Willowmoor Floodplain Restoration Project
Hydrologic Modeling
Technical Memorandum

January 2019

King County
A service provider to the
King County Flood Control District.
FUNDING:
Funding for this project has also been provided by:

[Logos of Salmon Recovery Funding Board, EPA, and City of Redmond]
# TABLE OF CONTENTS

1.0 INTRODUCTION .................................................................................................................. 1

2.0 HYDROLOGIC MODEL REFINEMENTS ............................................................................... 1
  2.1 Subbasin Modifications ........................................................................................................ 3
  2.2 Land Surface Representation .............................................................................................. 3
  2.3 Meteorological Inputs ......................................................................................................... 4

3.0 MODEL CALIBRATION ....................................................................................................... 7
  3.1 Bear Creek .......................................................................................................................... 9
  3.2 Issaquah Creek .................................................................................................................. 12
  3.3 Calibration Summary ......................................................................................................... 14

4.0 BASINWIDE MODEL APPLICATION ................................................................................. 15
  4.1 Lake Inflow Validation ....................................................................................................... 15
  4.2 Future Conditions Hydrology ........................................................................................... 16

5.0 REFERENCES .................................................................................................................... 17
LIST OF TABLES

Table 1. Willowmoor project hydrologic model areas .................................................................1
Table 2 Flow calibration targets ..................................................................................................7
Table 3 Simulated vs. observed mean monthly flows for Bear Creek (KC 02a, WY 2012-2017) ........ 10
Table 4 Large event comparison for Bear Creek ........................................................................ 11
Table 5 Simulated vs. observed mean monthly flows for Issaquah Creek (USGS 12121600, WY 2012-2017) ...... 12
Table 6 Large event comparison for Issaquah Creek HSPF simulation ...................................... 13
Table 7 Existing vs. Future Flow Frequency .............................................................................. 17

LIST OF FIGURES

Figure 1 Subbasin map indicating areas represented by the suite of Willowmoor HSPF models ..................2
Figure 2 Precipitation gage locations and zones used to distribute precipitation datasets within HSPF ........ 6
Figure 3 Streamflow gages used in HSPF calibration. ...............................................................8
Figure 4 Simulated versus observed total Lake Sammamish inflow (WY 2013-2017) ..................... 16
Figure 5 Flow frequency comparison for existing and future climate scenarios ............................17
1.0 INTRODUCTION

King County's Willowmoor Floodplain Restoration Project (project) is a multi-objective flood control and habitat restoration project for the Sammamish River Transition Zone (TZ) and left bank floodplain area. The TZ extends from the Lake Sammamish outlet weir approximately 1,400 feet downstream through Marymoor Park. Hydrologic modeling is being used in this project to provide continuous flow information spanning a range of seasonal and historical conditions over which the project will be evaluated. Flow timeseries produced by the hydrologic models provide input to hydraulic models that will be used to design project features (such as the split channel) and evaluate effectiveness in meeting the various habitat and flood control objectives.

Previous hydrologic studies for this project:

- Characterized the existing hydrologic setting for the project and provided recommendations for developing design hydrologic conditions for performance assessment of various project alternatives (King County, 2013) and
- Documented modifications to the existing hydrologic models and the development of future conditions scenarios (NHC, 2015).

The earlier phases of the project indicated a preference to update land use conditions represented in the hydrologic models (circa late 1990s) as well as potential for further improvement to model calibration. This memorandum documents updates and recalibration of the hydrologic models conducted as part of the preliminary design. The enhanced models were then used to develop existing and future climate flow inputs to Lake Sammamish and the Sammamish River.

2.0 HYDROLOGIC MODEL REFINEMENTS

The modeling area for this project includes the entire Lake Sammamish watershed and local drainage to the Sammamish River to NE 124th Street. Based on previous modeling efforts, this area is broken down into the six major subbasins listed in Table 1 and shown in Figure 1, each covered by a separate HSPF model.

Table 1. Willowmoor project hydrologic model areas

<table>
<thead>
<tr>
<th>Subbasin/Model Area</th>
<th>Drainage Area (square miles)</th>
<th>Receiving Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Issaquah Creek¹</td>
<td>61.5</td>
<td>Lake Sammamish</td>
</tr>
<tr>
<td>West Lake Sammamish Tribs</td>
<td>12.2</td>
<td>Lake Sammamish</td>
</tr>
<tr>
<td>East Lake Sammamish Tribs</td>
<td>15.7</td>
<td>Lake Sammamish</td>
</tr>
<tr>
<td>Evans Creek</td>
<td>15.5</td>
<td>Bear Creek</td>
</tr>
<tr>
<td>Bear Creek</td>
<td>33.9¹</td>
<td>Sammamish River</td>
</tr>
<tr>
<td>Sammamish River (Local)³</td>
<td>13.8</td>
<td>Sammamish River</td>
</tr>
</tbody>
</table>

¹ Includes Tibbetts Creek; ² Not including Evans Creek; ³ Includes Tosh Creek
Figure 1 Subbasin map indicating areas represented by the suite of Willowmoor HSPF models
As part of this work, portions of the Bear Creek and Sammamish River (Local) models were modified to incorporate more recent basin-specific modeling. Land cover distribution was redefined throughout the model area based on the 2011 National Land Cover Database (NLCD) (Homer et al., 2015), replacing land cover representing the mid to late 1990s used in previous modeling.

2.1 Subbasin Modifications

Except as described in this section, drainage area delineations and routing were carried over from previous modeling. Subbasin boundaries and flow routing for Bear Creek and Tosh Creek (a local tributary to the Sammamish River) were modified to incorporate more recent basin-specific modeling.

King County recently completed a watershed-scale model and stormwater plan for Bear Creek upstream of the Evans Creek confluence (King County, 2018a). This model (referred to herein as the 2018 model) included more detailed definition of basin boundaries and more comprehensive representation of storage and routing, including small streams and stormwater facilities. These refinements were incorporated into the Bear Creek model used for Willowmoor modeling. Where boundary conflicts occurred with the previous model subbasins, the 2018 model boundaries were used, which also required minor adjustments to subbasin boundaries in the Evans Creek and Sammamish River models and the portion of Bear Creek downstream of the Evans Creek confluence. Model representation of the portion of the Bear Creek subbasin from Evans Creek to the mouth was carried over from the previous Willowmoor modeling, with the 2011 land cover update.

Tosh Creek enters the Sammamish River from the west, upstream of the weir, and is anticipated to contribute directly to the side channel proposed as part of the project. The City of Redmond completed a basin study and stream restoration project on Tosh Creek in 2013, which included development of a detailed HSPF model (NHC, 2013) that was calibrated in subsequent work for Redmond in 2017. The Tosh Creek model used land cover delineated from high resolution 2011 aerial photos and includes local stormwater detention facilities. Due to the importance of Tosh Creek as a flow source for the proposed side channel, use of the higher resolution basin-specific model was preferred to the coarsely defined catchment within the Sammamish River (Local) subbasin model, despite some inconsistency with the overall basin modeling approach. Results from the Tosh Creek portion of the Sammamish River (Local) HSPF model were not used, and the basin-specific model was used to independently compute Tosh Creek flows.

2.2 Land Surface Representation

HSPF uses distinct types of hydrologic response units (HRUs) to represent runoff generation from different types of land surfaces. Each HRU represents a unique combination of land cover, soil/geology type, and slope categories that produce different runoff responses. A GIS overlay process was used to process the individual land surface datasets to compute areas of each HRU by model catchment for input to HSPF.

Reliable land cover data are important, especially in urban areas, as hydrograph volume and timing is highly sensitive to the amount of contributing impervious area; even vegetated (pervious) surfaces in developed areas produce significantly more runoff than the native forest condition. Previous modeling used land cover estimated from late 1990s satellite or aerial photo-based data. Since portions of the basin have experienced significant development since that time, one of the recommendations from the earlier work was to update the models to...
reflect more current land use conditions. Land cover distribution was updated with the 2011 National Land Cover Database (NLCD), which classifies approximately 98-foot square grid cells into one of 15 categories. The 15 NLCD categories were mapped to similar land use types used in the HSPF modeling. As in the County’s Bear Creek study (King County, 2018a), roads were imposed on to the NLCD data set based on the street network in King County’s GIS. Due to the coarser resolution of the NLCD grid, most roads are not captured in the NLCD mapping. Since road surfaces account for a large portion of impervious area, particularly in suburban and urban fringe areas characteristic of much of the basin, it is important to capture them in the model. Developed land cover types were split into pervious and (effective) impervious HRUs based on distributions used in the Bear Creek study (King County, 2018a). During calibration, further adjustments were made to the initial effective impervious distributions to better replicate observed flow hydrographs.

Surface geology definitions were based on a GIS shapefile dataset provided by King County (Burkey, personal communication). The geology dataset categorizes the basin soils and geology into three broad types that are linked to distinct runoff response characteristics: till, outwash, and bedrock. Till and outwash constitute the majority of the basin and are found in each of the subbasins, while bedrock is only mapped in the Issaquah Alps, within the Issaquah Creek subbasin. Small water bodies and defined wetland areas were assigned a saturated soil type, overriding the underlying geology classification.

Average slopes were computed from a LiDAR digital elevation model (DEM) (PSLC, 2011) with 30-foot square grid cells. HRU slope categories were then defined as: flat (<5 percent), low (5 – 10 percent), medium (10 – 15 percent), or steep (>15 percent).

2.3 Meteorological Inputs

The suite of HSPF models uses precipitation data from 16 King County rain gages to represent variability in precipitation across the larger watershed. As discussed in the Willowmoor Phase 2 modeling report (NHC, 2015), local data are used for the available period of record (typically starting in the late 1980s to early 2000s), and the records are extended back in time for longer duration runs based on rainfall patterns recorded at the long-term National Weather Service gage at SeaTac airport. Scaling factors are applied to translate the long-term data to individual gage locations to represent differences in annual precipitation volumes.

Point sensors such as rain gages do not capture variability over a larger area, so incorporating data from multiple gages distributed across each subbasin better represents the differences in rainfall due to variable storm tracks and variations in intensity over a storm, which improves the model’s ability to reproduce observed flow records. Consequently, as part of the Phase 2 model updates (NHC, 2015), multiple precipitation zones were defined in each model subbasin, with each zone using a unique combination of rain gage location and scaling factor. Scaling factors based on differences in mean annual precipitation between the gage location and the zone area were calibrated as part of the 2015 modeling and carried over for the current study. The rain gage locations and precipitation zones are shown in Figure 2.

Hourly precipitation records from all of the input rain gages were extended through water year 2017 using published precipitation data from King County. Two currently inactive rain gages—Blakely Ridge (02v) and Redmond UPD (18v)—were used in the original modeling and were extended in the present work with data from the Trilogy North (02vn) and Redmond Ridge (18v2) gages, respectively. The published data used to extend the
records contained some gaps that were filled with available data from nearby gages. Zero precipitation was assumed for several one-hour gaps in individual records that occurred between rain events. Longer gaps in the Hollywood Hill (51w) and Sammamish Plateau (SAMP) gages were filled from nearby gages with typically similar meteorological patterns.

The modeling used an evaporation data time series developed by King County and most recently updated for the 2018 Bear Creek modeling (King County, personal communication with J. Burkey, May 2018). The County dataset was extended through water year 2017 using daily potential evapotranspiration (ET) estimates from AgWeatherNet for WSU Puyallup (converted to pan evaporation for consistency with the earlier record). This approach is consistent with King County’s methodology for recent data updates.
Figure 2 Precipitation gage locations and zones used to distribute precipitation datasets within HSPF. Zones are labeled with an alphabetic character associated with the model subbasin (e.g. "I" for Issaquah Creek) and a zone number within that subbasin.
3.0 MODEL CALIBRATION

The HSPF models for Bear Creek and Issaquah Creek were calibrated to observed streamflow records near the mouth of each stream, Bear Creek at Union Hill Road (King County 02a) and Issaquah Creek near mouth (USGS 12121600), respectively. In addition to these two long-term gages, flow records at other points in the basin were used to inform parameter adjustments and validate the calibrated parameter set. Figure 3 shows a map of the flow gages used in the calibration process.

Calibration targets, shown in Table 2, were established in coordination with the project team based on past modeling experience (e.g. NHC, 2017; NHC and AquaTerra, 2013) and accuracy needs for this project. Targets were established over multiple time scales to assess model performance in representing both long-term (monthly and annual) volumes and individual storm peaks and volumes. Targets for simulation of individual events are much broader than for annual and seasonal volumes because individual events are more difficult to capture. Response to individual storms is significantly affected by spatial variability in precipitation, which also changes between events. Since the long-term models apply fixed distributions of precipitation from various gages, event to event changes are not fully captured. Although the same calibration targets were used throughout, in the context of the project, event peaks are more critical for Bear Creek while event volumes are more important for Issaquah Creek.

Table 2 Flow calibration targets

<table>
<thead>
<tr>
<th>Metric</th>
<th>Targeted Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual Mean Flow</td>
<td>Within ± 5% (average)</td>
</tr>
<tr>
<td>Monthly Mean Flows</td>
<td>Within ± 15% (average)</td>
</tr>
<tr>
<td>Event Peaks</td>
<td>Within ± 30% (individual events)</td>
</tr>
<tr>
<td>Event Volumes</td>
<td>Within ± 25% (individual events)</td>
</tr>
</tbody>
</table>
Figure 3  Streamflow gages used in HSPF calibration. Model performance targets applied to “calibration” gages on Bear and Issaquah creeks. “Supplemental” gages were used as checks on model parameter sets in areas that were not directly calibrated.
Potential calibration events were selected by identifying the largest discharge events at the calibration gages from water year 2005 through water year 2017. This range of years was large enough to encompass a range of high flow events but bounded by the assumption that the model most appropriately represents the 2011 development conditions. Six calibration events were identified for Bear Creek and eight for Issaquah Creek. The January 2009 event was excluded due to a rare extended period of lowland snow preceding the early January storm, such that precipitation inputs were not directly reflective of the available runoff.

As discussed in the previous section, a largely consistent set of HRUs was desired for all six of the subbasins contributing to the project area. Within areas with similar climate and geology, each HRU type would be expected to produce a consistent runoff response. Thus, the calibration focused on developing runoff parameter sets for each HRU that could be applied globally to all of the models. It is possible that better results could be achieved at individual gages with unique modifications applied to each subbasin, but without physical explanation for those differences, it becomes difficult to extrapolate the calibration to other subbasins and climate scenarios.

### 3.1 Bear Creek

Bear Creek calibration began with the smaller Evans Creek basin, using the Evans Creek at Union Hill Road (18a) stream gage near the Bear Creek confluence as an intermediate calibration point. The calibrated Evans Creek parameter set was then transferred to the other Bear Creek models, and final adjustments were made iteratively to the group of models to calibrate total Bear Creek flow at stream gage 02a.

Initial model results showed consistent overestimation of annual volume, mainly in spring and summer flows, and underestimation of winter event recessions. The evapotranspiration (ET) multiplier and groundwater distribution were adjusted to improve overall volume and seasonal distribution. Changes to interflow—the slower, shallow subsurface storm runoff component—parameters improved the hydrograph shape and storm runoff distribution to better match observed flows.

While most of the parameters were consistent across all of the models, differences in groundwater routing parameters were needed to achieve a good calibration at both the Evans Creek (18a) and Bear Creek (02a) gages. The ratio of groundwater routed to deep aquifers (DEEPFR in HSPF) and the parameter controlling seasonal variation in groundwater recession (KVARY) were allowed to vary between individual models to improve overall results.

Mean monthly flows produced by the calibrated models at 02a are compared to observed values in Table 3. Table 4 summarizes event calibration results, showing event hydrographs and comparisons of simulated to observed peak flows and event volumes. In all comparison graphics in this report, observed data are represented in red and simulated in blue.

---

1 Due to the rarity of extended periods of snow in the basin and the large uncertainty associated with additional meteorological inputs required to model snow response in HSPF, snow simulation was not part of this modeling effort. This is a standard assumption for hydrologic modeling in the Puget Sound lowlands.
As shown in Table 4, all six of the calibration events are within the targeted 25 percent accuracy for event volume (and five of the six are within 5 percent). Two of the events (December 2010 and February 2017) exceed the targeted peak calibration accuracy (within 30 percent), which is discussed below. On average, the Bear Creek peaks are 16 percent high and volumes are just slightly above observed (within one percent). Given variability in individual storm events, calibration results are judged to be acceptable.

The event hydrographs in Table 4 show a tendency to simulate a spikier, early peak in large events. This could suggest either too much impervious area in the models or lack of storage in the routing network that would have a tendency to attenuate and disperse these peaks. Given that event and overall volumes are well-simulated and small to moderate event response matches up well with observed, storage and routing seem likely to be a significant factor. Detailed routing representation to more fully account for basin storage (wetlands, detention facilities, floodplain storage, etc.) would require substantial effort beyond the scope of this project. Since calibration targets were met overall and slight over-simulation of Bear Creek peaks is conservative from the standpoint of the Willowmoor project, further refinements to address this issue may be considered during the preliminary design phase.

Table 3  Simulated vs. observed mean monthly flows for Bear Creek (KC 02a, WY 2012-2017)

<table>
<thead>
<tr>
<th>Period</th>
<th>Mean Flow (cfs)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>02a</td>
<td>HSPF</td>
<td>% Diff</td>
</tr>
<tr>
<td>October</td>
<td>51.4</td>
<td>48.8</td>
<td>-5%</td>
</tr>
<tr>
<td>November</td>
<td>113</td>
<td>122</td>
<td>+8%</td>
</tr>
<tr>
<td>December</td>
<td>136</td>
<td>144</td>
<td>+6%</td>
</tr>
<tr>
<td>January</td>
<td>124</td>
<td>134</td>
<td>+8%</td>
</tr>
<tr>
<td>February</td>
<td>150</td>
<td>160</td>
<td>+6%</td>
</tr>
<tr>
<td>March</td>
<td>150</td>
<td>163</td>
<td>+8%</td>
</tr>
<tr>
<td>April</td>
<td>95</td>
<td>93</td>
<td>-2%</td>
</tr>
<tr>
<td>May</td>
<td>58.3</td>
<td>56.3</td>
<td>-3%</td>
</tr>
<tr>
<td>June</td>
<td>35.4</td>
<td>32.1</td>
<td>-9%</td>
</tr>
<tr>
<td>July</td>
<td>23.7</td>
<td>22.4</td>
<td>-6%</td>
</tr>
<tr>
<td>August</td>
<td>20.3</td>
<td>19.6</td>
<td>-3%</td>
</tr>
<tr>
<td>September</td>
<td>25.2</td>
<td>23.3</td>
<td>-7%</td>
</tr>
<tr>
<td>Annual</td>
<td>81.6</td>
<td>84.4</td>
<td>+4%</td>
</tr>
</tbody>
</table>

Simulated flows corresponding to gaps in observed record not included in calculations.
Table 4 Large event comparison for Bear Creek

<table>
<thead>
<tr>
<th>Event Dates</th>
<th>Event Hydrograph Comparison</th>
<th>Peak Hourly Flow (cfs)</th>
<th>Event Volume (ac-ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9-12 Jan 2006</td>
<td><img src="image1" alt="Graph" /></td>
<td>Observed: 582</td>
<td>Observed: 660</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Simulated: 515</td>
<td>Simulated: 580</td>
</tr>
<tr>
<td></td>
<td></td>
<td>% Difference: -12</td>
<td>% Difference: -11</td>
</tr>
<tr>
<td>29 Jan-2 Feb 2006</td>
<td><img src="image2" alt="Graph" /></td>
<td>Observed: 777</td>
<td>Observed: 970</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Simulated: 918</td>
<td>Simulated: 1,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>% Difference: +18</td>
<td>% Difference: +4.0</td>
</tr>
<tr>
<td>2-7 Dec 2007</td>
<td><img src="image3" alt="Graph" /></td>
<td>Observed: 1,051</td>
<td>Observed: 1,200</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Simulated: 956</td>
<td>Simulated: 1,190</td>
</tr>
<tr>
<td></td>
<td></td>
<td>% Difference: -9.1</td>
<td>% Difference: -0.6</td>
</tr>
<tr>
<td>11-15 Dec 2010</td>
<td><img src="image4" alt="Graph" /></td>
<td>Observed: 1,065</td>
<td>Observed: 1,270</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Simulated: 1,476</td>
<td>Simulated: 1,270</td>
</tr>
<tr>
<td></td>
<td></td>
<td>% Difference: +39</td>
<td>% Difference: +0.4</td>
</tr>
<tr>
<td>7-12 Dec 2015</td>
<td><img src="image5" alt="Graph" /></td>
<td>Observed: 728</td>
<td>Observed: 1,080</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Simulated: 712</td>
<td>Simulated: 1,120</td>
</tr>
<tr>
<td></td>
<td></td>
<td>% Difference: -2.2</td>
<td>% Difference: +4.1</td>
</tr>
<tr>
<td>8-12 Feb 2017</td>
<td><img src="image6" alt="Graph" /></td>
<td>Observed: 804</td>
<td>Observed: 910</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Simulated: 1,320</td>
<td>Simulated: 950</td>
</tr>
<tr>
<td></td>
<td></td>
<td>% Difference: +64</td>
<td>% Difference: +4.8</td>
</tr>
</tbody>
</table>

Note: cfs = cubic feet per second, ac-ft = acre-feet. Red hydrograph trace is observed; blue is simulated.
3.2 Issaquah Creek

The Issaquah Creek model was calibrated to observed streamflow records at USGS station 12121600. As a starting point, the calibrated parameters from the Bear Creek models were transferred to the Issaquah Creek model. Since bedrock HRUs are not present in the Bear Creek watershed and thus were not considered in that calibration, bedrock parameter values were taken from the previous Issaquah Creek model and validated in this calibration effort. Runoff response and hydrograph shape were consistently good, and calibration targets at the mouth of Issaquah Creek were attained with adjustments only to the same groundwater parameters allowed to vary in the Bear Creek models. Volume comparisons for Issaquah Creek are provided in Table 5 and event calibration results summarized in Table 6.

Table 5 Simulated vs. observed mean monthly flows for Issaquah Creek (USGS 12121600, WY 2012-2017)

<table>
<thead>
<tr>
<th>Period</th>
<th>Mean Flow (cfs)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>12121600</td>
</tr>
<tr>
<td>October</td>
<td>79.9</td>
</tr>
<tr>
<td>November</td>
<td>194</td>
</tr>
<tr>
<td>December</td>
<td>231</td>
</tr>
<tr>
<td>January</td>
<td>220</td>
</tr>
<tr>
<td>February</td>
<td>267</td>
</tr>
<tr>
<td>March</td>
<td>277</td>
</tr>
<tr>
<td>April</td>
<td>183</td>
</tr>
<tr>
<td>May</td>
<td>122</td>
</tr>
<tr>
<td>June</td>
<td>71.6</td>
</tr>
<tr>
<td>July</td>
<td>39.6</td>
</tr>
<tr>
<td>August</td>
<td>25.9</td>
</tr>
<tr>
<td>September</td>
<td>34.0</td>
</tr>
<tr>
<td>Annual</td>
<td>145</td>
</tr>
</tbody>
</table>

Simulated flows corresponding to gaps in observed record not included in calculations.
### Table 6 Large event comparison for Issaquah Creek HSPF simulation (continued next page)

<table>
<thead>
<tr>
<th>Event Dates</th>
<th>Event Hydrograph Comparison</th>
<th>Peak Hourly Flow (cfs)</th>
<th>Events Volume (ac-ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9-13 Jan 2006</td>
<td><img src="image1.png" alt="Graph" /></td>
<td>Observed: 1,490</td>
<td>Observed: 1,980</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Simulated: 1,463</td>
<td>Simulated: 1,920</td>
</tr>
<tr>
<td></td>
<td></td>
<td>% Difference: -1.8</td>
<td>% Difference: -3.2</td>
</tr>
<tr>
<td>29 Jan-1 Feb 2006</td>
<td><img src="image2.png" alt="Graph" /></td>
<td>Observed: 1,303</td>
<td>Observed: 1,150</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Simulated: 1,530</td>
<td>Simulated: 1,330</td>
</tr>
<tr>
<td></td>
<td></td>
<td>% Difference: +18</td>
<td>% Difference: +15</td>
</tr>
<tr>
<td>6-10 Nov 2006</td>
<td><img src="image3.png" alt="Graph" /></td>
<td>Observed: 2,078</td>
<td>Observed: 2,020</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Simulated: 2,314</td>
<td>Simulated: 2,210</td>
</tr>
<tr>
<td></td>
<td></td>
<td>% Difference: +11</td>
<td>% Difference: +9.4</td>
</tr>
<tr>
<td>2-6 Dec 2007</td>
<td><img src="image4.png" alt="Graph" /></td>
<td>Observed: 1,960</td>
<td>Observed: 1,380</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Simulated: 2,619</td>
<td>Simulated: 2,050</td>
</tr>
<tr>
<td></td>
<td></td>
<td>% Difference: +34</td>
<td>% Difference: +49</td>
</tr>
<tr>
<td>11-14 Dec 2010</td>
<td><img src="image5.png" alt="Graph" /></td>
<td>Observed: 2,060</td>
<td>Observed: 1,900</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Simulated: 1,757</td>
<td>Simulated: 1,570</td>
</tr>
<tr>
<td></td>
<td></td>
<td>% Difference: -15</td>
<td>% Difference: -17</td>
</tr>
<tr>
<td>13-17 Nov 2015</td>
<td><img src="image6.png" alt="Graph" /></td>
<td>Observed: 1,458</td>
<td>Observed: 1,400</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Simulated: 1,383</td>
<td>Simulated: 1,510</td>
</tr>
<tr>
<td></td>
<td></td>
<td>% Difference: -5.1</td>
<td>% Difference: +8.2</td>
</tr>
</tbody>
</table>

Note: cfs = cubic feet per second, ac-ft = acre-feet. Red hydrograph trace is observed; blue is simulated.
<table>
<thead>
<tr>
<th>Event Dates</th>
<th>Event Hydrograph Comparison</th>
<th>Peak Hourly Flow (cfs)</th>
<th>Events Volume (ac-ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7-11 Dec 2015</td>
<td><img src="image1.png" alt="Graph" /></td>
<td>Observed: 1,998 Simulated: 1,849 % Difference: -7.5</td>
<td>Observed: 1,860 Simulated: 2,010 % Difference: +8.6</td>
</tr>
<tr>
<td>8-12 Feb 2017</td>
<td><img src="image2.png" alt="Graph" /></td>
<td>Observed: 1,500 Simulated: 1,522 % Difference: +1.5</td>
<td>Observed: 1,540 Simulated: 1,470 % Difference: -4.9</td>
</tr>
</tbody>
</table>

Note: cfs = cubic feet per second, ac-ft = acre-feet. Red hydrograph trace is observed; blue is simulated.

The December 2007 event is the only calibration event in the Issaquah Creek simulation that exceeded targeted calibration accuracy. Both the peak and the volume are significantly oversimulated. The model performs much better for other events of similar magnitude (November 2006, December 2010, and December 2015), so it is likely that the rainfall distribution over the watershed during the December 2007 event, which included several localized high-intensity cells, was not well-represented by the fixed gage distributions. On average, the Issaquah Creek peaks are just 4 percent high and volumes are 8 percent higher than observed. Despite the poor representation of the December 2007 event, calibration results are judged to be acceptable.

### 3.3 Calibration Summary

The model results for Bear and Issaquah creeks show a very good overall calibration. The mean monthly volume results show slight seasonal biases—higher in the winter and lower in the summer—but the deviations from observed are well within calibration targets. Event simulations are naturally more variable but do not show significant simulation bias.

Both the Bear and Issaquah Creek models tend to produce mean monthly flow volumes that are slightly high in winter months and low during summer months. These tendencies are conservative in terms of Willowmoor project design. Higher winter flow volumes would tend to exacerbate flooding conditions during the flood critical season. Slightly lower summer flows are similarly conservative since summer concerns (low lake level, high temperatures) are heightened at lower flows.

The event calibration focused on six large events on Bear Creek and eight events on Issaquah Creek. The simulation results in Table 4 and Table 6 show a mixture of over- and under-simulation of both peaks and volumes. This is typical of event simulations and indicates that there are no significant biases. As discussed in the context of the calibration targets, accurate event simulation is more difficult because spatial patterns in precipitation vary significantly from storm to storm and may not be well-captured for some events. Both the
Bear Creek and Issaquah Creek models slightly overestimate the calibration event peaks and volumes on average.

4.0  BASENWIDE MODEL APPLICATION

The calibrated model parameters for the Bear and Issaquah Creek models were transferred to the three "ungaged" subbasins contributing to the project area—East Lake Sammamish tributaries, West Lake Sammamish tributaries, and local Sammamish River drainage (with the exception of Tosh Creek discussed in Section 2.1). To select appropriate values for the groundwater parameters that varied within the calibrated models, simulated flows were compared to available streamflow from some of the small drainages (Lewis Creek, Laughing Jacobs Creek, Ebright Creek) encompassed by the Lake Sammamish tributaries models. Based on a high-level review of simulated volumes compared to observed, either Evans, Bear, or Issaquah values for the parameters were assigned to each model as a whole. For the Sammamish River local model, there was assumed to be no loss to deep groundwater. This is supported by the Tosh Creek calibration and anecdotal evidence of substantial groundwater inputs to the Sammamish River.

Following the final model updates, all of the models were run over the full available record (water years 1949-2017). Flows for the hydraulic modeling period (water years 2001-2017) were output to DSS file for direct input to HEC-RAS unsteady flow simulations.

4.1  Lake Inflow Validation

The final model validation was a comparison of total inflow to Lake Sammamish. For comparison purposes, the reconstructed daily lake inflow record computed as part of the preliminary weir analysis (King County, 2018b) is referred to as the observed record. Total inflow was estimated by adding outflow from the weir (King County gage 51m) to change in storage in the lake, based on the USGS lake level record (12122000). A 3-day centered moving average smoothing was applied to reconstructed inflows to eliminate spurious fluctuations.

Simulated inflow was computed by combining outflows from the Issaquah Creek (including Tibbetts Creek), West Lake Sammamish tribs, and East Lake Sammamish tribs models with computed net meteorological flux from the lake surface. The meteorological flux was calculated by subtracting evaporation (0.8 times the pan evaporation values in the evaporation dataset, consistent with HSPF models) from the precipitation data from King County's Marymoor gage (MARY). The net input was then multiplied by the lake area and converted from total hourly precipitation volume to average hourly flow. The combined hourly dataset was aggregated to a daily time step and smoothed (using the same 3-day centered moving average) for direct comparison with the observed record.

Over the hydraulic model simulation period (water years 2002-2017), the difference between the HSPF-modeled (simulated) and reconstructed (observed) average lake inflow datasets is less than half a percent: 201.9 cfs simulated versus 202.5 cfs observed. For water years 2013 through 2017, which is the hydraulic model calibration period, results were nearly as good, with an average simulated flow of 224.6 cfs compared to average observed flow of 222.4 (within one percent).
4.2 Future Conditions Hydrology

Uncertainty under potential climate change is one of the key variables in terms of future hydrology and project performance. While development will continue in parts of the Sammamish River (and especially Lake Sammamish) basin, it is reasonable to assume (as discussed in King County (2013)) that mitigation according to current stormwater management standards would preclude significant changes in runoff due to land use change. As part of the Phase 2 work (NHC, 2015), precipitation estimates were developed for a potential future climate condition, as simulated by a regionally accepted global climate model (GCM), for each of the input precipitation gages for the HSPF models. Detailed discussion of methodology and individual gage results are available in a technical appendix to the 2015 report. The recalibrated HSPF models were rerun with the alternative precipitation inputs developed in the earlier work to produce a plausible future hydrologic conditions scenario. It should be noted that estimation of changes in evaporation associated with higher temperatures was beyond the scope of this work. Evaporation changes would likely have little impact on storm flows (especially large events) but could have more substantial impact on summer flows and lake levels.

Flows into Lake Sammamish and out of Bear Creek were compared between existing and future scenarios. Flow changes associated with the simulated climate change scenario are relatively small. Mean annual flows increase by three to four percent, while maximum flows increase on the order of three to seven percent. Table 7 and Figure 5 compare existing and future flow frequency curves for inflows to Lake Sammamish and Bear Creek streamflows. In general, there are larger increases for more extreme events, which is consistent with the precipitation changes.
Table 7: Existing vs. Future Flow Frequency

<table>
<thead>
<tr>
<th>Location</th>
<th>2-Year Peak</th>
<th>10-Year Peak</th>
<th>100-Year Peak</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Existing</td>
<td>Future</td>
<td>% Diff</td>
</tr>
<tr>
<td>Lake Sammamish inflow</td>
<td>4,260</td>
<td>4,380</td>
<td>+2.8</td>
</tr>
<tr>
<td>Bear Creek</td>
<td>880</td>
<td>940</td>
<td>+6.5</td>
</tr>
</tbody>
</table>

Flow quantiles determined from Log Pearson 3 distribution fit by method of moments.

Figure 5: Flow frequency comparison for existing and future climate scenarios at Lake Sammamish (left) and Bear Creek mouth (right)

5.0 REFERENCES


King County (2018a). Bear Creek Watershed Management Study Watershed Modeling. Prepared by Department of Natural Resources and Parks Water and Land Resources Division. April 2018.

King County (2018b). Willowmoor Floodplain Restoration Project: Preliminary Weir Analysis Technical Memorandum. Prepared by Tetra Tech for Department of Natural Resources and Parks Water and Land Resources Division (King County) October 2018.


DISCLAIMER

This document has been prepared by Northwest Hydraulic Consultants Inc. in accordance with generally accepted engineering practices and is intended for the exclusive use and benefit of Tetra Tech and King County and their authorized representatives for specific application to the Willowmor Floodplain Restoration Project at the outlet of Lake Sammamish in King County, Washington. The contents of this document are not to be relied upon or used, in whole or in part, by or for the benefit of others without specific written authorization from Northwest Hydraulic Consultants Inc. No other warranty, expressed or implied, is made. Northwest Hydraulic Consultants Inc. and its officers, directors, employees, and agents assume no responsibility for the reliance upon this document or any of its contents by any parties other than Tetra Tech and King County.