Climate Change Model Calibration Documentation

1.1 Background

Hydrologic modelling has been conducted on Mimico Creek subwatershed as part of the Mimico Creek Geomorphic System Master Plan (MCGSMP). That modelling effort adopted the HSP-F model (Bicknell *et al*, 2001) to simulate hydrology in the watershed catchments and streamflow in the runoff receiving reaches. That study took advantage of modelling conducted for the Toronto Wet Weather Flow Management Master Plan (TWWFMMP, 2003). The MCGCMP modelling expanded and updated the earlier modelling by including the entire annual periods (i.e., including the colder months) and through calibration and validation for more recent time periods (i.e., 2010 through 2016). The hydrologic modelling conducted as part of the NCGSMP follows the same procedures as the MCGSMP, adopting the same model, modelling periods, discretization scheme for land uses and climate change scenarios.

The NCGSMP and MCGSMP versions of the model adopt a unique urban landform modelling scheme. This scheme was developed for the TWWFMMP to facilitate stormwater management (SWM) system modelling and evaluation. By this scheme, all unique urban landforms, with and without best management practices (BMPs), were modelled as generic response units. Future instream conditions were estimated by swapping BMP areas for the status quo blocks. Several source, conveyance and end-of-pipe SWM systems were formulated and tested in this manner.

The Newtonbrook Creek hydrologic model, updated and calibrated for the NCGSMP, has been validated for use as a tool for runoff and streamflow simulation. The model has been applied to estimating the hydrologic impacts of changes in future climates on streamflow as part of the climate change assessment. The model has also been used to generate streamflow in the reaches on a long term continuous basis. The HSPF streamflow output serves as input to a hydraulic model, and the quantification of cumulative excess stream power, a measure of potential damage and risk.

For the NCGSMP, the HSP-F based model has been applied to simulate catchment runoff in continuous multiple year simulations. The model discretization scheme divides the 505 hectare study area into 8 catchments and two separate streams, Newtonbrook Creek and Blue Ridge Creek. Newtonbrook Creek catchments, in the northern portion of the study area, consist of 4 catchments (360.3 hectares) and 4 reaches, while Blue Ridge Creek, also modelled as four catchments and 4 reaches, covers the southern portion (144.7 hectares). The Blue Ridge Creek catchments lie south of Steeles Avenue and are totally within the City of Toronto. About 207 hectares draining to Newtonbrook Creek lie north of Steeles Avenue outside of the City of Toronto. Catchment boundaries are based upon sewershed coverage.

A Water Survey of Canada (WSC) gauge is located on the Don Rivers East Branch near Thornhill (02HC056). This gauge is the nearest gauged site to the study area and represents the best possible site for assessing model calibration and performance. The drainage area represented by this gauge is about 37.3 km^2. The model has been calibrated and validated to this location after prorating for ariel differences.

1.2 Model Setup

Model setup involved discretization of the watershed for soil texture, landscape slopes and land use. Land use was taken from **Figure 1** along with catchment areas. Soil texture and slopes are not likely to significantly change with time and were not amended from the 2003 model version. The study area was characterized as a low slope area (< 2%) and containing mostly medium and fine textured soils. The stream reach discretization scheme, was revised to provide more spatial detail as required by the present day geomorphic assessment.

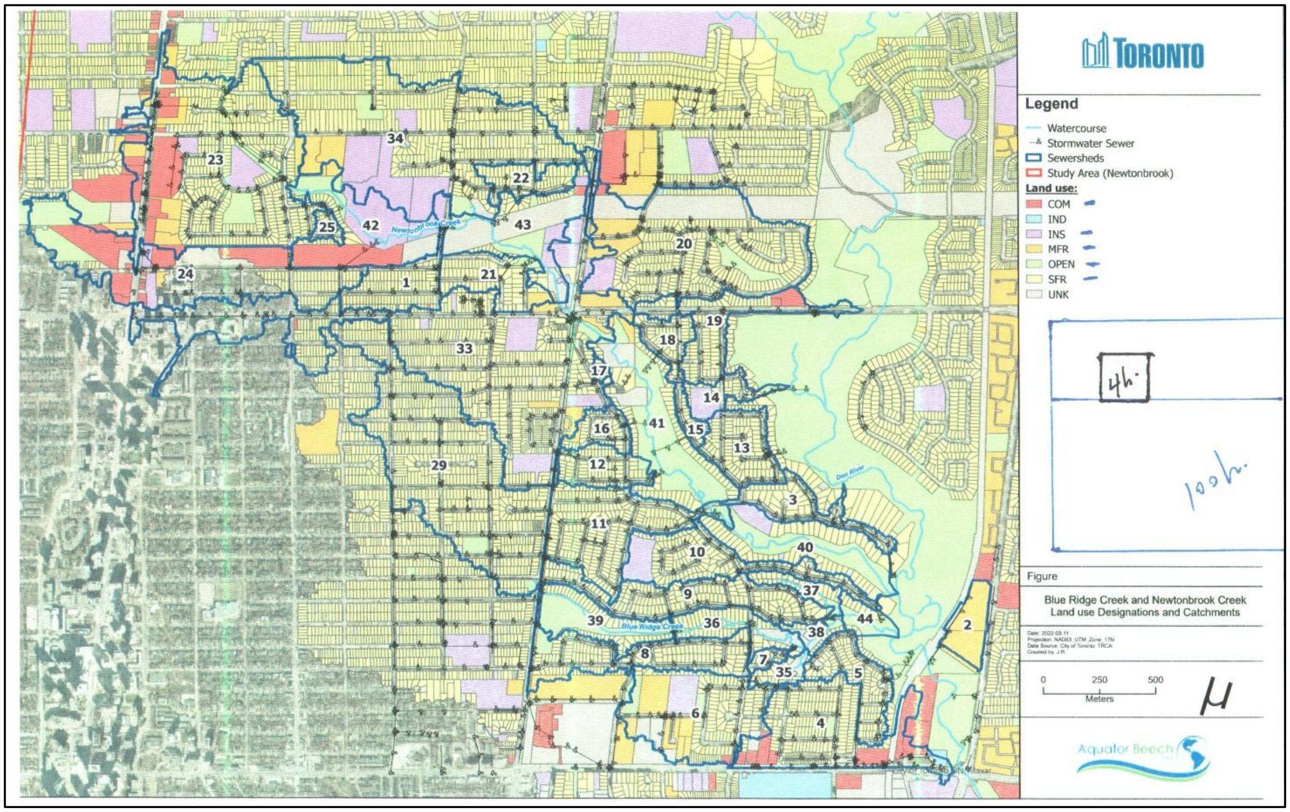

Figure 1: Land Use and Catchment Size for NCGSMP Study Area

Setup included preparation of meteorological time series data as model inputs. This included hourly inputs for observed air temperature, precipitation, solar radiation, wind speed, dewpoint temperature and potential evapotranspiration (PEVT). The Environment Canada meteorological stations at Pearson Airport (Stn #6158733) and Buttonville airport (Stn#6158731) are similar distances from the study area (about 10 to 15 kilometers).The Pearson Airport records are generally more complete in terms of the necessary meteorological parameters. This station was also used to represent Mimico Creek watershed for most parameters in the past. This includes air temperature, precipitation, wind speed and dewpoint temperature. A simple comparison of the suitability of the two sites indicated that for the modelling period (i.e., 2010 to 2016) the two stations were in relatively good agreement for precipitation with Buttonville values marginally higher than Pearson values. In calibration, it was necessary to factor the Pearson based precipitation numbers a bit higher to achieve the best calibration. This adjustment suggests that the annual trends in precipitation for the study area may lie between the totals for the two sites.

Solar radiation data (i.e., global horizontal irradiance) was sourced from the National Renewable Energy Laboratory (https://nsrdb.nrel.gov). That data is based upon large scale radiation modelling and a worldwide network of stationary and non-stationary (i.e., ships) observation sites.

PEVT has been estimated from solar radiation and air temperature with an algorithm based upon the work of Jensen and Haise (1963).

The period 2010 through 2016 has been adopted for model spinup, calibration and validation.

The 2003 model was applied to unfrozen open water conditions (i.e., April through October). For continuity, it was run for full years but not calibrated for winter nor was output summarized for the winter months. The NCGSMP model application includes the full yearly periods. While the winter periods are not supported with complete observational precipitation and streamflow data (i.e., data gaps exist) the continuity inherent in this method provides for a more thorough calibration and a complete view around seasonal and annual water balances. Also, the annual period is thought to be more valid for this assessment as future winter periods will be characterized by more open water and winter rainstorms.

In any hydrologic modelling exercise there will be discrepancies between simulated and observed streamflow for a variety of reasons including:

- inaccuracies and gaps in observational data (i.e., precipitation and streamflow), the model inputs;
- inaccuracies in the model formulation or model discretization scheme due to necessary simplifications; and
- imperfection in the multi-variant calibration process.

Many data gaps were found in the hourly observational precipitation data. If available, the daily rain and snow data was used to fill these gaps. **Figure 2** shows a comparison between monthly total precipitation from the hourly and daily databases after infilling of the hourly database. Precipitation measurement is commonly subject to missing periods of data, spatial disparities, instrument undercatch and site issues. Model calibration is compromised to some degree by this source of error/uncertainty.

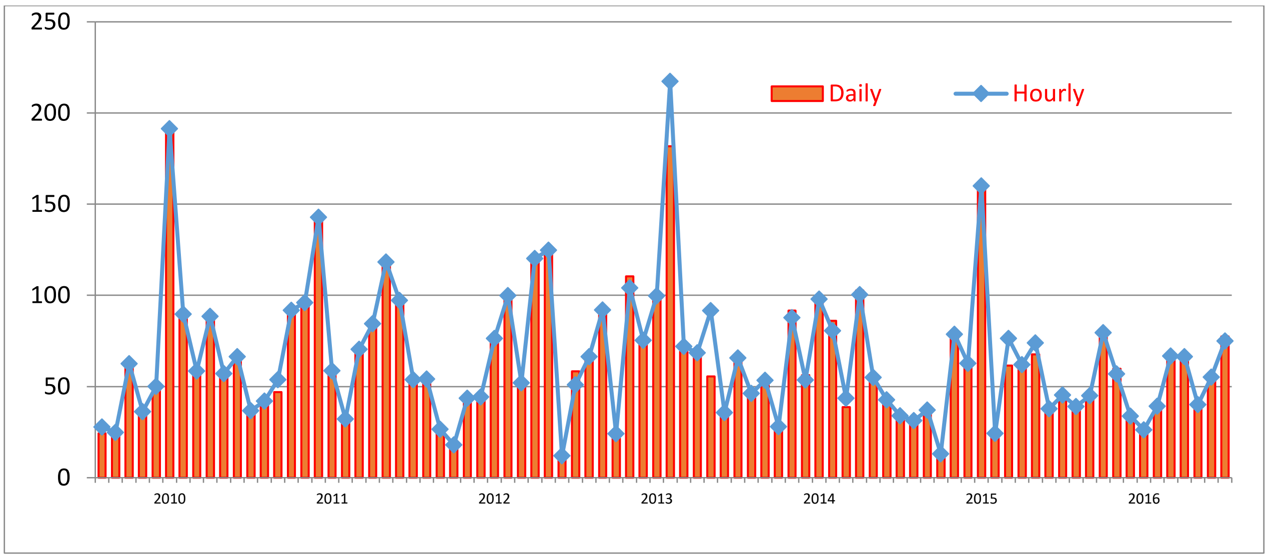

Figure 2: A comparison of monthly total precipitation at WSC #6158733 calculated from hourly and daily databases for 2010 to 2016.

1.3 Model Calibration

The TWWFMMP version of the hydrologic model was calibrated for the period 1994 to 1996 for the Don River. The model was run continuously, although there were gaps in winter period inputs and streamflow observations. As mentioned the winter period was not considered in the evaluation since winter was not expected to deliver major storms. Recent trends are apparent in that winter thunderstorms are now more common.

The calibration period for the updated model was 2011 to 2012 with 2010 used as a spinup year. Through the calibration/validation process adjustments were made to selected model parameters until good agreement was achieved between simulated and observed streamflow. Further adjustments were made to achieve good distribution of runoff across the seasons. Calibration of the snow accumulation and snowmelt portions of the model significantly affects spring runoff timing . Once good agreement in terms of runoff volumes was achieved attention was focused upon the flow distribution, the relative accuracy of the model to simulate baseflow and storm responses.

Figure 3 displays the total calibration period streamflow volume and the seasonal streamflow volumes simulated and observed at the gauged site. In this and following figures, the total streamflow for Newtonbrook and Blue

Ridge Creeks have been summed. Furthermore, the streamflow at the gauged site has been prorated downwards to account for the differences in drainage areas. The gauged site represents runoff from an area of 3730 hectares while the study area is about 505 hectares. Observed streamflow was reduced by a factor of 0.128 in order to compare these streamflow time series.

A high level of correspondence between simulated and observed total period streamflow was achieved by adjusting precipitation and PEVT, along with other critical parameters. Precipitation inputs were adjusted upwards by 5 % in calibration. Total seasonal values are in good agreement, displaying typical seasonal patterns.

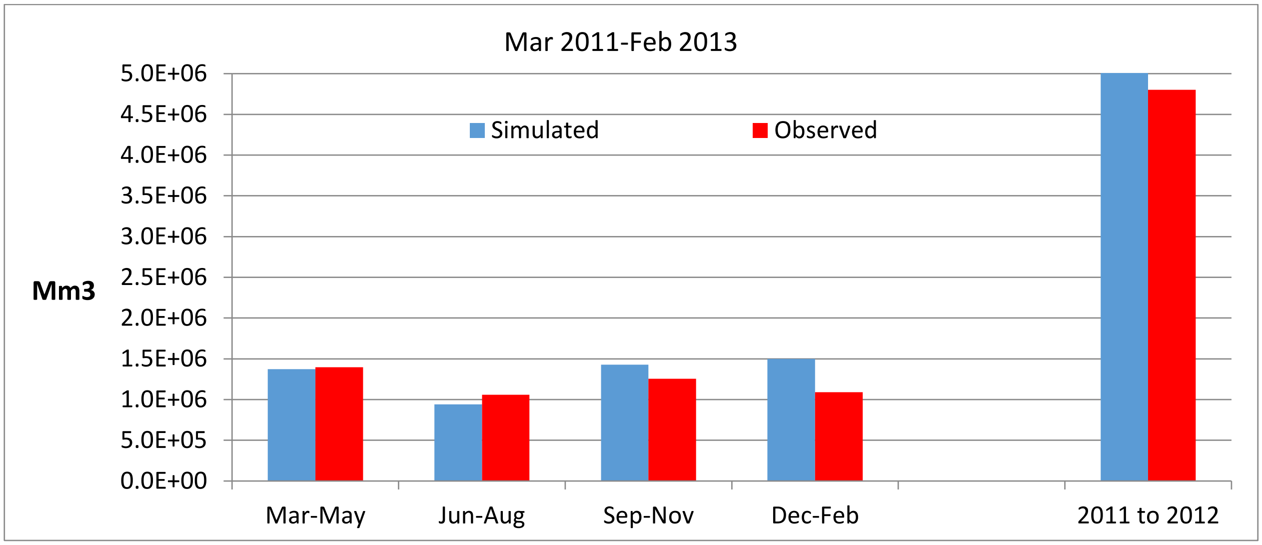

Figure 3: Total Simulated Seasonal and Annual Streamflow Volumes Compared with Adjusted Gauged Site Volumes, for the Calibration Period (2011 to 2012).

Figure 4 represents the frequency distribution of simulated and observed values for the calibration period. A logarithmic scale is used here to draw equal attention to low flow and high flow ranges. In this case agreement is relatively close with some discrepancies in the low and high flow ranges.

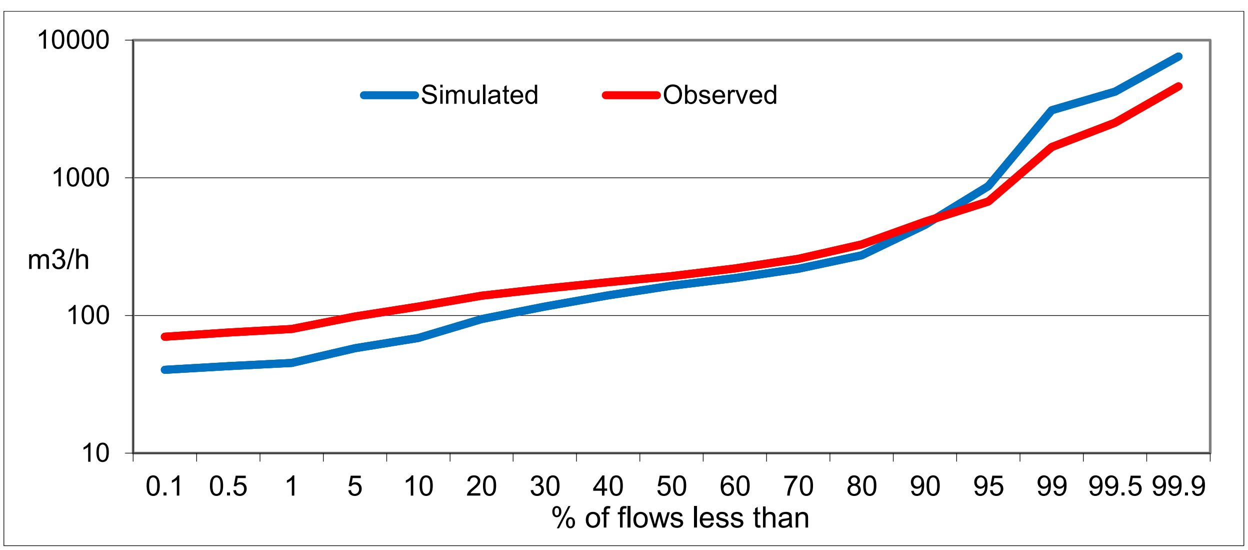

Figure 4: Simulated and Observed Flow Frequency Distributions, calibration period.

The result noted here displays a tendency for the study area streamflow distribution ("Simulated") to be somewhat peakier than the observed streamflow distribution at the gauged site. Simulated streamflows also tended to decrease to lower values for longer periods of time. This can be explained by the fact that the much smaller study area generates runoff made up of contributions from small urban headwater catchments. The majority of the catchments have residential, commercial and institutional land uses with roadways and green spaces along the creeks. Surface stormwater runoff is accelerated in such developments due to high levels of impervious surfaces (i.e., roofs, roads and parking areas) and urban stormwater infrastructure (i.e., curbs and sewers).

The streamflow observed at the gauged site is representative of a significantly larger area with more valley land green space and more variable land use types. In general the larger a drainage area is, so is the degree of flow attenuation, reducing peak flows and augmenting very low flow rates. The peakiness and tendency to very low flow for long periods, simulated for the study area, is felt to be realistic, when compared with the streamflow regime observed at the gauged site.

Figure 5 displays simulated and observed streamflow rates for a selected period in early 2013 as an example of the good agreement achieved through several runoff events. Note that a logarithmic scale is used to equally highlight low and high flow ranges in this comparison. The model is shown to respond to the onset of storms and to display agreement at the peaks and low flow periods of these storm events. Simulated peak streamflow values generally exceed the observed peak values for the reasons discussed above.

Also, the model may not agree in terms of peak flow rates in all events with some events apparently over predicted and others under predicted. Cumulatively, over seasons and years, the model should balance high and low flow events. This balance is confirmed in this study by the frequency distribution comparison of **Figure 3**.

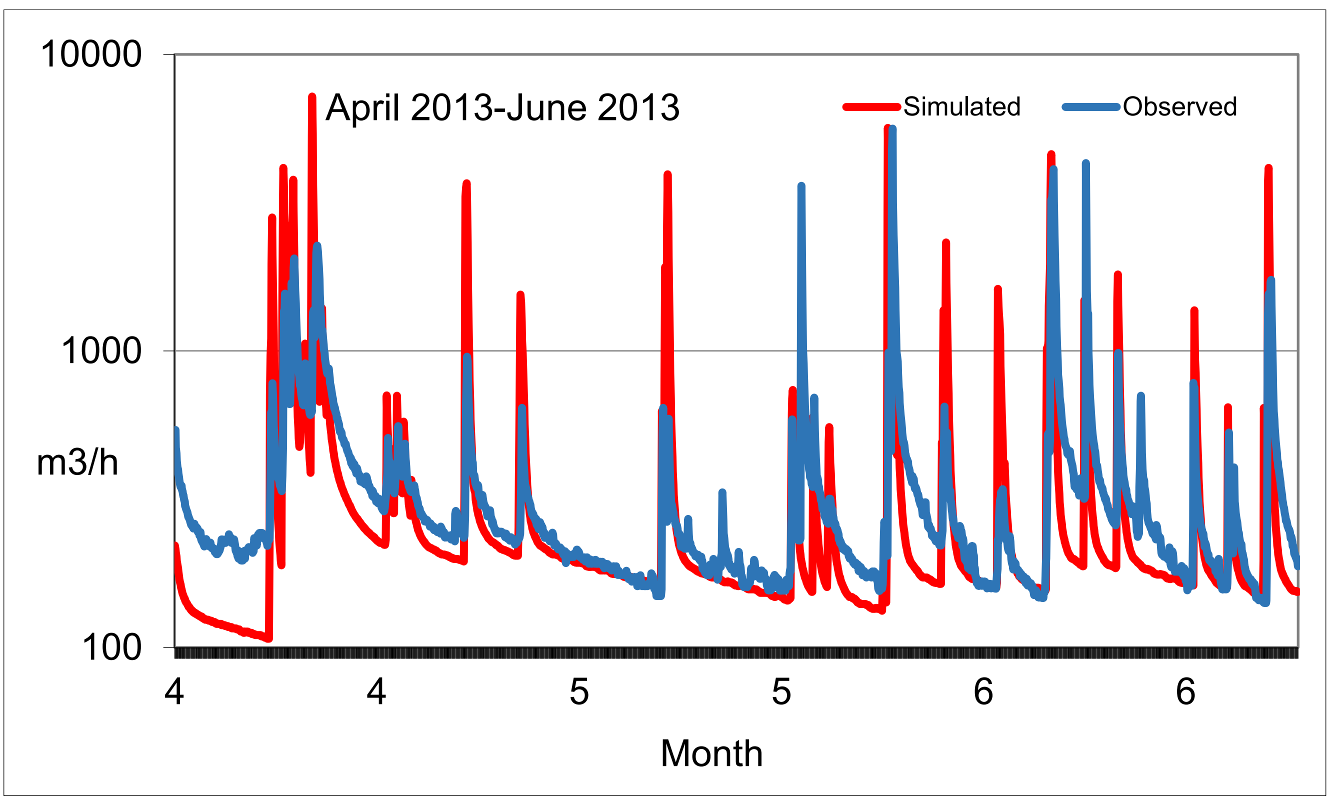

Figure 5: Simulated and Observed Study Area Streamflow, April to June 2013

1.4 Model Validation

The validation stage of the process is a test of the calibrated model under different conditions. Model validation and calibration are conducted in a feedback loop scheme with incremental fine tuning until satisfactory agreements are achieved. The TWWFMMP model was validated for the period 1991 to 1993. The updated model was validated through the period 2014 to February 2016. The streamflow record for the remainder of 2016 has many gaps and therefore was unsuitable for validation.

Figure 6 displays the total validation period simulated and observed streamflow volume for the study area. As mentioned, observed values were prorated for drainage area. Seasonal total are also shown. Total period flow volumes are in very close agreement. Spring total flows appear to be under predicted while summer flows are slightly above those reported. Overall, the validation period total flow is in good agreement as in the calibration phase.

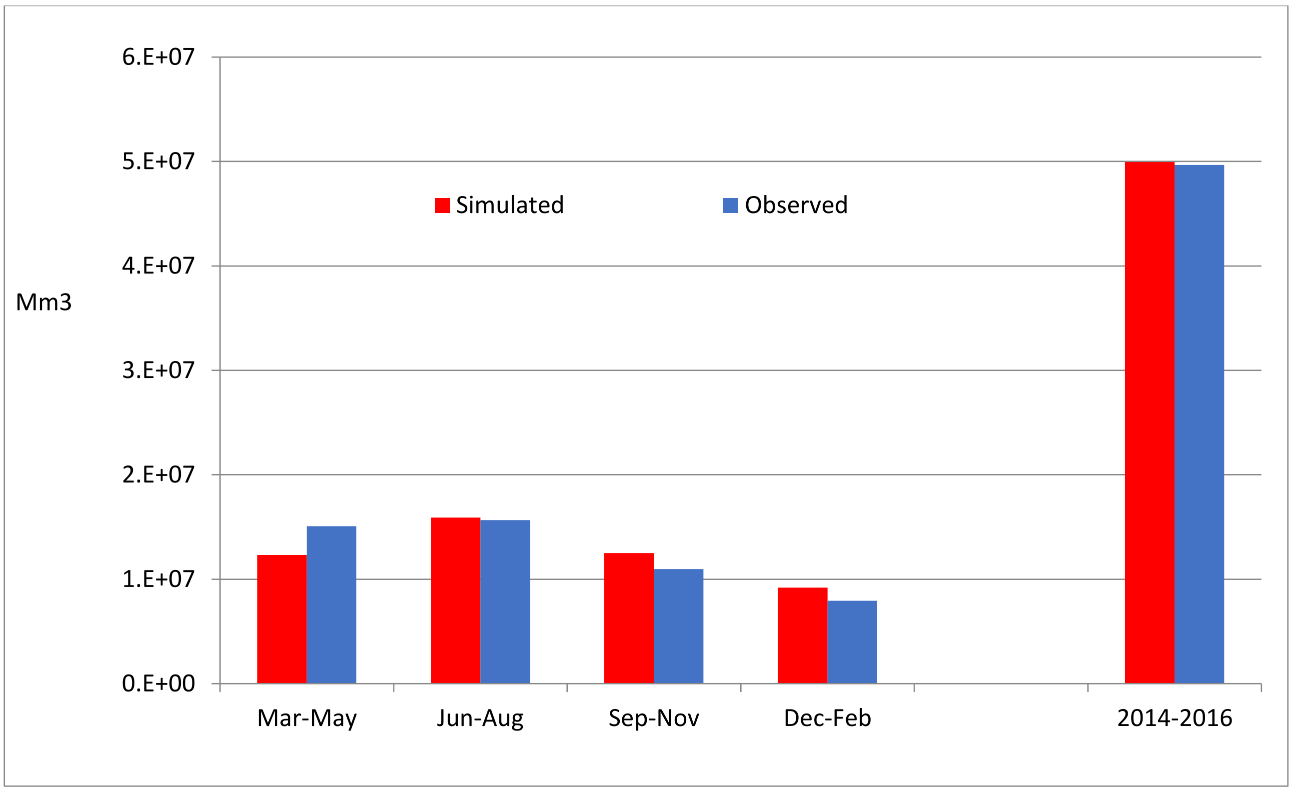

Figure 6: Seasonal and annual total streamflow volumes compared at the gauged site, validation period (2014 to February 2016).

Figure 7 displays the streamflow frequency distribution for the validation period. As reported earlier for the calibration period, the observed streamflow pattern is reflects the characteristics of a larger catchment area with more attenuation. The model has been setup to generate runoff typical of a small highly urbanized group of catchments.

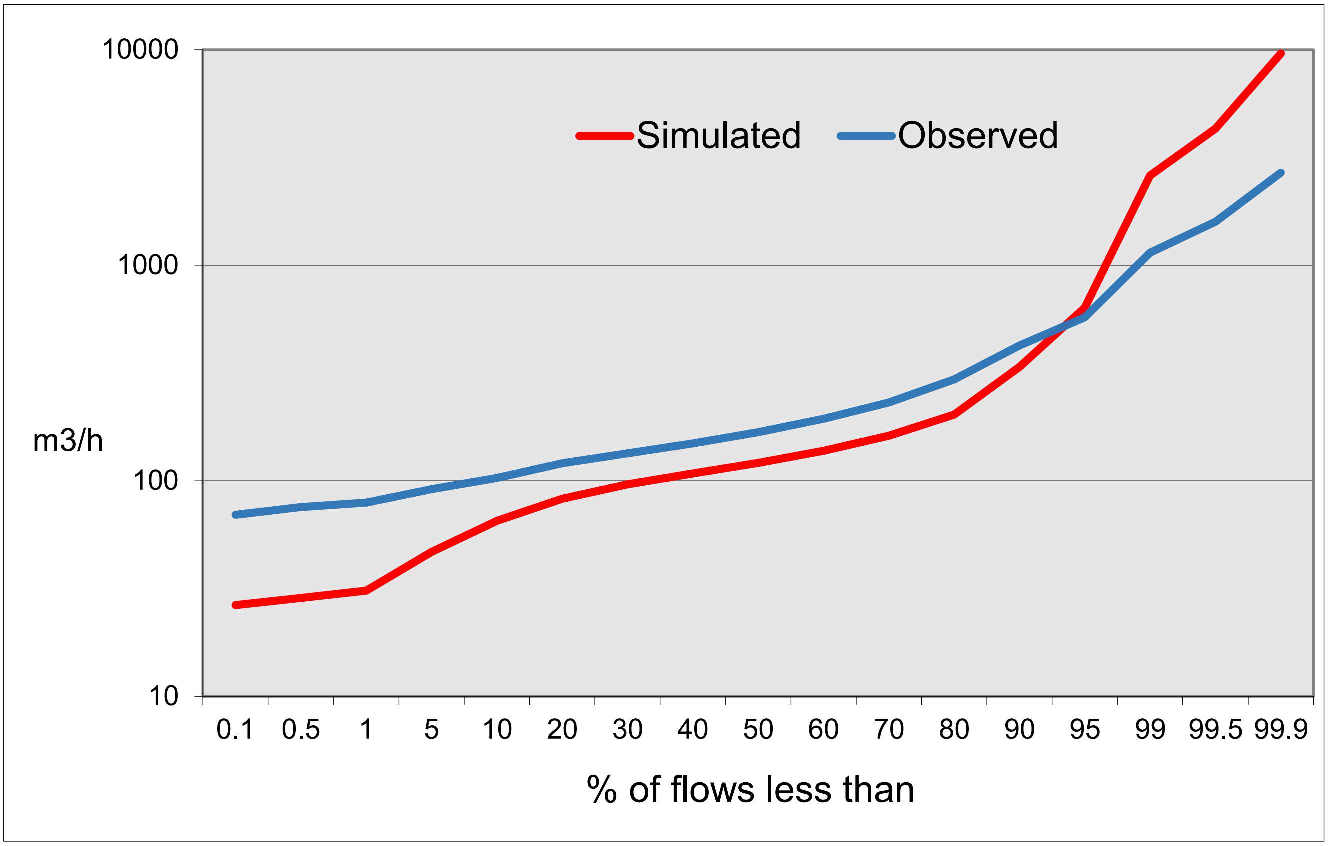

Figure 7: Simulated and Observed Flow Frequency Distributions, validation period.

Figure 8 is a selected validation time series containing several storms. This period was chosen to demonstrate the models capability to accurately respond to storm inputs in terms of timing and volume of runoff over several months. Generally simulated peak flow rates exceed those reported.

As in calibration, the model's apparent accuracy during the validation stage is of sufficient quality that the model can be applied to simulations of future climates and hydrologic response to these changes.

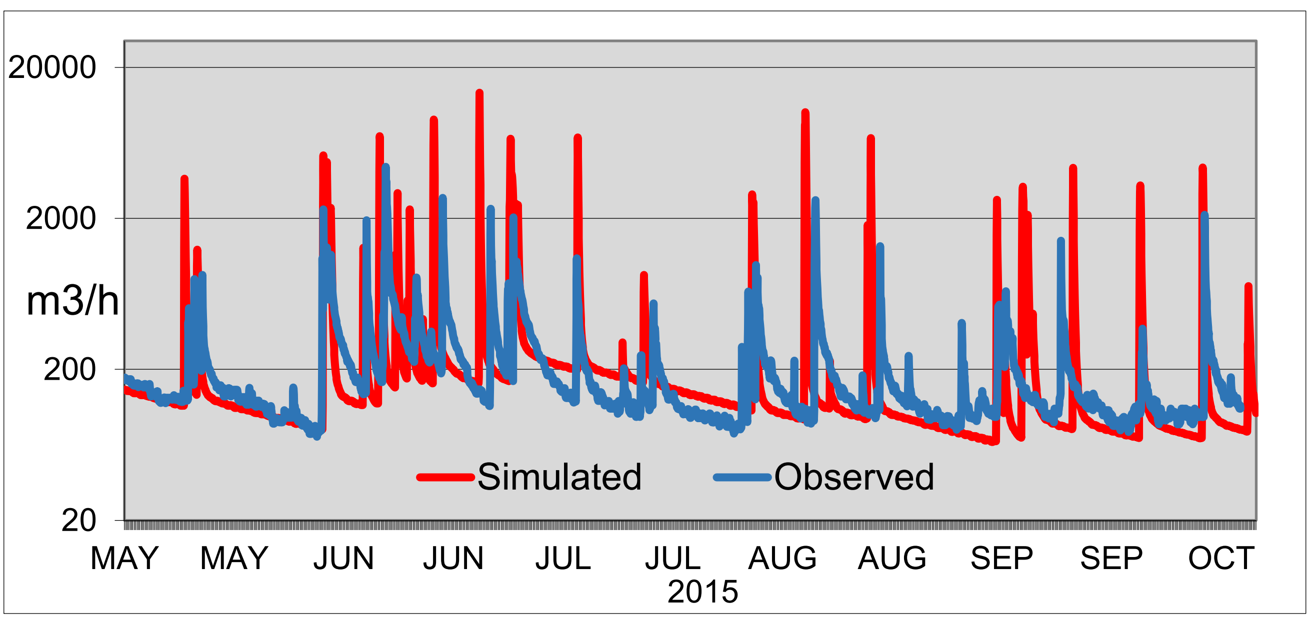

Figure 8: Simulated and Observed Streamflow at the mouth of Mimico Creek, June 2015.

1.5 Summary Comments

The hydrologic model discussed here has been setup with accurate spatial information. Land use types, soil texture and general topography in the study area are well established. The creeks physical characteristics are also well known and are reflected in the hydraulic representations in the model. The models weaknesses lie in the lack of detailed and nearby meteorological and hydrological information that would enable a very accurate level of calibration. Precipitation and streamflow are highly variable, both spatially and temporally.

The compromise introduced by the lack of site specific time series information is that the model cannot accurately represent any particular storm event with high resolution. However, it is a reasonable assumption that meteorological time series data collected at a more distant site, within kilometers or tens of kilometers, can represent a study site over longer periods of time (i.e., months and seasons), through many storms when compared in cumulative terms. While weather varies spatially and temporally for two sites, kilometers apart; they generally share the same climate.

The calibration discussed here could not achieve a high degree of fine-tuning, but does incorporate the climate characteristics necessary for site specific assessment. Therefore this calibrated model does reflect the characteristics necessary for climate and related risk assessment. As such, the model is applicable as a tool for assessing impact and risk associated with long term cumulative processes (i.e., erosion) and rare events (i.e., storms).