (TBC). The forecasted flows will be used to estimate the availability of surface water for operational planning purposes. Because Tampa Bay Water manages its water supply system proactively by planning the operation of its entire system for one week in advance, the Hillsborough River/Tampa Bypass Canal Flow Generation and Hydraulic Routing Model (HR/TBC model) was developed to produce forecasts for a seven-day period into the future.

WATERSHED DESCRIPTION

The Hillsborough River basin covers approximately 650 square miles and is supplied by several major tributaries and springs including Cypress Creek, Trout Creek, Blackwater Creek, and Crystal Springs. The United States Geological Survey (USGS) measures stream flow at a number of locations in the watershed including Trout Creek, Cypress Creek, Morris Bridge, Zephyrhills, and the Tampa Dam (see Figure 1). The basin consists primarily of large, flat areas, with many wetlands, that drain to the Hillsborough River during wet weather. Before reaching Tampa Bay, the Hillsborough River enters the Hillsborough River Reservoir (reservoir), which has served as a water supply source for the City of Tampa since the 1920s.

The basin is quite complex in its lower reaches, and includes a number of flow control structures and canals, including the TBC (see Figure 2). The TBC was constructed during the 1970s by the U.S. Army Corps of Engineers (USACE), primarily to provide flood control for the densely developed lower portion of the watershed in Tampa. During periods of exceptional flooding, water can be retained upstream of structure S-155 in a flood detention area and can be diverted to the TBC. More commonly, diversions from the river into the canal occur further downstream via structure S-161 on the Harney Canal. All excess TBC water is discharged into the Palm River via structure S-160. Both the Tampa Dam and structure S-160 provide saltwater barriers, preventing saltwater from moving upstream.

The TBC historically has been delineated into three "pools," the boundaries of which are defined by the structure that forms the backwater in each pool. The upper pool is upstream of S-159; the middle pool is upstream of S-162 (and includes the Harney Canal); and the lower pool is upstream of S-160 (see Figure 2).

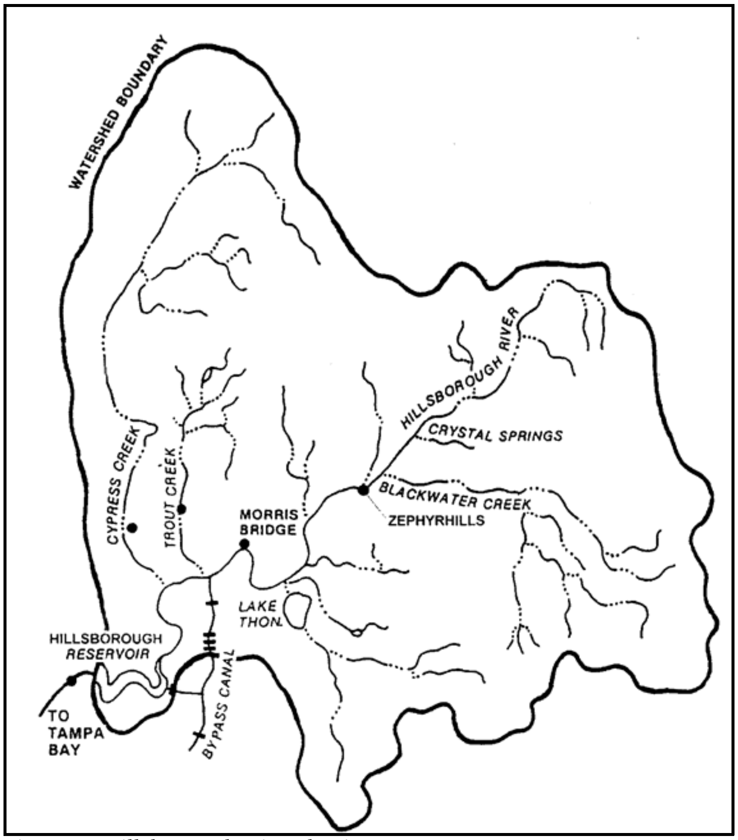

Figure 1. Hillsborough River basin.

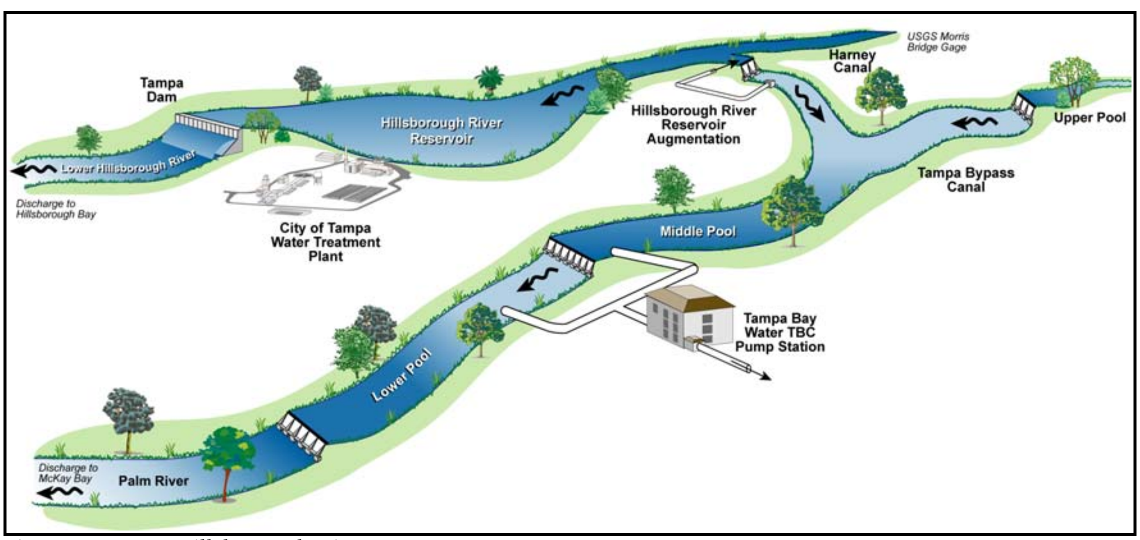

Figure 2. Lower Hillsborough River.

The TBC also has a significant impact on local groundwater flow patterns. The canal is hydraulically connected to the aquifer, and groundwater inflow provides baseflow to the middle and lower pools of the TBC. In the upper pool of the canal, stormwater runoff can recharge the groundwater system.

The complete HR/TBC model package includes several flow generation models and a hydraulic routing model. The flow generation models provide stream flow predictions for each of the major tributary streams at gauged locations. These include Cypress Creek, Trout Creek, and the main stem of the Hillsborough River (Morris Bridge and Zephyrhills gauges). The HR/TBC model tributary areas are defined as follows:

Upper Basin
- Cypress Creek—Cypress Creek watershed above USGS Gauge No. 02303800
- Trout Creek – Trout Creek watershed above USGS Gauge No. 02303350
- Upper Hillsborough River – Hillsborough River watershed above Zephyrhills (USGS Gauge No. 02303000)

Middle Basin:
- Hillsborough River watershed above Morris Bridge (USGS Gauge No. 02303330) and below Zephyrhills

Lower Basin:
- Hillsborough River upstream of Tampa Dam (USGS Gauge No. 02304500) and downstream of Morris Bridge
- TBC upstream of S-160 (not a USGS gauging site)

The hydraulic routing models route the flows generated by the flow generation models (at Cypress Creek, Trout Creek and the Hillsborough River at Morris Bridge) through the lower Hillsborough, including transfers from the Hillsborough River to the TBC via Harney Canal, and through the TBC. The hydraulic routing models also account for local groundwater and stormwater inflow occurring downstream of the flow generation model domains and above the Tampa Dam and structure S160. Operation of the structures located in the lower Hillsborough River is also included in the hydraulic routing model.

BASIN CHARACTERIZATION

To facilitate the development of the models a project-oriented database was constructed. This database utilized existing information available from public sources. No single data repository exists for all water data pertinent to this project. In addition, most sources do not maintain data sets for the entire period of record of interest for this study (September 1, 1988, through July 31, 2002). Data sources included Tampa Bay Water, SWFWMD, USGS, and the National Oceanic and Atmospheric Administration (NOAA).

For development of the Lower Basin hydrodynamic model additional data were needed regarding the geometry of the river and TBC, as well as details relating to the design and operation of the structures. The following sources provided the bulk of this information:

- Hillsborough River cross sections: Hillsborough County Public Works Department's SWMM Model
- Watersheds in the Lower Basin: Hillsborough County Public Works Department's Hillsborough River Watershed Management Plan
- As-Built Drawing of the Tampa Dam: City of Tampa
- As-Built Drawings of the TBC: SWFWMD (USACE)

- C Operation of Structures: City of Tampa, Tampa Bay Water, and SWFWMD
- C Historical Diversions and Withdrawals: Coordinated by Tampa Bay Water

Previous reports were obtained that studied flow, groundwater seepage, or any other relevant facet about the system. Interviews were conducted with the operator of the Tampa Dam, and SWFWMD staff to confirm the manner of operation of flow control gates on the structures. Additional field surveying or data collection was deemed unnecessary for development of the model.

FLOW FORECASTS FOR UPPER AND MIDDLE BASINS

The Lower Basin routing model requires the input of daily forecasted flows for the upcoming week from Cypress Creek, Trout Creek, and Morris Bridge. The final approach chosen to forecast these flow rates utilized artificial neural network models (ANNs). Approximately 14 years of data was used to train, validate, and test each ANN. For any date D, the flow forecasting objective was to be able to forecast flow rates at Cypress Creek, Trout Creek, and Morris Bridge at dates D + 1, D + 2,…, D + 7. This required seven ANNs; one for each day's forecast. Similarly at Zephyrhills, three ANNs were developed for dates D + 1, D + 2, and D + 3.

Because the Zephyrhills gauge is located upstream of the Morris Bridge gauge, the flow rates at these two locations were determined to be highly correlated. Analysis indicated an approximate three-day wave front travel time from the gauge at Zephyrhills to the gauge at Morris Bridge. Therefore, the most recent three days of history at Zephyrhills was determined to be important input for forecasting the next three days of flow at Morris Bridge. Similarly, forecasted flow rates at Zephyrhills for three days into the future were used as input into the Morris Bridge ANNs to improve the Morris Bridge predictions.

The forecasts were conducted in two stages for each gauge. First, an average flow rate for the forecast period was predicted (that is, a seven-day average flow rate for Cypress Creek, Trout Creek, and Morris Bridge; and a three-day average flow rate for Zephyrhills). Then this value was used as input into the daily ANNs. There was a separate ANN for each forecast day. For example, Cypress Creek had eight ANN models: the seven-day average flow, day one, day two, day three, day four, day five, day six, and day seven. ANNs were developed similarly for the other gauges, except that Zephyrhills had models for a period of only three days.

The developed ANNs provided reasonably accurate daily forecasts for seven days into the future, although after day three the accuracy diminishes rapidly. Because ANN models generally assume that recent historic patterns are valid in the near future, regular evaluation of this assumption will be necessary.

Example ANN Modeling

An example of the ANN modeling is presented for only Cypress Creek. Except for the duration of the forecast period, specific data available within each drainage sub-basin, and other minor input details, the process was the same for each gauge and the results were very similar.

Available data were reviewed and selected based on their representativeness of various hydrologic processes (e.g., lake water levels give an indication of long-term drought). Historical data utilized in the Cypress Creek included; flow rates for Cypress Creek at Worthington Gardens and near Sulphur Springs, area precipitation, surface water levels, and ground water levels. Additionally, the historically noted seven-day averaged flow rates, the 52-week lagged seven-day averaged flow rate, and the seven-day median flow for Cypress Creek Springs were included as input.

Figure 3 presents the results from the weekly average flow rate model. In the scatter plot, the ANN-forecast flow rate was plotted against the observed flow rate for each seven-day period. The entire historical record was included in the plots, which means that the data pairs from the training set, the validation set, and the testing set all are included. Also shown is the least squares linear fit of the observed versus the forecasted rates (thicker line) and the line on which the forecasted values equal the observed values (thinner line). The results illustrate that the seven-day average forecasts are quite accurate. Thus, including these forecasts as input for the training of the daily ANNS proved beneficial to their accuracy.

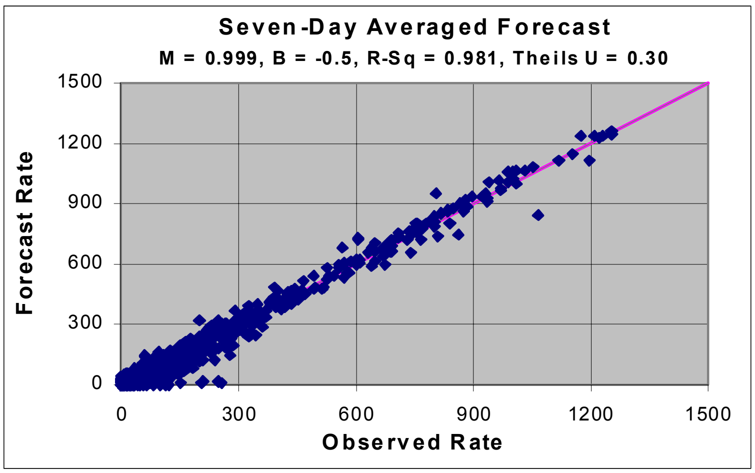

Figure 3. Seven-day averaged forecast at Cypress Creek.

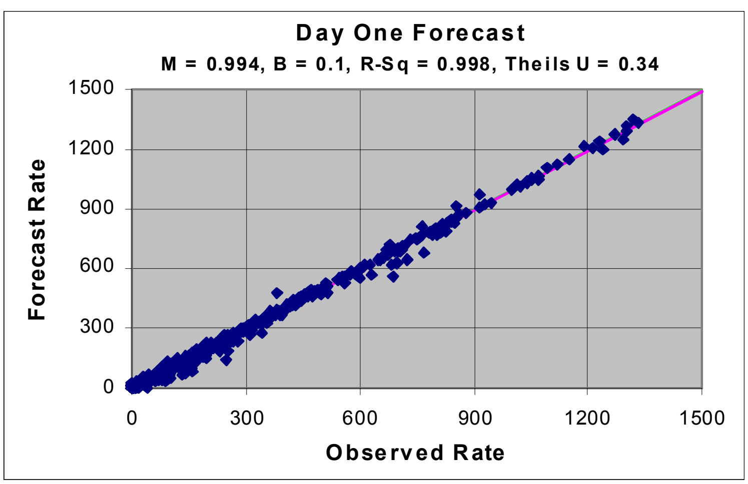

Figure 4. Day one forecast at Cypress Creek.

Separate ANNs were constructed for each forecasted day out to seven days into the future. The daily ANNs utilized input as described above and also included; daily observations over the previous few days, the historically noted daily median flow rate at Cypress Creek, and the seven-day average flow. The forecast for day one in the future was excellent (Figure 4). Even though the forecast accuracy diminishes the farther into the future the forecasts are made, the forecasts out to day seven are all reasonable.

These results were similar to the ANN results at Zephyrhills (albeit for three days) and Morris Bridge. The results were more variable at Trout Creek, however, which was attributed to the smaller sub-basin (more variable flow) and the lack of upstream flow monitoring. The Trout Creek sub-basin generally produces a small proportion of the total flow into the Lower Basin, so these forecasts typically have only a slight impact.

HYDRODYNAMIC MODELING OF THE LOWER BASIN

The HR/TBC model for the Lower Basin was developed using, HEC-RAS 3.0, to establish flow rates and water surface elevations at the Tampa Dam and structures S-160, S-161, and S-162. The overall configuration of the routing model is illustrated in Figure 2.

Procedures outside of HEC-RAS were developed to estimate the necessary boundary conditions. Boundary conditions input into the HEC-RAS model come from:

- Upper and Middle Basin flow forecasts utilizing the ANN models, as described previously. This is the primary flow contribution.
- Groundwater baseflow using a spreadsheet application and observed groundwater levels. This flow contribution is considered a small net effect in the Hillsborough River when compared to the flow range of interest (100 to 1,000 cfs) and was not included at this time. The baseflow in the TBC was included as part of the spring flow.
- Spring flow in the TBC, based on recent observed data.
- Local runoff predictions using NOAA forecasts of future precipitation and a spreadsheet application. The area of the watershed contributing to local runoff is approximately 59 square miles (mi^2), or approximately 9 percent of the total watershed draining to the Tampa Dam. These flows could be high on a given day, but the forecasts will be highly variable. Only larger storms contribute significant runoff.
- City of Tampa withdrawals from the reservoir based on historical use and anticipated future changes to the City's use pattern because of the ASR system.

Other inflow components include the direct precipitation onto the water surfaces and evaporation. These two features were not added at this time, but could easily be included into the model.

The geomorphology input data for HEC-RAS includes connectivity information for the stream segments, cross section coordinates, distances between the cross sections, Manning's roughness coefficients, and hydraulic structure information for all of the flood control structures and bridges. Because of the complexity of the lower basin, the model was split into separate applications: one for the Hillsborough River and one for the TBC.

The Hillsborough River model extends from the Tampa Dam to the Morris Bridge gauge, and includes Cow House Creek. The TBC model extends from just downstream of S-160 to S-159 and includes the Harney Canal downstream of S-161. The upper pool of the TBC was added as a lateral inflow boundary condition to Cow House Creek (S-163), since the gates of S-159 are normally kept in the closed position and the gates of S-163 are normally kept in the open position.

The cross section data for the Hillsborough River were based on Hillsborough County's SWMM model of the Hillsborough River basin. USACE (provided by SWFWMD) as-built drawings were utilized extensively to obtain cross section data for the TBC. Bridge information was not readily obtainable, so surrogate geometry data (i.e., typical pier spacing based on older drawings) were used for bridges. Bridges did not restrict flow in the range of interest.

The primary purpose of the TBC structures and the Tampa Dam is flood control. However, the main objective of this project was to develop tools for Tampa Bay Water's use to forecast water supply availability during normal to low flow conditions when only the slide gates of the TBC would be in operation to maintain water levels at target elevations. Furthermore, the Tampa Dam is normally operated manually to try to maintain target pool elevations, which may vary seasonally. This model was set up primarily for flow simulations generally between 100 cfs and 1,000 cfs through the Tampa Dam; however, the model seems to accurately depict the system when inflow is up to 1,200 cfs at the Morris Bridge gauge. Because HEC-RAS has no options available to model slide gates, the Navigation Dam option was used at structures to maintain target elevations. Therefore, structure boundary conditions require setting target pool elevations for each simulation. Generally, these elevations do not vary to a great degree, but some seasonal targets exist for the Tampa Dam and at S-162.

HEC-RAS simulations were conducted using observed USGS data for the upstream inflow at the three main tributaries, observed S-161 diversions, observed City of Tampa withdrawals, plus the observed Tampa Bay Water withdrawals during the last year. Groundwater contributions and local runoff were estimated using local data and the procedures described previously. The simulations were conducted for the purpose of adjusting model parameters until the model results reasonably replicated observed responses of the system.

The hydrodynamic model operates as expected. Figure 5 illustrates daily observed stage vs. daily simulated stage for the Hillsborough River at the Tampa Dam for the same time period. The daily difference in modeled flow through the Tampa Dam when compared to the observed data was sometimes high; however, the model generally simulated flow trends with reasonable accuracy. Uncertainties associated with the daily operating protocol for the Tampa Dam affect the model predictions of flow through the dam. For example, observed flow differences in the range of several hundreds of cfs or stage elevation changes within 0.2 ft can alter simulated flow and stage results on any given day. When the modeled target elevation matched the observed data, the simulated and observed flows typically were within 100 cfs of each other. However, dam releases on a given day could vary by up to 300 to 400 cfs because of increased inflow from rainfall events. Since allowed diversions are only a fraction (10 to 30 percent) of the flow through the dam when the flow is greater than 100 cfs, variations of flow through the dam do not directly translate to similar results for withdrawals.

The large flow spike near the end of the example simulation shown in Figure 5 is a result of runoff. This spike did not occur in the observed data, although there was a small increase in flow. The rainfall estimate was based on one gauge in the Lower Basin, so it may have been an isolated storm. Simulations were conducted with and without the addition of runoff. The simulation results for daily flows were not much different in the flow range of interest when runoff was included, but runoff was retained in the HR/TBC model.

FORECASTING ACCURACY

The final models combine both the upstream tributary forecasts (ANNs) and the hydrodynamic model simulations (HEC-RAS). Each component was developed and tested independently. However, the operation of the complete HR/TBC model was verified with the individual components implemented simultaneously. To verify operation of the complete model, potentially available water withdrawals were determined by applying the WUP rules to stage and flow predictions from the complete HR/TBC model. These predicted withdrawals were then compared to withdrawals determined by applying the WUP rules to observed stage and flow data.

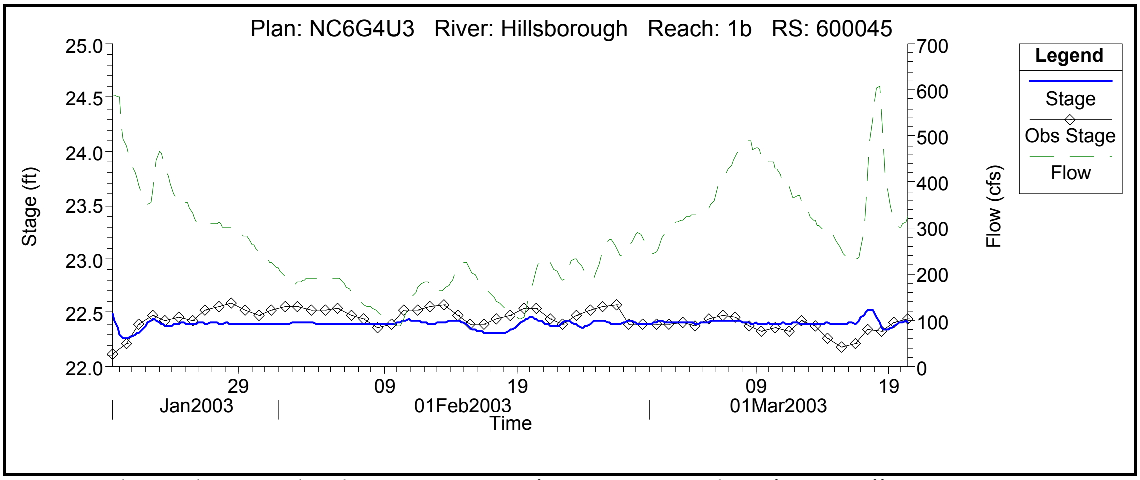

Figure 5. Observed vs. simulated stage upstream of Tampa Dam with surface runoff.

The prediction accuracy for the potential water diversions from the Hillsborough River was determined by computing the withdrawals using observed flow data, and then comparing similar predictions made using forecasted data. This process provided an estimate of the accuracy of the HR/TBC model's primary forecast components (i.e., the tributary flow generation models and the hydraulic routing model). Groundwater baseflow and local runoff was held constant for both scenarios because no data exists to confirm these values. Ultimately, the accuracy of the entire process will need to be monitored with actual use of the overall application.

Ten cases were selected to illustrate the accuracy of the model. Each case constitutes a seven-day period of time and a corresponding forecast, conducted on a Wednesday. These 10 cases were selected when flow through the Tampa Dam was in the range between 100 and 1,000 cfs (since this is of most interest when applying the model), and when sufficient data were available to compare the results. The dam is operated somewhat differently now (since about mid-2002) than it was during the historical period of record. The water level in the reservoir generally is kept at a more consistent and higher elevation than it was in the past. The historical observed flow rates through the dam perhaps varied more than they would now, increasing the variability in the simulations.

Considering all of the inputs to the combined model and given the operator's control of the water levels at the dam, the overall predictions were considered reasonable. Figure 6 summarizes the relationship between flow through the Tampa Dam predicted by forecasted flow and the observed flow. As the trend line indicates, flows were overestimated when the seven-day flow volume was less than approximately 4,000 cfs-d and underestimated when the seven-day flow volume was above this value. These results indicated that a good statistical fit existed between the two approaches (flow through the dam as predicted by observed inflow, and flow through the dam as predicted by forecasted inflow). The deviation present in some examples, however, illustrates that re-forecasting flows may be necessary when a large deviation occurs after only two or three days into the week.

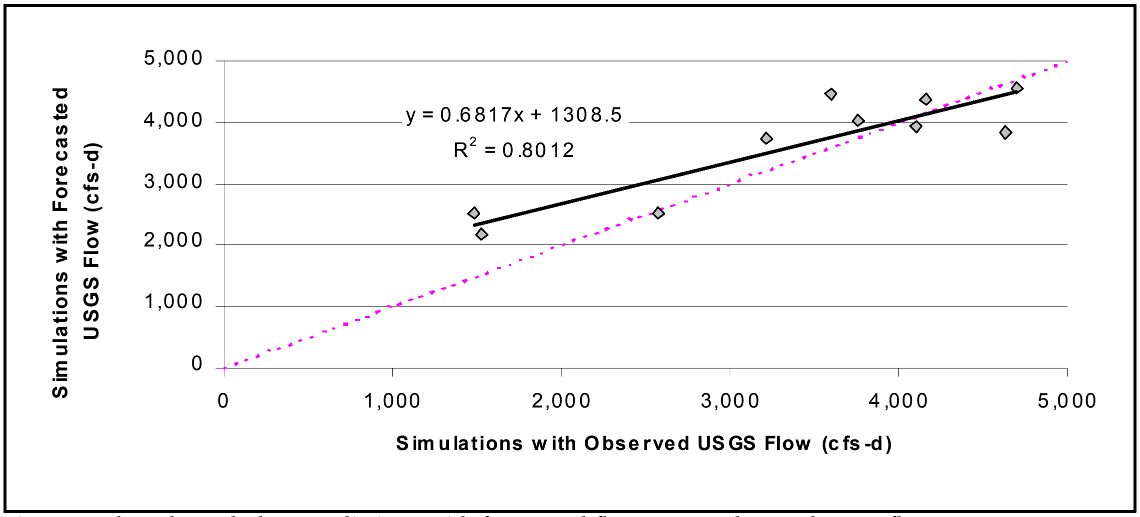

Figure 6. Flow through dam predictions with forecasted flow versus observed USGS flow.

While Figure 6 provides a comparison of flow through the dam, actual diversions for water supply are only a fraction of this flow. Furthermore, this fraction varies with the flow rate (between 0.10 and 0.30). The simulated flow through the dam must be used to estimate diversions through S-161 by applying the WUP rules. Figure 7 provides a comparison of the potential diversions at S-161 between the simulations conducted with the observed and forecasted flow rates. Except for one model run, the total volume that was diverted for each case was very similar. Therefore, this comparison indicates that the amount of water that was forecasted available for water supply was similar between the two scenarios (using observed inflow to the Lower Basin vs. forecasted inflow).

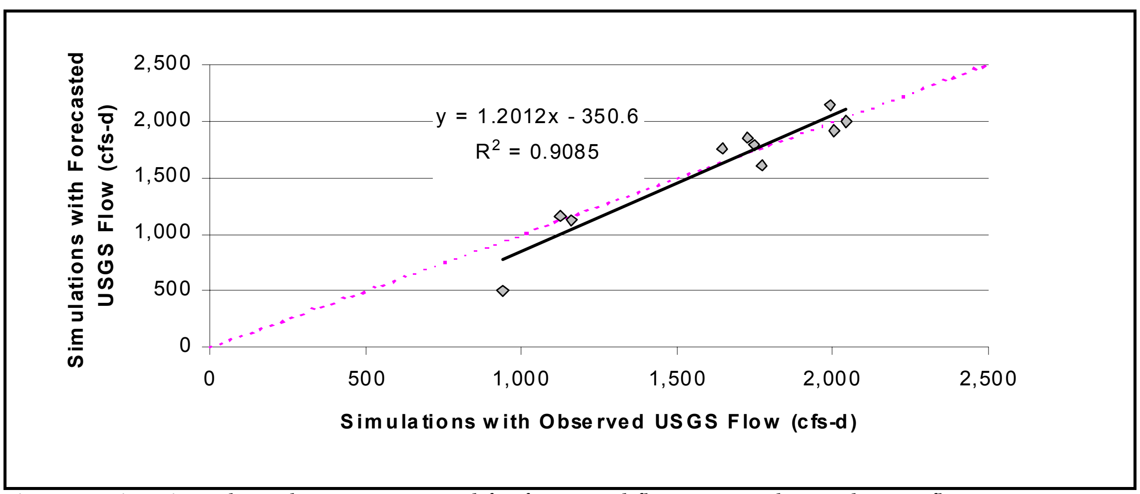

Figure 7. Diversions through S-161 computed for forecasted flow versus observed USGS flow.

A test of the validation of the TBC portion of the HR/TBC model was not conducted because of data limitations during the calibration period. Sparse data of sufficient quality were available since Tampa Bay Water only began monitoring flows through the flood control structures in September 2002. A review of these data indicated that spring flow dominated the overall flow in the TBC. Therefore, the prediction of the spring flow will mostly affect the accuracy of the projections. This issue needs further evaluation as additional flow data are collected and experience in operating the system is gained.

Overall, the HR/TBC model suite provides a good tool to assist in forecasting and managing surface water supply source from the HR/TBC. After additional experience with operating the model and improved knowledge of the system dynamics is gained, model parameters may be adjusted to improve the accuracy of model-predicted hydraulic responses (i.e., flows and stages). Maintaining a record of predictions as well as the actual observed flow will allow future diagnostic evaluations of the model's performance.

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