HYDROLOGIC MODELING IN SUPPORT OF WATERSHED BASED LAND USE PLANNING IN THURSTON COUNTY

FINAL HYDROLOGIC MODELING REPORT

Prepared for:

THURSTON COUNTY
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SINCE 1852

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Executive Summary

This report documents the application of watershed modeling to support land use management that protects aquatic resources in Thurston County, Washington. The Hydrologic Simulation Program-Fortran (HSPF) was used to characterize the hydroecological condition in three representative stream basins using selected flow and water quality metrics considered to be important for aquatic health and beneficial uses. A total of five land use scenarios per basin were simulated including "Pre-European", "Existing", and three alternative future land use conditions designated "Planned Trend", "Future Alternative 1"and "Future Alternative 2". Simulated model outputs for each of these scenarios were used to calculate the flow and water quality metrics. Comparisons between existing and historic scenarios and between alternative future scenarios provides an indication of the hydroecological status of the basins today, as well as what may be expected 25-30 years (year 2040) in the future with different combinations of land use policies, regulations, and restoration activities.

The basin modeling study reported herein is part of a larger project titled "The *Guiding Growth – Healthy Watersheds: Translating Science to Local Policy"* (SLP) that is funded by the U.S. Environmental Protection Agency (USEPA) through its National Estuary Program. The larger project goal is to develop a plan that accommodates projected population growth while preserving water resources. This planning area includes approximately 279 square miles within the watersheds of the Deschutes River, Totten Inlet, Eld Inlet, Budd Inlet, Henderson Inlet, and the Nisqually Reach. The boundaries of this planning area are shown in Figure E-1.

Modeling Project Roles

Model development, application and reporting was completed by staff of Northwest Hydraulic Consultants (NHC) under contract to the Thurston County Resource Stewardship Department. GIS and planning support was provided by the Thurston County Regional Planning Council (TRPC). Independent technical review of the modeling project was provided by a Science Advisory Team of highly qualified watershed planning and science professionals consisting of Derek Booth (Independent Consultant), Joan Lee (King County DNRP), Krista Mendelman (EPA), Stephen Stanley (Department of Ecology), and Scott Steltzner (Squaxin Island Tribe).

Basin Selection

Three basins were selected for detailed hydrologic modeling- McLane Creek, Black Lake, and Woodard Creek. These basins lie within the greater Eld Inlet, Budd Inlet, and Henderson Inlet watersheds respectively. These basins were selected for a detailed modeling study using several criteria including data availability to support modeling, basin representativeness in terms of geography, and concerns related to land use planning, water quality and aquatic resource protection. In addition, the support of affected jurisdictional stakeholders was a key criterion. These included the Squaxin Island Tribe and the cities of Tumwater, Olympia, and Lacey. McLane Creek is a rural and primarily forest covered basin with high aquatic resources values and very minor existing impact from urbanization. Black Lake is both urban and rural and includes an important recreational lake with ongoing water quality challenges, and Woodard Creek drains both a growing urban area and partially urbanized rural zones to Henderson Inlet, a sensitive, commercial shellfishing area.

Hydrologic Model

The Hydrologic Simulation Program Fortran (HSPF) is a comprehensive package for simulation of watershed hydrology and water quality. The model can simulate the flow and associated water quality processes on pervious and impervious land surfaces and in streams and well-mixed impoundments.

HSPF is one of a very few comprehensive models of watershed hydrology and water quality that allows the integrated simulation of land and soil contaminant runoff processes with in-stream hydraulic and sediment-chemical interactions.

HSPF was selected for this study because of a long history of successful applications of the model in western Washington and its ability to continuously simulate stream flow and pollutant concentrations in response to land use and stormwater management scenarios. HSPF has been the standard watershed model of choice in western Washington for basin-scale modeling since the 1980s, but it is only recently that the models water quality routines have been used to simulate pollutant loadings in streams in this region. The first such studies were conducted by King County (2003) in the Green-Duwamish and Lake Washington Basins. That earlier work was built on more recently by a study in the Juanita Creek basin (King County, 2012). King County's Juanita Creek study was focused on identifying and pricing different stormwater retrofit alternatives to achieve recovery of beneficial uses in a basin that is almost completely built out. In addition to simulation of flow hydrographs, this study applied model routines that tracked the concentrations of a range of pollutants, including suspended sediment, heat, dissolved oxygen, nutrients, copper, and fecal coliforms. While experience with continuous modeling watershed pollutant loading and resultant pollutant concentrations in streams with *any* model is both recent and limited, HSPF was considered an appropriate choice for this study given its regional success in simulating stream flow, and its long acceptance by EPA as a water quality model and TMDL development tool.

Historic, Existing, and Alternative Future Basin Modeling Scenarios

Five hydrologic modeling scenarios were represented in each of the three study basins, Pre-European, Existing Conditions, and three alternative future scenarios designated as "Planned Trend", "Future Alternative 1" and "Future Alternative 2". The purpose of the Pre-European simulation is to hindcast stream flows, water quality parameters, and their metrics for the near-pristine, primarily forested, watershed conditions that prevailed prior to land transformations to establish today's rural, suburban, and urban land uses. Pristine conditions, their flow regime, and water quality characteristics are used as a benchmark to judge the level of degradation associated with existing and alternative future conditions. Simulation of the existing conditions served two purposes; it allowed calibration of the HSPF model using the available flow and water quality data, and it provided a summary "report card" of hydroecological condition through comparison of its metric values with those of the Pre-European condition. Simulation of the three future alternatives provided a projection of how flow and water quality metrics are likely to shift in the future in response to different regulations and restoration actions. Together, the simulations provide a picture of how hydroecological conditions stand today and whether and to what degree flow regime and water quality metrics will improve or degrade relative to their existing levels when different management strategies for protecting and restoring aquatic resources are implemented. Details of each scenario are provided in Table E-1.

Table E-1: Modeling Scenario Descriptions	
Scenario	**Description**
Pre-European	No European immigration influences on clearing or development in the study area. This scenario provides an upper limit on what is achievable via complete watershed restoration.
Existing Conditions	Current land cover and population.
Planned Trend	30-year forecasted population growth with existing planning regulations (zoning and development requirements) and stormwater controls.
Future Alternative 1	30-year forecasted population growth with reduced density and LID flow control.
Future Alternative 2	30-year forecasted population growth with reduced density, LID flow control, stormwater retrofits, wetland restoration, and riparian restoration.

Model-Derived Metrics Used to Compare Scenarios

A set of flow and water quality metrics were selected to represent the impact of hydrologic change on aquatic resources and address key water quality constituents of concern in all three study basins. For hydrology, metrics were selected that are related to the health of the streams biotic community as measured by the Benthic Index of Biotic Integrity (B-IBI) and to fish passage conditions. DeGasperi et al. (2009) evaluated correlations between hydrologic metrics (flow regime statistics) and B-IBI data from around Puget Sound and found that the strongest correlations were exhibited by the following:

- **High Pulse Count (HPC) -** A "High Pulse" is an occurrence of daily average flow that is equal to or greater than a threshold set at twice the long-term daily average flow rate. The HPC statistic is simply a count of the number of discrete High Pulses that occur in a given water year (October 1^{st} through September 30^{th}).
- **High Pulse Range (HPR) -** Also using the High Pulse, the HPR statistic is a count of the number of days between the first high flow pulse and last high flow pulse during a water year.

Additionally, the **Average Annual 7-Day Minimum Flow –** defined as the annual minimum of the seven-day moving average of simulated hourly flows is a key metric affecting fish movement and availability of habitat.

A review of the water quality concerns for each basin led to the selection of the metrics representing the following water quality parameters:

- **Temperature** – All three basin streams violate temperature standards, and temperature is especially a concern in McLane Creek because of its high level of salmon productivity and existing loss of riparian cover. (Thurston County Watershed Characterization, 2012)
- **Fecal Coliform** –All three basins have high fecal coliform bacteria levels, but the problems in McLane Creek and the existing bacteria TMDL in Woodard Creek were the primary drivers in focusing on this parameter.
- **Nitrogen** – The Thurston County Environmental Health Division has placed a high priority on reducing nitrogen loads from all three of the study area basins. Nitrogen needs to be controlled to protect and improve the condition of marine waters in the County. This report focuses on nitrate + nitrite because the ammonium fraction is typically relatively small. We refer to the sum of nitrate and nitrite as "nitrate" throughout the report

- **Phosphorus –** A need to control phosphorus concentrations has been noted for Woodard Creek and Black Lake. The TMDL for Henderson Inlet (Ecology, 2011a) recommends that sources of phosphorus (the limiting nutrient) to Woodard Creek be controlled to protect and possibly improve dissolved oxygen levels in the Creek. Similarly, phosphorus control is recommended for control of toxic algae blooms in Black Lake (e.g., Thurston County, 2012).

Metrics were generally computed at two locations in each study basin, one at the mouth representing the entire basin, and one at an upstream point of interest. Average annual load per acre of upstream drainage was used as the metric for nitrogen and phosphorus. The frequency of violation of water quality standards were the metrics used for temperature and fecal coliform counts.

Key Simulation Results

Metrics were calculated from multi-decade, HSPF simulation records of hourly flows, temperatures, concentrations, and loads at two locations of interest in each basin for each scenario. A graphical summary of these results is presented in Figures E-2 through E-4. Existing levels of urbanization and land use have caused marked degradation compared to the pre-European, forested basin conditions across all five metrics and all basin locations, with the only exception being for flow regime in McLane Creek basin. Here, forest cover still predominates today and there is very little impervious area.

Overall, none of the selected metrics indicate substantial further degradation with any of the future scenarios; and for some parameters the alternative scenarios provide notable improvements over existing conditions. The lack of significant degradation between existing conditions and the Planned Trend scenario can be attributed to the imposition of much more substantial storm water flow control, water quality treatment measures, and critical areas protections going forward than have occurred in aggregate for past development. While future improvements in metric values are estimated to be minimal in most cases, restoration of stream temperatures under Future Alternative 2, especially in Kenneydell Creek in the Black Lake basin and also at the McLane Creek sites is noteworthy. As discussed, this alternative includes a substantial amount of wetland and riparian restoration in each basin, in addition to implementation of stormwater retrofits. These restoration measures are coupled with the more stringent stormwater requirements for new development that include LID practices. In addition to temperature restoration, this alternative also exhibits small to moderate improvements in nitrate and phosphorus loads.

In general, results indicate that the Planned Trend scenario holds the line at existing levels of degradation across all basin sites and metrics. Future 1, which includes the application of LID stormwater treatments and targeted downzoning, provides small reductions to existing degradation levels, and Future 2 which adds large amounts of riparian and wetland restoration and stormwater retrofits provides a proportionately larger restoration benefit.

Implications for Watershed Based Land Use Planning

This study was undertaken to help policy makers in Thurston County gain a better understanding of how anticipated future development may affect water flow and water quality, and whether management changes can assist in reducing or removing those impacts. To assist in this understanding, the project team intentionally selected three basins with different levels of current and projected growth and with different water resource concerns. The results of this modeling work should be used in conjunction with other information to inform the development of watershed plans for each basin. Public input also will undoubtedly inform how this work ultimately influences land use regulations.

In rural and lower density areas, future land development – which includes the clearing of trees and other vegetation as well as the installation of impervious surfaces – is anticipated to have the greatest potential influence on flows, temperature, and pollution loads in small streams. Land use regulations – including zoning, development regulations, and stormwater requirements – are the primary tools available to local jurisdictions to prevent degradation and protect existing critical habitat and ecological functions in the face of these landscape disturbances.

The Planned Trend scenario was developed to show the future impact of those rules and regulations that are currently in place. In general, the model results show that for these basins, anticipated future development under current regulations would lead to limited additional degradation, but these impacts are minor when compared with the changes from historic to current conditions that have already occurred. This indicates that current regulations – including UGA boundaries, zoning and critical area ordinances – when properly implemented, can be effective at minimizing the impact of new development.

A major caveat to these findings of minimal future degradation requires that modeling assumptions are actually realized. This emphasizes the need to enforce compliance with current regulations. The model also makes assumptions about the average amount of tree clearing and impervious surfaces that would occur in new development, although these are not required limits under County code. A next step in this study could include an evaluation of whether these assumptions should be more formally adopted as standards.

A second caveat is that these results apply only to the land use conditions that have been projected for the three study basins, which have a limited amount of remaining development potential under current land use regulations. For example, increases in total impervious area (TIA) for the Planned Trend scenario range from 1% to 4% or about 25% of existing impervious area for all three basins. For basins with a greater amount of undeveloped and subdividable lots, the cumulative impacts from new development may be much more pronounced.

While the Planned Trend scenario results indicate that there would be zero to slight degradation depending on which metric and basin site is considered, they also underscore the restoration benefit of accommodating population growth through re-development in existing developed areas. This is evident from the much larger amount of degradation indicated by the disparity between the Pre-Euro and Existing scenario metrics as compared with the relatively minor shifts between Existing and Planned Trend or other the other future scenarios. While one reason for this contrast is the smaller amount of projected future development compared to existing development, the other is that existing development has occurred with far less stormwater flow control, water quality treatment, and critical areas protections than will occur in the future. Under current, and soon to be implemented, stormwater regulations, re-development projects will incorporate flow control and water quality treatment measures that are equal to those represented by the Planned Trend scenario, and also the LID component of the Future Alternative 1 scenario. Therefore, re-development has the potential to partially reverse existing levels of degradation.

The Future Alternative 1 scenario was developed to characterize any benefits from potential regulatory changes, such as adjustments to zoning densities and urban growth area boundaries, as well as the introduction of LID flow control standards that will be required under the 2013-2018 Phase II Western Washington Municipal NPDES Stormwater Permit. The model results for this scenario showed small to moderate benefits to water quality in some areas when compared with the Planned Trend for development, particularly within the Black Lake basin, which is the area with the greatest projected increase in future development. This improvement was noted despite the assumption in the Planned Trend scenario that all development in the UGA would be converted to municipal sewer systems, which is unlikely to be implemented due to cost and over-estimate the water quality conditions under the Planned Trend scenario. The suggestion from these results is that removing these sensitive areas from the UGA will not have a negative impact on water quality when compared with the alternative, and may slightly improve conditions, though these results should be taken in consideration with other environmental and social factors before any final determination is made. In other areas, proposed zoning changes show little improvement over the Planned Trend scenario at the basin scale, although the effects of changes in particular sub-basins may be worthy of further study.

The Future Alternative 2 scenario includes substantial restoration of vegetation along stream corridors and stormwater retrofit projects, both non-regulatory management actions. The model results for this scenario showed significant improvement for many water quality parameters, particularly temperature. This outcome corresponds with the general finding that, for most parameters, the greatest change has already occurred between pre-European and existing conditions, and that improved conditions will result from a combination of restoration actions and thorough application of the latest storm water standards and related environmental regulations. In subbasins where there is minimal restoration opportunity, additional degradation is expected to be relatively small compared to existing levels as long regulations are applied and additional land development is not more extensive than assumed in this study. On the other hand, if older developed areas are re-developed, there is a potential to augment the restoration benefits accomplished by more direct activities such as restoration of wetland areas and riparian vegetation.

Given this pattern of identified impacts and degradation, the greatest opportunity for water quality improvements almost certainly lies in restoring ecological processes that already have been degraded by development that occurred under older regulations that provided less protection. Such restoration cannot be achieved through changes to regulation alone, but could be supported through incentive programs that encourage landowners to replant along stream corridors and/or provide funding for restoration projects, and through capital investment in stormwater retrofits to apply more treatment and flow control in older areas that were developed without this infrastructure. Additional work could study which stream reaches or sub-basins provide the greatest ecological lift with restoration.

All three future scenarios included an assumption that 20% of new development and re-development would not receive flow control or water quality treatment. The purpose of this assumption was to account for the fact that practically speaking, storm water facilities mandated by regulations are applied to less than 100% of development and are also less than 100% effective in achieving the level of control and treatment equal to applicable design standards. Small scale development is sometimes below regulatory thresholds, some flawed designs slip through the review process, construction may deviate from design plans, and facilities are too frequently poorly maintained and lose effectiveness over time. While these problems are not an argument for the abandonment of stormwater facilities as a means of mitigating the effects of land development on streams, they do stand as a caution against over-reliance on such measures to protect high value aquatic resources. In contrast, minimization of forest conversion to more intense land use, and preservation of natural areas with strong hydrologic linkages to these high value resources provides the most reliable protection.

This study provides a snapshot of how anticipated development in Thurston County may impact water resources in three small basins. Any full basin plan should consider a wide range of additional factors, including potential impacts to habitat for fish and wildlife (including endangered species), public services, floodplain management, as well as stakeholder and public input. While the results are limited to illustrating the effects on water flow and water quality, hydrology is the first among equals with regards to the impacts of urbanization on streams.

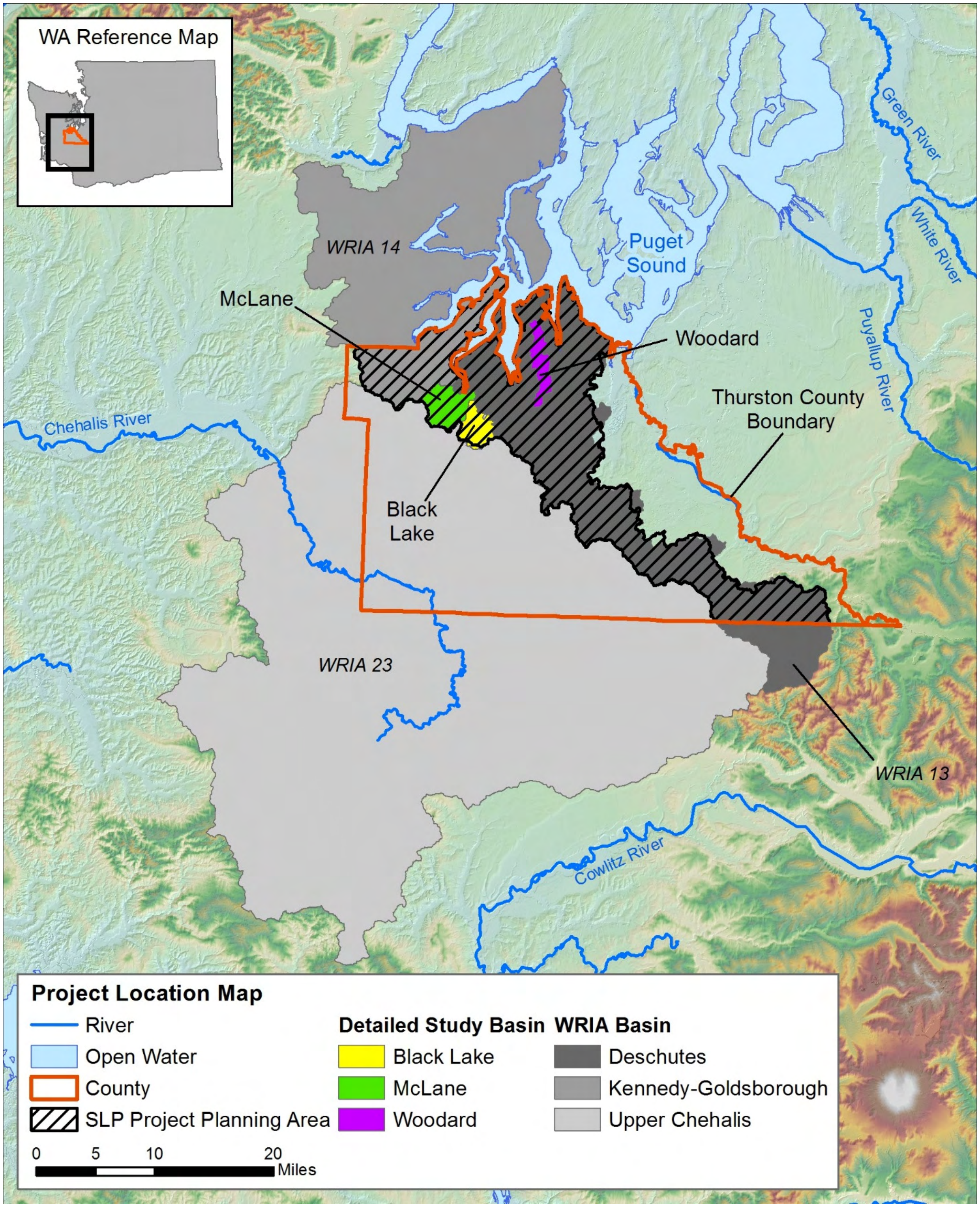
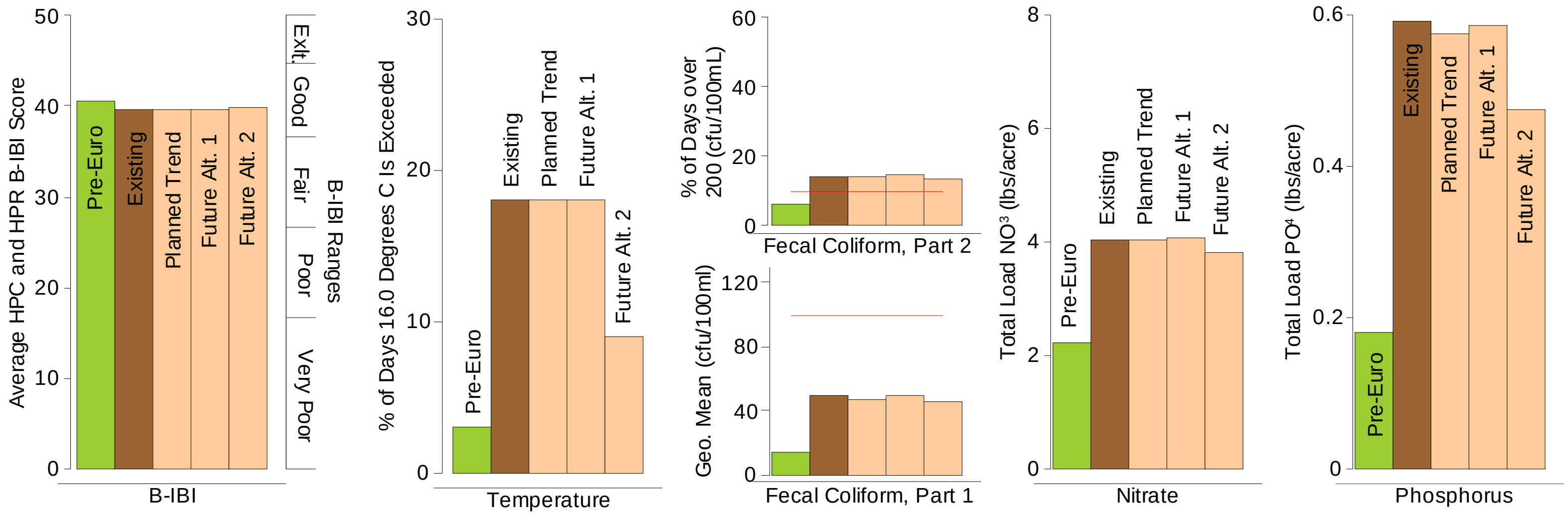


Figure E-1. Study Area and Selected Basins for Modeling

McLane Creek at Eld Inlet (Reach 51)



East Fork McLane Sub-Basin (Reach 67)

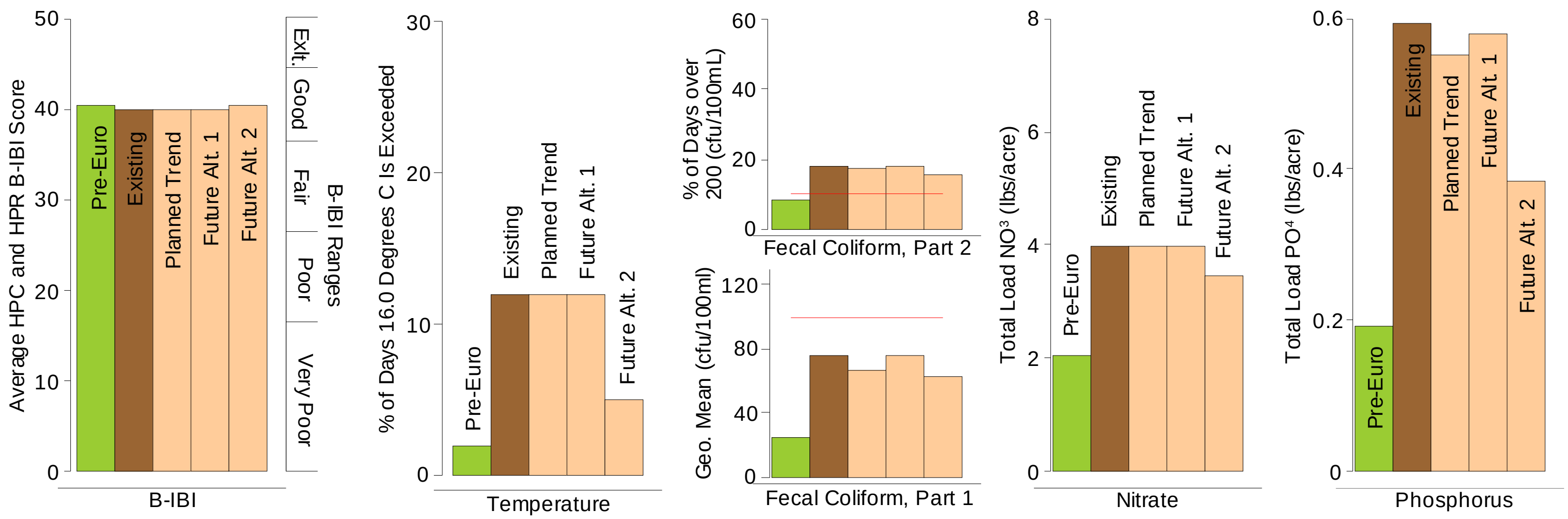
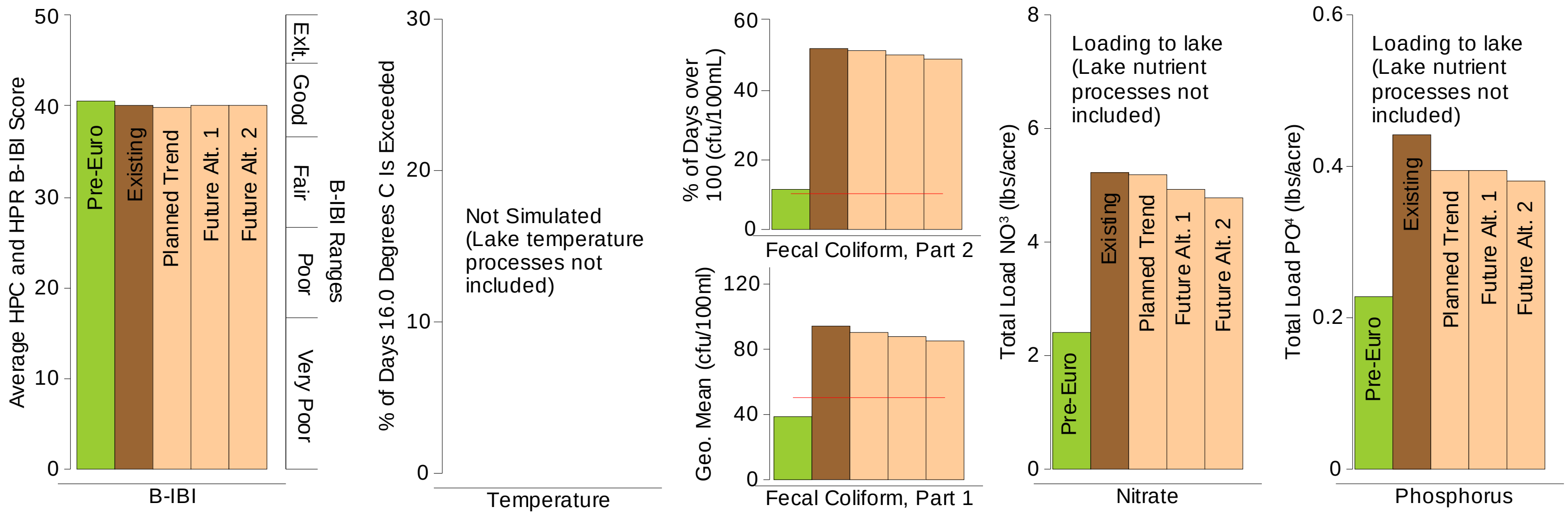


Figure E-2. Modeling Results, McLane Creek Basin

Black Lake Basin (Load into or out of Reach 36)



Black Lake, Kenneydell Park Stream Sub-Basin (Reach 17)

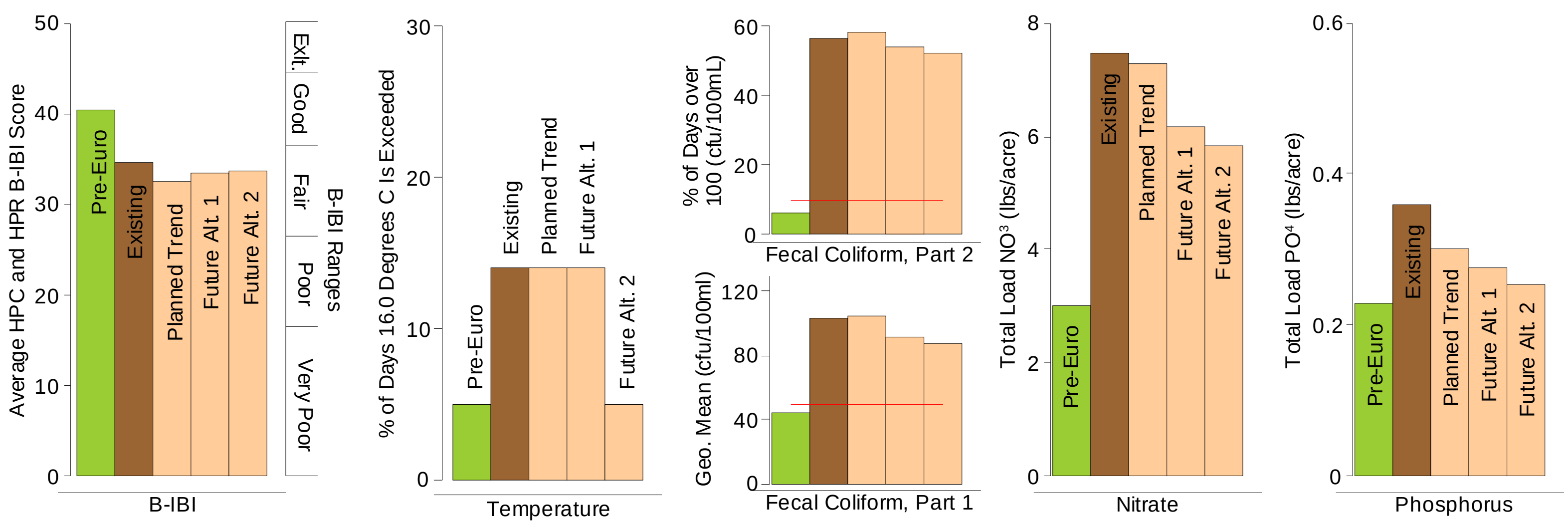
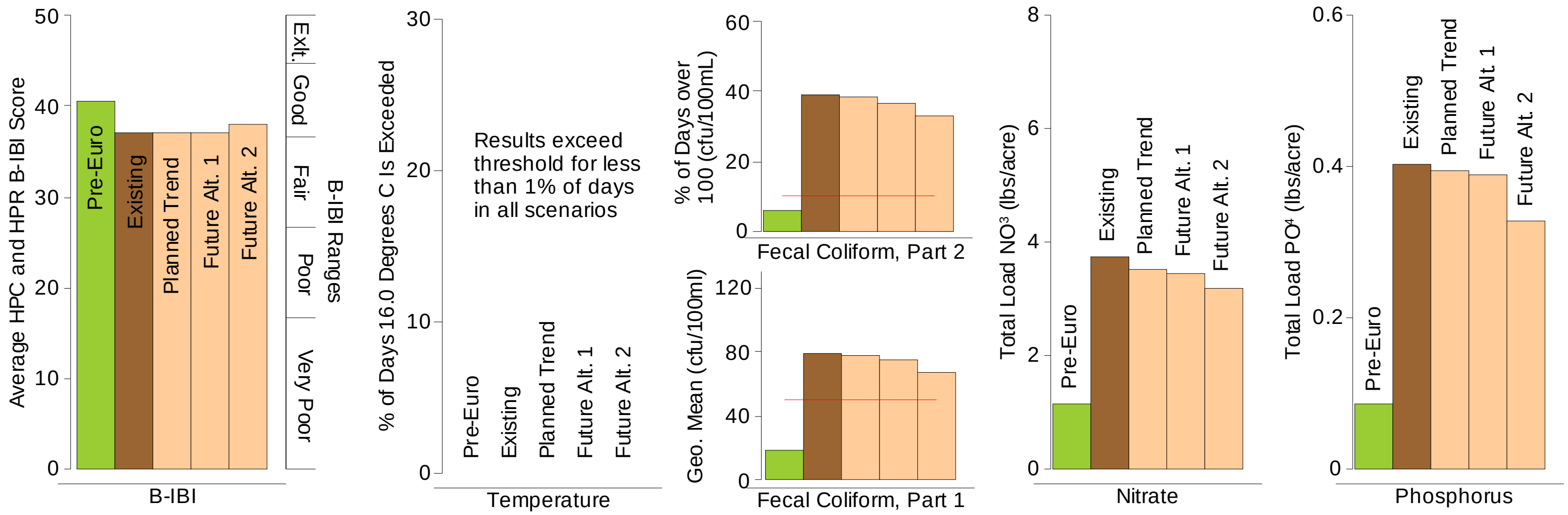


Figure E-3. Modeling Results, Black Lake Basin

Woodard Creek at Henderson Inlet (Reach 101)



Woodard Creek at UGA Boundary (Reach 117)

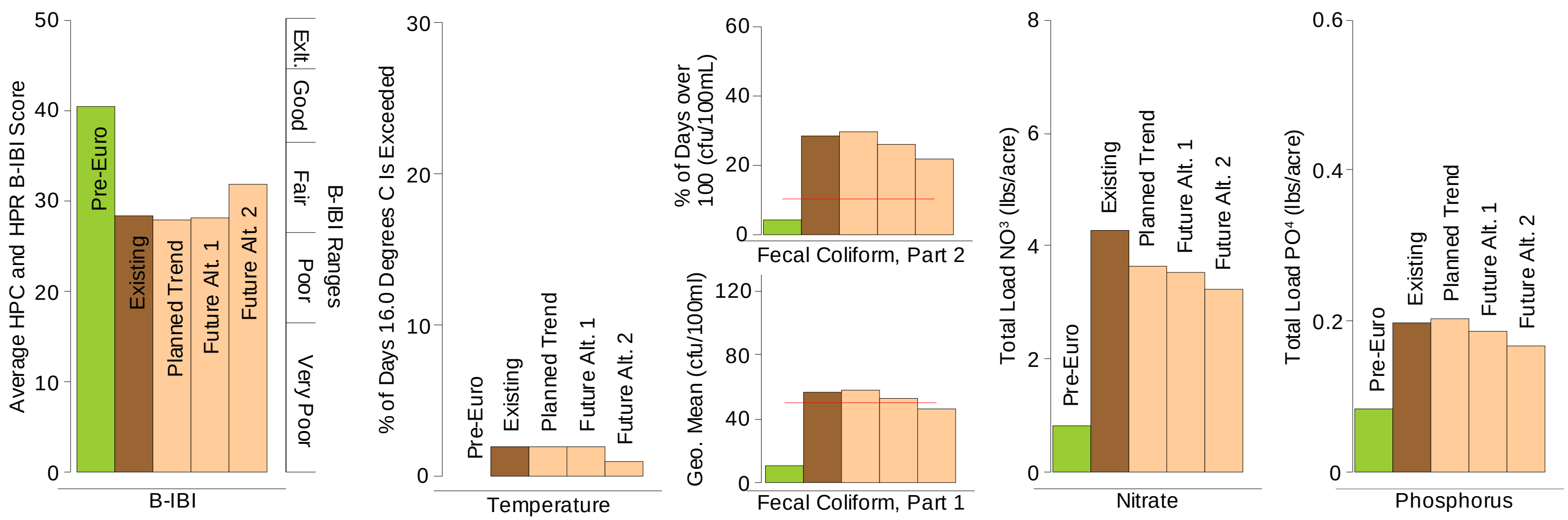


Figure E-4. Modeling Results, Woodard Creek Basin

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1 Introduction

1.1 Project Purpose and Overall Approach

The purpose of this report is to document the application of calibrated watershed models in support of land use management actions that protect aquatic resources in Thurston County, Washington. This objective is accomplished through modeling the hydroecological[1] response in three representative stream basins to five different land use scenarios. One scenario hindcasts the near-pristine, pre-European condition of the basins, another simulates existing conditions, and the remaining three project different future land use and watershed management alternatives. The primary use of the model results is in *estimating and comparing the magnitude of differences* between metrics of hydrologic and water quality response among scenarios for each of the three basins. In aggregate, these comparisons provide both an overview of the level of aquatic resource degradation caused by existing land development, as well as a projection of how different watershed management actions may reduce or increase this degradation in the future.

The watershed modeling study documented in this report is part of a larger project titled "The *Guiding Growth – Healthy Watersheds: Translating Science to Local Policy"* (SLP). Thurston County (the County) received funding from the U.S. Environmental Protection Agency (USEPA) through its National Estuary Program to develop a plan to accommodate projected population growth while preserving water resources in portions of the County that drain to the Puget Sound (excluding the Nisqually River). This planning area includes approximately 279 square miles within the watersheds of the Deschutes River, Totten Inlet, Eld Inlet, Budd Inlet, Henderson Inlet, and the Nisqually Reach. The County engaged Northwest Hydraulic Consultants Inc. (NHC) to provide hydrologic expertise in the development and application of hydrologic models to assess the impact of various land use planning and management options on water quality and aquatic resources. Three at-risk basins tributary to Puget Sound are studied in detail through the application of hydrologic modeling of historic and future land use scenarios.

The boundaries of the SLP planning area, shown in Figure 1, are defined by portions of the County lying within two continuous water resource inventory areas (WRIAs 13 and 14) defined by the Washington Administrative Code (WAC) 173-500-040 plus a small area of the Black Lake basin that is included in WRIA 23. For planning purposes, the County divided these study areas into subwatersheds that contribute runoff to five distinct inlets to the Puget Sound: Totten, Eld, Budd, Henderson, and the Nisqually Reach. These subwatersheds were divided into a total of 69 headwater and 3 non-headwater stream basins.

1.2 Background

Thurston County is located at the southern end of Puget Sound and is one of the fastest growing counties in Washington State. The 2012 population forecast developed by Thurston Regional Planning Council (TRPC) projects that the number of people living in Thurston County will increase by 150,000 over the next 25 years, an increase of more than 50%.

The SLP project was begun with the understanding that preventing impacts to ecological functions in the face of land-use changes is less expensive and often more effective than paying to restore natural forest cover and stream flow conditions after they have been extensively altered. The approach looks at landscape patterns from a basin scale by determining the management goals and policies that are most appropriate based on the current conditions and future potential of an area within its watershed context. The aim of the SLP project is to prevent basins that are in good condition from becoming impacted by future development,

[1] The term hydroecological as used herein describes stream attributes and corresponding watershed model outputs including stream discharge and water quality constituent concentrations and loads that are considered to impact the overall health and beneficial uses of aquatic resources. As a practical matter, the hydroecological status associated with any scenario is characterized by selected statistics or "metrics" derived from simulated, long term, time series of each output.

and to prevent basins that are partially impacted, but still provide ecological benefits, from becoming further degraded.

The watershed planning process began in 2010 and includes the following stages:

1. Evaluate basins based on current conditions and risk of impacts from future growth. (completed)
2. Perform a detailed study, including hydrologic modeling of historic and future land use scenarios, of three at-risk basins tributary to Puget Sound. (this report)
3. Develop recommended changes to management policies. (future stage)
4. Adopt and implement changes to land use practices. (future stage)
5. Monitoring/adaptive management. (future stage)

Much of the evaluation data for Stage 1 was collected in a report produced by TRPC entitled*, Basin Evaluation and Management Strategies for Thurston County* (2013). The results of Stage 2 are detailed in this report and will be used by the County to inform future project stages. The effectiveness of the policies developed and implemented through Stages 3 and 4 will be evaluated in Stage 5.

This study project team included staff from Thurston County's Resource Stewardship Department (Long Range Planning and Water Resources Divisions), TRPC, USEPA, and Northwest Hydraulic Consultants. The basin scenarios and management recommendations were developed with the input and assistance of planning and public works staff from the cities of Olympia, Tumwater, and Lacey, and the Squaxin Island Tribe, as well as members of the Municipal Stormwater Technical Advisory Committee for Thurston County (StormTAC), and the WRIA 13 Salmon Habitat Workgroup.

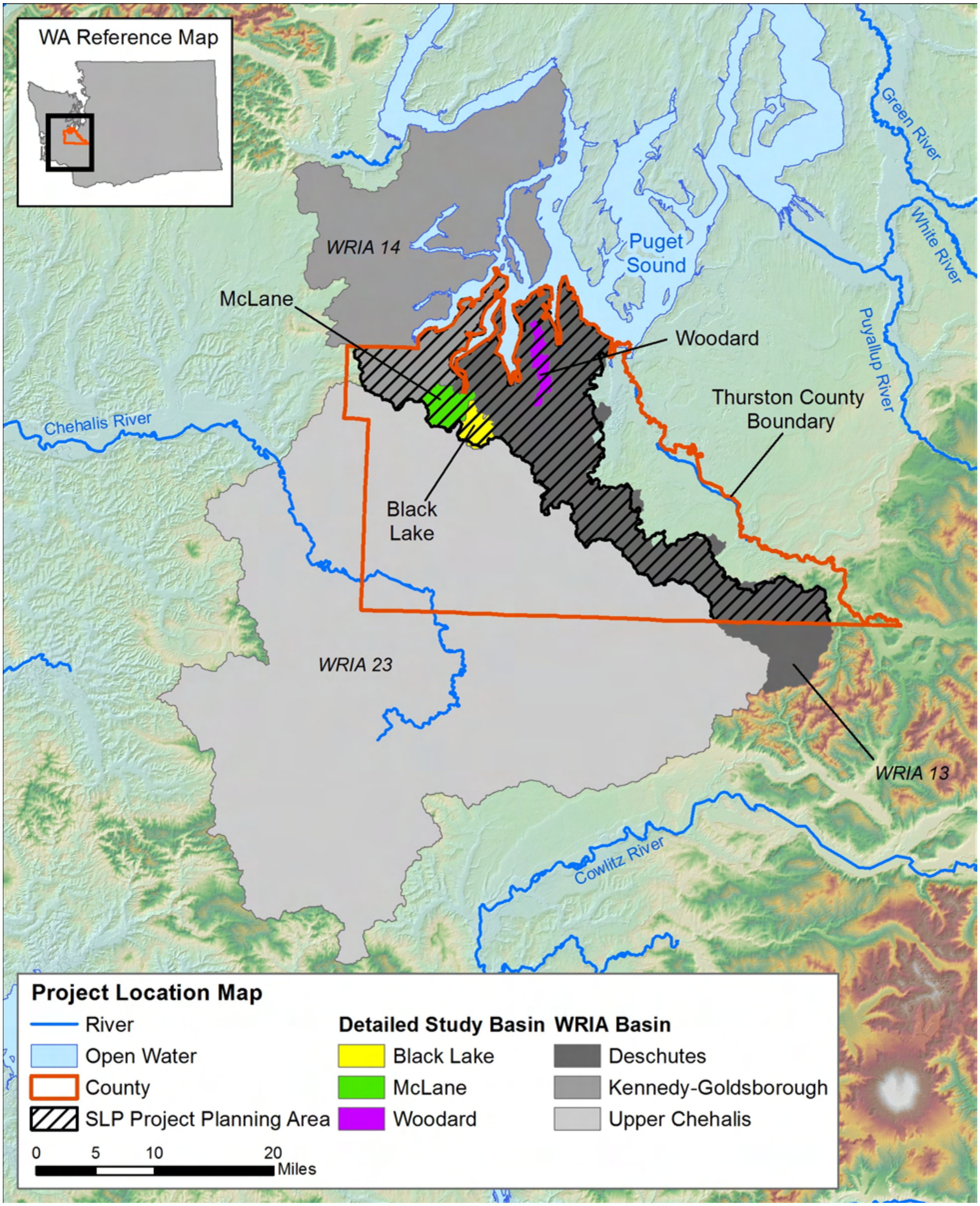

Figure 1: Project Location Map Showing the SLP Project Planning Area and Three Basins <u>Studied in Detail through the Application of Hydrologic Modeling</u>

1.3 Science Advisory Team

Thurston County requested that NHC convene a Science Advisory Team (SAT) as part of the project scope of work. The role of the SAT is to provide review and advice to the project team in the form of discussion, review, and comments on intermediate products and the final project report.

The SAT was engaged in the review of intermediate work products and the final project report. Intermediate work products subject to SAT review included:

a. Technical memorandum summarizing findings on project coordination and how the Thurston County Watershed Characterization results will be incorporated (Task 2 of NHC's scope of work)
b. Quality Assurance Project Plan (QAPP) for watershed modeling (Task 3 of NHC's scope of work)
c. One additional intermediate memorandum or report as requested by the NHC project manager (e.g., basin/subwatershed selection for hydrologic modeling)
d. Draft Final Hydrologic Modeling Report (Task 8 of NHC's scope of work). SAT member comments on the draft of this report are included in Appendix G.

The SAT consists of the following members:

- Derek Booth, Affiliate Professor, University of Washington
- Stephen Stanley, Wetlands Scientist, Washington State Department of Ecology
- Scott Steltzner, Research Fisheries Biologist, Squaxin Island Tribe
- Joan Lee, Rural and Regional Services Section Manager, King County DNRP/WLRD

1.4 Previous Grant, Watershed Characterization

The County's current watershed planning project was conceived as a venue to apply several new landscape-scale assessment tools, including those produced through the Thurston County Watershed Characterization (TCWC), which was developed with grant support from the U.S. Environmental Protection Agency. The TCWC uses a GIS-based method of landscape assessment to evaluate key ecological processes at both a landscape and site-scale. The County has completed four characterizations, including for Henderson Inlet Watershed (2007), Totten-Eld Inlet Watershed (2009), Deschutes Watershed (2011), and Nisqually Watershed (2013).

The TCWC assesses five ecological processes (delivery and movement of water, sediment, wood, pollutants, and heat) and habitat connectivity at the Drainage Analysis Unit (DAU) scale. Each DAU measures approximately 160 acres (0.25 square miles), and is ranked for each ecological process as Properly Functioning, At Risk, or Not Properly Functioning. DAUs that rank "At Risk" for multiple processes are assumed to have the greatest potential to provide functional lift (i.e. improvement) if restored. Potential natural resource sites identified from aerial photos within the watersheds are evaluated and ranked based on both site conditions and the condition of the DAU in which they are located.

As part of its scope of work, NHC conducted a thorough review of TCWC and outlined the limitations and appropriate uses of these data for the selection of detailed study basins and hydrologic modeling detailed in the remainder of this report. This review is detailed in a memorandum to the Science Advisory Team dated the 22nd of February 2013, and is included in Appendix (X).

2 Data Availability and QAPP

A Quality Assurance Project Plan (QAPP) was developed as an early step in the hydrologic modeling study. That document, dated March 13, 2013, is included as Appendix B of this report. The QAPP was prepared to address quality assurance issues related to the basin selection and hydrologic modeling documented in this report. The QAPP also references an additional NHC memorandum, dated January 14, 2013, that documents the availability of data within the larger study area. That memorandum is included as Appendix C. This was the first of two phases of data review. The first was conducted to support the QAPP and selection of the three basins that would be studied in detail through the application of hydrologic modeling (discussed in Section 3). Following basin selection a second phase of data review occurred. In this second phase needed datasets were acquired and further reviewed for use in calibration and application of the hydrologic model(s). Only a limited amount of new data (temperature) was collected as part of this project. A brief overview of the data used for modeling is provided in Section 4.7.

3 Basin Selection

As stated in the Introduction, the SLP project planning area includes all portions of the County that drain to Puget Sound (excluding the Nisqually River), but due to limited project resources only three basins were studied in detail through the application of hydrologic modeling of historic and future land use scenarios. Therefore, a rationale was needed to select these three basins from the 69 headwater and 3 non-headwater stream basins in the planning area. This Section of the report documents the basin selection criteria, the application of these criteria, and the resulting recommendation of basins to be modeled.

Results of the hydrologic model simulations performed on the three basins selected will support basin management decisions related to land use and stormwater regulations, capital projects, and other actions that are aimed at restoration, protection, and enhancement of aquatic resources and beneficial uses throughout the larger SLP project planning area.

3.1 Selection Criteria

Over several meetings and phone calls spanning what sometimes seemed like an interminable period of months, NHC, the County, and TRPC staff developed and prioritized a set of criteria as follows:

1. Adequacy of precipitation, flow, and water quality data
2. Stakeholder interest and jurisdictional cooperation
3. Existing ecological status of basin and aquatic resources
4. Anticipated future changes in basin land use and management
5. Purpose/Effectiveness of basin modeling to support protection, restoration, and enhancement measures
6. Representativeness of selected basin group

Criterion 1. Data availability

A minimum of two years of contemporaneous water quality, precipitation, and stream flow data are highly desirable for purposes of calibration and validation of a watershed model, and the absence or insufficiency in contemporaneous data sets at a stream location diminishes the prospects for credible hydrologic and pollutant runoff modeling. Data availability was evaluated through a detailed inventory of available data conducted by NHC (2013) for the entire project area. From this inventory, it was determined that water-quality data had been collected for a period exceeding two years in 17 out of the 69 mapped basins within the study area. These 17 basins were further ranked based on the availability of local contemporaneous precipitation and stream-flow data accompanying the water-quality data.

Seven out of the 17 basins with water-quality data had no qualifying stream flow data and were, therefore, eliminated from further consideration. The remaining ten basins were then ranked into three tiers of data richness and suitability to support basin modeling. These tiers are shown in Table 1 in descending order of data availability. The top set of six all have at least two years of contemporaneous precipitation, stream flow, and water quality data. The second tier have slightly less than two years, and the third tier represents a special case because the two Deschutes “basins” are not headwater basins of the Deschutes River, but are contributing sub-areas, and as such, present additional challenges to basin modeling.

Table 1: Thurston County Basins with Significant Flow and Water Quality Data Records			
Basin	**Watershed**	**Drainage Area (ac)**	**Note**
Tier 1 following Water-Quality Data Availability Screen			
Green Cove Creek	Eld	2220	**Very Close RG, > 2 yrs of Flow Data**
Percival Creek	Budd-Deschutes	5660	**Moderately Close RG, > 2 yrs of Flow Data**
Woodard Creek	Henderson	5310	**Moderately Close RG, > 2 yrs of Flow Data**
Black Lake	Budd-Deschutes	4390	**Adequately close RG, > 2 yrs of Flow Data**
McLane Creek	Eld	7090	**Adequately close RG, > 2 yrs of Flow Data**
Chambers Creek	Budd-Deschutes	8480	**Adequately close RG, > 2 yrs of Flow Data**
Tier 2 following Water-Quality Data Availability Screen			
Woodland Creek	Henderson	16280	**Moderately Close RG, < 2 full yrs of Flow Data**
Ellis Creek	Budd-Deschutes	940	**Moderately Close RG, < 2 yrs of Flow Data**
Tier 3 following Water-Quality Data Availability Screen			
Deschutes River (Mainstem Lower)*	Budd-Deschutes	11210	**Moderately Close RG, < 2 yrs of Flow Data, USGS E St gage and quality sites provide approximate lower boundary, upper boundary data lacking.**
Deschutes River (Mainstem Middle)*	Budd-Deschutes	23180	**Moderately Close RG, < 2 yrs of Flow Data, Vail Rd sites provide upper boundary for flow and quality, data for lower boundary of basin lacking.**
Note: "RG" = rain gage (precipitation data)			

Criterion 2. Stakeholder Interest and Jurisdictional Cooperation[2]

Stakeholder input was identified as an important factor in the basin selection process. By engaging key players early in the process, the results and recommendations of the project can be better targeted to their demonstrated needs and available resources, and thus are more likely to be successfully implemented.

Project staff from the County and TRPC conducted a series of meetings and outreach to jurisdictions, tribal managers, and other parties with interest in the basins under consideration. The object of this effort was to identify basins with strong stakeholder support, understand which jurisdictions might have the resources to assist in working on land-use changes within a basin in their area, learn about any ongoing or expected projects that might be complementary to this project, and gather information that could be used in developing future land-use scenarios for modeling. Comments were collected from the following groups between March 5 and March 20, 2013 (with abbreviations in Table 2):

[2] Material for Criterion 2 was contributed by Allison Osterberg, Associate Planner, Thurston County.

- City of Olympia, Community Planning & Development and Public Works (Oly)
- City of Tumwater, Community Development and Public Works (Tum)
- City of Lacey, Community Development and Public Works (Lacey)
- Water Resource Inventory Area 13 & 14 Salmon Habitat Restoration Workgroup (WRIA 13/14)
- Stormwater Technical Advisory Committee (StormTAC)
- Squaxin Island Tribe Natural Resources

These discussions revealed considerable support for the project overall, and for selecting several basins in particular. Out of the ten basins with sufficient data to support hydrologic and water-quality modeling, six were identified by the project team as having strong stakeholder support from one or more groups:

- McLane Creek
- Woodard Creek
- Deschutes River (Middle and Lower)
- Black Lake
- Woodland Creek

Descriptions of stakeholder input on all basins considered are summarized in Table 2. Of the entire suite of potential basins, Percival Creek basin (which is divided between the cities of Olympia and Tumwater) received the most conflicting input. It was noted as a basin of secondary interest to staff from Tumwater, after Black Lake, but it was not considered a priority basin to the City of Olympia.

Table 2: Stakeholder Input on Potential Basins for Modeling		
Basin	**Basin Preferred by Stakeholders**	**Stakeholder comments**
McLane Creek	Yes	• Preferred basin for WRIA 13/14 Salmon Habitat Restoration work group, which has done restoration work in the basin and has plans to do more. • Wild Fish Conservancy is conducting an extensive stream typing survey in this basin, focusing on Swift Creek. (WRIA 13/14)
Woodard Creek	Yes	• Preferred basin for City of Olympia. Staff indicate they know the least about this basin out of those in their jurisdiction, but it is an area they want to devote attention to—the future is not "established" in this basin, and there is much room still to build out. (Oly) • Basin is representative of other basins in the region: It has a large wetland complex, residential development, an urban corridor and rural lands. (Oly) • Basin is included in Challenge Grant study of infrastructure along Martin Way—would make a good tie in. (TRPC) • Basin was ranked highly by Ecology as a candidate for stormwater retrofit grant - that potential work would tie in with this project. (StormTAC)
Deschutes River (Lower)	Yes	• Modeling this basin could help Tumwater determine strategies to improve water quality and temperature. That information is less valued than information for Black Lake, because recent modeling information exists for Deschutes with TMDL. (Tum) • Basin is a priority for WRIA 13/14 Salmon Habitat Restoration work group, which has done restoration work in the basin and has plans to do more. (WRIA 13/14)
Deschutes River (Middle)	Yes	• Preferred basin for Squaxin Island Tribe. • Preferred basin for WRIA 13/14 Salmon Habitat Restoration work group, which has supported restoration work in the basin and has plans to do more.
Black Lake	Yes	• Preferred basin for City of Tumwater. Basin has considerable residential growth potential. Staff sees more value in modeling this basin than others suggested—less known about this basin than Deschutes, particularly about tributaries. (Tum)
Woodland Creek	Yes	• Preferred basin for City of Lacey. Residential and commercial growth expected in this basin; city has purchased a large area in upper/mid basin and is considering options, including sewer extensions—modeling could help city consider ways to mitigate environmental degradation as basin continues to develop. (Lacey) • Preferred basin for Squaxin Island Tribe, because of salmon resources.
Percival Creek	Mixed	• Northern half of basin is highly urbanized—Olympia staff sees little value in modeling and working in their part of this basin. (Oly) • Southern half of basin is less developed, with considerable development expected in City of Tumwater. Modeling could be valuable for this portion of the basin, especially for area around Trosper Lake. (Tum)
Green Cove Creek		• City staff feel this basin has been studied extensively—little political or technical value to be added by modeling this basin. (Oly)
Ellis Creek		• Basin is too small to make effective changes. (Oly)
Chambers		• Basin has been studied extensively and modeling will have little added value. (Oly)

Criterion 3. Existing Ecological Status

This criterion was assessed using multiple sources of information including cover data and basin narrative descriptions from the Basin Evaluation and Management Strategies Report (TRPC, 2013), Thurston County Watershed Characterization (Reynolds, Wood, and Stedman, 2012), and Ecology's Puget Sound Characterization Project (Stanley et al., 2012 and Wilhere et al., 2012).

<u>Basin Evaluation and Management Strategies Report (BEMSR)</u>: The BEMSR provides the most comprehensive summarization to date of existing basin and aquatic resource conditions in Thurston County, as well as projections of potential future basin cover. Key information characterizing existing basin conditions from this report were used to assist in basin selection for modeling, includes existing percent total impervious area, percent forest cover, and descriptions of existing water quality status.

<u>Thurston County Watershed Characterization (TCWC)</u>: TCWC evaluated the percentage of mature forest cover within the 67-meter (220 feet) buffer of streams within each Drainage Analysis Units (DAU). This evaluation was a component of the TCWC "Movement of Wood" assessment. NHC used GIS processing of TCWC ratings (Properly Functioniong [PF], At Risk [AR], Not Properly Functioning [NPF]) of DAUs to develop basin-average riparian conditions for all basins in the study area. The results were then binned using a Jenks classification[3] to provide three categories (poor, fair, good) that are indicative of riparian conditions relative to other basins within the study area.

<u>Puget Sound Characterization (PSC):</u> PSC provides several indicators of intrinsic hydrologic importance and degradation by analysis unit (AU), the drainage-based mapping unit that makes up a stream basin. Recently, a freshwater habitat index also has been developed for PSC (Wilhere et al., 2013) that ranks the relative importance of freshwater AU habitat in comparison with other AUs in a WRIA. This index considers both the intrinsic characteristics of an AU that are generally not affected by human impact (e.g., underlying geology), the level of basin degradation caused by human actions (basin impervious area), and the existing access and usage of AU streams by salmonids. As in the case of TCWC results for DAUs, the freshwater habitat ratings for AUs were averaged over each individual study area basin.

Table 3 summarizes basin ecological characteristics derived from each of these three sources. Although the entries in this table represent a selective and highly summarized assessment of conditions in each basin, they provide a reasonable thumbnail and ranking of their potential for supporting aquatic resources.

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[3] The Jenks Natural Breaks Classification is a data classification method designed to optimize the arrangement of a set of values into "natural" classes. This is done by seeking to minimize the average deviation from the class mean, while maximizing the deviation from the means of the other groups. The method reduces the variance within classes and maximizes the variance between classes.

Table 3: Indicators of Potential to Support Aquatic Resources						
Basin	**Watershed**	**Basin Area**	**2010 Total Impervious Area %**	**Percent Forest Cover**	**Relative Riparian Forest Integrity**	**Freshwater Habitat Value**
Green Cove Creek	Eld	2,219	12%	66%	High	Medium
McLane Creek	Eld	7,094	1%	73%	Low	High
Black Lake	Budd-Deschutes	4,392	8%	44%	Low	Low-Medium*
Chambers	Budd-Deschutes	8,478	20%	32%	Low	Low
Deschutes River (Lower)	Budd-Deschutes	11,213	15%**	42%**	Medium	Low
Deschutes River (Middle)	Budd-Deschutes	23,181	2%**	53%**	Medium	Low
Ellis Creek	Budd-Deschutes	937	8%	65%	Medium	Medium
Percival Creek	Budd-Deschutes	5,657	26%	46%	Medium	Medium
Woodard Creek	Henderson	5,311	15%	46%	Low	Medium
Woodland Creek	Henderson	16,279	22%	40%	Low	Low

*Black Lake was not mapped as part of the Puget Sound Basin and was therefore not rated in PSC by WDFW. The "Low-Medium" rating was estimated based on the rating for Percival Creek to which Black Lake is connected by Black Lake Ditch.

**Percentages reported for these non-headwater "Basins" are for the local area only and do not account for cumulative cover from the Deschutes Watershed upstream of the local basin.

McLane Basin ranks highest in overall ecological condition and aquatic resource value, given its top ratings in three out of four categories. It has the lowest existing impervious cover, highest existing forest cover, and highest salmon habitat conservation value of all of the basins. The only low ecological attribute listed for McLane is derived from TCWC's rating of the maturity of riparian vegetation, for which it is ranked "low". This overall picture for McLane is substantiated by additional information provided in the BEMSR and its appendices. For example, McLane had a relatively high average B-IBI score between 2002 and 2009 of 38.5; however, a 1999 study found canopy closure to be too low to maintain stream temperature. Forestry and agricultural land use predominate within the basin and it is on the 303d list for fecal coliform bacteria. Multiple salmonid species use the stream system including ESA-listed fall Chinook salmon.

Green Cove and Ellis Creek basins also rank high for existing ecological condition based on existing cover, riparian condition, and freshwater conservation value. These basins have Total Impervious Area (TIA) values of 12% and 8%, respectively, existing forest cover of at least 65%, and riparian condition and habitat conservation value that is medium or high.

The middle-Deschutes, Woodard and Black Lake basins rank somewhat lower than previously discussed basins. These basins have TIA values ranging from 2% and 15%, forest cover between 44% and 53%, and low-to-medium riparian vegetation conditions and habitat conservation value.

Percival, Woodland, Chambers and Lower Deschutes basins have the lowest overall potential to support aquatic resources. These basins have existing TIA values that range from 15% to 26%, forest cover from 32% to 46%, and low-to-medium riparian vegetation condition and freshwater habitat value.

Criterion 4. Potential Future Changes in Basin Land Use and Management

This criterion quantifies the potential threat to aquatic resources posed by changes in future land use and vegetation cover as basins build out in the future. The metrics used to evaluate this criterion include projected increases in basin impervious percentage and losses of existing forest cover. A summary of the metric values for each basin is shown in Table 4.

Future Increases in Impervious Area

McLane, Middle Deschutes, Ellis, and Black Lake all have existing levels of total impervious area that are below 10%. Of these, only Black Lake is projected to be significantly affected by future urbanization, with a near doubling of TIA from 8% to 15% at buildout. Black Lake is also unique among the listed basins because a significant portion of the basin (13%) is occupied by the lake itself, which receives drainage from the remainder of the basin. If loading of pollutants to the lake is the primary concern in evaluating land-use changes in the basin, then it is more appropriate to exclude lake area. When only the land associated with the drainage area to the lake is considered, then existing TIA in the Black Lake basin is closer to 9% and future TIA (again excluding the lake area) would be closer to 17%.

Green Cove, Woodard, and Lower Deschutes have existing TIA ranging from a low of 12% for Green Cove to a high of 15% for both Woodard and Lower Deschutes. Future projected increases in impervious percentage at buildout are all comparatively low to moderate, ranging from 2%-4% of the total basin area.

Chambers, Woodland, and Percival basins have existing TIA levels ranging from 20% to 26% and projected future increases in impervious percentages from 4% to 7% of the total basin area.

From the perspective of both the ratio of projected to existing total impervious cover as well as the simple magnitude of the future increment in imperviousness, Black Lake is the basin with the most dramatic projected increase in total impervious area.

Potential Future Loss of Forest Cover

McLane Creek, Lower Deschutes, and the Middle Deschutes basins have the highest projected reduction in forest cover at buildout ranging from 13% to 14% of the total basin area.

The second highest group is made up of Black Lake and Percival Creek basins, each with a projected reduction in forest cover at buildout of 6% of the total basin area.

In the remaining five basins, Green Cove, Ellis, Woodard, Woodland and Chambers, only small (0% to 2% of the total basin area) reductions in forest cover are projected at buildout.

Table 4: Projected Land Use Change (Increase in TIA and Forest Cover Loss[1])						
Basin	**Watershed**	**Basin Area[2] (acres)**	**2010 Total Impervious Area %**	**Increase in impervious % at Buildout**	**Percent Forest Cover**	**Potential Reduction in Forest % at Buildout**
Green Cove Creek	Eld	2,219	12%	2%	66%	0%
McLane Creek	Eld	7,094	1%	1%	73%	13%
Black Lake	Budd-Deschutes	4,392	8%	7%	44%	6%
Chambers	Budd-Deschutes	8,478	20%	4%	32%	2%
Deschutes River (Lower)	Budd-Deschutes	11,213	15%	4%	42%	13%
Deschutes River (Middle)	Budd-Deschutes	23,181	2%	1%	53%	14%
Ellis Creek	Budd-Deschutes	937	8%	1%	65%	0%
Percival Creek	Budd-Deschutes	5,657	26%	6%	46%	6%
Woodard Creek	Henderson	5,311	15%	3%	46%	1%
Woodland Creek	Henderson	16,279	22%	7%	40%	2%

[1]Potential loss of forest cover at buildout assumes that existing forested areas that are currently zoned for urban, rural and agricultural uses would be fully converted to non-forest cover.

[2] Basin areas reported in this table are based on TRPC (2012) delineations. Minor differences in the areas reported for the three selected basins appear later in this report and reflect additional refinement of basin boundaries.

Criterion 5. Likely Purpose and Effectiveness of Basin Modeling to Support Management Actions

Table 5 summarizes information provided by the Basin Evaluation and Management Strategies for Thurston County report (TRPC, 2013) that sheds light on how modeling might be used to address hydroecological concerns in each of the basins.

Table 5: Purpose/Benefits of Modeling Candidate Basins					
Basin	**Watershed**	**Existing and Future Flow and Quality/Habitat Concerns**	**Potential Key Model Outputs**	**Potential Management Decisions Supported by Modeling**	**Notes**
Green Cove Creek	Eld	Hydrology/Wetland Filling	Discharge (Q)	Zoning, Drainage Standards/LID	Many protections already in place
McLane Creek	Eld	Fecal Coliform, Phosphorus, Temperature, Fine Sediment, Riparian Cover	Q, Temp, Fecal Coliform, Sediment	Riparian and stream restoration, conservation easements, livestock/ag BMPs	High resource stream with minimal future land development
Black Lake	Budd-Deschutes	Flooding, sedimentation, lake algae blooms, Total P, PCB, Low riparian cover in Black Lake Ditch	Q, Total P, Temp, Fecal Coliform, Suspended Sediment	Zoning, Drainage Standards/LID, Stormwater Retrofits, Transfer of Development Rights (TDR)	Formerly headwaters of Black River, a tributary of the Chehalis, drains primarily to Percival Creek via Black Lake Ditch. Complex groundwater interaction. May be difficult to model lake quality processes and algae responses to land use. Stream flow data for one tributary to lake. No lake inflow quality data. In-lake quality data, and outlet ditch quality data.
Chambers	Budd-Deschutes	Impaired riparian buffer, high nitrates in groundwater, on 303(d) list for fecal coliform, fine sediment	Q, Fecal Coliform, fine sediment	Livestock BMPs, Fertilizer BMPs (Ag, golf course, residential), Stormwater Retrofits, Zoning, Drainage Standards/LID.	Highly altered drainage system, perennial mainstem, downstream of Rich Rd crossing.
Deschutes River (Lower)	Budd-Deschutes	DO, Temperature, Fecal Coliform, fine sediment, in-stream flow	See Notes Column	Zoning, riparian and stream restoration, conservation easements	Not a headwater basin. River problems are not solely caused only by local basin inputs. TMDL in progress.
Deschutes River (Middle)	Budd-Deschutes	DO, Temperature, Fecal Coliform, fine sediment, in-stream flow	See Notes Column	Riparian and stream restoration, conservation easements, livestock/ag BMPs	Not a headwater basin. River problems are not solely caused only by local basin inputs. TMDL in progress.
Ellis Creek	Budd-Deschutes	Fecal Coliform, Fine Sediment	Q, Sediment	Zoning, Drainage Standards/LID	Majority of basin is outside of Thurston County jurisdiction.
Percival Creek	Budd-Deschutes	DO, Temperature, Bank Erosion, Riparian Cover, Turbidity	Q, DO, Temperature, Sediment	Zoning, Drainage Standards/LID, Stormwater Retro-fits	To model whole basin requires inclusion of Black Lake. Could potential model southern headwater sub-basin including Trosper Lake and outlet stream. Flow but no

					water-quality data on this tributary. Majority of basin is outside of Thurston County jurisdiction.
Woodard Creek	Henderson	Clearing and existing impairment of riparian cover, fecal coliform (Part 2 failure), DO (303d), high N and P concentrations, urban runoff, septic systems, Henderson Inlet TMDL for Fecal Coliform (increased sensitivity due to Henderson shellfish beds).	Q, DO, Fecal Coliform	Zoning, Drainage Standards/LID, Stormwater Retrofits, TDR	
Woodland Creek	Henderson	Peak flows, low base flow, high temperature, fine sediment, and stream bank instability	Q, DO, Temperature, Sediment, Nitrate	Zoning, Drainage Standards/LID, Stormwater Retrofits	

3.2 Basin Selection Process

Basins to be screened and select for further study using hydrologic modeling were initially ranked by combining data availability and stakeholder interest criteria, with each of these considerations equally weighted. This results in the ranking of the 10 basins shown in Table 7.

Table 6: Initial Ranking of 10 Candidate Basins

Basin	Watershed	Data Availability Rank	Stakeholder Rank
McLane Creek	Eld	High	High
Black Lake	Budd-Deschutes	High	High
Woodard Creek	Henderson	High	High
Woodland Creek	Henderson	Medium	High
Green Cove Creek	Eld	High	Low
Deschutes River (Middle)	Budd-Deschutes	Low	High
Deschutes River (Lower)	Budd-Deschutes	Low	High
Chambers	Budd-Deschutes	High	Low
Upper Percival Creek*	Budd-Deschutes	Low	Medium
Ellis Creek	Budd-Deschutes	Medium	Low

In this initial screening, basins with a "low" score for either attribute were eliminated from further consideration. Upper Percival (marked with an asterisk) is a special case worthy of note. There was moderate stakeholder interest in the southern portion of the basin that drains the area around Trosper Lake; however, the available water quality data on this portion of the creek are limited compared to the County's sites on Black Lake Ditch or downstream of the confluence of the ditch with Percival Creek. So, while relative data availability for the entire Percival Creek basin was judged to be "High," availability for the southern portion of the creek upstream of its confluence with Black Lake Ditch is judged to be "Low".

The top four basins from this initial screening were then ranked according to their hydroecological importance and the potential for future impact on land development and land use practices.

Basin ranking based on indicators of support for aquatic resources used the four factors shown in Table 3, following scoring rules shown in Table 7. The sum of scores from the four factors was then averaged for a total score as shown in the "Support of Aquatic Resources" column of Table 10.

Table 7: Scoring Based on Indicators of Support for Aquatic Resources using Table 3 Values			
Factor from Table 3	**Score = 3**	**Score = 2**	**Score = 1**
TIA	TIA ≤ 10	10% < TIA ≤ 20%	TIA > 20%
Forest Cover (FC)	FC ≥ 65%	50% ≤ FC < 65%	FC < 50%
Relative Riparian Forest Integrity	High	Medium	Low
Salmon Habitat Value	High	Medium	Low

Quantifying the potential impact from future development utilized data from Table 4, which indicates potential changes in TIA and forest cover at buildout. Potential change scores for each of these parameters were based on a sliding scale related to TIA and forest cover under existing conditions as shown in Table 8 and Table 9.

Table 8: Future Impact Score Based on Existing Basin TIA and Potential Increase at Buildout			
Δ %TIA @ Buildout	TIA ≤ 10%	10% < TIA ≤ 20%	TIA > 20%
Δ > 10%	3	3	3
5% < Δ ≤ 10%	3	3	3
3% < Δ ≤ 5%	3	2	2
2% < Δ ≤ 3%	2	2	1
Δ < 2%	1	1	1

Table 9: Future Impact Score Based on Existing Basin Forest and Potential Forest Loss at Buildout			
Δ % FC @ Buildout	FC ≥ 65%	50% ≤ FC < 65%	FC < 50%
Δ > 10%	3	3	3
5% < Δ ≤ 10%	3	3	2
3% < Δ ≤ 5%	3	2	2
2% < Δ ≤ 3%	2	2	1
Δ < 2%	1	1	1

Basin ranking for vulnerability to future urbanization was based on values from Table 4 and rules in Tables 8 and 9. Scores for change in TIA and loss of forest cover were combined as shown in the "Potential Impacts of Future Development/Use" column of Table 10. Results of the second screening of the four basins rank McLane first, followed by Black Lake, with Woodard and Woodland tied for the 3rd position. As indicated by the values shown for these two basins, Woodard currently has a higher level of ecological function, but it is less threatened by growth and urbanization than Woodland.

Table 10: Second Screening of Basins

Basin	Watershed	Support of Aquatic Resources	Potential Impacts from Future Land Development/Use	Combined Average
McLane Creek	Eld	2.5	2.0	2.3
Black Lake	Budd-Deschutes	1.6	2.5	2.0
Woodard Creek	Henderson	1.5	1.5	1.5
Woodland Creek	Henderson	1.0	2.0	1.5

3.3 Representativeness and Diversity of Modeled Basins

Results of the ranking and screening shown in Table 10 suggest that if three basins are modeled, the selected basins should be McLane, Black Lake, and either Woodard or Woodland. While diversity of hydroecological concerns and basin management approaches represented by such a selection have not been used as criteria to arrive at this result, these criteria deserve some discussion. Fortuitously, the selected basins are located in three distinct Thurston County watersheds feeding major inlets to Puget Sound and more significantly, as a group, they provide a representative array of hydroecological concerns and potential basin management alternatives.

Acre for acre, the McLane Creek basin has the highest ecological function and best habitat in the WRIA 13 study area. Unlike any other selected basin, no portion of McLane is within an urban growth boundary. The primary challenges in McLane are to preserve existing aquatic habitat values, recover diminished riparian vegetation, forestall losses of forest cover that may accompany rural development, and encourage agricultural and livestock best management practices that protect stream quality.

Unlike McLane, Black Lake basin is expected to experience considerable future urban development. However, it is distinct from Woodard and Woodland because of the particular concerns for water quality and beneficial uses associated with the dominant physical feature of the basin — a lake that provides a high level of recreational use and esthetic enjoyment. Algal blooms and closures of Black Lake for swimming and other contact recreation are problems unique to Black Lake among the selected basins.

Woodard and Woodland, while similar in many respects, are distinct from the other two basins in the group. They are both stream basins draining to Henderson Inlet with significant amounts of existing urbanization (greater than 15% total impervious area). Stormwater retrofits that address past impacts, as well as careful consideration of how to target future urbanization to prevent further degradation, are both potential management directions which should be investigated in these basins. Of the two, Woodard presently provides a higher level of aquatic resource function, suggesting that retrofits and other measures aimed at protection and restoration should be considered here, while holding the degradation line for Woodland might be more appropriate.

3.4 Recommended Selection of Basins for Modeling

An initial set of ten candidate basins was developed using on an inventory of available climatic, stream flow, and water quality data. From the data availability perspective, these basins were broken into three categories reflecting relatively low, medium, and high levels of data availability. These data availability levels were combined with results of a survey of stakeholder interest in applying hydrologic modeling to address existing and potential future basin concerns. Four basins with the highest combined scores for these two criteria include McLane Creek, Black Lake, Woodard Creek, and Woodland Creek, which have been listed in descending order of existing support of aquatic resources in Table 10Table 1. Additionally, these basins were ranked in terms of their sensitivity to future land development which results in a similar order except that the Woodland and Woodard Creek positions are switched.

Based on the criteria discussed above, McLane Creek, Black Lake, and Woodard Creek basins were recommended to Thurston County for further study using hydrologic modeling in the SLP project. The logic for McLane and Black Lake rests on their distinct aquatic resource values and management concerns. Woodard Creek was selected over Woodland Creek as the third basin for hydrologic modeling because aquatic resource values are in better condition in Woodard Creek, making it a likely target for stormwater retrofits and other restorative actions. If some contingency had arisen (for example, undiscovered data quality problems) for one of the three selected basins, Woodland Creek was recommended as an alternate. Additionally, at a later stage of the project, if resources had allowed modeling a fourth basin, Woodland Creek would also have been modeled.

4 Model Simulation Plan

The model Simulation Plan is intended to provide a roadmap on how the model will be applied to simulate land use and management scenarios for the three selected Thurston County basins (McLane Creek, Black Lake, and Woodard Creek) identified in the previous section. The simulation plan aims to ensure that an appropriate level of output detail and data quality will be available to support project objectives. This roadmap outlines the modeling objectives, modeling approach, types and quality of data that will be used by the model, the model framework, and the calibration and validation goals.

4.1 Modeling Objectives

Modeling objectives for this study were designed to support the overall SLP project. They include: 1) assess the level of aquatic resource degradation caused by existing land development, and 2) provide a projection of how various land-use planning and management strategies may reduce or increase degradation.

While a hydrologic simulation model, such as that documented in the remainder of this report, can be an excellent tool for simulating changes in hydrology and water quality, it is important that stakeholders understand that some consequences of alternative land-use strategies are beyond the competence of hydrologic modeling and must be evaluated through other means. For example, hydrologic modeling does not specifically address impacts of land use change on terrestrial wildlife habitat. Nor does it address a host of political, and socio-economic concerns.

Modeling objectives for this study are accomplished through comparison of hydrologic and water quality metrics that are derived from model simulations of a set of land use and management scenarios.

4.1.1 Hydrologic Metrics

A set of hydrologic metrics were selected that focus on the impacts of an altered hydrologic regime to aquatic resources. Unlike a flood study, which focuses on flood frequency statistics that characterize risks of infrastructure damage, the metrics selected here are statistics that characterize the risks to mobilizing bed material, affecting benthic macro-invertebrates, and fish passage conditions.

DeGasperi et al. (2009) evaluated correlations between hydrologic metrics (flow statistics) and B-IBI data from around Puget Sound and highlighted a few that are well correlated with aquatic health. As part of this study, three of those metrics found to be well correlated with B-IBI data were selected to evaluate the scenarios:

- **High Pulse Count (HPC) -** A "High Pulse" is an occurrence of daily average flow that is equal to or greater than a threshold set at twice the long-term daily average flow rate. The HPC statistic is simply a count of the number of discrete High Pulses that occur in a given water year (October 1st through September 30th).
- **High Pulse Range (HPR) -** Also using the High Pulse, the HPR statistic is a count of the number of days between the first high flow pulse and last high flow pulse during a water year.
- **Average Annual 7-Day Minimum Flow –** The annual minimum of the seven-day moving average of simulated hourly flows. This can be a helpful statistic to characterize base flow, which is important for various factors, including fish passage.

The hydrologic metrics alone will provide a relative characterization of the change between scenarios but not the absolute habitat quality that is expected for each scenario. It must be acknowledged that estimation of B-IBI scores from hydrologic metrics as a way of judging the hydroecologic effectiveness of stormwater management—especially when the hydrologic metrics are based on model simulations—is at best an indication of how B-IBI scores would vary with flow. Real, field-based B-IBI scores can be affected by many non-hydrologic factors, including local hydraulics, substrate, water quality, and temporal variability. These effects are not necessarily captured by statistics calculated solely from stream flow data. A future improvement that is outside the current scope would be to estimate a synthetic B-IBI score that is based on local B-IBI data and/or more refined correlations from the Puget Sound Stream Benthos database that specifically target the conditions seen in the study area basins.

4.1.2 Water Quality Metrics and Constituents of Concern

Like the selected hydrologic metrics, the water quality metrics selected for investigation are those that will most impact the aquatic resources and have key beneficial uses in each basin. The review of water quality concerns presented in Section 3 was further expanded for the three selected basins to identify which quality parameters would be simulated. The resultant list includes:

- **Temperature** – This was selected because monitoring data show that all three basins have temperature violations, but the primary interest is on McLane basin where Thurston County Watershed Characterization (Reynolds et al., 2012) noted impacted riparian cover.
- **Fecal Coliform** – This was selected because monitoring data shows that all three basins have high fecal coliform bacteria levels, but the problems on McLane Creek and the existing TMDL for Woodard Creek were the primary drivers.
- **Nitrogen** – The Thurston County Environmental Health Division has placed a high priority on reducing nitrogen loads from all three of the study area basins. Nitrogen needs to be controlled to protect and improve the condition of marine waters in the County. The need was highlighted in the County's own ambient monitoring data and also the South Puget Sound Dissolved Oxygen Study (Ecology, 2011b), which identified the study area basins, and others in the County, as large sources of dissolved inorganic nitrogen (DIN) relative to other Puget Sound watersheds. DIN is the form of nitrogen that is the most available to algae. The models simulate both nitrate + nitrite and ammonium forms of DIN, but results discussed in Section 6 of this report focus only on nitrate + nitrite because the ammonium fraction is typically relatively small. We refer to the sum of nitrate and nitrite as "nitrate" throughout the remainder of this document.
- **Phosphorus –** A need to control phosphorus concentrations has been noted for Woodard Creek and Black Lake. The TMDL for Henderson Inlet (Ecology, 2011a) recommends that sources of phosphorus (the limiting nutrient) to Woodard Creek be controlled to protect and possibly improve dissolved oxygen levels in the Creek. Similarly, phosphorus control is recommended for control of toxic algae blooms in Black Lake (e.g., Thurston County, 2012).
- **Dissolved Oxygen –** In Woodard Creek, dissolved oxygen levels are of concern. Due to both data and resource limitations, this study does not explicitly simulate dissolved oxygen; however, phosphorus is a nutrient targeted for control that most strongly determines DO levels.

Water Quality Standards

The State of Washington's water quality standards, listed in WAC section 173-201A, provide a useful metric by which to measure many of the water quality variables of greatest concern within the study basins. The criteria for the study area constituents of concern are listed in Table 11; the requirements vary depending on the designated uses for each water body. Those uses include:

- **McLane Creek -** Contact recreation and core summer habitat for aquatic life uses. McLane is listed in Table 602 of WAC 173-201A.
- **Black Lake -** Core summer salmonid habitat and extraordinary primary contact recreation. Black Lake is not listed explicitly in the WAC but the fact that it is a lake provides it and its

feeder streams (i.e. Kenneydell Park Stream) with a higher level of protection than that provided for streams not listed in the WAC.

- **Woodard Creek -** Salmon and trout spawning, core rearing, and migration and extraordinary primary contact recreation because it is tributary to a shellfish harvest area. Tributaries to Henderson Inlet are treated as extraordinary due to the Ecology protection of South Puget Sound in Table 612 of WAC 173-201A .

Some water quality constituents, such as nutrients, do not have a state standard for streams but some guidance is available for nitrate + nitrite and total phosphorus.

Table 11: Water Quality Standards for Constituents of Concern

Parameter	Included in Model?	Reference to Freshwater Water Quality Standard (WAC references)	Numeric Criteria
Total Phosphorus	Yes	173-201A-230 (Code Reviser) Table 230 (1)	Action value for Puget Sound lakes is 20 µg/L. No standard for streams but EPA Publication 822-B-00-015 cites a regional reference condition of 19 µg/L
Nitrate + Nitrite	Yes		No standard for streams but EPA Publication 822-B-00-015 cites a regional reference condition of 0.26 mg/L
Dissolved Oxygen	No	173-201A-200 (1)(d) Table 200 (1)(c)	Core Summer Salmonid Habitat [applies to all three detailed study streams] 1-day minimum concentration: 9.5 mg/L
Fecal Coliform	Yes	173-201A-200 (2)(b) Table 200 (1)(c)	Extraordinary Contact Recreation: geometric mean value < 50 colonies /100 mL, with < 10 % exceeding 100 colonies /100 mL [applies to Black Lake and Woodard Creek] Primary Contact Recreation: geometric mean value < 100 colonies /100 mL, with < 10 % exceeding 200 colonies /100 mL [applies to McLane Creek]
Temperature	Yes	173-201A-200 (1)(c) Table 200 (1)(c)	Core Summer Salmonid Habitat [applies to all three detailed study streams] 7-day average of the daily maximum temperature (7-DADMax): 16°C (60.8°F)

4.2 Model Selection and Approach

There are dozens of models that target aquatic health issues similar to those being addressed by this project. For this project, the Hydrologic Simulation Program Fortran (HSPF) was selected as the sole model for application in this study because of its long history regionally and its ability to model the dynamics of both hydrology and water quality, the metrics being used to evaluate the proposed planning strategies. A review of past local and regional watershed modeling was performed by NHC in a memorandum dated March 5, 2013. Much of that review is replicated herein.

4.2.1 Past Experience with Watershed Modeling

Regional Experience

HSPF has been the standard watershed model of choice in western Washington for basin-scale modeling since the 1980s. Early basin planning studies in the region that applied HSPF were undertaken by King County (e.g., Coal Creek Basin Plan Technical Appendix, 1986; Bear Creek Current and Future Conditions Report, 1989; Hylebos Creek Current and Future Conditions Report, 1990). Simultaneously, in the late 1980s the US Geological Survey (Dinicola, 1990) undertook the challenge of developing a set of standard HSPF parameters that characterize the hydrologic behavior of typical impervious surfaces and vegetation-soil complexes that predominate in western Pierce, King, and Snohomish Counties. The ability of HSPF models using these "regional parameters" to, in many cases, directly simulate stream flow hydrographs that match field data (Dinicola, 2001), or to provide an efficient starting point for calibration where data were available, provided a great impetus to further applications of HSPF throughout western Washington by many municipal and county surface water management agencies.

Following successful applications of HSPF in its basin planning program, King County investigated methods for effective design of flow control facilities required to mitigate the effects of land development on both peak flow and erosive flow durations. These studies clearly demonstrated the superiority of a continuous hydrologic modeling approach with HSPF over single, design storm methods such as the Y&W or SCS-SBUH methods. Consequently, through its Surface Water Design Manual (1998), King County began to require land developers to use a continuous modeling approach to design facilities to meet flow control standards. To facilitate this, the County developed and distributed a user-friendly software package called the King County Runoff Time Series (KCRTS) which employed pre-run, HSPF-generated outputs based on the regional parameters. The benefits of applying a continuous hydrologic modeling approach based on HSPF to stormwater management quickly became evident to the Washington Department of Ecology which began requiring use of continuous models a few years later through its Stormwater Management Manual for Western Washington (2001). To assist land developers and local jurisdictions, Ecology developed a more powerful HSPF-based tool called the Western Washington Hydrology Model (WWHM). WWHM is essentially HSPF with a simplified graphical user interface that accesses regional parameters and a meteorological database that is suitable for the location of interest. It assists the user in simulating both pre-developed and post-developed runoff series and subsequently designing flow control BMPs that meet specified hydrologic standards.

Thurston County Experience

Thurston County has been active in basin hydrologic modeling since the early 1990s. Over the past twenty years, seven comprehensive drainage plans have been completed inside the Science to Local Policy planning area. As shown in Table A1 in Appendix A, the development of each of these drainage plans has involved the creation of a hydrologic model. The location of each of these legacy models can be found in Figure A1 in Appendix A. For the majority of these studies the model used was HSPF. Many of these basins have a significant amount of groundwater surface water interaction and a large amount of outwash soil. The existing conditions HSPF models were calibrated using 1–4 years of continuous precipitation and stream flow data.

There were two basins where HSPF was not used, Moxlie-Indian Creeks and McAllister/Eaton Creek. The Moxlie-Indian Creek basin is highly urbanized so a SWMM model with a design storm approach was adopted. The model was calibrated to two winter seasons and sporadic data from various wet and dry periods. For the McAllister/Eaton Creek basin, the documentation is rather unclear on whether a design storm approach was used with the SWMM model or HSPF was used to simulate runoff inputs to a HYDRA hydraulic model of the storm drain network.

All of the County applications of HSPF and its derivatives have focused on the impacts of land use change on stream flow regime characteristics such as peak flow, high flow durations, and summer base flow, or in one case, specifically on flow regime to support fish habitat. While the relationship of land use and associated hydrologic changes to water quality have been discussed in some of these applications, none of the HSPF water quality routines were activated and quality parameters such as water temperature, sediment, and pollutant concentrations were not expressly simulated.

Water Quality Modeling

While there are dozens of regional examples of basin precipitation-runoff modeling, mostly applying HSPF, very few applications have involved explicit simulation of pollutant concentrations and loads. Notable exceptions are the Sinclair Inlet and Dyes Inlet Watershed Study (Johnston et al., 2008) and Juanita Creek Basin Study (King County, 2012). In the first case, empirically based pollutant runoff coefficients for different land use and land cover categories were applied to HSPF-generated flows from different basins composed of these categories to estimate fecal coliform loading to marine waters under existing and future land use conditions. The results of this study were used in developing a fecal coliform TMDL and Water Quality Implementation plan (Ecology, 2012) for the inlets. In the Juanita Creek study (King County, 2012), the focus was on identifying and pricing different stormwater retrofit alternatives to achieve recovery of beneficial uses in a basin that is almost completely built out. This study made much fuller use of HSPF water quality routines to simulate a range of pollutants, including suspended sediment, heat, DO, nutrients, copper, and fecal coliforms.

Within the WRIA 13 and WRIA 14 study area, water quality simulation modeling has focused on receiving water hydro-dynamics, transport, and physio-chemical processes rather than the inflence of land use on pollutant loading from watersheds. The primary example of this type of modeling is the Department of Ecology's application of the QUAL2Kw and GEMSS models to temperature, pH, DO, and nutrients in the Deschutes River and South Puget Sound by Roberts et al. (2012). In that study water-quality processes in the entire lower 41 miles of the Deschutes River downstream of Deschutes Falls, Capitol Lake, and Budd Inlet were simulated. A QUAL2Kw model of the river was used to examine the nutrient response of the river to scenarios involving riparian vegetation, inputs from above the falls, and tributary inputs below the falls. And GEMSS modeling of Capitol Lake and Budd Inlet was aimed at investigating spatial distributions of nutrient concentrations under different point and nonpoint load assumptions for both the existing system, with Capitol Lake in place, and for a restored estuary that would replace Capitol Lake if the existing Capitol Lake Dam were removed.

4.2.2 Selection of HSPF

In recent decades, HSPF has been the model of choice in basin planning and stormwater-related applications within western Washington and specifically within the project area in the County. Almost all of these applications have applied HSPF water runoff and routing components, but have excluded water quality components. Notwithstanding, the availability of existing basin HSPF models within the project area, regional familiarity with appropriate HSPF parameter ranges, the recent successful application of the model by King County, coupled with EPA's historic support for HSPF as a water quality model and TMDL development tool, all suggest that this model is the logical choice for investigating land use practice impacts on flow and water quality in the current project.

4.3 Model Simulation Scenarios

Five hydrologic modeling scenarios were used to evaluate the land use planning and management strategies being considered by the Thurston County Resource Stewardship Department. These scenarios, listed with the objective of each in Table 12 below, include Pre-European, existing, and three future 30-year forecasted land-use condition simulations. The two “future alternative” scenarios each include two or more strategies that are being evaluated to determine their benefit to the aquatic system. Figures showing the land-cover associated with each scenario are included as Figure 2 through Figure 16.

Table 12: Modeling Scenario Objectives

Scenario	Objective
Pre-European	No European immigration influences on clearing or development in the study area. This scenario provides an upper limit on what is achievable via complete watershed restoration.
Existing Conditions	Current land cover and population.
Planned Trend	30-year forecasted population growth with existing planning regulations (zoning and development requirements) and stormwater controls.
Future Alternative 1	30-year forecasted population growth with reduced density and LID flow control.
Future Alternative 2	30-year forecasted population growth with reduced density, LID flow control, stormwater retrofits, wetland restoration, and riparian restoration.

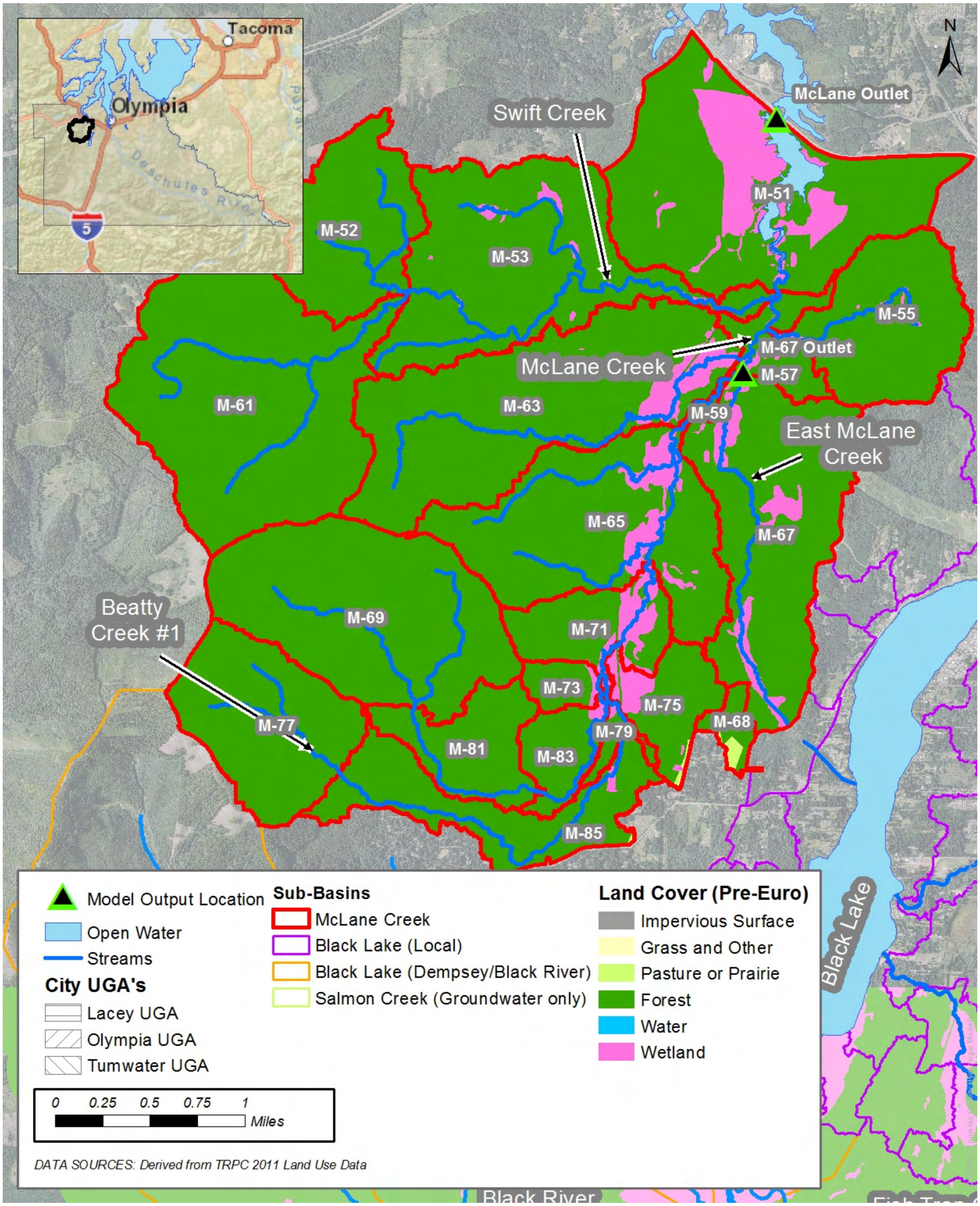


Figure 2: Land Cover for Pre-European Scenario, McLane Creek Basin

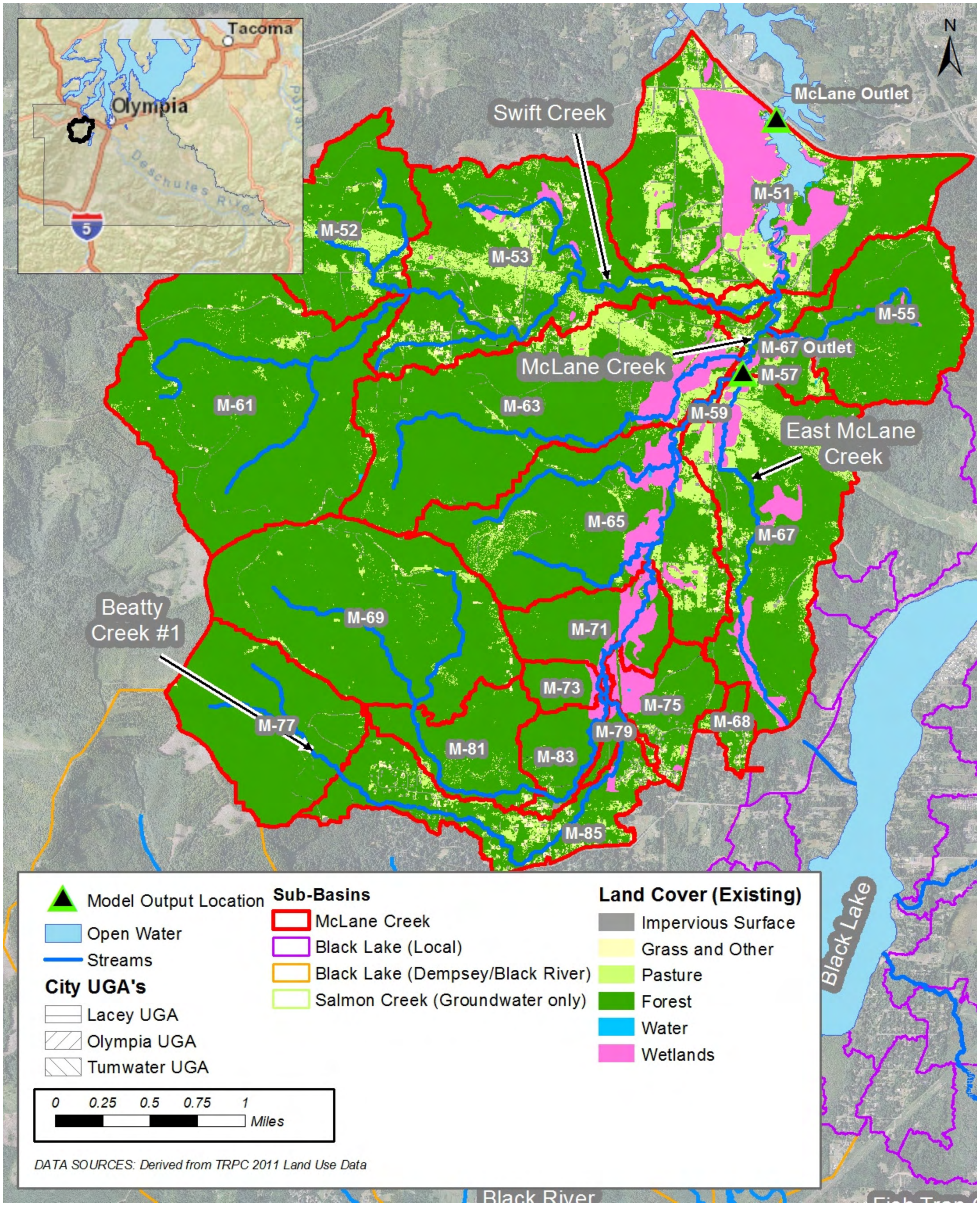


Figure 3: Land Cover for Existing Condition Scenario, McLane Creek Basin

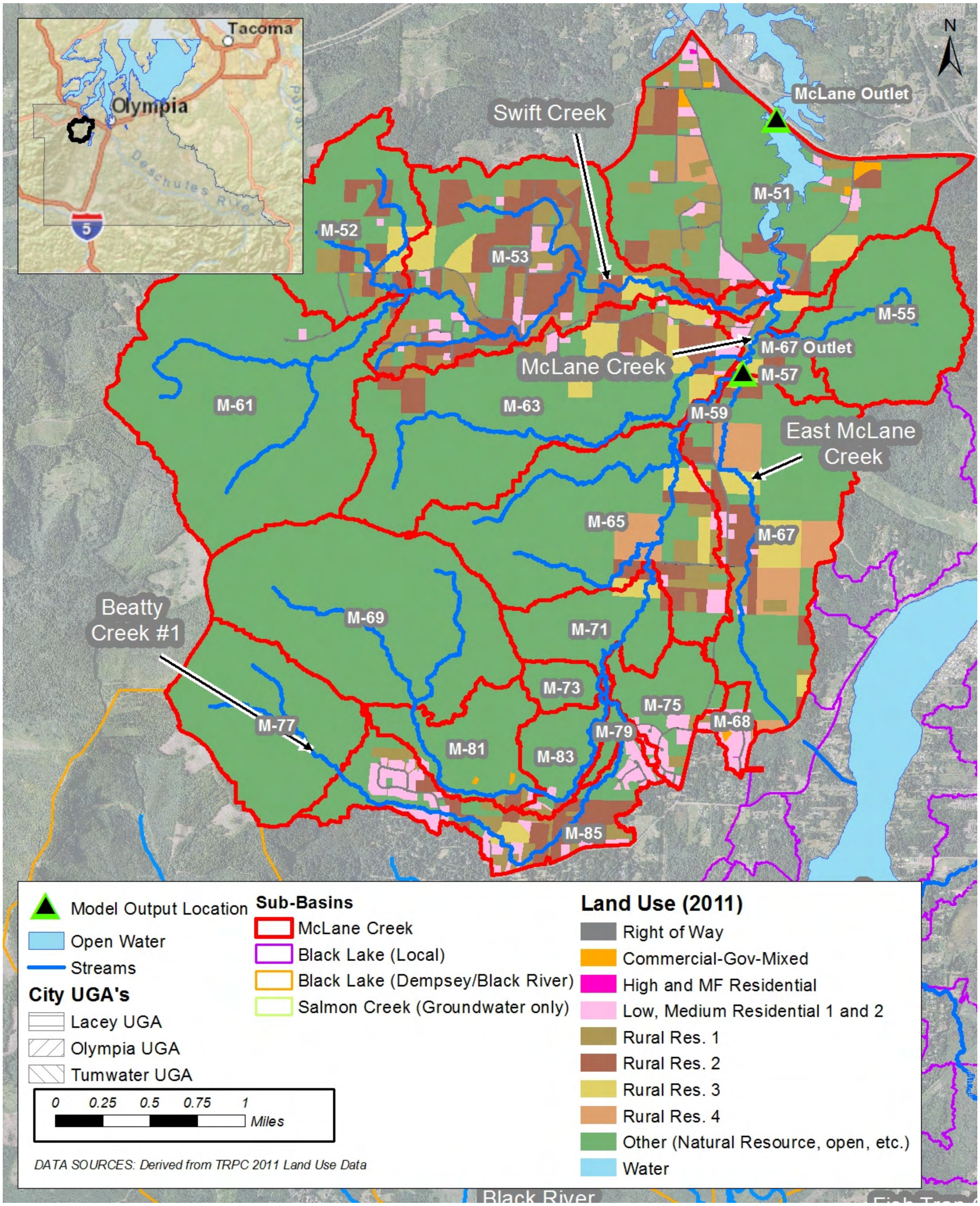


Figure 4: Land Use for Existing Condition Scenario, McLane Creek Basin

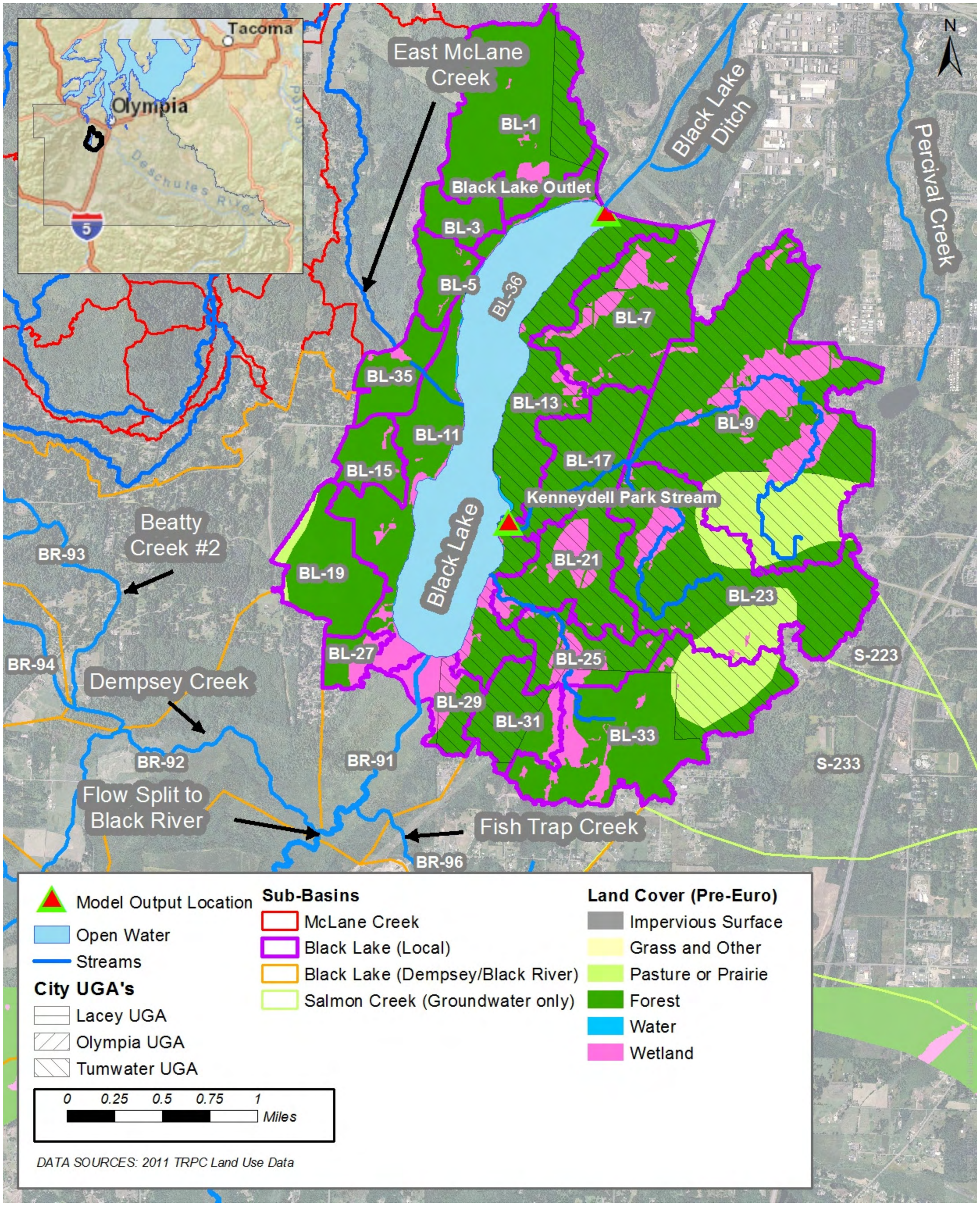


Figure 5: Land Cover for Pre-European Scenario, Black Lake Basin

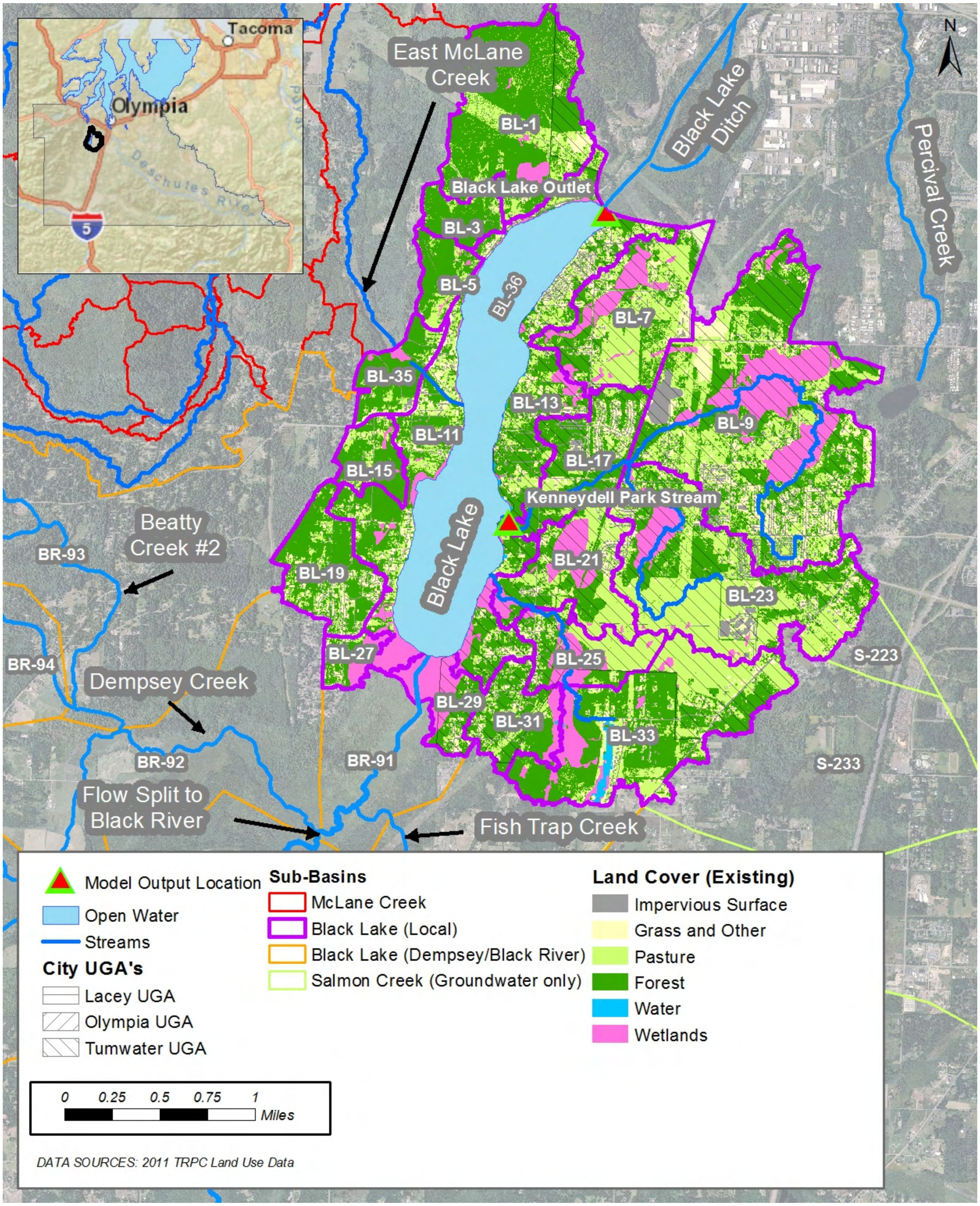


Figure 6: Land Cover for Existing Condition Scenario, Black Lake Basin

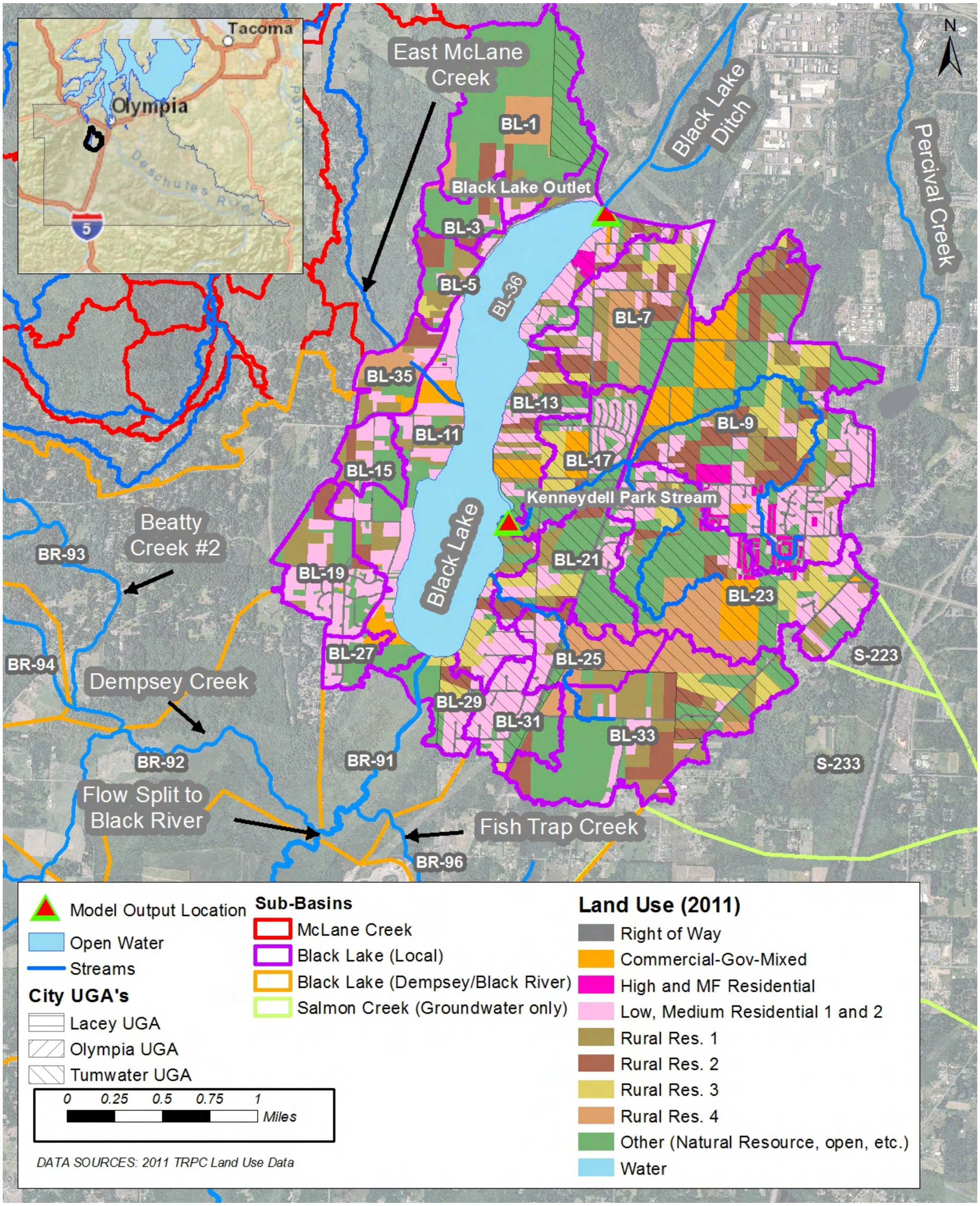


Figure 7: Land Use for Existing Condition Scenario, Black Lake Basin

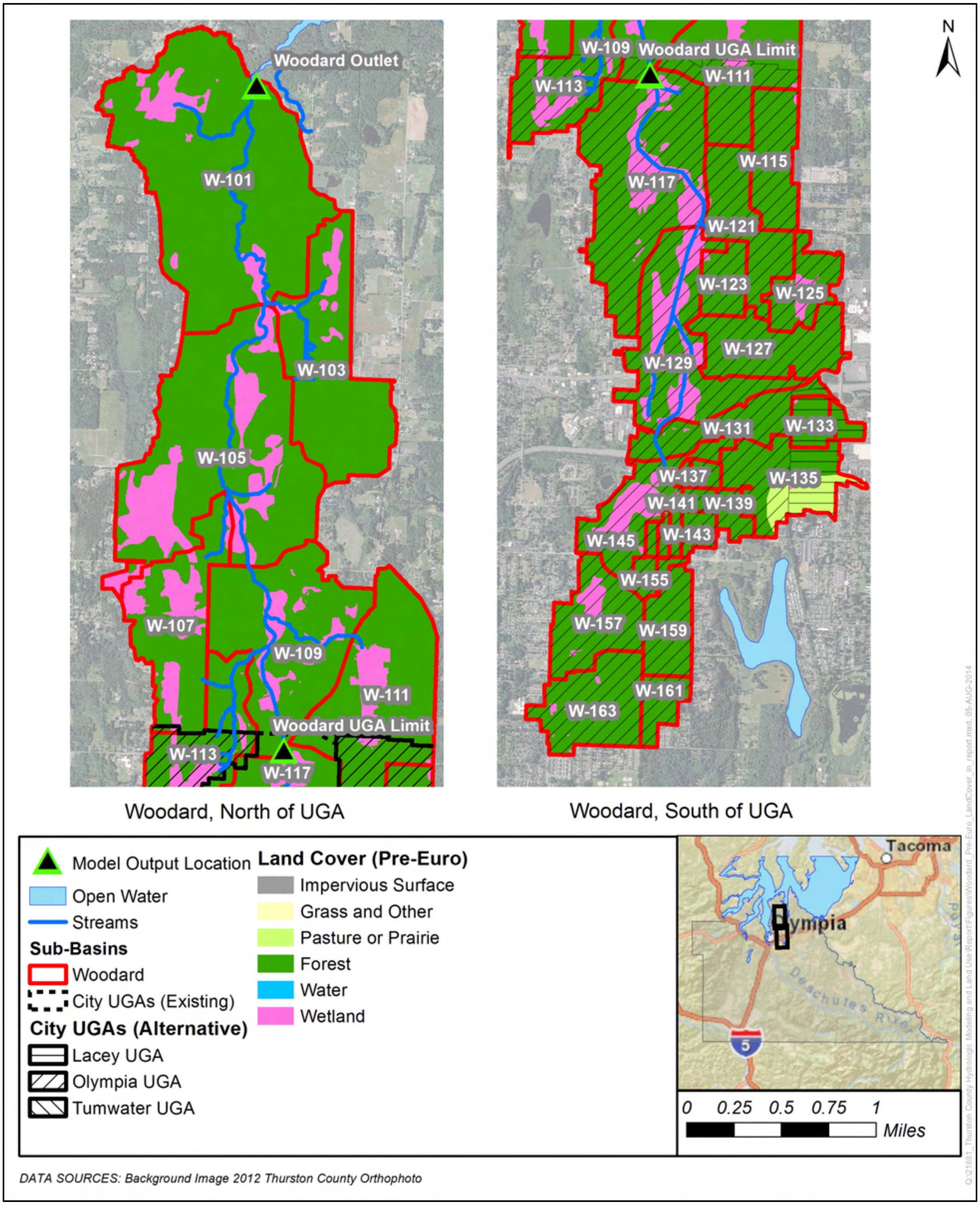


Figure 8: Land Cover for Pre-European Scenario, Woodard Creek Basin

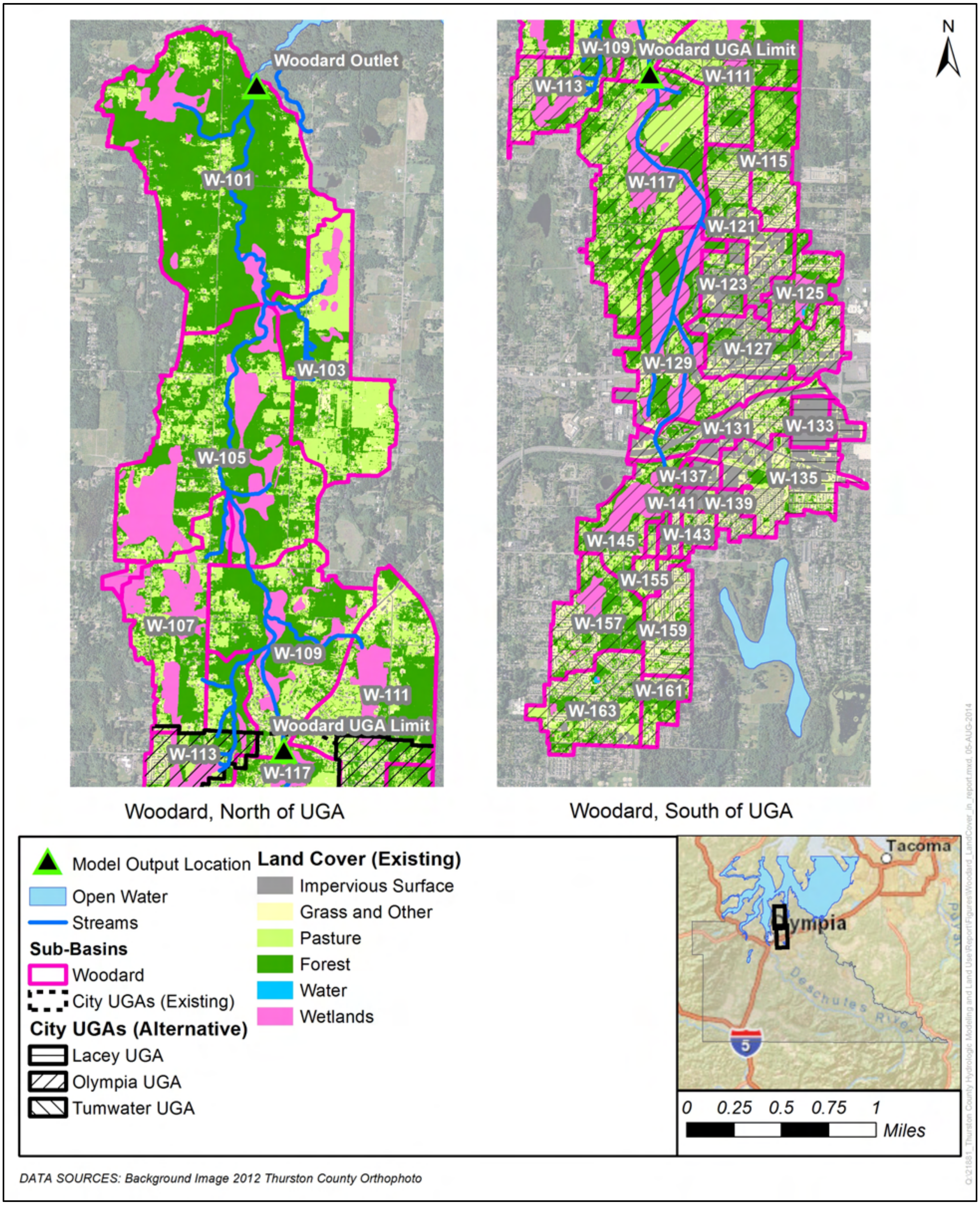


Figure 9: Land Cover for Existing Condition Scenario, Woodard Creek Basin

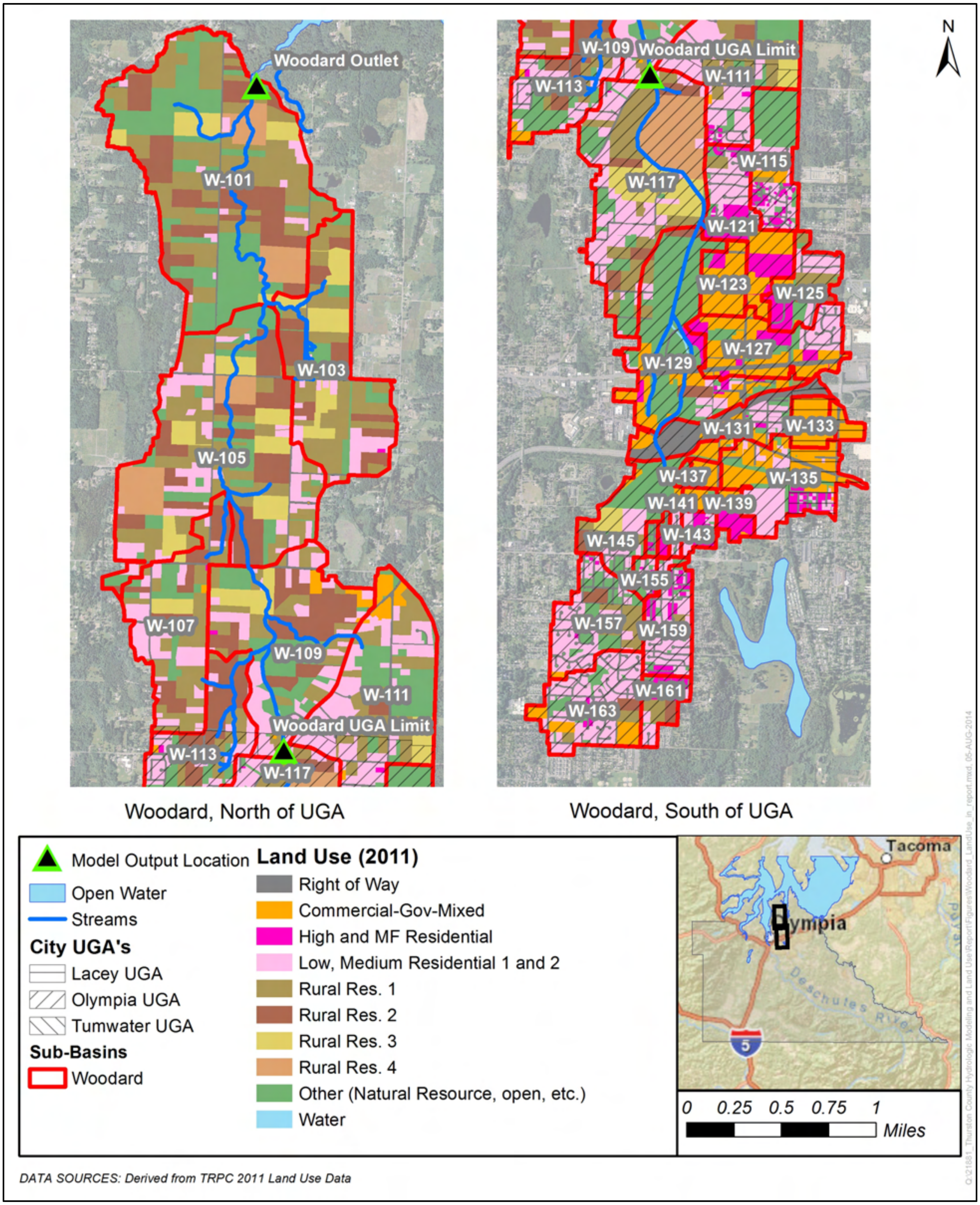


Figure 10: Land Use for Existing Condition Scenario, Woodard Creek Basin

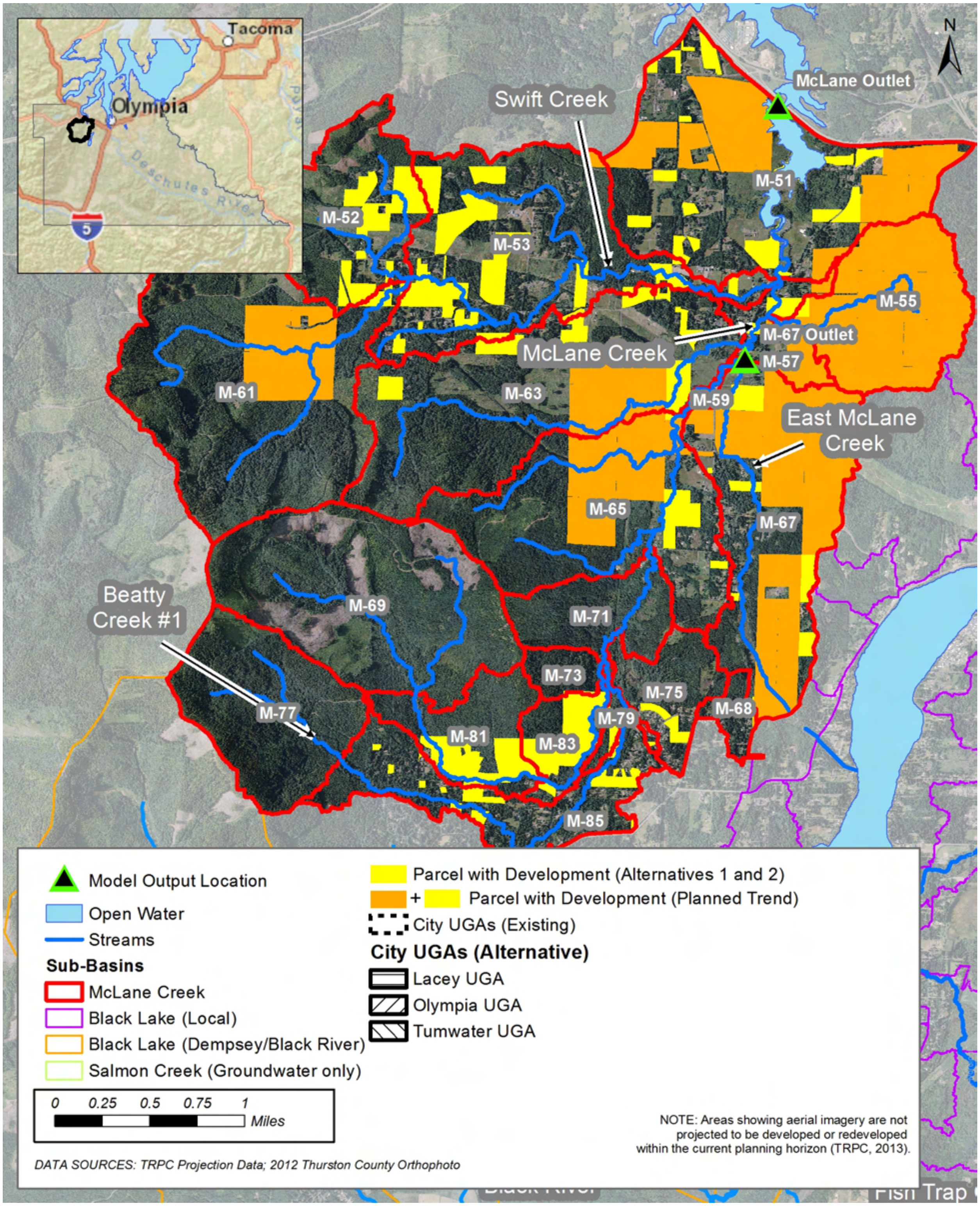


Figure 11: Future Development for Planned Trend, Future Alternative 1 and 2 Scenarios, McLane Creek Basin

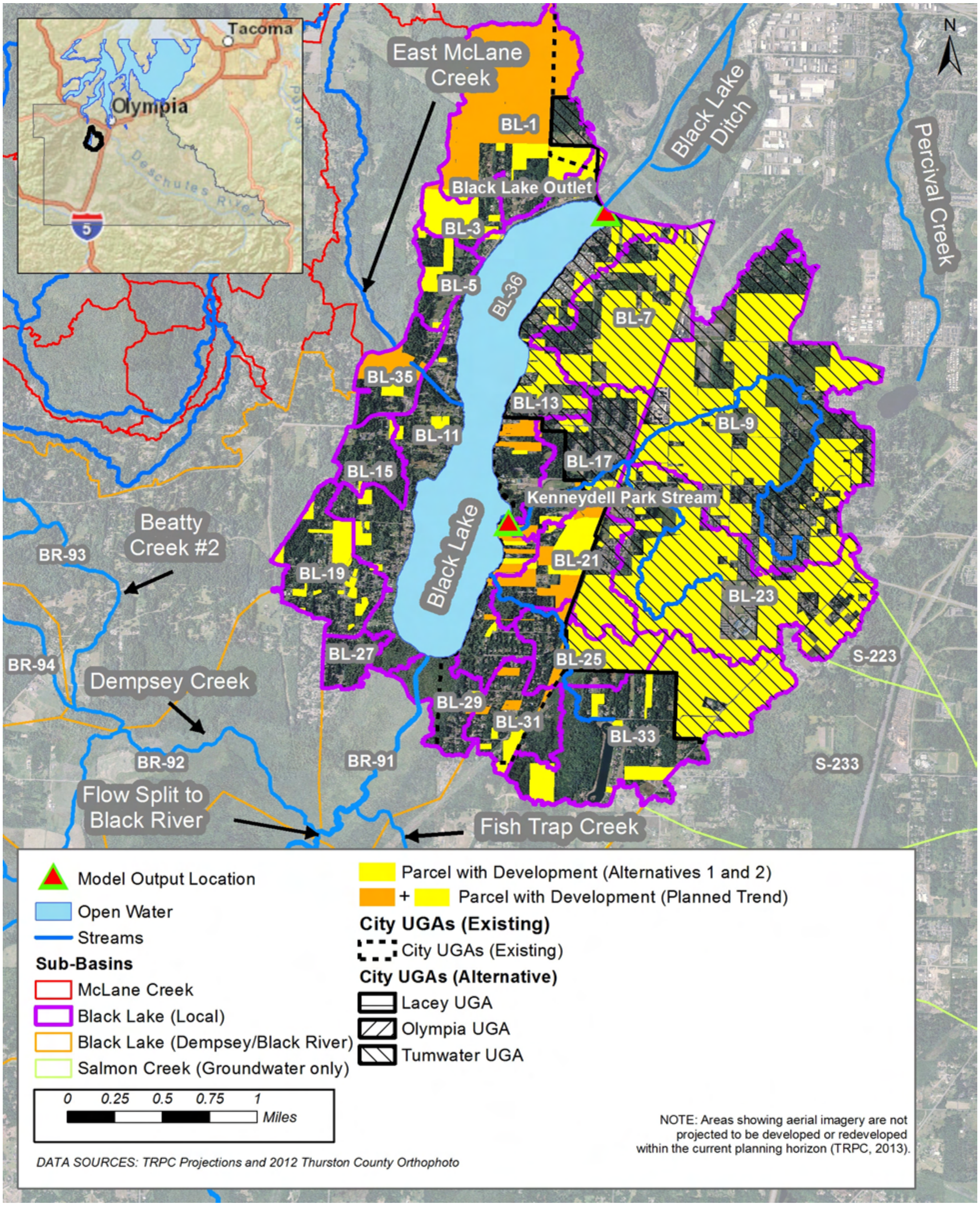


Figure 12: Future Development for Planned Trend, Future Alternative 1 and 2 Scenarios, Black Lake Basin

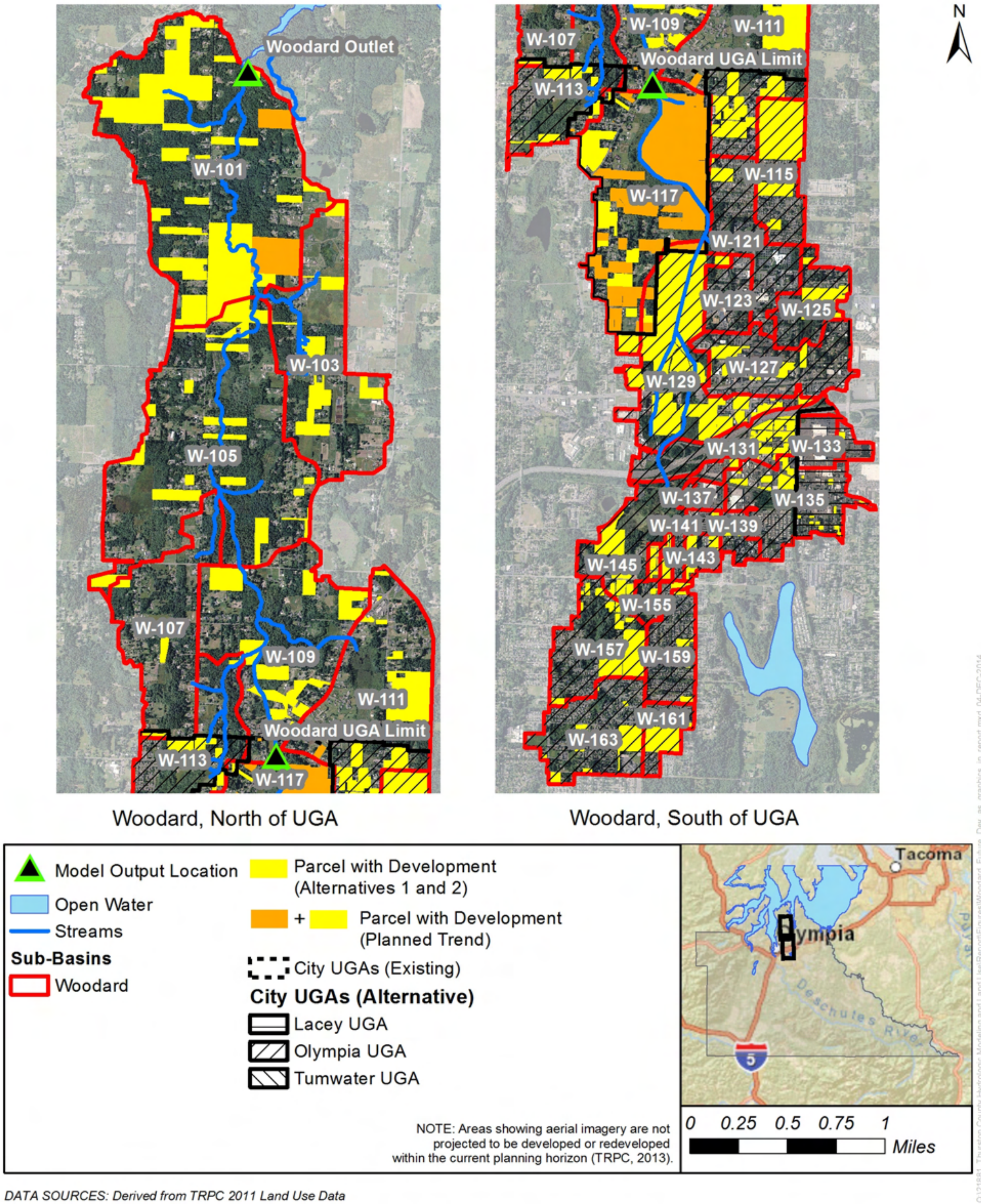


Figure 13: Future Development for Planned Trend, Future Alternative 1 and 2 Scenarios, Woodard Creek Basin

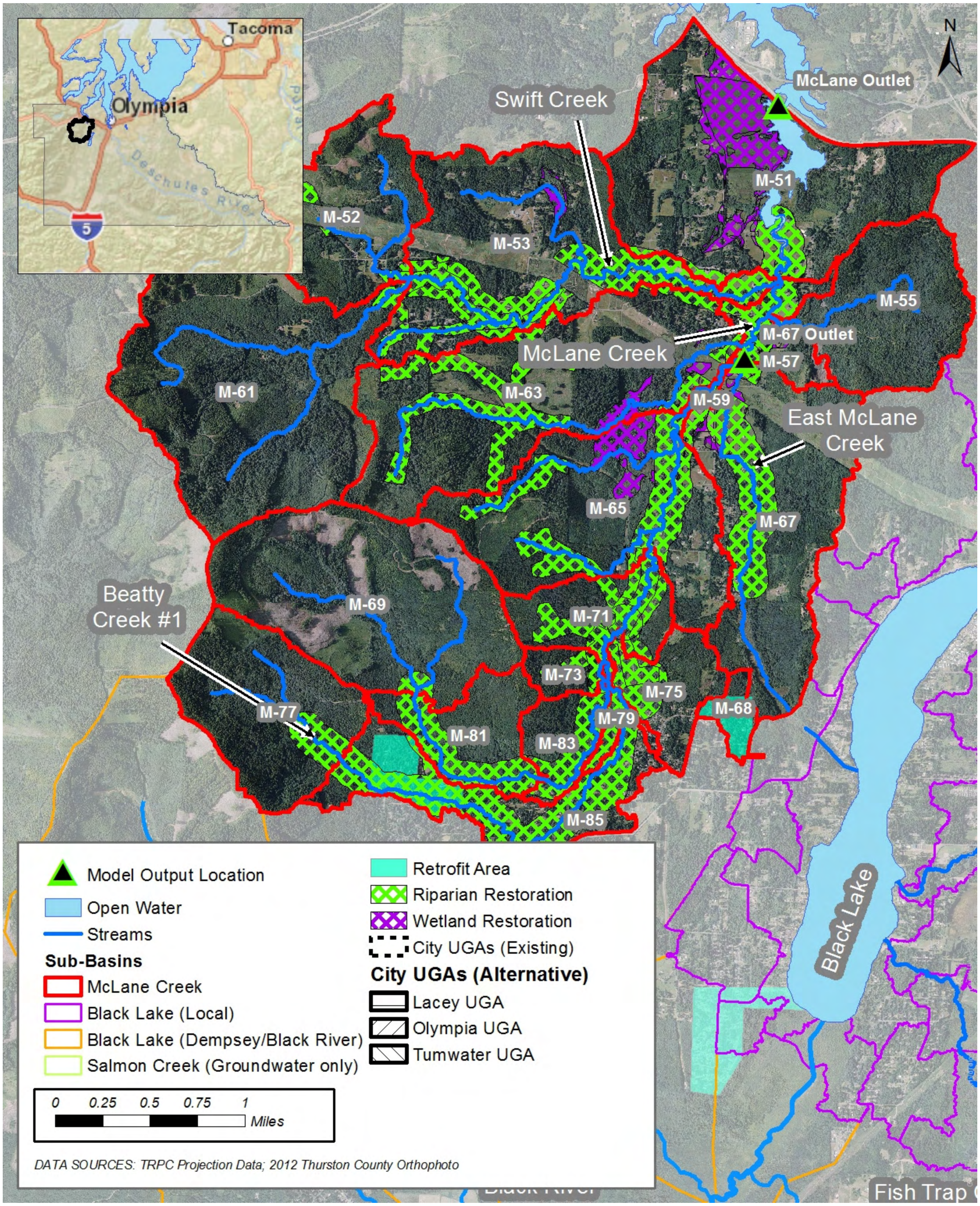


Figure 14: Restoration and Retrofits for Future Alternative 2 Scenario, McLane Creek Basin

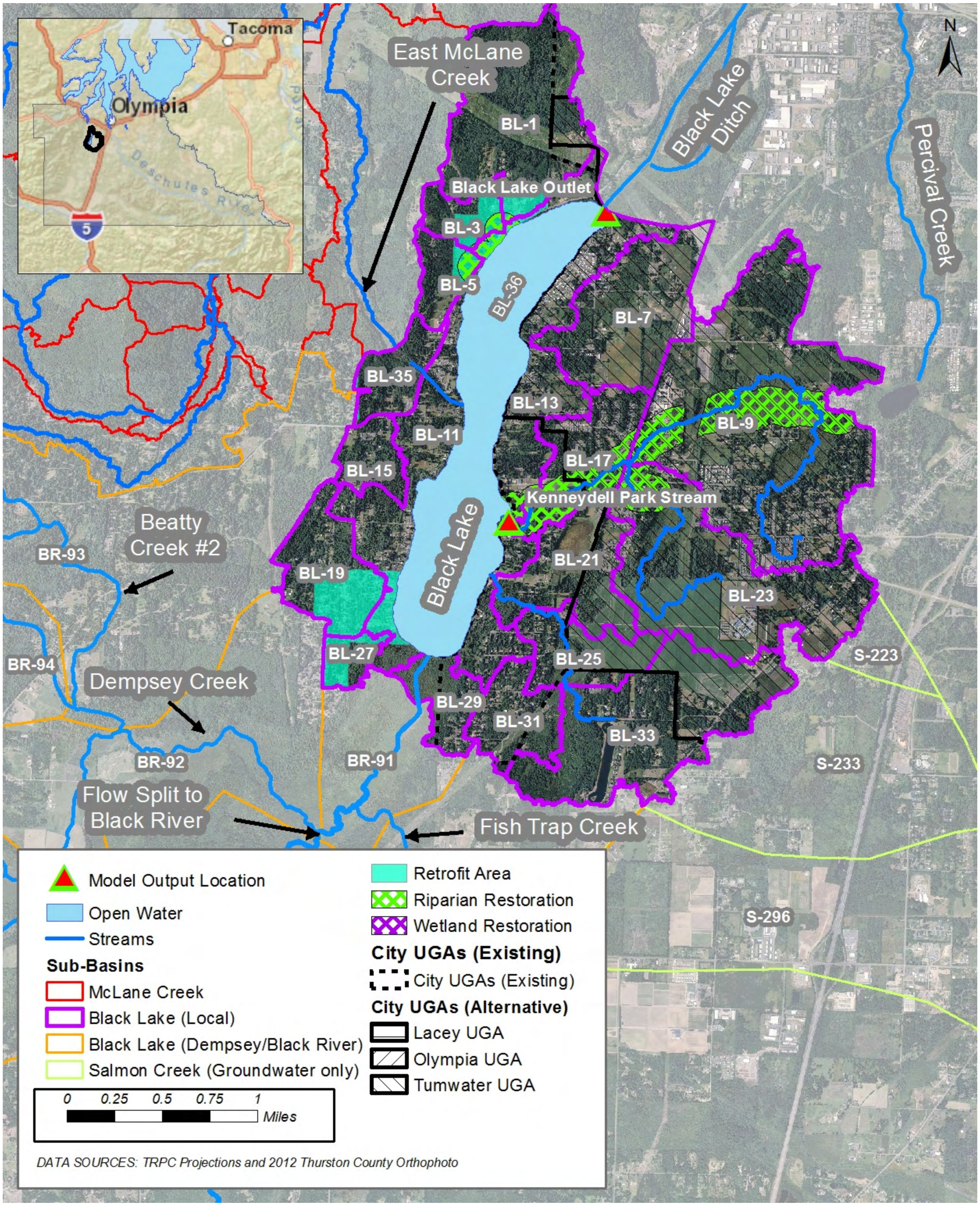


Figure 15: Restoration and Retrofits for Future Alternative 2 Scenario, Black Lake Basin

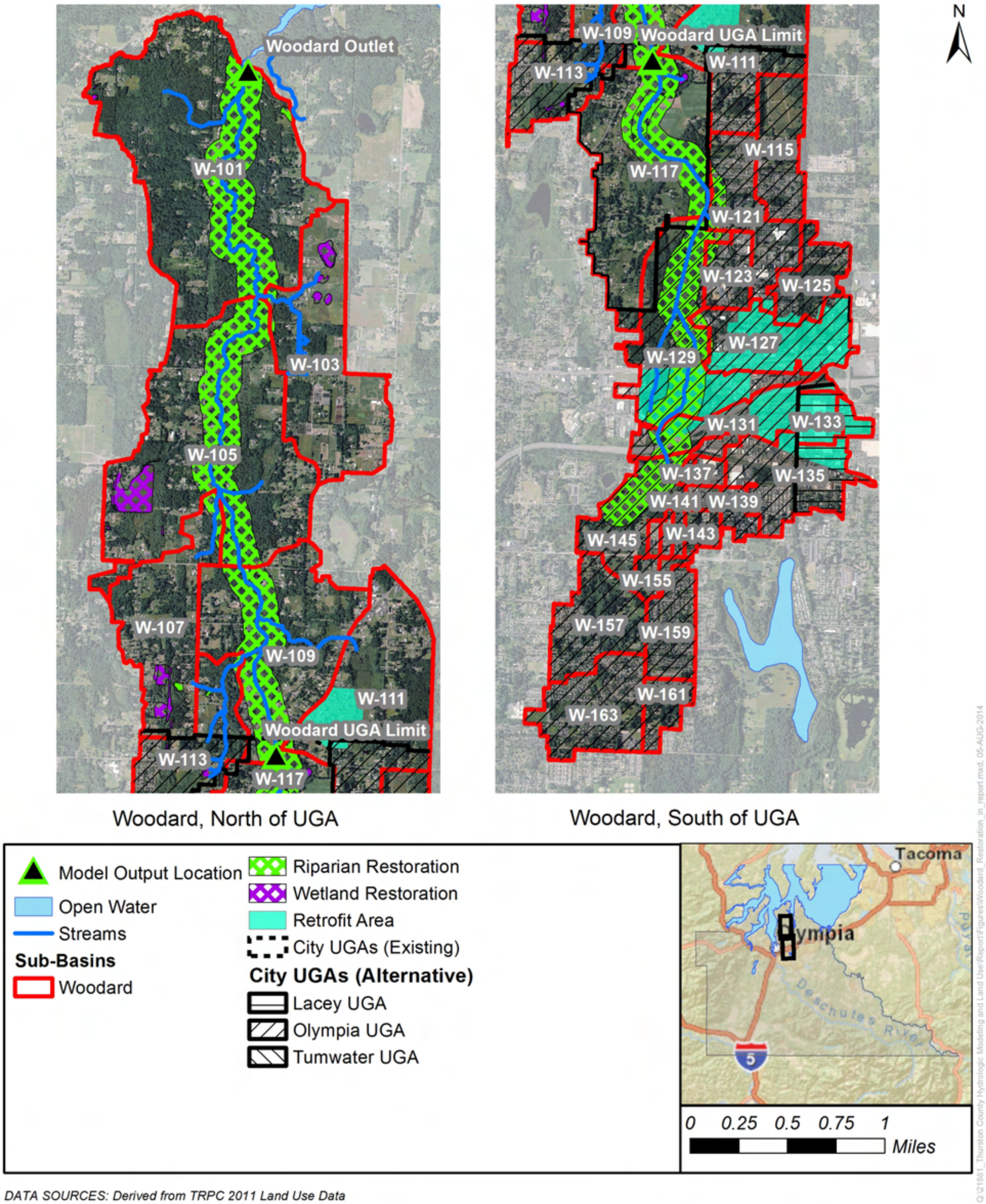


Figure 16: Restoration and Retrofits for Future Alternative 2 Scenario, Woodard Creek Basin

4.4 Model Segmentation and Watershed Characterization

Spatial scale needs to be reflected in the segmentation of both the land surface and runoff routing reaches, which include streams, lakes, and stormwater BMPs. Segmentation impacts the number and distribution of points within the drainage network where the model explicitly simulates and stores fluxes for subsequent review and analysis. HSPF treats certain features, such as rainfall regions, soil types, land slopes, and pollutant generation potential using a hydrologic response unit (HRU, denoted PERLND or IMPLND in HSPF) approach to land surface representation. These HRUs discharge to a linear routing network representing natural and artificial open water bodies and conveyance conduits (ponds, reservoirs, lakes, pipes, streams, river reaches). The land surface or a routing reach may need to be divided to allow more refined characterization of these features. The spatial scales and time-series data requirements for the land and routing modules are described below.

4.4.1 Watershed Delineation and Model Output Locations

Sub-basins and streams within each of the study area basins were delineated at locations that model output may need to be stored for user interpretation and also at locations where large stormwater facilities are explicitly represented by the model. Points selected for model output storage are: points of potential interest for planning (e.g., at the UGA boundary or the basin outlet) and locations with data for model calibration. These points were defined primarily through the use of LiDAR elevation data and inventories of the City of Olympia, City of Lacey, City of Tumwater, and County stormwater systems, and other reports such as Tumwater (2011).

The delineation resulted in 24 sub-basins and streams in the Black Lake basin, 20 in the McLane Creek basin, and 31 in the Woodard Creek basin. Areas of the sub-basins range from 0.6 to 1.4 square miles (with two exceptions in the Dempsey Creek tributary basin to Black Lake). The basin boundaries are presented for each of the three basins in Figure 17 through Figure 18.

The delineation of the drainage area to Black Lake was complicated and was refined as part of the hydrology calibration. On the south side of Black Lake, it was determined that a portion of inflows from Dempsey Creek and Fish Trap Creek flow into the lake via the wetland dividing the lake from the Black River watershed (Thurston County, 1993; and Foster Wheeler, 2003). Additionally, approximately 1,100 acres from the Salmon Creek watershed contribute groundwater to the streams on the southeast side of Black Lake (USGS, 1999; and PGG, 2001). Schematics illustrating the relationship of each sub-basin and stream reach to one another are provided as Figure 19 through Figure 21.

Two locations in each basin were noted as key points of interest by the project team for which model output data would be stored in the model output database for interpretation by the model user. These locations included the outlet from each basin (model reaches 51, 36, and 101), as well as one additional point within the interior of each. The interior points included East McLane (reach 67), Kenneydell Park Stream (reach 17), and the Woodard Creek UGA boundary (reach 117) in the McLane, Black Lake, and Woodard basins, respectively.

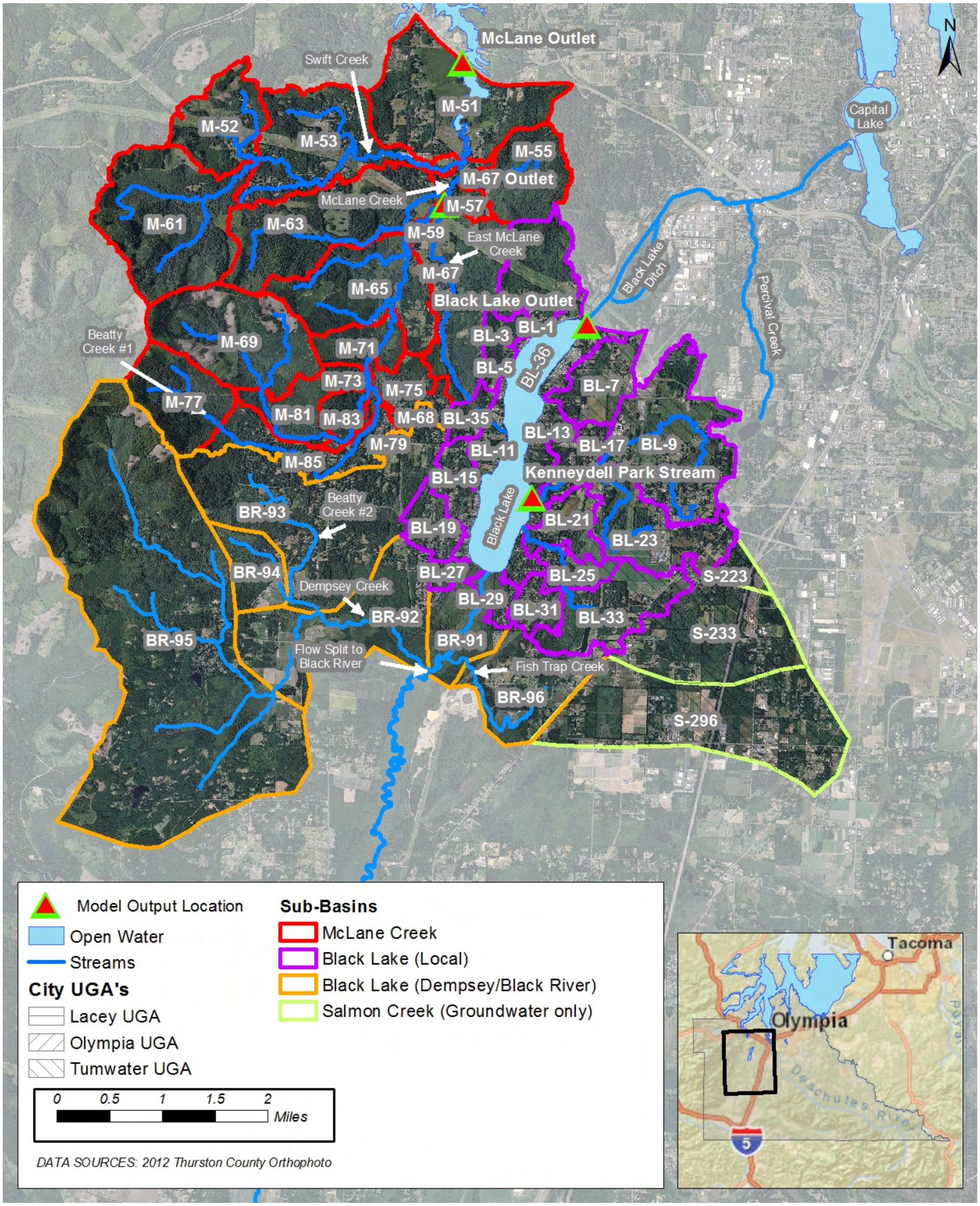
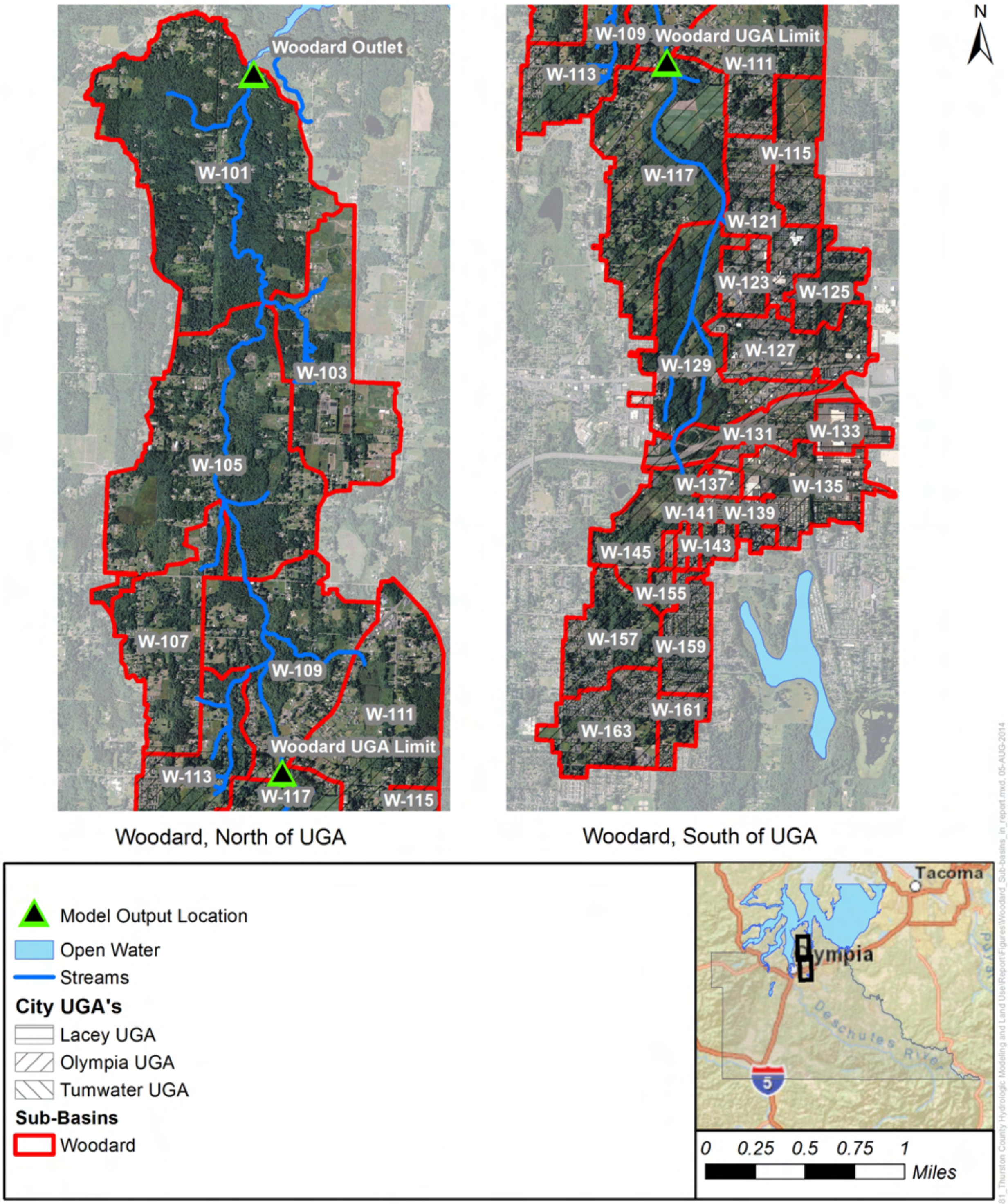
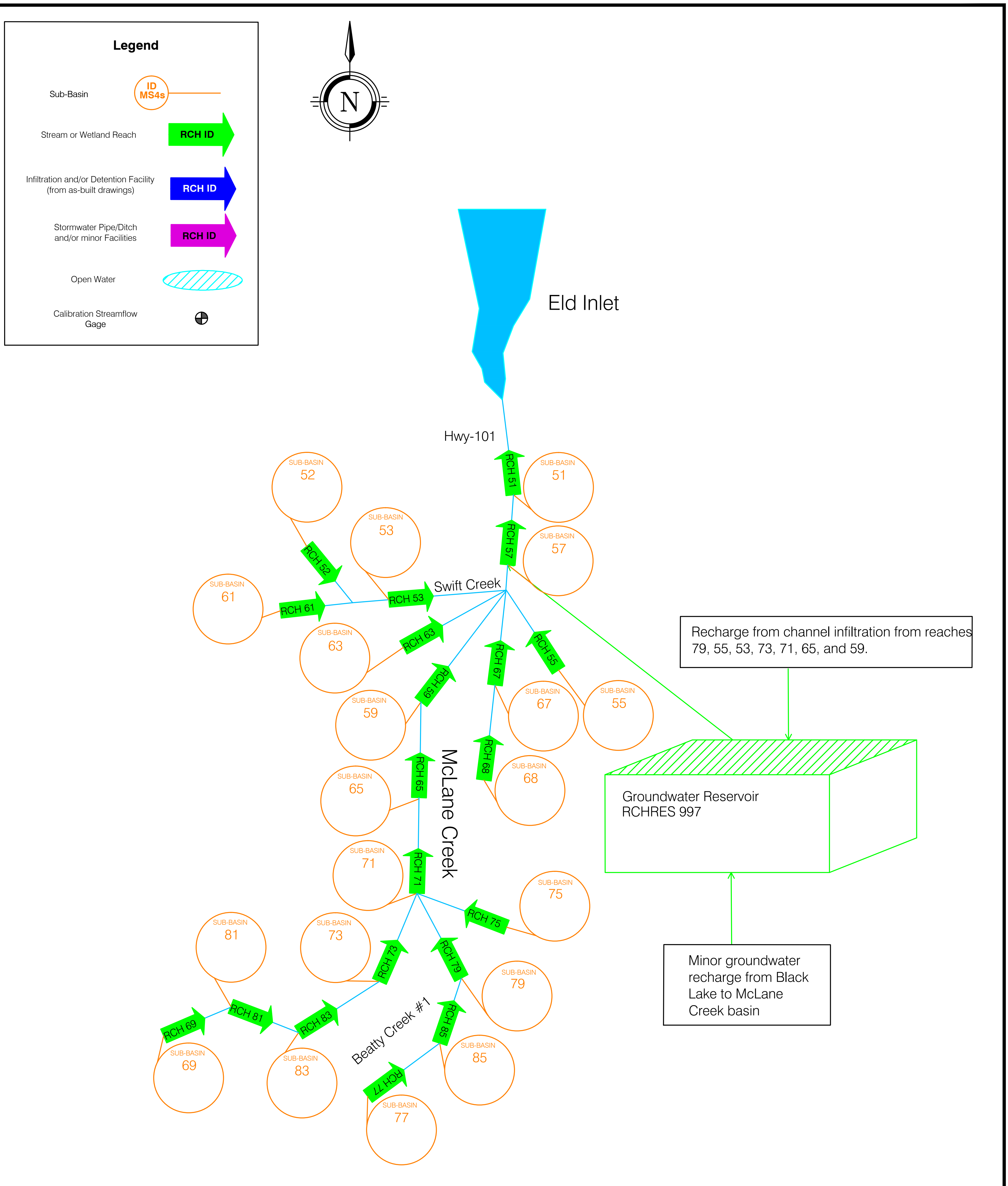


Figure 17: Sub-Basin Map of Complete McLane Creek and Black Lake Basins

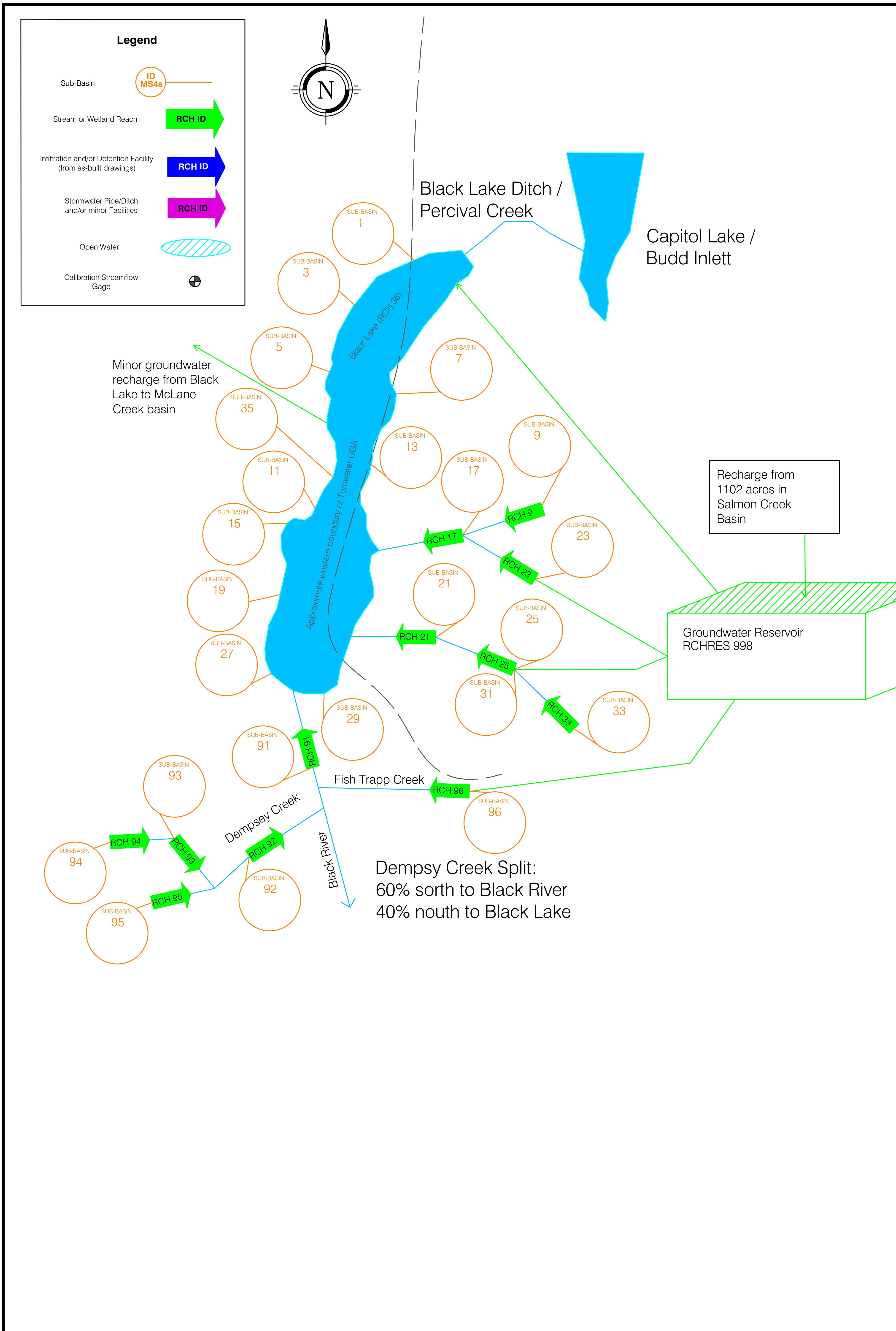


DATA SOURCES: Background Image 2012 Thurston County Orthophoto

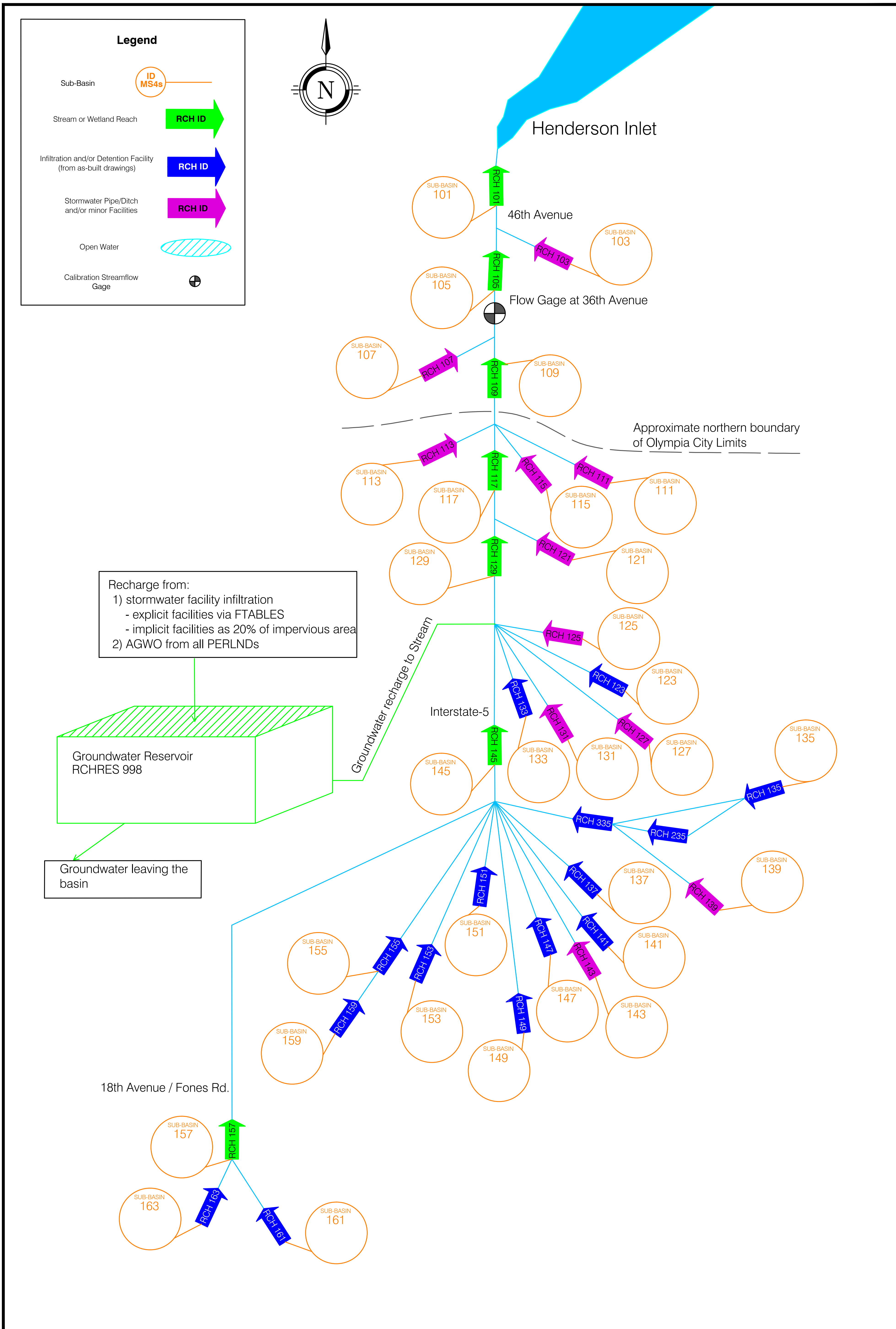
Figure 18: Sub-Basin Map of Woodard Creek Basin



SCALE:N/A	PROJECT # 21881	northwest hydraulic consultants nhc 16300 Christensen Rd Ste. 350 Seattle, WA 98188-3418 phone:(206) 241-6000 fax:(206) 439-2420 www.nhcweb.com	HSPF MODEL SCHEMATIC FOR MCLANE CREEK
DESIGNED: DLS			FIGURE: 19
DRAWN: MAO	DATE: 8/1/2013		



SCALE:N/A	PROJECT # 21881	northwest hydraulic consultants nhc 16300 Christensen Rd Ste. 350 Seattle, WA 98188-3418 phone:(206) 241-6000 fax:(206) 439-2420 www.nhcweb.com	HSPF MODEL SCHEMATIC FOR BLACK LAKE	FIGURE: 20
DESIGNED: DLS				
DRAWN: MAO	DATE: 8/1/2013			



SCALE:N/A	PROJECT # 21881	nhc northwest hydraulic consultants 16300 Christensen Rd Ste. 350 Seattle, WA 98188-3418 phone:(206) 241-6000 fax:(206) 439-2420 www.nhcweb.com	HSPF MODEL SCHEMATIC FOR WOODARD CREEK	FIGURE: 21
DESIGNED: DLS				
DRAWN: MAO	DATE: 8/1/2013			

4.4.2 Land Surface Representation

The pervious and impervious land surfaces in the model, respectively called PERLNDs and IMPLNDs in HSPF programming nomenclature, represent a unique combination of soil type, land use, land cover, and precipitation zone. These combinations give each PERLND and IMPLND type a unique hydrologic response and pollutant loading. In the study basins, there are 35 pervious surface combinations and 2 impervious surface combinations for each of four precipitation zones; this makes 140 unique PERLND types and 8 unique IMPLND types. The ID numbers and descriptions of each are summarized in Table 13.

Soil Types

PERLND soil types were defined by reviewing a NRCS SSURGO (NRCS, 2012) soils inventory of the study area and classifying the soils series into four soil types to be represented in the HSPF models. The soil types (outwash,till, Kitsap, and saturated) are the same as those used by previous USGS modeling in the County (1990 and 1995). Soils in each of the three study area basins are summarized in Table 14 and mapped in Figure 22 through Figure 24. Descriptions of each type are as follows:

- **Outwash** – Areas with glacial outwash deposits of gravel and other well-drained soils. These soils dominate the southern half of the Woodard basin and are found in smaller areas in the other basins.
- **Till** - Areas where glacier action has produced a highly compacted sub-layer of soil with low drainage and relatively high runoff. This is the dominant soil type in both McLane and Black Lake basins.
- **Kitsap** – Areas with greater soil-moisture storage capacities and slightly greater rates of vertical drainage through the substratum relative to till soils, making groundwater flow more important for those areas. Kitsap soils are found in the northern half of the Woodard basin. The soil type includes the Hoogdal and Skipopa soil series and is described by USGS (1995) as the following.

  > *"Kitsap segment types, not designated for basins previously investigated by Dinicola (1990), represent areas with soils derived from fine-grained lacustrine deposits. Kitsap segment types, like the till segment types, represent soils underlain by a substratum of low permeability. Kitsap soils, however, have greater soil-moisture storage capacities and, because of more interstitial pore space than till soils, they have slightly greater rates of vertical drainage through the substratum. Thus, subsurface flow is slightly less important, and ground-water flow is slightly more important in Kitsap segment types than in till segment types. In nonforested Kitsap segment types, as in till segment types, intense storms may produce Hortonian overland flow. In Kitsap segment types with flat slopes, saturation overland flow is an important mechanism. Accordingly, Kitsap segment types also were subdivided according to their land cover and slope."*

- **Saturated** – Areas with soils that are poorly drained and are of a wetland character.

Table 13: Summary of HSPF PERLNDs and IMPLNDs by Elevation Band				
PERLND/IMPLND ID by Elevation Band				PERLND or IMPLND Description
Zone 1	Zone 2	Zone 3	Zone 4	
PERLNDs				
7	107	207	307	Saturated
11	111	211	311	Till Forest Urban
14	114	214	314	Till Forest Rural
21	121	221	321	Till Pasture Urban
24	124	224	324	Till Pasture Rural 1
25	125	225	325	Till Pasture Rural 2
26	126	226	326	Till Pasture Rural 3
27	127	227	327	Till Pasture Rural 4
30	130	230	330	Septic Field (Special Case)
31	131	231	331	Till Grass Urban
32	132	232	332	Till Grass High Density Residential
33	133	233	333	Till Grass Low and Moderate Density Residential
34	134	234	334	Till Grass Rural
41	141	241	341	Kitsap Forest Urban
44	144	244	344	Kitsap Forest Rural
51	151	251	351	Kitsap Pasture Urban
54	154	254	354	Kitsap Pasture Rural 1
55	155	255	355	Kitsap Pasture Rural 2
56	156	256	356	Kitsap Pasture Rural 3
57	157	257	357	Kitsap Pasture Rural 4
61	161	261	361	Kitsap Grass Urban
62	162	262	362	Kitsap Grass High Density Residential
63	163	263	363	Kitsap Grass Low and Moderate Density Residential
64	164	264	364	Kitsap Grass Rural
71	171	271	371	Outwash Forest Urban
74	174	274	374	Outwash Forest Rural
81	181	281	381	Outwash Pasture Urban
84	184	284	384	Outwash Pasture Rural1
85	185	285	385	Outwash Pasture Rural2
86	186	286	386	Outwash Pasture Rural3
87	187	287	387	Outwash Pasture Rural4
91	191	291	391	Outwash Grass Urban
92	192	292	392	Outwash Grass High Density Residential
93	193	293	393	Outwash Grass Low and Moderate Density Residential
94	194	294	394	Outwash Grass Rural
IMPLNDs				
101	201	301	401	High Pollution Generating Impervious Surface
103	203	303	403	Low Pollution Generating Impervious Surface

Table 14: Soil Type by Basin

Basin	Soil Type				Basin Area (square miles)
	Till	Outwash	Saturated	Kitsap	
Woodard	20%	43%	19%	18%	7.9
Black Lake	37%	36%	26%	1%	19.2[1]
McLane Creek	61%	26%	11%	3%	12.7

[1] The area of the Black Lake basin, including Dempsey Creek and Fish Trap Creek tributaries, is 19.2 square miles but a flow split that diverts flows away from the basin results in only 13.1 square miles effectively reaching Black Lake. The remaining flows are routed to the Black River. Of the remaining 13.1 square miles only 7.7 are local to Black Lake, rather than Dempsey Creek or Fish Trap Creek.

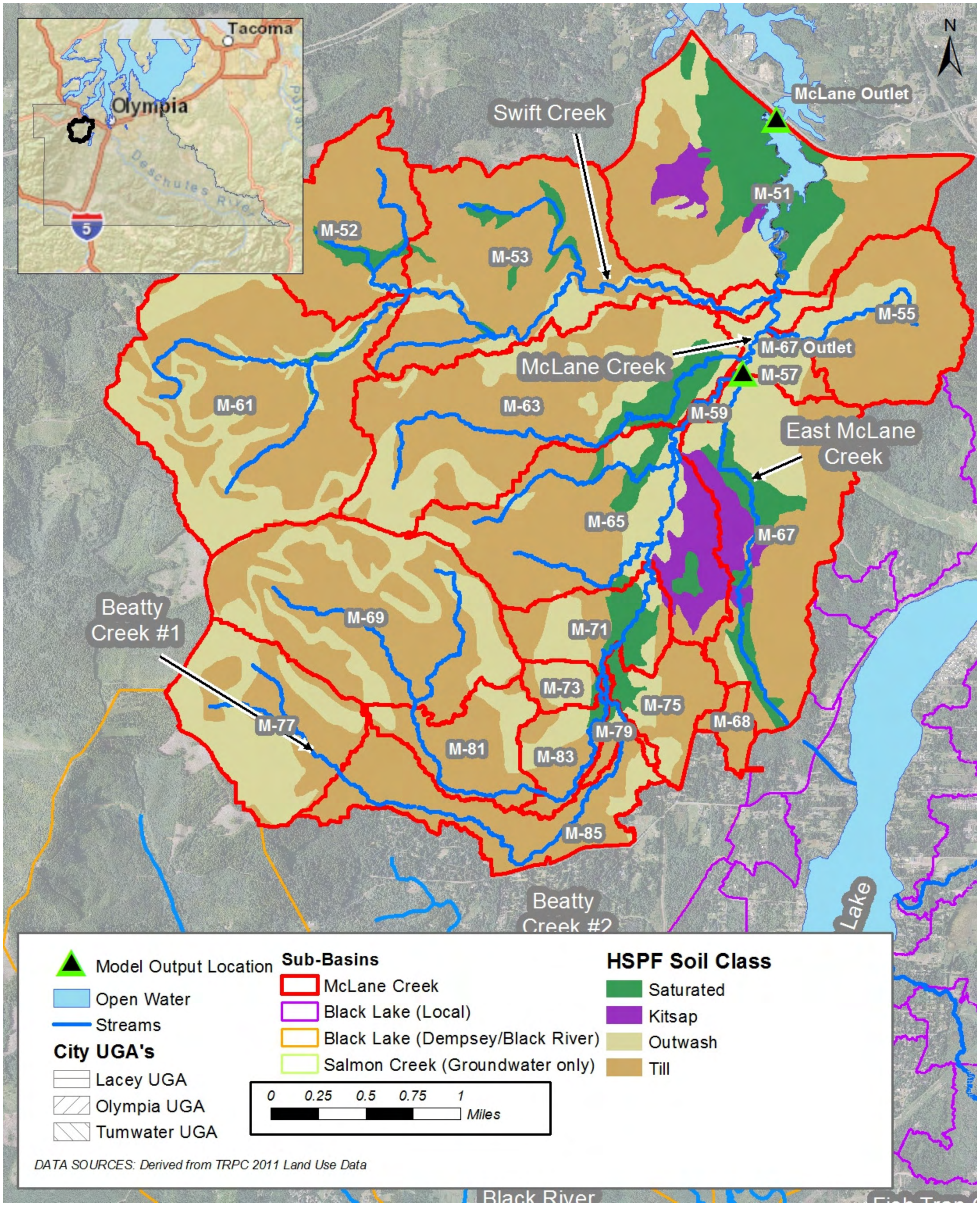


Figure 22: HSPF Soil Classes, McLane Creek Basin

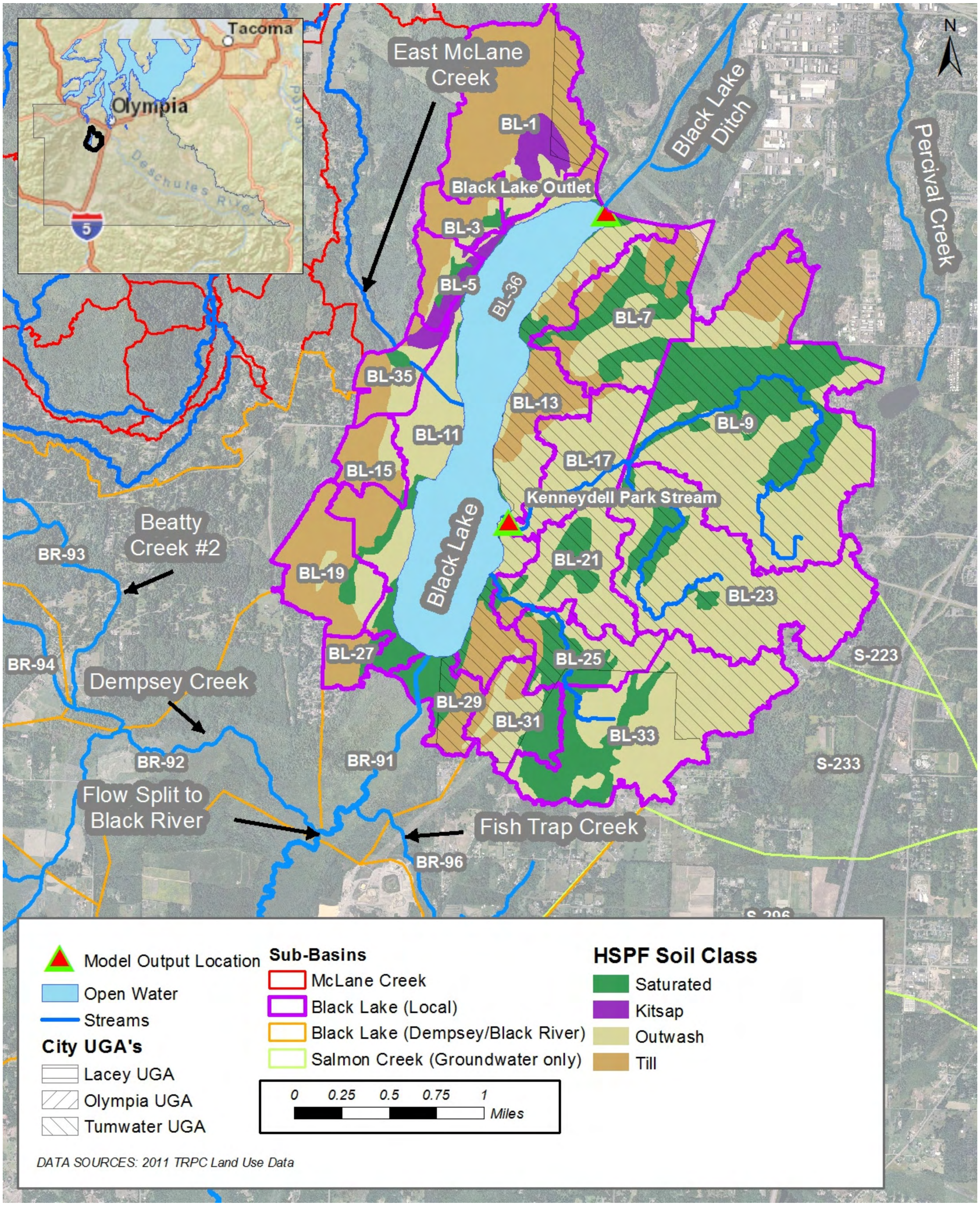


Figure 23: HSPF Soil Classes, Black Lake Basin

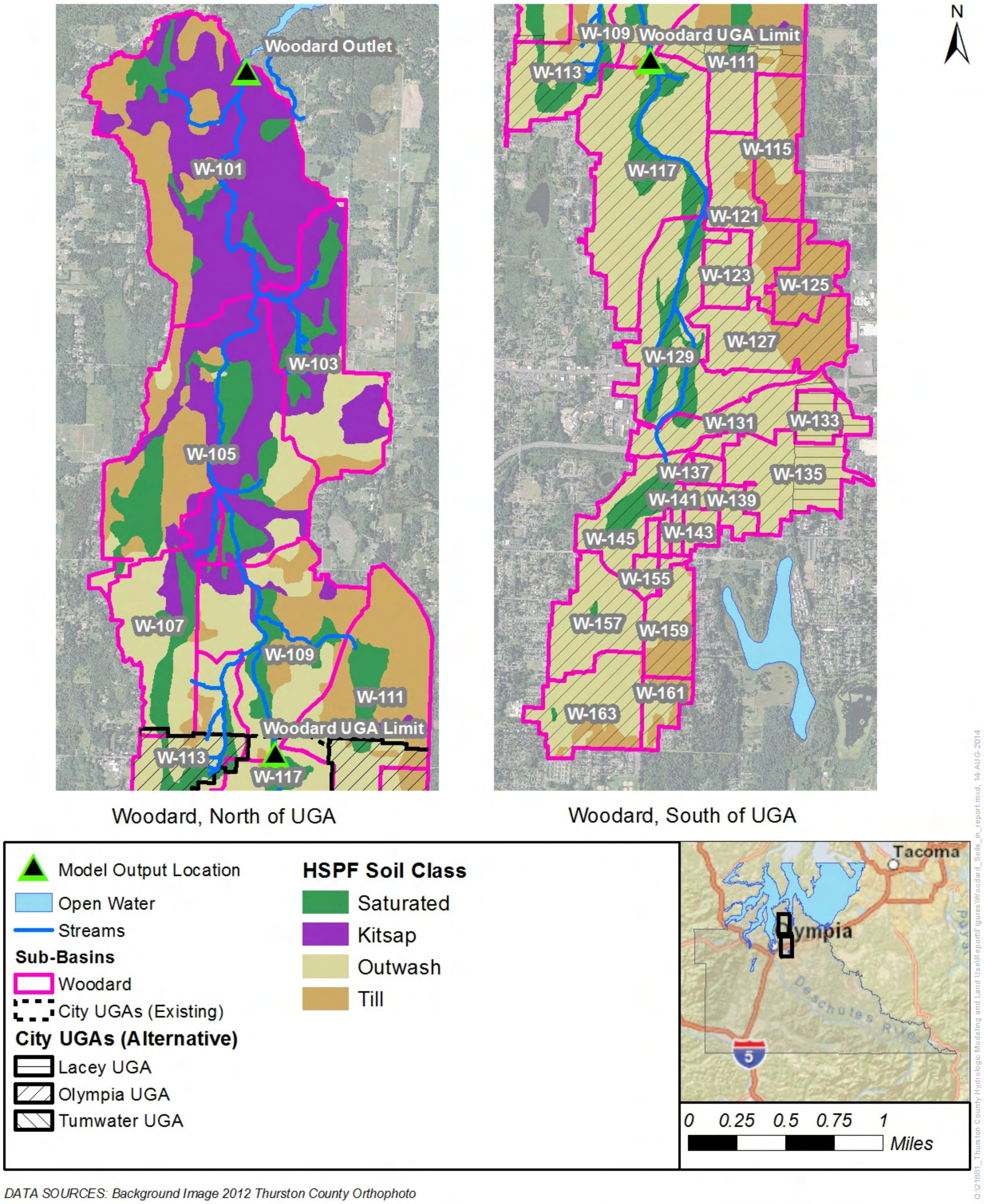


Figure 24: HSPF Soil Classes, Woodard Creek Basin

Land Cover and Land Use

In addition to soil type, the PERLNDS and IMPLNDS are also distinguished by land cover and land use. The study area models include three pervious land cover types and seven land use types. The land cover types (forest, pasture, and grass) each have a unique hydrologic response and have been used widely by HSPF modeling in the Northwest for decades (e.g., Dinicola, 1990). In order for water quality to be modeled, land use information also needs to be included in PERLNDS and IMPLNDS so that loading rates can reflect the activities that occur in each land use. Some activities that vary by land use include pets in residential, livestock or agricultural in rural, and industrial or automotive uses in urban land use areas.

The thirteen unique GIS data sets shown in Table 15 were used to characterize both land use and land cover in the Pre-European, existing, and 30-year forecasted scenarios. The resulting land cover areas used by the HSPF models are summarized by basin in Table 16, and by sub-basin in Appendix D.

The Pre-European scenario includes only forest, prairie, and wetland land covers and no anthropogenic land uses. The extents of prairie cover areas were delineated from 1850's GLO maps and wetland areas were assumed to be equivalent to those that currently exist in the TRPC wetlands inventory. With the exception of Black Lake, all other areas were treated as forest. Black Lake is not modeled as a land surface but explicitly as a water body in the HSPF model.

The existing scenario land cover dataset was developed from multiple data sources and represents a 2011 – 2012 condition. The base land cover dataset was a 2001 condition provided by TRPC. That dataset was updated by NHC by reclassifying pasture and forest covers, adding wetlands, and performing additional impervious area delineation. Pasture and forest covers were reclassified through the use of a vegetation height dataset that was calculated from two LiDAR elevation datasets, one reflecting a "with vegetation" condition and another "without vegetation" condition. Pasture or scrub-shrub covers in the TRPC dataset that were shorter than 3' were categorized as pasture cover and those taller than 3' were categorized as forest cover. The threshold was selected through trial and error to produce the best agreement with the areas that appear as pasture and forest in the 2012 orthophoto of the study area.

Existing land use information relied on a 2011 land use dataset provided by TRPC that characterized existing uses and a count of dwellings per parcel based on tax assessor and other information. NHC processed this information to develop the land use categories shown in Table 17 that vary as a function of housing density. Those categories were used for pre-processing and then further simplified into seven land uses that are reflected in the HSPF model PERLNDs in Table 13.

Parking lot, road, and rooftop impervious areas were manually delineated by NHC staff using a partial building footprint dataset, buffered roads inventory, and a 2012 orthophoto. Remaining impervious surfaces, including sidewalks, driveways, patios, and other non-roadway surfaces, referred to here as "other" impervious surfaces, were estimated based on land use class using detailed delineations of a few sample areas within the study area. The primary focus of the delineation was to classify High Pollution Generating Surfaces (HPGS) and Low Pollution Generating Surfaces (LPGS). HPGS includes all surfaces used by vehicles such as parking lots and roadways and the others are classified as LPGS.

The land use and land cover datasets used for the Planned Trend and Future Alternative 1 scenarios are similar to those used for the existing condition scenario except that additional impervious area was added to parcels forecasted by TRPC for development or redevelopment. For these parcels forecasted new impervious area and dwelling unit counts were added to the existing condition values. No forecast of future pervious cover was available so the new impervious area was assumed to convert equal areas of grass, pasture, and forest. The spatial location of development and remaining cover areas were then randomly distributed within each parcel in a manner that preserved the forecasted area totals.

Future Alternative 2 land use and land cover datasets are very similar with the exception of wetland, floodplain, and riparian restoration and the buyout of lots in the McLane basin. The land cover in the restoration areas were changed to forest in floodplain and riparian restoration areas and wetland cover in the wetland restoration areas. Existing land cover in parcels subject to buyout in the McLane basin were preserved and protected from future development.

Table 15: GIS Datasets used for Land Cover and Land Use Characterization				
Dataset	**Source**	**Type**	**Filename**	**Comment**
2011 Land Use	TRPC	Polygon	Parcels2011LandUse.shp	
2001 Land Cover	TRPC	Raster	landcov.img	see TRPC (2001)
Wetlands	TRPC	Polygon	wetlands_trpc.shp	
GLO Mapped 1850's Prairies	TRPC	Raster	pioneermap1850.tif and multiple panels	
30-year Forecast Land Use and Dwelling Units	TRPC	Table	FutureAlternative.mdb/ land11_impervious_FutAl t	Joins to 2011 Land Use polygon
Future Restoration Polygons	TCWC and TRPC	Polygon	Restoration_merge.shp	Future riparian and wetland restoration areas.
2012 Aerial Image	Thurston County	Raster	Thurston_P2012.sid	
Building Footprints	Thurston County	Polygon	bldg_ft_prn.shp	
Roads	Thurston County	Polyline	roads.shp	
Bare Earth LiDAR	Thurston County	Raster	HydroDEM	
All Return LiDAR	Thurston County	Point	Multiple .LAS files	
Vegetation Heights	NHC	Raster	veg_hght	
High and Low Pollution Generating Impervious Surfaces	NHC	Polygon	TIA_All_union_M1_MAO _and_Dempsey.shp	Manual delineation of roadway, rooftop, and parking areas from orthophotos

Table 16: Summary of Land Covers by Scenario										
Basin	Basin Area (sq. miles)	Forest	Pasture/ Prairie	Grass	High PGIS EIA	Low PGIS EIA	Wetland	Water	High PGIS TIA	Low PGIS TIA
Pre-European Scenario										
Black Lake	19.2[1]	72%	6%	0%	0%	0%	17%	5%	0%	0%
McLane Creek	12.7	89%	0%	0%	0%	0%	11%	0%	0%	0%
Woodard Creek	7.9	80%	1%	0%	0%	0%	19%	0%	0%	0%
Existing Condition Scenario										
Black Lake	19.2[1]	56%	14%	6%	2%	1%	16%	5%	3%	3%
McLane Creek	12.7	77%	12%	2%	1%	0%	7%	0%	2%	1%
Woodard Creek	7.9	36%	21%	14%	8%	4%	17%	0%	10%	8%
Planned Trend Scenario										
Black Lake	19.2[1]	55%	11%	9%	3%	2%	15%	5%	4%	6%
McLane Creek	12.7	77%	11%	3%	2%	0%	7%	0%	2%	2%
Woodard Creek	7.9	34%	19%	16%	9%	5%	17%	0%	11%	11%
Future Alternative 1 Scenario										
Black Lake	19.2[1]	55%	12%	8%	3%	2%	15%	5%	4%	5%
McLane Creek	12.7	77%	11%	2%	1%	0%	7%	0%	2%	1%
Woodard Creek	7.9	35%	20%	15%	9%	5%	17%	0%	11%	10%
Future Alternative 2 Scenario										
Black Lake	19.2[1]	56%	11%	8%	3%	2%	15%	5%	3%	5%
McLane Creek	12.7	81%	7%	2%	1%	0%	9%	0%	2%	1%
Woodard Creek	7.9	38%	17%	14%	9%	5%	17%	0%	10%	10%

[1] The Black Lake basin, including Dempsey Creek and Fish Trap Creek tributaries, is 19.2 square miles but a flow split that diverts flows away from the basin results in only 13.1 square miles effectively reaching Black Lake. The remaining flows are routed to the Black River. Of the remaining 13.1 square miles only 7.7 are local to Black Lake, rather than Dempsey Creek or Fish Trap Creek.

Table 17: Land Use Classes and Housing Densities			
Model Land Use Class	**GIS Land Use Class**	**Housing Density (DU/acre)**	**Comment**
Urban	Urban		Includes ROW, commercial, industrial, government, and mixed use
High Density Residential	Multi-Family Residential	> 15	
	High Density Residential	6.5-15	
Low-Moderate Residential	Moderate Density Residential 1	3.5-6.5	
	Moderate Density Residential 2	2-3.5	
	Low Density Residential	0.5-2	
Rural 1	Rural 1	0.2-0.5	
Rural 2	Rural 2	0.1-0.2	
Rural 3	Rural 3	0.05-0.1	
Rural 4	Rural 4	< 0.05	
None	Natural Resources		
	Open Spaces		
	Vacant Land		
	Wetland		

Precipitation Zones

The variability of rainfall throughout the study area was captured through the use of multiple precipitation zones. Zone 1 represents the lowland areas near Olympia and is the only zone used by the Woodard Creek model. Zones 2 and 3 were added to allow some lapsing of rainfall (i.e., change in precipitation with elevation) within the upland areas of McLane and Dempsey Creek (a portion of the Black Lake basin). The McLane and Black Lake basin models also have a Zone 4 defined at a similar elevation band to Zone 1, but which allows the use of the Little Rock rain gage during the calibration process. A single precipitation zone was applied within each model sub-basin.

4.4.3 Natural Stream/Lake/Wetland Representation

Natural surface water features within the study area include streams, lakes, and wetlands. The hydraulic properties of these features are defined within the HSPF model in tabulations referred to as FTABLES. An important characteristic defined by these tables is the volume of water stored within each reach of the model. This storage varies with stream discharge and was defined using attributes such as channel width and slope, wetland area, and the restriction from culverts downstream. A summary of the different types of natural stream reaches in each model basin are shown below. In Woodard Creek, channel width and depth attributes were assigned based on measurements documented during stream walks performed by the Wild Fish Conservancy (2007). In the Black Lake and McLane basins, stream size information was not directly available and instead was estimated based on basin area using relationships applied by EPA BASINS and documented in Ames et al. (2009). Natural surface water feature FTABLES are identical through all model scenarios except for the Pre-European scenario. In that scenario, the Woodard Creek reaches with culvert control are allowed to flow unrestricted.

Summary natural stream reach representation by sub-basin:

McLane Creek

- Stream channels and wetlands: 59, 63, 65, and 71
- Stream channels only: 51, 52, 53, 55, 57, 61, 67, 68, 69, 73, 75, 77, 79, 81, and 83

Black Lake

- Black Lake bathymetry (USGS, August 23, 1971): 36
- Stream channels and wetlands: 9, 21, 23, 25
- Stream channels only: 17, 33
- Stream channels only, copied from legacy model (Thurston County, 1993): 91, 92, 93, 94 and 95

Woodard Creek

- Stream channels and wetlands, no culvert control: 101, 105, and 129
- Stream channels and wetlands, with culvert control: 109, 117, 145, and 157

4.4.4 Stormwater BMP Representation

In addition to natural surface water features, there is also stormwater infrastructure, referred to as stormwater Best Management Practices (BMPs) that provide conveyance, flow control, and water quality treatment of flows in the basins. Ditches, pipes, and flow control facilities are defined using FTABLES in a similar manner as natural features. Stormwater inventories and as-built drawings made available from the City of Lacey, City of Olympia, City of Tumwater, and Thurston County, only documented significant ditches and flow control facilities within the Woodard Creek basin (see summary by sub-basin below). None of these facilities were included in the existing condition models for the other two basins. The largest flow control facilities in the Woodard basin (including both those with and without infiltration) were explicitly modeled based on as-built drawings and discussions with City of Olympia staff. Additionally, treatment from smaller infiltration facilities in outwash-dominated sub-basins in the Woodard Creek basin was also accounted for, though with less detail than the large facilities. The infiltration from these smaller facilities was accounted for by one of two methods. First, in basins that had larger explicitly modeled facilities, the infiltration capacity of the facility was increased slightly as an adjustment parameter during calibration. Secondly, in basins that did not include explicitly modeled facilities, 20% of impervious area runoff was routed directly to groundwater. This routing percentage assumption was derived based on review of GIS data, and also as a calibration parameter that was adjusted during model calibration. A complete listing of how facilities were represented in each basin is provided below.

Existing Flow Control Facilities in Woodard Creek, by sub-basin:

- Ditches/pipes: 103, 107, 111, 113, 115, 121, 125, 127, 131, 139, 143, 135
- Flow Control Facilities, explicit detention only: 163, and 335
- Flow Control Facilities, explicit with infiltration: 123, 133, 135, 137, 141, 147, 149, 151, 153, 155, 159, 161, and 235
- Flow Control Facilities, implicit infiltration: 115, 121, 125, 127, 131, 139, and 143

In the Planned Trend and Future Alternative 1 scenarios, flow control and water quality treatment facilities required under current and proposed stormwater regulations were added to the models. And in the Alternative 2 scenario, facilities were added for both new development and identified stormwater retrofit sites. Expected rates of bypass (no treatment) and applicable treatment standards for each future scenario are summarized in Table 18.

Table 18: Flow and Water-Quality Treatment Assumptions by Scenario			
Scenario	**Existing Development**	**New and Re-Development**[1]	**Retrofit Areas**
Existing	Flow Control: In the Woodard basin existing major facilities are represented explicitly and minor facilities are represented implicitly. No existing facilities are represented in the Black Lake and McLane basins. Water-Quality: No existing water-quality facilities are represented in any of the three basins, though they are reflected in the land use based pollutant loading rate factors derived through calibration (see Table 19).	None	None
Planned Trend	Same as existing scenario	• 20% is untreated • 80% is treated to flow duration standard and water quality treatment standard	None
Future Alternative 1	Same as existing scenario	• 20% is untreated • 20% is treated to flow duration standard and water quality treatment standard • 60% is treated to Ecology LID performance standard	None
Future Alternative 2	Same as existing scenario	• 20% is untreated • 20% is treated to flow duration standard and water quality treatment standard • 60% is treated to Ecology LID performance standard	• 40% remains untreated • 20% is treated to flow duration standard and water quality treatment standard • 40% is treated to Ecology LID performance standard

[1]Stormwater BMPs for redevelopment:
Medium density residential 2 and higher densities, entire parcel will be treated if the parcel is redeveloped.
Low density residential, 50% of the remaining parcel will be treated.
Rural zones, only the new impervious area will receive treatment.

The area of a parcel that is treated with a stormwater BMP when it is redeveloped varies depending on the density of redevelopment. In rural land use zones, it was assumed that only the new impervious area will receive treatment. But in areas of denser redevelopment, medium density residential 2 and higher, it was assumed that the entire parcel will be treated if the parcel is redeveloped. And redevelopment in low density residential areas will treat 50% of the remaining parcel (including impervious, forest, pasture and grass surfaces).

The stormwater flow control BMPs added to the HSPF model to treat new development and retrofit areas were sized at the sub-basin level, independently from areas receiving existing treatment or areas that bypass treatment. Facilities sized to match the flow duration standard were sized using the Western Washington Hydrology Model (WWHM) and those sized to meet the Ecology LID performance standard were modeled with a hydrologic and water quality response identical to that of forest (the intention of the standard). The primary intent of this was to reasonably and efficiently approximate the flow control performance of LID facilities. For water-quality treatment, this approach may over-estimate the removal rates to the extent that LID facilities do not fully infiltrate runoff from pollutant generating surfaces.

Facilities were sized as detention only in cases dominated by till soils. In areas dominated by outwash soils, runoff was routed directly to groundwater without the use of an FTABLE entirely. A summary of the facilities applied to each sub-basin in each scenario is provided in Table E1 in Appendix E.

Water-quality treatment in new or redevelopment and stormwater retrofit areas was applied as a removal efficiency, assuming that all new facilities will perform similar efficiency to that of stormwater wet ponds (CWP, 2007). Removal efficiencies are applied using HSPF's BMP routines for each constituent. Removal rates applied to new facilities in the study area basins included:

- Fecal Coliform – 70%
- Nitrate – 30%
- Total Phosphorus – 40%

Stormwater water-quality BMPs associated with existing, new or redevelopment, and retrofit areas are assumed to not affect pollutant loads contributed by septic systems.

4.5 Pollutant Loads to Watershed

The rate that pollutants are delivered to streams was simulated by HSPF's representation of the processes that mobilize each type of pollutant from the land surface. The loading rates are applied as 'load per land area' for each land use type but the actual model parameters used differ for pollutants that are sediment associated, simply build-up and wash-off, or have significant contributions to groundwater. Sediment associated loads are specified as potency factors and build-up and wash-off loads are specified as accumulation rates; we refer to all non-groundwater loads such as these as surface loading rates. The types of loading for the three pollutants modeled in this study were as follows:

- Phosphorus is assumed to be sediment-associated and also has significant contributions to groundwater.
- Nitrate is not sediment-associated but its primary mobilization is via contributions to groundwater.
- Fecal coliform is assumed to be non-sediment-associated; its primary mobilization is via build-up and wash-off processes.

In addition to applying loads based on land use, a more explicit representation of the loading of fecal coliform and nitrate from septic systems was also added to reflect the population served by septic systems and the expected performance of those systems. Both of these types of loading rates are discussed in detail in the subheadings below.

4.5.1 Land Use Based Pollutant Loads, Excluding Septic Systems

Regional and national loading rates from literature were used to assign the relative loads between different land uses. The loading rates were refined during the calibration process to match observed data where they were available. The relative surface (potency factor and accumulation rate) and groundwater loading rates for phosphorus and nitrate were derived from King County (2003) and are presented along with fecal coliform in Table 19 and Table 20 below, respectively. The loading rates vary by month, but only those for January are shown to simplify the tabulations.

The surface loading accumulation rate for fecal coliform was determined by calculating the mass of coliform generated by animals in each land use category. Model scenarios for conditions with reduced rural land-use densities were expected to result in a reduction in the number of large animals on hobby farms and corresponding loads. Unfortunately, no data documenting populations of animals in any of the study basins was available. Animal populations for populations considered most critical were instead estimated using information from other national studies (e.g. Virginia Tech, 2006 and Ecology 2006). Due to an uncertainty in the density of large animals in rural areas the density of animals in hobby farms was ultimately assumed to be uniform. A summary of these populations is provided in Table 21 and the resulting accumulation rates are reflected in Table 19.

Table 19: Land Use Based Surface Loading Rates *(only January values are shown)*			
Land Use Type (HSPF ID#)	**Potency Factor**	**Accumulation Rate**	
	Total Phosphorus - TP (lbs/ton of sediment)	**Nitrate - NO_3 (lbs/acre/day)**	**Fecal coliform (cfu x 10^6/acre/day)**
Wetland (7)	0.025	0.0002	170
Forest Urban (11,41,71)	0.4	0.0008	85
Forest Rural (14,44,74)	0.025	0.0002	155
Pasture Urban (21,51,81)	20.4	0.0010	79
Pasture Rural 1 (24,54,84) **[0.2-0.5 DU/acre]**	20.4	0.0010	171
Pasture Rural 2 (25,55,85) **[0.1-0.2 DU/acre]**	20.4	0.0010	179
Pasture Rural 3 (26,56,86) **[0.05-0.1 DU/acre]**	20.4	0.0010	179
Pasture Rural 4 (27,57,87) **[< 0.05 DU/acre]**	20.4	0.0010	179
Grass Urban w/ Till Soil (31)	0.36	0.0002	45
Grass Urban w/ Kitsap or Outwash Soil (61,91)	0.36	0.0002	45
Grass High Density Residential w/ Till Soil (32)	0.8	0.0002	176
Grass High Density Residential w/ Kitsap or Outwash Soil (62,92)	0.45	0.0002	176
Grass Moderate Density Residential w/ Till Soil (33)	0.8	0.0002	214
Grass High Density Residential w/ Kitsap or Outwash Soil (63,93)	0.8	0.0002	214
Grass Rural w/ Till Soil (34)	0.8	0.0002	113
Grass Rural w/ Kitsap or Outwash Soil (64,94)	0.8	0.0002	113

Table 20: Land Use Based Groundwater Concentrations *(only January values are shown)*		
Land Use Type (HSPF ID#)	**Groundwater Concentration (mg/L)**	
	Total Phosphorus - TP	**Nitrate - NO_3**
Wetland (7)	0.022	0.54
Forest Urban (11,41,71)	0.017	0.37
Forest Rural (14,44,74)	0.022	0.23
Pasture Urban (21,51,81)	0.034	1.2
Pasture Rural 1 (24,54,84) **[0.2-0.5 DU/acre]**	0.034	1.3
Pasture Rural 2 (25,55,85) **[0.1-0.2 DU/acre]**	0.034	1.3
Pasture Rural 3 (26,56,86) **[0.05-0.1 DU/acre]**	0.034	1.3
Pasture Rural 4 (27,57,87) **[< 0.05 DU/acre]**	0.034	1.3
Grass Urban w/ Till Soil (31)	0.025	3.1
Grass Urban w/ Kitsap or Outwash Soil (61,91)	0.025	3.1
Grass High Density Residential w/ Till Soil (32)	0.154	3.1
Grass High Density Residential w/ Kitsap or Outwash Soil (62,92)	0.011	3.1
Grass Moderate Density Residential w/ Till Soil (33)	0.013	1.3
Grass High Density Residential w/ Kitsap or Outwash Soil (63,93)	0.013	3.1
Grass Rural w/ Till Soil (34)	0.013	1.3
Grass Rural w/ Kitsap or Outwash Soil (64,94)	0.013	3.1

Table 21: Animal Population Estimates and Loading Rates					
	Livestock	Large Wildlife	Small Wildlife	Large Bird	Pets
Load per animal (cfu x 10^6/head/day)	420	350	50	1600	450
Land Use	Animal Density (animal/acre)				
Forest Urban	0	0	0.200	0.047	0
Forest Rural	0	0.20	0.200	0.047	0
Pasture Urban	0	0	0.078	0.047	0
Pasture Rural 1 (0.2-0.5 DU/acre)	0.2	0.02	0.078	0.047	0
Pasture Rural 2 (0.1-0.2 DU/acre)	0.2	0.05	0.078	0.047	0
Pasture Rural 3 (0.05-0.1 DU/acre)	0.2	0.05	0.078	0.047	0
Pasture Rural 4 (< 0.05 DU/acre)	0.2	0.05	0.078	0.047	0
Grass Urban	0	0	0.078	0.023	0
Grass High Density Residential	0	0	0.078	0.023	6.5
Grass Medium Density Residential	0	0	0.078	0.047	6.5
Grass Rural	0	0	0.078	0.047	0.5
Wetland	0	0.05	0.078	0.094	0

4.5.2 Septic System Sources of Nitrate and Fecal Coliform

In addition to non-septic system sources of nitrate and fecal coliform, the loading from septic system sources within the study area was also accounted for within the model. The representation of septic systems within the model was needed to allow the evaluation of planning strategies that result in more or fewer septic systems in each basin. The loading rates were determined using a GIS-based methodology similar to that used by the Ecology South Sound Septic loading study (Whiley, 2010). The method utilized a septic system inventory, soils data (fecal coliform only), and a drainage network (streams and storm system) to assign a higher loading rate to parcels considered to be a higher risk at discharging to the downstream lake or stream. Whiley (2010) recommended the use of a buffer of 150 meters (about 500 ft) around the South Puget Sound shoreline to identify high- and low-risk areas for Dissolved Inorganic Nitrogen (DIN) loading as part of Ecology's study. For the current study it was decided that a smaller buffer of 250 feet should be applied because: 1) when buffered, the drainage network covers much more area than a shoreline and the 150-meter buffer was less applicable to a stream than the Puget Sound shoreline, and 2) a previous septic system fecal coliform risk analysis performed by Thurston County Environmental Health utilized a buffer of 100 feet. The 250-foot buffer was selected as a compromise between these two to allow for a single buffer width to be applied for both fecal coliform and nitrate septic system load characterizations.

The resulting summary of septic-serviced dwelling units for each model scenario is provided in Table 22 below. The number of septic systems in each basin is fewer in the Planned Trend scenario than the Existing scenario because the model assumes sewer systems will be constructed to serve parcels inside the UGA and septic systems will be removed or abandoned. The number of septic systems in Future Alternatives 1 and 2 is higher than that of the Planned Trend because the UGA boundary is constricted and fewer homes will be converted to sewer service. Other factors, such as changes in loads due to other uses associated with development density, are included in the loading rates that vary by the land use category. Additional explanation of how septic system loading rates applied to the model is included in in the following section and discussion about the calibration of loading rates is provided in a later section of the report.

Table 22: Septic Serviced Dwelling Units By Risk Zone

Name	Woodard		Black Lake[1]		McLane	
	Fecal High Risk	NO_3 High Risk	Fecal High Risk	NO_3 High Risk	Fecal High Risk	NO_3 High Risk
Pre-Euro	0	0	0	0	0	0
Existing	523	1094	1181 [668+513]	1694 [1177+517]	254	354
Planned Trend	328	495	892 [355+537]	1209 [561+648]	338	474
Future Alt. #1	347	604	878 [458+420]	1376 [755+621]	331	438
Future Alt. #2	347	604	878 [458+420]	1376 [755+621]	331	438

[1] Values in brackets indicate the local and Dempsey Creek contributions to dwelling units in the Black Lake basin.

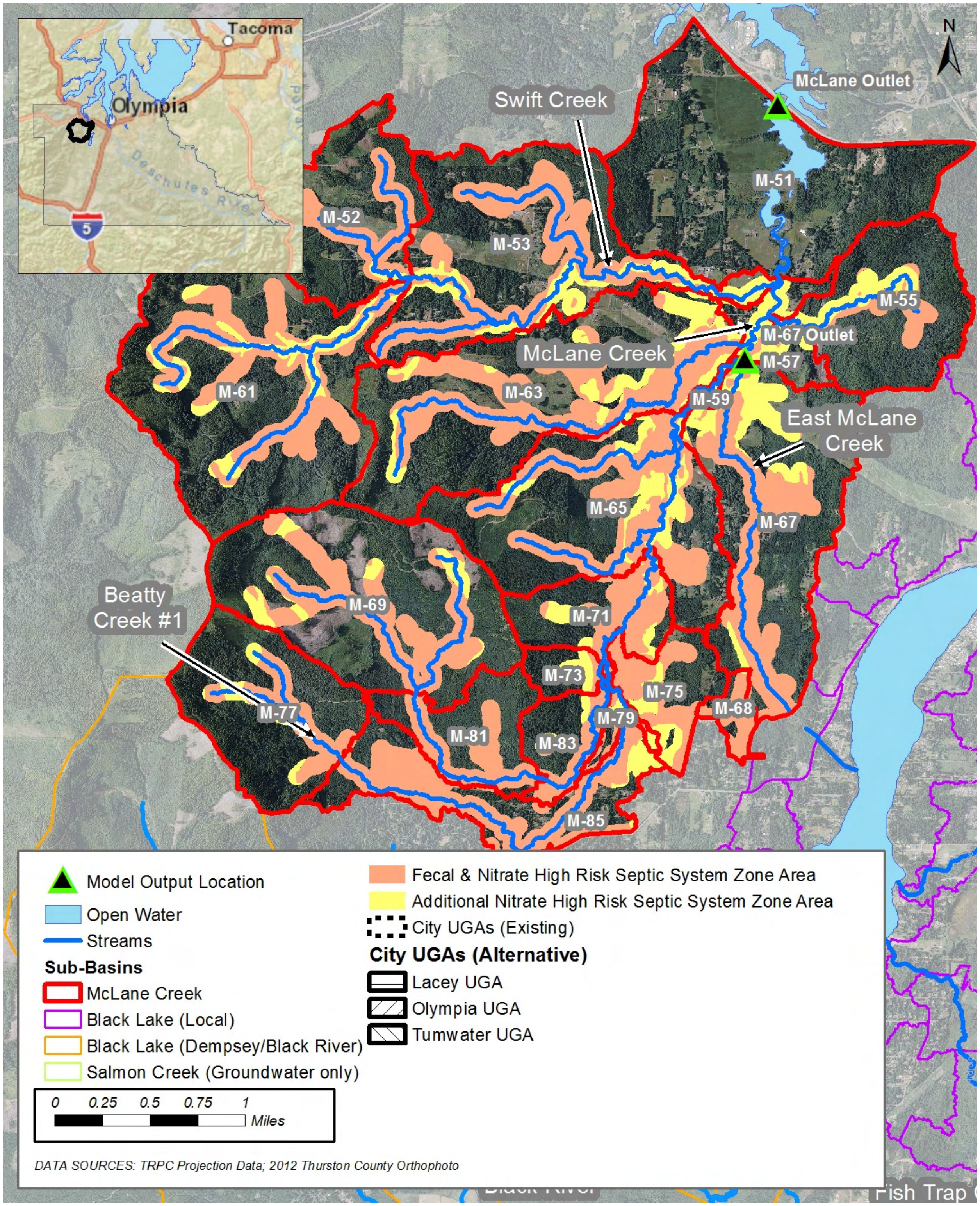


Figure 25: High and Low Septic System Zones, McLane Creek Basin

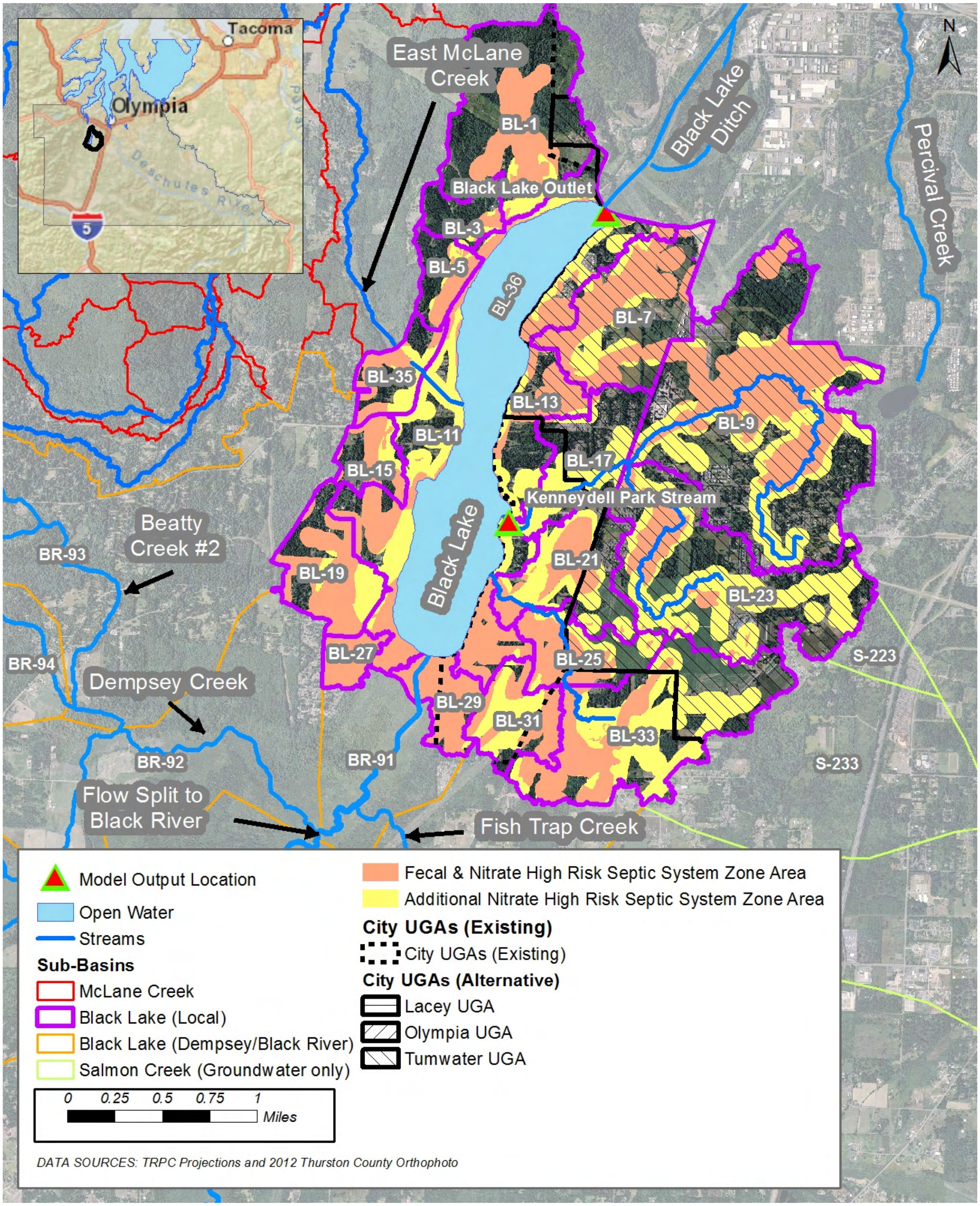


Figure 26: High and Low Septic System Zones, Black Lake Basin

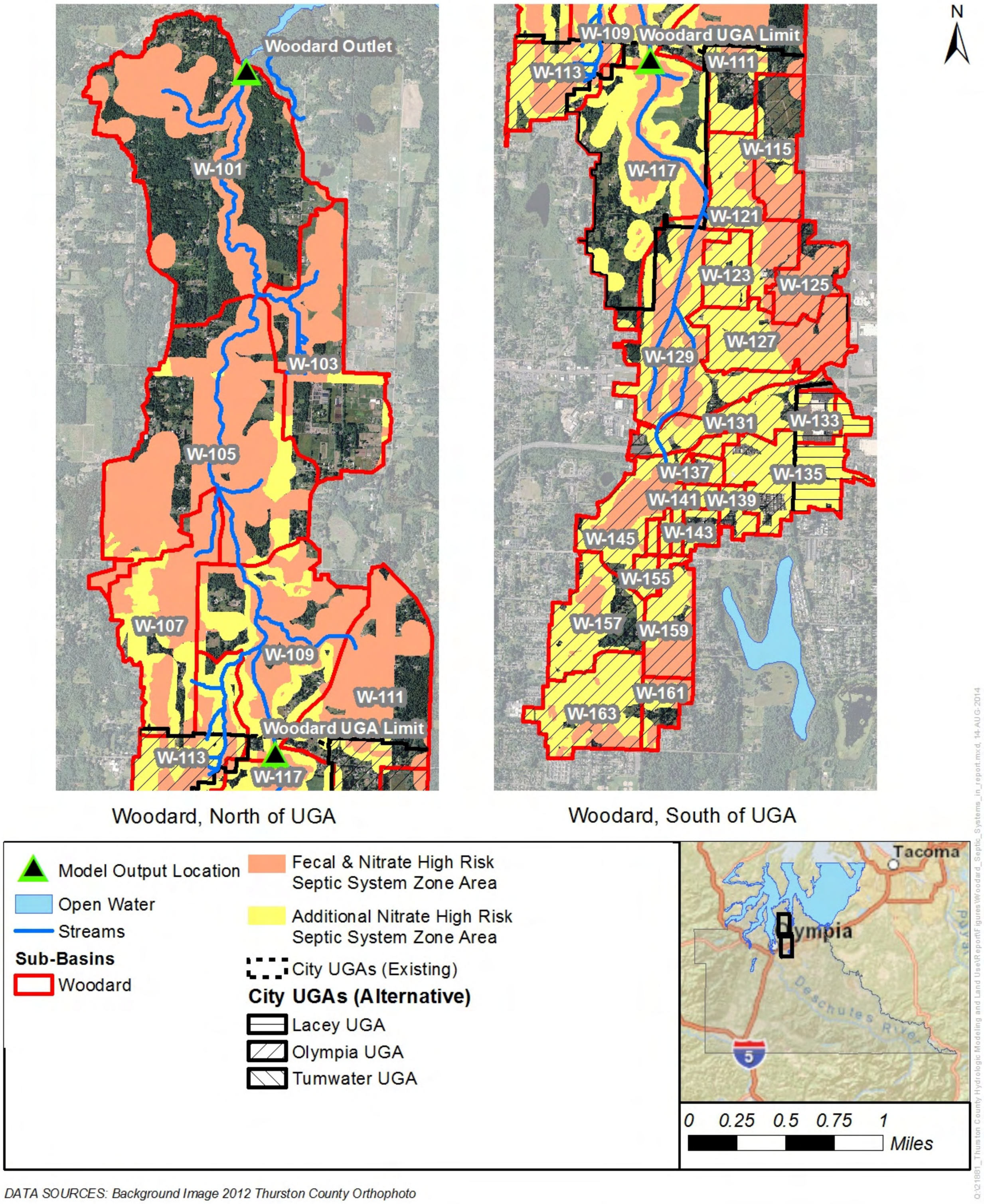


Figure 27: High and Low Septic System Zones, Woodard Creek Basin

4.5.2.1 Septic System Dissolved Inorganic Nitrogen (DIN) Loading Rate

Like Whiley (2010), a wastewater discharge rate of 69 gallons per person per day was applied to each septic system within the study area. That discharge, assuming 2.5 people per household, was assigned a DIN concentration of 31 mg/L. Within the high-risk zones, loads were reduced by 10% to account for reduction and capture from watershed processes. Outside of the high-risk zones, loads were reduced by 70%. Because most of the ammonia form of nitrogen is oxidized to nitrate when septic system effluent is in the soil, the DIN loading in each basin was assigned as a nitrate load. Loads, reduced by the representative watershed process factors, were applied as a time series directly to each stream in the study area for each scenario, similar to how a point source would be specified in the model. During calibration, nitrate loads from septic systems were further reduced by 75% to match observed in-stream data; the resulting load was 0.34 lb/month/dwelling unit. This may reflect that the high-risk buffer width for these basins was larger than it should have been and/or the reduction factors should be higher than those used by Whiley.

4.5.2.2 Septic System Fecal Coliform Loading Rate

Unlike nitrate, which is readily transported to receiving bodies via groundwater, fecal coliform pollutants need to be transported to receiving bodies via surface runoff. As a result, the modeling approach used for fecal coliform runoff was more physically based than that used for nitrate. And, in addition to the datasets used to determine high DIN loading risk zones, fecal coliform risk zones also reflect soils data. Any areas with high infiltration capacity were placed in a low-risk zone with effectively no load to receiving waters, regardless of proximity to a drainage course. Runoff from high-risk septic system drain fields were then modeled with the use of 500 square feet of grass land segment added to the model for every dwelling unit. The build-up and wash-off rates for the septic field were assigned based on the domestic loading rates to represent the load from failing systems in which the load is not properly treated by the soil. The failure rate was set at 24%, noting that failure rates ranging from 13 to 33% are typical. For each failing system the load of $2x10^9$ fecal coliform units (cfu) were loaded to the system (Geldreich, 1978). Again assuming 2.5 people per household, an accumulation rate of $102\ x10^9$ cfu/day/acre was applied to septic fields in the model [calculated as: production per household x failure rate / septic field area]. The model then allows that load to be conveyed to the receiving body when runoff is simulated from the grass surface.

4.6 Heat Budget and Temperature Calculations

Water temperatures in streams and well-mixed lakes can be calculated by tracking the net heat entering or leaving the water. HSPF includes six different types of heat transfer in its calculation of in-stream temperatures. These are:

- Net heat transport from incident shortwave radiation
- Net heat transport from longwave radiation
- Heat transport from conduction-convection
- Heat transport from evaporation
- Heat content of precipitation
- Net heat exchange with bed

Each type of heat transfer has a set of model parameters but the key parameter that varies as a function of canopy cover is the shade variable CFSAEX, the correction factor for solar radiation. The CFSAEX values for existing conditions in the three study area watersheds were calculated using a LiDAR-derived vegetation height to calculate the fraction of a 10-meter buffer around each stream reach that was shaded by trees of 20' – 50' or > 50' in height. A weighting scheme was then applied to calculate a CFSAEX value for each reach, which was varied during calibration to match the observed water temperatures in each reach. There are other factors that were varied during model calibration but those were not varied between model simulation scenarios. The CFSAEX shade factors for the Pre-Euro condition, existing condition, and future conditions Alternative 2 are presented in Table 23 below. Lower CFSAEX values correspond to more shade and less solar radiation reaching the stream. For lakes or ponds it was assumed that there was very little shade, and a CFSAEX factor of 0.9 was applied. Stream reaches with pipes were assumed to be completely shaded and a CFSAEX factor of 0.01 was applied.

Table 23: Stream Shade Factors

Stream Reach ID	Shade Factor CFSAEX		
	Pre-Euro Conditions	Existing Conditions	Future Conditions Alternative 2 "With Riparian Restoration"
Black Lake Basin			
9	1%	36%	23%
11	1%	9%	9%
13	1%	25%	15%
17	1%	20%	1%
21	1%	17%	17%
23	1%	38%	31%
25	1%	31%	31%
33	1%	30%	30%
35	1%	20%	20%
36	90%	90%	90%
McLane Creek Basin			
51	1%	45%	24%
52	1%	17%	15%
53	1%	14%	4%
55	1%	2%	1%
57	1%	20%	1%
59	1%	18%	1%
61	1%	12%	11%
63	1%	23%	11%
65	1%	15%	5%
67	1%	25%	12%
69	1%	17%	16%
71	1%	13%	1%
73	1%	11%	1%
75	1%	21%	1%
77	1%	1%	1%
79	1%	1%	1%
81	1%	7%	1%
83	1%	5%	1%
85	1%	3%	1%

Table 23: Stream Shade Factors, (Continued)			
Stream Reach ID	Pre-Euro Conditions	Existing Conditions	Future Conditions Alternative 2 "With Riparian Restoration"
Woodard Creek Basin			
101	1%	7%	1%
103	1%	23%	22%
105	1%	15%	1%
107	1%	7%	4%
109	1%	17%	1%
111	1%	28%	28%
113	1%	19%	19%
117	1%	26%	1%
121	1%	27%	16%
129	1%	29%	4%
131	1%	36%	1%
145	1%	28%	1%

4.7 Data Used by Model

The QAPP (referenced in Section 2 and included as Appendix B of this report) requires the Simulation Plan outline describe what data was used in both model setup and calibration/validation efforts, how the data were used, the time period during which the data were collected or used, and the quality requirements of the data, as appropriate. There was no formal monitoring program included in this project so, with the exception of temperature data, data collection consisted of identifying and acquiring existing datasets from various sources. Limitations of the available data did control the analyses performed in many cases.

An earlier data assessment memorandum was completed on January 14, 2013 (attached as Appendix C). That assessment inventoried data throughout the larger study area but did not do a complete QA/QC of that data. Following basin selection, the data needed for the modeled basins were further reviewed to determine what met the data-availability and data-quality requirements for model application.

4.7.1 Precipitation Data

Rainfall, measured with rain gages, is the predominant form of precipitation in the study area streams. Appendix B inventoried multiple rain gages within the vicinity of each of the three modeled basins. When fully reviewed, only three of those were found to be useful for short-term model calibration simulations. Those gages included the Olympia Airport (11U), Summit Lake (69U), and Little Rock (45U) and all were reported at 60-minute or shorter time intervals. The Olympia Airport was the only rain gage used for calibration for long-term simulation model runs (performed from 1956 through 2012).

The spatial density of rain gages can always be improved, but the coverage in the vicinity of McLane Creek and Black Lake basins was particularly sparse and affected the hydrologic calibration. We recommend that additional rain gages be located in these basins if additional calibration is performed as part of future work.

4.7.2 Meteorological Data

In addition to precipitation, the HSPF model requires six meteorological time series for the simulation of hydrology and water quality. These include pan evaporation, solar radiation, air temperature, dewpoint temperature, wind speed, and cloud cover. With the exception of pan evaporation and solar radiation, all of these parameters were available from the National Weather Service for the Olympia Airport station at hourly time intervals for the period of record 1956 - 2012.

Daily pan evaporation data were obtained from the Puyallup pan evaporation station, with winter months filled using the Jensen-Haise equation. The station operated from water year 1960-1997; monthly average values from the period of record were used for 1949-1959 and 1998-2012 to extend the record to the period used for the hydrologic modeling.

Solar radiation data used to run the model came from two different sources. An hourly time series of observed solar radiation data from the WSU AgWeather network at the Tumwater SW station was acquired for the period of August 11, 2011 through December 31, 2013 for use in calibration of water temperature, but data for long-term simulations had to be calculated from observed cloud cover data at the Olympia airport station. The calculation, performed within the EPA BASINS software package, estimates hourly solar radiation using the potential radiation based on the longitude and latitude of the study area and losses related to cloud cover.

4.7.3 Stream Stage and Flow Data

A record of stream flows are needed to facilitate calibration of the model water balance, including runoff from land surface segments and in this case groundwater inflows from adjacent basins. The primary data used for this purpose were Thurston County long-term monitoring sites, of which there is one in each of the three basins: McLane Creek at Delphi Road (reach 57), Black Lake Ditch at Belmore Rd. (reach 36), and Woodard Creek at 36th Avenue NE (reach 109). The County provided NHC with records of water levels (a.k.a. stage) that included the following periods:

- **McLane Creek**: 2001 –2013 (note: County monitoring methods changed in 2007 and less is known about data collected prior to that year)
- **Black Lake Ditch**: 2007 – 2012
- **Woodard Creek:** 2000 – 2013 (note: County monitoring methods changed in 2007 and less is known about data collected prior to that year)

To be useful for calibration, these water level records must be post-processed to calculate stream flows. This is typically done by applying one or more rating curves that define a relationship between recorded stage and discharges made with manual stream gaging equipment. For the McLane Creek and Black Lake sites, this proved to be complicated.

The McLane Creek gage site is noted by County staff to be impacted by gravel transport and deposition, large logs, and seasonal downstream beaver activity. These dynamics at the site result in frequent vertical shifts in the stage-discharge rating curve for the site, making calculation of a continuous record of flows difficult. Instantaneous discharge measurements made manually with a current meter by the County and Washington State Department of Ecology staff between 1983 and 2013 are the primary data used for calibration. Three different rating curves were applied to the continuous stage data and used to calculate three potential continuous flow records. These were helpful in evaluating the timing and peak flows but were secondary in the calibration to the instantaneous flow records.

The Black Lake Ditch site is located at the upstream end of a ditch that is impacted by seasonal vegetation growth and beaver activity. Like the McLane Creek site, these conditions made calculation of a continuous time-series of stages at this site difficult. Again, manual instantaneous discharge measurements made with a current meter by the County staff between 2008 and 2013 were the primary data used for calibration. At this site, two different rating curves were applied to the continuous stage data to calculate two potential continuous flow records. Again, these were helpful in evaluating the timing and peak flows but were secondary in the calibration to the instantaneous flow records.

At the Woodard Creek site, the stream channel is much less dynamic and the stage-discharge rating curves for the site were more readily applied to calculate a continuous record of stream flows. Instantaneous discharge measurements made with manual stream gaging equipment by the County staff between 1986 and 2013 were used here as well, but were a secondary dataset used in model calibration.

In addition to the primary monitoring sites in each basin, three secondary sites were also used in the calibration. These sites included Fish Trap Creek (reach 96) on the southeast side of the Black River divide wetland, the Black River divide wetland itself (reach 91), and McLane Creek's Swift Creek tributary (reach 53). These include:

- **Fish Trap Creek** – monitoring data was a daily record for the period 1999 – 2000 that was digitized from a Salmon Creek basin monitoring program (Larson, 2001).
- **Black River divide wetland** – monitoring data included an instantaneous discharge measurement made by Foster Wheeler on March 27, 2003 that documented 9.9 cfs flowing north toward Black Lake.
- **Swift Creek** – Instantaneous measurements collected by Washington State Department of Ecology between 1993 and 2010.

While not used directly as flow targets for calibration, estimates of stream flows and depths observed by NHC staff were also used as checks of simulated flows at sites with no other monitoring information. These estimates were made visually during a field reconnaissance by NHC staff on July 24, 2013 without the aid of instrumentation.

4.7.4 Water Quality Data

There are five water quality monitoring locations in the study area that were used as part of this study. These include two Thurston County Department of Public Health and Social Services long-term monitoring sites, one special project site with fecal coliform data, and two sites established by NHC during this project for temperature monitoring.

As noted in the original data review in Appendix B, the Thurston County Department of Public Health and Social Services long-term monitoring sites all include routine temperature, conductivity, pH, dissolved oxygen, turbidity, fecal coliform, total phosphorus, nitrite/nitrate, ammonia, plus additional parameters for lakes. Their monitoring program also includes data for Black Lake but that data was not used for calibration because no calibration of the lake was performed due to some limitations associated with HSPF. A summary of those sites and the data available for each is as follows:

- McLane Creek at Delphi Road (County ID ELDMC0000, HSPF model reach 57)
- Woodard Creek at the 4100 block of Libby Rd. (County ID HENWO0000, HSPF model reach 109)

In addition to the County's long-term monitoring sites, some short-term fecal coliform monitoring has also been performed at Kenneydell Park on Black Lake (Thurston County, 2012). The report from this monitoring includes results from samples collected between 2004 and 2012 on the Kenneydell Park Stream (HSPF model reach 17) at its outfall into Black Lake. The report summarizes the annual geometric mean, and range of fecal coliform results calculated from between three and eight samples collected each year. These data were used to calibrate fecal coliform loading into Black Lake.

During data review NHC noted a lack of continuous temperature monitoring data in the upper reaches of McLane Creek and decided to deploy two temperature loggers during the duration of this project. The loggers, HOBO Tidbits, recorded temperature at 15-minute intervals between July 24, 2013 and November 18, 2013. Locations of logger deployment were:

- McLane Creek at 6200 block of Chelsie Ln SW (Ecology EIM site ID 14MCLANEMC5, and HSPF model reach 81)
- McLane Creek at Delphi Road Upper Crossing (Ecology EIM site ID 14MCLANEMC2, HSPF model reach 59)

5 Model Calibration

Calibration of the HSPF model is a key step in model development that is necessary for the model to accurately simulate existing conditions. The calibration of the study models was performed for hydrologic, temperature, and water-quality (Fecal Coliform, Nitrate, and Phosphorus) parameters. Ideally calibration of simulated suspended sediment loads would also have been possible, but no such data were available. The lack of a suspended sediment calibration influenced selection of water quality output parameters, by restricting the output to dissolved forms rather than the sediment-associated forms of pollutants.

5.1 Hydrology Calibration

Calibration of all three basins was performed to achieve simulated stream flows that are within adequate agreement with observed seasonal volumes and individual storm peaks. The calibration began with the PERLND and IMPLND parameters used in these basins by USGS (1995); calibration was refined by revising the model representation of wetland storage and routing in the model with only minor changes in the original USGS land surface runoff parameters. As stated previously in Section 4.7.3, beaver activity and in adequate documentation of unstable stage-discharge rating curves at the McLane Creek and Black Lake ditch flow monitoring sites deemed the available continuous flow data at those sites to be considered poor relative to that typically used by NHC for calibration of hydrologic models. As a result, the calibration focused on instantaneous discharge measurements made using a current meter. Quantitative statistics on the quality of the calibration were not possible as a result.

McLane Creek

In the McLane Creek basin, the period 1985 through 2013 was used for calibration of simulated hydrology with an emphasis placed on the more recent 2002 through 2013 period. During calibration runs it was noted that upstream reaches in the model had excessive amounts of base flow but the lower reach in the model, at the gage site, had a shortage. It was also noticed during field reconnaissance that McLane Creek and its tributaries have a stream bed dominated by gravel and cobble that would allow flows to be conveyed sub-surface in some reaches. The solution was to allow a loss of baseflow through the bed of the stream in the upper reaches that is routed to the downstream reach upstream of the flow gage (reach 57).

Simulated flows from the resulting calibration, plotted with observed flows at an annual scale, are included in Figure 28 through Figure 39. The observed flows calculated from recorded stages shown in the figures are one of three rating curves that were developed for the site. The rating curve used to calculate the observed flow time-series was selected for each water year such that it was in the best agreement the manual flow measurements made during that period. No single rating curve provides a good match with flow measurements for all years. During some years, the observed flows are affected by beaver activity or other dynamic conditions resulting in significant differences between the simulated and observed flows (e.g., October 2009 and 2010). The resulting calibration was evaluated primarily for its agreement with manual flow measurements. The calibration provides a good match with those points and is considered adequate for the purposes of this study. We recommend that additional stage-discharge rating curve development be performed as part of future monitoring for the purposes of hydrologic modeling of this reach of McLane Creek (where the system is so dynamic).

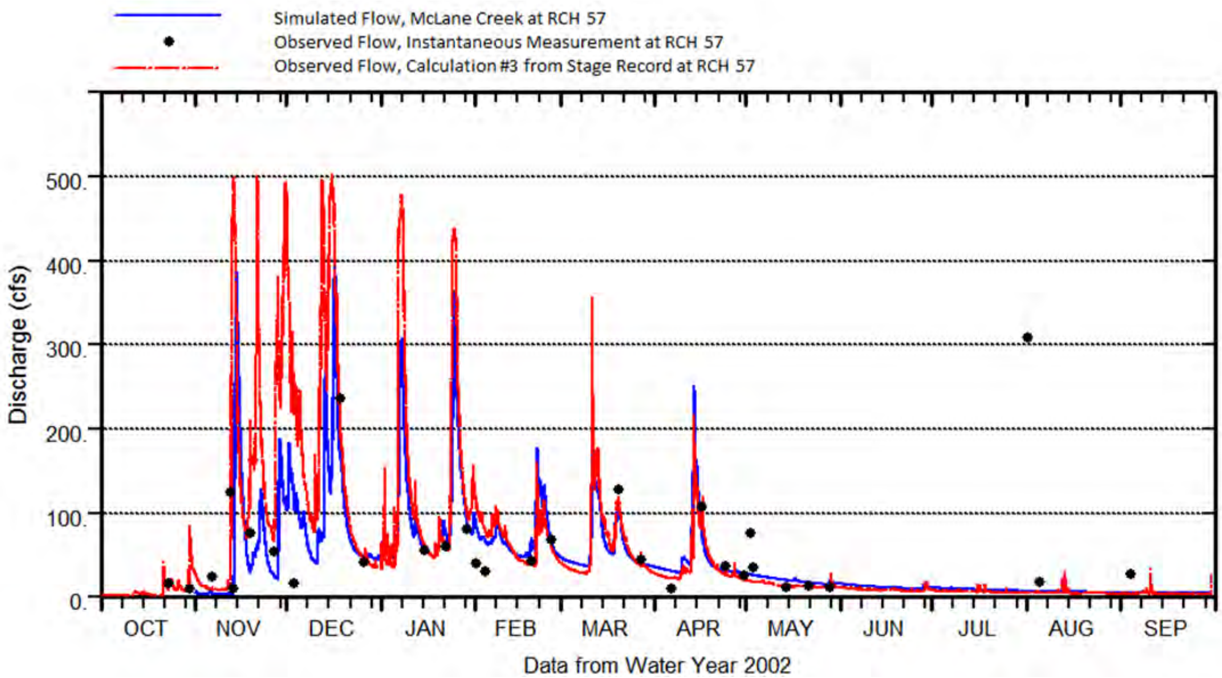


Figure 28: Simulated and Observed Flows at McLane Creek Reach 57, Water-Year 2002

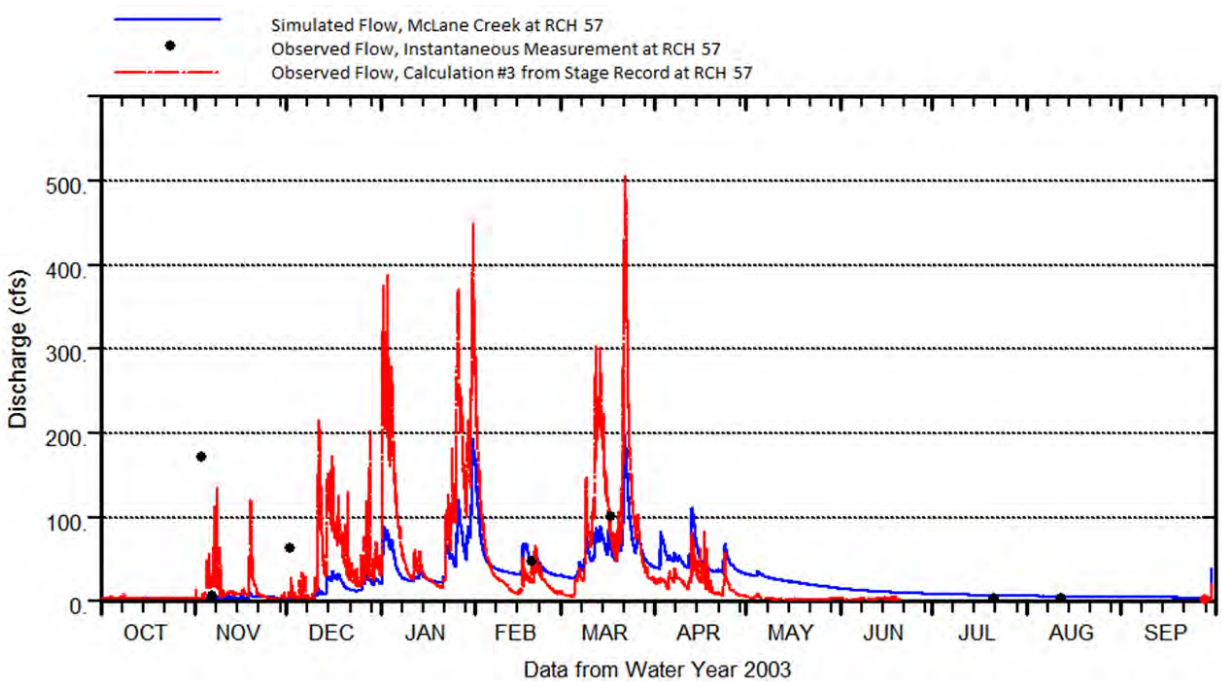


Figure 29: Simulated and Observed Flows at McLane Creek Reach 57, Water-Year 2003

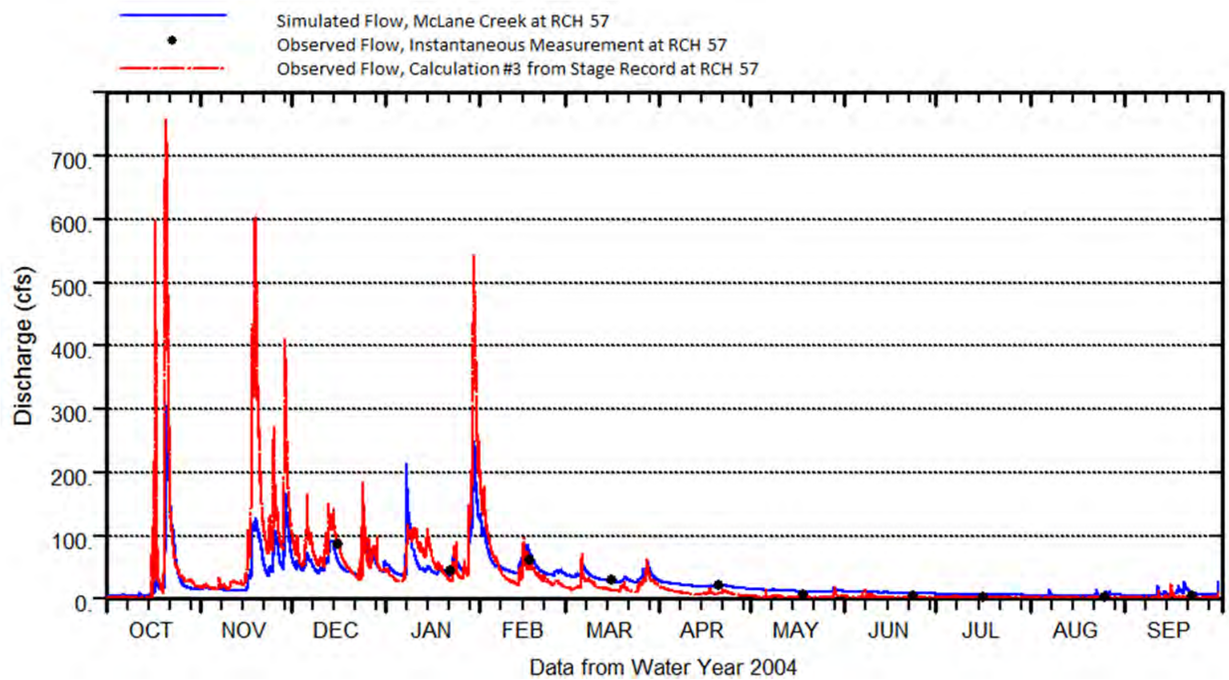


Figure 30: Simulated and Observed Flows at McLane Creek Reach 57, Water-Year 2004

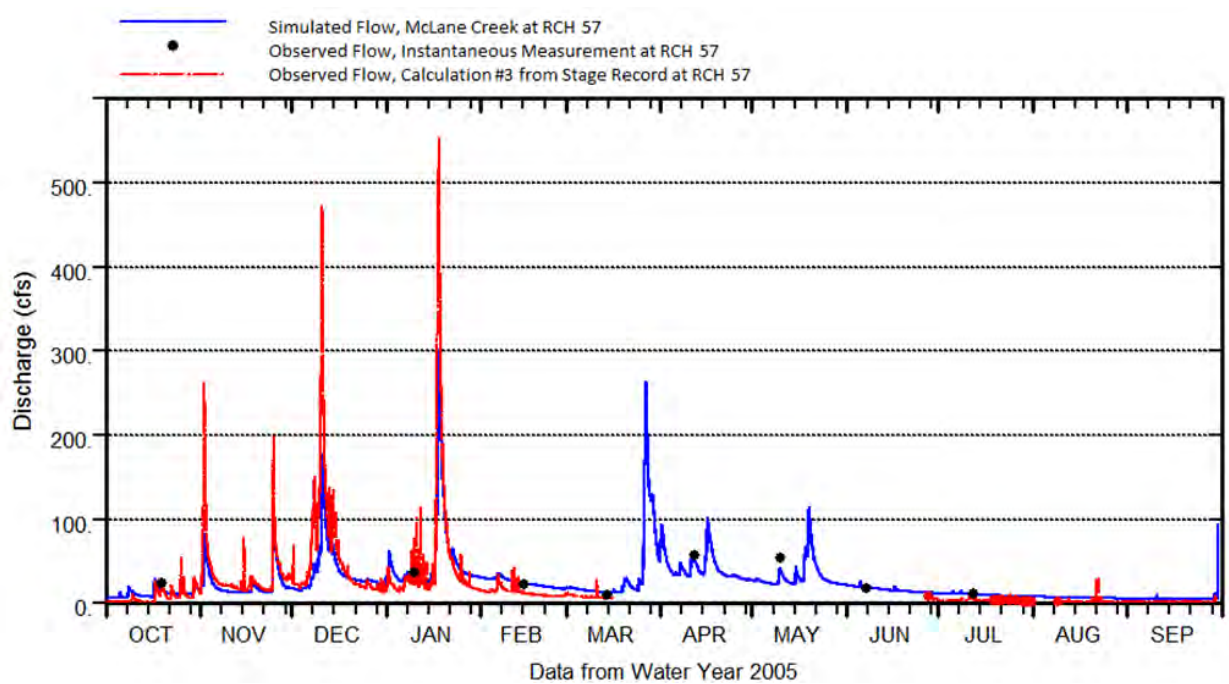


Figure 31: Simulated and Observed Flows at McLane Creek Reach 57, Water-Year 2005

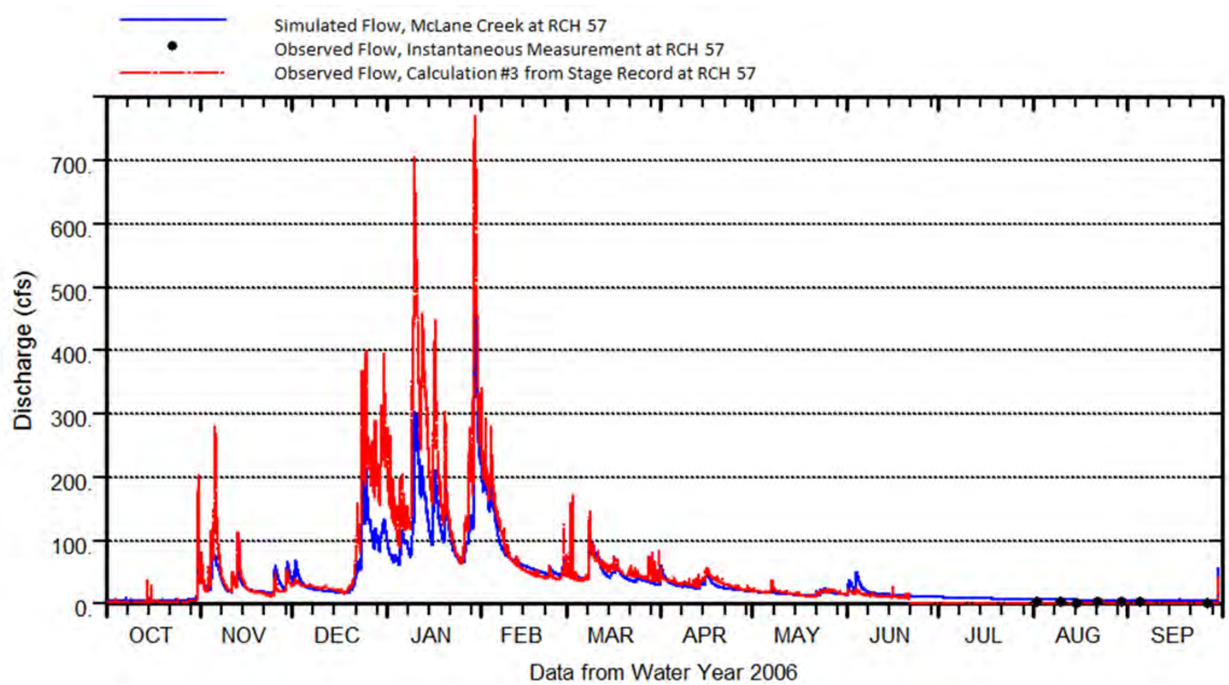


Figure 32: Simulated and Observed Flows at McLane Creek Reach 57, Water-Year 2006

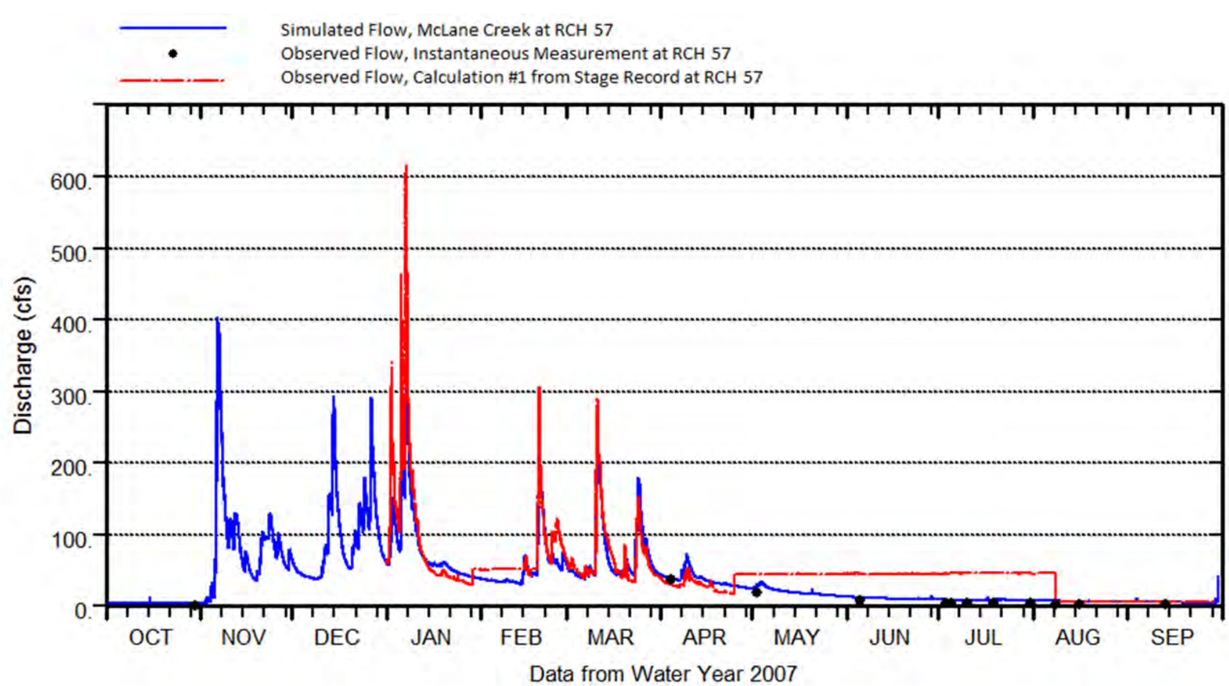


Figure 33: Simulated and Observed Flows at McLane Creek Reach 57, Water-Year 2007

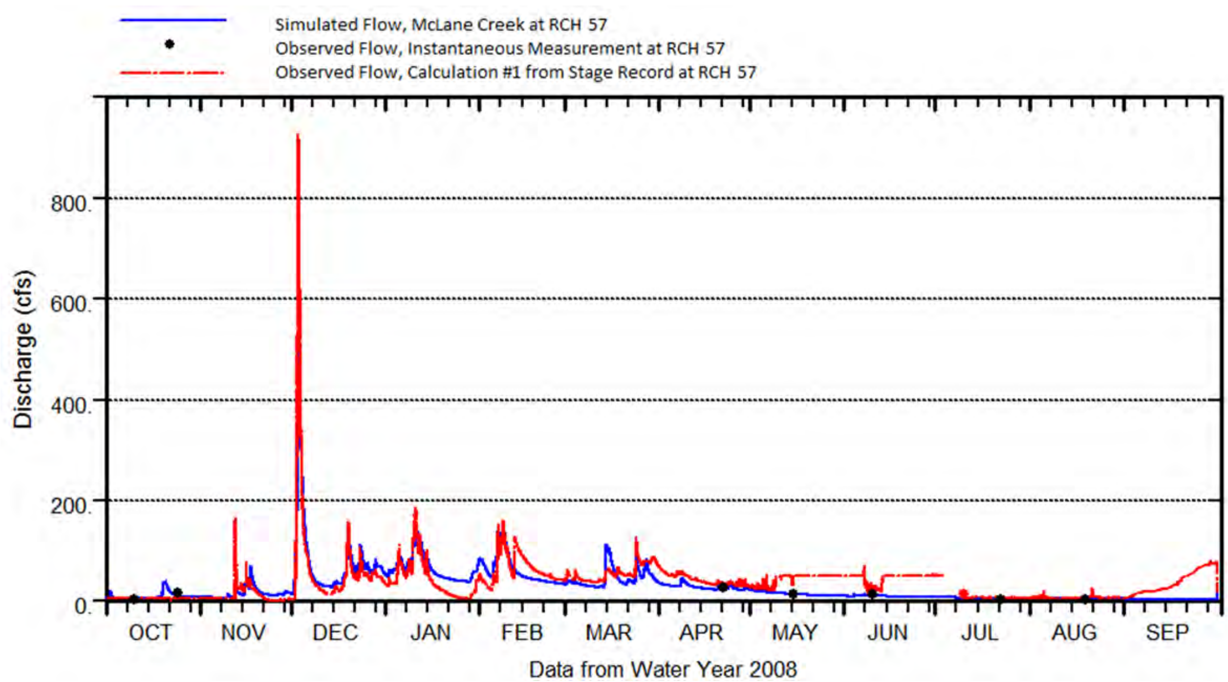


Figure 34: Simulated and Observed Flows at McLane Creek Reach 57, Water-Year 2008

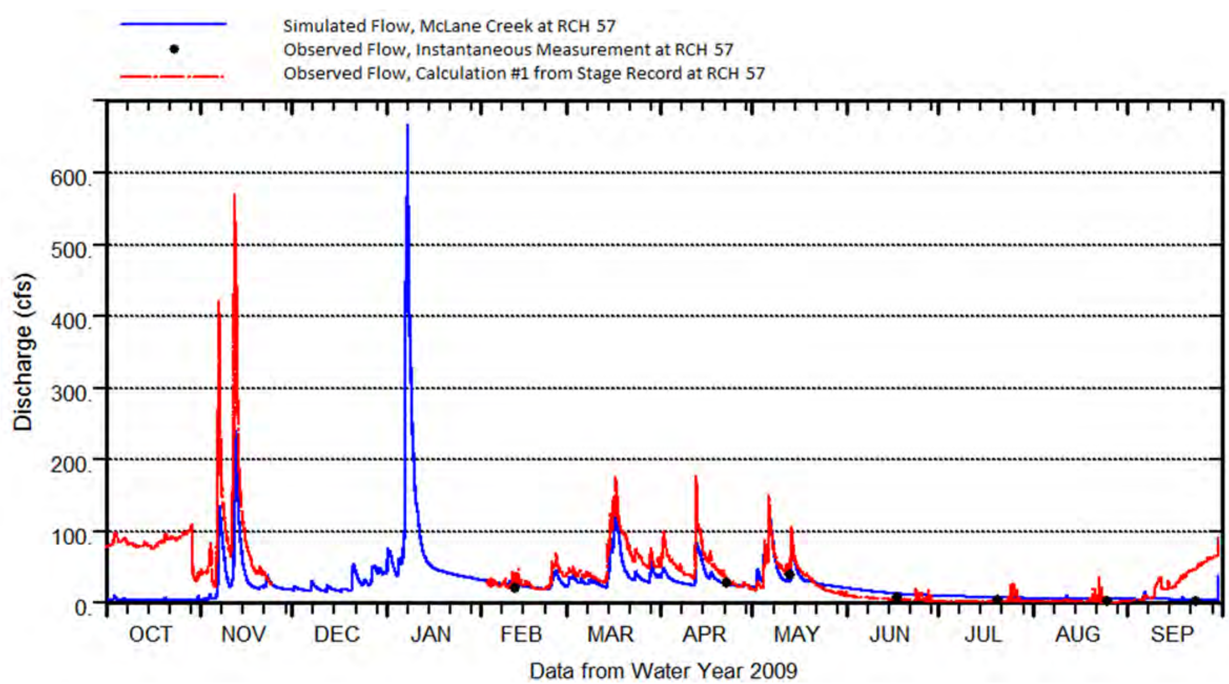


Figure 35: Simulated and Observed Flows at McLane Creek Reach 57, Water-Year 2009

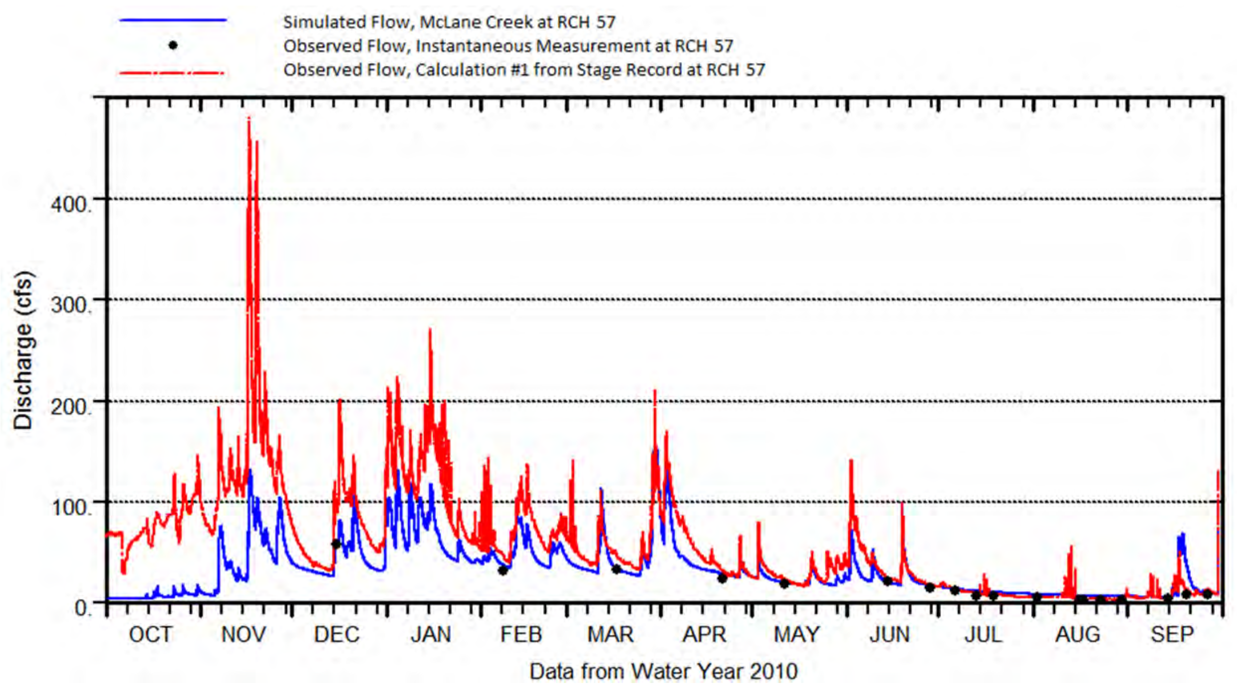


Figure 36: Simulated and Observed Flows at McLane Creek Reach 57, Water-Year 2010

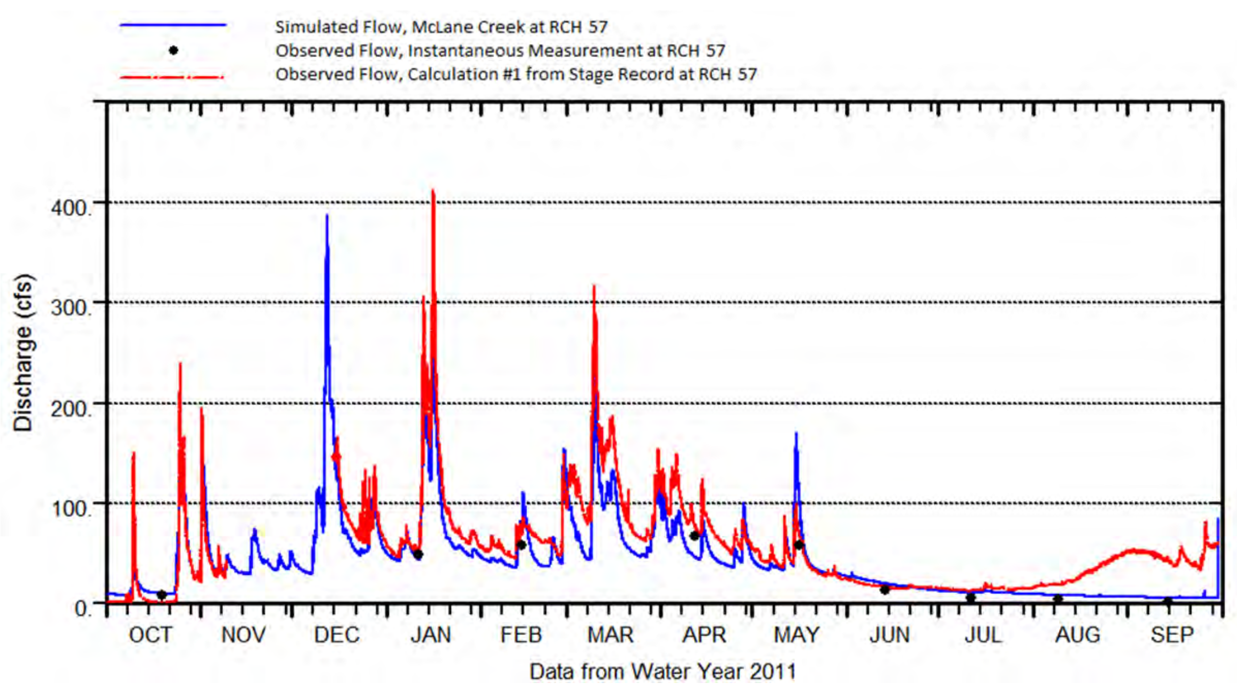


Figure 37: Simulated and Observed Flows at McLane Creek Reach 57, Water-Year 2011

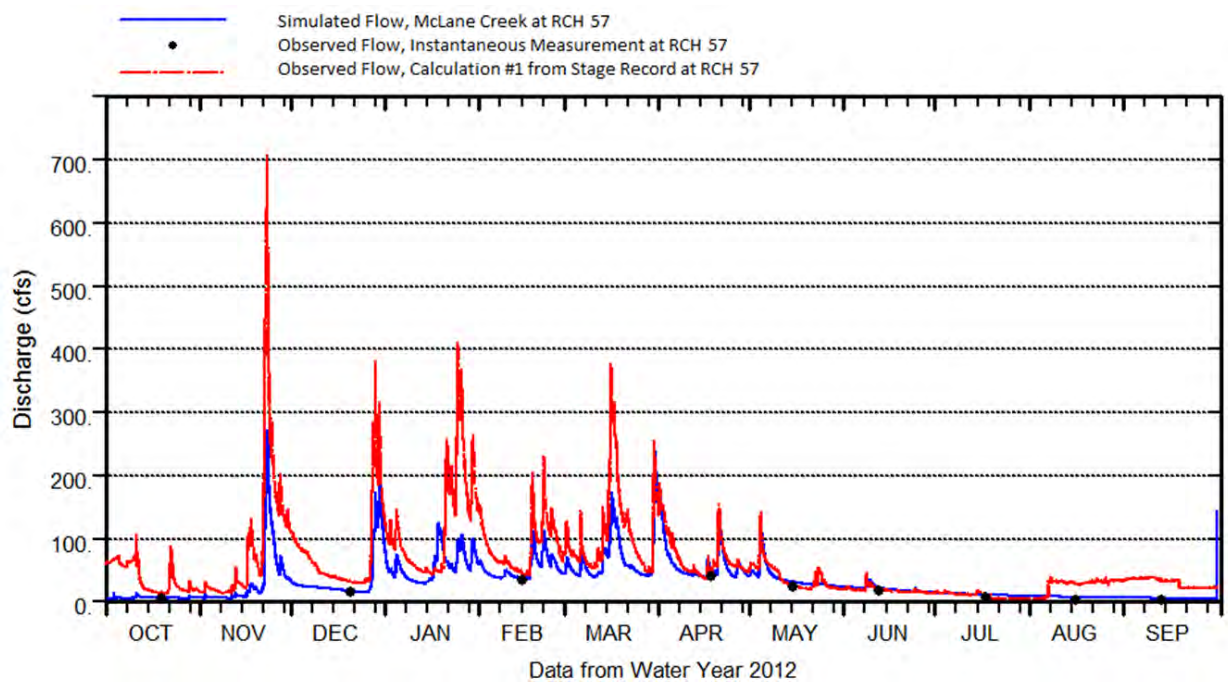


Figure 38: Simulated and Observed Flows at McLane Creek Reach 57, Water-Year 2012

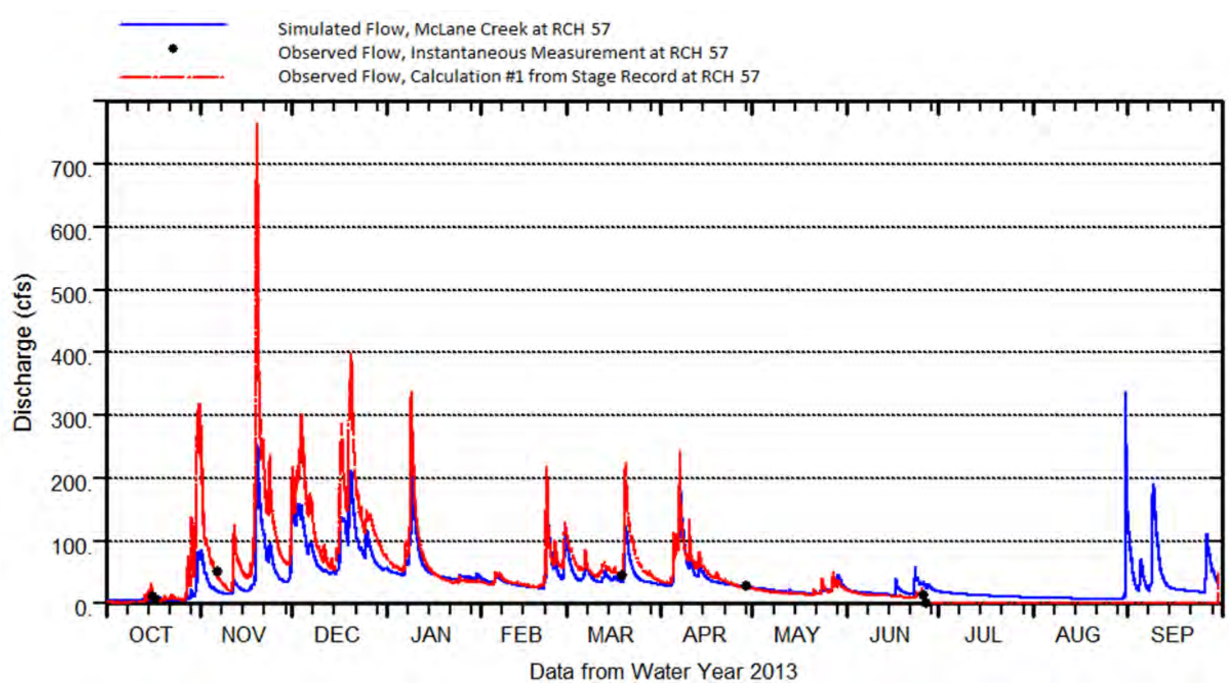


Figure 39: Simulated and Observed Flows at McLane Creek Reach 57, Water-Year 2013

Black Lake

In the Black Lake basin, the period 2008 through 2011 was used for calibration of simulated hydrology. Initially, the simulated annual and seasonal streamflow volumes were significantly less than those observed at the Black Lake Ditch gaging station. Three potential sources of additional inflow to the lake were evaluated while investigating this error. Those included under-estimated rainfall, additional surface water drainage area, and additional groundwater inflows.

First, the potential under-estimate of the modeled rainfall in the basin was addressed by reviewing the rainfall records at Olympia Airport (11U), Summit Lake (69U), Little Rock (45U), and assigning a rainfall zone to each sub-basin to allow a spatial variation of rainfall within the model. This improved the trend of certain storm events but did not address the cumulative volume shortage.

Second, the surface water drainage area was reviewed with additional data. A hydrologic investigation of the Black River reported in Foster Wheeler (2003) concluded that flows from the wetland divide between Black Lake and the Black River were flowing north rather than south. As part of that study, the divide in the wetland was observed and a flow of approximately 10 cfs was observed flowing north in to Black Lake. The report quotes Thurston County's Bob Mead as stating that *"The water upwelling is so strong that it creates a stationary flow zone in the river along that reach."* Based on the location of the divide along the wetland, south of Fish Trap Creek near the confluence of Dempsey Creek, it was assumed that all of Fish Trap Creek and a fraction of Dempsey Creek should be routed into Black Lake. These are model sub-basins 91 through 96. The split of Dempsey Creek was adjusted during calibration, ultimately ending with 40% routed to Black Lake and 60% routed to the Black River. This split is similar to that included in previous HSPF modeling of the Lake by Thurston County (1993). It should be noted that this flow split is likely more complicated than simply a single split that applies across all flow ranges. We would recommend taking a closer look at this inflow location if additional hydrologic monitoring and/or modeling of Black Lake is performed.

The third modification that was made to the Black Lake basin HSPF model was adding groundwater inflows from an area southeast of Black Lake. A report by the Pacific Groundwater Group (PGG, 2001) reports that groundwater flows toward Black Lake from approximately 1100 acres of rural land within the Salmon Creek drainage basin. This area was added to the HSPF model as a pasture cover with only groundwater routed toward Black Lake. The groundwater area was routed into two Black Lake tributaries (reaches 23 and 25), Fish Trap Creek (reach 96), and, only during wet years, directly to Black Lake (reach 36). The 2001 report specifically mentioned Fish Trap Creek as having a large amount of groundwater inflow, which is consistent with a record of daily flows collected in the stream between 2000 and 2001. The rate of groundwater flow from Salmon Creek into these tributaries was calibrated using the daily flow record at Fish Trap Creek.

Simulated flows from the resulting calibration, plotted with observed flows at an annual scale, are included in Figure 40 through Figure 44. The observed flows calculated from recorded stages shown in the figures are one of two rating curves that were developed for the site. The rating curve used for the flows shown is in closer agreement to the manual flow measurements made during the winter months and the rating curve not presented is in closer agreement with flow measurements made during the summer months. No single rating curve provides a good match with flow measurements throughout the year but only one was presented for clarity. The resulting calibration was evaluated primarily for its agreement with manual flow measurements. The calibration provides a good match with those points and is considered adequate for the purposes of this study. We recommend that additional stage-discharge rating curve development be performed as part of future monitoring for the purposes of hydrologic modeling of this reach.

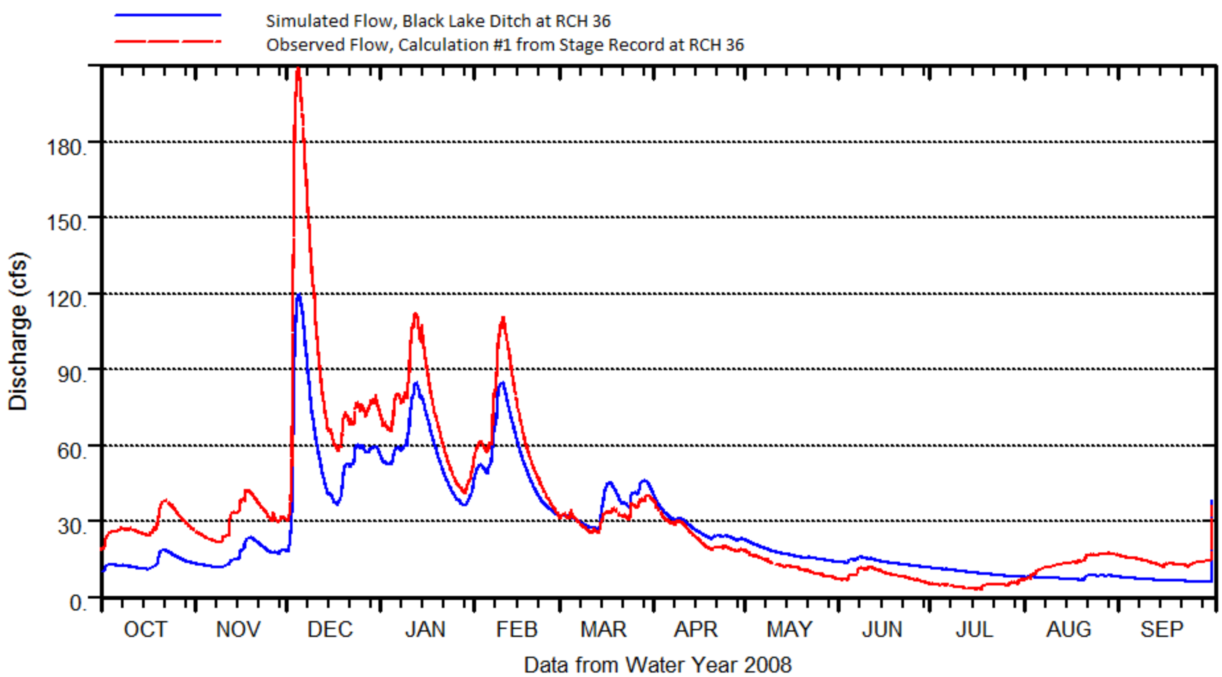


Figure 40: Simulated and Observed Flows at Black Lake Ditch Reach 36, Water-Year 2008

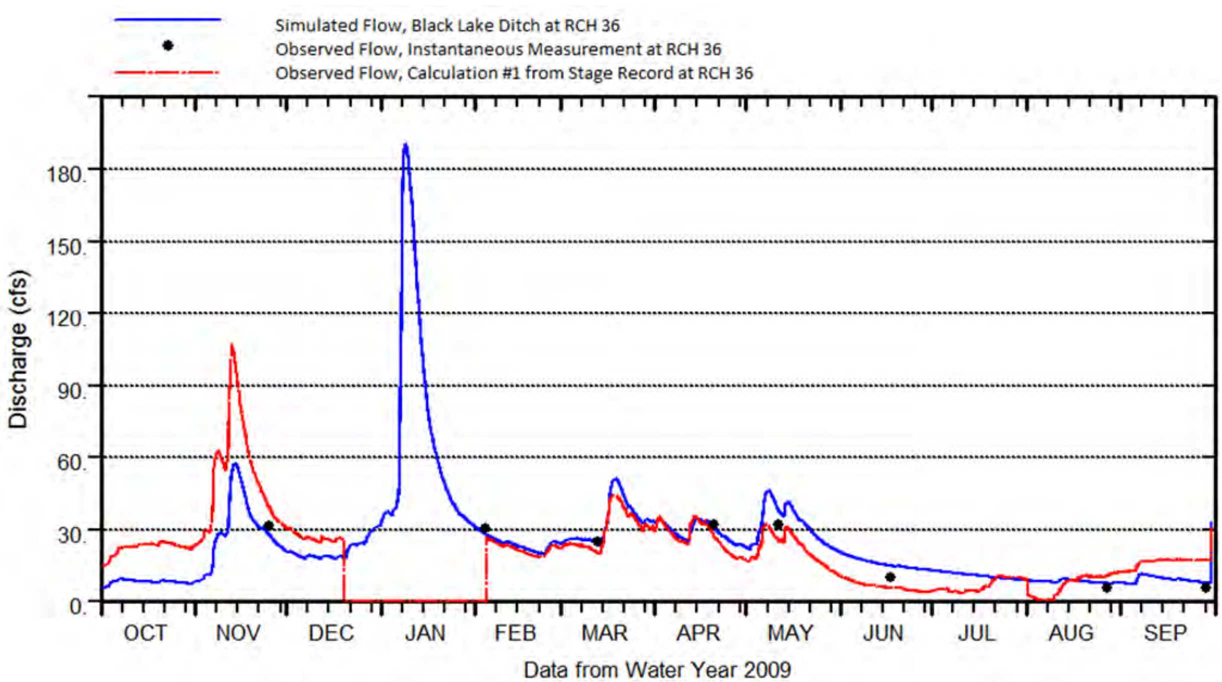


Figure 41: Simulated and Observed Flows at Black Lake Ditch Reach 36, Water-Year 2009

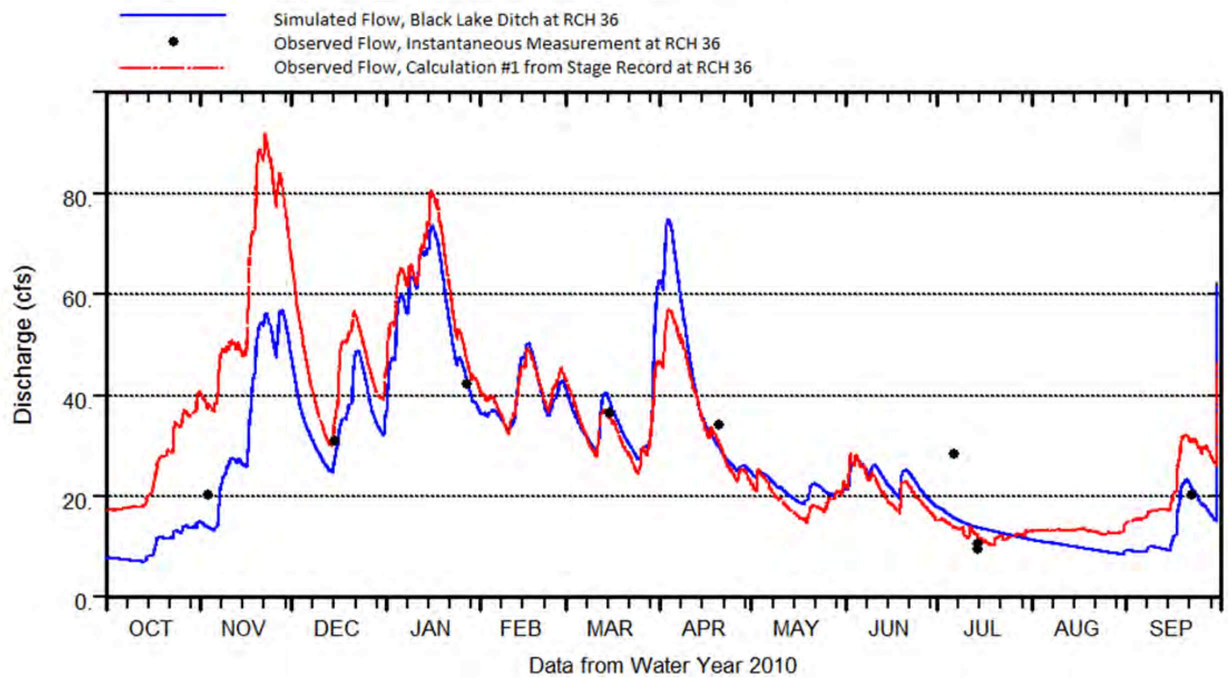


Figure 42: Simulated and Observed Flows at Black Lake Ditch Reach 36, Water-Year 2010

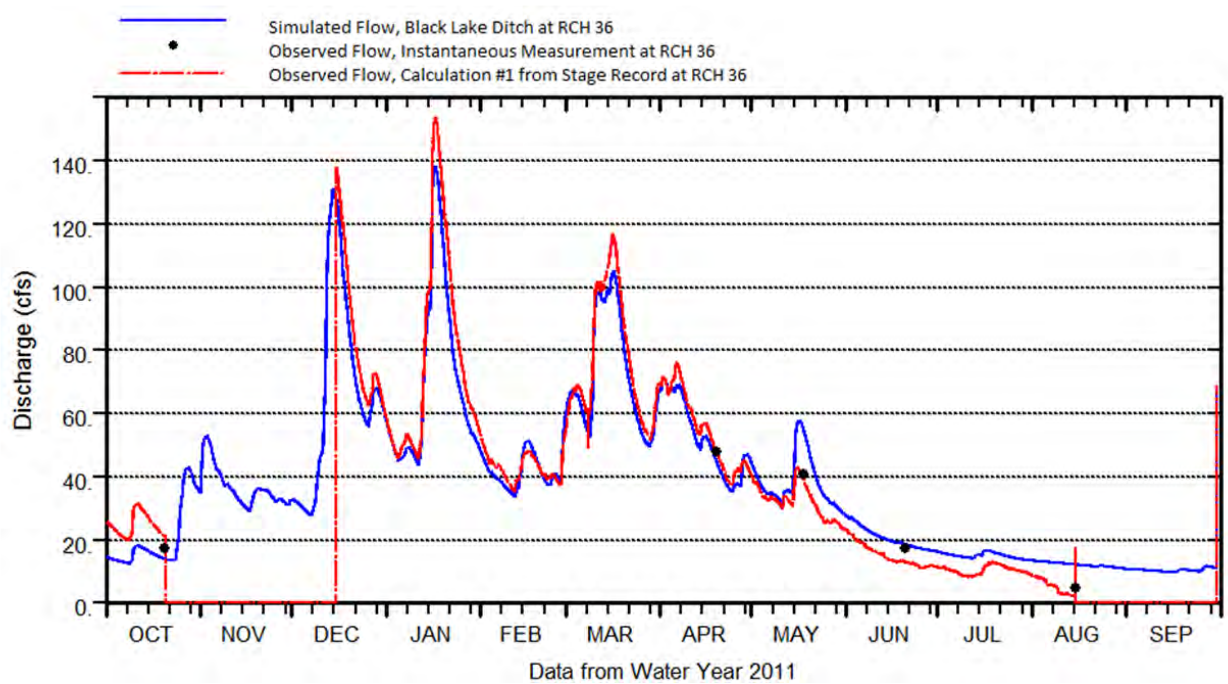


Figure 43: Simulated and Observed Flows at Black Lake Ditch Reach 36, Water-Year 2011

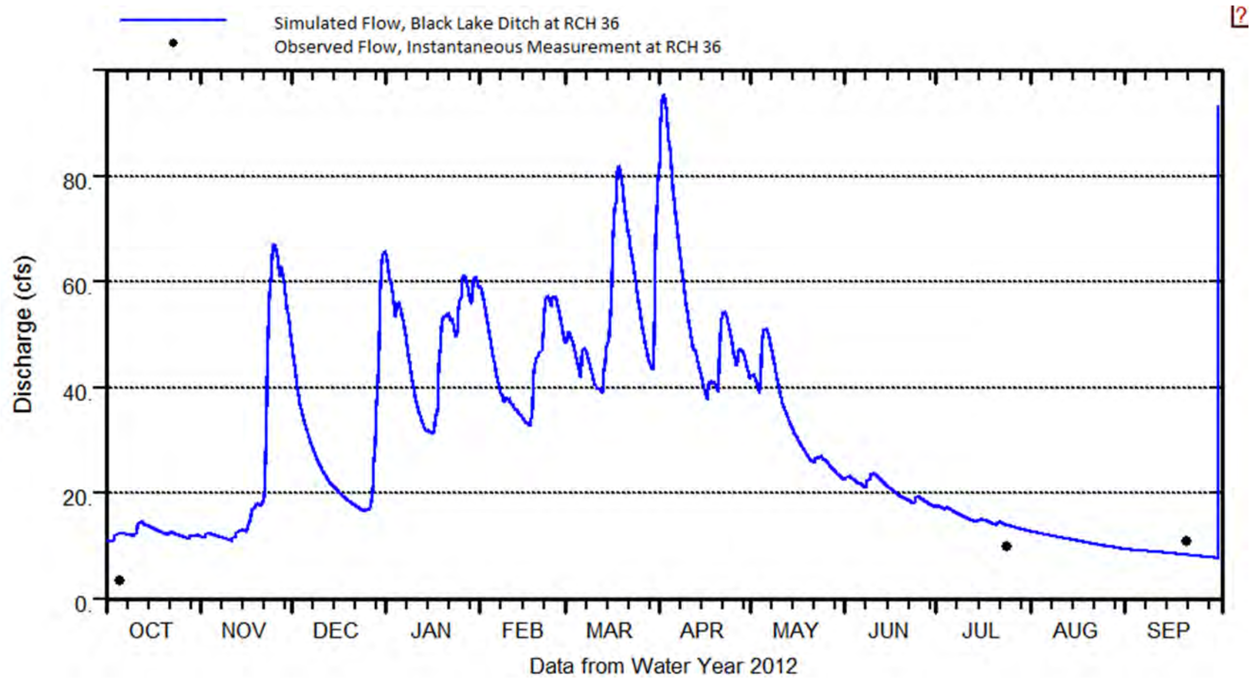


Figure 44: Simulated and Observed Flows at Black Lake Ditch Reach 36, Water-Year 2012

Woodard Creek

In Woodard Creek basin the period October 2007 through November 2012 was used for calibration of simulated hydrology. The calibration was achieved by three primary means: modifying the timing and routing of groundwater flows discharging from the southern half of the study area, revising stormwater control BMPs, and revising the representation of wetland storage along the stream corridor.

Due to the outwash soils in the southern portion of the basin, the role of groundwater in the basin is significant and additional control on the timing and routing of groundwater flows was needed to match the observed seasonal volumes of flows in the stream. The model is configured to collect groundwater from the upland basins south of model reach 109, and route it at a controlled rate into stream reaches 109, 117, 129, 145, and out of the Woodard basin. This groundwater is modeled as a linear reservoir that releases different flow rates during wet periods vs. dry periods but roughly half the flows leave the basin during most water years. This pattern of groundwater flows leaving the basin is consistent with flow patterns simulated with a USGS groundwater model of Thurston County (USGS, 1999).

Two additional adjustments, providing consideration for the numerous smaller infiltration facilities the basin, additionally reduced simulated peak storm discharges and bring them into closer agreement with observed values as part of the calibration process. These facilities, previously discussed in Section 4.4.4, were not explicitly modeled with their own FTABLES in HSPF. The first adjustment increased the assumed infiltration rate from explicitly modeled infiltration facilities to 2.0 inches / hour, nearly double the 1.0 inches / hour expected by City staff for facilities in the basin. This higher infiltration rate is likely higher than what actually occurs in the explicitly modeled facilities, but compensates for smaller facilities in each basin that are not explicitly with their own FTABLE in HSPF. The second adjustment was to route 20% of the impervious surface area in basins with known infiltration facilities that did not have any explicit representation in the basin. The 20% factor was derived based on inventorying smaller facilities located on outwash soils and adjusting the parameter to provide the best match to observed peak storm discharges.

Simulated flows from the resulting calibration are plotted with observed flows at an annual scale are included in Figure 45 through Figure 50. The match is good and considered adequate for the purposes of this study. If any flaw in the match, it is likely that peaks in some years appear to be overestimated but in others are under estimated. Changing the land surface runoff parameters could improve this but it would be difficult to improve the match in all years.

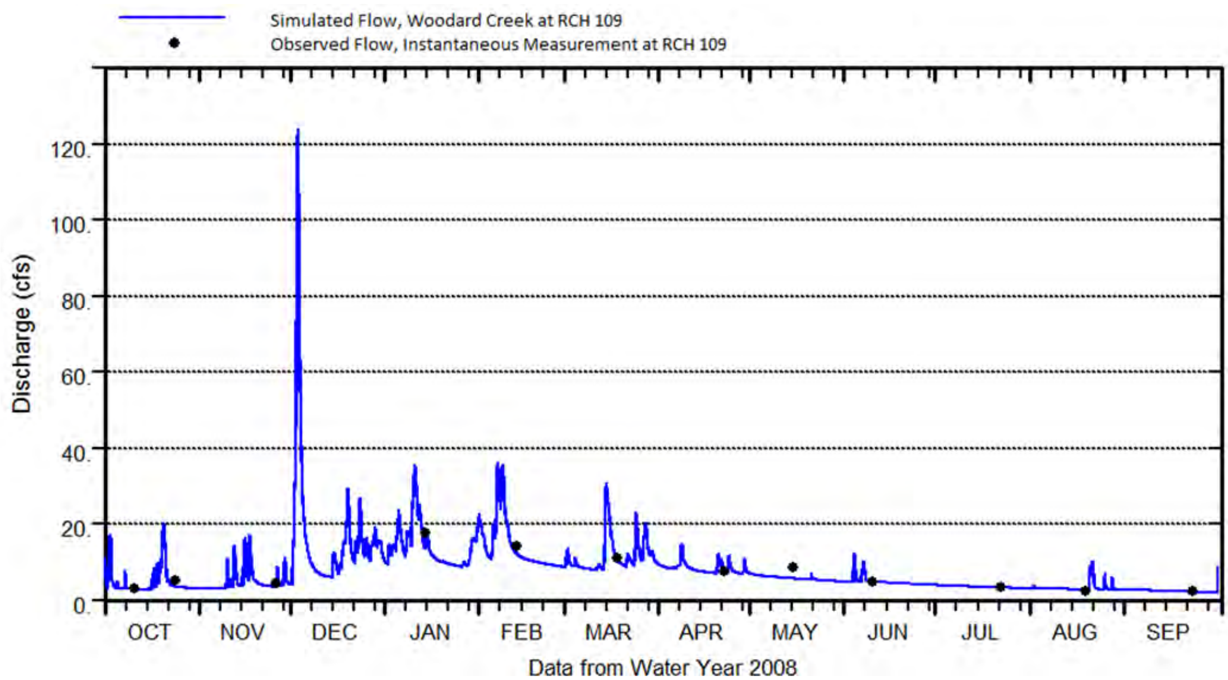


Figure 45: Simulated and Observed Flows at Woodard Creek Reach 109, Water-Year 2008

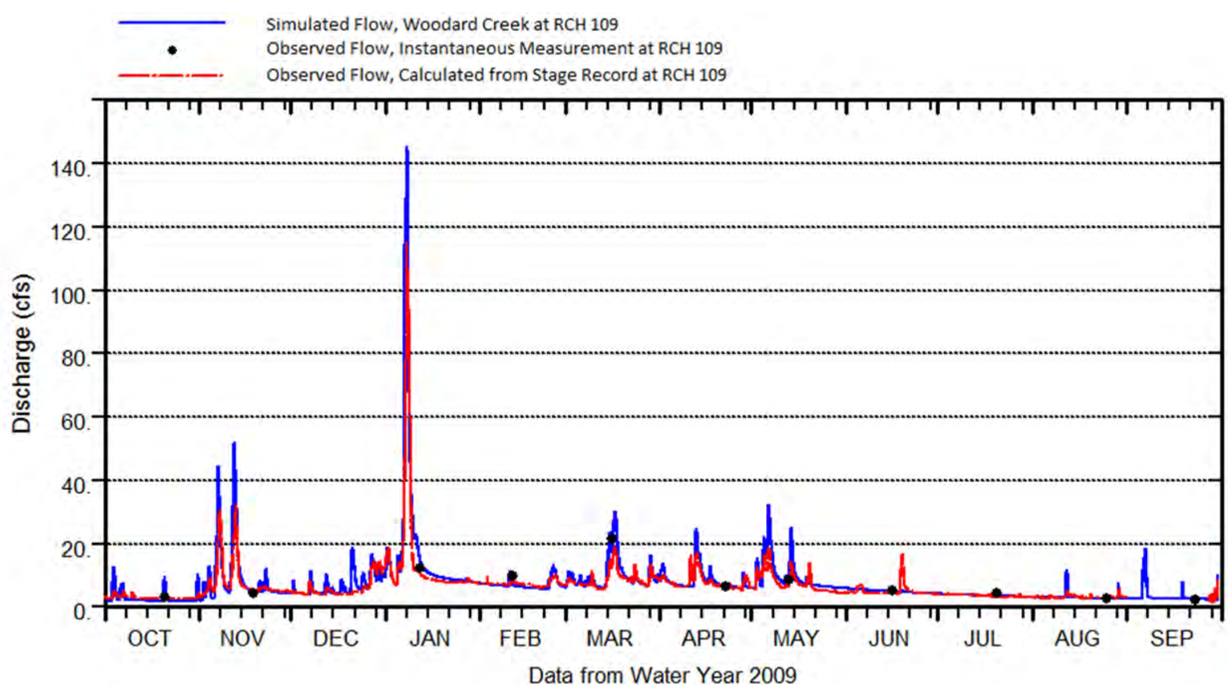


Figure 46: Simulated and Observed Flows at Woodard Creek Reach 109, Water-Year 2009

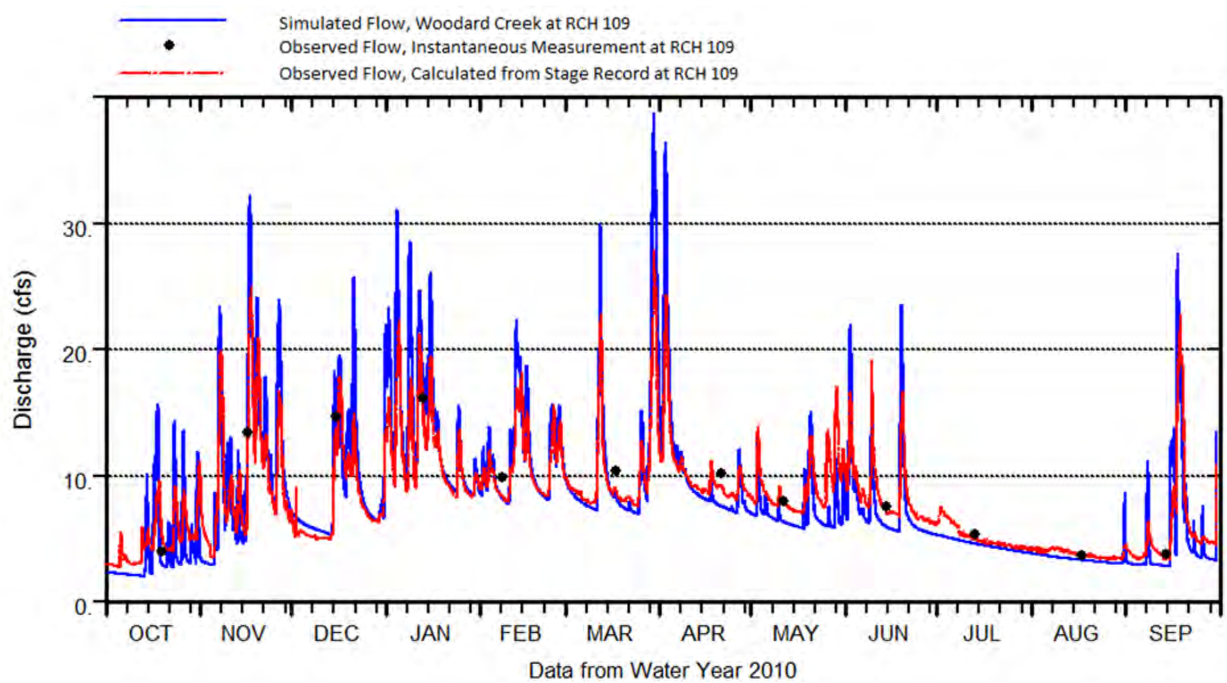


Figure 47: Simulated and Observed Flows at Woodard Creek Reach 109, Water-Year 2010

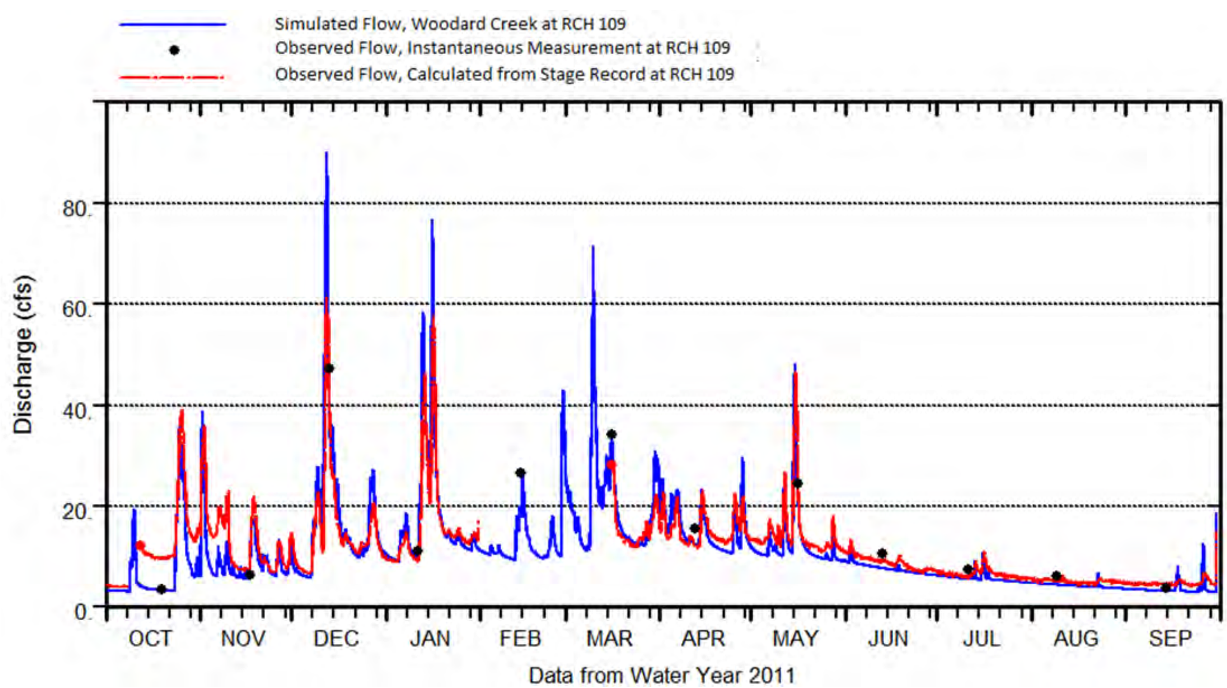


Figure 48: Simulated and Observed Flows at Woodard Creek Reach 109, Water-Year 2011

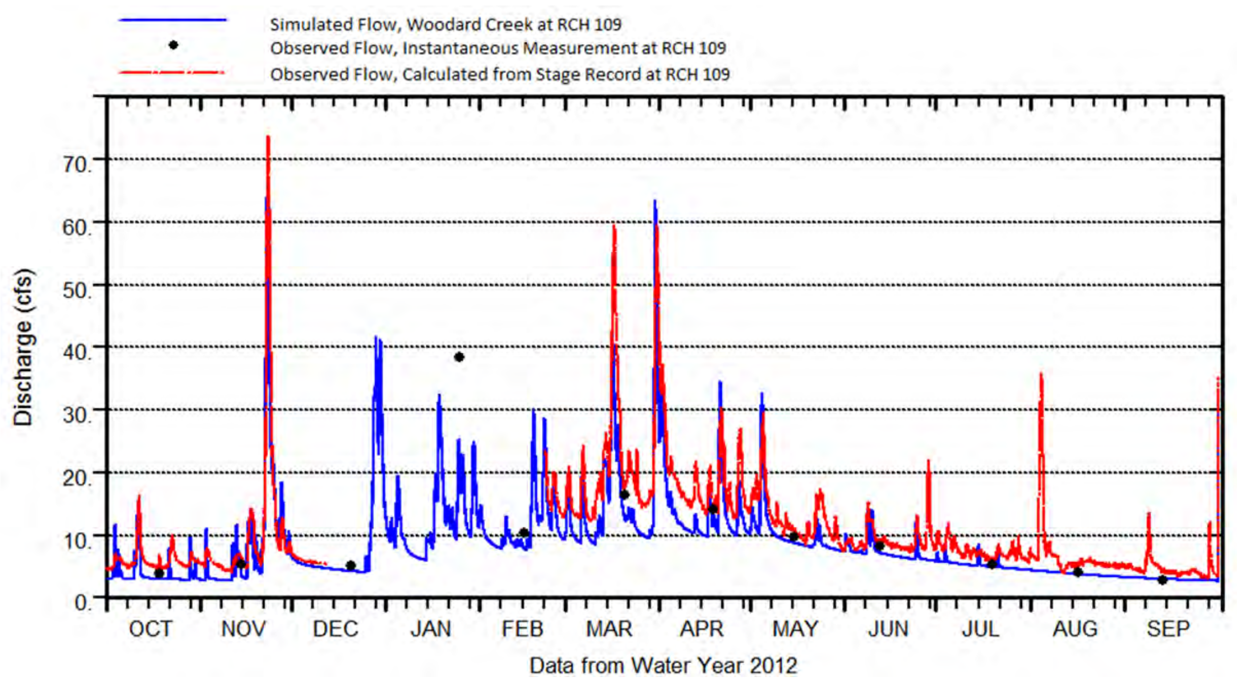


Figure 49: Simulated and Observed Flows at Woodard Creek Reach 109, Water-Year 2012

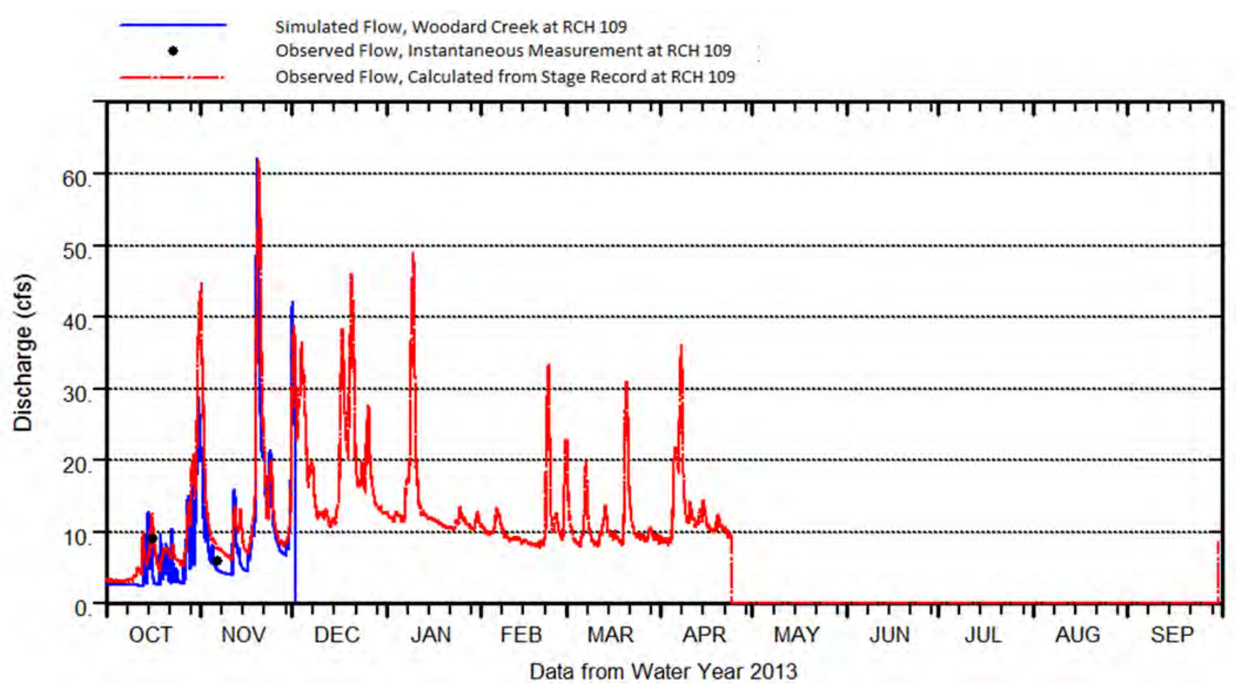


Figure 50: Simulated and Observed Flows at Woodard Creek Reach 109, Water-Year 2013

5.2 Water Quality Calibration

5.2.1 Temperature

Water temperature calibration within HSPF is performed by adjusting the thermal heat budget of the stream reach until simulated temperatures have an acceptable match with observed temperatures. The temperature of runoff from the land surface can be modified but the model is most sensitive to instream parameters. Temperature calibration was performed in the McLane Creek and Woodard Creek basins by modifying the following parameters: a bed heat conduction parameter (KMUD), the atmospheric longwave radiation coefficient (KATRAD), ground temperatures (TGRND), and the shade parameter (CFSAEX). The model was found to be the most sensitive to the CFSAEX parameter. The model is best suited to simulate temperatures in larger streams where groundwater and hyporheic flows inputs are small relative to the total flow in the stream. The calibration results described here indicate that some of the headwater streams included in the model may be small enough that the model cannot accurately match observed temperatures.

Four stream locations were used in the calibration:

- **McLane Creek at Chelsie Lane (reach 81)** – This site includes most of its riparian cover and was used to represent a shade parameter set for streams with full canopy cover and also those of the smallest stream size.
- **McLane Creek at Delphi Road Upper Site (reach 59) –** This site includes partial riparian cover and is of a relatively larger stream size.
- **McLane Creek at Delphi Road Lower Site (reach 57)** – This site is similar to reach 59 but includes the cumulative McLane Creek basin.
- **Woodard Creek at 36th Avenue (reach 109)** – This site is larger and reflects the urbanized portion of the Woodard Creek basin.

No data were available for calibration in the Black Lake Basin.

McLane Creek at Chelsie Lane (reach 81)

The calibration at Chelsie Lane was performed for the period of July 24 through November 18, 2013. There were special challenges associated with the small size of the stream that resulted in the use of one parameter set for very small streams with basin areas less than 1.5 square miles and another for larger streams. That parameter set included a KMUD value of 50 (kcal/m^2/°C/interval), a KATRAD coefficient of 9.0 (unitless), and a CFSAEX value that reflected the calculated shade for each reach. The shade value for reach 81 was 0.07 (unitless), reflecting near full shade.

Figure 51 plots simulated stream temperatures from the resulting calibration with observed temperatures during August 2013. The simulated temperatures are close but tend to over-estimate daily maximums in many days. This likely due to the small size of this stream and the influence of hyporheic flow that is not explicitly represented by the model. The calibration of this reach could not be improved further without degrading results at larger downstream reaches. The error in the calibration for this reach is less concerning because temperature output was only queried at reaches further downstream, where the calibration error is less.

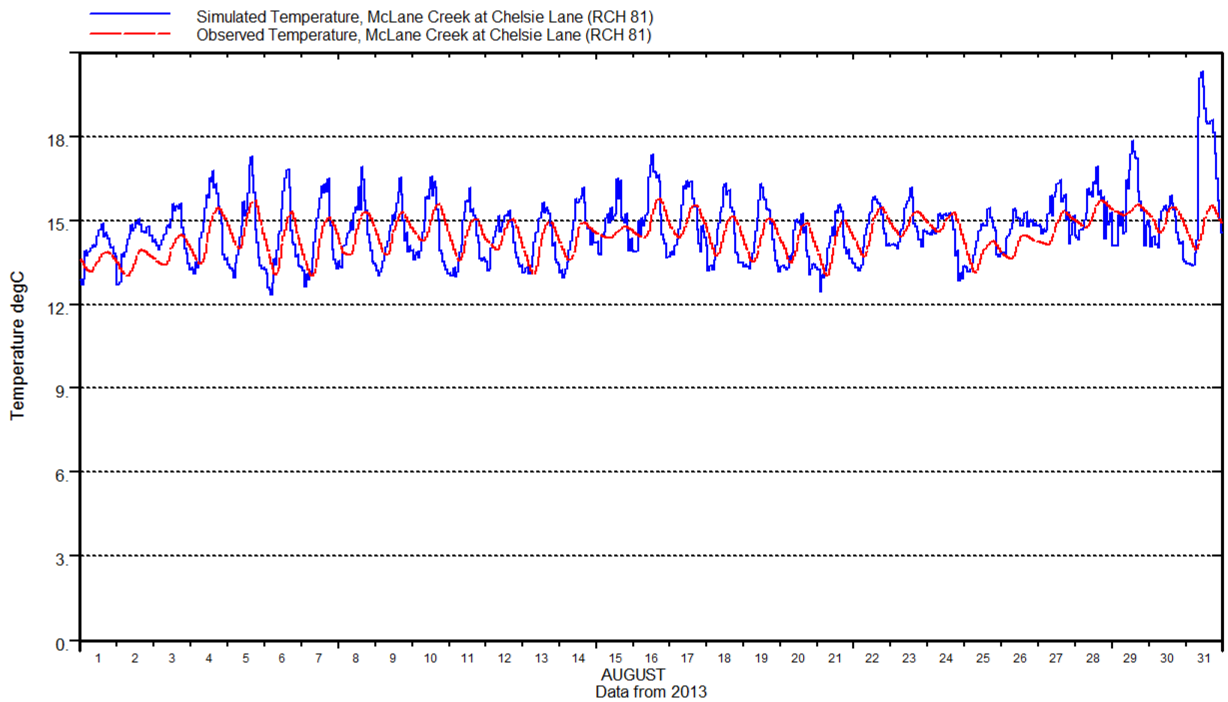


Figure 51: Simulated and Observed Stream Temperature at McLane Creek Reach 81, August 2013

McLane Creek at Delphi Road Upper Site (reach 59)

The calibration at the Delphi Road upper site was performed for the period of July 24 through November 18, 2013. This stream was assigned the parameter set used for streams with greater than 1.5 square miles of drainage area. That parameter set included a KMUD value of 100, a KATRAD value of 12.0, and a CFSAEX shade value of 0.18, reflecting a partially shade reach; the shade values for all upstream reaches were presented previously in Table 23. The different KMUD and KATRAD values needed for calibration of smaller streams, relative to larger streams, is thought to account for hyporheic flow and other processes not explicitly represented by the model.

Simulated stream temperatures from the resulting calibration are plotted with observed temperatures for the summer month of August 2013 in Figure 52. The resulting match between simulated and observed temperatures is good, with marked improvement from those at reach 81.

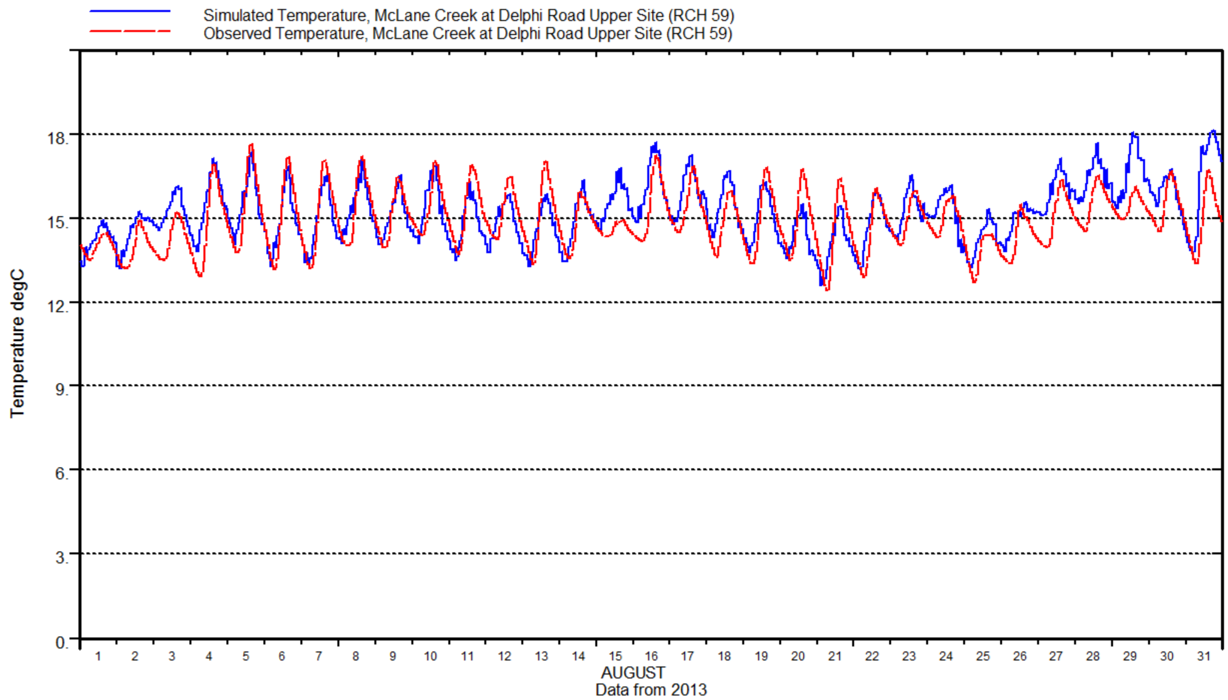


Figure 52: Simulated and Observed Stream Temperature at McLane Creek Reach 59, August 2013

McLane Creek at Delphi Road Lower Site (reach 57)

The calibration at the Delphi Road lower site was performed for the period of July 2008 through July 2012. The focus of the calibration at this site was to calibrate temperatures across multiple seasons through use of the more extensive temperature dataset. This was done by adjusting the ground temperatures seasonally. Like reach 59, this stream was assigned the parameter set used for streams with greater than 1.5 square miles of drainage area. That parameter set included a KMUD value of 100, a KATRAD value of 12.0, and CFSAEX shade value of 0.20, reflecting a partially shaded reach; the shade values for all upstream reaches were presented previously in Table 23.

Simulated stream temperatures from the resulting calibration with observed temperatures are plotted at the annual scale in Figure 53 through Figure 56. The resulting match between simulated and observed temperatures is good.

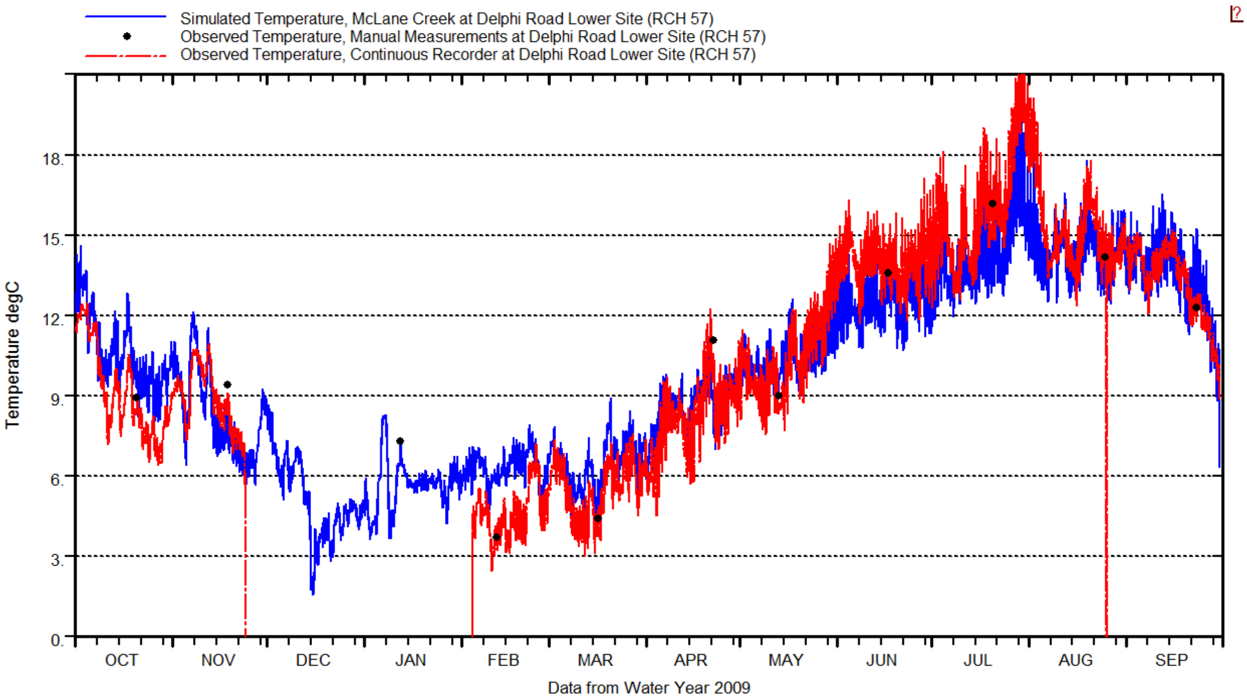


Figure 53: Simulated and Observed Stream Temperature at McLane Creek Reach 57, water-year 2009

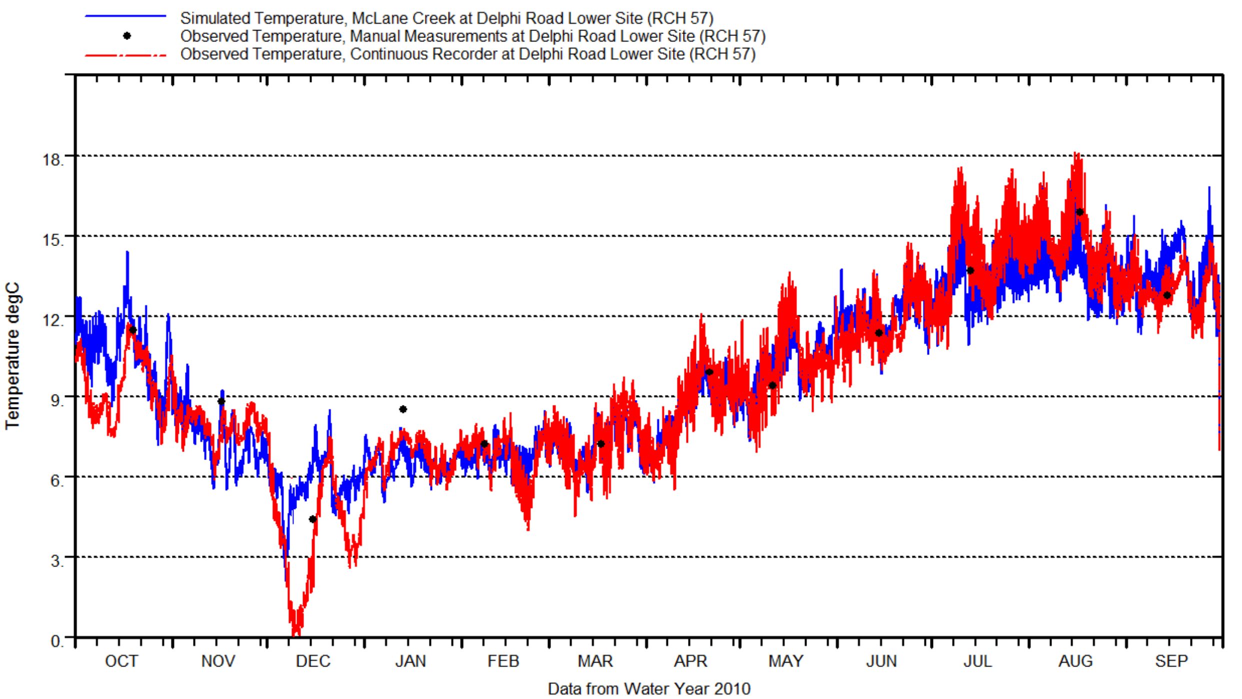


Figure 54: Simulated and Observed Stream Temperature at McLane Creek Reach 57, water-year 2010

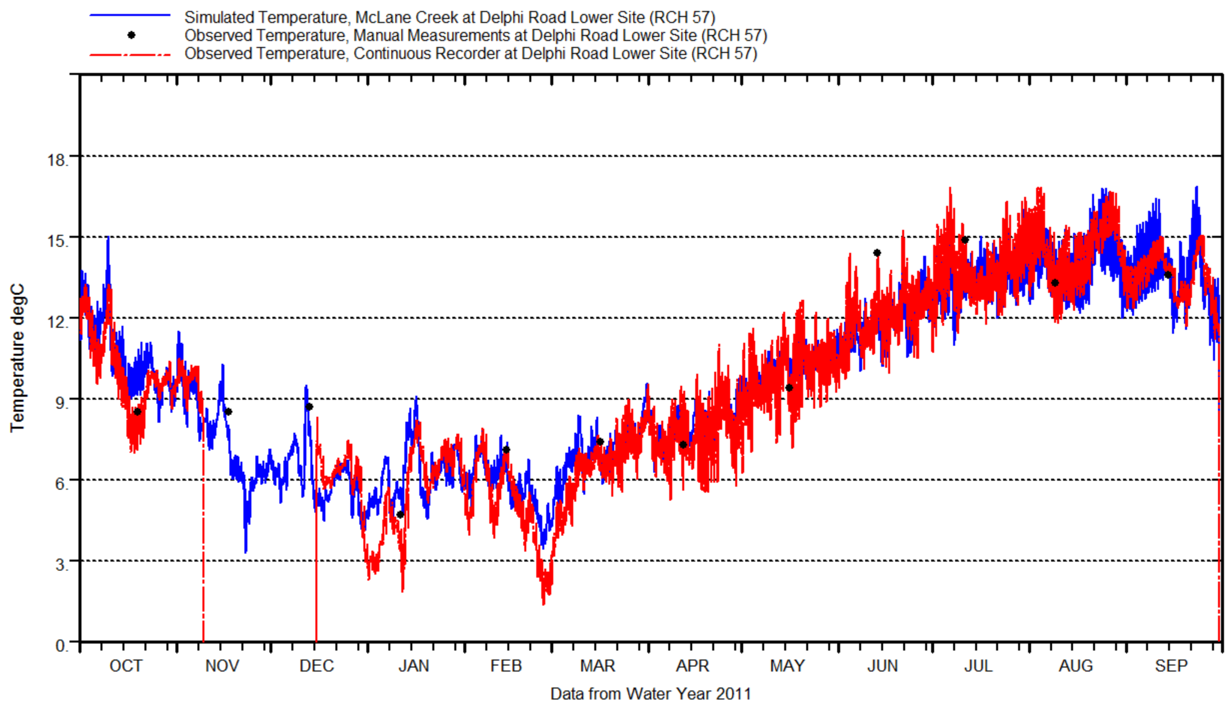


Figure 55: Simulated and Observed Stream Temperature at McLane Creek Reach 57, water-year 2011

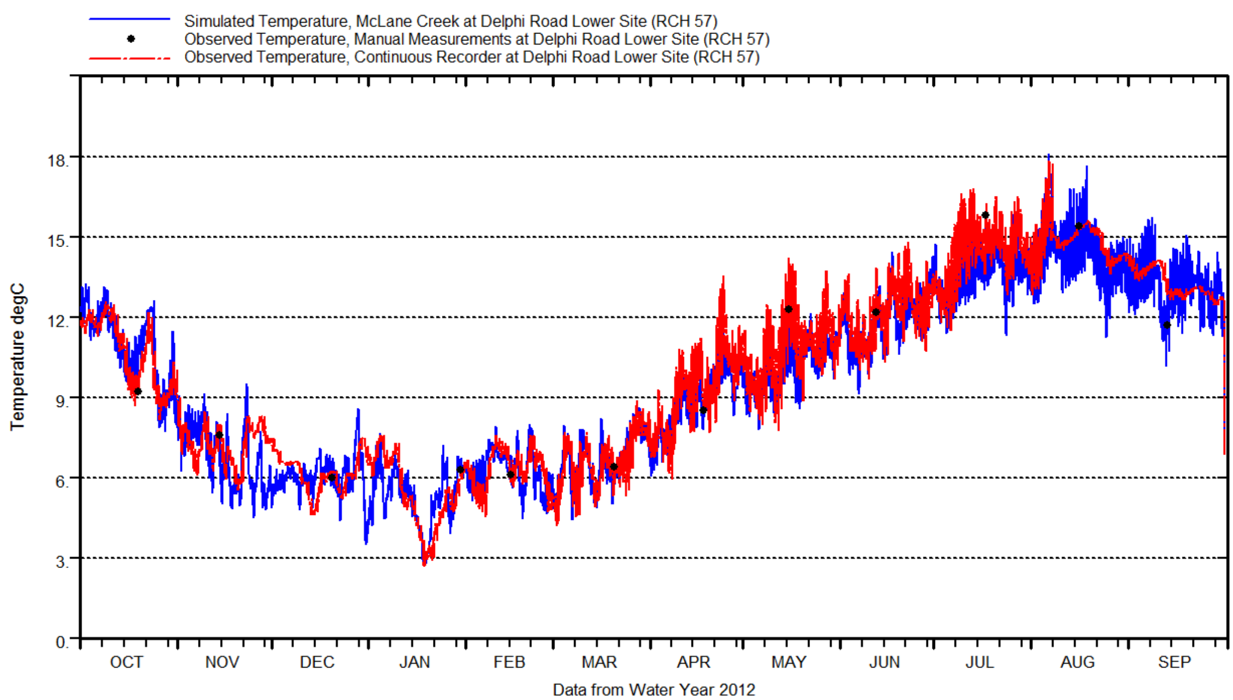


Figure 56: Simulated and Observed Stream Temperature at McLane Creek Reach 57, water-year 2012

Woodard Creek at 36th Avenue (reach 109)

The calibration at the Woodard Creek 36th Avenue site was performed for the period June 2000 through March 2004 and November 2007 through July 2008; the only periods with valid temperature data. The focus of the calibration at this site was to calibrate temperatures for a more urbanized area with an outwash-dominated soil type, and also to validate the calibration in Woodard Creek. Like reaches 57 and 59, this stream was assigned the parameter set used for streams with greater than 1.5 square miles of drainage area. That parameter set included a KMUD value of 100, a KATRAD value of 12.0, and CFSAEX shade value of 0.17, reflecting a partially shaded reach; the shade values for all upstream reaches were presented previously in Table 23. Temperatures from the groundwater routing reach were set to equal the long-term average air temperature at the Olympia Airport of 10.2 degrees C.

Simulated stream temperatures from the resulting calibration are plotted with observed temperatures at the annual scale in Figure 57 through Figure 62, and August 2001 is shown in Figure 63. The resulting match between simulated and observed temperatures is okay, though not as close as McLane reaches 57 and 59. The errors are possibly related to the increased role of groundwater in this basin for which temperature is currently represented with a constant 10.2 degree C inflow. This calibration was determined to be adequate because it does replicate the annual temperature maximums fairly well at the basin outlet, which is the key metric and locations that are used to evaluate each planning scenario.

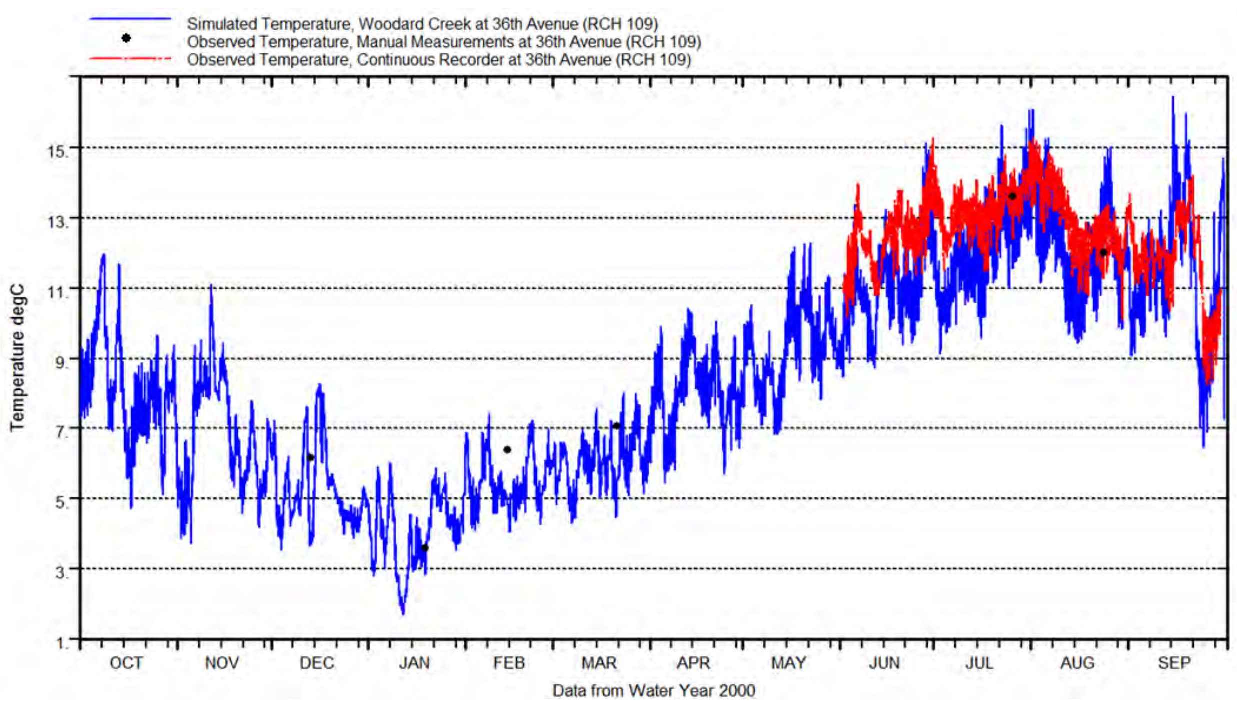


Figure 57: Simulated and Observed Stream Temperature at Woodard Creek Reach 109, water-year 2000

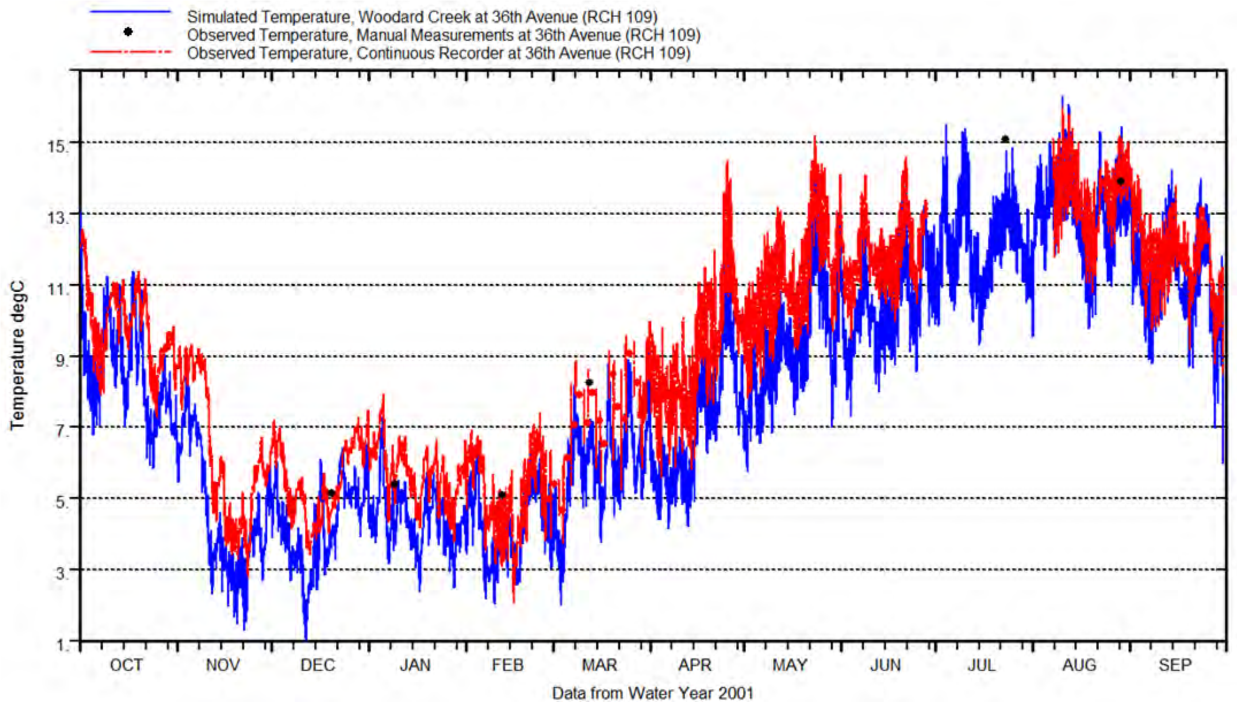


Figure 58: Simulated and Observed Stream Temperature at Woodard Creek Reach 109, water-year 2001

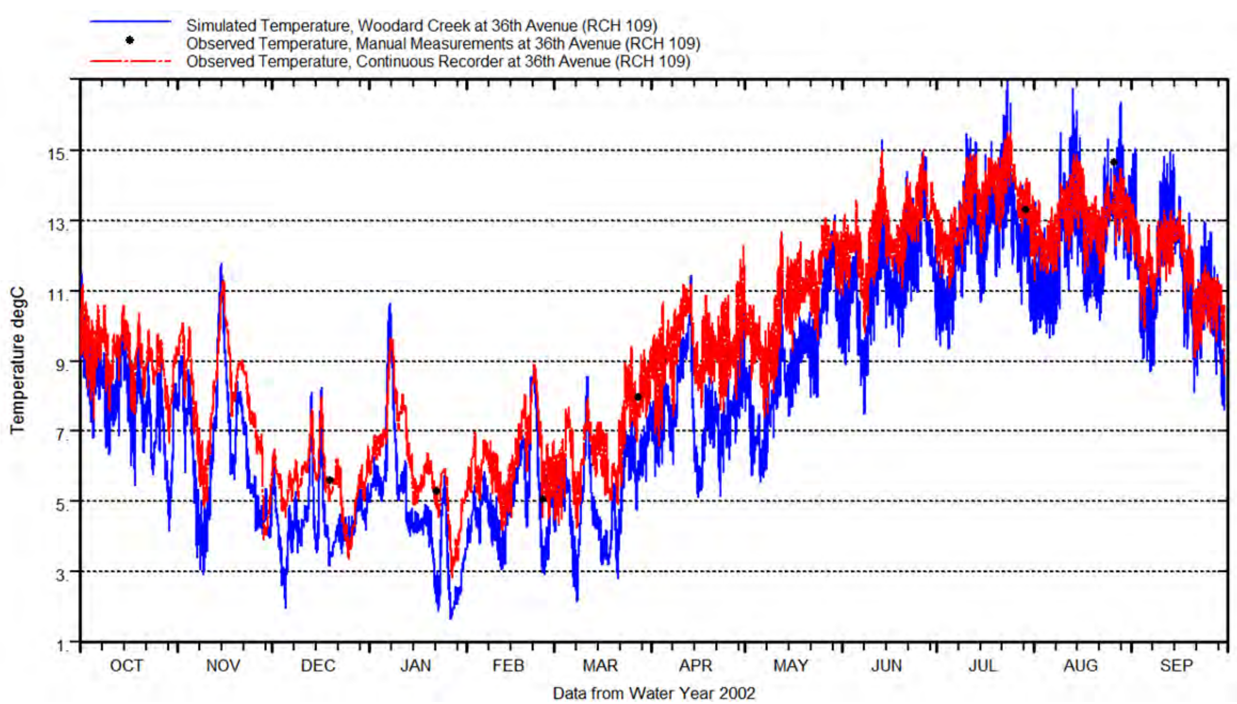


Figure 59: Simulated and Observed Stream Temperature at Woodard Creek Reach 109, water-year 2002

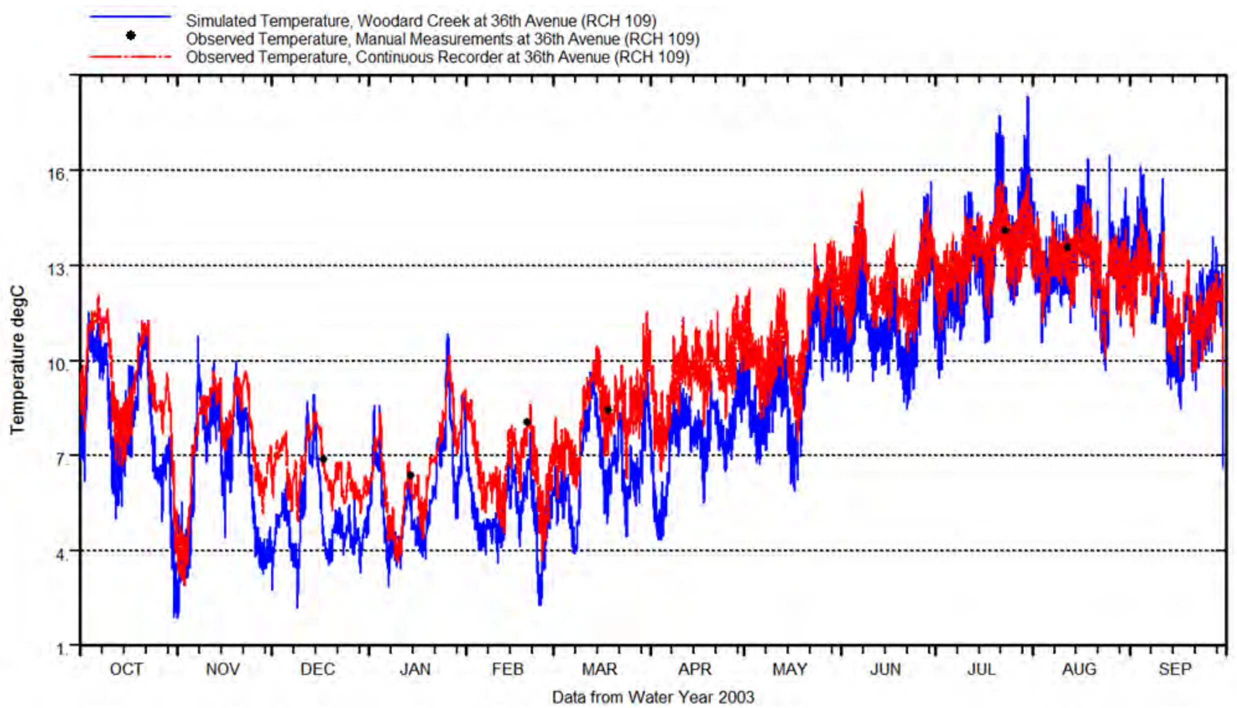


Figure 60: Simulated and Observed Stream Temperature at Woodard Creek Reach 109, water-year 2003

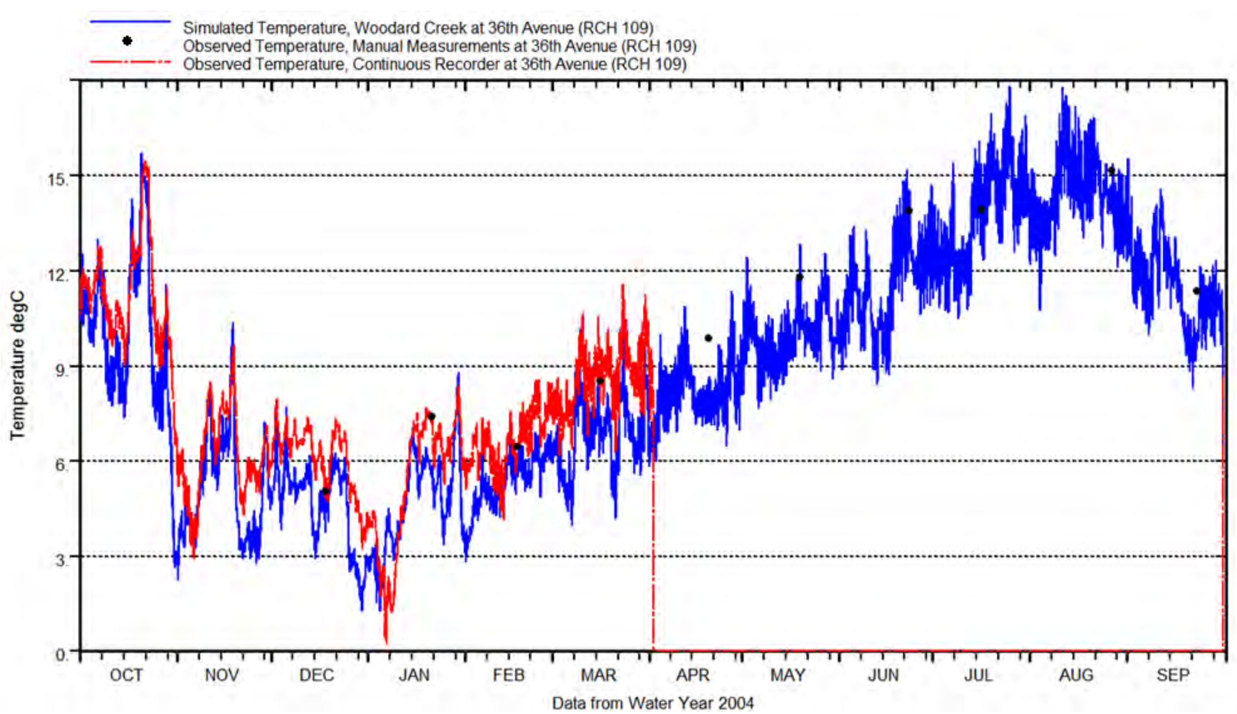


Figure 61: Simulated and Observed Stream Temperature at Woodard Creek Reach 109, water-year 2004

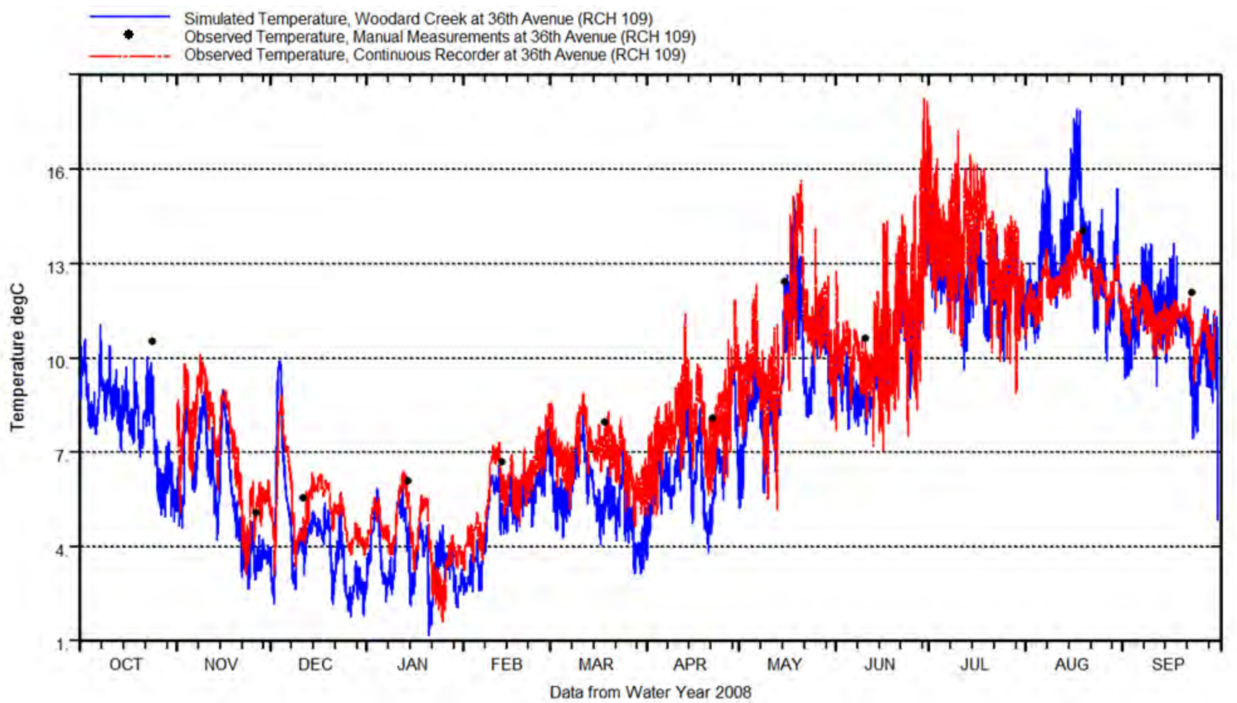


Figure 62: Simulated and Observed Stream Temperature at Woodard Creek Reach 109, water-year 2008

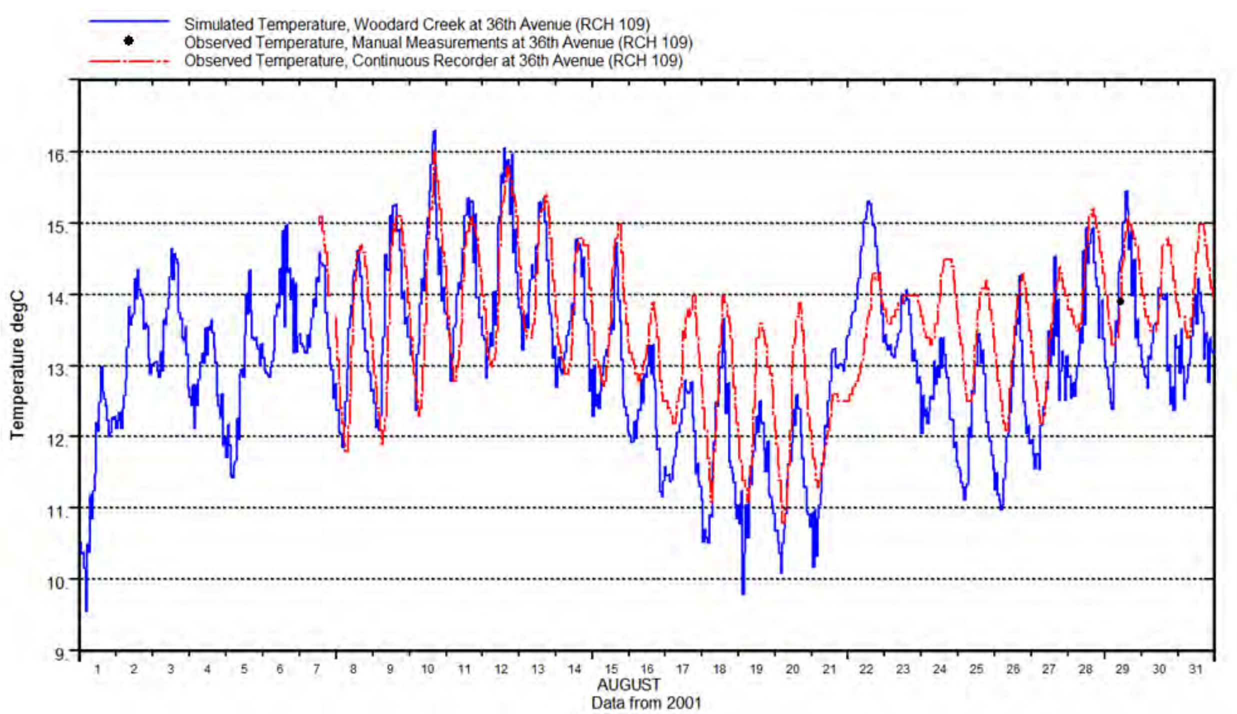


Figure 63: Simulated and Observed Stream Temperature at Woodard Creek Reach 109, August 2001

5.2.2 Fecal Coliform

There are no local data characterizing the relative contribution of sources for fecal coliform in the study area. For the purposes of calibration, it was assumed that in the existing basin condition each of three land-cover categories,--impervious surfaces (rooftops and roads), septic systems, and other pervious surfaces--provide comparable relative contributions to fecal loads during storm conditions.

The calibration was perform using observed data from the County's routine monitoring program at the McLane Creek Delphi Road lower site (Reach 57) and Woodard Creek 36th Avenue site (Reach 109) that were collected between 2002 and 2013, and data from a short-term monitoring program at Kenneydell Park (Reach 17) that collected five to eight samples per year between 2004 and 2012. Raw data from the Kenneydell Park site were not available but geometric mean and % exceedance values for each of those years are reported in Thurston County (2012). Because of the nature of fecal coliform, the data are typically very erratic and matching specific counts determined from instantaneous grab samples with any consistency is impractical. To overcome this limitation, the calibration was performed to target the observed Part 1 and Part 2 water-quality standards applicable to each basin rather than comparing individual storm events. In addition to matching these values, cumulative frequency plots that compare the frequency of all loads were also used to validate the quality of the calibration at the McLane Creek and Woodard Creek sites. The resulting calibration is shown for each site in Table 24 and for the Delphi Road and 36th Avenue sites, see Figure 64 and Figure 65 below. The calibrations match observed frequencies well, particularly in the regions of the curve that are related to Part 2 of the standard, 200 colonies per 100 mL in McLane Creek and 100 at Woodard Creek and Kenneydell Creek. A considerable amount of effort was expended to improve the fit of the upper part of the curve in Woodard Creek but it was not feasible to do so and preserve the same parameter set in all basins.

Table 24: Fecal Coliform Calibration Results

	McLane Creek		Woodard Creek		Kenneydell Park Stream	
Years	**2002 - 2012**		**2002 - 2012**		**2004 - 2012**	
	Geometric Mean (colonies / 100 mL)	**% Exceeding 200 colonies / 100 mL**	**Geometric Mean (colonies / 100 mL)**	**% Exceeding 100 colonies / 100 mL**	**Geometric Mean (colonies / 100 mL)**	**% Exceeding 100 colonies / 100 mL**
Observed	61	19	59	33	109	60
Simulated	56	16	66	32	103	56

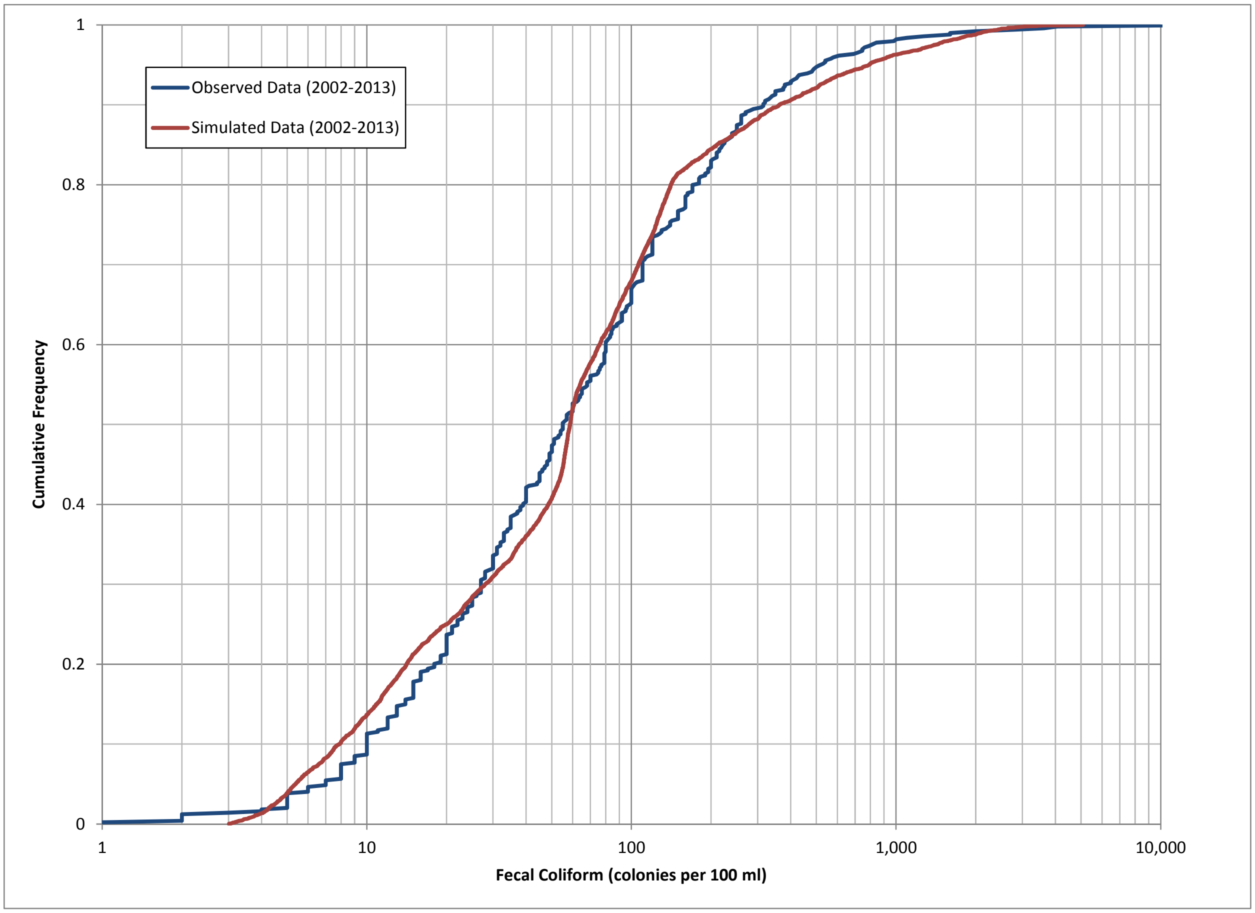


Figure 64: Cumulative Frequency of Fecal Coliform, McLane Creek at Delphi Road (Reach 57)

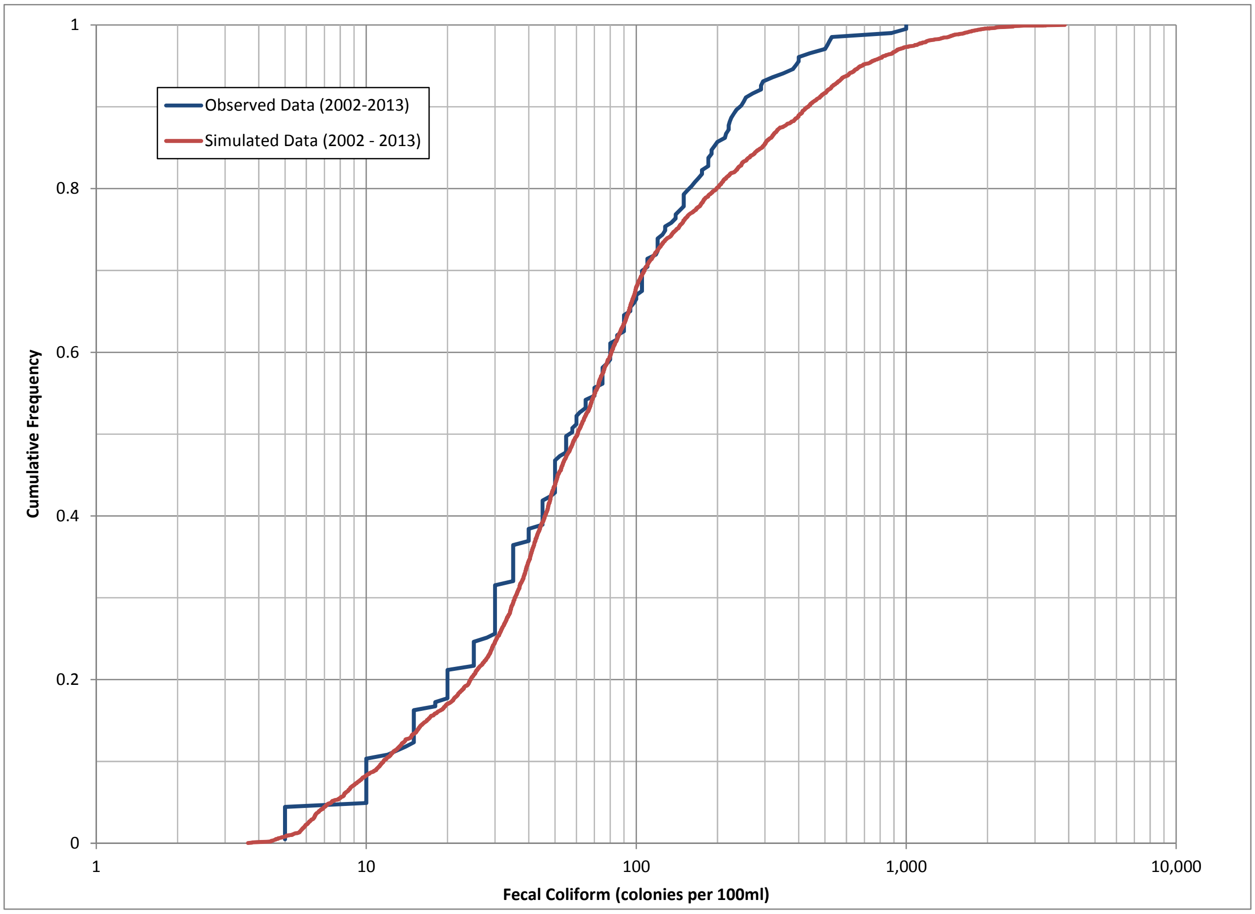


Figure 65: Cumulative Frequency of Fecal Coliform, Woodard Creek at 36th Avenue (Reach 109)

5.2.3 Nitrate

Nitrate (NO_3) was calibrated to match observed long-term average concentrations during both summer and winter storm conditions. One variable in the nitrate calibration that did not have any in-basin data was the relative contribution of the septic system and non-septic system loads to nitrogen. In the Woodland Creek basin, located immediately east of Woodard Creek, Thurston County Environmental Health found that 70% of the surface nitrogen load and 76% of the groundwater based nitrogen load came from septic system (Thurston County, 2007). For the current study, it was assumed that septic systems provide 60% to 80% of the total nitrate load.

The long-term average of nitrate concentrations simulated at the Woodard Creek at Libby Road[4] site (reach 109) between the years 2002 and 2012 was 0.680 mg/L. This is 7% lower than the average 0.735 mg/L of samples collected by Thurston County during that period. Following calibration, 62% of the total simulated nitrate load, was of septic system origin, a value comparable to the range estimated by Environmental Health.

The long-term average of nitrate concentrations simulated at the McLane Creek at Delphi Road site (reach 57) between the years 2002 and 2012 was 0.324 mg/L. This is 2% higher than the average 0.319

[4] The Libby Road water-quality site is a short distance downstream from the 36th Avenue flow monitoring site, but both are within HSPF reach 109.

mg/L of samples collected by Thurston County during that period. Following calibration, 79% of the total simulated nitrate load was of septic system origin.

5.2.4 Phosphorus

No formal calibration of phosphorus data was performed as part of this study due to a lack of associated suspended sediment data. Suspended sediment data is required to calibrate sediment loading from the land surface and, more importantly, suspended sediment transport within stream reaches. Total phosphorus is associated with sediment and without suspended sediment data, or calibration of the model sediment routines to data, a total phosphorus calibration could also not be formally performed. The resulting data were checked against the total phosphorus concentrations observed by Thurston County Environmental Health, but the parameters originally translated from other HSPF water-quality modeling in a similar basin were applied without modification to improve the match to observed data. That basin, Newaukum Creek, is located near Enumclaw, WA and was selected because it has a similar land use composition to the study area basins and the pollutant loading rates had been calibrated to observed data by King County.

The long-term average of total phosphorus concentrations simulated at the McLane Creek at Delphi Road site (reach 57) between the years 2002 and 2012 was 46 µg/L. This is 35% higher than the average 34 µg/L of samples collected by Thurston County during that period. This is a fairly poor match but is not surprising given the lack of a suspended sediment calibration.

The long-term average of total phosphorus concentrations simulated at the Woodard Creek at Libby Road site[5] (reach 109) between the years 2002 and 2012 was 45 µg/L. This is 10% higher than the average 41 µg/L of samples collected by Thurston County during that period. This is a surprisingly good match given the lack of calibration but additional uncertainty in the result must be accepted due to the lack of a suspended sediment calibration.

5.2.5 Simulated Pollutant Runoff Loading Rates

The calibration of fecal coliform, nitrate, and phosphorus was performed to match observed in-stream concentrations with the load for each land use type adjusted based on literature and/or other work in the region. For the purposes of interpretation of the simulated loading results is helpful to review how much pollutant runs off of the different soil, cover, and land use combinations represented by HSPF PERLNDs and IMPLNDs. Table 25 below provides this summary for all of the PERLNDs and IMPLNDs in the HSPF model. The loading rates reflect a number of simulated water-quality processes including surface build-up and washoff, sediment association, interflow concentrations, and groundwater concentrations as well as the amount of surface runoff relative to interflow or groundwater flow. When interpreting output from different land-use / land-cover scenarios, it is helpful to note the extreme categories for each pollutant, pasture for fecal coliform and phosphorus on till or Kitsap soils, and moderately high nitrate loads for residential uses on till or Kitsap soils. No land uses or cover types have high loads from outwash soils. If local field data differing from these loading rates was found, the calibration could be adjusted while still matching in-stream concentrations at the monitoring stations used for calibration.

[5] The Libby Road water-quality site is a short distance downstream from the 36th Avenue flow monitoring site, but both are within HSPF reach 109.

Table 25: Simulated Unit Area Pollutant Runoff Rates				
HSPF Soil-Cover Land-Use Combination	IMPLND/ PERLND ID	Average Annual Pollutant Runoff Rates (per year)		
		Fecal Coliform	Nitrate	Phosphorus
		cfu x 10^{-9}/acre	lbs/acre	lbs/acre
Impervious Areas				
High Pollution Generating Impervious Surface	101	18.5	2.5	0.042
Low Pollution Generating Impervious Surface	103	9.3	1.2	0.039
Pervious Areas				
Saturated	7	7.0	1.4	0.064
Till Forest Urban	11	2.0	1.9	0.090
Till Forest Rural	14	2.1	1.4	0.040
Till Pasture Urban	21	46.1	3.5	3.5
Till Pasture Rural 1 - 4[1]	24 - 27	46.5	6.4	3.5
Septic Field (Special Case)	30	NA	NA	NA
Till Grass Urban	31	17.0	3.6	0.24
Till Grass High Density Residential	32	18.3	22.3	0.28
Till Grass Low and Moderate Density Residential	33	7.6	10.6	0.24
Till Grass Rural	34	6.6	10.6	0.24
Kitsap Forest Urban	41	0.72	0.84	0.04
Kitsap Forest Rural	44	0.74	0.60	0.02
Kitsap Pasture Urban	51	20.9	1.7	1.7
Kitsap Pasture Rural 1 - 4[1]	54 - 57	20.9	3.1	1.7
Kitsap Grass Urban	61	5.4	2.9	0.20
Kitsap Grass High Density Residential	62	5.9	3.0	0.064
Kitsap Grass Low and Moderate Density Residential	63	6.1	8.4	0.19
Kitsap Grass Rural	64	5.7	8.4	0.19
Outwash Forest Urban	71	0.026	0.00026	0.000032
Outwash Forest Rural	74	0.048	0.000047	0.0000025
Outwash Pasture Urban	81	0.20	0.0048	0.17
Outwash Pasture Rural 1 - 4[1]	84 - 87	0.43	0.0048	0.17
Outwash Grass Urban	91	0.17	0.0021	0.0027
Outwash Grass High Density Residential	92	0.65	0.0021	0.0035
Outwash Grass Low and Moderate Density Residential	93	0.79	0.0013	0.0059
Outwash Grass Rural	94	0.42	0.0013	0.0059
[1] Pollutant runoff rates for rural densities 2 through 4 were not summarized but are similar to rural 1				

5.3 Reliability of Model Simulated Flow and Derived Metrics

This section provides a qualitative assessment of the reliability of model-simulated data and derived flow and water quality metrics. Reliability, or uncertainty, are important considerations when interpreting and applying modeling results to watershed planning and management decisions. Reliability is the term used herein to describe the modeler's confidence in relative differences in selected flow and water quality metrics among the study scenarios for each respective basin. A thorough, quantitative assessment of "model uncertainty" in which model outputs are compared to relevant measured values of known precision is beyond the scope of this project, it is nevertheless important to provide watershed managers a description of sources of uncertainty and a qualitative assessment of how to weigh uncertainty when factoring model results into the formulation of policies, programs, or projects for the study basins or other areas of the County. As stated earlier, metrics used to compare five different land use and management scenarios (Pristine, Existing, and three future alternatives) are derived from simulated time series data of stream flow, temperature, fecal coliform bacteria counts, total nitrogen, and total phosphorus concentrations. The reliability of comparisons across scenarios for metrics derived from each of these time series is discussed below.

Uncertainty in derived metrics is affected by the availability and quality of observed data and the model's skill in tracking those data after calibration. Even when a very good match between simulated time series and observed high-quality, local data values is achieved, uncertainty remains in mixed land use basins because the data generally reflect a single location that integrates the effects of several land use/soil-cover types whose individual representation is required to properly simulate different mixes of types that make up the study's different scenarios. Thus, regional and national data sets must be relied on to characterize an appropriate spread of model parameter values among these types. When it comes to flow simulation in the greater Puget Sound lowland, extensive data collection and past modeling provide a fairly high level of confidence in distinguishing among these types; however, available information and confidence is much less for the water quality parameters.

Flow - the ability of the three basin models to match flow records composed of direct measurements with a current meter and indirect measurements based on continuous stage monitoring and conversion to discharges via a rating curve is demonstrated in the calibration section of this report. Based on a visual comparison of simulated and measured time series and/or manual instantaneous discharge measurements made with a current meter, the three calibrated models generally track observed measurements very well with 79% of simulated values greater than the annual mean flow within 25% of measured instantaneous discharge measurements. The calibration bias across all three stations is within 1%, with no basin biased by more than 13% when compared to all manual discharge measurements. However, this only reflects a single, approximately stationary land use and management scenario in each basin and does not quantitatively assess the ability of the model calibrated under one land cover and management scenario to simulate flows resulting from changes in land use and management scenarios in the same basin. It is worth noting that the model calibration in McLane Creek and Black Lake did not place much weight on matching observed peaks because few manual discharge measurement were made during large storms and the rating curves are not considered reliable at the high end of the flow range.

To demonstrate this ability more convincingly using data would require two data sets from the same gage site in the same basin, one reflecting an earlier calibration period and associated land cover and management scenario, and a later one reflecting known and distinctly different basin land cover and/or management. This would allow some assessment of the model's ability to predict hydrologic changes in a basin. In reality, the existence of such data sets and associated studies is quite rare and regional confidence in HSPF's ability to estimate hydrologic change in basins resulting from land management is not founded on such studies. Rather, it is based on long experience with many dozens of calibration studies, and relatively fewer validation studies, performed over a wide range of Puget Sound lowland cover, soils, and topographic conditions which have repeatedly demonstrated the model's ability to track measured flows at multiple spatial and temporal scales (See for example, Dinicola, 1990; King County Bear Creek Calibration, 1988; King County Green-Duwamish Watershed Assessment, 2003; and Appendix E of King County, 2012 Juanita Calibration to name a few).   This ability, to match measured flow data in different basins with widely differing levels of land development has led hydrologists and agencies to conclude that HSPF is currently the most reliable tool available for predicting changes in flows within the same basin resulting from land cover and management changes in Puget Sound.   The acceptance of HSPF for this purpose is also bolstered by a very well documented set of mathematical algorithms (Bicknell etc,) that explicitly account for different soil and cover conditions, represent the interaction of essential components of the land phase of the hydrologic cycle, and provide a rational, scientific basis for computing runoff and routing flows.

Based on the forgoing discussion, the ability of the calibrated model to represent changes in flow regime resulting from a shift from one land use and management scenario to another as very reliable as long as the changes land cover and stormwater management associated with each scenario is well understood and defined.

Temperature – Similar to flow, the ability of the HSPF models to match measurements of temperature was also demonstrated in the calibration section of the report. A visual comparison of time-series of simulated and observed temperatures at three sites within the study area (2 in the McLane basin and 1 in the Woodard basin) shows a good match at the two downstream sites (Mclane Reach 59 and Woodard 109) and a fair match at the upstream site (Mclane Reach 81). The slightly poorer quality of match at the upstream McLane Creek site is evidence that the stream size is pushing the lower limits of what can be explicitly modeled with HSPF's temperature algorithms. That said, the model still does a good job of matching downstream temperatures under existing conditions where problems are more likely to exist. The relatively small amount of heat associated with the error at the upstream site is less important in the overall basin heat budget further downstream.

Like flow, the calibration only reflects a single, shade condition in each stream and the model results for future management scenarios require estimating what shade will exist under restored stream corridor conditions associated with each scenario and how those conditions should be parameterized by a single factor for each stream reach. The value of the shade reduction factor for the fully restored condition was assigned the same shade value used for the fully forested upstream site on McLane Creek.

The reliability of the model to simulate temperature in management scenarios is between fair and good. In order to provide a higher grade to the reliability of the model the following would be needed: monitoring of fully shaded streams covering the range of stream widths expected to be restored would be performed and used for calibrating future conditions model parameters, detailed data would be collected to characterize hyporheic flow or other factors besides shading that may affect stream temperature throughout the basin, a more detailed representation of the stream heat budget than that available in HSPF could be utilized.

Fecal Coliform Bacteria - The ability of the HSPF models to match statistics of fecal coliform bacteria measurements was demonstrated in the calibration section of the report. The statistics calculated for simulated and observed fecal coliform loads are in good agreement; for the geometric mean, a common metric used for fecal coliform, they were within 12% of one another.

Like temperature and flow, the fecal coliform calibration reflects the model performance at matching existing conditions, but to an even higher degree the ability of the model to predict changes in fecal coliform load resulting from land cover and management changes requires even more assumptions. The accuracy of the calculated change in load when a rural parcel develops to high density residential is limited by the accuracy of both the existing and future loading rates for these two classes, the corresponding rates of pollutant removal, and the load from a septic or sewer system to the receiving water. For example, in Table 25, one can see that the fecal coliform loading rate for rural pasture land uses is more than double that for high density residential uses (not counting the load from the septic system). The loading rates for these two categories were based on typical numbers of animals found on parcels with those uses, and an assumption of no formal pollutant removal BMPs. If the rural parcel had no animals and the urban use had dozens of domestic pets, the loading rates could even be reversed. Additionally, the representation of fecal loads from septic systems required an assumption regarding the failure rate of septic systems, the attenuation of pollutants from leaking systems, and in the future condition, which systems would be replaced by sewer connections. All of these assumptions reduce the reliability of the model to predict changes in pollutant load. However, the loading rates used are at least moderately robust because they produced good calibrations between three unique basins with varying land use density. The transferability of parameters between basins suggests that the land uses are reasonably parameterized, and that the reliability of future loading estimates is fair.

Total Nitrogen – The ability of the HSPF models to match the average nitrogen load calculated from long-term monitoring programs is demonstrated in the calibration section of the report. The simulated long-term average load is within 7% percent in both the Woodard and McLane Creek basins, no observed data was available for streams tributary to Black Lake.

Like fecal coliform, the nitrogen calibration reflects the model performance at matching existing conditions nitrogen loads, but the ability of the model to predict changes in nitrogen load resulting from land cover and management changes requires several assumptions including pollutant loading rates, pollutant removal rates, and septic system performance. Unlike fecal coliform, which required an estimate of the number of animals in a given land use under existing and future conditions, the total nitrogen load was assigned just as a loading rate per acre and also as a function of the number of septic systems but all of the same uncertainties apply and are very similar. The loading rates used are again considered moderately robust due to the match achieved when transferring them between basins, but also due to their consistency with values used by others (e.g. King County, 2003). The reliability of future total nitrogen loading estimates is fair.

Total Phosphorus – The ability of the HSPF models to match the average total phosphorus load calculated from long-term monitoring programs is demonstrated in the calibration section of the report. The simulated long-term average load is within 10% percent in the McLane Creek basin but only 35% within the Woodard Creek, no observed data was available for streams tributary to Black Lake. Additionally the total phosphorus calibration is considered poorer than that of nitrogen due to the lack of suspended sediment data, to which phosphorus is closely associated.

The model's ability to predict changes in total phosphorus load resulting from land cover and management changes is affected by the same types of assumptions for loading and removal rates as total nitrogen, except that septic system loads are considered small and are ignored. Given the slightly poorer match between to total phosphorus concentrations between the basins suggests a little less confidence in the loading rates used for each land use. However, the calibration deficiency is offset by the absence of uncertainty associated with septic system loading associated with total nitrogen simulation, the resulting reliability of future total phosphorus loading estimates comparable is also considered fair.

Summary of Qualitative Assessment of Model Uncertainty

Table 26 lists factors affecting uncertainty for flow and water quality metrics that are derived from respective simulations of each modeled scenario. Values in the right-hand most column of Table 26 provide guidance on the percentage difference between metric values indicating moderate to strong evidence of a difference in water resource impact between the scenarios. When differences between metrics are less than these values, evidence of a difference in impact is proportionately weaker. As shown, relative differences between scenarios of less than 5% for flow metrics, and 10% for B-IBI, temperature, and fecal coliform metrics are judged to provide weaker evidence of a difference in impact from the scenario. A relative difference of 20% in average annual loads is the suggested minimum level to conclude there is moderate to strong evidence of different impacts to nutrient (Total P and nitrate) loads.

These guidelines can be used in comparing the outcomes of different scenarios as reflected by modeling results, summarized in Figure 66 through Figure 68. As has been noted previously, differences between modeled scenario results that are too small to provide moderate or stronger evidence of impact at the basin outlets and sub-basin locations presented in Table 26 may show stronger evidence of differences at other locations within the basin stream network, particularly where the distinguishing factors between two scenarios are more pronounced.

Table 26: Qualitative Assessment of Model Uncertainty

Constituent	Source of Model Calibration Parameters	Quality of Observed Data	Calibration Accuracy	Model Skill[1]	Change Thresholds Indicating Significant Differences Among Acenarios[2]
Flow (HPC and HPR)	Local data	Fair	Very good	Very good	10% for B-IBI score 5% for flow metrics
Temperature (% of time standard exceeded)	Local data (Woodard and McLane only)	Very Good	Good	Good	10%
Fecal coliform (Part 1, geo. mean; Part 2, % of time standard exceeded)	Local data	Fair (random grabs)	Very good	Fair	10%
Nitrate (average annual load)	Local data (Woodard and McLane Only)	Fair (random grabs)	Good	Fair	20%
Phosphorus (average annual load)	Regional parameters	Fair (random grabs), (no suspended sediment data)	NA	Poor	20%

[1] Model skill is the overall assessment of the model's ability to discriminate among scenarios

[2] Relative to existing values

6 Planning Scenario Simulation Results

An indication of the restoration potential of each future alternative is provided by the extent to which existing flow metrics, temperature and bacteria standard violations, and nutrient loads are shifted in the direction of their simulated Pre-European values. Figure 66 through Figure 68 provide a graphical comparison of the metric results associated with each modeled scenario[6], basin, and output location; the results for each parameter are discussed in the sub-sections that follow. Tabulations of resulting values from the five simulation scenarios are also provided in Table F1 through Table F29 in Appendix F; each scenario was described previously in Table 12. To a large extent, simulated differences in fecal and nutrient results for the scenarios shown in the figures are driven by differences in land surface loading rates shown in Table 25 and, in some cases, by the presumed presence or non-presence of septic systems or treatment BMPs.

Note that the only modeling results within the Black Lake Basin that apply to its outlet at Black Lake Ditch are those related to flow. Fecal coliforms, N and P results for this basin represent only the land areas that drain to the lake and do not include simulation of instream or in-lake processes such as vertical stratification, algal uptake or decay, the interactions of lake sediments on nutrient cycling, or others. This is also the case for phosphorus (P) at the other five reported sites (Kenneydell Creek in Black Lake and two creek sites each in McLane Creek and Woodard Creek basins). For all other water quality parameters at these five sites, instream processes are represented.

6.1 Simulated Hydrologic Metrics

Three flow metrics are reported, High Pulse Count (HPC), High Pulse Range (HPR), and average annual 7-day minimum flow. The first two of these three have been shown to have good correlation with B-IBI scores (DeGasperi et al., 2009)- a biological indicator of overall stream health that is derived from directly sampling macroinvertebrates species diversity at a stream site and calculating a score ranging from 10 to 50. Aquatic health descriptors of Very Poor, Poor, Fair, Good, and Excellent are associated with B-IBI score ranges of 10-16, 17-26, 27-36, 37-44, and 45-50, respectively.

King County (2012) presented general equations relating B-IBI based on data presented by DeGasperi et al. (2009). These equations predict B-IBI based on their observed correlation with several individual flow metrics; however, no single hydrologic metric (or group of metrics) should be considered a substitution for actual B-IBI measurements, since flow regime is only one of several factors that can influence macroinvertebrate biodiversity at a site, and even the full suite of flow metrics represents only a partial characterization of flow regime. Furthermore, as has been noted by King County, the equations are general approximations derived from basins and stream sites with very different physical characteristics and may not represent conditions in specific streams.

An example of this is illustrated by the HPC value for the Existing scenario at the outlet of McLane Creek (Table F1). The predicted B-IBI value, based on an HPC of 8.7 using the semi-logarithmic King County regression equation, would be 25 (Poor), yet the average of B-IBI values based on monitoring of McLane Creek over 8 years near the basin outlet was 39 (Good) (Thurston County, 2013). Given this level of mismatch between this prediction and observation, the approach to interpreting the B-IBI related, flow metrics in this study is to utilize the King County equations as indicators of the relative differences between B-IBI scores under different scenarios, rather than predictors of absolute values of B-IBI. For purposes of interpreting the impact of hydrologic regime change on aquatic health, the Pre-Euro

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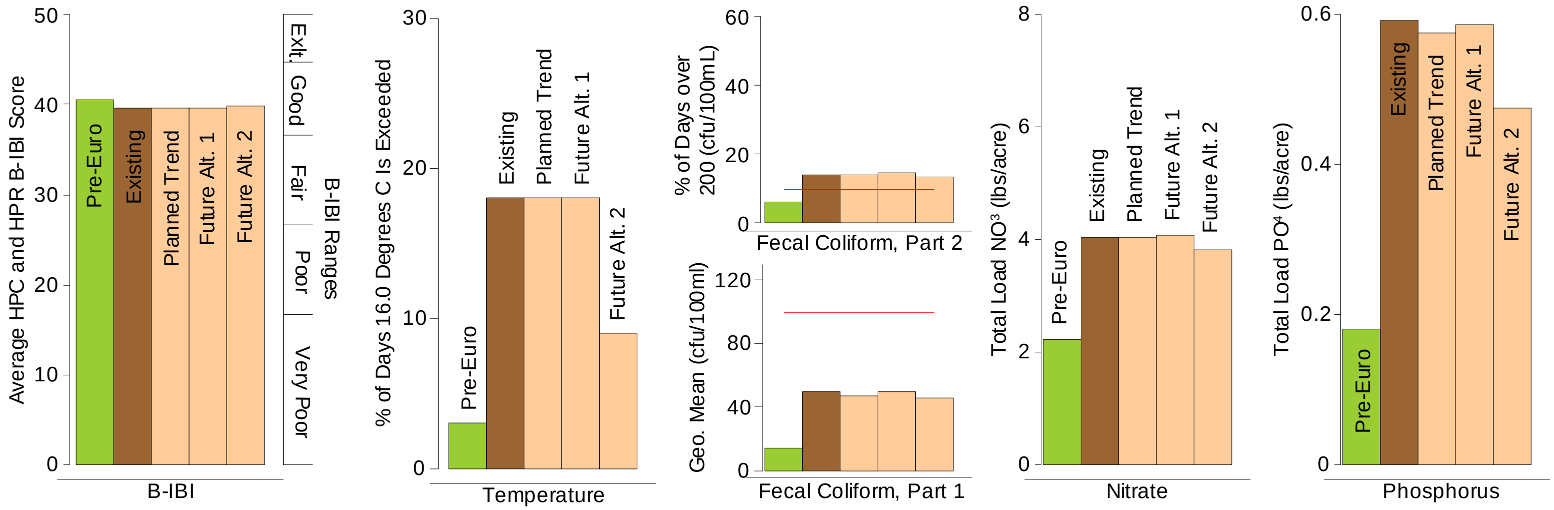
[6] 7-Day Minimum Average Flow results are not presented graphically but can be found in tabulated form in the Appendix.

condition is assumed to represent “Good” (equivalent B-IBI score of 40.5) conditions; B-IBI categories (Good, Fair, Poor, Very Poor) for the other scenarios are estimated by the differences between their HPCs and HPRs and those of the Pre-European condition using the King County equations. The results of this approach are shown in Table 27, along with percentage change in the average annual 7-day minimum flow compared to the presumed Pre-European condition.

McLane Creek at Eld Inlet (Reach 51)



East Fork McLane Sub-Basin (Reach 67)

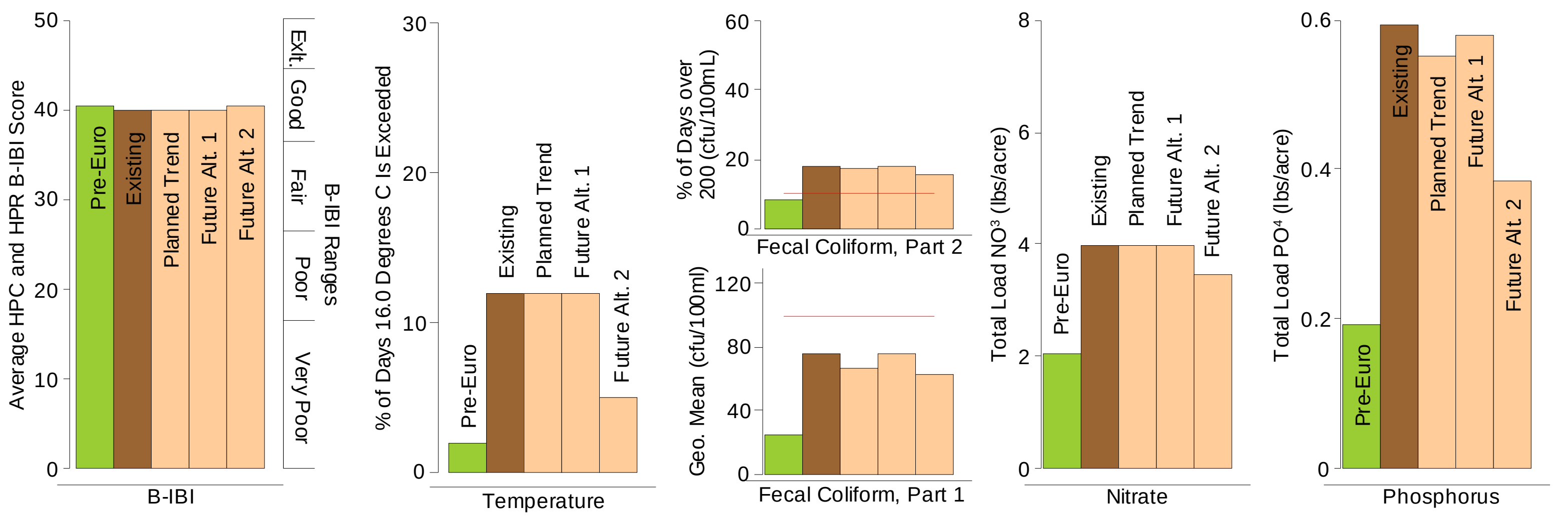


Figure 66: Summary Plots of All Pollutants, McLane Creek Basin (note: horizontal red line on fecal charts represents the violation threshold)

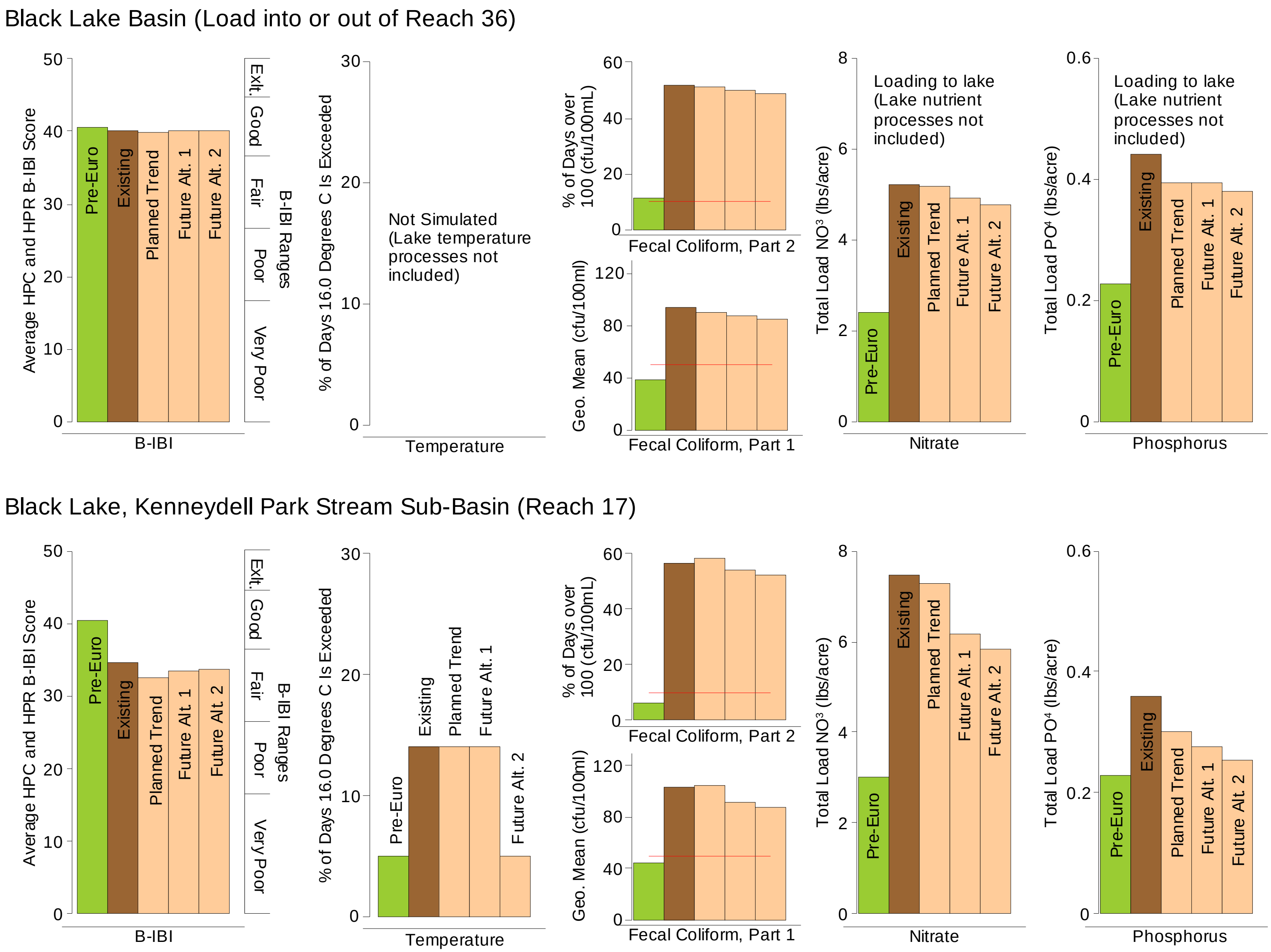
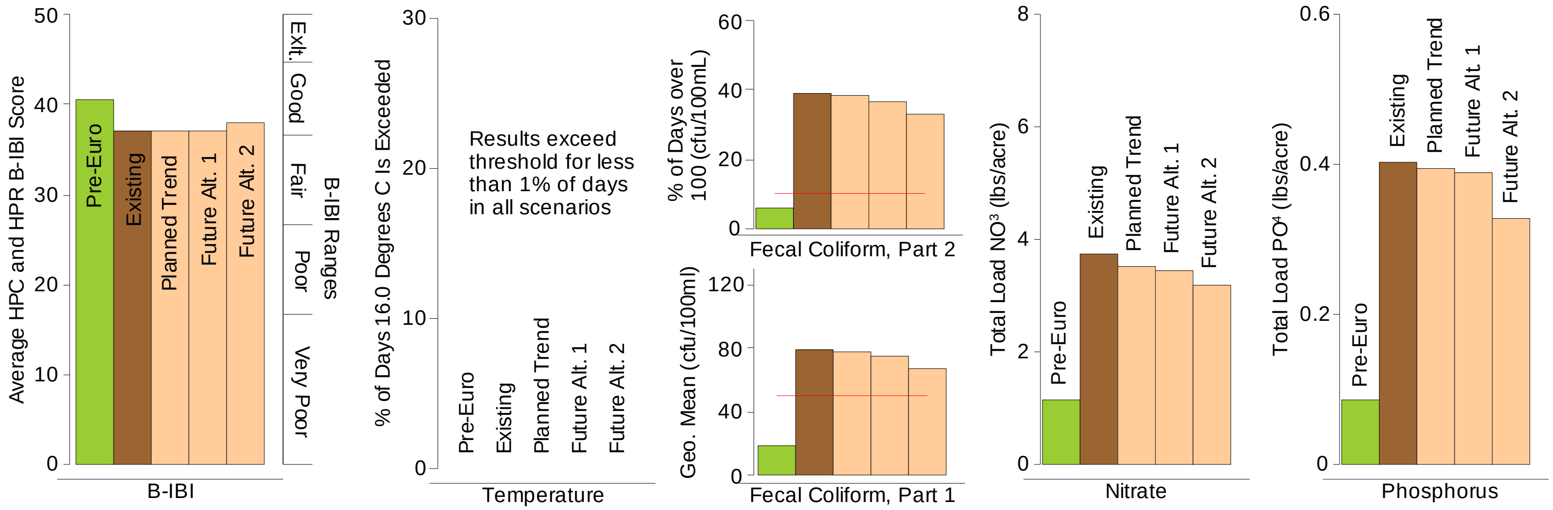


Figure 67: Summary Plots of All Pollutants, Black Lake Basin (note: horizontal red line on fecal charts represents the violation threshold)

Woodard Creek at Henderson Inlet (Reach 101)



Woodard Creek at UGA Boundary (Reach 117)

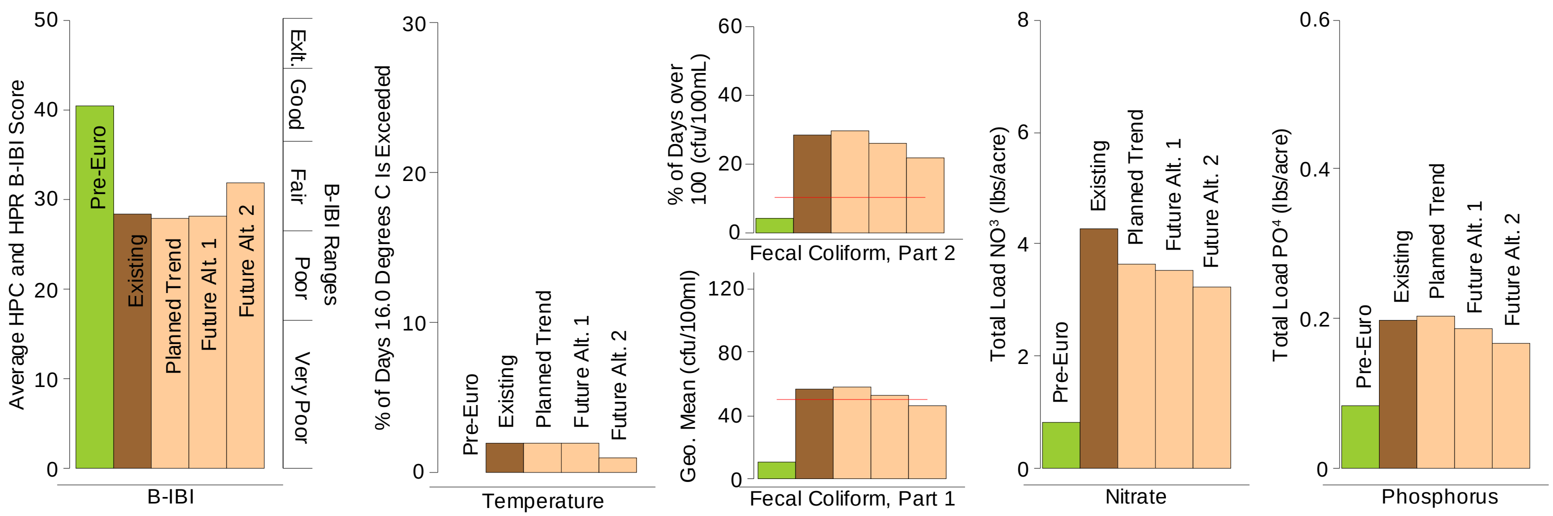


Figure 68: Summary Plots of All Pollutants, Woodard Creek Basin (note: horizontal red line on fecal charts represents the violation threshold)

Table 27: Relative Hydroecological Condition Associated with Flow Metrics			
Scenario	**High Pulse Count (HPC)-indicated condition[1]**	**High Pulse Range (HPR)-indicated condition[1]**	**Change in Average Annual 7-Day Minimum Flow Compared to Pre-Euro[2]**
McLane Creek at Eld Inlet (Reach 51)			
Pre-Euro	Good	Good	NA
Existing	Good	Good	0.0%
Planned Trend	Good	Good	1.0%
Future Alt. 1	Good	Good	1.0%
Future Alt. 2	Good	Good	0.0%
East McLane Creek Tributary at Confluence with McLane Creek (Reach 67)			
Pre-Euro	Good	Good	NA
Existing	Good	Good	2.4%
Planned Trend	Good	Good	2.4%
Future Alt. 1	Good	Good	2.4%
Future Alt. 2	Good	Good	0.0%
Black Lake at Discharge From Lake to Black Lake Ditch (Reach 36)			
Pre-Euro	Good	Good	NA
Existing	Good	Good	2.8%
Planned Trend	Good	Good	2.8%
Future Alt. 1	Good	Good	2.8%
Future Alt. 2	Good	Good	2.8%
Kenneydell Park Stream at Black Lake (Reach 17)			
Pre-Euro	Good	Good	NA
Existing	Fair	Fair	0.0%
Planned Trend	Fair	Fair	0.0%
Future Alt. 1	Fair	Fair	0.0%
Future Alt. 2	Fair	Fair	0.0%
Woodard Creek at Henderson Inlet (Reach 101)			
Pre-Euro	Good	Good	NA
Existing	Fair	Good	-9.1%
Planned Trend	Fair	Good	-9.1%
Future Alt. 1	Fair	Good	-9.1%
Future Alt. 2	Good	Good	-9.1%
Woodard Creek at UGA (Reach 117)			
Pre-Euro	Good	Good	NA
Existing	Fair	Fair	-5.9%
Planned Trend	Fair	Fair	-5.9%
Future Alt. 1	Fair	Fair	-5.9%
Future Alt. 2	Fair	Fair	-5.9%

[1]B-IBI Pre-Euro scores for all conditions assumed to be in the middle of the "Good" range (B-IBI = 40.5)
[2]Percentage change compared to Pre-Euro

Relative B-IBI-based Categories Derived from Simulated HPC and HPR

Estimation shifts of B-IBI-based aquatic health category appear generally consistent between the HPC- and HPR-derived results. Results for Woodard Creek at Henderson Inlet represent a minor exception; here, HPC results are at the high end of "Fair" and the HPR results are at the low end of "Good" for three of the four post-Euro scenarios.

In addition to the general consistency between HPC and HPR results, there is generally no categorical difference among the existing and future scenarios. Most notable are the downward shifts in category from "Good" in the Pre-Euro condition to "Fair" in the Existing condition at the Kenneydell Park site, and at the Woodard Creek UGA site; none of the future scenarios provides sufficient restoration to return synthetic B-IBI values to the "Good" range at these sites. At the Woodard Creek UGA site, Future Alternative 2, which includes extensive riparian restoration and retrofits, provides about half the ecological lift required to return site to the "Good" range. At both McLane Creek sites, "Good" conditions (no categorical change from Pre-Euro conditions) are indicated for both existing and all alternative future scenarios. The same appears to be true for the outlet of Black Lake to Black Lake ditch. Although there is considerably more post-Euro land cover change in the Black Lake basin than in McLane Creek basin, the resultant flashiness of inflows to the lake are damped out by the lake's storage, which smooth out the flows to the Black Lake ditch. This is evident from comparing the flow to the ditch with the results for Kennydell Park Creek which drops from "Good" to "Fair" going from Pre-Euro to Existing and all three future scenarios. At the Woodard Creek basin outlet, indicated B-IBI categories have dropped from the middle of the "Good" range assumed for Pre-European conditions, to the border between "Good" and "Fair" under existing conditions. Here again, only Future Alternative 2 provides any lift, albeit at a smaller level than at the upstream, UGA boundary site. This suggests a slight hydroecological advantage at the basin scale of the additional restoration measures incorporated into Future Alt 2.

Relative Changes in Average 7-Day Minimum Flow

Absent significant rain during the summer, stream flows decline gradually as stored groundwater is depleted. Minimum flows generally occur in late summer and early fall before the initiation of the rainy season. In heavily urbanized basins, groundwater recharge is partially cut off by impervious surfaces and less infiltrative pervious surfaces. Absent significant landscape irrigation, minimum flows decline compared to pre-developed basin conditions. In basins undergoing limited rural development, changes to minimum flow are generally small and sometimes minimum flows are augmented due to the water harvesting effect of partial forest clearing which reduces evapo-transpiration losses. While it is often correctly assumed that forest clearing and land development increases storm runoff, reduces water available for percolation, and therefore lowers summer base flow, there can be a counterbalancing effect if dense tree cover is replaced by shallow-rooted vegetation that is not irrigated by pumping water locally. In this case, the replacement vegetation may consume less water overall- potentially providing more water to sustain streams during the summer and fall. To a small extent, this appears to be the case for McLane Creek at both the basin scale and sub-basin scale.

In the Kenneydell Park Creek sub-basin of Black Lake the counterbalancing effects of forest clearing on recharge and base flow discussed above appear to be roughly equal. Thus, no difference in minimum flows is evident among the scenarios. In contrast, at the Black Lake outlet, the overall increase in basin water yield and the damping effect of the lake's storage and slow release of water results in an increase in minimum flows of approximately 3%.

In Woodard Creek, changes in minimum flows associated with the modeled post-Euro scenarios depends on a complex of factors including the concentration of both urbanization and outwash type soils in the southern part of the basin. On these type soils, conversion of forest to grass or pasture likely results in reduced evapo-transpiration loss, which partly counterbalances the diversion of groundwater recharge by impervious surfaces. In the northern, rural part of the basin, till soils dominate and losses of base flows are reinforced rather than counterbalanced because of more limited recharge on pasture and grass till compared to forest till. As a result, reductions in minimum flows for all post-Euro scenarios at the basin outlet are more severe on a percentage basis (9.1% loss) than at the UGA boundary (5.9 % loss). As with the B-IBI-based flow metrics, variation among the different post-Euro (Existing and three future scenarios) is generally small compared with the difference between Pre-Euro and the collective post-Euro scenarios.

6.2 Temperature

The effects of the planning strategies on stream temperatures were evaluated by looking at how frequently each of the three state standards were violated in each scenario. While only one standard applies to each basin, based on the designated uses for the stream, all three thresholds are presented for comparison. The temperature standard thresholds, described in Table 11, are values of the 7-day average of the daily maximum temperature, or 7-DADMax, which is the arithmetic average of seven consecutive measures of daily maximum temperature. The 7-DADMax for any individual day is calculated by averaging the daily maximum temperature for that date with the daily maximum temperatures of the three days prior and the three days after that date. Calculated temperature results are shown graphically in Figure 66 through Figure 68 and tabulated in Table F7 through Table F11.

McLane Creek

In the McLane Creek basin, the designated use requires that the stream temperatures be below the threshold of 16 degrees C. All of the simulated scenarios, including Pre-Euro, exceed that criterion, at least 2% of the time. However, the Future Alternative 2 scenario is effective at cutting the frequency of temperature violations down by half from 18% under Existing and Planned Trend conditions to 9% of the time at the basin outlet (reach 51) and from 12% to 5% at McLane East (reach 67). This is a direct result of the extensive riparian restoration associated with this alternative.

Black Lake

In the Black Lake basin, the designated use requires that the stream temperatures remain below the threshold of 16 degrees C. The standard is violated in all scenarios, including the Pre-European condition, at least 5% of the time. The Future Alternative 2 scenario is effective at reducing temperature violations in the Kenneydell Park Stream (reach 17) to the Pre-European level of 5% of all days, down from 14% of all days in the Existing, Planned Trend and Future Alternative 1 scenarios.

Woodard Creek

In the Woodard Creek basin the designated use requires that the stream temperatures be below the threshold of 16.0 degrees C. The simulation results indicate this standard is consistently met for all scenarios near the mouth of the creek and modeling results are consistent with observed data.

At the UGA boundary, modeled temperature standard exceedances in Woodard Creek occur 2% of the time under existing conditions and also in Planned Trend and Future Alt 1 scenarios. In Future Alt 2, exceedance frequency of the other scenarios is approximately cut in half from 2% to 1%, about half the restoration to the Pre-European condition.

The temperature results show the most dramatic increase in effect of all of the simulation metrics in the Future Alternative 2 scenario and very little in the others. This is expected given that Future Alternative 2 is the only future scenario with any change in riparian shade. This is largely due to the fact that the outlined riparian restoration shown in Figure 5 through Figure 13 is fairly aggressive and includes the majority of the streams in the study basins. Aside from riparian shade, there are also some thermal heating from stormwater ponds that could be reflected in the Planned Trend and Future Alternative 1 scenario results but no evidence of that effect is seen in the simulation results. The results indicate reductions in stream temperatures would improve the aquatic resources if ambitious riparian restoration measures are conducted in the McLane Creek and Black Lake basins. The Woodard Creek basin riparian corridor is largely intact, making riparian restoration there less beneficial.

6.3 Fecal Coliform

The effects of alternative planning strategies on fecal coliform were evaluated by looking at both Part 1 and Part 2 of the state water-quality standard. The standard, described in Table 11, varies by the recreational use that is designated for the water body. The most common standard, for primary contact recreation, requires an overall geometric mean be below 100 colonies per 100 mL and also that 90% of samples be below 200 colonies per 100 mL. This primary contact recreation standard applies to McLane Creek basin, but Black Lake and Woodard Creek basins are subject to the higher, "extraordinary" primary contact recreation standard. The Part 1 threshold for the higher standard is 50 colonies per 100 mL and Part 2 is 90% < 100 colonies per 100 mL. Geometric mean values, calculated from one sample for each day of the long-term (1956 through 2012) simulations are shown graphically in Figure 66 through Figure 68 and tabulated in Table F12 through Table F16. The concentration assigned to each day was the noontime simulated value, a time that is common for sampling from an ambient monitoring program.

McLane Creek

At both sites in the McLane Creek basin (reaches 67 and 51), all of the scenarios had mean simulated fecal coliform concentrations that were below Part 1 of the state criterion (100 colonies per 100 mL); whereas, except for Pre-Euro, all scenarios violated Part 2 (90% < 200 cfu/100 mL). The number of days the Part 2 threshold of 200 cfu / 100mL was exceeded is roughly double in the existing scenario relative to that of the pre-Euro scenario at both sites, exceeding the threshold 14% and 18% of the time at the East McLane site and basin outlet respectively. Existing condition model results for the basin outlet are generally consistent with the field monitoring results reported by Thurston County Environmental Health at the Delphi Road site, with no Part 1 violations having been reported in field monitoring since 2000 but violations of Part 2 of the standard during most years. Fecal coliform is still a concern in McLane Creek due to Part 2 violations alone. There are only very small differences between each scenario, but Future Alternative 2 performs best, due to restoration of riparian pasture areas to forest cover and the bacteria loading levels associated with these different cover types.

Black Lake

At both sites in the Black Lake basin (reaches 17 and 36), all of the scenarios except for Pre-Euro had mean simulated fecal coliform concentrations that were above the state Part 1 and Part 2 criterion for extraordinary primary contact recreation (50 colonies per 100 mL and 90% exceeding 100 colonies per 100 mL). The number of days the Part 2 threshold of 100 cfu / 100 mL was exceeded is more than 5 times higher in the existing scenario relative to that of the pre-Euro scenario at both analysis points, exceeding the threshold 56% and 52% of the time in Kenneydell Park Stream and for the total area contributing to the lake, respectively. Existing condition model results for the Kenneydell Park Stream are consistent with the field monitoring results reported by Thurston County Environmental Health, with violations of Part 1 of the standard in all years monitored. It is predicted that fecal coliform concentrations in Kenneydell Park Stream will increase slightly under current planning regulations but would decrease in both Future Alternative 1 and 2. However, total loading of fecal coliform to the lake is predicted to decrease, at least slightly, under all future scenarios. The Future Alternative 2 scenario lowers the magnitude of the violations to below the existing level, providing partial restoration at both sites in the basin. The UGA boundary in this basin would be revised slightly in Alternative 1 or 2, so the improvements over Planned Trend in Kenneydell Park Stream and at the basin outlet are the cumulative effects of the UGA boundary and stormwater treatment requirements for both alternatives, and the additional conversion to forest as part of the riparian restoration strategy for Alternative 2.

Woodard Creek

Like Black Lake, all of the scenarios in the Woodard Creek basin except for Pre-Euro had mean simulated fecal coliform concentrations that were above the state Part 1 and Part 2 criterion for extraordinary primary contact recreation at the basin outlet (reach 101). A similar result is evident at the UGA boundary (reach 117), except that Future Alternative 2 is slightly under the violation level for Part 1. The number of days the Part 2 threshold of 100 cfu / 100 mL was exceeded is roughly four times higher in the existing scenario relative to that of the pre-Euro scenario at both sites, exceeding the threshold 28% and 39% of the time at the UGA boundary site and basin outlet respectively. The Existing scenario results are consistent with the field monitoring data reported by Thurston County Environmental Health, with violations of Part 1 of the standard being observed in some years and violations of the Part 2 standard observed in most years. At the Woodard basin outlet (reach 101), there is a 4% reduction in fecal coliform concentrations between the Planned Trend and Alternative 1 scenarios and an additional 10% reduction in the Alternative 2 scenario. Even larger reductions are seen at the UGA boundary (reach 117), with a 10% reduction between the Planned Trend and Alternative 1 scenarios and an additional 11% reduction in the Alternative 2 scenario.

6.4 Nitrate

The effects of the planning strategies on nitrate load was evaluated from the average annual load of nitrate to each point of interest. There is no state standard for nitrate in streams so the benefit of each scenario was evaluated based on the overall reduction in load. The average annual loads are shown graphically in Figure 66 through Figure 68 and tabulated in Table F18 through Table F23 below.

McLane Creek

In the McLane Creek basin there was very little difference in simulated nitrate loads at the basin outlet (reach 51), but there was a small reduction in Future Alternative 2 scenario in the East Fork McLane site (reach 67). That reduction achieved approximately a 25% restoration of the pre-Euro scenario loading rates, roughly half of the existing condition scenario loading rate at both sites. The cause of the reduction simulated in east McLane, 14% relative to the Planned Trend and Future Alternative 1 scenarios, is similar to the cause of the fecal coliform concentrations in that reach. Stormwater retrofits in sub-basins 67 and 68 are providing increased water-quality treatment, and a substantial amount of area being converted from pasture to forest as part of the riparian restoration strategy is contributing lower nitrate loads.

Black Lake

In the Black Lake basin there was very little difference in total simulated nitrate loads to the lake (total load entering reach 36), but there was a moderate reduction in Future Alternative 1 and 2 scenarios in the Kenneydell Park Stream (reach 17) with about 30% and 37% restorations to pre-European conditions, respectively. The pre-Euro scenario loads were less than half that of the Existing condition scenario at both sites. The cause of the reduction at the Kenneydell Park Stream site is different from that in East McLane. The tributary area to reach 17 is not receiving stormwater retrofits so the reduction here is due to increased water-quality treatment and reductions in development density. There is a smaller 3% reduction in loads between the Existing and Planned Trend scenarios at this site as well, due to the combined effects of converting septic systems to sewers within the UGA and increased water-quality treatment (conventional, non-LID, only).

Woodard Creek

In the Woodard Creek basin, reductions in nitrate, compared with Existing conditions, are simulated in all Future scenarios at both the outlet (reach 101) and the UGA boundary (reach 117). These reductions range from 6% to 15% at the basin outlet and 14% to 24% at the UGA boundary. The reductions at the UGA boundary primarily reflect replacement of septic systems by sewers. Greater reductions seen in Future Alternative 1 and 2 are due to increased stormwater treatment associated with redevelopment and retrofits, use of LID treatment technologies, and conversion of pasture and other land covers to forest as part of the riparian restoration strategies. The reductions downstream of the UGA boundary, can be inferred from the difference between the UGA boundary and the basin boundary totals for each scenario. These are all very small. Future Alternative 2, providing about 24% restoration at the UGA boundary compared with existing conditions, is marginally superior to the other future alternatives. None of the scenarios approach the simulated pre-Euro loads, which are less than a quarter of the existing condition loads at both sites. This is due to the lack of forest restoration in any scenario. All non-forest pervious land covers have nitrate (as well as phosphorus and fecal coliform) runoff rates of more than twice that of the forested condition in all three basins. To restore the Pre-European rates, the existing pasture areas would need to be treated for nutrient removal, or returned to a non-livestock, non-agricultural, or forested use. The model assumes that all pasture areas have some livestock or agricultural uses.

6.5 Phosphorus

The effects of the planning strategies on phosphorus load was evaluated by looking at the average annual load of phosphorus to each point of interest. There is no state standard for phosphorus in streams so the benefit of each scenario was evaluated based on the overall reduction in load. The average annual loads are shown graphically in Figure 66 through Figure 68 and tabulated in Table F24 through Table F29 below.

McLane Creek

In the McLane Creek basin, similar trends were observed in simulated phosphorus loads at the basin outlet (reach 51) and in East McLane (reach 67). Phosphorus loading levels have approximately tripled under existing conditions at both sites, relative to the pre-Euro scenario. At both sites, phosphorous loads in the Planned Trend and Alternative 1 scenarios are similar to the existing condition scenario. Alternative 2 is more effective at both sites, with a reductions of 28% and 52% of the existing condition loads relative to the pre-euro scenario at the basin outlet and East Mclane sites respectively. The decrease at the basin outlet is due to the fairly large-scale conversion of non-forest cover to forest that is associated with the riparian restoration strategy of this alternative, while the decrease in the East McLane sub-basin can be attributed to the combined effects of stormwater retrofits in this sub-basin and the conversion of land cover associated with the riparian restoration strategy.

Black Lake

Restoration potential for phosphorus loading is most viable in the Black Lake basin, where phosphorus loading to the lake is a key driver of algal blooms that affect recreational uses. Under existing conditions, phosphorus loading from the entire basin is estimated to have approximately doubled relative to the pre-Euro scenario. All of the future scenarios have a similar, moderate restoration benefit of cutting the increase in loading by about 24%. The reduction seen in the Planned Trend scenario comes from additional stormwater treatment associated with redevelopment and a reduction in loading rates associated with land use conversion. Unlike the modeling approach for fecal coliform and nitrate, there is no linkage between expected conversions septic systems and rates of phosphorus loading to the stream. As a result, all of the reduction simulated under the Planned Trend scenario is due to changes in the land use type and density. There is only a small benefit associated with Future Alternative 2 relative to the other two future scenarios.

At the Kenneydell Park Stream site (reach 17), there is restoration benefit under all three future scenarios but the benefit is generally greater and most pronounced for the Future Alternative 2 scenario which cuts back the increase from Pre-European to Existing conditions by 76%. The Future Alternative reductions in this reach are associated with increased additional stormwater treatment associated with redevelopment and retrofits as well as the effects of converting pasture and other covers to forest as part of the riparian restoration strategies.

Woodard Creek

In Woodard Creek, phosphorus loads have increased by more than a factor of four at the basin outlet relative to the pre-European condition. There is very little difference in the phosphorus loads between the Existing, Planned Trend and Future Alternative 1 scenarios in the basin, but there is a modest improvement in Future Alternative 2. At the basin outlet (reach 101), the simulated Future Alternative 2 load is 14% less than the Alternative 1 simulated load. At the UGA boundary, the Future Alternative 2 load is 10% less than the Alternative 1 simulated load. The reduction associated with this scenario is related to the combined effects of stormwater retrofits and land-cover change associated with the conversion of pasture and other covers to forest as part of the riparian restoration strategy.

6.6 Summary of Future Scenarios Compared to Existing Conditions

The simulated model results show varying levels of positive or negative impacts from the Planned Trend and Future Alternative scenarios, depending on the metric of concern and the output location evaluated. Table 28 through Table 30 present a summary of the impacts of future scenarios compared to existing conditions for each of the three study area basins. In cases when the results differ between the overall basin and the local basin, both results are shown in parenthesis as (basin) and (local), but in cases when similar results are expected at both the basin and local scale only one impact condition is provided. An assessment of overall aquatic health benefit is provided in the right column of each table. It represents an overall assessment of the impact of the land management scenario considering all of the metrics evaluated. The overall aquatic health benefit in a basin can be scored as 'small', 'moderate', 'high', or in cases that have both positive and negative impacts receive a score of 'mixed' benefit.

McLane Creek Basin

In the McLane Creek basin, a small local aquatic health benefit is expected under the Future Alternative 1 scenario, and a moderate basin-wide benefit is expected in Alternative 2. There is an expected reduction in fecal coliform under the Future Alternative 1 scenario in the East Fork McLane sub-basin, but it does not provide a reduction at the basin outlet. There are no improvements for the other metrics under this Alternative; overall, this alternative has no evident water-quality benefits in this sub-basin. The Future Alternative 2 scenario does provide a substantial benefit with significant reductions in stream temperatures, moderate reductions in fecal coliform, and local reductions in nitrate loads.

Table 28: McLane Creek Basin Summary of Impacts

Scenario	Metric Impact Result					Overall Aquatic Health Benefit
	Hydrology /B-IBI	Temperature[1]	Fecal Coliform	Nitrate	Phosphorus	
Planned Trend	Remains "Good"	No change (frequent violations)	No change	No significant change	Small decrease	No significant change [2]
Future Alternative 1	Remains "Good"	No change (frequent violations)	No change (basin), Reduction (local)	No significant change	No significant change	None (basin)[2], Small (local)
Future Alternative 2	Remains "Good"	Many fewer violations	Reduction	No significant change (basin), Moderate reduction (local)	Large reduction	Moderate [2]

[1] Temperature standard for McLane Creek and its tributaries is 16.0 Degrees C

[2] Phosphorus is not a key water-quality parameter for McLane Creek (due to the lack of DO problems in the Creek, and that it doesn't contribute to water-body sensitive to Phosphorus) and was ignored in the overall aquatic health benefit rating.

Black Lake Basin

Black Lake basin has mixed impacts that are expected to occur under the forecasted Planned Trend, but both Alternative 1 and 2 show benefits to aquatic health. Under the Planned Trend scenario the fecal coliform loads are expected to increase in Kenneydell Park Stream but decrease at the basin outlet; there is also an expected reduction in phosphorus loads, which is the opposite of the McLane Creek basin. A moderate improvement in aquatic health is expected under the Future Alternative 1 and 2 scenarios in the Black Lake basin based on moderate reductions in fecal coliform, nitrate, and phosphorus and an improvement in stream temperatures, with the greatest improvements seen under Future Alternative 2.

Table 29: Black Lake Basin Results Summary of Impacts						
Scenario	Metric Impact Result					Overall Aquatic Health Benefit
	Hydrology /B-IBI	Temperature[1]	Fecal Coliform	Nitrate	Phosphorus	
Planned Trend	Remains "Good" (basin), "Fair" (local)	No change (frequent violations)	Small decrease (basin), Small increase (local)	No significant change	Moderate Reduction	Mixed
Future Alternative 1	Remains "Good" (basin), "Fair" (local)	No change (frequent violations)	Reduction	Moderate Reduction	Moderate Reduction	Moderate
Future Alternative 2	Remains "Good" (basin), "Fair" (local)	Reduced to Pre-Euro violation frequency	Reduction	Moderate Reduction	Moderate Reduction	Moderate
[1] Temperature standard for Black Lake tributaries is 16.0 degrees C						

Woodard Creek Basin

Like Black Lake, the Woodard Creek basin has mixed impacts that are expected to occur under the Planned Trend scenario, whereas both Future Alternative 1 and 2 show moderate improvement. Under the Planned Trend the fecal coliform loads are expected to increase slightly at the UGA boundary but decrease at the basin outlet; there is also an expected reduction in nitrate loads. A small to moderate improvement in aquatic health is expected under the Future Alternative 1 and 2 scenarios in the Woodard basin based on moderate reductions in fecal coliform, small to moderate reductions in nitrate, and a moderate reduction in phosphorus.

Table 30: Woodard Creek Basin Results Summary of Impacts						
Scenario	**Metric Impact Result**					**Overall Aquatic Health Benefit**
	Hydrology /B-IBI	**Temperature[1]**	**Fecal Coliform**	**Nitrate**	**Phosphorus**	
Planned Trend	No Significant change	No change (few violations)	Small reduction (basin), Small increase (local)	Small reduction (basin), Moderate Reduction (local)	No significant change	Mixed
Future Alternative 1	No Significant change	No change (few violations)	Small reduction	Small Reduction	No significant change	Moderate
Future Alternative 2	Small Improvement	Slight improvement	Reduction	Small to moderate Reduction (basin vs. local)	Moderate Reduction	Moderate

[1] Temperature standard for Woodard Creek and its tributaries is 16.0 degrees C

Summary

In summary, Future Alternative 2 clearly outperforms the other two future alternatives with respect to restoring pre-European conditions in each basin. This is most dramatically demonstrated by the reduced temperature violations at both McLane Creek sites and at the Woodard Creek UGA boundary, and to a lesser extent for the other flow and quality metrics and model output sites. With the exception of the B-IBI-related metric at the McLane sites and at the Black Lake outlet site, changes in stream conditions between pre-European and Existing conditions are generally greater than any differences among the three future scenarios considered: most of the long-term degradation of these watersheds has already occurred, and none of the scenarios are successful at rolling it back.

6.7 Recommendations for Additional Monitoring and Modeling Activities

The following activities are recommended for the County's consideration pursuant to improving model skill and reducing uncertainty in the application of results to support watershed management actions:

- Monitoring or Data Collection
    - Water-quality monitoring targeting individual land uses
    - Collect suspended sediment data (none are currently available)
    - Perform more detailed inventory of animal density by land use category, used for fecal coliform loading calculations
    - Collect field or other GIS data to identify fields used as pasture (grazed) land from those used as grassland (ungrazed)
    - Collect flow and water-quality data at intermediate locations within each study area to allow for model calibration (or validation) at more than a single location in each basin.
    - Field monitoring and/or hydraulic modeling to confirm flow split from Dempsey Creek into Black Lake (including any seasonal component)
- Scenario Development
    - Add more complete representation of LID pollutant removal rates
    - Further evaluation of assumptions regarding relative nitrate and fecal loading rates from septic systems
    - Lake receiving water-modeling for Black Lake (currently only loads to lake are included in model)
- Model Application
    - Query existing model at additional locations that are expected to have dramatic differences between scenarios than the basin outlet and one sub-area queried thus far (minimal effort activity suggested a first step for additional modeling activity)
    - Simulate scenario to estimate the maximum possible benefits from stormwater retrofits within a basin or sub-basin

7 Implications for Watershed-Based Land Use Planning

This study was undertaken to help policy makers in Thurston County gain a better understanding of how anticipated future development may affect water flow and water quality, and whether management changes can assist in reducing or removing those impacts. To assist in this understanding, the project team intentionally selected three basins with different levels of current and projected growth and with different water resource concerns. The results of this modeling work should be used in conjunction with other information to inform the development of watershed plans for each basin. Public input also will undoubtedly inform how this work ultimately influences land use regulations.

In rural and lower density areas, future land development – which includes the clearing of trees and other vegetation as well as the installation of impervious surfaces – is anticipated to be the greatest potential influence on flows, temperature, and pollution loads in small streams. Land use regulations – including zoning, development regulations, and stormwater requirements – are the primary tools available to local jurisdictions to prevent degradation and protect existing critical habitat and ecological functions in the face of these changes.

The Planned Trend scenario was developed to show the future impact of those rules and regulations that are currently in place. In general, the model results show that for these basins, anticipated future development under current regulations would lead to some limited additional degradation, but these impacts are minor when compared with the changes from historic to current conditions that has already occurred. This indicates that current regulations – including UGA boundaries, zoning and critical area ordinances – when properly implemented for the development forecasted by TRPC, can be effective at minimizing the impact of new development. The major caveat to this finding is that to see these results, development in these basins must match the assumptions of the model, and this emphasizes the need to enforce compliance with current regulations. The model also makes assumptions about the average amount of tree clearing and impervious surfaces that would occur in new development, although these are not required limits under County code. A next step in this study could include an evaluation of whether these assumptions should be more formally adopted as standards.

A second caveat is that these results apply only to the land use conditions predicted for these three basins, which have a limited amount of remaining development potential under current land use regulations. For example, increases in total impervious area (TIA) for the Planned Trend scenario range from 1% to 4% or about 25% of existing impervious area for all three basins. For basins with a greater amount of undeveloped and subdividable lots, the cumulative impacts from new development may be much more pronounced.

The Future Alternative 1 scenario was developed to characterize any benefits from potential regulatory changes, such as adjustments to zoning densities and urban growth area boundaries, as well as the introduction of LID flow control standards that will be required under the 2013-2018 Phase II Western Washington Municipal NPDES Stormwater Permit. The model results for this scenario showed small to moderate benefits to water quality in some areas when compared with the Planned Trend for development, particularly within the Black Lake basin, which is the area with the greatest projected increase in future development. This improvement was noted despite the assumption in the Planned Trend scenario that all development in the UGA would be converted to municipal sewer systems, which is unlikely to be implemented due to cost and over-estimate the water quality conditions under the Planned Trend scenario. The suggestion from these results is that removing these sensitive areas from the UGA will not have a negative impact on water quality when compared with the alternative, and may slightly improve conditions, though these results should be taken in consideration with other environmental and social factors before any final determination is made. In other areas, proposed zoning changes show little improvement over the Planned Trend scenario at the basin scale, although the effects of changes in particular sub-basins may be worthy of further study.

The Future Alternative 2 scenario includes substantial restoration of vegetation along stream corridors and stormwater retrofit projects, both nonregulatory management actions. The model results for this scenario showed significant improvement for many water quality parameters, particularly temperature. This outcome corresponds with the general finding that, for most parameters, the greatest change has already occurred between pre-European and existing conditions, and that improved conditions will result from a combination of restoration actions and thorough application of the latest storm water standards and related environmental regulations. In subbasins where there is minimal restoration opportunity, additional degradation is expected to be relatively small compared to existing levels as long as regulations are applied and additional land development is not more extensive than assumed in this study.

Given this pattern of identified impacts and degradation, the greatest opportunity for water quality improvements almost certainly lies in restoring ecological processes that already have been degraded by development that occurred under older regulations that provided less protection. Such restoration cannot be achieved through changes to regulation but could be supported through incentive programs that encourage landowners to replant along stream corridors and/or provide funding for restoration projects, and through capital investment in stormwater retrofits to apply more treatment and flow control in older areas that were developed without this infrastructure. Additional work could study which stream reaches or sub-basins provide the greatest ecological lift with restoration.

All three future scenarios included an assumption that 20% of new development and redevelopment would not receive flow control or water quality treatment. The purpose of this assumption was to account for the fact that practically speaking, storm water facilities mandated by regulations are applied to less than 100% of development and are also less than 100% effective in achieving the level of control and treatment equal to applicable design standards. Small scale development is sometimes below regulatory thresholds, some flawed designs slip through the review process, construction may deviate from design plans, and facilities are too frequently poorly maintained and lose effectiveness over time. While these problems are not an argument for the abandonment of stormwater facilities as a means of mitigating the effects of land development on streams, they do stand as a caution against over-reliance on such measures to protect high value aquatic resources. In contrast, preservation of natural areas with strong hydrologic linkages to these high value resources provides the most reliable protection.

While this study provides a snapshot of how anticipated development in Thurston County may impact water resources in three small basins, the results are limited to illustrating the effects on water flow and water quality. Any full basin plan should consider a wide range of additional factors, including potential impacts to habitat for fish and wildlife (including endangered species), public services, floodplain management, as well as stakeholder and public input. Though hydrology is the first among equals with regards to the impacts of urbanization on streams.

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Appendix A

Legacy Thurston County Precipitation-Runoff Models

Table A1: Legacy Thurston County Precipitation-Runoff Models

Study/Basin Name	Year Completed	Jurisdiction	Model Used	Objectives/results/comment	Reference
Moxlie-Indian Creeks	1993	City of Olympia and Thurston County	EPA-SWMM, Design Storm Method	Existing and Future Flows, Basin Planning. Highly urbanized areas. Flood management oriented.	Thurston County and City of Olympia, 1993. Indian Creek and Moxlie Creek Comprehensive Drainage Basin Plan, Thurston County and City of Olympia .
Percival Creek	1993	Cities of Olympia and Tumwater and Thurston County	HSPF v 8	Existing and Future Flows, Basin Planning for flood management	Cities of Olympia and Tumwater and Thurston County, 1993. Percival Creek Comprehensive Drainage Basin Plan, Cities of Olympia and Tumwater and Thurston County.
McAllister/Eato n Creek	1994	Thurston County Water & Waste Management	EPA-SWMM, Design Storm driven, Horton Infiltration	Existing and Future Flows, Basin Planning for flood management	Thurston County, 1994. McAllister/Eaton Creek Comprehensive Drainage Basin Plan, Thurston County Water & Waste Management Storm and Surface Water Program. [SWMM model information in appendix G, Brown and Caldwell performed modeling]
McAllister/Eato n Creek	1994	Thurston County Water & Waste Management	HSPF and HYDRA Modeling	Existing and Future Flows,	Thurston County, 1994. McAllister/Eaton Creek Comprehensive Drainage, Thurston County. Basin Plan, Thurston Water & Waste Management Storm and Surface Water Program.
Woodland and Woodard Creek	1994	Cities of Olympia and Lacey and Thurston County	HSPF	Model Calibration	Beyerlein, D.C. and J.T. Brascher. 1994. Woodland and Woodard Creek HSPF Calibration for Thurston County, Washington. Beyerlein, D.C. and J.T. Brascher. 1994. Woodland and Woodard Future Conditions, Thurston County, Washington, Final Results Prepared for Thurston County by Aqua-Terra Consultants, Everett, W A.
Woodland and Woodard Creek	1995	Cities of Olympia and Lacey and Thurston County	HSPF	Analysis of current and future stream flow regime and wetland level fluctuations	Thurston County, City of Lacey and the City of Olympia, 1995. Woodland and Woodard Creek Comprehensive Drainage Basin Plan, Thurston County, City of Lacey and the City of Olympia.
Chambers/War d/Hewitt	1995	Thurston County	HSPF	Existing and Future Flows, Basin Planning	Thurston County Storm and Surface Water Program, 1995. Chambers/Ward/Hewitt Comprehensive Drainage Basin Plan, adopted by the City of Olympia and Thurston County. [Hydrology and water quality section (4) refers to a calibration report for Chambers Creek (Aqua Terra, 1994)]
Green Cove	1996	Thurston County		Model Calibration, using daily rainfall to observed flow and wetland levels	Aqua Terra Consultants. 1996. Green Cove Calibration Report, Thurston County, Washington, Final Results. Prepared for Thurston County Department of Water and Waste Management by D.C. Beyerlein and J.T. Brascher. Seattle, W A.
Black River	1996	Thurston County Water & Waste Management	HSPF	Existing and Future Flows, Basin Planning	Personal Communication, Joe Brascher, Clear Creek Solutions, February 8, 2013
Green Cove	1998	City of Olympia and Thurston County	HSPF	Analysis of current and future stream flow regime and wetland level fluctuations	Thurston County and City of Olympia, 1998. Green Cove Creek Comprehensive Drainage Basin Plan, Thurston County and City of Olympia.
Deschutes River Basin	2000	City of Olympia/FEMA	HSPF	Flood Study of Capitol Lake. HSPF model of the entire Deschutes River Basin calibrated to USGS stream gage data. Work performed by Clear Creek Solutions.	URS Group Inc., 2003. Capitol Lake Floodplain Analysis, Prepared for Federal Emergency Management Agency Region X.
Woodland Creek	~2000	Thurston County and Thurston Regional Planning Council	HSPF	Evaluation of flows to support fish habitat	Personal Communication, Joe Brascher, Clear Creek Solutions, February 8, 2013
Salmon Creek	2001	Thurston County	HSPF v 10	Existing and Future Flows, Basin Planning for flood management	URS Group Inc., 2001. Salmon Creek Basin HSPF Calibration Report, prepared for Thurston County.
Salmon Creek	2004	Thurston County	HSPF v 10	Existing and Future Flows, Basin Planning for flood management	Thurston County, 2004. Salmon Creek Comprehensive Drainage Basin Plan, Thurston County Water & Waste Management Storm and Surface Water Utility.
Moxlie-Indian Creeks	2008-2012	City of Olympia	EPA-SWMM5	Analysis of impacts of future sea level rise on flooding in the City of Olympia	Personal Communication, Joe Brascher, Clear Creek Solutions, February 8, 2013
Deschutes River, Capitol Lake, Budd Inlet	2012	Department of Ecology	QUAL2Kw, GEMSS (River, Lake, Estuarine Receiving Water Modeling)	Support of TMDL Development through river water quality modeling under existing and alternative riparian shading scenarios, Lake/estuary and Inlet quality modeling under existing and alternative loading, lake management, or lake replacement and estuary restoration alternatives.	Roberts, M. Ahmed, A., Pelletier, G., D. Osterberg. 2012. Deschutes River, Capitol Lake, and Budd Inlet Temperature, Fecal Coliform Bacteria, Dissolved Oxygen, pH, and Fine Sediment Total Maximum Daily Load Technical Report, Water Quality Study Findings. Department of Ecology Publication No. 12-03-008, Olympia, WA.

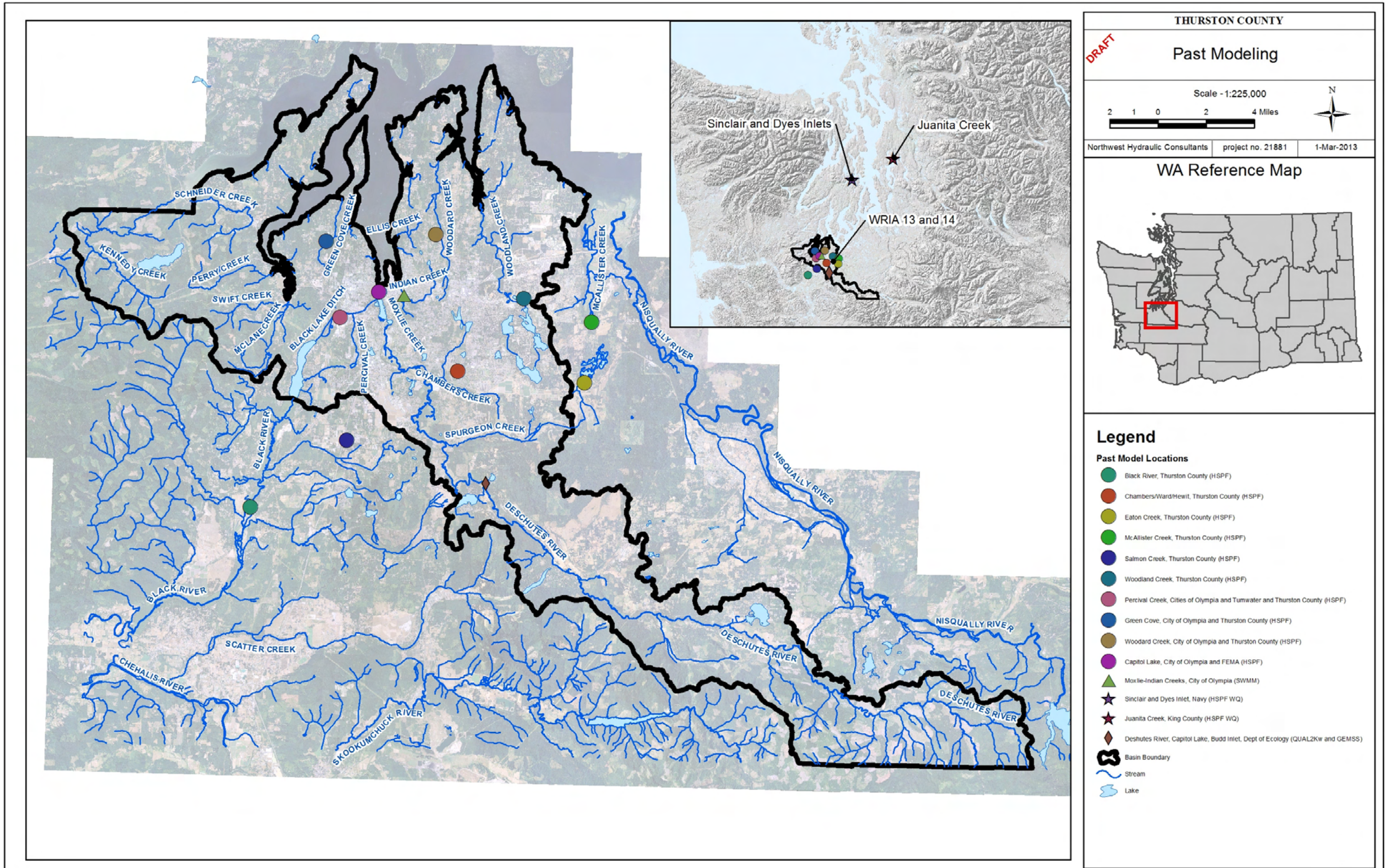

Figure A1: Locations of Past Thurston County Models

Appendix B

Quality Assurance Project Plan (QAPP)

March 13, 2013

Quality Assurance Project Plan

EPA "Science to Local Policy" Grant # PO-00J12401-1

Hydrologic Modeling to Support Watershed-Based Land-Use Planning

Prepared for:
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Revision 0 – March 13, 2013

______	______	David Hartley (signature)	April 24, 2013
Melissa Whitaker Project Officer EPA/Region 10	Date	David Hartley Project Leader Northwest Hydraulic Consultants	Date
______	______	John Imhoff (signature)	4/24/13
Ginna Grepo-Grove Approving Quality Assurance Official EPA/Region 10	Date	John Imhoff Quality Assurance Officer AQUA TERRA Consultants	Date
Cindy Wilson (signature)	4/25/13	______	______
Cindy Wilson Grant Manager Thurston County, WA	Date		Date

This quality assurance project plan (QAPP) has been prepared according to the guidance provided in EPA Requirements for Quality Assurance Project Plans (EPA QA/R-5, 2001) to ensure that environmental and related data collected, compiled, and/or generated for this project are complete, accurate, and provide the type, quantity, and quality required for their intended use. The QAPP is consistent with EPA Guidance for Quality Assurance Plans for Modeling (EPA QA/G-5M, 2002); EPA Manual 5360 A1 (EPA, 2000); and EPA Order 5360.1 A2 (EPA, 2000). Northwest Hydraulic Consultants and its subcontractors will conduct work in conformance with the procedures detailed in this QAPP.

This QAPP is one of the contractor requirements and is used to communicate to all interested parties the QA/QC procedures that will be followed to ensure that the quality objectives for the Science to Local Policy watershed modeling project are achieved throughout this project. The QAPP is a commitment by Northwest Hydraulic Consultants that must be approved by EPA Region 10.

Contents

Foreword: The information contained in this QAPP is presented in the order, and includes the heading topics, suggested by EPA's "Guidance for Quality Assurance Project Plans for Modeling (EPA QA/G-5M). For the sake of completeness all major headings from this guidance document have been included. In some cases, specifying the quality procedures needed to support certain project activities (i.e., heading topics) depends on efforts, decisions and deliverables that will developed as part of the project work. In other cases, in recognition of EPA's graded approach to QA/QC (see Section 5), a project does not require a particular type of QA/QC activity included among the heading topics.

1. Distribution List

Name and Title	Organization and Contact Information
Melissa Whitaker *Project Officer*	U.S. EPA, Region 10 (ETPA-087) 1200 Sixth Avenue, Suite 900 Seattle, WA 98101 Whitaker.Melissa@epa.gov 206-553-2119 (voice) 206-553-1775(fax)
Ginna Grepo-Grove *Approving Quality Assurance Official*	U.S. EPA, Region 10 (OEA-095) 1200 Sixth Ave, Suite 900 Seattle, WA 98101 grepo-grove.gina@epa.gov 206-553-1632 (voice) 206-553-0165 (fax)
David Hartley *Project Leader*	Northwest Hydraulic Consultants 16300 Christensen Road, Suite 350 Seattle, WA 98188-3422 dhartley@nhcweb.com 206-241-6000 (voice) 202-439-2420 (fax)
Cindy Wilson *Grant Manager*	Thurston County Planning Department 2000 Lakeridge Drive SW Olympia, WA 98502-6045 wilsonc@co.thurston.wa.us 360-754-3355 x5475 (voice) 360-754-2939(fax)
John Imhoff *Quality Assurance Officer*	AQUA TERRA Consultants 735 Main Street, P.O. Box 323 Ouray, CO 81427 jcimhoff@aquaterra.com 970-325-4283 (voice) 970-325-4328 (fax)

2. Project Organization

The key individuals for ensuring that the project meets all QA and QC objectives are Melissa Whitaker and Ginna Grepo-Grove from the EPA; David Hartley from Northwest Hydraulic Consultants and John Imhoff from AQUA TERRA Consultants.

2.1 U.S. EPA QA/QC Responsibilities

Melissa Whitaker (in consultation with the technical monitor) will provide the overall project oversight as the Project Officer. Ms. Whitakers's responsibilities include reviewing and approving the QAPP.

Ginna Grepo-Grove is the Quality Assurance Manager at Region 10. Her responsibilities include reviewing and approving the QAPP and ensuring that the QA/QC practices and requirements specific to Region 10 are achieved.

2.2 Northwest Hydraulic Consultants QA/QC Responsibilities

David Hartley is the Project Leader for Northwest Hydraulic Consultants, responsible for directing and coordinating technical work and interaction with the EPA Grant Manager. He will also track the budget, prepare monthly progress reports and perform administrative functions.

John Imhoff is the Quality Assurance Officer for AQUA TERRA and for the Project Team. Mr. Imhoff is the individual responsible for developing this QAPP. He will also be responsible for reviewing all QA/QC activities that the Northern Hydraulic Consultants Team performs for this project.

Figure 1 illustrates the project organizational chart and indicates both the technical and the QA lines of communication.

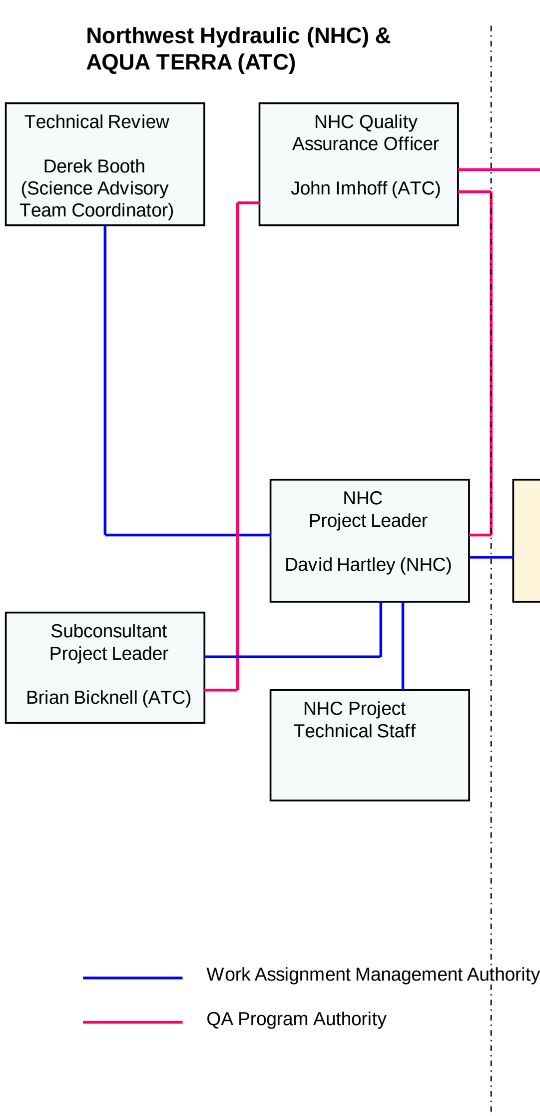

Figure 1. Project Organizational Chart

3. Problem Definition/Background

This Quality Assurance Project Plan (QAPP) has been prepared to address quality assurance issues related to tasks in **EPA Grant # PO-00J12401-1: Hydrologic Modeling to Support Watershed Based Land Use Planning**. Northwest Hydraulic Consultants will conduct work for this project in conformance with the procedures detailed in this QAPP.

In Summer 2010, EPA awarded more than $21 million to state, tribal and federal organizations for the restoration and protection of Puget Sound. A portion of this bulk award was dedicated to watershed management assistance program grants. One such grant was awarded to Thurston County and was entitled "Watershed Characterization – From Best Available Science to Local Policy Implementation." Through this grant Thurston County will coordinate with the cities of Lacey, Olympia, Tumwater, Rainier and Yelm to implement watershed-based land-use plans and regulations. This project will integrate stakeholders, the scientific community, and policy makers to work at a watershed scale to accommodate projected growth while protecting aquatic ecosystem processes. The grant from EPA supports planning in portions of Thurston County that drain to Puget Sound. This planning area includes approximately 279 square miles within the watersheds of the Deschutes River, Totten Inlet, Eld Inlet, Budd Inlet, Henderson Inlet, and the Nisqually Reach.

Thurston County contracted with Northwest Hydraulic Consultants (NHC) to provide hydrologic expertise in the development and application of hydrologic and water quality models to assess the impact of various land-use planning and management options on water quality and aquatic resources. This assessment is expected to be instrumental in the development of data and knowledge that informs land-use planning decisions based on best available science (BAS). The modeling will require calibration to existing watershed conditions using available quantity and quality data and will subsequently be used to simulate future flow and water quality conditions for alternative land-use and stormwater-management scenarios.

As part of the watershed modeling and analysis work, NHC will be responsible for incorporating relevant data and results of previous EPA-supported work by Thurston County on Watershed Characterization together with other sources of information on Thurston County stream basins. This QAPP describes the QA/QC procedures that NHC will use in providing the required technical support to Thurston County.

4.0 Project Description and Schedule

Tasks 1, 2 and 3 of NHC's Scope of Work entail the coordinating a Science Advisory Team (SAT); performing a watershed characterization review in coordination with Thurston County; and preparing this QAPP. Major technical activities that must be addressed in the QAPP include recommending basins for hydrologic modeling (Task 4); selecting a hydrological model for application (Task 5); developing the hydrological models for the sub-watersheds (Task 6); and evaluating alternative scenarios (Task 7). Each activity has inherent QA/QC requirements and requires management and QA/QC oversight by qualified personnel, and consequently each is discussed in a separate section below.

4.1 Recommending Basins for Hydrologic Modeling (Task 4)

The following discussion describes the approach that was used to identify, compare and rank candidate basins for modeling and evaluation. The study was designed with the flexibility to select a sub-set of basins (from among dozens) that provide the most favorable combination of analysis needs and available data. Fuller elaboration of the types of data that will be used to develop the model and the data acquisition procedures is provided in Section 9.

For this task NHC worked with Thurston County to recommend basins for hydrologic modeling. The recommendation was based on the results of an evaluation of a combination of data quality and availability and basin conditions such as presence of high value resources, potential for land-use change, existing or anticipated water quality problems, and other factors.

NHC evaluated the availability of water quality and quantity data information within the planning area and those sub-watersheds to determine the potential for development of hydrologic models. The planning area for this project will include the following locations:

- Deschutes (WRIA 13): 222 square miles in central Thurston County,
- Kennedy-Goldsborough (WRIA 14): 48 square miles in northwestern Thurston County, and
- Black Lake Basin (mapped by Washington Department of Ecology in WRIA 23): 8 square mile basin which formerly drained south to the Chehalis River via the Black River, but for many decades has drained via a constructed ditch (Black Lake Ditch) to Percival Creek and Capitol Lake (WRIA 13).

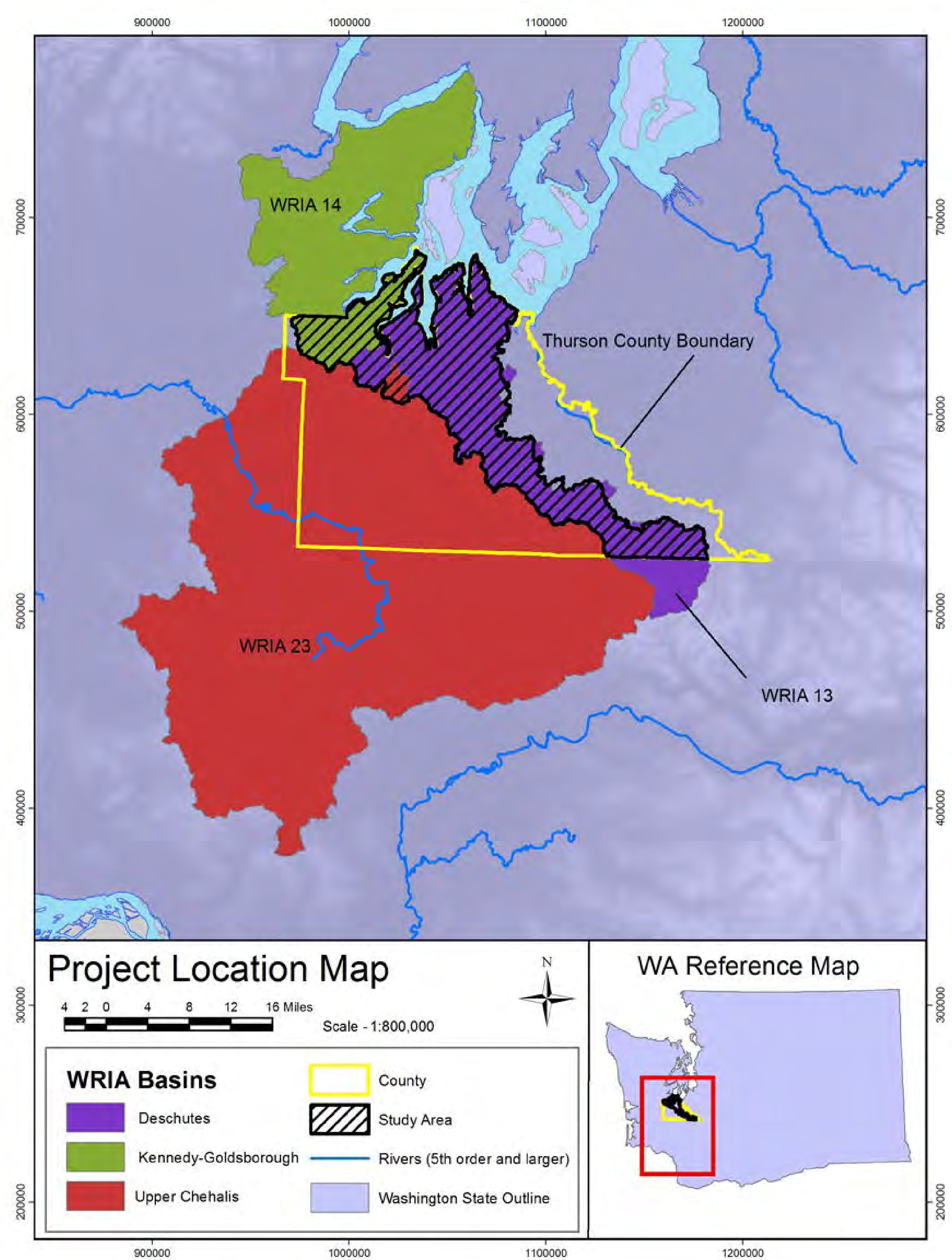

Figure 1: Project Location Map, Thurston County and WRIAs 13, 14 and 23

To date NHC has evaluated the availability of precipitation, flow and water quality data in Thurston County. These data were reviewed for their suitability for calibrating a hydrologic model of stream flow and water quality.

As shown in Table 1, relevant data in Thurston County are available from four different agencies: Thurston County, NOAA, the Department of Ecology and the USGS. Thurston County is the primary source of precipitation data with 17 gages in the county. Currently the USGS and the Ecology's Environmental Assessment Program (http://www.ecy.wa.gov/programs/eap/index.html) are only collecting continuous flow and water quality data on large rivers such as the Deschutes. Although the USGS has collected continuous flow for creeks and streams in the past, the Thurston County monitoring program is the only source of recent continuous flow data at these locations. Long-term water quality data on creeks and streams is currently only being collected by Thurston County. Data from a large number of shorter term studies are also available from the Ecology Environment Information Management (EIM) database (http://www.ecy.wa.gov/eim/). These data may be useful to supplement the Thurston County water quality data.

Table 1 Precipitation, Flow, and Water Quality Data Available in Thurston County

Data Type	Source	Period of Record	Comment
Precipitation Data	Thurston County	1988 - Current	Limited information available regarding data prior to ~2000
	NOAA	1949 - Current	Olympia airport gage is in the Study Area
Continuous Flow Data	Thurston County	1980's - Current	Currently operating gages also collect temperature data. Quality\Availability of data prior to 2000 is difficult to ascertain.
	Ecology Environmental Assessment Program	2002 - 2005	Gages located on the Deschutes River.
	USGS	1949 - Current	More recent and current gages are primarily located on the Deschutes River.
Water Quality Data	Thurston County	1971 - Current	Includes Temperature, Conductivity, pH, DO, Turbidity, Fecal Coliform, TP, Nitrite/Nitrate, Ammonia, plus additional parameters for lakes.

	Ecology Environmental Assessment Program	2002 - 2012	Gages located on the Deschutes River. Includes Temperature, Conductivity, pH, DO, Turbidity, TSS, Fecal Coliform, SRP, TP, Ammonia, TN, Zinc, Chromium and others
	Ecology EIM	1973 - Current	Typically data from shorter term studies. Includes hundreds of parameters that vary by site.
	USGS	1968 - 2007	Very limited data collected after 1999. Includes hundreds of parameters that vary by site.

Since the specific need is for data that can be used to calibrate hydrologic and water quality models within the project area comprised of WRIAs 13 and 14, a data review was carried out for each basin in the draft Basin Evaluation and Management Strategies for Thurston County from October 2012 (TC and TRPC, October, 2012). Ideal basins for model calibration would have a recent period of several years of contemporaneous precipitation, flow, and water quality data.

The first step in the review process was to rate each basin based on the distance between the basin centroid and the nearest precipitation gage with at least five years of data collected from 2005 to the present. Basin ratings using this criterion are shown in Table 2. While some of the basins have better precipitation data coverage than others, they all have sufficiently proximate precipitation sites with long enough records to support model calibration.

Table 2 Precipitation Gage Basin Rating

Basin Rating	Distance of Basin Centroid from
Excellent	≤ 1 mile
Good	1 < distance ≤ 2 mile
Fair	distance > 2 mile

Next, basins were selected that had a minimum of two years of continuous flow data collected from 2005 to the present that overlapped with the period of precipitation record from the closest rain gage.

The final step in this process was to select basins that had a minimum of two years of contemporaneous precipitation, flow **and** water quality data. Ten basins were identified that satisfied this requirement as well (see QAPP Appendix A).

In addition to these 10 basins, there were seven additional basins that had precipitation and water quality data but less than two years of flow data. While basins with no flow record preclude direct calibration of a hydrologic model, an acceptable model might be developed if parameter values could be reasonably transferred from a nearby calibrated basin with similar geologic and land cover characteristics. These basins were retained on the candidate list as a contingency (see QAPP Appendix B).

All seventeen basins with water quality records of greater than two years length were sorted and grouped into tiers in descending order of data richness. The resulting matrix is included as Appendix C of this QAPP and also includes basic land-cover information (% forest cover, total impervious area, effective impervious area). This information is sourced from the draft Basin Evaluation and Management Strategies for Thurston County, WRIAs 13 and 14 Report (TC and TRPC, October, 2012) and the Estimates of Current and Future Impervious Report (TC and TRPC, March, 2011). The results and discussion for Task 4 are provided in a technical memorandum (NHC, 2013a).

Together with the County, NHC will develop a matrix of criteria to rank the 10 candidate basins and develop a recommendation of 3-5 candidate basins for modeling. NHC will document the data review and ranking procedure in a memorandum, which will be appended to the County's Baseline Conditions Report (aka Basin Evaluation and Management Strategies for Thurston County).

4.2 Selecting a Hydrological Model for Application (Task 5)

The following discussion describes the evolution of the approach that was used to identify and recommend the model that will be used to perform the simulations that are required for this project.

At the onset of the project, it was anticipated that a targeted, high-level review of screening, planning, and process watershed water quality and hydrologic models would be undertaken by the team. A decision matrix approach was proposed for use to judge model categories and specific models. The decision matrix would be based on the key questions that the County wishes to address, data assessment (as described in Section 4.1) and the following desired model capabilities:

1. Simulation of runoff quantity and quality at multiple landscape scales;
2. Ability to interface with GIS data to represent existing and proposed land use scenarios;
3. Ability to be calibrated to what data are available within each sub-watershed;
4. Ability to incorporate previous HSPF modeling efforts;
5. Ability to model water quality/quantity improvement resulting from a) changes in land use density or development regulations, b) preservation/restoration of wetland and riparian areas, and installation of stormwater best management practices; and
6. Usability by Thurston County personnel at project completion for additional scenario modeling and to allow for future improvements based on new data.

As the project progressed, Thurston County perceived an opportunity to leverage and expand the Task 4 data evaluation effort as a more straightforward and efficient means of arriving at a conclusion concerning the best model to use for this project's simulations. The approach was to assemble and evaluate past regional experience and model applications for hydrology and water quality and use the results as a primary factor in model selection. This effort was summarized in a draft technical memorandum (NHC, 2013b) that concluded with the recommendation of EPA's Hydrological Simulation Program – FORTRAN (HSPF) (Bicknell et al., 2011) as the model of choice. The memorandum concluded:

> In recent decades, HSPF has been the model of choice in basin planning and stormwater-related applications within western Washington and specifically within the project area in Thurston County. Almost all of these applications have applied HSPF water runoff and routing components, but have excluded water quality components. Notwithstanding, the availability of existing basin HSPF models within the project area, regional familiarity with appropriate HSPF parameter ranges, the recent successful application of the model by King County, coupled with EPA's historic support for HSPF as a water quality model and TMDL development tool, all suggest that this model is the logical choice for investigating land-use practice impacts on flow and water quality in the current project.

The draft memorandum will be submitted to Thurston County for consideration and comment, and will be followed up with a Final Memorandum.

4.3 Developing Hydrological Models for Sub-watersheds (Task 6)

Once the memorandum that addresses previous model applications and model selection has been reviewed and accepted by the County, model development will be undertaken for the selected basins from Task 5 using spatial and time series data that have been assembled and reviewed in Task 4. Those previous tasks will determine not only the overall model selection but also the modeling strategy for the selected model with regard to what model options will be activated and which pollutants of concern will be simulated. Regardless of model selection, GIS overlay analysis will be necessary to represent basin surficial geology and topography, as well as hydrography and land-use/land-cover conditions that are sufficiently contemporaneous or consistent with available discharge, water level, and pollutant concentration data. This will enable a calibration of the model for both flow and a selected set of pollutants that will have been determined primarily through the data assessment activity from Task 4. The primary outcome of Task 5 will be documentation of the "goodness of fit" between the model and the available flow and pollutant data records.

To supplement the County's prior modeling results, NHC will access and compile existing calibration results from non-County sources that are not already in the County's possession to the extent that they are readily available at no cost; however, NHC will not purchase data or perform any field measurements of water quantity, quality, or meteorological data as part of this project scope of work.

A memorandum will be prepared that describes the model calibration results.

4.4 Evaluating Alternative Scenarios (Task 7)

NHC will compare a reference condition commensurate with the pre-Euroamerican land cover to existing and projected future land-use conditions with different management options. The County will work with NHC to formulate a list of scenarios. The County will provide estimates of future impervious area and land use under each scenario as GIS files. Five modeling scenarios are anticipated as follows:

- **Scenario A. Existing/Calibration Conditions (2005-2012)** – this is the approximate basin condition with regard land cover, surface flow routing, and stormwater management that has been in place during the selected model calibration period(s) for which flow, meteorological, and water quality data are available.

- **Scenario B. Pre-Developed Condition (pre-Euroamerican)** – assumes natural forest, prairie, and wetland conditions existing prior to Euroamerican settlement.

- **Scenarios C, D, and E. Future Conditions (2040)** – up to three future conditions will be modeled reflecting different combinations of future land-development patterns and development regulations that may potentially be in place by 2040. One of these runs is likely to represent full buildout under existing zoning and development regulations.

NHC will undertake hydrologic modeling for each of the alternative scenarios. The modeling will predict the future pollutant loading of the selected water quality and water quantity parameters for each of these scenarios.

Assuming that HSPF is used for modeling, input and output data for this task will be managed using a WDM database format. For purposes of comparison, NHC team will propose a series of flow and water quality metrics (peak flow frequency, minimum base flow, total annual pollutant load, acute concentration, etc.) to the County and designated stakeholders for review and approval. These will be used to compare outcomes from modeled scenarios. A memorandum will be prepared that describes the scenarios and compares the results of scenario modeling.

4.5 Project Schedule

Table 3 provides a tentative list of completion dates for the tasks included in NHC's Scope of Work.

Table 3. Hydrologic Services for Watershed Based Land Use Planning

Current Estimated Project Schedule

Task	October-12	November-12	December-12	January-13	February-13	March-13	April-13	May-13	June-13	July-13	August-13	September-13	October-13	November-13	December-13
Task 1 - Assemble and Coordinate Science Team	■	■	■	■	■	■	■	■	■	■	■	■	■		
Task 2 Grant 1 Watershed Characterization Review and Coordination	■	■	■	■	■										
Task 3 - Quality Assurance Project Plan		■	■	■	■	■	■								
Task 4 - Needs Assessment and Sub-Watershed Selection	■	■	■	■	■	■	■								
Task 5 - Hydrologic Model Selection			■	■											
Task 6 - Hydrologic Model Creation							■	■	■	■					
Task 7 - Alternative Scenarios							■	■	■						
Task 8 - Project Report and Data Transfer									■	■	■	■	■	■	
Task 9 - Project Management and Stakeholder Meetings	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■

5. Quality Objectives and Criteria for Model Inputs/Outputs

The Quality Assurance/Quality Control (QA/QC) goals for this project are:

- Objectivity—all work should be based on a methodology and utilize a set of evaluation criteria that can be explicitly stated and applied.
- Thoroughness—all elements of the study should be carried out and documented in a thorough manner.
- Consistency—all work should be performed and documented in a consistent manner.

- Transparency—the documentation will make clear the sources of the data used, the assumptions used in the modeling, and the results obtained.

EPA defines a *graded approach* as “the process of basing the level of application of managerial controls applied to an item or work according to the intended use of the results and degree of confidence needed in the quality of the results” (EPA, 1998). This is an important element of the Quality System because it allows the application of quality assurance and quality control activities to be adapted to meet the rigor needed by the project at hand. Models that provide an initial “ballpark” estimate or non-regulatory priorities, for example, would not require the same level of quality assurance and planning as models that will be used to set regulatory requirements. There are no explicit categorizations or other specific guidelines for applying the graded approach, but USEPA (2002) provides general information and examples.

In applying the graded approach, two aspects are important for defining the level of QA effort that a modeling project needs: intended use of the model and the project scope and magnitude.

The intended use of the model is a determining factor in the level of QA needed because it is an indication of the seriousness of the potential consequences or impacts that might occur due to quality problems. For example, higher standards would be set for projects that involve potentially large consequences, such as Congressional testimony, development of new laws and regulations, or the support of litigation. More modest levels of defensibility and rigor would be acceptable for data used for technology assessment or “proof of principle,” where no litigation or regulatory action are expected. The objective of modeling for this project is to support decision making related to basin management, stream protection, and restoration measures which may include local zoning and land use regulation. EPA’s QA/QC guidance (2002) suggests that an appropriate level of quality assurance for model application of this type can be achieved by:

- Use of accepted data gathering methods,
- Use of widely accepted models, and
- Audits and/or data reviews.

The data acquisition methods and data that will be used for this study meet the first and third requirements (see Section 9.1), and the use of USEPA’s HSPF model satisfies the second requirement.

Other aspects of the QA effort can be established by considering the scope and magnitude of the project. The scope of the model development and application determines the complexity of the project; more complex models need more QA effort. The HSPF model is relatively complex. However, the Project Team has considerable experience in applying the model, and the study area is rich in both monitored data and model parameter values that have been developed for the many localized HSPF applications. Model applications performed by experienced personnel and supported by ample data have great promise for success, both from a technical and a

QA/QC perspective, provided that the quality procedures that are established by the QAPP are adhered to.

The magnitude of the project defines the resources at risk if quality problems lead to rework and delays. Since multiple sub-watersheds will be modeled, in the unlikely event of a significant quality problem occurring, it is likely that only a portion of the study work would be affected. We do not believe that resource risk is such that the level of QA/QC expended for this project warrants elevation from the level that EPA suggests for typical technology assessments and “proof of principle” modeling projects.

USEPA (2000, 2002) also emphasizes a systematic planning process to determine the type and quality of output needed from modeling projects. This begins with a Modeling Needs and Requirements Analysis, which includes the following components:

- Assess the need(s) of the modeling project
- Define the purpose and objectives of the model and the model output specifications
- Define the quality objectives to be associated with model outputs

The first item (needs assessment) is defined by the grant’s scope of work. In essence, simulation models are needed to estimate hydrologic and water quality impacts of change related to land use, specifically urbanization. As such, the ability of the models to represent the relative impact of various land use changes is of greatest importance, while obtaining a precise estimate of flow or water quality time series is of less direct interest.

The quality objectives for the model follow directly from the purposes and objectives. In general, the modeling effort needs to be designed to achieve an appropriate level of accuracy and certainty in answering the principal study question. This process takes into account the following elements:

- The accuracy and precision needed for the model to predict a given quantities at the application sites of interest to satisfy study questions
- The appropriate criteria for making a determination of whether the models are accurate and precise enough on the basis of past general experience combined with site-specific knowledge and completeness of the conceptual models
- How the appropriate criteria would be used to determine whether model outputs achieve the needed quality

Where a model achieves good fit to monitored data it can generally assume a strong role in evaluating management decisions that result from impact analysis. Conversely, where a model achieves only a fair or poor fit it should assume a much less prominent role in the overall weight-of-evidence evaluation of management options. Model performance objectives will be discussed in more detail in Section 8.1.

6. Special Training Requirements/Certification

Northwestern Hydraulic Consultant’s President is responsible for ensuring that all staff receive initial and periodic refresher training on the company’s quality system and specialized quality-related training, as appropriate. (Note: Such training is provided by a Quality Assurance Officer with the appropriate technical specialties.) The President maintains documentation of staff training, as well as files on all personnel which contain any relevant qualifications, certifications, accreditations, and licenses.

The Project Leader (PL) will be responsible for identifying the specific skills needed on this project and for assigning staff with appropriate training, skills, and certifications. If special additional training requirements are identified, the PL will be responsible for arranging for that training to take place prior to the start of the relevant task. (Currently, we do not anticipate the need for staff training in order to perform this project, subject to the outcome of the model selection effort.)

This project will be performed by staff having a strong technical background and extensive experience in environmental science, engineering and modeling. The Project Team will include experts for the models that are selected (see Section 4.2) for performing the Thurston County modeling. The staff devoted to this project will be experienced in the issues and requirements involved in performing hydrologic and water quality modeling to assess the impacts of land use development.

7. Documentation and Records

A **document** is any written or pictorial information describing, defining, specifying, reporting, or certifying activities, requirements, procedures, or results. A **record** is a document that furnishes objective evidence of the items or activities and that has been verified and authenticated as technically complete and correct. Records may include photographs, drawings, magnetic tape, and other data-recording material. Generally speaking, *documents* comprise efforts that are complete and organized to describe the results of a significant element of the project effort, whereas *records* are more specific and limited data elements that often lack contextual explanation. Recognizing this distinction, products considered to be records will be archived at NHC unless specifically requested by Thurston County or EPA Region 10. Products considered to be documents will be delivered to Thurston County and/or EPA Region 10 to be included in EPA's project archive.

The NHC Project Leader, Dr. David Hartley, will be responsible for ensuring that all project-related documents and records are managed in accordance with the procedures described below. Project-specific documents or records will be clearly identified by:

- Title
- Author or responsible person
- Date
- Report or document number (if applicable)
- Project-related information (i.e., contract number, project number, task or sub-task number, if applicable, and project code)

Documents and records that will be collected and archived for the Thurston County modeling study include, but are not limited to:

Documents

- Work plan
- Project quality plans (e.g., the QAPP)

- Significant interim drafts and all review drafts and final drafts of all established deliverables (see Section 17 of this QAPP)
- Internal working papers, e.g. technical memos, spreadsheet analyses, GIS documents
- Peer review documents (if developed)

Records

- Interview notes
- Working notes and calculations
- Assessment results and findings
- Calibration data
- Data usability results
- Field notes
- Other records required for statutory or contract-specific compliance

All documents will be subject to review by the NHC PL to ensure their conformance with technical requirements and quality system requirements. Documents will be released to Thurston County and EPA Region 10 following authorization by the PL and, when required, the Quality Assurance Officer (QAO). The PL shall ensure that records are developed, authenticated, and maintained to reflect the achievement of quality goals. Through adoption of these document-specific quality control procedures, NHC intends to ensure that records and documents reflect completed work, in keeping with specifications of Section 3.6 of EPA QA/R-2.

Throughout the course of the project, the project-specific indexing and filing system will meet the following minimum performance specifications:

- All documents and records will be physically or electronically retrievable.
- Primary copies of all physical documents and records will be stored in filing cabinets or other appropriate storage space on NHC's premises. Any backup copies of physical documents and records will be stored separately.
- Any documents subject to confidential business information (CBI) restrictions will be stored in strict accordance with NHC's CBI plan.

All documents and records will be listed and identified with respect to retention schedules. All documents in the first list above (e.g., work plans; QAPPs) are subject to an automatic disposition schedule that requires their retention for 10 years, unless a longer time is required by the particular grant under which they were created or is required for other purposes. Within one month of their creation, all other documents and records will be classified for retention/disposition.

Upon completion of this project, a complete set of all the documents and records will be appropriately filed for long-term storage.

If any change(s) in this QAPP are required during the study, a memo will be sent to each person on the distribution list describing the change(s), following approval by the appropriate persons. The memos will be attached to the QAPP. QA/QC activities, including periodic inspections that are made by the QA/QC officer to ensure that required procedures are being followed, will be logged and described in the final report. Deviations from planned procedures will be documented and corrective measures implemented. The report will also include a description of the types of project records that were maintained and the project documents that were prepared.

8. Model Calibration

Model calibration is the process of adjusting model inputs within acceptable limits until the resulting predictions give good correlation with observed data. Commonly, calibration begins with the best estimates for model input based on measurements and subsequent data analysis. Results from initial simulations are then used to improve the concepts of the system or to modify the values of the model input parameters. Model calibration and validation should strive to minimize differences between model predictions and observed measurement data. Hence, the availability of abundant observed data is an essential element of successful calibration.

Likewise, the experience and judgment of the modelers will be a significant factor in calibrating the model(s) accurately and efficiently. The NHC Project Leader will direct the model calibration efforts, and will be assisted by competent modelers that have significant experience with the model(s) which they are applying. Modeling procedures and model results will be routinely reviewed by senior-level modelers at NHC, and may be subjected to additional review by Thurston County and/or EPA Region 10. Results will also be made available to interested stakeholders.

Further, the model should meet pre-specified quantitative measures of accuracy to establish its acceptability in answering the principal study questions related to the hydrologic and water quality impacts of land development.

The model calibration process proceeds through both qualitative and quantitative analyses. Qualitative measures of calibration progress are commonly based on the following:

- Graphical time-series plots of observed and predicted data
- Graphical transect plots of observed and predicted data at a given time interval
- Scatter plots of observed versus predicted values in which the deviation of points from a 45 degree straight line gives a sense of fit
- Tabulation of measured and predicted values and their deviations

After the model set up has been achieved, the Project Team will perform model calibration and validation. The watershed models will be calibrated to the best available data, including literature values and interpolated or extrapolated values using existing field data. If multiple data sets are available, an appropriate time period and corresponding data set will be chosen on the basis of factors characterizing the data set, such as corresponding weather conditions, amount of data, and temporal and spatial variability of data.

A model is considered calibrated when it reproduces data within an acceptable level of accuracy, as described in Section 8.1 and itemized for watershed models in Table 4 (quantitative measures). The target level of accuracy for this project will be that which corresponds in Table 4 to ‘Good’ results. Accuracy targets are highly dependent on the amount and quality of available data, and consequently the targets will be finalized after data assessment has been completed.

A set of parameters used in a calibrated model might not accurately represent field values, and the calibrated parameters might not represent the system under a different set of boundary conditions or hydrologic stresses. Therefore, a model validation period helps establish greater confidence in the calibration and the predictive capabilities of the model. A site-specific model is considered validated if its accuracy and predictive capability have been proven to be within acceptable limits of error independently of the calibration data.

Table 4. General percent error calibration/validation targets for watershed models (applicable to monthly, annual, and cumulative values) (Donigian 2000).

	% Difference Between Simulated and Recorded Values		
	Very Good	Good	Fair
Hydrology/Flow	< 10	10 - 15	15 - 25
Sediment	< 20	20 - 30	30 - 45
Water Temperature	< 7	8 – 12	13 - 18
Water Quality/Nutrients	< 15	15 - 25	25 - 35

The set of calibration targets that are presented in Table 4 are applicable to the watershed model (i.e., HSPF) that has been recommended for use in this study.

In general, model validation is performed using a data set separate from the calibration data. If only a single time series is available, the series may be split into two subseries, one for calibration and another for validation. If the model parameters are changed during the validation, this exercise becomes a second calibration, and the first calibration needs to be repeated to account for any changes. Representative stations will be used to guide parameter adjustment to get an accurate representation of the conditions of the individual subwatersheds and streams. The calibration and validation process will be documented for inclusion in the technical reports. In this project, model validation will be performed for hydrology/flow if there are more than two years of good quality contemporaneous precipitation and stream flow data. Validation of sediment, temperature, and other water quality constituents may be constrained by the availability and quality of the data for specific constituents.

8.1 Specified Performance and Acceptance Criteria

Calibration and validation will be achieved by considering qualitative *and* quantitative measures, involving both graphical comparisons and statistical tests. For flow simulations where continuous records are available, all these techniques will be employed, and the same comparisons will be performed, during both the calibration and validation phases. Comparisons of values for simulated and observed state variables will be performed for daily, monthly, and annual values, in addition to flow-frequency duration assessments. Statistical procedures will include error statistics, correlation and model-fit efficiency coefficients, and goodness-of-fit tests, as appropriate. Figure 2 provides value ranges for both correlation coefficients (R) and coefficient of determination (R^2) for assessing model performance for both daily and monthly flows. The figure shows the range of values that may be appropriate for judging how well the model is performing based on the daily and monthly simulation results. As shown, the ranges for daily values are lower to reflect the difficulties in exactly duplicating the timing of flows, given the uncertainties in the timing of model inputs, mainly precipitation.

Figure 2. R and R^2 value ranges for model performance (Donigian, 2002).

For water quality constituents, model performance will be based primarily on visual and graphical presentations as the frequency of observed data will likely be inadequate for accurate statistical measures.

Given the uncertain state-of-the-art in model performance criteria, the inherent errors in input and observed data, and the approximate nature of model formulations, **absolute** criteria (i.e. ± “X” physical units) for watershed model acceptance or rejection are not generally considered appropriate by most modeling professionals.

9. Data Acquisition Requirements

Data quality objectives (DQOs) are qualitative and quantitative statements that clarify the intended use of the data, define the type of data needed to support the decision, identify the conditions under which the data should be collected, and specify tolerable limits on the probability of making a decision error due to uncertainty in the data (if applicable). Data users develop DQOs to specify the data quality needed to support specific decisions.

The following DQO for streamflow is an example of one that will be adopted for this study:

> We will primarily use flow data identified with a 'Good' rating by the USGS, which corresponds to 95% of daily values being within 10%. If data of lesser quality are used, due to sparse coverage, data limitations, etc., they will be identified and the consequences of their use will be explicated.

Definition of explicit, achievable DQOs is dependent upon the abundance and types of relevant data. A Model Simulation Plan will include a data assessment which will enable refinement of the DQOs. DQOs for data types other than streamflow will be established in that plan to guide the modeling efforts.

Data of known and documented quality are essential to the success of any water quality modeling study, which in turn generates data to use in establishing watershed management strategies. The Project Team will accomplish model setup, calibration, and validation for the project governed by this QAPP using data available from previous monitoring activities and studies. The QA process for this project consists of using appropriate data, data analysis procedures, modeling methodology and technology, administrative procedures, and auditing. To a large extent, the quality of a modeling study is determined by the expertise of the modeling and quality assessment teams. NHC will address quality objectives and criteria for input/output data in the context of: (1) evaluating the quality of the data used and (2) assessing the results of the model application.

The quality of an environmental analysis program is achieved by means of three steps: (1) establishing scientific assessment quality objectives, (2) evaluating program design for whether the objectives can be met, and (3) establishing assessment and measurement quality objectives that can be used to evaluate the appropriateness of the methods used in the program. The quality of a data set is a measure of the types and amount of error associated with the data.

Sections 5 and 9 of this QAPP describe DQOs and criteria for model inputs and outputs for this project, written in accordance with *EPA's Guidance for the Data Quality Objectives Process* (EPA QA/G-4) (USEPA, 2000).

9.1 Review of Secondary Data

Secondary data will be used to test and verify the correctness and accuracy of the models. Secondary data are data collected by EPA for another purpose, or collected by an organization or organizations not under the direction of EPA, that are useful to support the development of the model applications.

Data sources for precipitation, stream flow and water quality have been previously described in Section 4.1. Of the originating organization two are Federal (NOAA, USGS), and the QA/QC of federal data sources is traditionally accepted without review. Another source, the Washington Department of Ecology's "Ecology Environmental Assessment Program" has stringent QA/QC requirements as described in the Program's QA protocols (http://www.ecy.wa.gov/programs/eap/quality.html). Likewise, Thurston County data collection conforms to well-established SOP protocols and QA/QC guidelines (TC, 2012; TC, 2009a; TC, 2009b). Different data sets in Ecology's EIM database come from different sources (including volunteers) and we will evaluate the source of each data set before considering it for use.

To supplement the precipitation, stream flow and water quality noted above, NHC's client (Thurston County) will provide the following GIS data layers:

- County boundaries,
- City boundaries,
- UGA boundaries,
- WRIA boundaries,
- Sub-watershed boundaries,
- Watershed characterization group boundaries (coastal, lowland, or mountainous),
- Hydrology,
- Presence of fish or suitable habitat by stream,
- Culverts,
- Soils,
- Wetlands,
- Floodplains and high ground water areas,
- LiDAR,
- Land cover (2006)
- Impervious surfaces (2006),
- Future impervious surface estimates for 2030, and

- Color aerial photos

The quality of a data set is a measure of the type and amount of error associated with the data. Sources of error are commonly grouped into two categories: sampling error and measurement error: These kinds of errors, as well as processing errors, can affect the accuracy and interpretation of results. For various reasons it is possible that not all secondary data evaluated for potential use in developing, calibrating and testing the models will be judged acceptable for uses to support this project. The data acquisition procedures that will be followed for this project include database review and management practices that will reduce sources of error and uncertainty in the use of the data. NHC will determine the factors to be evaluated to assess whether the data provided by a secondary source are acceptable for use in developing, calibrating or testing the models for this project. The Project Team will use the following general approach to evaluate the quality of secondary data to support the watershed modeling:

- Maintain a continuing dialog with the EPA and Thurston County Grant Managers on technical data issues
- Establish appropriate data quality targets while recognizing the limits of the data
- Document and present the decisions and results

Currently, it is anticipated that most data used in the project will have been collected or developed by a variety of sources commonly used for watershed model development. Often these data will be available in electronic format and will include *metadata* that will be valuable for assessing the QA/QC imposed on the data collection and processing. In cases where multiple sources of data are available, the Project Team will use the best available data with the highest quality. Data of unknown quality will be incorporated into the model only if approved by the Thurston County, and the data's inclusion status will be documented. If there is no information available regarding the data, the data will either not be used or qualified with, "The quality of this specific secondary data set used in developing the watershed model could not be determined."

The Project Team may retrieve secondary data from its in-house databases by downloading from high-quality federal data sources. Information from studies and surveys found to be of unacceptable quality will not be used to supplement model development. The Simulation Plan will describe the data used for model development, the time period during which the data were collected, and the quality requirements of the data, as appropriate.

The data quality objectives for this project will encompass aspects of both laboratory analytical results obtained as secondary data and database management to reduce sources of errors and uncertainty in the use of the data. Data commonly required for populating a database for use in calibrating watershed models are listed in Table 3. The data listed in the table are exemplary, and as such are not intended to be all-inclusive.

Whenever possible, the Project Team will download secondary data electronically from various sources to reduce the possibility of introducing errors during data entry. Secondary data will be organized into a standard model application database. The Project Team will use a screening process to scan through the database and flag data that are outside typical ranges for the site for a given parameter; the Project Team will not use values outside typical ranges to develop model calibration data sets or model kinetic parameters. For data that will be used in the models, the source of the data, the time period for which the data were collected, and an indication of how the data will be used will be included in the Model Simulation Plan. The Model

Simulation Plan will document the specific data planned for use in both model setup and calibration/validation efforts, since these aspects of the model application cannot be detailed until after model selection. As the modeling effort proceeds, project reporting will include identification of the data sources used in each step of the model application process, e.g., the GIS coverages used in model setup, the meteorologic data used to drive the model, the point source loading data used as model input, and the observed data used in model calibration and validation.

9.2 Data Sources Performance and Acceptance Criteria

Data to be used as input to the modeling effort will be judged acceptable for their intended use if they meet acceptance criteria. As described above, the Project Team, in consultation with the EPA and Thurston County Grant Managers, will establish the factors that will be considered to determine whether the data provided in secondary sources are acceptable for use in developing, calibrating, or testing the models for this project. Acceptance criteria that will be used for this project will include data reasonableness, completeness, representativeness, and comparability.

- Data reasonableness: Data sets will be checked for reasonableness. For example, flow gaging data obtained from USGS have undergone quality review for reasonableness. This is not always the case for water quality data, and accordingly graphical methods will be used to evaluate potential anomalous entries that may represent data entry or analytical errors. In addition, all dates will be checked through queries to ensure that no mistyped dates and corresponding information are loaded into the models without clarification from the agency from which the data were collected.
- Data completeness: Data sets will be checked to determine if any data are missing. In any complex model study, it is inevitable that there will be some data gaps. These data gaps and the assumptions used in filling the gaps will be documented for inclusion in the technical reports.
- Data representativeness: Data sets will be checked for representativeness of geospatial data. Sampling station data will be checked through queries and mapping in an effort to avoid loading mistyped geospatial data (e.g., locations outside the watershed) and corresponding information into the models without clarification from the agency from which the data were collected. In addition, acceptance criteria will be collected from available QAPPs, sampling and analysis plans, standard operating procedures (SOPs), laboratory reports, and other correspondence for a given source of measurement data. The data assessment and quality guidelines associated with a given type of measurement will be developed from these sources and included in the Simulation Plan (see Section 5.3). The data will be reviewed and compared with the performance and acceptance criteria in this QAPP. Data not meeting the acceptance criteria requirements will be rejected and their status documented, as deemed appropriate by the Thurston and/or the NHC PL.
- Data comparability: Data sets will be checked with respect to variables of interest, commonality of units of measurement, and similarity in analytical and QA procedures. The Project Team will ensure additional comparability of data by similarity in geographic, seasonal, and sampling method characteristics.

Table 3. Secondary environmental data to be assembled for watershed and water quality modeling in the Thurston County model applications.

Data type	Example measurement endpoint(s) or units
Geographic or location information (typically in GIS format)	
Hydrologic unit code (HUC) boundaries	shapefile map
Hydrography	shapefile map
Land use	shapefile map, acres
Topography	digital elevation model, meters
Population distributions	shapefile map, number
Soils (including soil characteristics)	shapefile map, hydrologic group, etc.
Water quality and biological monitoring statio	latitude and longitude, decimal degrees
Permitted point source discharge locations	latitude and longitude, decimal degrees
Dam locations	latitude and longitude, decimal degrees
Flow	
Historical record (daily)	cfs
Peak flows (daily maximum)	cfs
Storm hydrographs (hourly or less)	cfs
Meteorological data	
Rainfall	inches
Temperature	°C
Potential evapotranspiration	inches
Wind speed	miles per hour
Dew point	°C
Humidity	percent or grams per cubic meter
Cloud cover	percent
Solar radiation	watts per square meter
Water quality (surface water, ground water)	
Total suspended sediment (TSS)	mg/L
Nutrient concentrations	mg/L
Permit limits	flow, cfs and concentration, mg/L, µg/L
Additional anecdotal information as appropriate	

10. Data Management

The anticipated data management mechanism for tabular data for this project is the USGS' Watershed Database Management (WDM) file. This product has been used effectively for decades to provide extensive data base management capabilities for HSPF simulations. The data management mechanism for the GIS data for this project is a geodatabase that is compatible with ArcGIS v 10.X

10.1 Inherited QA for Source Data

Metadata is used to describe the pedigree of the source data. As spatial data is re-projected or otherwise updated, additions will be made to the metadata.

10.2 Data Manipulation

Two types of data will be integrated to support the Thurston County project: GIS data and timeseries data. Both types of data change format as they are loaded into a project, and thus are subject to possible errors. New data types are also subject to these types of errors. Considerations involved in data manipulation are described below and include:

- Preventing errors
- Detecting errors
- Correcting errors

Preventing Errors in Manipulation

Errors in data manipulation are minimized by automating the data manipulation processes. GIS data are projected automatically using a standard projection library. When a new type of GIS data is added to the project, we will automatically change the projection of that data to match the projection of the project (State Plane South). When timeseries data are added, they will be imported into the standard WDM database formats automatically. Having these processes occur automatically minimizes the mistakes that could occur during this process.

Detecting Errors in Manipulation

When a new dataset is processed for adding to the project data management mechanisms, the data at the end of the process will be checked versus the data at the beginning of the process to ensure accuracy. GIS and timeseries data will be checked visually. If the new dataset is very large, the manipulation processes will be automated by writing and testing software scripts. We will visually inspect all of the data for a selected sub-set of the dataset during testing of the software scripts. If that test succeeds the software will be run as a 'production run' for manipulating the entire data set.

After the production run, we will verify that the results exactly duplicate what was produced during software testing. If that verification holds, we begin to visually cross-check a small portion of the data. Typically we would visually inspect all of the data for a second sub-set of the dataset during this phase as well, and then we visually cross-check a small portion of the manipulated data records, perhaps one per thousand, throughout the entire data set. If at any point in the process errors are found the entire process must be re-run. If re-run, at the end of that process the visual cross-check will be performed again. When no errors are found the checking will be ceased.

Correcting Errors in Manipulation

Since the manipulation processes will be performed in an automated manner, using custom computer software scripts, the ‘fixes’ will be accomplished by fixing the automated conversion software. After the software has been corrected the entire visual check process is performed again.

11. Hardware/Software Configuration

The requirement for this section of the QAPP is to provide information on the types of computer equipment, hardware, and software to be used on the project, including information on how they will be used (e.g., for conducting the specified data management procedures). While the necessary hardware/software configurations for the Thurston County project cannot be specified until the model that will be applied in the project has been approved and the approach to applying it has been developed and described in the Simulation Plan, a significant determinant in model selection will be the ability of the County to query all data and replicate, modify, and extend simulation runs using standard WINDOWs-based PC systems with currently installed software- i.e. standard business productivity software (Microsoft Office), ESRI ArcGIS 10.X, plus readily available, non-proprietary/public domain modeling software available for download from EPA or other government sites. Further specification of the modeling software that will be used in this project will be provided in the Simulation Plan.

12. Assessment and Oversight Actions

As described in Section 9, non-project-generated data will be used for model development and calibration. The DQOs were discussed in Section 5 of this document. Modelers will cross-check data for bias, outliers, normality, completeness, precision, accuracy, and other potential problems. Data generated outside the project will be obtained primarily from quality-assured databases maintained by USEPA, USGS, and other entities. Additional data may be obtained from either published or non-published sources. The published data will have some degree or form of peer review. Typically, modelers examine these data as part of a data quality assessment. Unpublished databases are also examined in light of a data quality assessment. Data provided by EPA or other sources will be assumed to meet precision objectives established by those entities.

The QA program under which this project will operate includes surveillance, with independent checks of the secondary data that will be used for modeling. (No field data collection is planned or expected in this project.) The essential steps in the QA program are as follows:

- Identify and define the problem
- Assign responsibility for investigating the problem
- Investigate and determine the cause of the problem
- Assign and accept responsibility for implementing appropriate corrective action
- Establish the effectiveness of and implement the corrective action
- Verify that the corrective action has eliminated the problem

The model calibration procedure is discussed in Section 8. Model results will generally be checked by comparing results to those obtained by other models or by comparing them to hand calculations. Visualization of model results will help determine whether model simulations are realistic. Model calculations will be compared to field data. If adjustments to model parameters are made to obtain a fit to the data, the modelers will provide an explanation and justification that must agree with scientific knowledge and fit within reasonable ranges of process rates as found in the literature. Performing control calculations and post-simulation validation of predictions are also major components of the QA process.

Many of the possible technical problems can be solved on the spot by staff, for example, by modifying the technical approach or correcting errors or deficiencies in implementation of the approach. Immediate corrective actions are considered standard operating procedures, and they are noted in records for the project. Problems that cannot be solved in this way require more formalized, long-term corrective action.

If quality problems that require attention are identified, NHC will determine whether attaining acceptable quality requires either short- or long-term actions. If a failure in an analytical system occurs (e.g., performance requirements are not met), the Project Team technical modelers will be responsible for corrective action and will immediately inform the QAO, as appropriate. Subsequent steps taken will depend on the nature and significance of the problem.

The NHC PL has primary responsibility for monitoring the activities of this project and identifying or confirming any quality problems. He will also bring these problems to the attention of the QAO, who will initiate the corrective action system described above, document the nature of the problem, and ensure that the recommended corrective action is carried out.

The EPA and Thurston County Grant Managers and NHC Technical Monitor and PL will be notified of major corrective actions. Corrective actions can include the following:

- Re-emphasizing to staff the project objectives, the limitations in scope and/or budget, the need to adhere to the agreed-upon schedule and procedures, and the need to document QA and QC activities
- Securing additional commitment of staff time to devote to the project
- Retaining outside consultants to review problems in specialized technical areas
- Changing procedures

Performance audits are quantitative checks on different segments of project activities; they are appropriate for data analysis, data-processing and modeling activities. The QAO is responsible for periodically implementing internal assessments during the data entry and analysis phases of the project. As data entries, model codes, calculations, or other activities are checked, the NHC QAO will sign and date a hard copy of the material, as appropriate, and provide this to the NHC PL for inclusion in the administrative record. Additional performance audits will consist of comparisons of model results with observed historical data.

Subject to the concurrence of the EPA and Thurston County Grant Managers, the NHC PL may perform or oversee the following qualitative and quantitative assessments of model performance periodically to ensure that the model is performing the required task while meeting the quality objectives:

- Data acquisition assessments
- Model calibration studies
- Sensitivity analyses
- Uncertainty analyses
- Data quality assessments
- Model evaluations
- Internal peer reviews

Internal peer reviews, as needed, will be documented in the project and QAPP files. Documentation will include the names, titles, and positions of the peer reviewers, their report findings, and the project management's documented responses to their findings.

The NHC PL will perform surveillance activities throughout the duration of the project to ensure that management and technical aspects are being properly implemented according to the schedule and quality requirements specified in this QAPP and the approved work plan. These surveillance activities will include assessing how project milestones are achieved and documented; corrective actions implemented; budgets adhered to; peer reviews performed; data managed; and whether computers, software, and data are acquired in a timely manner.

System audits are qualitative reviews of project activity to check that the overall quality program is functioning, and that the appropriate QC measures identified in the QAPP are being implemented. If requested by the EPA Grant Manager, and additional funding is provided by EPA, the QAO or designee will conduct an internal system audit of the project and report results to the EPA Grant Manager and the NHC PL.

Critical to the implementation of any quality system is promoting and retaining an environment conducive to open and frank communication among members of the quality and technical staff. To that end, QA/QC responsibilities and authority are distributed throughout the various functional contribution teams comprised of project technical staff as well as with the quality assurance staff. When disputes regarding quality system policies, procedures, or requirements arise which are not readily resolved at the lowest management level possible (closest to the issue), senior-level staff will be notified to ensure objectivity and to preserve the independence of the quality management organization in the resolution of those issues. This approach ensures that the needs of the Project Team are included in the consideration of the satisfaction and compliance with quality policy or requirements. Final authority to resolve disputes involving NHC quality system issues lies with the Principal-in-Charge with the assistance of the Quality Assurance Officer. It should be noted that dispute resolution entails engagement of the Assessment and Response processes. Responses to disputes are based on corrective action investigation and findings and remedy options. Level of escalation and rate of recurrence dictate whether significant corrective actions should include modification of policies described in the project-specific quality guidance (QAPP).

13. Reports to Management

In order to successfully perform this project, there is a need for close and frequent communication between the individuals indicated in the project organizational chart (Figure 1). This communication will be achieved by continually exercising the lines of communication that are indicated in that figure. As part of the standard reporting requirements, NHC provides written monthly progress reports to Thurston County on each task including issues or problems that are encountered, and Thurston County reports overall project progress to EPA. Additionally, NHC will convene periodic Science Advisory Team (SAT) meetings that include the EPA technical Grant Manager for the purpose of reviewing technical deliverables as specified in the NHC scope of work.

In addition to monthly written progress reports, we will communicate frequently via e-mail and fax to assure that all Project Team members are kept current. As needed, these verbal communications will be supplemented by development and distribution of technical memoranda presenting results of software tests, model performance evaluations, and other assessments such as output data quality assessments, significant quality assurance problems and recommended solutions. When deemed necessary, we will follow up electronic communications with phone calls in order to resolve remaining issues. An additional opportunity for communication and resolution of QA issues will be presented by the discussion and feedback occurring at each of the project breakpoints that are identified in Section 17.

14. Departures from Validation Criteria

Along with Section 15 (Validation Methods), this element of the QAPP describes the acceptance criteria presented in Section 5 (Quality Objectives and Criteria for Model Inputs/Outputs), which evaluate the model and its components based on its ability to produce results that can be used to achieve project objectives. For example, this element would state acceptance criteria associated with the degree to which each model output item has met its quality specifications. The possible types of discrepancies that may arise when the acceptance criteria and other QAPP specifications are not met in their entirety are also addressed, along with the effects that such discrepancies are likely to have on the outcome of the model development and application processes.

Section 5 notes that:

> Definition of explicit, achievable quality objectives and calibration and validation targets is dependent upon the abundance of relevant data, the selection of model(s) and the intended use of the model(s). The work that will be performed in this study to produce the Model Simulation Plan will enable refinement of these elements of the QAPP.

15. Validation Methods

The purpose of this element is to describe, in detail, the process for making a final assessment of whether model components and their outputs satisfy the requirements specified throughout the QAPP. The appropriate methods of evaluation will be determined by the quality objectives developed first in general terms in Section 5 (Quality Objectives and Criteria for Model Inputs/Outputs).

Evaluation of whether model components and their outputs are satisfying the DQOs will be an ongoing process during the model calibration and validation stage of the project. In-progress assessments of validation issues will be discussed between a team including both technical and QA representatives from Thurston County and NHC. The results of performing evaluations will be logged and integrated into the project documentation at the conclusion of the project.

16. Reconciliation with User Requirements

The purpose this element is to outline and specify, if possible, methods for evaluating (relative to project requirements) the model outputs that the project generates. These methods include scientific evaluations of the model predictions to determine if they are of the right type, quantity, and quality to support their intended use. This element discusses the procedures in place to determine whether the final set of model results meets the requirements for the data quality assessment. This element should also discuss how departures from the underlying assumptions or output criteria associated with statistical procedures applied in the data quality assessment will be addressed, the possible effects of departures from assumptions or specified output criteria on the model results, and what potential modifications will need to be made to adjust for these departures. Finally, the discussion should specify model limitations that may impact the usability of the results.

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Appendix A. Basins with Contemporaneous Precipitation, Flow and Water Quality

Basin	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Deschutes River (Mainstem Lower)*													
FG USGS Deschutes River @ E St	x	x	x	x	x	x	x	x	x	x	x	x	x
FG Deschutes River @ Rich Rd				x	x	x							
RG 11U	x	x	x	x	x	x	x	x	x	x	x	x	x
WQ DESCH0300	x	x	x	x	x	x	x	x	x	x	x	x	x
WQ DESSP0500	x	x	x	x	x	x	x	x	x	x	x	x	x
Deschutes River (Mainstem Middle)*													
FG Deschutes River @ Waldrick Rd				x	x	x							
FG Deschutes River near Rainier				x	x	x							
FG USGS @ Vail Rd	x	x	x	x	x	x	x	x	x	x	x	x	x
RG 55U				x	x	x	x	x	x	x	x	x	
RG 59U										x	x	x	x
RG 13U	x	x	x	x	x	x	x	x	x	x	x	x	x
WQ DESDE0025									x	x	x	x	x
WQ DESDE0045	x	x	x	x	x	x	x	x	x	x	x	x	x
WQ DESRE1100	x	x	x	x	x	x	x	x	x	x	x	x	x
Deschutes River (Mainstem Upper)*													
FG USGS @ Vail Rd	x	x	x	x	x	x	x	x	x	x	x	x	x
RG 13U	x	x	x	x	x	x	x	x	x	x	x	x	x
WQ DESDE0045	x	x	x	x	x	x	x	x	x	x	x	x	x
Woodland Creek													
FG Woodland Cr @ Draham Rd	Still operating but unsure of start date (Assumed two years of flow data)												
FG Woodland Cr near Layce			x	x	x								
FG Woodland Cr @ Pleasant Glade Rd													
RG 18U	x	x	x	x	x	x	x	x	x	x	x	x	
RG 18W			x	x	x	x	x	x	x	x	x	x	x
WQ HENWL0000	x	x	x	x	x	x	x	x	x	x	x	x	x
WQ HENWL0800						x	x	x	x	x	x	x	x
Chambers													
FG Chambers Ditch	Still operating but unsure of start date (Assumed two years of flow data)												
FG Chambers Cr @ Rich Rd			x	x	x	x	x	x	x	x	x	x	x
RG 18 U	x	x	x	x	x	x	x	x	x	x	x	x	
RG 11U	x	x	x	x	x	x	x	x	x	x	x	x	x
RG 10U				x	x	x	x	x	x	x	x	x	x
WQ DESCH0300	x	x	x	x	x	x	x	x	x	x	x	x	x

* Basin is not a headwater basin.

LEGEND

Partial Year

Full Year

Proximity of Basin to Rain Gage

Excellent (≤ 1 mile)

Good (1 < distance ≤ 2 mile)

Fair (> 2 Miles)

Appendix A. Basins with Contemporaneous Precipitation, Flow and Water Quality Cont.

Basin	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Black Lake													
FG Black Ditch @ Black Lake								x	x	x	x	x	x
RG 23U				x	x	x	x	x	x	x	x	x	x
RG 11U	x	x	x	x	x	x	x	x	x	x	x	x	x
WQ BUDBD0000						x	x	x	x	x	x	x	x
Percival Creek													
FG Percival Creek			x	x	x	x			x	x	x	x	x
RG 23U				x	x	x	x	x	x	x	x	x	x
WQ BUDPE0000	x	x	x	x	x	x	x	x	x	x	x	x	x
WQ BUDBD0000						x	x	x	x	x	x	x	x
Green Cove Creek													
FG Green Cove Cr @ 36th	x	x	x	x	x	x	x	x	x	x	x	x	x
RG 32U			x	x	x	x	x	x	x	x	x	x	x
WQ ELDGC0000	x	x	x	x	x	x	x	x	x	x	x	x	x
McLane Creek													
FG McLane Cr @ Delphi Rd Bridge		x	x	x	x	x	x	x	x	x	x	x	x
RG 69U	x	x	x	x	x	x	x	x	x	x	x	x	x
RG 23U				x	x	x	x	x	x	x	x	x	x
RG32U			x	x	x	x	x	x	x	x	x	x	x
WQ ELDMC0000			x	x	x	x	x	x	x	x	x	x	x
Woodard Creek													
FG Woodard Cr @ 36th						x	x	x	x	x	x	x	x
RG 20U			x	x	x	x	x	x	x	x	x	x	x
WQ HENWO0000	x	x	x	x	x	x	x	x	x	x	x	x	x

LEGEND

- Partial Year
- Full Year

Proximity of Basin to Rain Gage

- Excellent (≤ 1 mile)
- Good (1 < distance ≤ 2 mile)
- Fair (> 2 Miles)

Appendix B. Basins with Contemporaneous Precipitation and Water Quality, but < 2-yrs of Flow Data

Basin	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Ellis Creek													
FG Ellis Cr @ Eat Bay Drive							x	x					
RG 20U			x	x	x	x	x	x	x	x	x	x	x
WQ BUDEL0000			x	x	x	x	x	x	x	x	x	x	x
Mission Creek													
RG 20U			x	x	x	x	x	x	x	x	x	x	x
WQ BUDMI0000	x	x	x	x	x	x	x	x	x	x	x	x	x
Indian Creek													
RG 20U			x	x	x	x	x	x	x	x	x	x	x
WQ BUDIN0010	x	x	x	x	x	x	x	x	x	x	x	x	x
Moxlie Creek													
RG 23U				x	x	x	x	x	x	x	x	x	x
RG 20U			x	x	x	x	x	x	x	x	x	x	x
WQ BUDIN0010	x	x	x	x	x	x	x	x	x	x	x	x	x
Schneider Creek (West Bay)													
RG 23U				x	x	x	x	x	x	x	x	x	x
RG 32U			x	x	x	x	x	x	x	x	x	x	x
WQ BUDSC0000	x	x	x	x	x	x	x	x	x	x	x	x	x
Schneider Creek (Totten)													
RG 33W							x	x	x	x	x	x	x
WQ TOTSC0040								x	x	x	x	x	x
WQ TOTSC0000	x	x	x	x	x	x	x	x	x	x	x	x	x
Reichel Lake													
RG 13U	x	x	x	x	x	x	x	x	x	x	x	x	x
WQ DESRE1100	x	x	x	x	x	x	x	x	x	x	x	x	x

LEGEND

Partial Year

Full Year

Proximity of Basin to Rain Gage Excellent (< 1 mile) Good (< 2 Miles) Fair (> 2 Miles)

Appendix C. Cover Characteristics for Headwater Basins with >2 Years of Water Quality Data,
(Ordered from Best to Worst for Hydrologic Data Availability)

Basin	Watershed	Drainage Area (ac)	2006 %Forest Cover	2006 %TIA	2006 %EIA	Buildout %TIA	Buildout %EIA	Note
Green Cove Creek	Eld	2220	60-80	12	9	14	10	Very Close RG, > 2 yrs of Flow Data
Percival Creek	Budd-Deschutes	5660	40-60	25	21	32	26	Moderately Close RG, > 2 yrs of Flow Data
Woodard Creek	Henderson	5310	40-60	14	11	17	13	Moderately Close RG, > 2 yrs of Flow Data
Black Lake	Budd-Deschutes	4390	40-60	8	6	14	10	Rain Gage over 2 mi distant, > 2 yrs of Flow Data
McLane Creek	Eld	7090	60-80	1	0.7	2	1	Rain Gage over 2 mi distant, > 2 yrs of Flow Data
Chambers Creek	Budd-Deschutes	8480	20-40	18	15	23	18	Rain Gage over 2 mi distant, > 2 yrs of Flow Data
Woodland Creek	Henderson	16280	40-60	21	18	29	23	Moderately Close RG, < 2 full yrs of Flow Data
Ellis Creek	Budd-Deschutes	940	60-80	7	5	9	6	Moderately Close RG, < 2 yrs of Flow Data,
Deschutes River (Mainstem Lower)*	Budd-Deschutes	11210	40-60	15	12	20	15	Rain Gage over 2 mi distant, < 2 yrs of Flow Data, USGS E St gage and quality sites provide approximate lower boundary, upper boundary data lacking.
Deschutes River (Mainstem Middle)*	Budd-Deschutes	23180	40-60	2	1	3	2	Moderately Close RG, < 2 yrs of Flow Data, Vail Rd sites provide upper boundary for flow and quality, data for lower boundary of basin lacking.
Mission Creek	Budd-Deschutes	730	40-60	24	18	29	23	Very Close RG, > no flow gage, adjacent to Ellis Basin
Indian Creek	Budd-Deschutes	1490	20-40	28	23	33	26	Very Close RG, > no flow gage, adjacent to Ellis Basin

Appendix C. Cover Characteristics for Headwater Basins with >2 Years of Water Quality Data, continued

Moxlie Creek	Budd-Deschutes	2510	20-40	40	34	44	37	Moderately Close RG, no adjacency to basin with flow gage
Schneider Creek (West Bay)	Budd-Deschutes	670	40-60	21	16	28	21	Moderately Close RG, no adjacency to basin with flow gage
Schneider Creek (Totten)	Totten	5360	60-80	2	1	3	2	RG> 2 mi distant, no adjacency to basin
Reichel Lake	Budd-Deschutes	4470	60-80	2	1	2	1	RG> 2 mi distant, no adjacency to basin
Deschutes River (Mainstem Upper)*	Budd-Deschutes	22440	60-80	1	0.5	1	0.5	Not topographically defined. Cuts off at County Line, no meteorological, flow, or quality data for upper boundary at County Line.

Appendix C

Data Assessment Memorandum

January 14, 2013

Memorandum

Northwest Hydraulic Consultants
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DATE: 1/14/2013 NHC PROJECT: 21881

TO: File

COMPANY/AGENCY: Thurston County

FROM: Sam Gould, David Hartley, and Derek Stuart

SUBJECT: Data Assessment

Northwest Hydraulic Consultants (NHC) evaluated the availability of precipitation, flow and water quality data in Thurston County. The data was reviewed for its suitability for calibrating a hydrologic model of stream flow and water quality. This memo provides a summary of the data reviewed, as well as the data available for modeling in each basin.

As shown in Table C1 ~~and Figure 1~~, flow, and water quality data in Thurston County is available from four different agencies: Thurston County, NOAA, the Department of Ecology and the USGS. Thurston County is the primary source of precipitation data with 17 gages in the county. Currently the USGS and the Ecology's Environmental Assessment Program are only collecting continuous flow and water quality data on large rivers such as the Deschutes. Although the USGS has collected continuous flow for creeks and streams in the past, the Thurston County monitoring program is the only source of recent continuous flow data at these locations. Long term water quality data on creeks and streams is currently only being collected by Thurston County. Data from a large number of shorter term studies are also available from the Ecology Environment Information Management (EIM) database. This data may be useful as a supplement to the Thurston County water quality data.

Table C1 Precipitation, Flow, and Water Quality Data Available in Thurston County

Data Type	Source	Period of Record	Comment
Precipitation Data	Thurston County	1988 - Current	Limited information available regarding data prior to ~2000
	NOAA	1949 - Current	Olympia airport gage is in the Study Area
Continuous Flow Data	Thurston County	1980's - Current	Currently operating gages also collect temperature data. Quality\Availability of data prior to 2000 is difficult to ascertain.
	Ecology Environmental Assessment Program	2002 - 2005	Gages located on the Deschutes River.
	USGS	1949 - Current	More recent and current gages are primarily located on Rivers, i.e. the Deschutes River.
Water Quality Data	Thurston County	1971 - Current	Includes Temperature, Conductivity, pH, DO, Turbidity, Fecal Coliform, TP, Nitrite/Nitrate, Ammonia, plus additional parameters for lakes.
	Ecology Environmental Assessment Program	2002 - 2012	Gages located on the Deschutes River. Includes Temperature, Conductivity, pH, DO, Turbidity, TSS, Fecal Coliform, SRP, TP, Ammonia, TN, Zinc, Chromium and others
	Ecology EIM	1973 - Current	Typically data from shorter term studies. Includes hundreds of parameters that vary by site.
	USGS	1968 - 2007	Very limited data collected after 1999. Includes hundreds of parameters that vary by site.

As noted above, a large amount of precipitation, flow, and water quality data has been collected throughout Thurston County, however we are only concerned with data that can be used to calibrate hydrologic and water quality models within the project area comprised of WRIAs 13 and 14. Therefore, a data review was carried out for each basin in the draft Basin Evaluation and Management Strategies for Thurston County from October 2012. The review was structured to identify the data available for calibrating a model in each basin. Both flow and water quality are significantly influenced by land use so it is important that the data is recent and coincident with the land use condition represented in the model for calibration. The ideal basin for model calibration will have a recent period of several years of contemporaneous precipitation, flow, and water quality data.

The first step in the review process was to rate each basin based on the distance between the basin centroid and the nearest precipitation gage with at least five years of data collected from 2005 to the present. Basin ratings using this criterion are shown in Table C2 ~~and depicted cartographically in Figure 2~~. As shown, while some of the basins are have better precipitation data coverage than others, they all have sufficiently proximate precipitation sites with long enough records to support model calibration.

Table C2 Precipitation Gage Basin Rating

Basin Rating	Distance of Basin Centroid from Precipitation Gage
Excellent	≤ 1 mile
Good	1 < distance ≤ 2 mile
Fair	distance > 2 mile

Next, basins were selected that had a minimum of two years of continuous flow data collected from 2005 to the present that overlapped with the period of precipitation record from the closest rain gage. This resulted in 10 basins being selected ~~as shown in Figure 3~~.

The final step in this process was to select basins that had a minimum of two years of contemporaneous precipitation, flow and water quality data. Ten basins have two years of contemporaneous data. These basins are shown in ~~Figure 4 and~~ Table C3. These basins have the best available data for calibration.

In addition to these 10 basins, there were seven additional basins that had precipitation and water quality data, but less than two years of flow of data. These basins are shown in ~~Figure 5 and~~ Table C4. While basins with no flow record preclude direct calibration of a hydrologic model, an acceptable model might be developed if parameter values could be reasonably transferred from a nearby calibrated basin with similar geologic and land cover characteristics.

In Table C5 below, all seventeen basins with water quality records of greater than two year length are sorted and grouped into tiers in descending order of hydrologic data richness. The table also includes basic land cover information. This information is sourced from the draft Basin Evaluation and Management Strategies for Thurston County, WRIAs 13 and 14 Report (TC and TRPC, October, 2012) and the Estimates of Current and Future Impervious Report (TC and TRPC, March, 2011). In particular, Appendix H of the draft Evaluation and Management Strategies document provides a lot of basin evaluation data in a convenient and compact form.

<u>Tier 1 Basins</u>

All six basins in the first group have greater than two years of contemporaneous stream flow, water quality and precipitation records. Within this tier, the only distinguishing factor is the distance to the nearest available rain gage site.

Green Cove tops the list of these basins. It has one of the highest existing canopy covers (66%) among the entire list of seventeen basins. TIA was 12% in 2006 and is only expected to rise to 14% at buildout.

Percival Creek runs a close second in terms of data availability. With 25% TIA in 2006, it is one of the most developed basins for which significant records of water quality data are available, and it is expected to gain an additional 7% at buildout for a total of 32%.

Woodard Creek falls in the middle of the entire range for forest cover (46%) and TIA (14%). TIA is expected to rise by about 30% over 2006 values at buildout.

Black Lake had a low-to moderate level of development in 2006 with a total of 87% of the basin in forest, lake, or unaltered wetlands and 8% TIA in 2006. Expected TIA at buildout is 14%, a 75% increase.

McLane Creek is the most pristine basin for which significant amounts of water quality data have been collected. With 73% forest cover in 2006, approximately 1% TIA in 2006 and 2% at buildout, McLane Creek may provide a good approximation of background water quality for constituents that are associated with urbanization. However, verification of this hypothesis would require closer examination of the water quality data from the McLane Creek site.

Chambers Creek forest cover was 32% in 2006. Both Olympia and Lacey urban growth areas cover the northern half of Chambers Creek. Future TIA is projected to rise from 18% to 23% at buildout.

<u>Tier 2 Basins</u>

The second tier of basins includes Woodland Creek and Ellis Creek. The only thing that distinguishes these basins from the top data availability tier is that contemporaneous flow records on these streams is somewhat less than 2 years.

Woodland Creek is the largest basin and majority contributor of fresh water to Henderson Inlet. A chain of lakes forms the basin's headwaters. The basin is almost completely within Lacey's urban growth boundary. Notwithstanding, forest cover in 2006 was 40%. TIA is expected to rise from 21% in 2006 to 29% at buildout.

Ellis Creek lies generally north of the Olympia's UGA boundary. It is a small coastal basin that drains to the east side of Budd Inlet. Ellis Creek stands out as one of the least developed of all basins with water quality data. Forest cover in 2006 was 65% while TIA was estimated at 7%. TIA is expected to rise to 9% at buildout.

<u>Tier 3 Basins</u>

Tier 3 Basins include the lower and middle mainstem Deschutes basins. These are distinct from other basins in the project area because they are not headwater basins. Therefore to calibrate and simulate the impact of land use practices within these basins on contemporaneous precipitation, flow and water quality data at or near the upstream and downstream limits of the sub-basins. Furthermore, these two contemporaneous data sets need to be co-contemporaneous with each other. Therefore, although there are several USGS water quality and flow gaging sites along the Deschutes within these two adjacent basins, two years of complete contemporaneous data sets at or sufficiently close to the sub-basin boundaries are generally not available.

Lower mainstem Deschutes basin had 42% forest cover in 2006 and was covered by 15% TIA. TIA is expected to increase to 20% at buildout. There is a substantial and apparently complete data set available near the downstream boundary of this basin, however; contemporaneous data at or near the upstream boundary are incomplete which makes calibration of this non-headwaters basin problemmatic.

Middle mainstem Deschutes basin also had 53% forest cover in 2006 and TIA only accounted for 2% of basin area. TIA is expected to increase to 3% at buildout. It appears that urban development in the middle Deschutes is confined to the UGA of the City of Rainier which makes up approximately 5% of the basin area. Multiple years of contemporaneous flow and water quality records exist at the Vail Road site, approximately six miles downstream from the upstream basin boundary. At this location, the river has already received drainage from approximately 36% of the middle Deschutes basin. A water quality site has operated within a mile of the downstream basin boundary at Waldrick Road since 2008. It has 3 years of overlap with the water quality record upstream at Vail Road; however, there is only a brief, non-overlapping flow record from 7/2003 to 2/2005 at this downstream site.

The lack of a contemporaneous flow record near the dividing boundary between the Middle and Lower Deschutes creates challenges to calibrating a flow and water quality model representing the separate contributions of either of these two basins; however, with some additional approximations and assumptions, models of either basin could be developed and their influence on flow and quality in the mainstem Deschutes could be estimated.

Tier 4 Basins

Tier 4 basins are ones with reasonable precipitation data coverage and water quality data. They lack any flow gaging data; however, they have at least some common boundary with another basin that has flow and water quality data. Tier 4 basins include Mission and Indian Creek basins, each of which shares some boundary with Ellis Creek- a Tier 2 basin. Modeling either Mission Creek or Indian Creek would require model calibration using Ellis Creek data and a transfer of parameters to comparable geologic/soil-cover-land use areas within the target basin. This approach is less desirable from the standpoint of model reliability than one in which precipitation, flow and water quality data are available for the study basin.

Mission Creek is a small headwater basin of slightly over one square mile that contributes directly to the east side of Budd Inlet. Indian Creek basin is approximately twice as large as Mission Creek. Indian Creek heads at Bigelow Lake. The creek crosses I-5 twice and parallels the highway for approximately one mile before entering Moxlie Creek which flows into the East Bay of Budd Inlet. Mission Creek and Indian Creek basins are both urbanized with 24% and 28% TIA and forest cover of 45% and 37% respectively. In both basins forest cover is concentrated in the stream corridors and headwater areas. TIA is expect to increase to approximately 29% in Mission Creek and 33% in Indian Creek at buildout.

Tier 5 Basins

Tier 5 basins lack flow data or even adjacency to basins with contemporaneous flow data. Modeling of these basins would have to utilize hydrologic parameters that are calibrated and “borrowed” from the nearest basins with sufficient data sets on the assumption that areas with similar land uses, topography, soils, and surficial geology can be represented by the same parameters sets. These basins are the least desirable group from the data availability perspective, and the Upper Deschutes is most problematic because it is not a topographical headwaters basin, and there is neither flow nor water quality data at the basin’s upper boundary which is mapped at the Thurston-Lewis County line.

Table C3: Basins with > two years of contemporaneous precipitation, flow and water quality data

Basin	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Deschutes River (Mainstem Lower)*													
FG USGS Deschutes River @ E St	x	x	x	x	x	x	x	x	x	x	x	x	x
FG Deschutes River @ Rich Rd				x	x	x							
RG 11U	x	x	x	x	x	x	x	x	x	x	x	x	x
WQ DESCH0300	x	x	x	x	x	x	x	x	x	x	x	x	x
WQ DESSP0500	x	x	x	x	x	x	x	x	x	x	x	x	x
Deschutes River (Mainstem Middle)*													
FG Deschutes River @ Waldrick Rd				x	x	x							
FG Deschutes River near Rainier				x	x	x							
FG USGS @ Vail Rd	x	x	x	x	x	x	x	x	x	x	x	x	x
RG 55U				x	x	x	x	x	x	x	x	x	
RG 59U										x	x	x	x
RG 13U	x	x	x	x	x	x	x	x	x	x	x	x	x
WQ DESDE0025									x	x	x	x	x
WQ DESDE0045	x	x	x	x	x	x	x	x	x	x	x	x	x
WQ DESRE1100	x	x	x	x	x	x	x	x	x	x	x	x	x
Deschutes River (Mainstem Upper)*													
FG USGS @ Vail Rd	x	x	x	x	x	x	x	x	x	x	x	x	x
RG 13U	x	x	x	x	x	x	x	x	x	x	x	x	x
WQ DESDE0045	x	x	x	x	x	x	x	x	x	x	x	x	x
Woodland Creek													
FG Woodland Cr @ Draham Rd	Still operating but unsure of start date (Assumed two years of flow data)												
FG Woodland Cr near Layce			x	x	x								
FG Woodland Cr @ Pleasant Glade Rd													
RG 18U	x	x	x	x	x	x	x	x	x	x	x	x	
RG 18W			x	x	x	x	x	x	x	x	x	x	x
WQ HENWL0000	x	x	x	x	x	x	x	x	x	x	x	x	x
WQ HENWL0800						x	x	x	x	x	x	x	x
Chambers													
FG Chambers Ditch	Still operating but unsure of start date (Assumed two years of flow data)												
FG Chambers Cr @ Rich Rd			x	x	x	x	x	x	x	x	x	x	x
RG 18 U	x	x	x	x	x	x	x	x	x	x	x	x	
RG 11U	x	x	x	x	x	x	x	x	x	x	x	x	x
RG 10U				x	x	x	x	x	x	x	x	x	x
WQ DESCH0300	x	x	x	x	x	x	x	x	x	x	x	x	x

* Basin is not a headwater basin.

LEGEND

Partial Year

Full Year

Proximity of Basin to Rain Gage

Excellent (≤ 1 mile)

Good (1 < distance ≤ 2 mile)

Fair (> 2 Miles)

Basin	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Black Lake													
FG Black Ditch @ Black Lake								x	x	x	x	x	x
RG 23U				x	x	x	x	x	x	x	x	x	x
RG 11U	x	x	x	x	x	x	x	x	x	x	x	x	x
WQ BUDBD0000						x	x	x	x	x	x	x	x
Percival Creek													
FG Percival Creek			x	x	x	x			x	x	x	x	x
RG 23U				x	x	x	x	x	x	x	x	x	x
WQ BUDPE0000	x	x	x	x	x	x	x	x	x	x	x	x	x
WQ BUDBD0000						x	x	x	x	x	x	x	x
Green Cove Creek													
FG Green Cove Cr @ 36th	x	x	x	x	x	x	x	x	x	x	x	x	x
RG 32U			x	x	x	x	x	x	x	x	x	x	x
WQ ELDGC0000	x	x	x	x	x	x	x	x	x	x	x	x	x
McLane Creek													
FG McLane Cr @ Delphi Rd Bridge		x	x	x	x	x	x	x	x	x	x	x	x
RG 69U	x	x	x	x	x	x	x	x	x	x	x	x	x
RG 23U				x	x	x	x	x	x	x	x	x	x
RG32U			x	x	x	x	x	x	x	x	x	x	x
WQ ELDMC0000			x	x	x	x	x	x	x	x	x	x	x
Woodard Creek													
FG Woodard Cr @ 36th						x	x	x	x	x	x	x	x
RG 20U			x	x	x	x	x	x	x	x	x	x	x
WQ HENWO0000	x	x	x	x	x	x	x	x	x	x	x	x	x

LEGEND

- Partial Year
- Full Year

Proximity of Basin to Rain Gage

- Excellent (≤ 1 mile)
- Good (1 < distance ≤ 2 mile)
- Fair (> 2 Miles)

Table C4: Basins with < two years of contemporaneous precipitation, flow and water quality data

Basin	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Ellis Creek													
FG Ellis Cr @ Eat Bay Drive							x	x					
RG 20U			x	x	x	x	x	x	x	x	x	x	x
WQ BUDEL0000			x	x	x	x	x	x	x	x	x	x	x
Mission Creek													
RG 20U			x	x	x	x	x	x	x	x	x	x	x
WQ BUDMI0000	x	x	x	x	x	x	x	x	x	x	x	x	x
Indian Creek													
RG 20U			x	x	x	x	x	x	x	x	x	x	x
WQ BUDIN0010	x	x	x	x	x	x	x	x	x	x	x	x	x
Moxlie Creek													
RG 23U				x	x	x	x	x	x	x	x	x	x
RG 20U			x	x	x	x	x	x	x	x	x	x	x
WQ BUDIN0010	x	x	x	x	x	x	x	x	x	x	x	x	x
Schneider Creek (West Bay)													
RG 23U				x	x	x	x	x	x	x	x	x	x
RG 32U			x	x	x	x	x	x	x	x	x	x	x
WQ BUDSC0000	x	x	x	x	x	x	x	x	x	x	x	x	x
Schneider Creek (Totten)													
RG 33W							x	x	x	x	x	x	x
WQ TOTSC0040								x	x	x	x	x	x
WQ TOTSC0000	x	x	x	x	x	x	x	x	x	x	x	x	x
Reichel Lake													
RG 13U	x	x	x	x	x	x	x	x	x	x	x	x	x
WQ DESRE1100	x	x	x	x	x	x	x	x	x	x	x	x	x

LEGEND

- Partial Year
- Full Year

Proximity of Basin to Rain Gage

- Excellent (< 1 mile)
- Good (< 2 Miles)
- Fair (> 2 Miles)

Table C5: Cover Characteristics for Headwater Basins with >2 Years of Water Quality Data,
(Ordered from Best to Worst for Hydrologic Data Availability)

Basin	Watershed	Drainage Area (ac)	2006 %Forest Cover	2006 %TIA	2006 %EIA	Buildout %TIA	Buildout %EIA	Note
Green Cove Creek	Eld	2220	60-80	12	9	14	10	Very Close RG, > 2 yrs of Flow Data
Percival Creek	Budd-Deschutes	5660	40-60	25	21	32	26	Moderately Close RG, > 2 yrs of Flow Data
Woodard Creek	Henderson	5310	40-60	14	11	17	13	Moderately Close RG, > 2 yrs of Flow Data
Black Lake	Budd-Deschutes	4390	40-60	8	6	14	10	Rain Gage over 2 mi distant, > 2 yrs of Flow Data
McLane Creek	Eld	7090	60-80	1	0.7	2	1	Rain Gage over 2 mi distant, > 2 yrs of Flow Data
Chambers Creek	Budd-Deschutes	8480	20-40	18	15	23	18	Rain Gage over 2 mi distant, > 2 yrs of Flow Data
Woodland Creek	Henderson	16280	40-60	21	18	29	23	Moderately Close RG, < 2 full yrs of Flow Data
Ellis Creek	Budd-Deschutes	940	60-80	7	5	9	6	Moderately Close RG, < 2 yrs of Flow Data,
Deschutes River (Mainstem Lower)*	Budd-Deschutes	11210	40-60	15	12	20	15	Rain Gage over 2 mi distant, < 2 yrs of Flow Data, USGS E St gage and quality sites provide approximate lower boundary, upper boundary data lacking.
Deschutes River (Mainstem Middle)*	Budd-Deschutes	23180	40-60	2	1	3	2	Moderately Close RG, < 2 yrs of Flow Data, Vail Rd sites provide upper boundary for flow and quality, data for lower boundary of basin lacking.
Mission Creek	Budd-Deschutes	730	40-60	24	18	29	23	Very Close RG, > no flow gage, adjacent to Ellis Basin
Indian Creek	Budd-Deschutes	1490	20-40	28	23	33	26	Very Close RG, > no flow gage, adjacent to Ellis Basin

Table C5: Cover Characteristics for Headwater Basins with >2 Years of Water Quality Data, continued								
Moxlie Creek	Budd-Deschutes	2510	20-40	40	34	44	37	Moderately Close RG, no adjacency to basin with flow gage
Schneider Creek (West Bay)	Budd-Deschutes	670	40-60	21	16	28	21	Moderately Close RG, no adjacency to basin with flow gage
Schneider Creek (Totten)	Totten	5360	60-80	2	1	3	2	RG> 2 mi distant, no adjacency to basin with flow gage
Reichel Lake	Budd-Deschutes	4470	60-80	2	1	2	1	RG> 2 mi distant, no adjacency to basin with flow gage
Deschutes River (Mainstem Upper)*	Budd-Deschutes	22440	60-80	1	0.5	1	0.5	Not topographically defined. Cuts off at County Line, no meteorological, flow, or quality data for upper boundary at County Line.

Appendix D

HSPF Model Basin Cover Percentages

Table D1: Pre-European Scenario Land Cover Percentages										
Sub-Basin	Basin Area (sq. Miles)	Land Cover Type								
		Forest	Pasture/ Prairie	Grass	High PGIS EIA	Low PGIS EIA	Wetland	Water	High PGIS TIA	Low PGIS TIA
Black Lake										
1	0.61	97%	0%	0%	0%	0%	3%	0%	0%	0%
3	0.10	92%	0%	0%	0%	0%	8%	0%	0%	0%
5	0.11	88%	0%	0%	0%	0%	12%	0%	0%	0%
7	0.45	62%	0%	0%	0%	0%	38%	0%	0%	0%
9	1.30	44%	22%	0%	0%	0%	34%	0%	0%	0%
11	0.99	37%	0%	0%	0%	0%	10%	52%	0%	0%
13	0.88	51%	0%	0%	0%	0%	8%	41%	0%	0%
15	0.12	95%	0%	0%	0%	0%	5%	0%	0%	0%
17	0.29	100%	0%	0%	0%	0%	0%	0%	0%	0%
19	0.27	85%	10%	0%	0%	0%	5%	0%	0%	0%
21	0.32	70%	0%	0%	0%	0%	30%	0%	0%	0%
23	0.80	64%	22%	0%	0%	0%	13%	0%	0%	0%
25	0.21	54%	0%	0%	0%	0%	46%	0%	0%	0%
27	0.07	61%	0%	0%	0%	0%	39%	0%	0%	0%
29	0.14	42%	0%	0%	0%	0%	58%	0%	0%	0%
31	0.20	71%	0%	0%	0%	0%	29%	0%	0%	0%
33	0.70	49%	23%	0%	0%	0%	28%	0%	0%	0%
35	0.15	92%	0%	0%	0%	0%	8%	0%	0%	0%
McLane Creek										
51	1.39	65%	0%	0%	0%	0%	35%	0%	0%	0%
52	0.64	94%	0%	0%	0%	0%	6%	0%	0%	0%
53	1.16	94%	0%	0%	0%	0%	6%	0%	0%	0%
55	0.61	99%	0%	0%	0%	0%	1%	0%	0%	0%
57	0.18	95%	0%	0%	0%	0%	5%	0%	0%	0%
59	0.02	77%	0%	0%	0%	0%	23%	0%	0%	0%
61	1.51	99%	0%	0%	0%	0%	1%	0%	0%	0%
63	1.34	90%	0%	0%	0%	0%	10%	0%	0%	0%
65	1.05	83%	0%	0%	0%	0%	17%	0%	0%	0%
67	1.06	81%	0%	0%	0%	0%	19%	0%	0%	0%
68	0.08	82%	18%	0%	0%	0%	0%	0%	0%	0%
69	1.17	100%	0%	0%	0%	0%	0%	0%	0%	0%
71	0.32	67%	0%	0%	0%	0%	33%	0%	0%	0%
73	0.09	89%	0%	0%	0%	0%	11%	0%	0%	0%
75	0.26	75%	3%	0%	0%	0%	22%	0%	0%	0%
77	0.67	100%	0%	0%	0%	0%	0%	0%	0%	0%
79	0.06	80%	0%	0%	0%	0%	20%	0%	0%	0%
81	0.34	100%	0%	0%	0%	0%	0%	0%	0%	0%
83	0.19	93%	0%	0%	0%	0%	7%	0%	0%	0%

85	0.54	99%	0%	0%	0%	0%	1%	0%	0%	0%
Dempsey Creek/Black River										
91	0.48	23%	0%	0%	0%	0%	77%	0%	0%	0%
92	1.42	54%	4%	0%	0%	0%	42%	0%	0%	0%
93	2.25	75%	21%	0%	0%	0%	4%	0%	0%	0%
94	0.38	92%	0%	0%	0%	0%	8%	0%	0%	0%
95	6.16	92%	0%	0%	0%	0%	8%	0%	0%	0%
96	0.84	70%	0%	0%	0%	0%	30%	0%	0%	0%
Woodard Creek										
101	1.17	86%	0%	0%	0%	0%	14%	0%	0%	0%
103	0.51	81%	0%	0%	0%	0%	19%	0%	0%	0%
105	1.00	65%	0%	0%	0%	0%	35%	0%	0%	0%
107	0.38	61%	0%	0%	0%	0%	39%	0%	0%	0%
109	0.57	80%	0%	0%	0%	0%	20%	0%	0%	0%
111	0.56	85%	0%	0%	0%	0%	15%	0%	0%	0%
113	0.29	74%	0%	0%	0%	0%	26%	0%	0%	0%
115	0.17	99%	0%	0%	0%	0%	1%	0%	0%	0%
117	0.62	77%	0%	0%	0%	0%	23%	0%	0%	0%
121	0.21	98%	0%	0%	0%	0%	2%	0%	0%	0%
123	0.09	98%	0%	0%	0%	0%	2%	0%	0%	0%
125	0.12	85%	0%	0%	0%	0%	15%	0%	0%	0%
127	0.23	100%	0%	0%	0%	0%	0%	0%	0%	0%
129	0.42	57%	0%	0%	0%	0%	43%	0%	0%	0%
131	0.17	96%	0%	0%	0%	0%	4%	0%	0%	0%
133	0.06	99%	0%	0%	0%	0%	1%	0%	0%	0%
135	0.26	69%	31%	0%	0%	0%	0%	0%	0%	0%
137	0.01	83%	0%	0%	0%	0%	17%	0%	0%	0%
139	0.06	100%	0%	0%	0%	0%	0%	0%	0%	0%
141	0.02	100%	0%	0%	0%	0%	0%	0%	0%	0%
143	0.04	100%	0%	0%	0%	0%	0%	0%	0%	0%
145	0.23	62%	0%	0%	0%	0%	38%	0%	0%	0%
147	0.01	88%	0%	0%	0%	0%	12%	0%	0%	0%
149	0.01	100%	0%	0%	0%	0%	0%	0%	0%	0%
151	0.01	100%	0%	0%	0%	0%	0%	0%	0%	0%
153	0.01	100%	0%	0%	0%	0%	0%	0%	0%	0%
155	0.03	86%	0%	0%	0%	0%	14%	0%	0%	0%
157	0.21	87%	0%	0%	0%	0%	13%	0%	0%	0%
159	0.13	100%	0%	0%	0%	0%	0%	0%	0%	0%
161	0.07	100%	0%	0%	0%	0%	0%	0%	0%	0%
163	0.24	98%	0%	0%	0%	0%	2%	0%	0%	0%

Table D2: Existing Scenario Land Cover Percentages										
Sub-Basin	**Basin Area (sq. Miles)**	**Land Cover Type**								
		Forest	**Pasture/ Prairie**	**Grass**	**High PGIS EIA**	**Low PGIS EIA**	**Wetland**	**Water**	**High PGIS TIA**	**Low PGIS TIA**
Black Lake										
1	0.61	73%	20%	3%	1%	0%	3%	0%	1%	1%
3	0.10	77%	12%	3%	2%	0%	6%	0%	2%	2%
5	0.11	62%	23%	4%	2%	0%	9%	0%	3%	4%
7	0.45	21%	42%	11%	4%	1%	22%	0%	5%	4%
9	1.30	26%	20%	18%	6%	3%	26%	0%	8%	6%
11	0.99	19%	9%	8%	2%	1%	9%	52%	3%	3%
13	0.88	26%	12%	10%	3%	2%	6%	41%	3%	5%
15	0.12	69%	18%	5%	2%	1%	5%	0%	2%	5%
17	0.29	59%	13%	18%	7%	3%	0%	0%	10%	8%
19	0.27	59%	13%	16%	6%	2%	3%	0%	8%	9%
21	0.32	26%	35%	8%	3%	1%	27%	0%	4%	4%
23	0.80	25%	44%	14%	4%	2%	11%	0%	4%	6%
25	0.21	13%	39%	6%	2%	0%	39%	0%	3%	4%
27	0.07	29%	5%	18%	6%	4%	39%	0%	8%	9%
29	0.14	28%	5%	6%	2%	1%	58%	0%	3%	4%
31	0.20	40%	19%	10%	4%	1%	27%	0%	6%	6%
33	0.70	36%	32%	7%	2%	0%	23%	0%	3%	3%
35	0.15	69%	10%	8%	5%	1%	8%	0%	7%	4%
McLane Creek										
51	1.39	42%	35%	5%	3%	0%	14%	0%	5%	2%
52	0.64	77%	16%	2%	2%	0%	4%	0%	2%	1%
53	1.16	72%	17%	4%	2%	0%	5%	0%	3%	2%
55	0.61	94%	3%	1%	1%	0%	1%	0%	1%	0%
57	0.18	69%	21%	3%	3%	0%	5%	0%	3%	2%
59	0.02	25%	40%	8%	4%	0%	23%	0%	6%	2%
61	1.51	96%	2%	1%	1%	0%	1%	0%	1%	0%
63	1.34	79%	10%	2%	1%	0%	9%	0%	1%	1%
65	1.05	73%	10%	1%	1%	0%	15%	0%	1%	1%
67	1.06	63%	20%	1%	1%	0%	14%	0%	2%	1%
68	0.08	74%	11%	8%	5%	2%	0%	0%	6%	8%
69	1.17	96%	2%	1%	0%	0%	0%	0%	1%	0%
71	0.32	66%	1%	0%	0%	0%	33%	0%	0%	0%
73	0.09	89%	0%	0%	0%	0%	11%	0%	0%	0%
75	0.26	66%	4%	4%	3%	1%	22%	0%	4%	3%
77	0.67	99%	1%	0%	0%	0%	0%	0%	1%	0%
79	0.06	69%	3%	4%	4%	1%	20%	0%	5%	3%
81	0.34	96%	3%	1%	0%	0%	0%	0%	0%	0%
83	0.19	87%	2%	2%	1%	0%	7%	0%	2%	1%

85	0.54	78%	12%	7%	2%	1%	1%	0%	3%	5%
Dempsey Creek / Black River										
91	0.48	18%	3%	2%	1%	0%	77%	0%	1%	1%
92	1.42	47%	7%	4%	2%	0%	40%	0%	3%	2%
93	2.25	75%	9%	6%	3%	0%	7%	0%	4%	3%
94	0.38	80%	8%	3%	1%	0%	8%	0%	2%	2%
95	6.16	83%	6%	2%	1%	0%	8%	0%	2%	1%
96	0.84	38%	29%	7%	2%	0%	25%	0%	2%	2%
Woodard Creek										
101	1.17	70%	14%	3%	1%	0%	12%	0%	1%	3%
103	0.51	23%	58%	6%	2%	0%	12%	0%	2%	3%
105	1.00	38%	24%	6%	2%	0%	30%	0%	2%	4%
107	0.38	28%	26%	9%	3%	1%	33%	0%	4%	5%
109	0.57	42%	25%	11%	2%	1%	19%	0%	3%	5%
111	0.56	38%	25%	17%	4%	2%	14%	0%	5%	8%
113	0.29	35%	24%	14%	3%	2%	22%	0%	4%	6%
115	0.17	40%	20%	26%	8%	6%	1%	0%	10%	12%
117	0.62	32%	35%	7%	3%	1%	22%	0%	4%	5%
121	0.21	23%	6%	32%	21%	16%	2%	0%	24%	21%
123	0.09	28%	1%	22%	30%	16%	2%	0%	32%	17%
125	0.12	39%	5%	20%	12%	9%	15%	0%	13%	14%
127	0.23	21%	3%	26%	35%	16%	0%	0%	38%	19%
129	0.42	28%	10%	12%	9%	3%	39%	0%	10%	4%
131	0.17	13%	8%	26%	45%	5%	2%	0%	55%	8%
133	0.06	0%	0%	9%	68%	22%	1%	0%	72%	23%
135	0.26	9%	7%	37%	30%	16%	1%	0%	33%	23%
137	0.01	67%	14%	1%	3%	0%	16%	0%	4%	0%
139	0.06	8%	3%	26%	31%	32%	0%	0%	33%	34%
141	0.02	6%	9%	16%	48%	20%	0%	0%	51%	21%
143	0.04	22%	17%	38%	7%	16%	0%	0%	8%	22%
145	0.23	26%	15%	12%	9%	3%	35%	0%	11%	6%
147	0.01	60%	9%	3%	18%	0%	10%	0%	22%	2%
149	0.01	17%	1%	24%	35%	23%	0%	0%	38%	24%
151	0.01	22%	31%	17%	24%	6%	0%	0%	30%	13%
153	0.01	27%	17%	39%	12%	5%	0%	0%	15%	19%
155	0.03	17%	19%	36%	11%	9%	9%	0%	14%	18%
157	0.21	37%	14%	25%	8%	4%	13%	0%	11%	12%
159	0.13	17%	11%	47%	14%	11%	0%	0%	17%	23%
161	0.07	34%	16%	29%	10%	12%	0%	0%	12%	17%
163	0.24	28%	16%	36%	12%	6%	2%	0%	15%	17%

Table D3: Planned Trend Scenario Land Cover Percentages										
Sub-Basin	Basin Area (sq. Miles)	Land Cover Type								
		Forest	Pasture/ Prairie	Grass	High PGIS EIA	Low PGIS EIA	Wetland	Water	High PGIS TIA	Low PGIS TIA
Black Lake										
1	0.61	70%	18%	6%	2%	1%	3%	0%	2%	5%
3	0.10	75%	12%	5%	2%	0%	5%	0%	3%	5%
5	0.11	61%	22%	5%	2%	0%	9%	0%	3%	5%
7	0.45	19%	19%	31%	6%	6%	20%	0%	8%	14%
9	1.30	24%	14%	23%	9%	7%	24%	0%	11%	14%
11	0.99	18%	9%	8%	2%	1%	9%	52%	3%	4%
13	0.88	25%	10%	12%	3%	3%	6%	41%	4%	8%
15	0.12	69%	18%	6%	2%	1%	5%	0%	2%	5%
17	0.29	55%	12%	20%	8%	5%	0%	0%	11%	12%
19	0.27	58%	13%	17%	7%	3%	2%	0%	9%	10%
21	0.32	23%	18%	19%	6%	8%	25%	0%	8%	15%
23	0.80	20%	27%	25%	9%	9%	10%	0%	10%	20%
25	0.21	12%	26%	14%	6%	3%	39%	0%	8%	14%
27	0.07	28%	5%	18%	6%	4%	39%	0%	8%	9%
29	0.14	28%	5%	6%	2%	1%	58%	0%	3%	4%
31	0.20	38%	17%	12%	5%	3%	26%	0%	7%	9%
33	0.70	33%	23%	13%	5%	3%	23%	0%	6%	11%
35	0.15	68%	10%	8%	5%	1%	8%	0%	7%	4%
McLane Creek										
51	1.39	42%	35%	6%	4%	0%	14%	0%	5%	3%
52	0.64	77%	16%	2%	2%	0%	3%	0%	2%	2%
53	1.16	72%	17%	4%	2%	0%	5%	0%	3%	3%
55	0.61	92%	3%	2%	1%	0%	1%	0%	2%	3%
57	0.18	68%	21%	4%	3%	0%	5%	0%	4%	4%
59	0.02	25%	40%	8%	4%	0%	23%	0%	6%	2%
61	1.51	96%	2%	1%	1%	0%	1%	0%	1%	1%
63	1.34	79%	10%	2%	1%	0%	8%	0%	1%	2%
65	1.05	73%	10%	2%	1%	0%	15%	0%	1%	2%
67	1.06	63%	20%	2%	1%	0%	14%	0%	2%	3%
68	0.08	74%	11%	8%	5%	2%	0%	0%	6%	8%
69	1.17	96%	2%	1%	0%	0%	0%	0%	1%	0%
71	0.32	66%	1%	0%	0%	0%	33%	0%	0%	0%
73	0.09	89%	0%	0%	0%	0%	11%	0%	0%	0%
75	0.26	65%	4%	5%	3%	1%	22%	0%	4%	3%
77	0.67	99%	1%	0%	0%	0%	0%	0%	1%	0%
79	0.06	68%	3%	5%	4%	1%	20%	0%	6%	5%
81	0.34	94%	3%	2%	1%	0%	0%	0%	1%	2%
83	0.19	86%	2%	3%	2%	0%	7%	0%	2%	3%

85	0.54	77%	12%	7%	2%	1%	1%	0%	3%	5%
Dempsey Creek / Black River										
91	0.48	18%	3%	2%	1%	0%	77%	0%	1%	1%
92	1.42	47%	7%	4%	2%	0%	39%	0%	3%	3%
93	2.25	74%	9%	6%	3%	1%	6%	0%	4%	4%
94	0.38	79%	8%	4%	2%	0%	8%	0%	2%	3%
95	6.16	82%	6%	3%	1%	0%	8%	0%	2%	2%
96	0.84	38%	28%	7%	2%	0%	24%	0%	2%	3%
Woodard Creek										
101	1.17	69%	14%	4%	1%	0%	12%	0%	2%	4%
103	0.51	23%	58%	6%	2%	0%	11%	0%	2%	4%
105	1.00	38%	24%	6%	2%	0%	29%	0%	2%	4%
107	0.38	28%	26%	9%	3%	1%	33%	0%	4%	6%
109	0.57	42%	23%	12%	3%	1%	19%	0%	4%	6%
111	0.56	37%	24%	18%	5%	3%	14%	0%	6%	10%
113	0.29	35%	22%	16%	4%	2%	22%	0%	5%	8%
115	0.17	28%	14%	33%	13%	11%	1%	0%	16%	26%
117	0.62	29%	22%	19%	5%	5%	21%	0%	6%	12%
121	0.21	22%	5%	33%	22%	16%	2%	0%	24%	22%
123	0.09	28%	1%	22%	30%	16%	2%	0%	32%	17%
125	0.12	34%	4%	21%	14%	13%	15%	0%	16%	18%
127	0.23	17%	2%	26%	37%	18%	0%	0%	41%	21%
129	0.42	21%	4%	15%	13%	9%	38%	0%	15%	11%
131	0.17	12%	5%	25%	48%	8%	2%	0%	58%	9%
133	0.06	0%	0%	9%	68%	22%	1%	0%	72%	23%
135	0.26	9%	6%	36%	31%	18%	1%	0%	34%	24%
137	0.01	67%	14%	1%	3%	0%	16%	0%	4%	0%
139	0.06	7%	1%	24%	33%	35%	0%	0%	35%	37%
141	0.02	4%	0%	19%	54%	23%	0%	0%	57%	25%
143	0.04	14%	0%	39%	12%	35%	0%	0%	13%	37%
145	0.23	25%	14%	13%	9%	4%	35%	0%	11%	8%
147	0.01	35%	1%	6%	25%	23%	9%	0%	30%	24%
149	0.01	0%	1%	5%	54%	0%	0%	0%	57%	0%
151	0.01	11%	14%	15%	32%	26%	0%	0%	38%	28%
153	0.01	19%	14%	38%	17%	12%	0%	0%	20%	25%
155	0.03	16%	18%	37%	11%	10%	9%	0%	14%	19%
157	0.21	31%	10%	31%	10%	6%	13%	0%	12%	18%
159	0.13	16%	10%	47%	15%	12%	0%	0%	18%	25%
161	0.07	27%	13%	33%	13%	14%	0%	0%	15%	25%
163	0.24	26%	15%	38%	13%	7%	2%	0%	15%	20%

Table D4: Future Alternative 1 Scenario Land Cover Percentages										
Sub-Basin	Basin Area (sq. Miles)	Land Cover Type								
		Forest	Pasture/ Prairie	Grass	High PGIS EIA	Low PGIS EIA	Wetland	Water	High PGIS TIA	Low PGIS TIA
Black Lake										
1	0.61	72%	20%	4%	1%	0%	3%	0%	1%	1%
3	0.10	76%	12%	4%	2%	0%	5%	0%	3%	5%
5	0.11	61%	22%	5%	2%	0%	9%	0%	3%	5%
7	0.45	19%	19%	31%	6%	6%	20%	0%	8%	14%
9	1.30	24%	14%	23%	9%	7%	24%	0%	11%	14%
11	0.99	18%	9%	8%	2%	1%	9%	52%	3%	4%
13	0.88	25%	10%	12%	3%	2%	6%	41%	4%	7%
15	0.12	69%	18%	6%	2%	1%	5%	0%	2%	5%
17	0.29	56%	13%	19%	8%	4%	0%	0%	10%	11%
19	0.27	58%	13%	17%	7%	3%	2%	0%	9%	10%
21	0.32	25%	23%	17%	4%	5%	25%	0%	5%	9%
23	0.80	21%	30%	24%	7%	8%	10%	0%	8%	18%
25	0.21	13%	35%	8%	3%	2%	39%	0%	4%	8%
27	0.07	28%	5%	18%	6%	4%	39%	0%	8%	9%
29	0.14	28%	5%	6%	2%	1%	58%	0%	3%	4%
31	0.20	40%	19%	10%	4%	1%	27%	0%	6%	7%
33	0.70	33%	26%	12%	4%	2%	23%	0%	5%	9%
35	0.15	68%	10%	8%	5%	1%	8%	0%	7%	4%
McLane Creek										
51	1.39	42%	35%	5%	4%	0%	14%	0%	5%	2%
52	0.64	77%	16%	2%	2%	0%	3%	0%	2%	1%
53	1.16	72%	17%	4%	2%	0%	5%	0%	3%	3%
55	0.61	94%	3%	1%	1%	0%	1%	0%	1%	0%
57	0.18	68%	21%	4%	3%	0%	5%	0%	3%	3%
59	0.02	25%	40%	8%	4%	0%	23%	0%	6%	2%
61	1.51	96%	2%	1%	1%	0%	1%	0%	1%	0%
63	1.34	79%	10%	2%	1%	0%	9%	0%	1%	1%
65	1.05	73%	10%	1%	1%	0%	15%	0%	1%	1%
67	1.06	63%	20%	2%	1%	0%	14%	0%	2%	1%
68	0.08	74%	11%	8%	5%	2%	0%	0%	6%	8%
69	1.17	96%	2%	1%	0%	0%	0%	0%	1%	0%
71	0.32	66%	1%	0%	0%	0%	33%	0%	0%	0%
73	0.09	89%	0%	0%	0%	0%	11%	0%	0%	0%
75	0.26	65%	4%	5%	3%	1%	22%	0%	4%	3%
77	0.67	99%	1%	0%	0%	0%	0%	0%	1%	0%
79	0.06	68%	3%	5%	4%	1%	20%	0%	6%	5%
81	0.34	94%	3%	2%	1%	1%	0%	0%	1%	3%
83	0.19	85%	2%	3%	2%	0%	7%	0%	2%	3%

85	0.54	77%	12%	7%	2%	1%	1%	0%	3%	5%
Dempsey Creek / Black River										
91	0.48	18%	3%	2%	1%	0%	77%	0%	1%	1%
92	1.42	47%	7%	4%	2%	0%	40%	0%	3%	2%
93	2.25	74%	9%	6%	3%	1%	6%	0%	4%	4%
94	0.38	80%	8%	3%	1%	0%	8%	0%	2%	2%
95	6.16	83%	6%	2%	1%	0%	8%	0%	2%	2%
96	0.84	38%	28%	7%	2%	0%	24%	0%	2%	3%
Woodard Creek										
101	1.17	69%	14%	3%	1%	0%	12%	0%	1%	4%
103	0.51	23%	58%	6%	2%	0%	11%	0%	2%	4%
105	1.00	38%	24%	6%	2%	0%	29%	0%	2%	4%
107	0.38	28%	26%	9%	3%	1%	33%	0%	4%	6%
109	0.57	42%	23%	12%	3%	1%	19%	0%	4%	6%
111	0.56	37%	24%	18%	5%	3%	14%	0%	6%	10%
113	0.29	35%	22%	16%	4%	2%	22%	0%	5%	8%
115	0.17	28%	14%	33%	13%	11%	1%	0%	16%	26%
117	0.62	31%	34%	8%	3%	2%	22%	0%	4%	7%
121	0.21	22%	5%	33%	22%	16%	2%	0%	24%	22%
123	0.09	28%	1%	22%	30%	16%	2%	0%	32%	17%
125	0.12	34%	4%	21%	14%	13%	15%	0%	16%	18%
127	0.23	17%	2%	26%	37%	17%	0%	0%	41%	21%
129	0.42	21%	4%	15%	13%	8%	38%	0%	15%	10%
131	0.17	12%	5%	25%	48%	8%	2%	0%	58%	9%
133	0.06	0%	0%	9%	68%	22%	1%	0%	72%	23%
135	0.26	9%	6%	36%	31%	18%	1%	0%	34%	24%
137	0.01	67%	14%	1%	3%	0%	16%	0%	4%	0%
139	0.06	7%	1%	24%	33%	35%	0%	0%	35%	37%
141	0.02	4%	0%	19%	54%	23%	0%	0%	57%	25%
143	0.04	14%	0%	39%	12%	35%	0%	0%	13%	37%
145	0.23	25%	14%	13%	9%	4%	35%	0%	11%	8%
147	0.01	35%	1%	6%	25%	23%	9%	0%	30%	24%
149	0.01	0%	1%	5%	54%	0%	0%	0%	57%	0%
151	0.01	11%	14%	15%	32%	25%	0%	0%	38%	26%
153	0.01	19%	14%	38%	17%	12%	0%	0%	20%	25%
155	0.03	16%	18%	37%	11%	10%	9%	0%	14%	19%
157	0.21	31%	10%	31%	10%	6%	13%	0%	12%	18%
159	0.13	16%	10%	47%	15%	12%	0%	0%	18%	25%
161	0.07	27%	13%	33%	13%	14%	0%	0%	15%	25%
163	0.24	26%	15%	38%	13%	7%	2%	0%	15%	20%

Table D5: Future Alternative 2 Scenario Land Cover Percentages										
Sub-Basin	Basin Area (sq. Miles)	Land Cover Type								
		Forest	Pasture/ Prairie	Grass	High PGIS EIA	Low PGIS EIA	Wetland	Water	High PGIS TIA	Low PGIS TIA
Black Lake										
1	0.61	73%	20%	4%	1%	0%	3%	0%	1%	1%
3	0.10	78%	11%	4%	2%	0%	5%	0%	2%	5%
5	0.11	65%	20%	4%	2%	1%	9%	0%	2%	5%
7	0.45	19%	19%	31%	6%	6%	20%	0%	8%	14%
9	1.30	29%	11%	21%	8%	7%	25%	0%	10%	14%
11	0.99	19%	8%	8%	2%	1%	9%	52%	2%	4%
13	0.88	26%	10%	12%	3%	2%	6%	41%	4%	7%
15	0.12	69%	18%	6%	2%	1%	5%	0%	2%	5%
17	0.29	70%	6%	13%	6%	4%	0%	0%	9%	10%
19	0.27	58%	13%	17%	5%	4%	2%	0%	6%	13%
21	0.32	26%	23%	17%	4%	5%	25%	0%	5%	9%
23	0.80	24%	29%	23%	7%	8%	10%	0%	8%	17%
25	0.21	13%	35%	8%	3%	2%	39%	0%	4%	8%
27	0.07	28%	5%	18%	4%	5%	39%	0%	4%	13%
29	0.14	28%	5%	6%	2%	1%	58%	0%	3%	4%
31	0.20	40%	19%	10%	4%	1%	27%	0%	6%	7%
33	0.70	33%	26%	12%	4%	2%	23%	0%	5%	9%
35	0.15	68%	10%	8%	5%	1%	8%	0%	7%	4%
McLane Creek										
51	1.39	50%	18%	4%	3%	0%	25%	0%	4%	2%
52	0.64	77%	16%	2%	2%	0%	3%	0%	2%	1%
53	1.16	78%	13%	3%	2%	0%	5%	0%	2%	3%
55	0.61	94%	3%	1%	1%	0%	1%	0%	1%	0%
57	0.18	81%	11%	1%	1%	0%	6%	0%	2%	2%
59	0.02	66%	3%	6%	2%	0%	23%	0%	3%	0%
61	1.51	96%	2%	1%	1%	0%	1%	0%	1%	0%
63	1.34	81%	8%	1%	1%	0%	9%	0%	1%	1%
65	1.05	76%	7%	1%	1%	0%	15%	0%	1%	1%
67	1.06	69%	11%	1%	1%	0%	18%	0%	2%	1%
68	0.08	74%	11%	8%	3%	3%	0%	0%	4%	10%
69	1.17	96%	2%	1%	0%	0%	0%	0%	1%	0%
71	0.32	67%	0%	0%	0%	0%	33%	0%	0%	0%
73	0.09	89%	0%	0%	0%	0%	11%	0%	0%	0%
75	0.26	66%	3%	4%	3%	1%	22%	0%	4%	3%
77	0.67	99%	1%	0%	0%	0%	0%	0%	0%	0%
79	0.06	73%	3%	2%	2%	1%	20%	0%	2%	4%
81	0.34	97%	1%	1%	0%	0%	0%	0%	1%	2%
83	0.19	90%	1%	1%	0%	0%	7%	0%	1%	2%

85	0.54	89%	4%	3%	1%	1%	1%	0%	1%	5%
Dempsey Creek / Black River										
91	0.48	18%	3%	2%	0%	0%	77%	0%	1%	1%
92	1.42	47%	7%	4%	2%	1%	40%	0%	2%	2%
93	2.25	75%	9%	6%	3%	1%	6%	0%	4%	4%
94	0.38	80%	8%	3%	1%	0%	8%	0%	2%	2%
95	6.16	83%	6%	2%	1%	0%	8%	0%	2%	2%
96	0.84	38%	28%	7%	2%	0%	24%	0%	2%	3%
Woodard Creek										
101	1.17	72%	12%	3%	1%	0%	12%	0%	1%	3%
103	0.51	23%	55%	6%	2%	0%	14%	0%	2%	4%
105	1.00	42%	17%	5%	1%	0%	33%	0%	2%	4%
107	0.38	29%	23%	9%	3%	1%	36%	0%	4%	5%
109	0.57	51%	17%	9%	2%	1%	19%	0%	3%	5%
111	0.56	37%	24%	18%	4%	3%	14%	0%	5%	10%
113	0.29	35%	20%	16%	4%	2%	23%	0%	5%	7%
115	0.17	28%	14%	33%	13%	11%	1%	0%	16%	26%
117	0.62	37%	28%	8%	3%	2%	22%	0%	4%	7%
121	0.21	27%	5%	31%	21%	15%	2%	0%	23%	21%
123	0.09	30%	0%	22%	29%	16%	2%	0%	31%	17%
125	0.12	34%	4%	21%	13%	13%	15%	0%	15%	18%
127	0.23	20%	2%	25%	34%	19%	0%	0%	36%	24%
129	0.42	31%	3%	11%	9%	8%	39%	0%	10%	10%
131	0.17	22%	4%	22%	37%	14%	2%	0%	42%	21%
133	0.06	0%	0%	9%	68%	22%	1%	0%	72%	23%
135	0.26	9%	6%	36%	31%	18%	1%	0%	33%	25%
137	0.01	70%	11%	1%	3%	0%	16%	0%	4%	0%
139	0.06	7%	1%	24%	33%	35%	0%	0%	35%	37%
141	0.02	4%	0%	19%	54%	23%	0%	0%	57%	25%
143	0.04	14%	0%	39%	12%	35%	0%	0%	13%	37%
145	0.23	32%	8%	12%	9%	4%	36%	0%	10%	8%
147	0.01	35%	1%	6%	25%	23%	9%	0%	30%	24%
149	0.01	0%	1%	5%	54%	0%	0%	0%	57%	0%
151	0.01	11%	14%	15%	32%	25%	0%	0%	38%	26%
153	0.01	19%	14%	38%	17%	12%	0%	0%	20%	25%
155	0.03	16%	18%	37%	11%	10%	9%	0%	14%	19%
157	0.21	31%	10%	31%	10%	6%	13%	0%	12%	18%
159	0.13	16%	10%	47%	15%	12%	0%	0%	18%	25%
161	0.07	27%	13%	33%	13%	14%	0%	0%	15%	25%
163	0.24	26%	15%	38%	13%	7%	2%	0%	15%	20%

Appendix E

Model FTABLE Routing

Table E1: FTABLEs for HSPF Scenarios				
Sub-Basin	Scenario			
	Existing	Planned Trend	Alternative 1	Alternative 2
Black Lake				
1	Natural FTABLE	FTABLE	FTABLE	FTABLE
3	Natural FTABLE	No FTABLE	No FTABLE	FTABLE
5	Natural FTABLE	No FTABLE	No FTABLE	FTABLE
7	Natural FTABLE	FTABLE	FTABLE	No Retrofit
9	Natural FTABLE	FTABLE	FTABLE	No Retrofit
11	Natural FTABLE	FTABLE	FTABLE	FTABLE
13	Natural FTABLE	FTABLE	FTABLE	No Retrofit
15	Natural FTABLE	No FTABLE	No FTABLE	No Retrofit
17	Natural FTABLE	No FTABLE+infilt	No FTABLE+infilt	No Retrofit
19	Natural FTABLE	FTABLE	FTABLE	FTABLE
21	Natural FTABLE	No FTABLE+infilt	No FTABLE+infilt	No Retrofit
23	Natural FTABLE	No FTABLE+infilt	No FTABLE+infilt	No Retrofit
25	Natural FTABLE	No FTABLE+infilt	No FTABLE+infilt	No Retrofit
27	Natural FTABLE	No FTABLE	No FTABLE	FTABLE
29	Natural FTABLE	No FTABLE	No FTABLE	No Retrofit
31	Natural FTABLE	No FTABLE+infilt	No FTABLE+infilt	No Retrofit
33	Natural FTABLE	No FTABLE+infilt	No FTABLE+infilt	No Retrofit
35	Natural FTABLE	No FTABLE	No FTABLE	FTABLE
McLane Creek				
51	Natural FTABLE	FTABLE	FTABLE	No Retrofit
52	Natural FTABLE	FTABLE	FTABLE	No Retrofit
53	Natural FTABLE	FTABLE	FTABLE	No Retrofit
55	Natural FTABLE	FTABLE	No FTABLE+infilt	No Retrofit
57	Natural FTABLE	No FTABLE	No FTABLE	No Retrofit
59	Natural FTABLE	No FTABLE	No FTABLE	No Retrofit
61	Natural FTABLE	FTABLE	FTABLE	No Retrofit
63	Natural FTABLE	FTABLE	FTABLE	No Retrofit
65	Natural FTABLE	FTABLE	No FTABLE+infilt	No Retrofit
67	Natural FTABLE	FTABLE	FTABLE	FTABLE
68	Natural FTABLE	No FTABLE	No FTABLE	FTABLE
69	Natural FTABLE	No Development	No Development	No Retrofit
71	Natural FTABLE	No Development	No Development	No Retrofit
73	Natural FTABLE	No FTABLE	No FTABLE	No Retrofit
75	Natural FTABLE	No FTABLE	No FTABLE	FTABLE
77	Natural FTABLE	No Development	No Development	No Retrofit
79	Natural FTABLE	FTABLE	FTABLE	No Retrofit
81	Natural FTABLE	FTABLE	FTABLE	No Retrofit
83	Natural FTABLE	FTABLE	FTABLE	No Retrofit
85	Natural FTABLE	FTABLE	FTABLE	FTABLE

Dempsey Creek / Black River				
91	Natural FTABLE	No Development	No Development	FTABLE
92	Natural FTABLE	FTABLE	FTABLE	FTABLE
93	Natural FTABLE	FTABLE	FTABLE	FTABLE
94	Natural FTABLE	FTABLE	No FTABLE+infilt	No Retrofit
95	Natural FTABLE	FTABLE	FTABLE	No Retrofit
96	Natural FTABLE	FTABLE	FTABLE	No Retrofit
Woodard Creek				
101	Natural FTABLE	FTABLE	FTABLE	No Retrofit
103	Dummy Fac.	No FTABLE	No FTABLE	No Retrofit
105	Natural FTABLE	No FTABLE	No FTABLE	No Retrofit
107	Dummy Fac.	No FTABLE	No FTABLE	No Retrofit
109	Natural FTABLE	FTABLE	FTABLE	No FTABLE+infilt
111	Dummy Fac.	FTABLE	FTABLE	FTABLE
113	Dummy Fac.	FTABLE	FTABLE	No Retrofit
115	Dummy Fac.+20pct infilt	FTABLE	FTABLE	No Retrofit
117	Natural FTABLE	No FTABLE+infilt	No FTABLE+infilt	No Retrofit
121	Dummy Fac.+20pct infilt	No FTABLE	No FTABLE	FTABLE
123	Fac. FTABLE	No FTABLE	No FTABLE	No FTABLE+infilt
125	Dummy Fac.+20pct infilt	FTABLE	FTABLE	FTABLE
127	Dummy Fac.+20pct infilt	No FTABLE+infilt	No FTABLE+infilt	FTABLE
129	Natural FTABLE	No FTABLE+infilt	No FTABLE+infilt	FTABLE
131	Dummy Fac.+20pct infilt	No FTABLE+infilt	No FTABLE+infilt	No FTABLE+infilt
133	Fac. FTABLE	No Development	No Development	No FTABLE+infilt
135	Fac. FTABLE	No FTABLE+infilt	No FTABLE+infilt	No FTABLE+infilt
137	Fac. FTABLE	No Development	No Development	No Retrofit
139	Dummy Fac.+20pct infilt	No FTABLE+infilt	No FTABLE+infilt	No Retrofit
141	Fac. FTABLE	No FTABLE+infilt	No FTABLE+infilt	No Retrofit
143	Dummy Fac.+20pct infilt	No FTABLE+infilt	No FTABLE+infilt	No Retrofit
145	Natural FTABLE	No FTABLE+infilt	No FTABLE+infilt	No Retrofit
147	Fac. FTABLE	No FTABLE	No FTABLE	No Retrofit
149	Fac. FTABLE	No FTABLE+infilt	No FTABLE+infilt	No Retrofit
151	Fac. FTABLE	No FTABLE+infilt	No FTABLE+infilt	No Retrofit
153	Fac. FTABLE	No FTABLE	No FTABLE	No Retrofit
155	Fac. FTABLE	No FTABLE	No FTABLE	No Retrofit
157	Natural FTABLE	No FTABLE+infilt	No FTABLE+infilt	No Retrofit
159	Fac. FTABLE	FTABLE	FTABLE	No Retrofit
161	Fac. FTABLE	FTABLE	FTABLE	No Retrofit
163	Fac. FTABLE	No FTABLE+infilt	No FTABLE+infilt	No Retrofit

Appendix F

Hydrologic and Water Quality Metric Results Tabulations

Hydrologic Metrics Results Tables

McLane Creek

Table F1: B-IBI Metrics for McLane Mainstem near Eld Inlet (Reach 51)			
Scenario	High Pulse Count	High Pulse Range	Avg. Annual 7-day Minimum Flow
		(Days)	(cfs)
Pre-Euro	8.5	136	5.2
Existing	8.9	140	5.3
Planned Trend	8.9	140	5.3
Future Alt. 1	9.0	140	5.3
Future Alt. 2	8.9	139	5.2

Table F2: B-IBI Metrics for East McLane Creek (Reach 67)			
Scenario	High Pulse Count	High Pulse Range	Avg. Annual 7-day Minimum Flow
		(Days)	(cfs)
Pre-Euro	9.0	134.5	0.42
Existing	9.3	137.3	0.43
Planned Trend	9.3	137.3	0.43
Future Alt. 1	9.3	137.3	0.43
Future Alt. 2	9.1	134.0	0.42

Black Lake

Table F3: B-IBI Metrics for Discharge From Lake to Black Lake Ditch (Reach 36)			
Scenario	High Pulse Count	High Pulse Range	Avg. Annual 7-day Minimum Flow
		(Days)	(cfs)
Pre-Euro	3.6	88	7.2
Existing	3.7	91	7.4
Planned Trend	3.8	92	7.4
Future Alt. 1	3.7	91	7.4
Future Alt. 2	3.7	91	7.4

Table F4: B-IBI Metrics for Kenneydell Park Stream at outlet to Black Lake (Reach 17)			
Scenario	High Pulse Count	High Pulse Range	Avg. Annual 7-day Minimum Flow
		(Days)	(cfs)
Pre-Euro	6.1	104.3	1.2
Existing	9.4	137.5	1.2
Planned Trend	10.3	154.8	1.2
Future Alt. 1	10.1	144.4	1.2
Future Alt. 2	9.8	143.0	1.2

Woodard Creek

Table F5: B-IBI Metrics for Woodard Creek near Henderson Inlet (Reach 101)			
Scenario	High Pulse Count	High Pulse Range	Avg. Annual 7-day Minimum Flow
		(Days)	(cfs)
Pre-Euro	7.6	120.2	3.3
Existing	9.4	137.0	3.0
Planned Trend	9.4	138.6	3.0
Future Alt. 1	9.4	137.9	3.0
Future Alt. 2	8.9	133.0	3.0

Table F6: B-IBI Metrics for Woodard Creek at UGA Boundary (Reach 117)			
Scenario	High Pulse Count	High Pulse Range	Avg. Annual 7-day Minimum Flow
		(Days)	(cfs)
Pre-Euro	6.5	101.4	1.7
Existing	12.6	185.5	1.6
Planned Trend	12.9	187.9	1.6
Future Alt. 1	12.8	187.7	1.6
Future Alt. 2	11.1	156.6	1.6

Temperature Results Tables

McLane Creek

Table F7: Temperature Metrics for McLane Mainstem near Eld Inlet (Reach 51)			
Scenario	% of Days Temperature Threshold[a] Is Exceeded		
	13 °C	16 °C	17.5 °C
Pre-Euro	29%	3%	0%
Existing	38%	18%	7%
Planned Trend	38%	18%	7%
Future Alternative 1	38%	18%	7%
Future Alternative 2	33%	9%	1%

Table F8: Temperature Metrics for East McLane Creek (Reach 67)			
Scenario	% of Days Temperature Threshold[a] Is Exceeded		
	13 °C	16 °C	17.5 °C
Pre-Euro	31%	2%	0%
Existing	36%	12%	1%
Planned Trend	36%	12%	1%
Future Alternative 1	36%	12%	1%
Future Alternative 2	33%	5%	0%

Black Lake

Simulated Black Lake ditch (reach 36) temperature results are not available because HSPF does not include lake thermal stratification.

Table F9: Temperature Metrics for Kenneydell Park Stream at outlet to Black Lake (Reach 17)			
Scenario	% of Days Temperature Threshold[a] Is Exceeded		
	13 °C	16 °C	17.5 °C
Pre-Euro	33%	5%	0%
Existing	37%	14%	2%
Planned Trend	37%	14%	1%
Future Alternative 1	37%	14%	1%
Future Alternative 2	33%	5%	0%

Woodard Creek

Table F10: Temperature Metrics for Woodard Creek near Henderson Inlet (Reach 101)			
Scenario	% of Days Temperature Threshold[a] Is Exceeded		
	13 °C	16 °C	17.5 °C
Pre-Euro	9%	0%	0%
Existing	15%	0%	0%
Planned Trend	15%	0%	0%
Future Alternative 1	15%	0%	0%
Future Alternative 2	12%	0%	0%

Table F11: Temperature Metrics for Woodard Creek at UGA Boundary (Reach 117)			
Scenario	% of Days Temperature Threshold[a] Is Exceeded		
	13 °C	16 °C	17.5 °C
Pre-Euro	11%	0%	0%
Existing	24%	2%	0%
Planned Trend	24%	2%	0%
Future Alternative 1	24%	2%	0%
Future Alternative 2	13%	1%	0%

Fecal Coliform Results Tables

McLane Creek

Table F12: Fecal Coliform Geometric Mean of Daily Maximum Values for McLane Mainstem near Eld Inlet (Reach 51)		
Scenario	Geometric Mean (cfu/100 mL)	Percent of Days over 200 (cfu/100 mL)
Pre-Euro	14	6%
Existing	50	14%
Planned Trend	47	14%
Future Alternative 1	49	15%
Future Alternative 2	46	14%

Table F13: Fecal Coliform Geometric Mean of Daily Maximum Values for East McLane Creek (Reach 67)		
Scenario	Geometric Mean (cfu/100mL)	Percent of Days over 200 (cfu/100 mL)
Pre-Euro	24	8%
Existing	76	18%
Planned Trend	67	18%
Future Alternative 1	76	18%
Future Alternative 2	62	15%

Black Lake

Table F14: Fecal Coliform Geometric Mean of Daily Maximum Values for Kenneydell Park Stream at outlet to Black Lake (Reach 17)		
Scenario	Geometric Mean (cfu/100 mL)	Percent of Days over 100 (cfu/100 mL)
Pre-Euro	45	6%
Existing	103	56%
Planned Trend	104	58%
Future Alternative 1	92	54%
Future Alternative 2	87	52%

Table F15: Fecal Coliform Geometric Mean of Load to Black Lake (Reach 36)		
Scenario	Geometric Mean (cfu/100 mL)	Percent of Days over 100 (cfu/100 mL)
Pre-Euro	38	11%
Existing	94	52%
Planned Trend	91	51%
Future Alternative 1	87	50%
Future Alternative 2	85	49%

Woodard Creek

Table F16: Fecal Coliform Geometric Mean of Daily Maximum Values for Woodard Creek near Henderson Inlet (Reach 101)		
Scenario	Geometric Mean (cfu/100 mL)	Percent of Days over 100 (cfu/100 mL)
Pre-Euro	18	6%
Existing	79	39%
Planned Trend	78	38%
Future Alternative 1	75	37%
Future Alternative 2	67	33%

Table F17: Fecal Coliform Geometric Mean of Daily Maximum Values for Woodard Creek at UGA Boundary (Reach 117)		
Scenario	Geometric Mean (cfu/100 mL)	Percent of Days over 100 (cfu/100 mL)
Pre-Euro	10	4%
Existing	57	28%
Planned Trend	59	29%
Future Alternative 1	53	26%
Future Alternative 2	46	22%

Nitrate Loading Results Tables

McLane Creek

Table F18: Nitrate Load to McLane Mainstem near Eld Inlet (Reach 51)		
Scenario	Total Load NO_3 (lbs)	Unit Area NO_3 Load (lbs/acre)
Pre-Euro	18200	2.2
Existing	32900	4.0
Planned Trend	32900	4.0
Future Alternative 1	33000	4.1
Future Alternative 2	31000	3.8

Table F19: Nitrate Load to East McLane Creek (Reach 67)		
Scenario	Total Load NO_3 (lbs)	Unit Area NO_3 Load (lbs/acre)
Pre-Euro	1500	2.1
Existing	2900	4.0
Planned Trend	2900	4.0
Future Alternative 1	2900	4.0
Future Alternative 2	2500	3.4

Black Lake

Table F20: Nitrate Load to Black Lake (Reach 36)		
Scenario	Total Load NO_3 (lbs)	Unit Area NO_3 Load (lbs/acre)
Pre-Euro	20300	2.4
Existing	43800	5.2
Planned Trend	43500	5.2
Future Alternative 1	41300	4.9
Future Alternative 2	40100	4.8

Table F21: Nitrate Load to Kenneydell Park Stream at outlet to Black Lake (Reach 17)		
Scenario	Total Load NO_3 (lbs)	Unit Area NO_3 Load (lbs/acre)
Pre-Euro	4600	3.0
Existing	11400	7.5
Planned Trend	11100	7.3
Future Alternative 1	9400	6.2
Future Alternative 2	8900	5.8

Woodard Creek

Table F22: Nitrate Load to Woodard Creek near Henderson Inlet (Reach 101)		
Scenario	Total Load NO_3 (lbs)	Unit Area NO_3 Load (lbs/acre)
Pre-Euro	5800	1.1
Existing	19000	3.8
Planned Trend	17800	3.5
Future Alternative 1	17500	3.5
Future Alternative 2	16100	3.2

Table F23: Nitrate Load to Woodard Creek at UGA Boundary (Reach 117)		
Scenario	Total Load NO_3 (lbs)	Unit Area NO_3 Load (lbs/acre)
Pre-Euro	1400	0.8
Existing	7100	4.3
Planned Trend	6100	3.7
Future Alternative 1	5900	3.5
Future Alternative 2	5400	3.2

Phosphorus Loading Results Tables

McLane Creek

Table F24: Phosphorus Load to McLane Mainstem near Eld Inlet (Reach 51)		
Scenario	Total Load PO_4 (lbs)	Unit Area PO_4 Load (lbs/acre)
Pre-Euro	1470	0.18
Existing	4810	0.59
Planned Trend	4670	0.57
Future Alternative 1	4770	0.59
Future Alternative 2	3870	0.48

Table F25: Phosphorus Load to East McLane Creek (Reach 67)		
Scenario	Total Load PO_4 (lbs)	Unit Area PO_4 Load (lbs/acre)
Pre-Euro	140	0.19
Existing	430	0.59
Planned Trend	400	0.55
Future Alternative 1	420	0.58
Future Alternative 2	280	0.39

Black Lake

Table F26: Phosphorus Load to Black Lake (Reach 36)		
Scenario	**Total Load PO_4 (lbs)**	**Unit Area PO_4 Load (lbs/acre)**
Pre-Euro	**1920**	**0.23**
Existing	**3700**	**0.44**
Planned Trend	**3310**	**0.39**
Future Alternative 1	**3310**	**0.39**
Future Alternative 2	**3200**	**0.38**

Table F27: Phosphorus Load to Kenneydell Park Stream at outlet to Black Lake (Reach 17)		
Scenario	**Total Load PO_4 (lbs)**	**Unit Area PO_4 Load (lbs/acre)**
Pre-Euro	**350**	**0.23**
Existing	**550**	**0.36**
Planned Trend	**460**	**0.30**
Future Alternative 1	**420**	**0.27**
Future Alternative 2	**390**	**0.26**

Woodard Creek

Table F28: Phosphorus Load to Woodard Creek near Henderson Inlet (Reach 101)		
Scenario	**Total Load PO_4 (lbs)**	**Unit Area PO_4 Load (lbs/acre)**
Pre-Euro	**430**	**0.09**
Existing	**2040**	**0.40**
Planned Trend	**2000**	**0.40**
Future Alternative 1	**1970**	**0.39**
Future Alternative 2	**1660**	**0.33**

Table F29: Phosphorus Load to Woodard Creek at UGA Boundary (Reach 117)		
Scenario	**Total Load PO_4 (lbs)**	**Unit Area PO_4 Load (lbs/acre)**
Pre-Euro	**140**	**0.08**
Existing	**330**	**0.20**
Planned Trend	**340**	**0.20**
Future Alternative 1	**310**	**0.19**
Future Alternative 2	**280**	**0.17**

Appendix G

Science Advisory Team (SAT) Comments on Hydrologic Modeling Report and Actions Taken in Response

Review comments on the final hydrologic modeling report were received from the following SAT members, Stephen Stanley, Derek Booth, Krista Mendelman and Joan Lee. No comments were received from Scott Steltzner. Some comments were provided in-line within the draft document and others were received in the format of an email or review letter. A summary of the primary comments from each review is included in the bulleted list below and the email and review letter formats of those comments are included in the pages that follow.

- Stephen Stanley
  - Primary Comments:
    - Suggested dropping the use of the synthetic BIBI score and using the hydrologic metrics directly.
    - Proposed a numeric rating scheme.
    - That the graphic representation of future development scenarios could be clearer.
    - Identified a lack of discussion of the 7-day minimum flows.
  - Significant Changes in Response to Reviewer:
    - The graphic representation of future development were revised.
    - Additional reference to the 7-day minimum flow results was incorporated as a footer in the document.
- Derek Booth
  - Primary Comments:
    - The report would benefit from a clear statement of purpose (for the report) alongside the statement of purpose (for the project).
    - Additional discussion of uncertainty is needed.
  - Most Significant Changes in Response to Reviewer:
    - Added of first paragraph of Section 1.1, shifting Section 6.6 of the draft to Section 5.3, and
    - Provided additional discussion related to model reliability.
    - Many other minor comments were also addressed within the text of the report.
- Krista Mendelman
  - Primary Comments:
    - The caveats and salient issues in section 7 should be highlighted.
    - That differences in impervious cover between the existing condition and planned trend should be stated and a comment added regarding any limitations the model may have on picking up those changes.
    - Further development of the statement about the change from predevelopment to current conditions, considering need for protection of large intact, undisturbed areas should be considered.
  - Most Significant Changes in Response to Reviewer:
    - Added paragraph that starts with phrase "All three future…" in Section 7.
- Joan Lee
  - Primary Comments:
    - An expression of the issues that arise with the difference between calibrated

and measured data, and/or the reason it doesn't matter for purposes of the project should be added.

    - A recommendation on whether you thought there was adequate return on investment relative to the cost of modeling water quality parameters or whether the results themselves merited the effort should be added.
    - That were 5-10 pages of your professional conclusions with respect to the work its near term and potential longer term value be added.
    - That a reflection on the potential impacts of climate change and how that might be factored into the analysis or recommendations be added.
- Most Significant Changes in Response to Reviewer:
    - The discussion of model reliability and uncertainty was expanded.
    - The discussion of management implications was expanded.

Response from Stephen Stanley
4 page comment letter
Plus comments inline with text (not included)

October 31, 2014

David Hartley, P.E., Ph.D. Principal
Northwest Hydraulic Consultants
16300 Christensen Road, Suite 350
Seattle, WA 98188

Re: Comments on Thurston Hydrologic Modeling for Watershed Based Land Use Planning

Dear David,

Provided below are my primary comments on NHC's "condensed" version of the Thurston Hydrologic Modeling for Watershed Based Land Use Planning. Additional comments within the body of the document are also attached.

Overall this modeling effort represents an innovative and smart approach to using watershed data to compare different land use scenarios relative to the impacts for water quality and water flow processes. This type of mid scale watershed modeling is very much needed by local governments, so the methods developed in this analysis should be useful to other jurisdictions throughout Puget Sound.

There are several suggested refinements and changes to how the model results are presented, which may improve the utility of this approach.

1) Use of the Synthetic BIBI Index. Even though the methods described for converting High Pulse Count data into a BIBI score makes perfect sense, there seems to be a lack of "sensitivity" in the results relative to understanding which land use scenarios have greater or lesser impacts. Part of this is due to the use of relatively large buckets for translating the HPC scores to a BIBI score, which results primarily in the same score being selected for almost all the watersheds examined. In other words, the higher resolution of the HPC data has been lost in an effort to present a synthetic biological index. Because, as you state in the introduction, that this overall watershed analysis is a relative comparison of conditions and not a measurement of actual rates and quantities of water flow and water quality processes, it seems unnecessary to convert any of this output data into another metric that is less definitive.

It is suggested that you drop the BIBI index and use the High Pulse Count data directly to establish a normalized score for the basins modeled. This will give you a better idea of the "trend" of improvement or degradation for each land use scenario, which is the appropriate way to interpret the modeling results. The synthetic index concept should still be presented since it may be useful in other watersheds outside of the study area that have a wider range of land use conditions than studied, from degraded to intact (hence greater range of HPC values and synthetic BIBI values).

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2) Summary of Impacts, Tables 14 to 16. These summary tables along with the bar graphs comparing the modeling results, will help local governments, decision makers and citizens to better understand the results of the watershed modeling. The final column in these tables, however, that reports the overall "Aquatic Health Benefit" does not seem to accurately represent the difference in results as shown in data for each of the model metrics (e.g. temperature, nutrients, pathogens).

To correct this, it is suggested that a simple scoring system be employed for each metric (along with any necessary weighting) and then the results averaged for a final score. This could simply be a "0" for no change or improvement, "1" for low or minor improvement, a "2" for moderate improvement, and a "3" for highest degree of improvement. Again, we are wishing to see trends in improvement and these scores should help tease that out. For example, using this scoring system for table 16, one can determine that there is a distinct difference between Alternative Future 1 and 2 (which are both reported as moderate) for the Woodard Creek Basin.

Table 16: Woodard Creek Basin Results Summary of Impacts

Scenario	Metric Impact Result					Overall Aquatic Health Benefit
	Hydrology /B-IBI	Temperature[1]	Fecal Coliform	Nitrate	Phosphorus	
Planned Trend	No Significant change 0	No change (few violations) 0	Small reduction (basin), Small increase (local) 1	Small reduction (basin), Moderate Reduction (local) 1.5	No significant change 0	Mixed 0.5
Future Alternative 1	No Significant change 0	No change (few violations) 0	Small reduction 1	Small Reduction 1	No significant change 0	Moderate 0.4
Future Alternative 2	Small Improvement 1	Slight improvement 1	Reduction 1	Small to moderate Reduction (basin vs. local) 1.5	Moderate Reduction 2	Moderate 1.5

[1] Temperature standard for Woodard Creek and its tributaries is 16.0 Degrees C

Applying this scoring system to the results for Table 14 and 15 (McLane Creek and Black Lake) also helps sort out that Alternative 2 is providing for a trend in improvement that is greater than that provided by either the Planned Trend or Alternative 2.

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Table 14: McLane Creek Basin Summary of Impacts

Scenario	Metric Impact Result					Overall Aquatic Health Benefit
	Hydrology /B-IBI	Temperature[1]	Fecal Coliform	Nitrate	Phosphorus	
Planned Trend	Remains "Good" 0	No change (frequent violations) 0	No change 0	No significant change 0	Small decrease 1	No significant change [2] 0.2
Future Alternative 1	Remains "Good" 0	No change (frequent violations) 0	No change (basin), Reduction (local) 0	No significant change 0	No significant change 0	None (basin)[2], Small (local) 0
Future Alternative 2	Remains "Good" 0	Many fewer violations 3	Reduction 1	No significant change (basin), Moderate reduction (local) .5	Large reduction 3	Moderate [2] 1.5

[1] Temperature standard for McLane Creek and its tributaries is 16.0 Degrees C

[2] Phosphorus is not a key water-quality parameter for McLane Creek and was ignored in the overall aquatic health benefit rating.

Table 15: Black Lake Basin Results Summary of Impacts

Scenario	Metric Impact Result					Overall Aquatic Health Benefit
	Hydrology /B-IBI	Temperature[1]	Fecal Coliform	Nitrate	Phosphorus	
Planned Trend	Remains "Good" (basin), "Fair" (local) 0	No change (frequent violations) 0	Small decrease (basin), Small increase (local) 1	No significant change 0	Moderate Reduction 2	Mixed Low 0.6
Future Alternative 1	Remains "Good" (basin), "Fair" (local) 0	No change (frequent violations) 0	Reduction 1	Moderate Reduction 2	Moderate Reduction 2	Moderate 0.8
Future Alternative 2	Remains "Good" (basin), "Fair" (local) 0	Reduced to Pre-Euro violation frequency 3	Reduction 1	Moderate Reduction 2	Moderate Reduction 2	Moderate 1.6

[1] Temperature standard for Black Lake tributaries is 16.0 Degrees C

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Thank you for the opportunity to review and comment on this important document. If you have any questions regarding these comments please contact me via email or by phone (425 358 1303).

Regards,

Stephen Stanley
Aquatic Ecologist

4215 NE 105th Street Seattle, WA 98125 sjstanley314@gmail.com

Response from Derek Booth
2 page comment letter
Plus comments inline with text (not included)

Some overarching comments on *Thurston County Hydrologic Modeling for Watershed Based Land Use Planning* (Northwest Hydraulic Consultants, draft of August 2014):

This is a very ambitious project that can stand as an example how the modeling of past, present, and future land-use scenarios can be evaluated by their impact to aquatic resources. There's really nothing in the overall structure of either the approach or its presentation in the text that I would change. That said, the current draft could be strengthened somewhat, in ways that are best discussed in the context of the requested review scope:

a. Provide a scientific and technical review of materials provided by Thurston County subcontractor Northwest Hydraulic Associates (NHC), including the report: "*Thurston County Hydrologic Modeling for Watershed Based Land Use Planning.*" The services will include a review of:

   i. the application of methods used in the modeling work;

   ii. the interpretation of results as communicated in the draft report;

   iii. uncertainty associated with the methods used; as well as

   iv. the adequacy of the study for informing land use management decisions, such as changes to zoning and urban growth area boundaries, development regulations, and preservation of sensitive lands.

b. Communicate review outcomes to the COUNTY and NHC as a member of the Scientific Advisory Team for the Watershed Science to Local Policy project. Identify:

   i. whether the methods or conclusions included in the report could be improved or enhanced, and if so,

   ii. specific guidance on how the analysis could be improved to make the study results valid.

With regard to each, in turn:

a.i. (Application of methods) I have no fundamental complaints with this; the authors are adept in the use of HSPF in matters such as those explored in this report. I do find the discussion of the calibration to be rather sparse, which has bearing on the interpretation and application of the results. Normally I would expect to see a stand-alone "calibration report," and perhaps one does exist (although not referenced, as I recall, in the reviewed document). Indeed, the report would benefit from a clear statement of purpose (for the report) alongside the statement of purpose (for the project), the latter of which constituting Section 1.1 of the report. The implication is that the report is a comprehensive presentation of the project, but the reader is left with some uncertainty about whether that is actually the case. I doubt there is sufficient time/budget left to fill in any gaps in expectations (mine, at least), but a clear statement of what the document does and does not include would be welcome.

a.ii. (Interpretation of results) I find this dimension of the report a little thin—it's fine, as far as it goes, but too much of the narrative of Section 6 (Simulation Results) is simply a text description of tables and graphs rather than a fully insightful consideration of what they "mean," particularly with respect to data quality and uncertainty (next comment).

a.iii. (Uncertainty) I found this the least well developed aspect of the report and have made numerous comments throughout the text where a more sophisticated (and, in places, *any*) discussion of uncertainty would have been welcomed. This is not just a desire for rigor and completeness, it speaks directly to the potential applicability of the results to future management actions.

a.iv. (Adequacy of the study for informing land use management decisions) This draft of the report arrives at credible, defensible positions, and the County can move forward with them. However, the text of the report itself could be improved to highlight the key findings (the second to last paragraph of the main report is a good example of successful expression) without either implying a false precision of the simulation results (it's not needed to support those key findings) or convoluted scoring or rating schemes (that don't advance the discussion any better than just a narrative discussion of basin conditions already achieves). isn't yet there, although the end is in sight. Although the report is a credible foundation for providing management guidance—there certainly isn't anything else out there that can do a better job—it is still too focused on an insufficiently critical presentation of the "results" without a sophisticated evaluation of what they do (and do not) mean. I have no doubt that the project team has the expertise to refine this presentation—but whether for matters of scheduling or budget, the present product falls somewhat short of expressing the foundation for future management actions in a clear and accessible document.

b.i. (Improvement of methods or conclusions) I have no issue with the methods—but too many of the judgments made in their implementation are insufficiently documented, and their associated uncertainties too quickly glossed over. I suspect that the conclusions that can be derived from this study are deceptively simple and straightforward, and this outcome is largely borne out by the present text. Thus, I see no need for significant alteration of re-tooling of the study outcomes, and I am hopeful that the suggestions of the Advisory Committee can help the project team strengthen the presentation of supporting information needed to support those conclusions and recommendations.

b.ii. (Specific guidance on improvements) Be careful what you wish for! MS Word tells me that I've made 827 revisions and comments within the text itself; this should keep everyone busy for a little while.

Derek B. Booth, PhD
University of Washington
October 17, 2014

Response from Krista Mendelman
Comments provided via email, 4 pages.

Dear David,

Thank you for the opportunity to comment on the Thurston County Hydrologic Modeling for Watershed Based Land Use Planning. The report was a pleasure to read. I found it very clear while thoroughly documenting the modeling efforts. I only have a few minor thoughts directed at making sure that the full details of your findings are not overlooked.

Section 7 is just packed with information that is really important for the county to consider as they move forward. Is there a way to highlight the caveats and salient issues in this section (bullets, summary list, etc)? I just think about the folks out there who will want to stop at "current regulations could lead to some limited additional degradation but these impacts are minor…(and that regulations when) properly implemented, can be effective at minimizing the impact of new development" without trying to understand the rest of what you say.

In the third paragraph on page 119, I might suggest that the discussion on the second caveat be a bit more specific and actually state the differences in impervious cover between the existing condition and planned trend (about 1% ?) and that the ability of the model to pick up those changes (and actual changes in stream conditions) is limited. You say it but maybe just be more specific to this effort.

One additional thought – do you feel comfortable going one step further with your statement about the change from predevelopment to current condition being where the most degradation happened and adding something like – the model suggests that protection of large intact, undisturbed areas is worth additional consideration/attention by the county?

That is it. Obviously a lot of hard work and attention to detail went into this.

Krista

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Krista Mendelman
USEPA Region 10 (OWW-193)
1200 6th Ave. Suite 900
Seattle, WA 98101
Phone: 206-553-1571
Fax: 206-553-0165

Hi David.

Regarding the protection comment, I agree with what you are saying and questioned my question when I wrote it… does the model demonstrate this or not given the changes in regulations? I went ahead and put it in my comments because new development and redevelopment regulations are not totally protective because of thresholds at the lower end, variances (grandfathering), compliance and enforcement are all factors in their effectiveness (as you so rightly pointed out). It will be interesting to see how this all plays out in our streams as new regulations are implemented. As I said, include only what you are comfortable including based on your results.

Leaves falling, salmon pushing up stream, shadows lengthening, spiders spinning large webs… have a wonderful fall weekend.

Krista

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From: David Hartley [mailto:DHartley@nhcweb.com]
Sent: Thursday, October 09, 2014 5:01 PM
To: Mendelman, Krista
Subject: RE: Your Review of Thurston County Hydrologic Modeling Report Requested by October 9.

Hello Krista,

Thanks for your comments. They are all very constructive and helpful. I think we can address/incorporate most of them. I especially like your final suggestion regarding setting aside tracts of land. I certainly believe it is true, but I am not sure the modeling study demonstrates it. While it is definitely the case that modeling demonstrates existing development has generally had a larger impact than projected future impact, we shouldn't forget that existing development largely occurred with less attention and investment in stormwater management systems and stream protection than what is required as of the Ecology 2012 manual. If we were to run a scenario which imposed current stormwater regulations on existing development, I doubt the model would continue to show such a big difference between existing hydrology and water quality and the forest condition as it does in the report.

Am I making sense and also speaking to your comment, or is my brain a little fried here at the end of the day?

Great to hear from you, regardless.

David

David M. Hartley, P.E., Ph.D. | Principal Hydrologist

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dhartley@nhcweb.com | www.nhcweb.com

Hi David.

Regarding the protection comment, I agree with what you are saying and questioned my question when I wrote it… does the model demonstrate this or not given the changes in regulations? I went ahead and put it in my comments because new development and redevelopment regulations are not totally protective because of thresholds at the lower end, variances (grandfathering), compliance and enforcement are all factors in their effectiveness (as you so rightly pointed out). It will be interesting to see how this all plays out in our streams as new regulations are implemented. As I said, include only what you are comfortable including based on your results.

Leaves falling, salmon pushing up stream, shadows lengthening, spiders spinning large webs… have a wonderful fall weekend.

Krista
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Am I making sense and also speaking to your comment, or is my brain a little fried here at the end of the day?

Great to hear from you, regardless.

David

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Thanks for your thoughts, David. I continue to learn from your expertise.

Krista
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Krista Mendelman
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Phone: 206-553-1571
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From: David Hartley [mailto:DHartley@nhcweb.com]
Sent: Wednesday, October 15, 2014 9:30 AM
To: Mendelman, Krista
Subject: RE: Your Review of Thurston County Hydrologic Modeling Report Requested by October 9.

Hi Krista,

I totally agree regarding the limited protection provided by regulation of new development and redevelopment. The problem of thresholds for imposition of requirements has been recognized for a long time and we built some assumptions into our modeling of future conditions to account for that. In addition to the items you list which are real, lack of maintenance of stormwater facilities is a real, pervasive problem in my experience. Inspection and maintenance is often poor. It is not sexy and does not get either the scientific or political support that it deserves.

It really needs a much bigger profile and discussion than it gets. In my opinion, it should be featured as a major topic of applied research and discussion at stormwater workshops and conferences- it almost never is.

Response from Scott Steltzner
No comments provided, response via email, 1 page.

From: Scott Steltzner <ssteltzner@squaxin.us>
To: "DHartley@nhcweb.com" <DHartley@nhcweb.com>
Date: 11/06/2014 10:11 AM
Subject: RE: Thurston County Hydrologic Modeling Review...one last request.

Hi David,

Squaxin doesn't really have any comments. We didn't have time to do a meaningful review.

Scott

From: DHartley@nhcweb.com [mailto:DHartley@nhcweb.com]
Sent: Wednesday, October 29, 2014 6:08 PM
To: Scott Steltzner; sjstanley314@gmail.com
Cc: Osterba@co.thurston.wa.us; DStuart@nhcweb.com
Subject: Thurston County Hydrologic Modeling Review...one last request.

Hello Scott and Stephen,

So far, I have received comments from SAT members Krista Mendelman, Derek Booth, and Joan Lee.

At this point, it is long past the deadline for submitting comments on the full report, but it would be great to get some kind of reaction from both of you. The full report is quite daunting and at this point we couldn't even respond to any more detailed reviews. That said, I have prepared a much stripped down version of the report with no appendices and a lot of less critical methodological details removed.

Could I trouble you to take a look at the attached pdf, read the brief introduction (p 4), quickly skip through the middle section and take a look at Section 6 and Section 7 (pages 60-80)? This is the final section of the report and it contains the modeling results of the alternatives analysis and implications for basin management.

I would welcome a simple email with any comments you care to make; however general. I will keep the door open to receive something from you for another week.

Thanks for anything you can do.

David

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Response from Joan Lee
Comments provided via email, 1 page.

From: "Lee, Joan" <Joan.Lee@kingcounty.gov>
To: David Hartley <DHartley@nhcweb.com>
Date: 10/17/2014 03:31 PM
Subject: RE: I haven't forgotten...just a little slammed

Hey David
Well I don't have tons of comments, mostly because I simply can't spend the time to fully absorb your work. But here are a few for your consideration:

1. This is really interesting and clear thinking work that shows the strengths and weaknesses of modeling efforts. I am very interested in the "stay the course" recommendations on implementation of current regulations, recognizing that McLane started with some benefits that more urbanized basins won't have
2. I was interested in the challenges with calibrating the flashiness of the HSPF model. It seemed like getting the peaks to match whether hydrology or temperature was a particular challenge. I don't recall seeing a general dismissal of that variability, but if there's not something in there, you might want to express the issues that arise with the difference between calibrated and measured spikes, and/or the reason it doesn't matter for purposes of the modeling. Also, I don't recall seeing a recommendation on whether you thought there was adequate ROI relative to the cost of modeling water quality parameters or whether the results themselves merited the effort. I guess where that thinking takes me is to your two page Chapter 7 and wishing that were 5-10 pages of your professional conclusions with respect to the work its near term and potential longer term value. It would also be interesting to have a reflection on the potential impacts of climate change and how that might be factored into the analysis or recommendations, particularly since the planning horizon is the next 25 years.
3. Beavers appear to present some consternation in the modeling. They are presenting a growing consternation to us as resource managers and we are actively working to get strategies together to determine where we can let beavers thrive for their own sake and for the ecological benefits they provide and where we need a containment strategy to protect restoration projects or infrastructure or to be good neighbors.
4. My next comment is very small, but hopefully you will laugh at the little irony.....the page after the appendix b section divider (for the QAPP) is upside down.

Sorry I can't provide much more than that. It's a real pleasure to read and/or scan your work David, and the thoroughness of it. I think what you are doing contributes to increasing clarity on right use of modeling and proper drawing out of conclusions.

Joan