Photo source: NHC

Hydrology Study of High-Risk Areas
E9 Flow Control Assessment

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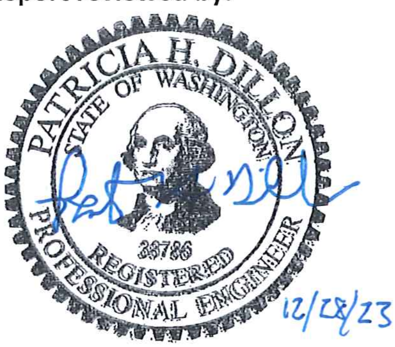

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APPENDICES

1 INTRODUCTION

This report documents work conducted by Northwest Hydraulic Consultants (NHC) for the City of Sammamish (City) between Summer 2021 and Fall 2023 to assess the hydrology of the Inglewood and Thompson basins, focused on flow control standards and needs. This work builds on previous studies as discussed in section 1.1 below.

1.1 Background and Motivation

The City of Sammamish has experienced substantial growth in recent years, leading to concern about the adequacy of existing policies for protecting ecologically sensitive areas. One aspect of this is the disruptive effects of development on the hydrologic cycle and impacts on small streams. An area of specific concern is the development projected to occur within the Sammamish Town Center subarea (shown in Figure 1.1). The City of Sammamish hired Northwest Hydraulic Consultants, Inc. (NHC) to perform a hydrologic study of the watersheds that would be affected by development in Sammamish Town Center. As Town Center straddles the basin divide of the Inglewood and Thompson basins, those watersheds were used to define the study limits.

Work began with a review of existing studies of the basins, including the existing basin plans and geologic mapping, with a focus on identifying gaps in current understanding. This study was identified on the 2021 Council-adopted City of Sammamish Work Plan as E8 and resulted in updated surface geology mapping by GeoEngineers, a report to the City (NHC, 2021), and the hydrometric monitoring documented in this report. The current work (E9) builds on the review and data collection with the development of two hydrologic models used to evaluate the effectiveness of stormwater management practices in mitigating impacts of development on streamflows. The 2010 basin plan and associated modeling (Parametrix, 2010; MGS, 2009) provided a key source of background information on the dominant hydrologic processes in the study watersheds and were influential in shaping both conceptual understanding and model implementation for this study.

1.2 Basin Overview

The Inglewood and Thompson basins, which respectively are drained by George Davis and Ebright creeks, originate on the Sammamish Plateau and descend westward to enter Lake Sammamish midway along its eastern shore. Both are characterized by generally mild slopes in the upper portions of the basin on the plateau, with a relatively steep fall through a ravine followed by a return to moderate slopes as the creeks reach the lowland areas near the shores of Lake Sammamish.

Like many basins in the Puget Sound region, the soils are dominated by low-permeability glacial till 'caps' on hills and ridges on the plateau (including most of the Town Center area), with highly permeable recessional outwash deposits in the topographically lower areas near where the creeks presently flow. This is particularly noticeable in the Inglewood basin, where shallow outwash deposits readily take up surface flows, which then re-emerge as baseflow when the creek drops below the till-outwash contact (geologic boundary) in the George Davis Creek ravine. This is documented in the 2010 basin plan (Parametrix, 2010) and observable in the field, as discussed in Section 2. This shallow groundwater storage provides tremendous natural attenuation of peaks along much of George Davis Creek. While the mechanism is different and the effect less substantial, several large wetlands in the Thompson basin also naturally attenuate flows in Ebright Creek. Topographic and soil information for the two watersheds are depicted in Figure 1.1.

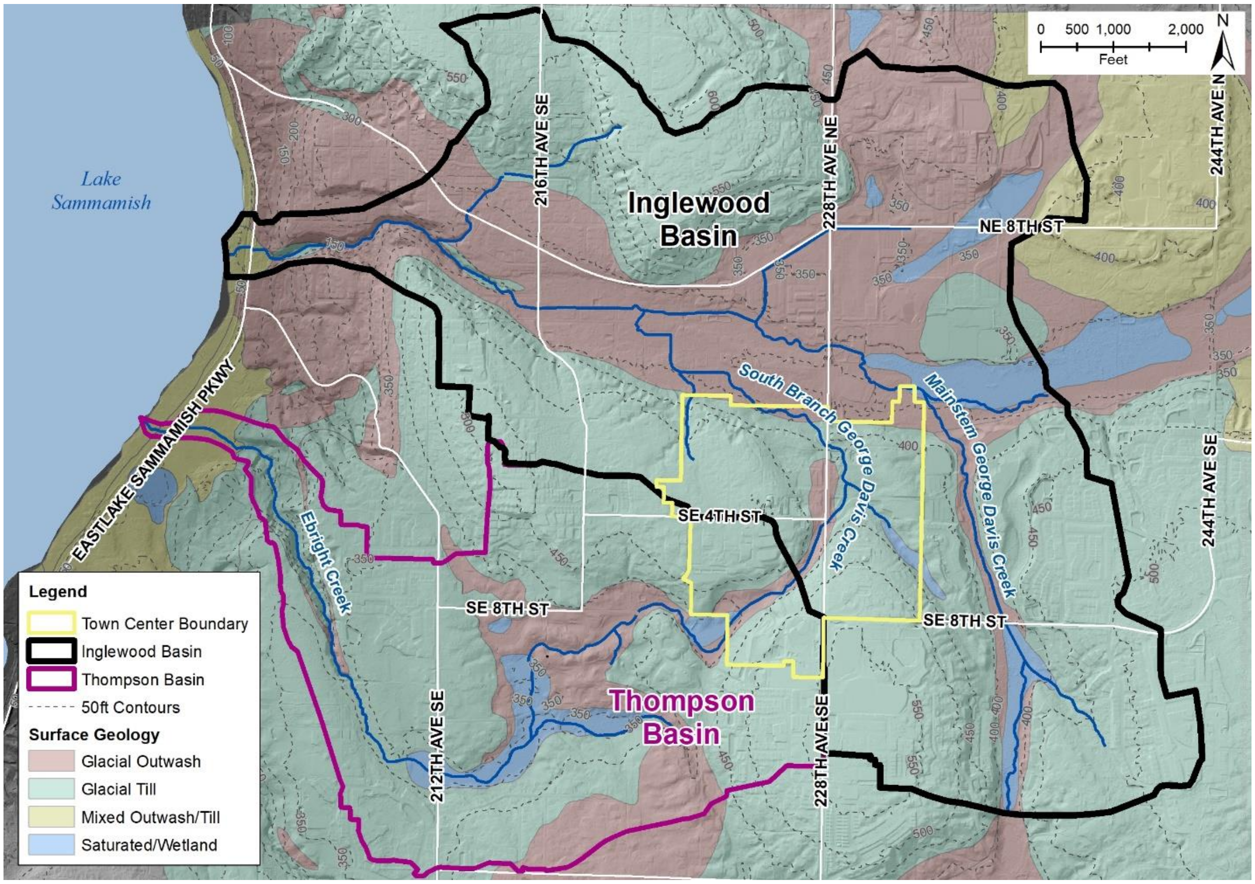


Figure 1.1 Study area with basin boundaries, topographic, and geologic information

Land use in both basins is primarily single-family residential, with pockets of institutional (schools, churches, and government buildings) and commercial areas. Much of the Town Center area remains undeveloped, but concentrated commercial and multi-family residential uses are also present there (and projected to increase in the future). Existing stormwater treatment within the basins is largely site- or development-scale vaults and ponds, with no regional facilities in either basin. About half the current facilities were constructed before 1998 and would provide some water quality and peak flow control only. Roughly one-third were built between 1998 and 2009 and would be expected to meet current flow control and water quality standards (Core Requirements 3 and 8) but not the newer flow control best management practices (BMPs) requirement (Core Requirement 9). More than 20% of the combined basin area – primarily north of NE Inglewood Hill Road in Inglewood and west of 212th Avenue SE in Thompson – does not drain to mapped water quality or flow control facilities.

2 FIELD INVESTIGATION AND DATA COLLECTION

In September 2021, NHC conducted a field visit to assess the watershed response to the onset of fall rains after a sustained summer dry period (providing an indication of where perennial and groundwater-fed flows are present) and to identify locations for stream gage installations.

In the Inglewood basin, both the mainstem and south branch of George Davis Creek were dry at all locations visited above and most of the way down the ravine, except at the 216th Avenue NE crossing, where runoff flowing north from the Thompson/Inglewood basin divide entered the main channel. Even here, the tributary flow was absorbed into the ground within 50 feet of entering the main channel. Still, cobbles were found deposited in culverts, indicating substantial transport capacity at high flows. Flow was observed in the lower part of George Davis Creek upstream of East Lake Sammamish Parkway, likely primarily fed by groundwater seeps and springs in the lower part of the ravine. To monitor how these flow patterns change through the water year, two stream gaging locations were selected in the Inglewood basin. Runoff from the Town Center area was monitored through a driveway culvert (Upper George Davis site in Figure 2.1) near 223rd Place NE. Approximately 160 acres drain to that location. Overall basin discharge was monitored with a stage recorder installed in lower George Davis Creek, approximately 350 feet upstream of East Lake Sammamish Parkway (Lower George Davis), where the contributing area is roughly 1,610 acres.

Reconnaissance of the smaller Thompson basin was more limited, but Ebright Creek was also observed to be dry upstream of the wetlands in the vicinity of 212th Avenue SE. To supplement the King County's station 15h near the mouth of Ebright Creek (drainage area of 760 acres), NHC selected a single gage site in the upper part of the Thompson basin, at the culvert under the access driveway (extending south from 218th Avenue SE) in Big Rock Park North (Upper Ebright site). The drainage area to that location is approximately 210 acres.

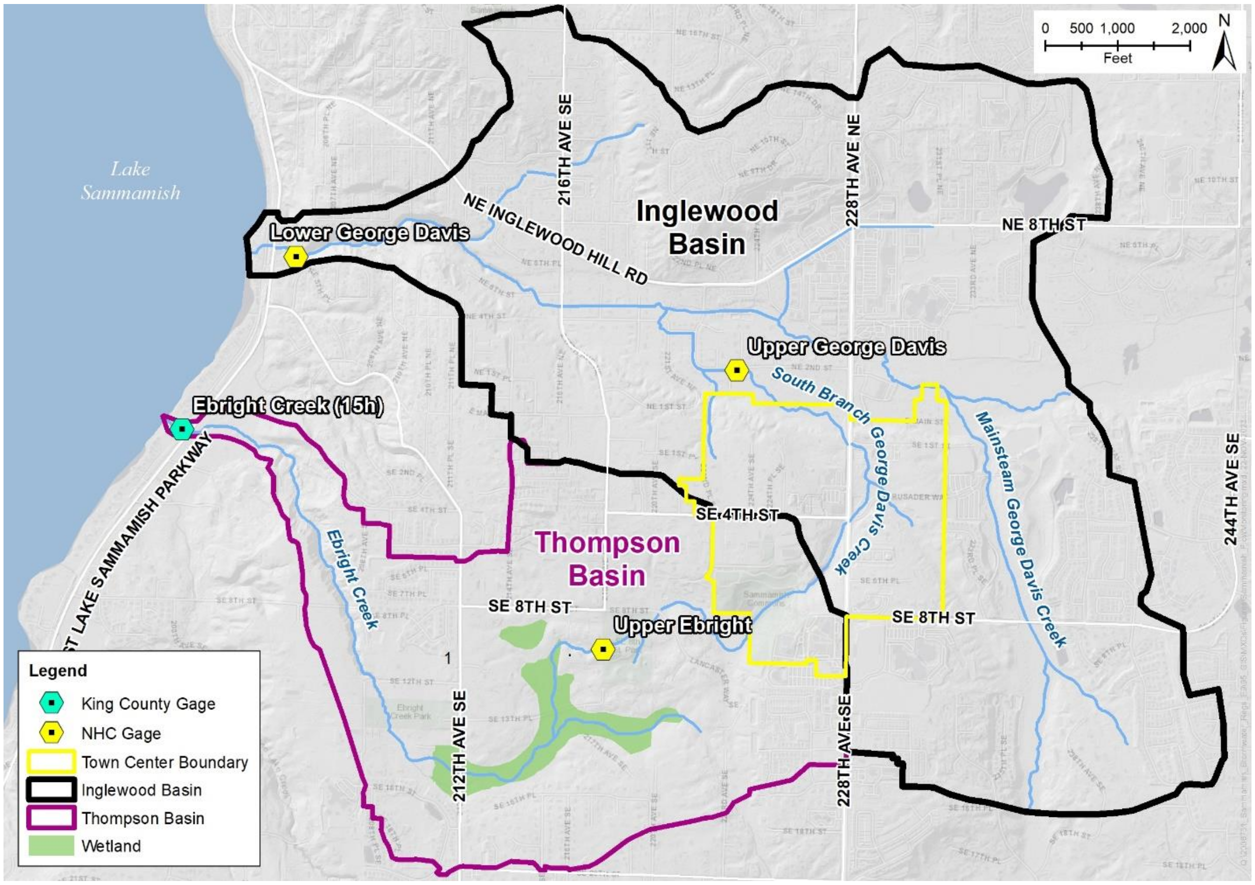


Figure 2.1 Stream gage sites within the study basins

Flow data from the stream gage sites are shown in Figure 2.2A-D, below. These data span from November 2021 to June 2022, the period for which all four sites were active. Flow data from the Upper George Davis and Upper Ebright gages were developed from measured depth and mean velocity, while a stage-discharge rating curve was used to translate measured depth to flow at the Lower George Davis site. The rating curve was derived from a HEC-RAS model of lower George Davis Creek developed in previous work for the City. Further details regarding the hydrometric work can be found in Appendix A.

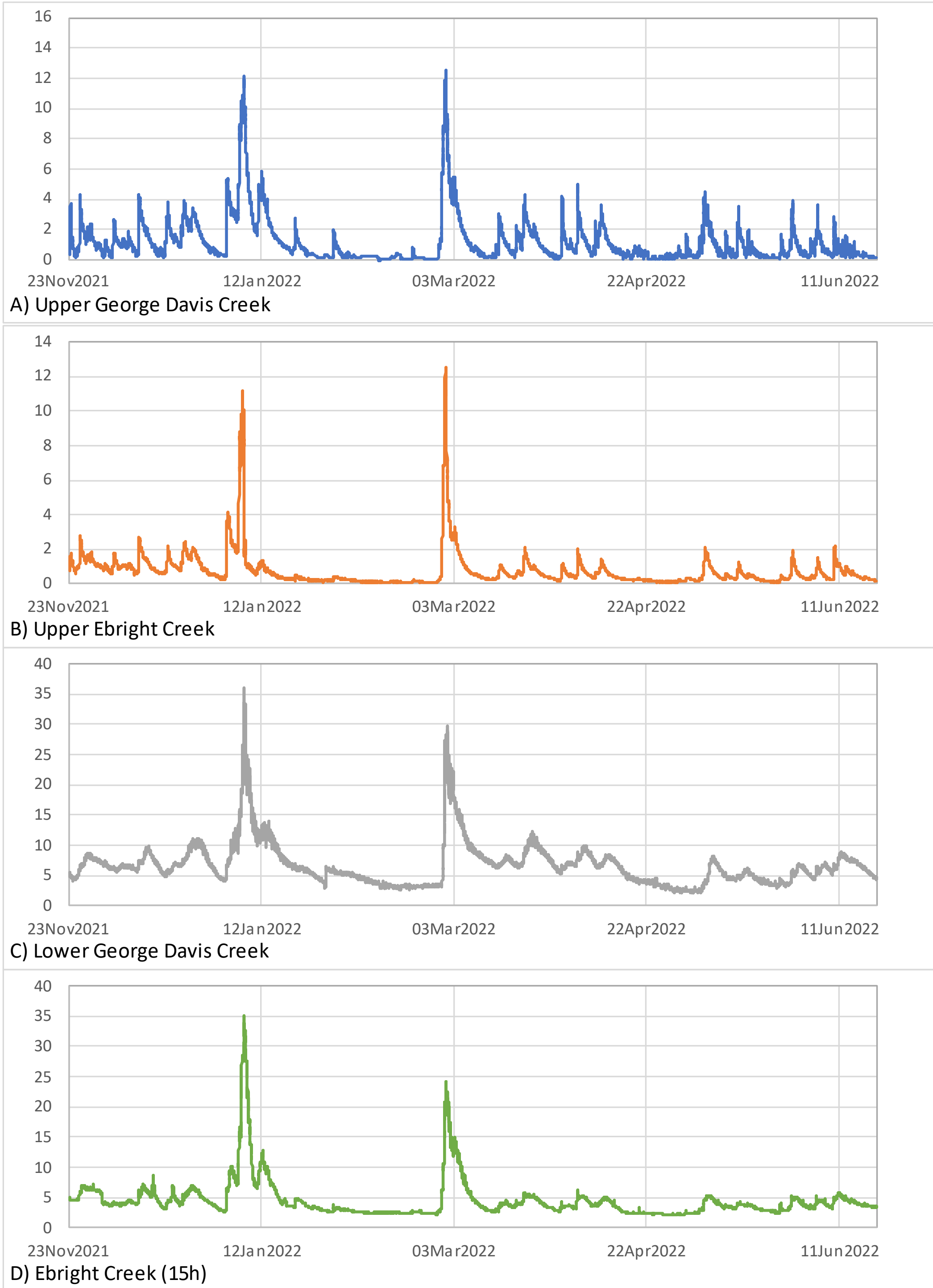


Figure 2.2 Observed flow at George Davis and Ebright Creek gages, November 2021 - June 2022. Data for figures A-C collected by NHC, for figure D by King County.

The flow monitoring data suggest several differences in flow patterns across the basins. First, the peak flows at the upper George Davis gage are appreciably flashier – with small storm flows rising faster and higher – than those at the upper Ebright gage. This is likely a result of wetland storage upstream of the upper Ebright gage (near the southwest corner of the Town Center area). Peaks at the lower George Davis gage for all but the largest two observed events have a broader, more attenuated shape, with more gradual increase and decreases in storm flows while baseflows remain elevated and stable. This is consistent with the effect of the enhanced groundwater storage in the Inglewood basin. Lower Ebright Creek (15h) generally shows a muted response to minor storm events, in contrast to the abrupt flow increases in the two larger storms. This is attributed to the large wetland between the Upper Ebright gage and 212th Ave SE (see Figure 1.1). It is notable that peak flows in the larger events are very similar between George Davis and Ebright creeks, even though the Inglewood basin is more than twice the size of the Thompson basin, dramatically demonstrating the capacity of the shallow aquifers for flow attenuation.

3 HYDROLOGIC MODELING

For this study, NHC conducted hydrologic modeling using Hydrological Simulation Program – Fortran (HSPF) software. HSPF provides flexibility in representing surface and subsurface processes and is the standard for stormwater modeling in western Washington. The model requires input timeseries for precipitation and evaporation and uses distinct 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 that produce different runoff responses. Runoff from each subbasin is then computed by adding the responses from each HRU according to their area distribution within the subbasin. The combined runoff from each subbasin is routed downstream via model elements representing natural or constructed channels or storage features.

3.1 Model Development

Individual HSPF models were developed for each creek basin. Both models incorporated existing stormwater facilities, which were characterized in the model based on as-built drawings from the City's engineering record drawing portal. Not every pond or vault was added, but newer and larger facilities – expected to have more impact on in-stream flows – were incorporated, resulting in the development of facility-specific hydraulic routing tables for ten facilities in the Inglewood basin and seven in the Thompson basin. Natural hydraulic elements, including streams and wetlands, were also included in the model. Where available (primarily for wetlands), routing elements were adapted from previous work (MGS, 2009). Elsewhere, simplified stream or pipe system routing was applied.

Additional groundwater elements were included in the Inglewood basin model to conceptually represent shallow aquifers for subbasins where rainfall and runoff are intercepted by substantial outwash deposits. This follows from the approach used in the 2010 basin plan modeling (MGS, 2009). The overall model segmentation, along with hatching for subbasins with corresponding aquifer elements, is shown in Figure 3.1.

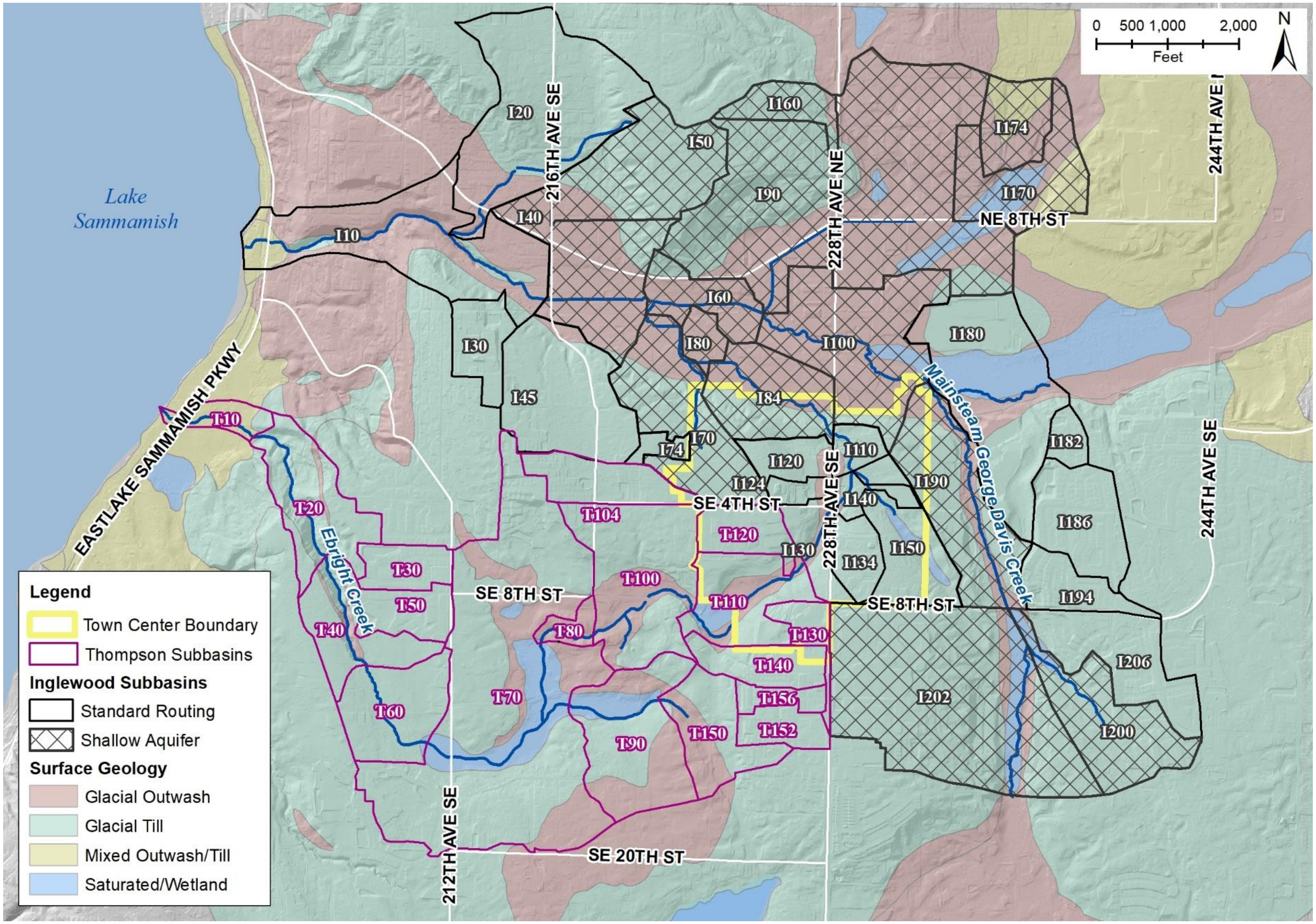


Figure 3.1 Model subbasins with Inglewood basin routing approach based on underlying surface geology. Hatched subbasins represent areas modeled with shallow groundwater storage and channel infiltration.

In the hatched subbasins, standard HSPF processes were used to partition precipitation into surface runoff, interflow, and water that percolates into the groundwater layer. The groundwater component was then routed to a corresponding aquifer storage, essentially doubling the groundwater attenuation effects. Outflow from the aquifer elements was then routed to the local stream reach, conceptually representing re-emergence of shallow groundwater into the stream. Each stream reach flowing over outwash soils was also set up to infiltrate a portion of its flow through the channel bottom, with the re-infiltrated runoff directed to the next downstream aquifer, while excess surface flow continued to the downstream channel reach. No shallow groundwater storage or streamflow infiltration was modeled in the ravine (subbasin I10), consistent with the geological data and observed groundwater emergence.

Following development of both models and checks to ensure model mass conservation, model simulation results were compared with observed flow data from the project stream gages and King County station 15h. Model routing and parameter adjustments were made to improve the simulation accuracy, as detailed below.

3.2 Model Calibration

The Inglewood and Thompson basin models were calibrated in a coupled manner. That is, model parameters were adjusted globally to achieve an overall match to flow patterns at all gages, rather than optimizing individual subbasin response to local stream observations. King County's Ebright Creek (15h) gage was first used to calibrate overall volumes since this site has the longest record and captures a wider range of hydrologic conditions.

Compared to the gage data, initial model runs consistently showed low flow volumes (particularly summer baseflows) in lower Ebright Creek and higher than observed flows in lower George Davis Creek. Based on these results and the relative physiographic settings of the two basins, a regional groundwater connection was hypothesized. This was modeled by adding a constant monthly groundwater transfer from the Inglewood basin (subbasin I40 in Figure 3.1) to lower Ebright Creek (subbasin T20). A regional groundwater connection appears reasonable based on the geologic mapping, and this adjustment markedly improved the performance of both models.

Two land surface parameter sets were tested in both models: the so-called Puget Sound regional parameters (Dinicola, 1990) and the calibrated parameters determined in previous modeling of the Lake Sammamish basin for King County Willowmoor project (King County, 2019). Comparison to observed flows indicated that the Willowmoor parameters produced better results for the Thompson and Inglewood basin models. Additional parameter adjustments were tested, but often had the effect of improving the calibration in one basin but worsening it in the other. As a result, the Willowmoor parameters were adopted without modification for both models.

The infiltration rate used to simulate channel losses (reinfiltration) to the shallow aquifer elements was also adjusted during calibration. Based on a comparison of the upper and lower George Davis Creek gage data, channel infiltration was reduced in the upper plateau reaches and increased in the central corridor (the reach parallel to NE 4th Street), where there is a wider channel and a much broader area of mapped outwash that could take up water from the stream. This adjustment balanced simulation of event peaks at both George Davis Creek gages.

Calibration plots (observed versus simulated flows) for all four gage sites are shown in Figure 3.2A-D. The plots show generally good agreement between modeled and observed flows. The model slightly underestimates the two larger events in the monitoring period, but it is difficult to draw conclusions about overall accuracy due to the short monitoring period and limited rating curve. Note that runoff during the January 2022 event was affected by snow accumulation and melt, which are not represented in this model. Although individual event hydrographs for small to moderate events are not consistently captured on upper George Davis Creek, the model clearly replicates the flashier nature of the upland response compared to flows near the mouth. Baseflows are generally well-captured across the study area. Lower Ebright Creek shows the best results overall, with peaks, hydrograph shapes, and baseflows all represented well. This is encouraging since this site has the longest record and a more robust rating curve developed by King County from dozens of direct flow measurements. As previously noted regarding the observed flows, simulated peaks in the larger events are also very similar between George Davis and Ebright creeks, despite the basin size discrepancy. This further emphasizes the highly attenuated nature of flows in George Davis Creek.

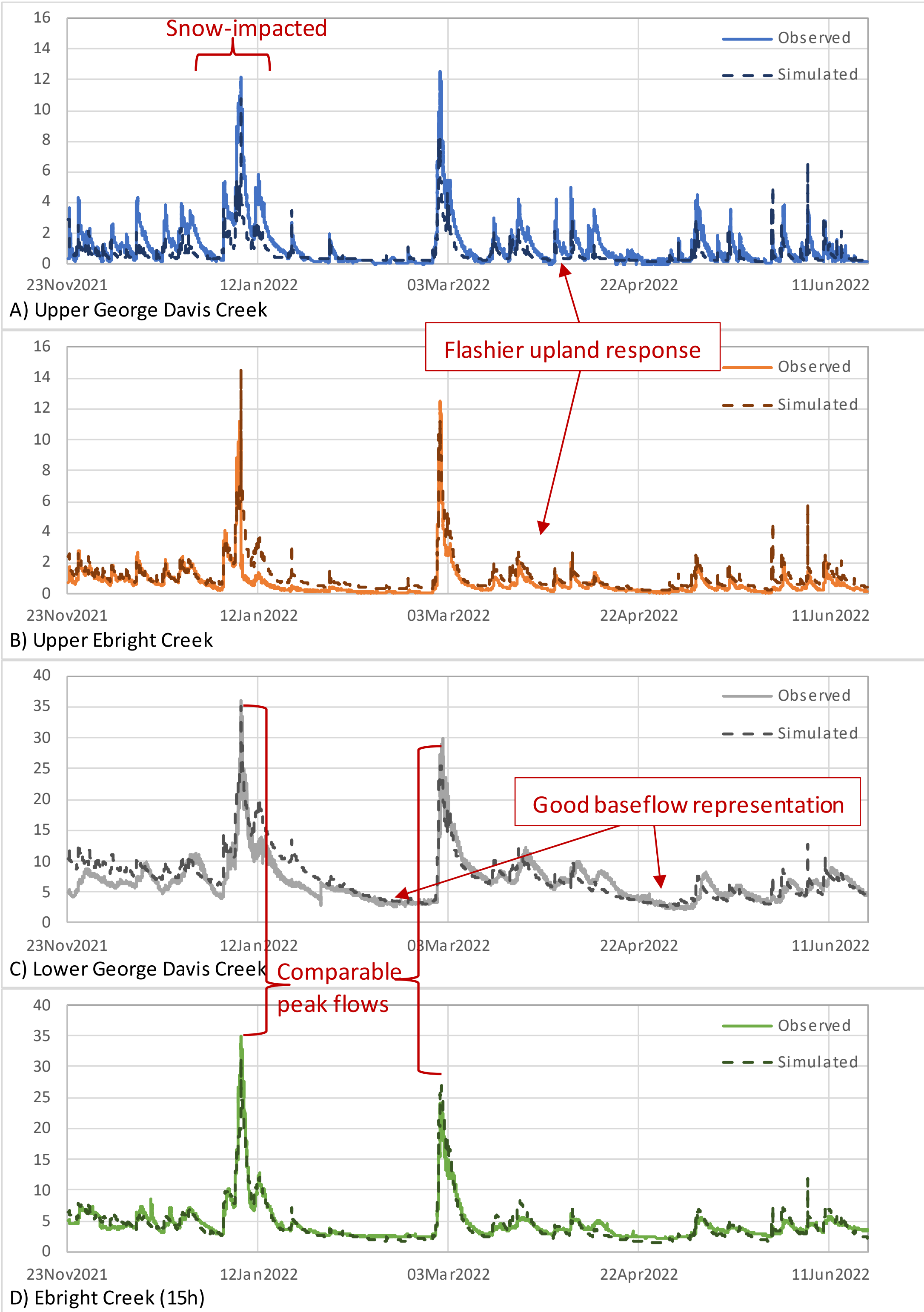


Figure 3.2 Observed and calibrated flows at all four available gage sites. Modeled flows are shown as solid colored lines, observed as dashed colored lines.

4 MODEL APPLICATION AND RESULTS

4.1 Scenario Development

Following calibration of the existing conditions models, two alternative land use scenarios were simulated. The first was a predevelopment scenario, in which the entire basin was assumed to be forested (with no change to underlying geology) and only natural channel and wetland elements used for hydraulic routing. The second was a build-out scenario, which involved adding impervious surface to represent projected development and redevelopment. Buildable area assumptions were based the 2019 King County Urban Growth Capacity Study and provided as a parcel-scale analysis by the City (Sammamish, 2022). The analysis considered parcel zoning, current land use, development regulations, critical areas, and other factors to determine allowable development area on each parcel, with percent impervious based on zoning.

For modeling purposes, developable portions of the parcels within each subbasin were consolidated into a single redevelopment subarea, with the remaining subbasin area maintained at existing land cover. A hypothetical flow control facility for the developing portion of each subbasin was sized to meet existing flow control standards using methods of the Western Washington Hydrology Model (WWHM), including infiltration for areas with outwash soils. Long-term simulations (1948-2022) of the existing, predevelopment, and build-out scenarios were performed for both the Inglewood and Thompson basins.

4.2 Model Results

Points of interest include flow at the outlets of the subbasins containing portions of Town Center in both basins (subbasin I84 and T110), flow at the mouth of both creeks, and stage in the Ebright wetland between Big Rock Park and Ebright Creek Park (Figure 4.1). These analysis points show the anticipated response of the watershed at locations that are relevant to discussions relating to development concerns, to understanding impacts in the watershed overall, and to a potentially sensitive ecological area.

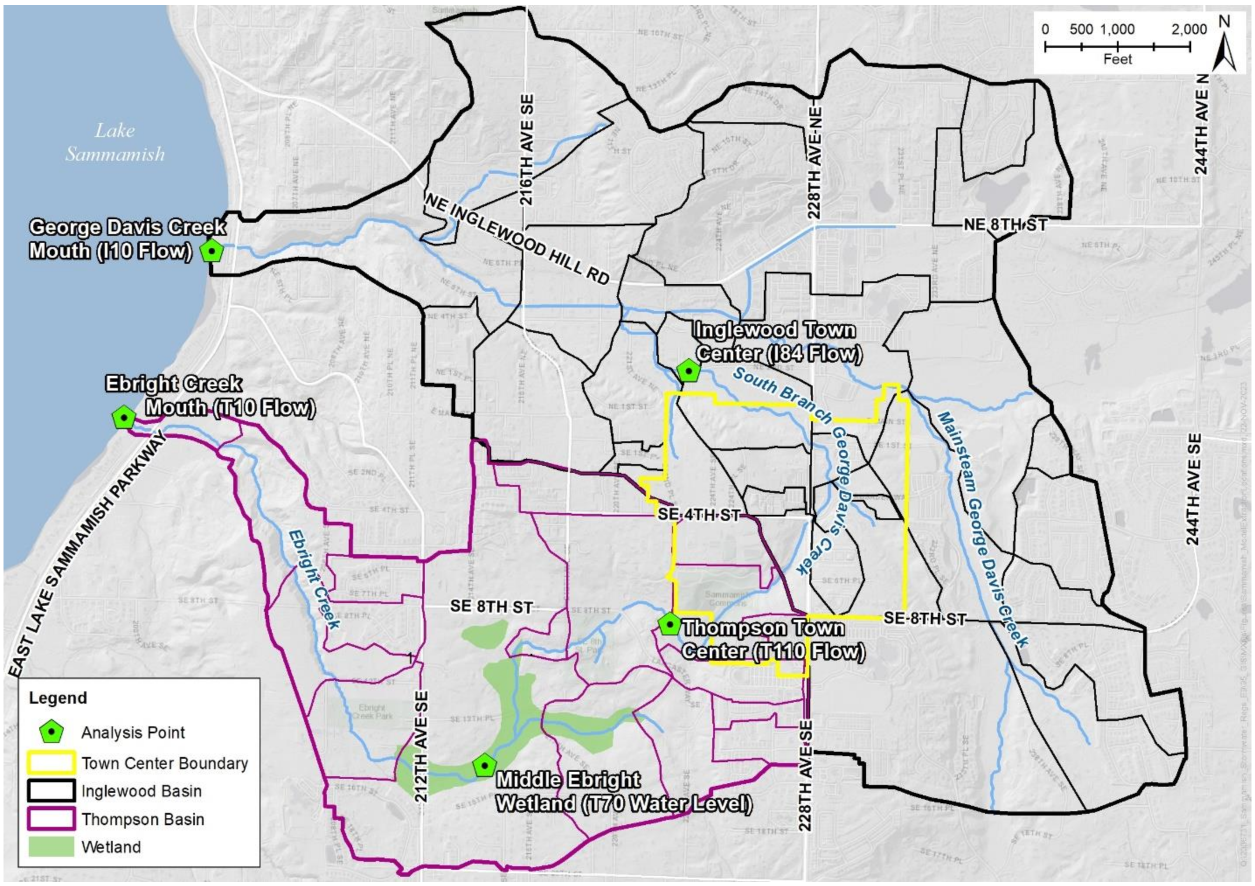
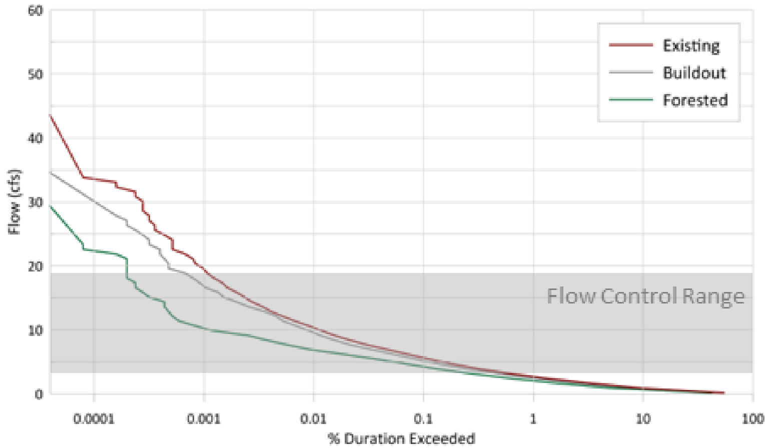
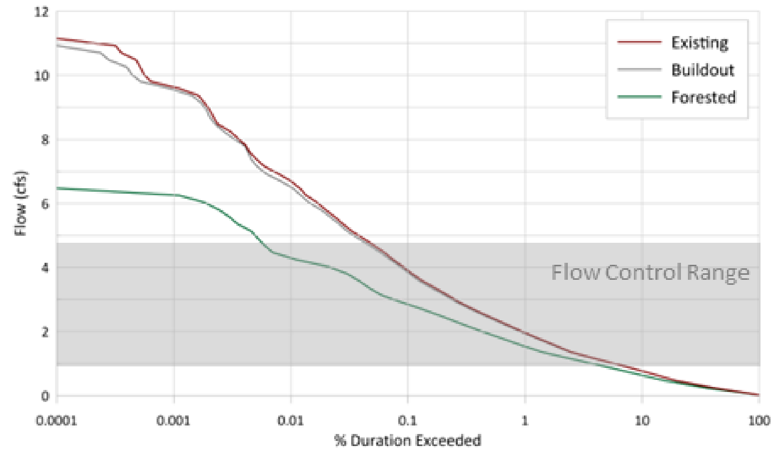


Figure 4.1 Analysis points for scenario comparison

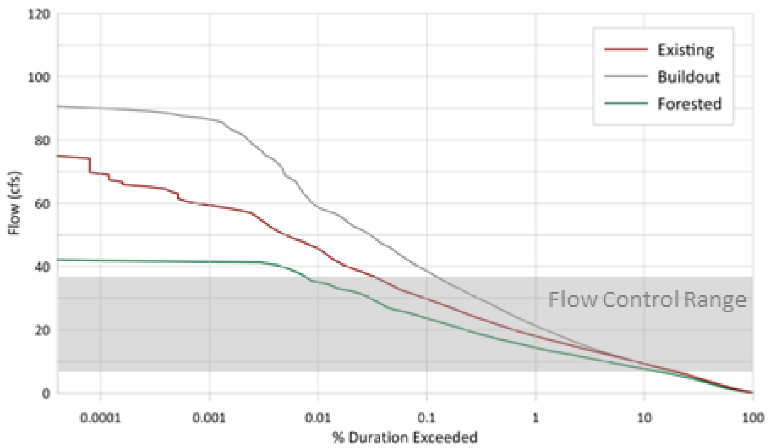
Flow duration and flow frequency curves were developed for the four flow points shown in the figure, along with a stage duration curve for the Ebright wetland. These curves are shown in Figure 4.2A-E and Figure 4.3A-D. The results show that buildout scenario duration curves track very closely with existing conditions in the Thompson basin (Figure 4.2B, D, and E), indicating that the effects of additional development are being mitigated by the associated flow control. In the Inglewood basin, development impacts are similarly mitigated in the upstream Town Center area (Figure 4.2A), but the buildout scenario produces consistently higher flows at the mouth of George Davis Creek (Figure 4.2C).



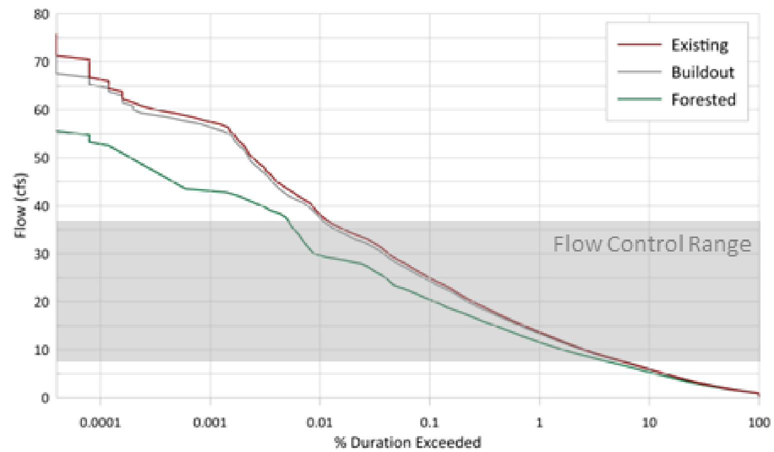
A) Inglewood Town Center Runoff: Flow Duration Curves



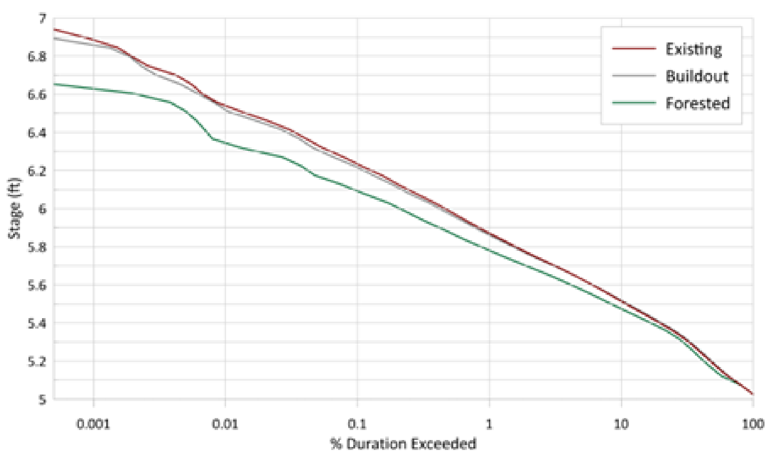
B) Thompson Town Center Runoff: Flow Duration Curves



C) George Davis Creek at Mouth: Flow Duration Curves

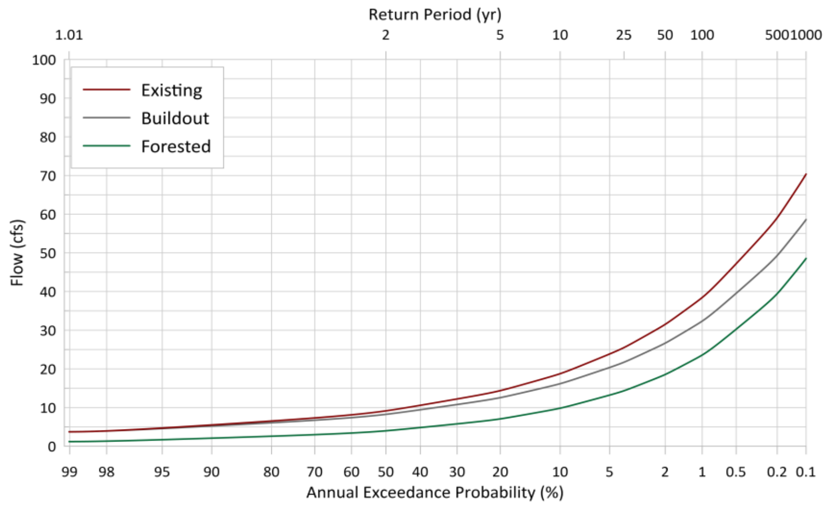


D) Ebright Creek at Mouth: Flow Duration Curves

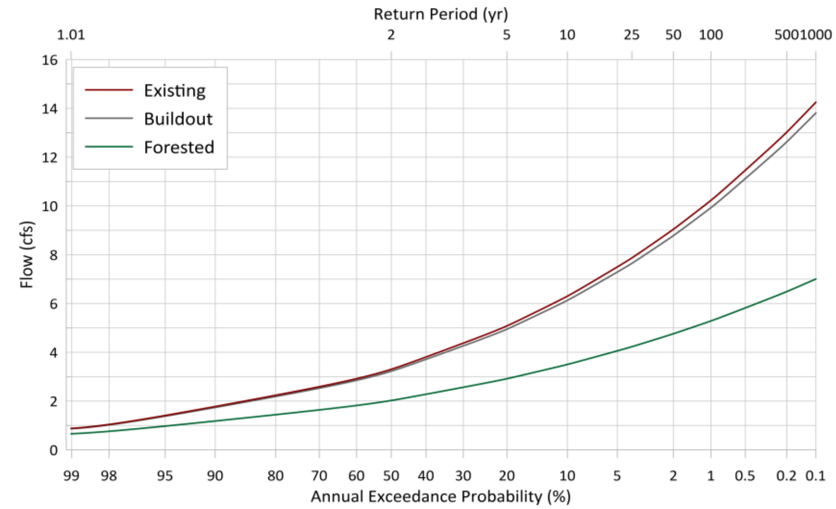


E) Middle Ebright Wetland: Stage Duration Curves

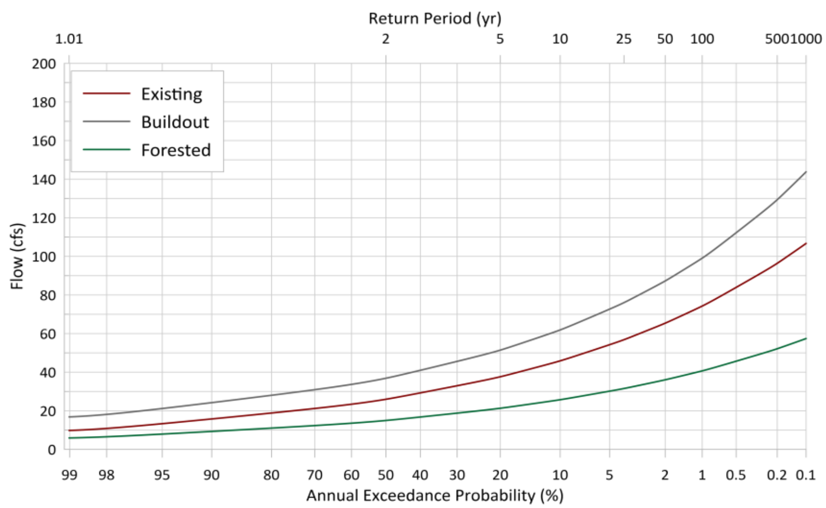
Figure 4.2 Modeled flow duration curves at selected analysis points



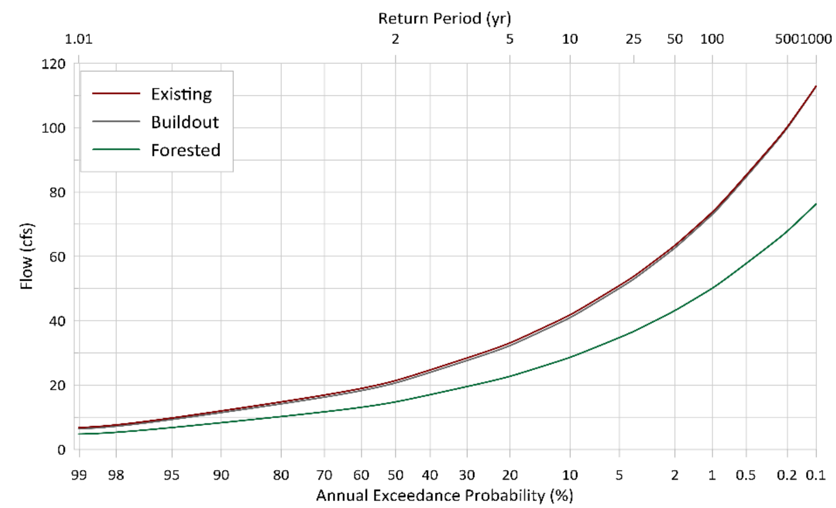
A) Inglewood Town Center Runoff: Flow Frequency Curves



B) Thompson Town Center Runoff: Flow Frequency Curves



C) George Davis Creek at Mouth: Flow Frequency Curves



D) Ebright Creek at Mouth: Flow Frequency Curves

Figure 4.3 Modeled flow frequency curves at selected analysis points.

In the Inglewood basin, flow increases are the result of higher impervious surface runoff and reduced groundwater storage opportunity due to less infiltration in the built-out areas. As discussed previously, natural hydrologic attenuation through the groundwater system is particularly pronounced in the Inglewood basin. When pervious surfaces are covered during development, land surface storage and groundwater connections are interrupted, and we attempt to replicate their function through constructed storage facilities (ponds, vaults, etc.).

Without taking full advantage of natural infiltration processes, however, detention ponds can't fully mimic undeveloped conditions. Thus, ponds and control structures sized using standard WWHM routines (based on typical western Washington conditions) will not fully attenuate flows in the areas with shallow groundwater storage (hatched areas in Figure 3.1). This response is revealed through the HSPF basin-wide modeling and reflects limitations inherent to the WWHM model. To be clear, this response is not due to inadequacies with current standards, but current modeling constraints. This is consistent with our experience that areas with higher infiltration require more flow control volume (after development) because the target release flows (based on forested conditions) are lower. The ponds associated with future development in the build-out model are adequate for till and for outwash with typical infiltration properties – as evidenced by the lack of flow impacts to Ebright Creek – but do not account for the special case of enhanced groundwater infiltration and storage present in the Inglewood basin. This explains the flow increases from existing to buildout scenario in Figure 4.2C and Figure 4.3C.

For the Inglewood Town Center area, the reductions in high flows from existing to buildout (seen in Figure 4.2A and Figure 4.3A) are notable. These suggest that the flow control associated with future development is not only mitigating for new development but also essentially retrofitting some under-detained existing surfaces. Much of the Town Center area sits on relatively impermeable till soils, which generate a flashy (surface flow dominated) response. Though still not intensely developed, the current land surface generates more runoff than a forested area, only some of which is detained or reinfiltrated to shallow groundwater in the outwash areas at the downstream edges of the drainage basin. In the buildout scenario, flows from new and redeveloped surfaces would be detained to match forested flow rates, resulting in a net reduction in storm flows compared to existing. This pattern has been similarly observed in modeling studies of predominantly till basins in other parts of western Washington.

Compared to forested conditions, higher flows are still apparent throughout the duration and frequency curves (Figure 4.2 and Figure 4.3). This is expected, since much of the existing development receives little or no flow control based on development under older standards. Extensive retrofits would be required to address this gap.

5 CONCLUSIONS

The model study indicates that future development in Town Center and the Thompson basin will occur under standards that are adequately protective of stream resources from a stormwater flow control point of view. In the Inglewood subbasin outside of Town Center, there is a possibility that stormwater facilities sized using standard procedures will not be able to match Inglewood basin forested flow durations, resulting in flow increases relative to both existing and forested conditions. This is a result of the significant infiltration and flow attenuation associated with the Inglewood outwash geology, which increases the storage volume required to replicate predevelopment conditions, compared to more typical regional response as modeled in WWHM. Thus, deviations from standard design practice may be required to match developed flows to forested flows if significant infiltration is not achieved with development.

Elements of the King County Surface Water Design Manual (King County, 2021) that promote opportunities for infiltration can help the City maintain connections with shallow groundwater storage that naturally attenuates George Davis Creek flows. In particular:

- Core Requirement #3: Flow Control Facilities, which can emphasize infiltration vs. detention facilities
- Core Requirement #9: Flow Control BMPs, which requires infiltration and dispersion BMPs in addition to required flow control facilities
- Portions of Core Requirement #4: Conveyance System, such as requirements to implement vegetation lined ditches where feasible
- Core Requirement #8: Water Quality Facilities, which lays out the need for appropriate pre-treatment.

In addition to maintaining development standards, a focus on stormwater retrofits for areas that developed under earlier, less stringent flow control standards is essential. The stormwater treatment effectiveness mapping and GIS screening conducted for the Stormwater Strategy project (City of Sammamish, 2021) can support identifying priority and potential sites for retrofit projects.

Consideration of the above conclusions positions the City well to ensure that streams and wetlands are protected from hydrologic hazards as Sammamish continues to grow, without requiring lengthy and expensive additional policy development work.

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APPENDIX A

FIELD DATA COLLECTION

A.1 Hydrometric Installations

A.2 Field Data Post-processing

A.1 Hydrometric Installations

Following the basin reconnaissance visit and monitoring site selection, NHC installed three hydrometric stations at the locations shown in Figure 2.1. Sites 1 and 2 were equipped with Unidata Starflow 6526 instruments mounted in culverts, which record water depth and depth-averaged velocity, while site 3 was equipped with a Solinst Levellogger in a stilling well, which records water depth. Photos 1-3 show sites 1-3, respectively. Data were collected from November 2021, prior to the largest events of the winter, through June 2022, when the creeks in the upper portions of both basins were dry at sites 1 and 2. Site inspection and maintenance visits were generally conducted monthly over that period to download data, clean sensors, replace batteries, and ensure that instruments were continuing to function as intended.

Photo 1 Upper George Davis Creek under driveway culvert near 223rd Pl NE. Note sediment buildup

Photo 2 Upper Ebright Creek gauge site at outlet of culvert in Big Rock Park North. Note clean pipe bottom and low velocities upstream of fence

Photo 3 Lower George Davis Creek stage recorder inside PVC stilling well

A.2 Field Data Post-processing

The Starflow depth and velocity data were converted to discharges using measured culvert geometry to compute a cross-sectional area for a given flow depth and multiplying by the average measured velocity. At lower flows, velocities measured by the Starflow instruments were determined to be more subject to outlier measurements, and at site 2, a backwater condition was identified at higher stages. Both of these factors necessitated that manual adjustments and data cleaning be performed on the velocities before credible flow estimates could be computed. Residual uncertainty remains in the discharge data, but these are the cleaned time series for sites 1 and 2 that are shown in Figure 2.2A and B.

For site 3, the recorded water depth measurements were converted to discharge by means of a rating curve from a 1D HEC-RAS model developed for a culvert replacement project downstream of the monitoring location (NHC, 2020). The gauge was installed between two model cross-sections, so rating curves were developed based on both sections (ST 703 and 748 in the model) and the compared to field discharge estimates before adopting the curve based on the more upstream section. The adopted rating curve is shown in Figure A.1, and the flow time series at site 3 shown in Figure 2.2C. There is still substantial uncertainty in the adopted rating curve, as there were limited field measurements available to validate the curve, but it appears to provide credible estimates of flow from the monitoring data.

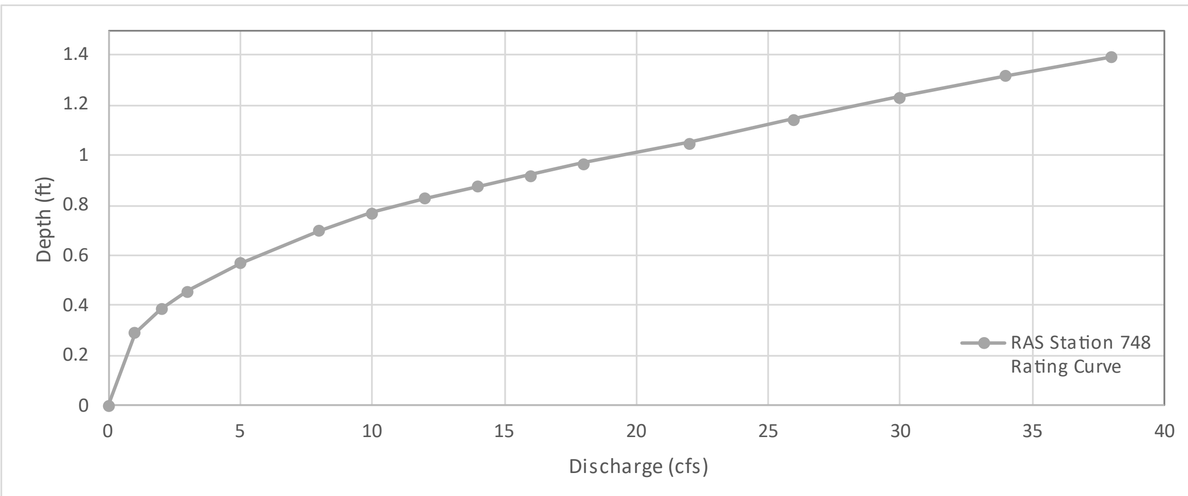

Figure A.1 Site 3 rating curve used for flow estimation from level logger water depths

It should be noted that the January 2022 storm event resulted in several inches of sediment accumulating around the base of the stilling well as it was caught upstream of woody debris stuck against the mounting post. This was cleared during the January 28 site visit and the sediment generally flushed immediately downstream, but January flows remain somewhat questionable. This could account for the substantially higher peak in the January event at the lower George Davis gauge, where both upper George Davis and Ebright records show similar peak flows for the January and March events.