Bear Creek Watershed Management Study Watershed Modeling

April 4, 2018

King County

Department of Natural Resources and Parks
Water and Land Resources Division
Science and Technical Support Section
King Street Center, KSC-NR-0600
201 South Jackson Street, Suite 600
Seattle, WA 98104
206-477-4800 TTY Relay: 711
www.kingcounty.gov/EnvironmentalScience

Alternate Formats Available

This page intentionally left blank.

Bear Creek Watershed Management Study

Watershed Modeling

Prepared for:

This plan is required for compliance with NPDES Permit conditions S5.C.5.c (Phase 1) and S5.C.4.g (Phase 2). Submitted on behalf of King County, Snohomish County, City of Redmond, City of Woodinville, and Washington State Department of Transportation

Submitted by:

Scott Miller and Jeff Burkey
King County Water and Land Resources Division
Department of Natural Resources and Parks

King County
Department of
Natural Resources and Parks
Water and Land Resources Division

This page intentionally left blank.

Acknowledgements

The authors would like to thank the following people for their contributions to this project and this report:

- Bill Leif, P.E., Snohomish County
- Andy Rheaume, City of Redmond
- Asha D'Souza and Tom Hansen, P.E. (Retired), City of Woodinville
- Elsa Pond and Richard Gersib (Retired), Washington State Department of Transportation

Citation

King County. 2018. Bear Creek Watershed Modeling Report. Prepared by Scott Miller and Jeff Burkey, Water and Land Resources Division. Seattle, Washington.

This page intentionally left blank.

Table of Contents

Figures

Tables

Appendices

This page intentionally left blank.

EXECUTIVE SUMMARY

The Bear Creek Watershed Modeling Report was developed to support the Bear Creek Watershed Management Study (the Study) in accordance with Special Condition S5.C.5.c of the 2012-2018 National Pollutant Discharge Elimination System (NPDES) Phase I Municipal Stormwater Permit (the Permit). King County was the lead agency for developing the modeling and this report.

Bear Creek currently supports a wide range of salmonids including Chinook, sockeye, coho, kokanee, steelhead, and coastal cutthroat. The stream's water quantity and quality, however, are challenged with runoff flashiness, high levels of fecal coliform bacteria, and elevated water temperatures. Aquatic habitat has been degraded in many areas of the watershed, limiting the amount of high quality fish habitat.

Substantial development occurred in the watershed prior to requirements for effective stormwater controls. Many developed areas in the watershed have no stormwater flow control or water quality treatment facilities. The majority of flow control and water quality treatment stormwater facilities that have been built in the watershed were designed using outdated standards and are thus underperforming relative to current requirements and objectives. While subject to treatment and flow control requirements, infill of urban areas and increasing levels of disturbance in rural areas are predicted in the future.

Watershed modeling was used to evaluate the impacts of future changes in land use and land cover in the Bear Creek study area. The models were used to assess possible stormwater strategies to achieve specific targets for a number of metrics used as an indicator of stream health. The metrics include: stream flows (flashiness), macroinvertebrates (B-IBI scores), water temperature, suspended sediment, bacteria (fecal coliforms), and metals (copper and zinc). Stormwater mitigation strategies were evaluated on how well they met specific objectives for the study.

The modeling effort combined two types of watershed models: Hydrologic Simulation Program FORTRAN (HSPF) and System for Urban Stormwater Treatment and Analysis Integration (SUSTAIN). Each model has different strengths. HSPF has been managed by EPA for several decades and has a robust ability to characterize the types of impact changes in the landscape have on receiving waterbodies. A key strength in SUSTAIN is its ability to assess the relationship between the effectiveness of stormwater mitigation strategies and their costs, information that can be used to evaluate how well a given strategy meets restoration targets and at what cost.

For this study, HSPF was used to simulate stream flow rates, water temperature, total suspended solids, bacteria, copper, and zinc. All HSPF water quality output except for temperature were used as inputs to SUSTAIN. HSPF simulated Bear Creek flows and water quality for three different landscape scenarios at the catchment scale: a forested landscape, existing conditions (circa 2011), and a future scenario where additional development occurs with no additional stormwater flow control or water quality treatment in place.

SUSTAIN was used to estimate the costs and effectiveness of adding a full suite of stormwater management facilities to the future scenario.

To perform the modeling work, the watershed was divided into six different HSPF models encompassing a total of 155 distinct catchments. All HSPF models were calibrated for stream flows and water quality at four primary points of comparison. Comparing model output to observed data at secondary locations, referred to as "guidance points", shows more variability. Making the same comparisons for water quality, the simulated concentrations were consistently lower than observed. Simulated water temperatures were calibrated at the 12 primary points, and were nearly as good at the guidance points.

The SUSTAIN model incorporated a suite of stormwater BMPs organized in a "treatment train." The treatment train is defined as the assumed logic to select and sequence stormwater BMPs. The list of BMPs evaluated are:

- raingardens
- roadside bioretention
- cisterns
- permeable pavement
- gravity wells
- infiltration ponds
- wet+dry ponds (Retention/Detention), and
- wetponds

Construction, acquisition, design, maintenance, life spans, and end of life replacement costs were developed for each of the BMPs. Total costs were estimated assuming a 100 year period for implementing them throughout the basin. Costs are presented in 2017 dollars and do not include inflation. Discount rates were not applied to the estimates of total costs.

Optimization of the SUSTAIN models were based on reductions of flashiness as calculated using high pulse counts (HPCs) as the metric. Water quality concentrations were evaluated after a strategy was selected. Projections of B-IBI scores were based on the relationship established between HPCs and B-IBI.

The target HPC indicative of a healthy stream has on average 9 high pulse counts per year. Based on the relationship between HPCs and B-IBI scores, this is equivalent to a B-IBI score of 60 (on a scale of 0-100). The selected strategy to mitigate future conditions achieves this target B-IBI score for all SUSTAIN model domains (projected B-IBI scores ranged from mid-60's to low 70's, all in the "good" category). On average, the distribution of BMPs needed to achieve this includes:

- 1.7 raingardens per parcel,
- 3,300 feet of roadside bioretention per mile of road,
- 1 in 5 houses have a 3,000 gallon cistern,

- 2300 square feet of permeable pavement per 1 acre of impervious area,
- 1 gravity well per 10 parcels, and
- 1 stormwater pond per 6 parcels.

Based on model outputs, the estimated cost of fully implementing this strategy is about $1.17 billion. About 70 percent ($820 million) of the estimated costs were assumed to be public dollars, as they involve construction of stormwater facilities and/or an incentive program to pay for installation of LIDs (e.g., raingardens) on private property. The remaining costs (estimated at $350 million) were estimated to fall to the property owners in the study area. For example, property owners would be responsible for ongoing maintenance; or, developers paying for impacts from their new and redevelopment activities. The estimated costs average $31.5 million and $13.5 million per square mile for public and private sectors, respectively. It should be emphasized that these costs reflect current knowledge and assumptions. As our understanding of stormwater and watershed processes improve over time, actual costs for achieving the goals would likely be substantially less than current estimates.

Consistent with the permit-defined objectives, the strategy identified by the models meet all water quality criteria with the exception of stream temperature, and in one instance, copper. While riparian cover would reduce ambient temperatures to some extent, it is not clear whether a mature forested landscape would be sufficient to cause stream temperatures to meet current temperature standards.

ABBREVIATIONS AND ACRONYMS

ASGWC	Areas Susceptible to Groundwater Contamination
B-IBI	Benthic Index of Biotic Integrity
BMP	Best Management Practice
CAO	Critical Areas Ordinance
CSP	Conservation Stewardship Program
CWM	Cooperative Watershed Management
DO	dissolved oxygen
Ecology	Washington State Department of Ecology
EDT	Ecosystem Diagnosis Treatment
EPA	Environmental Protection Agency
ESRP	Estuary and Salmon Restoration Program
FCBMP	Flow-control Best Management Practice
GROSS	Grants of Regional or Statewide Significance
HOA	Home Owners Association
HSPF	Hydrological Simulation Program—FORTRAN
LCI	Land Conservation Initiative
LID	Low Impact Development
LWCF	Land and Conservation Water Fund
MAMP	Monitoring and Assessment Management Plan
NFWF	National Fish and Wildlife Foundations
NPDES	National Pollutant Discharge Elimination System
PBRS	Public Benefit Open Space Rating System
RCO	Recreation and Conservation Office
RCPP	Regional Conservation Partnership Program
REET	Real Estate Excise Tax
SUSTAIN	System for Urban Stormwater Treatment and Analysis Integration
SWM	Surface Water Management
STS	Science and Technical Services Section
SWDM	King County Surface Water Design Manual
SWS	Stormwater Services Section
TMDL	Total Maximum Daily Load
TSS	total suspended solids
UGA	Urban Growth Area
U.S.	United States

WAC	Washington Administrative Code
WHPA	Wellhead Protection Area
WLRD	King County Water and Land Resources Division
WPZ	Wellhead Protection Zones
WRIA	Water Resource Inventory Area
WSDOT	Washington State Department of Transportation

This page intentionally left blank.

1.0 INTRODUCTION

This Bear Creek Watershed-scale stormwater study (the Study) was developed in accordance with Special Condition S5.C.5.c of the 2012-2018 National Pollutant Discharge Elimination System (NPDES) Phase I Municipal Stormwater Permit (the Permit). King County was the lead agency for developing the Study, with participation, as required by applicable NPDES permits, Snohomish County (Phase I S5.C.5.c.vi), the City of Woodinville (Phase II S5.C.4.g.iv), the City of Redmond (Phase II S5.C.4.g.iv), and the Washington State Department of Transportation (WSDOT) (S5.A.4.a).

The Permit-defined objective of watershed-scale stormwater planning is to identify a stormwater management strategy or strategies that would result in hydrologic and water quality conditions that fully support “existing uses,” and “designated uses” throughout the stream system. These uses are defined in Washington Administrative Code (WAC) 173-201A and include core summer salmonid habitat, salmon spawning, rearing and migration; and recreational, water supply, and miscellaneous uses.

As required by the Permit, stormwater management strategies evaluated by the Study include changes to development-related codes, rules, and standards; and potential future structural retrofit projects. These strategies target improvements to instream flow metrics and water quality parameters. Structural strategies considered range from installation of flow control best management practices (FCBMPs, a.k.a. Low Impact Development, LIDs – bioretention, drywells, permeable pavement, etc.) and facilities (detention/treatment ponds, vaults, etc.); to tree planting along degraded stream corridors (aimed at reducing stream temperatures).

To arrive at recommended strategies, an assessment of future hydrologic, biologic, water quality, and habitat conditions in the watershed was performed. Existing stream flow metrics, Benthic Index of Biotic Integrity (B-IBI) scores, concentrations of dissolved copper and zinc, temperature, and fecal coliforms were quantified and then utilized to calibrate (or compare to discrete observed values for B-IBI) a continuous runoff model. These calibrated models were then linked to evaluate the effectiveness and estimated costs of proposed mitigation strategies under future land use conditions.

1.1 Study Area

The study area is approximately 25.9 square miles with 87 miles of stream length in the study area. The selected study area begins upstream of where Evans Creek enters into Bear Creek. While the Cottage Lake drainage areas are included in the modeling, the analyses looking at future actions excluded Cottage Lake and areas drainage to the Lake. The defined study area also includes four other jurisdictions: Snohomish County, City of Redmond, City of Woodinville, and a sliver of Washington State Department of Transportation mitigation site (Figure 1).

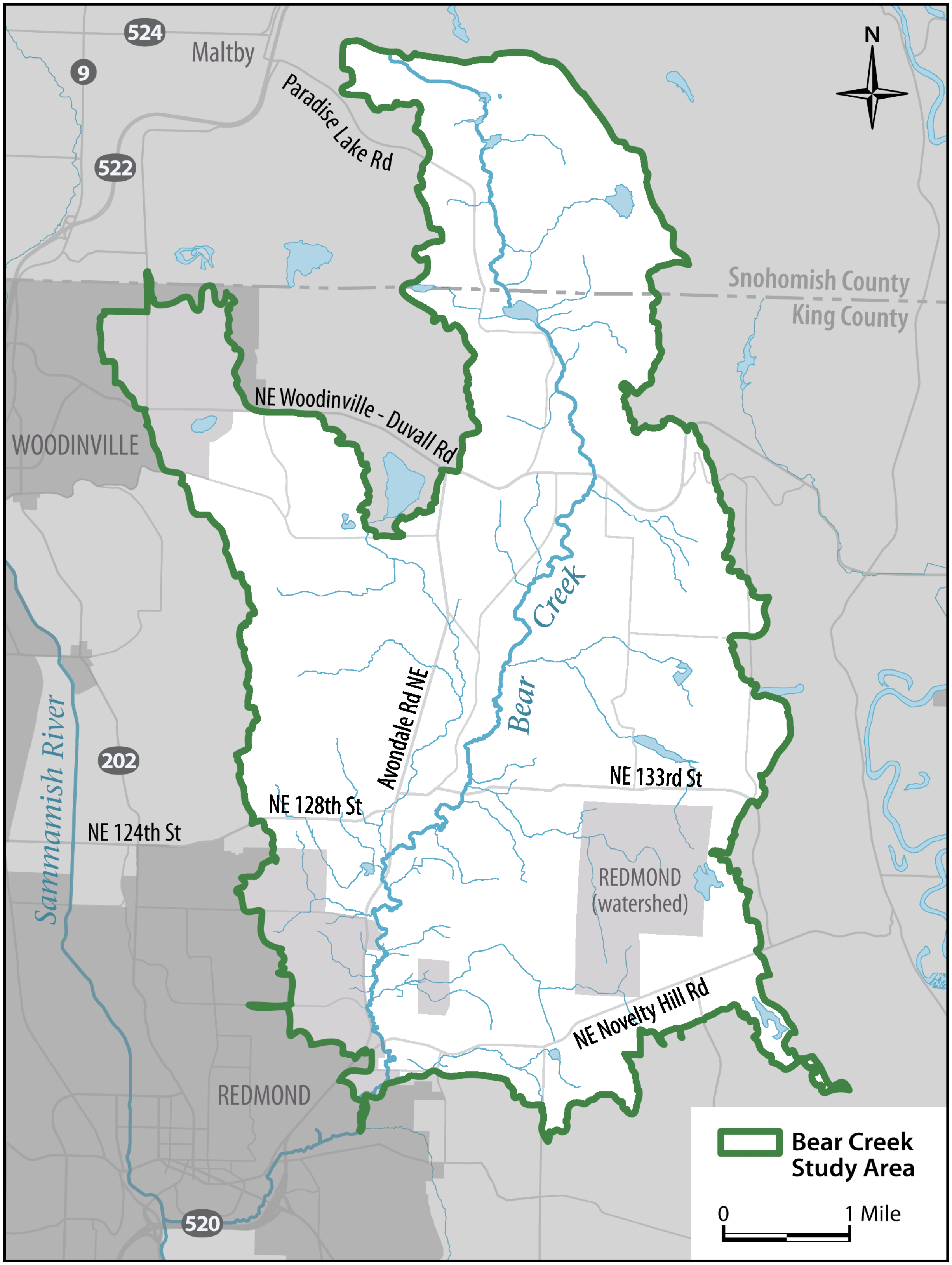

Figure 1 Bear Creek study area. Cities of Redmond and Woodinville are shaded within the green outlined study area boundary.

1.2 Background

Substantial development has already occurred and more is expected in the Bear Creek study area. The study area currently is home to an estimated population of about 27,000 people. Land use, based on satellite imagery from 2011, is composed largely of a mixture of light urban, medium urban, deciduous/mixed forest, and grass. Future land use was estimated using current jurisdiction comprehensive land use plans, and the zoning regulations contained within them. Current land use regulations set limits for the amount of impervious surfaces allowed for a given density. Projected future land use assumes these limits will be reached at some point in the future. This increase reflects the substantial growth pressures anticipated in this basin.

Based on monitoring data, Bear Creek's water quality is currently challenged. High levels of fecal coliform bacteria, elevated water temperatures, and low dissolved oxygen levels are all documented. B-IBI scores, an indicator of overall stream health, are only in the "Fair" range. Even so, Bear Creek contains many miles of high-quality aquatic resources. It supports a wide range of salmonids, including Chinook[1], sockeye, coho, kokanee, steelhead, and coastal cutthroat.[2] The Bear Creek watershed was identified by Ecology as a targeted watershed for stormwater retrofit planning[3], with a watershed integrity index of 9 (based on a scale of 1 (low integrity) to 9 (high integrity)). An integrity index of 9 characterizes the basin as a high value resource and high potential to be restored. Ecology has also identified the mainstem of Bear Creek as requiring special protection for native char, salmon, and trout spawning and incubation.

1.3 Goals and objectives

The objective of the watershed modeling is to provide the necessary analyses to support development of a strategy to restore Bear Creek back to clean waters and healthy habitat reflective of such a high value resource. This will be done by developing a set of models to evaluate past, present, and future conditions and what actions may be necessary to mitigate projected future impacts and unmitigated actions from the past.

---

[1] ESA listed as threatened species.

[2] Kerwin, J., 2001. Salmon and Steelhead Habitat Limiting Factors Report for the Cedar - Sammamish Basin (Water Resource Inventory Area 8). Washington Conservation Commission. Olympia, WA

[3] Assessed by Ecology in support of National Estuary Program Watershed Protection & Restoration Grant Program 2015 (http://www.ecy.wa.gov/puget_sound/docs/grants/2015TargetWatershedsStormwaterRetrofit.pdf)

2.0 MODEL DEVELOPMENT

Two types of models were used in this watershed analysis: Hydrologic Simulation Program FORTRAN (HSPF) and System for Urban Stormwater Treatment and Analysis Integration (SUSTAIN). These models are complimentary to each other with each having different strengths. Both model frameworks are distributed by EPA.

HSPF is used to simulate stream flows and water chemistry in the study area. Stream flows and water chemistry are used as inputs for SUSTAIN when evaluating effectiveness of stormwater strategies. Water temperature can only be simulated in HSPF. In addition, HSPF was also be used to simulate three scenarios for stream flow flashiness: (1) forested, (2) existing, and (3) future with no additional mitigation. The strengths of SUSTAIN are evaluating stormwater mitigation strategies. SUSTAIN will be used for two scenarios, future with no additional mitigation, and future with additional mitigation.

2.1 HSPF

HSPF is a quasi-physically based, lumped parameter watershed model capable of simulating continuous hydrologic cycle for water quantity and multiple water quality constituents. Mechanisms in HSPF simulations are grouped into two categories: land segment runoff and hydraulic routing.

Land segments are comprised of two types, pervious and impervious. Pervious land segment types are conceptually defined with three possible routing layers; surface, shallow subsurface, and deeper subsurface, controlling flow runoff and pollutant generation. Transmission through these layers is interdependent on rainfall intensity and duration on the surface, storage capacity, and infiltration rates among all three layers.

Impervious land segments (IMPLNDs) are defined as one layer with potential surface storage and zero infiltration capacity. Runoff rates and pollutant generation depend on rainfall intensity, duration, and storage. Only a nominal amount of storage is specified in the model so storage plays a minor role in runoff and pollutant generation from impervious surfaces.

Hydraulic routing in HSPF is defined by the user and can be as simple or complex as needed. The relationship between stage, surface area, and storage in HSPF is conceptually independent of any channel geometry but must be unchanging over time. This limitation prohibits time varying downstream influences and any potential flow reversals.

While the parameters defining these land segments and conveyance mechanism are not physically based, they are indexed to algorithms characterizing physical conditions. Further technical details on the HSPF model can be found in the user manual (Bicknell et al., 2005).

2.2 SUSTAIN

The modeling approach used in this study is based on the capabilities and application guidance for the SUSTAIN model (U.S. EPA et al. 2009, Shoemaker et al. 2011, Lee et al. 2012). The latest release of SUSTAIN (Version 1.2, revised March 2013) was used in this project.

This study uses SUSTAIN's external modeling approach with aggregate BMP representation. The external modeling approach was selected to utilize HSPF models developed for this study. Hourly HSPF model outputs from October 1948 through September 2012 for flow, total suspended solids (TSS), fecal coliforms, dissolved copper, and zinc were provided as input to SUSTAIN. Given limitations in computer memory and feasibility of model run times, SUSTAIN simulated time periods were a subset of the of the HSPF simulation time period.

2.3 Drainage Infrastructure

The municipal separate storm sewer system (MS4) is the collection of built drainage infrastructure elements serving to treat and convey surface water runoff. The MS4 includes facilities that regulate flow and improve water quality, as well as conveyance in the forms of ditches, culverts, and pipes. Mapped conveyance elements in and surrounding the Bear Creek watershed are mapped in Figure 2. The stormwater facilities and conveyances affect the study using the recently mapped stormwater conveyances. The Cottage Lake drainage area is included in this figure to illustrate the full extent of the modeled area that extends beyond the study area but is still part of the full Bear Creek drainage basin.

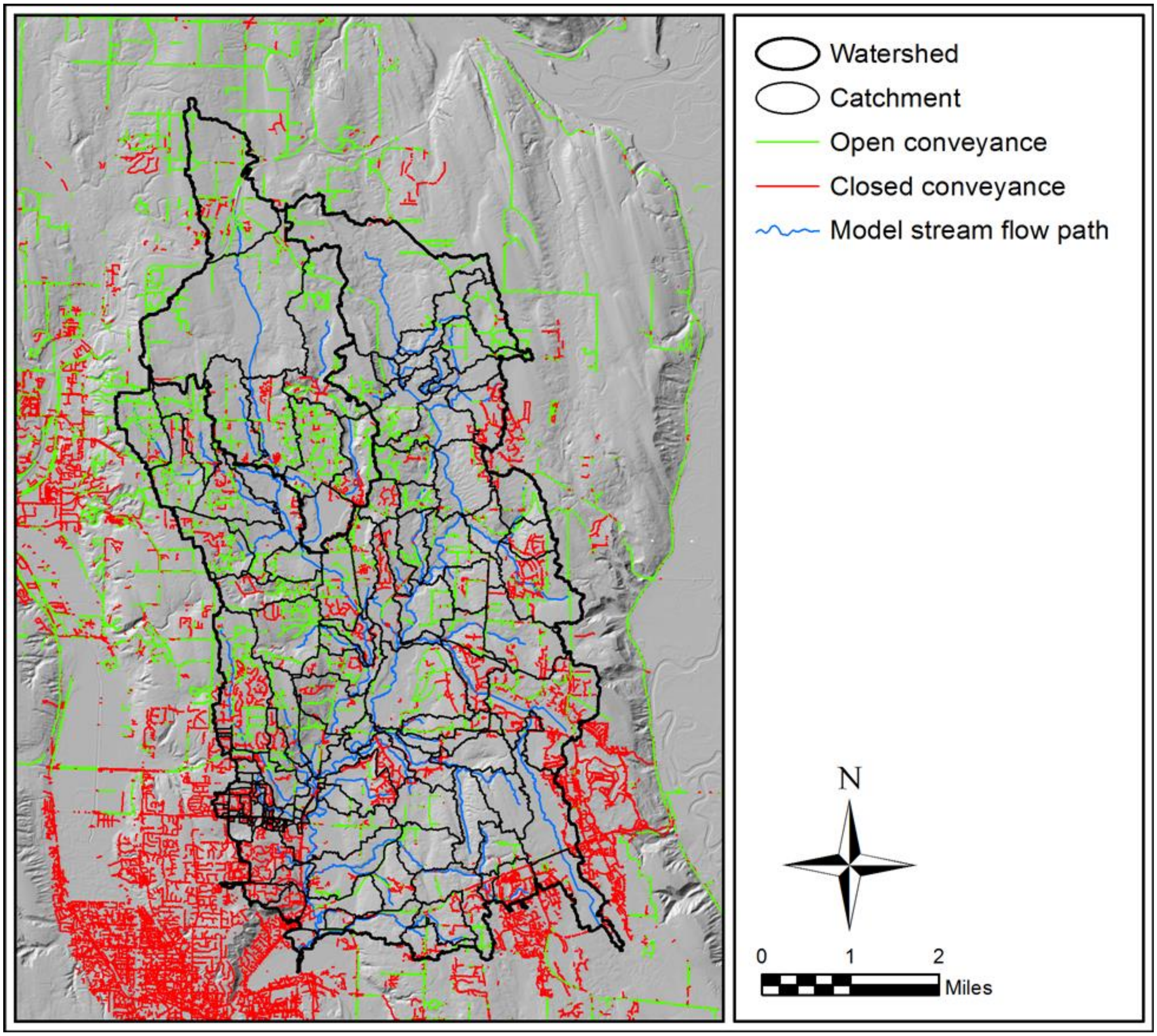

Figure 2 **Map of conveyance elements in municipal separate storm sewer systems**

2.4 Catchment Delineations and Model Domains

2.4.1 HSPF

The HSPF drainage basin is the landscape area that drains to Bear Creek above the confluence of Evans Creek with Bear Creek. It includes the Bear Creek Watershed-scale Stormwater Management study area, the Cottage Lake drainage basin, and a groundwater transfer basin north of the head of Bear Creek (Figure 3).

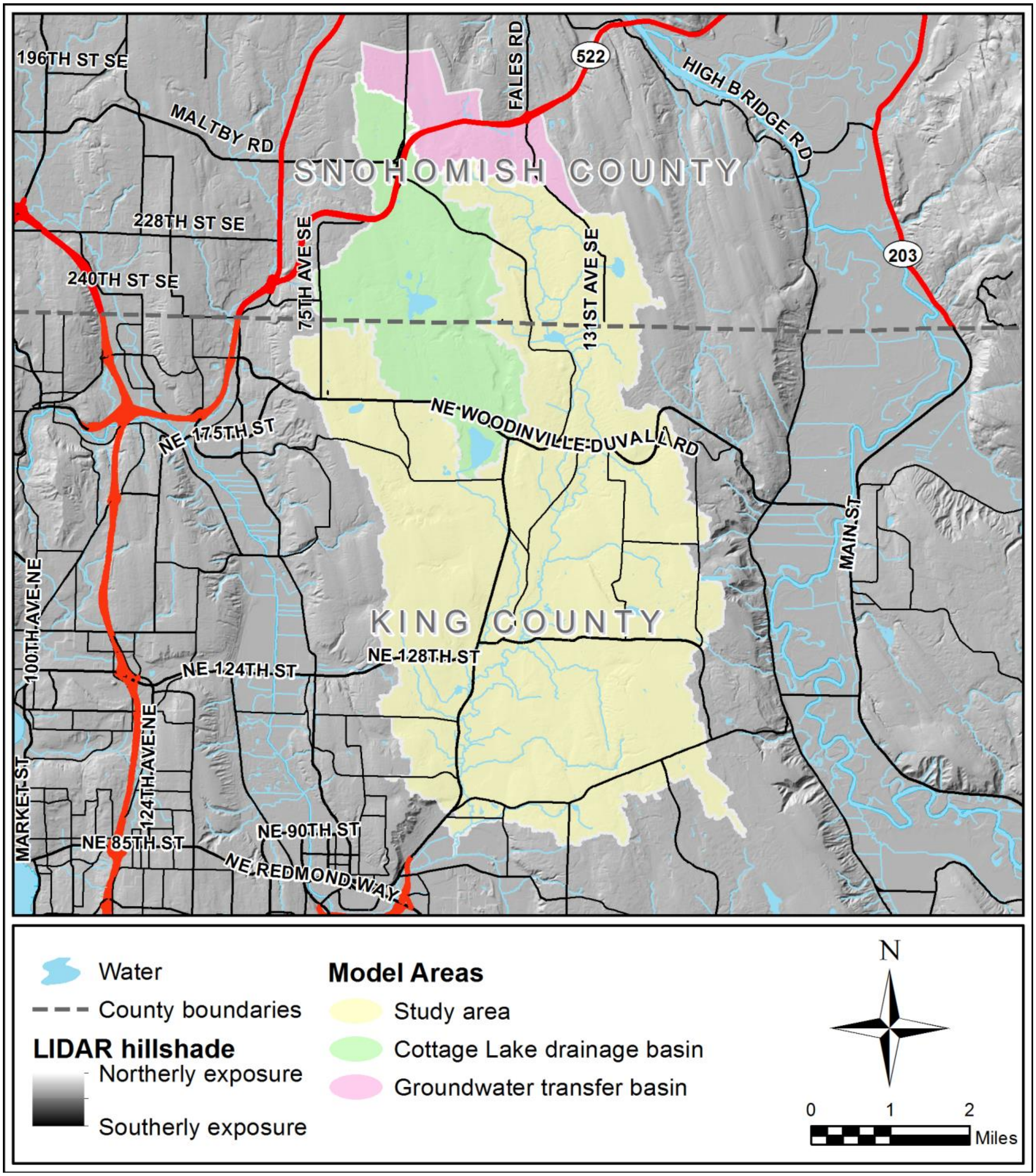

Figure 3 HSPF model drainage basin.

Model domains were defined by locations of selected current flow gauges on digitized stream networks. Each domain has multiple separate stream channels or conveyance systems, but these are grouped into a few model domains to keep the number of separate models within reasonable limits. This is justifiable because model calibration data are not available for each of these smaller channels and systems. This definition process resulted in a total of 6 separate HSPF models ranging in size from 0.6 to 11.7 square miles in area.

Within each modeled area, catchments were delineated to simulate influences from major landscape features as well maintaining consistency between internal model time steps and travel times of runoff in a catchment. Delineations for the catchments were based on several factors; including topographically defined flow directions. Human alterations of the drainage network can modify topographic flow paths. For example, as urbanization occurs, construction of roads and storm sewer networks can sometimes direct flows opposite to what would be expected. Municipal separate storm sewer system (MS4) conveyance elements have been mapped by each jurisdiction in the model area, and this was used to refine catchment delineations.

A total of 155 catchments were defined for the development of the HSPF models (including Cottage Lake drainage basin). Model catchments ranged in size from 0.6 acres up to 1,428 acres. The average catchment size was approximately 143 acres (Figure 4).

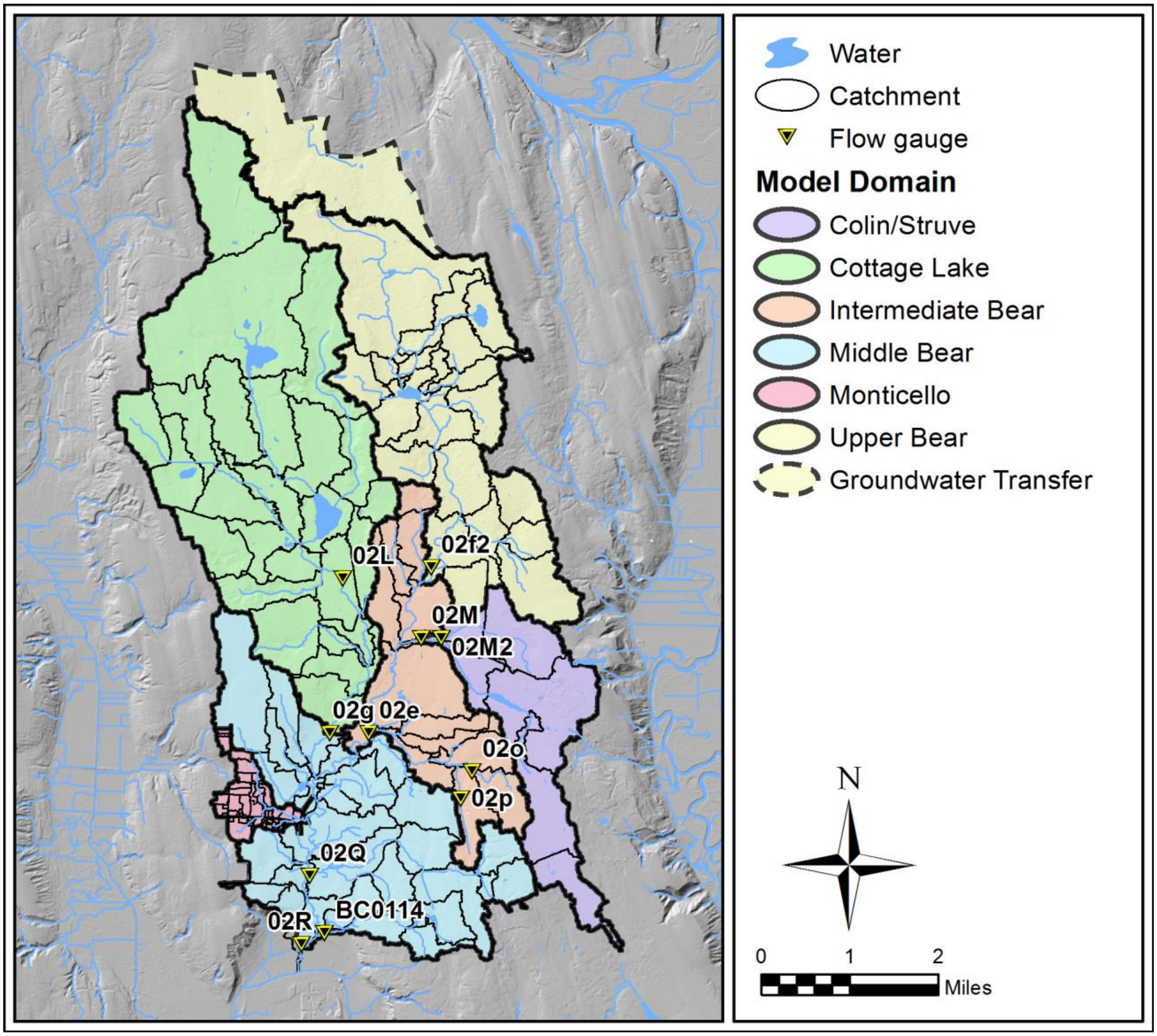

Figure 4 HSPF model domains and catchments.

2.4.2 SUSTAIN

SUSTAIN has two functional limitations. The amount of memory needed to run a simulation, and the amount of time to run an optimization. SUSTAIN requires the software to load the model and all input data into memory before running hundreds to tens of thousands of simulations for each treatment train scenario. In addition, the software was developed using 32-bit architecture which limits the amount of memory it can use at one time (i.e., 2 gigabytes). Limited memory use forces the need to subdivide the HSPF models into smaller model domains for SUSTAIN simulations. After the memory constraints are addressed, the duration it takes to run a single simulation becomes a factor. Given how the optimization process will need to run several thousands of times for each model domain, a simulation needs to complete in a few seconds. The more complex (and larger) the model, the longer the run time. Simulating a single water year would take less than 10 seconds to complete for all the model domains making it reasonable to continue with the optimization runs.

The study area was segmented into seventeen SUSTAIN model domains. For the purposes of this report, the four SUSTAIN models that comprise the Monticello Creek basin (i.e., MON027, MON034, MON039, and MON030) will be referred to jointly and in aggregate as MON030 (Table 1 and Figure 5). Thus for purposes of reporting, there are fourteen SUSTAIN model domains.

Table 1 List of SUSTAIN model domains and number of acres.

Model Domain	Area (acres)
BEA800	1598
BEA590	2776
BEA410	1912
BEA370	2212
BEA310	941
BEA270	341
BEA240	710
BEA280	1952
BEA260	858
BEA210	256
BEA120	1147
MON030	359
BEA020	400
BEA010	992

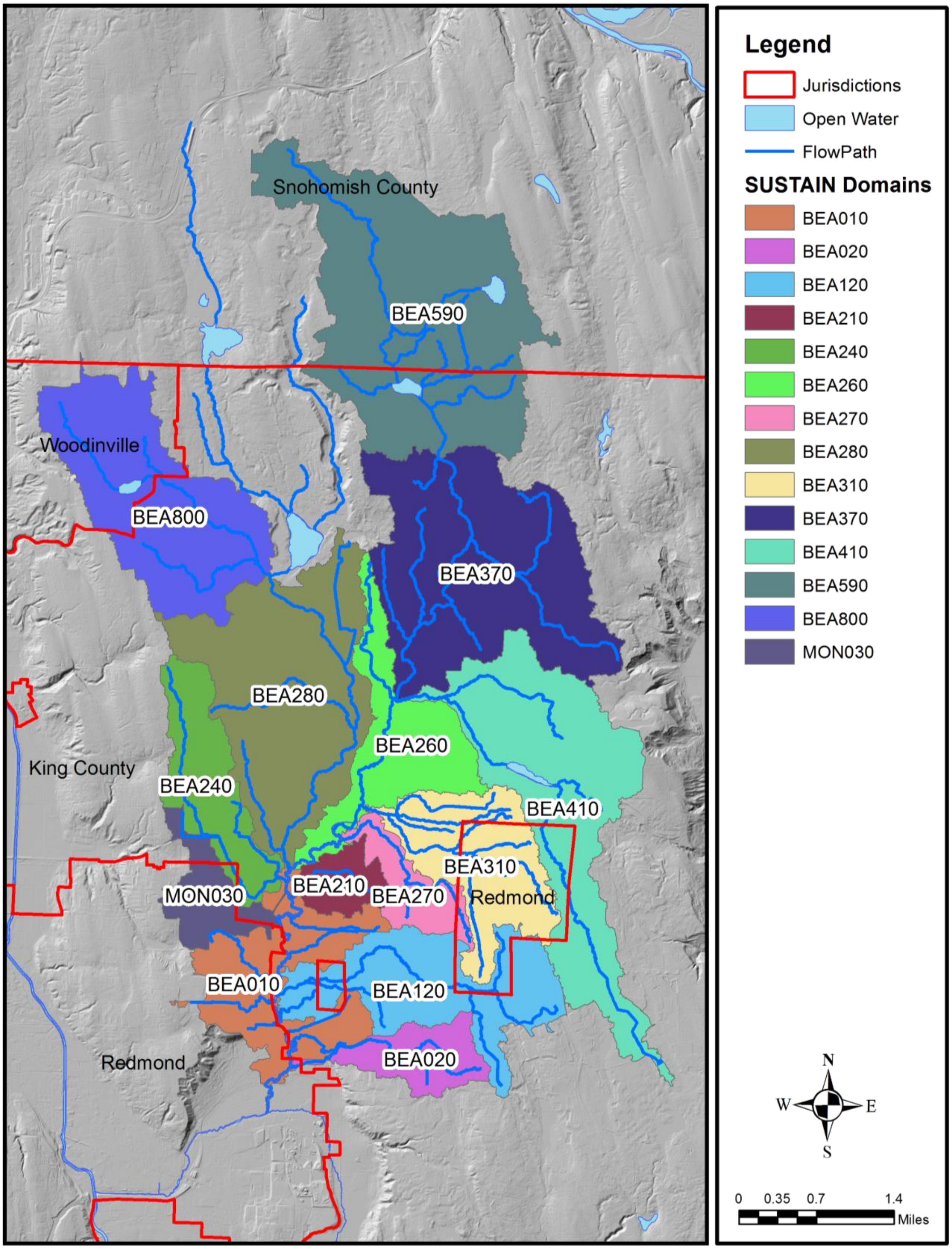

Figure 5 Map of SUSTAIN Model Domains.

2.5 Existing (2011) Land Use and Land Cover

The landscape can be described as a land cover (e.g., forested) or a land use (e.g., residential). Land cover defines elements that can make up a land use (e.g., forest, grass, impervious, etc.) and/or physical composition of the land surface, which may include grass, asphalt, trees, bare ground, water, etc. Land cover is distinct from land use despite the two terms often being used interchangeably. Land use is a description of how people utilize the land. Examples of land use include urban and agricultural land uses.

Data on land use and land cover are usually obtained with remote sensing equipment. Standard practice has these either collected using low altitude (airplane mounted) equipment or high altitude from low orbiting satellites. Data acquisition from satellite imagery is more common and substantially more cost effective for large study areas that are tens or hundreds of square miles in extent. The trade-off in satellite imagery is resolution. Current available satellite imagery is coarser (i.e., 30m grid) than low altitude (< 1m grid), but usually meets the needs of most watershed studies (including this study) involving numerical modeling.

Existing conditions for this study was established using a combination of the National Land Cover Database 2011 (NLCD 2011) (Homer et al., 2015) and externally mapped wetlands and roads. The combination of data result in 16 land use categories ranging from snow/bare rock to forest to heavy urban. Table 2 summarizes the categories used in the 2011 land use.

Table 2 Land use categories in the 2011 satellite-derived dataset, a narrative description of each one and the final land cover categories used in the development of the HSPF model.

Grid Code	Description
11	**Open Water** - areas of open water, generally with less than 25% cover of vegetation or soil.
12	**Perennial Ice/Snow** - areas characterized by a perennial cover of ice and/or snow, generally greater than 25% of total cover.
Developed	
21	**Developed, Open Space** - areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20% of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.
22	**Developed, Low Intensity** - areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20% to 49% percent of total cover. These areas most commonly include single-family housing units.
23	**Developed, Medium Intensity** - areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50% to 79% of the total cover. These areas most commonly include single-family housing units.

Grid Code	Description
24	**Developed High Intensity** -highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80% to 100% of the total cover.
Barren	
31	**Barren Land (Rock/Sand/Clay)** - areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.
Forest	
41	**Deciduous Forest** - areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species shed foliage simultaneously in response to seasonal change.
42	**Evergreen Forest** - areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species maintain their leaves all year. Canopy is never without green foliage.
43	**Mixed Forest** - areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75% of total tree cover.
Shrubland	
52	**Shrub/Scrub** - areas dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions.
Herbaceous	
71	**Grassland/Herbaceous** - areas dominated by gramanoid or herbaceous vegetation, generally greater than 80% of total vegetation. These areas are not subject to intensive management such as tilling, but can be utilized for grazing.
Planted/Cultivated	
81	**Pasture/Hay** - areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20% of total vegetation.
82	**Cultivated Crops** - areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20% of total vegetation. This class also includes all land being actively tilled.
Wetlands	
90	**Woody Wetlands** - areas where forest or shrubland vegetation accounts for greater than 20% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.
95	**Emergent Herbaceous Wetlands** - areas where perennial herbaceous vegetation accounts for greater than 80% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.

Grid Code	Description
External Source	
25	**Roads** - external data source integrated into satellite data to explicitly model road surfaces.
90	**Wetlands** - a composite of wetland coverages integrated into satellite data to improve accuracy of land use designations.

Some of the scenarios to be evaluated include the application of different treatment trains depending on the land use that otherwise would have similar runoff responses. Pollutant loadings are differentiated among impervious surfaces for evaluating cost effectiveness resulting from different simulated treatment BMPs. These conditions require separately tracking impervious surfaces for low, medium, and high development categories as well as relative fractions of road surfaces among the three categories.

Wetlands in the lower Puget Sound basin include non-forested and forested wetlands. As indicated in Table 2 (first column), only non-forested wetlands were identified. Local data that is more accurate and complete was integrated (KC DNRP-GIS, King County Wetlands 2014) into the land cover to better represent existing wetlands that include forested wetlands.

Similar to wetlands, a roads layer was integrated into the land use data to more accurately characterize roads in the watershed study area.

Land uses with negligible acreages (less than two percent) and likely to be constant among scenarios in the study area (i.e., shorelines and snow/bare rock) are merged with other existing categories to minimize the number evaluated. This framework results in converting the list of 14 land uses to 16 land cover categories. Table 3 summarizes the amount of area for each and Figure 6 is a map of existing conditions for the study area.

Table 3 Percent of basin (25.9 mi^2) and an additional groundwater source area (2.2 mi^2) by land use for current (2011) conditions.

Code	Description	Area (acres)	% of Study Area	Groundwater Basin (acres)
11	Open Water	60.40	0.4%	
21	Developed, Open Space	3892.78	23.5%	435.1
22	Developed, Low Intensity	2993.19	18.1%	276.0
23	Developed, Medium Intensity	455.41	2.7%	64.8
24	Developed, High Intensity	61.89	0.4%	21.1
25	Roads	1438.38	8.7%	
31	Barren Land	23.09	0.1%	
41	Deciduous Forest	749.61	4.5%	70.4
42	Evergreen Forest	2800.99	16.9%	256.3

Code	Description	Area (acres)	% of Study Area	Groundwater Basin (acres)
43	Mixed Forest	2807.54	17.0%	202.8
52	Shrub/scrub	187.45	1.1%	5.6
71	Grassland/Herbaceous	134.52	0.8%	35.2
81	Pasture	111.35	0.7%	
82	Cultivated Crops	20.74	0.1%	
90	Woody Wetlands	709.66	4.3%	38.0
95	Emergent Herbaceous Wetlands	113.78	0.7%	2.8

The Bear Creek basin is approximately 52 percent developed with residential, commercial, and industrial land use (Table 3). Excluding open water, wetlands, and trees, the study area is considered 54 percent disturbed.

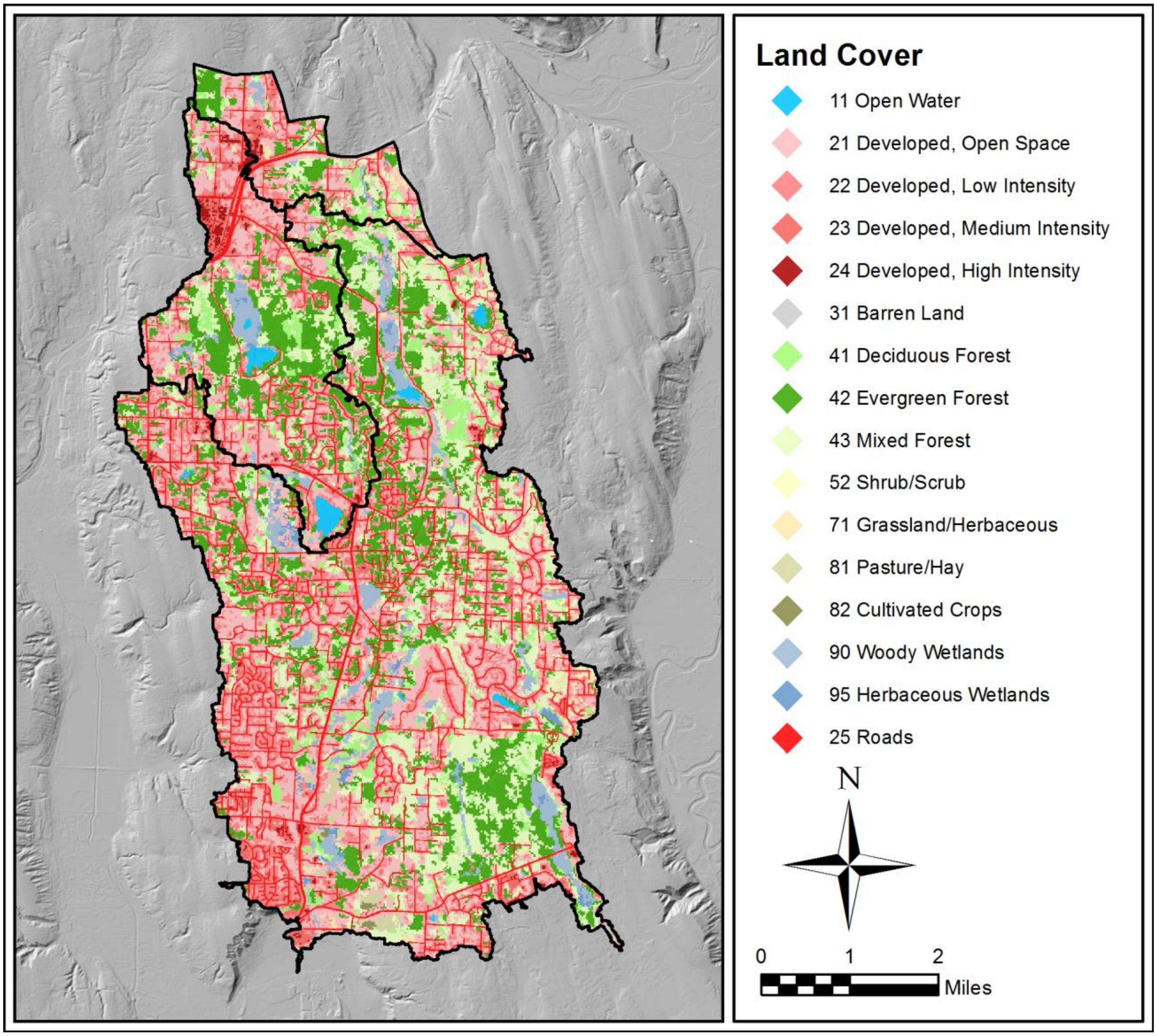

Figure 6 2011 NLCD land cover, augmented with mapped wetlands and road surfaces.

2.6 Fully Forested Conditions

A forested land cover provides a benchmark for comparison to current conditions and stormwater management approaches modeled in SUSTAIN. Aside from existing open water bodies and wetlands, all land use/cover are assumed to be forested (Figure 7). Surficial geology and topographic slopes remain the same among land use scenarios. All conveyances (i.e., the modeled stream reaches, small lakes, and stormwater infrastructure – culverts, pipes, ponds, etc.) defined in existing conditions are kept the same for forested conditions, so the effects of channel modification or loss/addition of large wood to the stream channel are not included in these simulations.

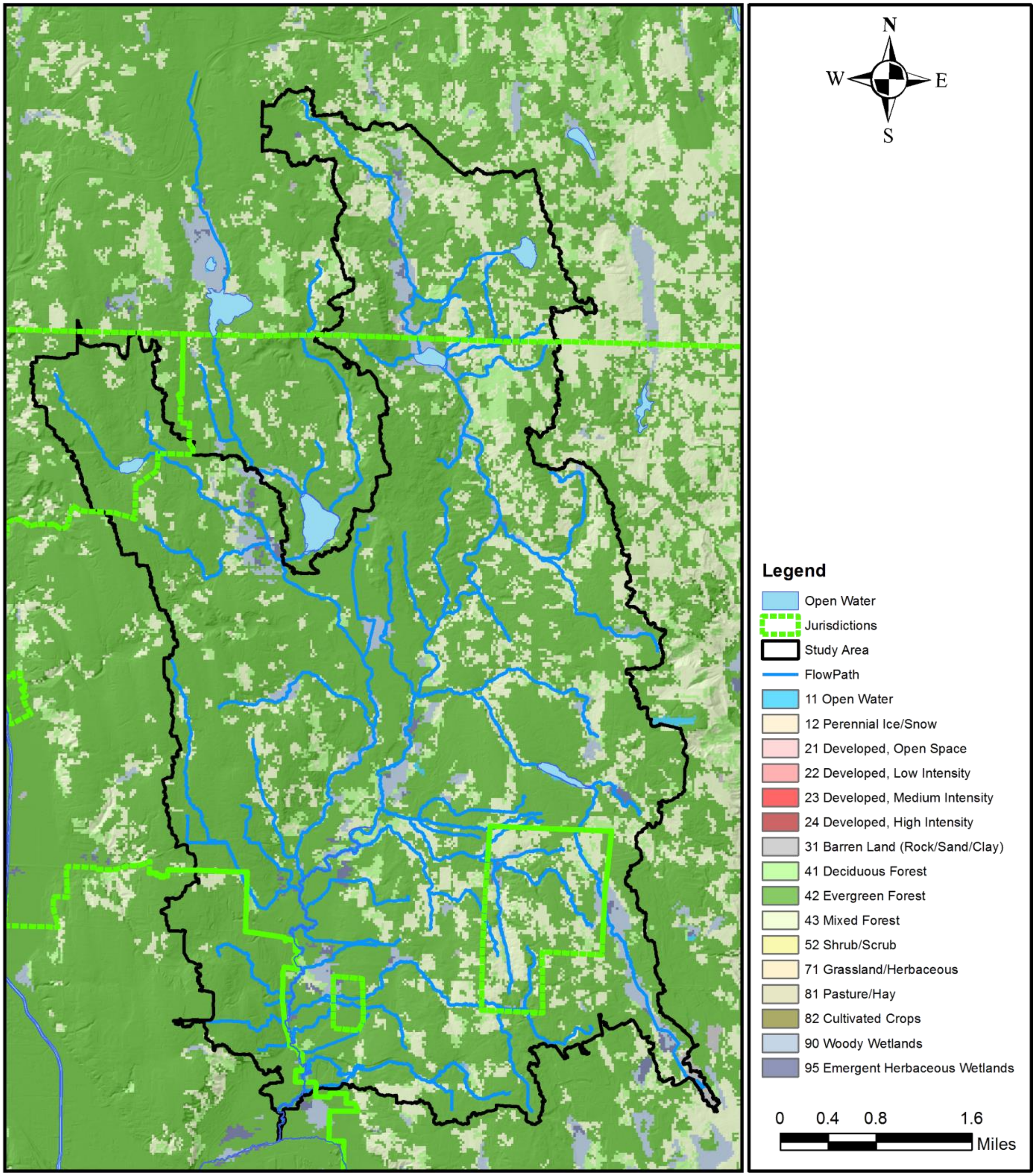

Figure 7 Map illustrating a forested landscape scenario.

2.7 Future Conditions

Future land use and land cover (LULC) conditions are derived from each jurisdiction's current land use zonings. The land use zonings are assumed not to change in the future. In the rural areas of the watershed, there are large portions of the landscape that were developed prior to adoption of the Washington State Growth Management Act (GMA) in 1990. As a consequence, portions of the development in the rural area occurred at greater densities than the current zoning. Where parcels are developed at greater densities than the zoning, the existing density superseded the current zoning (i.e., no down-zoning was applied).

2.7.1 Land use zoning

Each local jurisdiction defines zoning codes to be used within that jurisdiction. Because each jurisdiction has its own codes, different codes may represent a similar land use or the same codes may represent a functionally different land use. Zoning codes may have different names and classifications, but define similar function. The total impervious areas allowed on a parcel for a given zoning code may be different. Table 4 summarizes the zoning codes by jurisdiction and the allowed maximum impervious[4] surface on a parcel that were used to develop the future land use for this study.

Table 4 Summary of zoning codes by jurisdiction and allowed maximum total impervious surfaces used to project future conditions.

Zoning Code Source	Zoning	Fraction of parcel allowed to be impervious
KC T21.12.020	R-1	0.30
	R-12	0.85
	R-18	0.85
	R-24	0.85
	R-4	0.55
	R-48	0.90
	R-6	0.70
	R-8	0.75
	RA-10	0.15
	RA-2.5	0.25
	RA-20	0.13
	RA-5	0.20
	UR	0.30
KC T21A.12.04	A-10	0.15

[4] Refers to the total impervious surface (TIA).

Zoning Code Source	Zoning	Fraction of parcel allowed to be impervious
	A-35	0.10
	CB	0.85
	F	0.10
	I	0.90
	M	0.25
	NB	0.85
	O	0.75
	RB	0.90
Woodinville T21.20.010	CBD	0.85
	GB	0.85
	I	0.90
	NB	0.85
	O	0.75
	P	0.10
	P/I	0.80
	R-1	0.20
	R-12	0.85
	R-18	0.85
	R-24	0.85
	R-4	0.55
	R-48	0.90
	R-48/O	0.90
	R-6	0.70
	R-8	0.75
	TB	0.85
Redmond Zoning Code T21.04.010	AP	0.10
	BC	0.85
	BCDD1	0.00
	BCDD2	0.00
	BP	0.85
	CTR	0.85
	EH	0.85
	GC	0.85
	I	0.85
	MDD3	0.10
	MP	0.85
	NC1	0.85

Zoning Code Source	Zoning	Fraction of parcel allowed to be impervious
	NC2	0.85
	NDD1	0.85
	NDD2	0.85
	NDD3	0.85
	OBAT	0.85
	OT	0.85
	OV1	0.85
	OV2	0.85
	OV3	0.85
	OV4	0.85
	OV5	0.85
	R-1	0.20
	R-12	0.85
	R-18	0.85
	R-20	0.85
	R-3	0.60
	R-30	0.85
	R-4	0.60
	R-5	0.60
	R-6	0.65
	R-8	0.70
	RA-5	0.20
	RIN	0.65
	RR	0.90
	RVBD	0.90
	RVT	0.75
	SMT	0.90
	TR	0.80
	TSQ	0.95
	TWNC	0.95
	UR	0.10
	VV	0.80
Snohomish County Title 30.21.020	A-10	0.15
	A-10-SA	0.15
	BP	0.85
	CB	0.85
	CITY	0.85

Zoning Code Source	Zoning	Fraction of parcel allowed to be impervious
	CRC	0.75
	F	0.10
	F and R	0.10
	F and R O*	0.10
	FS	0.90
	GC	0.85
	HI	0.90
	IP	0.90
	LAKE	0.00
	LDMR	0.40
	LI	0.85
	MC	0.70
	MHP	0.80
	MR	0.50
	NB	0.85
	PCB	0.85
	PIP	0.85
	PRD SA-1	0.20
	PRD-12,50*	0.55
	PRD-20,00*	0.30
	PRD-20,000	0.30
	PRD-7,200	0.70
	PRD-7,200*	0.70
	PRD-8,400	0.55
	PRD-9,600	0.55
	PRD-CB	0.85
	PRD-LDMR	0.40
	PRD-MR	0.50
	PRUD	0.85
	R-12,500	0.55
	R-20,000	0.30
	R-5	0.60
	R-7,200	0.70
	R-7,200(P*	0.70
	R-8,400	0.55
	R-8,400(P*	0.55
	R-9,600	0.55

Zoning Code Source	Zoning	Fraction of parcel allowed to be impervious
	R-9,600(P*	0.55
	RB	0.85
	RC	0.02
	RD	0.10
	RFS	0.90
	RI	0.85
	RRT-10	0.15
	RU	0.10
	SA-1	0.20
	T	0.60
	TRIBES	0.10
	UC	0.85
	WFB	0.10
	WSDOT	0.50

2.7.2 Future Land Use Categories

The number of zoning codes are reduced to a more generalized suite of categories. The categories used characterize commercial land uses, various densities of residential development including rural densities, and parks (including parcels of land already acquired for land conservation purposes) among all jurisdictions. The list of future land use categories are summarized in Table 5 and illustrated as a map in Figure 8.

Future development that occurs in areas identified as environmentally sensitive (Figure 9) were assumed to occur with less impact by assuming a smaller footprint and/or less disturbance, and with increased forest retention.

More detail on distribution of land cover is found in section 2.12.

Table 5 Summary of future land use.

SYMBOL	Description	Area (acres)	Percent of Study Area
ROAD	Roads	1145.41	6.9%
COM	Commercial	0.00	0.0%
O3	Office Park 3	0.00	0.0%
O2	Office Park 2	48.58	0.3%
O1	Office Park 1	95.75	0.6%
HD5	High Density Residential 5	442.03	2.7%
HD4	High Density Residential 4	408.89	2.5%
HD2	High Density Residential 2	203.69	1.2%
HD1	High Density Residential 1	47.80	0.3%
HD0	High Density Residential 0	1095.56	6.6%
R1	Residential 1 ac	3775.20	22.8%
RA2.5	Rural Area 2.5 acres	2029.27	12.3%
RA5	Rural Area 5 acres	4553.49	27.5%
RA10	Rural Area 10 acres	1.53	0.0%
Ag2	Agriculture 2	0.00	0.0%
Ag1	Agriculture 1	0.00	0.0%
Park	Park	1290.42	7.8%
FP	Forest Preserve	0.00	0.0%
Wet	Wetlands	1381.52	8.3%
LC1	Land Conservation Type 1	3.33	0.0%
Water	Open Water	38.11	0.2%

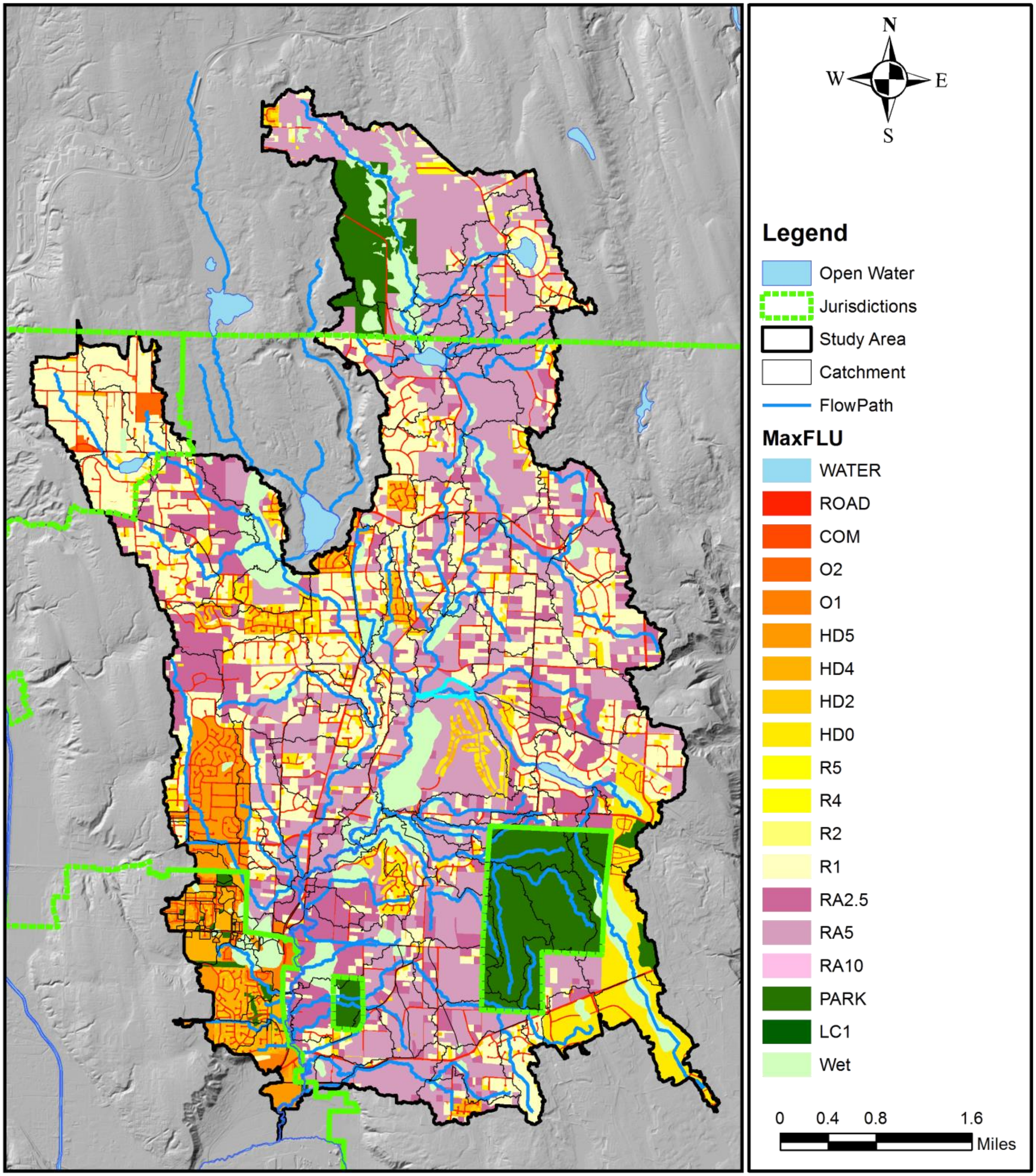

Figure 8 Map illustrating future land use.

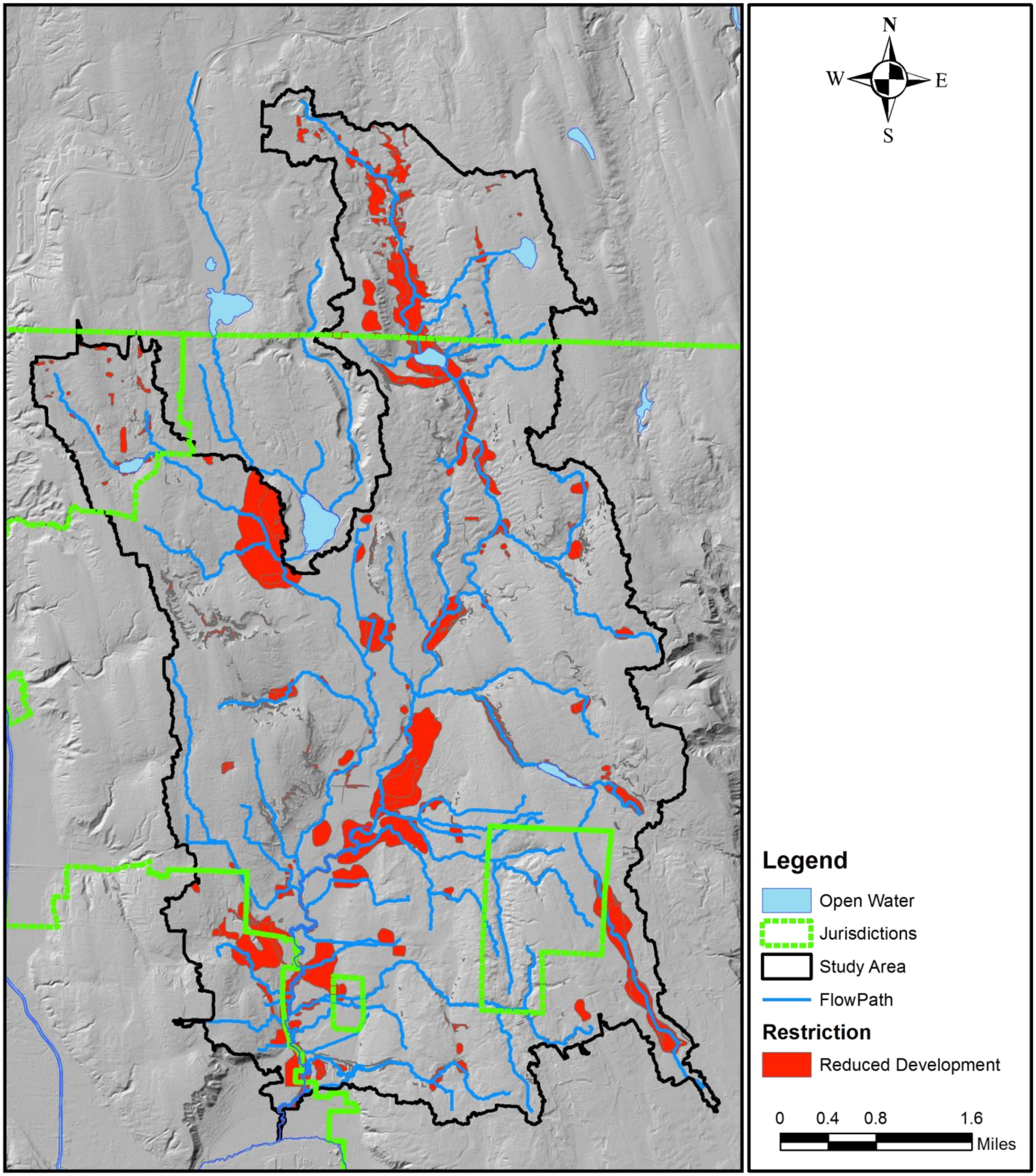

Figure 9 A map of environmentally sensitive areas are shown in red.

2.7.3 Defining Triggers for Mitigation

Future land use conditions were further parsed to differentiate how the future development might trigger stormwater mitigation. The categories defined are based on ownership, condition/age of structure on the property, and the assessed value of the structure relative to land value[5]. They are symbolized as: Govt, NewDev, ReDev_H, ReDev_M, ReDev_L, Unchanged, and ROW and defined below and shown in Figure 10. Table 6 summarizes the amount of area of each in the study area. Each category is assumed to potentially receive stormwater mitigation as part of a development requirement or as a retrofit. The consequences of this determination in modeling results are reflected in how costs are distributed between private (e.g., mitigation paid for by the developer) and public (e.g., mitigation subsidized using tax payer dollars) funds when summing up cost estimates for selected stormwater mitigation strategies in this study.

Govt – land owned by local, state, or federal government. Any mitigation that will occur will occur as retrofit.

NewDev – zoned for development but presently identified as vacant or has zero assessed improved property value (i.e., assumes no structure present on the property). New mitigation will occur in response to developer impacts.

ReDev_H – a high likelihood of redevelopment to occur that would trigger on-site mitigation. This was determined using three factors: (1) year built- generally before 1990, (2) quality of assessed building condition- generally rated fair or worse, and (3) assessed value of land improvements- generally far less than 50% of total value.

ReDev_M – a moderate likelihood that redevelopment may occur and triggering on-site mitigation. Parcels in this category were primarily residuals of not being assigned one of the other categories.

ReDev_L – a low likelihood that redevelopment would occur and/or trigger on-site mitigation. The Assessor's characterization of building condition was the primary deciding metric used. If the assessor characterized the structure in good shape or better, it was assumed to be low likelihood there would be enough redevelopment or improvements to the property to trigger on-site mitigation.

Unchanged – generally associated with property that is developed and owned by either; a government agency, a utility, a school, or exists as a park or native vegetation. Any mitigation that might occur will occur as retrofits.

ROW – right-of-way for road network. Any mitigation that occurs will occur as retrofits.

---

[5] The data used were obtained from both King and Snohomish counties' assessor's database.

Table 6 Summary of types of future development.

Future Development	Mitigation Type	Area (sq. mi.)	% of study area	% of study area
Govt	Retrofit	3.475	13.4%	81%
ReDev_M		3.292	12.7%	
ReDev_L		10.688	41.1%	
Unchanged		1.784	6.9%	
ROW		1.819	7.0%	
NewDev	New	2.586	10.0%	19%
ReDev_H		2.339	9.0%	
Total		25.983		

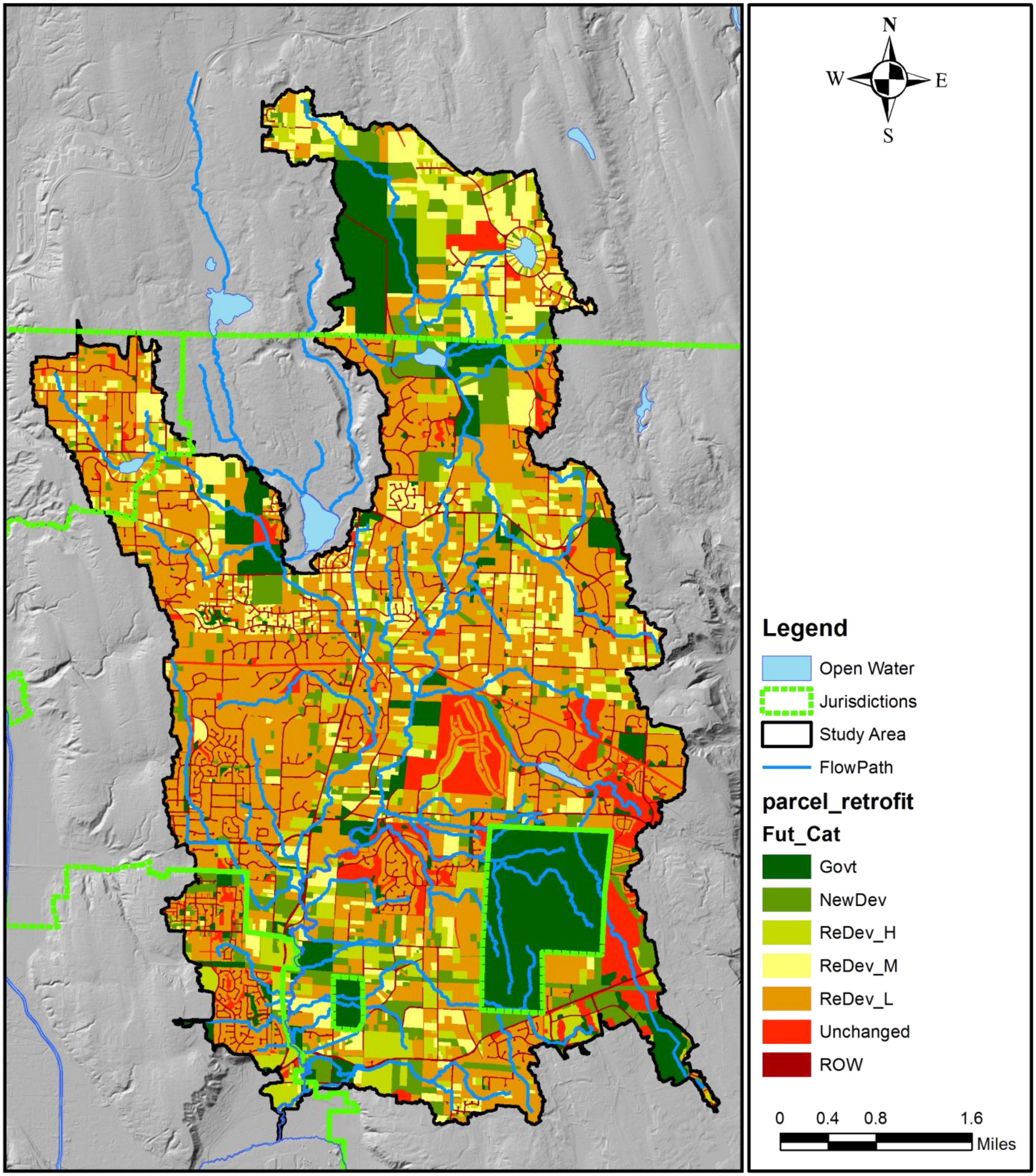

Figure 10 Map projecting where mitigation occurs as retrofit or as new development.

2.8 Surficial Geology

Surficial geology data are used to define the relative surface soil infiltration rates in the models. Data for the study area are available from the USGS (1995) and King County (1997). Surficial geology was generalized into three categories, till (low permeability), outwash (high permeability), and saturated (high permeability with low capacity because of frequent saturation). For this study, areas with bedrock were assumed to behave like till soils (USGS 1995). A map of the soils are shown in Figure 11 (King County 1997).

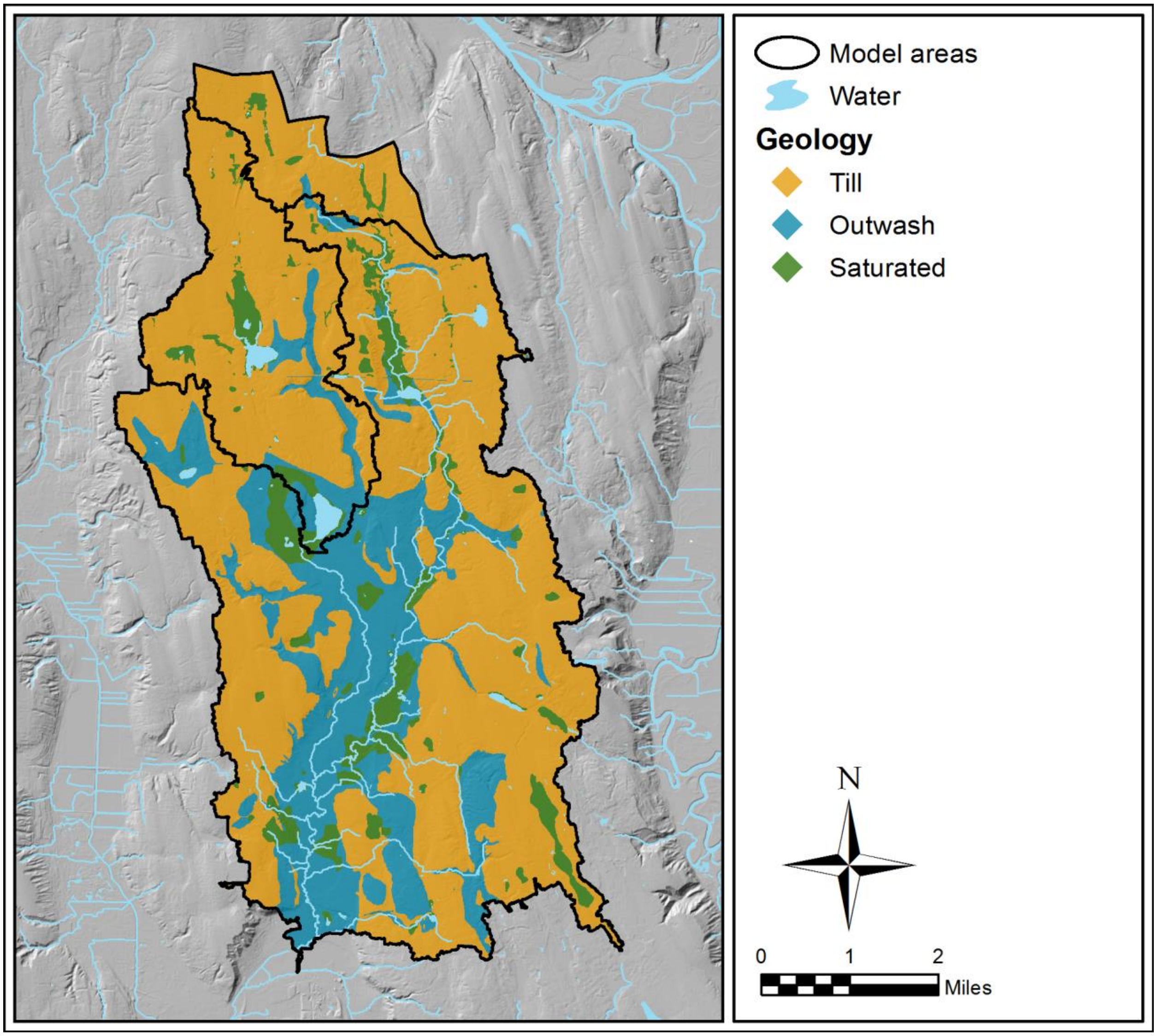

Figure 11 **Map showing surficial geology generalized to three categories: till, outwash, and saturated.**

2.9 Topographic Slope

A digital elevation model generated from LiDAR (Light Detection And Ranging) data (King County 2003) was used to aggregate topographic slopes into four categories: less than 5 percent, 5 to 10 percent, 10 to 15 percent, and greater than 15 percent (Figure 12).

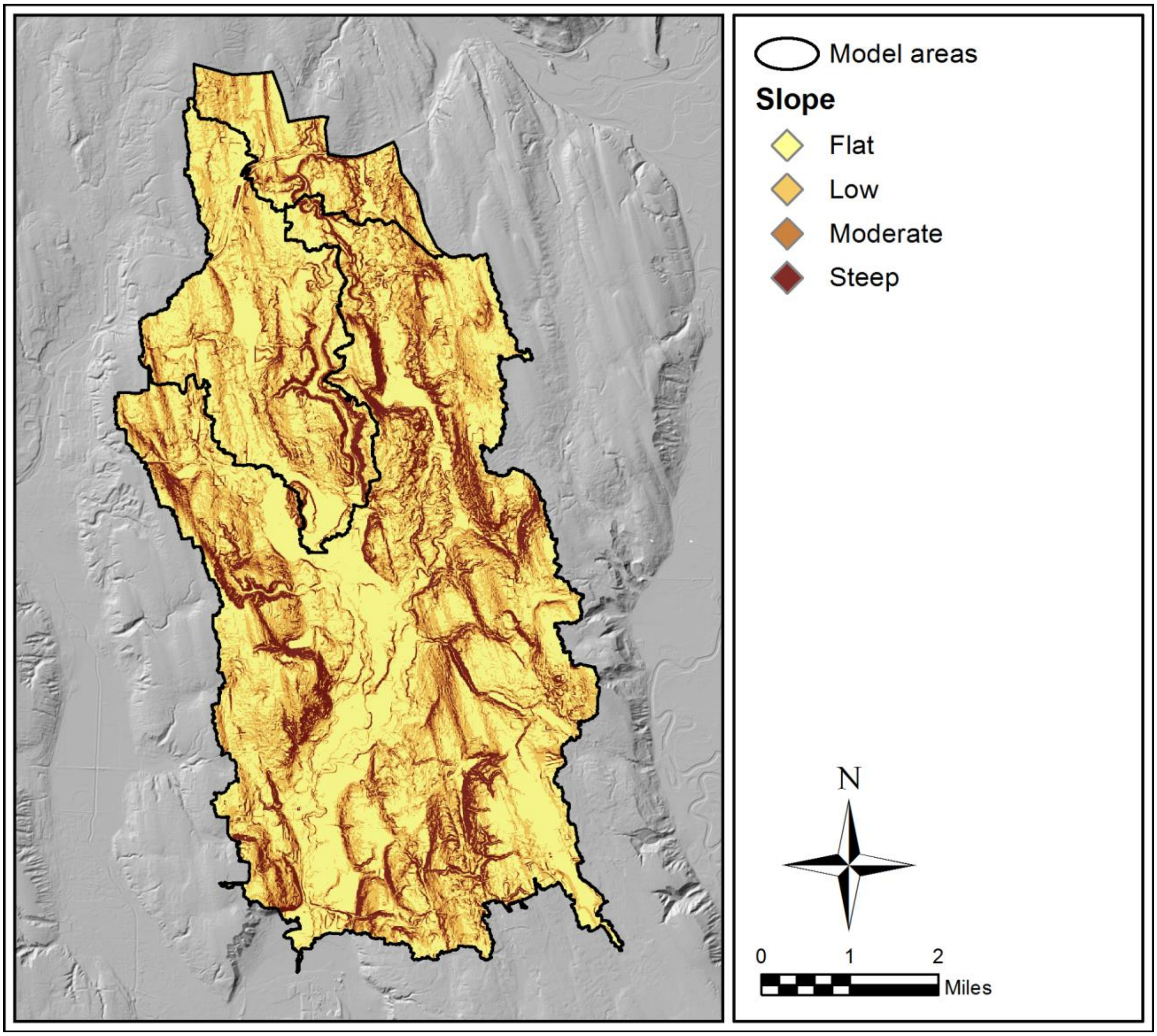

Figure 12 Topographic slope classes.

2.10 Atmospheric Data

Atmospheric data used for watershed modeling included hourly precipitation and daily evapotranspiration data. Precipitation data came primarily from a King County network of six precipitation monitoring stations in or near the study area. Precipitation data from a National Weather Service station at Sea-Tac International Airport and an evaporation data from a station at Washington State University (WSU) Extension were used to develop atmospheric input data for the HSPF models. The locations of these stations are shown in Figure 6.

For a given model domain, one or more rain gauges were used to create a composite time series that better represented the spatially varying rainfall patterns across the model domain. When more than one gauge was used, the geographic locations of the gauges relative to the model domain and spatial patterns in annual rainfall based on a gridded annual average precipitation dataset (Daly 2000) were used to help define weighting of the gauge data.

The precipitation data used to develop inputs to the HSPF models spanned various time periods and sometimes contained gaps in the records. Records from the nearest available gauge were used to fill in missing data.

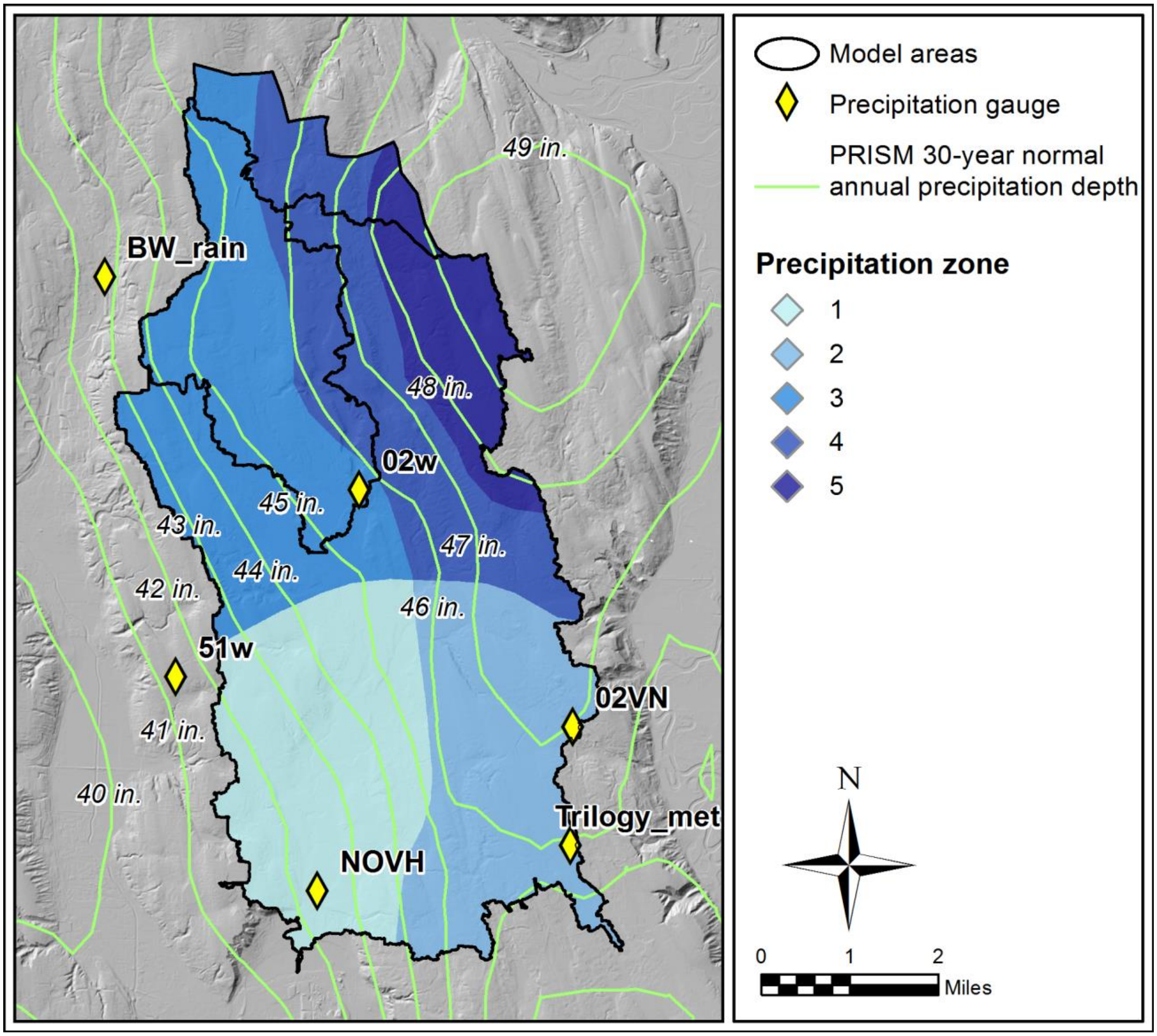

Figure 13 Precipitation gauges and model precipitation zones.

2.11 Estimating Roof Areas

Three raster datasets were used to estimate the amount of roof area in a catchment. The data sets used were the King County Impervious Surface data (circa 2009), a digital ground model (DGM), and a digital surface model (DSM). Any impervious surface that had an elevation of 10 feet or greater above the DGM was assumed to be roof. Table 7 summarizes the amount of roof for each catchment.

Table 7 Amount of total impervious surface areas (acres of TIA) and roof (acres) by catchment.

KC_ID	TIA	Roof	% Roof	KC_ID	TIA	Roof	% Roof	KC_ID	TIA	Roof	% Roof
BEA010	20.1	7.1	35.2%	BEA290	32.9	11.6	35.4%	BEA625	8.8	3.6	40.5%
BEA020	1.4	0.2	15.8%	BEA300	6.5	1.2	18.6%	BEA630	34.4	9.6	27.8%
BEA030	14.4	3.9	27.3%	BEA310	25.0	7.4	29.8%	BEA640	2.6	1.0	36.4%
BEA040	23.5	5.5	23.2%	BEA315	10.6	2.8	26.6%	BEA650	3.5	1.4	41.7%
BEA050	26.2	7.3	28.0%	BEA320	3.7	0.8	20.7%	BEA660	111.7	41.7	37.3%
BEA060	26.2	8.8	33.4%	BEA325	1.5	0.3	19.6%	BEA665	28.0	7.7	27.6%
BEA070	5.0	1.0	20.3%	BEA330	15.3	3.1	20.4%	BEA670	42.7	17.2	40.3%
BEA080	32.1	9.0	27.9%	BEA335	30.1	8.1	27.0%	BEA690	23.7	7.3	30.9%
BEA100	16.6	5.2	31.1%	BEA350	108.2	31.1	28.7%	BEA700	44.5	13.9	31.3%
BEA110	31.6	11.3	35.6%	BEA360	53.5	18.8	35.1%	BEA710	44.0	17.0	38.6%
BEA120	36.8	9.6	26.0%	BEA370	39.1	13.2	33.9%	BEA720	23.1	8.1	35.0%
BEA121	3.5	1.1	32.1%	BEA380	22.3	7.9	35.5%	BEA725	11.7	4.0	34.1%
BEA130	10.2	2.2	21.2%	BEA390	28.0	10.9	38.9%	BEA730	72.6	26.0	35.8%
BEA131	17.4	6.5	37.7%	BEA400	20.7	7.6	36.7%	BEA740	47.2	15.1	32.0%
BEA140	23.1	6.7	28.8%	BEA410	2.9	1.5	51.6%	BEA750	31.6	11.8	37.2%
BEA141	9.4	3.8	40.3%	BEA420	31.7	9.3	29.3%	BEA760	72.7	25.0	34.3%
BEA150	8.4	2.5	30.1%	BEA430	165.5	59.2	35.8%	BEA770	53.3	20.6	38.7%
BEA151	5.9	2.0	33.1%	BEA450	40.9	14.8	36.1%	BEA780	20.7	6.9	33.1%
BEA155	29.7	9.3	31.4%	BEA460	34.0	23.9	70.1%	BEA800	45.2	16.3	36.2%
BEA160	7.0	2.0	29.0%	BEA480	26.3	7.5	28.5%	BEA820	59.1	25.2	42.6%
BEA170	49.3	11.6	23.5%	BEA490	57.6	18.3	31.9%	BEA830	41.4	16.5	39.8%
BEA180	14.6	4.4	30.4%	BEA500	44.0	16.7	37.9%	BEA840	70.1	29.2	41.6%
BEA190	72.9	24.7	33.9%	BEA510	34.5	11.2	32.6%	BEA850	60.2	26.7	44.4%
BEA200	71.5	17.1	24.0%	BEA525	24.6	8.3	33.7%	BEA860	63.4	26.2	41.3%
BEA210	9.5	1.9	20.0%	BEA530	73.4	23.4	31.9%	BEA900	32.5	12.1	37.1%
BEA220	38.3	11.1	29.1%	BEA540	22.1	7.0	31.7%	BEA910	45.7	16.4	35.9%
BEA230	12.8	1.4	10.8%	BEA550	30.6	10.9	35.6%	BEA920	77.2	23.4	30.3%
BEA240	30.3	7.0	23.1%	BEA570	30.5	11.0	36.1%	BEA940	79.4	25.6	32.2%
BEA245	24.8	5.5	22.2%	BEA580	30.4	11.4	37.5%	BEA950	58.3	20.2	34.7%
BEA250	170.0	54.3	31.9%	BEA590	26.0	6.9	26.5%	BEA960	164.8	58.0	35.2%
BEA260	8.4	2.5	30.1%	BEA600	32.2	8.9	27.8%	BEA970	259.4	50.0	19.3%

KC_ID	TIA	Roof	% Roof	KC_ID	TIA	Roof	% Roof	KC_ID	TIA	Roof	% Roof
BEA270	26.7	8.9	33.5%	BEA610	25.7	9.8	38.0%	BEA990	69.4	22.5	32.5%
BEA275	39.6	12.3	31.0%	BEA620	6.9	2.9	41.3%	MON030	135.9	37.3	27.4%
BEA280	29.8	7.6	25.3%								

2.12 Hydrologic Response Unit Definitions

The intersection of land use, geology, slope, and rainfall zones are combined and become a Hydrologic Response Unit (HRU). The potential number of unique HRUs generated from this process can number in the 100's in a single model. The architecture of HSPF allows for this and still be feasible to run multiple simulations. Because SUSTAIN needs to run thousands of simulations, feasibility becomes an issue in both required computer memory and model runtime. The number of HRUs needed to be reduced when building the SUSTAIN models. The reduction was based on selecting the group of HRUs within the same rainfall zone that had the largest amount of area within the HSPF model. This reduced the number of HRUs from hundreds to a little over one hundred in total.

Impervious surfaces associated with land cover categories are not assumed to be 100 percent effective in generating runoff that almost immediately reaches a stream. There are inherent losses of impervious surface runoff to pervious areas where infiltration may occur. As the relative amount of impervious surface increases, the less opportunity there is for impervious runoff to run on to pervious surfaces and infiltrate. The fraction of total impervious area (TIA) that is effective in generating immediate runoff to streams is referred to as effective impervious area (EIA). The remaining impervious area and often the disturbed pervious areas are classified as "grass." For example, a residential area may be 50% total impervious with roof tops, driveways, streets and 50% lawn. The total area considered effective impervious may only be 15% when accounting for splash blocks for roof downspouts, driveways sloping towards lawns, etc. The remainder of the residential area, the remaining impervious and pervious areas (i.e., 85%), then behaves more like lawn (i.e., disturbed pervious area). In rural portions of the study area, parcels can be significantly larger. For larger parcels, there is a general propensity to retain some of the natural tree canopy. Thus, for larger parcels, there is also the retention of forest, shrubs, etc.

EIA assumptions are initially based on previous studies conducted in the Puget Sound region (e.g., Dinicola 1990 & 2001, Elmer 2001, and King County 2009). Initial estimates of EIA fractions for each land use category were adjusted based on professional judgment regarding the character of particular developed areas. Some roads might be curbed, may have storm sewer networks, etc., which may more efficiently direct runoff to storm drains and/or stream systems. The same density of development in another area may have no curbs and no storm network. Thus, the effect of those impervious areas will behave differently for the same total impervious area.

Not all storm water management infrastructure that may be present in the drainage area was explicitly modeled. They become implicit in the system by adjusting the EIA fractions.

These adjustments to EIA were made in the calibration process and are further described in Section 3.0.

2.13 Hydraulic Conveyances

2.13.1 Integrating Existing Stormwater Facilities

The Bear Creek project team reviewed stormwater regulations history and existing stormwater infrastructure (King County, 2017g). The review tabulated an inventory of existing ponds and vaults in the Bear Creek Basin, and summed the detention storage (current) in the basin provided by those facilities. Stormwater facilities within the City of Redmond were not explicitly accounted for in the Bear Creek hydraulics except for Monticello Creek. All flow control facilities in Monticello Creek were inventoried and explicitly put into the watershed models.

Each facility was then characterized into a stage-surface area-storage volume-discharge relationship (i.e., FTABLE). Each pond's FTABLE was integrated into the model's catchment reaches (i.e., FTABLE). Thus while the existing stormwater ponds may not be explicitly modeled individually, they were accounted for in storage volumes and conveyance capacities defined for each catchment reach (may be more than one pond added to a given reach).

2.14 Stream Flow and Water Temperature

Stream flows are used as part of the model development for calibrating watershed models and to a lesser degree defining catchment delineations. Some existing gauging stations were continued and some were established as part of the overall study to support HSPF model development. Six of the twelve stream gauging stations were used as primary points of calibration (Table 8 and Figure 14).

There were twenty-one stream temperature stations available for comparisons. Twelve were used as primary points of comparisons for calibration. The remaining were used for guidance. For more details regarding the existing data available for use in model development, the reader is referred to King County (2017a).

The periods of available data at each station ranged from one year to as many as 20+ years—gauges that had less than one year of data or were upstream of a primary calibration point were used as guidance only. Data recorded in 15 minute increments were aggregated to average hourly values for model calibration.

Table 8 Summary of stream flow gauges used to calibrate the HSPF models. (G) indicates a gage used for guidance.

Model Domain	Gauge Name	Flow	Temp
Cottage Lake	02G	✓	✓
Upper Bear	02F2	✓	✓
Colin/Struve	02M	✓	✓
Intermediate Bear	02E	✓	✓
Middle Bear	02R	✓	✓
Monticello	BC0119	✓	✓
Cottage Lake	02L	G	✓
Colin/Struve	02M2	G	
Seidel	02o	G	
Seidel	02p	G	
Stensland	BC0114	G	
Mackey	02Q	G	
	ET484		✓
	BCP06		✓
	02M		✓
	BCP02		✓
	BCP03		✓
	BCP09		G
	C484		G
	J484		G
Seidel	S. Seidel		G
Seidel	E. Seidel		G
	BCP04		G
	BCP10		G
Paradise Lake	BCP01		G
	N484		G
Monticello Creek	BCP08		G

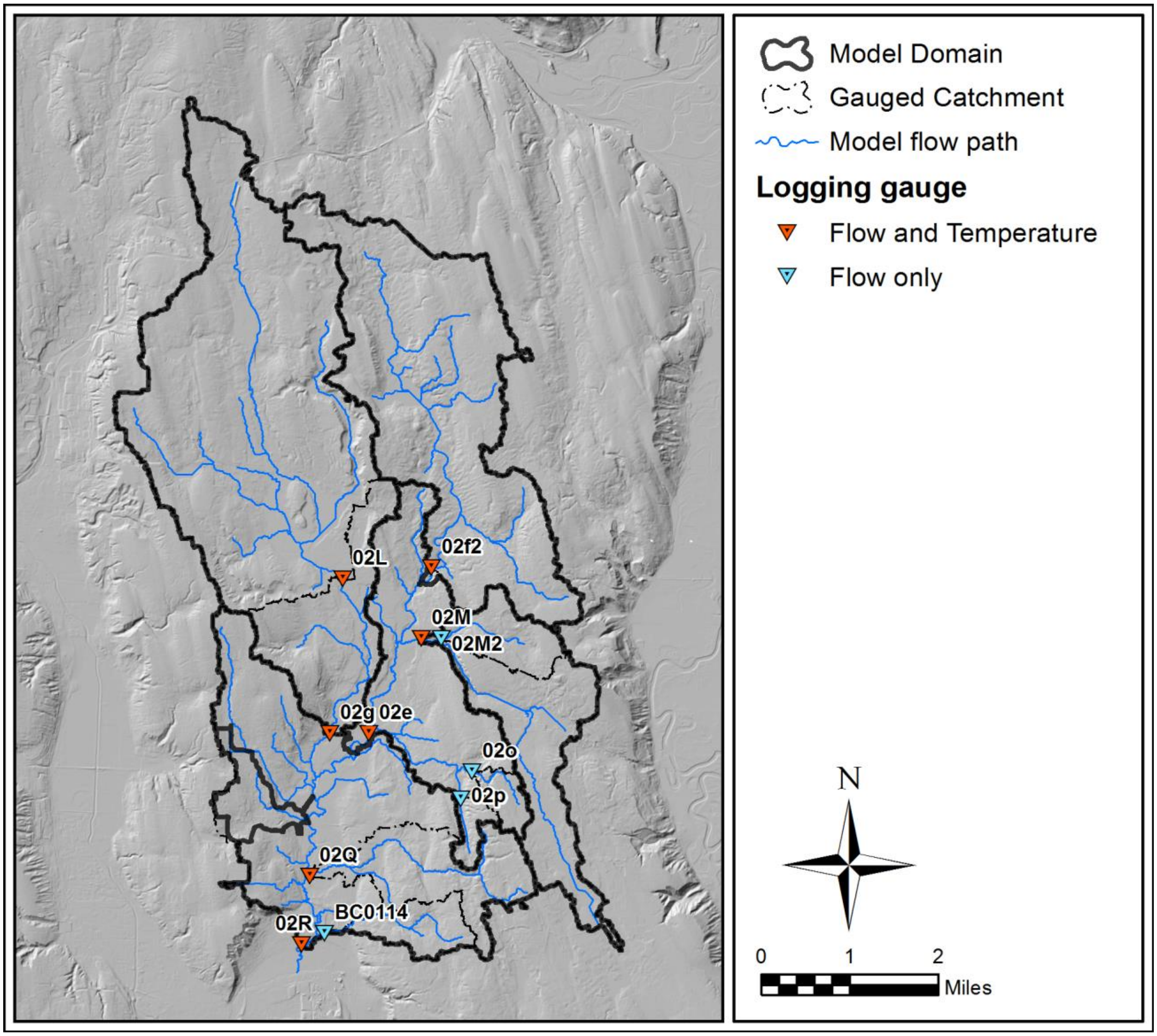

Figure 14 Map of stream flow gauges used for model development.

2.15 General Water Quality

Fecal coliform, total suspended solids (TSS), copper, and zinc concentration data from eleven locations were used during the calibration. During the calibration process, matching simulated to observed data was prioritized at the outlets of the three model domains listed below in Table 9. Locations of water quality data available for calibration are shown in Figure 15.

Table 9 Summary of water quality monitoring stations used for model development.

Model Domain	Station ID
Cottage Lake	N484
Upper Bear	BCP10
Colin/Struve	BCP04
Monticello	BCP0119
Used for Guidance	BCP02
Used for Guidance	BCP03
Used for Guidance	BCP01
Used for Guidance	BCP06
Used for Guidance	J484
Used for Guidance	ET484
Used for Guidance	BCP09
Used for Guidance	C484

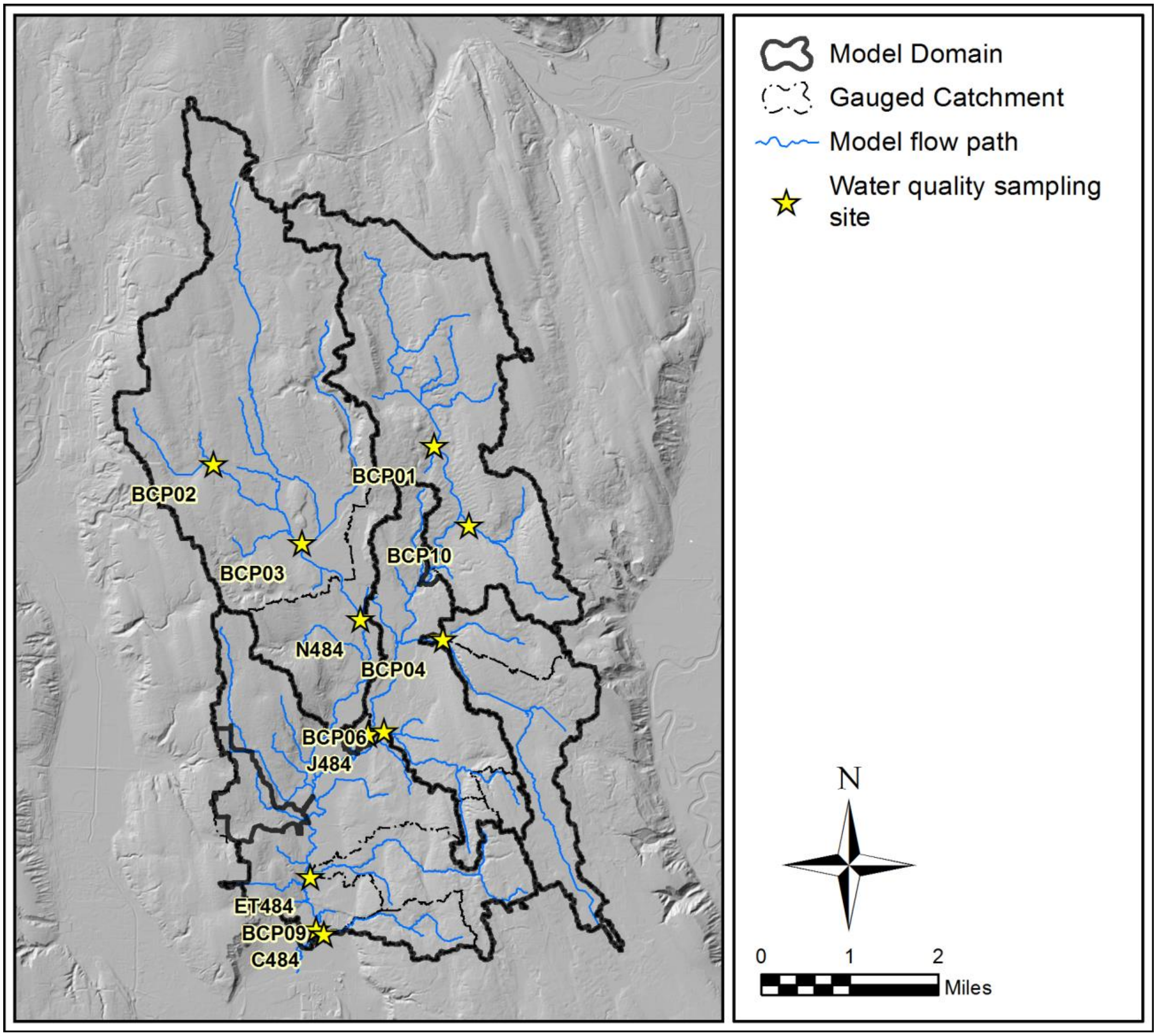

Figure 15 Map of water quality monitoring stations used for model development.

2.16 Benthic Index of Biotic Integrity (B-IBI)

Measuring diversity and abundance of the in-stream biological community has been well established as a measure of overall stream health and is part of the permit requirement for this watershed planning effort. Biological data collected by different agencies in 2014 at 35 locations within the study area were used as guidance in selection from among several regression models correlating B-IBI and stream flashiness. The regression models evaluated correlating stream flashiness and recorded B-IBI scores were established from past efforts (e.g., King County 2012, Horner, 2013, and King County 2015, 2017f) in the Puget Sound region.

B-IBI scores are grouped into five categories characterizing stream health. The scoring system has shifted from a score of 10-50 (Morley 2000) to a score of 0-100 (King County

2014). The five categories are: very poor (0-20), poor (20-40), fair (40-60), good (60-80), and excellent (80-100). B-IBI scores recorded in 2014 varied from *very poor* to *excellent*, with the majority of locations classified as *fair* to *good* (Figure 16).

There are limitations (i.e., weaknesses) associated with using regression models of stream flashiness with recorded B-IBI scores. Environmental stressors that can influence the B-IBI score include more than simply stream flashiness. Thus, while projections of B-IBI scores may be made using stream flashiness exclusively, true responses of the benthic community are dependent on the health of other habitat conditions as well. This is particularly realized in measures of B-IBI in the Redmond Watershed Preserve—a forested drainage area with B-IBI scores in the fair and very poor range.

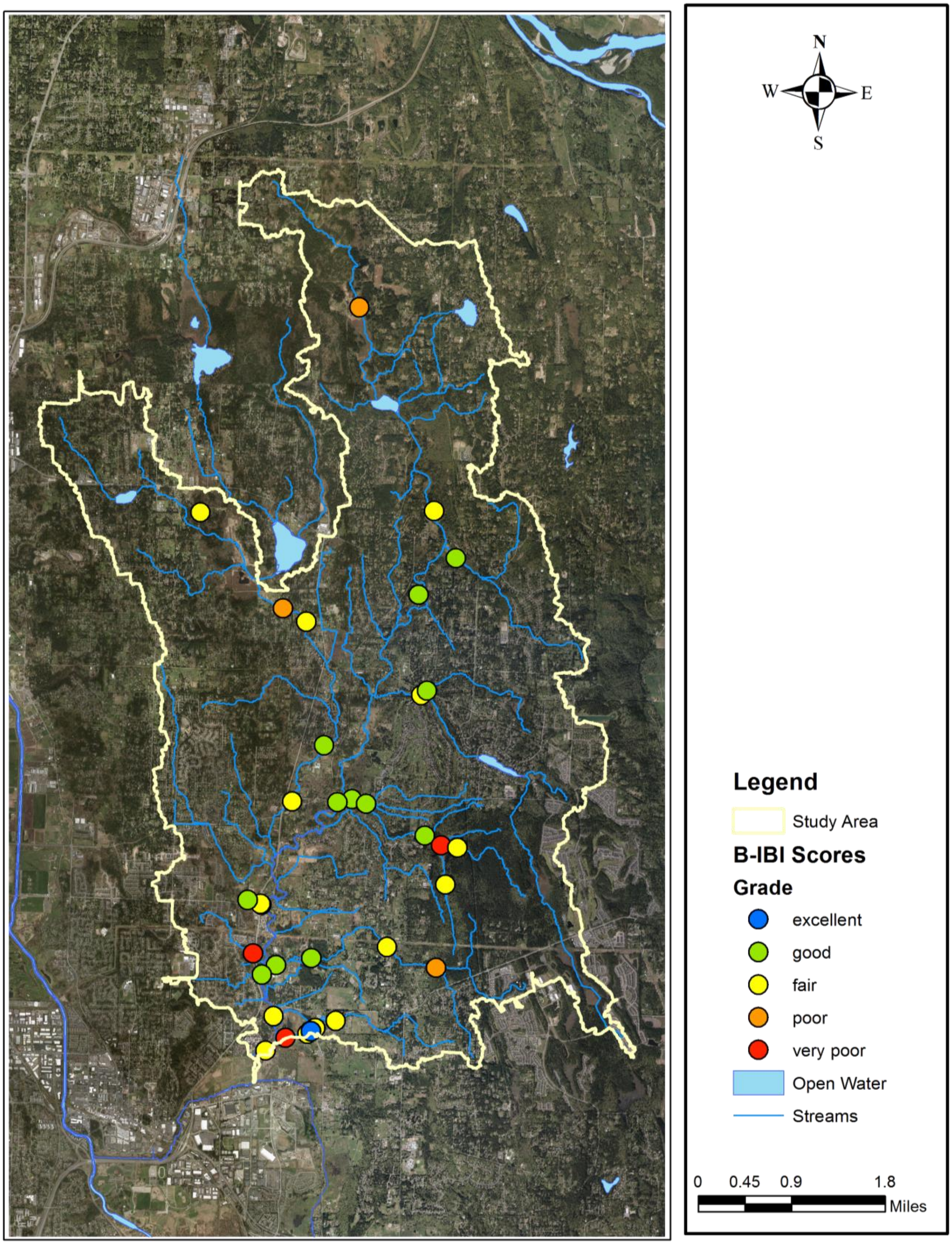

Figure 16 B-IBI scores recorded in 2014.

Regressions from four different studies were evaluated for use in the Bear Creek watershed study. Juanita Creek and WRIA 9 studies were identified as a permit requirement to be considered as part of the watershed planning process. The other two were explored as alternative methods for analysis. The four studies evaluated are listed below with a short description of relevance to this study.

Juanita Creek Stormwater Retrofit (King County 2012) is a permit expectation. Nine flashiness metrics (e.g., High Pulse Counts, etc.) were used to develop regressions based on data used in the DeGasperi (2009) study.

WRIA 9 Stormwater Retrofit (King County 2014) is a permit expectation. Four flashiness metrics were explored and used to correlate to B-IBI scores, one of which was High Pulse Counts (HPC). Regressions used were a combination of Logit and transformed regressions models.

WRIA 8 Status and Trends (King County 2015) is an alternative method. Correlations were found between B-IBI scores and stream flashiness (HPC), fines in the streambed, riparian shading, and volumes of large wood in the stream. Regressions were developed using that dataset.

Bear Creek study (King County 2017f) is an alternative method. A report that expanded the data set used to include all of the Puget Sound region, WRIA 8 data, and evaluated the established flashiness metrics defined in the above mentioned studies.

A comparison of HPC regressions based on the different studies mentioned above are listed below in Table 10 and plotted in Figure 17. Some of the studies used regressions based on the B-IBI scoring system 10-50. In those cases, regressions were redefined using the 0-100 B-IBI scoring system for comparisons purposes. Some additional regressions are provided for alternative flashiness metrics (Table 11).

Table 10 Summary of HPC regressions from four different studies based on B-IBI score 0-100.

Regression	Slope	Intercept
Juanita Creek	-3.7341	72.0174
WRIA 9*	-0.066	4.5
Puget Sound	-1.3421	64.8163
WRIA 8	-2.9567	86.8309

*WRIA 9 used a transformed model. The predicted values in the Figure 17 are the exp().

Table 11 Summary of additional regressions from two different recent studies.

Regression	(B-IBI, 0-100)		
	Metric	Intercept	Slope
WRIA 8	HPC	86.831	-2.957
	HPD	11.531	9.322
	HPR	88.3741	-0.1759
	TQmean	-29.11	235.23
WRIA 9*	HPR	4.69	-0.005

*WRIA 9 used a transformed model (natural log).

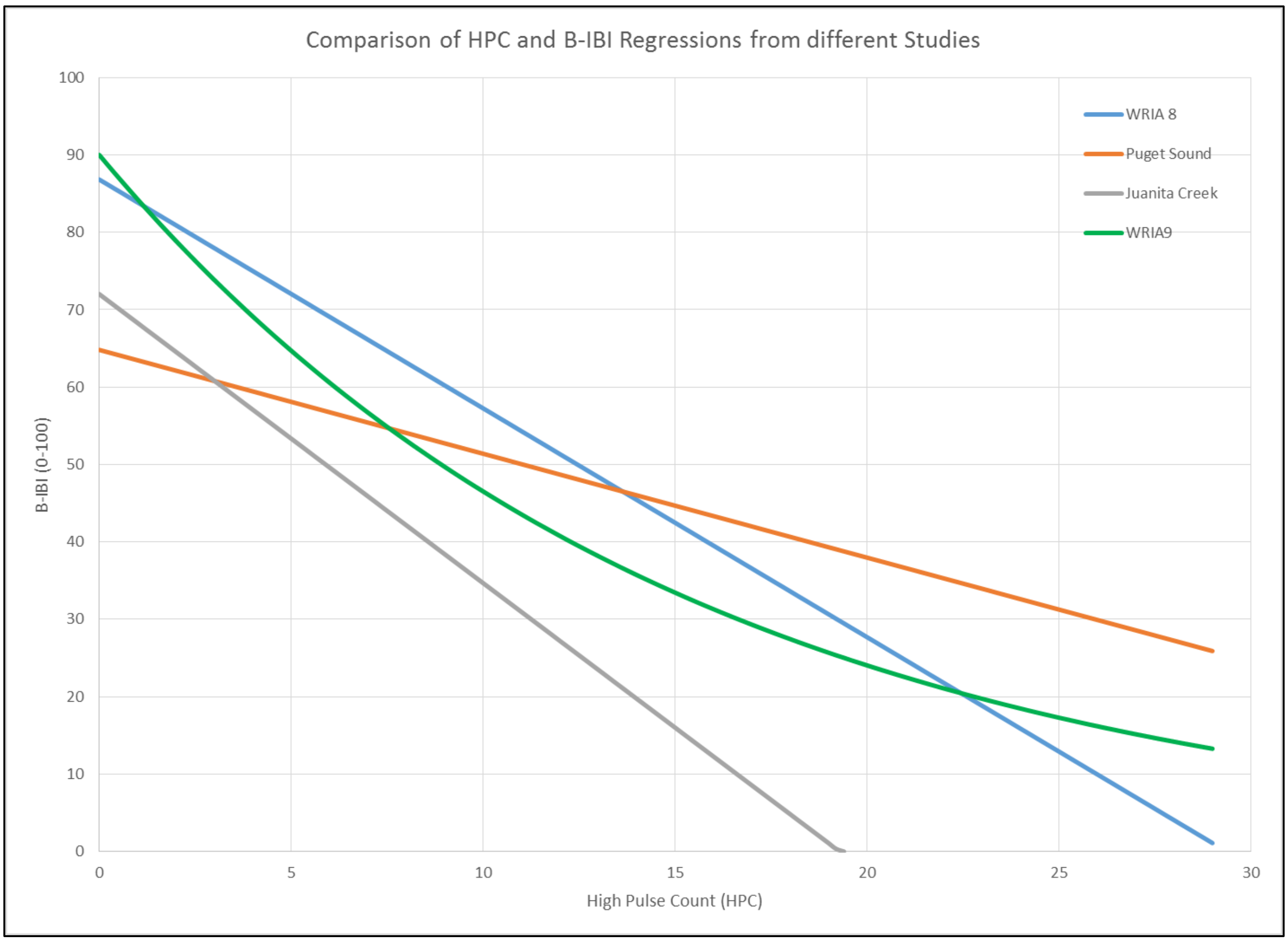

Figure 17 Comparison of regressions among studies for High Pulse Counts (HPCs) using the B-IBI scale of 0-100.

The high pulse count (HPC) hydrologic flashiness metric has repeatedly been demonstrated to have one of the strongest relationships between flashiness and B-IBI (e.g., DeGasperi 2009, King County 2012, King County 2013, and King County 2014). In addition, the only *flashiness* metric calculated internally in SUSTAIN is the HPC. Given these findings and SUSTAIN's functionality, HPC is the primary metric used for evaluating stormwater mitigation strategies effectiveness. All other metrics are for additional information, to support comparisons of results from other studies, and for permit compliance.

2.17 Metrics and Targets

Metrics used for measuring effectiveness in stormwater strategies include: Fecal coliforms, B-IBI using flow rates, water temperature, and dissolved copper and zinc.

2.17.1 Fecal Coliforms

Fecal coliform requirements have a series of criteria dependent on magnitudes and fraction of time occurred. A 30-day geometric mean is used for comparing to the criteria. There are three levels of concentration evaluated using a 30-day geometric mean of simulated concentrations: Extraordinary, Primary, and Secondary. The thresholds associated with each are 50, 100, and 200 (CFUs/100ml) respectively. When evaluating based on fraction of time, the concentrations for the three categories are 100, 200, and 400 (CFUs/100ml).

2.17.2 B-IBI

Guidance provided by Ecology defines a target for B-IBI scores in two ways: absolute and relative. In absolute terms, stormwater strategies should achieve a B-IBI score that reflects a stream in *good* or better biological conditions. At the time when the NPDES permit was written requiring this watershed modeling effort, the B-IBI scoring system ranged from 10-50 with a score of 38-44 equal to good biological conditions. Since then, the B-IBI scoring system has been updated and now ranges from 0-100. Good biological conditions using this scale range from 60 to 80. Thus the target used for defining success is achieving a B-IBI score of 60 or greater.

As previously discussed, the level of uncertainty in the correlation between flashiness and B-IBI is not trivial. One of the benefits of developing a watershed model is the ability to make reasonable comparisons when uncertainty is known (or unknown). Whatever the uncertainty might be, the watershed model keeps the error/bias the same. Thus, an alternative target for B-IBI can be tied to a modeling scenario. Again as described by Ecology's guidance document, an alternative B-IBI score can be based on 90-percent of calculated B-IBI score using a forested land cover scenario. These values are described in section 3.1.11 after the calibration of the HSPF models.

2.17.3 Water Temperature

Water temperature criteria are variable during the year and also dependent on the salmonid species of concern in that stream system. Temperature water quality standards are defined in the WAC and based on the statistic of the seven day average of the daily maximum water temperatures (7-DADMax). Criteria set for water temperatures in the study area are based on two seasons:

- May 16 through September 14, 7-DADMax ≤ 16 °C
- Sept 15 through May 15, 7-DADMax ≤ 13 °C

2.17.4 Copper and Zinc

Washington State dissolved copper and zinc water quality standards are dependent on concentrations of hardness in the water. Analyzed concentrations of hardness within the Bear Creek study area between the years 2006 and 2016 (Figure 18) were used for establishing thresholds on a monthly basis. Equations using hardness to define the criteria for metals concentrations are found in Washington State Administrative Code (WAC 173-201A-240). Table 12 summarizes the target concentrations for acute and chronic concentrations for copper and zinc using those equations found in the WAC.

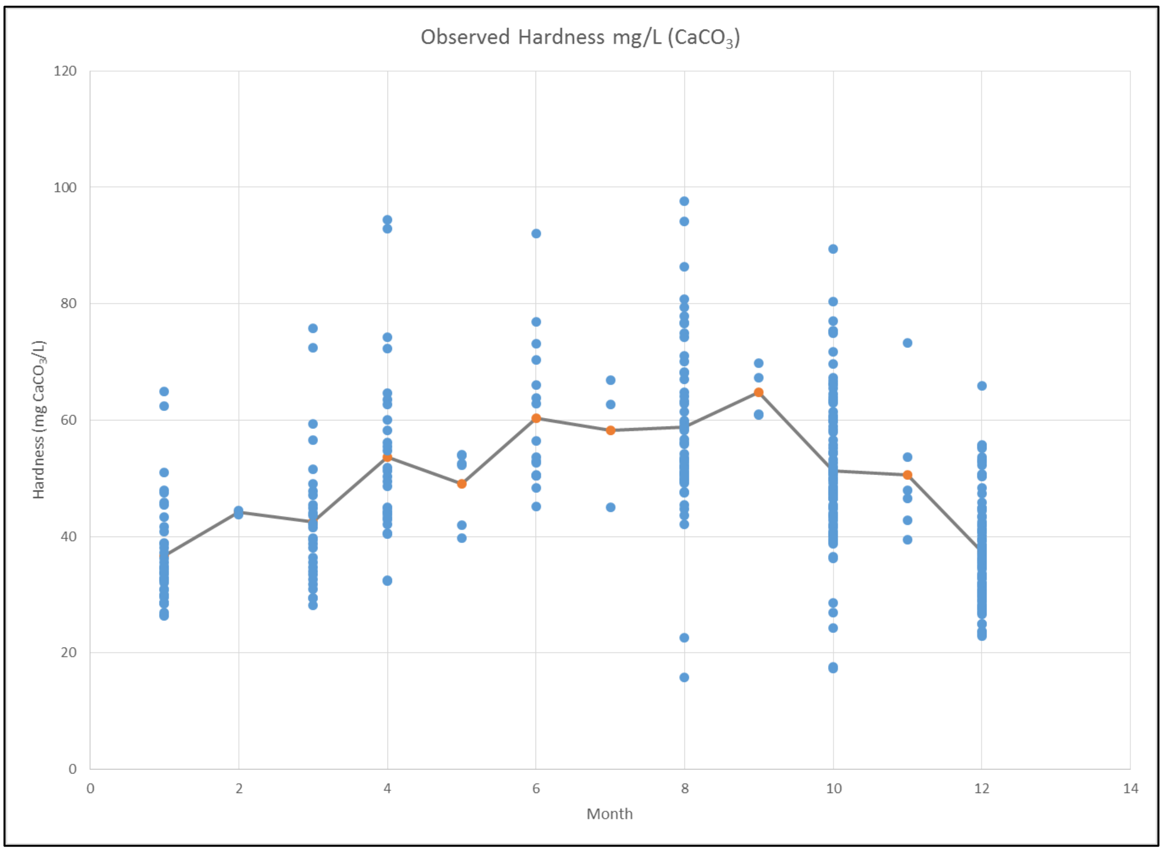

Figure 18 Hardness ($CaCO_3$) concentrations collected in the Bear Creek study area during the years 2006-2016. A plot of the month average is provided as a line.

Table 12 Average monthly hardness concentrations and WAC-201 criteria for acute and chronic concentrations of dissolved copper and zinc.

Month	Hardness (mg/L)	Dissolved Cu (ug/L)		Dissolved Zn (ug/L)	
		Acute	Chronic	Acute	Chronic
1	36.64	6.61	4.81	48.88	44.63
2	44.15	7.88	5.64	57.25	52.28
3	42.53	7.60	5.47	55.46	50.65
4	53.69	9.47	6.67	67.56	61.70
5	49.08	8.70	6.18	62.62	57.18
6	60.37	10.58	7.37	74.63	68.14
7	58.20	10.22	7.15	72.35	66.06
8	58.78	10.31	7.21	72.96	66.63
9	64.75	11.30	7.83	79.19	72.31
10	51.29	9.07	6.42	65.00	59.35
11	50.60	8.96	6.34	64.26	58.68
12	37.38	6.73	4.90	49.72	45.40

2.18 BMP Treatment Train

The treatment train sequence of BMPs is as follows:

- cistern to bioretention (rain garden)
- permeable pavement to bioretention (road bio-swale),
- bioretention (either) to stacked wet+dry (RD) pond,
- RD pond to wet pond,
- wet pond to gravity well, and
- gravity well to stream.

As part of the optimization in SUSTAIN, when anyone one or more of the BMPs listed above are not part of a solution run, SUSTAIN will shunt the stormwater effectively by-passing the omitted BMP and conveying the runoff to the next included BMP in the treatment train. There are no underdrains assumed in the BMPs and permeable pavement is assumed to include a sand filtration layer to provide enhanced treatment.

Figure 19 is an illustration of the sequence of BMPs in the treatment train listed above.

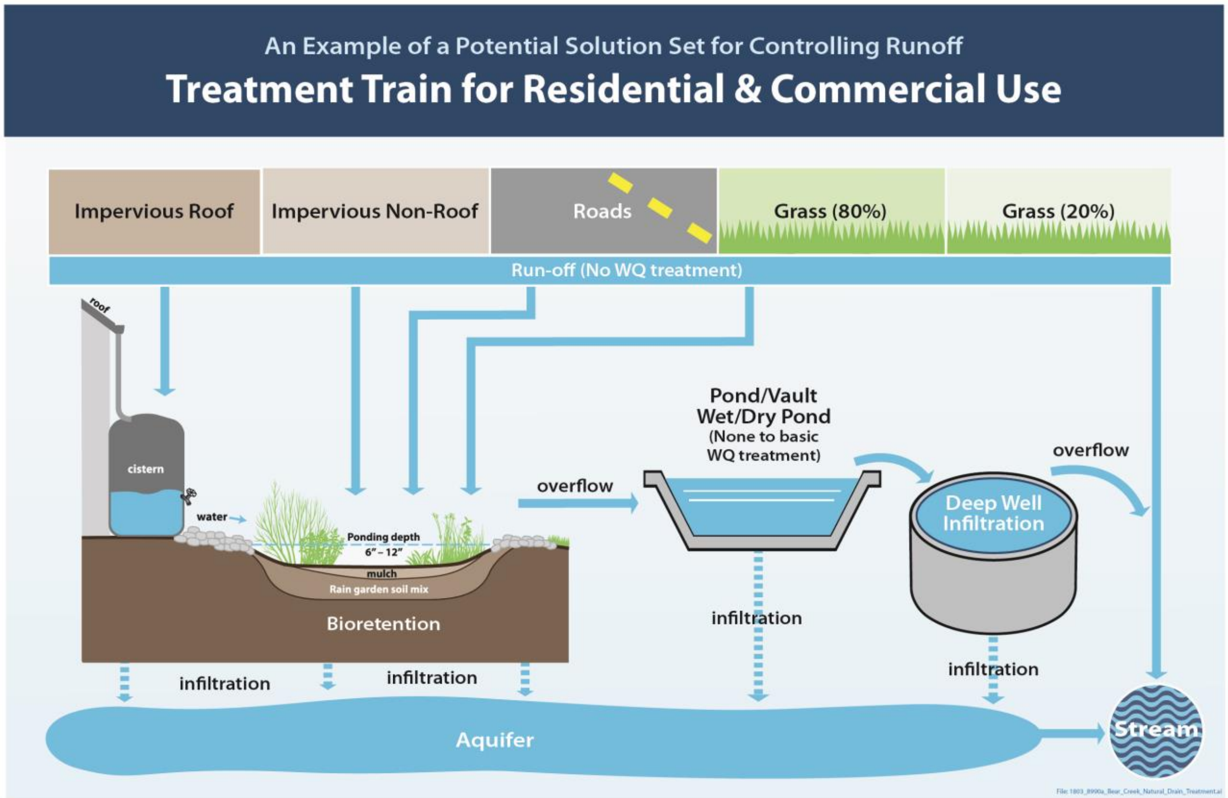

Figure 19 Illustration of treatment train of BMPs.

2.18.1 BMP Costs

Cost estimates for BMPs were derived from various resources in the region. Foremost was the work estimating BMPs in the King County WRIA 9 Stormwater Retrofit project that resulted in a database of regional cost estimates for various types of BMPs (Herrera 2012).

BMP unit costs used in the SUSTAIN optimization runs are listed in Table 13 below.

Table 13 Summary of BMP unit costs used in optimization.

BMP	Unit Price
Bioretention OW	$16,165
Bioretention OW Roads	$23,245
Bioretention Till	$26,309
Bioretention Till Road	$15,315
Cistern	$2,913
Permeable Pavement	$155,733
Gravity Well	$84,228
Infiltration Pond	$158,443
Dry+Wet Pond	$314,194
Wetpond	$78,938

However, these cost estimates were subsequently refined (Table 14) during post analyses of the modeling results. Costs were split into five categories: (1) construction, (2) soft costs, (3) maintenance, (4) land acquisition, and (5) replacement.

1. Construction costs are assumed to be what it takes to put something on/in the ground and are keyed to either the volume of excavation or surface area of the BMP. Costs generally are assumed to be construction and materials.
2. Soft costs are indicative of preliminary design costs, permitting, and costs of activities associated with leading up to construction. Soft costs are based on a percentage of the construction costs.
3. Maintenance costs include soil replacement in bioretention and are amortized on a yearly basis.
4. Land acquisition costs are costs associated with acquiring a parcel of land that has a structure on it. The county Assessor's database was used to calculate the median assessed value (land plus improvements) per acre in the King County portion of the study area ($744,876/acre = $17.1/SF). Land acquisition was only applied to the larger facilities (i.e., ponds and the gravity well).
5. Replacement costs are estimates based on replacing control structures for ponds, and equivalently full replacement for gravity wells, permeable pavements, and bio-retention BMPs.

The total cost (public and private) for any particular BMP used for the cost effectiveness analyses, includes assumed maintenance and replacement costs that would occur over a 100 year time period.

<u>Note:</u> All costs are in 2017 dollars with no adjustments made for inflation or discount rates.

Table 14 Refined Unit BMP dimensions, costs, and replacement schedules used after optimization runs were completed.

BMP	Length (ft)	Width (ft)	Depth (ft)	Construction	Land Acquisition	Soft Cost	Maintenance (annual)	Replacement	Replacement Schedule (years)
Bioretention Outwash	8.8	8.8	1	$2,448	$0	30%	$98	$3,182	50
Bio Roads Outwash	48	2	1	$1,198	$0	30%	$122	$1,557	50
Bioretention Till	11.2	11.2	1	$3,965	$0	30%	$160	$5,154	50
Bio Roads Till	73	2	1	$1,825	$0	30%	$185	$2,372	50
Cistern*		10	5	$2,319	$0	0%	$0	$2,319	50
Permeable Pavement	200	10	1	$17,660	$0	0%	$380	$17,660	15
Gravity Well	3.65	3.65	40	$56,000	$228	50%	$0	$84,000	50
Infiltration Pond	82	27.3	4	$73,963	$38,280	12%	$537	$15,400	30
Dry+Wet Pond	125.7	41.9	4.09	$177,931	$90,063	12%	$1292	$15,400	30
Wet pond	76.8	17.6	5	$55,824	$23,114	12%	$406	$15,400	30

*Width is diameter

Note: all costs are in 2017 dollars, with no adjustments made for inflation or discount rates.

2.18.1.1 Public and Private Costs

In addition to development of the unit costs, BMP costs were also differentiated between public and private costs. Public costs are costs assumed to be paid for by local jurisdictions. Private costs are costs that would be paid for by developers or land owners. All projected new and redevelopment stormwater costs are assumed to be provided by the private sector. All maintenance and replacement of LIDs on private property are assumed to be provided for by the private sector. Installation of BMPs on private property are assumed to be paid for by local jurisdictions (i.e., the public sector). A full list identifying public and private costs are shown in Table 15.

Table 15 Cost assignments for public and private actions.

Dollar Type	Development	BMP	PP
Capital	New-, Re-development	Bioretention	Private
		Cisterns	Private
		Perm Pvmt	Private
		Bio- Roads	Private
		Ponds	Private
		Gravity Well	Private
	Retro	Bioretention	Public
		Cisterns	Public
		Perm Pvmt	Public
		Bio- Roads	Public
		Ponds	Public
		Gravity Well	Public
O&M	New + ReDev	Bioretention	Private
		Cisterns	Private
		Perm Pvmt	Private
		Bio- Roads	Private
		Ponds	Private
		Gravity Well	Private
	Retro	Bioretention	Private
		Cisterns	Private
		Perm Pvmt	Private
		Bio- Roads	Public
		Ponds	Public
		Gravity Well	Public
Replacement	New + ReDev	Bioretention	Private
		Cisterns	Private
		Perm Pvmt	Private
		Bio- Roads	Private
		Ponds	Private

Dollar Type	Development	BMP	PP
		Gravity Well	Private
	Retro	Bioretention	Private
		Cisterns	Private
		Perm Pvmt	Private
		Bio- Roads	Public
		Ponds	Public
		Gravity Well	Public

2.19 Simulating Past, Present, and Future Conditions

Five scenarios were simulated in total. Three were simulated in HSPF and two were simulated using SUSTAIN. The three HSPF scenarios used existing infrastructure (i.e., conveyances and mitigation) for all three landscape scenarios (i.e., forested, existing, and future land use). The two SUSTAIN scenarios both used future land use with one scenario using existing stormwater infrastructure and the second scenario using recommended mitigation intended to meet flashiness and water quality targets.

SUSTAIN results are based on a simulated time period of 10 years (10/1/2002 through 9/30/2012). However, simulated hydrology for forested and existing conditions were only done in HSPF. As a result, flood frequencies were computed using two different lengths of data. A ten year period to compare to SUSTAIN results, and a historical rainfall period that would presumably be more accurate computing extreme events over several decades. The longer simulation period spans 63 years (10/1/1948 – 9/30/2012). This allows for results from SUSTAIN to be extrapolated to theoretically more accurate flood frequencies estimates based on over six decades of data versus one decade.

2.20 Cost Effectiveness Optimization

Optimization was done on how effective a simulated stormwater strategy might be versus the cost of that strategy. For this study, optimization was based on reducing the number of high pulse counts (HPC) at a point of interest in the stream system. Costs shown in the figures include public and private capital costs, operation and maintenance, and any property acquisition needed to place a stormwater BMP.

3.0 CALIBRATION

3.1 HSPF

3.1.1 Calibration Methods

3.1.1.1 Flow Rates

HSPF simulates flow from four surface and subsurface land components: surface runoff from impervious areas directly connected to the channel network (EIA), surface runoff from pervious areas, interflow from pervious areas, and groundwater flow. Because observed stream flow is a composite of inputs from these four components, the relative amounts of each of these components must be inferred from the examination of many events over several years of continuous simulation.

The approach to hydrologic model calibration involves a successive examination of the following four characteristics of the watershed hydrology, in the order shown: (1) annual water balance, (2) seasonal and monthly flow volumes, (3) baseflow, and (4) storm events. Simulated and observed values for reach characteristic are examined and critical parameters are adjusted to attain acceptable levels of agreement (discussed further below).

The annual water balance specifies the ultimate destination of incoming precipitation and is indicated as:

$$\text{Runoff} = \text{Precipitation} - \text{Actual Evapotranspiration} - \text{Deep Percolation} - \Delta\text{Soil Moisture}$$

HSPF requires inputs for precipitation and potential evapotranspiration (PET), which effectively drive the hydrology of the watershed. Both precipitation and evaporation inputs must be accurate and representative of the watershed conditions. It is often necessary to adjust the input data derived from neighboring stations that may be some distance away in order to reflect conditions on the watershed. HSPF allows the use of factors that uniformly adjust the input data to watershed conditions, based on local precipitation and evaporation patterns. In addition to the input meteorologic data series, the critical parameters that govern the annual water balance are as follows:

lower zone soil moisture storage (inches).

vegetation evapotranspiration index (dimensionless).

infiltration index for division of surface and subsurface flow (inches/hour).

upper zone soil moisture storage (inches).

fraction of groundwater inflow to deep recharge (dimensionless).

Evapotranspiration is adjusted to cause a change in the long-term runoff component of the water balance that are monthly. Changes in lower zone soil and vegetation evapotranspiration affect the actual evapotranspiration by making more or less moisture available to evaporate or transpire. Both the lower zone and infiltration index also have a major impact on percolation and are important in obtaining an annual water balance. In addition, on extremely small watersheds (less than 200 to 500 acres) that contribute runoff only during and immediately following storm events, the upper soil zone parameter can also affect annual runoff volumes because of its impact on individual storm events (described below). Whenever there are losses to deep groundwater, such as recharge, or subsurface flow not measured at the flow gage, fraction of groundwater inflow is used to represent this loss from the annual water balance.

The focus of the next stage in calibration is the baseflow component. This portion of the flow is adjusted in conjunction with the seasonal/monthly flow calibration (previous step) because moving runoff volume between seasons often means transferring the surface runoff from storm events in wet seasons to low-flow periods during dry seasons. By adjusting the infiltration index, runoff can be shifted to either increase or decrease groundwater or baseflow conditions. The shape of the groundwater recession; i.e., the change in baseflow discharge, is controlled by the following parameters:

AGWRC - groundwater recession rate (per day).

KVARY - index for nonlinear groundwater recession.

AGWRC is calculated as the rate of baseflow (i.e., groundwater discharge to the stream) on one day divided by the baseflow on the previous day; thus AGWRC is the parameter that controls the rate of outflow from the groundwater storage. Using hydrograph separation techniques, values of AGWRC are often calculated as the slope of the receding baseflow portion of the hydrograph; these initial values are then adjusted as needed through calibration. The KVARY index allows users to impose a nonlinear recession so that the slope can be adjusted as a function of the groundwater gradient. KVARY is usually set to zero unless the observed flow record shows a definite change in the recession rate (i.e., slope) as a function of wet and dry seasons.

3.1.1.2 Sediment

Sediment calibration follows the hydrologic calibration. Calibration of watershed sediment erosion is more uncertain than hydrologic calibration. The process is analogous to hydrologic calibration where the major sediment parameters are modified to increase agreement between simulated and recorded monthly sediment loss and storm event sediment removal. Additionally, observed monthly sediment loss is often not available. The sediment calibration parameters are not as distinctly separated between those that affect monthly sediment and those that control storm sediment loss. Annual sediment losses are often the result of only a few major storms during the year.

Sediment loadings to the stream channel are estimated by land use category from literature data (Horner 1994, Burton 2002), or local sources (King County 2007), and then adjusted for delivery to the stream with estimated sediment delivery ratios. Model parameters are then adjusted so that model calculated loadings are consistent with these estimated loading ranges. The loadings are further evaluated in conjunction with instream sediment transport calibration that extends to a point in the watershed where suspended sediment concentration data are available. The objective is to represent the overall sediment behavior of the watershed using sediment loading rates that are consistent with available values and providing a reasonable match with instream sediment data.

Once the sediment loading rates are calibrated, the sediment calibration then focuses on the channel processes of deposition, scour, and transport that determine both the total sediment load and the outflow sediment concentrations. Although the sediment load from the land surface is calculated in HSPF as a total input, it is divided into sand, silt, and clay fractions for simulation of instream processes. Each sediment size fraction is simulated separately, and storages of each size are maintained for both the water column (i.e., suspended sediment) and the bed.

In HSPF, the transport of the sand (non-cohesive) fraction is commonly calculated as a power function of the average velocity in the channel reach in each time step. This transport capacity is compared to the available inflow and storage of sand particles; the bed is scoured if there is excess capacity to be satisfied, and sand is deposited if the transport capacity is less than the available sand in the channel reach. For the silt and clay (i.e., non-cohesive) fractions, shear stress calculations are performed by the hydraulics submodule and are compared to user-defined critical, or threshold, values for deposition and scour for each size. If the calculated shear stress falls between the critical scour and deposition values, the suspended material is transported through the reach. After all scour and/or deposition fluxes have been determined, the bed and water column storages are updated and outflow concentrations and fluxes are calculated for each time step.

In HSPF, sediment transport calibration involves numerous steps in determining model parameters and appropriate adjustments needed to insure a reasonable simulation of the sediment transport and behavior of the channel system. These steps are usually as follows:

1. Divide input sediment loads into appropriate size fractions
2. Run HSPF to calculate shear stress in each reach to estimate critical scour and deposition values
3. Estimate initial parameter values and storages for all reaches
4. Adjust scour, deposition and transport parameters to impose scour and deposition conditions at appropriate times; e.g., scour at high flows, deposition at low flows
5. Analyze sediment bed behavior and transport in each channel reach
6. Compare simulated and observed sediment concentrations, bed depths, and particle size distributions, where available
7. Repeat steps 1 through 6 as needed

Rarely is there sufficient observed local data to accurately calibrate all parameters for every stream reach. Consequently, model calibration focused on sites with observed data and simulation results in all parts of the watershed were reviewed to insure that the model results were consistent with field observations, historical reports, and expected behavior from past experience. Ideally comprehensive datasets available for storm runoff should include both tributary and mainstem sampling sites. Observed storm concentrations of TSS should be compared with model results, and the sediment loading rates by land use category should be compared with the expected targets and ranges, as noted above.

An iterative procedure of parameter evaluation and refinement was used to determine parameter values to use in the watershed models. Data available for calibration generally ranged from approximately one year up to ten years of simulation. Since the models were based on 2011 land use/land cover conditions; the observed data used in model calibration ranged from 2008 to 2016.

3.1.1.3 Water Temperature

Water Temperature is modeled by performing an energy balance in each stream segment. Heat and energy inputs to the stream are determined from the temperature of nonpoint, point, and boundary inflows; and from meteorologic data (solar radiation, air temperature, dew point temperature, wind speed, and cloud cover). In the respective pervious and impervious land segments, water temperature and heat content (in units of BTUs) of surface runoff and interflow are estimated from air temperature, using a simple regression equation; and groundwater runoff temperatures/heat are user-defined, based on local groundwater temperatures. All of the parameters for these processes are specified on a monthly basis to represent seasonal variability. In stream reaches, the heat transport submodule performs the energy balance and estimates the stream water temperature. Radiational energy transfers at the water surface are estimated from solar radiation (shortwave) and cloud cover and temperature (longwave) data. Evaporative transfers are determined from wind, air temperature, and dew point temperature data. Conduction/convection transfers are determined from air temperature and wind. Finally, energy transfers between the underlying ground and the stream are estimated from ground temperature.

3.1.1.4 Fecal Coliforms

Fecal Coliforms is simulated to generate nonpoint loadings in units of 10^9 CFUs (10^9 organisms). Fecal Coliform loadings are assumed to be determined by the surface runoff, interflow, and groundwater. The surface runoff is determined by specifying accumulation/washoff parameters, and the subsurface (interflow and groundwater) components are modeled as user-defined concentrations, with monthly variation. In stream reaches, fecals are simulated in the general water quality constituent section and is assumed to undergo first-order decay. Fecals can optionally be associated with sediment, but the current model assumes it is dissolved because most prior simulations of coliform material with HSPF have been done this way, and thus provide tested parameter sets.

3.1.1.5 Copper and Zinc

There are limited copper and zinc data at all the sampling stations. Therefore, calibration focused on the outlet of each model domain for the upper three model domains. The calibration procedure involved adjusting the land use-specific interflow and groundwater concentrations and the surface parameters (potency factors) to achieve a statistical fit with the available data. Copper and zinc are assumed to be 100 percent sediment-associated in runoff, so all surface loading was modeled in the sorbed phase, and the data supports the association of high copper and zinc levels with storms. The instream adsorption/ desorption rates and adsorption equilibrium coefficients were adjusted to achieve reasonable behavior and a good match between the dissolved and total forms of copper. Adsorption rates for suspended sediment are five orders of magnitude higher than bed sediments, reflecting greater mixing and turbulence in the water column, and the lack of exposure of particles in the bed to the water column. This also helps to avoid large seasonal fluctuations in the baseline concentration caused by rapid sorption to the bed during periods of high concentration (storms) and slow desorption during periods of lower concentration. The calibrated adsorption equilibrium coefficients are the same for suspended and bed sediments.

3.1.2 Calibrated HSPF Model Domains

Model domains are mapped on Figure 4 and Table 16 summarizes which parameters were calibrated in each domain. Stations used for calibration either were the primary driver for parameter adjustment or used as guidance during the calibration process. Stream flow gauges and water quality gauges were not necessarily located within the same catchment.

Table 16 Summary of calibrated model domains and catchments and parameters calibrated. Diamond marks indicate temperature data exists at the stream flow gage in addition to the WQ station. For a complete list of water temperature stations used see Table 26.

Usage	Domain	Catchment	Station (Flow)	Flow	Catchment	Station (WQ)	Temperature	Fecal Coliform	TSS	Copper	Zinc
Primary	Cottage Lake	BEA700	02G	✓	BEA760	N484	♦	✓	✓	✓	✓
Primary	Upper Bear	BEA500	02F2	✓	BEA525	BCP10	♦	✓	✓	✓	✓
Primary	Colin/Struve	BEA410	02M	✓	BEA480	BCP04	♦	✓	✓	✓	✓
Primary	Intermediate Bear	BEA300	02E	✓		02E	♦				
Primary	Monticello Creek	MON030	BCP0119	✓		BCP0119	✓	✓	✓	✓	✓
Primary	Middle Bear	BEA010	02R	✓	BEA010	02R	✓				
Guidance	Cottage Lake	BEA760	02L	✓		02L	✓				
Guidance	Cottage Lake	Cold Creek			BEA840	BCP02	✓	✓	✓	✓	✓
Guidance	Cottage Lake	Cottage Lake Outlet			BEA900	BCP03	✓	✓	✓	✓	✓
Guidance	Colin/Struve	BEA480	02M2	✓	BEA410	02M	♦				
Guidance	Upper Bear				BEA590	BCP01	✓	✓	✓	✓	✓
Guidance	Intermediate Bear	BEA325	02O	✓		E. Seidel	♦				
Guidance	Intermediate Bear	BEA320	02P	✓		S. Seidel	♦				
Guidance	Middle Bear	BEA120	02Q	✓		ET484	♦				
Guidance	Middle Bear	BEA020	BC0114	✓		BCP09	♦				

3.1.3 Land Use Land Cover Assumptions

For any given land use/land cover, there can be up to three types of HRUs characterizing the runoff (i.e., impervious road, and other impervious and pervious areas). The estimated portions of impervious areas assigned to any particular land use/land cover are provided in Table 17. Assumptions converting future land use into HRUs are provided in Table 18. Land use areas that are also considered environmentally sensitive (e.g., steep slopes, saturated soils, etc.) have assumed impervious surfaces reduced 40% and forest retention increased. Table 19 summarizes those assumptions.

Since wetlands are not a land use zoning category, wetlands were integrated into the zoning data. Any area mapped as a wetland would supersede the surficial geology layer and assign it to saturated soils. However, it was noticed that in development of the future land use watershed models, the areas of intersection between the future zoning and wetlands retained the 40% reduced impervious assumptions assigned to the zoning classification. The pervious fractions of the zonings were assigned saturated soil conditions associated with wetlands. This retention of reduced impervious surfaces translates into an extra 350 acres (about 2% more) of impervious surface that likely would remain wetlands in the future (Table 20).

Table 17 Distribution of Existing land use assumptions to Hydrologic Response Units (HRUs)

Code	Description	Residential Lawns/Grass			Cleared Lands	Grass Other	Forest	Open Water	Scrub	Ag.	Wetlands	Effective Impervious Area		
		Road	High	Low								Low	High	Roads
11	Open Water							1.000						
12	Perennial Ice/Snow								1.000					
21	Developed, Open Space			0.956								0.044		
22	Developed, Low Intensity			0.954								0.046		
23	Developed, Medium Intensity			0.717								0.283		
24	Developed, High Intensity		0.352										0.648	
25	Roads	0.280												0.720
31	Barren Land				0.600							0.400		
41	Deciduous Forest						1.000							
42	Evergreen Forest						1.000							
43	Mixed Forest						1.000							
52	Shrub/scrub								1.000					
71	Grassland/Herbaceous					1.000								
81	Pasture									1.000				
82	Cultivated Crops									1.000				
90	Woody Wetlands										1.000			
95	Emergent Herbaceous Wetlands										1.000			

Table 18 Distribution of future land use assumptions to Hydrologic Response Units (HRUs)

		Lawns						Open	Effective Impervious Areas		
SYMBOL	**Description**	**Road**	**High**	**Low**	**Agriculture**	**wetlands**	**Forest**	**Water**	**Low**	**High**	**Roads**
ROAD	Roads	0.174									0.826
COM	Commercial		0.174							0.826	
O3	Office Park 3		0.226							0.774	
O2	Office Park 2		0.279							0.721	
O1	Office Park 1		0.331							0.669	
HD5	High Density Residential 5		0.383							0.617	
HD4	High Density Residential 4		0.487							0.513	
HD2	High Density Residential 2			0.591						0.409	
HD1	High Density Residential 1			0.696						0.304	
HD0	High Density Residential 0			0.800						0.200	
R1	Residential 1 ac			0.854			0.050		0.096		
RA2.5	Rural Area 2.5 acres			0.252	0.200		0.400		0.148		
RA5	Rural Area 5 acres			0.304	0.200		0.400		0.096		
RA10	Rural Area 10 acres			0.156	0.300		0.500		0.044		
Ag2	Agriculture 2				0.956				0.044		
Ag1	Agriculture 1				0.960				0.040		
Park	Park			0.130			0.850		0.020		
FP	Forest Preserve			0.090			0.900		0.010		
Wet	Wetlands					1.000					
LC1	Land Conservation Type 1			1.000							
Water	Open Water							1.000			

Table 19 Assumed distribution of land use within identified sensitive areas.

SYMBOL	Description	Lawns			Agriculture	wetlands	Forest	Open Water	Effective Impervious Areas		
		Road	High	Low					Low	High	Roads
ROAD	Roads	0.174									0.826
COM	Commercial		0.670							0.330	
O3	Office Park 3		0.691							0.309	
O2	Office Park 2		0.711							0.289	
O1	Office Park 1		0.732							0.268	
HD5	High Density Residential 5		0.753							0.247	
HD4	High Density Residential 4		0.795							0.205	
HD2	High Density Residential 2			0.537			0.300			0.163	
HD1	High Density Residential 1			0.578			0.300			0.122	
HD0	High Density Residential 0			0.620			0.300			0.080	
R1	Residential 1 ac			0.912			0.050		0.038		
RA2.5	Rural Area 2.5 acres			0.241	0.100		0.600		0.059		
RA5	Rural Area 5 acres			0.262	0.100		0.600		0.038		
RA10	Rural Area 10 acres			0.083	0.200		0.700		0.017		
Ag2	Agriculture 2				0.383		0.600		0.017		
Ag1	Agriculture 1				0.384		0.600		0.016		
Park	Park			0.092			0.900		0.008		
FP	Forest Preserve			0.046			0.950		0.004		
Wet	Wetlands					1.000					
LC1	Land Conservation Type 1			1.000			0.000				
Water	Open Water							1.000			

Table 20 Summary of land cover for existing and future conditions.

Land cover	LU 2011	Future	LU 2011	Future
	(acres)		(percent of watershed)	
Grass	6037.3	6776.5	37.3%	42.0%
Cleared	0.0	0.0	0.0%	0.0%
Pasture	102.0	988.3	0.6%	6.1%
Scrub	620.4	269.3	3.8%	1.7%
Forest	6037.2	3936.2	37.3%	24.4%
Open Water*	60.5	82.3	0.4%	0.5%
Other EIA	487.6	1893.7	3.0%	11.7%
Road EIA	1241.7	925.6	7.7%	5.7%
Saturated	1615.0	1268.0	10.0%	7.9%
Total acres	16201.6	16139.7	100.0%	100.0%

*large bodies of open water are accounted for in the surface areas in the hydraulic routing (i.e., FTABLES.)

3.1.4 Model Calibration Assessment

No one test can assess the quality of a calibrated model. Therefore, a suite of metrics are used as a basis to evaluate model calibration that range from comparison of modeled and observed annual and seasonal flow volumes to instantaneous simulated (Table 21). Understanding how well the models perform for these metrics provides objective information regarding the quality of model calibration. Additional detail for some of the more complicated statistics in the table is included below.

3.1.4.1 Goodness of fit statistic descriptions

The Pearson (R) correlation can range from $-1 \leq R \leq 1$ where negative values represent inverse correlations and values close to 1.0 indicate well correlated predictions. The coefficient of determination (r-squared) ranges from $0 \leq r2 \leq 1.0$. The r2 value represents how much variance in the data can be explained by the model. The closer to 1.0 the better the model characterizes predicted conditions. It is possible for a model calibration metric to have high correlation and high coefficient of determination but have low prediction skill (as measured for example by ME or Nash-Sutcliffe) if there is a systematic bias in model calibration.

Two other model calibration evaluation statistics are the Nash-Sutcliffe skill score and the non-parametric Kruskal-Wallis (KW) paired difference test. Nash-Sutcliffe (NS) values can theoretically range from $-\infty < NS \leq +1.0$, representing model calibration skill. The closer to 1.0, the more skill a model has in representing existing conditions.

The KW statistical test evaluates whether the ranked distributions are significantly different based on an a priori-selected p-value that could range from $0 < p < 1$, although conventionally a value of 0.05 is selected to minimize the false rejection of a true null hypothesis. The null hypothesis is that the two datasets are not different. However, in this case we'd like some assurance that the datasets are not different, which suggests using a larger p-value. Therefore, KW tests with p-values ≥ 0.10 are considered to lack evidence for rejecting the null hypothesis, possibly similar when $0.05 \leq p < 0.10$, and very likely different when $0 < p < 0.05$.

3.1.4.2 Differences in magnitude statistic descriptions

Quantifying model error through various paired-comparison metrics (i.e., magnitude statistics above) provides another way of evaluating the quality of the model calibration. The Root Mean Square Error (RMSE) and Mean Absolute Error (MAE) emphasize the magnitudes of the errors without regard to direction or sign of the errors. The two are very similar when interpreting results, but the RMSE weights more heavily less frequent, larger simulation errors and MAE is equally influenced by larger and smaller errors.

Two statistics are used for quantifying magnitude and direction of error – mean error (ME) and relative percent difference (RPD). ME is the average of all simulation errors including cancellation of errors when some errors are positive and others are negative. RPD is the average of the simulation error divided by the observed value. The RPD complements the assessment using ME by providing an assessment of the relative rather than the absolute error. For example, a model error of 1 cfs is relatively large when average values are similar in scale (e.g., 1 cfs and RPD = 100%). That relative error is substantially less in magnitude when the absolute error is the same (1 cfs), but the average of observed values are much greater (e.g., 100 cfs and RPD = 1%).

The model calibration metrics used in the development of the HSPF models for flow rates are listed in Table 21 and for water chemistry listed in Table 22.

Table 21 Summary of statistics used assessing calibration for stream flows (magnitudes and volumes).

General Description	Metric	Description
Volume Based Metrics	Mean Winter (cfs)	Average flow between winter solstice and spring equinox
	Mean Spring (cfs)	Average flow between spring equinox and summer solstice
	Mean Summer (cfs)	Average flow between summer solstice and fall equinox
	Mean Fall (cfs)	Average flow between fall equinox and winter solstice
	Mean Flow (cfs)	Mean annual flow rate
	Geometric Mean (cfs)	Flow rates throughout the year are generally log-normal in distribution. While the arithmetic mean is a measure of true volumes, the geometric mean more accurately represents typical flow rates and less affected by extreme events that would likely be considered outliers in a normal distribution.
	January	Similar to seasonal flow rates above, mean monthly flow rates are evaluated.
	February	
	March	
	April	

General Description	Metric	Description
	May	
	June	
	July	
	August	
	September	
	October	
	November	
	December	
Different ranges of the distribution	10 Percentile	Computing the distribution of flow rates in the hydrologic regime, percentiles are used to characterize model calibration skill over a range of percentiles representing low to high flows.
	25 Percentile	
	50 Percentile	
	75 Percentile	
	90 Percentile	
Extreme Condition metrics	Mean Annual Max. (cfs)	The average of annual maximum flow rates.
	Mean Annual 7-Day Low (cfs)	The average of annual minimum 7-day average flow rates
	Mean Daily max (cfs)	The average of instantaneous daily maximum flow rates
Type of Analyses	Statistic	Description
Goodness of fit applied to hourly data (or other as indicated)	Pearson (R)	Correlation coefficient.
	r-squared (r^2)	The coefficient of determination.
	Nash-Sutcliffe (NS)	An index measuring the model's ability to accurately simulate observed conditions.
	Kruskal-Wallis (KW)	A non-parametric equivalency test comparing ranked distributions of simulated and observed datasets.
	Relative Percent Difference (RPD)	The difference between simulated and observed relative to observed.
Differences in magnitudes	Mean Error (ME)	The total error, which includes cancellation of errors often also referred to as "bias."
	Root Mean Square Error (RMSE)	Root Mean Square Error emphasizes larger errors.
	Mean Absolute Error (MAE)	Mean Absolute Error does not include cancellation of errors and therefore provides a measure similar to ME, but does not indicate the average sign of errors – i.e., under or over prediction.
	Slope of Regression (m)	The further departure from 1.0 the more the simulations is biased ($m < 1$, model under simulates, $m > 1$, model over simulates). Conversely, the closer to 1.0 the better the calibration.

Table 22 Summary of statistics used for water quality calibration.

Statistic	Description
r-squared (R2)	The coefficient of determination.
Relative Percent Difference (RPD)	The difference between simulated and observed relative to observed.
Slope of regression (m)	The further departure from 1.0 the more the simulations is biased (m < 1, model under simulates, m > 1, model over simulates). Conversely, the closer to 1.0 the better the calibration.

3.1.5 Flow Rates

Simulated flow rates compare well to observed at all of the primary locations (i.e., near the outlets for each model domain). In general, the simulated hourly outputs show peaks that are slightly larger in magnitude (Figure 20), but overall the models are well calibrated (Figure 21 and Figure 22). Results of the lower modeling domain near the outlet of the study area (BEA010, KC Gauge 02R) are summarized below in Table 23. Calibration results for the remaining model domains are summarized in Appendix B in Table 51 through Table 62. Similarly, calibration plots for the remaining models are shown in Figure 48 through Figure 80 found in Appendix B.

Table 23 Summary of simulated flow rate calibration statistics for outlet of study area (KC gauge 02R, BEA010)

Metric	Obs	Sim	RPD
	(cfs)		
Mean Spring (cfs)	34.3	36.6	7%
Mean Summer (cfs)	14.7	16.7	14%
Mean Fall (cfs)	77.9	68.2	-13%
Mean Winter (cfs)	102.9	106.0	3%
Mean Flow (cfs)	66.01	64.28	-3%
GeoMean (cfs)	43.71	45.04	3%
Mean Annual Max. (cfs)	289.3	314.0	9%
Mean Annual 7-Day Low (cfs)	26.96	33.55	24%
Mean Daily max (cfs)	76.14	78.50	3%
Annual Volumes (inches)	34.74	34.66	0%
	(inches)		
January	3.58	3.61	1%
February	3.21	3.48	8%
March	2.50	2.77	11%
April	1.48	1.56	5%
May	0.96	1.00	4%
June	0.53	0.64	20%
July	0.45	0.54	21%
August	0.54	0.63	18%
September	0.81	0.78	-4%
October	1.32	1.20	-10%
November	3.13	2.64	-16%
December	4.83	4.30	-11%
	(total inches modeling period)		

Metric	Obs	Sim	RPD
	(cfs)		
10 Percentile	27.72	26.99	-3%
25 Percentile	59.81	57.89	-3%
50 Percentile	34.33	36.30	6%
75 Percentile	19.31	21.76	13%
90 Percentile	7.56	7.96	5%

Equivalency Tests	Kruskal-Wallis		One-way ANOVA	
	p-value	> 0.10	p-value	> 0.10
Seasonal Volume	1.00	Pass	0.99	Pass
Hourly	0.00	Fail	0.01	Fail
Daily Means	0.28	Pass	0.53	Pass
Annual Vol. (inches)	0.83	Pass	0.99	Pass
Monthly Vol. (inches)	0.97	Pass	0.91	Pass
Peak Annual	0.83	Pass	0.91	Pass
Min 7DAvg	0.83	Pass	0.78	Pass
Daily Max.	0.24	Pass	0.37	Pass

Prediction Statistic (hourly)	Value
Pearson	0.94
Mean Err (cfs)	-1.73
RMSE (cfs)	18.40
R-square	0.89
MAE (cfs)	11.80
Nash-Sutcliffe	0.88

High Pulse Counts (HPCs) require complete years of data to be valid. Since several of the gauges only have one complete year of data, that common year (i.e., water year 2015) was used for all comparisons. Table 24 summarizes by gage what the observed and simulated HPCs were for that year.

Table 24 Comparison of HPCs between observed and simulated for WY2015.

Catchment	Gauge	WY 2015 (HPC)	
		Obs	Sim
BEA700	02G	9	9
BEA500	02F2	7	8
BEA410	02M	11	10
BEA300	02E	11	11
MON030	BCP0119	17	17
BEA010	02R	11	8
BEA480	02M2	11	15
BEA325	02O	10	10
BEA120	02Q	10	11
BEA020	BC0114	10	11

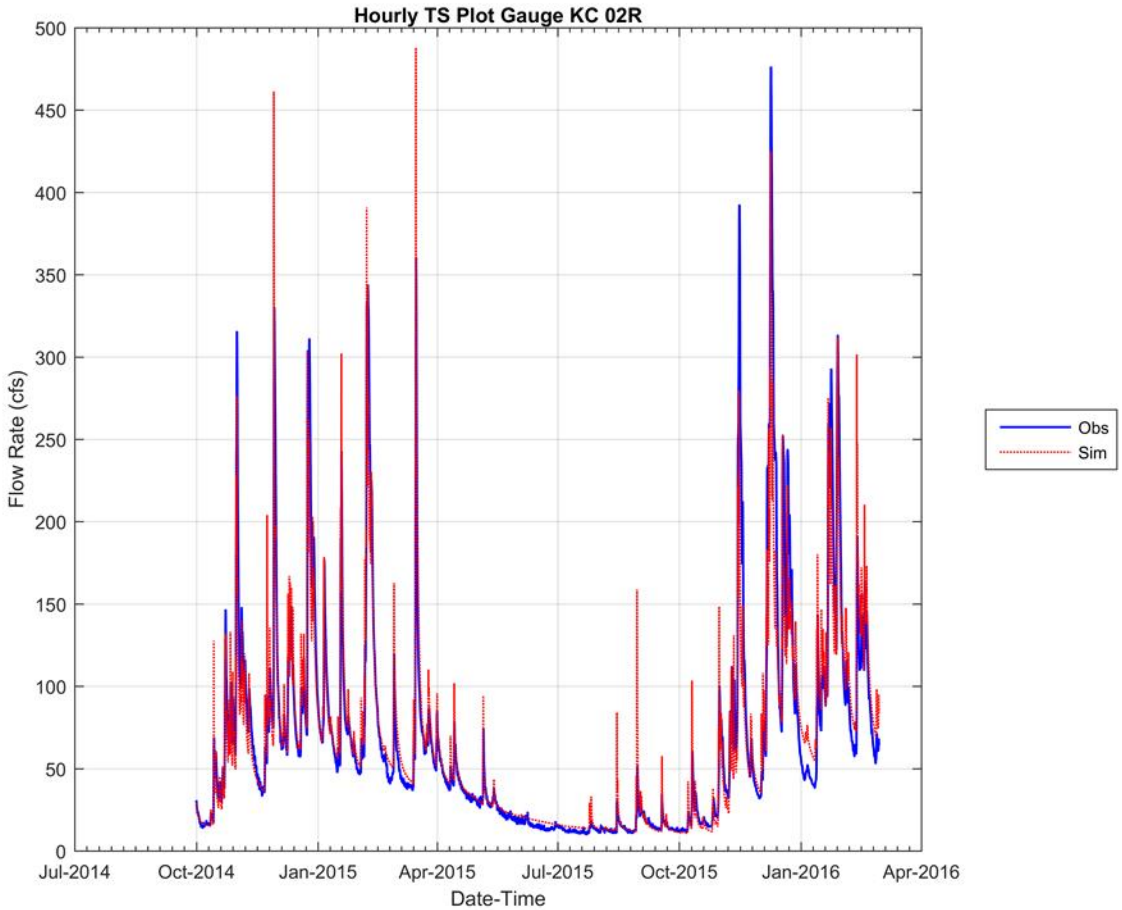

Figure 20 Gauge 02R time series flow plot

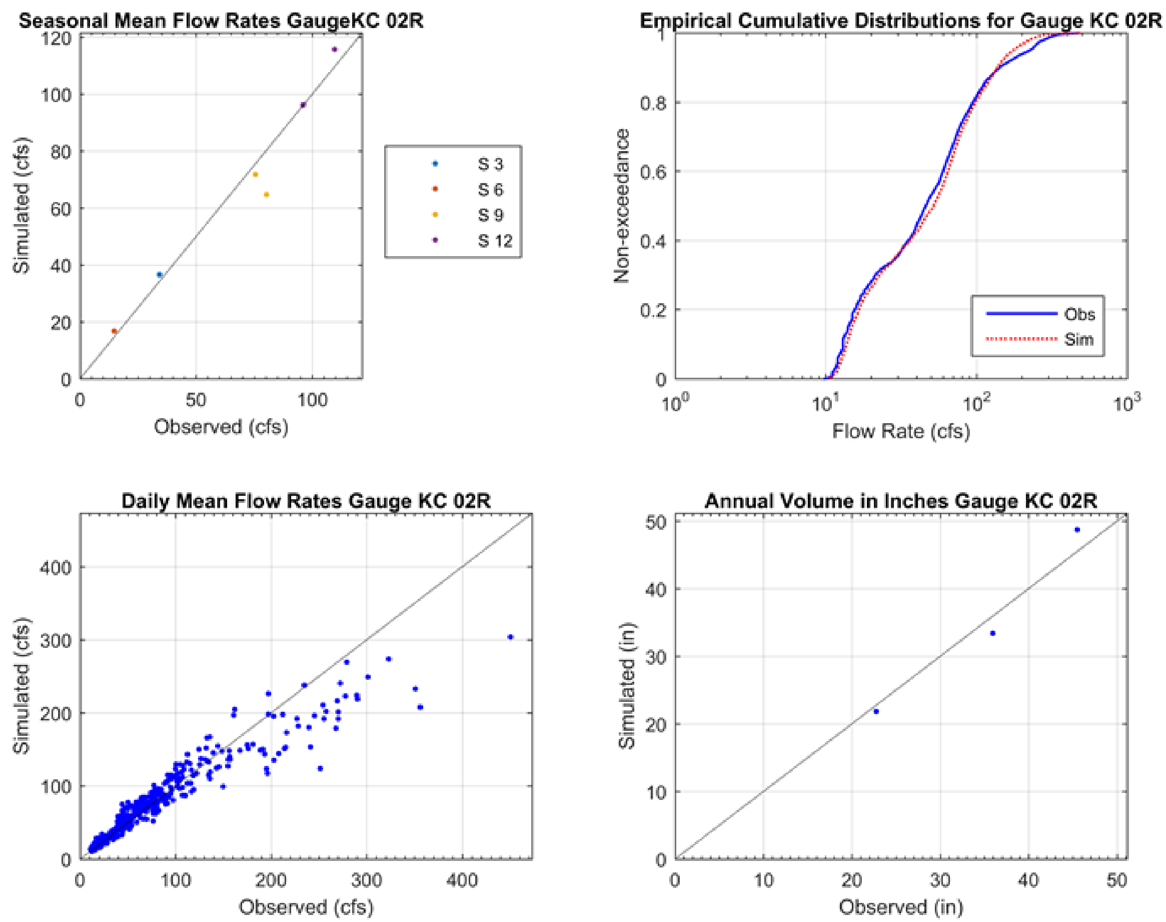

Figure 21 Gauge 02R flow calibration plot 1

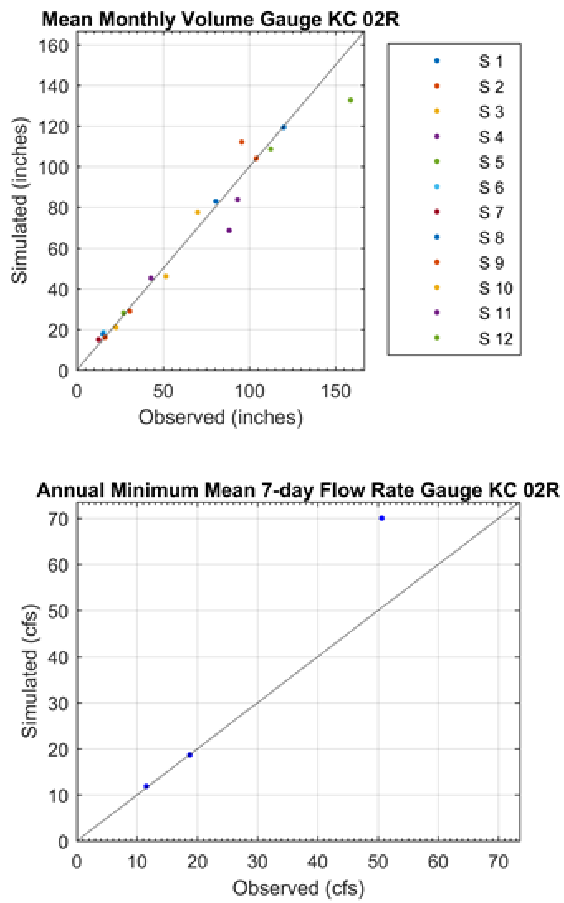

Figure 22 Gauge 02R flow calibration plots 2

3.1.6 TSS

The sediment loadings are generated using the surface storage and surface runoff results from the hydrologic simulation. Simulating TSS does not take into account any episodic events that are discrete in nature (e.g., bank failure) and not easily predictable. Thus, the smaller the drainage area, the more difficult the calibration since there is less mixing that occurs to *smooth* out the data. The goal for TSS calibration is to reasonably simulate annual mass loadings and instantaneous concentrations that will be used as inputs to SUSTAIN. Emphasis was given to the mainstem nearest to the outlet when multiple monitoring stations within a single basin were available. Parameter adjustments made within a model applied to the entire model domain, thus if more than one station was available, those stations were also used for additional comparison purposes.

Results of the calibrated model domains are summarized in Table 25 and illustrated in Figure 126 through Figure 137 in Appendix E.

Table 25 Summary of calibration of TSS for HSPF models.

	N484 (BEA760)	BCP10 (BEA525)	BCP04 (BEA480)	BCP0119 (MON030)
R2	0.781	0.556	0.355	.231
RPD	0.410	0.573	0.953	-0.886
m	1.18	0.413	0.368	0.081

3.1.7 Temperature

Water temperature was calibrated for the six HSPF model domains. Hourly and daily maximum temperatures compare well to observed, with Monticello Creek having the greatest error with a difference of 1.7-percent versus the other three that were all less than 1-percent different from observed. Overall, only two of the locations (BEA320 and BEA325) used as guidance did not calibrate well and would warrant further investigation. The simulated water temperature error was generally within 1 to 2 degrees Fahrenheit of observed.

Table 26 below summarizes the statistics used to describe model accuracy and plot for BEA010 is shown in in Figure 23 in this section and all other locations are shown in Figure 85 through Figure 104 in Appendix C.

Table 26 Summary of calibration of water temperature for HSPF. Rows circled in bold are primary points of comparison.

Catchment	Station	Pearson Correlation	Mean Error	RMSE	R-square	Mean Absolute Error	Nash-Sutcliffe
BEA010	02R	0.93	-1.55	3.02	0.87	2.31	0.84
BEA120	ET484	0.98	0.03	1.58	0.97	1.26	0.94
BEA300	02e	0.92	0.69	2.96	0.84	2.25	0.82
BEA310	BCP06	0.99	1.10	1.11	0.97	0.84	0.91
BEA410	02M	0.96	0.19	2.05	0.92	1.65	0.91
BEA500	02F2	0.96	0.35	2.67	0.91	2.06	0.91
BEA700	02G	0.96	-0.10	2.16	0.92	1.68	0.92
BEA760	02L	0.93	1.10	2.87	0.87	2.20	0.85
BEA840	BCP02	0.91	2.73	2.77	0.83	1.95	0.70
BEA900	BCP03	0.98	0.16	1.95	0.95	1.44	0.94
MON030	BC0119	0.89	-0.97	3.17	0.79	2.43	0.75
BEA020	BCP09	0.96	-2.10	3.12	0.92	2.46	0.85
BEA060	C484	0.98	-0.46	1.71	0.96	1.26	0.95
BEA300	J484	0.98	1.58	1.51	0.96	1.18	0.91
BEA320	S. Seidel	0.90	-1.91	3.14	0.80	2.44	0.07
BEA325	E. Seidel	0.86	-2.95	3.44	0.75	2.67	-0.60
BEA480	BCP04	0.98	1.78	1.50	0.96	1.14	0.90
BEA525	BCP10	0.97	2.34	2.00	0.94	1.59	0.79
BEA640	BCP01	0.97	-1.08	2.04	0.94	1.65	0.91
BEA720	N484	0.97	0.36	1.98	0.94	1.53	0.93
MON030	BCP08	0.91	0.89	3.34	0.83	2.43	0.79

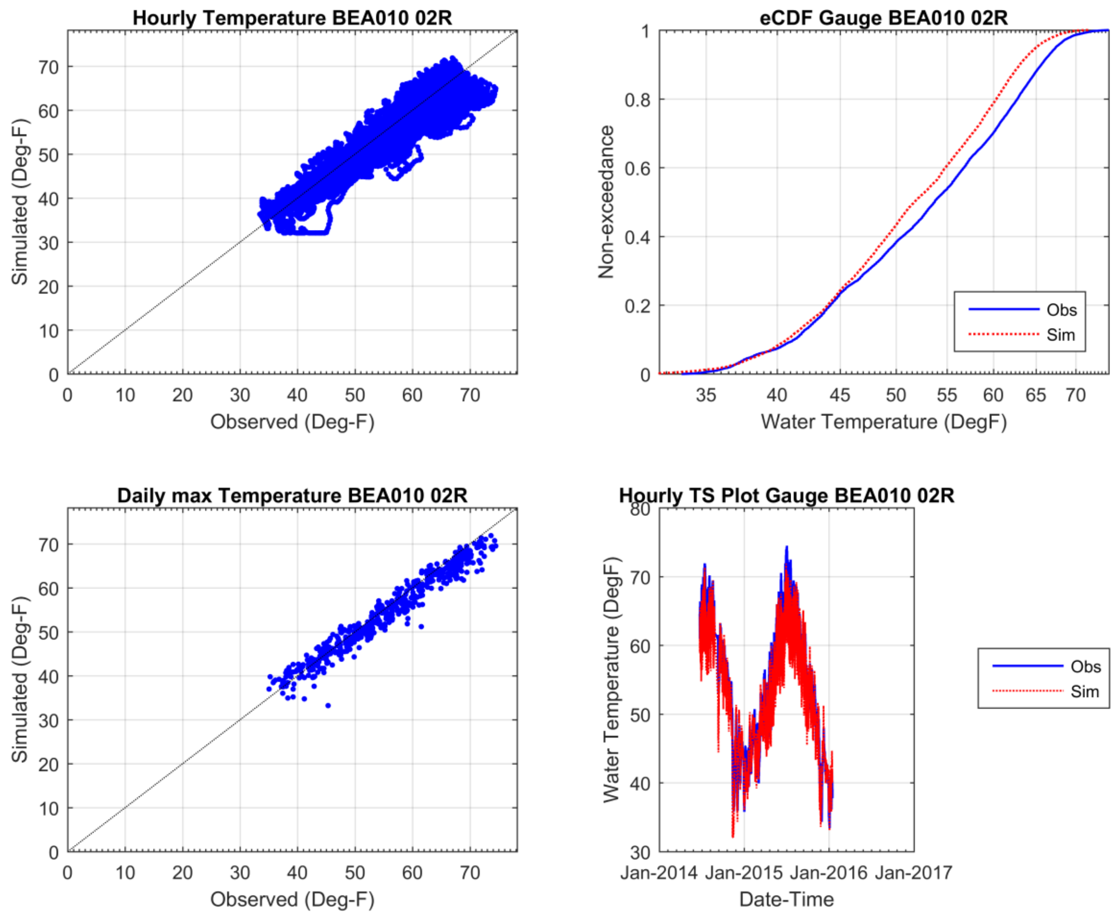

Figure 23 Calibration of water temperature for 02R (BEA010).

3.1.8 Fecal Coliforms

Fecal coliform concentrations are extremely variable and difficult to predict. One reason for this is that many of the larger loadings of bacterial material probably occur not only during storms, but also during somewhat random but "catastrophic" events. Examples of such events might include failure or illicit sewer connections of waste disposal facilities, which can produce large, unpredictable concentrations. Efforts were made to attain general agreement between the simulated concentrations by adjusting loading rates, both surface and subsurface runoff-associated by land use. Because of the difficulty in matching actual observed values, the explanatory regression coefficient (i.e. r-square) is used more as guidance than a test of acceptability but still necessary for evaluation given metrics used in scenario analyses are dependent on absolute thresholds of concentrations. Due to the high concentrations and variability, calibrated loading rates for this study should not be used for any other basin. The calibration statistics are summarized in Table 27 and illustrated in Figure 105 through Figure 125 in Appendix D.

Table 27 Summary of Fecal Coliform calibration statistics.

	N484	BCP10	BCP04	BCP0119
R2	0.367	0.486	0.423	0.085
RPD	0.560	1.640	1.451	1.059
m	0.135	0.219	0.357	0.819

3.1.9 Copper

Copper was assumed to be sediment associated, so all surface loadings were modeled in the sorbed (i.e. attached) phase. Dissolved copper was the primary parameter used for calibration with calculated statistics and total copper concentrations were used as guidance during the calibration process. Total Copper concentrations were calibrated by adjusting the land use-specific interflow and groundwater concentrations and the surface parameters (potency factors) to achieve a fit with the available data. Dissolved copper included adjustments in the partition coefficients as well as the adsorption/desorption rates.

The level of model accuracy is generally better modeling total copper as opposed to dissolved copper which is dependent on other time varying environmental factors such as hardness and concentration of suspended solids. Since metrics used to evaluate modeled scenarios relies on acute and chronic concentrations, the same higher level of statistical (Table 28) scrutiny is applied to simulated results on instantaneous concentrations of dissolved copper. Plots of the calibrations are shown in Figure 140 through Figure 153 in Appendix F.

Table 28 Summary of dissolved copper calibration.

	N484	BCP10	BCP04	BCP0119
R2	0.408	0.405	0.229	0.07
RPD	0.48	0.407	0.454	0.171
m	0.913	0.527	0.586	0.713

3.1.10 Zinc

Zinc was simulated the same way copper was and has similar results. Calibration statistics are summarized in table below and illustrated in Figure 154 through Figure 167 in Appendix G.

Table 29 Summary of dissolved zinc calibration.

	N484	BCP10	BCP04	BCP0119
R2	0.460	0.352	0.267	0.378
RPD	0.320	0.370	0.435	-0.259
m	0.667	0.959	0.467	0.732

3.1.11 Simulating B-IBI

Comparisons of B-IBI is comprised of simulating high pulse counts (HPC) and using the HPC regressions listed in section 2.16 to project B-IBI scores in the study area. They were then compared to the B-IBI scores recorded in 2014. Given the B-IBI scores are grouped into five categories (i.e., very poor, poor, fair, good, and excellent), a second comparison is done using the same categories. Selection of the best fitting regression is construed as "calibration" for this study.

The segmentation of catchments was not driven by locations of B-IBI monitoring stations, thus some catchments may contain more than one B-IBI station, and if a B-IBI station was reasonably close to an upstream boundary, the adjacent upstream catchment was also compared using that same B-IBI score. Two figures (Figure 24 and Figure 25) are presented for comparison to illustrate differences in simulated projections using a different regressions. The color scheme representing B-IBI scores is the same in both figures. Figure 24 illustrates a comparison between observed B-IBI and simulated using WRIA 8 regression on the high pulse count. Visually, Figure 25 conveys a different interpretation. The Juanita Creek regression in this example consistently under estimates B-IBI scores by one or two categories. For example, the Juanita Creek regression may estimate a B-IBI category of Poor for a catchment, but the observed value may be Fair or Good. Thus, using the Juanita Creek regression will overestimate the need for reducing high pulse counts in order to achieve a certain level of stream health (e.g., good) based on B-IBI scores.

Three (WRIA 8, Puget Sound, and WRIA 9) of the four regressions generally provide similar levels of accuracy when comparing simulated to observed in the Bear Creek study area. Interestingly, the remaining two each have larger biases and in opposite directions. The Juanita Creek regression, on average, will estimate a B-IBI score 19 points lower than observed—essentially a whole category too low. The most accurate regression among the five was the WRIA 8 regression that on average estimated a B-IBI score 2.5 points above observed (Table 30). Performing the same comparison based on categories of B-IBI scores (i.e., very poor – excellent) produced similar results (Table 30).

The development of each regression within each of the studies were all reasonable in their accuracy based on the data sets they used. This disparity comparing regressions elucidates the sensitivity when selecting a regression and applying it outside the bounds of the study it was originally developed in.

Table 30 Simulated B-IBI accuracy using HPC regressions. The bold selection identifies which regression most accurately represents observed conditions.

Metric	Statistic	WRIA 8	Puget Sound	Juanita Creek	WRIA 9
Score Difference (Sim-Obs)	Mean	2.5	-3.6	-18.9	-6.7
	RMSE	21.7	19.8	28.0	21.9
Category* Difference (Sim-Obs)	Mean	0.3	-0.2	-0.8	-0.2

*Categories are assigned a value from 1 to 5: Very Poor = 1, Poor = 2, Fair = 3, Good= 4, Excellent = 5

The regression derived from the WRIA 8 study were used as the primary method to calculate B-IBI scores and consequently the stream health category. The HPCs defining the categories are summarized in the following table.

Table 31 Defining ranges of HPCs and their representative biological condition (i.e., stream health).

Biological Condition	B-IBI Score	HPC
Excellent	80-100	< 2.4
Good	60-80	2.4 - 9
Fair	40-60	9 - 16
Poor	20-40	16 - 22.6
Very Poor	0-20	> 22.6

B-IBI targets are established using one of two methods, absolute and relative (section 2.17.2). After calibration of the flow rates and selection of the regression to be used, the relative targets of B-IBI can be calculated from outputs of a simulated forested condition. Evaluating every catchment in the study area, the B-IBI score average was 69.0 based on a forested land cover scenario. In addition, only one catchment (BEA330) had a forested B-IBI score less than 60 (i.e., 59.1). Thus for simplicity, the absolute score of 60 (i.e., biological condition classified as good) was used as the criteria of success for the entire modeling domain.

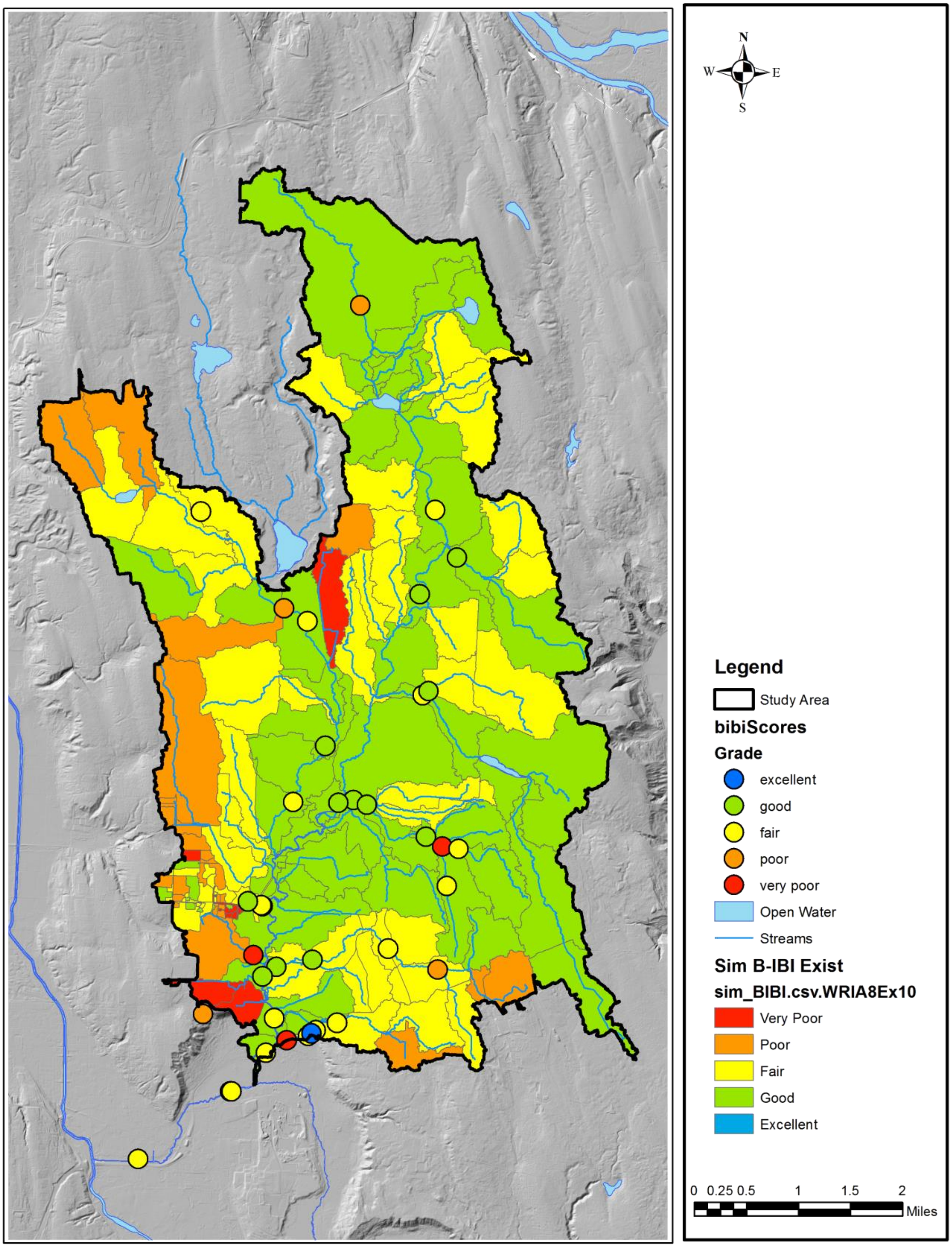

Figure 24 A comparison of simulated HPC and observed B-IBI using WRIA 8 regression.

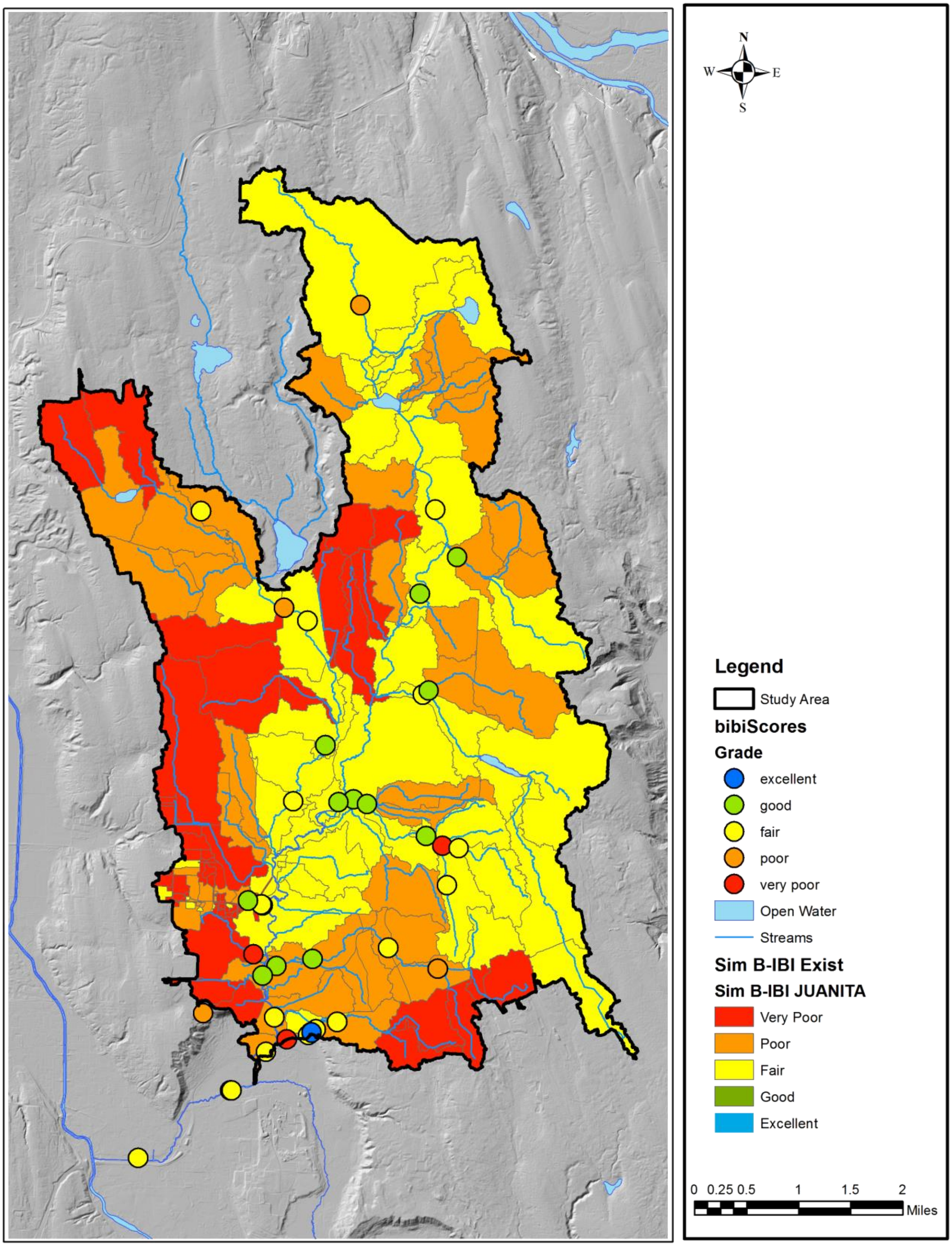

Figure 25 A comparison of simulated HPC and observed B-IBI using Juanita Creek regression.

3.2 SUSTAIN

The calibrated unit area runoff from HRUs in the HSPF models are used as external inputs into SUSTAIN models. The calibration of SUSTAIN takes the form of comparing simulated flows in SUSTAIN to the simulated flows in HSPF, and the adjustment of parameters in SUSTAIN to matching effectiveness in water quality treatment that has been recommended by Ecology.

3.2.1 Selection of Water Year for Simulation

Due to the complexity of the SUSTAIN models and the number of iterations needed for a reasonable optimization, it was necessary to scale down the number of simulation years to one year. Using the HSPF model outputs for existing conditions at each catchment, the HPC was calculated for each simulated water year between 1950 and 2012. Then each water year was ranked by the number of catchments that were within the 63 year average HPC±1. The most recent water year (1998) in that group was used for SUSTAIN optimization runs on HPC.

Table 32 Top five water years with number of catchments that are within the average HPC ± 1. Bolded year indicates year selected for optimization.

WY	# of Catchments
1975	77
1958	68
1955	64
1998	**63**
1953	62

Simulated flow rates in SUSTAIN compared well to HSPF simulations. The difference generally was in base flow conditions and the magnitude of the peaks in the flashiness. The calculated flashiness metric HPC of SUSTAIN (HPC = 21) remained comparable to HSPF (HPC = 18). A time series plot is shown in Figure 26 comparing simulated HSPF and simulated SUSTAIN at the mouth of the study area (i.e., catchment BEA010).

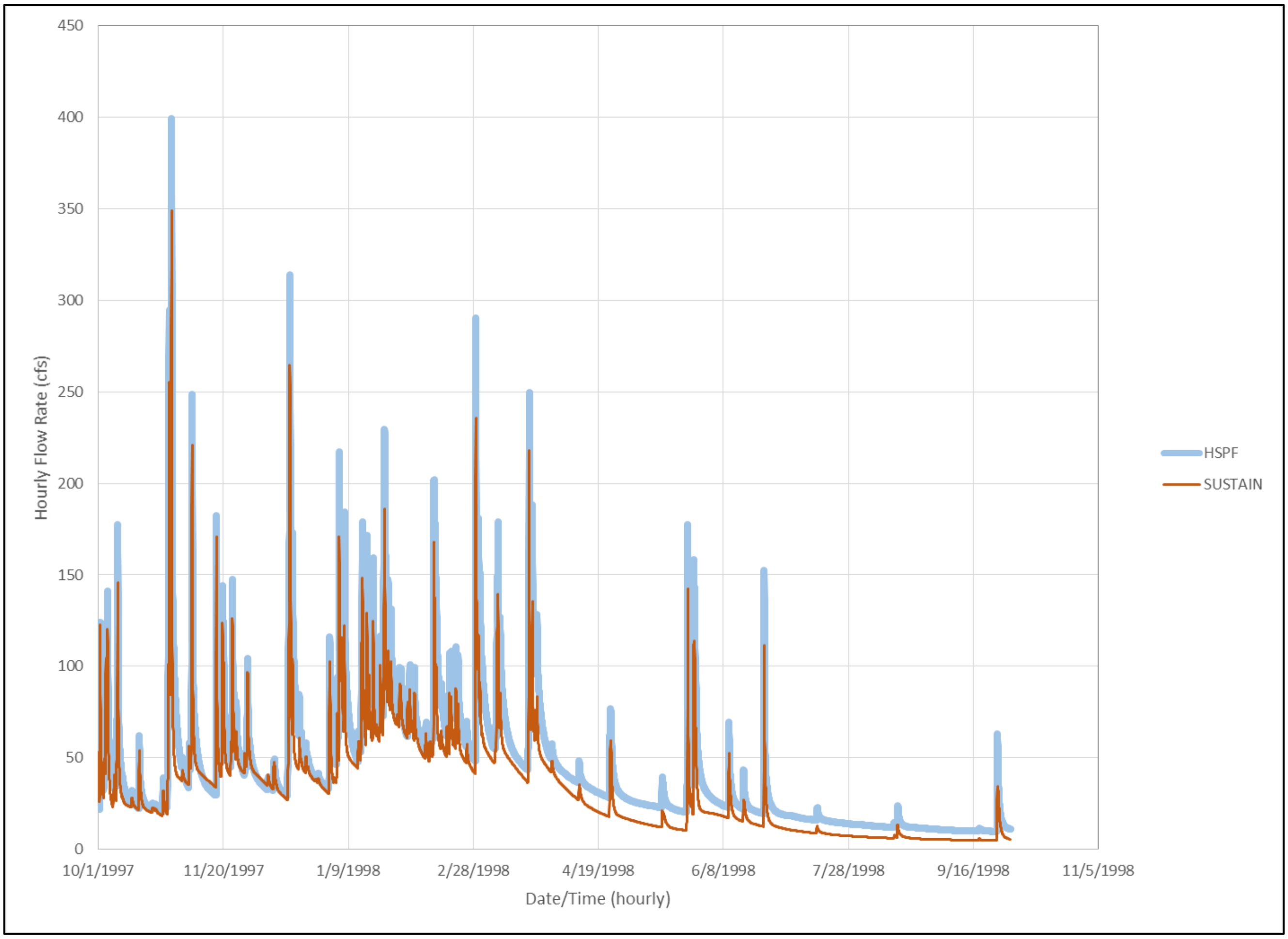

Figure 26 Comparison of mean daily flow rates between HSPF and SUSTAIN at the mouth of the study area (BEA010). HPC (HSPF) = 18, HPC (SUSTAIN) = 21.

3.2.2 BMP Treatment Efficiencies

Types of BMPs included as part of the treatment train in the SUSTAIN modeling are as follows:

- Cisterns
- Bioretention (two designs)
- Pervious Pavement
- Combined wet/dry detention pond
- Infiltration pond
- Wetpond
- Gravity well infiltration

The calibration of HRUs did not specifically differentiate impervious surfaces that are pollutant generating (PGS) and non-pollutant generating (NPGS). Thus, even though it is policy to assume roofs are NPGS, in the model they still are generating pollutant runoff. To address this, cisterns are assumed to be 100-percent effective in removal of pollutants. In addition, all stormwater that infiltrates into native soils are assumed to be 100-percent treated. As recommended by Washington State Department of Ecology, the assumed removal rates per BMP and pollutant are summarized in Table 33 below.

Table 33 Summary of modeled BMPs and their treatment targeted effectiveness on pollutants.

Removal Efficiency for Modeled BMPs								
BMP	Surface water treatment				Infiltration to native soils treatment			
	TSS	Fecal	Copper	Zinc	TSS	Fecal	Copper	Zinc
Cistern*	100%	100%	100%	100%	N/A	N/A	N/A	N/A
Permeable Pavement	80%	50%	30%	60%	100%	100%	100%	100%
Bioretention	0%	0%	0%	0%	100%	100%	100%	100%
Bioretention Roads	0%	0%	0%	0%	100%	100%	100%	100%
Infiltration Pond	0%	0%	0%	0%	100%	100%	100%	100%
RD Pond	80%	85%	0%	30%	100%	100%	100%	100%
Wet Pond	80%	85%	0%	30%	100%	100%	100%	100%
Gravity Well	0%	0%	0%	0%	100%	100%	100%	100%

*Cisterns only treat assumed roof runoff. Removal of pollutants from roofs is assumed 100% effective. This is to replicate zero pollutant loadings from surfaces that are assumed to be non-pollutant generating (i.e., roofs).

Parameters in SUSTAIN were adjusted to match the specified efficiencies. However, given the design standards used to size the BMPs, some have slightly higher removal efficiencies because of the ratio of stormwater that infiltrates versus outflows on the surface. Thus, the combined efficiencies are summarized in Table 34 below.

Table 34 Realized combined effectiveness of removal efficiencies by BMP by pollutant in simulations.

BMP	Volume of Treatment			
	TSS	Fecal	Copper	Zinc
Cistern	93%	93%	92%	92%
Permeable Pavement	50%	50%	50%	50%
Bioretention*	0%	0%	0%	0%
Bioretention Roads*	0%	0%	0%	0%
Infiltration Pond	50%	50%	50%	50%
RD Pond	85%	85%	49%	70%
Wet Pond	85%	85%	22%	50%
Gravity Well	100%	100%	100%	100%

*Does not include treatment due to infiltration to groundwater

4.0 WATERSHED MODELING RESULTS

The focus of this modeling effort uses SUSTAIN and its ability to evaluate the effectiveness in thousands of permutations in the stormwater treatment train and the cost associated with each permutation. These two functions enable SUSTAIN to optimize on the cost-effectiveness for the suite of strategies evaluated.

The objective of the modeling is to design a stormwater strategy that reduces flashiness enough to support a biological stream health considered *good* or better, and reduce concentrations of pollutants that exceed Washington state water quality standards.

SUSTAIN modeling outputs include:

- flow rates,
- concentrations for,
    - TSS – total suspended solids
    - Fecals – Fecal coliforms
    - Copper – dissolved copper
    - Zinc—dissolved zinc

The simulation time period used for assessment was the most recent 10 years available—10/1/2002 through 9/30/2012. The first year of the ten years should be considered more of an initialization of the model outputs rather than part of the final analysis. However, the first year of outputs are kept in the results analyzed.

4.1 Cost Effectiveness Optimization

Cost effectiveness was evaluated for each of the thirteen SUSTAIN model domains in the watershed study area (Figure 5). When reporting the cost-effectiveness for a model domain, it includes all cost-effectiveness results from upstream model domains. Thus any discussion of results for BEA010 encompasses the entire study area, not just the identified model domain labeled BEA010 in Figure 5.

Figure 27 illustrates the cost (x-axis) associated for each solution and how effective it is in reducing flashiness (HPC) and increasing projected B-IBI scores (y-axis) for the study area (i.e., BEA010). Figure 27 and all other cost-effective figures (Figure 168 through Figure 181 in Appendix H) include five elements to provide added context when interpreting the results.

(1) Unmitigated future (red dashed horizontal line) – a projected baseline B-IBI score for simulated future conditions with no additional mitigation (i.e., what would B-IBI be like if the projected future occurred with no additional mitigation).

(2) Target (solid green horizontal line) – the identified threshold when a simulated solution would equal or exceed a projected B-IBI score of 60.

(3) All solutions (gray circles) – all of the thousands of simulated treatment trains evaluated.

(4) Best Solutions (orange circles) – the more effective solutions for the lesser range of costs. Note more than just the most cost effective solution are included because of the need to consider alternative solutions to achieve a broader range of success in other areas and for water quality aside from the optimized location evaluated.

(5) Selected (blue circle) – the cost-effectiveness of the selected strategy that has been identified to achieve the desired targets within the watershed study area.

The most optimized solution would be to select a strategy that just meets the target B-IBI score of 60. The most cost-effective strategy to just meet this target at the outlet of the study area (BEA010) would about $885 million (Figure 27). This solution applies various types of mitigation distributed within the study area, such that some areas upstream of the outlet (BEA010) do not meet the target scores. Specifically, model domains BEA800 and BEA240 did not achieve a B-IBI score of 60 using the optimized afore mentioned strategy. Thus, more effective strategies (and more costly) were selected to achieve targeted B-IBI scores among a greater number of catchments in the study area. This adjustment propagates downstream affecting BEA280, and ultimately at the outlet of the study area (BEA010). Consequently, the revised selected strategy for BEA010 projects a B-IBI score greater than the target of 60, but still remains within the biological conditions classified as *good* (i.e., a B-IBI score between 60-80).

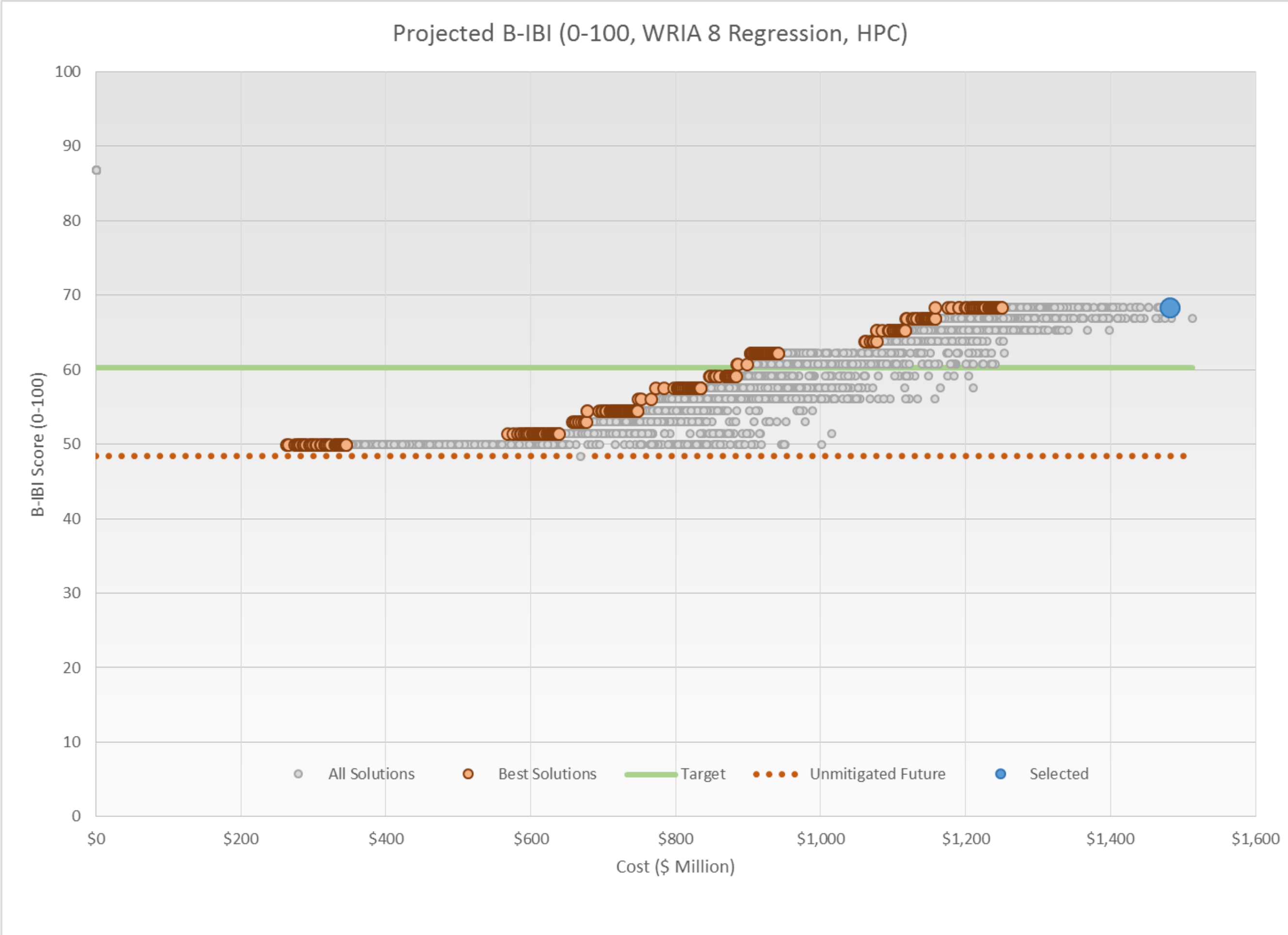

Figure 27 Cost-effectives curve for mouth of watershed study area (BEA010).

The results of the selected solution in Figure 27 are summarized in Table 35 and detailed in

Table 36 below. The contents of the table includes: the number of raingardens on private property (Parcels) and roadside bioretention in road right-of-ways (Right-of-Way). Parcels with high infiltration are labeled with OW (outwash), parcels with low infiltration are labeled till. The number of cisterns capturing runoff from roofs. The number of 1000 square-foot permeable pavement units are for low traffic areas (i.e., non-road and non-roof impervious surfaces). The number of gravity wells with high infiltration capacity are intended for poor draining soils and infiltration ponds are located over high permeability soils. Combined dry and wet ponds (i.e., Dry+Wet and Wet Ponds) provide flow control and water quality treatment in poorly draining soil areas.

Table 35 Summary of number of BMPs for the selected strategy.

Number of Unit BMPs										
	Bioretention							Stormwater Ponds		
Catchment	Parcels (OW)	Right-of-Way (OW)	Parcels (Till)	Right-of-way (Till)	Cistern	Permeable Pavement	Gravity Wells	Infiltration	Dry+Wet	Wet pond
All	10831	4160	9217	5057	2167	3013	1305	436	476	1148

Table 36 Number of BMPs per catchment for selected strategy.

Number of Unit BMPs										
	Bioretention							Stormwater Ponds		
Catchment	Parcels (OW)	Right-of-Way (OW)	Parcels (Till)	Right-of-way (Till)	Cistern	Permeable Pavement	Gravity Well	Infiltration	Dry+Wet	Wetpond
BEA010	411	114	0	0	63	17	7	3	0	11
BEA020	21	20	0	0	2	2	1	1	0	1
BEA030	177	52	75	43	19	27	16	7	3	9
BEA040	38	1	87	71	20	11	14	7	3	1
BEA050	32	154	25	118	18	33	27	0	1	12
BEA060	341	284	87	48	28	97	8	10	1	23
BEA070	224	56	12	20	6	15	5	1	0	1
BEA080	37	147	14	36	60	83	13	6	7	5
BEA100	309	28	44	35	17	37	3	0	3	8
BEA110	3	1	0	0	4	0	28	0	0	0
BEA120	425	51	74	15	10	29	6	4	7	12
BEA130	155	41	55	57	10	19	10	1	0	6
BEA140	66	14	155	33	9	16	11	4	5	12
BEA150	76	15	57	18	9	11	7	2	3	6
BEA160	22	15	17	22	3	3	1	0	1	1
BEA170	3	1	113	99	21	38	12	7	1	11
BEA180	32	0	43	11	15	10	5	3	1	5
BEA190	70	93	684	47	117	122	25	0	10	12
BEA200	136	200	226	68	53	149	7	13	17	23
BEA210	51	19	6	14	14	13	9	1	0	14
BEA220	56	12	18	26	57	1	2	0	1	0
BEA230	69	93	0	0	4	24	5	2	0	6
BEA240	75	17	130	228	21	56	4	1	7	8
BEA245	516	15	162	151	28	101	12	10	3	20
BEA250	0	0	151	1183	78	688	92	0	42	89

Number of Unit BMPs										
	Bioretention							Stormwater Ponds		
Catchment	Parcels (OW)	Right-of-Way (OW)	Parcels (Till)	Right-of-way (Till)	Cistern	Permeable Pavement	Gravity Well	Infiltra tion	Dry+ Wet	Wetpond
BEA260	124	10	0	0	12	30	9	9	0	10
BEA270	15	13	36	34	22	8	9	1	1	6
BEA275	76	23	169	19	59	23	13	0	3	33
BEA280	772	115	75	5	7	45	7	11	5	8
BEA290	30	2	190	162	26	38	7	3	6	3
BEA300	145	31	0	0	4	12	3	8	0	1
BEA310	7	9	80	29	20	7	9	2	0	5
BEA315	1	0	10	18	5	4	6	3	1	0
BEA320	32	1	18	2	2	9	1	0	0	2
BEA325	23	2	14	10	1	4	1	2	0	1
BEA330	3	2	5	11	6	20	4	0	1	6
BEA335	5	1	25	32	7	15	6	0	1	9
BEA350	262	202	184	245	41	55	52	28	24	46
BEA360	197	205	64	54	103	27	6	1	2	14
BEA370	121	1	44	36	29	37	41	3	4	5
BEA380	289	28	39	6	13	17	3	2	13	17
BEA390	304	66	44	3	23	37	29	6	6	27
BEA400	193	3	52	44	14	9	6	3	1	3
BEA410	28	0	29	1	4	4	0	0	0	1
BEA420	51	4	55	74	10	9	6	5	4	8
BEA430	19	1	158	381	72	16	3	2	3	0
BEA450	0	0	164	24	36	11	5	0	6	1
BEA460	0	0	68	77	64	45	4	0	5	16
BEA480	20	1	27	19	7	6	0	2	3	10
BEA490	13	2	219	56	49	14	11	3	0	7
BEA500	552	29	174	15	29	15	72	18	1	44
BEA510	51	4	180	14	20	7	40	3	2	20
BEA525	86	28	93	24	14	14	16	10	19	8
BEA530	21	8	459	234	10	50	8	13	20	27
BEA540	37	7	164	71	22	22	6	7	3	39
BEA550	3	5	453	44	40	20	3	4	4	9
BEA570	69	3	307	85	70	53	58	29	5	76
BEA580	3	4	48	134	26	10	8	16	4	35
BEA590	10	1	66	18	9	16	32	8	1	27
BEA600	0	0	169	28	10	3	28	0	7	27
BEA610	26	7	61	22	6	8	34	2	1	2
BEA620	2	1	49	3	2	6	2	14	4	5

Number of Unit BMPs										
	Bioretention							Stormwater Ponds		
Catchment	Parcels (OW)	Right-of-Way (OW)	Parcels (Till)	Right-of-way (Till)	Cistern	Permeable Pavement	Gravity Well	Infiltration	Dry+ Wet	Wetpond
BEA625	0	0	27	4	5	3	14	1	7	4
BEA630	0	1	100	18	1	4	1	1	13	4
BEA640	0	1	14	6	4	2	8	7	2	1
BEA650	0	0	52	3	3	3	1	0	4	2
BEA660	55	5	185	93	48	52	130	1	4	26
BEA665	0	0	143	5	5	3	3	0	5	6
BEA670	0	0	46	47	12	6	9	0	13	7
BEA690	11	3	17	27	2	15	28	3	2	5
BEA700	877	138	211	29	71	98	23	20	5	16
BEA710	931	315	177	16	47	100	18	2	10	23
BEA720	121	105	39	9	27	9	8	2	4	5
BEA725	8	21	294	40	16	21	11	1	2	9
BEA730	207	42	593	90	38	36	31	5	29	43
BEA740	267	445	43	5	47	99	19	1	12	24
BEA760	124	216	57	4	89	56	18	2	2	25
BEA770	549	305	63	69	86	52	15	15	9	15
BEA780	226	12	288	112	29	59	14	14	8	28
BEA800	18	5	68	7	6	13	20	6	6	3
BEA820	46	1	316	17	6	6	12	3	5	33
BEA830	83	1	22	27	11	7	3	6	0	2
BEA840	218	21	117	6	24	16	6	7	2	3
BEA850	85	15	31	7	4	7	12	21	1	7
BEA860	59	28	87	39	6	18	16	17	5	3
MON030	11	218	0	0	0	0	7	0	50	0

Based on the number of BMPs identified in

Table 36 and the refined BMP cost estimates in Table 37, the estimated cost for this stormwater strategy is $1.17 billion. This refined cost estimate is carried forward in the Bear Creek Watershed Study report.

Table 37 Summary of estimated stormwater costs for the selected strategy using refined BMP unit cost estimates.

Jurisdiction	Expense Type	Cost Incurred by Juris. or Private Indiv./Entity	Total Watershed Study Area
King County	Capital	Private	$31,834,067
		Public	$415,396,981
	O & M	Private	$137,455,246
		Public	$101,197,667
	Replacement	Private	$72,394,244
		Public	$61,551,811
Snohomish County	Capital	Private	$2,306,068
		Public	$48,200,630
	O & M	Private	$9,648,885
		Public	$8,744,347
	Replacement	Private	$4,207,661
		Public	$17,124,618
Redmond	Capital	Private	$63,169,118
		Public	$134,435,652
	O & M	Private	$17,889,819
		Public	$8,179,422
	Replacement	Private	$7,647,120
		Public	$4,934,007
Woodinville	Capital	Private	$588,290
		Public	$14,535,400
	O & M	Private	$4,567,804
		Public	$3,359,387
	Replacement	Private	$2,780,073
		Public	$2,597,469
All	All	Private	$354,488,396
		Public	$820,257,390
		Total	$1,174,745,786

4.2 Flood Frequencies

Flood frequencies and flashiness in stream flow rates were evaluated for each catchment using HSPF results and at the outlets of the SUSTAIN model domains.

Flood frequencies were evaluated using both watershed models, HSPF and SUSTAIN. SUSTAIN results are evaluated on a simulated 10 year window of future conditions. Flood frequencies using HSPF were evaluated based on two time periods: the 10 years window for comparisons to SUSTAIN results, and a 63 year window for a more accurate assessment of the statistics and to allow for more compatible comparisons to previous studies. HSPF flood frequencies were calculated for the following conditions (all include existing hydraulic conveyances): forested (Table 38), existing land use (Table 39), and future land use (Table 40). SUSTAIN results based on simulated 10 years of data for future conditions are summarized in Table 41.

The flood frequencies appear about 30 percent greater when using the 10 year period over the 63 year period for existing and future conditions. In the forested land use scenario, the smaller model domains show decreases in flood frequencies when using the 10 year period versus the 63 year period. This is important to know when evaluating impacts on flood frequencies using mitigation strategies from SUSTAIN based on a 10 year window of time.

SUSTAIN results from the selected stormwater strategy yield a small reduction in future mitigated conditions (2343 cfs) relative to existing (2426 cfs) based on the same 10 year window of analysis. For comparison, the projected future conditions without any additional mitigation indicates an increase in flood frequencies of about 30 percent compared to existing conditions. Flood frequencies are reduced in all SUSTAIN model domains with the exception of Monticello Creek (MON030). The flow rates from future mitigation are clearly reduced relative to future without any additional mitigation (Figure 194 in Appendix I), yet the flood frequency estimate shows an increase in the larger flood frequency quantiles (i.e., the 50 year and 100 year return periods, see Table 41). This is a result of the steeper slope in the regression when projecting out to larger less frequent flood events.

Table 38 Flood frequencies for HSPF simulated forested conditions with existing mitigation only.

Return Period	Simulated Forest Conditions (HSPF)															
	1.11-yr		2-yr		5-yr		10-yr		20-yr		25-yr		50-yr		100-yr	
Sim Years	63yrs	10yrs	63yrs	10yrs	63yrs	10yrs	63yrs	10yrs	63yrs	10yrs	63yrs	10yrs	63yrs	10yrs	63yrs	10yrs
BEA010	82	93	187	245	330	466	446	654	574	867	618	942	766	1192	930	1476
BEA020	2	2	4	4	6	5	8	6	9	7	10	7	11	8	13	9
BEA120	3	3	5	5	8	8	10	10	13	12	14	12	16	15	20	17
BEA210	1	1	2	1	2	2	3	2	3	2	3	3	4	3	4	3
BEA240	0	0	1	1	1	1	1	1	1	1	1	1	2	1	2	1
BEA260	45	63	121	176	232	352	324	507	428	688	464	752	584	972	718	1227
BEA270	1	1	2	2	3	3	4	4	5	4	6	5	7	5	8	6
BEA280	14	9	30	29	52	62	71	90	91	122	99	133	123	171	151	213
BEA310	7	13	24	39	53	84	78	126	106	175	116	193	148	256	183	329
BEA370	21	29	49	65	87	113	119	153	153	196	165	211	206	261	250	317
BEA410	10	7	22	24	40	55	57	88	77	130	85	146	112	205	145	280
BEA590	12	17	28	32	49	50	65	63	83	76	89	81	110	95	133	111
BEA800	3	2	6	6	11	14	16	21	22	31	24	34	31	46	41	61
MON030	1	1	3	3	5	7	7	11	9	16	10	18	13	24	17	32

Table 39 Flood frequencies for HSPF simulated existing conditions with existing mitigation only.

Return Period	Simulated Existing Conditions (HSPF)															
	1.11-yr		2-yr		5-yr		10-yr		20-yr		25-yr		50-yr		100-yr	
Sim Years	63yrs	10yrs	63yrs	10yrs	63yrs	10yrs	63yrs	10yrs	63yrs	10yrs	63yrs	10yrs	63yrs	10yrs	63yrs	10yrs
BEA010	225	238	421	536	671	920	872	1224	1092	1551	1168	1662	1421	2027	1705	2426
BEA020	5	5	10	12	16	20	20	26	25	32	27	35	33	41	39	49
BEA120	11	11	16	19	22	27	26	32	31	37	32	39	36	44	41	50
BEA210	3	3	5	5	7	8	8	10	10	12	10	12	11	15	13	17
BEA240	2	2	3	4	5	7	7	9	8	11	8	12	10	14	12	16
BEA260	106	128	234	320	409	590	555	815	717	1065	774	1152	965	1442	1180	1766
BEA270	3	4	6	7	10	11	12	14	14	17	15	18	17	21	19	24
BEA280	65	67	103	124	149	186	184	229	222	272	234	286	276	330	323	374
BEA310	8	15	29	44	60	91	85	133	113	182	122	199	152	260	185	330
BEA370	49	57	97	127	159	218	209	289	264	366	283	393	347	479	418	573
BEA410	20	20	47	60	91	128	132	193	182	272	200	302	264	405	341	529
BEA590	22	29	44	53	70	78	90	96	111	114	118	120	141	139	165	158
BEA800	19	19	31	38	46	61	57	77	69	93	73	99	87	116	101	134
MON030	7	7	14	18	22	33	29	45	37	59	40	64	50	80	61	99

Table 40 Flood frequencies for HSPF simulated future conditions with existing mitigation only.

Return Period	Simulated Future Unmitigated Conditions (HSPF)															
	1.11-yr		2-yr		5-yr		10-yr		20-yr		25-yr		50-yr		100-yr	
Sim Years	63yrs	10yrs	63yrs	10yrs	63yrs	10yrs	63yrs	10yrs	63yrs	10yrs	63yrs	10yrs	63yrs	10yrs	63yrs	10yrs
BEA010	324	341	584	738	906	1233	1160	1616	1435	2022	1529	2159	1840	2607	2186	3090
BEA020	7	7	14	17	22	27	28	35	34	43	36	45	44	53	51	61
BEA120	18	18	26	30	34	42	39	50	45	57	47	60	52	67	58	75
BEA210	6	6	9	10	12	14	14	18	17	21	17	23	20	26	22	30
BEA240	4	5	7	8	10	12	11	14	13	17	13	18	15	20	17	22
BEA260	152	182	317	425	533	745	708	999	901	1274	967	1368	1188	1677	1435	2014
BEA270	6	6	10	12	14	17	17	22	20	26	21	27	24	31	28	36
BEA280	96	97	148	175	205	256	246	311	289	365	303	382	349	436	398	490
BEA310	13	21	38	56	73	108	101	152	131	202	141	219	174	279	208	346
BEA370	69	79	128	167	202	276	261	361	325	451	347	482	421	581	502	688
BEA410	28	30	71	92	136	190	195	277	264	378	289	413	376	533	478	671
BEA590	30	36	56	68	86	102	109	126	133	150	141	158	167	182	196	208
BEA800	31	30	48	57	67	87	81	108	96	129	101	136	117	158	134	181
MON030	14	13	22	27	32	44	39	57	47	70	50	74	59	88	69	103

Table 41 SUSTAIN flood frequencies for simulated future conditions with existing and recommended additional mitigation.

Return Period (years)	Flood Frequencies based on SUSTAIN Simulated Flow Rates (cfs) for WY2003 - 2012													
	BEA010		BEA020		BEA120		BEA210		BEA240		BEA260		BEA270	
	Future	Mitigated	Future	Mitigated	Future	Mitigated	Future	Mitigated	Future	Mitigated	Future	Mitigated	Future	Mitigated
1.11	306	136	7	4	20	12	9	6	35	8	111	56	7	2
2	675	354	23	12	46	32	19	14	67	20	266	153	18	9
5	1158	686	50	26	84	64	33	26	105	38	482	309	34	22
10	1545	979	74	40	115	92	43	36	135	53	663	452	47	35
20	1966	1320	104	58	150	125	55	48	166	70	865	622	62	51
25	2111	1442	115	65	162	136	59	52	177	76	936	683	67	57
50	2589	1859	152	90	204	177	72	65	211	95	1172	896	84	79
100	3117	2343	196	120	250	223	86	80	249	117	1439	1149	104	105

Return Period (years)	BEA280		BEA310		BEA370		BEA410		BEA590		BEA800		MON030	
	Future	Mitigated	Future	Mitigated	Future	Mitigated	Future	Mitigated	Future	Mitigated	Future	Mitigated	Future	Mitigated
1.11	100	45	9	6	65	26	22	18	29	18	39	12	15	6
2	189	95	30	23	119	50	69	57	52	34	85	36	29	16
5	290	159	67	55	176	77	150	127	78	51	145	76	46	32
10	364	208	104	89	216	97	227	196	96	63	192	113	58	46
20	440	262	151	133	256	116	322	281	114	75	244	158	70	63
25	465	280	168	150	269	123	357	313	120	79	261	175	74	69
50	545	339	230	212	310	143	479	426	138	92	319	232	88	90
100	630	404	306	290	353	164	627	563	157	105	383	300	102	114

4.3 Flashiness

Simulated flashiness was evaluated using both HSPF and SUSTAIN. HSPF simulations were summarized for each catchment and based on 63 years of simulation. SUSTAIN results are provided at the outlets of each model domain and based on a 10 year period.

4.3.1 HSPF

Average high pulse counts for forested conditions ranged from on average one per year up to seven per year (see Table 42 below and first two columns in Table 65 in Appendix O). This variability is generally driven by the surficial geology. Areas underlain by less permeable soils (aka till soils) will generate more runoff than if the same landscape is underlain with more permeable soils. All drainage areas for Cold Creek and Cottage Lake tributary have average annual HPC less than three. Flashiness for this portion of the watershed is also benefiting from the effects Cottage Lake has dampening storm flows. The rest of the watershed has average annual HPCs ranging from three to seven.

Under existing condition, the HPCs ranged from 5 to 34, with a watershed wide average of 13.5. Areas with greater densities of development and/or large portions of the landscape devoid of trees generated the larger HPCs within the watershed (see Table 42 below and third column in Table 65 in Appendix O). Most HPCs were below 9 along the mainstem of Bear Creek and its tributaries. The catchments with greater flashiness were on the western side of the watershed where the amount of development is highest.

Projected future conditions with no additional mitigation amplifies the flashiness in drainage areas that may have been partially developed with densities exceeding rural zoning (i.e. one house per 2.5 acres). Similarly to existing conditions, areas along the mainstem of Bear Creek and headwaters of the western tributaries are projected with average annual HPCs at or below 9.0 (see Table 42 and fourth column in Table 65 in Appendix O).

Table 42 Summary of area wide HSPF simulated high pulse counts.

	Simulated WY1950-2012		
	High Pulse Counts		
Statistic	Forested	Existing	Future
Maximum	7.2	34.3	34.3
Minimum	1.0	5.1	5.9
Average	3.4	13.5	16.6
Std. Dev.	1.2	6.3	6.8

4.3.2 SUSTAIN

Flashiness was calculated for two different time periods. The first time period was used during the optimization process for feasibility running the 10,000s of simulations (see section 3.2.1 for more detail). The second time period was used for evaluating effectiveness of the recommended stormwater strategies. The comparison of calculated HPCs between the two time periods is instructional when considering the single year was selected to best represent the majority of catchments HPCs in that single year is close to the long term average. As is shown in Table 43 below, the HPCs in future conditions with no additional mitigation is higher in the single year than using the average of a ten year period for evaluating success of the strategies. However, the ten year simulation period is closer to the long-term average. This suggests that while the ten year average more closely represents the watershed study at the outlets of the model domains, the catchments within the model domains may be more variable and under estimated in flashiness using individual years as a basis.

The selected mitigation strategy further illustrates that for the single year simulation, the HPCs do not all meet the established target of less than or equal to 9.0.The calculated average HPCs for the ten year period do achieve the target with values below 9.0 (Table 43).

Additional flashiness metrics (Table 44) are provided for comparison of results from this study and other watershed studies and for permit compliance.

Table 43 Summary of SUSTAIN simulated high pulse counts.

Model Domain	Simulated High Pulse Counts			
	WY 1998		WY2003 - 2012	
	Future	Mitigated	Future	Mitigated
BEA010	16	10	11.9	4.8
BEA020	17	12	11.2	4.7
BEA120	18	14	13.2	7.2
BEA210	16	10	11.4	7
BEA240	27	11	20.9	7
BEA260	14	7	9.3	4.2
BEA270	17	12	11	4.7
BEA280	13	9	11	4.6
BEA310	14	10	6.7	4.7
BEA370	10	1	9.6	3.8
BEA410	14	14	7.4	6
BEA590	7	3	7	4.9
BEA800	18	9	13.6	4.1
MON030	26	7	20.4	6.4

Table 44 Summary of flashiness metrics based on SUSTAIN modeling results.

SUSTAIN Model	WY2003 - 2012													
	7-Day Min				HPC (events)		HPR (days)		HPD (days)		TQmean		RB Index	
	Julian Day	(cfs)	Julian Day	(cfs)										
	Future		Mitigated		Future	Mitigated	Future	Mitigated	Future	Mitigated	Future	Mitigated	Future	Mitigated
BEA010	260	9.37	257	9.73	11.9	4.8	234	139	3.52	8.36	0.37	0.40	0.24	0.11
BEA020	236	0.01	236	0.02	11.2	4.7	202	143	5.99	18.42	0.39	0.40	0.25	0.12
BEA120	235	0.01	236	0.02	13.2	7.2	232	151	4.64	9.68	0.37	0.38	0.29	0.17
BEA210	251	0.01	240	0.02	11.4	7	248	157	4.29	10.95	0.40	0.41	0.28	0.19
BEA240	236	0.04	239	0.08	20.9	7	296	149	2.47	9.09	0.30	0.41	0.58	0.15
BEA260	275	4.69	268	4.82	9.3	4.2	172	110	4.95	11.13	0.38	0.40	0.20	0.10
BEA270	236	0.00	236	0.00	11	4.7	208	123	6.20	16.91	0.37	0.38	0.26	0.13
BEA280	260	4.05	251	4.15	11	4.6	204	135	3.49	7.05	0.38	0.41	0.20	0.10
BEA310	233	0.01	234	0.01	6.7	4.7	151	126	11.40	16.38	0.37	0.37	0.16	0.12
BEA370	285	4.33	281	4.49	9.6	3.8	186	82	2.85	6.15	0.39	0.42	0.18	0.08
BEA410	237	0.07	237	0.07	7.4	6	153	147	12.34	13.33	0.37	0.37	0.19	0.16
BEA590	285	2.81	282	2.81	7	4.9	140	102	3.58	4.56	0.40	0.41	0.14	0.09
BEA800	239	0.06	236	0.07	13.6	4.1	234	112	4.49	17.73	0.38	0.41	0.29	0.10
MON030	242	0.34	294	0.47	20.4	6.4	292	175	1.95	2.34	0.25	0.35	0.47	0.16

4.4 B-IBI

Simulated B-IBI projections are based on calculated high pulse counts (HPCs) and using the WRIA 8 regression (see section 2.16). Projections of B-IBI were evaluated using results from HSPF and SUSTAIN. The HSPF results are provided at a catchment scale for the entire watershed study area, whereas the SUSTAIN results are presented at a courser scale for each of the model domains. B-IBI scores are presented in tables in Appendix O and include B-IBI projections using the other regressions previously mentioned for comparisons among other watershed studies. Additionally, two scoring systems are presented (i.e., 10-50 and 0-100).

4.4.1 HSPF

Simulated B-IBI for forested conditions range from good (60-80) to excellent (80-100) in score. The catchments for estimated conditions of excellent, when fully forested, are in the Cottage Lake tributary and Cold Creek. The rest of the watershed area is estimated to be in the B-IBI "good" range (Figure 28). Table 65 in Appendix O summarizes B-IBI scores by catchment and include the two methods of number schemes.

Existing conditions is more variable in stream health with scores ranging from very poor to good, with lower scores in areas with denser development. Existing conditions were modeled to have good B-IBI along most of the mainstem of Bear Creek and for about half of the eastern tributary areas (Figure 29 and Table 66 in Appendix O).

Future (HSPF) conditions with no addition mitigation reflect lower B-IBI scores relative to existing conditions where development infills in the urban and rural areas. Areas in the future that are expected to remain rural in development generally remain in the good category. This includes portions in Snohomish County and Struve and Seidel Creeks (Figure 30 and Table 67).

4.4.2 SUSTAIN

Simulated future conditions using SUSTAIN are presented at the model domain scale and include future conditions with no additional mitigation and future conditions with the selected mitigation strategy. As is shown in Figure 31, future conditions are expected to degrade in areas with increases in development. Conversely, using the selected stormwater strategy achieves the target B-IBI scores greater than 60 for all of the model domains (see Table 45, Table 46, Figure 32, and Figure 32).

Table 45 Simulated future B-IBI using SUSTAIN and WRIA 8 regressions.

Model Domain	Sim B-IBI Score (WRIA 8, 0-100)							
	HPCs		HPR		HPD		TQmean	
	Future	Mitigated	Future	Mitigated	Future	Mitigated	Future	Mitigated
BEA010	52	73	47	64	44	89	58	65
BEA020	54	73	53	63	67	100	63	65
BEA120	48	66	48	62	55	100	58	60
BEA210	53	66	45	61	52	100	65	67
BEA240	25	66	36	62	35	96	41	67
BEA260	59	74	58	69	58	100	60	65
BEA270	54	73	52	67	69	100	58	60
BEA280	54	73	52	65	44	77	60	67
BEA310	67	73	62	66	100	100	58	58
BEA370	58	76	56	74	38	69	63	70
BEA410	65	69	61	63	100	100	58	58
BEA590	66	72	64	70	45	54	65	67
BEA800	47	75	47	69	53	100	60	67
MON030	27	68	37	58	30	33	30	53

Table 46 Simulated future B-IBI using SUSTAIN and WRIA 9 regressions.

Model Domain	Sim B-IBI Score (WRIA 9, 0-100)			
	HPCs		HPR (days)	
	Future	Mitigated	Future	Mitigated
BEA010	41	66	34	54
BEA020	43	66	40	53
BEA120	38	56	34	51
BEA210	42	57	32	50
BEA240	23	57	25	52
BEA260	49	68	46	63
BEA270	44	66	38	59
BEA280	44	66	39	55
BEA310	58	66	51	58
BEA370	48	70	43	72
BEA410	55	61	51	52
BEA590	57	65	54	65
BEA800	37	69	34	62
MON030	23	59	25	45

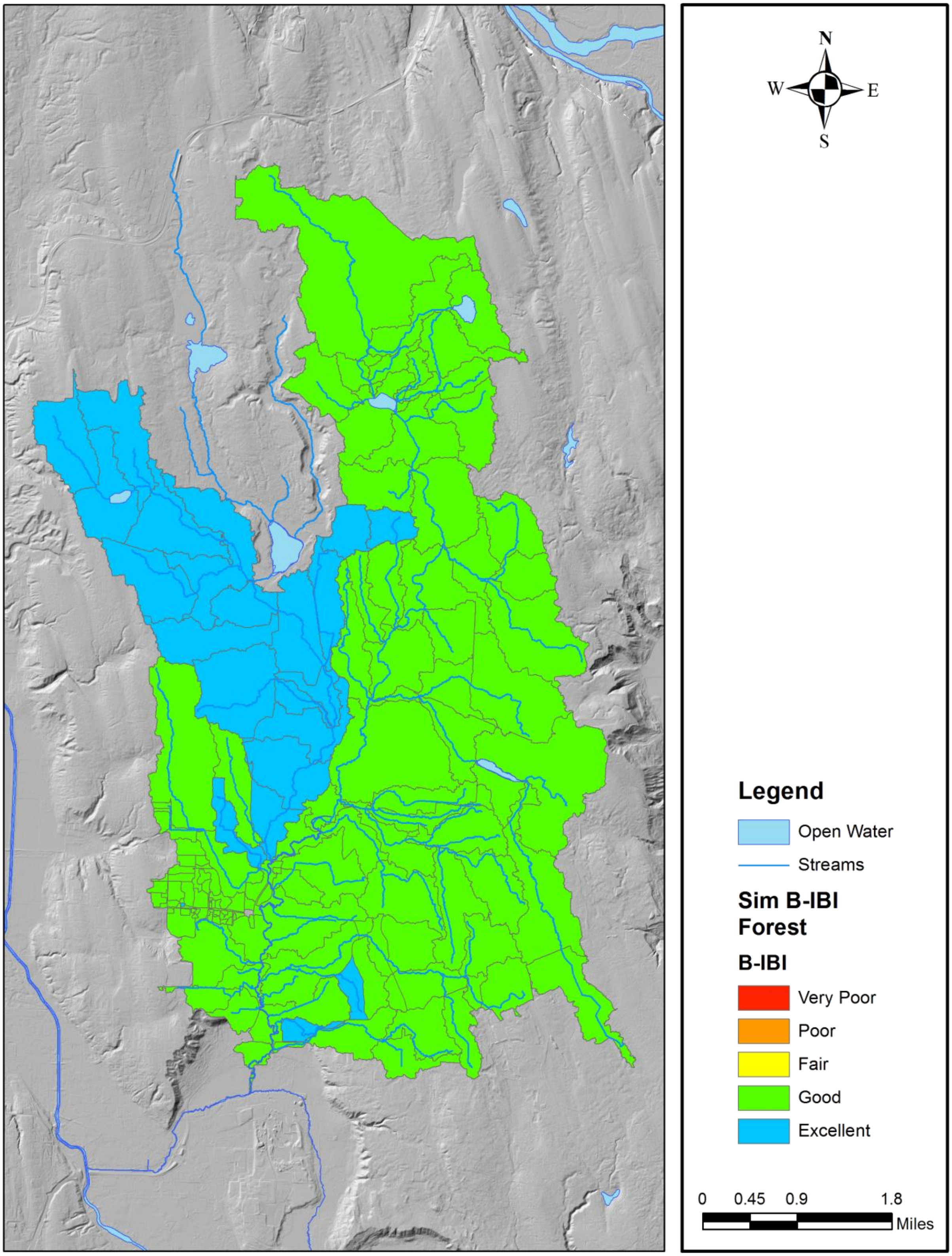

Figure 28 HSPF simulated (63 years) of forested conditions of B-IBI scores.

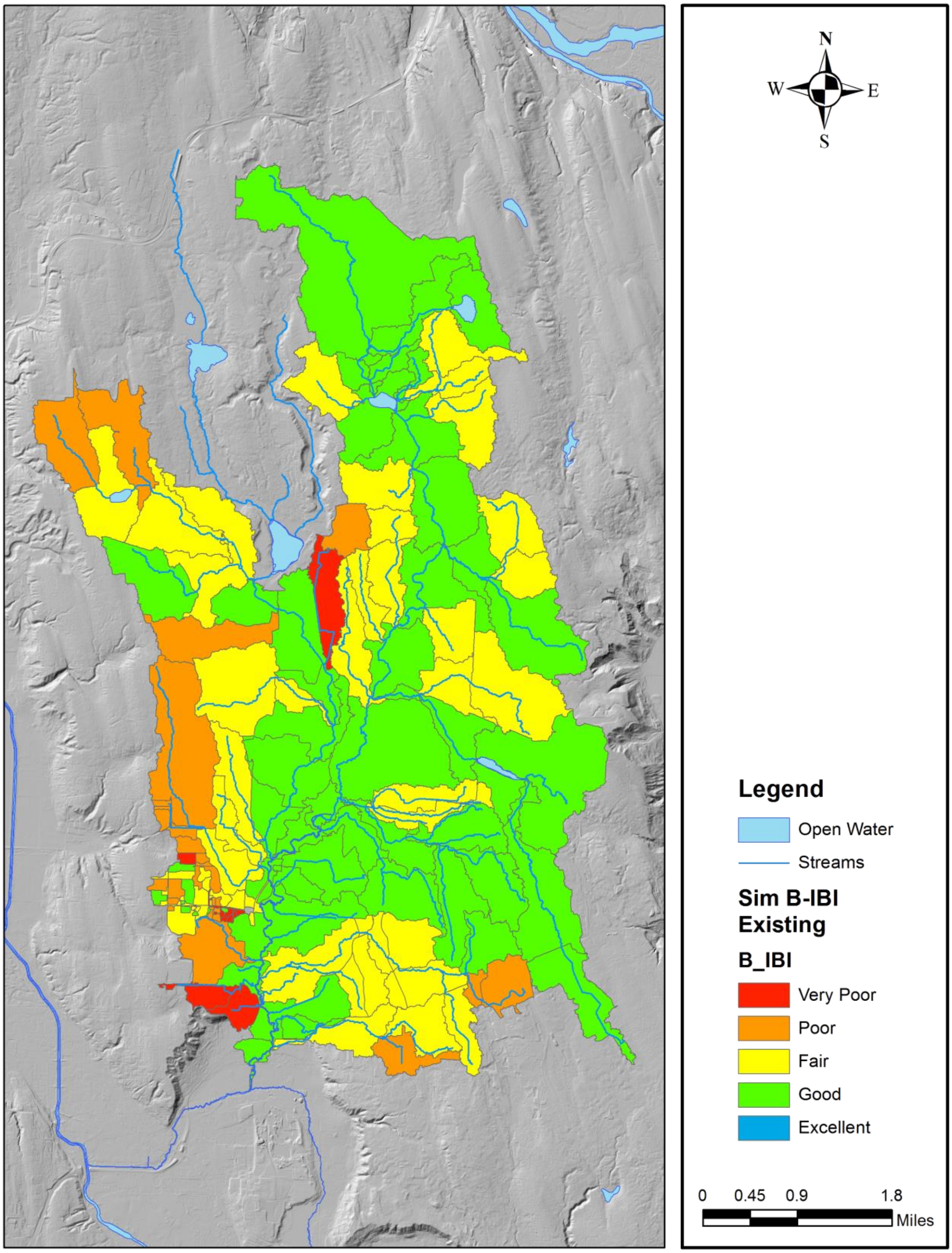

Figure 29 HSPF simulated (63 years) existing conditions of B-IBI scores.

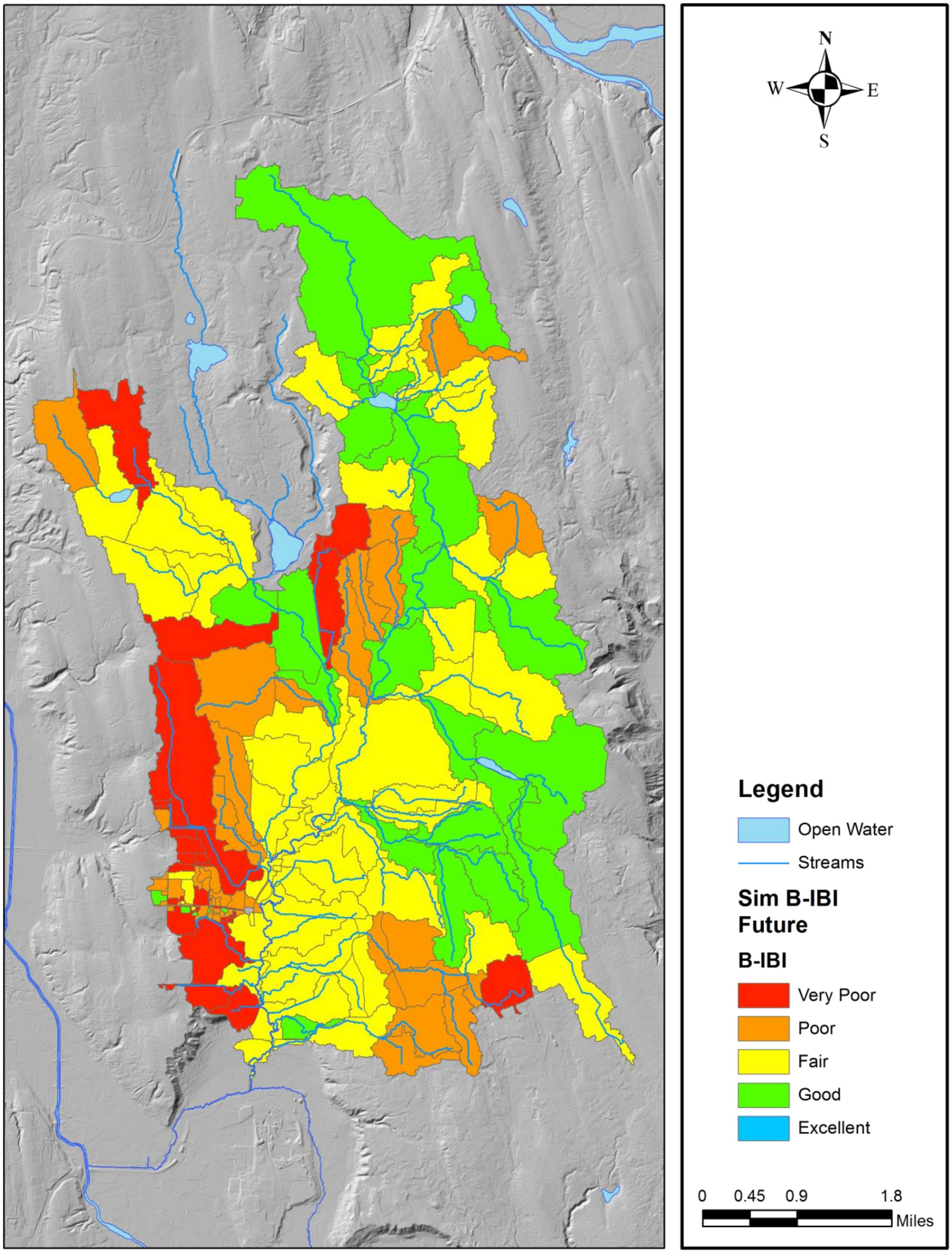

Figure 30 HSPF simulated (63 years) future B-IBI scores.

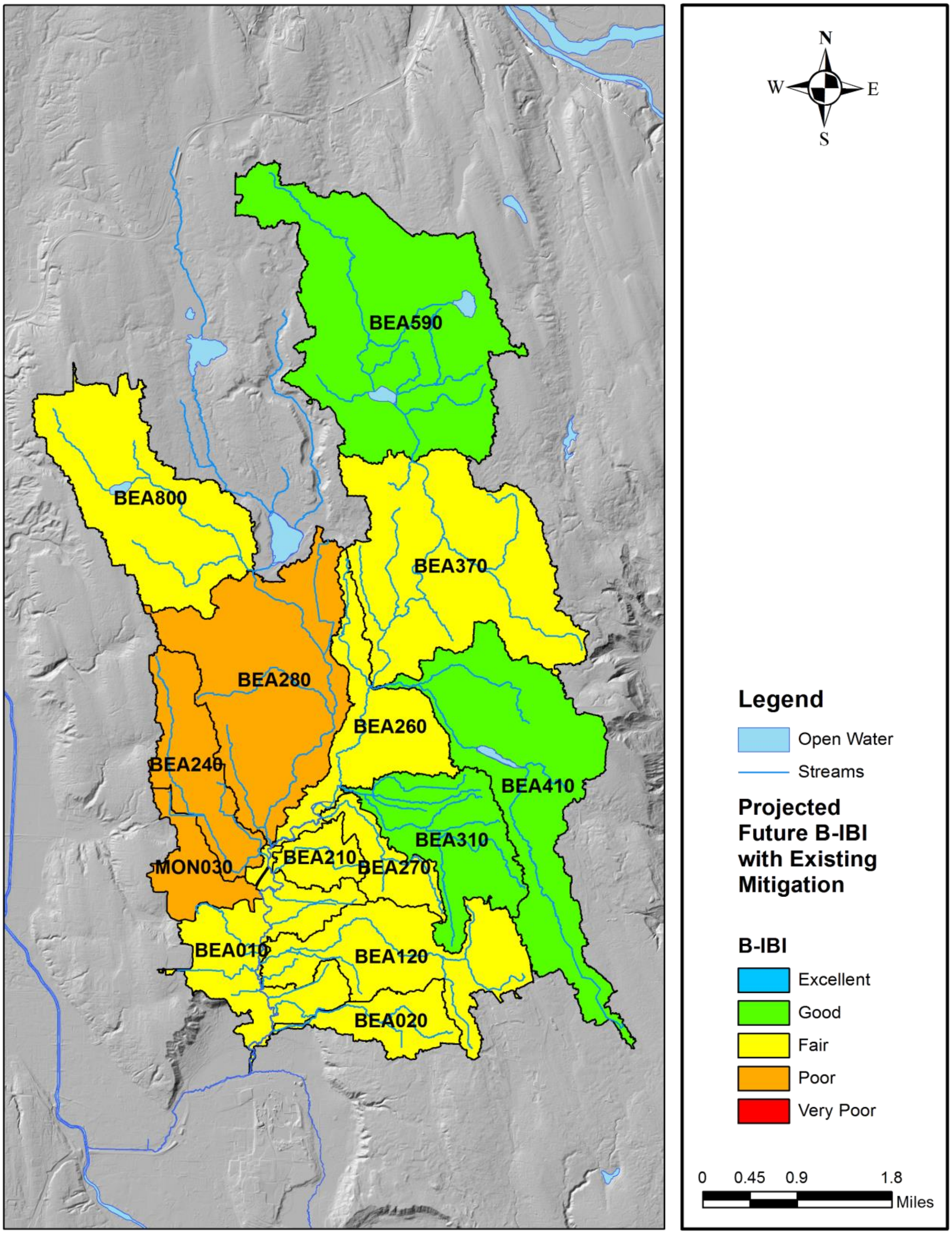

Figure 31 Simulated future (10 years) projections of B-IBI with existing mitigations (WRIA 8, HPCs).

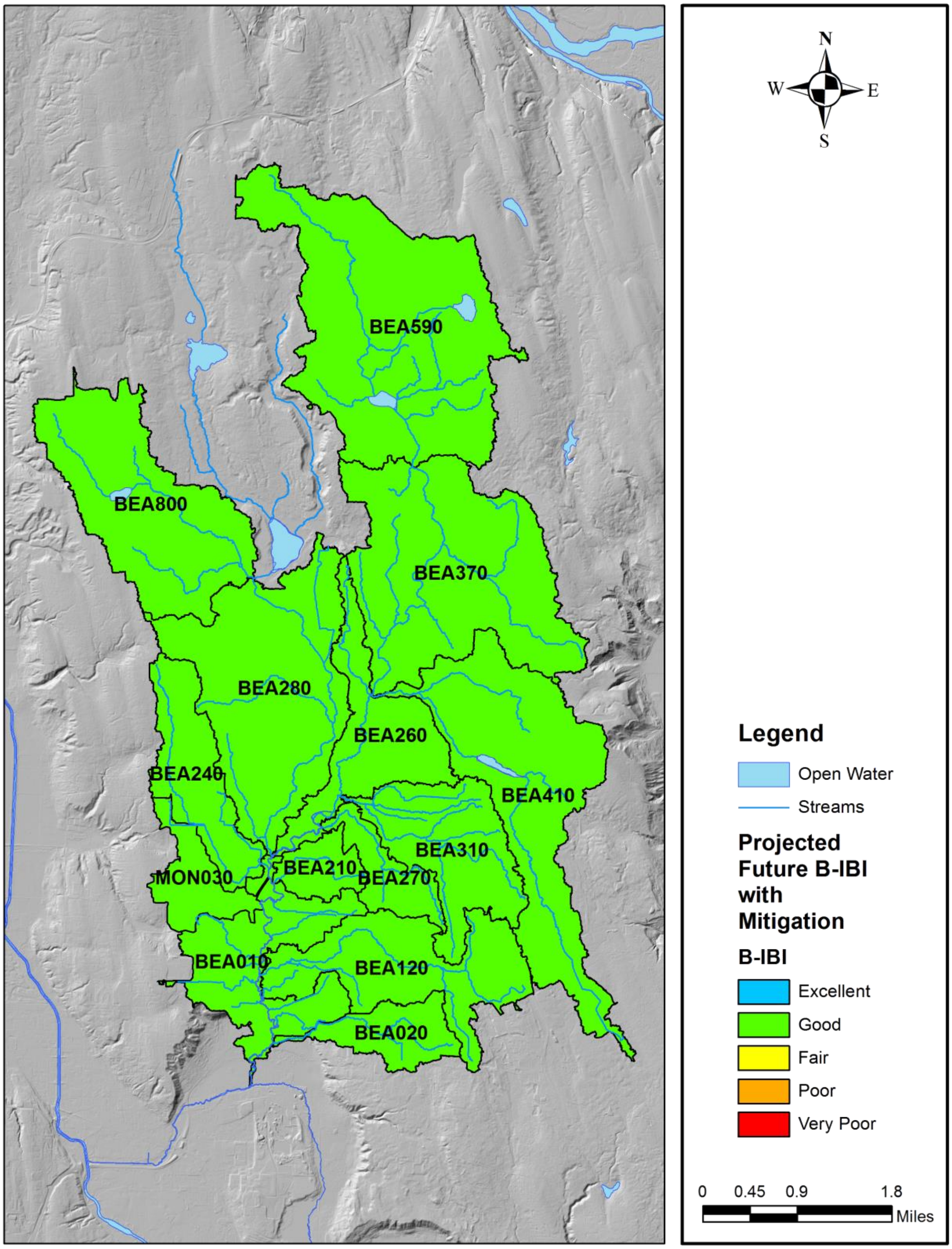

Figure 32 Simulated future (10 years) projections of B-IBI with recommended mitigations (WIRA 8, HPCs).

4.5 Water Quality

Results of simulated water temperatures are based on HSPF modeling. SUSTAIN was used for fecal coliforms, dissolved copper and zinc concentrations.

Water temperature exceedances occur almost throughout the watershed assuming full riparian vegetation providing 90-percent effective shade to the stream (Figure 33). Even when assuming a fully forested landscape the effective shade on the stream is not enough and only marginally improves stream temperatures relative to future land use with full riparian cover (Figure 34). The difference between future land use with riparian fully vegetated and forested occurs in the model domains of BEA590 and BEA800 (Table 47). Exceedances are less during the winter months but still ubiquitous (Table 48) even with the lower temperature threshold (i.e. > 13 ^{o}C) during those months.

Stream temperatures get close to achieving state water quality standards when assuming a microclimate benefit occurs with the full forested riparian cover. Assuming a 1-4 degree drop in air and ground temperatures (Bartholow 2000) occurs, stream temperatures approach full compliance, but not completely. A full listing of simulated water temperature exceedances by catchment can be found in Table 63 and Table 64 in Appendix J.

Simulations of future conditions with no additional mitigation (Table 49) and future conditions with additional mitigation (Table 50) indicate no exceedances will occur for fecal coliforms and the metals except for model domain BEA310. Results in that model domain seem anomalous compared to the other SUSTAIN domains and the exceedances are based on a single event over the 10 year simulation time period. While fecal coliforms technically do not exceed the state water quality standards, the simulated hourly concentrations are highly variable and will likely range into the 1000s of cfu/100ml. Even when considering the selected mitigation strategy is applied, the hourly fecal concentrations can be above 400 (cfu/100ml). The plots of simulated hourly concentrations for BEA010 are presented in this section (Figure 35 and Figure 40), and plots for the other 13 other model domains are presented in the appendices J-N (see Figure 195 through Figure 259).

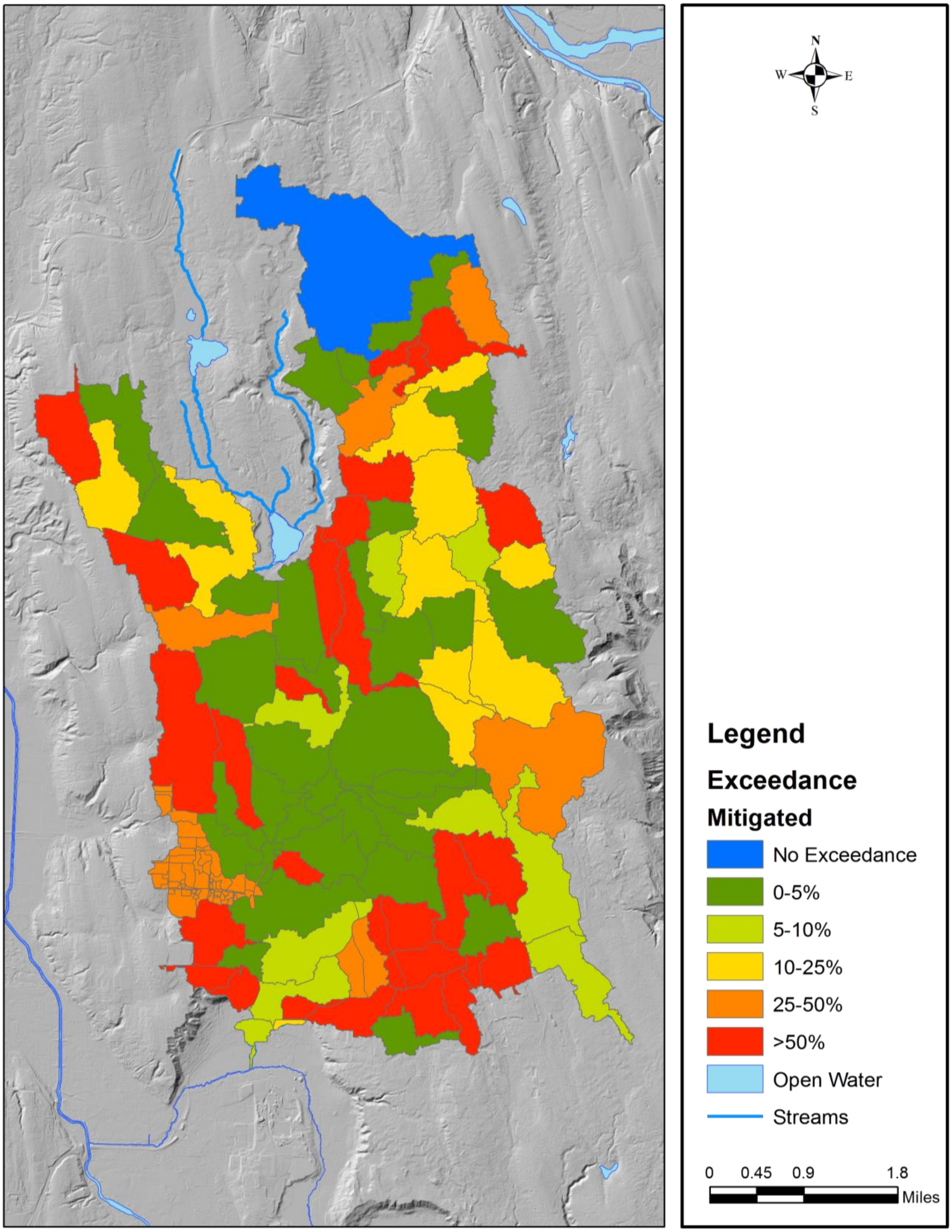

Figure 33 Simulated summer water temperature exceedances (percent of time) by catchment for future mitigated conditions.

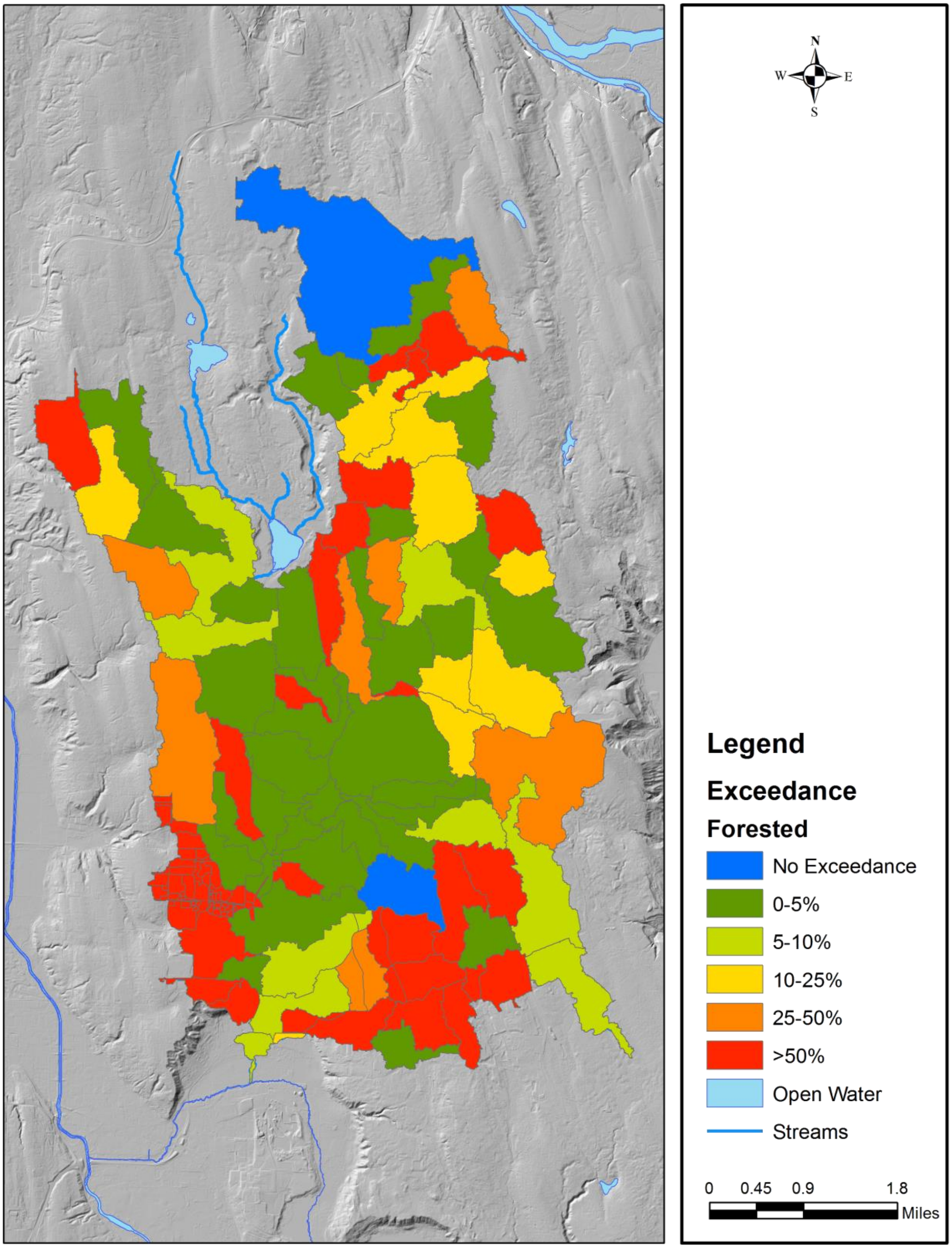

Figure 34 Simulated summer water temperature exceedances (percent of time) by catchment for forested conditions.

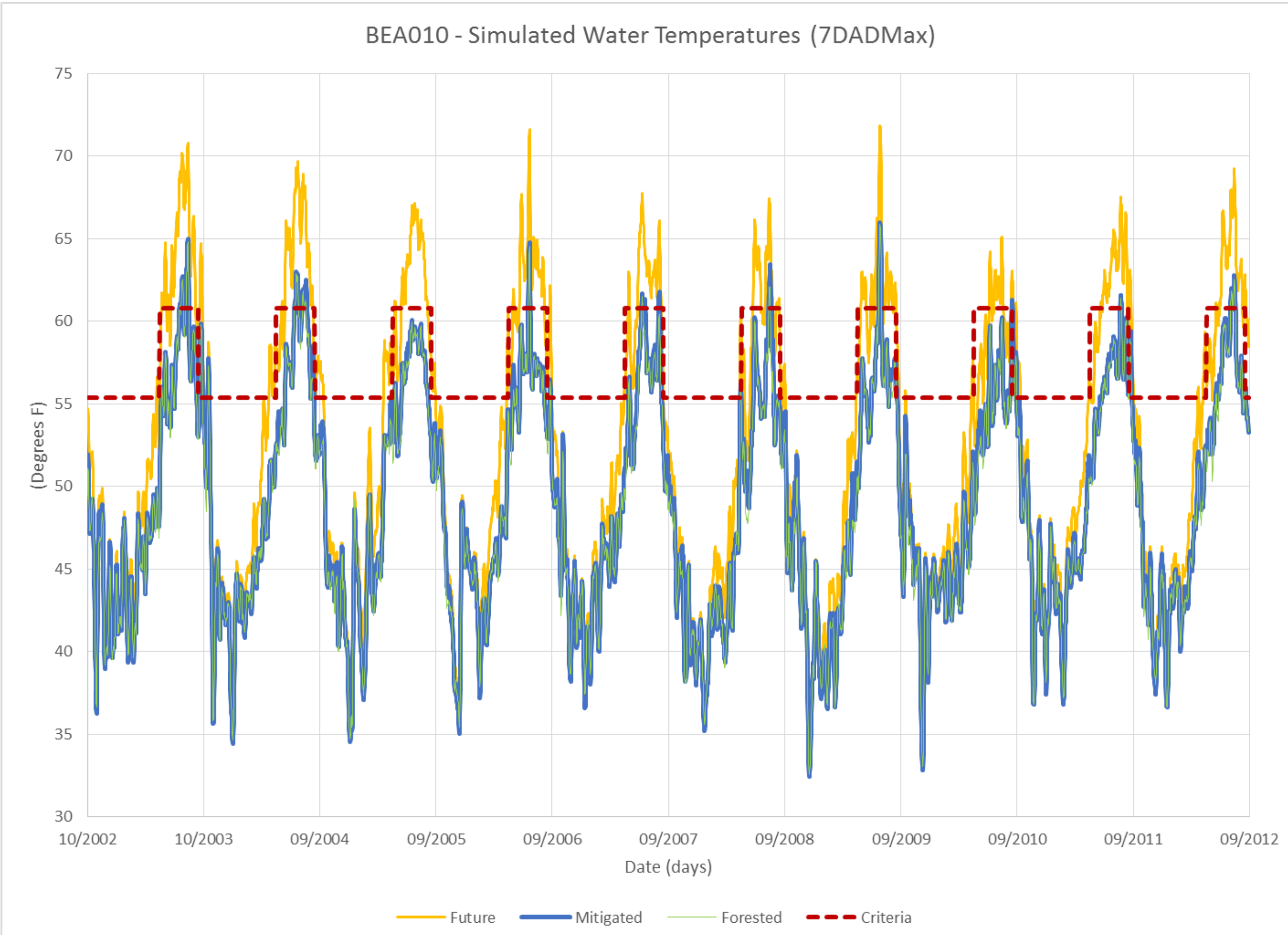

Figure 35 Simulated 7-DADMax water temperature for BEA010.

Table 47 Summary of exceedances of summer water temperatures for forested, existing, future, future mitigated, and microclimate.

Catchment	# of Days (Summer)					Percent of Time (Summer)					Diff. (Mit-Forest)
	Forested	Existing	Future	Mitigated	Micro-climate	Forested	Existing	Future	Mitigated	Micro-climate	
BEA010	411	4557	4608	506	138	5%	58%	59%	6%	2%	1%
BEA020	1639	6342	6361	1701	961	21%	81%	81%	22%	12%	1%
BEA120	666	3874	3946	667	214	9%	50%	51%	9%	3%	0%
BEA210	5220	5199	5228	5132	5628	67%	67%	67%	66%	72%	-1%
BEA240	199	4948	5106	270	52	3%	63%	65%	3%	1%	1%
BEA260	156	5552	5555	198	19	2%	71%	71%	3%	0%	1%
BEA270	81	1718	1804	132	17	1%	22%	23%	2%	0%	1%
BEA280	166	1460	1496	165	22	2%	19%	19%	2%	0%	0%
BEA310	11	2541	2575	13	0	0%	33%	33%	0%	0%	0%
BEA370	247	3875	6351	287	33	3%	50%	81%	4%	0%	1%
BEA410	5260	5256	5246	5202	5493	67%	67%	67%	67%	70%	-1%
BEA590	1110	6788	6743	1484	494	14%	87%	86%	19%	6%	5%
BEA800	679	942	1102	1093	338	9%	12%	14%	14%	4%	5%
MON030	3970	5352	4946	2426	1726	51%	69%	63%	31%	22%	-20%

Table 48 Summary of exceedances of winter water temperatures for forested, existing, future, future mitigated, and microclimate.

Catchment	# of Days (Winter)					Percent of Time (Winter)					Diff. (Mit-Forest)
	Forested	Existing	Future	Mitigated	Micro-climate	Forested	Existing	Future	Mitigated	Micro-climate	
BEA010	256	1401	1436	321	108	2%	9%	9%	2%	1%	0%
BEA020	1182	2535	2565	1128	873	8%	16%	16%	7%	6%	0%
BEA120	301	1158	1199	348	122	2%	7%	8%	2%	1%	0%
BEA210	3117	3381	3492	3261	2871	20%	22%	22%	21%	18%	1%
BEA240	128	1424	1494	206	69	1%	9%	10%	1%	0%	1%
BEA260	306	2360	2364	371	88	2%	15%	15%	2%	1%	0%
BEA270	87	582	633	173	49	1%	4%	4%	1%	0%	1%
BEA280	107	476	482	127	34	1%	3%	3%	1%	0%	0%
BEA310	180	1351	1381	203	24	1%	9%	9%	1%	0%	0%
BEA370	474	1583	2865	572	133	3%	10%	18%	4%	1%	1%
BEA410	3276	3289	3249	3181	2708	21%	21%	21%	20%	17%	-1%
BEA590	821	2944	3018	1277	695	5%	19%	19%	8%	4%	3%
BEA800	353	427	477	471	162	2%	3%	3%	3%	1%	1%
MON030	735	2037	1899	843	541	5%	13%	12%	5%	3%	1%

Table 49 Summary of exceedances of fecals and metals for future conditions.

Model Domain	Future									
	Fecals (cfu/100ml)						Cu (ug/L)		Zn (ug/L)	
	Extraordinary	Primary	Secondary	Extraordinary	Primary	Secondary	Acute	Chronic	Acute	Chronic
	Occurrences, Geometric Mean			Fraction of Time, Observations			Occurrences			
Criteria ->	50	100	200	100	200	400	Hardness dependent			
BEA010	0	0	0	0%	0%	0%	0	0	0	0
BEA020	1582	1394	837	2%	1%	1%	23	139	1	2
BEA120	1021	0	0	2%	1%	0%	1	1	0	0
BEA210	0	0	0	1%	0%	0%	0	0	0	0
BEA240	0	0	0	0%	0%	0%	0	0	0	0
BEA260	0	0	0	0%	0%	0%	0	0	0	0
BEA270	1436	662	0	1%	1%	1%	0	0	0	0
BEA280	1814	761	596	2%	1%	1%	0	0	0	0
BEA310	681	437	0	1%	1%	0%	1	2	1	1
BEA370	0	0	0	0%	0%	0%	0	0	0	0
BEA410	0	0	0	0%	0%	0%	1	1	0	0
BEA590	0	0	0	0%	0%	0%	0	0	0	0
BEA800	0	0	0	1%	0%	0%	0	0	0	0
MON030	0	0	0	0%	0%	0%	0	0	0	0

Table 50 Summary of exceedances of fecals and metals for future mitigated conditions.

Model Domain	Future Mitigated									
	Fecals (cfu/100ml)						Cu (ug/L)		Zn (ug/L)	
	Extraordinary	Primary	Secondary	Extraordinary	Primary	Secondary	Acute	Chronic	Acute	Chronic
	Occurrences, Geometric Mean			Fraction of Time, Observations			Occurrences			
Criteria =>	50	100	200	100	200	400	hardness dependent			
BEA010	0	0	0	1%	0%	0%	0	0	0	0
BEA020	0	0	0	1%	0%	0%	0	0	0	0
BEA120	0	0	0	1%	1%	0%	0	0	0	0
BEA210	0	0	0	1%	1%	0%	0	0	0	0
BEA240	0	0	0	1%	0%	0%	0	0	0	0
BEA260	0	0	0	0%	0%	0%	0	0	0	0
BEA270	0	0	0	1%	0%	0%	0	1	0	0
BEA280	417	0	0	2%	1%	0%	0	0	0	0
BEA310	0	0	0	0%	0%	0%	4	6	1	1
BEA370	0	0	0	0%	0%	0%	0	0	0	0
BEA410	0	0	0	0%	0%	0%	1	1	0	0
BEA590	0	0	0	0%	0%	0%	0	0	0	0
BEA800	0	0	0	1%	0%	0%	0	0	0	0
MON030	0	0	0	0%	0%	0%	0	0	0	0

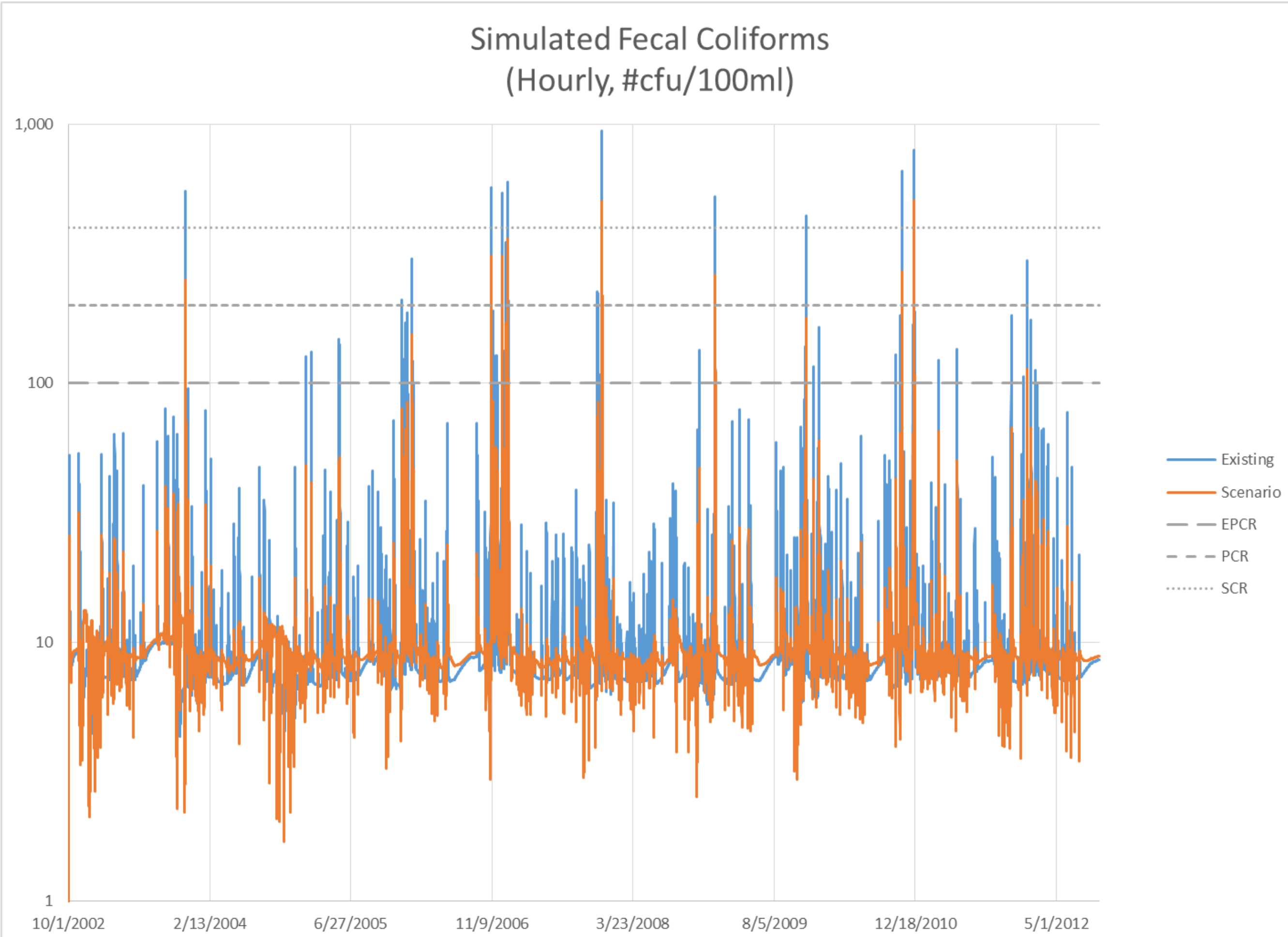

Figure 36 Simulated hourly fecal coliform concentrations (# cfu/100ml) for BEA010.

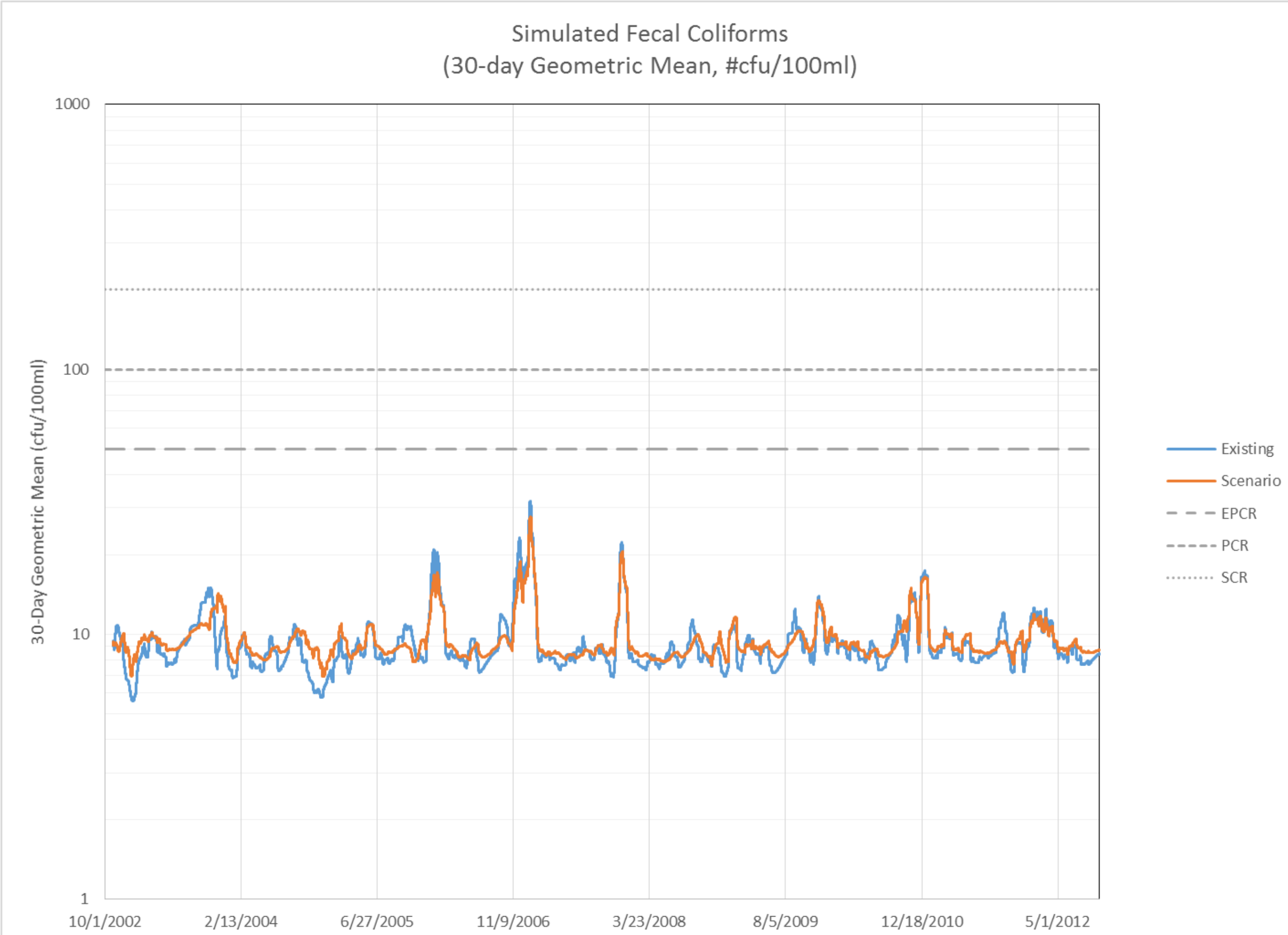

Figure 37 Simulated 30-day geometric means of fecal coliform concentrations for BEA010.

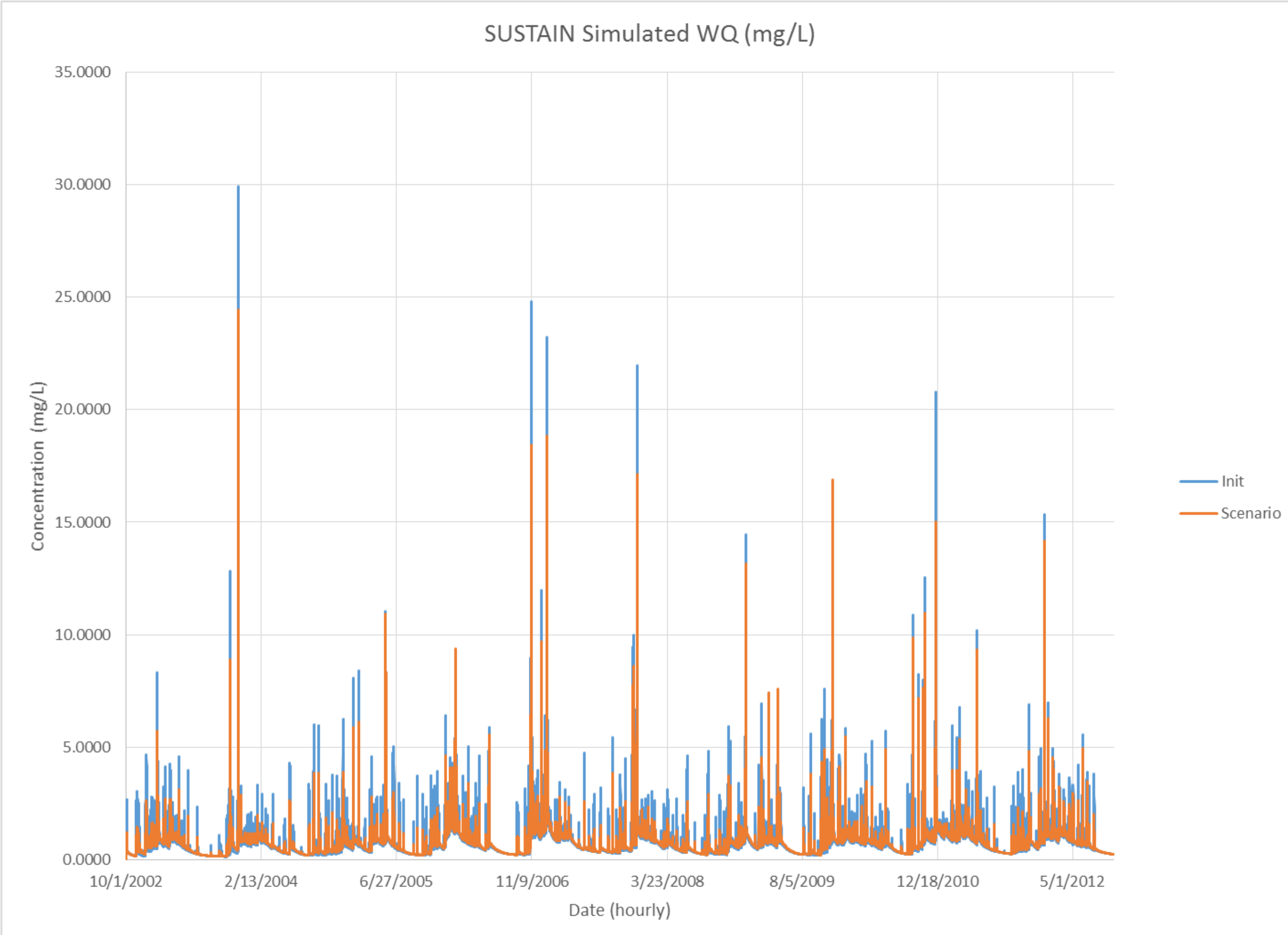

Figure 38 Simulated hourly concentrations of TSS for BEA010.

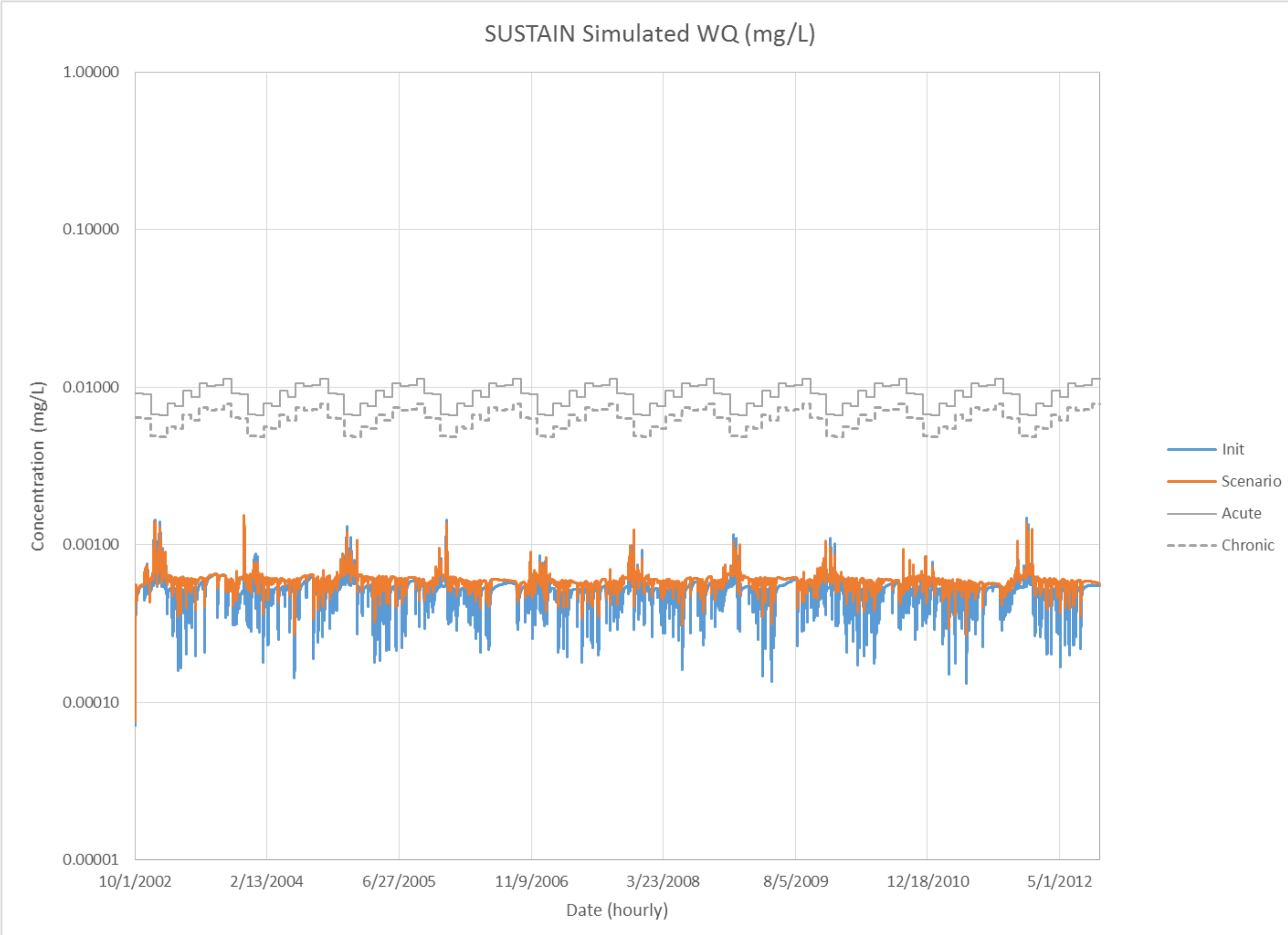

Figure 39 Simulated hourly concentrations of dissolved copper for BEA010.

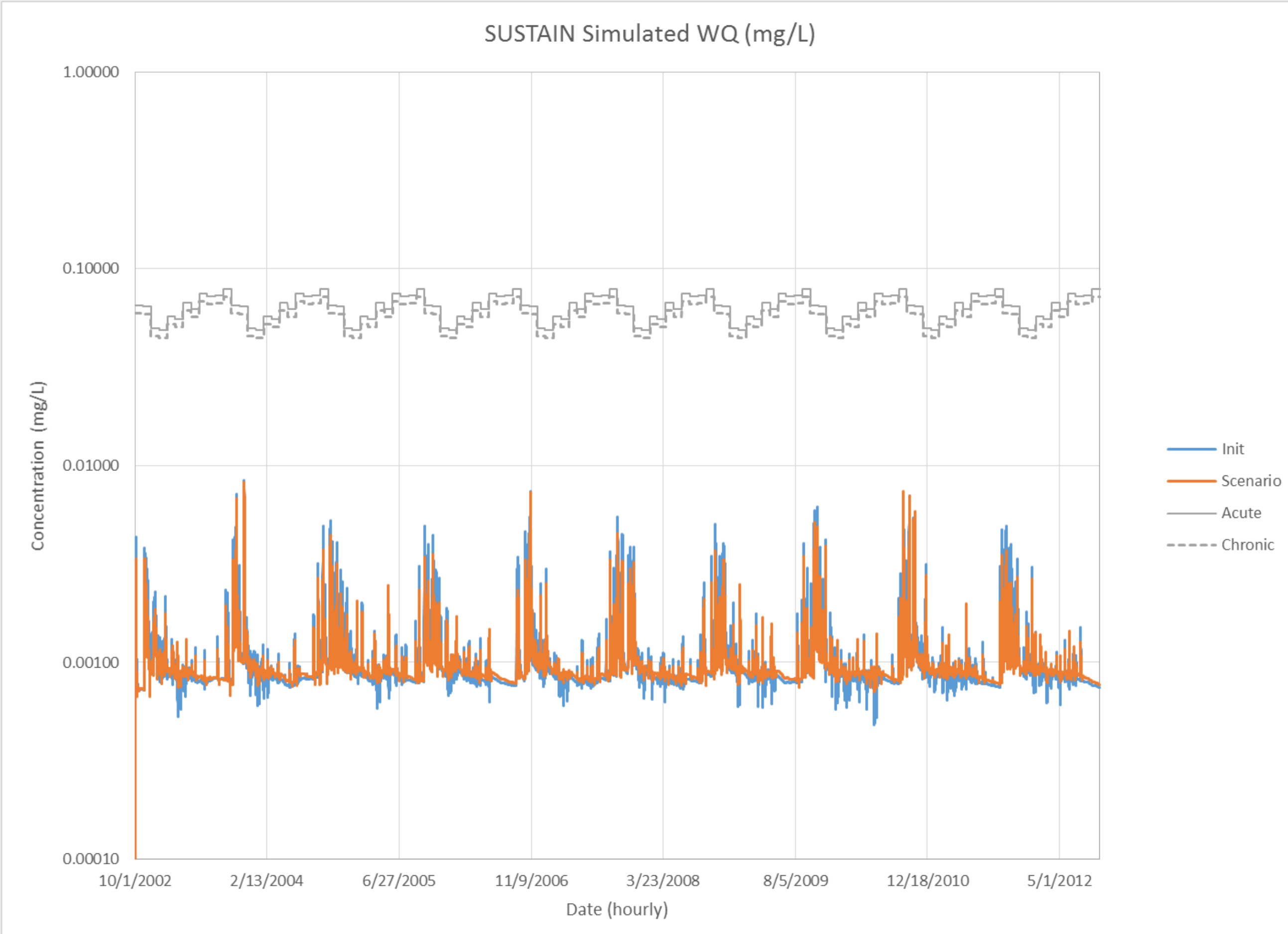

Figure 40 Simulated hourly concentrations of dissolved zinc for BEA010.

4.6 Alternative Land Use Scenario

As previously mentioned, each jurisdiction has zoning regulations that limits the amount of total impervious surface allowed on a parcel of land. This alternative scenario looks at what gains may be realized when reducing the maximum amount of impervious surfaces allowable on a parcel of land instead of engineering a solution only using BMPs.

In this scenario, one of the smaller SUSTAIN model domains (BEA240) was used to test this land use alternative. The drainage area is about 705 acres and highly developed (Figure 41). To achieve a projected minimum B-IBI score of 60, the cost of the recommended strategy to get there is estimated to be about $220 million (Figure 42 Performing a re-analysis of the drainage area with the reduced impervious surfaces results in a substantial reduction in costs to achieve the same target B-IBI score. The twenty-five percent reduction in impervious surfaces translates into a reduced cost estimate from $220 million to about $87 million (Figure 43). Given the shape of the curve in Figure 42, it indicates a large cost for incremental small gains when achieving those last few points in the B-IBI score. Making a comparison using optimal point in the curve (i.e., the “knee” in the curve), the unaltered land use scenario achieves a B-IBI score of 58 at a cost of approximately $86 million.

Conversely, the cost to achieve a B-IBI of 59 assuming a 25 percent reduction in impervious surfaces is estimated to be about $70 million. Thus, if allowing for B-IBI scores close to the target but not achieving it, the cost differential is about $16 million versus $133 million to achieve a B-IBI score of 60.

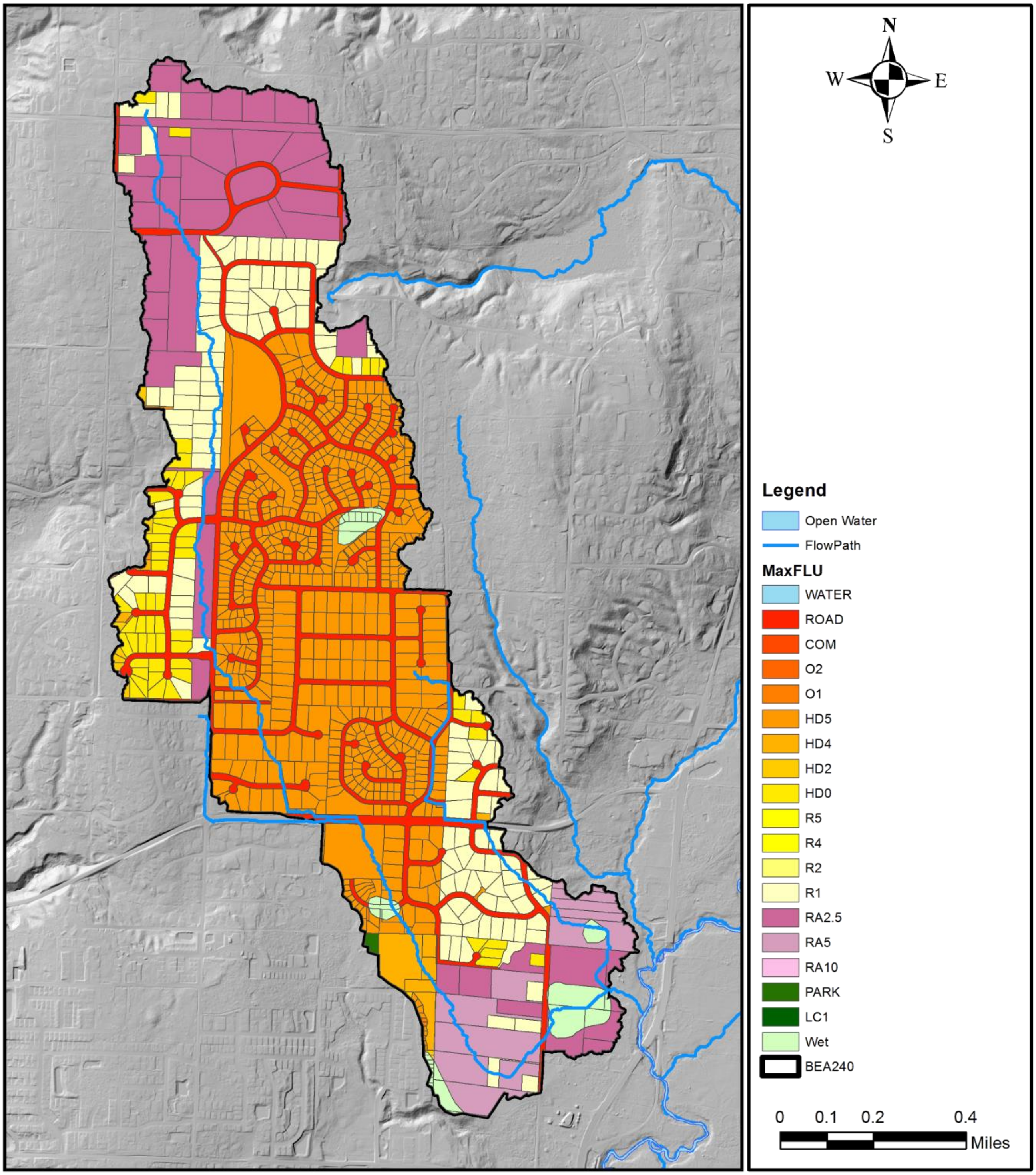

Figure 41 Future land use for BEA240.

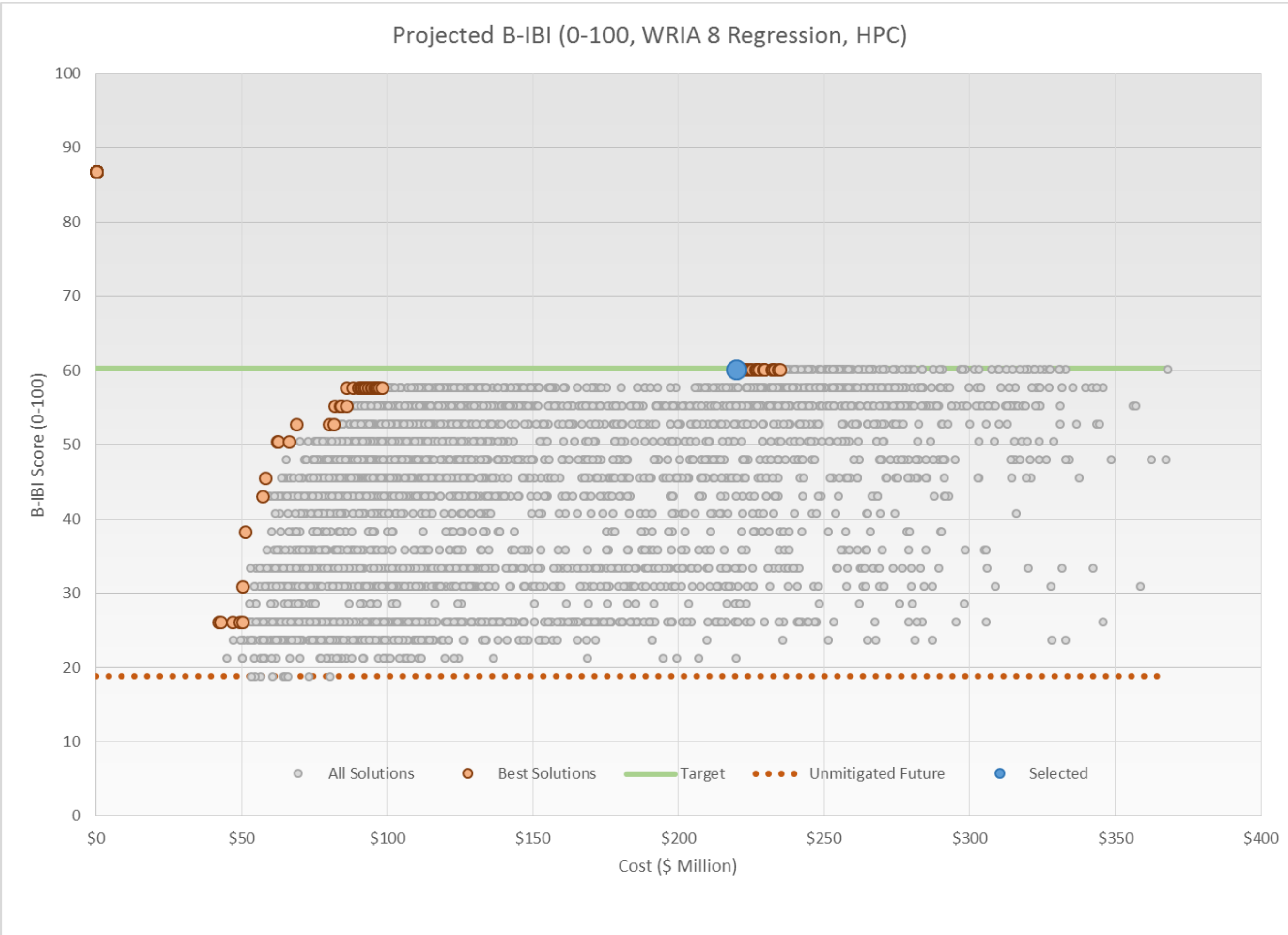

Figure 42 Cost-effectiveness curve for BEA240.

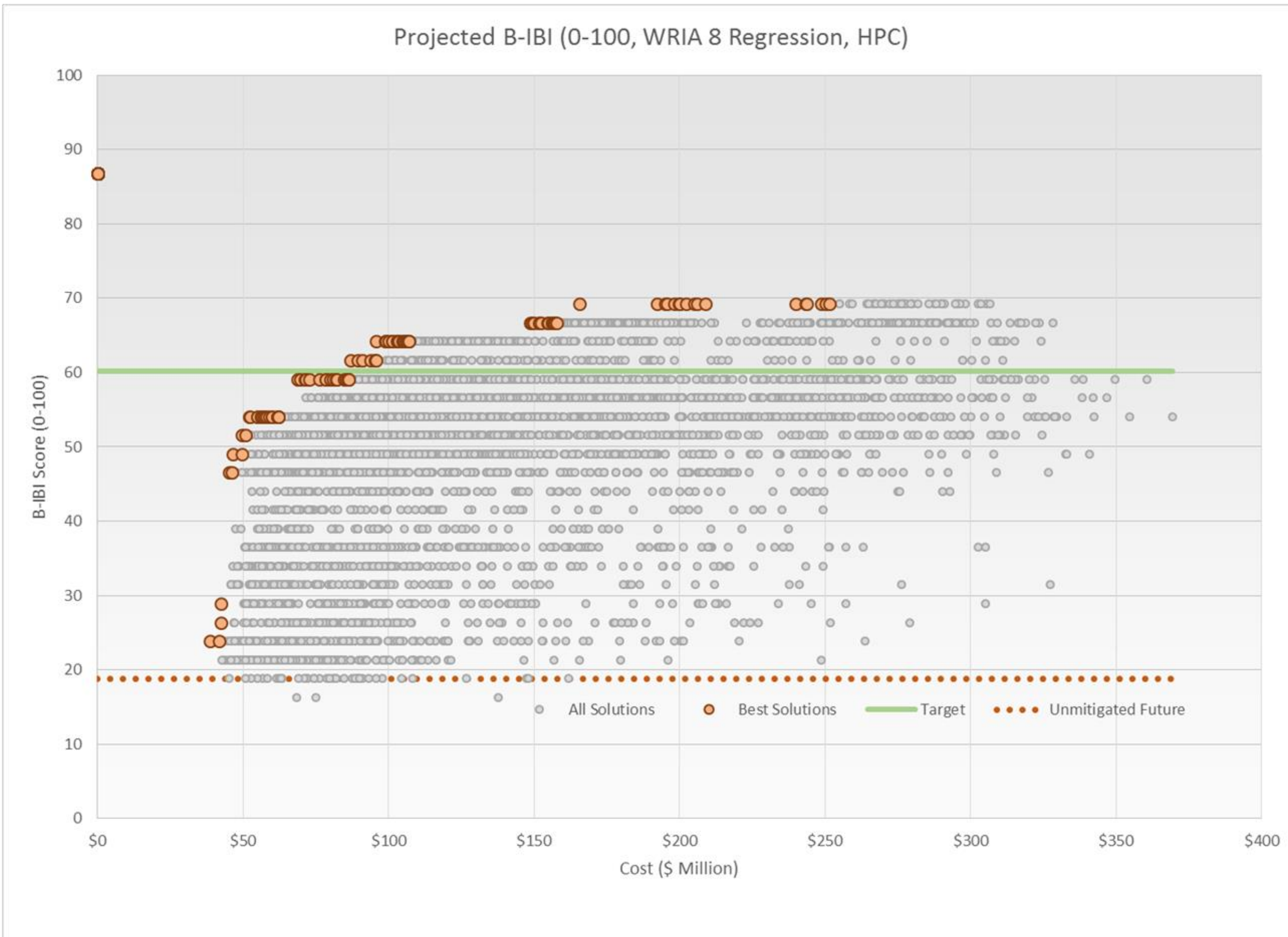

Figure 43 Alternative cost-effectiveness curve assuming a 25-percent reduction in maximum allowable impervious surfaces.

5.0 SUMMARY AND DISCUSSION

Using watershed models vastly improves the understanding of the linkage between stormwater management and stream health. This is accomplished by:

- using results to infill where data does not exist,
- project past, current, and future conditions,
- simplifying a complex system, and
- evaluating the effectiveness of stormwater management strategies by isolating various elements.

Two models were used in this watershed analysis: Hydrologic Simulation Program FORTRAN and System for Urban Stormwater Treatment and Analysis Integration. These models are complimentary to each other with each having different strengths. Both model frameworks are distributed by EPA.

5.1 Model Development and Calibration

The watershed study area was segmented into six HSPF model domains that encapsulate 153 catchments. Each of the models were calibrated for stream flows, sediment, fecal coliforms, copper, zinc, and water temperature. Model accuracy comparing simulated flow rates to observed flows were variable, but when focusing on the primary points of interest they are adequately calibrated. Pearson correlations ranged from 0.75 to 0.96 and averaged 0.89 among all the points of comparison. The average R-square among the models was 0.80, and the average Nash-Sutcliffe was 0.75.

The water quality calibrations are indicative of typical modeling results when simulating sediment, fecal coliforms, copper, zinc, and water temperature. A common outcome is that the smaller the modeling basin, the more difficult it is to calibrate because of any episodic events that occur have less opportunity to diffuse and attenuate before being observed. The model calibrations are reasonable at the four primary points of comparison of bacteria and metals used for assessing statistical accuracy. Simulated stream temperature accuracies were adequate for 19 of the 21 location used as primary and guidance assessments. When evaluating model accuracy for bacteria and metals at the other locations used for guidance, the models mostly under simulate for all the parameters evaluated. This does suggest that evaluating conditions at finer scale (e.g., single catchments) should be used with caution.

The WRIA 8 regression correlating high pulse counts to B-IBI scores was the most accurate for calculated B-IBI scores for observed data in the Bear Creek study area. Based on a B-IBI scale of 0-100, the average difference between simulated and observed B-IBI scores were on average only 2.5 points off. The RMSE was 21.7. This suggests, that there is some variability in model (and regression) accuracy but on average it does quite well. Comparing B-IBI scores by category (i.e., very poor, poor, fair, good, and excellent), the modelling results on average project the same health category as observed.

The selection of the single water year (1998) had the fourth highest number of catchments with a high pulse count equal to the 63 year average, it was flashier than the average of the ten year period (wy 2003-2012) used for analyses when evaluating outcomes at the SUSTAIN model domain scale.

5.2 Land Use

The watershed is approximately 52 percent developed (i.e., not covered in native vegetation) for existing conditions. Future projections increase loss of native vegetation by 15 percent (67 percent of the watershed is developed). There is an estimated increase of 1090 acres[6] of effective impervious surface under the future scenarios relative to existing conditions. Thus for existing conditions, approximately 11 percent of the watershed is covered with effective impervious surfaces increasing to 17.5 percent in the future.

5.3 BMPs

The calibration of the BMP treatment efficiencies in SUSTAIN were close to the targets specified by Ecology in their guidance memo directed toward the Phase I permittees doing these watershed studies. Some of the BMPs with infiltration did end up with greater efficiency than targeted because of the assumed 100 percent treatment within the infiltration flow pathway (again an Ecology recommendation). The individual effectiveness of the BMPs that were above the recommended targets by Ecology could have been reduced. However, that would have required adjusting the soil parameters to decrease infiltration capacities. This would be counter to specifications by King County Stormwater Design Manual requirements as well as Ecology's.

SUSTAIN modeling could not enforce water quality treatment to occur prior to gravity well use. To force this dependency during the optimization process is not possible in SUSTAIN. During the optimization, the inclusion or not of any one BMP within the treatment train are independent. Thus, when a gravity wells are identified in the solution, the recommended water quality treatment BMPs may need to be increased to account for the capacity of gravity wells to infiltrate the runoff.

5.4 Effectiveness of Selected Strategy

Initially focusing at the mouth of the study area (BEA010) and targeting a B-IBI score of 60, some of the SUSTAIN model domains upstream did not achieve a B-IBI score of 60. Optimized strategies upstream of the lower most SUSTAIN model (BEA010) were revised to achieve scores of 60 or greater among all the model domains. This increased the effectiveness reducing HPCs downstream and elevates the projected B-IBI score above 60 at BEA010.

---

[6] If considering the over estimation of impervious surfaces in wetland areas, the 1090 acres increase is reduced to 750 acres.

Two possible methodological improvements were identified for developing the cost-effectiveness curves. The first possible improvement would be to increase the number of simulations during a SUSTAIN model run. The second possible improvement would be to change the BMP limits in the catchments to improve on finding a lesser expensive solutions for the same effectiveness.

As shown in section 4.4, the selected strategy achieves a projected B-IBI score ranging from 66 to 76 among the SUSTAIN model domains. Similarly, the selected strategy achieves all water quality targets as well (water temperature is the exception). Simulated water temperature mostly do not meet targets, even with 100 percent forest cover producing 90 percent effective shade (see section 5.6).

The watershed study area includes about 12,000 private parcels. The number of BMPs identified in the selected strategy is equivalent to about:

- 1.7 raingardens per parcel,
- 46 units (or 3,300 ft) of bio-retention swale per mile of road,
- 1 in 5 houses have a 3,000 gallon cistern,
- 2300 square feet of permeable pavement per 1 acre of EIA,
- 1 gravity well per 10 parcels, and
- 1 stormwater pond per 6 parcels.

In terms of LIDs, a little over 2 forms of LIDs per parcel (excluding bio-swales) are needed.

5.5 Cost of Selected Strategy

The estimated cost associated with the selected strategy treating the entire watershed study area is estimated to total $1.17 billion in 2017 dollars with no adjustment for inflation or discount rates. Three quarters of that ($820 million) is estimated to be public dollars (i.e., money spent by King County and its partners). The remaining $354 million is the estimated cost for the property owners to maintain their BMPs. These estimates are assuming a 100 year time frame. Characterizing costs in total annual sums of public and private costs portrays the needed investments as a more plausible outcome. Starting in year 11, the annual stormwater costs increase from $7 million per year to $16 million per year in year 100—assuming the selected strategy is fully implemented by year 100 for the entire study area. This increase is because as more BMPs come online, there is more needed maintenance. At year 100, the annual costs estimates would be considered in perpetuity at that point (i.e., on-going).

5.6 Water Temperatures

Simulated water temperatures, even assuming fully forested landscape and full riparian cover providing 90 percent effective shade on the stream, project water temperatures will exceed state water quality standards throughout the watershed study area. Assuming a microclimate effect is created from a fully forested riparian corridor, approximately a 1-4 degrees Fahrenheit drop in temperature would be needed to be close in achieving state water quality standards. Simulating over a 63 year period indicates stream temperatures will not be 100 percent fully compliant even with an assumed microclimate benefit.

5.7 Flood Frequencies

Simulated existing conditions as part of this study result in increased flood frequencies when compared to simulated existing conditions in the past basin planning effort done in the 1990's. For example, the 100-year flood frequency for the same catchment outlet (i.e., B2- Bear Creek Current and Future conditions report) for existing conditions (i.e., 1985 land use) is estimated to be 1,103 cfs. Existing conditions in this study estimates a 100 year flood frequency of 1,705 cfs (63 year window used). Increased flood frequency relative to 1990 conditions was expected due to an additional 26 years of development that occurred.

Current conditions today are similar to the previous Basin Plan's future projections assuming a stormwater design standards reduced two year future mitigated flood frequency flow rates back to forested conditions. This is consistent with the amount of development that has occurred since that previous analysis was done, including the old designs for over 80 percent of the stormwater ponds in the study area.

Mitigated future flood frequencies smaller than the 100 year are substantially reduced compared to conditions today. The 100 year event is only marginally reduced. This projection should greatly reduce the impacts that Bear Creek has on the outflows of Lake Sammamish. Previous studies conducted on the lake outflows have determined that when Bear Creek flows exceed 300 cfs entering into the Sammamish River, it starts to backwater outflows from the lake thus increasing lake stages. Future mitigated conditions exceed 300 cfs less frequently than current conditions. Areas that are prone to frequent flooding in the Bear Creek watershed study area (e.g., NE 165th Street), will likely continue to flood but likely with less frequency. Additional measures would be needed to mitigate those situations.

Flood frequencies calculated on SUSTAIN results should only be used to scale up (or down) flood frequencies developed from HSFP modeling.

5.8 Alternative Land Use Management Strategy

To achieve a target B-IBI score of 60, the modeled strategy costs over $200 million. When reducing the footprint on a parcel, the cost to achieve the same B-IBI score is less than $90 million. However, if achieving a score of 58 or 59 is acceptable, then the difference between the two scenarios in cost drops markedly to about $15 million. Only one example catchment was evaluated and it is unclear whether similar results would occur in other catchments. If in the future there is an interest and willingness by the public to possibly work towards reducing the amount of impervious area in the watershed, this may have a benefit of reducing the costs implementing BMPs while achieving the goal of restoring Bear Creek to a clean water and healthy habitat.

6.0 APPLYING THE SCIENCE WITH FUTURE ACTIONS

Implementing the selected strategy is projected to be an expensive and drawn out process. Only through the desire and support of the public and policy makers will Bear Creek be restored back to its full potential.

These modeling results provide guidance on what recommended actions are needed to achieve certain objectives. The models will likely be instrumental when implementing the strategy. For example, assessing the feasibility when specifically locating a BMP and installing it is well beyond the scope of this study. Yet, it's very likely that alternative BMPs and locations will need to be considered given environmental and logistical constraints. In the future, these models can be updated to test alternatives, which may stem from advancements in science and technology, and/or changes in land use management activities (e.g., reducing footprints).

A more immediate use of the results may include considering the cost associated with how much gain is achieved restoring the health of the watershed (as measured in flashiness and B-IBI scores). For example, the overall cost of the selected strategy would be greatly reduced if the science and/or decision makers determine that a score less than 60 would support the overall goal of a healthy creek.

There is uncertainty in many aspects of watershed modeling. For example,

- the relationship defined between flashiness and stream health (as indexed to B-IBI scores) needs more study by the scientific community; or,
- how much redevelopment that will occur versus the need to retrofit. This could substantially shift the burden of the costs from the public back to the developer.
- Lastly, projected shifts in future rainfall intensities were not evaluated as part of this study. Impacts of projections of rainfall are part of another effort sponsored by Washington State Department of Ecology and King County Department of Natural Resources and Parks and include University of Washington Bothell and the Climate Impacts Group (CIG) as partners.

7.0 REFERENCES

Bartholow, J.M., 2000. Estimating cumulative effects of clearcutting on stream temperatures. Rivers, 7(4), 284-297.

Burton, G. Allen and Robert Pitt. 2002. Stormwater Effects Handbook A toolbox for Watershed Managers, Scientists, and Engineers. Lewis Publishers, Boca Raton, Florida. http://www.epa.gov/ednnrmrl/publications/books/handbook/toc.pdf

Daly, C.. 2000. Director, PRISM Group, Northwest Alliance for Computational Science & Engineering (NACSE), http://www.prism.oregonstate.edu/

DeGasperi, C.L., H.B. Berge, K.R. Whiting, J.J. Burkey, J.L. Cassin, and R.R. Fuerstenberg. 2009. Linking hydrologic alteration to biological impairment in urbanizing streams of the Puget Lowland, Washington, USA. *Journal of the American Water Resources Association* 45: 512-533

Dinicola, R.S. 1990. Characterization and simulation of rainfall-runoff relations for headwater basins in western King and Snohomish Counties, Washington: U.S. Geological Survey Water-Resources Investigation Report 89-4052.

Dinicola, R.S. 2001. Validation of a numerical modeling method for simulating rainfall-runoff relations for headwater basins in western King and Snohomish Counties, Washington. U.S. Geological Survey Water Suppy Paper 2495. http://pubs.er.usgs.gov/publication/wsp2495

Herrera. 2012. Technical Memorandum- Puget Sound Stormwater BMP Cost Database. Prepared by Herrera Environmental Consultants. Seattle, WA.

Homer, C.G., Dewitz, J.A., Yang, L., Jin, S., Danielson, P., Xian, G., Coulston, J., Herold, N.D., Wickham, J.D., and Megown, K., 2015, Completion of the 2011 National Land Cover Database for the conterminous United States-Representing a decade of land cover change information. Photogrammetric Engineering and Remote Sensing, v. 81, no. 5, p. 345-354

Horner, R. J. Skupien, E. Livington, and H. Shaver. 1994. Fundamentals of Urban Runoff Management: Technical an Institutional Issues. Terrene Institute. Washington, D.C.

Horner, R.R. 2013. Development of a Stormwater Retrofit Plan for Water Resources Inventory Area 9: Flow and Water Quality Indicators and Targets. King County Water and Land Resources Division, Seattle, Washington.

King County. 1997. King County Surficial Geology. King County Department of Natural Resources and Parks, GIS.

King County. 2003. LiDAR Digital Ground Model (DGM) Elevation and Hillshade: King County, WA.

King County. 2009. King County Surface Water Design Manual 2009. http://www.kingcounty.gov/environment/waterandland/stormwater/documents/surface-water-design-manual.aspx

King County. 2007. Water Quality Statistical and Pollutant Loadings Analysis – Green-Duwamish Watershed Water Quality Assessment. Prepared by Herrera Environmental Consultants. Seattle, WA.

King County. 2012. Stormwater Retrofit Analysis for Juanita Creek Basin in the Lake Washington Watershed. Ecology Grant: G0800618. Prepared by Jeff Burkey, Mark Wilgus P.E., and Hans Berge. King County Department of Natural Resources and Parks. Water and Land Resources Division. Seattle, Washington.

King County. 2014. Wetlands defined from Critical Area Ordinance surveys in King County: King County, King County, WA.

King County. 2015. Monitoring for Adaptive Management: Status and Trends of Aquatic and Riparian Habitats in the Lake Washington/Cedar/Sammamish Watershed (WRIA 8). King County Water and Land Resources Division. Seattle, Washington.

King County. 2017a. Bear Creek Watershed-scale Stormwater Plan: Existing Water Quality Conditions. Prepared by Timothy Clark and Eric Ferguson, Water and Land Resources Division. Seattle, WA.

King County. 2017b. Analysis of Long-term Trends in the Bear Creek Watershed. Prepared by Timothy Clark, Water and Land Resources Division. Seattle, WA.

King County. 2017c. Assessment of Bear Creek Watershed Riparian Areas. Prepared by Jen Vanderhoof, Water and Land Resources Division. Seattle, WA.

King County. 2017d. Assessment of Bear Creek Watershed Wetlands. Prepared by Jen Vanderhoof, Water and Land Resources Division. Seattle, WA.

King County. 2017e. Bear Creek Watershed Juvenile Salmon Habitat Use. Prepared by Josh Kubo, Water and Land Resources Division. Seattle, WA.

King County. 2017f. Benthic Macroinvertebrate Status and Trends in the Bear Creek Study Area. Prepared by Steven Brady, Water and Land Resources Division. Seattle, WA.

King County. 2017g. Stormwater Regulations History and Existing Stormwater Infrastructure in the Bear Creek Watershed. Prepared by Mark Wilgus, Water and Land Resources Division. Seattle, WA.

King County. 2017h. Watershed Model Development for Bear Creek Stormwater Retrofit Planning Project. Prepared by Scott Miller and Jeff Burkey, Water and Land Resources Division. Seattle, WA.

King County. 2018. Bear Creek Watershed-scale Stormwater Management Plan. Prepared by Water and Land Resources Division, Seattle, WA. April 4.

King County. 2015. Monitoring for Adaptive Management: Status and Trends of Aquatic and Riparian Habitats in the Lake Washington/Cedar/Sammamish Watershed (WRIA 8). King County Water and Land Resources Division. Seattle, Washington.

King County. 2014. Recalibration of the Puget Lowland Benthic Index of Biotic Integrity (B-IBI). Prepared by Jo Opdyke Wilhelm, (Water and Land Resources Division [WLRD]); Leska Fore (Statistical Design), Deb Lester (WLRD) and Elene Dorfmeier (WLRD). Seattle, Washington.

Lee, J.G., A. Selvakumar, K. Alvi, J. Riverson, and J.X. Zhen. 2012. A watershed-scale design optimization model for stormwater best management practices. Environmental Modeling & Software 37:6-18.

Shoemaker L., Riverson J., Alvi K., Zhen J., and Murphy, R. 2011. Report on Enhanced Framework (SUSTAIN) and Field Applications for Placement of BMPs in Urban Watersheds. EPA/600/R-11/144. Prepared by Tetra Tech, Inc., Fairfax, VA for National Risk Management Research Laboratory, United States Environmental Protection Agency, Cincinnati, OH.

U.S. EPA. 2009. SUSTAIN - A Framework for Placement of Best Management Practices in Urban Watersheds to Protect Water Quality. EPA/600/R-09/095. Prepared by Tetra Tech, Inc., Fairfax, VA for National Risk Management Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency (U.S. EPA), Cincinnati, OH.

United States Geological Survey (USGS). 1995. Geohydrology and Ground-Water Quality of East King County, Washington. WRIR 94-4082.

This page intentionally left blank.

APPENDIX A: Composite Precipitation Records

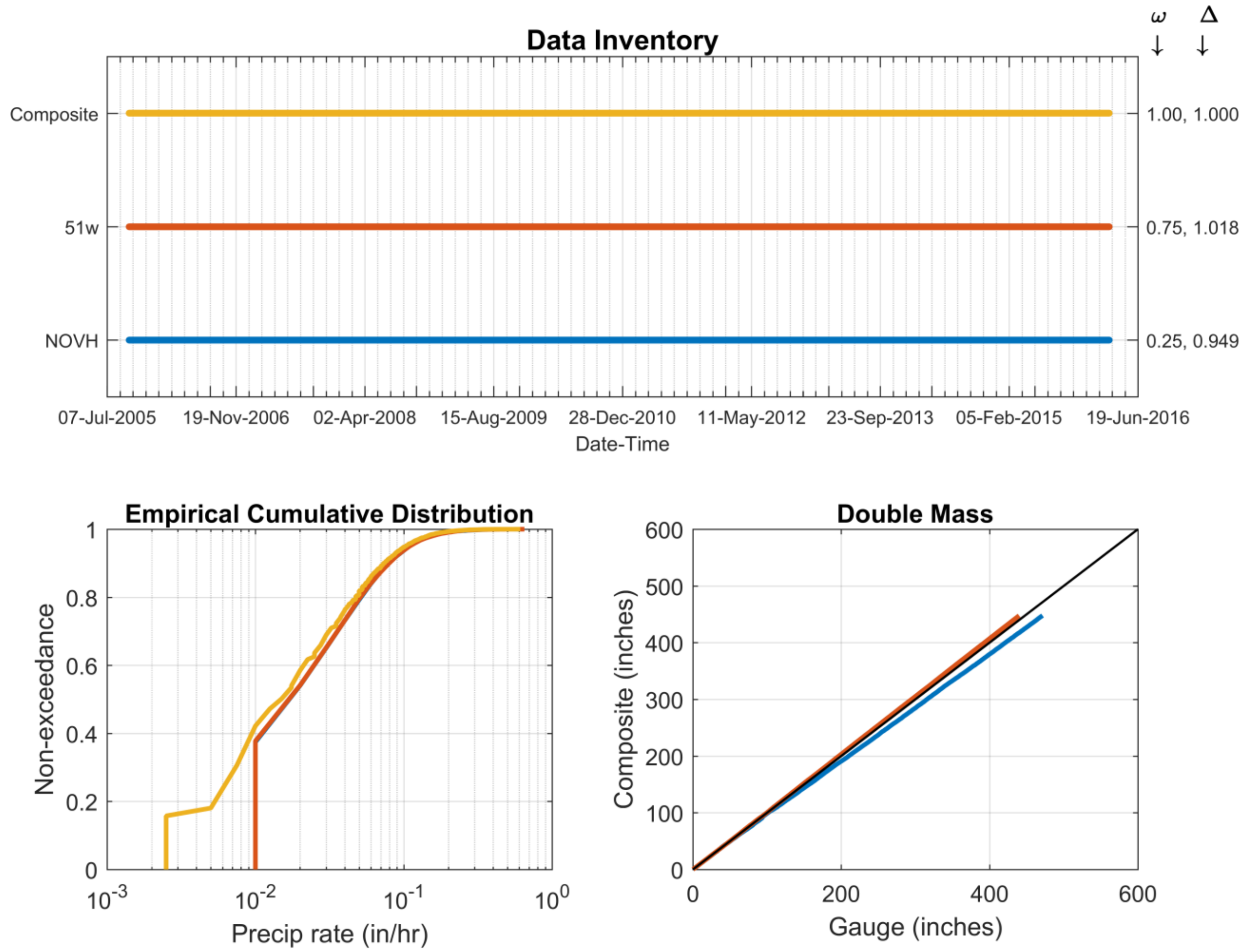

Figure 44 Zone 1 precipitation record composition.

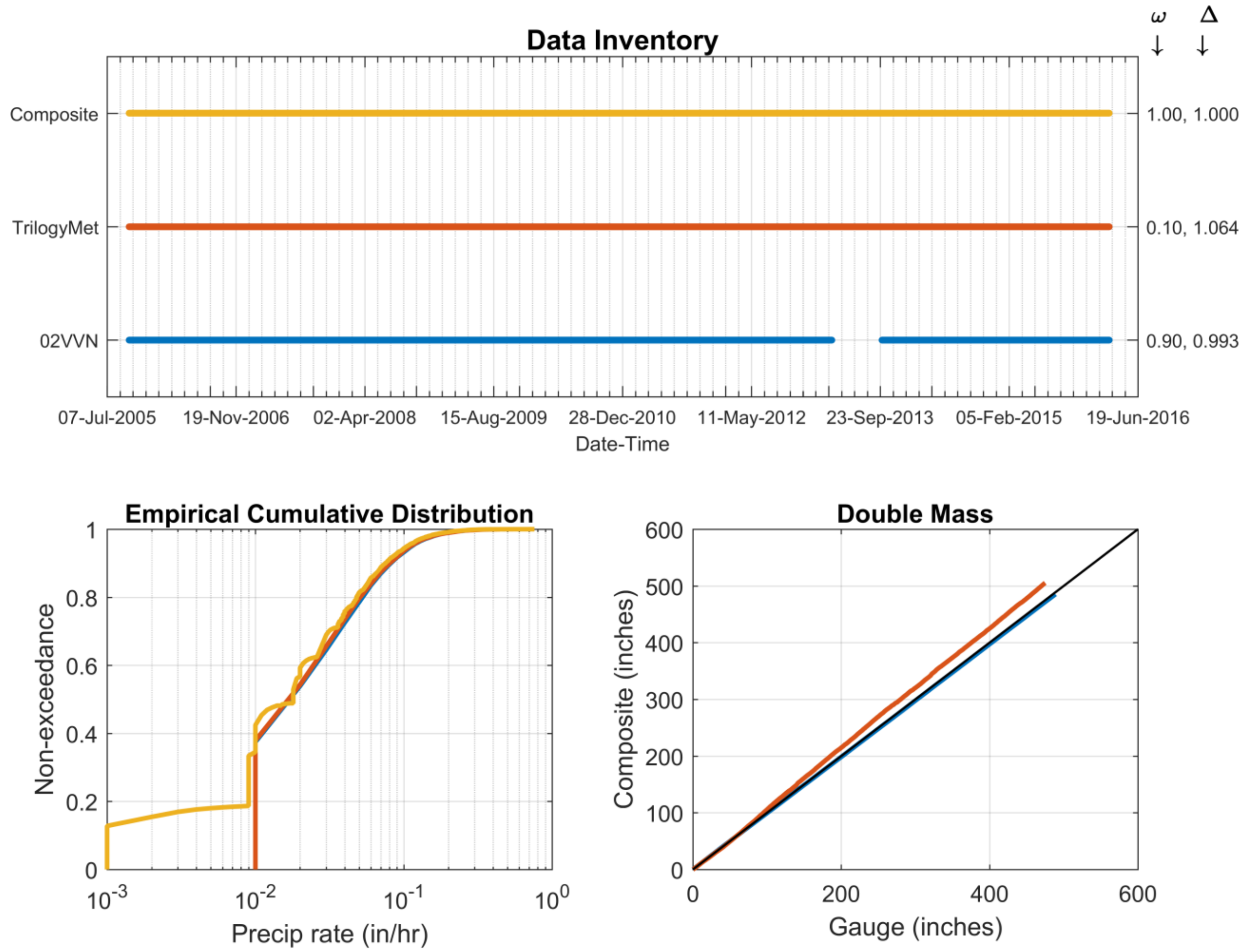

Figure 45 Zone 2 precipitation record composition.

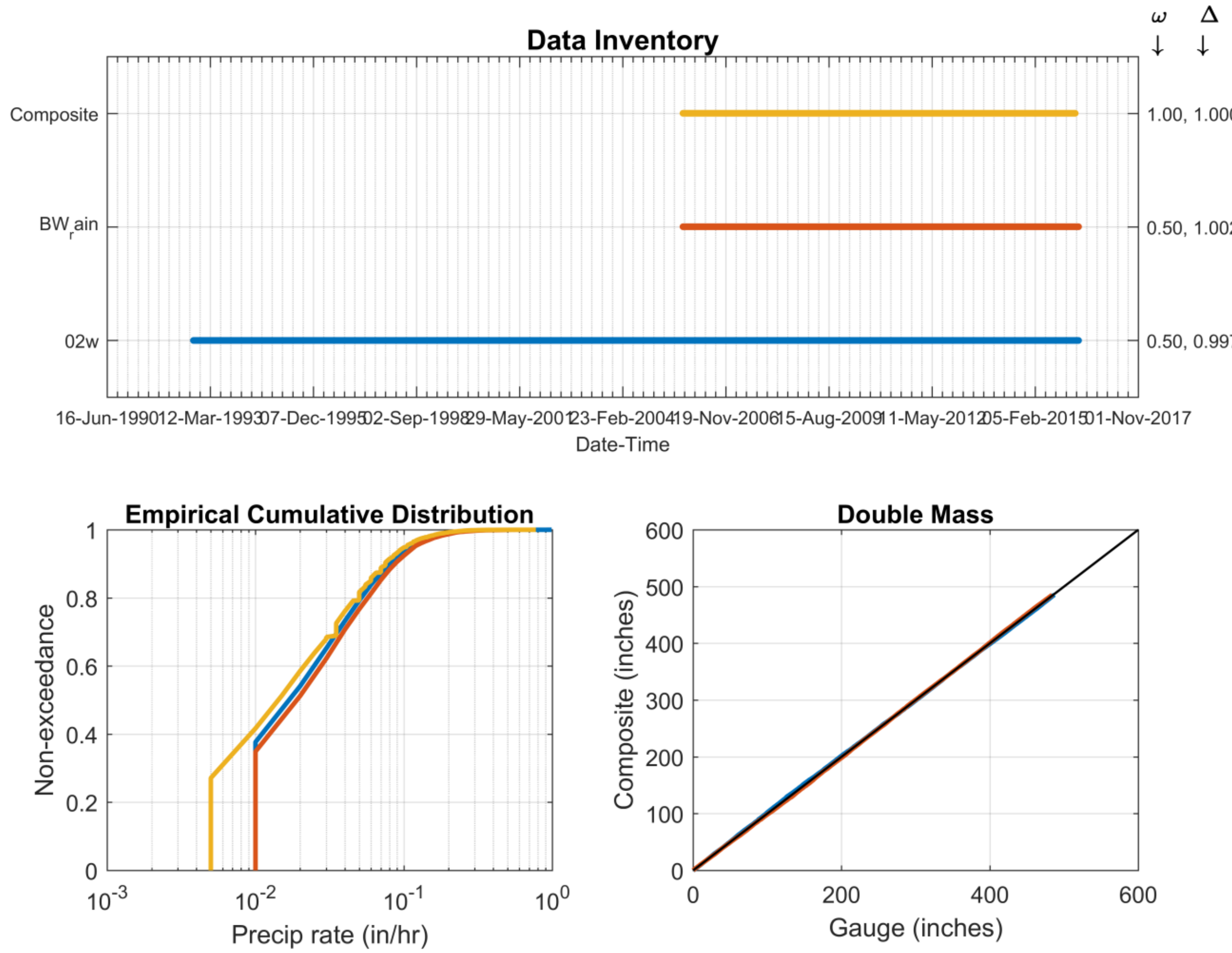

Figure 46 Zone 3 precipitation record composition.

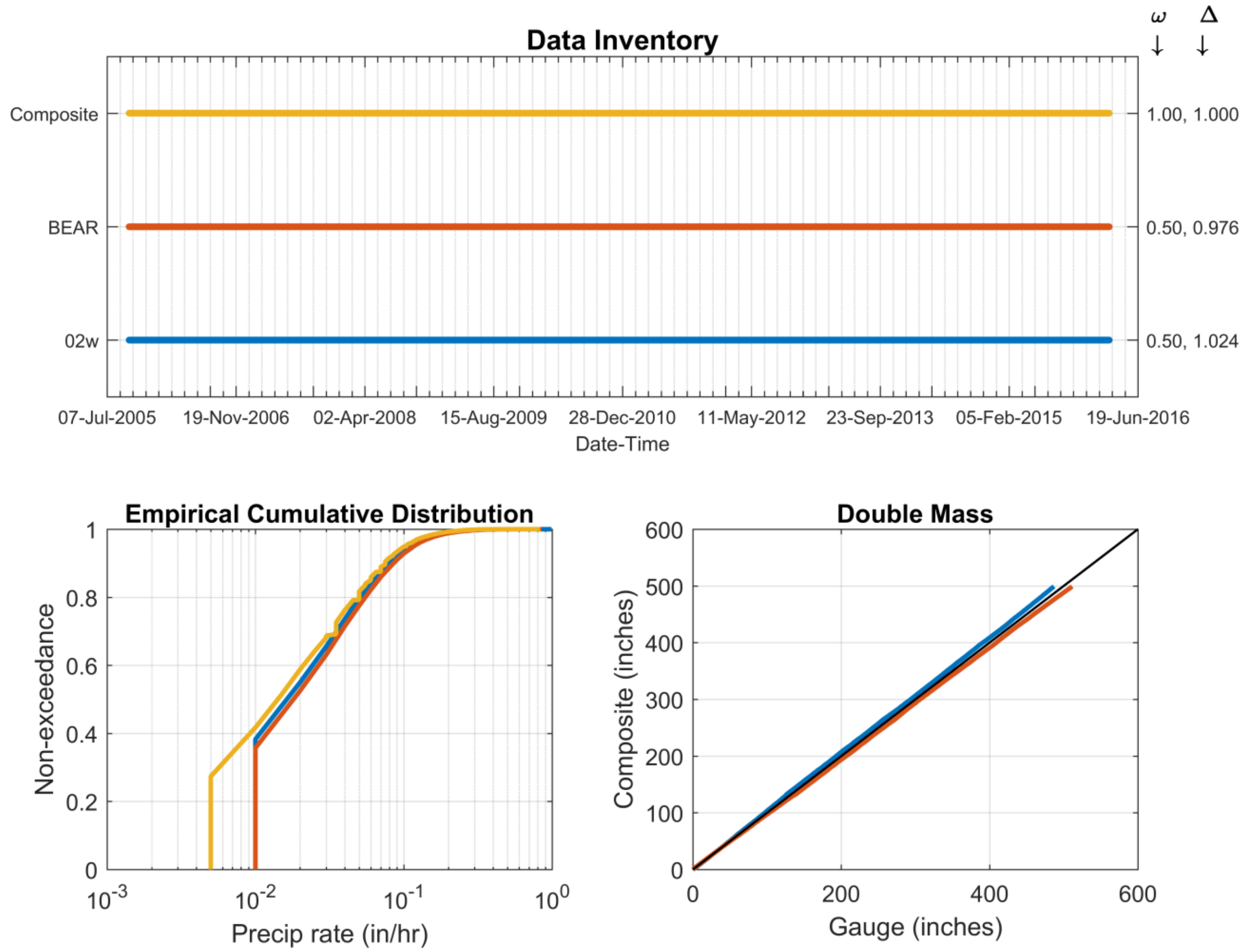

Figure 47. Zone 4 precipitation record composition.

This page intentionally left blank.

APPENDIX B: Hydrologic Calibration

Table 51 Summary of flow rate calibration statistics for 02L.

Metric	Obs (cfs)		Sim (cfs)	RPD
Mean Spring (cfs)	8.9		10.9	23%
Mean Summer (cfs)	5.7		6.1	8%
Mean Fall (cfs)	20.4		15.1	-26%
Mean Winter (cfs)	30.3		27.6	-9%
Mean Flow (cfs)	15.40		14.09	-8%
GeoMean (cfs)	10.92		11.00	1%
Mean Annual Max. (cfs)	54.6		56.6	4%
Mean Annual 7-Day Low (cfs)	11.66		11.01	-6%
Mean Daily max (cfs)	16.89		16.33	-3%
Annual Volumes (inches)	29.05		27.26	-6%
January	3.76		3.30	-12%
February	2.84		3.01	6%
March	1.70		2.08	22%
April	1.28		1.60	25%
May	0.94		1.11	17%
June	0.59		0.75	27%
July	0.54		0.64	18%
August	0.73		0.75	2%
September	0.71		0.74	4%
October	0.89		0.85	-5%
November	2.54		1.84	-28%
December	4.76		3.26	-31%
10 Percentile	21.40		19.59	-8%
25 Percentile	49.38		41.99	-15%
50 Percentile	27.60		26.35	-5%
75 Percentile	12.60		13.49	7%
90 Percentile	7.57		8.13	7%
Equivalency Tests	Kruskal-Wallis		One-way ANOVA	
	p-value	> 0.10	p-value	> 0.10
Seasonal Volume	1.00	Pass	0.96	Pass
Hourly	0.00	Fail	0.52	Pass
Daily Means	0.33	Pass	0.86	Pass
Annual Vol. (inches)	0.44	Pass	0.92	Pass
Monthly Vol. (inches)	0.77	Pass	0.83	Pass
Peak Annual	1.00	Pass	0.96	Pass
Min 7DAvg	1.00	Pass	0.95	Pass
Daily Max.	0.55	Pass	0.77	Pass

Prediction Statistic (hourly)	Value
Pearson	0.92
Mean Err (cfs)	-1.30
RMSE (cfs)	4.16
R-square	0.85
MAE (cfs)	2.89
Nash-Sutcliffe	0.81
Skill Score	0.57

Skill Score: 1 - RMSE/STDobs

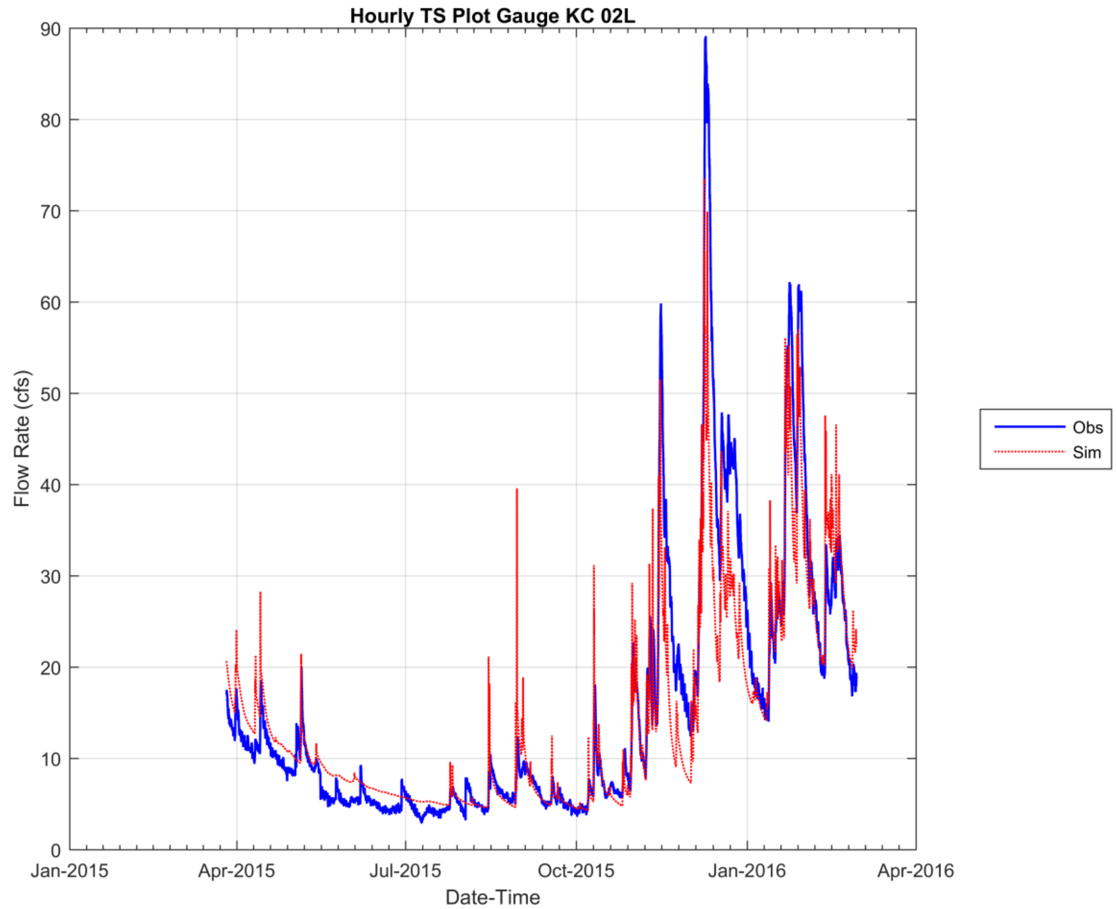

Figure 48 Gauge 02L time series flow plot

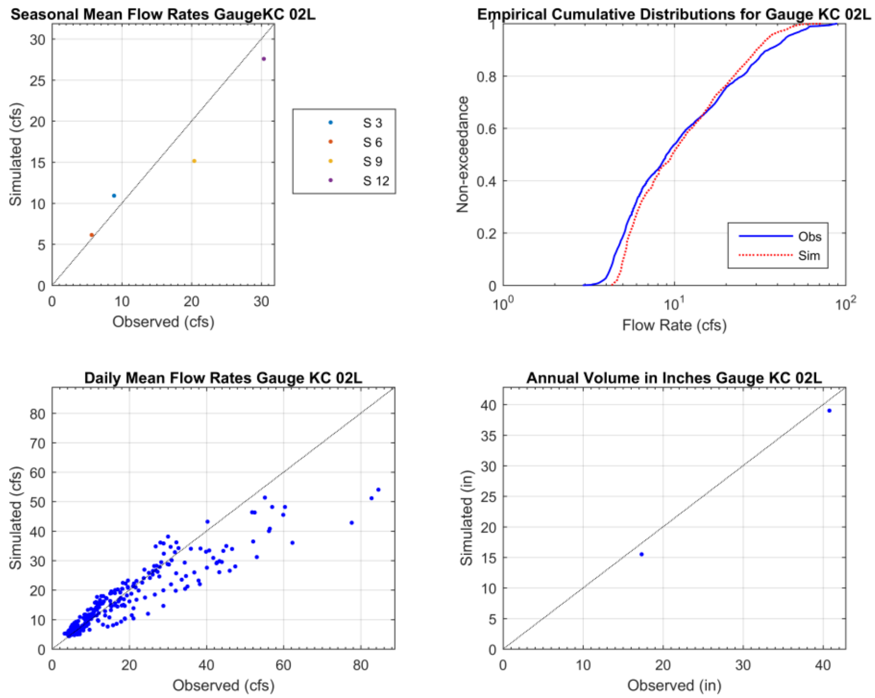

Figure 49 Gauge 02L flow calibration plots 1

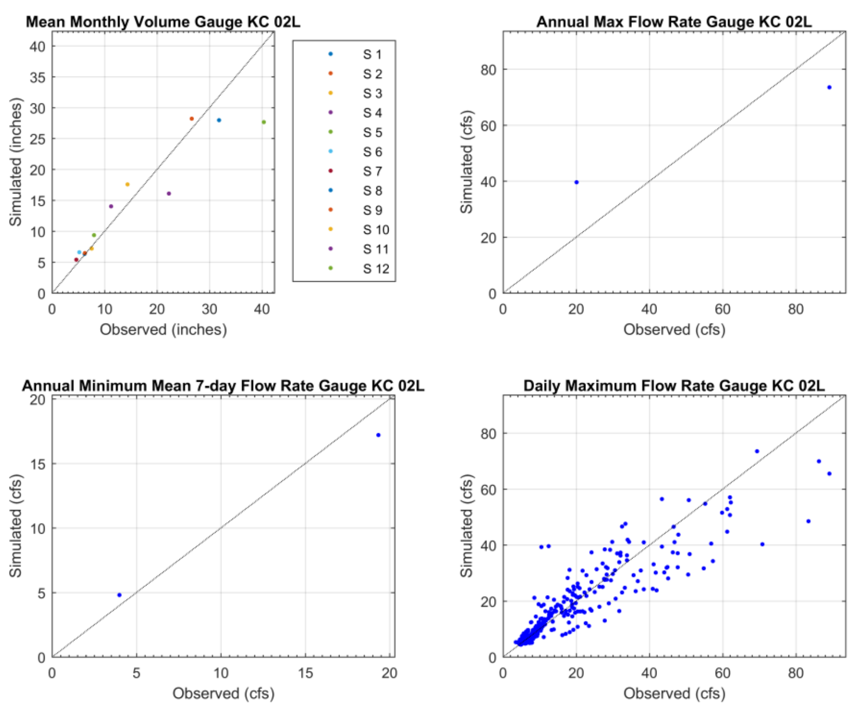

Figure 50 Gauge 02L flow calibration plots 2

Table 52 Summary of flow rate calibration statistics for 02G.

Metric	Obs (cfs)		Sim (cfs)	RPD
Mean Spring (cfs)	18.2		20.4	12%
Mean Summer (cfs)	8.0		8.6	8%
Mean Fall (cfs)	19.0		16.0	-16%
Mean Winter (cfs)	29.6		27.3	-8%
Mean Flow (cfs)	17.94		17.36	-3%
GeoMean (cfs)	14.54		14.42	-1%
Mean Annual Max. (cfs)	84.5		104.9	24%
Mean Annual 7-Day Low (cfs)	9.49		9.70	2%
Mean Daily max (cfs)	19.91		20.96	5%
Annual Volumes (inches)	26.86		27.57	3%
January	2.55		2.35	-8%
February	2.48		2.46	-1%
March	3.01		2.98	-1%
April	2.03		2.18	7%
May	1.26		1.49	19%
June	0.92		1.04	12%
July	0.77		0.83	7%
August	0.76		0.79	5%
September	0.83		0.94	13%
October	1.18		1.10	-7%
November	2.02		1.65	-19%
December	3.00		2.34	-22%
10 Percentile	20.83		20.16	-3%
25 Percentile	39.15		37.96	-3%
50 Percentile	25.63		26.35	3%
75 Percentile	15.38		16.06	4%
90 Percentile	9.97		9.91	-1%
Equivalency Tests	Kruskal-Wallis		One-way ANOVA	
	p-value	> 0.10	p-value	> 0.10
Seasonal Volume	0.86	Pass	0.97	Pass
Hourly	0.74	Pass	0.12	Pass
Daily Means	0.72	Pass	0.89	Pass
Annual Vol. (inches)	0.77	Pass	0.93	Pass
Monthly Vol. (inches)	0.90	Pass	0.81	Pass
Peak Annual	0.15	Pass	0.22	Pass
Min 7DAvg	1.00	Pass	0.96	Pass
Daily Max.	0.28	Pass	0.21	Pass
Prediction Statistic (hourly)	Value			
Pearson	0.90			
Mean Err (cfs)	-0.58			
RMSE (cfs)	4.91			
R-square	0.82			
MAE (cfs)	3.24			
Nash-Sutcliffe	0.81			
Skill Score	0.57			

Skill Score: 1 - RMSE/STDobs

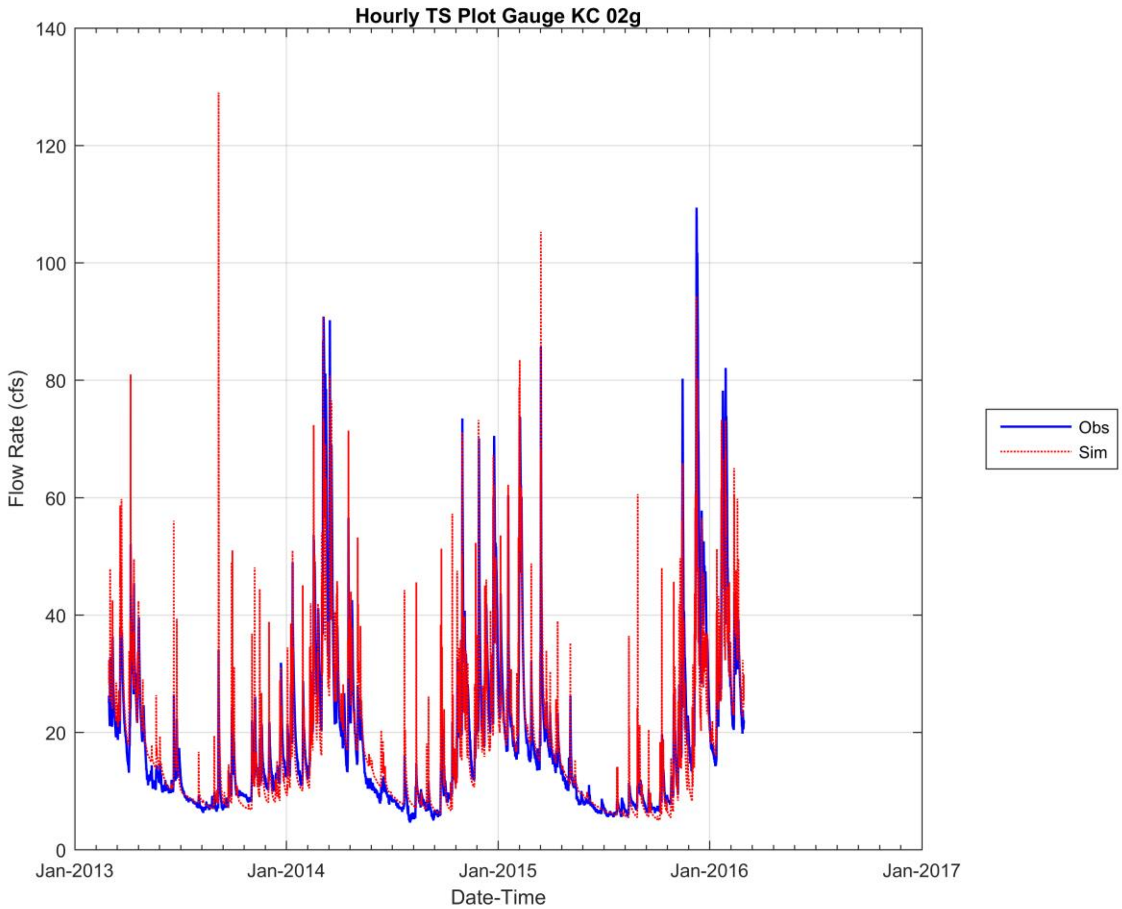

Figure 51 Gauge 02G time series flow plot

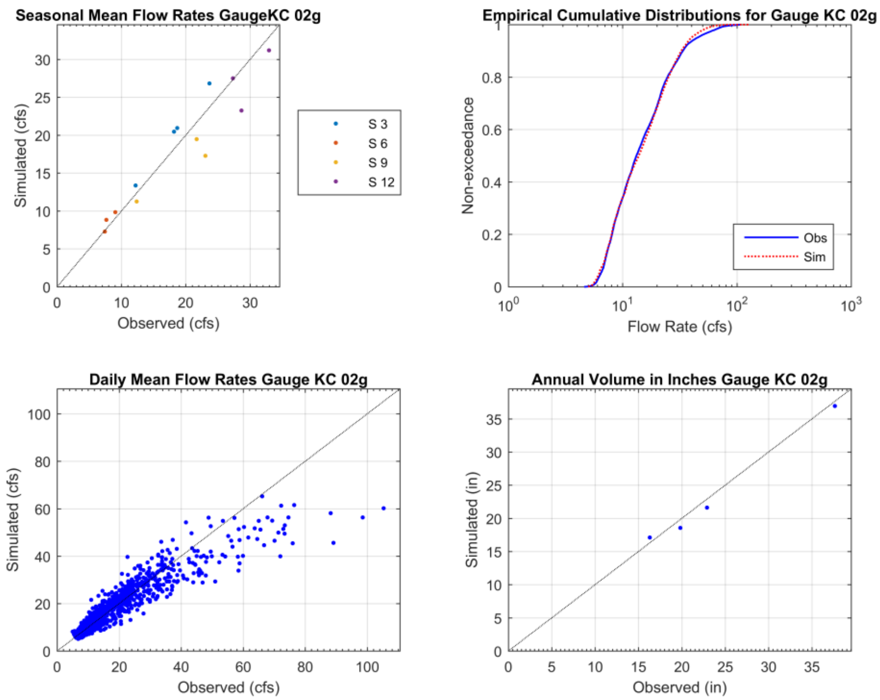

Figure 52 Gauge 02G flow calibration plots 1

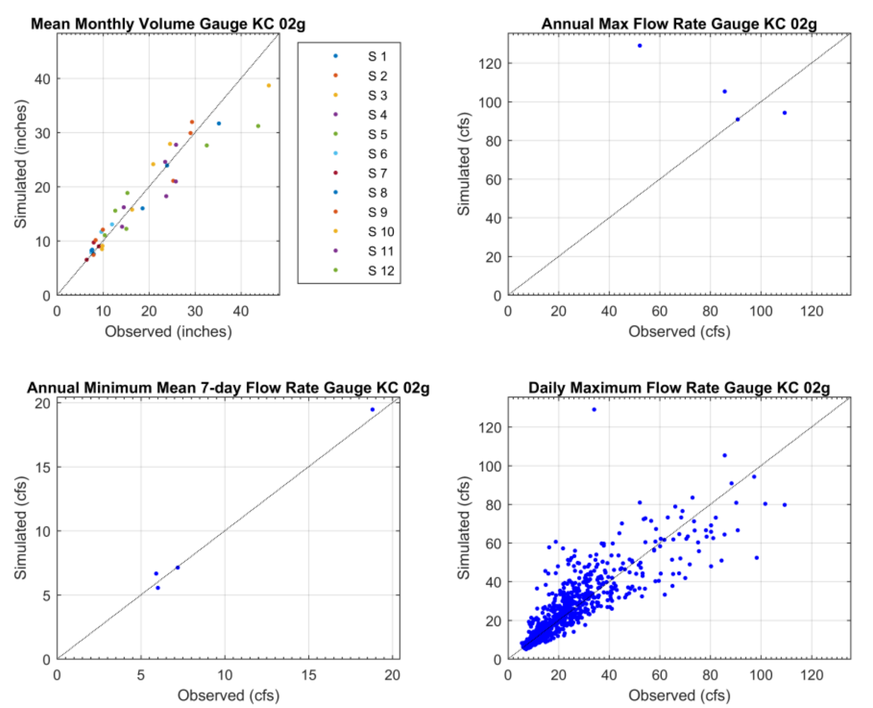

Figure 53 Gauge 02G flow calibration plots 2

02F2

Table 53 Summary of flow rate calibration statistics for 02F2.

Metric	Obs (cfs)		Sim (cfs)	RPD
Mean Spring (cfs)	15.4		17.4	13%
Mean Summer (cfs)	5.9		6.3	7%
Mean Fall (cfs)	18.8		15.2	-19%
Mean Winter (cfs)	29.4		29.0	-1%
Mean Flow (cfs)	16.56		16.27	-2%
GeoMean (cfs)	12.27		12.32	0%
Mean Annual Max. (cfs)	115.6		82.4	-29%
Mean Annual 7-Day Low (cfs)	8.10		8.94	10%
Mean Daily max (cfs)	18.58		18.20	-2%
Annual Volumes (inches)	38.92		40.04	3%
January	4.47		4.33	-3%
February	4.22		4.43	5%
March	4.86		4.91	1%
April	3.18		3.50	10%
May	1.67		2.23	33%
June	1.09		1.39	28%
July	0.94		1.12	19%
August	0.93		1.01	9%
September	1.20		1.02	-14%
October	1.79		1.29	-28%
November	3.56		2.97	-17%
December	5.53		4.63	-16%
10 Percentile	33.44		32.84	-2%
25 Percentile	68.63		68.60	0%
50 Percentile	42.09		42.94	2%
75 Percentile	22.24		23.50	6%
90 Percentile	13.14		13.04	-1%
Equivalency Tests	Kruskal-Wallis		One-way ANOVA	
	p-value	> 0.10	p-value	> 0.10
Seasonal Volume	0.94	Pass	1.00	Pass
Hourly	0.16	Pass	0.57	Pass
Daily Means	0.72	Pass	0.88	Pass
Annual Vol. (inches)	0.77	Pass	0.93	Pass
Monthly Vol. (inches)	0.98	Pass	0.91	Pass
Peak Annual	0.39	Pass	0.37	Pass
Min 7DAvg	1.00	Pass	0.88	Pass
Daily Max.	0.88	Pass	0.83	Pass
Prediction Statistic (hourly)	Value			
Pearson	0.92			
Mean Err (cfs)	-0.30			
RMSE (cfs)	5.15			
R-square	0.86			
MAE (cfs)	3.29			
Nash-Sutcliffe	0.85			
Skill Score	0.62			

Skill Score: 1 - RMSE/STDobs

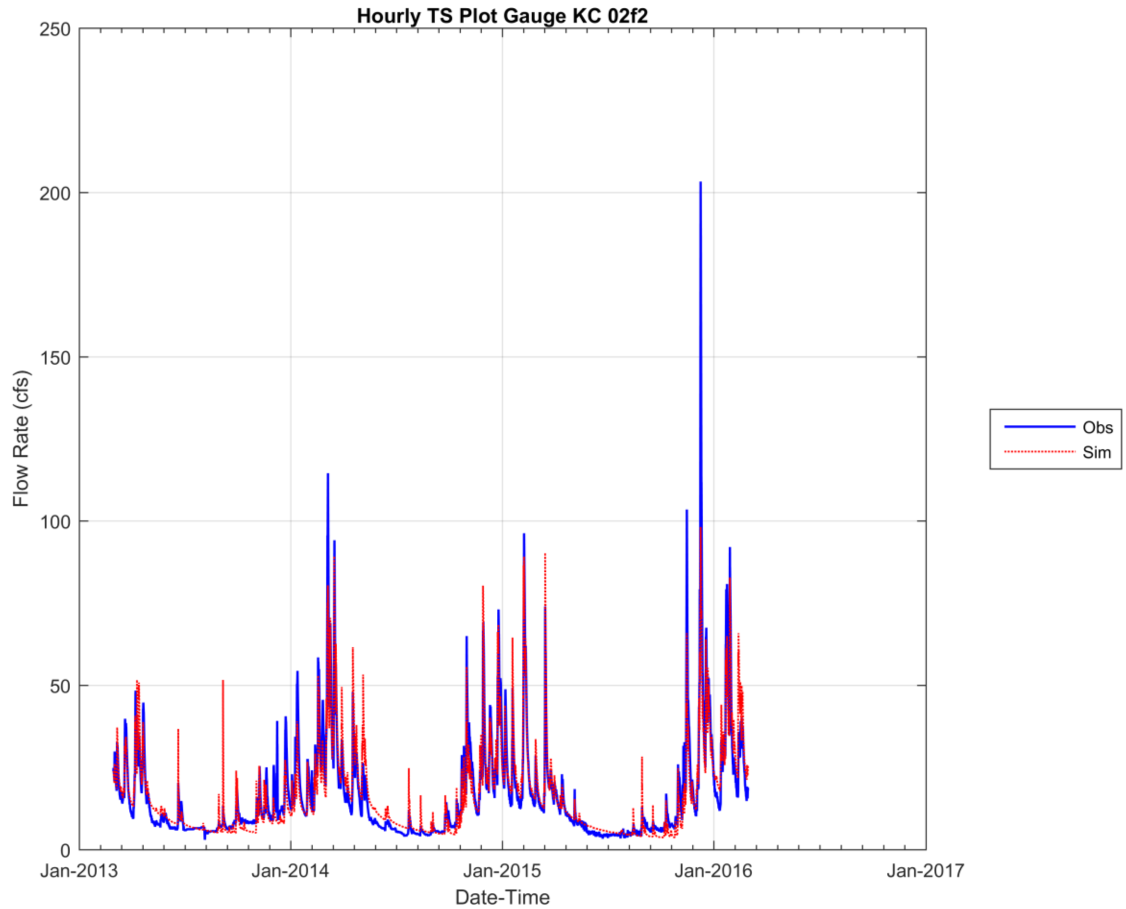

Figure 54 Gauge 02F2 time series flow plot

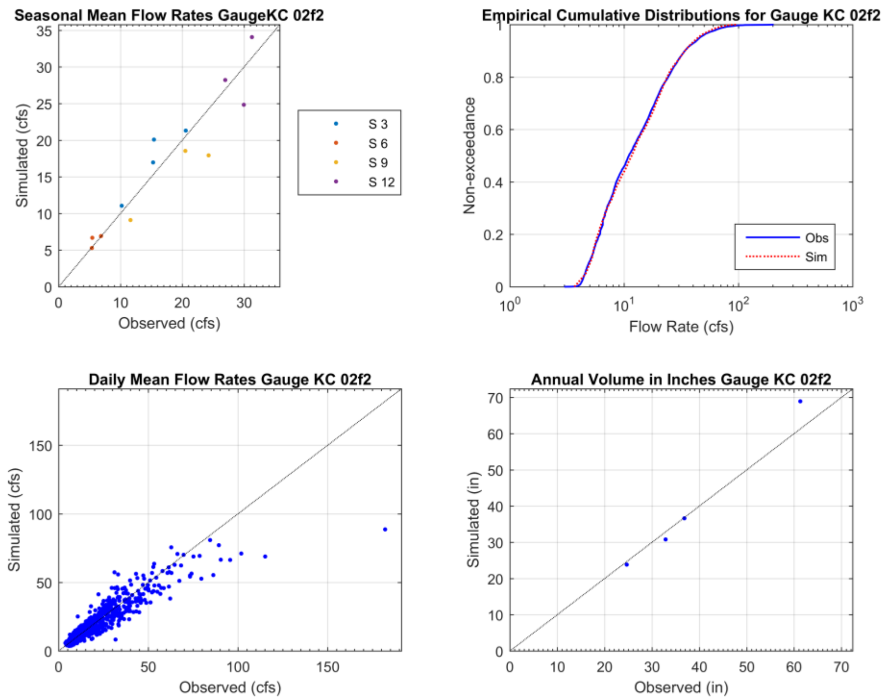

Figure 55 Gauge 02F2 flow calibration plots 1

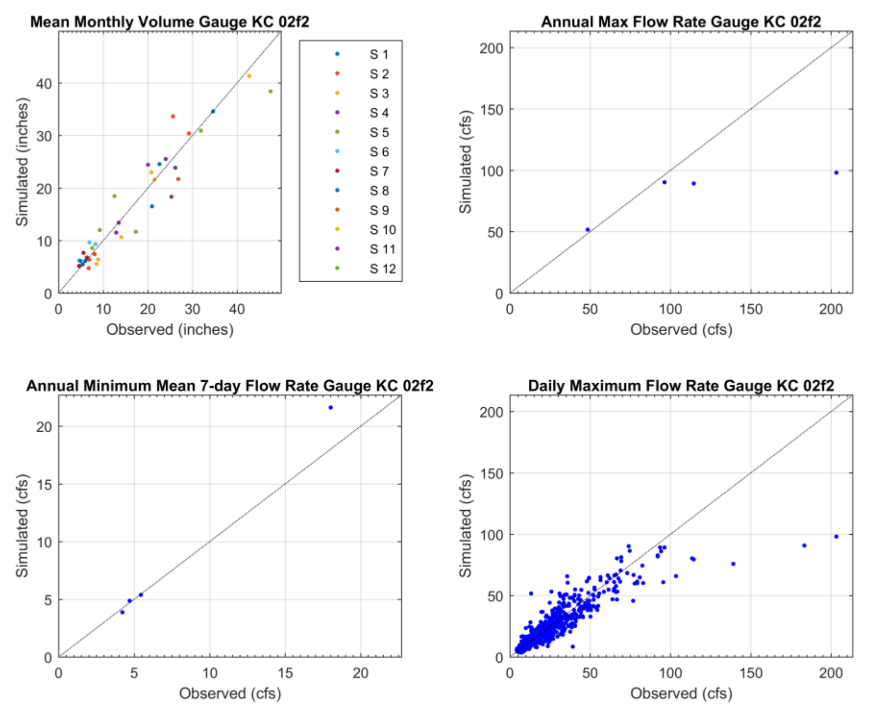

Figure 56 Gauge 02F2 flow calibration plots 2

Table 54 Summary of flow rate calibration statistics for 02M2.

Metric	Obs (cfs)	Sim (cfs)	RPD	
Mean Spring (cfs)	0.8	0.9	8%	
Mean Summer (cfs)	0.1	0.1	19%	
Mean Fall (cfs)	1.8	2.2	19%	
Mean Winter (cfs)	0.5	1.0	102%	
Mean Flow (cfs)	1.43	1.53	7%	
GeoMean (cfs)	0.52	0.44	-15%	
Mean Annual Max. (cfs)	21.5	22.1	3%	
Mean Annual 7-Day Low (cfs)	0.57	0.45	-21%	
Mean Daily max (cfs)	1.93	2.10	9%	
Annual Volumes (inches)	29.77	31.82	7%	
January	3.48	3.43	-1%	
February	3.59	3.48	-3%	
March	4.59	4.61	1%	
April	1.72	1.82	6%	
May	0.81	0.92	14%	
June	0.19	0.14	-24%	
July	0.13	0.14	12%	
August	0.13	0.21	61%	
September	0.27	0.24	-10%	
October	0.97	1.03	5%	
November	2.37	3.28	38%	
December	4.31	4.92	14%	
10 Percentile	25.59	27.40	7%	
25 Percentile	67.79	74.19	9%	
50 Percentile	32.80	39.94	22%	
75 Percentile	12.96	12.84	-1%	
90 Percentile	2.73	2.08	-24%	
Equivalency Tests	Kruskal-Wallis		One-way ANOVA	
	p-value	> 0.10	p-value	> 0.10
Seasonal Volume	0.89	Pass	0.93	Pass
Hourly	0.05	Fail	0.00	Fail
Daily Means	0.69	Pass	0.06	Fail
Annual Vol. (inches)	0.77	Pass	0.88	Pass
Monthly Vol. (inches)	0.82	Pass	0.77	Pass
Peak Annual	0.83	Pass	0.85	Pass
Min 7DAvg	0.77	Pass	0.82	Pass
Daily Max.	0.23	Pass	0.01	Fail
Prediction Statistic (hourly)	Value			
Pearson	0.95			
Mean Err (cfs)	0.10			
RMSE (cfs)	0.69			
R-square	0.89			
MAE (cfs)	0.42			
Nash-Sutcliffe	0.88			
Skill Score	0.65			

Skill Score: 1 - RMSE/STDobs

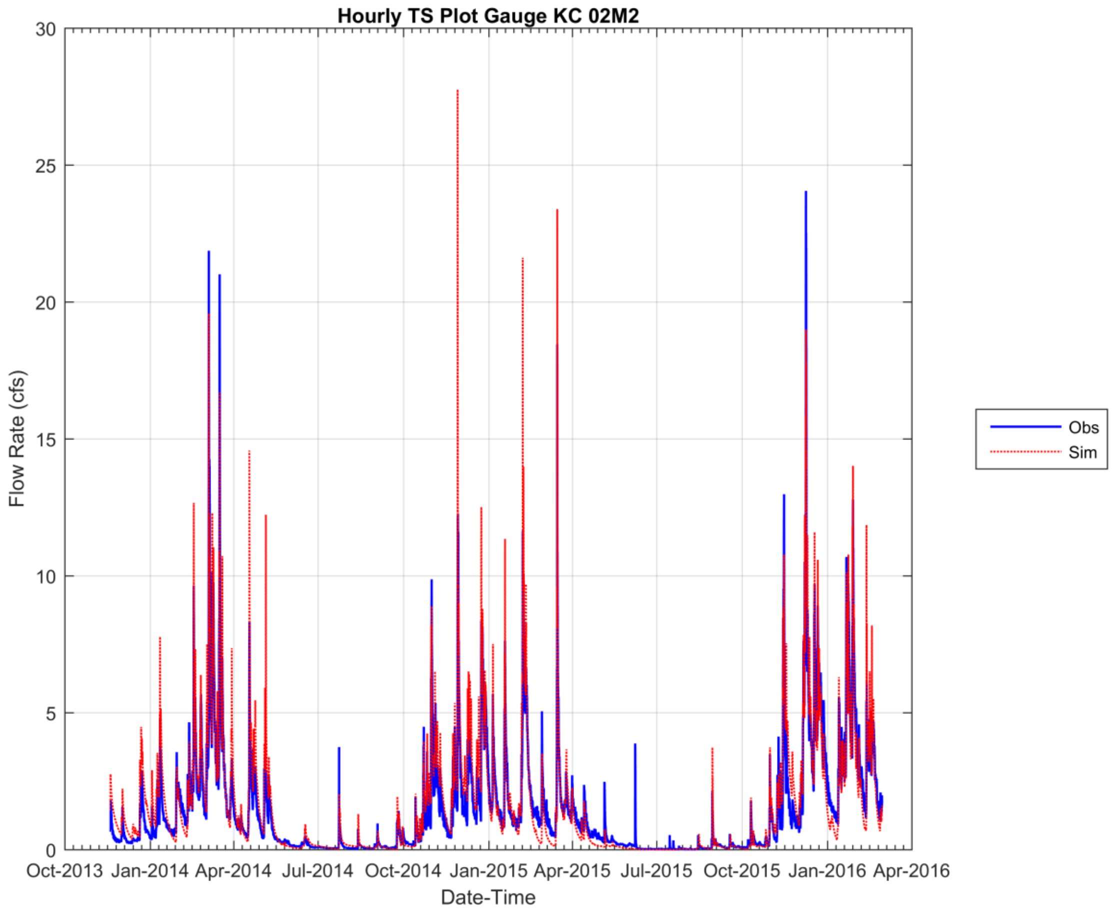

Figure 57 Gauge 02M2 time series flow plot

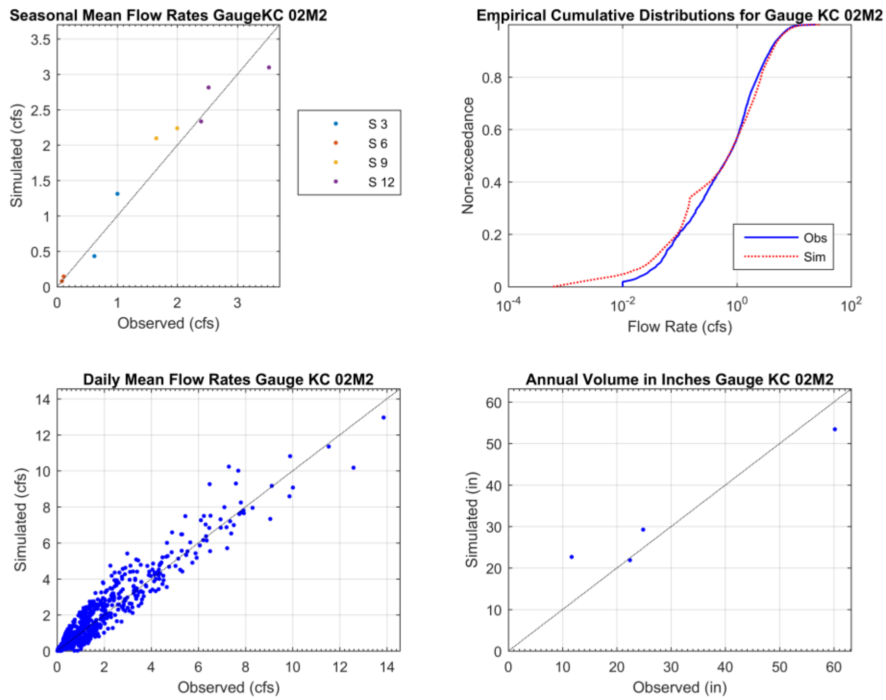

Figure 58 Gauge 02M2 flow calibration plots 1

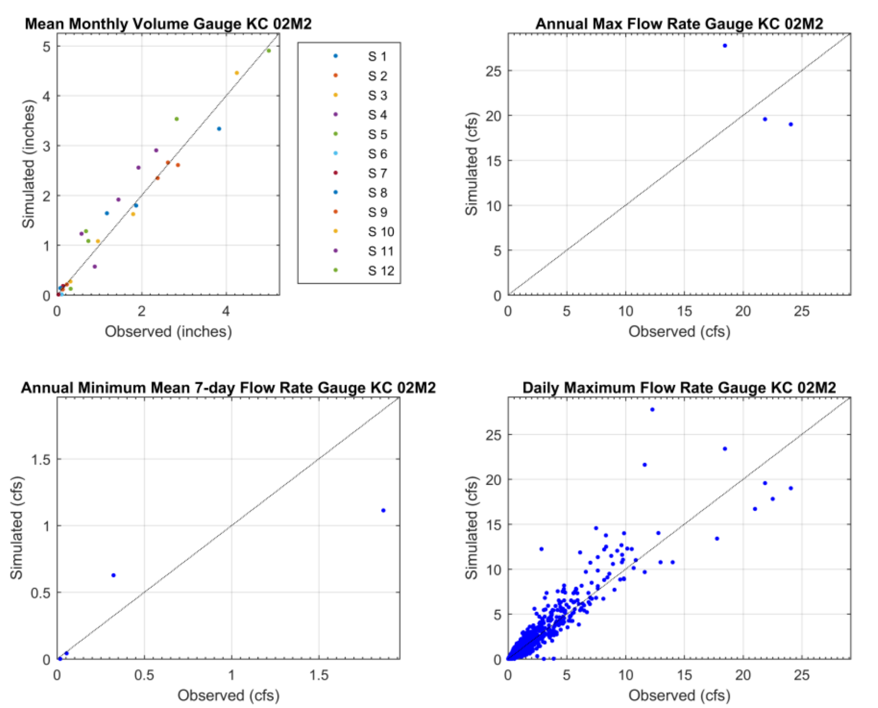

Figure 59 Gauge 02M2 flow calibration plots 2

Table 55 Summary of flow rate calibration statistics for 02M.

Metric	Obs (cfs)	Sim (cfs)	RPD	
Mean Spring (cfs)	3.7	3.4	-6%	
Mean Summer (cfs)	0.3	0.4	53%	
Mean Fall (cfs)	6.6	8.2	25%	
Mean Winter (cfs)	2.8	4.0	43%	
Mean Flow (cfs)	5.55	5.86	6%	
GeoMean (cfs)	1.83	1.80	-2%	
Mean Annual Max. (cfs)	63.8	54.3	-15%	
Mean Annual 7-Day Low (cfs)	2.39	1.87	-22%	
Mean Daily max (cfs)	7.02	7.11	1%	
Annual Volumes (inches)	28.69	31.12	8%	
January	3.38	3.34	-1%	
February	3.36	3.38	1%	
March	4.66	4.40	-6%	
April	1.89	1.82	-4%	
May	1.13	0.95	-16%	
June	0.20	0.15	-28%	
July	0.07	0.12	84%	
August	0.08	0.16	118%	
September	0.20	0.24	20%	
October	0.82	1.00	22%	
November	2.23	3.24	46%	
December	4.39	4.78	9%	
10 Percentile	25.24	26.64	6%	
25 Percentile	70.38	72.21	3%	
50 Percentile	33.23	39.10	18%	
75 Percentile	11.96	13.46	13%	
90 Percentile	1.92	2.47	29%	
Equivalency Tests	Kruskal-Wallis		One-way ANOVA	
	p-value	> 0.10	p-value	> 0.10
Seasonal Volume	0.96	Pass	0.87	Pass
Hourly	0.00	Fail	0.28	Pass
Daily Means	0.24	Pass	0.73	Pass
Annual Vol. (inches)	0.39	Pass	0.82	Pass
Monthly Vol. (inches)	0.82	Pass	0.80	Pass
Peak Annual	0.51	Pass	0.46	Pass
Min 7DAvg	1.00	Pass	0.80	Pass
Daily Max.	0.90	Pass	0.15	Pass
Prediction Statistic (hourly)	Value			
Pearson	0.96			
Mean Err (cfs)	0.31			
RMSE (cfs)	2.07			
R-square	0.92			
MAE (cfs)	1.36			
Nash-Sutcliffe	0.92			
Skill Score	0.72			

Skill Score: 1 - RMSE/STDobs

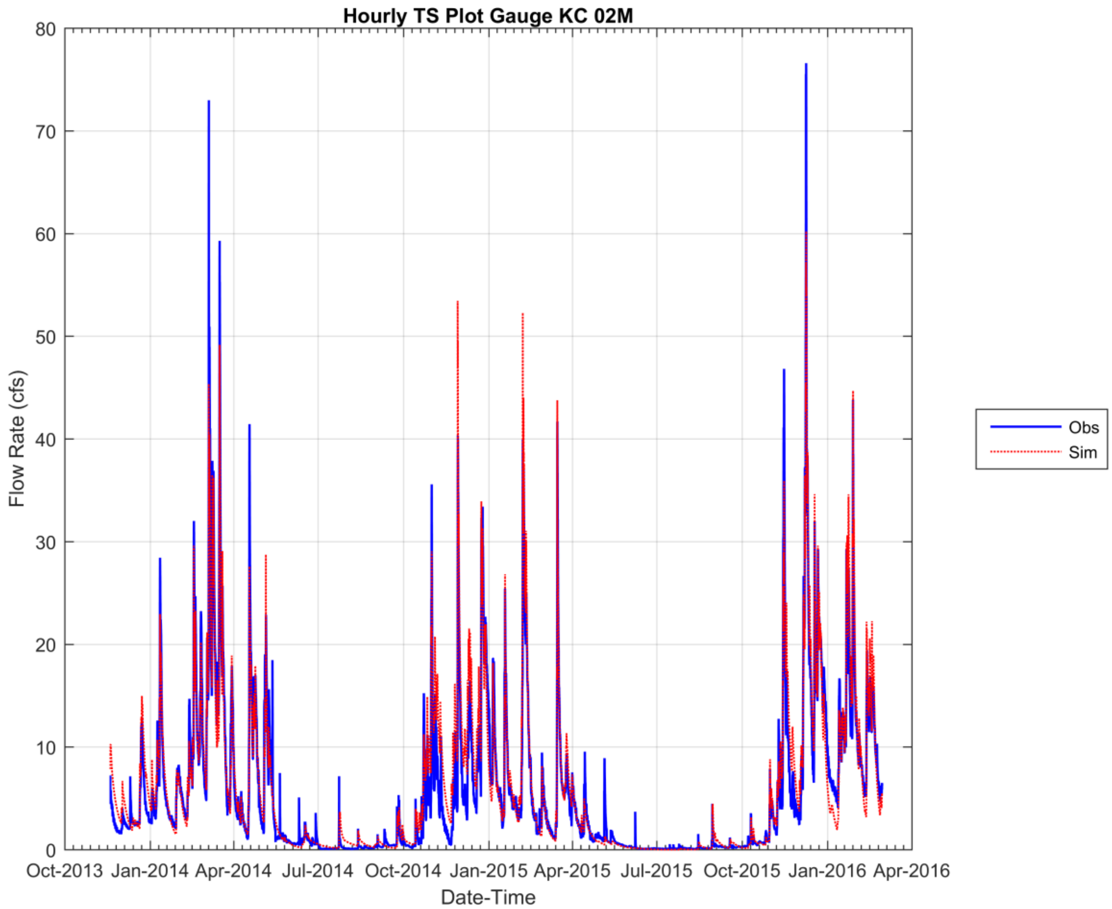

Figure 60 Gauge 02M time series flow plot

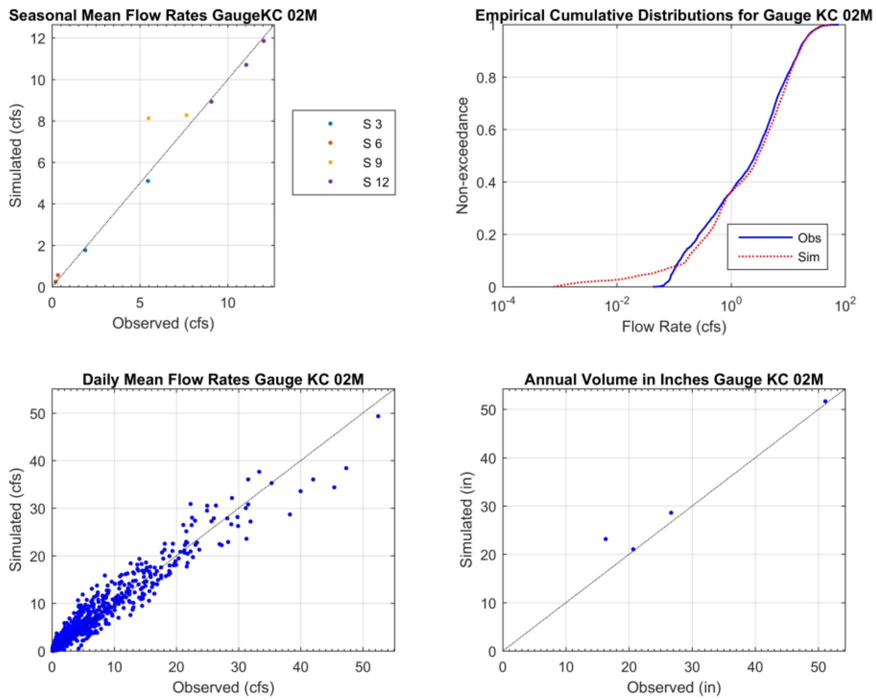

Figure 61 Gauge 02M flow calibration plots 1

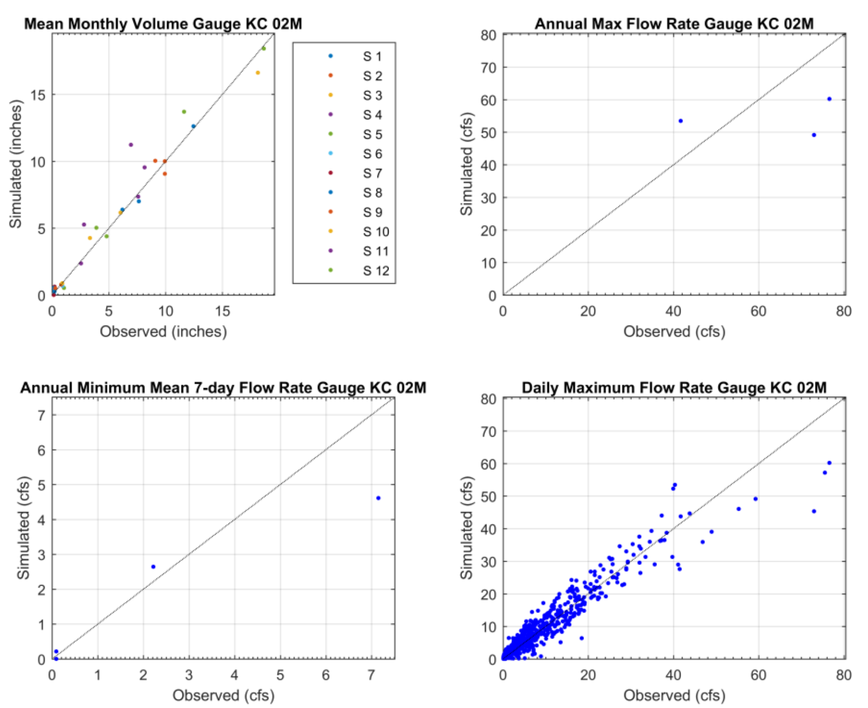

Figure 62 Gauge 02M flow calibration plots 2

Table 56 Summary of flow rate calibration statistics for 02O.

Metric	Obs	Sim	RPD
	(cfs)		
Mean Spring (cfs)	0.3	0.4	63%
Mean Summer (cfs)	0.1	0.2	88%
Mean Fall (cfs)	0.1	0.2	118%
Mean Winter (cfs)	0.5	0.8	54%
Mean Flow (cfs)	0.45	0.70	54%
GeoMean (cfs)	0.27	0.50	82%
Mean Annual Max. (cfs)	4.5	7.8	76%
Mean Annual 7-Day Low (cfs)	0.21	0.45	111%
Mean Daily max (cfs)	0.57	0.84	48%
Annual Volumes (inches)	25.34	38.92	54%
January	3.17	4.58	44%
February	2.63	4.40	68%
March	2.29	3.42	49%
April	1.27	1.92	51%
May	0.73	1.33	81%
June	0.61	1.01	67%
July	0.52	0.98	90%
August	0.36	0.84	133%
September	0.37	0.74	99%
October	0.69	1.16	68%
November	2.36	3.57	51%
December	4.03	5.52	37%
10 Percentile	20.08	31.01	54%
25 Percentile	46.22	69.08	49%
50 Percentile	25.28	43.52	72%
75 Percentile	11.58	18.92	63%
90 Percentile	5.12	10.27	100%

Equivalency Tests	Kruskal-Wallis		One-way ANOVA	
	p-value	> 0.10	p-value	> 0.10
Seasonal Volume	0.34	Pass	0.30	Pass
Hourly	0.00	Fail	0.00	Fail
Daily Means	0.00	Fail	0.00	Fail
Annual Vol. (inches)	0.28	Pass	0.38	Pass
Monthly Vol. (inches)	0.04	Fail	0.09	Fail
Peak Annual	0.51	Pass	0.50	Pass
Min 7DAvg	0.28	Pass	0.47	Pass
Daily Max.	0.00	Fail	0.00	Fail

Prediction Statistic (hourly)	Value
Pearson	0.85
Mean Err (cfs)	0.25
RMSE (cfs)	0.33
R-square	0.73
MAE (cfs)	0.19
Nash-Sutcliffe	0.44
Skill Score	0.25

Skill Score: 1 - RMSE/STDobs

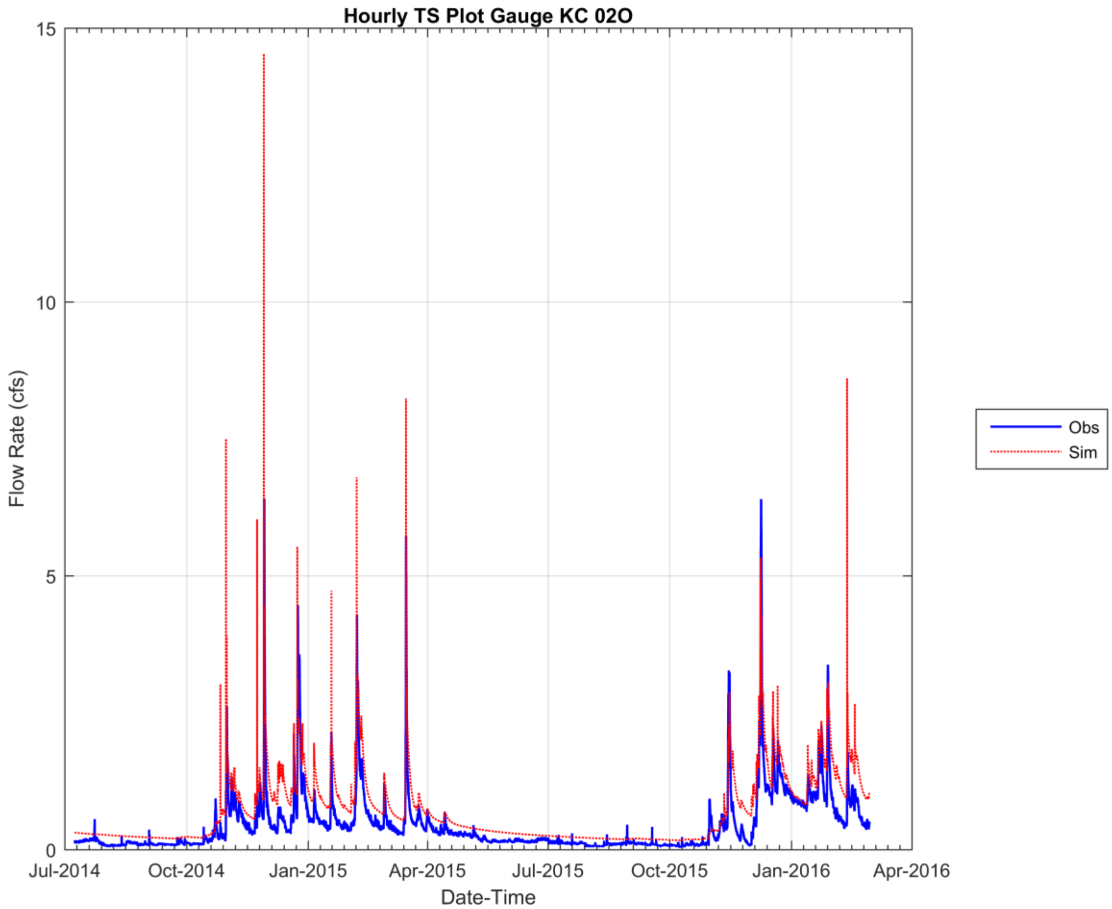

Figure 63 Gauge 02O time series flow plot

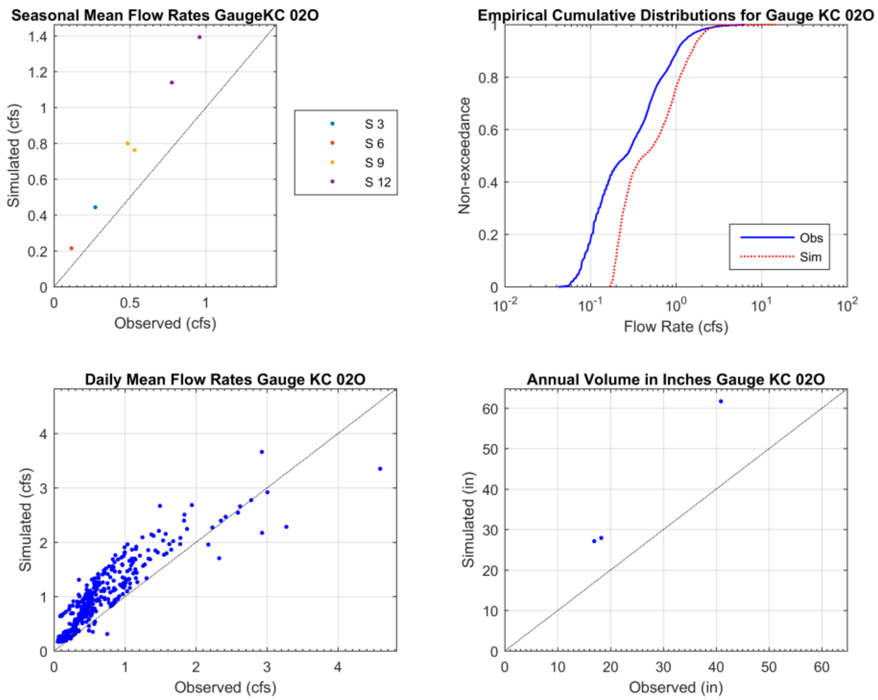

Figure 64 Gauge 02O flow calibration plots 1

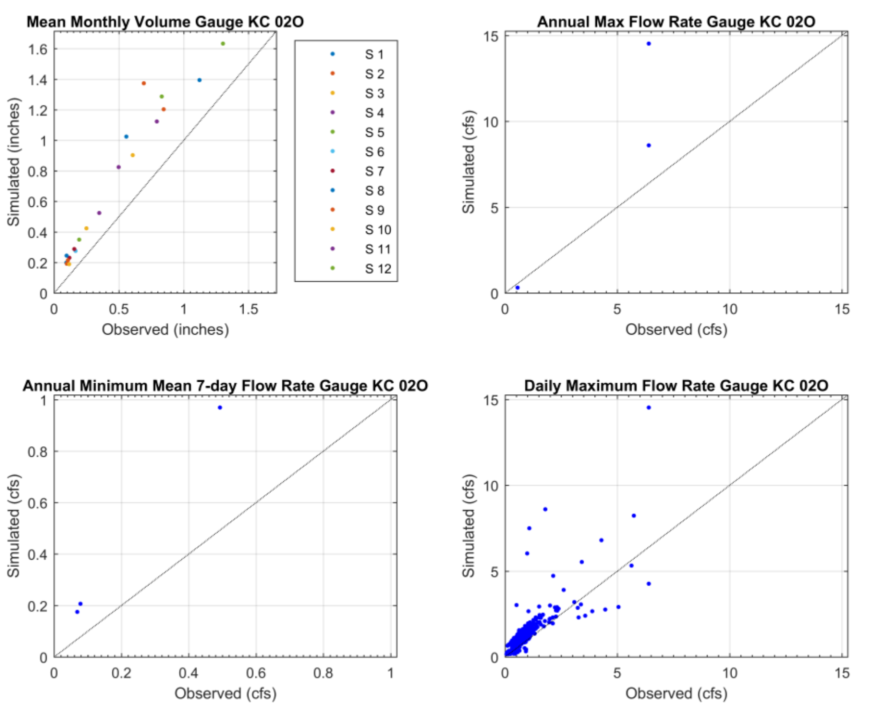

Figure 65 Gauge 02O flow calibration plots 2

Table 57 Summary of flow rate calibration statistics for 02P.

Metric	Obs	Sim	RPD
	(cfs)		
Mean Spring (cfs)	0.4	0.4	-15%
Mean Summer (cfs)	0.2	0.2	-29%
Mean Fall (cfs)	0.3	0.2	-26%
Mean Winter (cfs)	0.6	0.5	-6%
Mean Flow (cfs)	0.55	0.58	4%
GeoMean (cfs)	0.44	0.42	-5%
Mean Annual Max. (cfs)	4.0	9.1	125%
Mean Annual 7-Day Low (cfs)	0.30	0.37	23%
Mean Daily max (cfs)	0.75	0.78	4%
Annual Volumes (inches)	34.71	40.64	17%
January	3.72	4.51	21%
February	3.29	4.37	33%
March	3.88	3.37	-13%
April	2.89	2.15	-26%
May	0.96	1.26	32%
June	1.07	1.02	-5%
July	1.21	0.97	-20%
August	1.20	0.81	-32%
September	1.09	0.63	-42%
October	4.17	3.82	-8%
November	2.84	3.23	14%
December	4.74	5.07	7%
10 Percentile	31.44	32.68	4%
25 Percentile	54.51	66.49	22%
50 Percentile	39.75	46.27	16%
75 Percentile	28.96	28.38	-2%
90 Percentile	13.06	10.71	-18%

Equivalency Tests	Kruskal-Wallis		One-way ANOVA	
	p-value	> 0.10	p-value	> 0.10
Seasonal Volume	0.92	Pass	0.93	Pass
Hourly	0.00	Fail	0.00	Fail
Daily Means	0.26	Pass	0.24	Pass
Annual Vol. (inches)	0.83	Pass	0.62	Pass
Monthly Vol. (inches)	0.76	Pass	0.86	Pass
Peak Annual	0.51	Pass	0.36	Pass
Min 7DAvg	0.83	Pass	0.79	Pass
Daily Max.	0.00	Fail	0.00	Fail

Prediction Statistic (hourly)	Value
Pearson	0.75
Mean Err (cfs)	0.02
RMSE (cfs)	0.35
R-square	0.57
MAE (cfs)	0.19
Nash-Sutcliffe	0.41
Skill Score	0.23

Skill Score: 1 - RMSE/STDobs

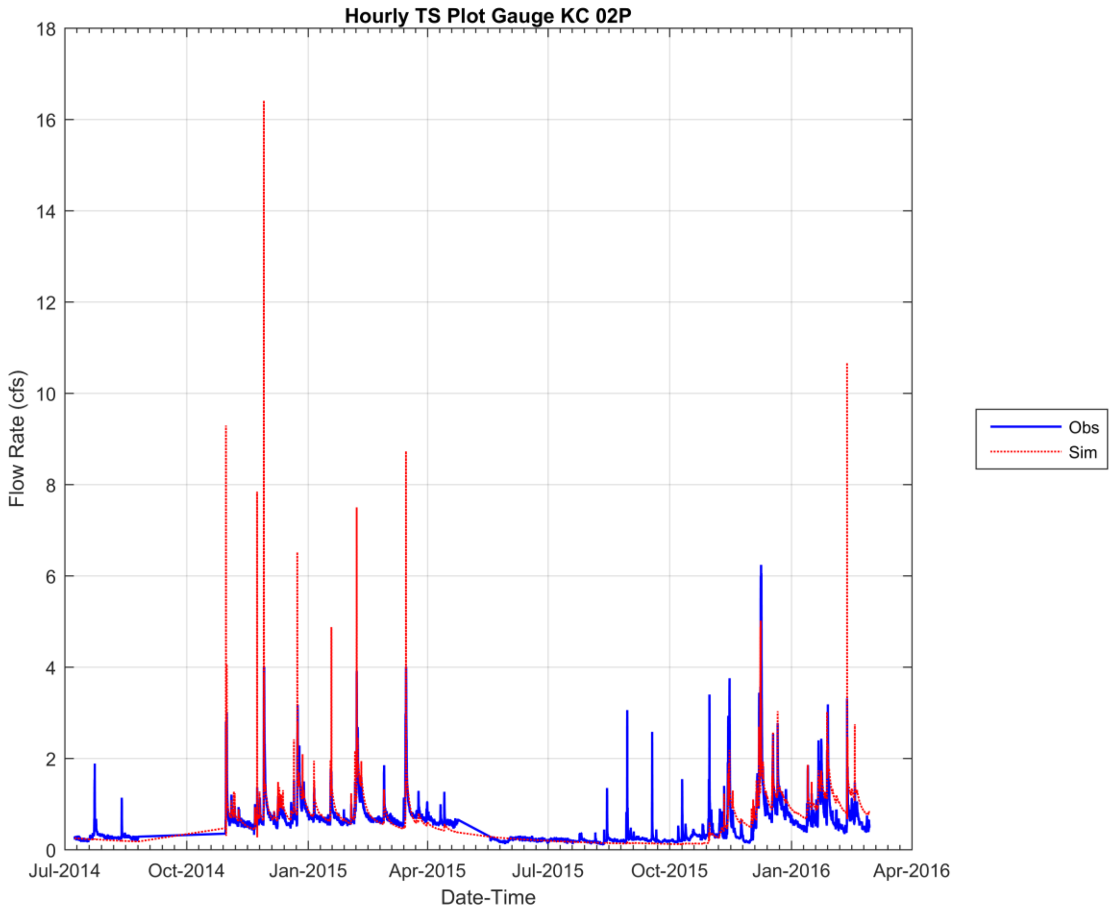

Figure 66 Gauge 02P time series flow plot

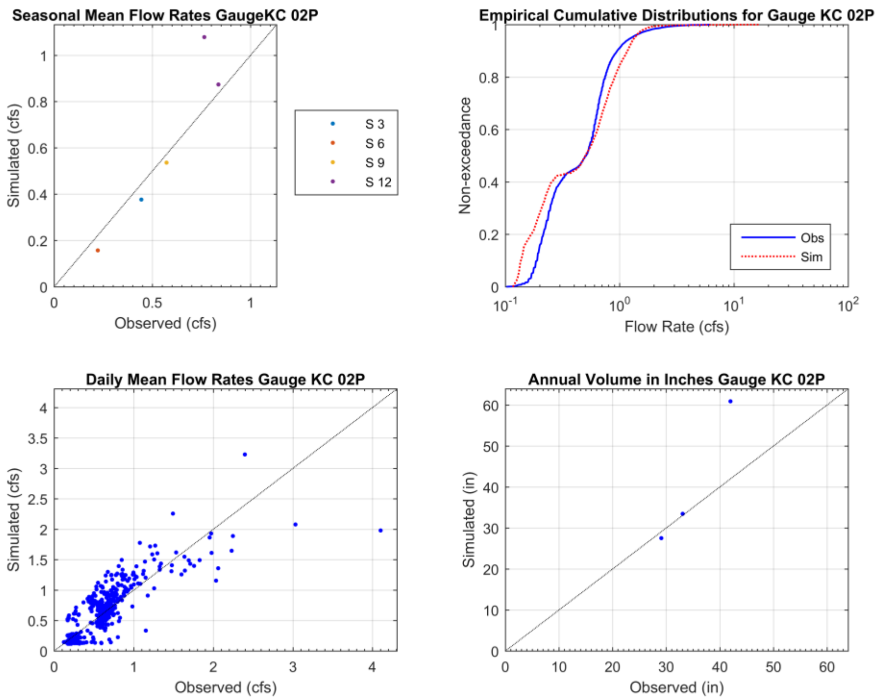

Figure 67 Gauge 02P flow calibration plots 1

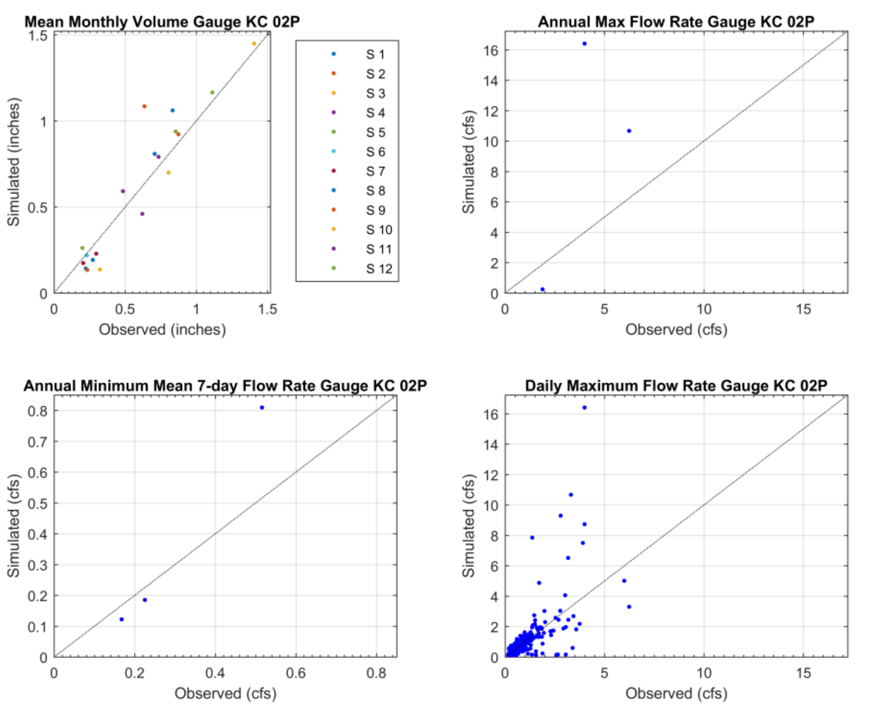

Figure 68 Gauge 02P flow calibration plots 2

Table 58 Summary of flow rate calibration statistics for 02E.

Metric	Obs (cfs)		Sim (cfs)		RPD
Mean Spring (cfs)	27.9		28.8		3%
Mean Summer (cfs)	8.7		9.4		7%
Mean Fall (cfs)	33.8		29.4		-13%
Mean Winter (cfs)	55.1		52.6		-5%
Mean Flow (cfs)	29.82		28.68		-4%
GeoMean (cfs)	19.94		20.30		2%
Mean Annual Max. (cfs)	207.8		221.8		7%
Mean Annual 7-Day Low (cfs)	12.59		14.17		13%
Mean Daily max (cfs)	34.81		34.21		-2%
Annual Volumes (inches)	34.86		35.09		1%
January	4.01		3.86		-4%
February	3.82		3.91		2%
March	4.69		4.30		-8%
April	2.91		2.96		2%
May	1.44		1.74		21%
June	0.84		1.03		23%
July	0.59		0.81		37%
August	0.74		0.74		-1%
September	0.95		0.80		-16%
October	1.47		1.18		-20%
November	3.36		2.96		-12%
December	5.03		4.42		-12%
10 Percentile	29.86		28.72		-4%
25 Percentile	65.14		63.43		-3%
50 Percentile	38.44		37.55		-2%
75 Percentile	18.15		19.15		6%
90 Percentile	9.47		9.65		2%
Equivalency Tests	Kruskal-Wallis		One-way ANOVA		
	p-value	> 0.10	p-value	> 0.10	
Seasonal Volume	0.82	Pass	0.96	Pass	
Hourly	0.00	Fail	0.02	Fail	
Daily Means	0.51	Pass	0.61	Pass	
Annual Vol. (inches)	0.77	Pass	0.99	Pass	
Monthly Vol. (inches)	0.92	Pass	0.83	Pass	
Peak Annual	0.77	Pass	0.79	Pass	
Min 7DAvg	0.39	Pass	0.88	Pass	
Daily Max.	0.94	Pass	0.96	Pass	
Prediction Statistic (hourly)	Value				
Pearson	0.95				
Mean Err (cfs)	-1.14				
RMSE (cfs)	8.01				
R-square	0.91				
MAE (cfs)	4.75				
Nash-Sutcliffe	0.90				
Skill Score	0.68				

Skill Score: 1 - RMSE/STDobs

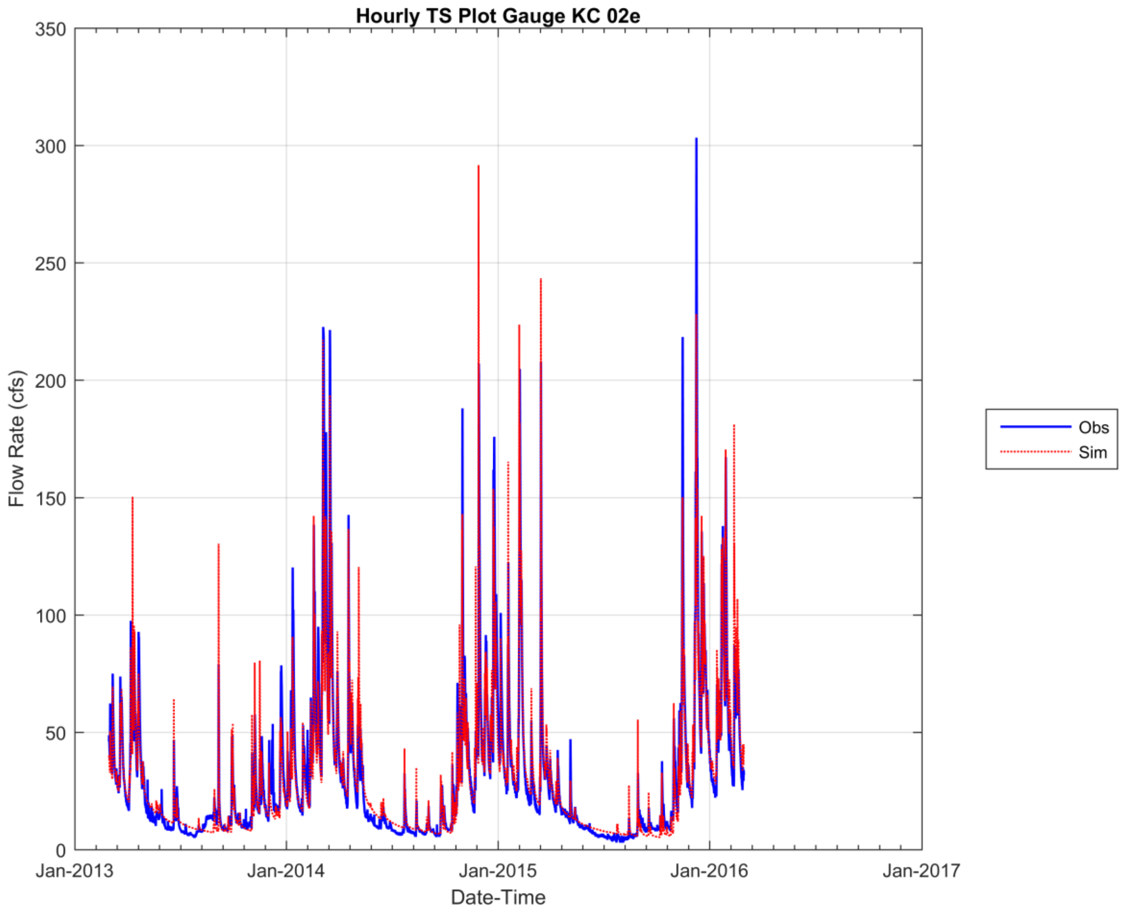

Figure 69 Gauge 02E time series flow plot

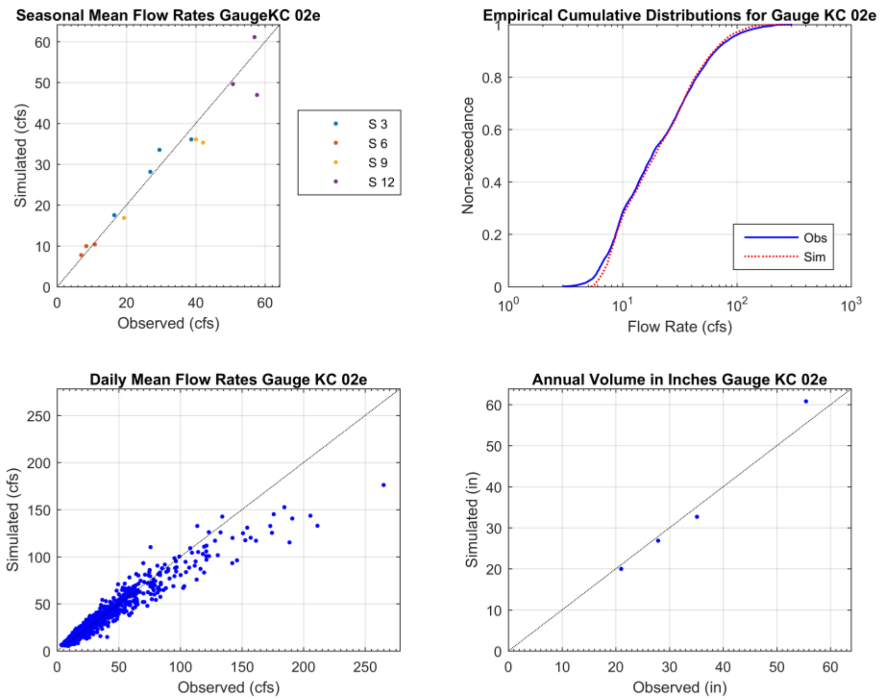

Figure 70 Gauge 02E flow calibration plots 1

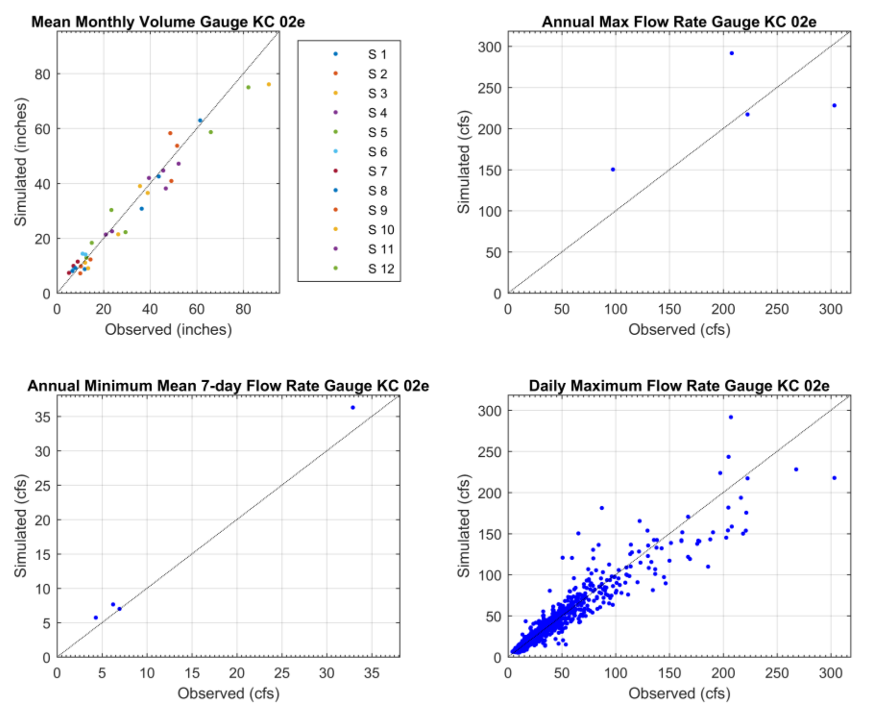

Figure 71 Gauge 02E flow calibration plots 2

Table 59 Summary of flow rate calibration statistics for 02Q.

Metric	Obs (cfs)		Sim (cfs)	RPD
Mean Spring (cfs)	1.4		2.1	44%
Mean Summer (cfs)	0.4		0.4	7%
Mean Fall (cfs)	2.4		2.5	4%
Mean Winter (cfs)	2.9		2.6	-10%
Mean Flow (cfs)	2.18		2.47	14%
GeoMean (cfs)	1.36		1.55	14%
Mean Annual Max. (cfs)	25.1		16.9	-32%
Mean Annual 7-Day Low (cfs)	0.94		1.26	34%
Mean Daily max (cfs)	3.08		3.18	3%
Annual Volumes (inches)	18.80		21.23	13%
January	1.99		2.41	21%
February	2.04		2.40	18%
March	2.74		2.96	8%
April	1.14		1.68	47%
May	0.71		1.07	50%
June	0.37		0.42	13%
July	0.25		0.29	19%
August	0.24		0.25	4%
September	0.29		0.38	30%
October	1.06		0.95	-11%
November	1.45		1.29	-11%
December	2.25		2.36	5%
10 Percentile	16.50		18.75	14%
25 Percentile	34.81		41.42	19%
50 Percentile	20.66		27.08	31%
75 Percentile	11.37		14.58	28%
90 Percentile	4.47		5.15	15%
Equivalency Tests	Kruskal-Wallis		One-way ANOVA	
	p-value	> 0.10	p-value	> 0.10
Seasonal Volume	0.60	Pass	0.80	Pass
Hourly	0.00	Fail	0.00	Fail
Daily Means	0.00	Fail	0.02	Fail
Annual Vol. (inches)	0.56	Pass	0.74	Pass
Monthly Vol. (inches)	0.61	Pass	0.54	Pass
Peak Annual	0.13	Pass	0.09	Fail
Min 7DAvg	0.77	Pass	0.74	Pass
Daily Max.	0.08	Fail	0.51	Pass
Prediction Statistic (hourly)	Value			
Pearson	0.89			
Mean Err (cfs)	0.30			
RMSE (cfs)	1.00			
R-square	0.79			
MAE (cfs)	0.76			
Nash-Sutcliffe	0.78			
Skill Score	0.53			

Skill Score: 1 - RMSE/STDobs

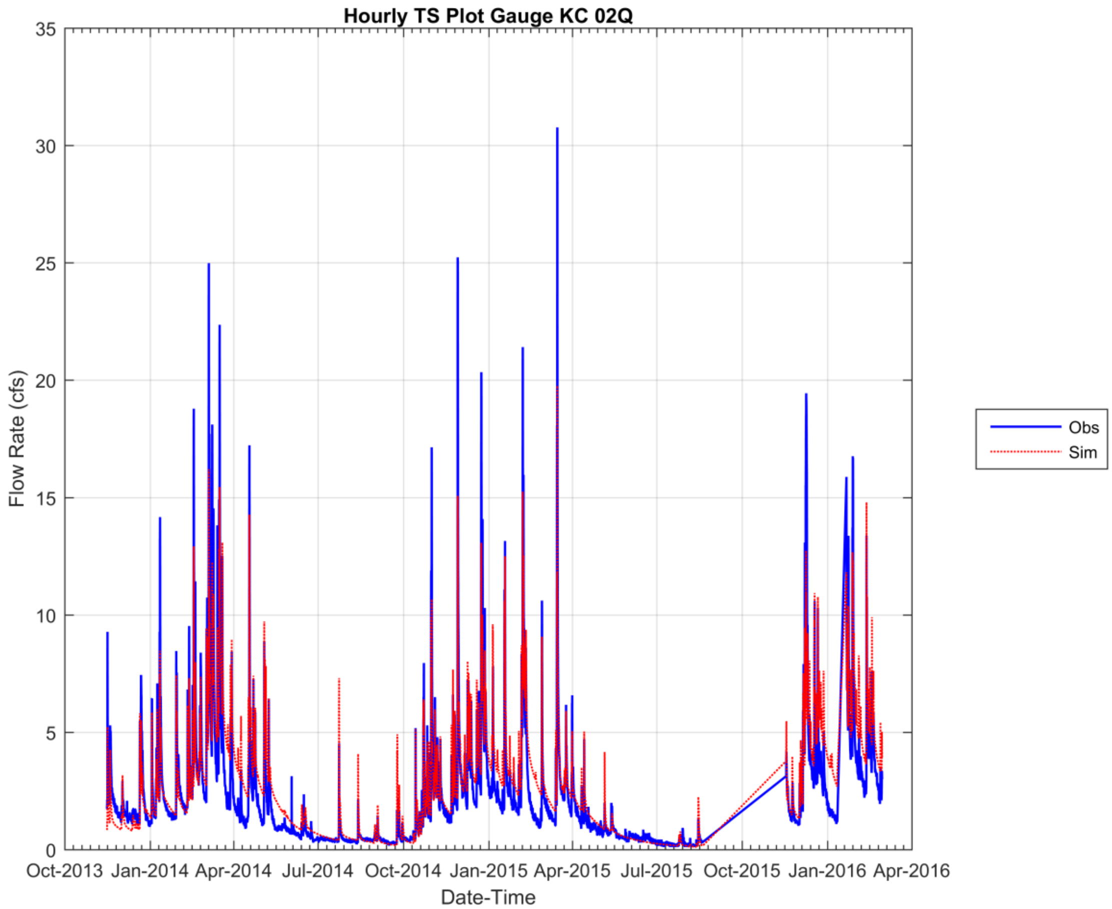

Figure 72 Gauge 02Q time series flow plot

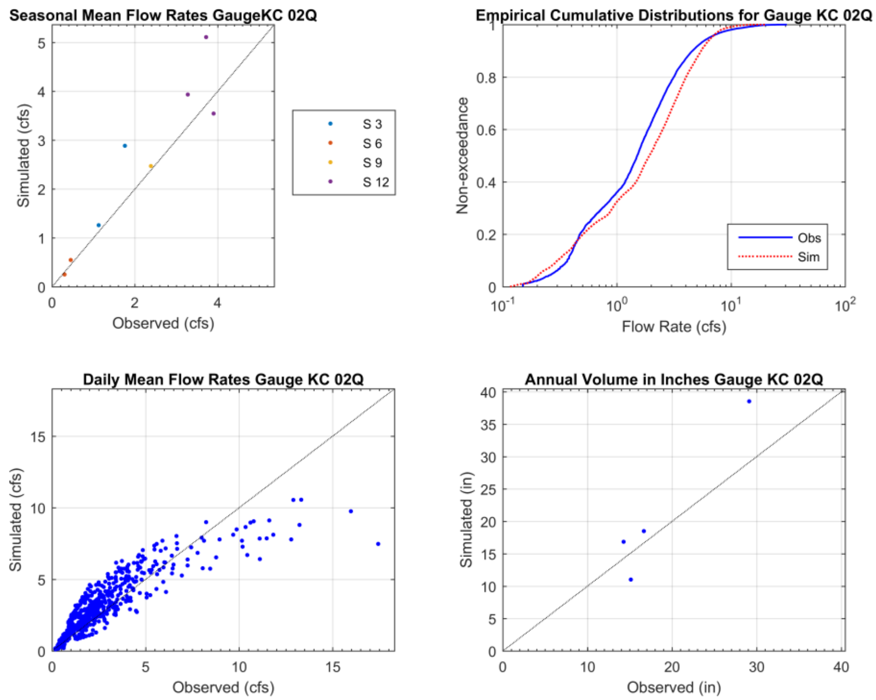

Figure 73 Gauge 02Q flow calibration plots 1

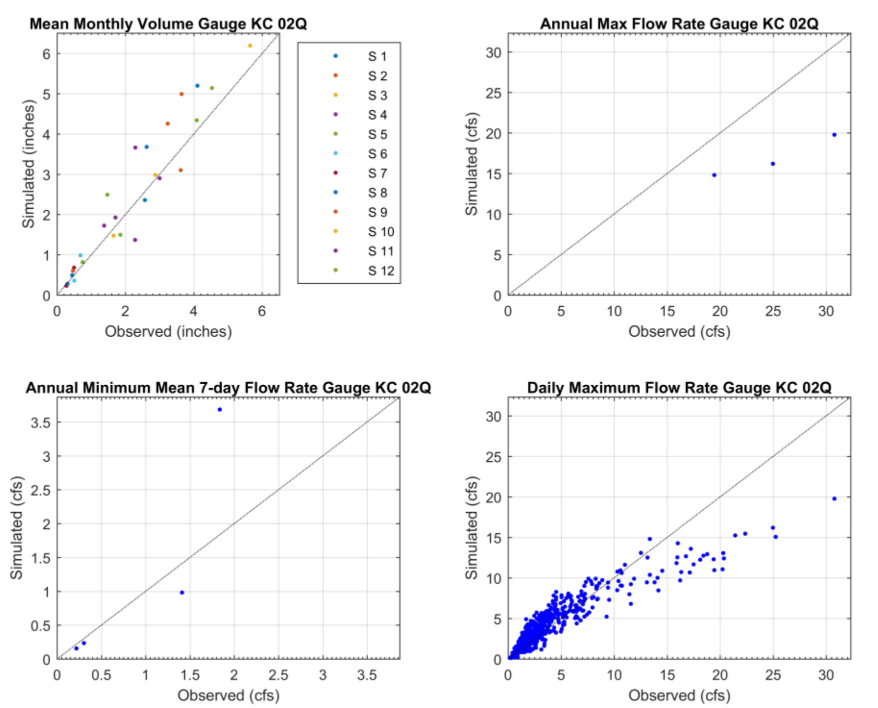

Figure 74 Gauge 02Q flow calibration plots 2

BCP0114

Table 60 Summary of flow rate calibration statistics for BCP0114.

Metric	Obs (cfs)		Sim (cfs)		RPD
Mean Spring (cfs)	1.3		1.6		29%
Mean Summer (cfs)	0.6		0.3		-44%
Mean Fall (cfs)	1.9		1.4		-24%
Mean Winter (cfs)	2.5		3.0		22%
Mean Flow (cfs)	1.51		1.53		2%
GeoMean (cfs)	1.03		0.85		-18%
Mean Annual Max. (cfs)	26.3		13.8		-47%
Mean Annual 7-Day Low (cfs)	0.70		0.67		-4%
Mean Daily max (cfs)	2.31		1.87		-19%
Annual Volumes (inches)	37.74		40.06		6%
January	3.61		4.39		22%
February	3.52		4.42		26%
March	3.99		4.87		22%
April	2.75		3.49		27%
May	1.42		1.91		35%
June	0.89		0.87		-3%
July	0.86		0.51		-40%
August	1.03		0.49		-52%
September	1.28		0.67		-48%
October	1.96		1.06		-46%
November	3.96		2.64		-33%
December	4.14		4.58		11%
10 Percentile	29.42		29.91		2%
25 Percentile	58.57		70.95		21%
50 Percentile	35.53		42.59		20%
75 Percentile	19.91		20.45		3%
90 Percentile	10.59		6.23		-41%
Equivalency Tests	Kruskal-Wallis		One-way ANOVA		
	p-value	> 0.10	p-value	> 0.10	
Seasonal Volume	0.94	Pass	0.78	Pass	
Hourly	0.00	Fail	0.00	Fail	
Daily Means	0.01	Fail	0.00	Fail	
Annual Vol. (inches)	1.00	Pass	0.78	Pass	
Monthly Vol. (inches)	0.58	Pass	0.92	Pass	
Peak Annual	0.02	Fail	0.01	Fail	
Min 7DAvg	0.25	Pass	0.96	Pass	
Daily Max.	0.00	Fail	0.00	Fail	
Prediction Statistic (hourly)	Value				
Pearson	0.78				
Mean Err (cfs)	0.03				
RMSE (cfs)	1.02				
R-square	0.61				
MAE (cfs)	0.69				
Nash-Sutcliffe	0.58				
Skill Score	0.35				

Skill Score: 1 - RMSE/STDobs

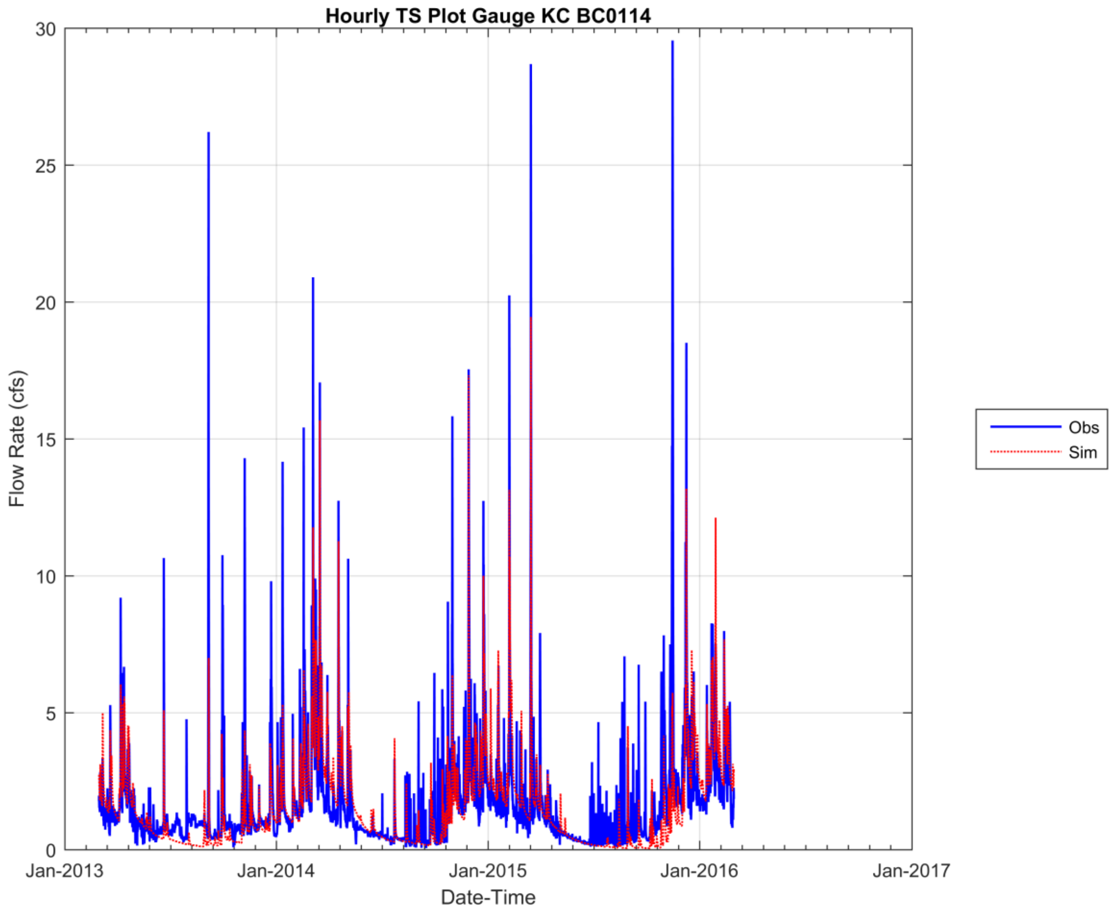

Figure 75 Gauge BCP0114 time series flow plot

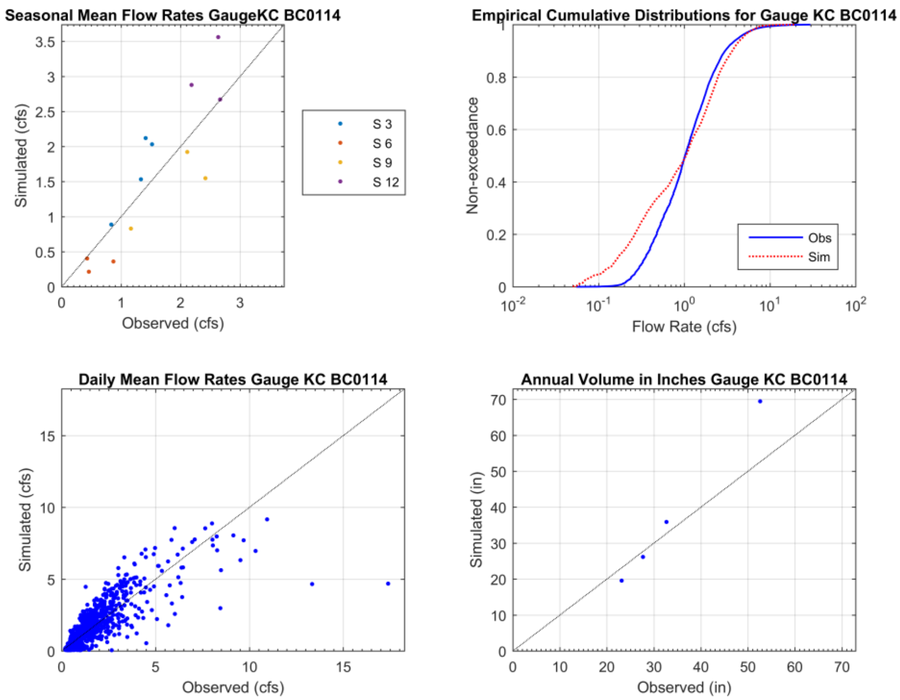

Figure 76 Gauge BCP0114 flow calibration plots 1

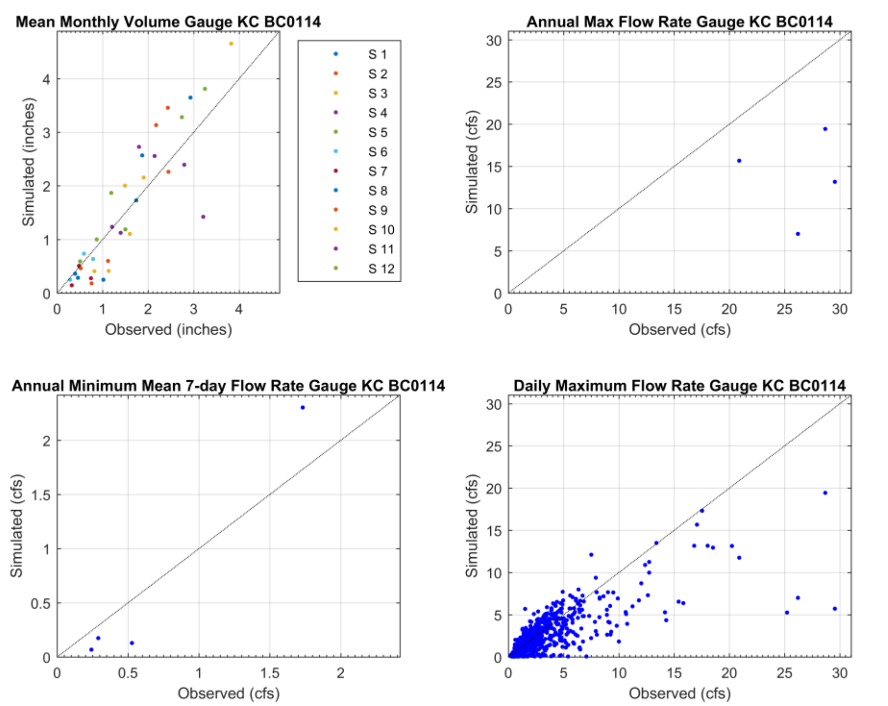

Figure 77 Gauge BCP0114 flow calibration plots 2

Table 61 Summary of flow rate calibration statistics for 02R.

Metric	Obs		Sim		RPD
	(cfs)				
Mean Spring (cfs)	34.3		36.6		7%
Mean Summer (cfs)	14.7		16.7		14%
Mean Fall (cfs)	77.9		68.2		-13%
Mean Winter (cfs)	102.9		106.0		3%
Mean Flow (cfs)	66.01		64.28		-3%
GeoMean (cfs)	43.71		45.04		3%
Mean Annual Max. (cfs)	289.3		314.0		9%
Mean Annual 7-Day Low (cfs)	26.96		33.55		24%
Mean Daily max (cfs)	76.14		78.50		3%
Annual Volumes (inches)	34.74		34.66		0%
January	3.58		3.61		1%
February	3.21		3.48		8%
March	2.50		2.77		11%
April	1.48		1.56		5%
May	0.96		1.00		4%
June	0.53		0.64		20%
July	0.45		0.54		21%
August	0.54		0.63		18%
September	0.81		0.78		-4%
October	1.32		1.20		-10%
November	3.13		2.64		-16%
December	4.83		4.30		-11%
10 Percentile	27.72		26.99		-3%
25 Percentile	59.81		57.89		-3%
50 Percentile	34.33		36.30		6%
75 Percentile	19.31		21.76		13%
90 Percentile	7.56		7.96		5%
Equivalency Tests	Kruskal-Wallis		One-way ANOVA		
	p-value	> 0.10	p-value	> 0.10	
Seasonal Volume	1.00	Pass	0.99	Pass	
Hourly	0.00	Fail	0.01	Fail	
Daily Means	0.28	Pass	0.53	Pass	
Annual Vol. (inches)	0.83	Pass	0.99	Pass	
Monthly Vol. (inches)	0.97	Pass	0.91	Pass	
Peak Annual	0.83	Pass	0.91	Pass	
Min 7DAvg	0.83	Pass	0.78	Pass	
Daily Max.	0.24	Pass	0.37	Pass	
Prediction Statistic (hourly)	Value				
Pearson	0.94				
Mean Err (cfs)	-1.73				
RMSE (cfs)	18.40				
R-square	0.89				
MAE (cfs)	11.80				
Nash-Sutcliffe	0.88				
Skill Score	0.65				

Skill Score: 1 - RMSE/STDobs

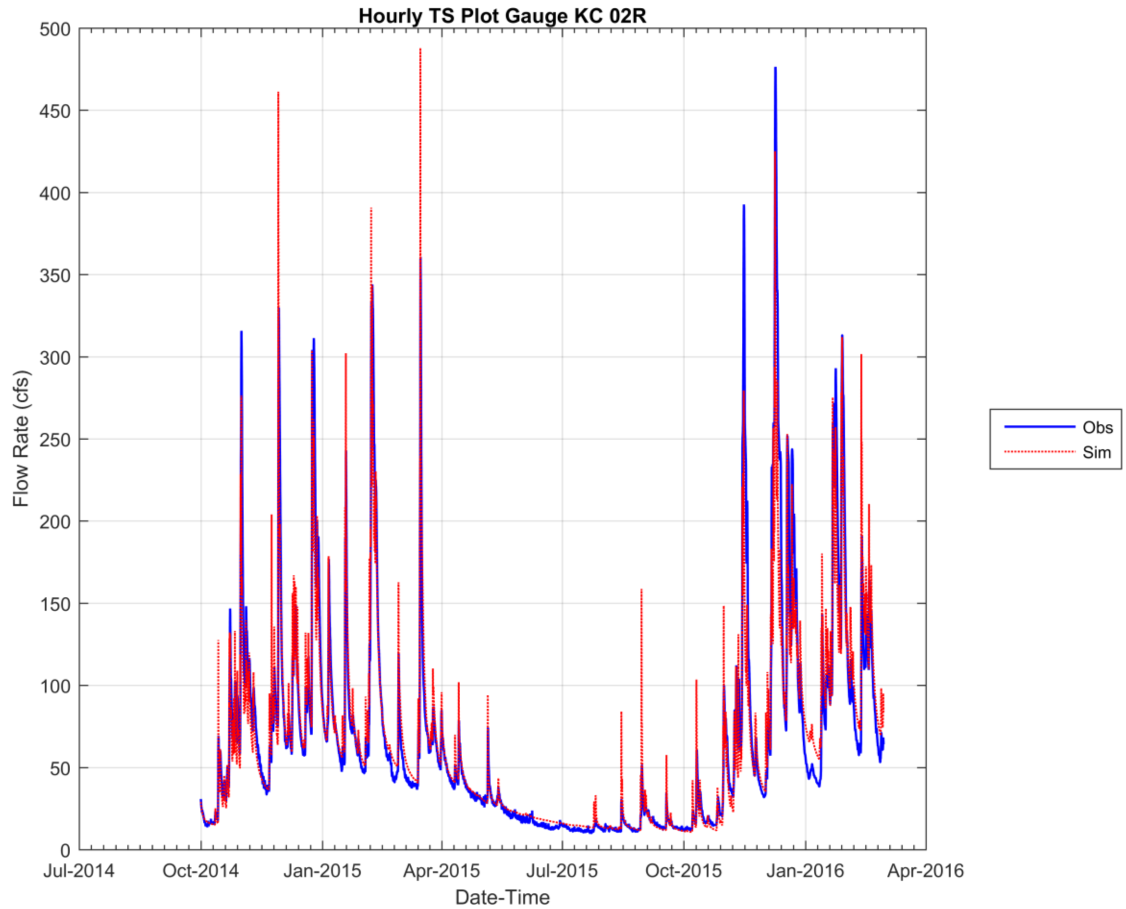

Figure 78 Gauge 02R time series flow plot

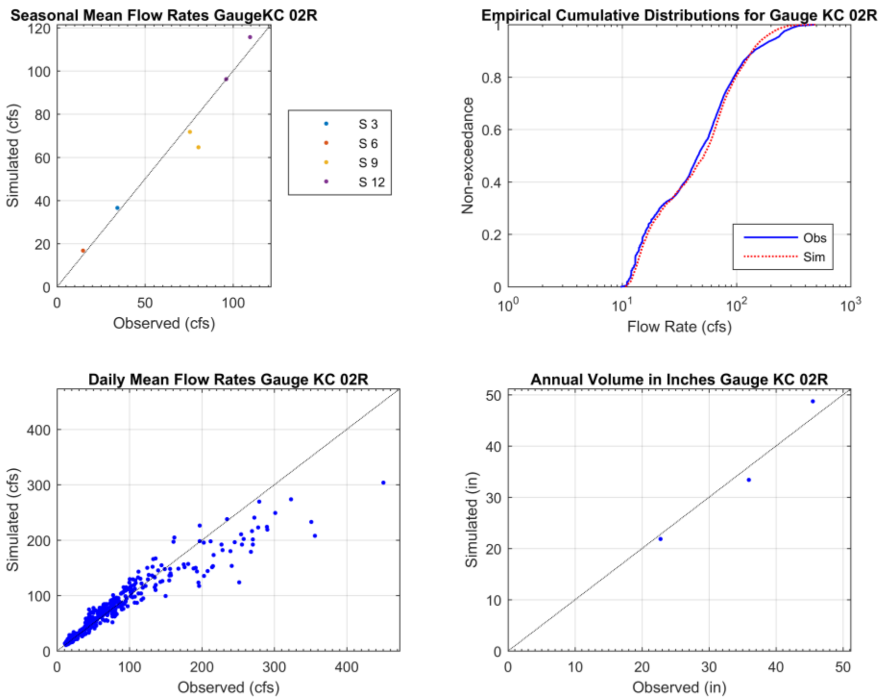

Figure 79 Gauge 02R flow calibration plot 1

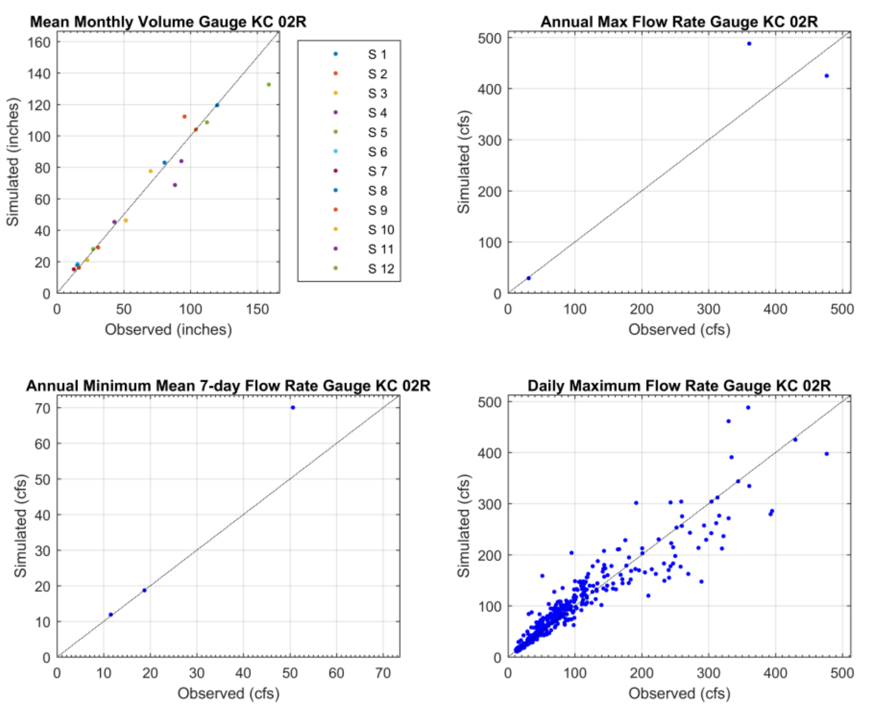

Figure 80 Gauge 02R flow calibration plots 2

Table 62 Summary of flow rate calibration statistics for BCP0119.

Metric	Obs (cfs)		Sim	RPD
Mean Spring (cfs)	0.5		0.6	26%
Mean Summer (cfs)	0.3		0.4	26%
Mean Fall (cfs)	1.6		1.5	-7%
Mean Winter (cfs)	1.6		1.7	12%
Mean Flow (cfs)	0.99		1.01	1%
GeoMean (cfs)	0.53		0.53	-1%
Mean Annual Max. (cfs)	15.7		13.3	-15%
Mean Annual 7-Day Low (cfs)	0.36		0.51	41%
Mean Daily max (cfs)	1.53		1.68	10%
Annual Volumes (inches)	23.72		27.74	17%
January	2.34		2.99	28%
February	3.36		3.53	5%
March	2.73		2.99	10%
April	1.17		1.43	23%
May	0.63		0.84	33%
June	0.49		0.68	38%
July	0.45		0.58	30%
August	0.57		0.63	11%
September	0.90		0.78	-13%
October	2.03		1.79	-12%
November	3.62		3.36	-7%
December	5.47		5.20	-5%
10 Percentile	23.98		24.32	1%
25 Percentile	58.08		59.54	3%
50 Percentile	28.56		30.99	9%
75 Percentile	11.13		13.75	23%
90 Percentile	5.08		4.46	-12%
Equivalency Tests	Kruskal-Wallis		One-way ANOVA	
	p-value	> 0.10	p-value	> 0.10
Seasonal Volume	0.67	Pass	0.79	Pass
Hourly	0.29	Pass	0.67	Pass
Daily Means	0.93	Pass	0.94	Pass
Annual Vol. (inches)	0.28	Pass	0.35	Pass
Monthly Vol. (inches)	0.79	Pass	0.91	Pass
Peak Annual	0.51	Pass	0.74	Pass
Min 7DAvg	0.83	Pass	0.76	Pass
Daily Max.	0.33	Pass	0.62	Pass
Prediction Statistic (hourly)	Value			
Pearson	0.88			
Mean Err (cfs)	0.01			
RMSE (cfs)	0.63			
R-square	0.77			
MAE (cfs)	0.31			
Nash-Sutcliffe	0.77			
Skill Score	0.52			

Skill Score: 1 - RMSE/STDobs

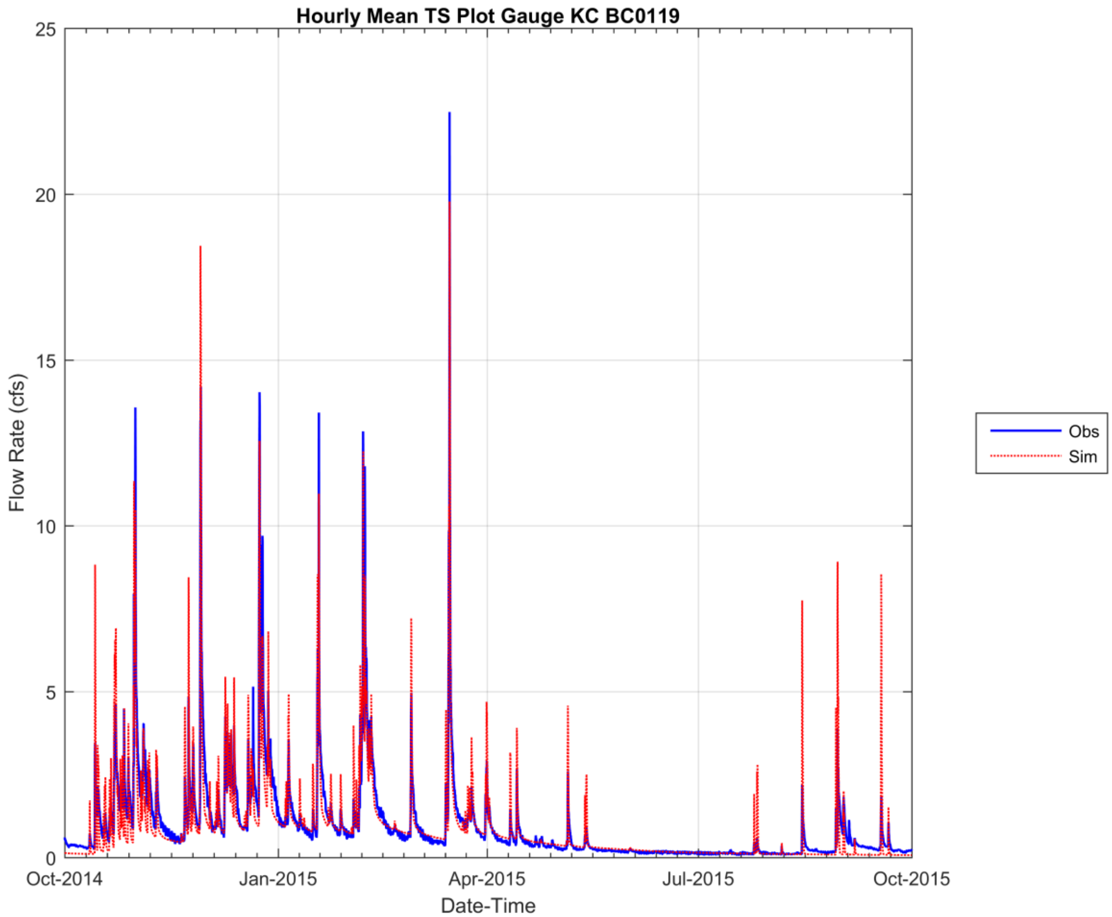

Figure 81 Gauge BCP0119 time series flow plot WY 2015

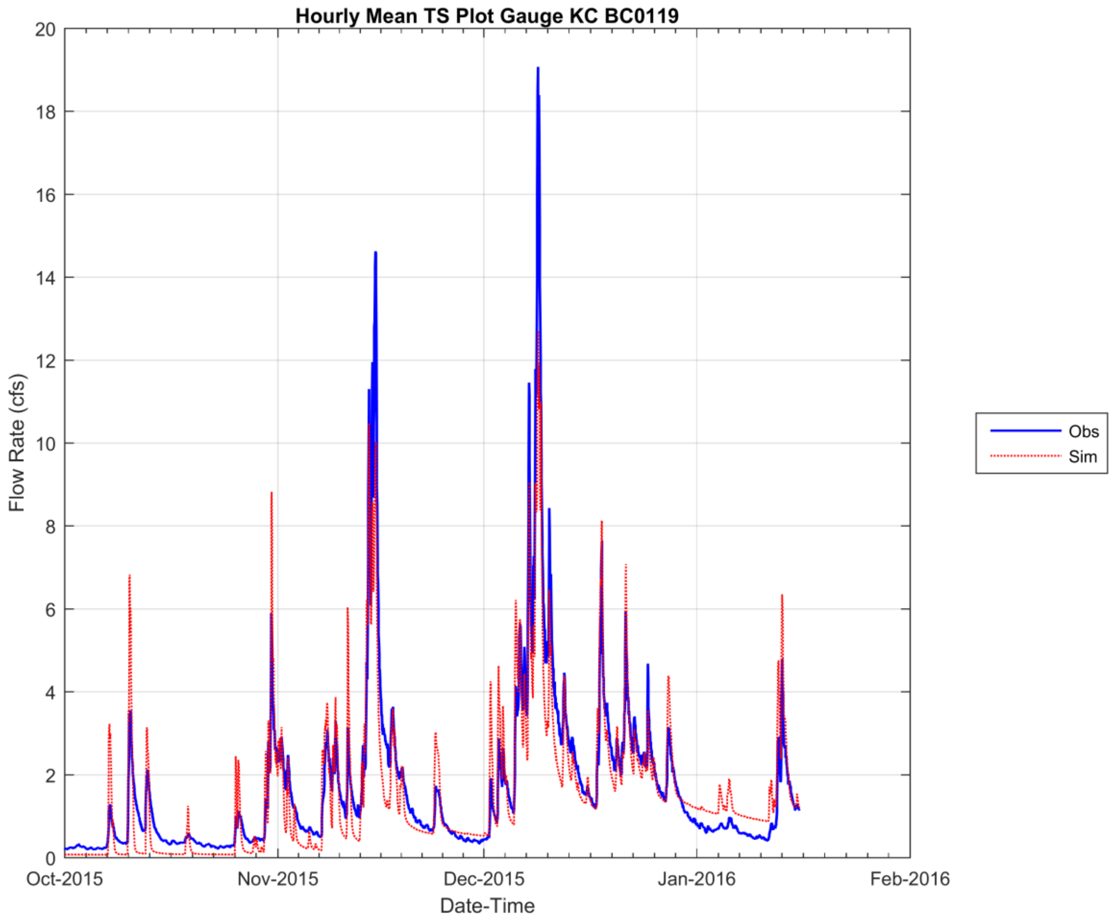

Figure 82 Gauge BCP0119 time series flow plot WY 2016

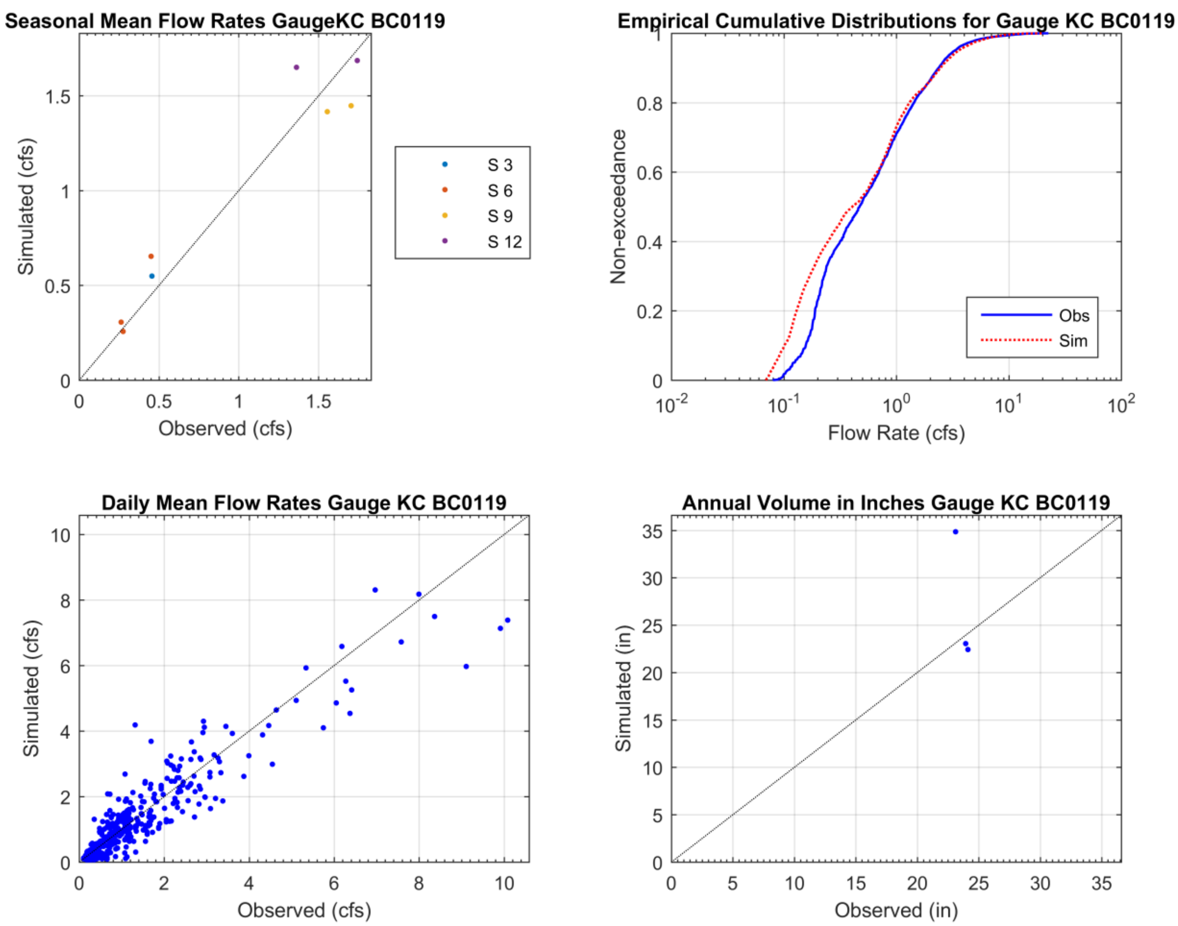

Figure 83 Gauge BCP0119 flow calibration plot 1

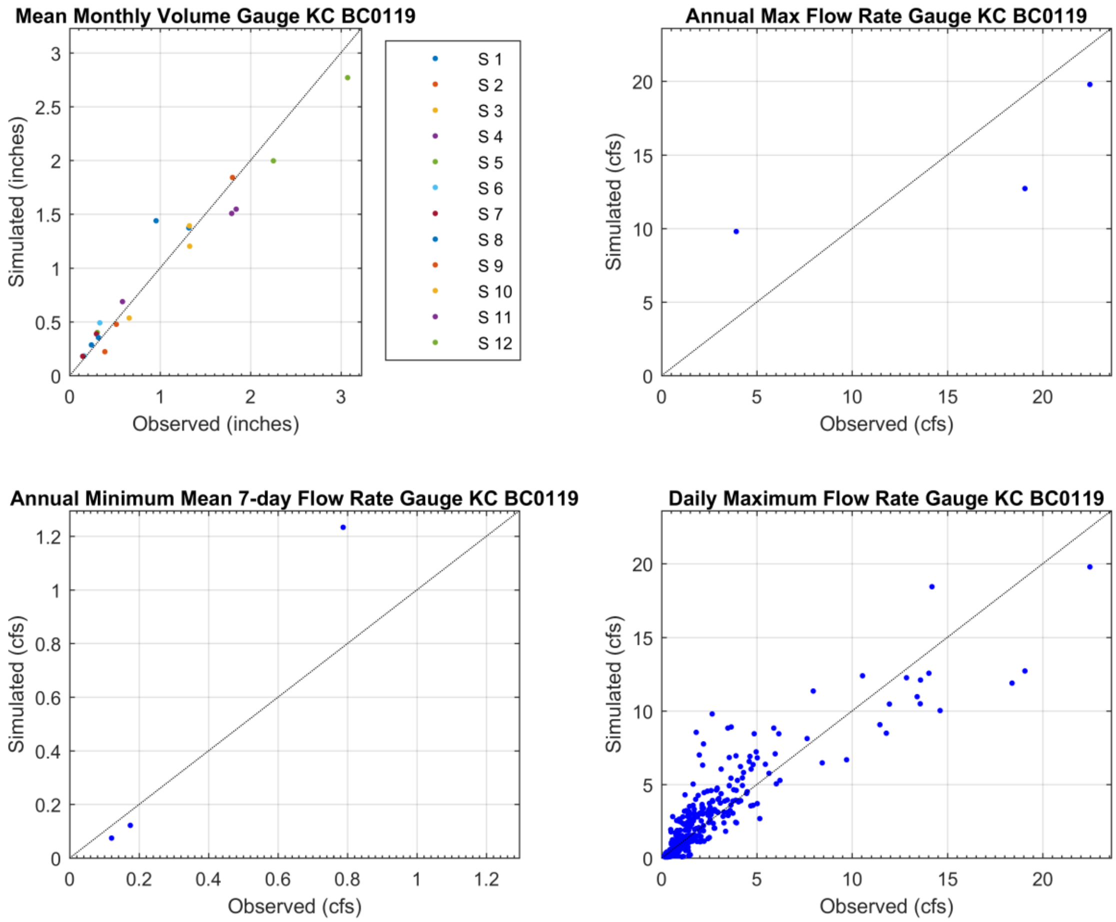

Figure 84 Gauge BCP0119 flow calibration plot 2

APPENDIX C: Temperature Calibration

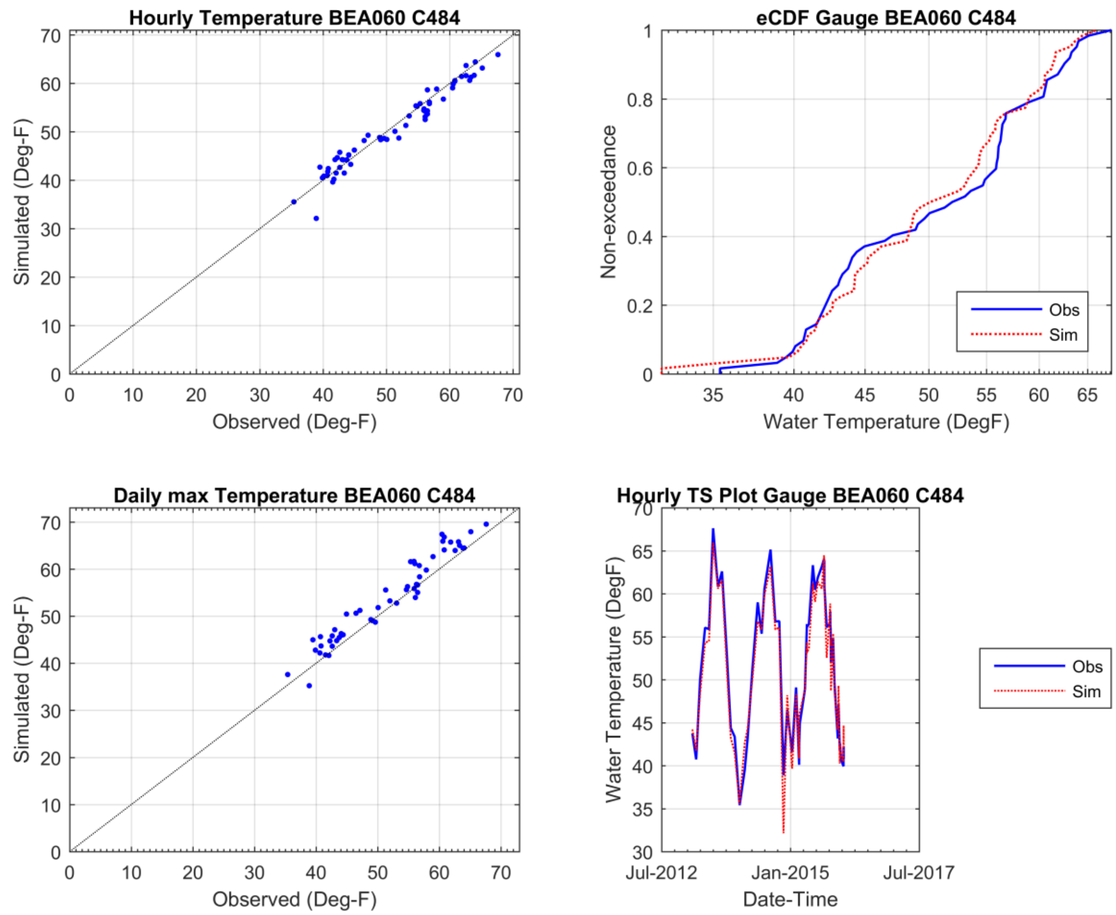

Figure 85 Gage C484 water temperature calibration.

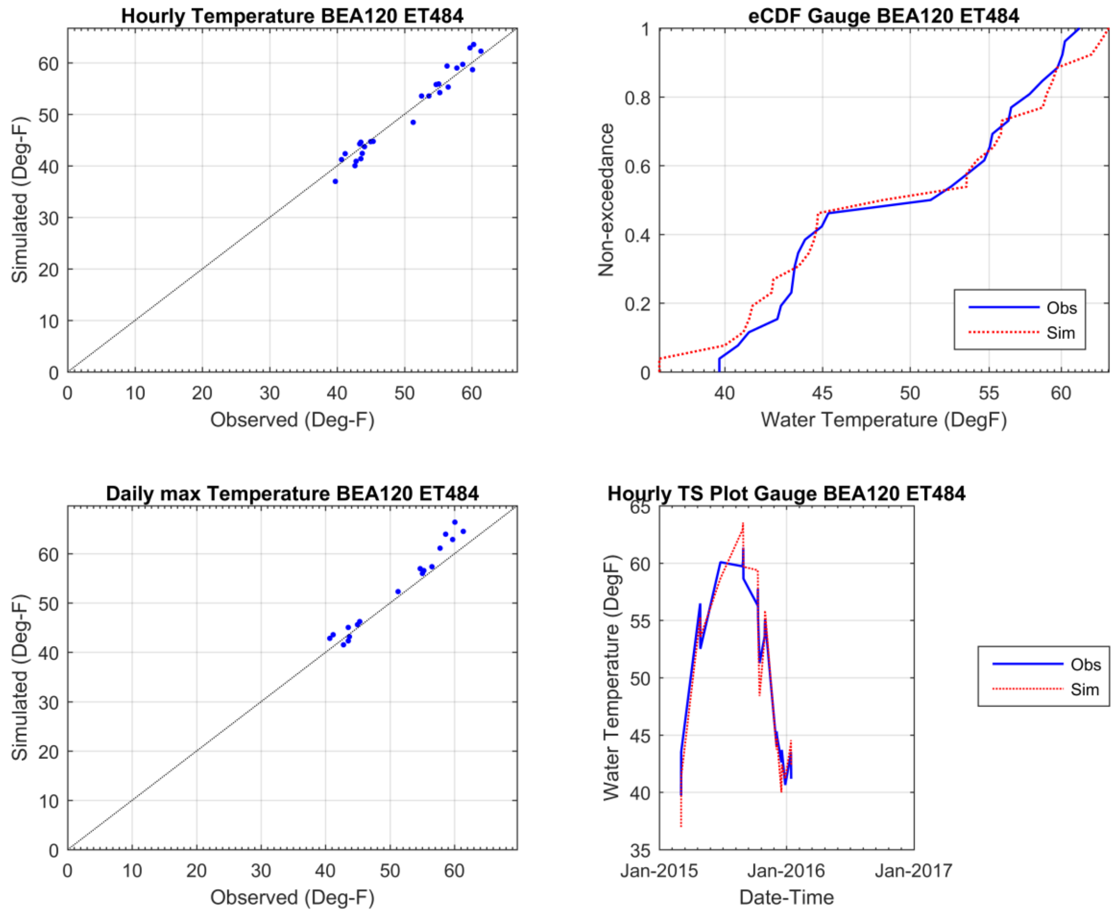

Figure 86 Gage ET484 water temperature calibration.

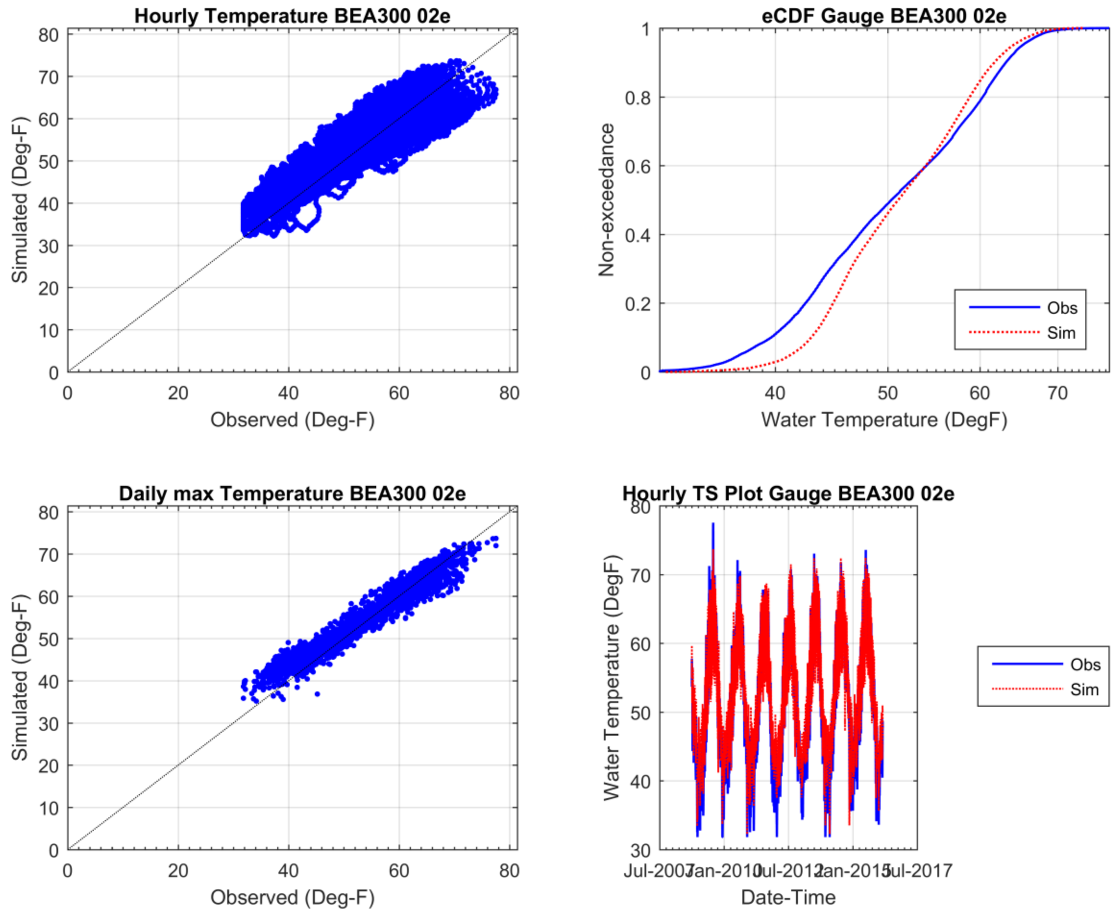

Figure 87 Gage 02e water temperature calibration.

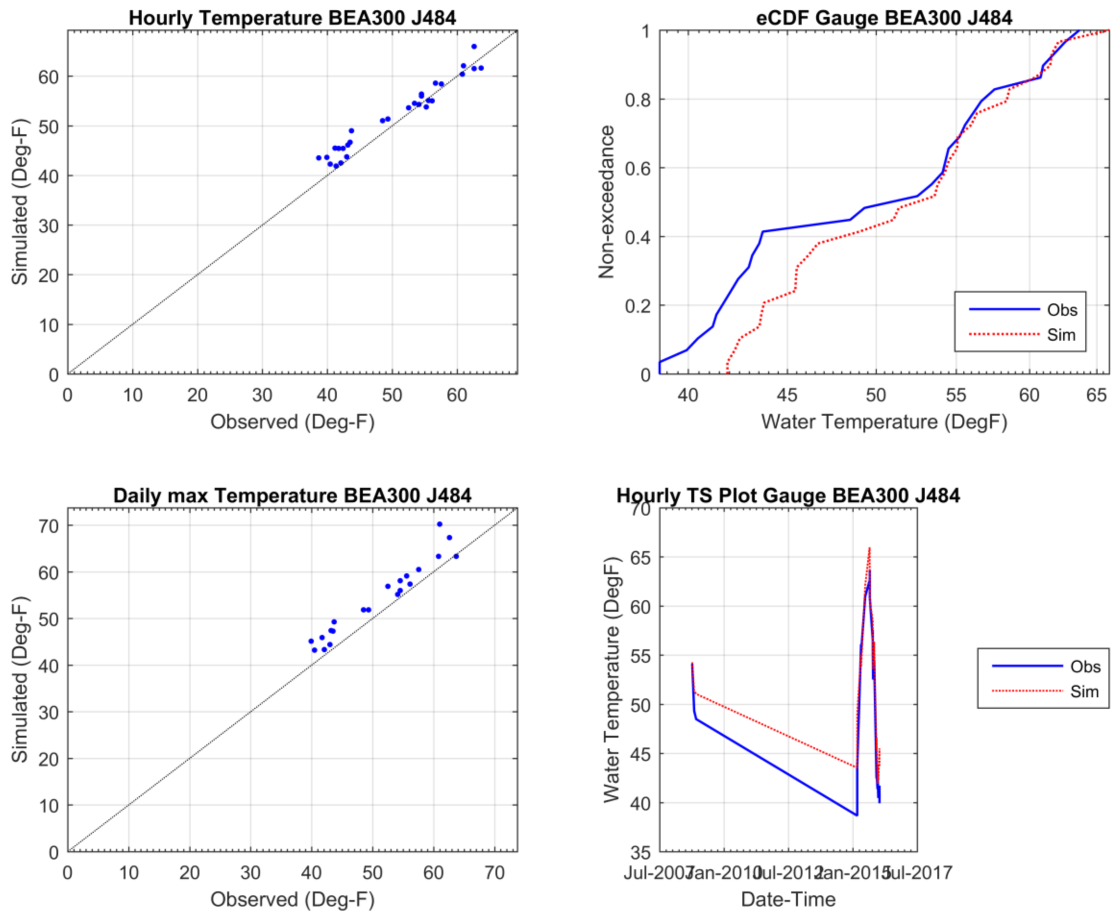

Figure 88 Gage J484 water temperature calibration.

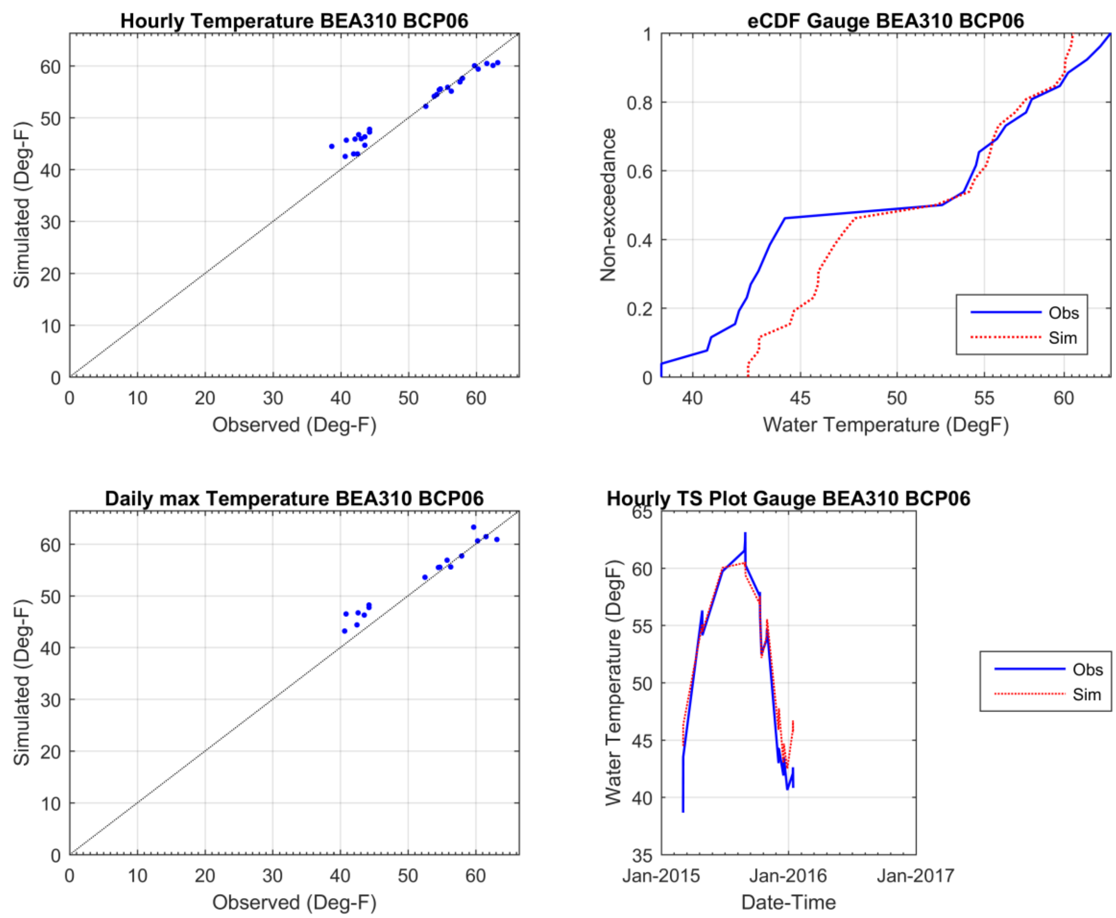

Figure 89 Gage BCP06 water temperature calibration.

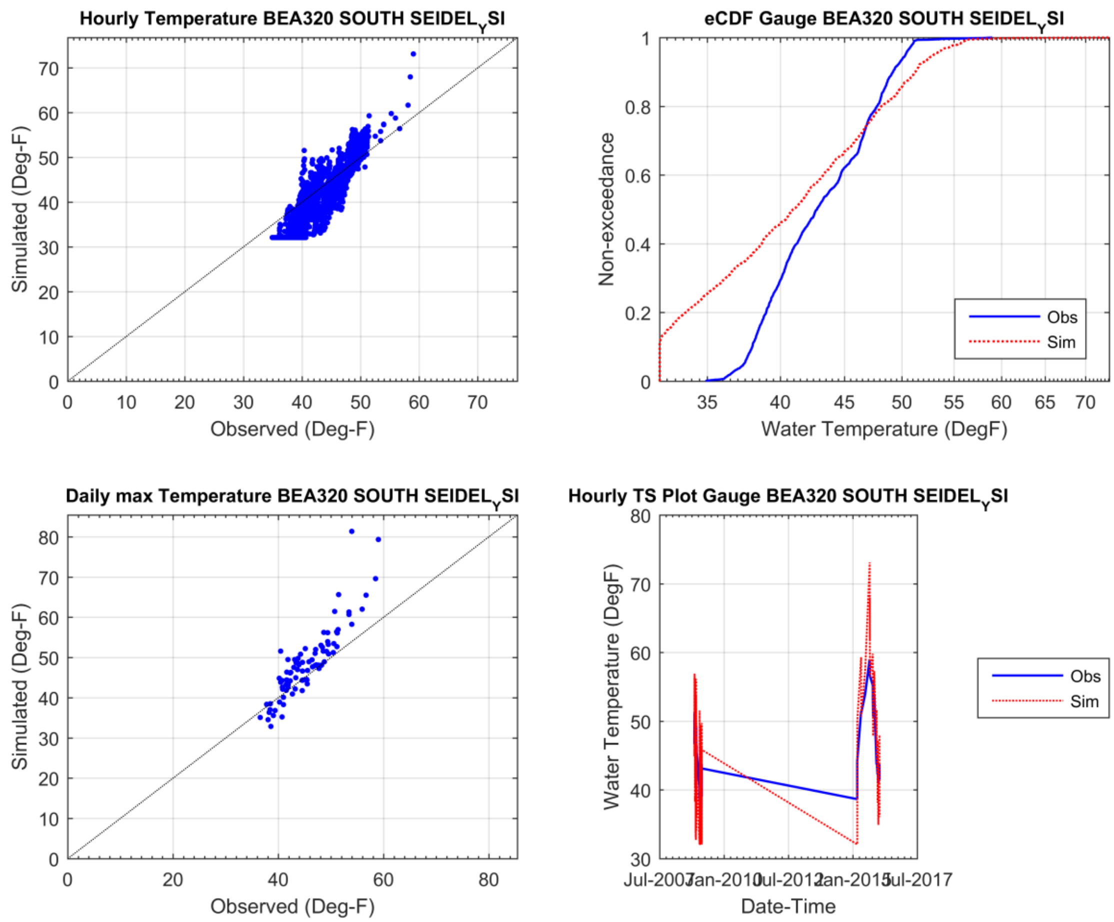

Figure 90 Gage South Seidel water temperature calibration.

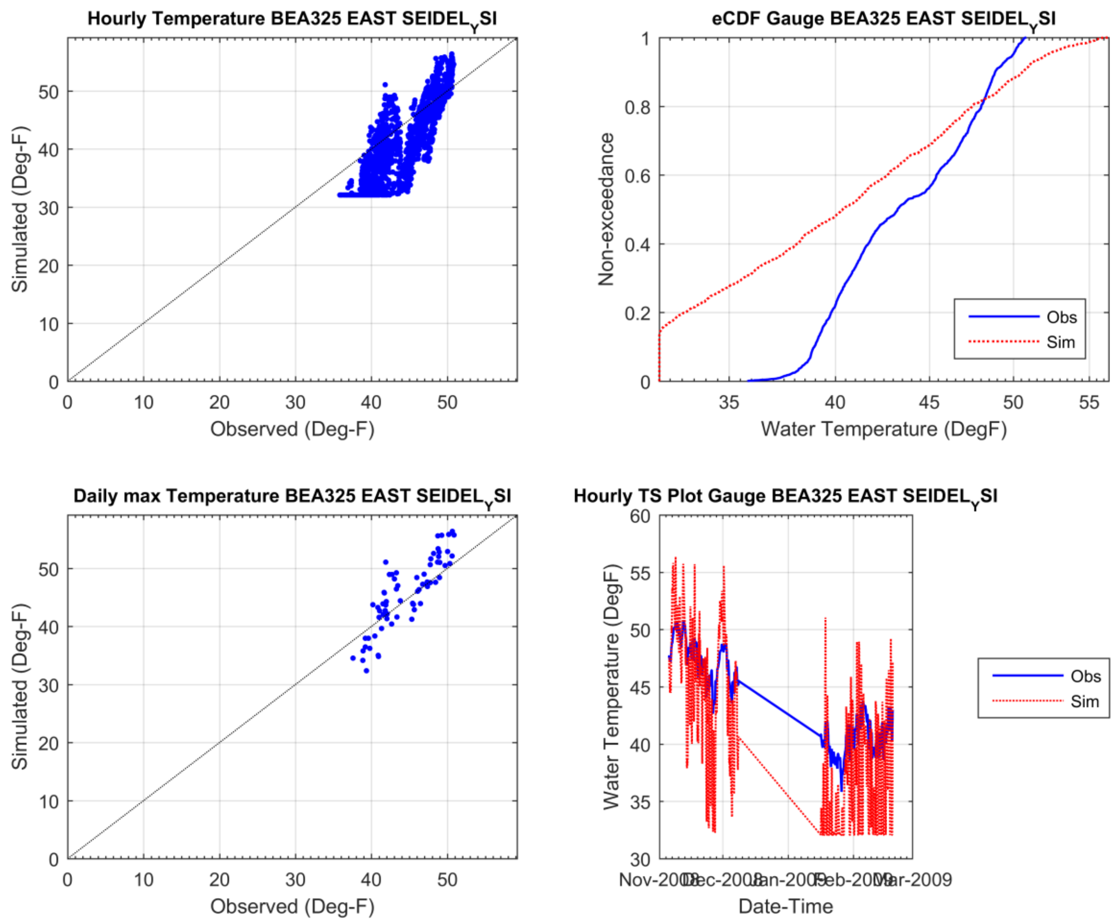

Figure 91 Gage East Seidel water temperature calibration.

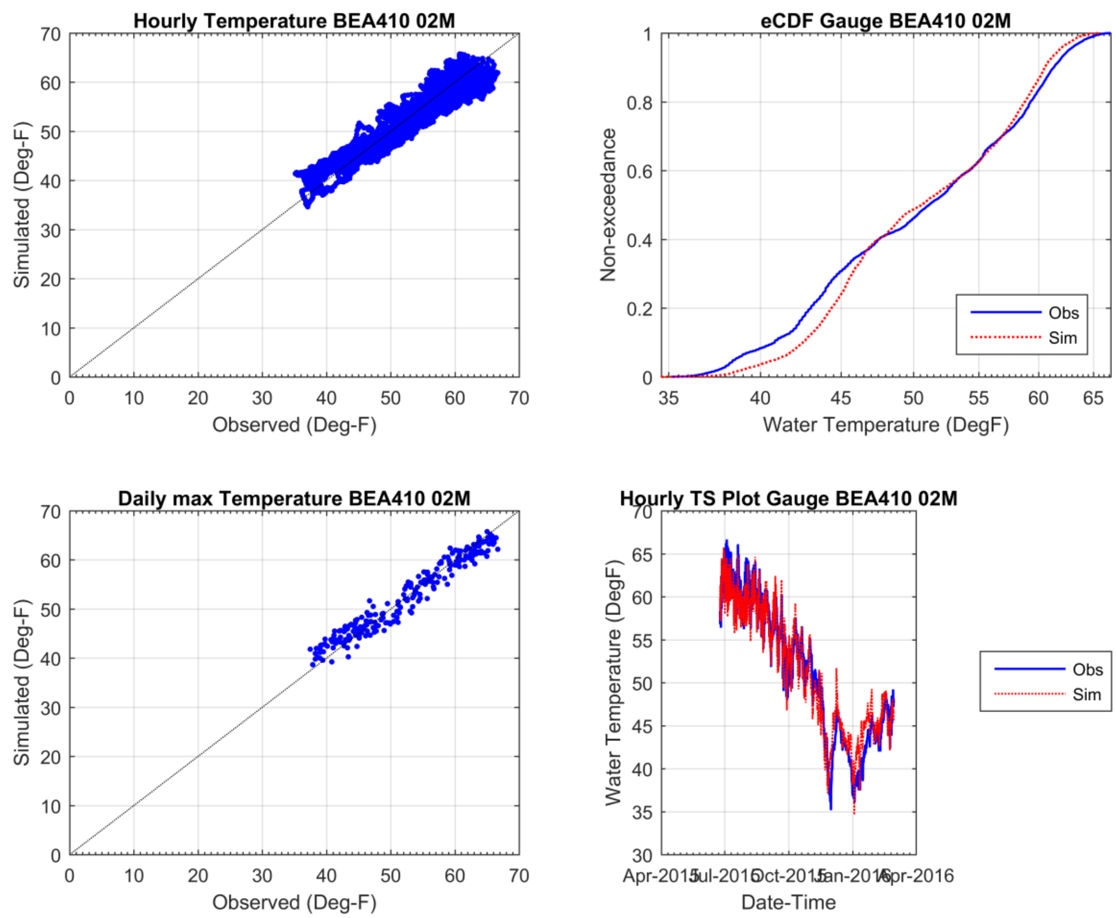

Figure 92 Gage 02M water temperature calibration.

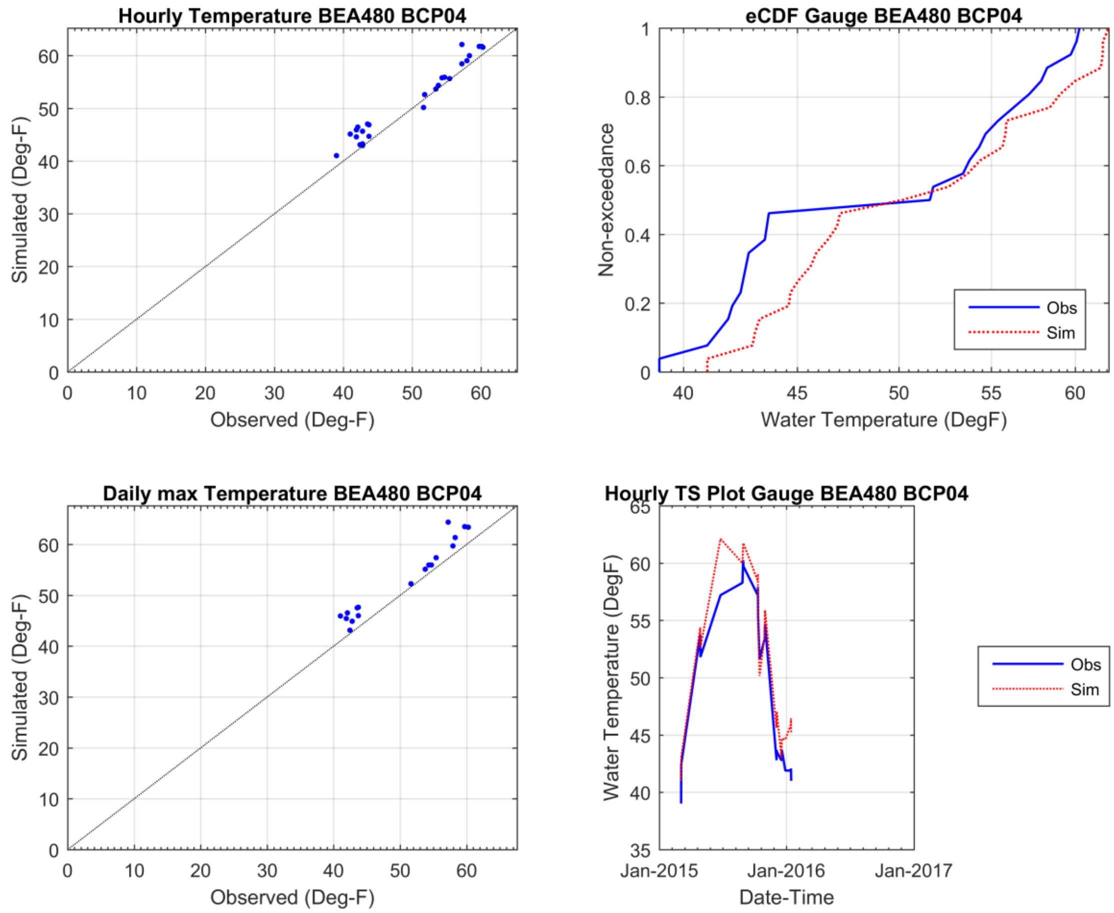

Figure 93 Gage BCP04 water temperature calibration.

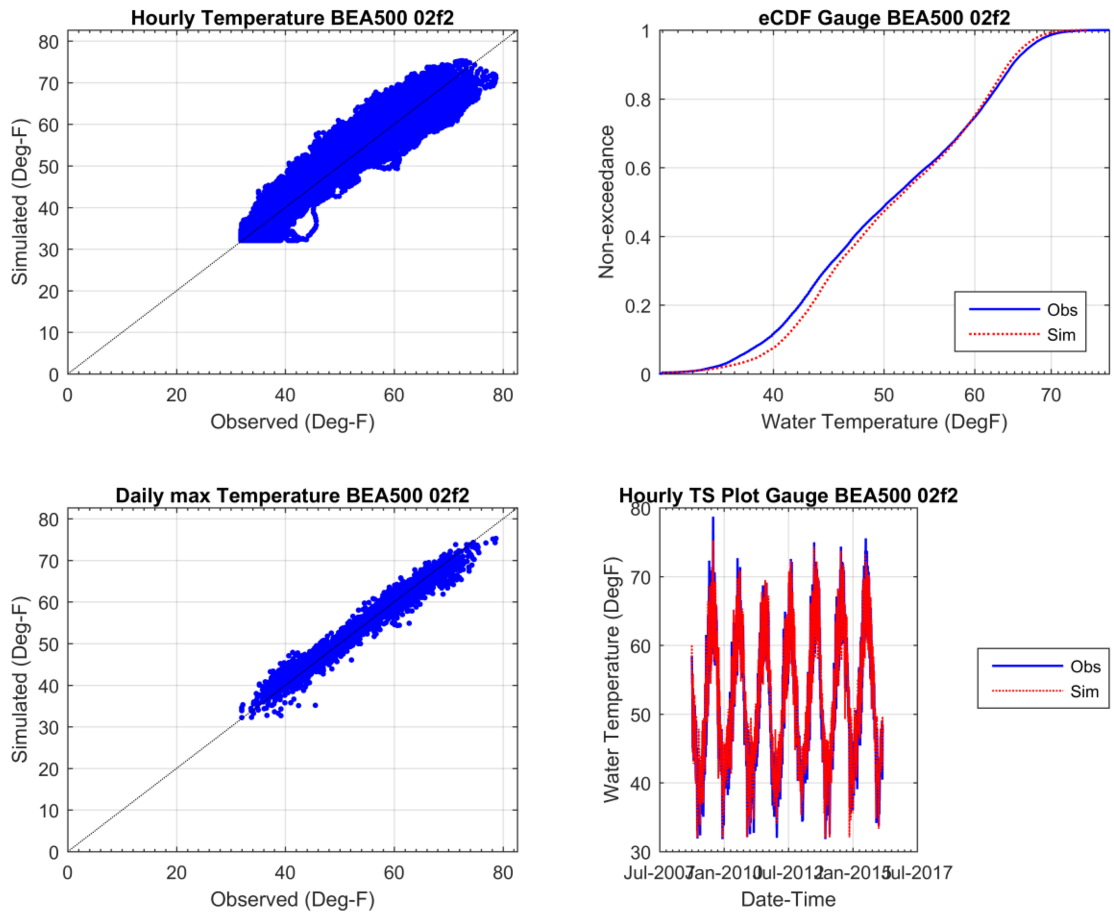

Figure 94 Gage 02f2 water temperature calibration.

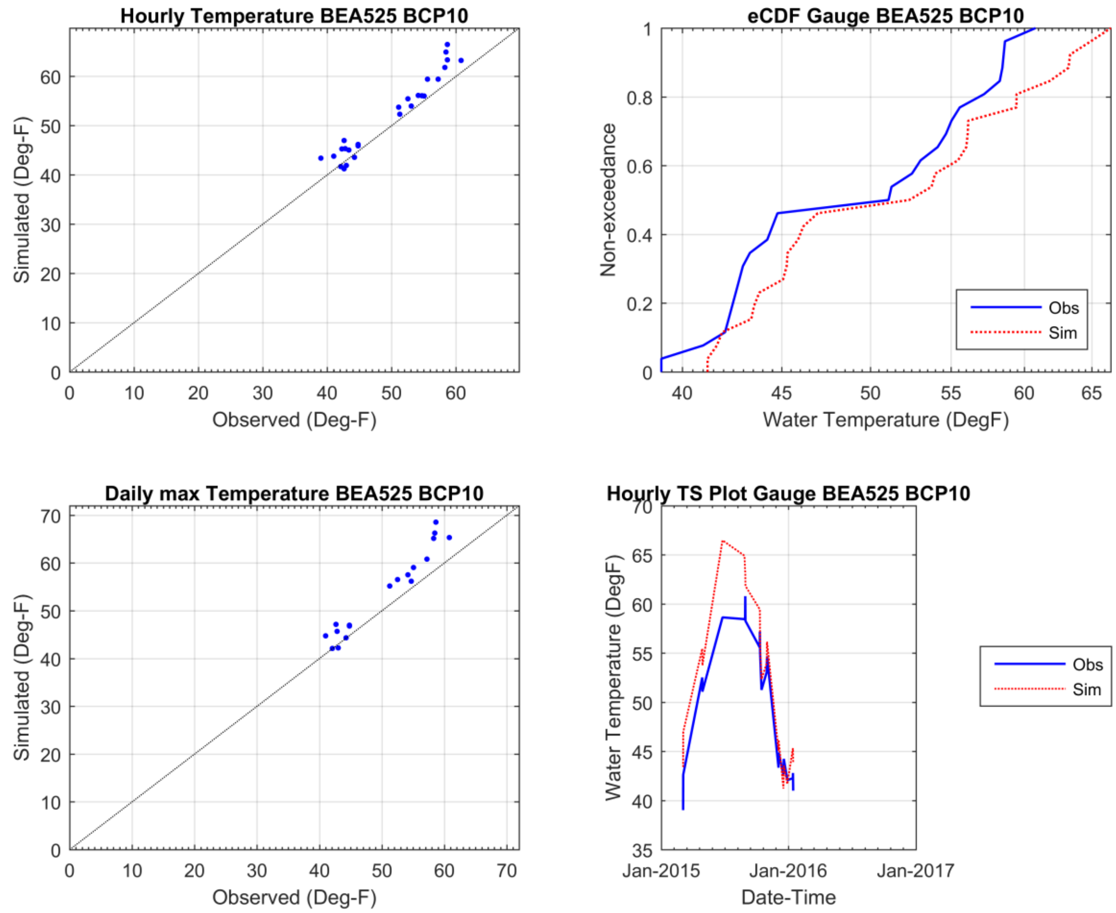

Figure 95 Gage BCP10 water temperature calibration.

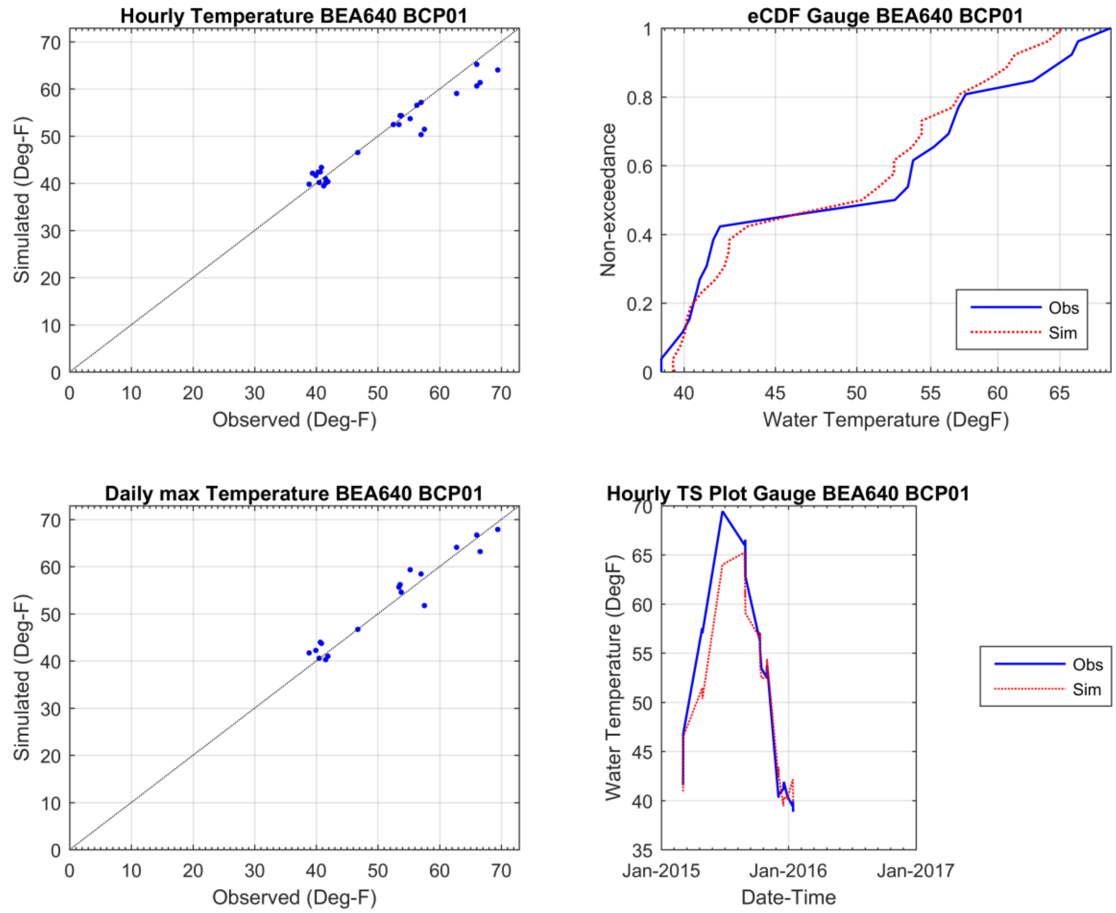

Figure 96 Gage BCP01 water temperature calibration.

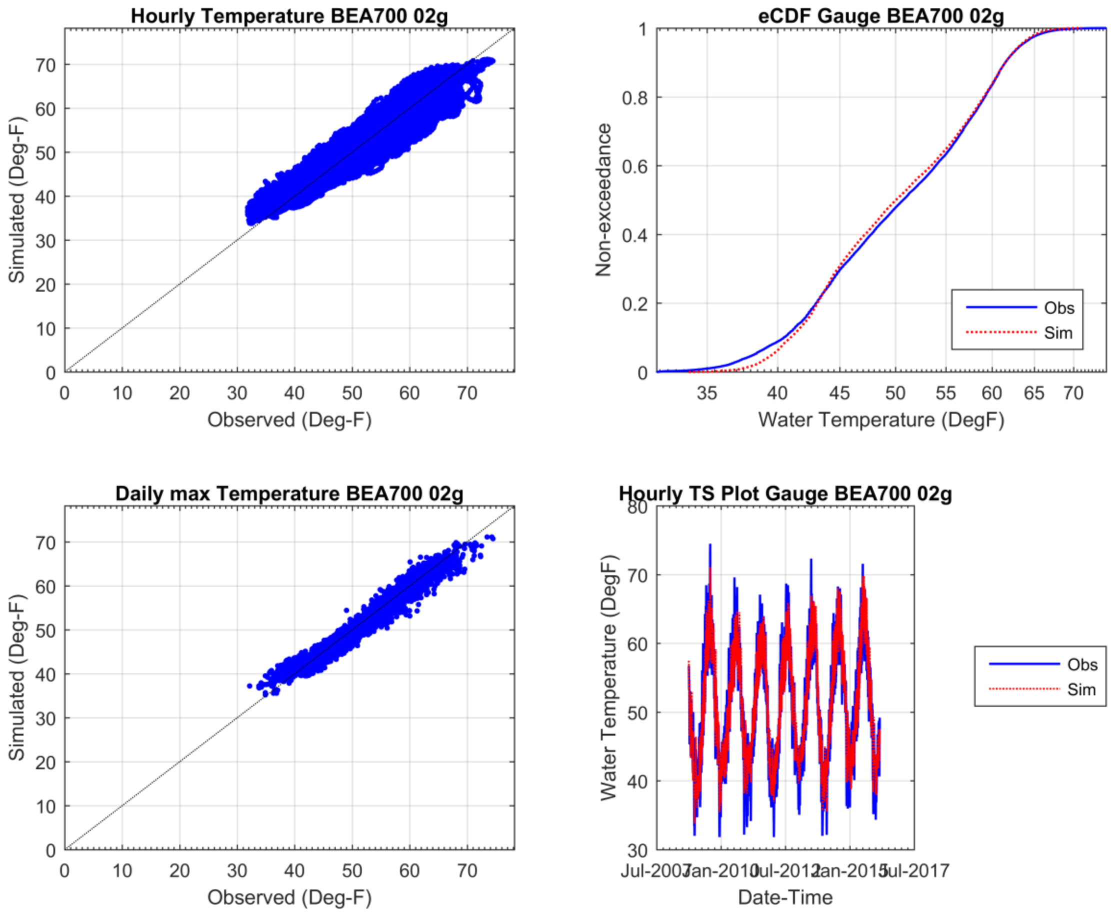

Figure 97 Gage 02g water temperature calibration.

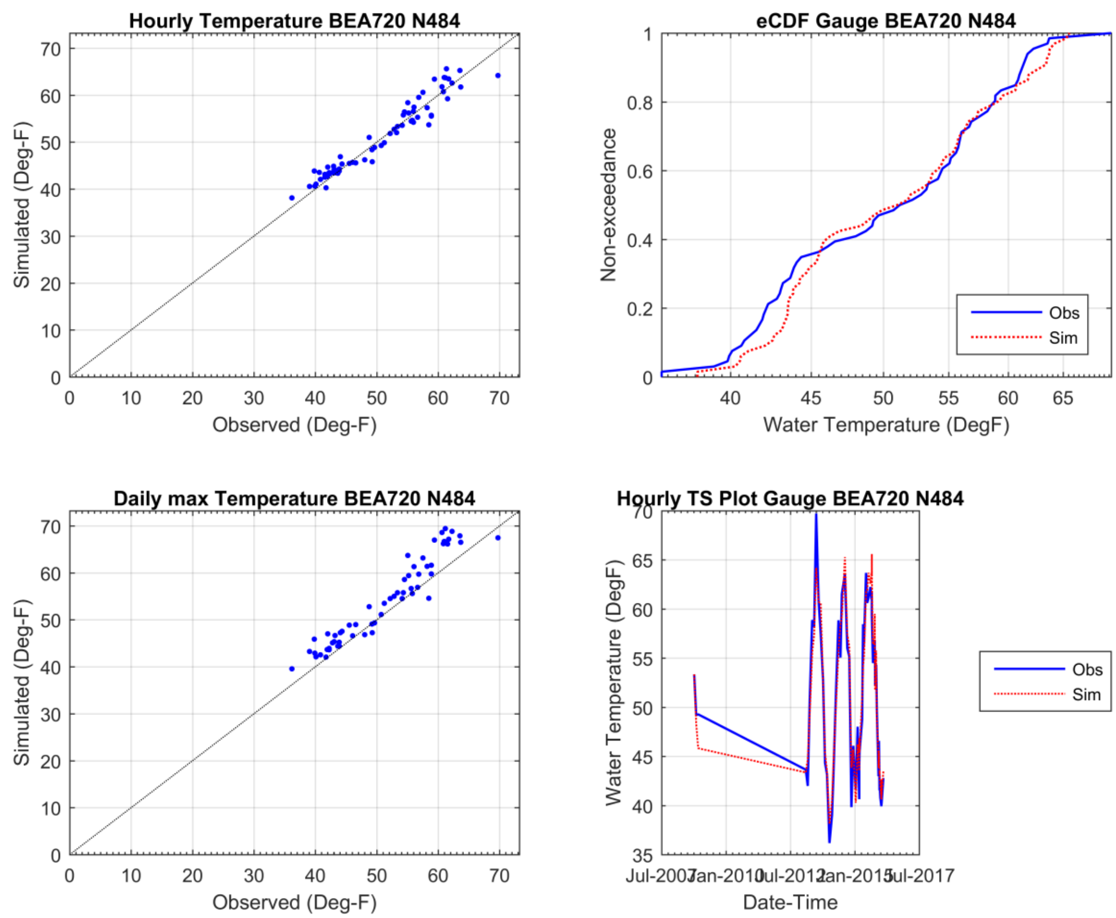

Figure 98 Gage N484 water temperature calibration.

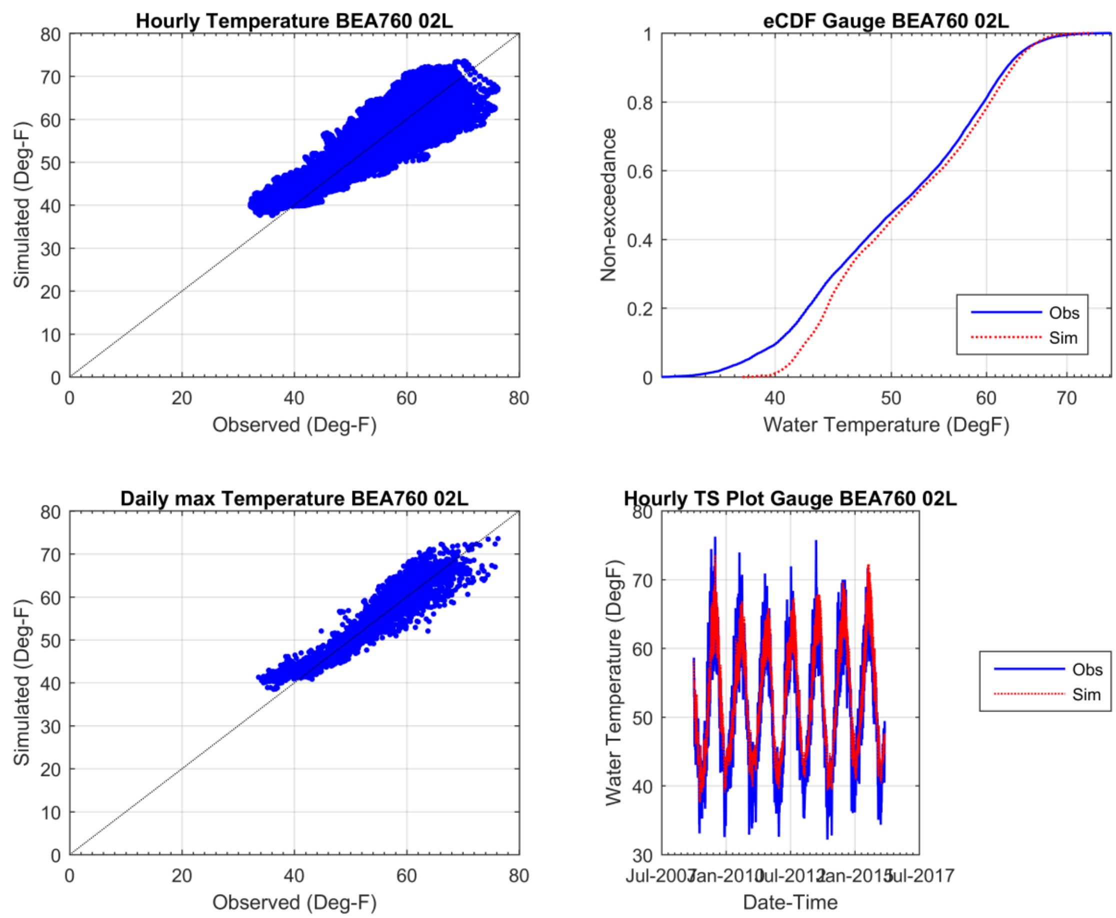

Figure 99 Gage 02L water temperature calibration.

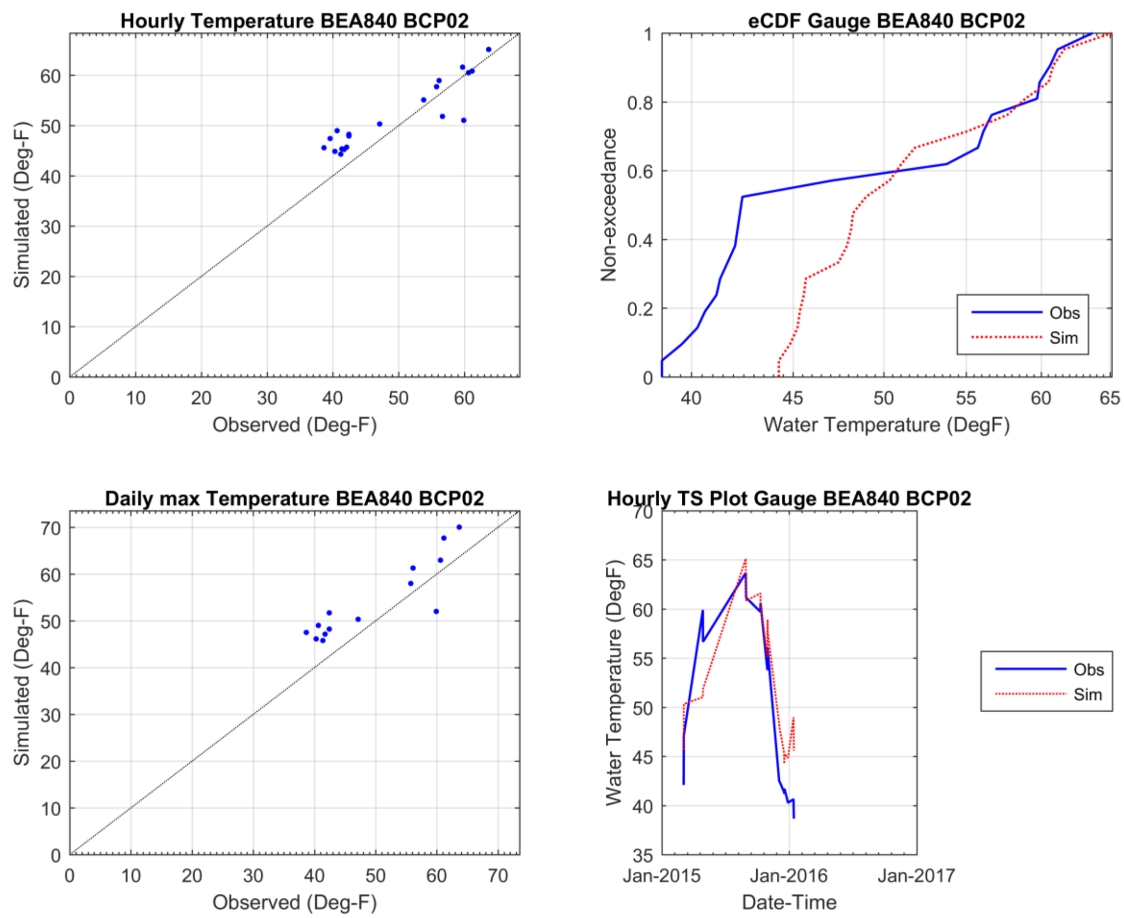

Figure 100 Gage BCP02 water temperature calibration.

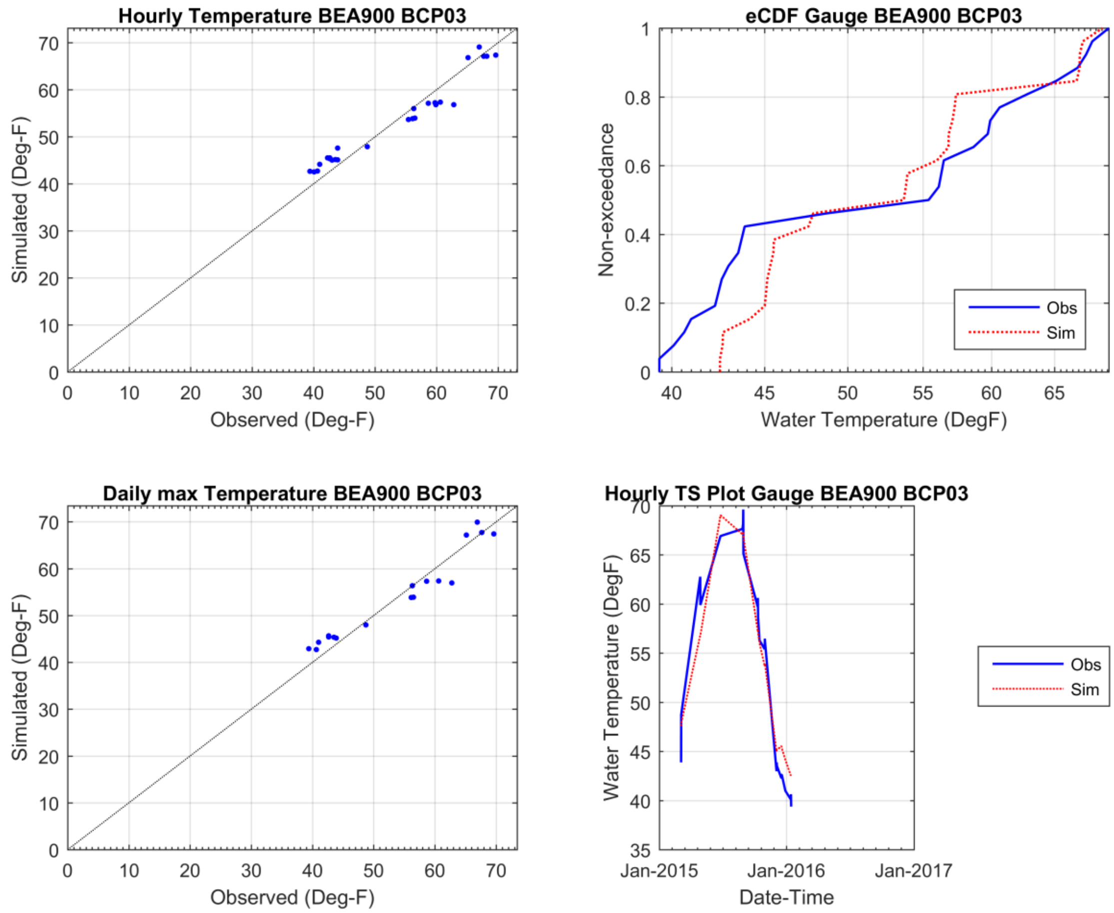

Figure 101 Gage BCP03 water temperature calibration.

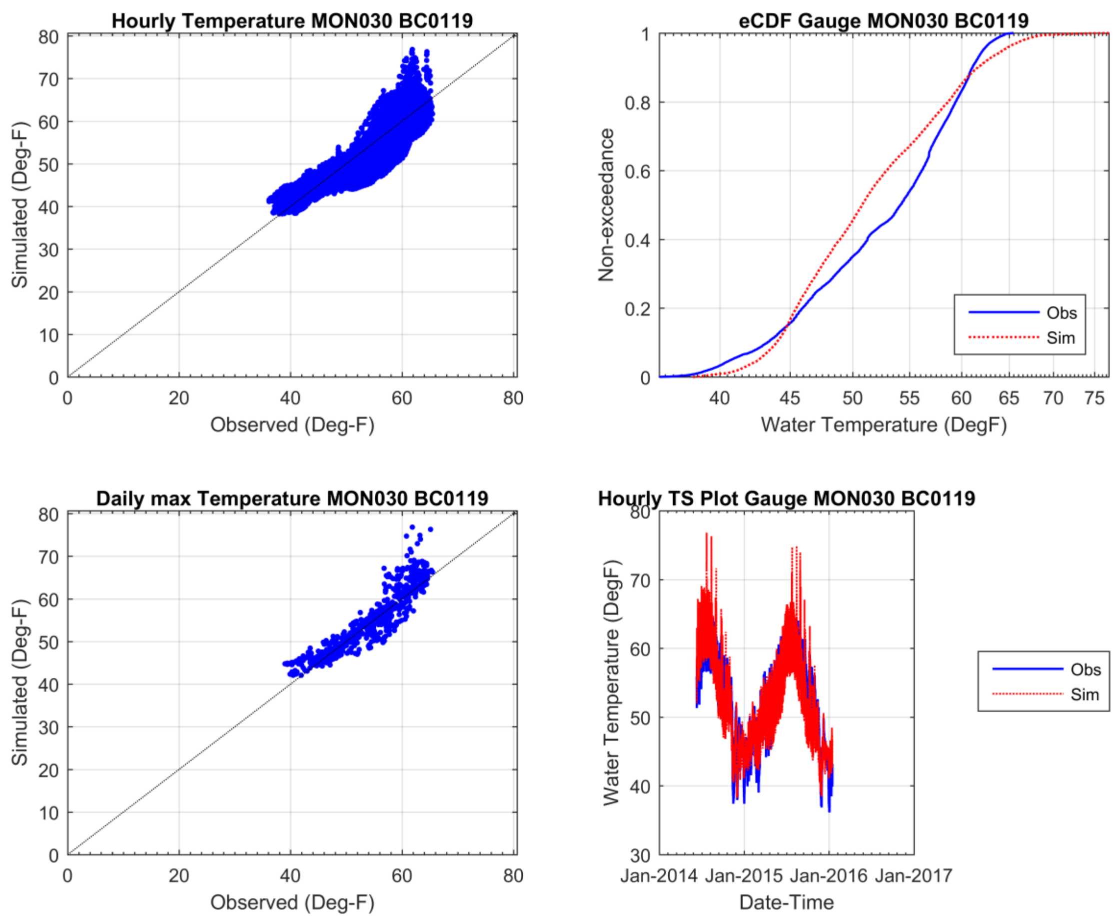

Figure 102 Gage BC0119 water temperature calibration.

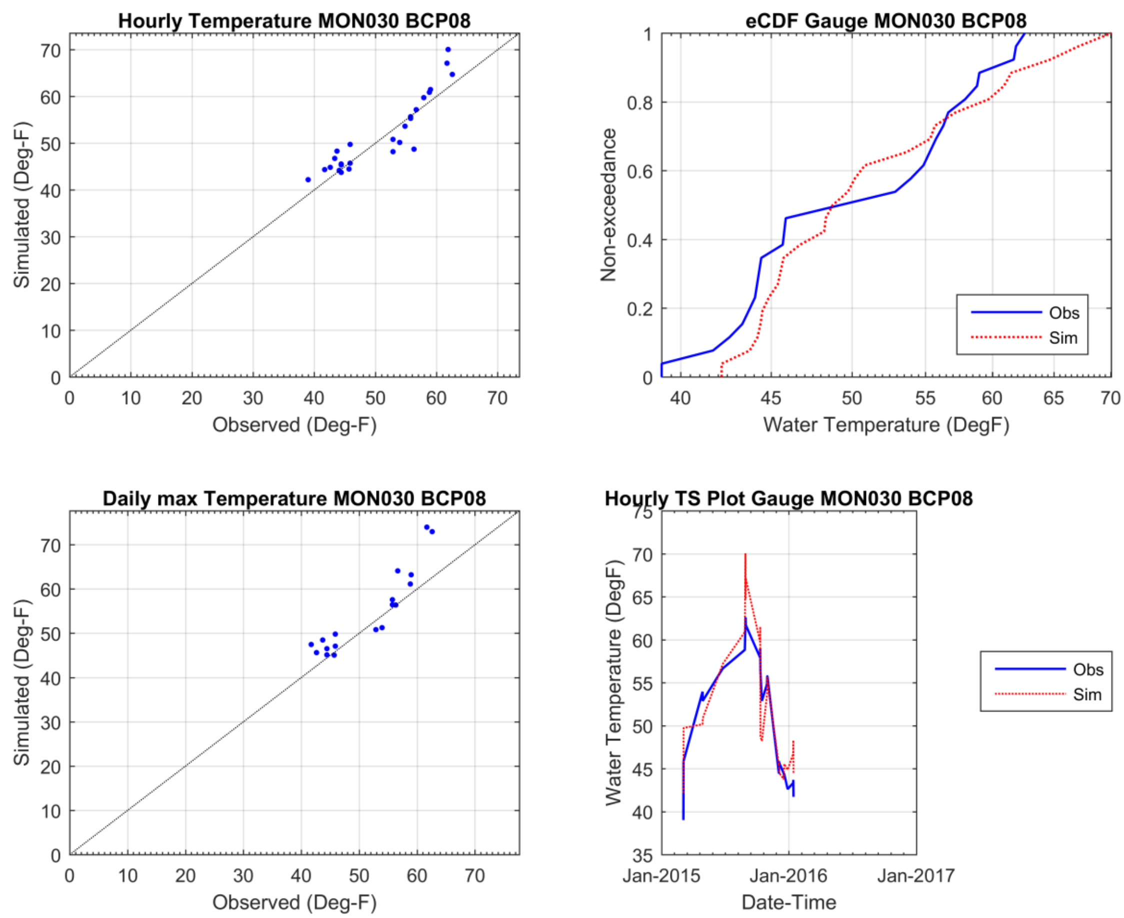

Figure 103 Gage BCP08 water temperature calibration.

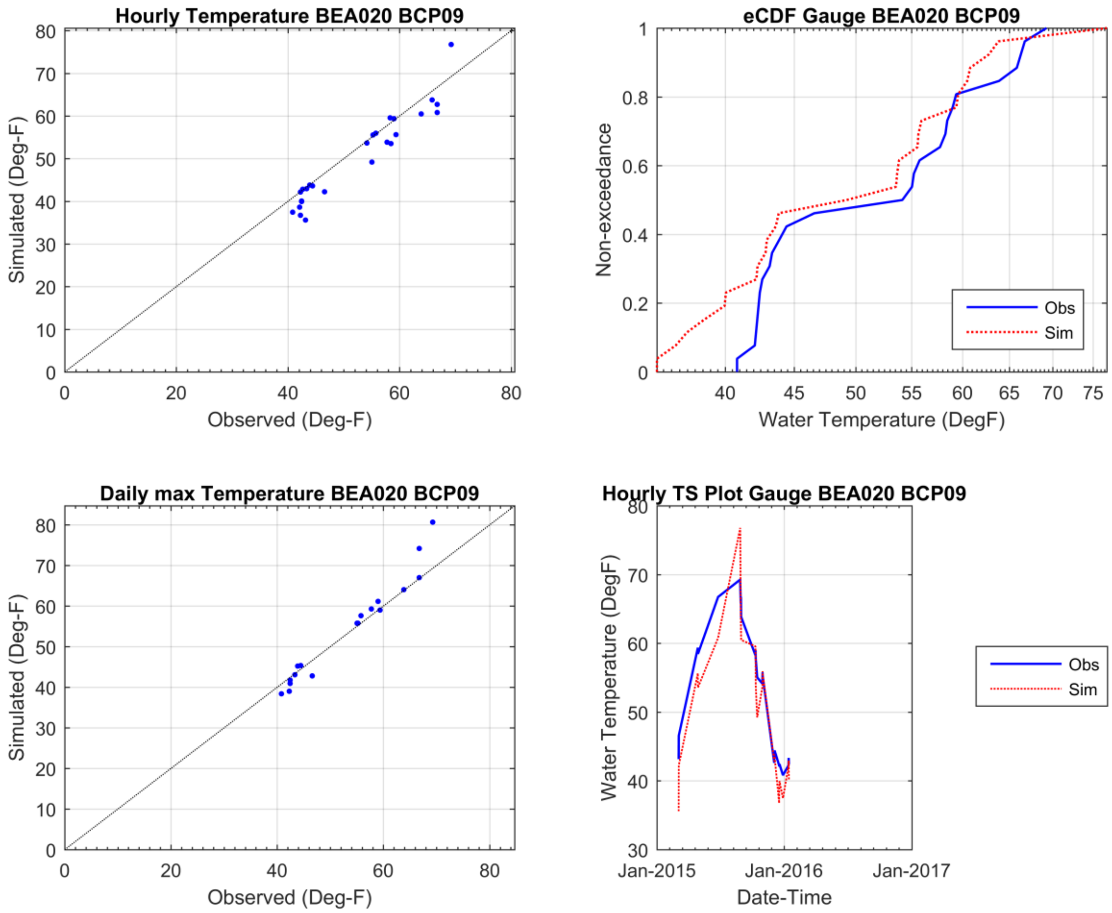

Figure 104 Gage BCP09 water temperature calibration.

This page intentionally left blank.

APPENDIX D: Fecal Coliform Calibration

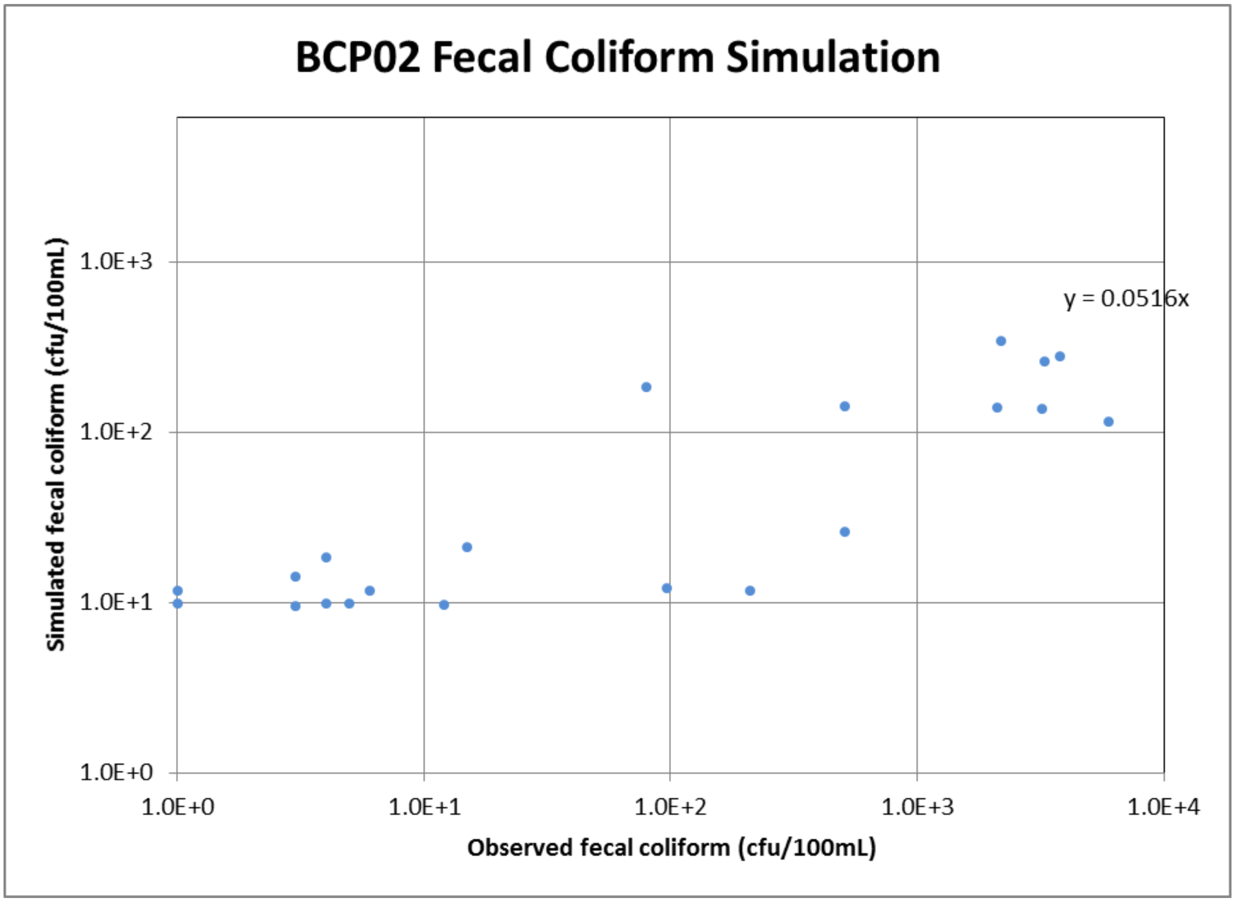

Figure 105 Water quality station BCP02 fecal coliform calibration regression

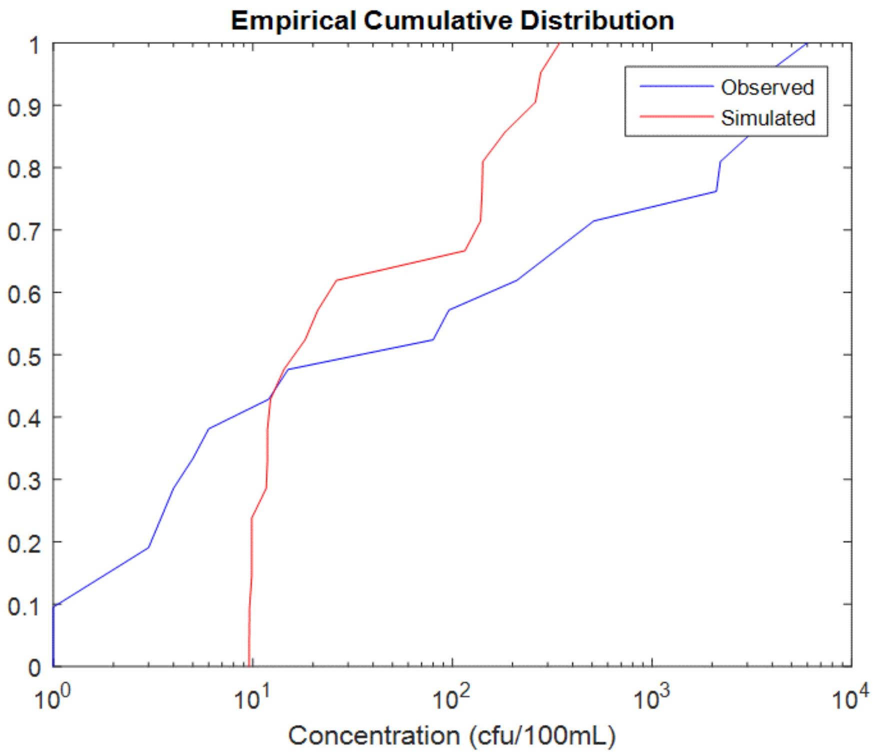

Figure 106 Water quality station BCP02 fecal coliform calibration cumulative distribution function

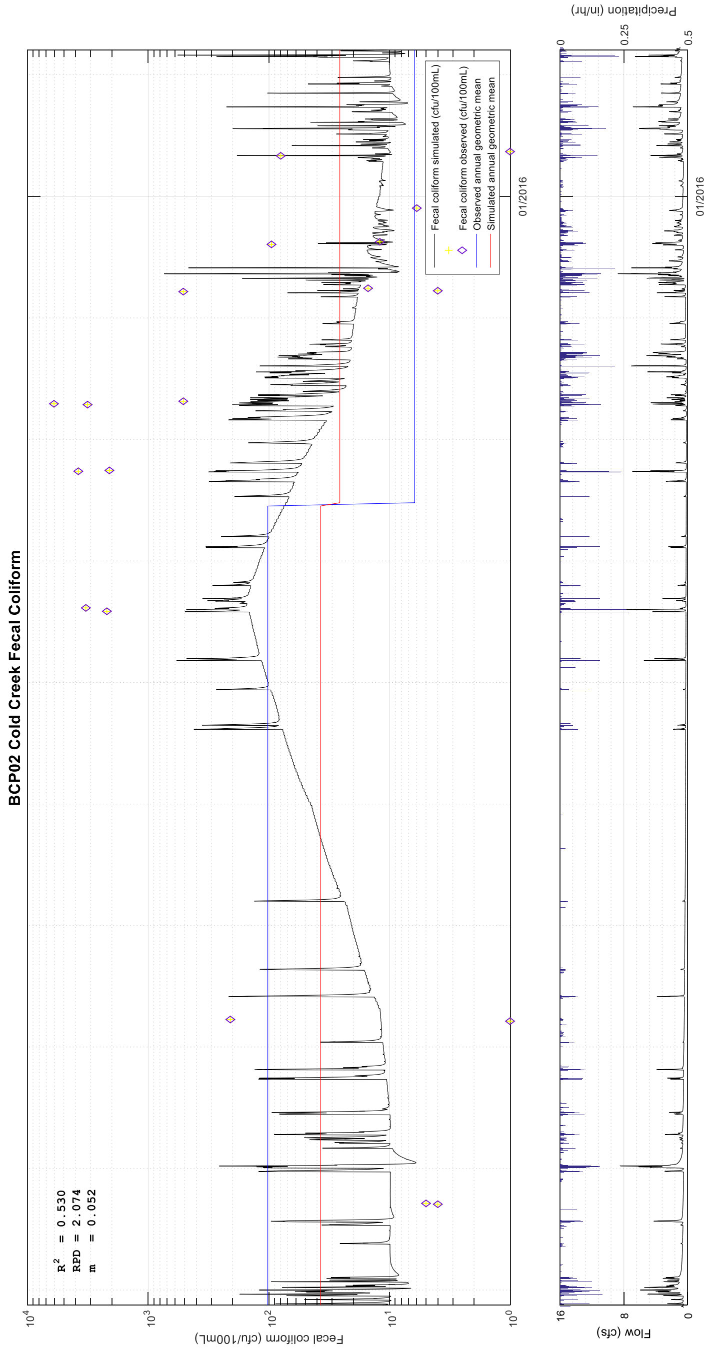

Figure 107 Water quality station BCP02 fecal coliform time series plot

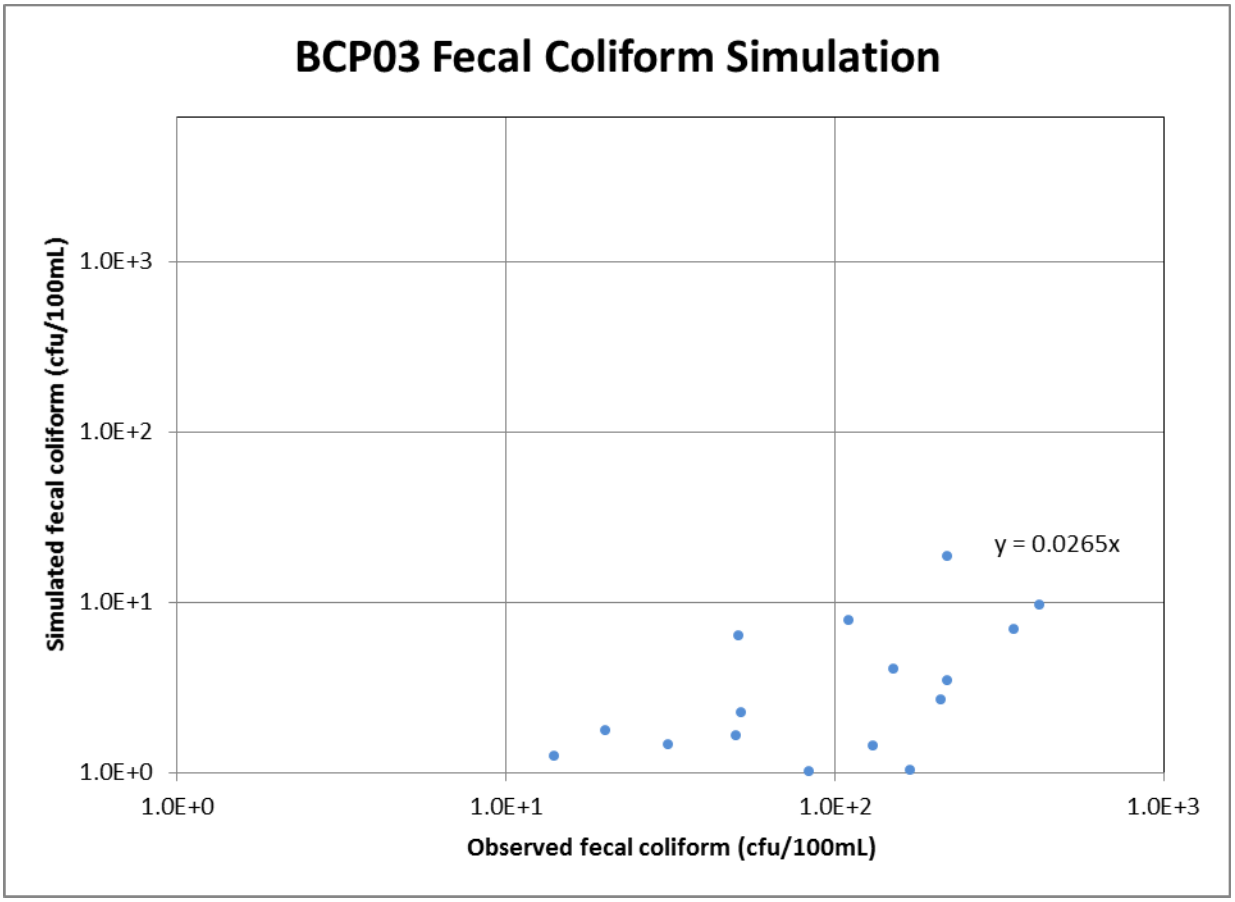

Figure 108 Water quality station BCP03 fecal coliform calibration regression

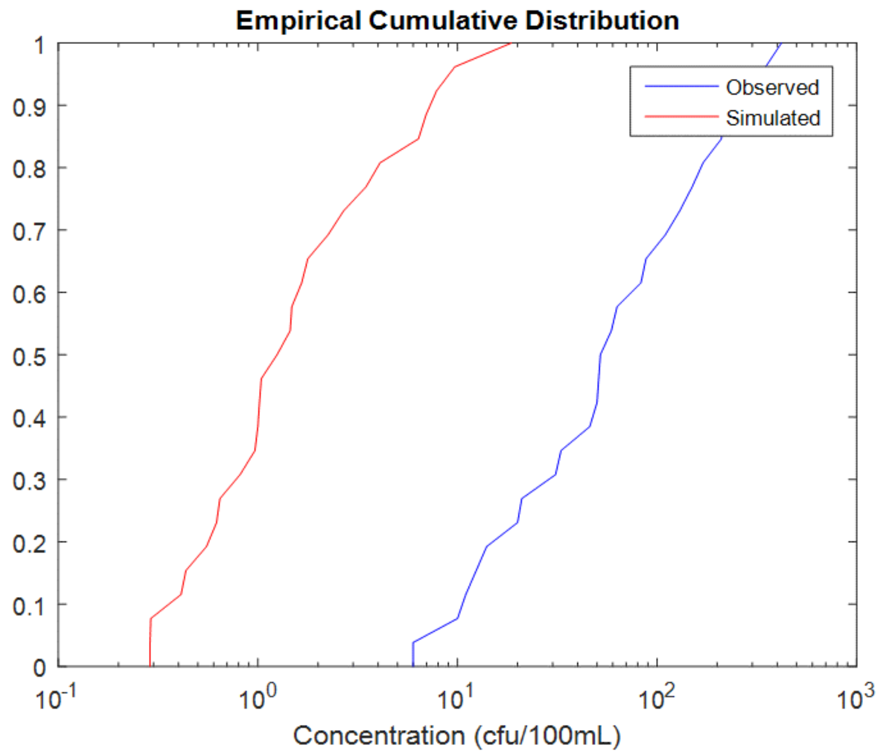

Figure 109 Water quality station BCP03 fecal coliform calibration cumulative distribution function

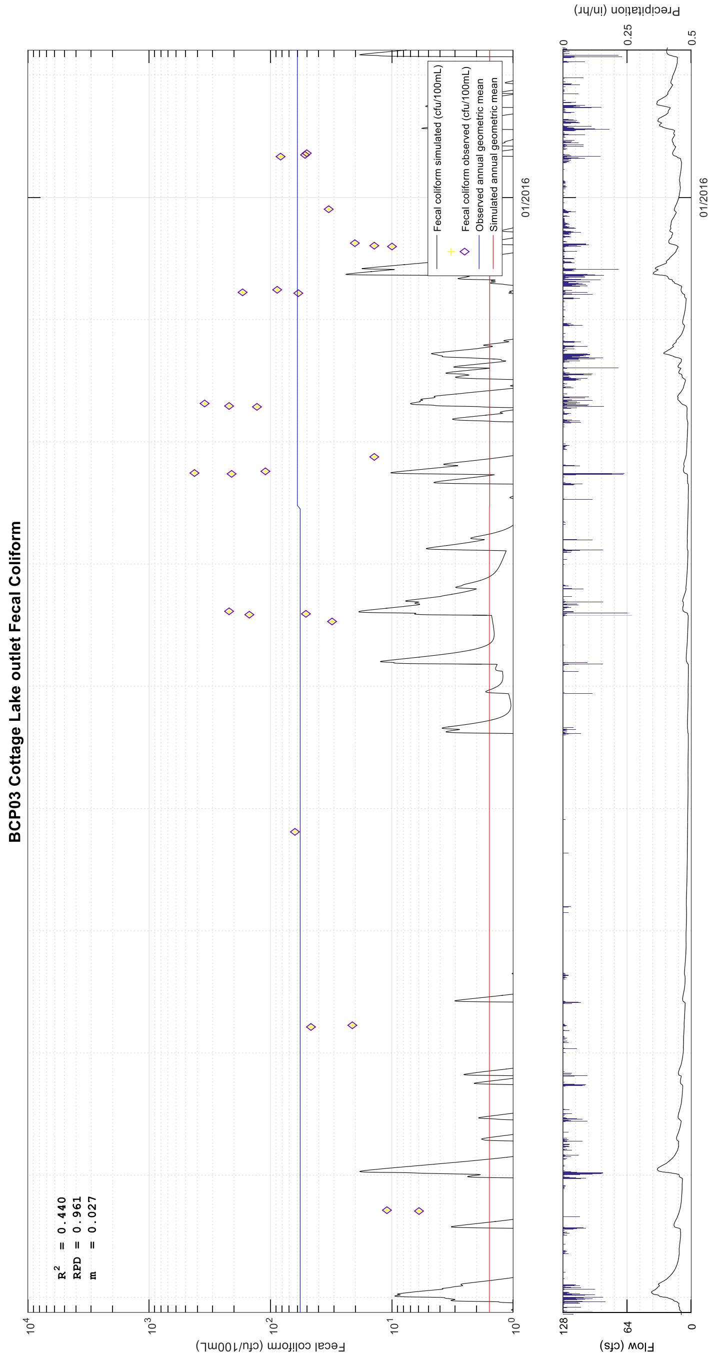

Figure 110 Water quality station BCP03 fecal coliform time series plot

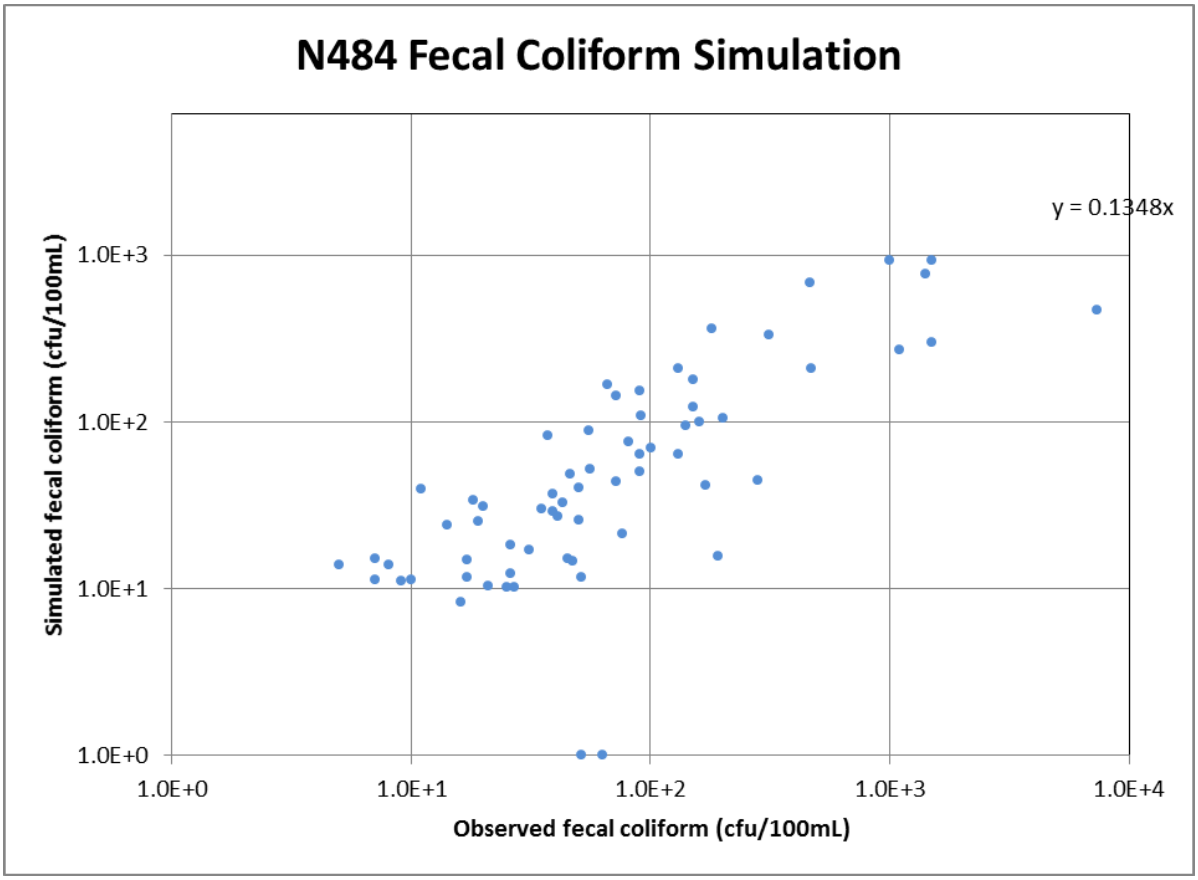

Figure 111 Water quality station N484 fecal coliform calibration regression

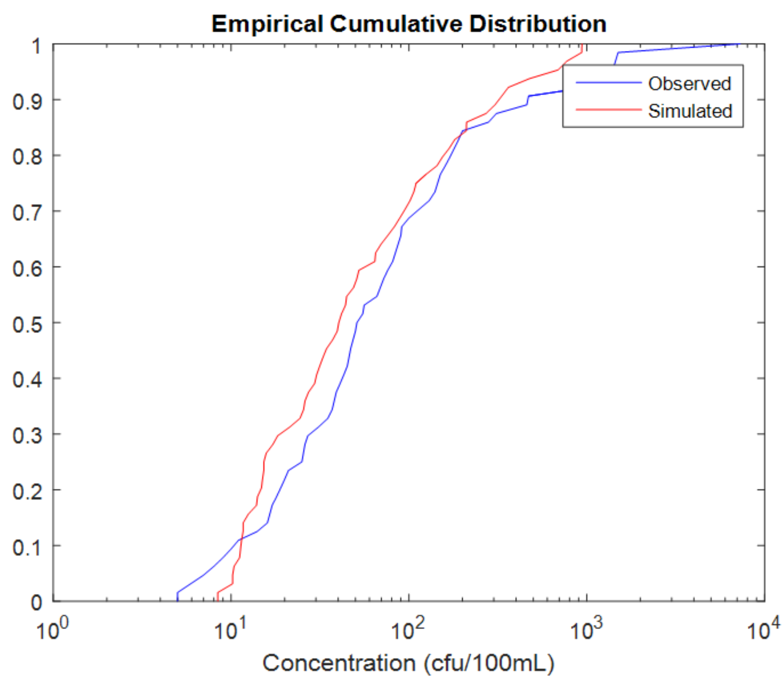

Figure 112 Water quality station N484 fecal coliform calibration cumulative distribution function

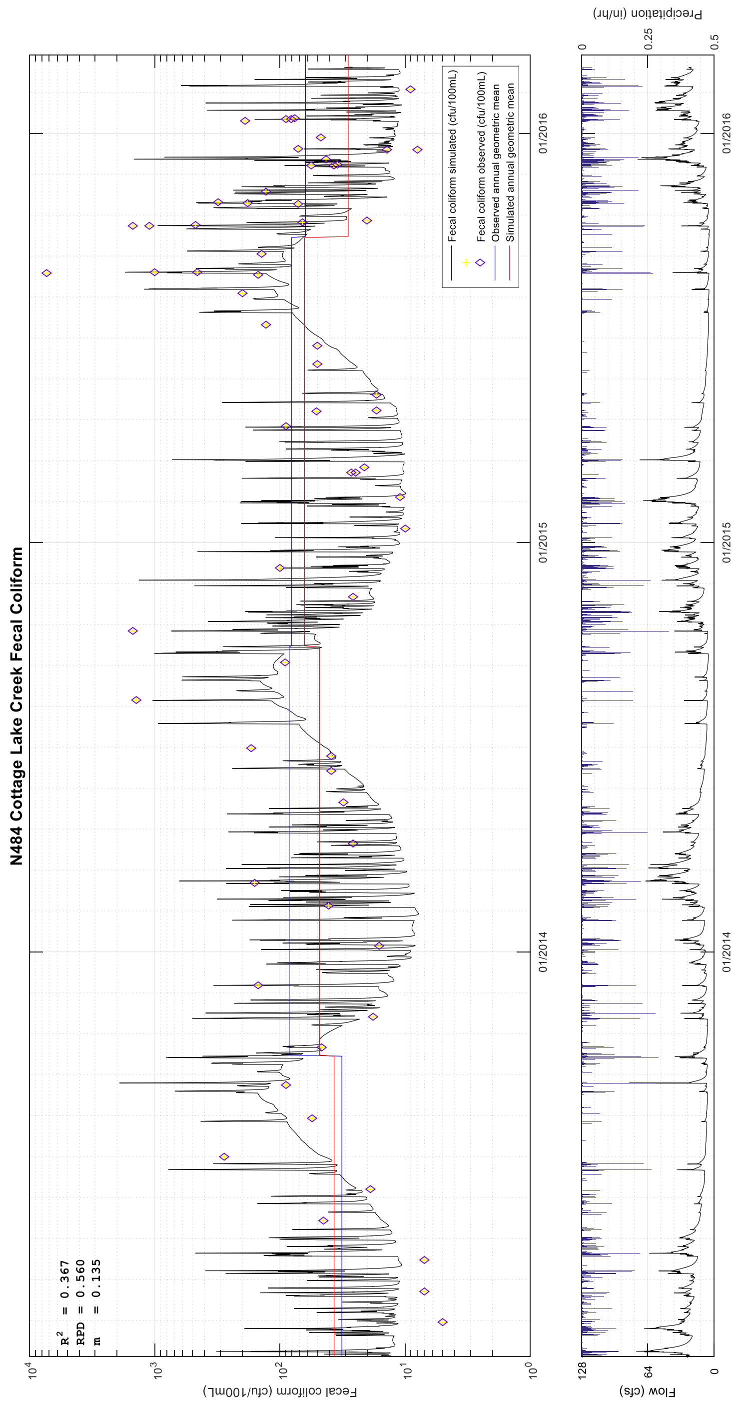

Figure 113 Water quality station N484 fecal coliform time series plot

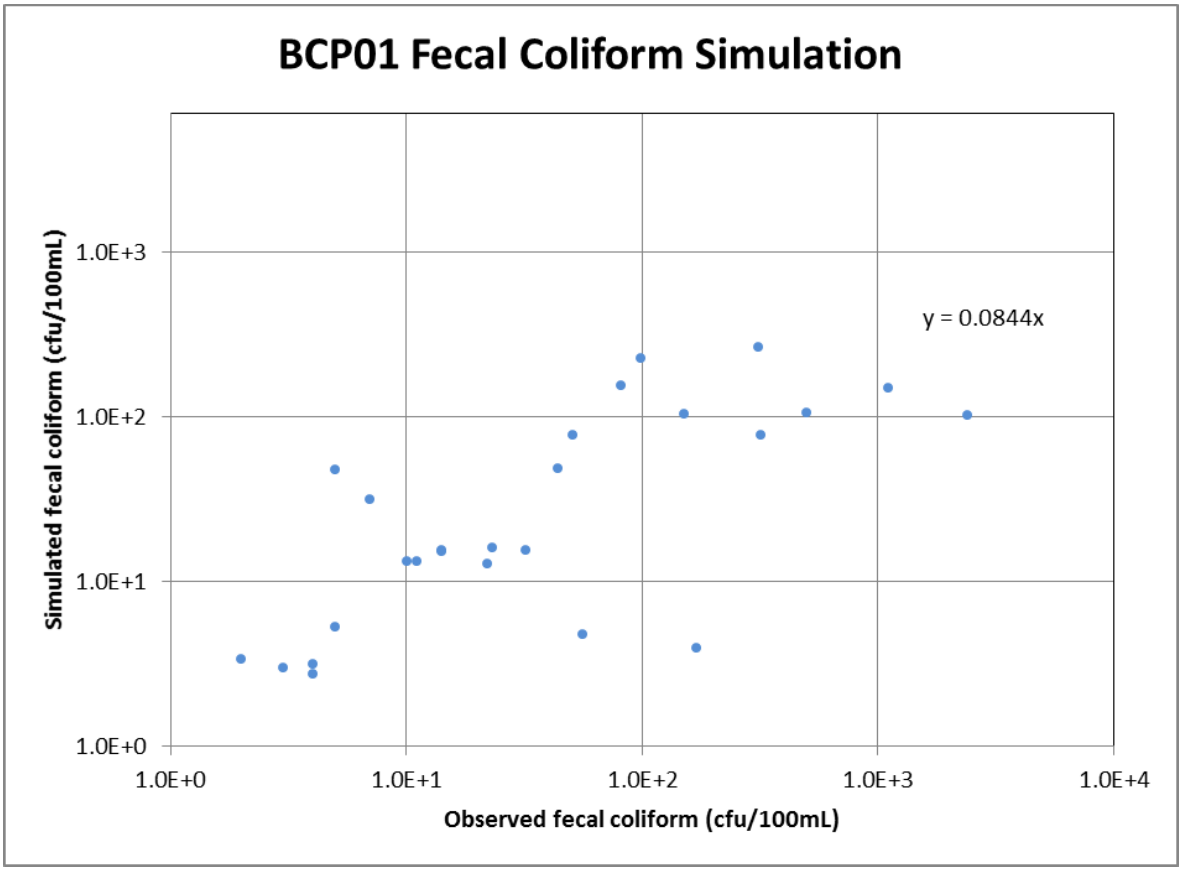

Figure 114 Water quality station BCP01 fecal coliform calibration regression

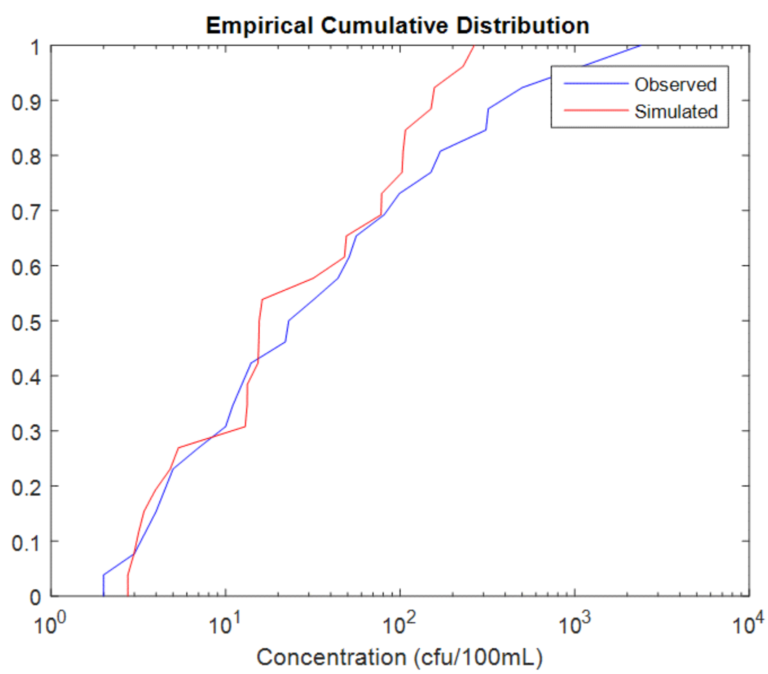

Figure 115 Water quality station BCP01 fecal coliform calibration cumulative distribution function

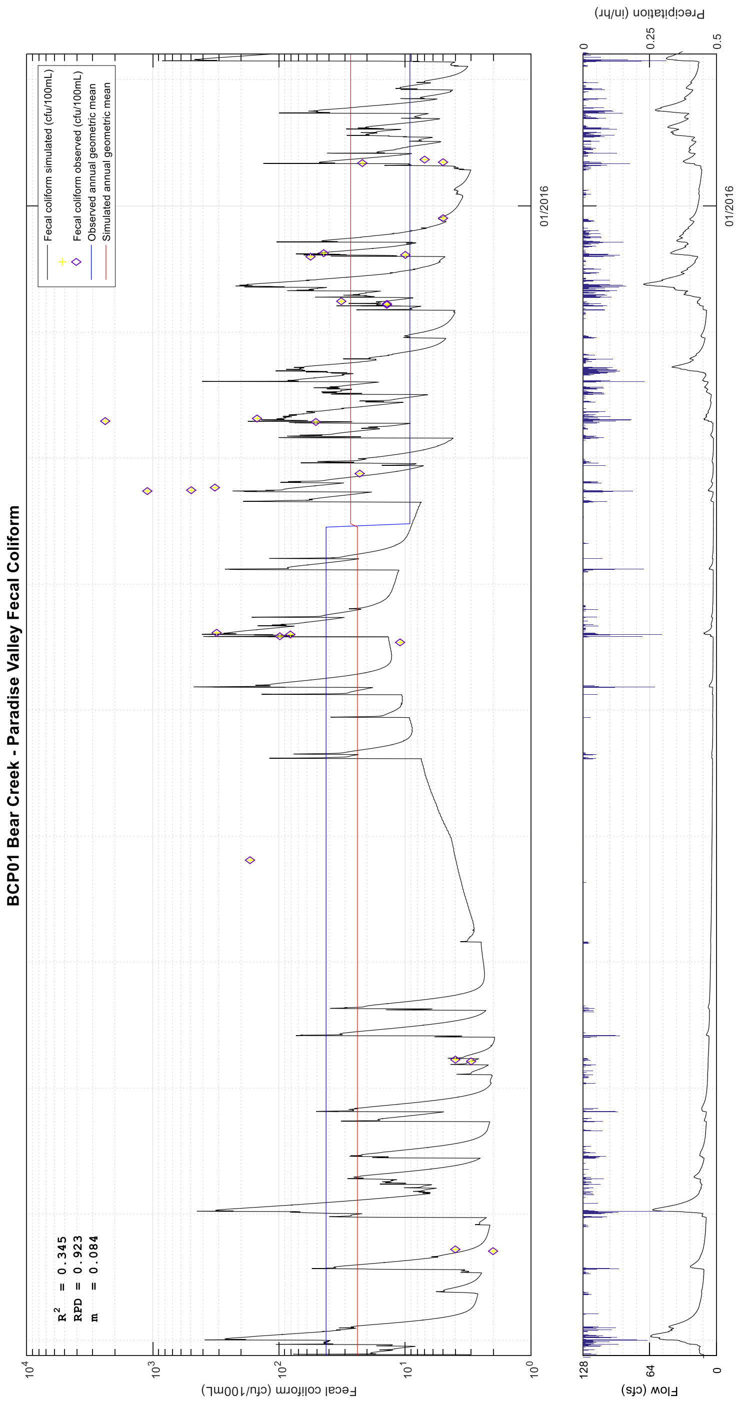

Figure 116 Water quality station BCP01 fecal coliform time series plot

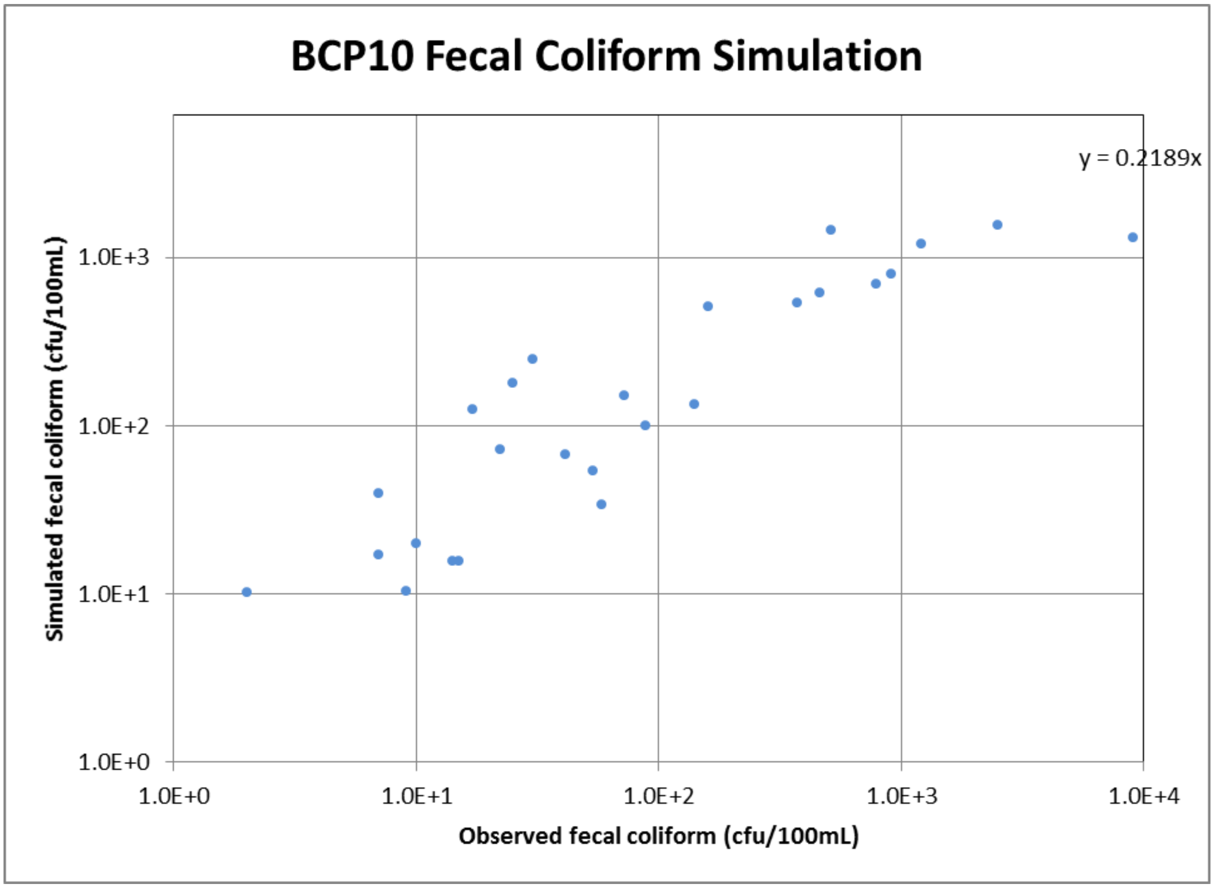

Figure 117 Water quality station BCP10 fecal coliform calibration regression

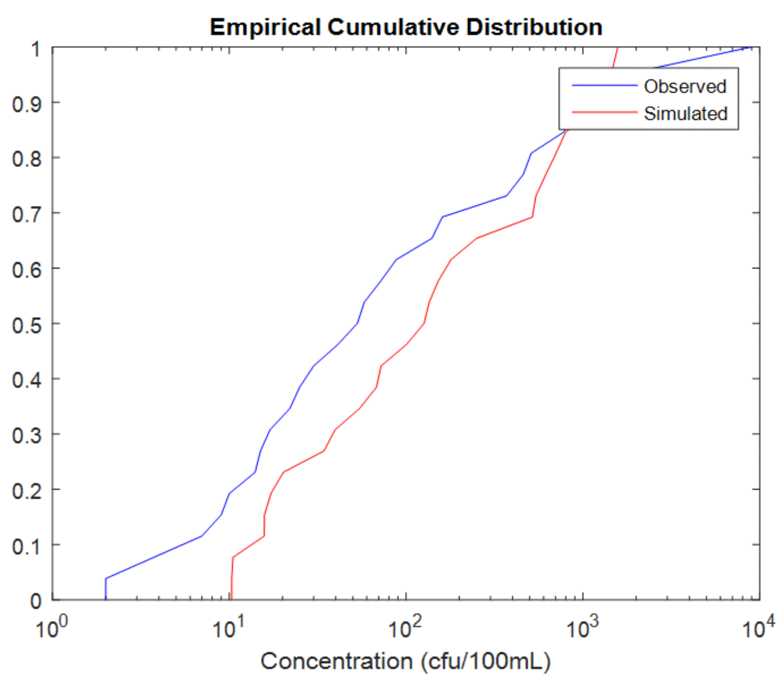

Figure 118 Water quality station BCP10 fecal coliform calibration cumulative distribution function

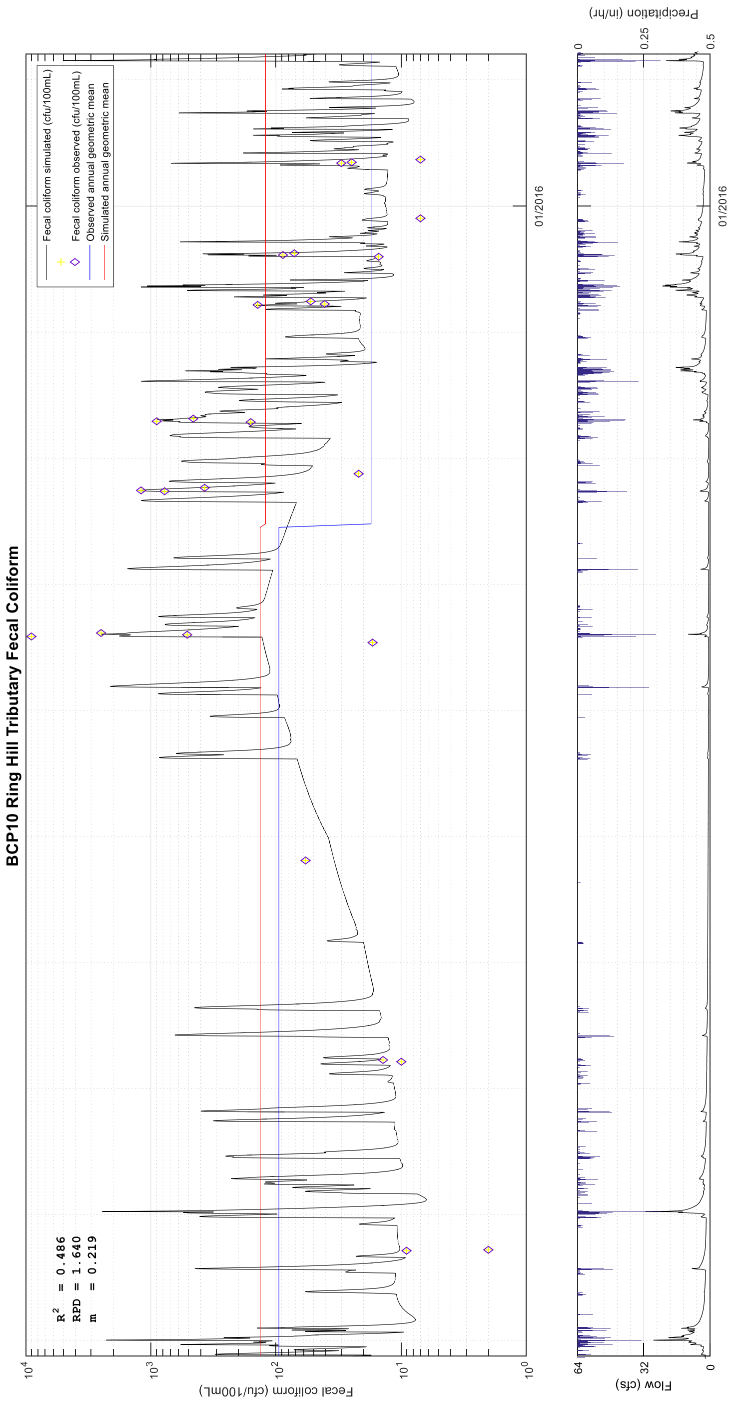

Figure 119 Water quality station BCP10 fecal coliform time series plot

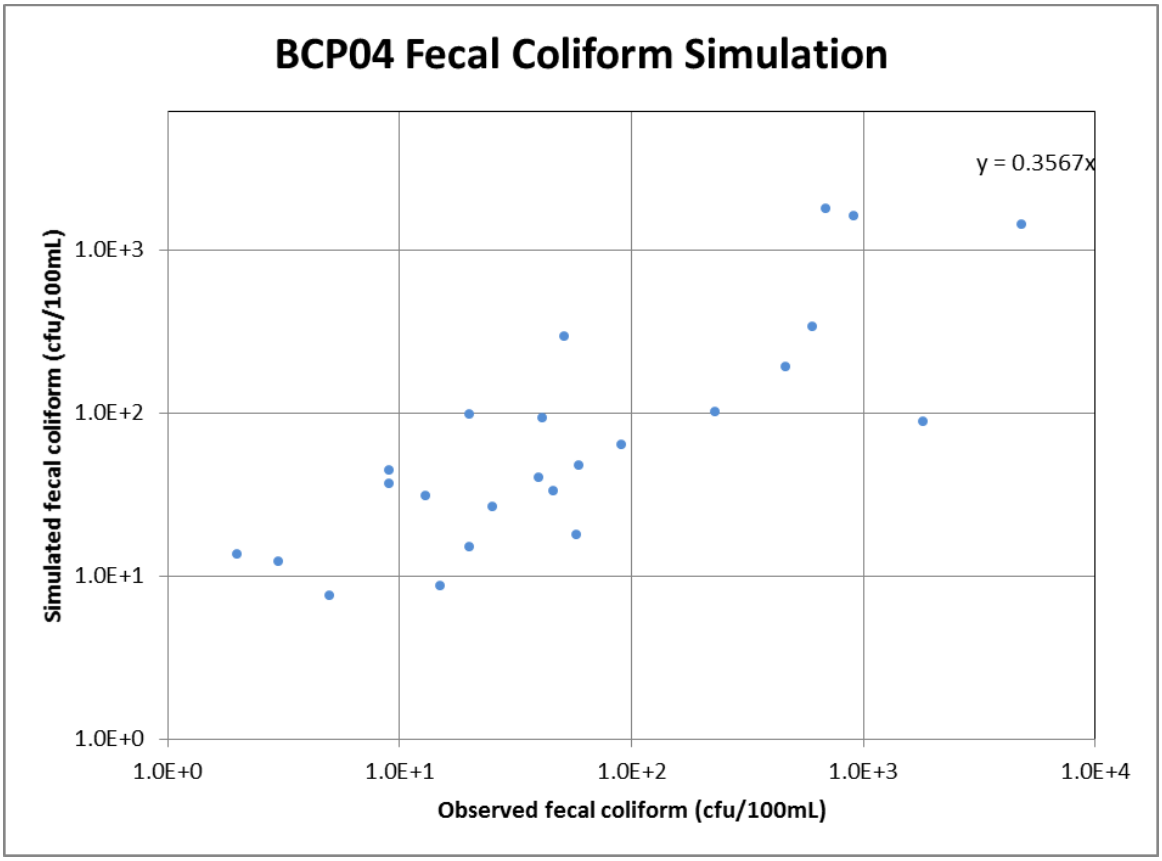

Figure 120 Water quality station BCP04 fecal coliform calibration regression

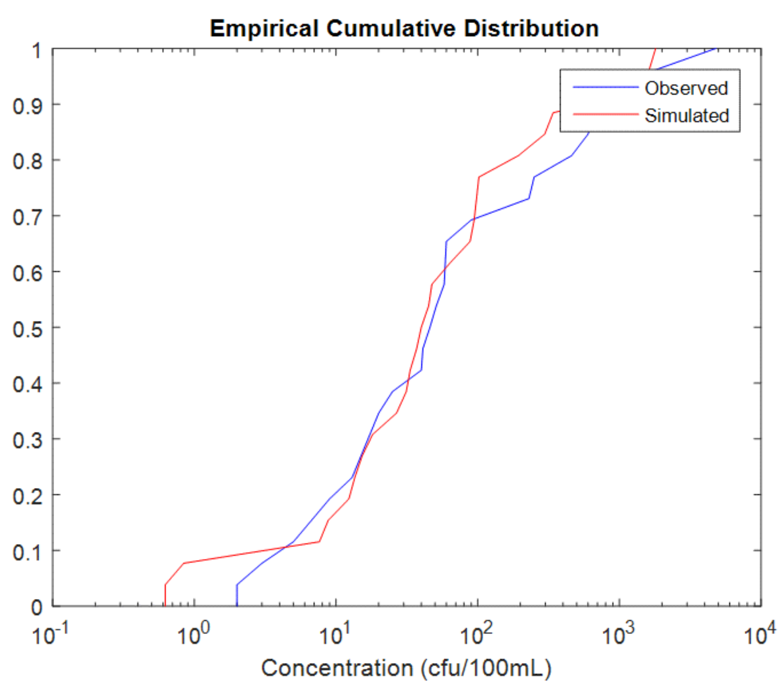

Figure 121 Water quality station BCP04 fecal coliform calibration cumulative distribution function

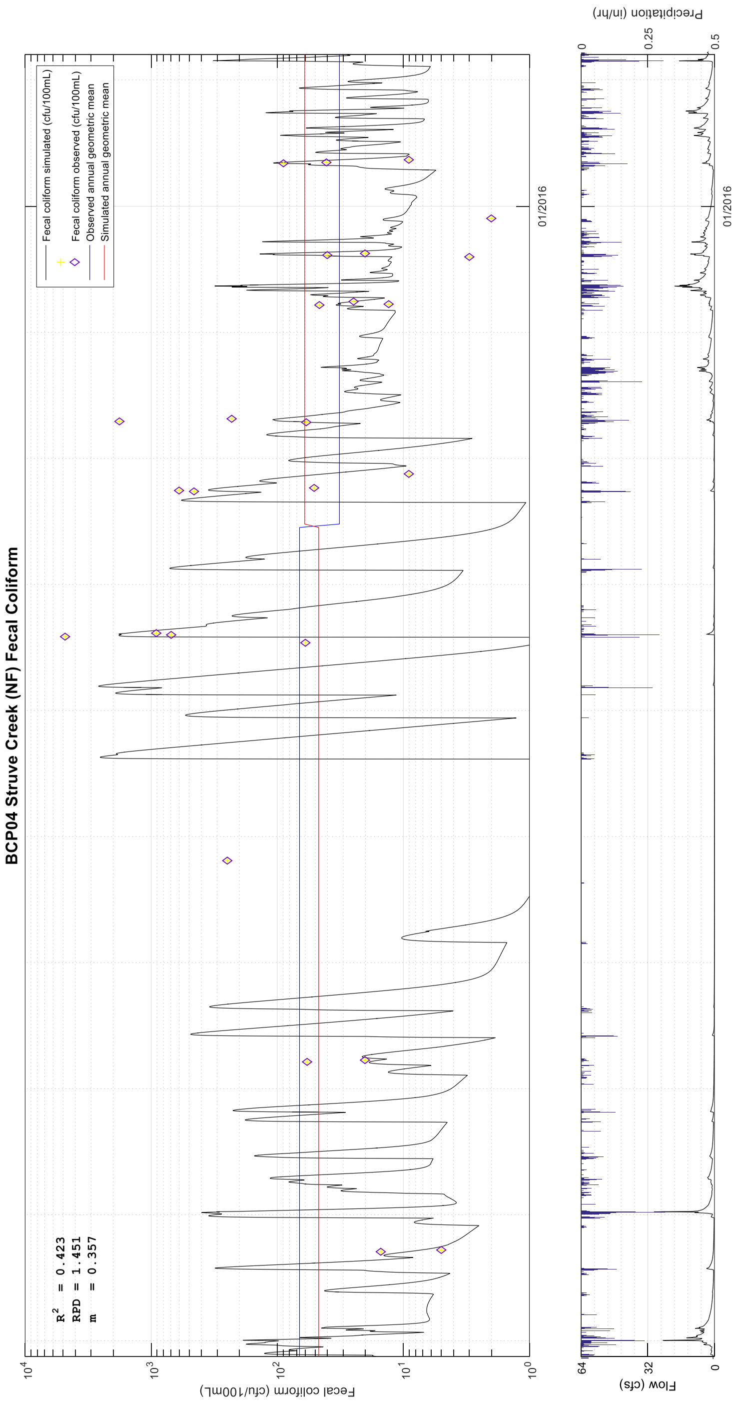

Figure 122 Water quality station BCP04 fecal coliform time series plot

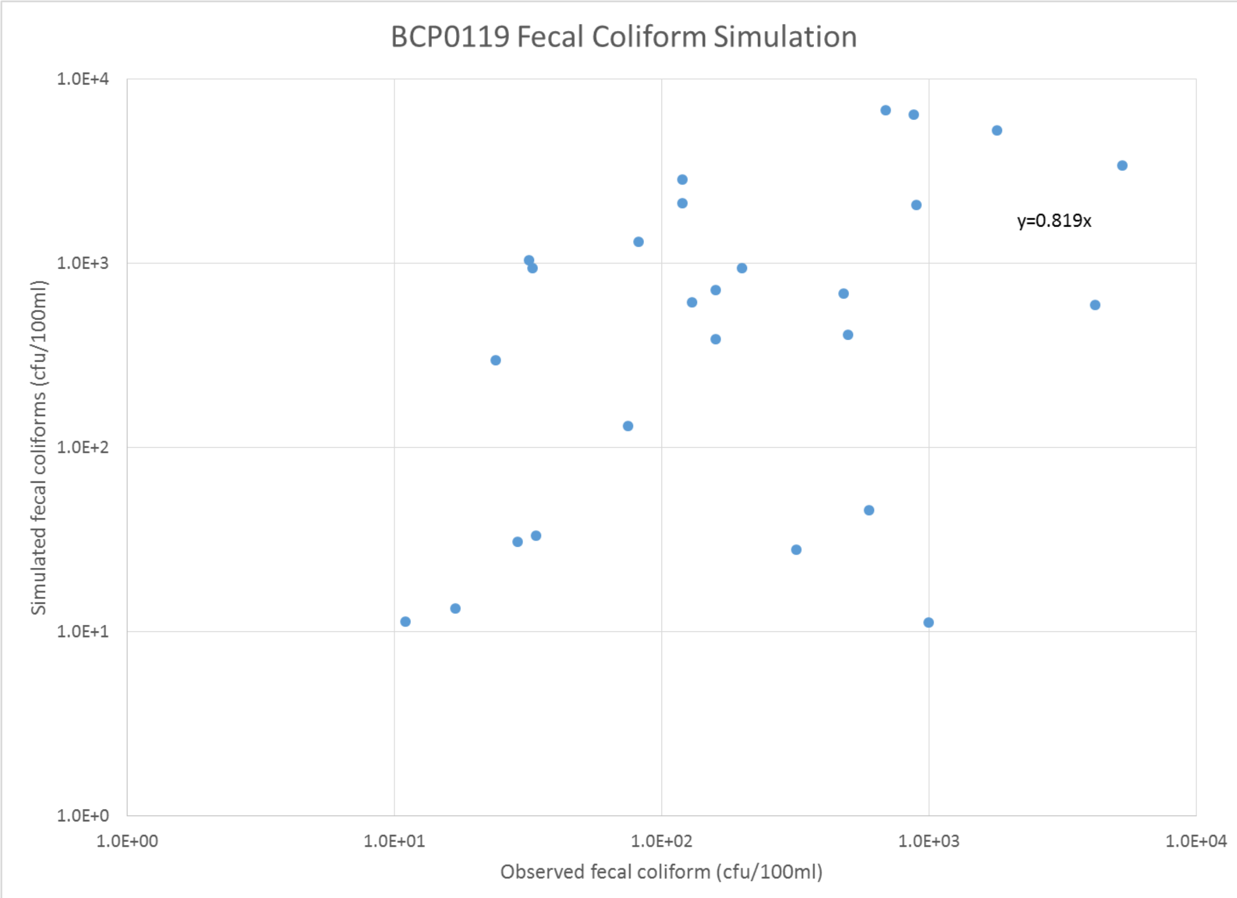

Figure 123 Water quality station BCP0119 fecal coliform scatter plot.

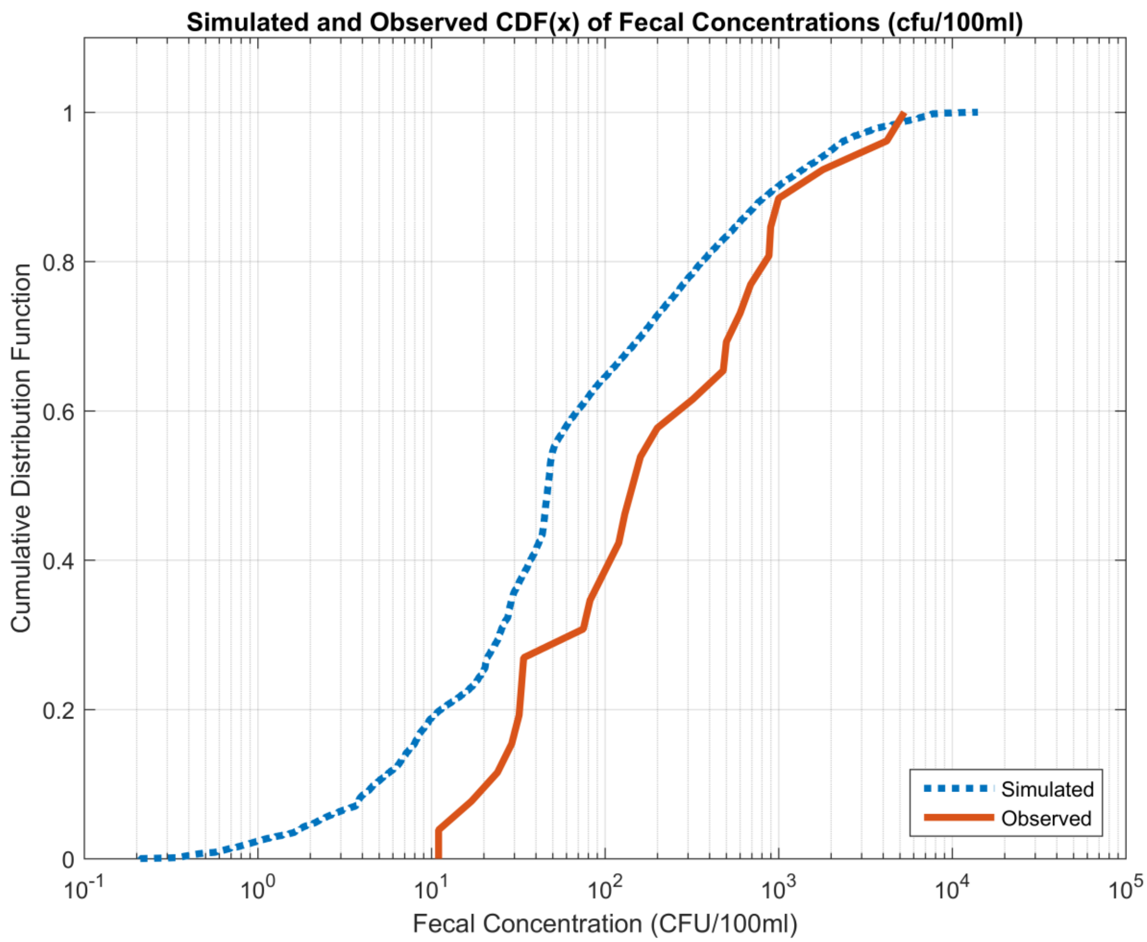

Figure 124 Water quality station BCP0119 (MON030) fecal coliform calibration cumulative distribution function.

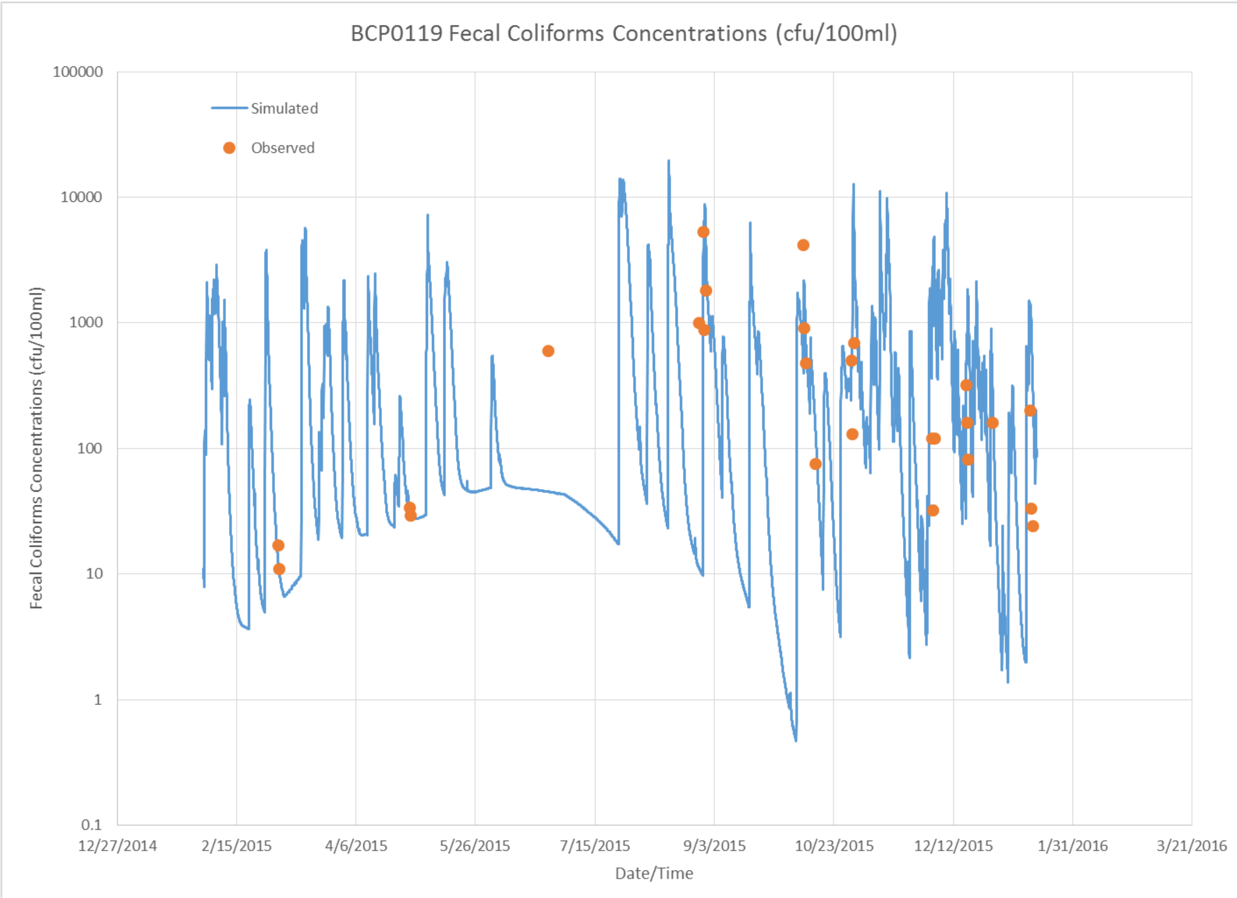

Figure 125 Water quality station BCP0119 (MON030) fecal coliform time series calibration plot.

APPENDIX E: Suspended Sediment Calibration

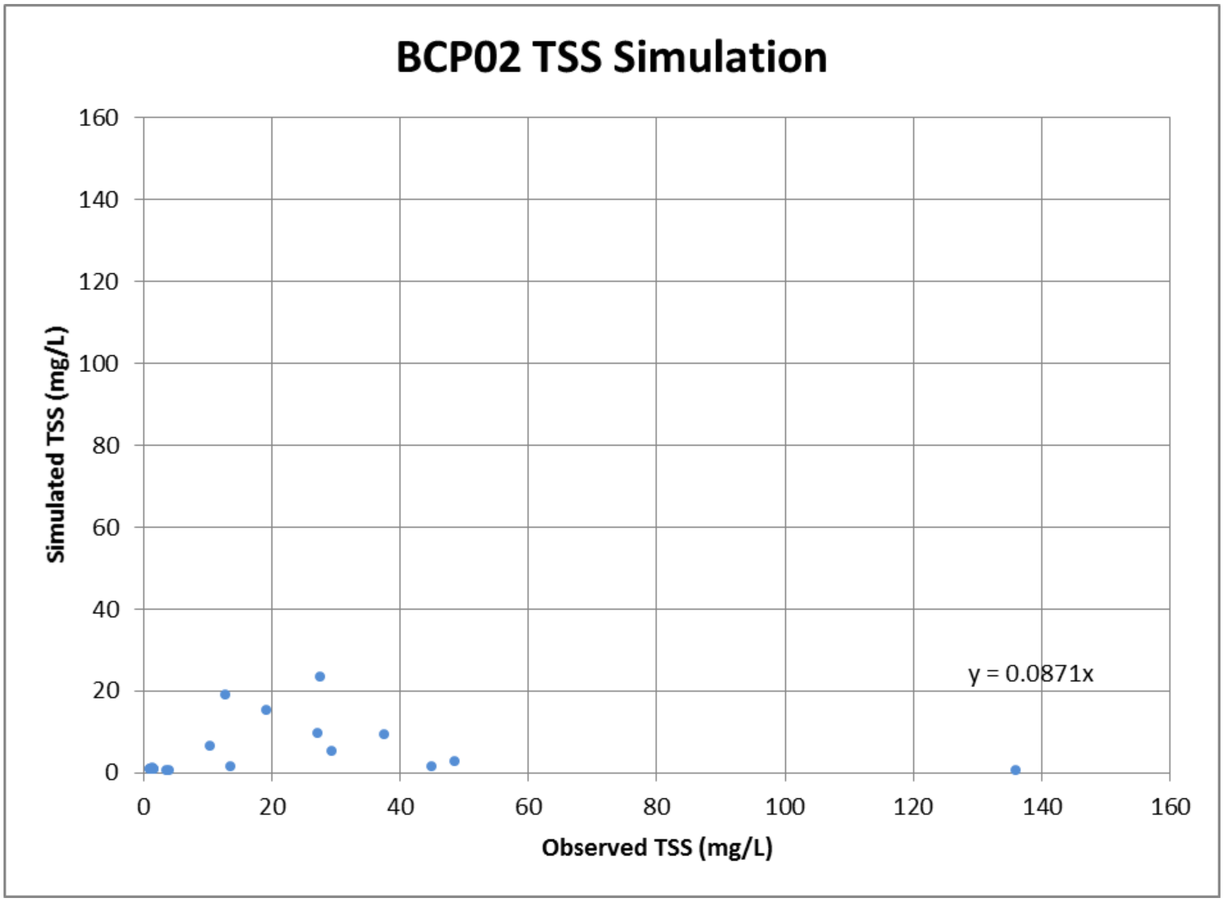

Figure 126 Water quality station BCP02 total suspended solids calibration

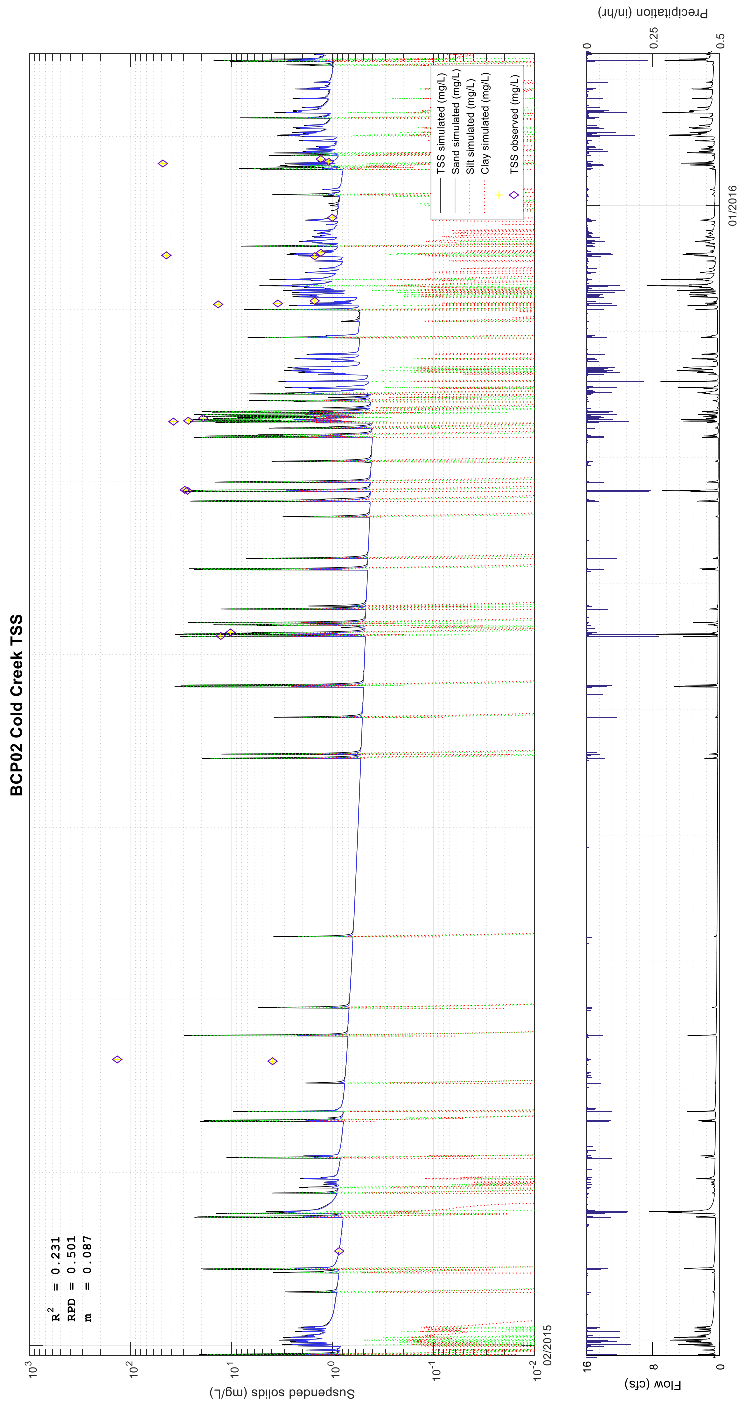

Figure 127 Water quality station BCP02 total suspended solids time series plot

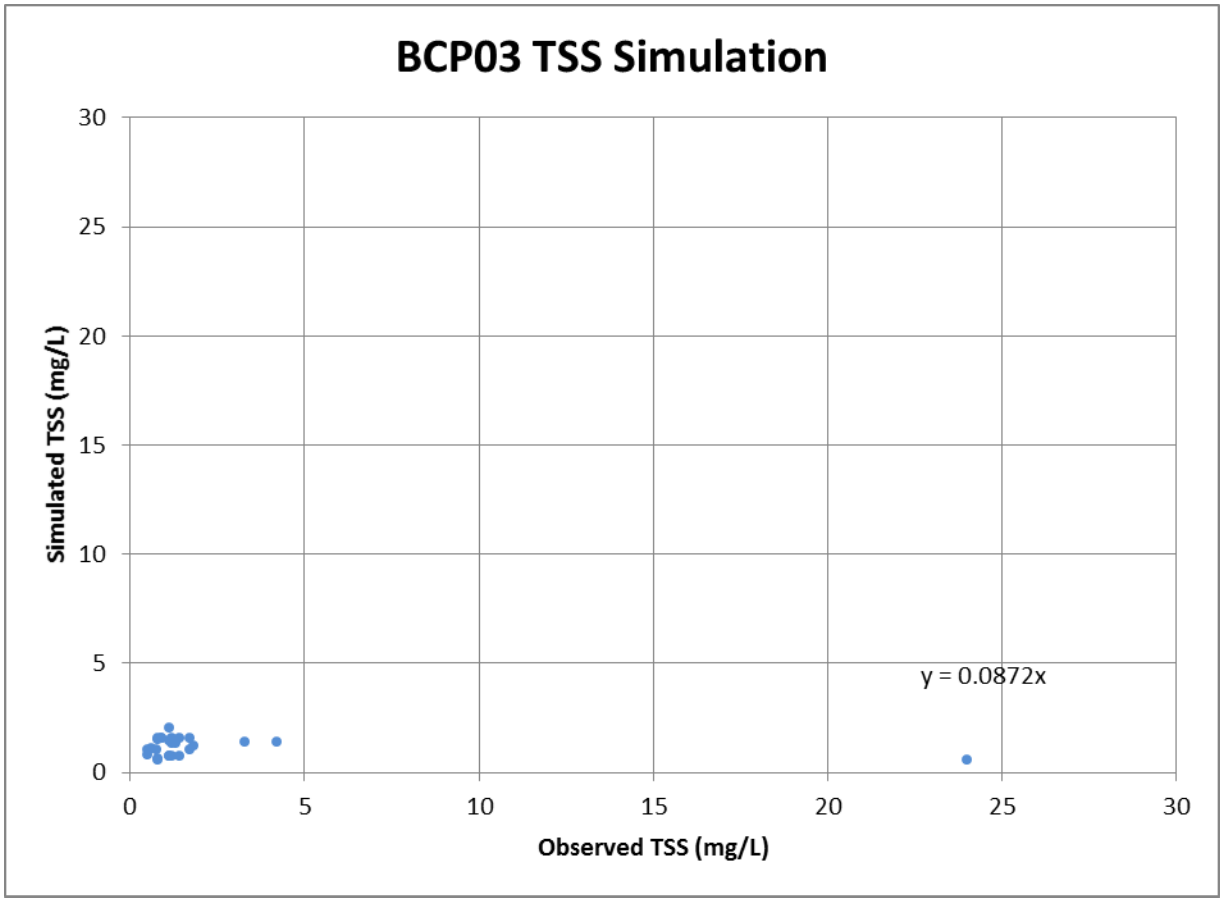

Figure 128 Water quality station BCP03 total suspended solids calibration regression

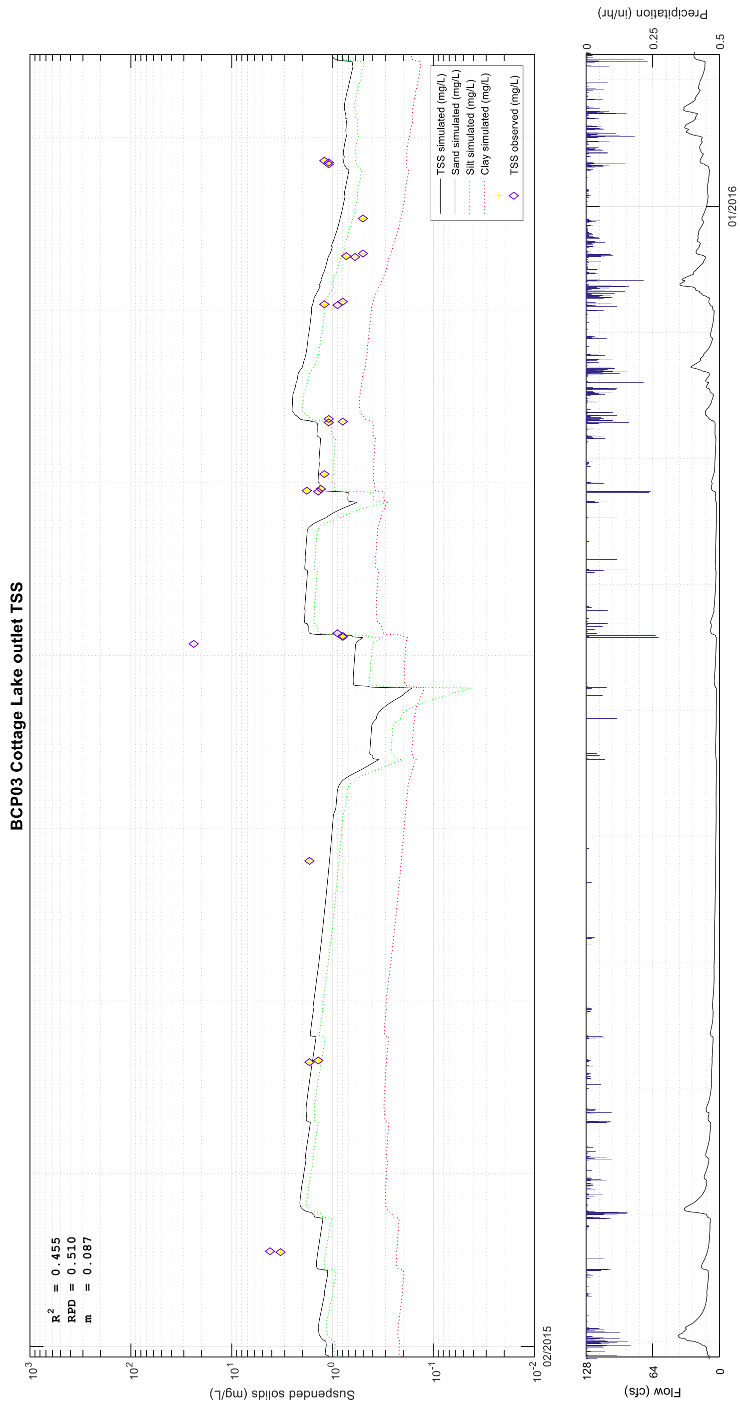

Figure 129 Water quality station BCP03 total suspended solids time series plot

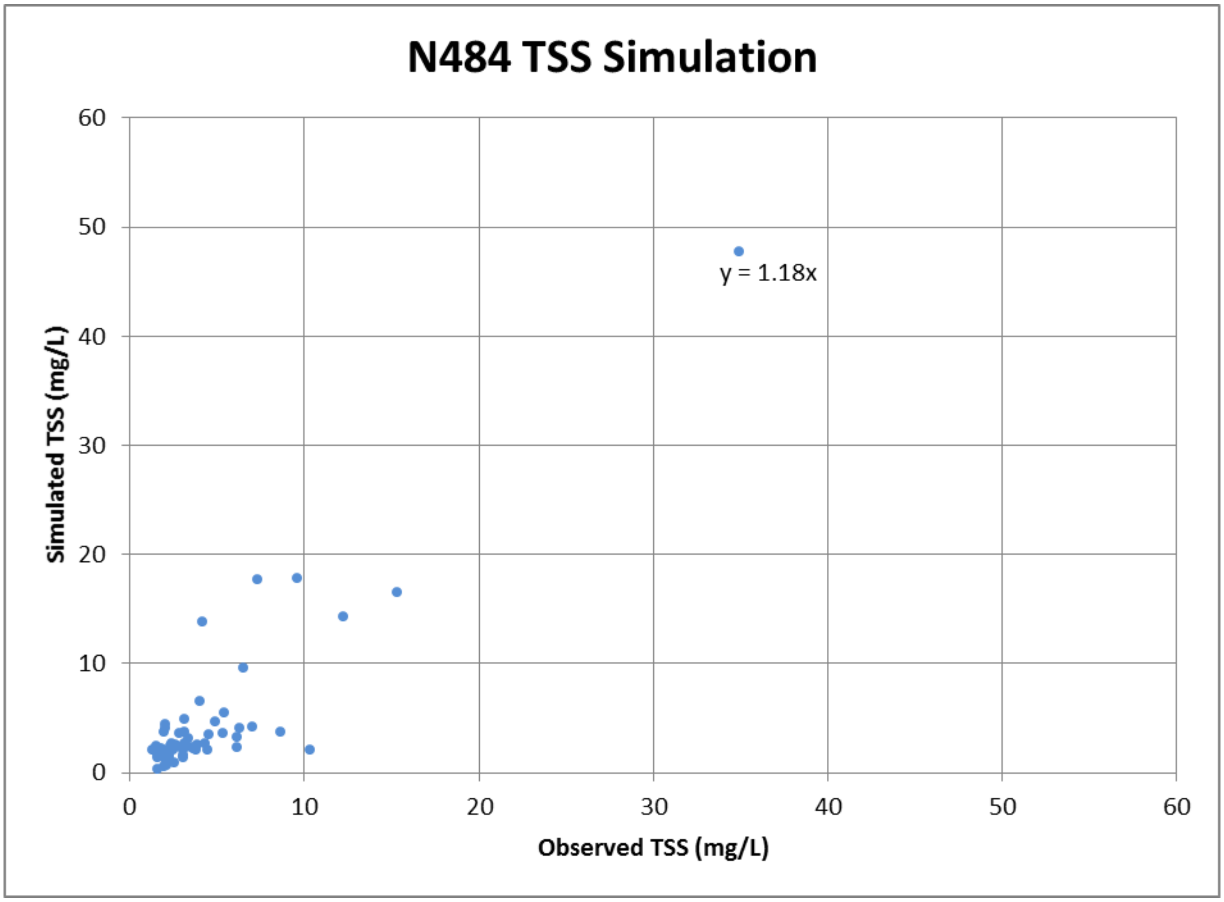

Figure 130 Water quality station N484 total suspended solids calibration regression

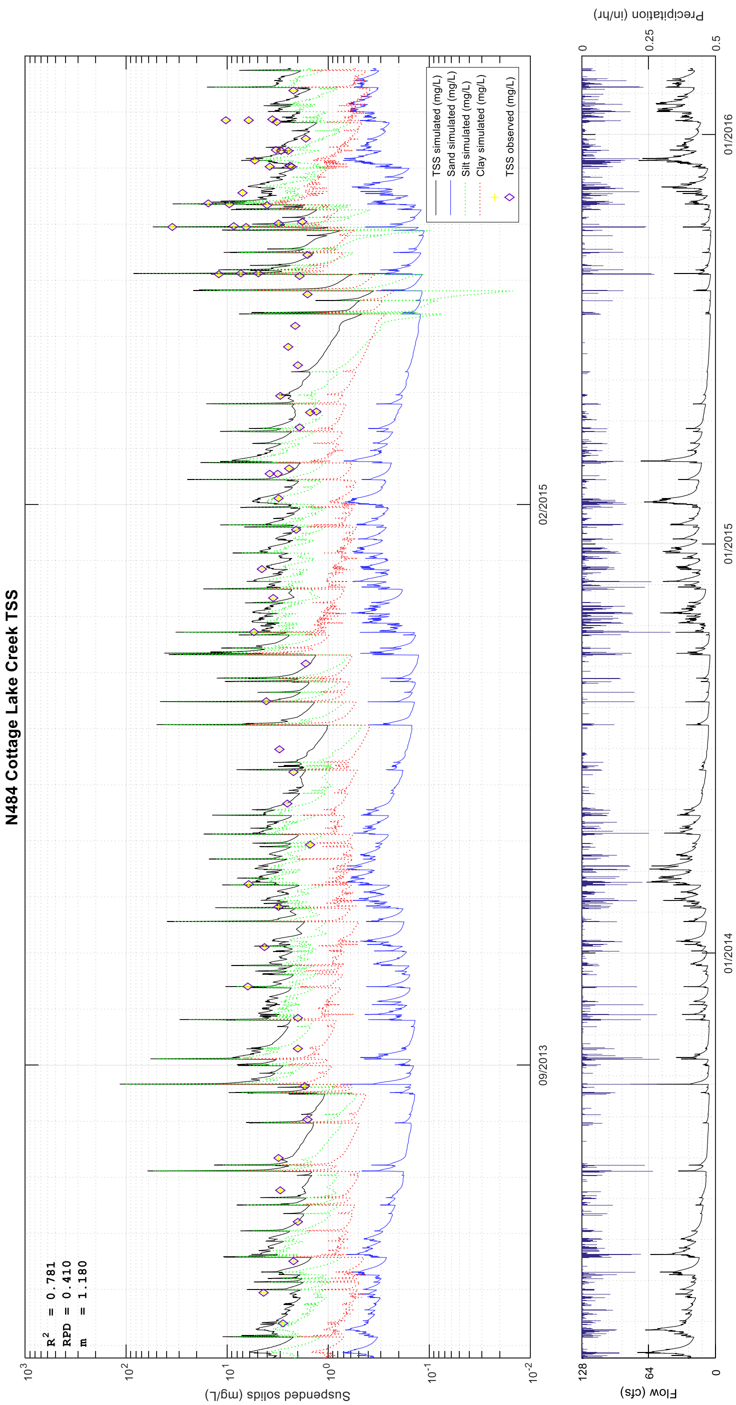

Figure 131 Water quality station N484 total suspended solids time series plot

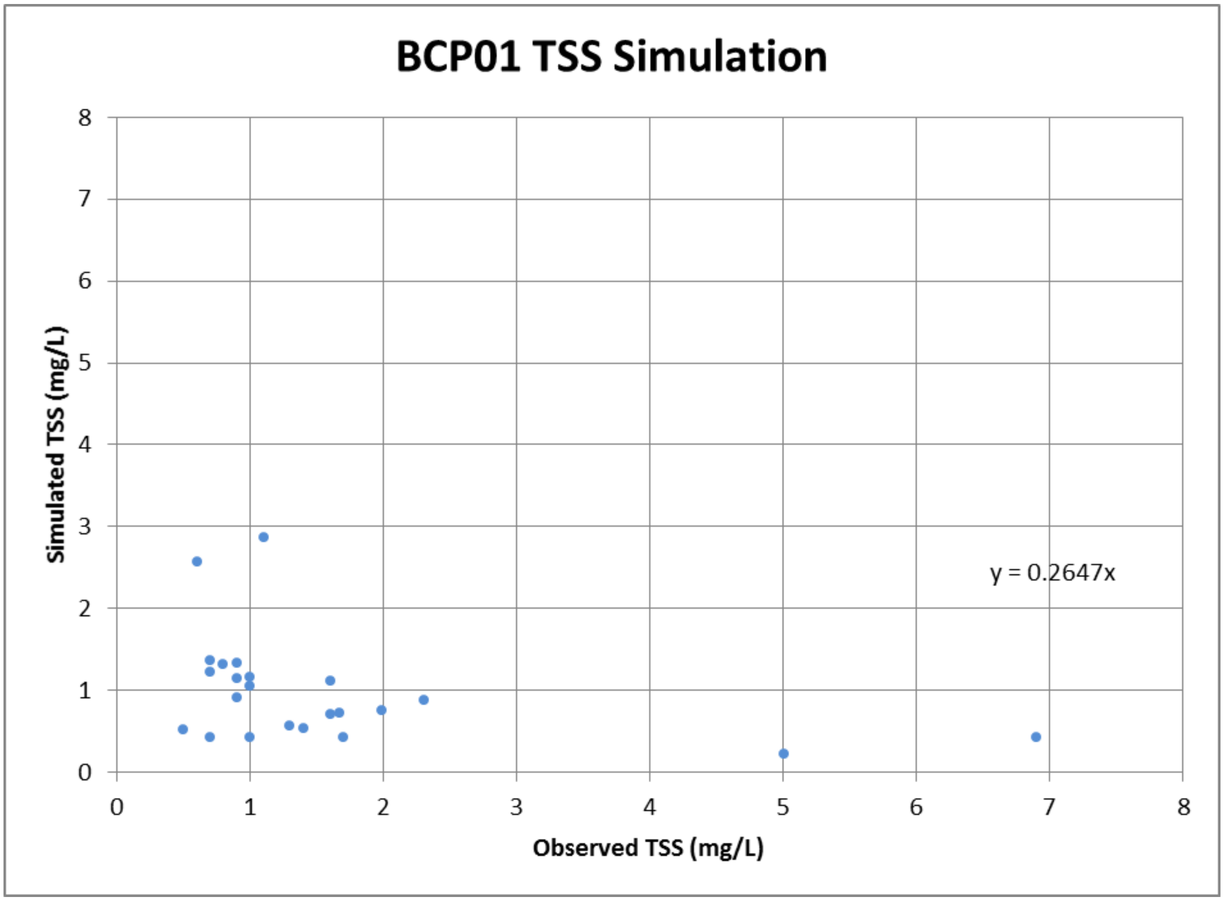

Figure 132 Water quality station BCP01 total suspended solids calibration regression

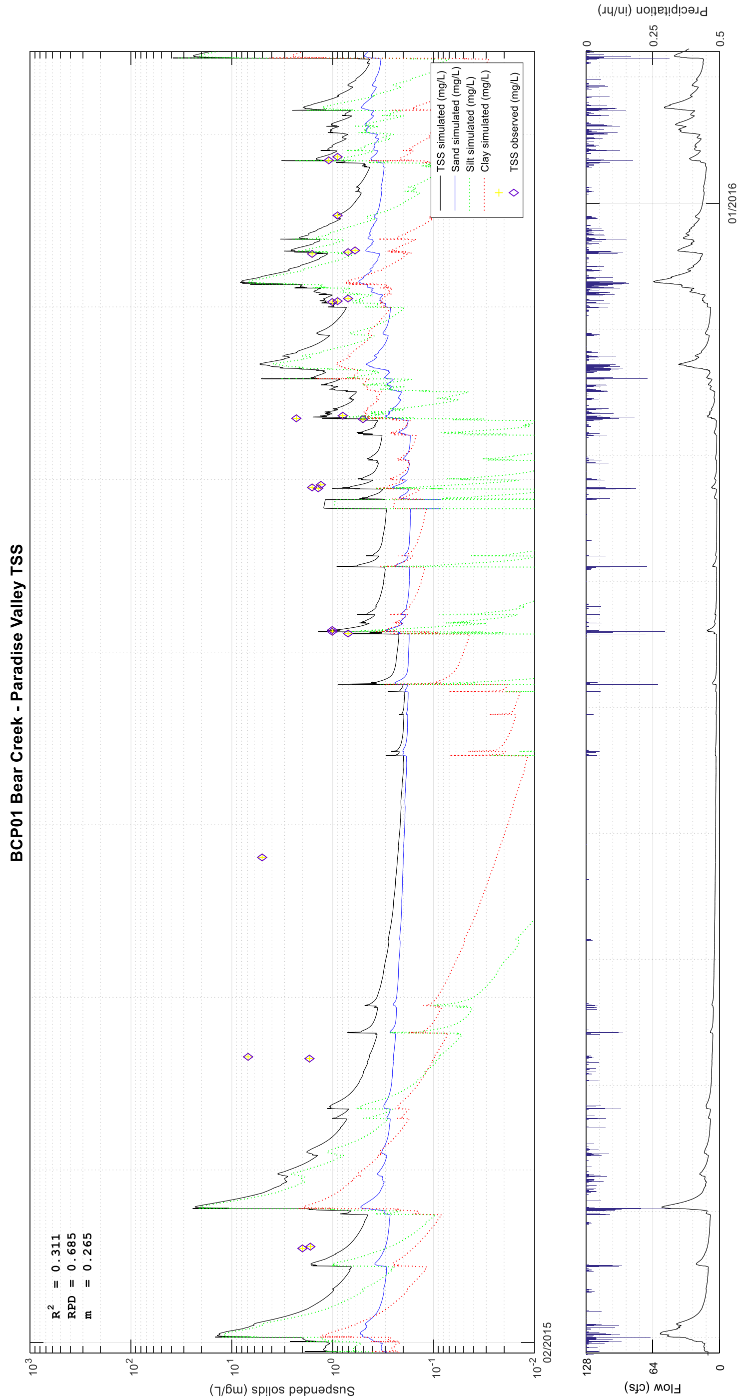

Figure 133 Water quality station BCP01 total suspended solids time series plot

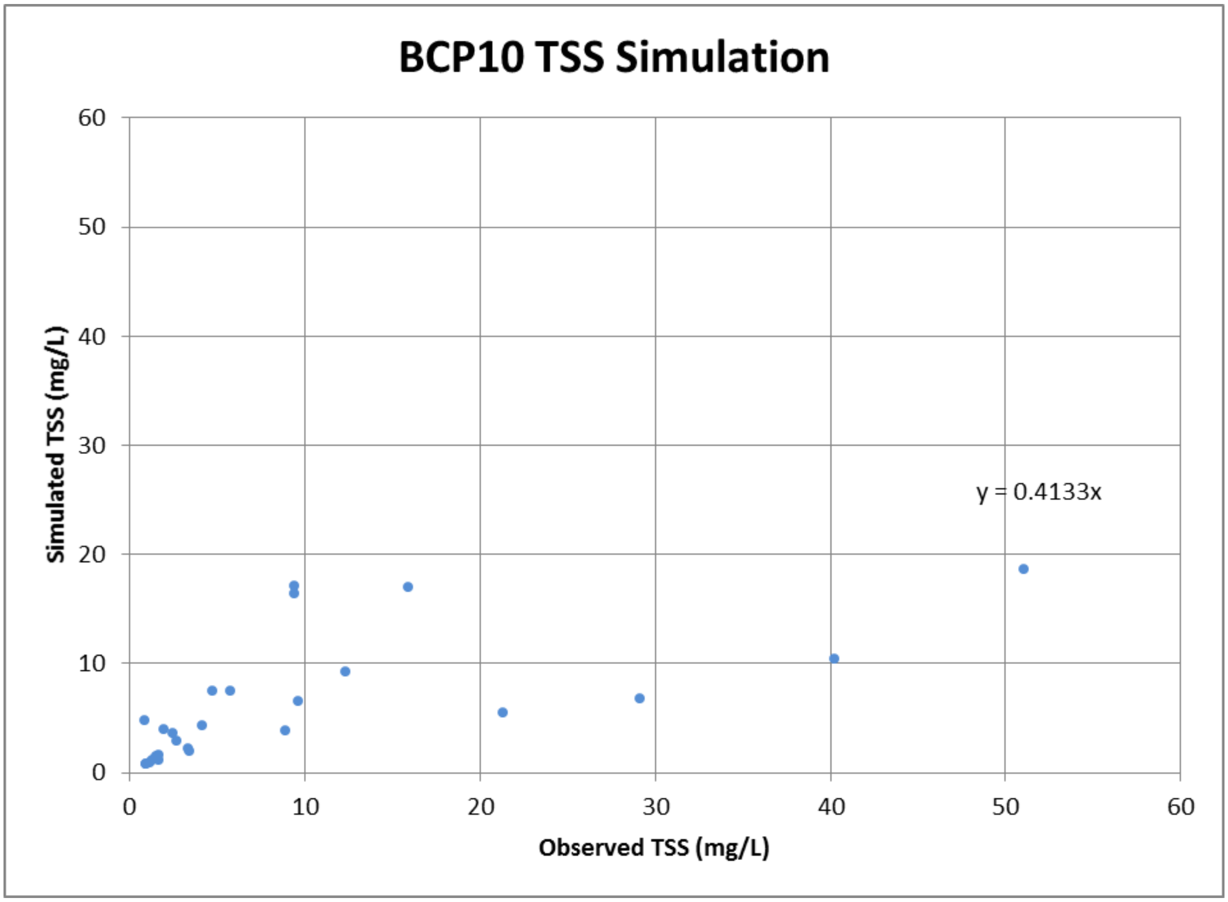

Figure 134 Water quality station BCP10 total suspended solids calibration regression

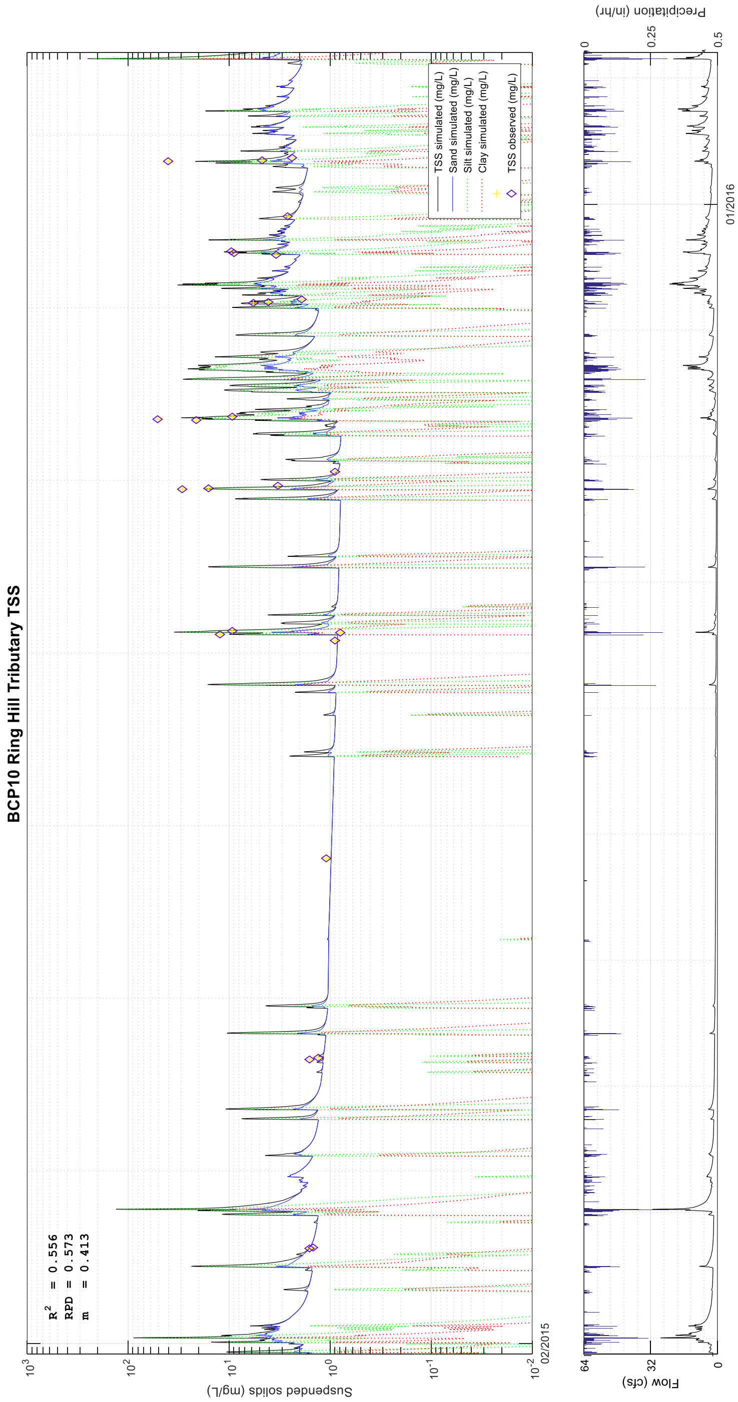

Figure 135 Water quality station BCP10 total suspended solids time series plot

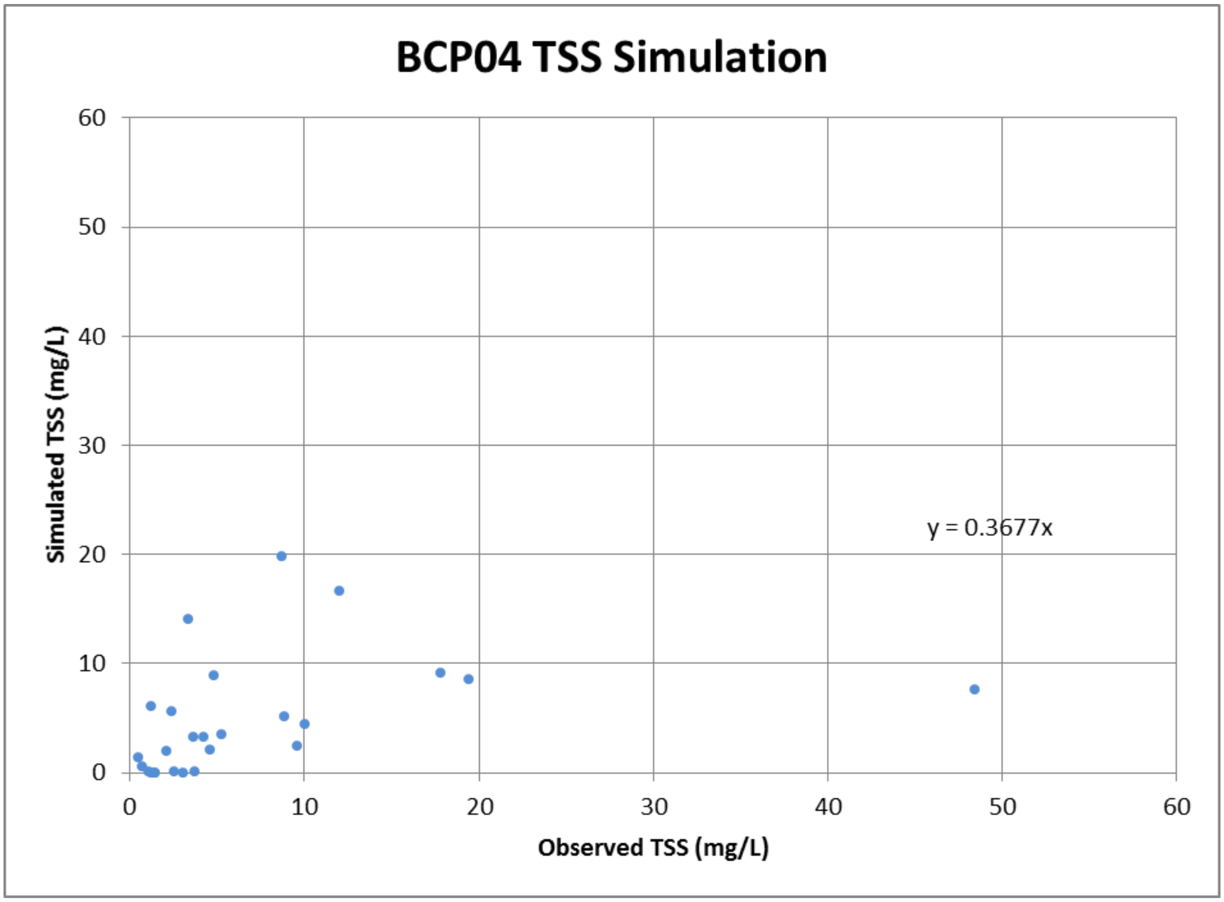

Figure 136 Water quality station BCP04 total suspended solids calibration regression

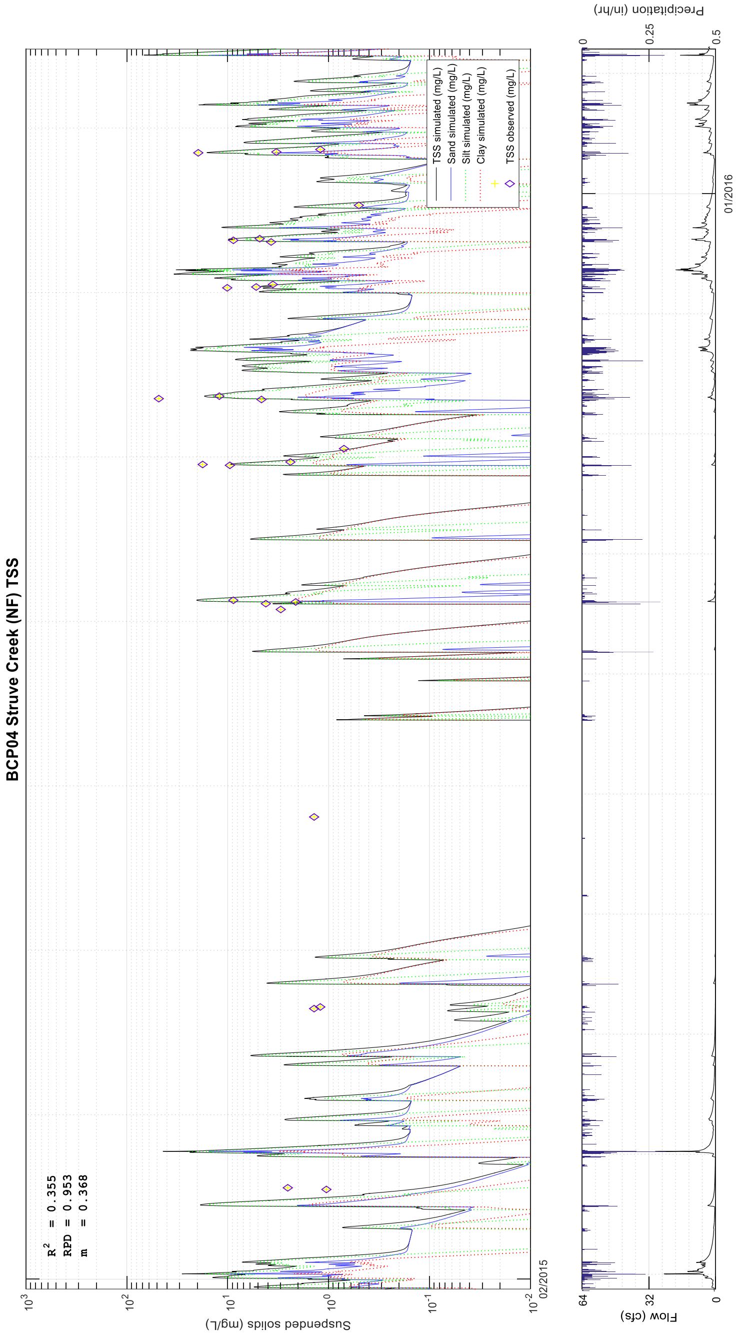

Figure 137 Water quality station BCP04 total suspended solids time series plot

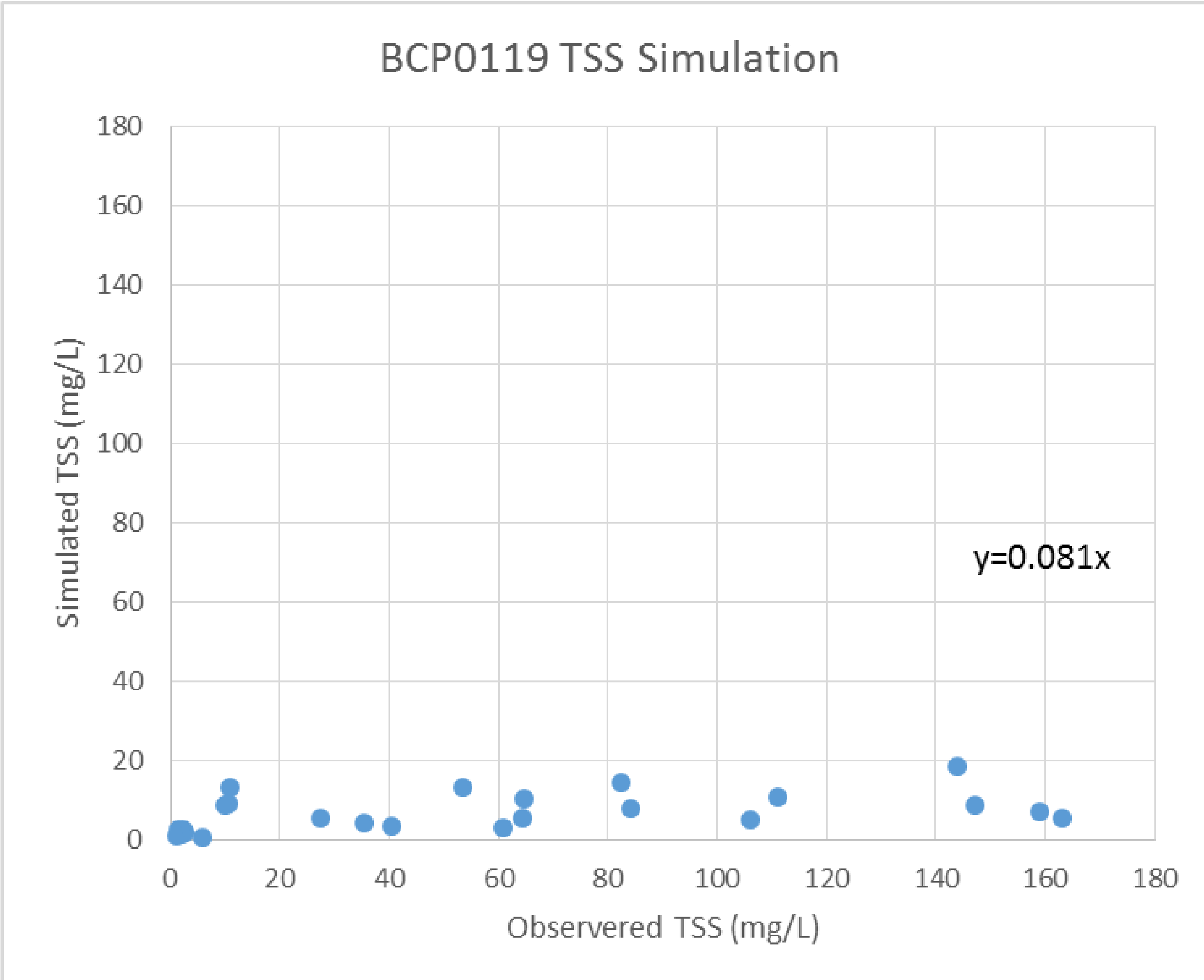

Figure 138 Water quality station BCP0119 total suspended solids scatter plot

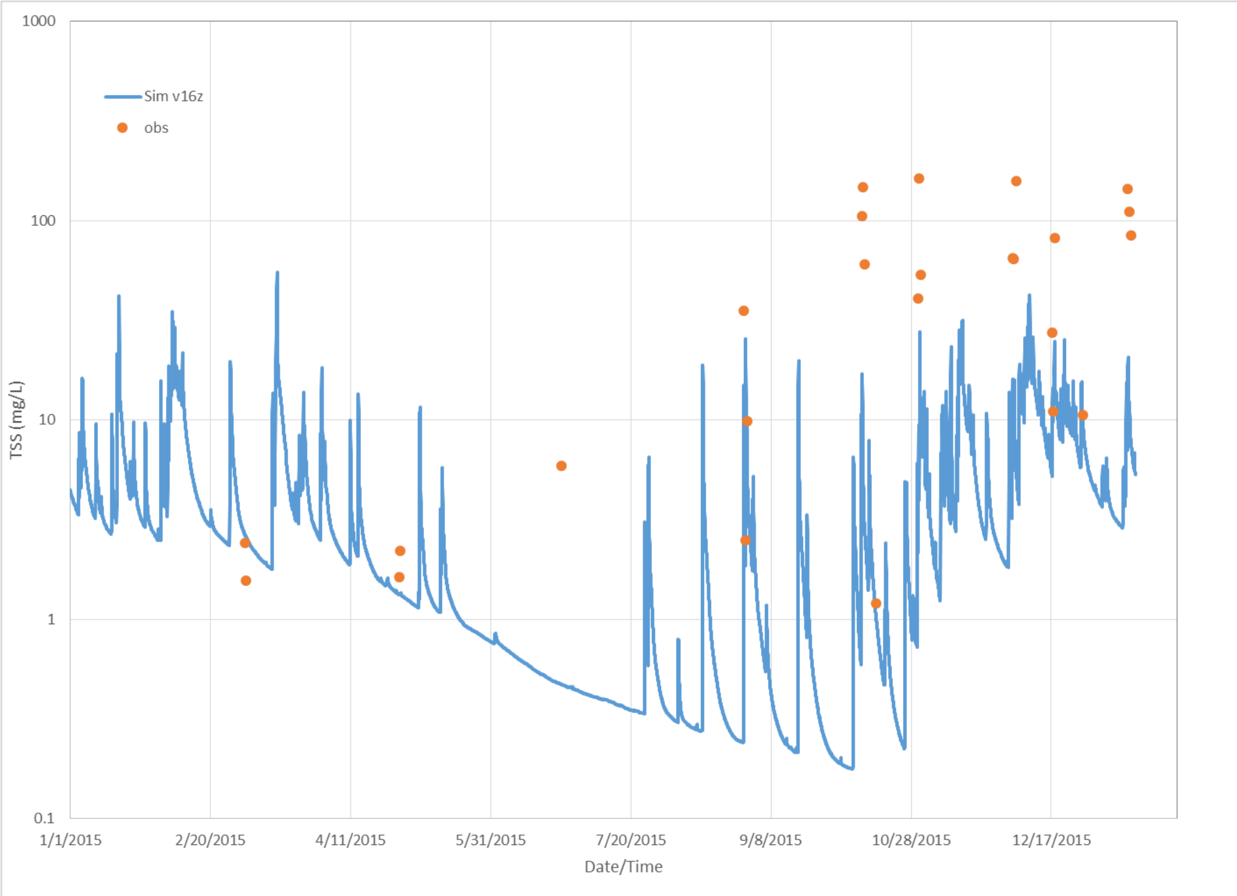

Figure 139 Water quality station BCP0119 total suspended solids time series plot

This page intentionally left blank.

APPENDIX F: Copper Calibration

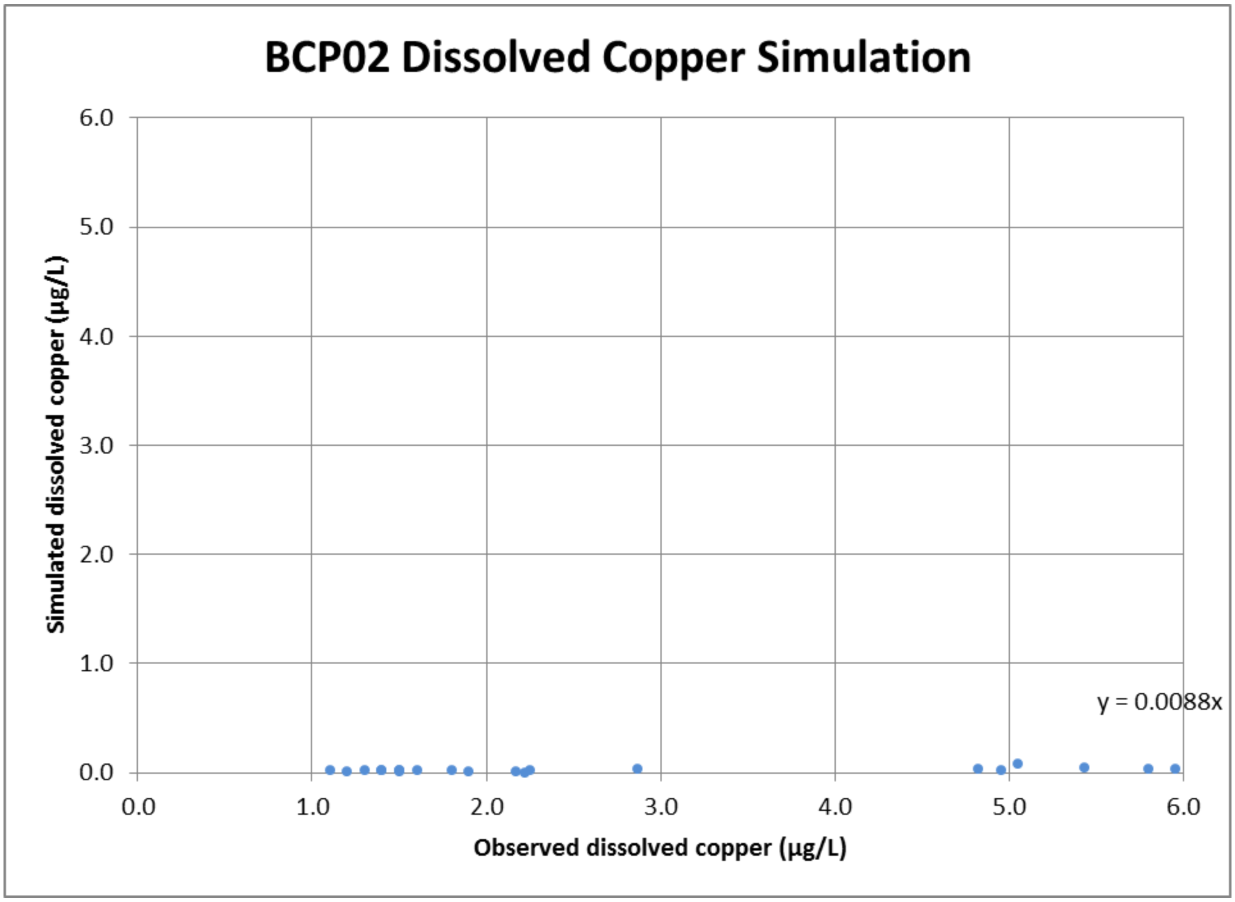

Figure 140 Water quality station BCP02 dissolved copper calibration regression

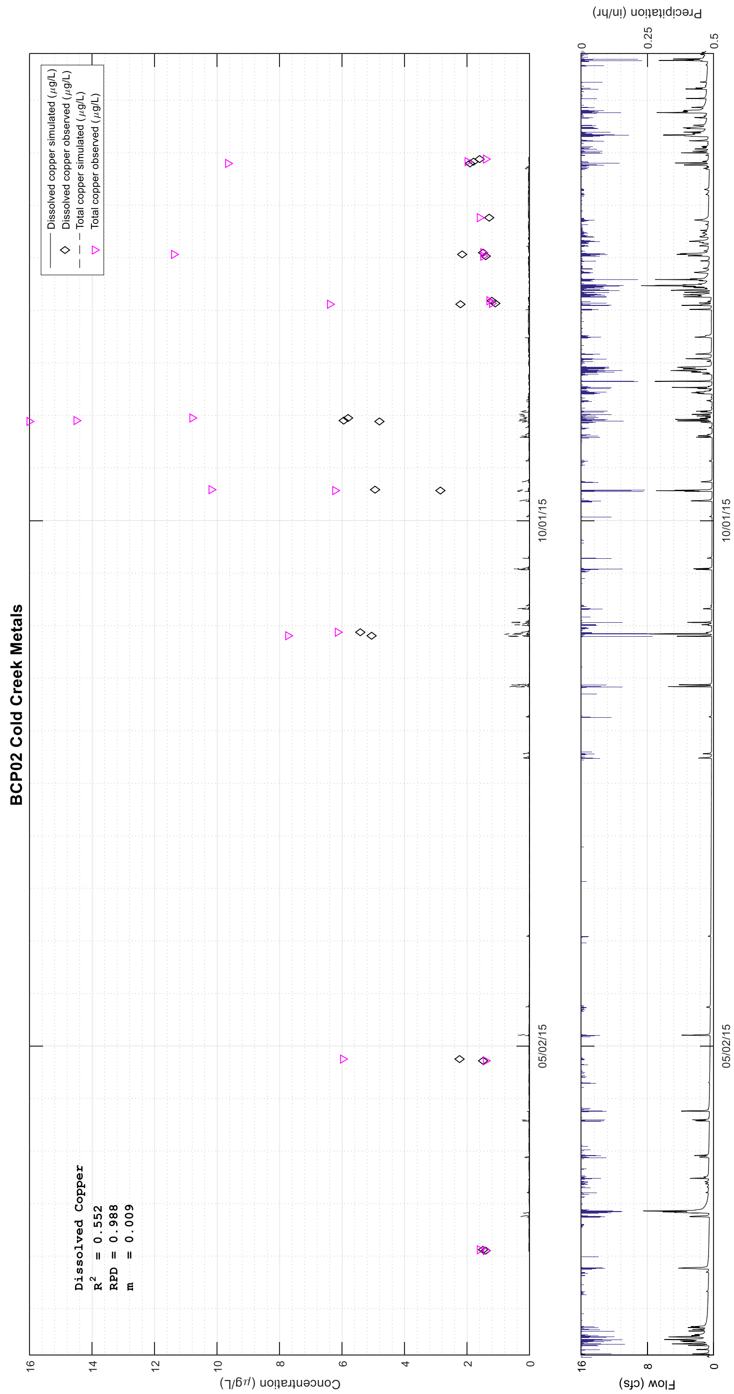

Figure 141 Water quality station BCP02 copper time series plot

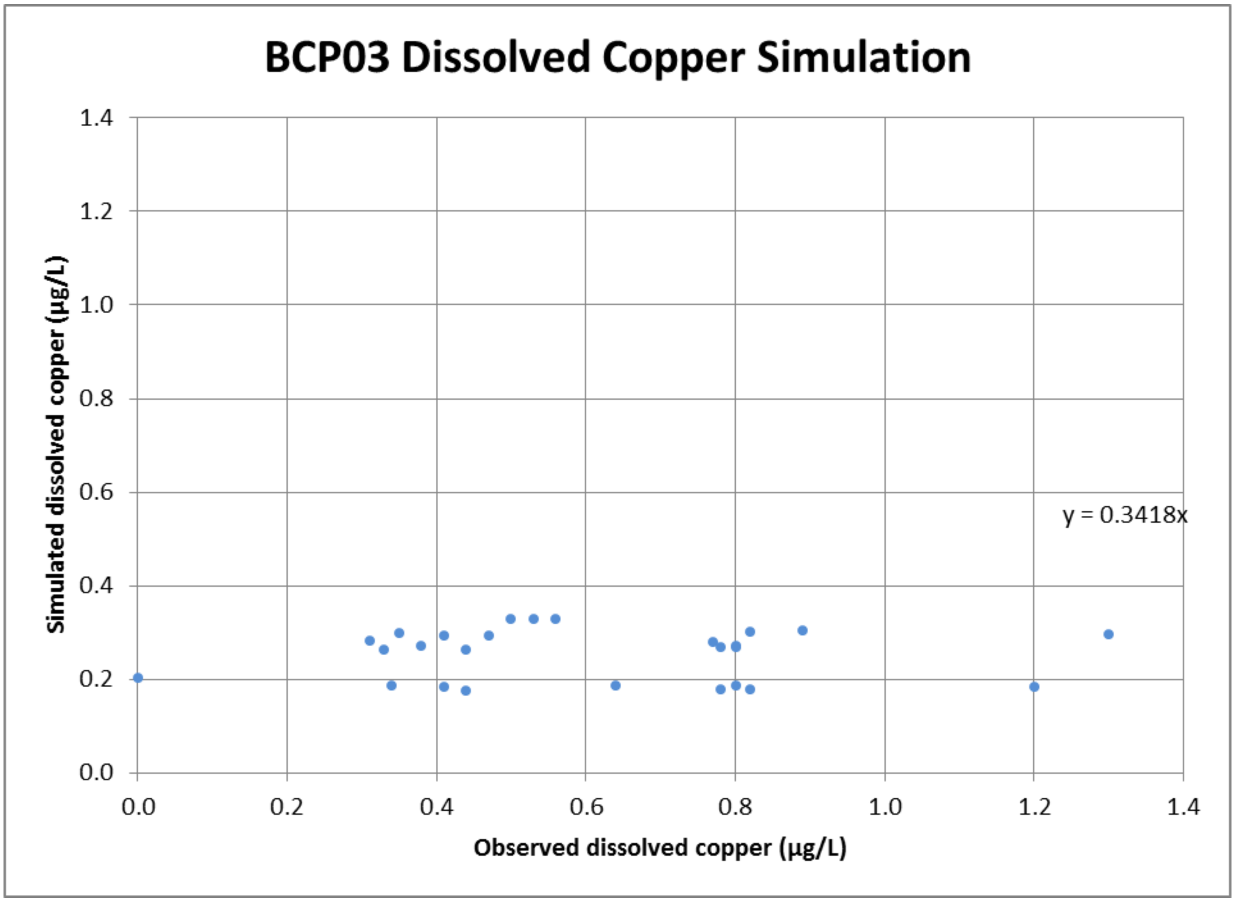

Figure 142 Water quality station BCP03 dissolved copper calibration regression

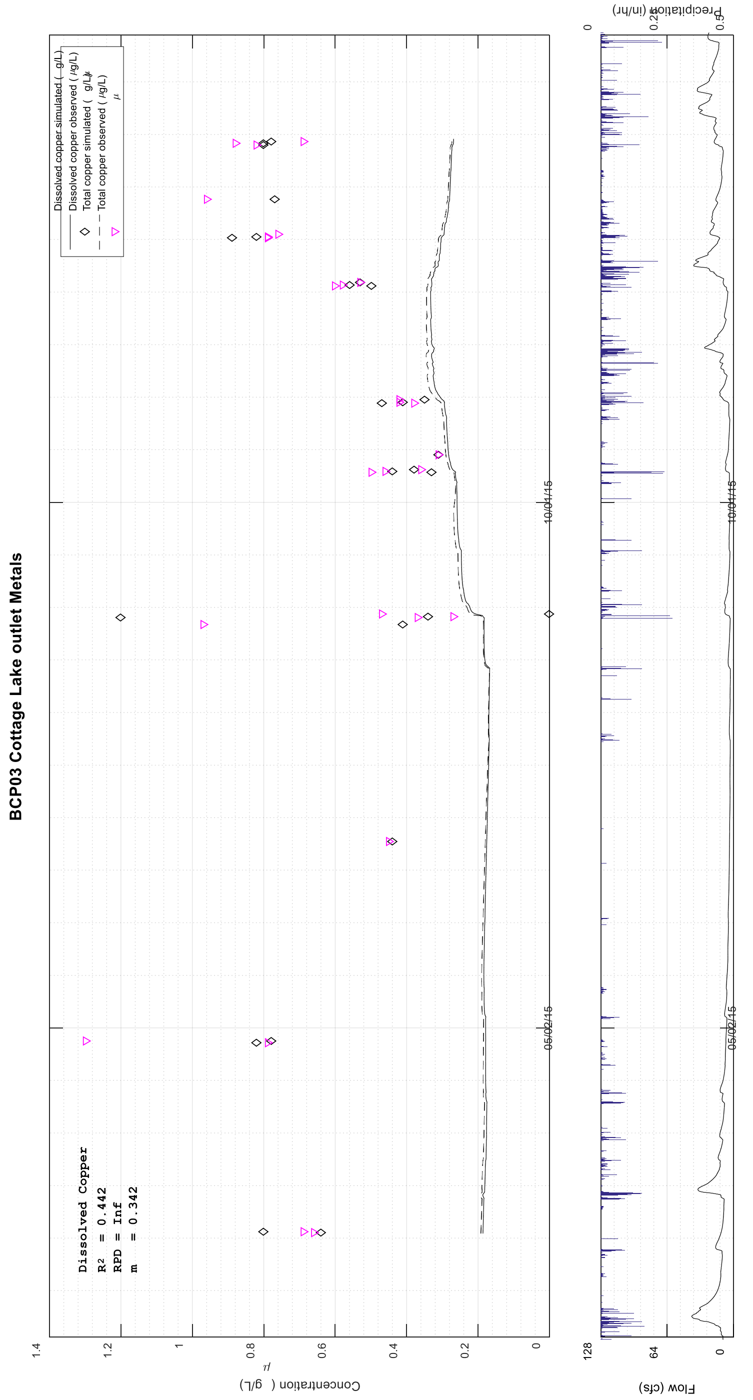

Figure 143 Water quality station BCP03 copper time series plot

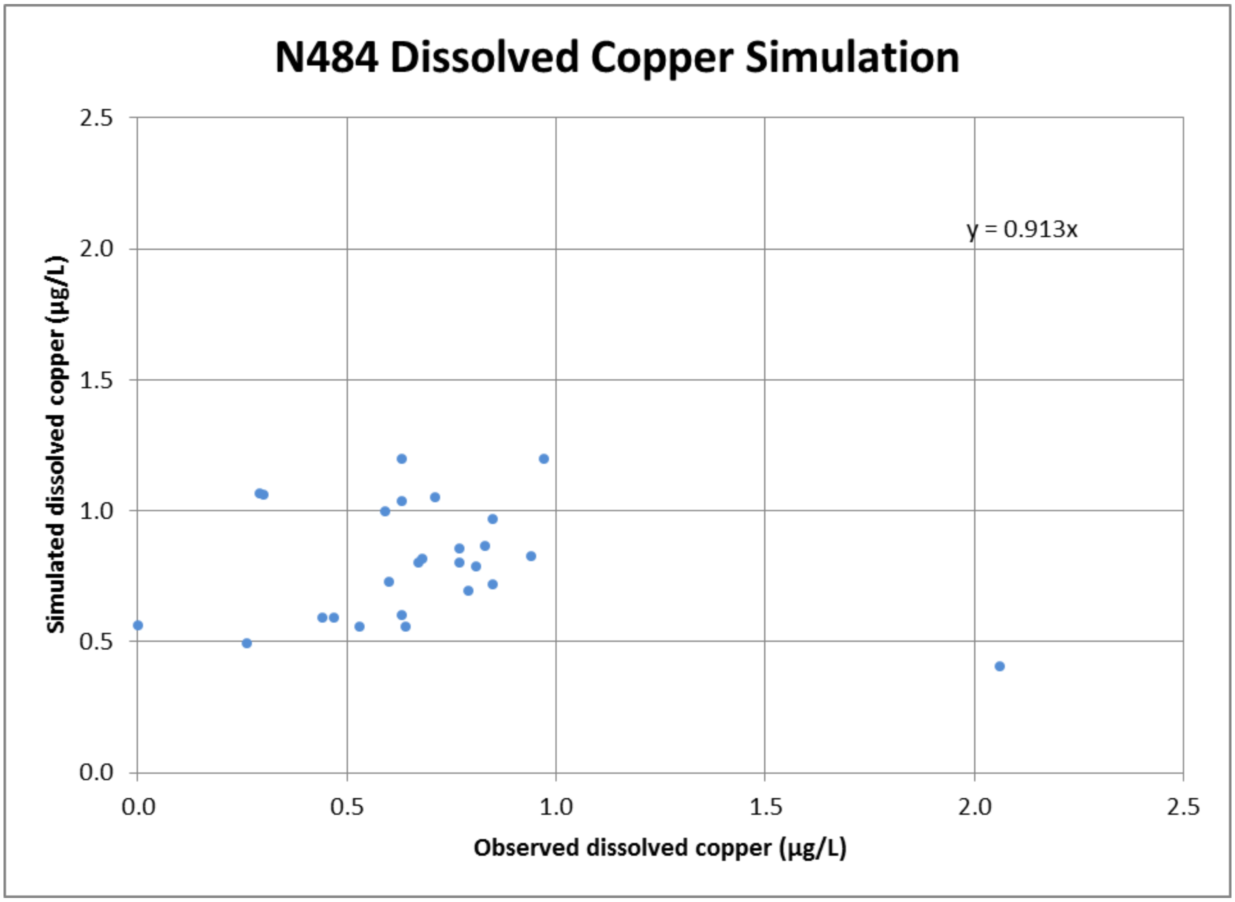

Figure 144 Water quality station N484 dissolved copper calibration regression

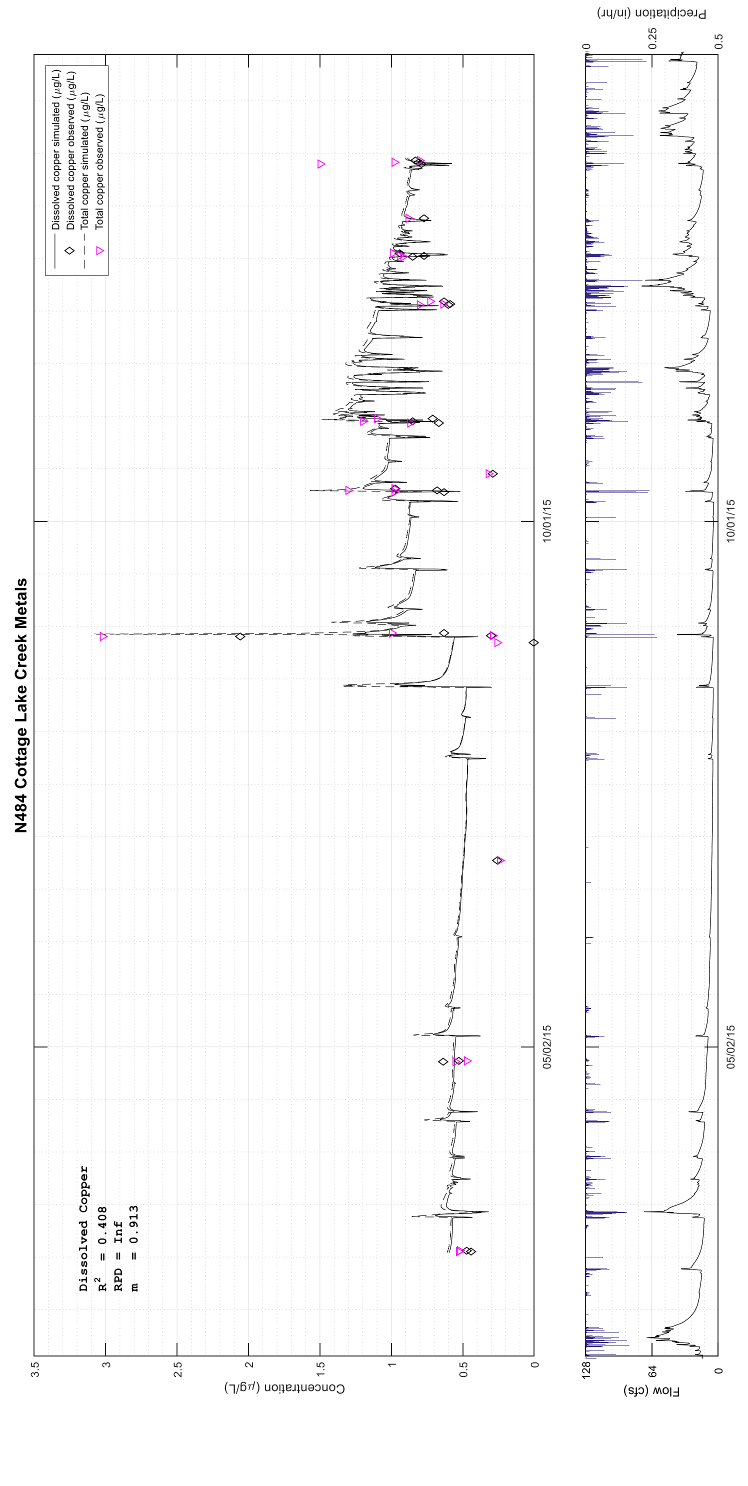

Figure 145 Water quality station N484 copper time series plot

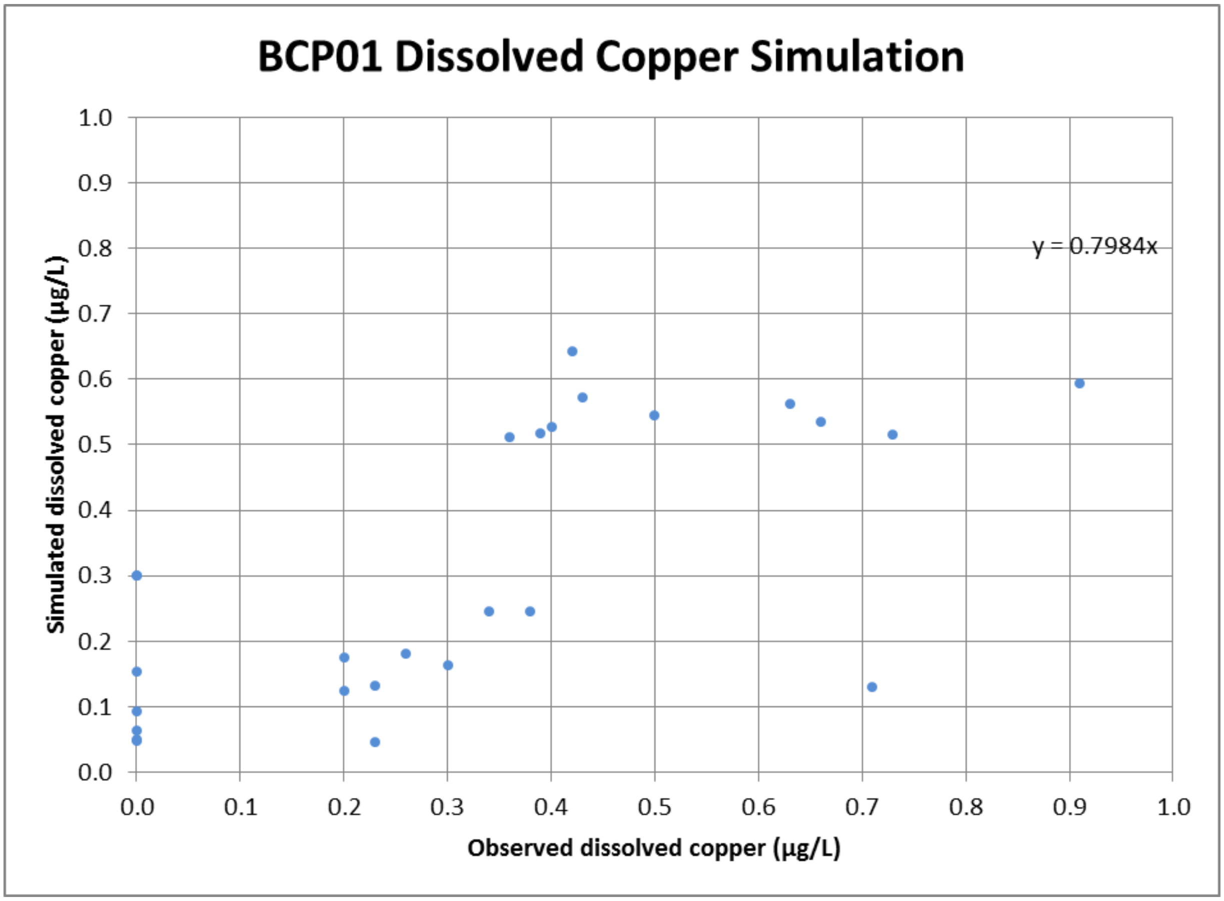

Figure 146 Water quality station BCP01 dissolved copper calibration regression

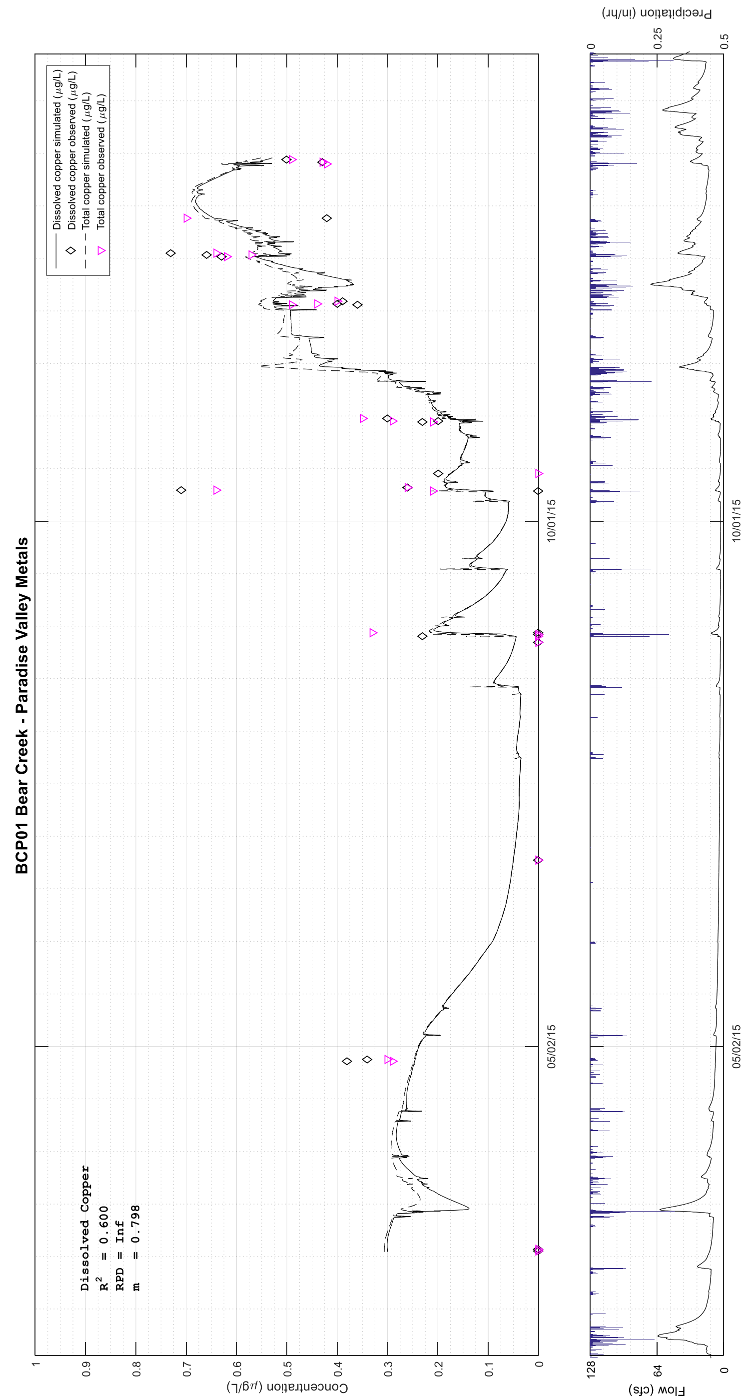

Figure 147 Water quality station BCP01 copper time series plot

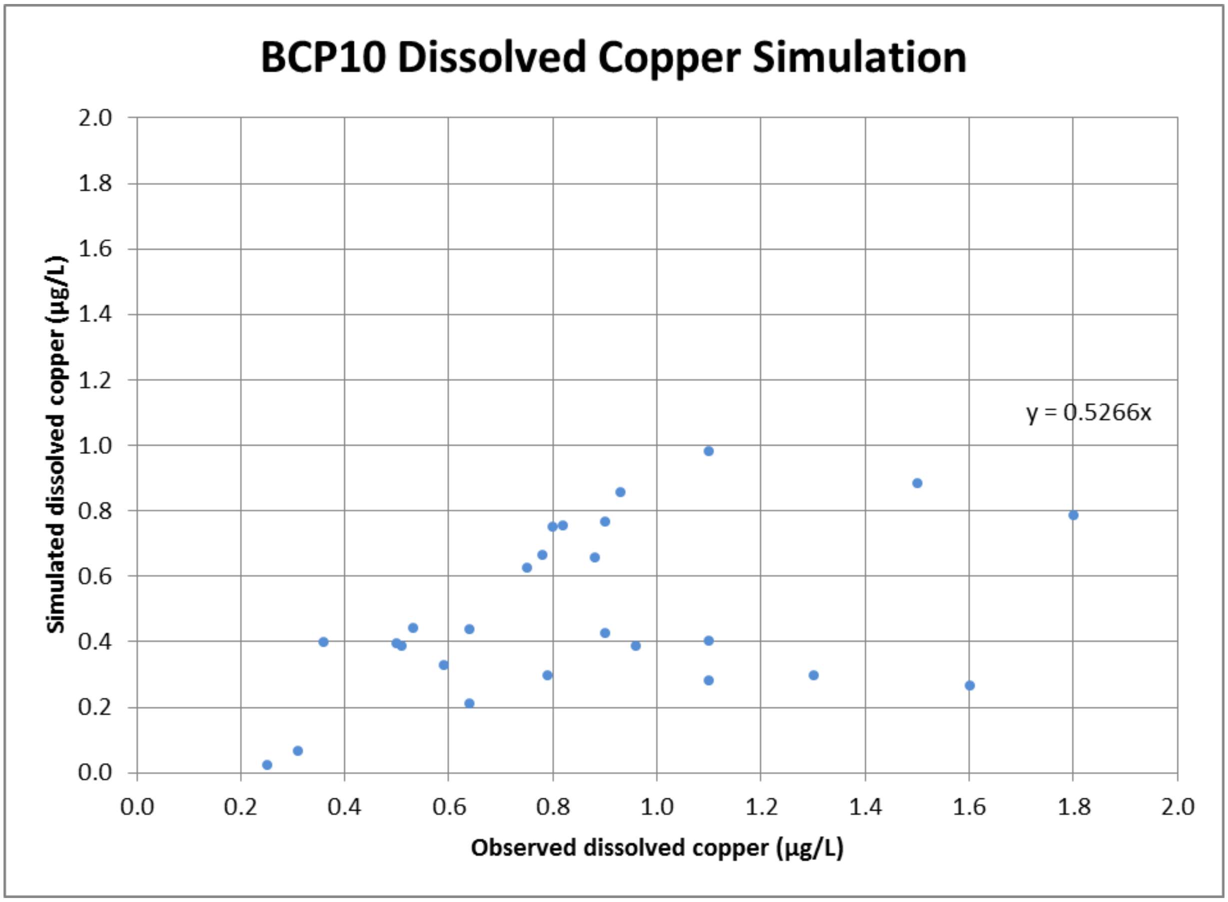

Figure 148 Water quality station BCP10 dissolved copper calibration regression

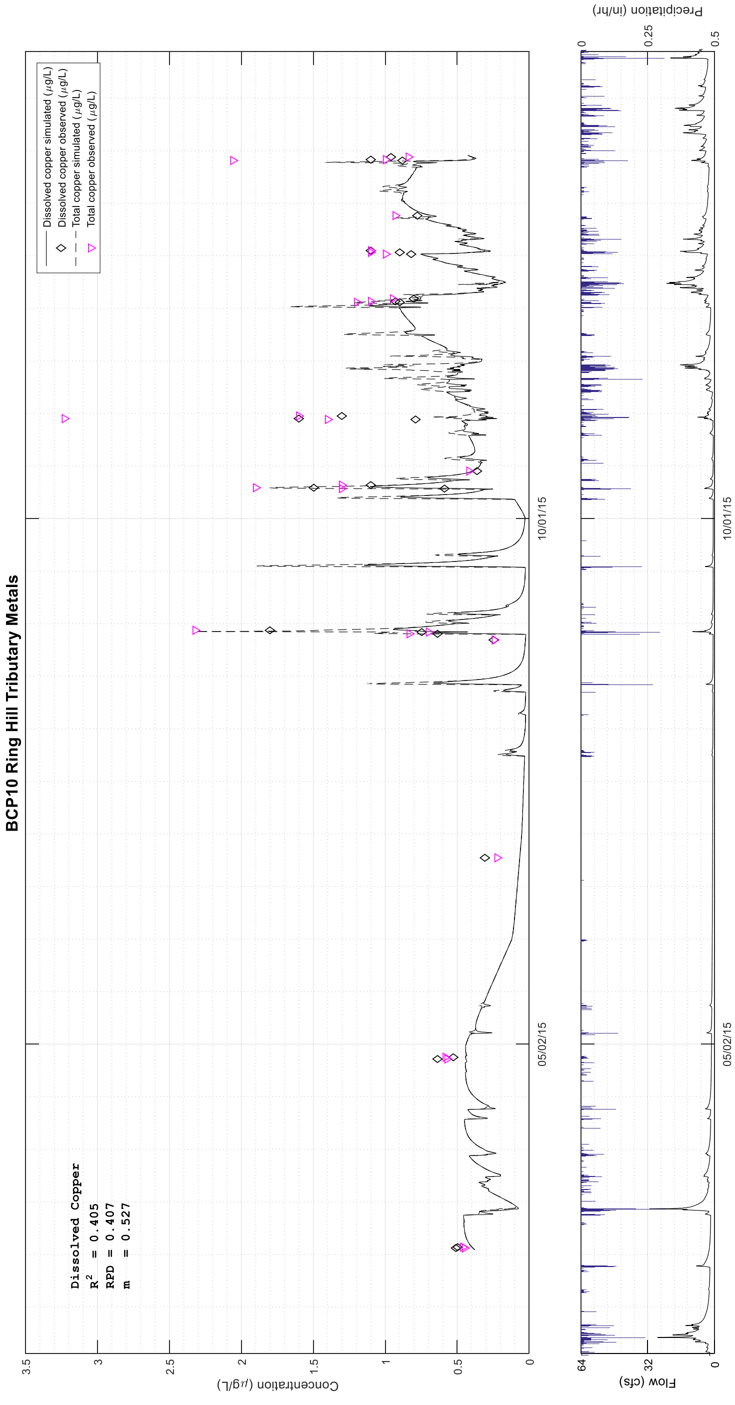

Figure 149 Water quality station BCP10 copper time series plot

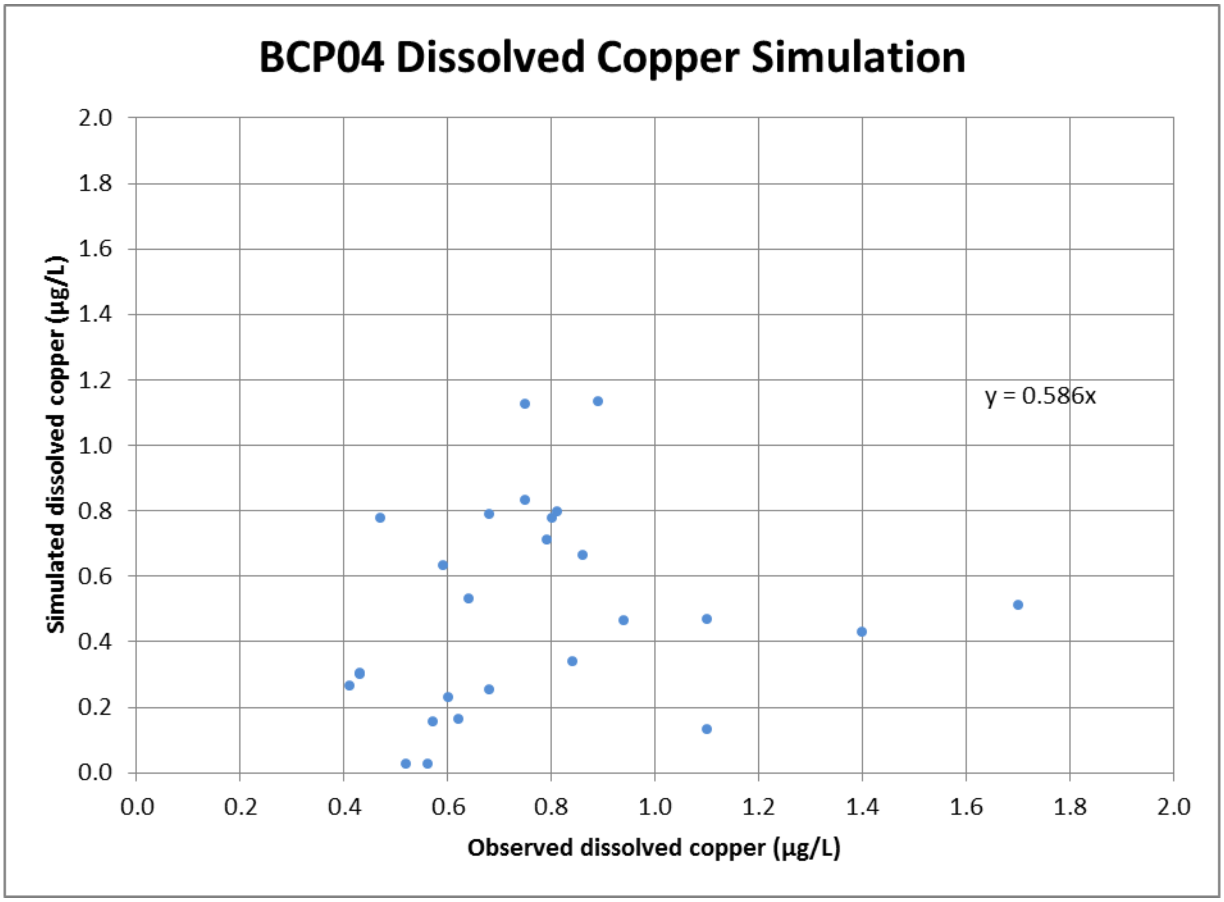

Figure 150 Water quality station BCP04 dissolved copper calibration regression

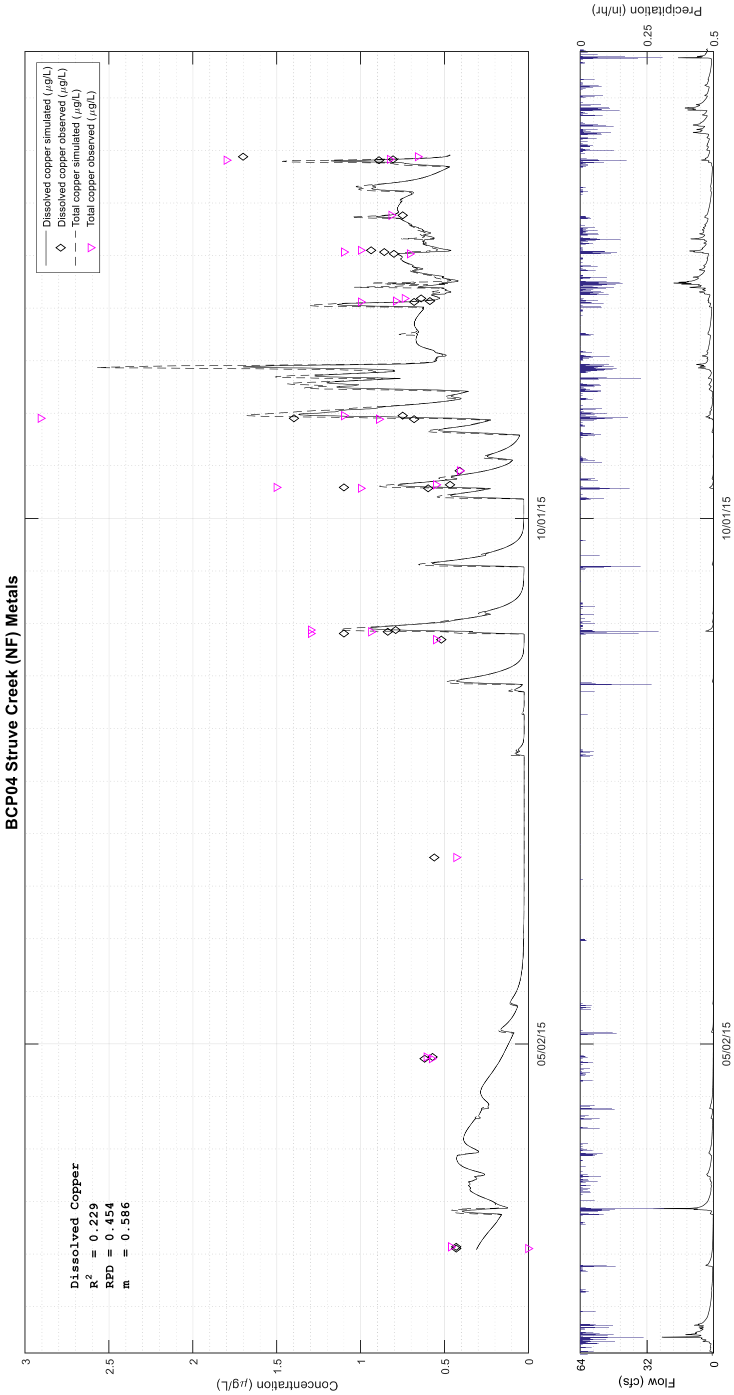

Figure 151 Water quality station BCP04 copper time series plot

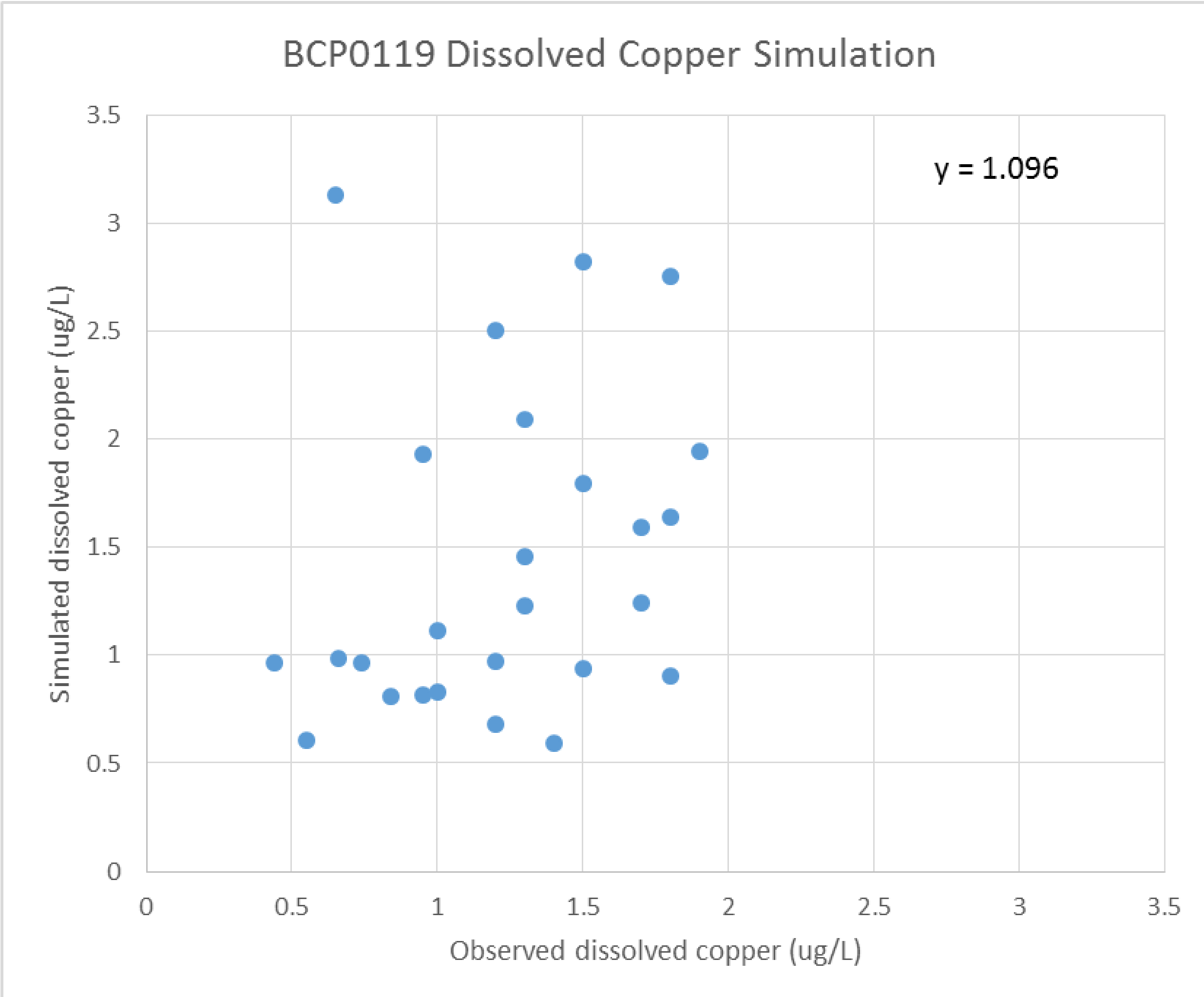

Figure 152 Water quality station BCP0119 dissolved copper scatter plot calibration.

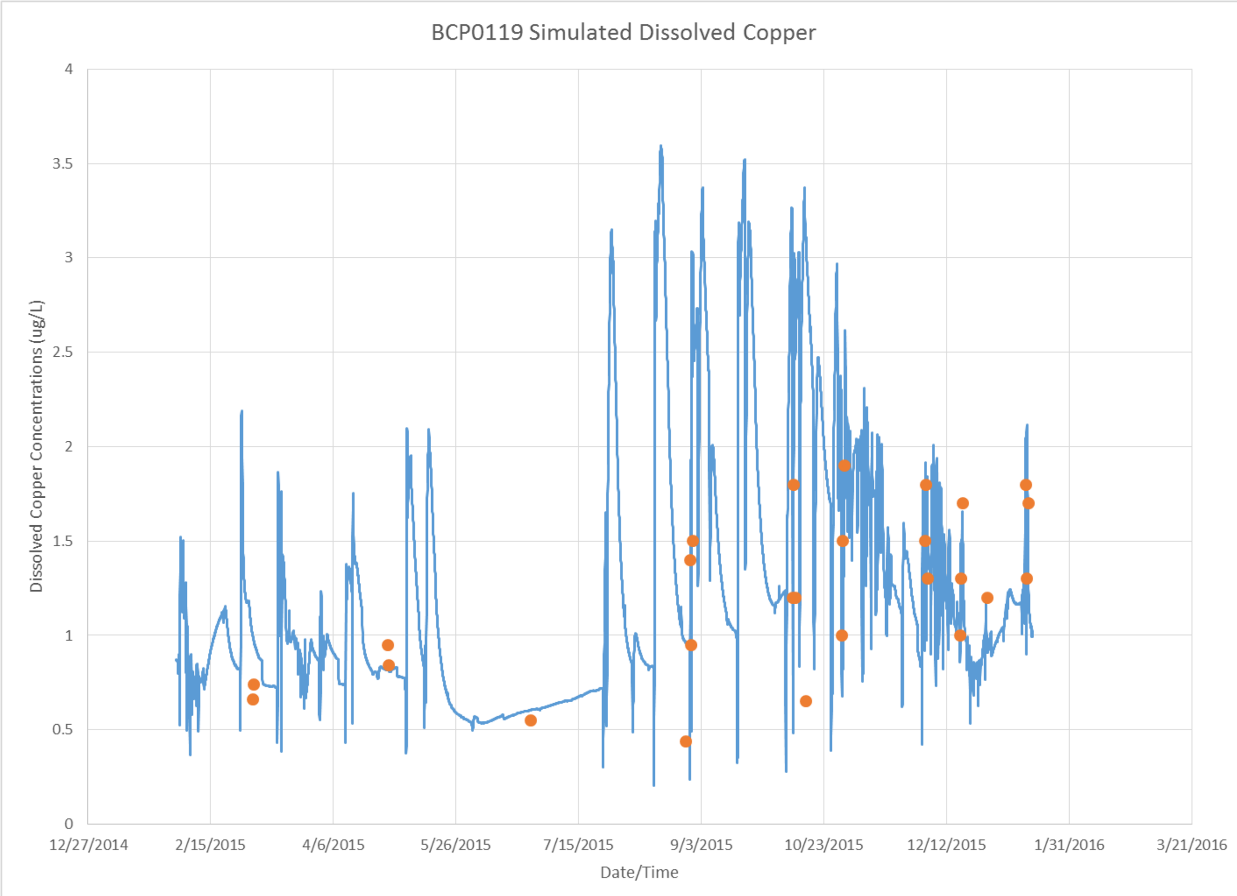

Figure 153 Water quality station BCP0119 copper time series plot. Red circles are observed dissolved copper concentrations.

APPENDIX G: Zinc Calibration

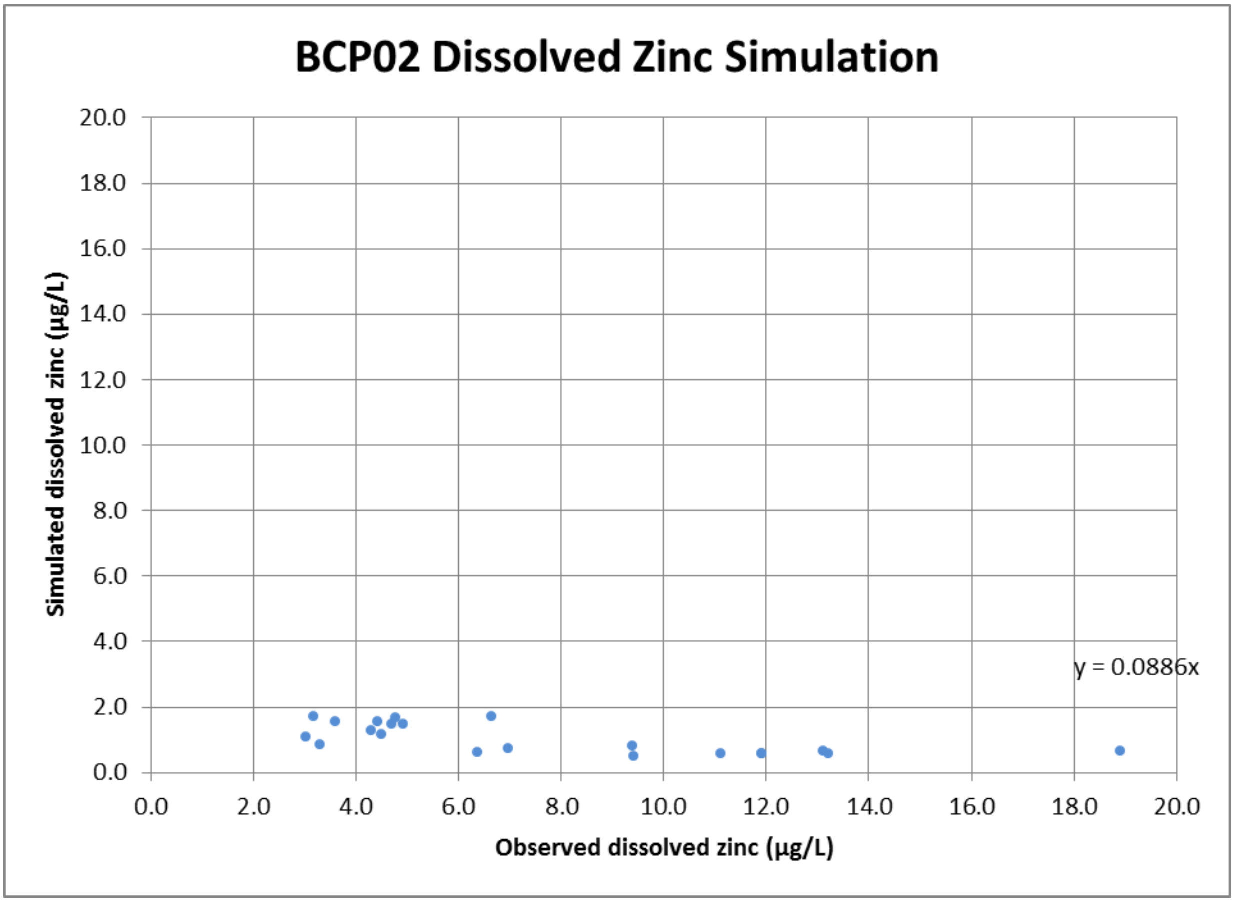

Figure 154 Water quality station BCP02 dissolved zinc calibration regression

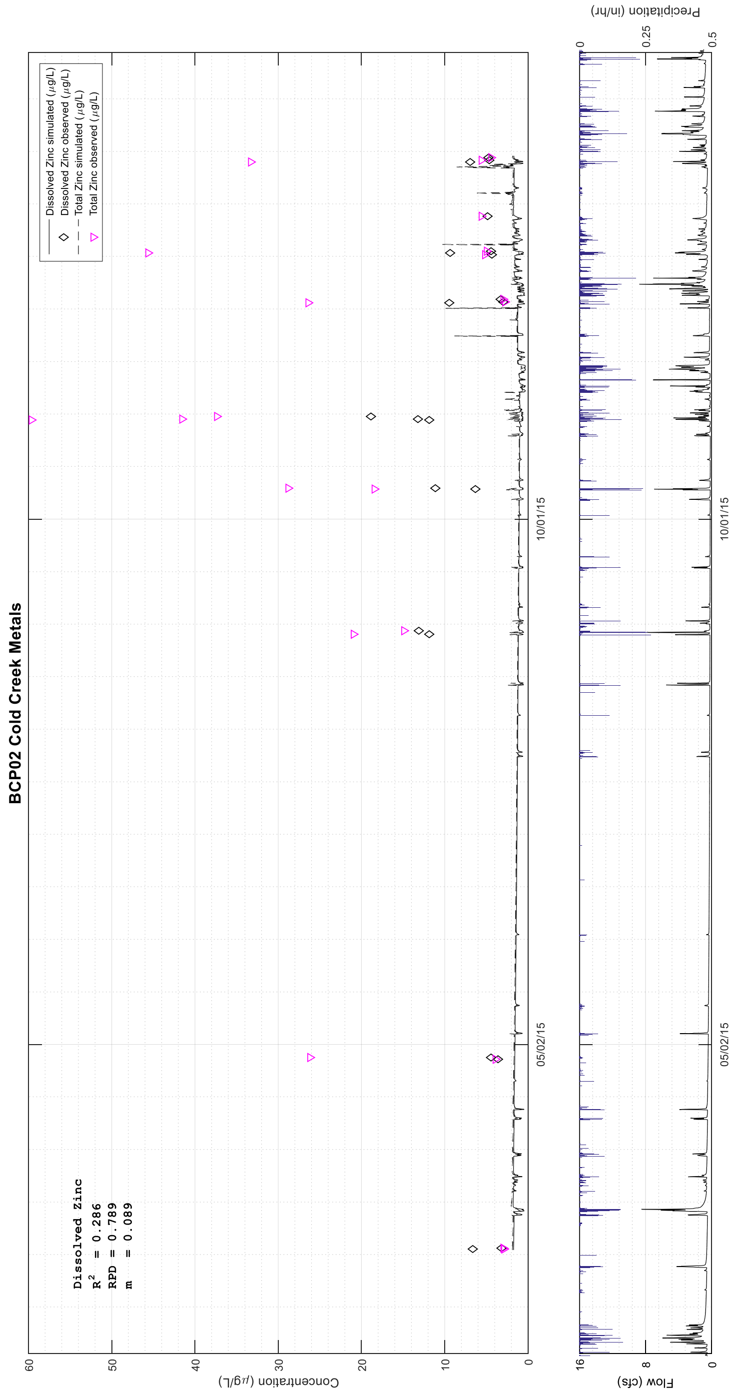

Figure 155 Water quality station BCP02 zinc time series plot

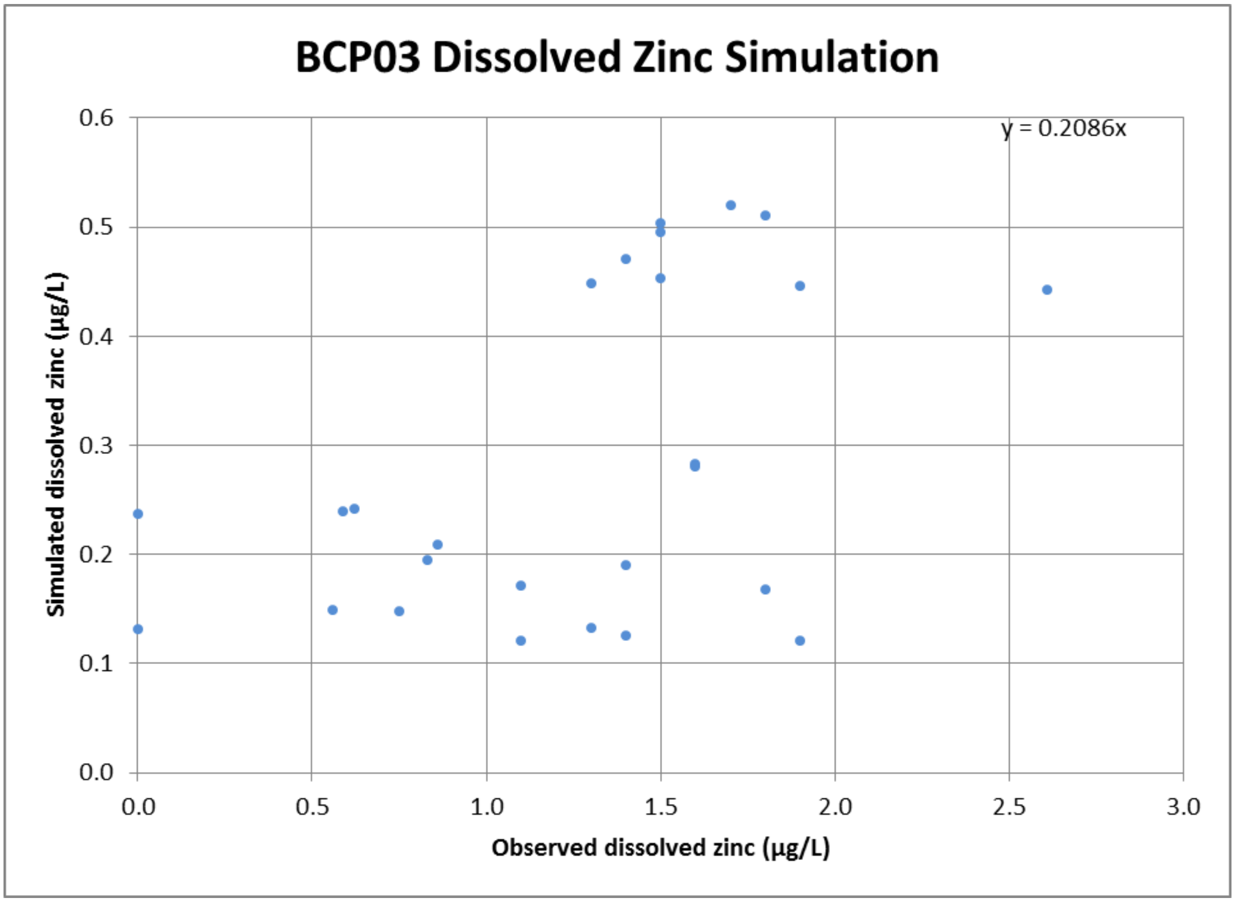

Figure 156 Water quality station BCP03 dissolved zinc calibration regression

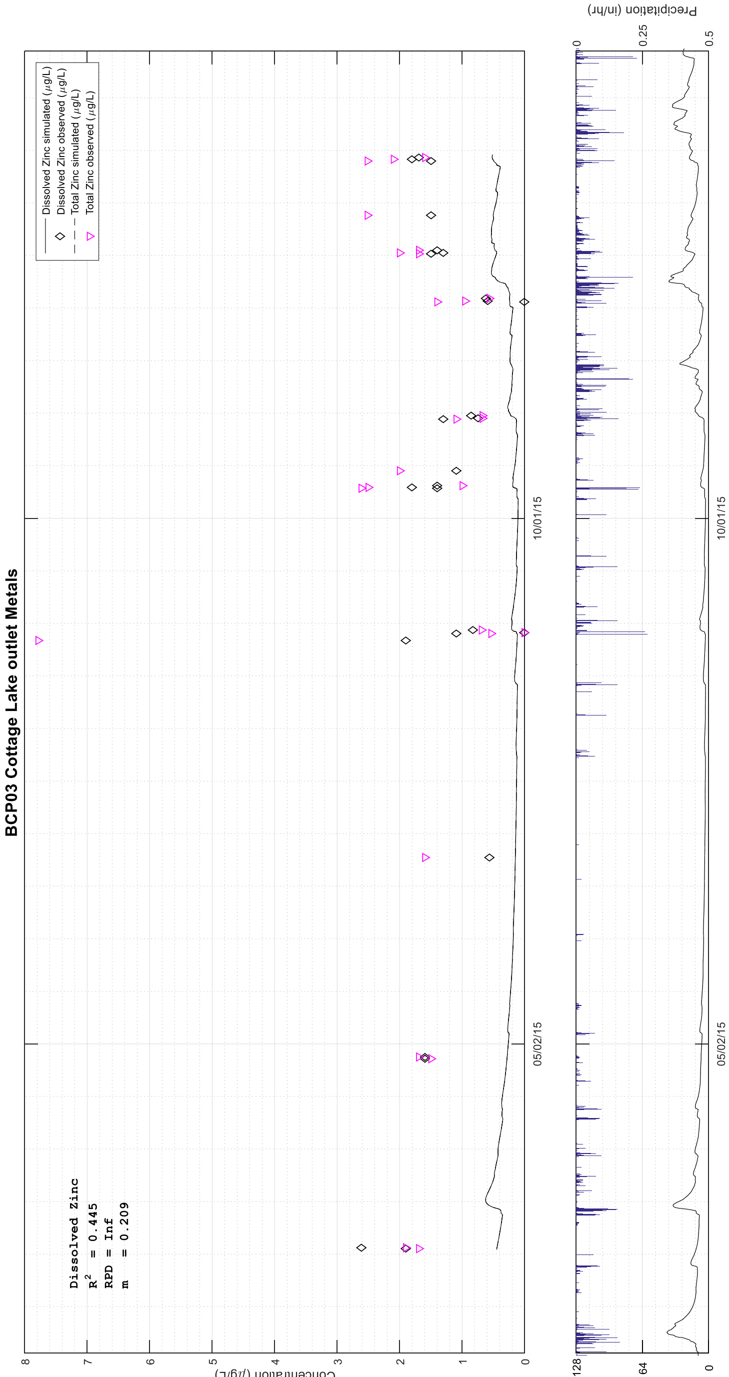

Figure 157 Water quality station BCP03 zinc time series plot

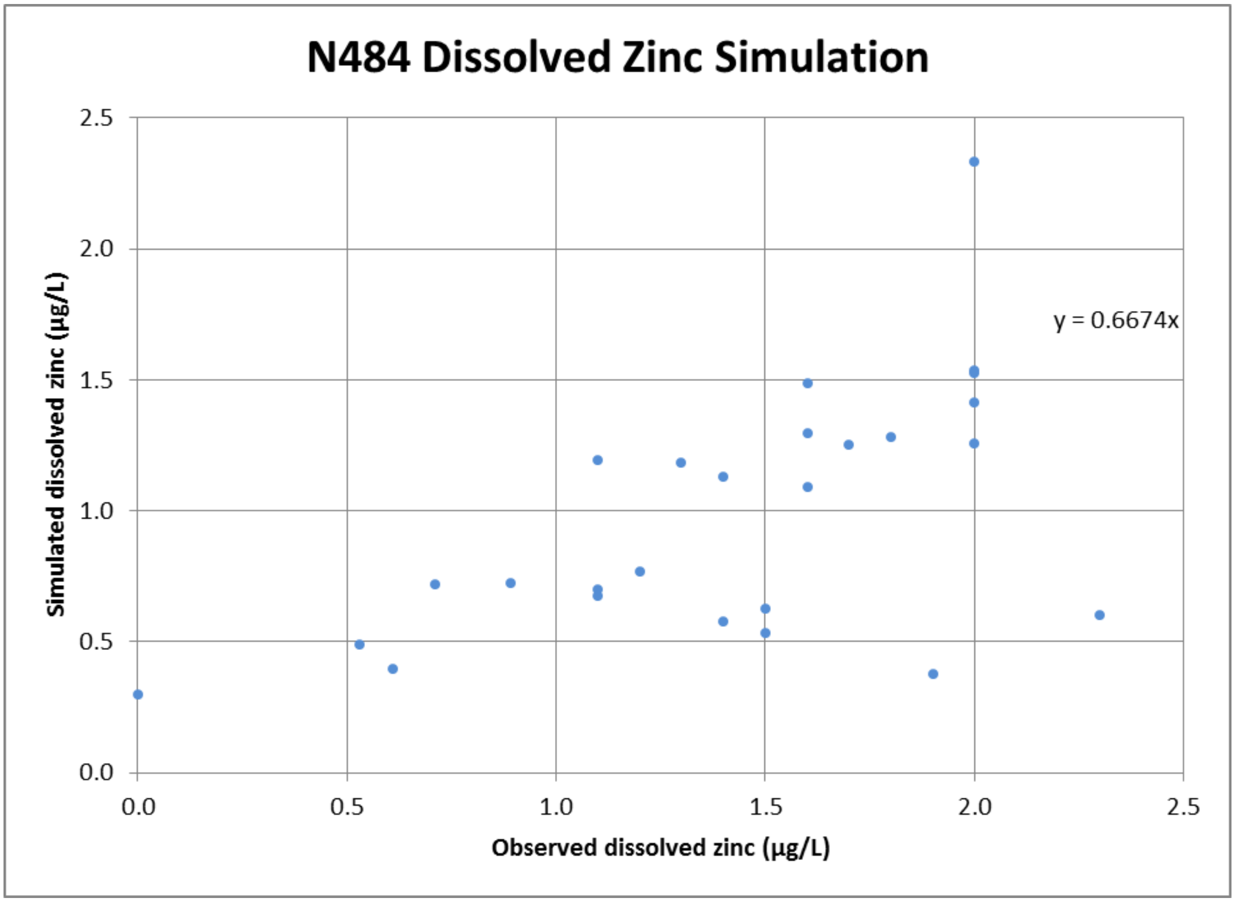

Figure 158 Water quality station N484 dissolved zinc calibration regression

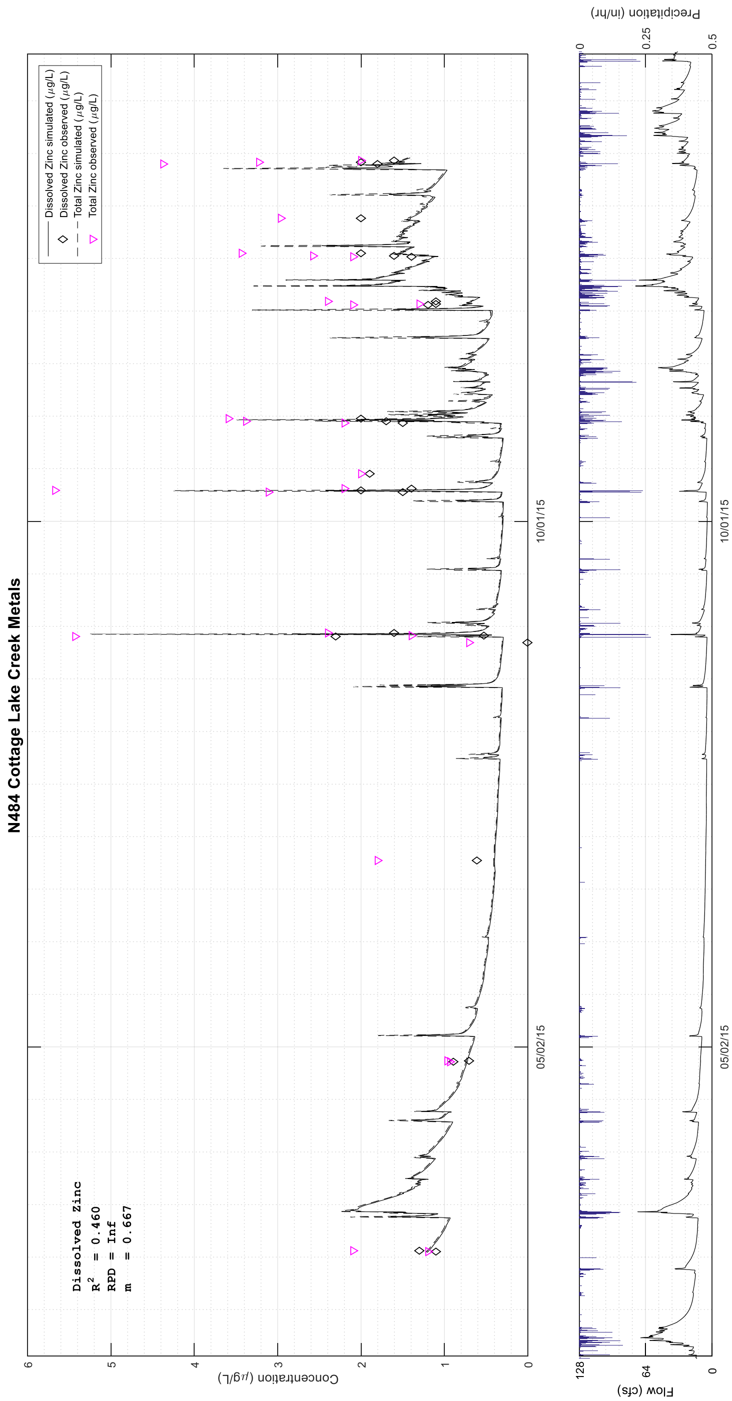

Figure 159 Water quality station N484 zinc time series plot

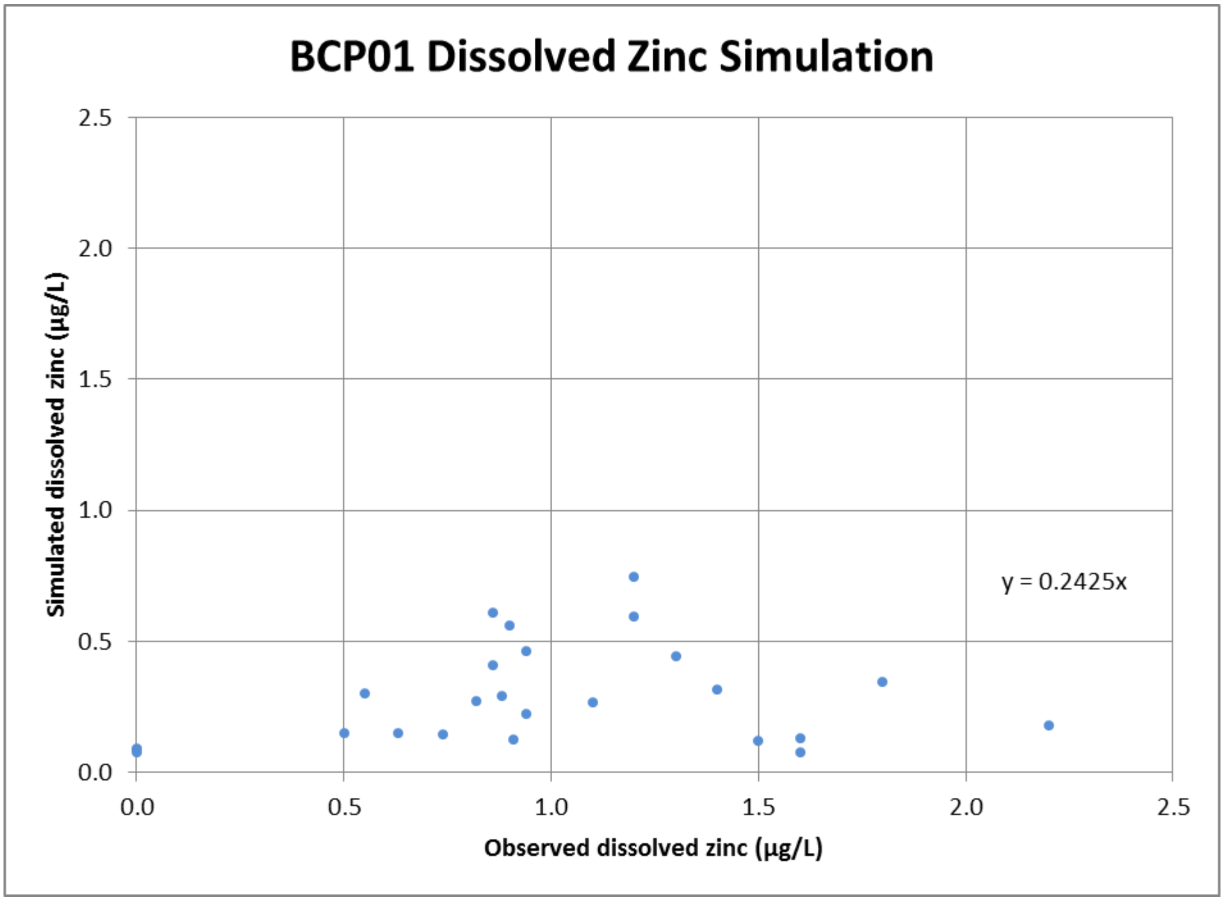

Figure 160 Water quality station BCP01 dissolved zinc calibration regression

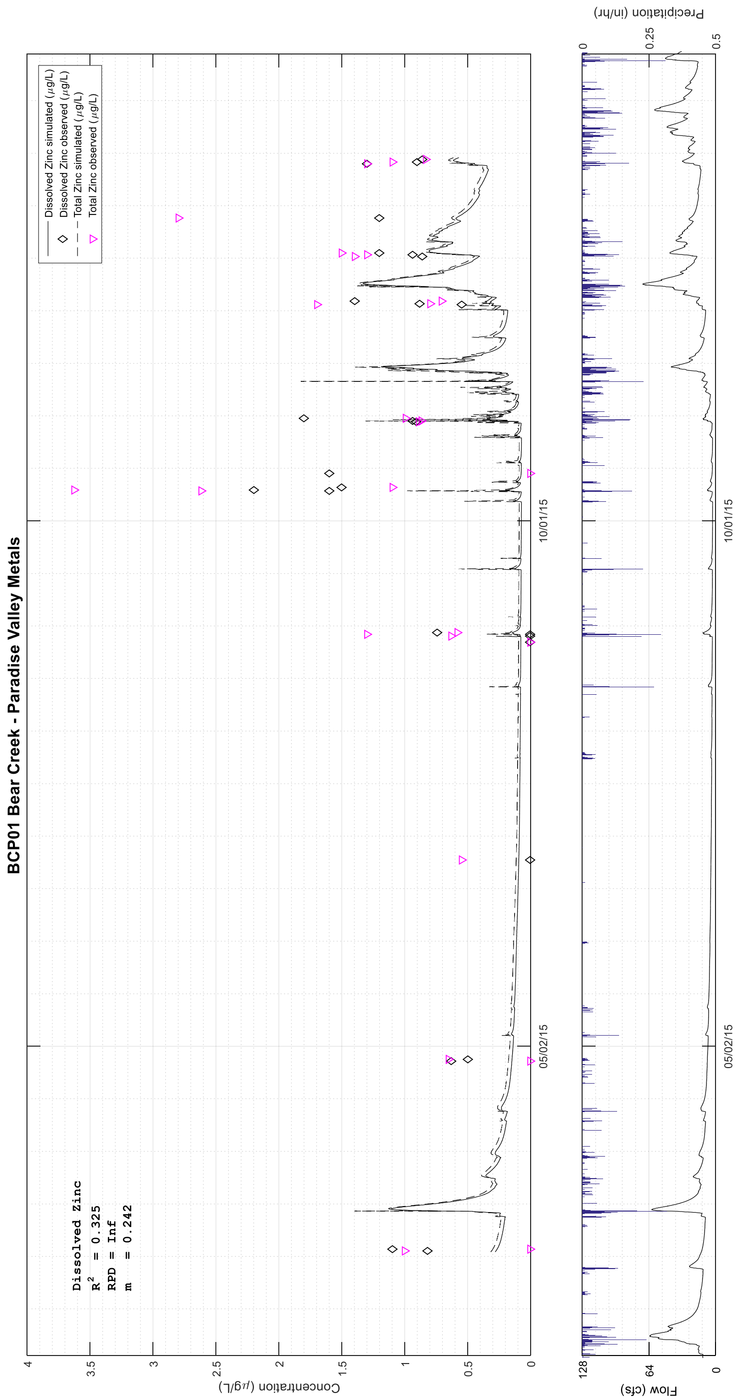

Figure 161 Water quality station BCP01 zinc time series plot

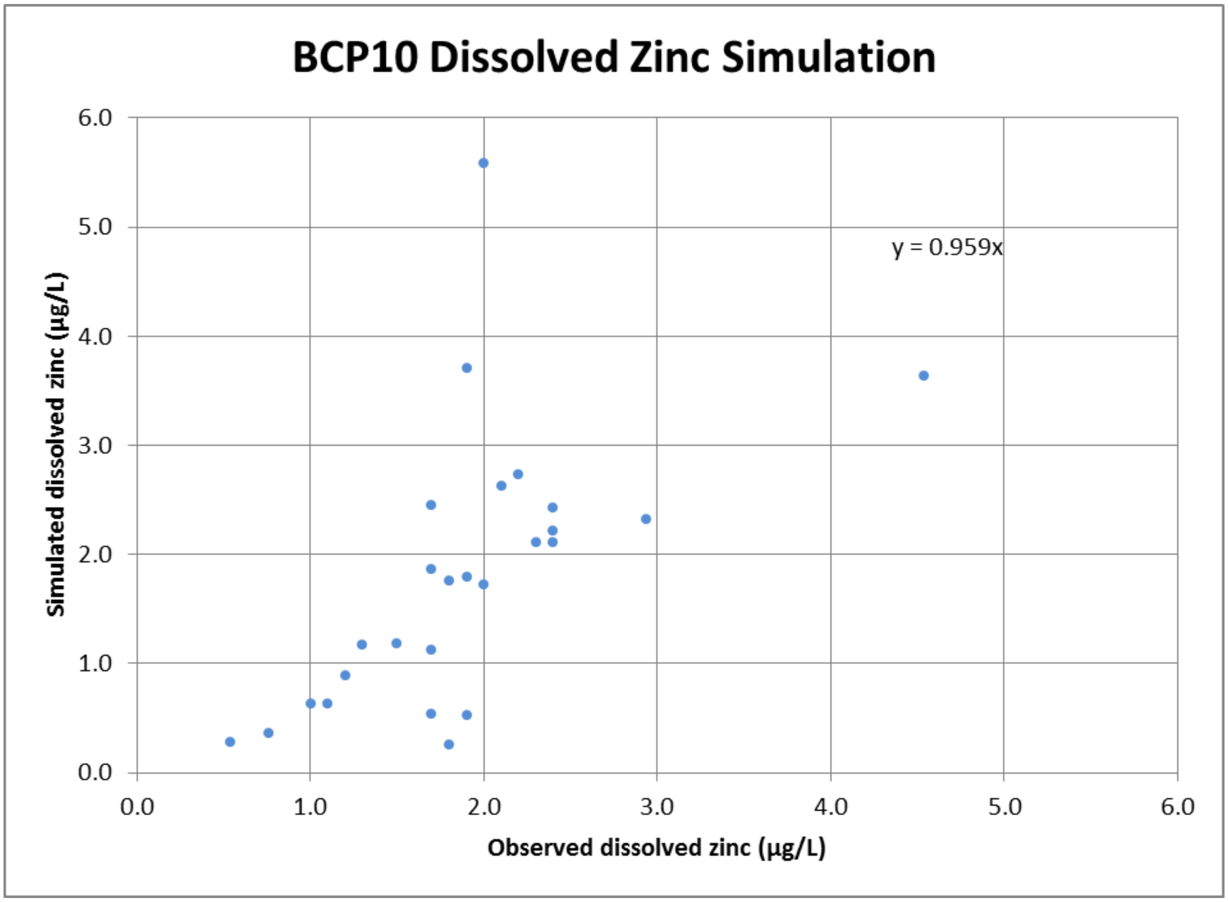

Figure 162 Water quality station BCP10 dissolved zinc calibration regression

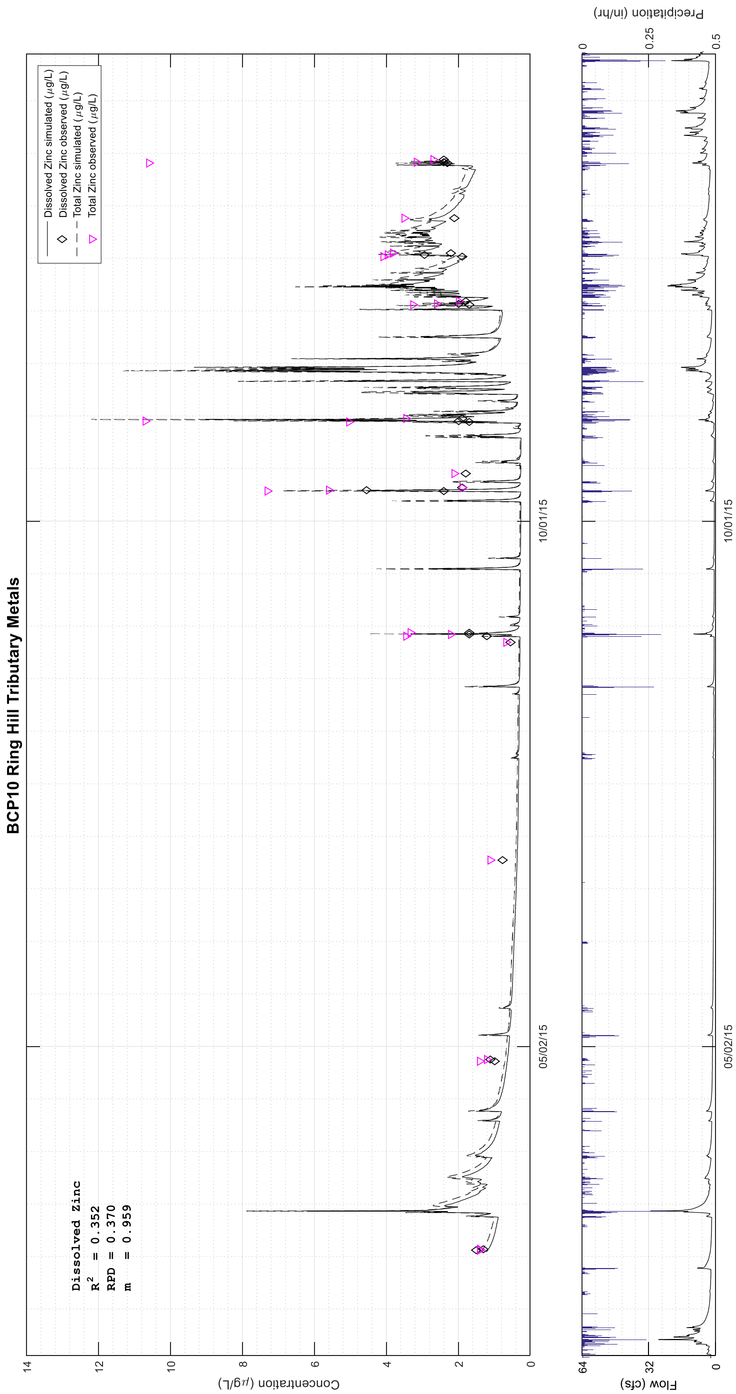

Figure 163 Water quality station BCP10 zinc time series plot

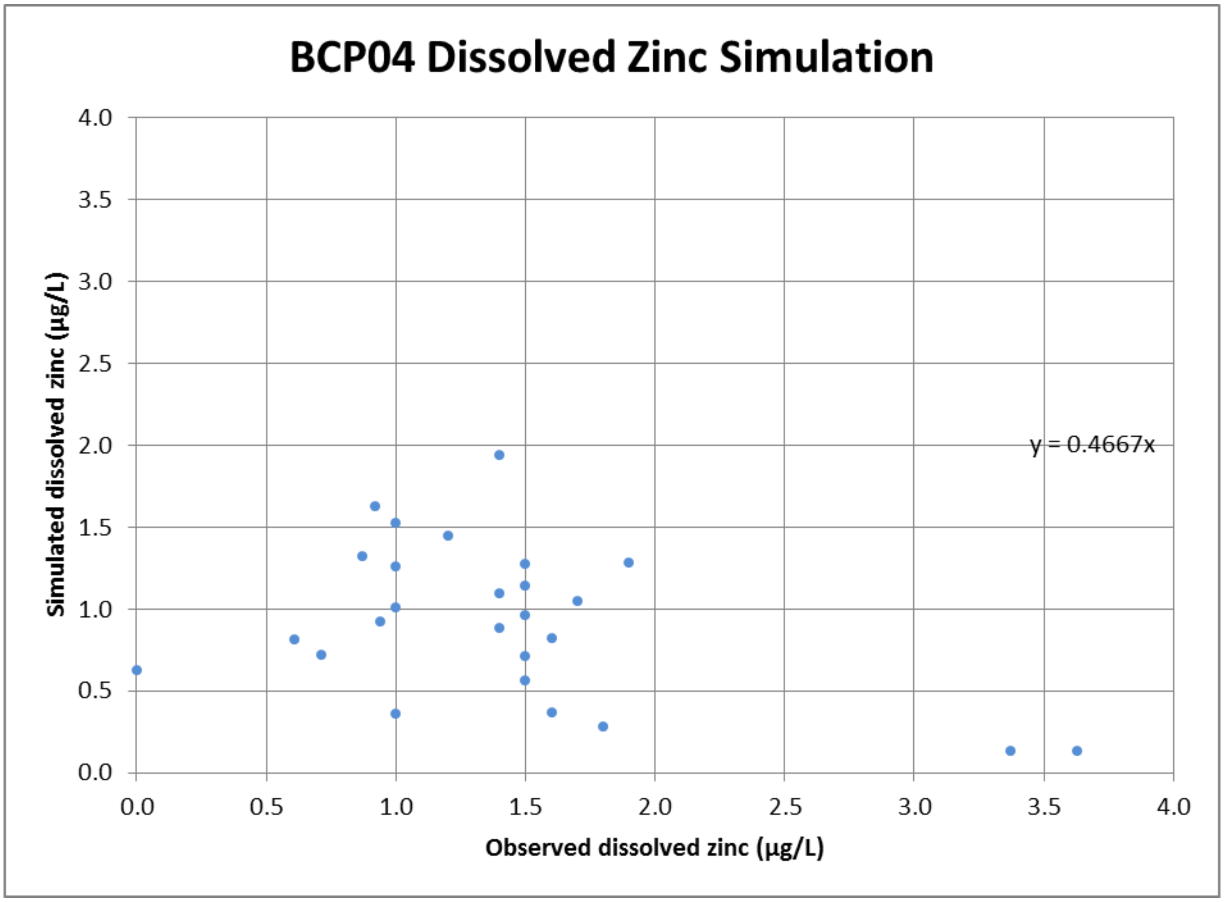

Figure 164 Water quality station BCP04 dissolved zinc calibration regression

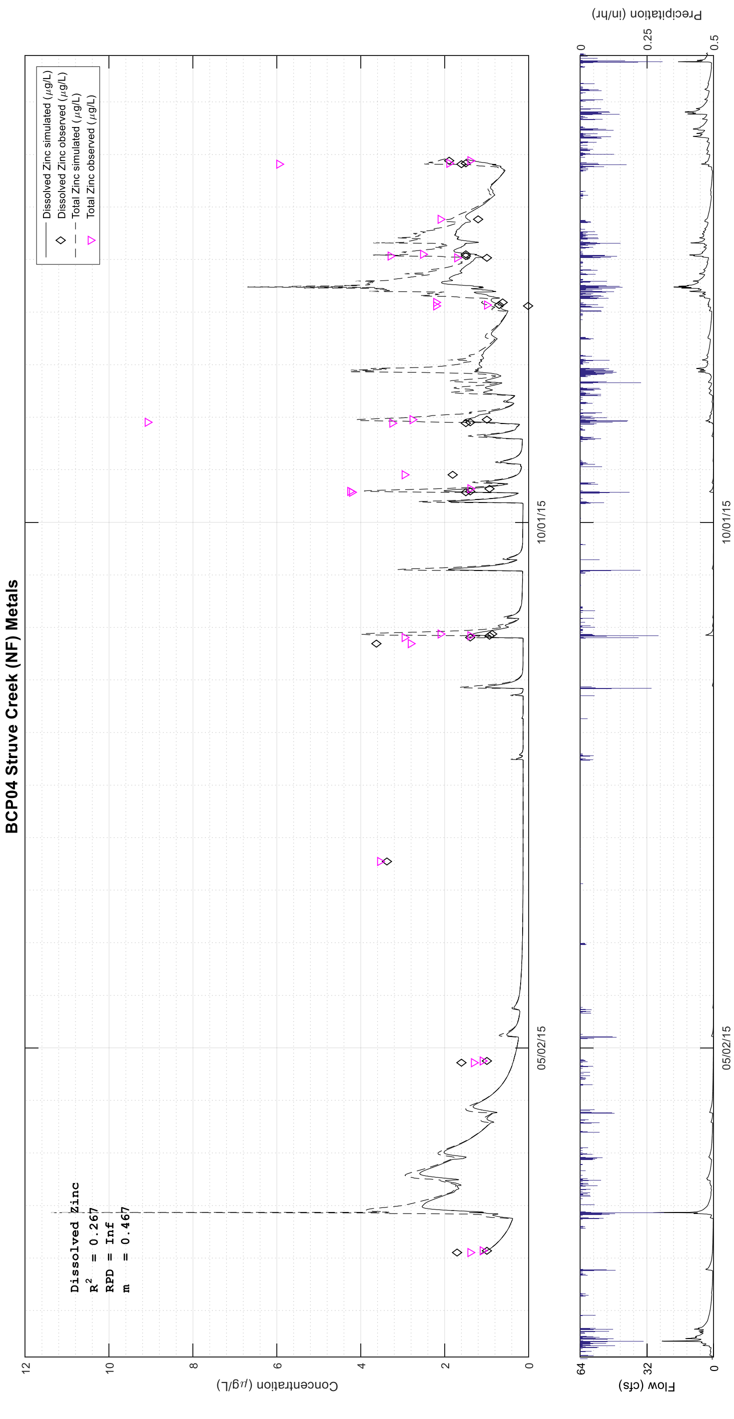

Figure 165 Water quality station BCP04 zinc time series plot

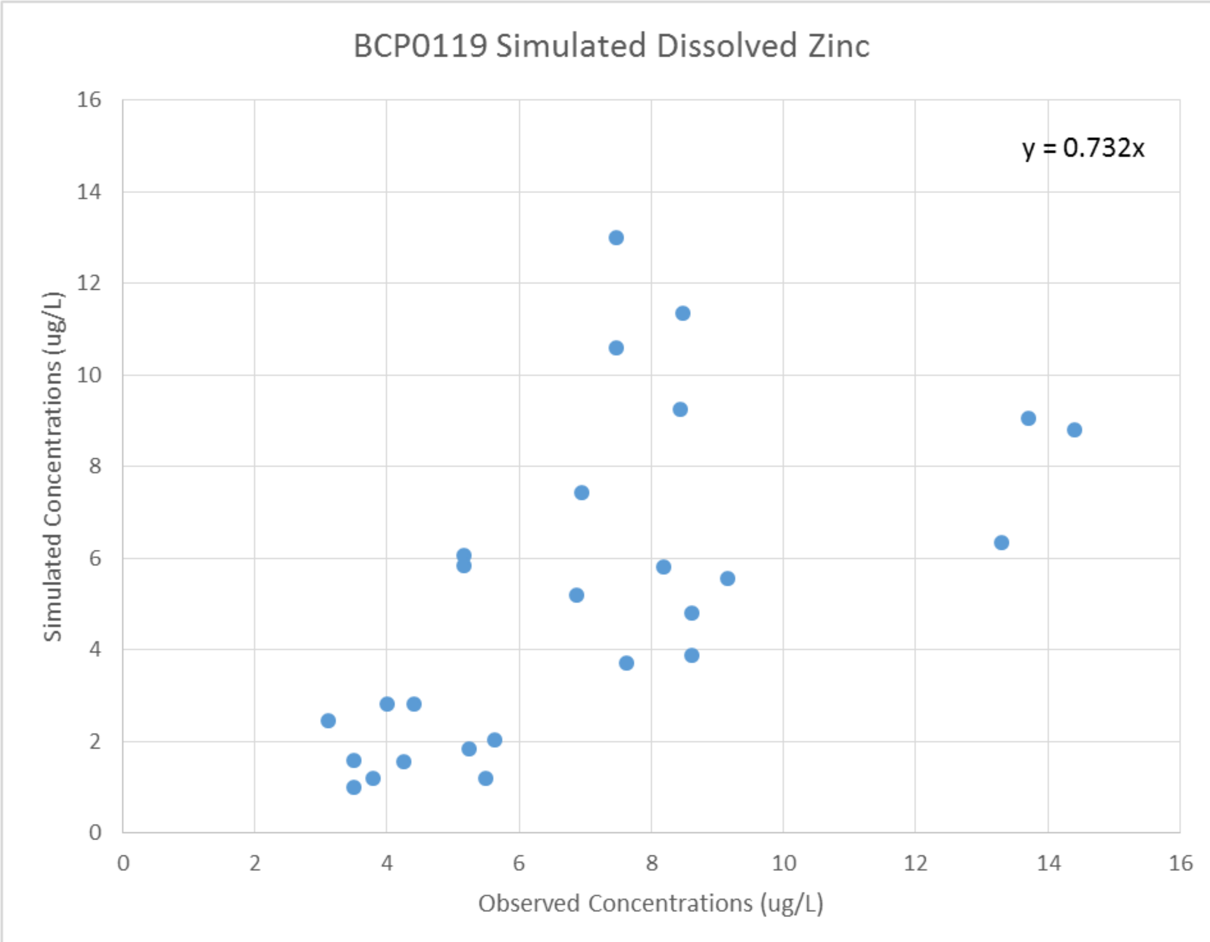

Figure 166 Water quality station BCP0119 zinc scatter plot calibration.

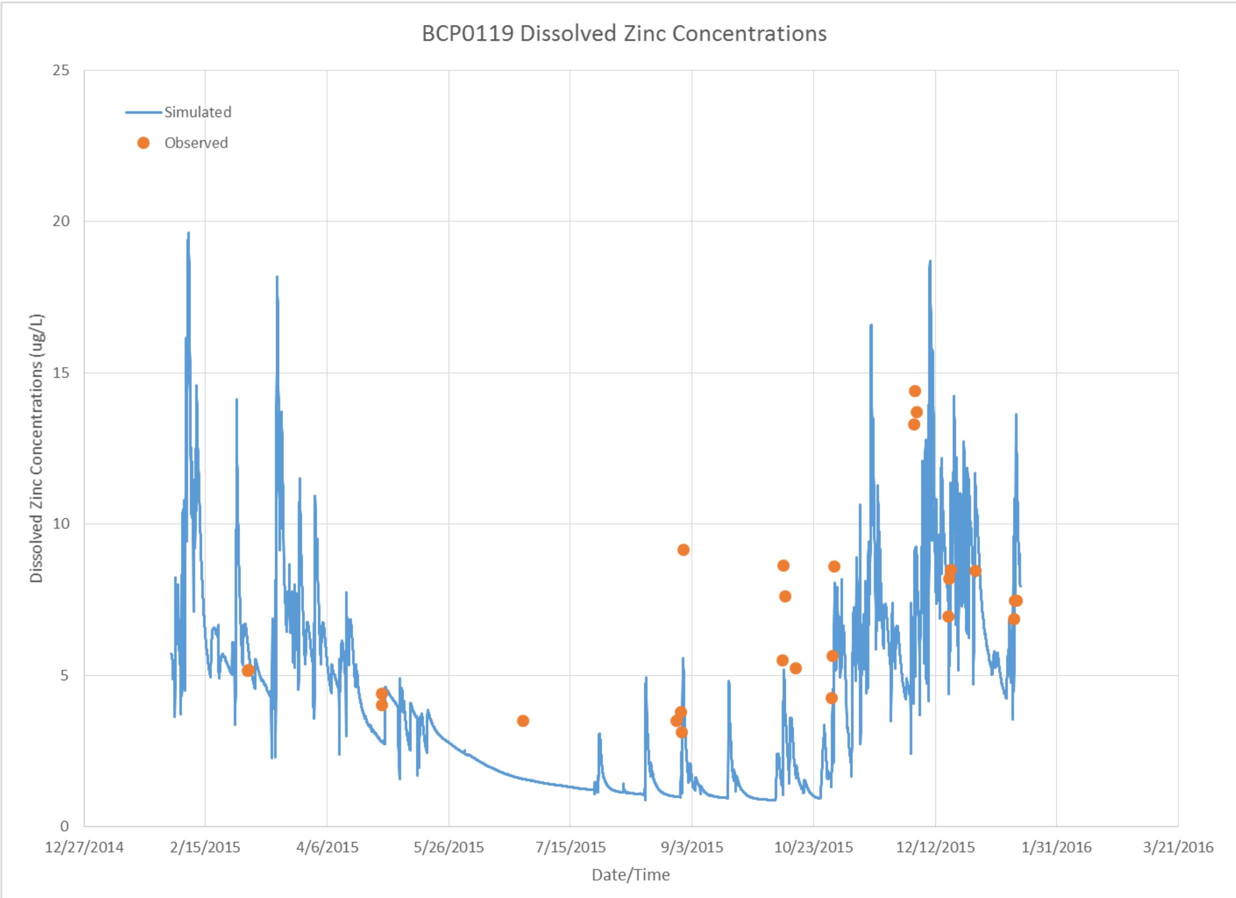

Figure 167 Water quality station BCP0119 zinc calibration time series plot.

APPENDIX H: SUSTAIN Cost-Effectiveness Curves

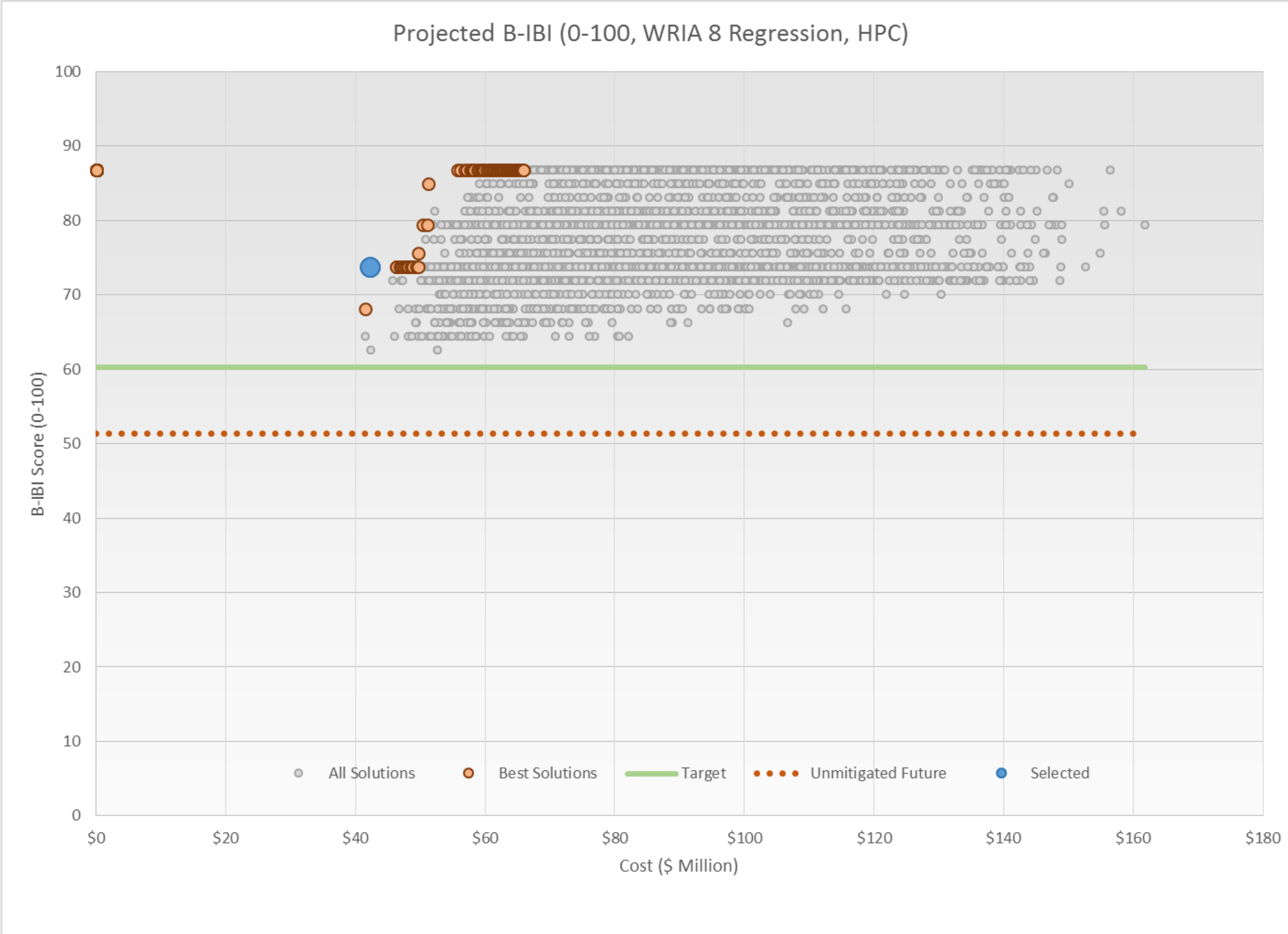

Figure 168 Cost-Effectiveness Curve for BEA020.

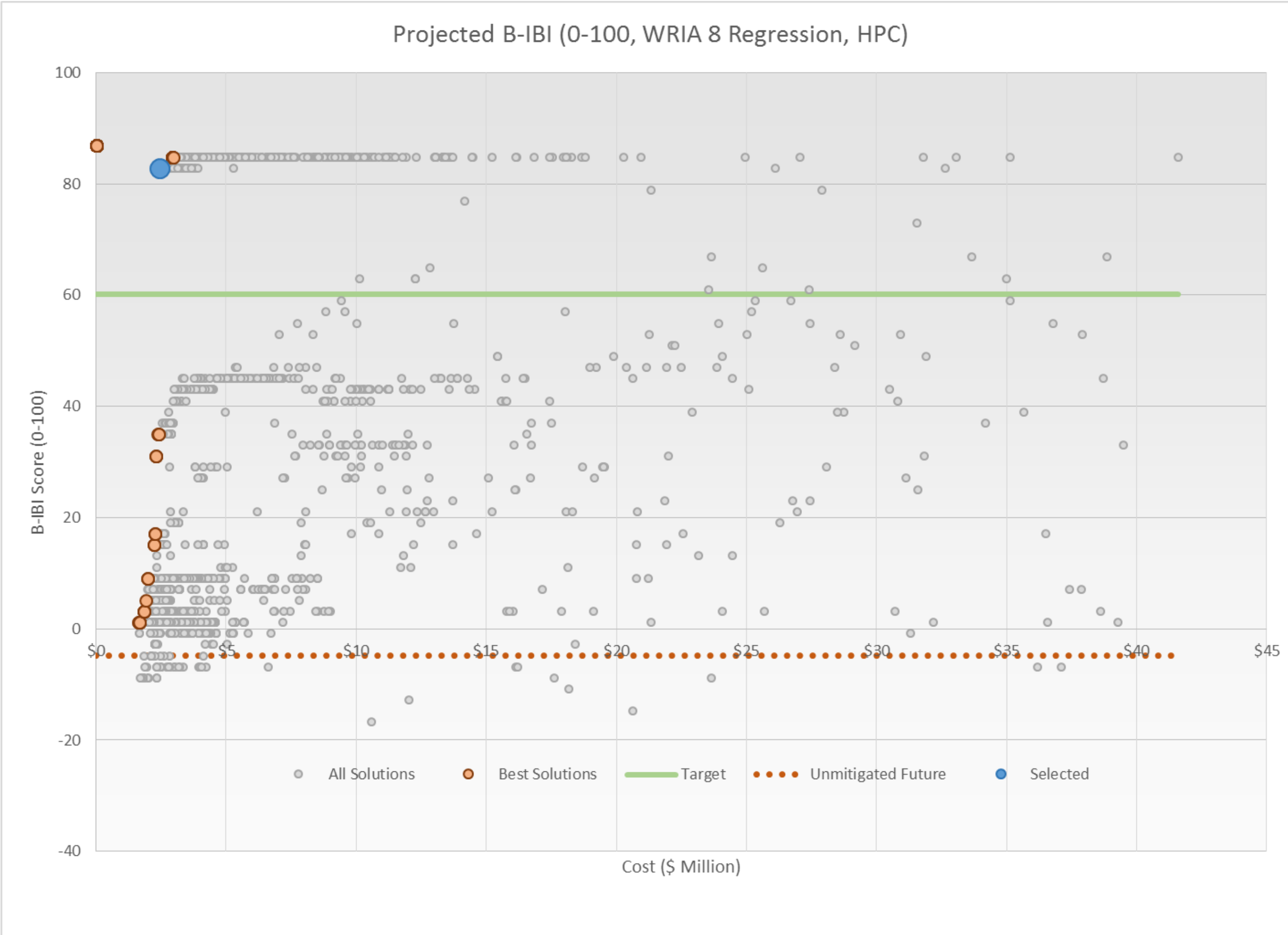

Figure 169 Cost-Effectiveness Curve for BEA110

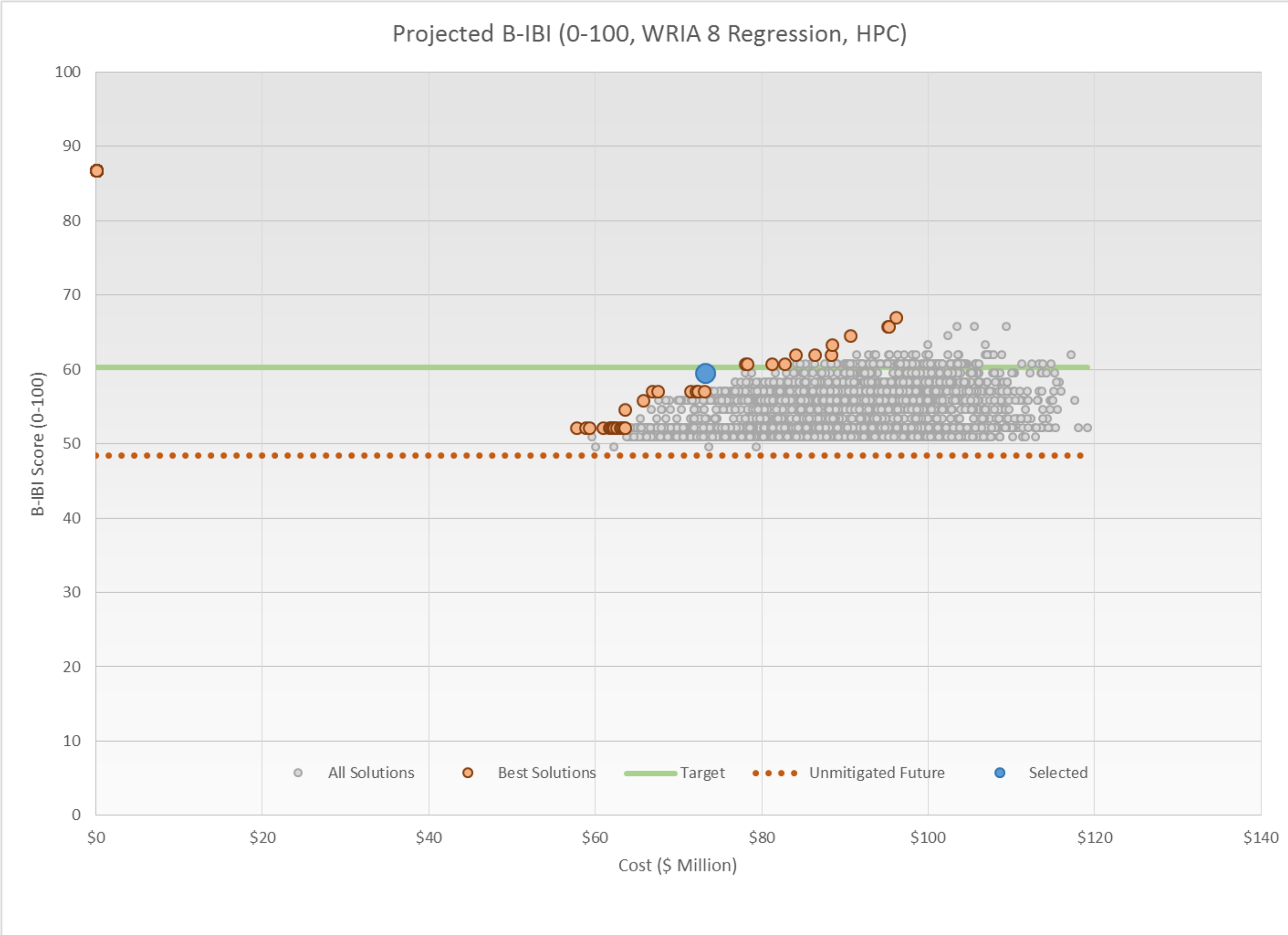

Figure 170 Cost-Effectiveness Curve for BEA120

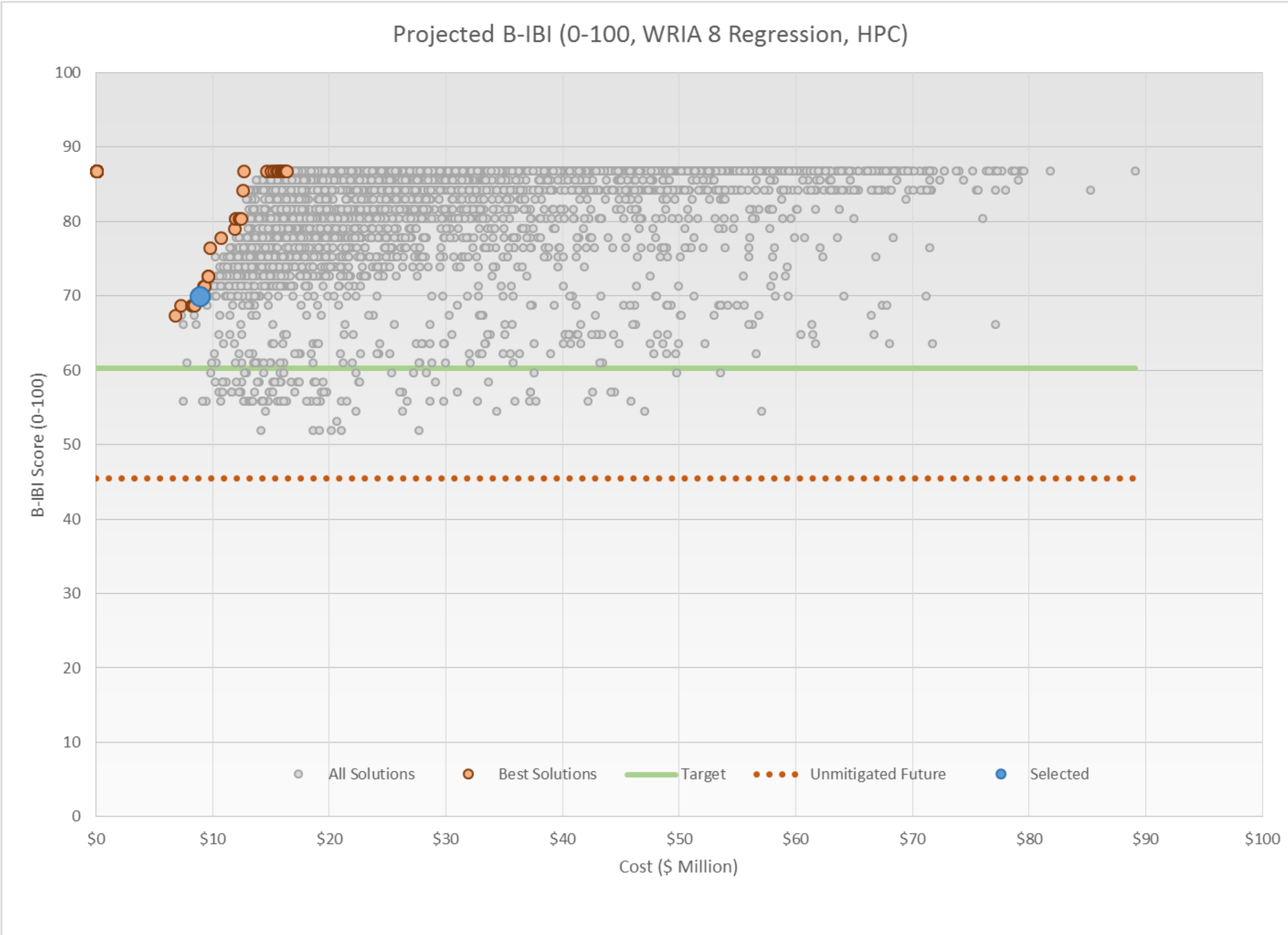

Figure 171 Cost-Effectiveness Curve for BEA210

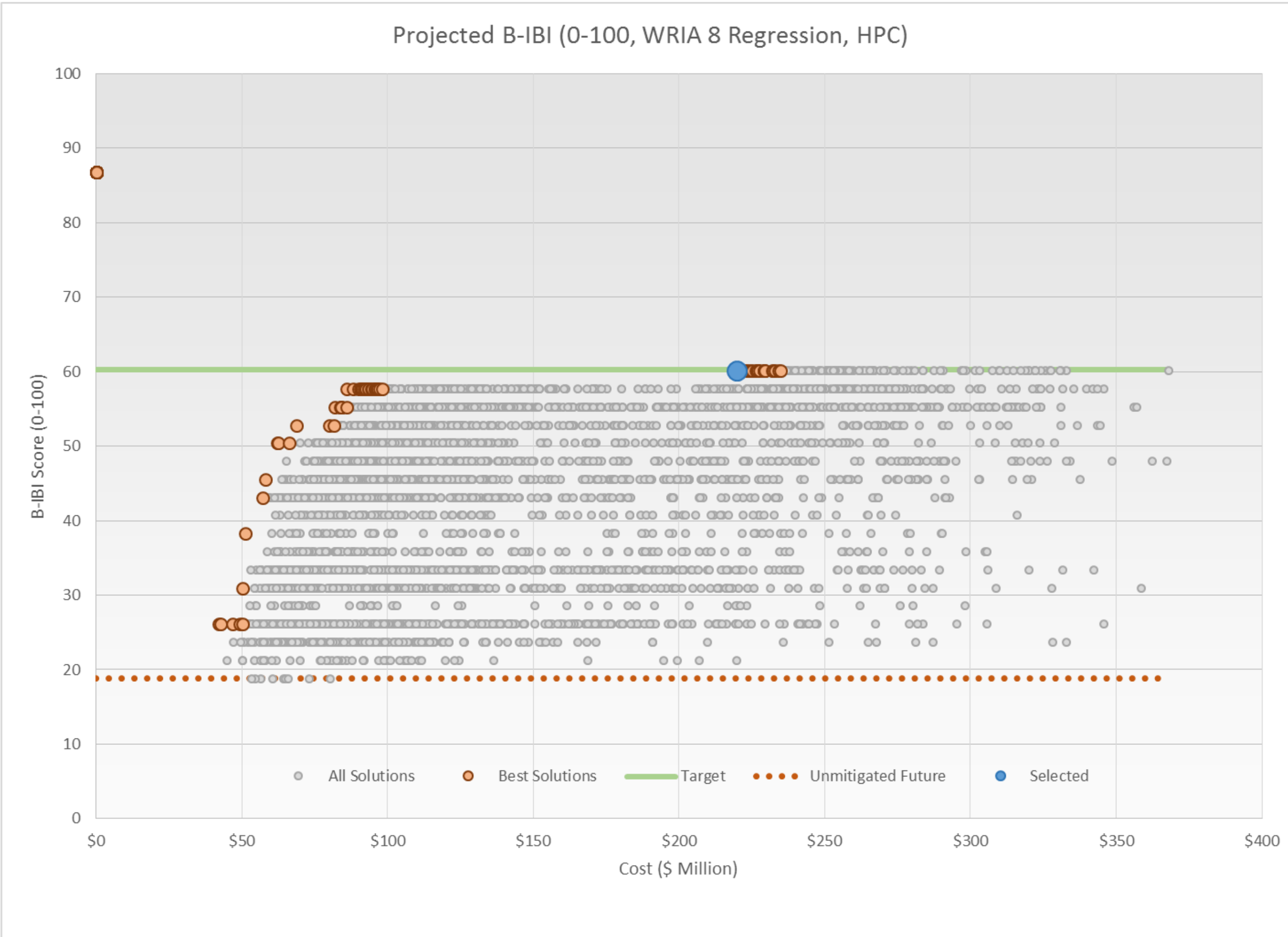

Figure 172 Cost-Effectiveness Curve for BEA240

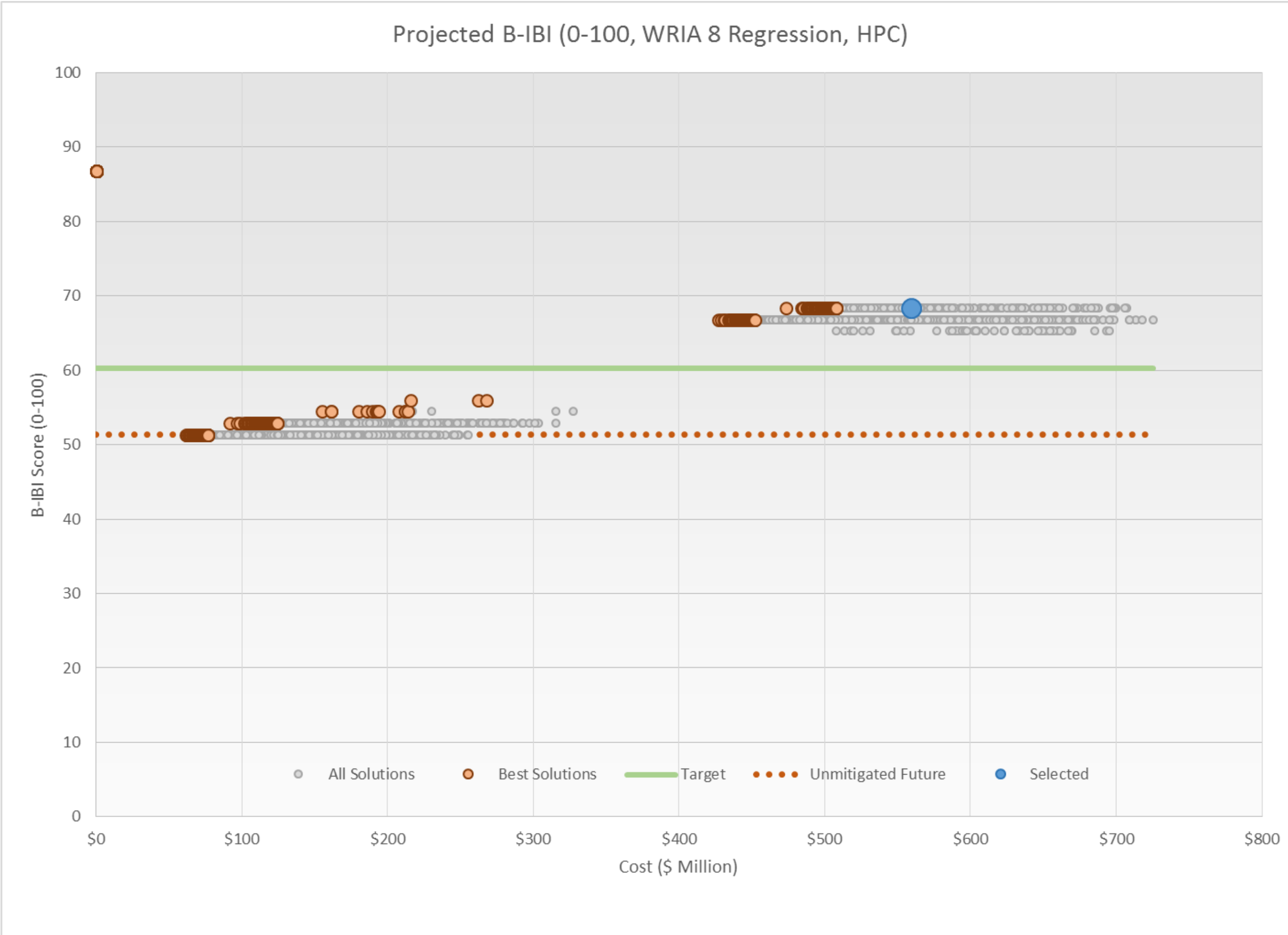

Figure 173 Cost-Effectiveness Curve for BEA260

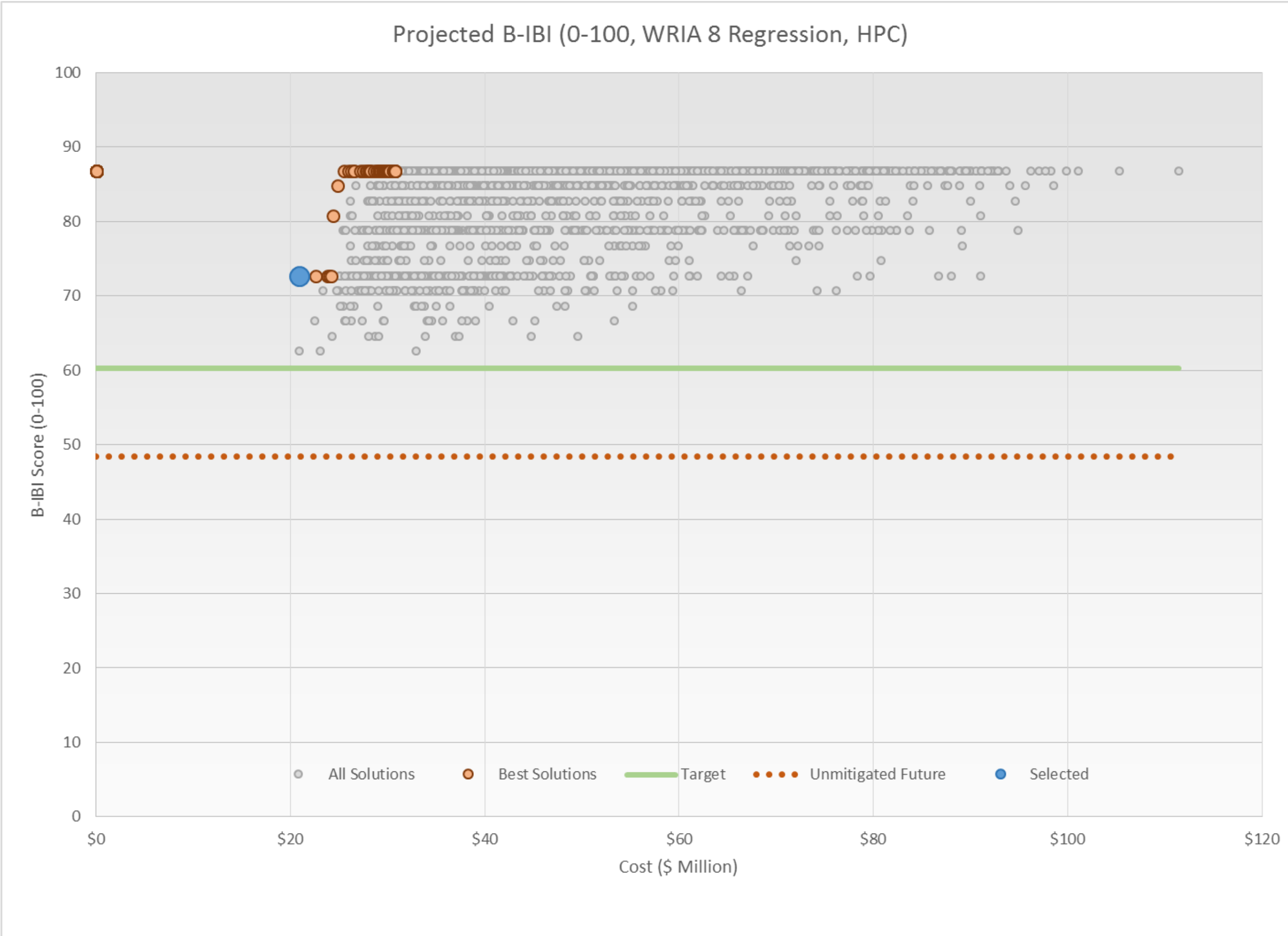

Figure 174 Cost-Effectiveness Curve for BEA270

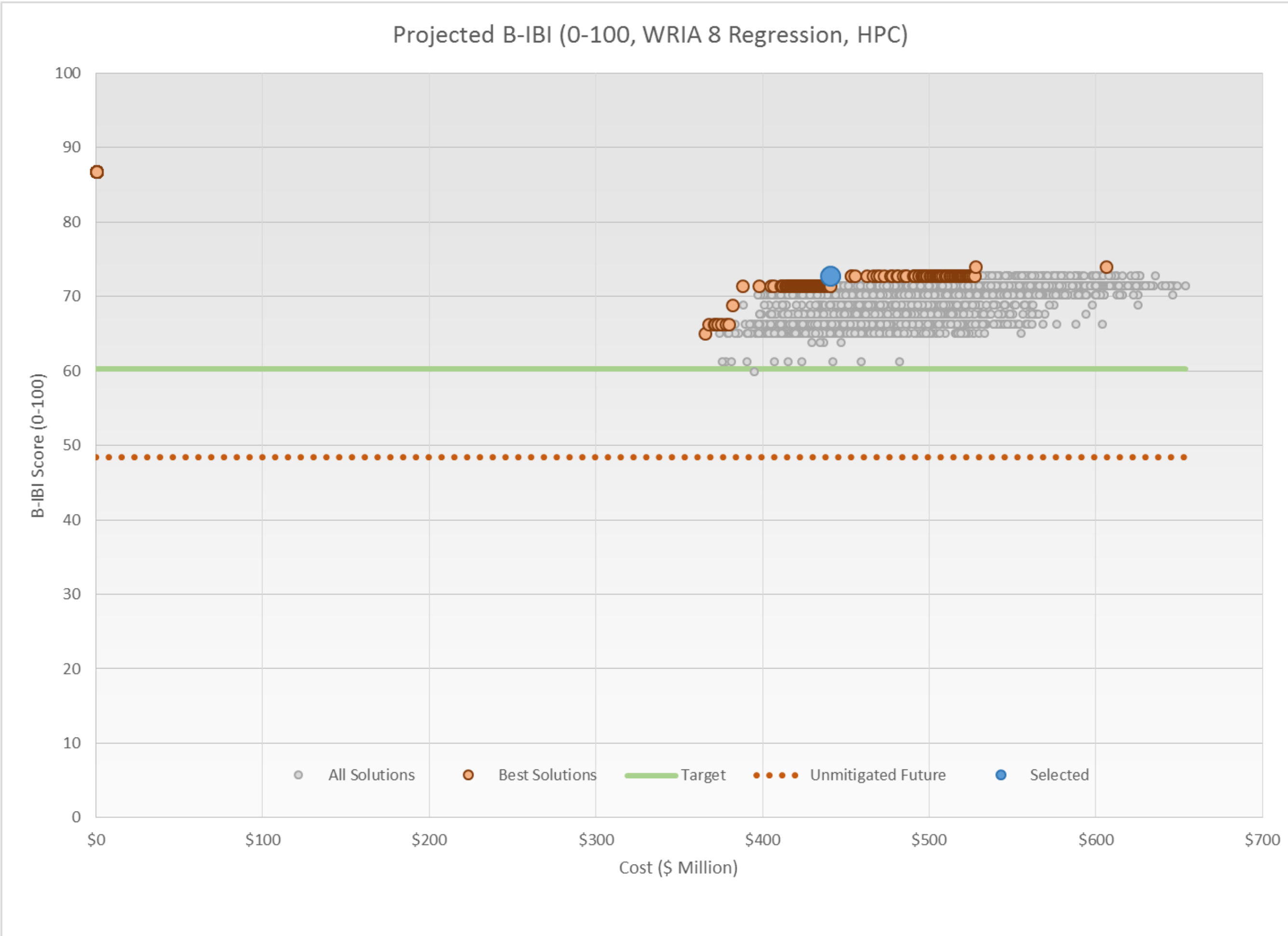

Figure 175 Cost-Effectiveness Curve for BEA280

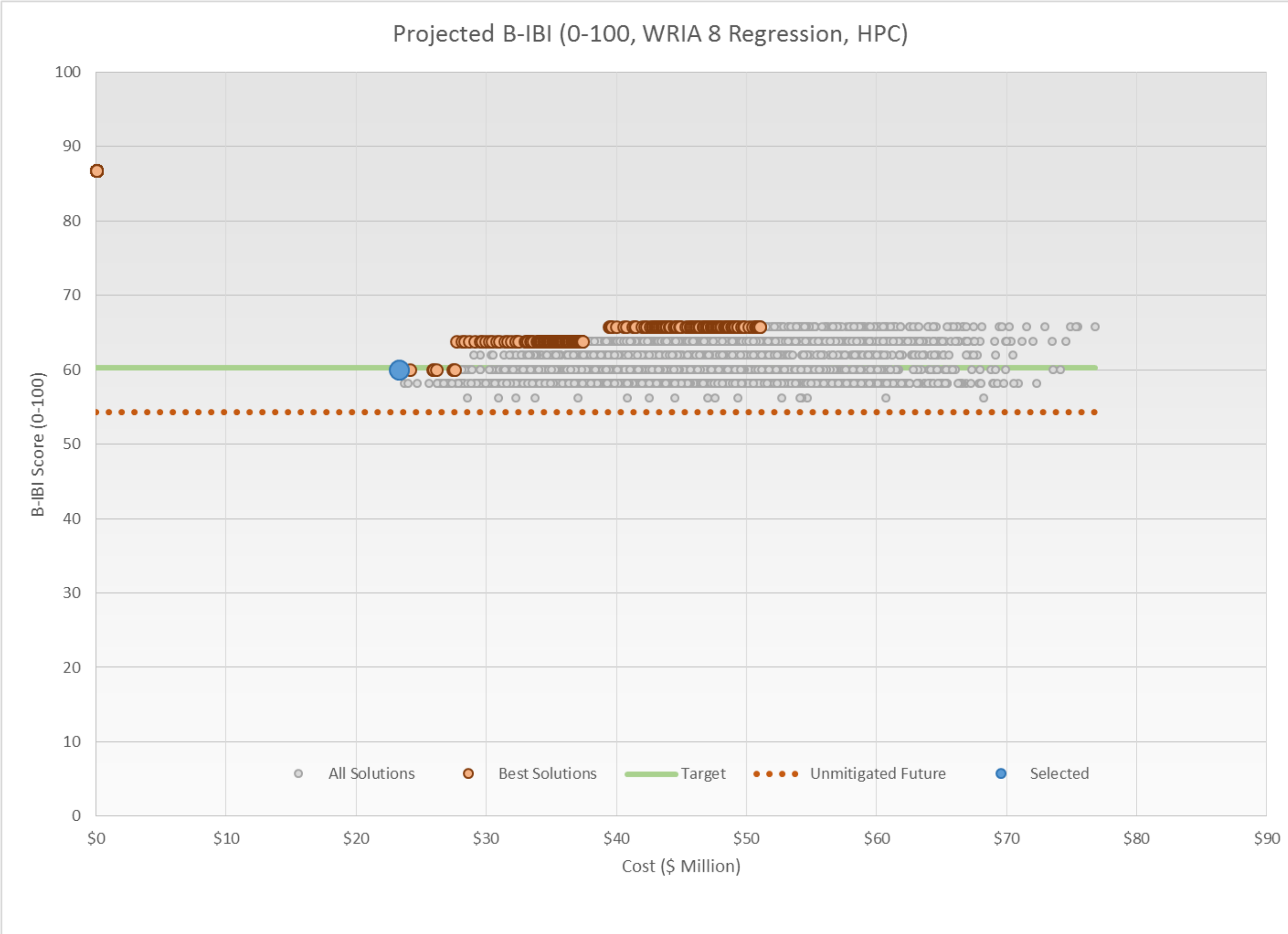

Figure 176 Cost-Effectiveness Curve for BEA310

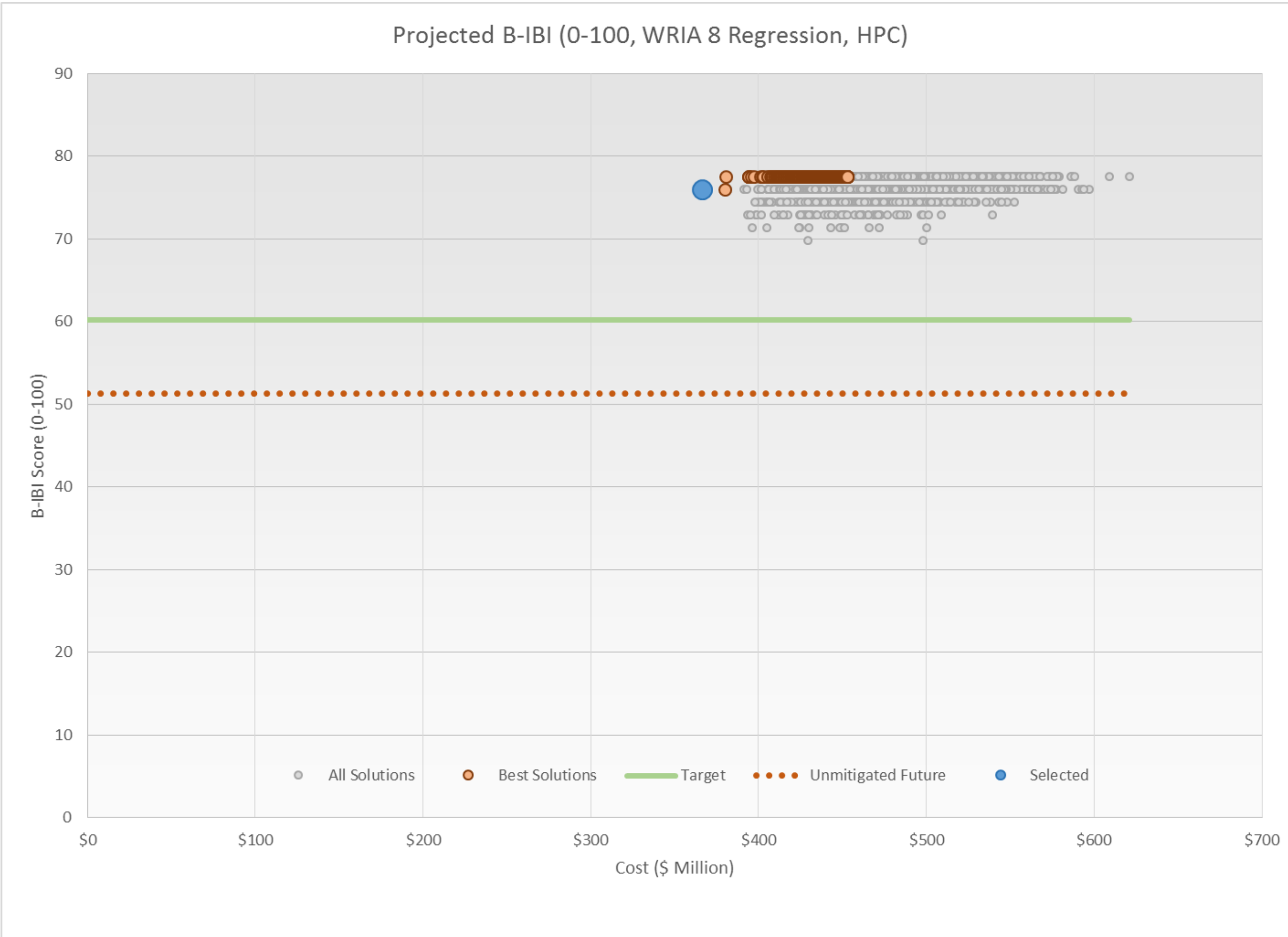

Figure 177 Cost-Effectiveness Curve for BEA370

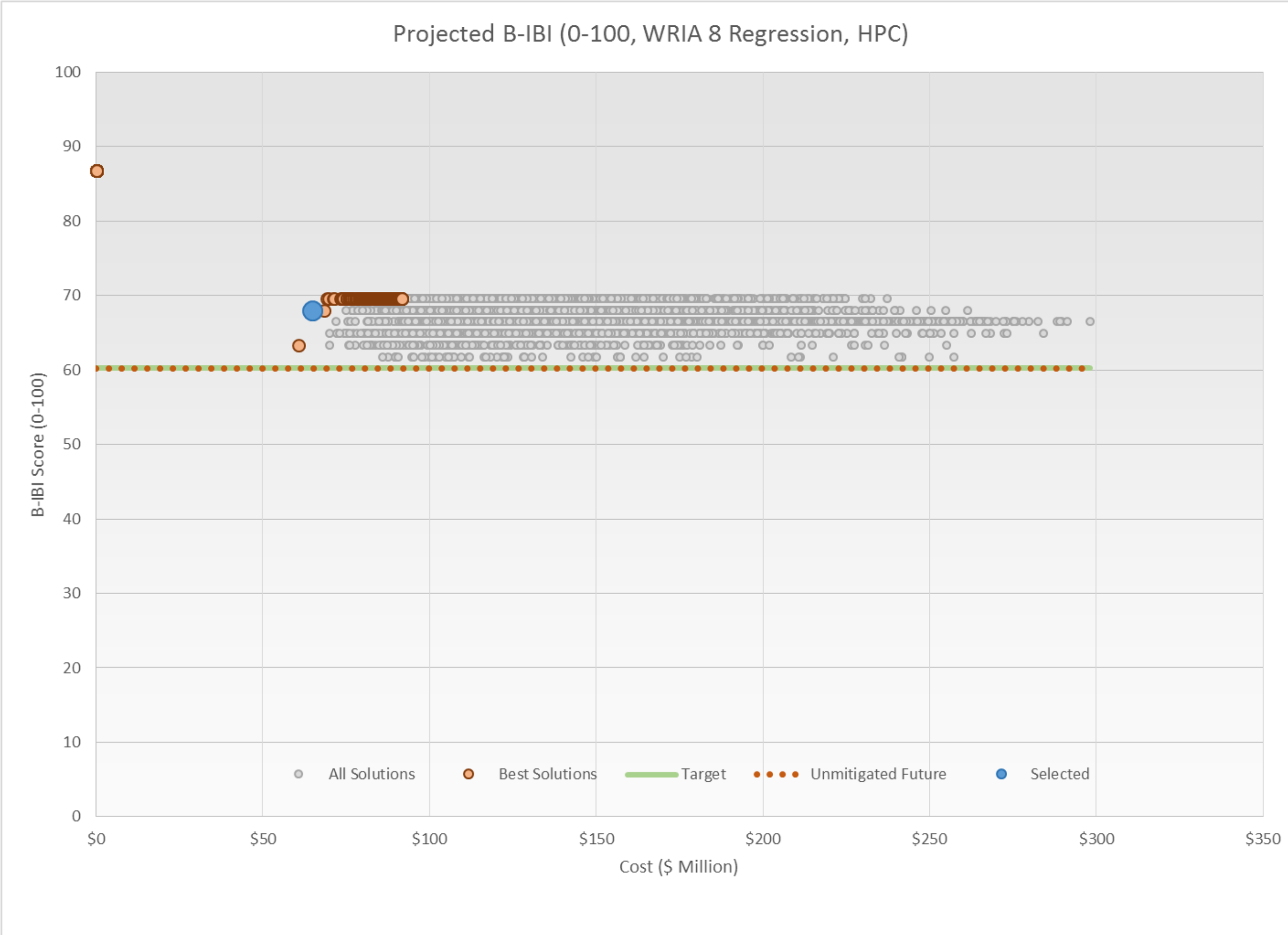

Figure 178 Cost-Effectiveness Curve for BEA410

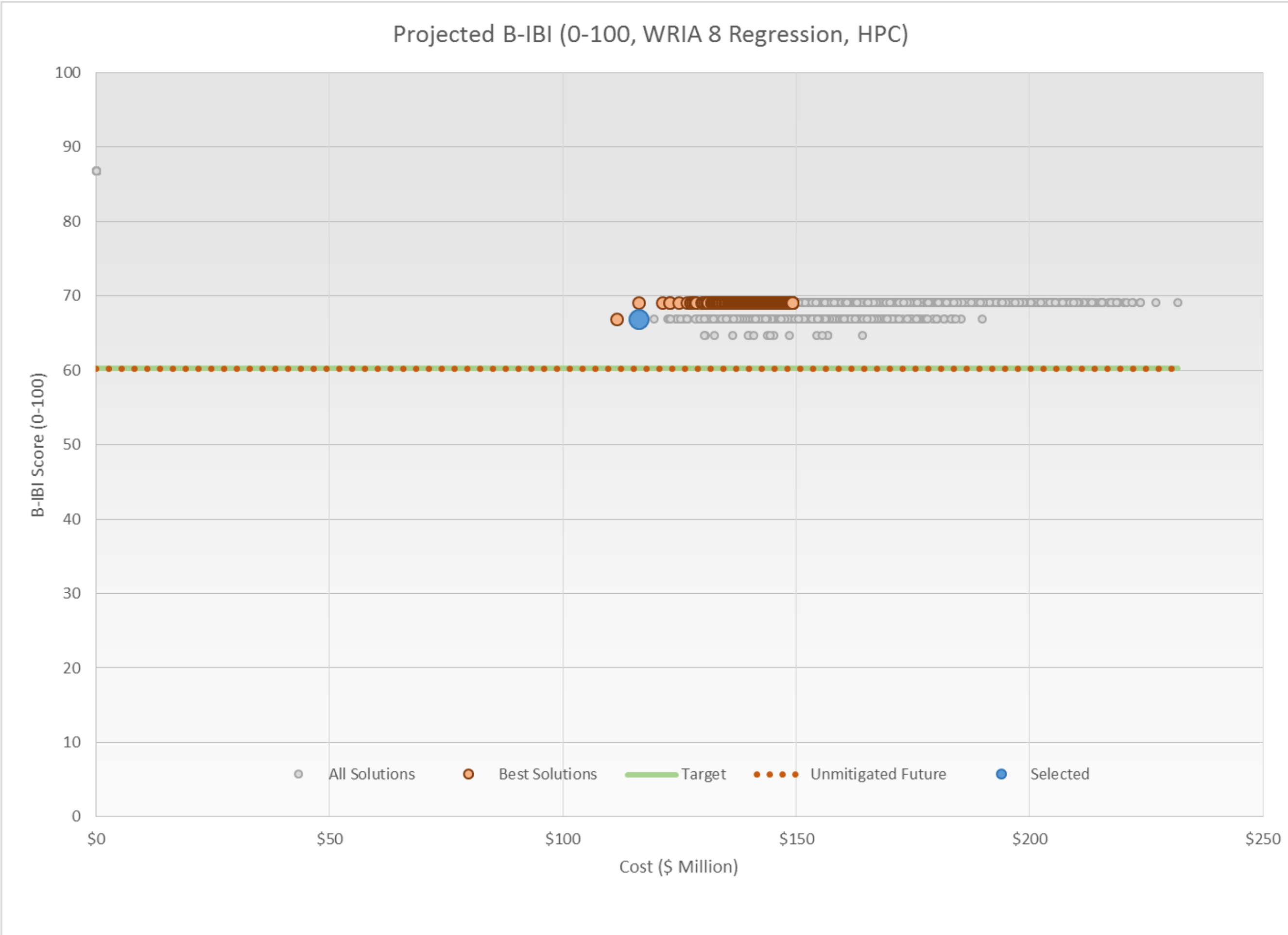

Figure 179 Cost-Effectiveness Curve for BEA590

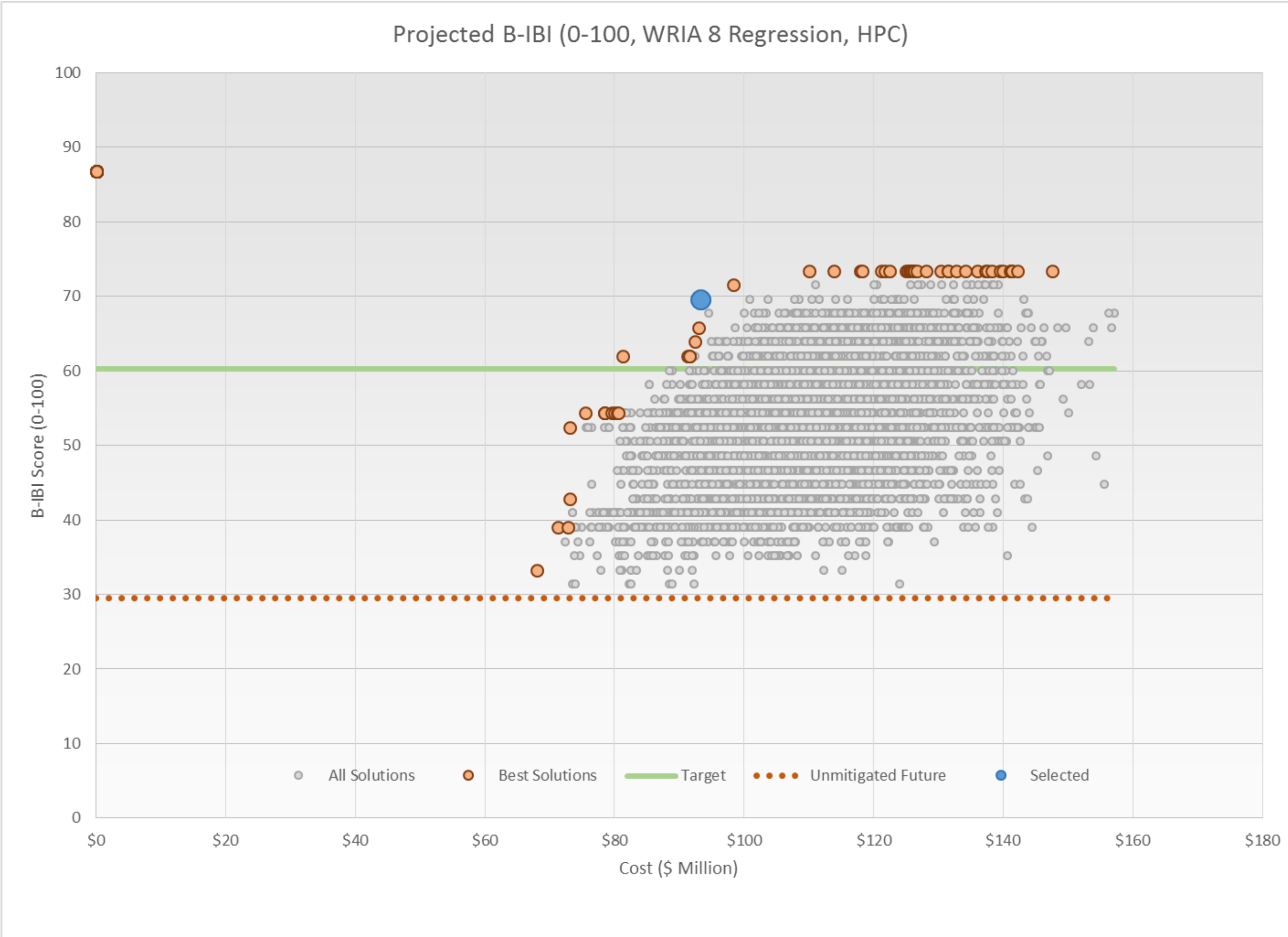

Figure 180 Cost-Effectiveness Curve for BEA800

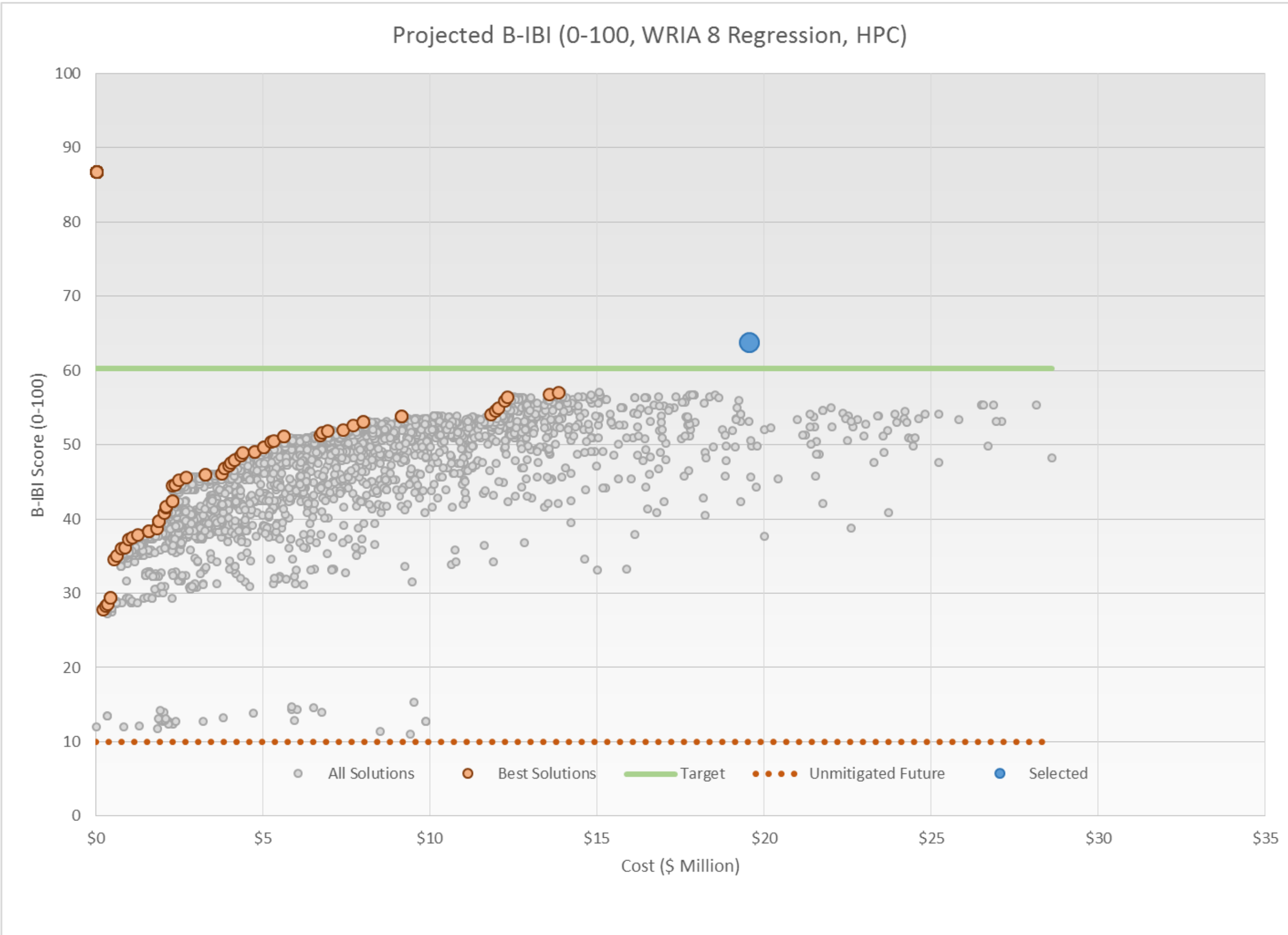

Figure 181 Cost-Effectiveness Curve for MON030. Note: only public costs are shown in this figure.

This page intentionally left blank.

APPENDIX I: Simulated Flows

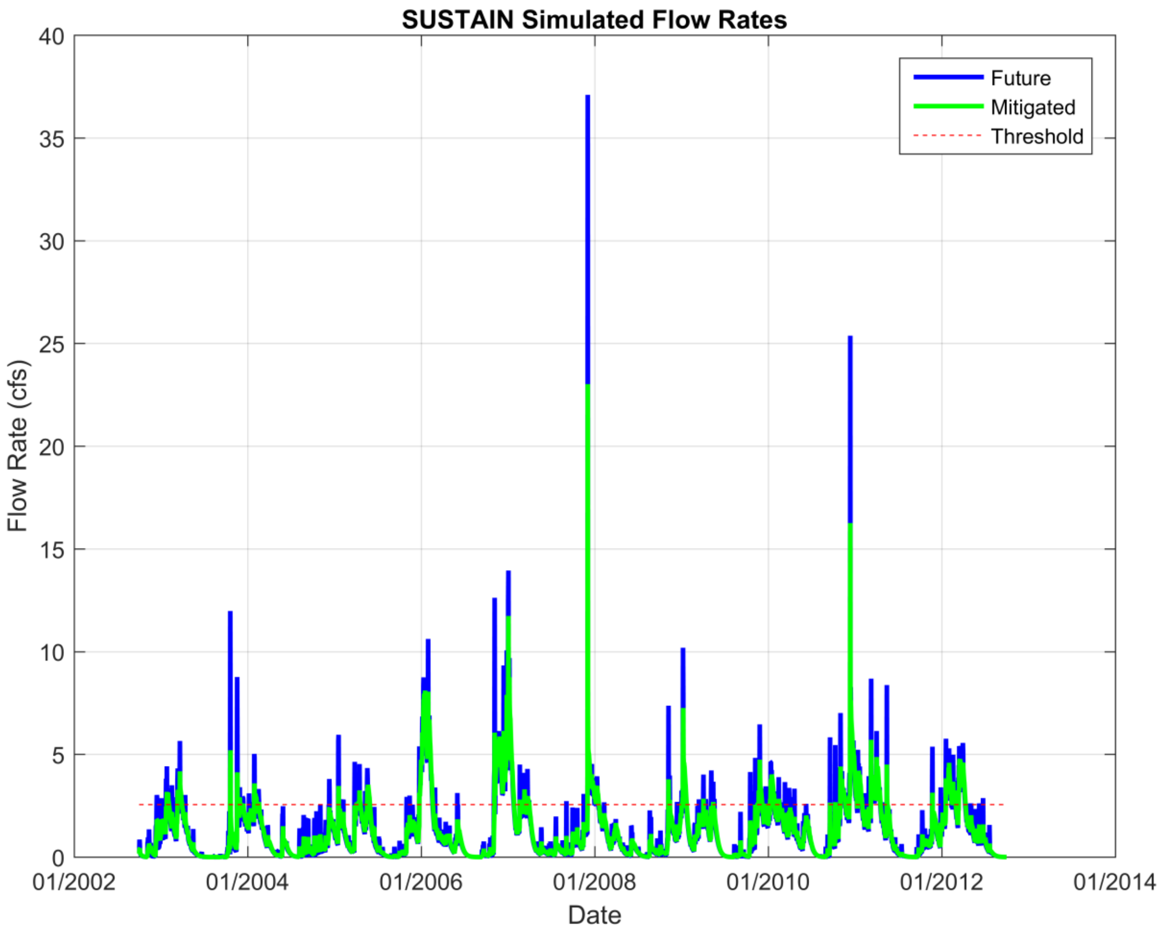

Figure 182 SUSTAIN simulated future flow rate for BEA020

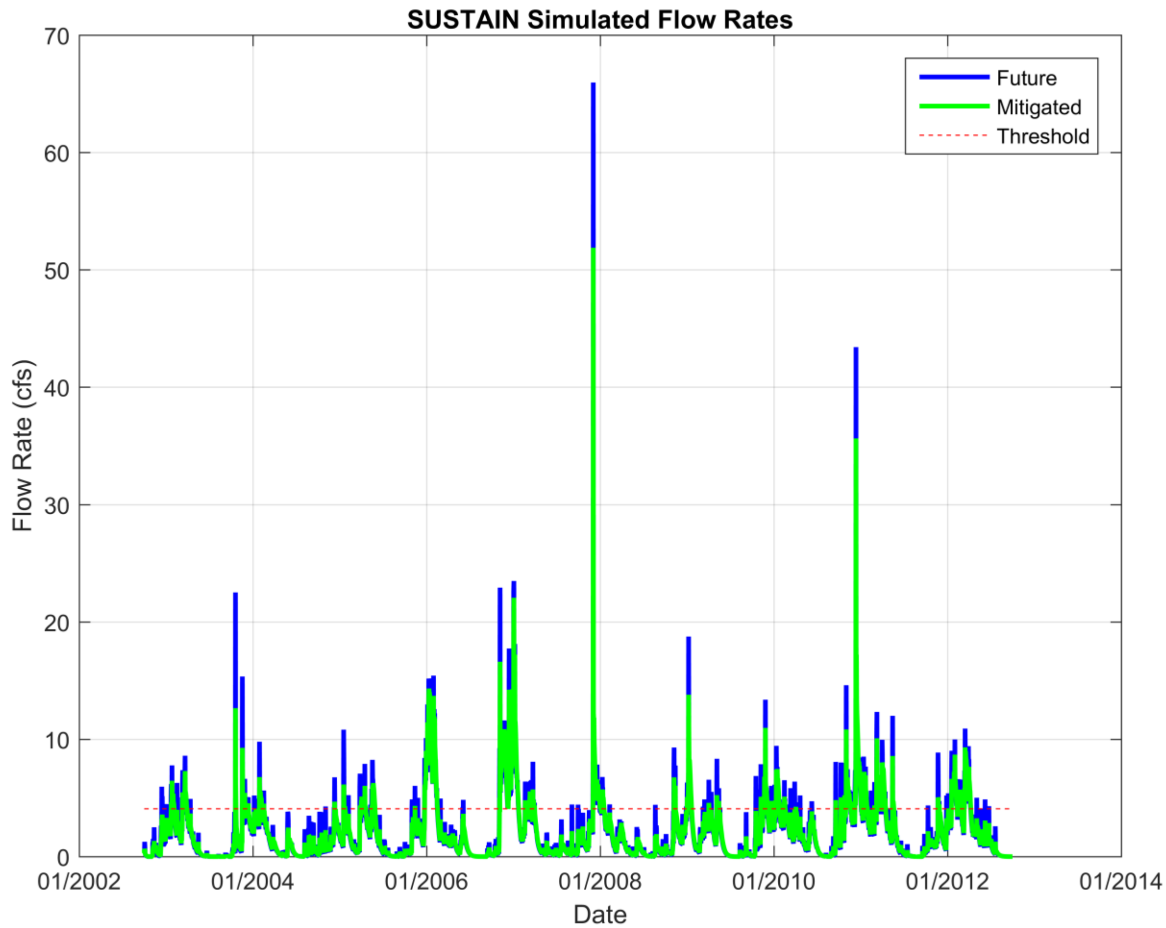

Figure 183 SUSTAIN simulated future flow rate for BEA120

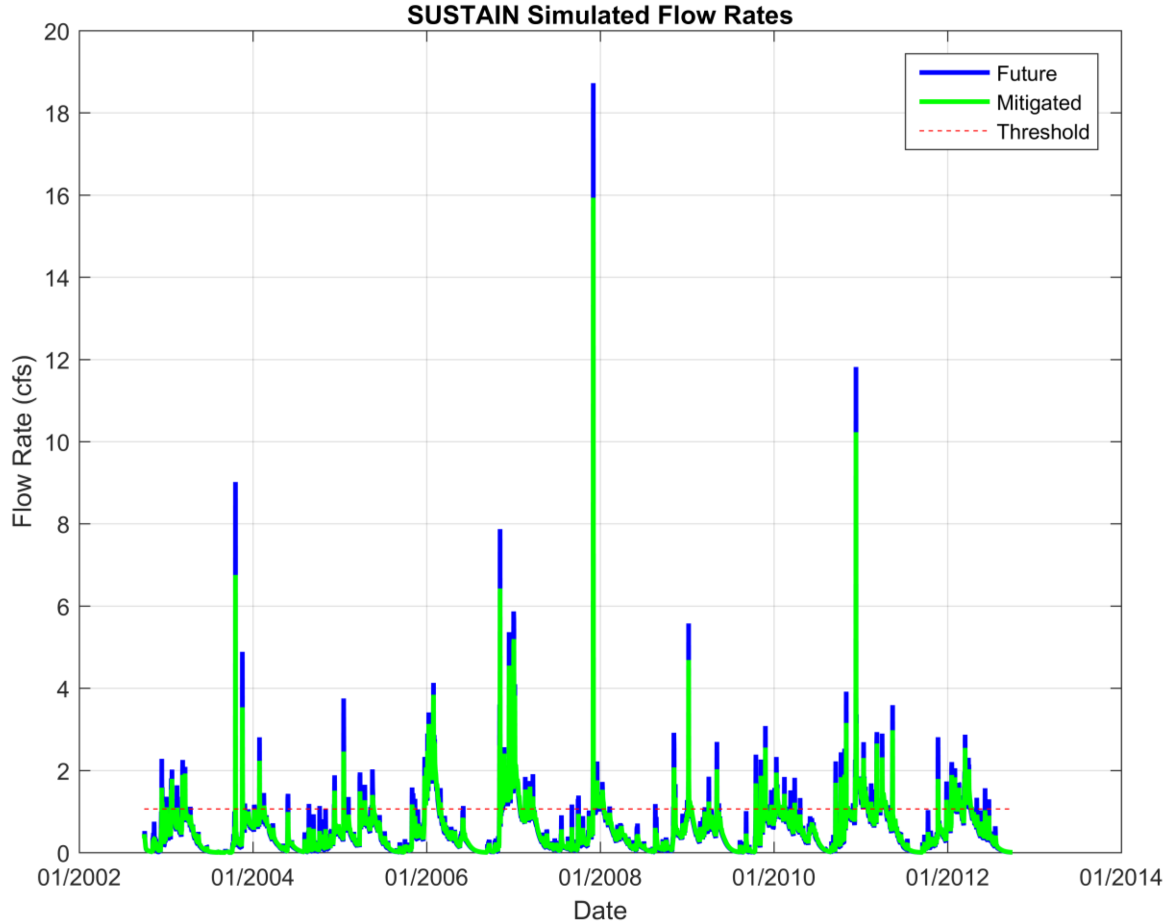

Figure 184 SUSTAIN simulated future flow rate for BEA210

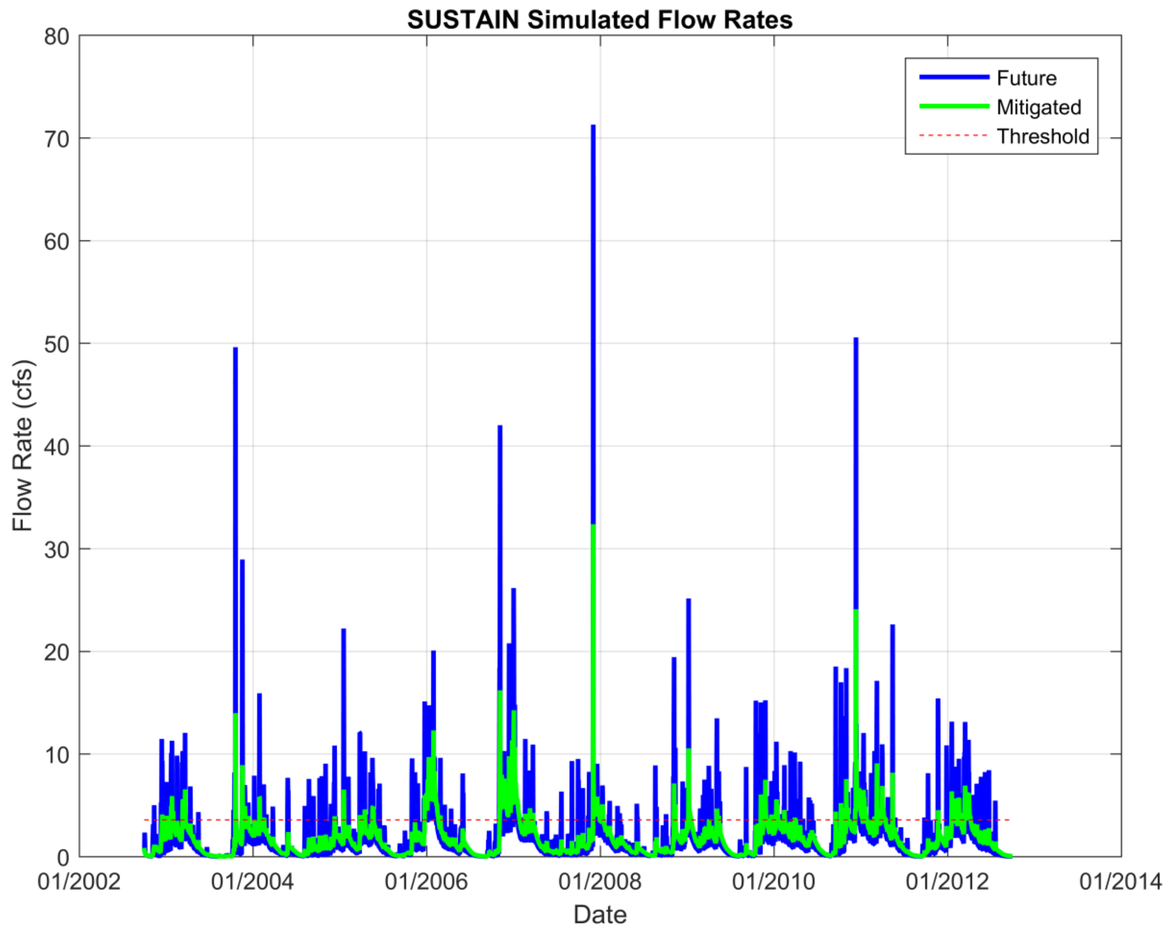

Figure 185 SUSTAIN simulated future flow rate for BEA240

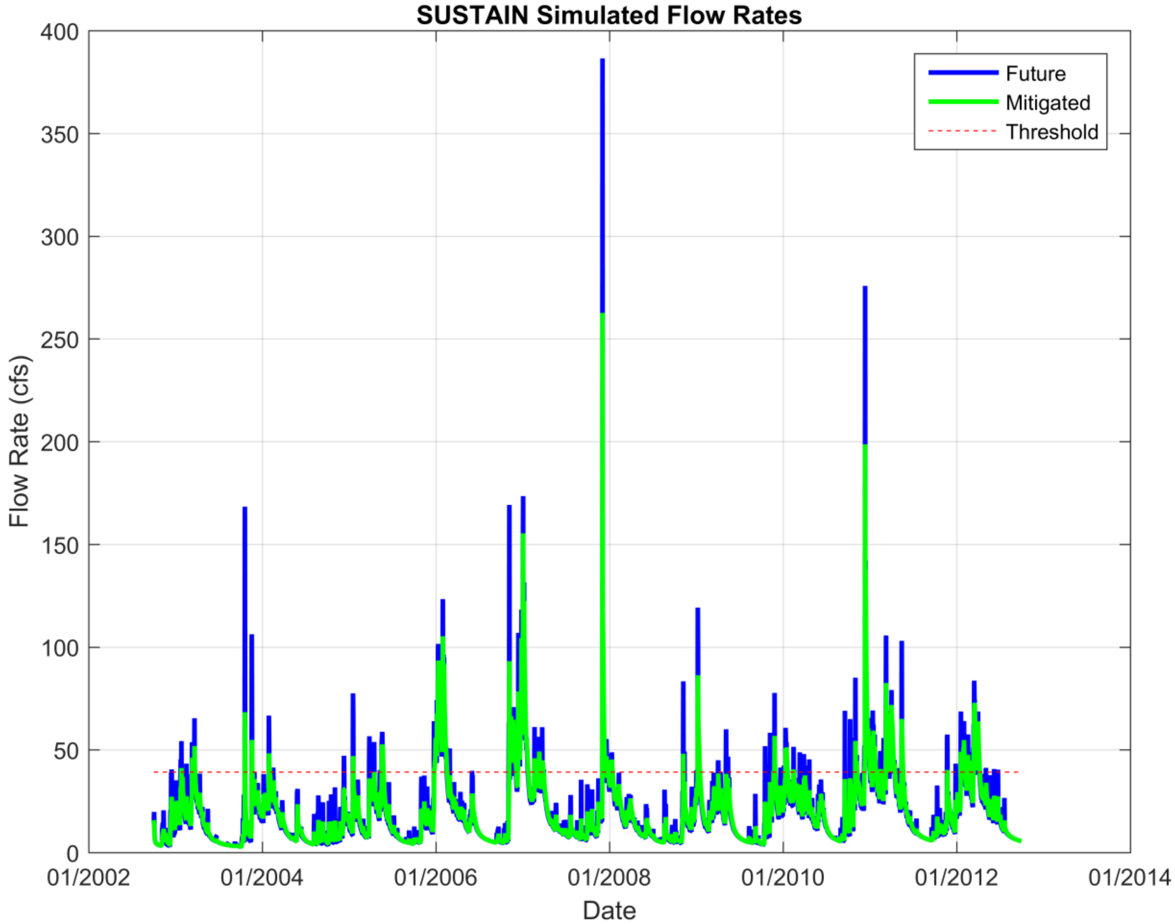

Figure 186 SUSTAIN simulated future flow rate for BEA260

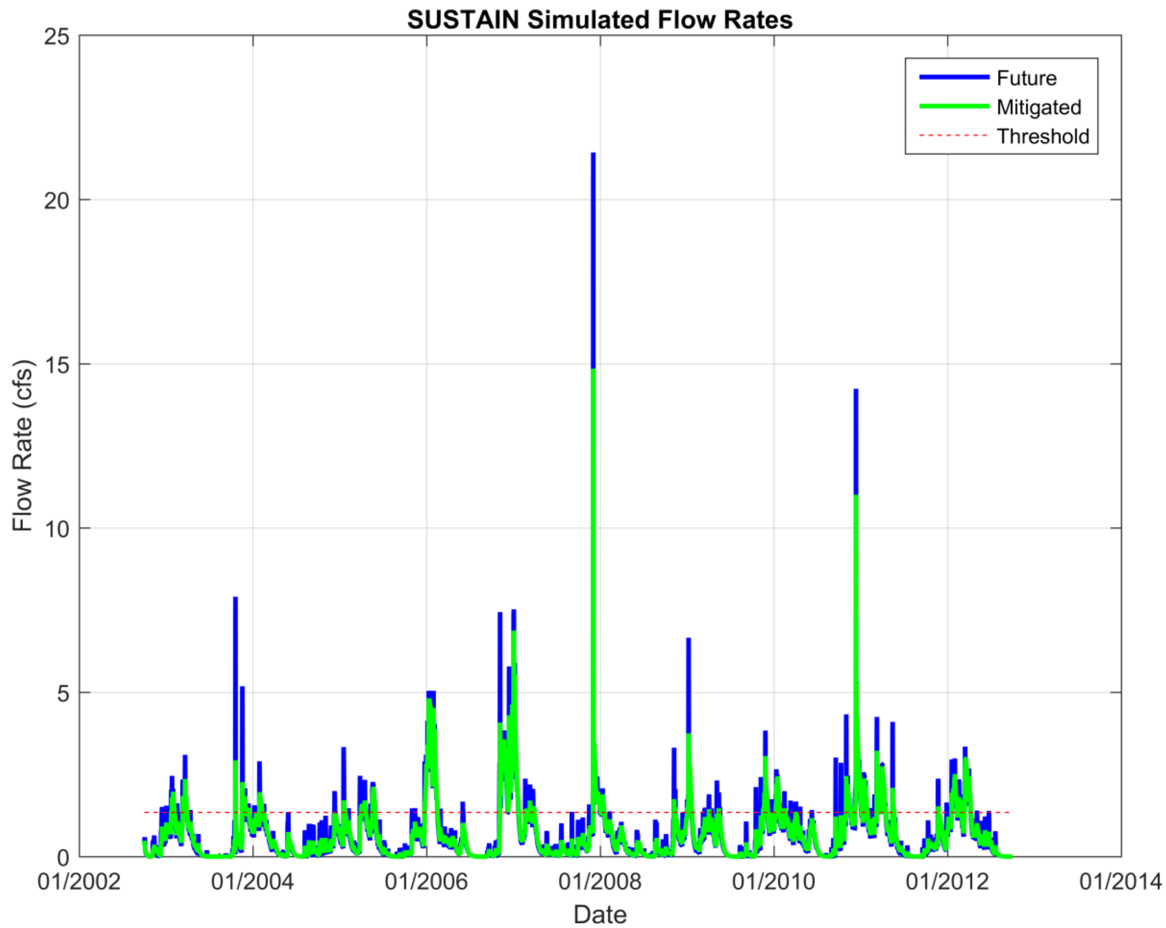

Figure 187 SUSTAIN simulated future flow rate for BEA270

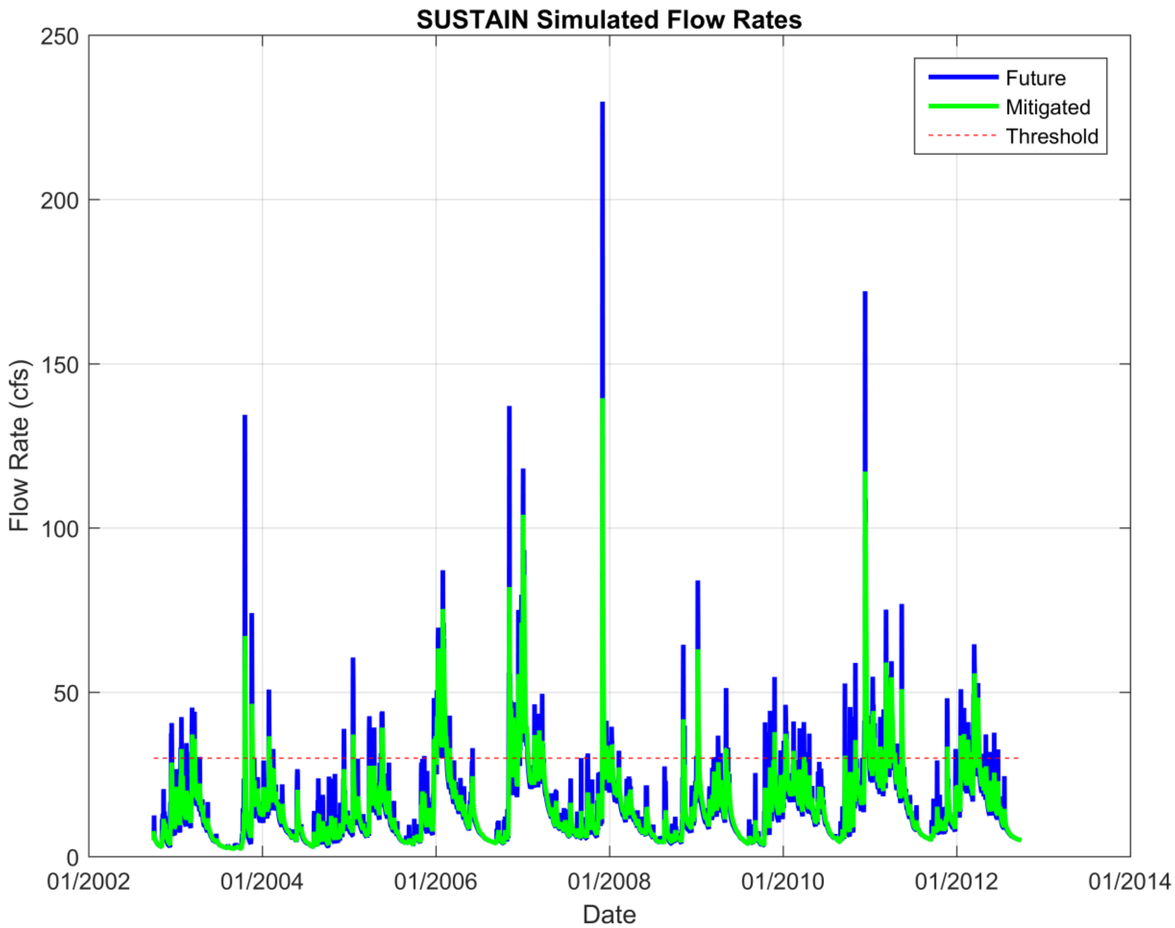

Figure 188 SUSTAIN simulated future flow rate for BEA280

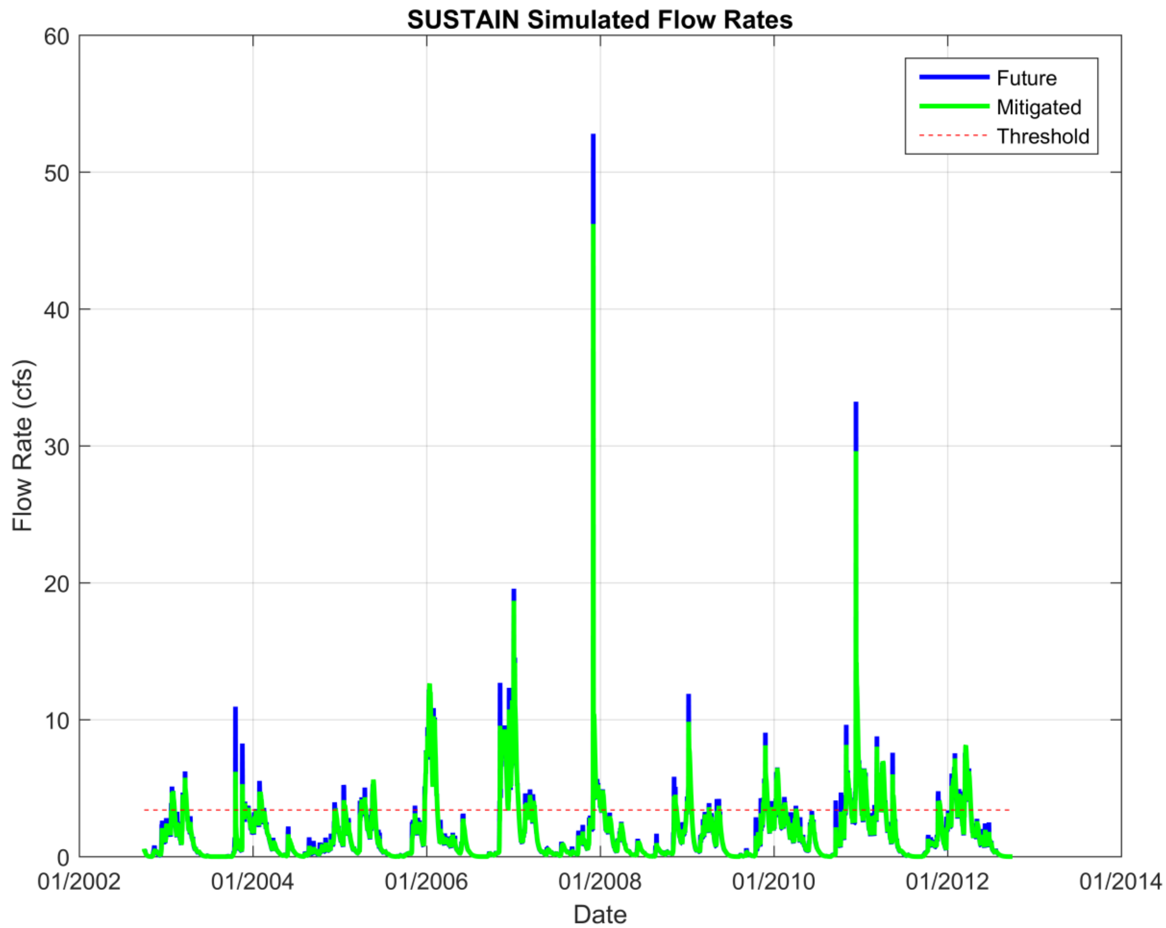

Figure 189 SUSTAIN simulated future flow rate for BEA310

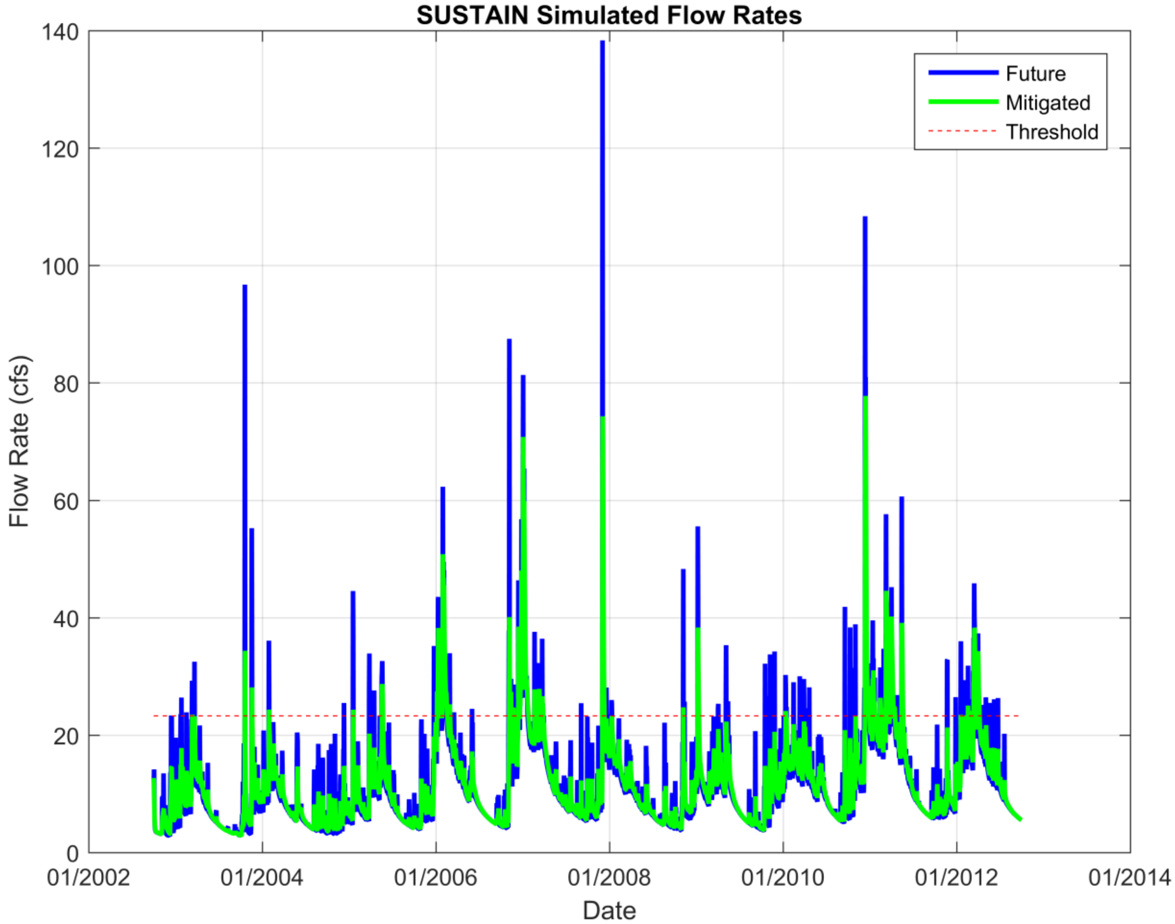

Figure 190 SUSTAIN simulated future flow rate for BEA370

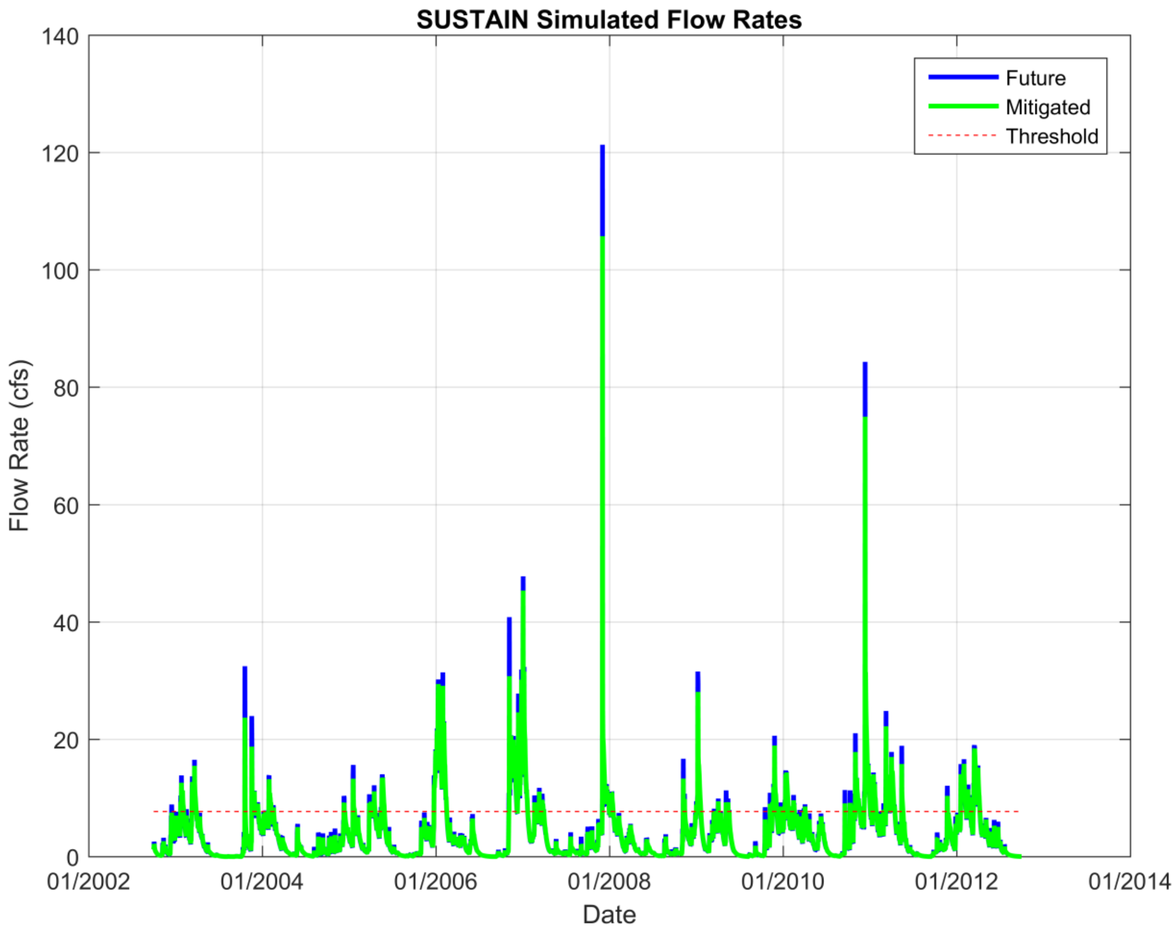

Figure 191 SUSTAIN simulated future flow rate for BEA410

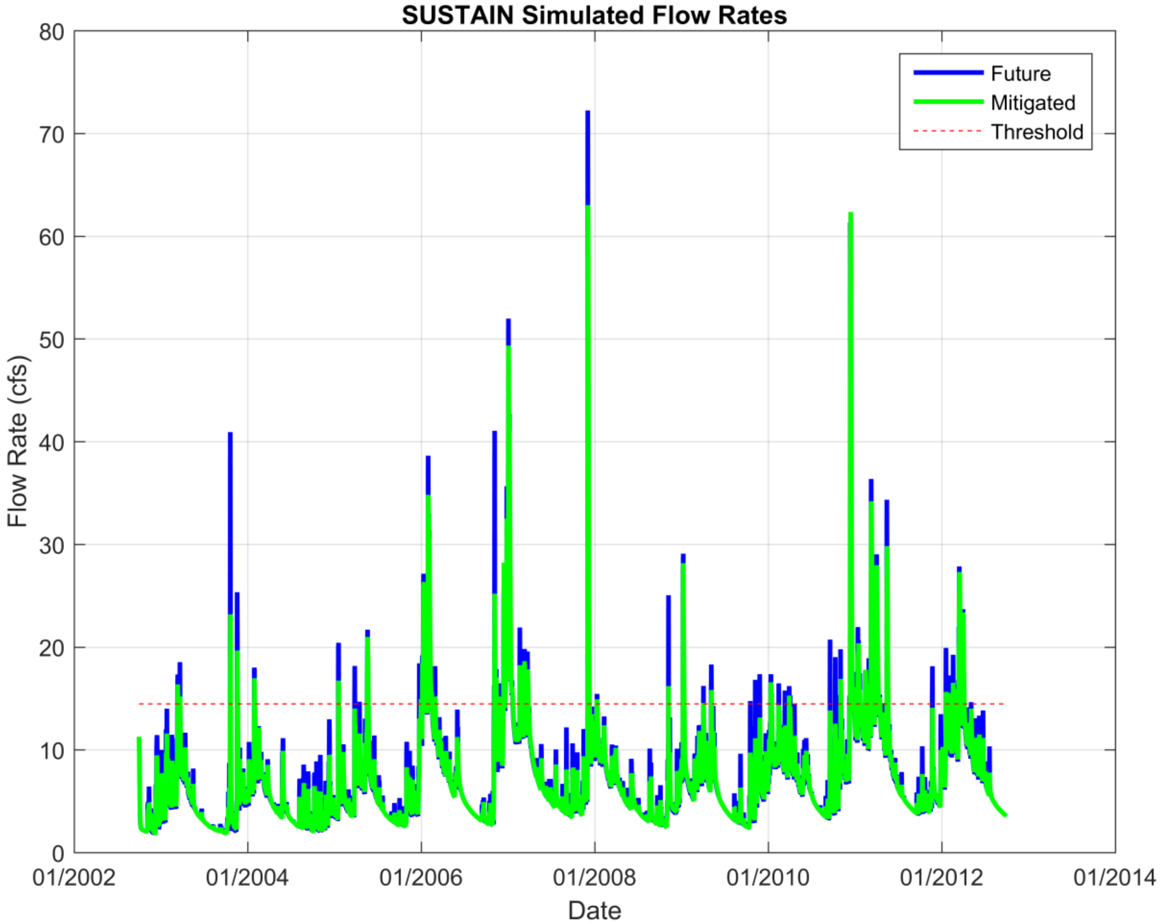

Figure 192 SUSTAIN simulated future flow rate for BEA590

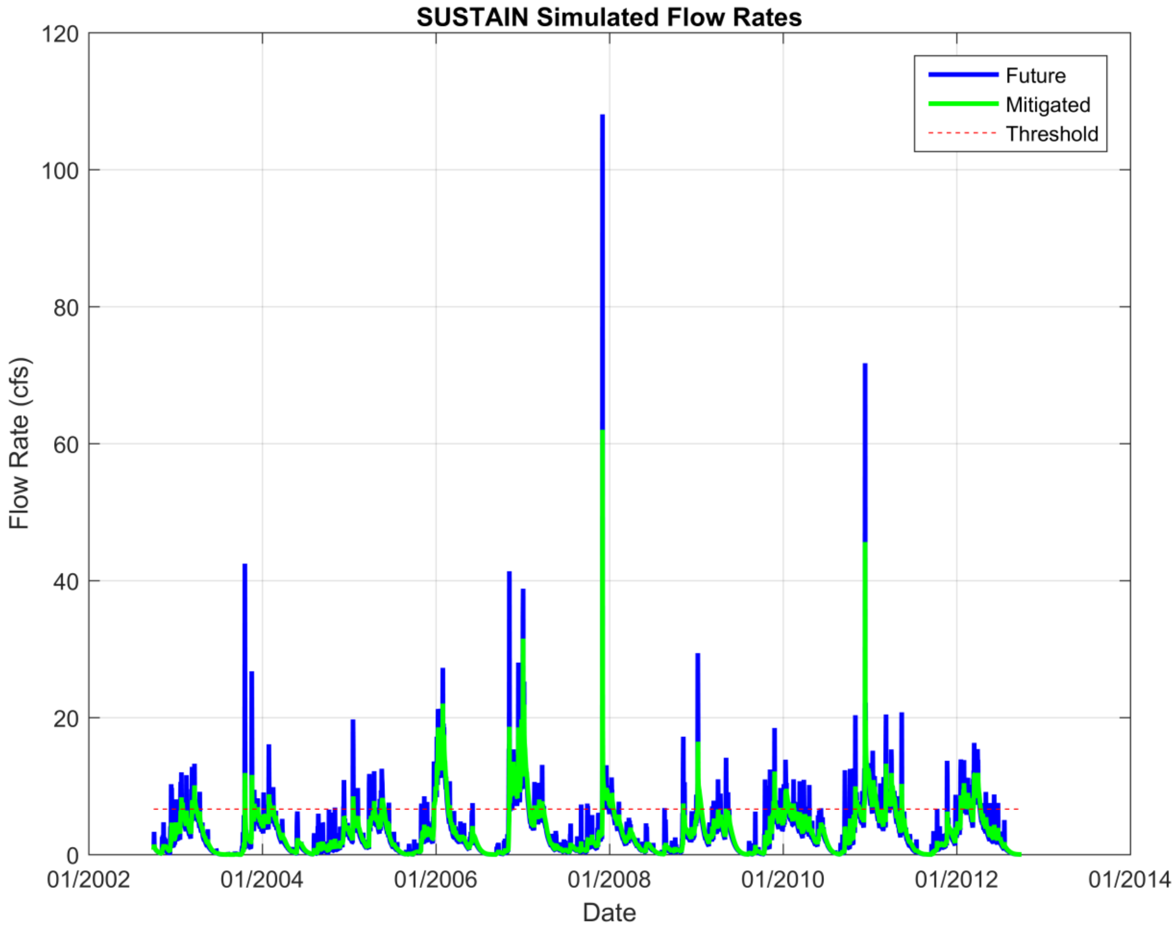

Figure 193 SUSTAIN simulated future flow rate for BEA800

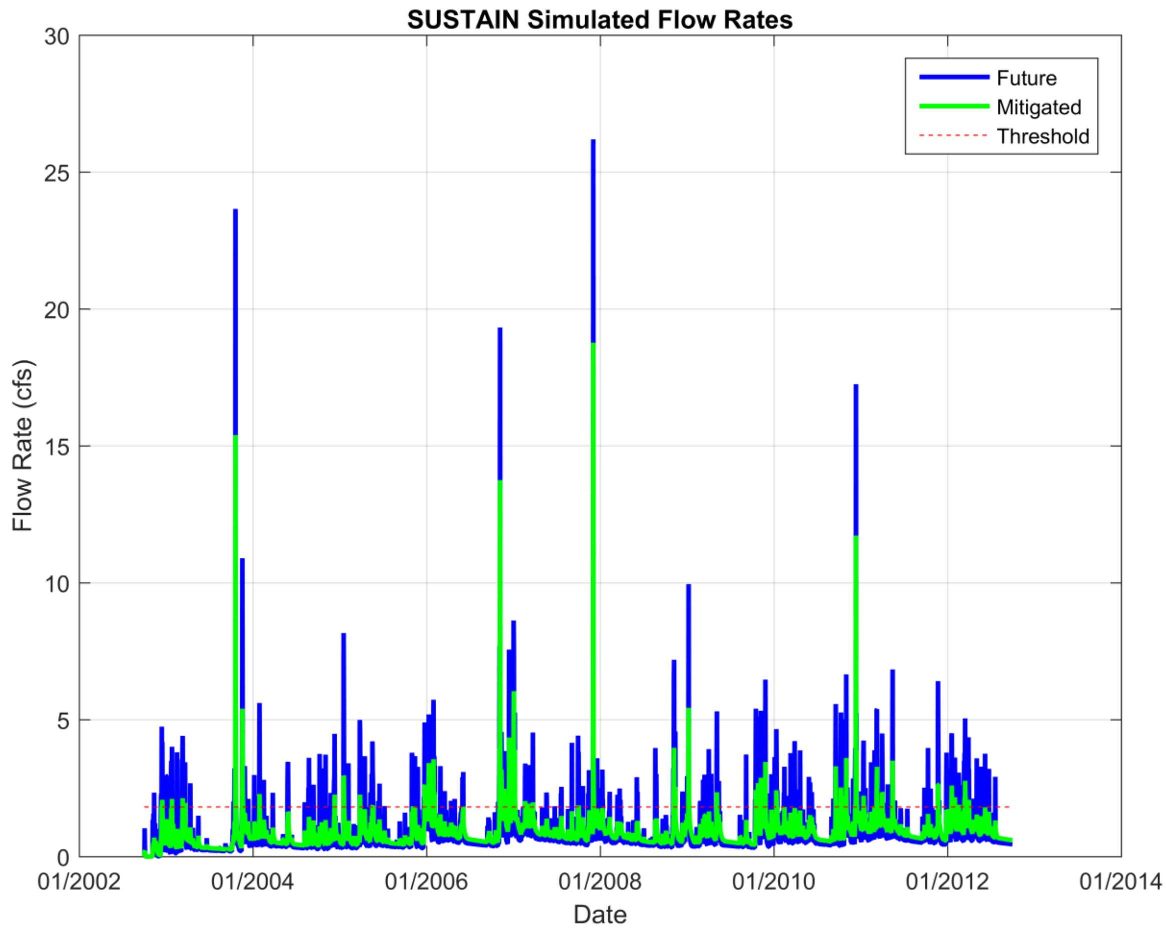

Figure 194 SUSTAIN simulated future flow rate for MON030

APPENDIX J: Simulated Water Temperature

Table 63 Summarization of simulated summer water temperature exceedances.

Catchment	# of Days (63 Summers)				Percent of Time (Summer)				Diff. (Mit-Forest)
	Forested	Existing	Future	Mitigated	Forested	Existing	Future	Mitigated	
BEA010	411	4557	4608	506	5%	58%	59%	6%	1%
BEA020	1639	6342	6361	1701	21%	81%	81%	22%	1%
BEA030	5620	5634	5644	5635	72%	72%	72%	72%	0%
BEA040	12	1486	1554	95	0%	19%	20%	1%	1%
BEA050	4372	5020	5036	4446	56%	64%	64%	57%	1%
BEA060	443	4043	4101	564	6%	52%	53%	7%	2%
BEA070	4466	5207	5215	4044	57%	67%	67%	52%	-5%
BEA080	5590	5605	5634	5626	72%	72%	72%	72%	0%
BEA100	211	4079	4117	251	3%	52%	53%	3%	1%
BEA110	5747	5771	5803	5792	74%	74%	74%	74%	1%
BEA120	666	3874	3946	667	9%	50%	51%	9%	0%
BEA121	666	3874	3946	667	9%	50%	51%	9%	0%
BEA130	2697	4642	4638	1807	35%	59%	59%	23%	-11%
BEA131	2697	4642	4638	1807	35%	59%	59%	23%	-11%
BEA140	5704	5710	5714	5705	73%	73%	73%	73%	0%
BEA141	5704	5710	5714	5705	73%	73%	73%	73%	0%
BEA150	5833	5837	5863	5850	75%	75%	75%	75%	0%
BEA151	5833	5837	5863	5850	75%	75%	75%	75%	0%
BEA155	5833	5837	5863	5850	75%	75%	75%	75%	0%
BEA160	3629	4412	4472	4179	46%	57%	57%	54%	7%
BEA170	5889	5902	5909	5907	75%	76%	76%	76%	0%
BEA180	21	893	939	26	0%	11%	12%	0%	0%
BEA190	5504	5613	5638	5634	70%	72%	72%	72%	2%
BEA200	197	4025	4060	229	3%	52%	52%	3%	0%
BEA210	5220	5199	5228	5132	67%	67%	67%	66%	-1%
BEA220	165	3404	3430	190	2%	44%	44%	2%	0%
BEA230	169	4115	4127	190	2%	53%	53%	2%	0%
BEA235	142	5439	5582	323	2%	70%	71%	4%	2%
BEA240	199	4948	5106	270	3%	63%	65%	3%	1%
BEA245	129	3548	3827	195	2%	45%	49%	2%	1%
BEA250	2318	4681	5005	3799	30%	60%	64%	49%	19%
BEA260	156	5552	5555	198	2%	71%	71%	3%	1%
BEA270	81	1718	1804	132	1%	22%	23%	2%	1%

Catchment	# of Days (63 Summers)				Percent of Time (Summer)				Diff. (Mit-Forest)
	Forested	Existing	Future	Mitigated	Forested	Existing	Future	Mitigated	
BEA275	0	178	238	35	0%	2%	3%	0%	0%
BEA280	166	1460	1496	165	2%	19%	19%	2%	0%
BEA290	5053	5328	5411	5336	65%	68%	69%	68%	4%
BEA300	110	5292	6117	141	1%	68%	78%	2%	0%
BEA310	11	2541	2575	13	0%	33%	33%	0%	0%
BEA315	500	3320	3369	546	6%	43%	43%	7%	1%
BEA320	5778	5778	5778	5778	74%	74%	74%	74%	0%
BEA325	5855	5855	5855	5855	75%	75%	75%	75%	0%
BEA330	7	3659	3746	8	0%	47%	48%	0%	0%
BEA335	6	3448	3530	8	0%	44%	45%	0%	0%
BEA350	179	4973	6292	311	2%	64%	81%	4%	2%
BEA360	2037	4923	4908	3089	26%	63%	63%	40%	13%
BEA370	247	3875	6351	287	3%	50%	81%	4%	1%
BEA380	10	5130	5191	14	0%	66%	66%	0%	0%
BEA390	2487	4983	5067	582	32%	64%	65%	7%	-24%
BEA400	53	2643	2828	18	1%	34%	36%	0%	0%
BEA410	5260	5256	5246	5202	67%	67%	67%	67%	-1%
BEA420	1247	2744	2734	1279	16%	35%	35%	16%	0%
BEA430	3321	3929	3933	3343	43%	50%	50%	43%	0%
BEA450	460	1113	1105	436	6%	14%	14%	6%	0%
BEA460	527	6092	6076	529	7%	78%	78%	7%	0%
BEA480	1114	2850	2866	1122	14%	37%	37%	14%	0%
BEA490	1181	5745	5794	1448	15%	74%	74%	19%	3%
BEA500	543	6498	6488	858	7%	83%	83%	11%	4%
BEA510	90	1126	1216	172	1%	14%	16%	2%	1%
BEA525	339	5919	5992	455	4%	76%	77%	6%	1%
BEA530	136	5849	5928	222	2%	75%	76%	3%	1%
BEA540	1524	6150	6273	1518	20%	79%	80%	19%	0%
BEA550	5819	5843	5876	5867	75%	75%	75%	75%	1%
BEA570	784	6834	6728	1392	10%	88%	86%	18%	8%
BEA580	5525	5767	5783	5614	71%	74%	74%	72%	1%
BEA590	1110	6788	6743	1484	14%	87%	86%	19%	5%
BEA600	208	5749	5790	250	3%	74%	74%	3%	1%
BEA610	1923	5792	5815	2151	25%	74%	74%	28%	3%
BEA620	5801	5801	5803	5803	74%	74%	74%	74%	0%
BEA625	1206	6209	6316	1137	15%	80%	81%	15%	-1%
BEA630	5834	5869	5905	5894	75%	75%	76%	75%	1%
BEA640	7	5436	5512	19	0%	70%	71%	0%	0%
BEA650	5733	5733	5733	5733	73%	73%	73%	73%	0%
BEA660	0	2749	2857	0	0%	35%	37%	0%	0%

Catchment	# of Days (63 Summers)				Percent of Time (Summer)				Diff. (Mit-Forest)
	Forested	Existing	Future	Mitigated	Forested	Existing	Future	Mitigated	
BEA665	315	6680	6748	373	4%	86%	86%	5%	1%
BEA670	2411	5972	5980	2443	31%	76%	77%	31%	0%
BEA690	58	6680	6799	152	1%	86%	87%	2%	1%
BEA700	218	1140	1175	235	3%	15%	15%	3%	0%
BEA710	330	1652	1705	400	4%	21%	22%	5%	1%
BEA720	233	1714	1791	302	3%	22%	23%	4%	1%
BEA725	4170	4763	5004	4940	53%	61%	64%	63%	10%
BEA730	7	419	489	22	0%	5%	6%	0%	0%
BEA740	5659	5663	5669	5669	72%	73%	73%	73%	0%
BEA750	5112	5463	5516	5516	65%	70%	71%	71%	5%
BEA760	220	2253	2437	313	3%	29%	31%	4%	1%
BEA770	549	1580	2832	2517	7%	20%	36%	32%	25%
BEA780	189	2123	2270	242	2%	27%	29%	3%	1%
BEA800	679	942	1102	1093	9%	12%	14%	14%	5%
BEA820	2157	3554	3851	3531	28%	46%	49%	45%	18%
BEA830	70	670	820	154	1%	9%	11%	2%	1%
BEA840	43	1316	1630	164	1%	17%	21%	2%	2%
BEA850	1046	587	587	1084	13%	8%	8%	14%	0%
BEA860	4972	5573	5671	5645	64%	71%	73%	72%	9%
BEA900	66	1661	1661	67	1%	21%	21%	1%	0%
BEA910	124	832	832	158	2%	11%	11%	2%	0%
BEA920	0	97	97	1	0%	1%	1%	0%	0%
BEA940	241	2096	2090	302	3%	27%	27%	4%	1%
BEA950	418	1623	1614	442	5%	21%	21%	6%	0%
BEA960	105	665	666	99	1%	9%	9%	1%	0%
BEA970	46	3140	2898	422	1%	40%	37%	5%	5%
BEA990	5719	5763	5763	5749	73%	74%	74%	74%	0%
MON018	0	92	92	0	0%	1%	1%	0%	0%
MON029	0	5	5	0	0%	0%	0%	0%	0%
MON030	3970	5352	4946	2426	51%	69%	63%	31%	-20%

Table 64 Summarization of simulated winter water temperature exceedances.

Catchment	# of Days (63 winters)				Percent of Time (winter)				Diff. (Mit-Forest)
	Forested	Existing	Future	Mitigated	Forested	Existing	Future	Mitigated	
BEA010	256	1401	1436	321	2%	9%	9%	2%	0%
BEA020	1182	2535	2565	1128	8%	16%	16%	7%	0%
BEA030	4001	4204	4231	4216	26%	27%	27%	27%	1%
BEA040	44	916	962	268	0%	6%	6%	2%	1%
BEA050	1192	1439	1446	1242	8%	9%	9%	8%	0%
BEA060	270	1280	1308	351	2%	8%	8%	2%	1%
BEA070	2660	3413	3293	2217	17%	22%	21%	14%	-3%
BEA080	4823	4852	4931	4922	31%	31%	32%	32%	1%
BEA100	181	1304	1323	230	1%	8%	9%	1%	0%
BEA110	4451	4506	4588	4570	29%	29%	29%	29%	1%
BEA120	301	1158	1199	348	2%	7%	8%	2%	0%
BEA121	301	1158	1199	348	2%	7%	8%	2%	0%
BEA130	2099	1882	1804	941	13%	12%	12%	6%	-7%
BEA131	2099	1882	1804	941	13%	12%	12%	6%	-7%
BEA140	4244	4313	4363	4326	27%	28%	28%	28%	1%
BEA141	4244	4313	4363	4326	27%	28%	28%	28%	1%
BEA150	3995	4024	4065	4045	26%	26%	26%	26%	0%
BEA151	3995	4024	4065	4045	26%	26%	26%	26%	0%
BEA155	3995	4024	4065	4045	26%	26%	26%	26%	0%
BEA160	1868	1877	1906	1702	12%	12%	12%	11%	-1%
BEA170	3820	3830	3836	3829	25%	25%	25%	25%	0%
BEA180	46	411	466	76	0%	3%	3%	0%	0%
BEA190	4076	4770	5089	5038	26%	31%	33%	32%	6%
BEA200	170	1302	1309	206	1%	8%	8%	1%	0%
BEA210	3117	3381	3492	3261	20%	22%	22%	21%	1%
BEA220	116	864	881	147	1%	6%	6%	1%	0%
BEA230	174	1368	1378	200	1%	9%	9%	1%	0%
BEA235	635	2003	1900	342	4%	13%	12%	2%	-2%
BEA240	128	1424	1494	206	1%	9%	10%	1%	1%
BEA245	89	935	1049	148	1%	6%	7%	1%	0%
BEA250	1624	2312	2602	1919	10%	15%	17%	12%	2%
BEA260	306	2360	2364	371	2%	15%	15%	2%	0%
BEA270	87	582	633	173	1%	4%	4%	1%	1%
BEA275	27	364	443	191	0%	2%	3%	1%	1%
BEA280	107	476	482	127	1%	3%	3%	1%	0%
BEA290	2660	3047	3226	2984	17%	20%	21%	19%	2%
BEA300	385	2262	2863	513	2%	15%	18%	3%	1%
BEA310	180	1351	1381	203	1%	9%	9%	1%	0%
BEA315	537	1439	1457	569	3%	9%	9%	4%	0%

Catchment	# of Days (63 winters)				Percent of Time (winter)				Diff. (Mit-Forest)
	Forested	Existing	Future	Mitigated	Forested	Existing	Future	Mitigated	
BEA320	4238	4241	4246	4239	27%	27%	27%	27%	0%
BEA325	3965	3965	3967	3965	25%	25%	25%	25%	0%
BEA330	148	1984	2019	228	1%	13%	13%	1%	1%
BEA335	156	1889	1928	226	1%	12%	12%	1%	0%
BEA350	488	2036	2899	658	3%	13%	19%	4%	1%
BEA360	2113	3596	3664	2211	14%	23%	24%	14%	1%
BEA370	474	1583	2865	572	3%	10%	18%	4%	1%
BEA380	213	2895	2927	347	1%	19%	19%	2%	1%
BEA390	2135	2928	3031	1362	14%	19%	19%	9%	-5%
BEA400	303	1964	2033	361	2%	13%	13%	2%	0%
BEA410	3276	3289	3249	3181	21%	21%	21%	20%	-1%
BEA420	713	1062	1065	760	5%	7%	7%	5%	0%
BEA430	1230	1418	1423	1251	8%	9%	9%	8%	0%
BEA450	387	598	605	391	2%	4%	4%	3%	0%
BEA460	380	2205	2195	439	2%	14%	14%	3%	0%
BEA480	618	1072	1096	675	4%	7%	7%	4%	0%
BEA490	641	2177	2209	875	4%	14%	14%	6%	2%
BEA500	545	2638	2689	791	4%	17%	17%	5%	2%
BEA510	292	838	863	449	2%	5%	6%	3%	1%
BEA525	441	2342	2381	554	3%	15%	15%	4%	1%
BEA530	292	2289	2317	432	2%	15%	15%	3%	1%
BEA540	856	2551	2627	934	6%	16%	17%	6%	1%
BEA550	4123	4192	4257	4246	26%	27%	27%	27%	1%
BEA570	849	3232	3287	1412	5%	21%	21%	9%	4%
BEA580	3393	4369	4384	3866	22%	28%	28%	25%	3%
BEA590	821	2944	3018	1277	5%	19%	19%	8%	3%
BEA600	323	2082	2104	360	2%	13%	14%	2%	0%
BEA610	928	2043	2051	970	6%	13%	13%	6%	0%
BEA620	4182	4182	4188	4183	27%	27%	27%	27%	0%
BEA625	734	2565	2776	1022	5%	16%	18%	7%	2%
BEA630	4076	4182	4223	4210	26%	27%	27%	27%	1%
BEA640	40	2008	2034	94	0%	13%	13%	1%	0%
BEA650	4485	4485	4485	4484	29%	29%	29%	29%	0%
BEA660	2	1018	1069	14	0%	7%	7%	0%	0%
BEA665	448	2880	2933	526	3%	19%	19%	3%	1%
BEA670	995	2118	2123	1004	6%	14%	14%	6%	0%
BEA690	293	3250	3313	514	2%	21%	21%	3%	1%
BEA700	159	437	455	180	1%	3%	3%	1%	0%
BEA710	219	558	574	243	1%	4%	4%	2%	0%
BEA720	193	607	639	236	1%	4%	4%	2%	0%

Catchment	# of Days (63 winters)				Percent of Time (winter)				Diff. (Mit-Forest)
	Forested	Existing	Future	Mitigated	Forested	Existing	Future	Mitigated	
BEA725	2763	3040	3189	3126	18%	20%	20%	20%	2%
BEA730	40	478	542	134	0%	3%	3%	1%	1%
BEA740	4656	4659	4670	4669	30%	30%	30%	30%	0%
BEA750	4659	5005	5190	5190	30%	32%	33%	33%	3%
BEA760	206	767	827	271	1%	5%	5%	2%	0%
BEA770	918	1933	2685	2445	6%	12%	17%	16%	10%
BEA780	197	726	764	248	1%	5%	5%	2%	0%
BEA800	353	427	477	471	2%	3%	3%	3%	1%
BEA820	1959	1984	2043	1914	13%	13%	13%	12%	0%
BEA830	100	392	467	216	1%	3%	3%	1%	1%
BEA840	109	993	1116	358	1%	6%	7%	2%	2%
BEA850	328	245	246	338	2%	2%	2%	2%	0%
BEA860	2961	3354	3466	3402	19%	22%	22%	22%	3%
BEA900	175	623	623	180	1%	4%	4%	1%	0%
BEA910	143	492	492	195	1%	3%	3%	1%	0%
BEA920	14	155	155	36	0%	1%	1%	0%	0%
BEA940	222	791	782	286	1%	5%	5%	2%	0%
BEA950	256	610	607	276	2%	4%	4%	2%	0%
BEA960	153	369	366	157	1%	2%	2%	1%	0%
BEA970	130	1929	1656	730	1%	12%	11%	5%	4%
BEA990	3981	4233	4233	4193	26%	27%	27%	27%	1%
MON018	0	12	12	0	0%	0%	0%	0%	0%
MON029	0	0	0	0	0%	0%	0%	0%	0%
MON030	735	2037	1899	843	5%	13%	12%	5%	1%

APPENDIX K: Simulated Fecal Coliforms

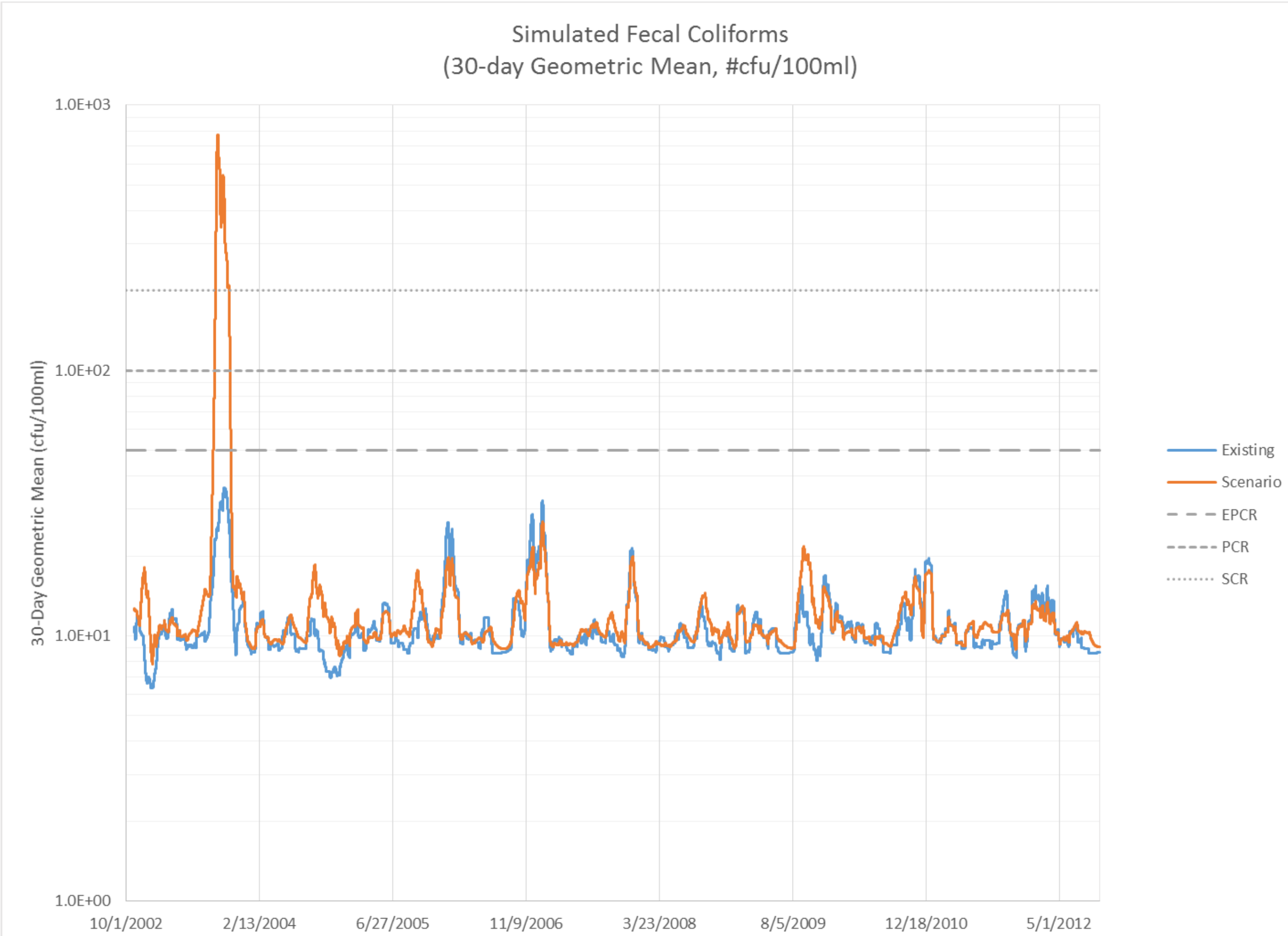

Figure 195 BEA020 simulated 30-day geometric mean concentrations of fecal coliforms per 100ml.

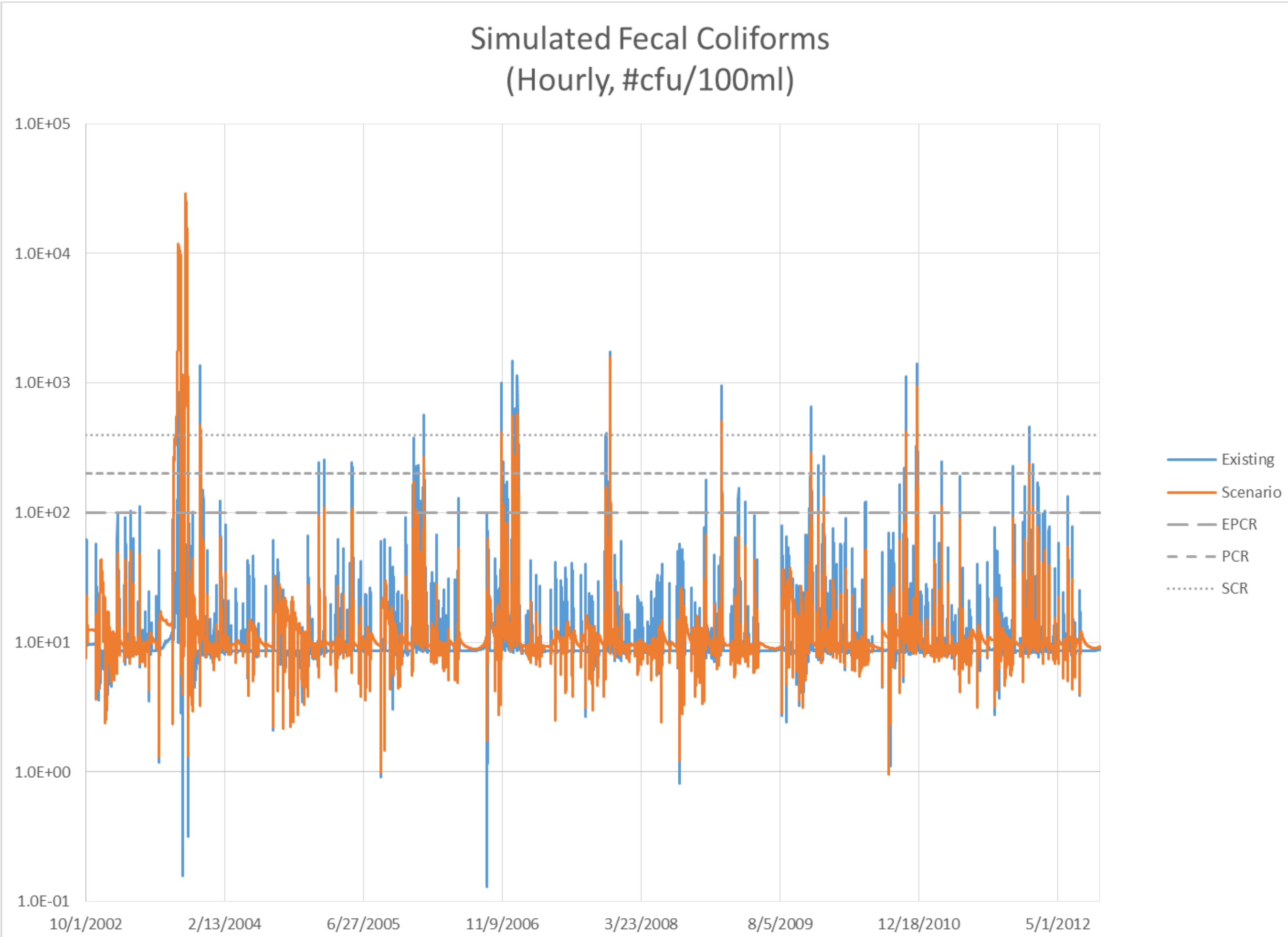

Figure 196 BEA020 simulated hourly concentrations of fecal coliforms per 100ml.

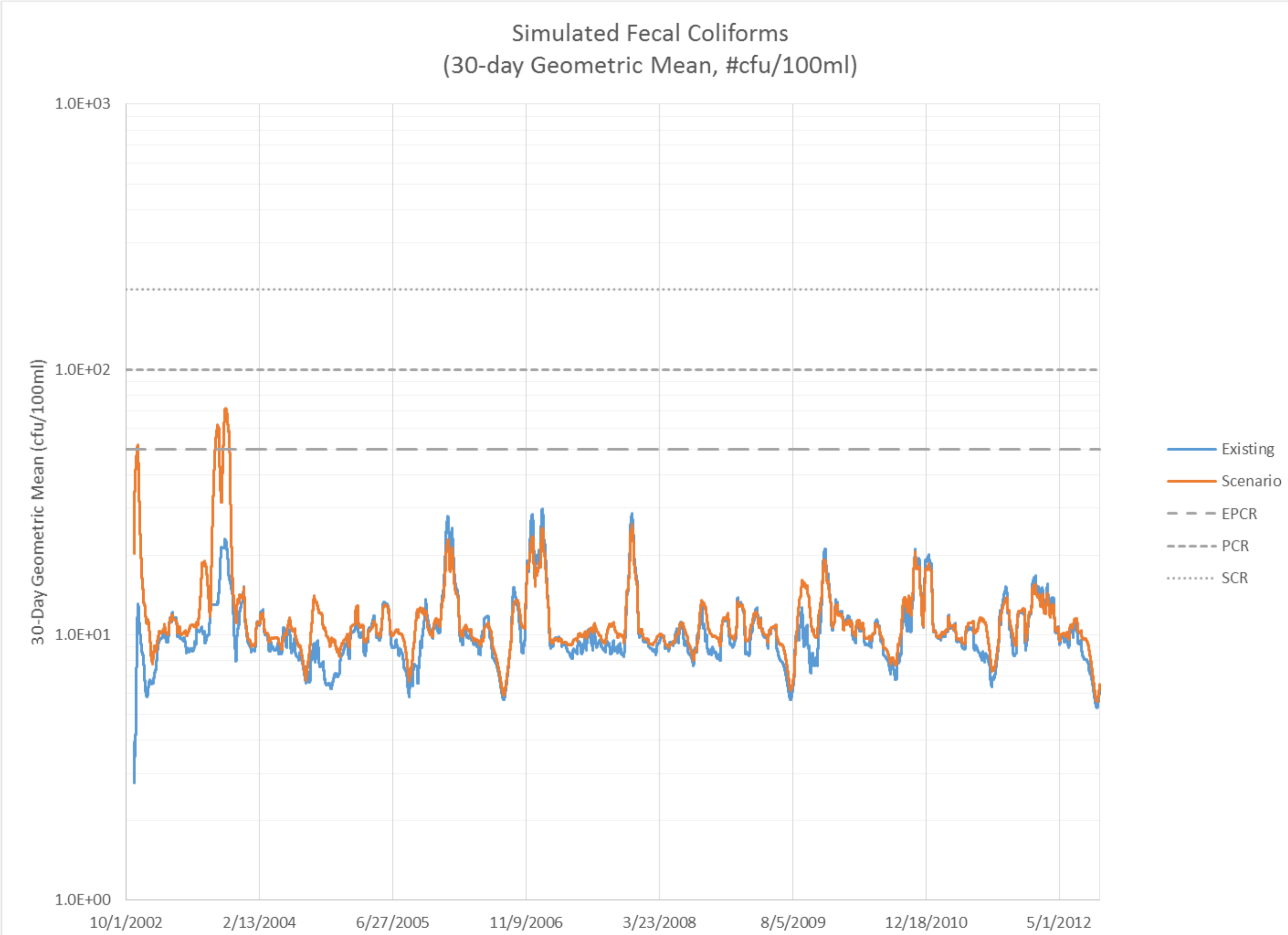

Figure 197 BEA120 simulated 30-day geometric mean concentrations of fecal coliforms per 100ml.

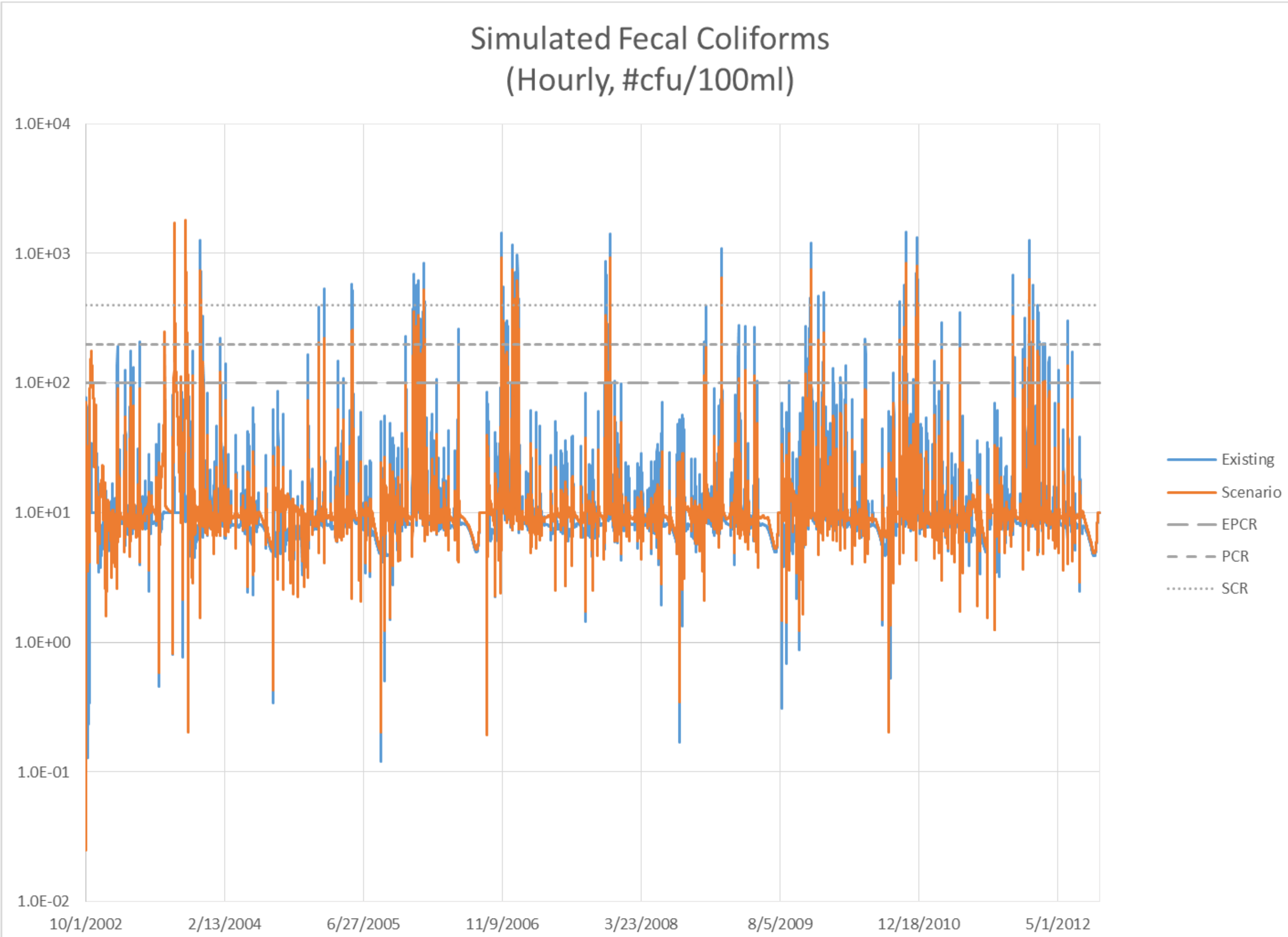

Figure 198 BEA120 simulated hourly concentrations of fecal coliforms per 100ml.

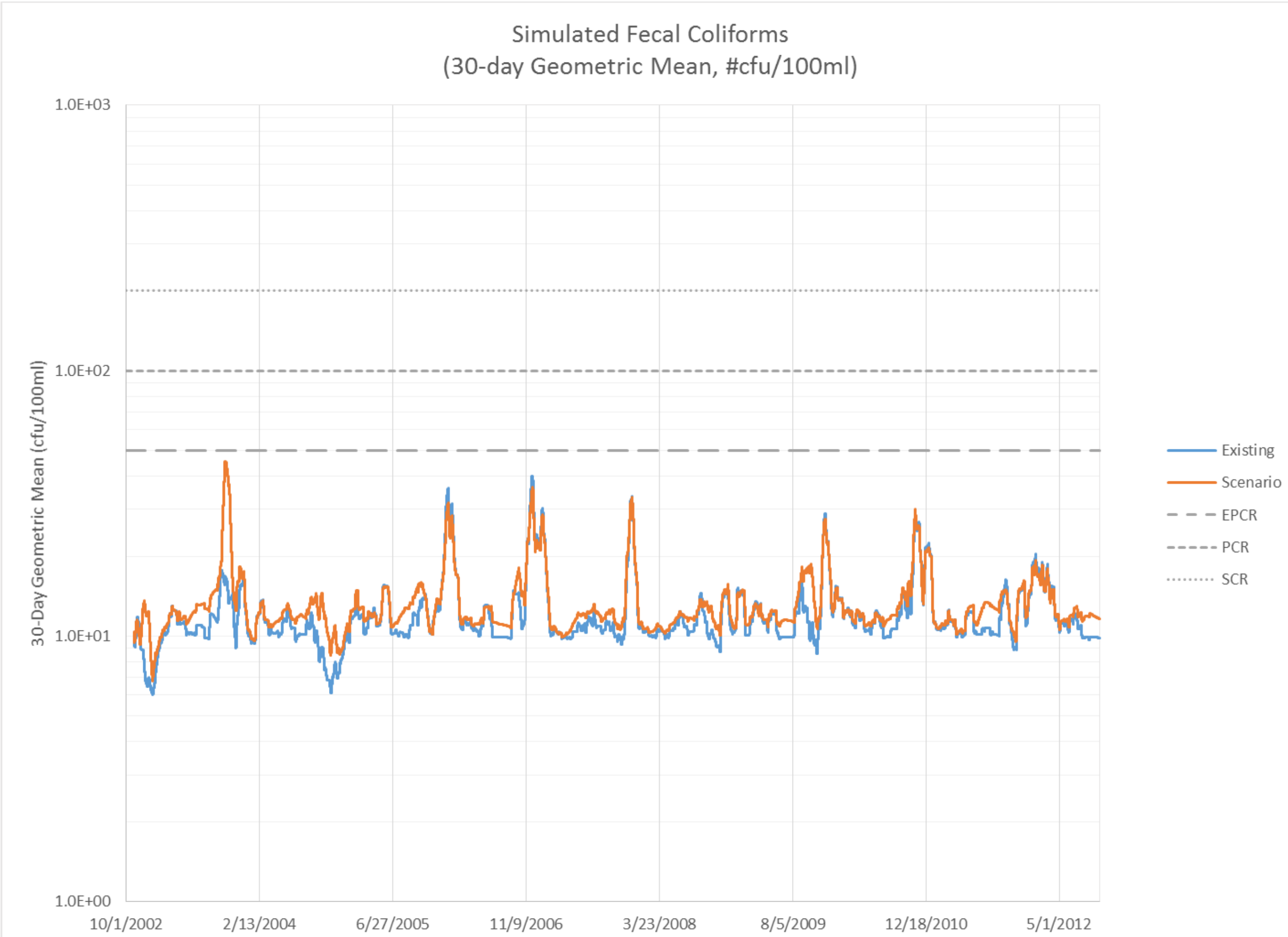

Figure 199 BEA210 simulated 30-day geometric mean concentrations of fecal coliforms per 100ml.

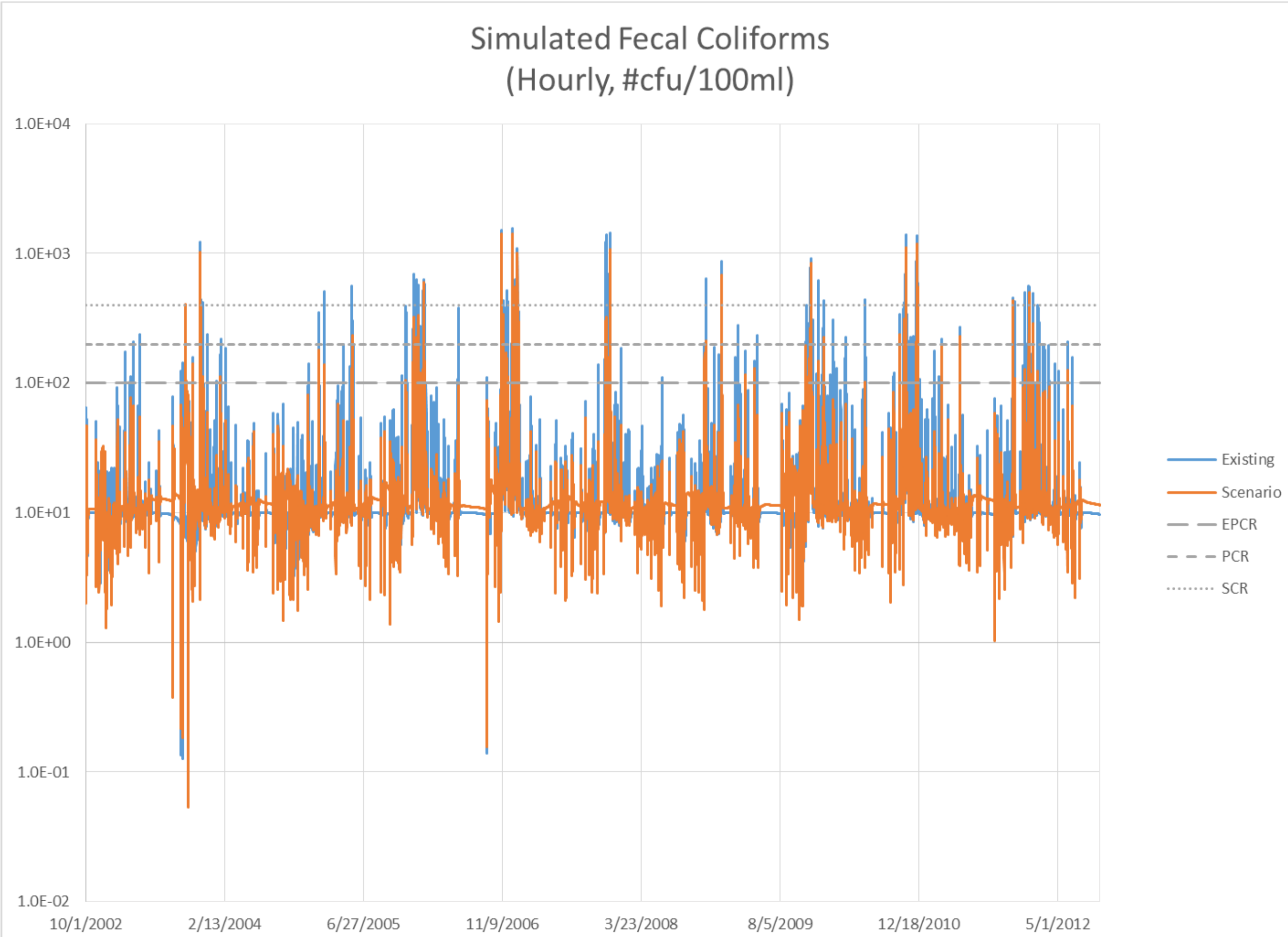

Figure 200 BEA210 simulated hourly concentrations of fecal coliforms per 100ml.

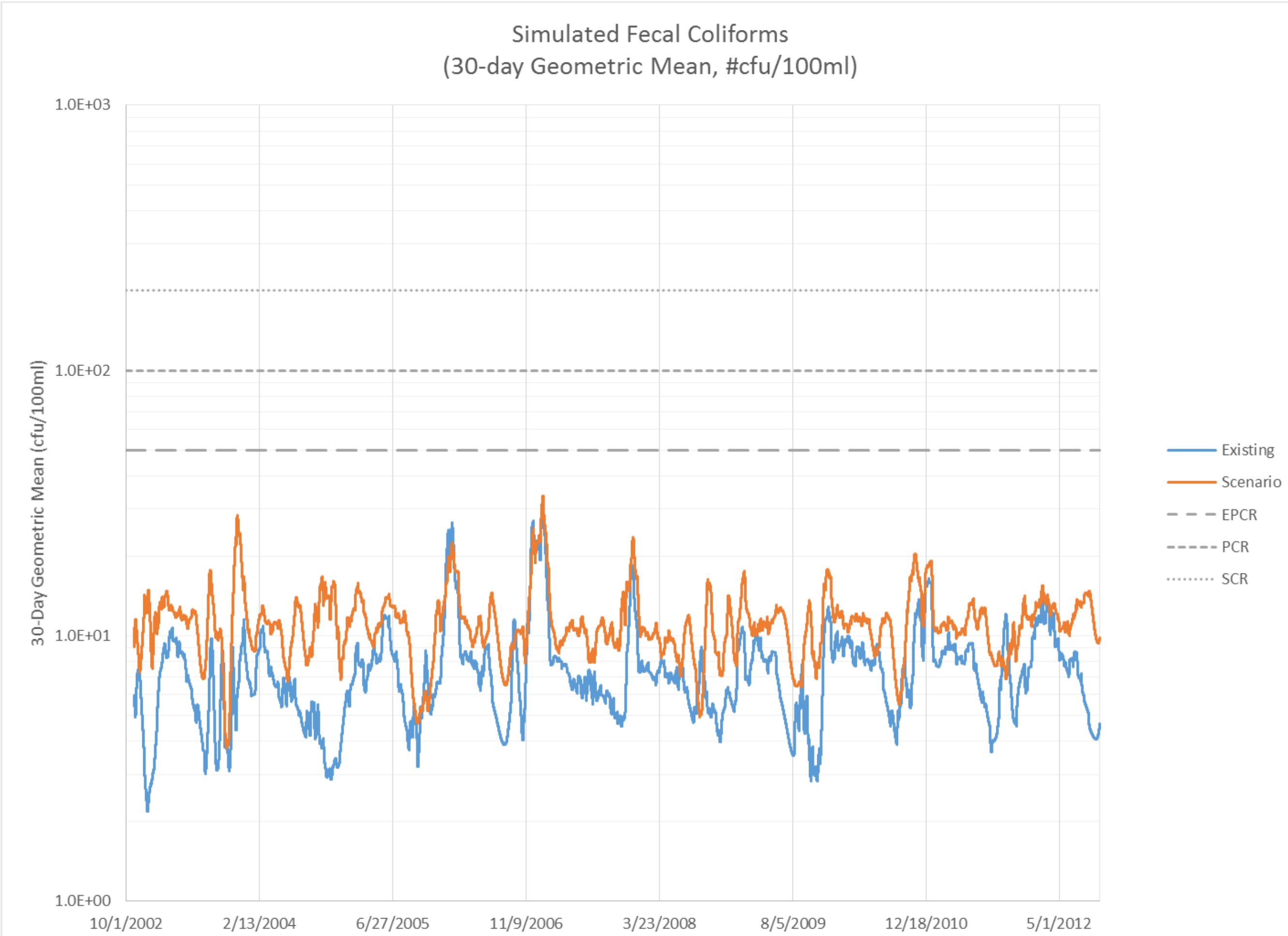

Figure 201 BEA240 simulated 30-day geometric mean concentrations of fecal coliforms per 100ml.

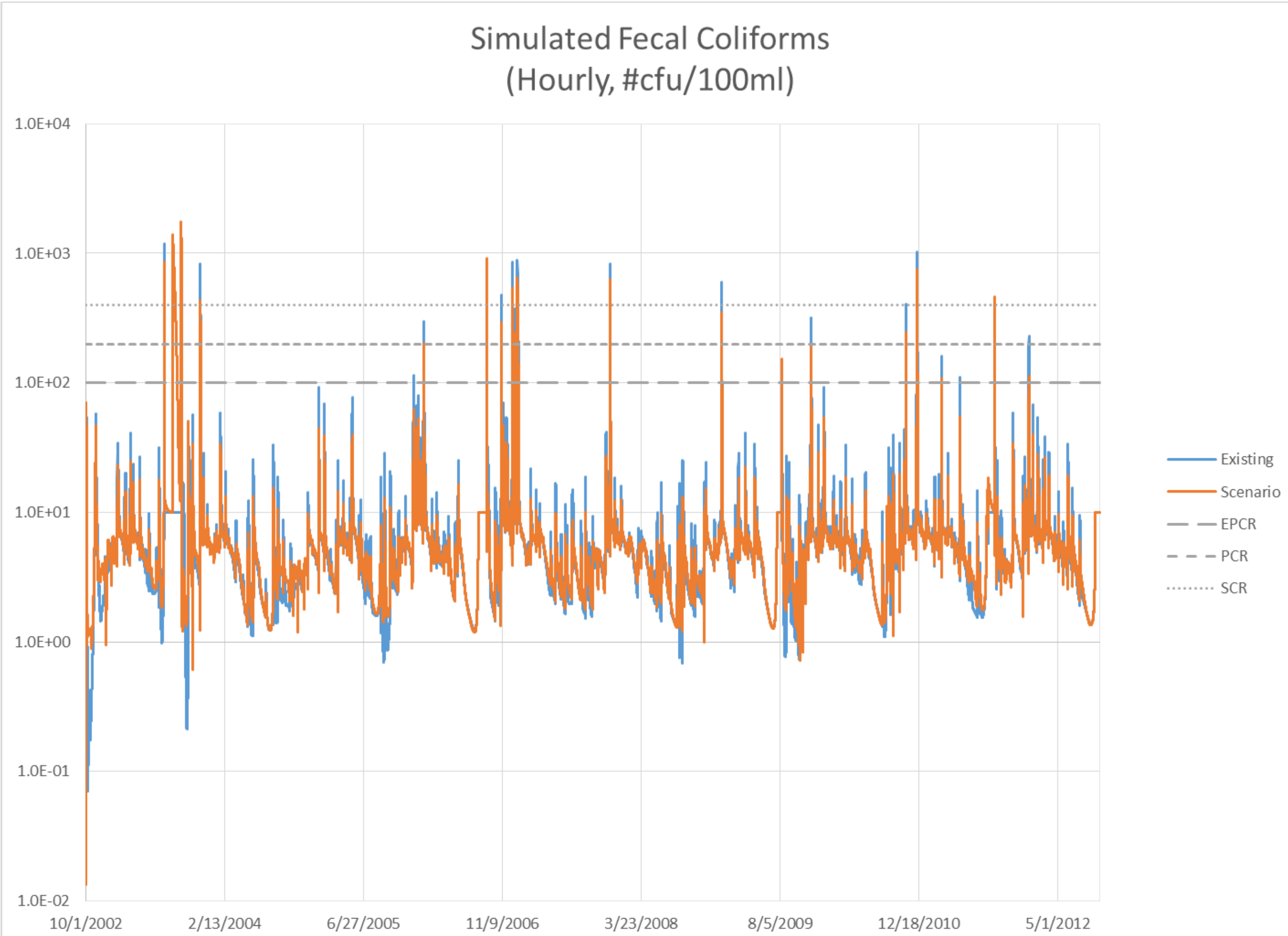

Figure 202 BEA240 simulated hourly concentrations of fecal coliforms per 100ml.

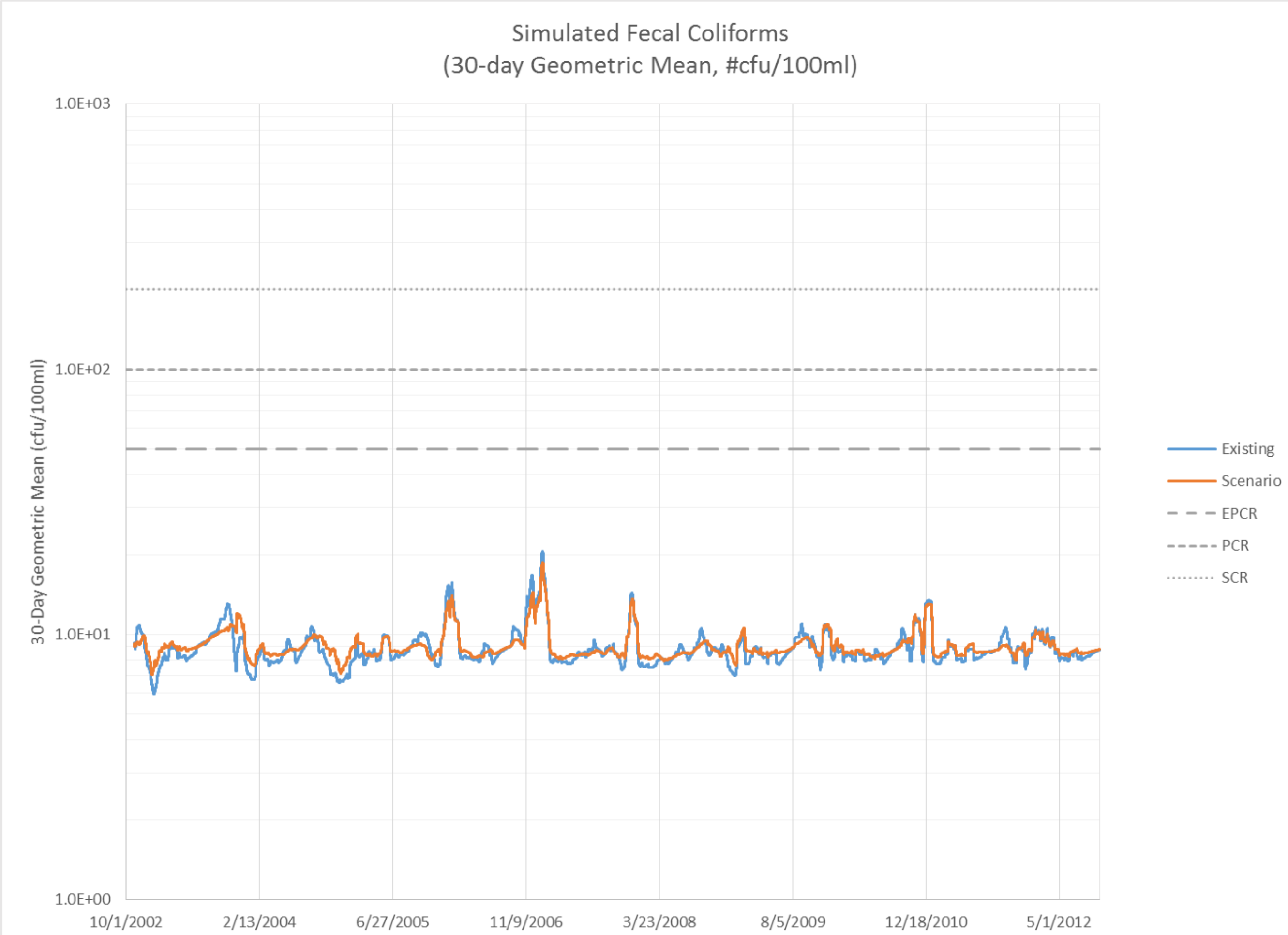

Figure 203 BEA260 simulated 30-day geometric mean concentrations of fecal coliforms per 100ml.

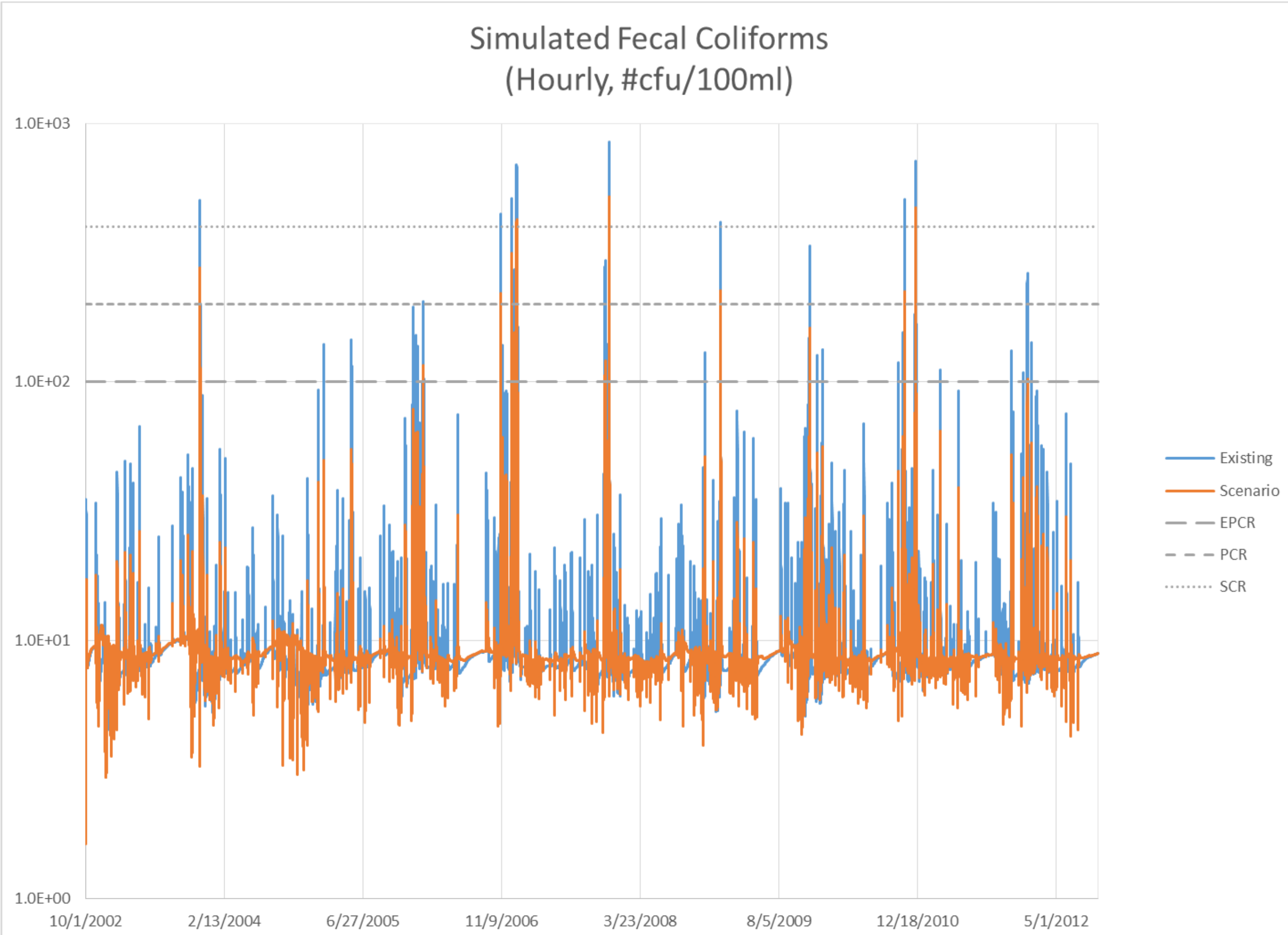

Figure 204 BEA260 simulated hourly concentrations of fecal coliforms per 100ml.

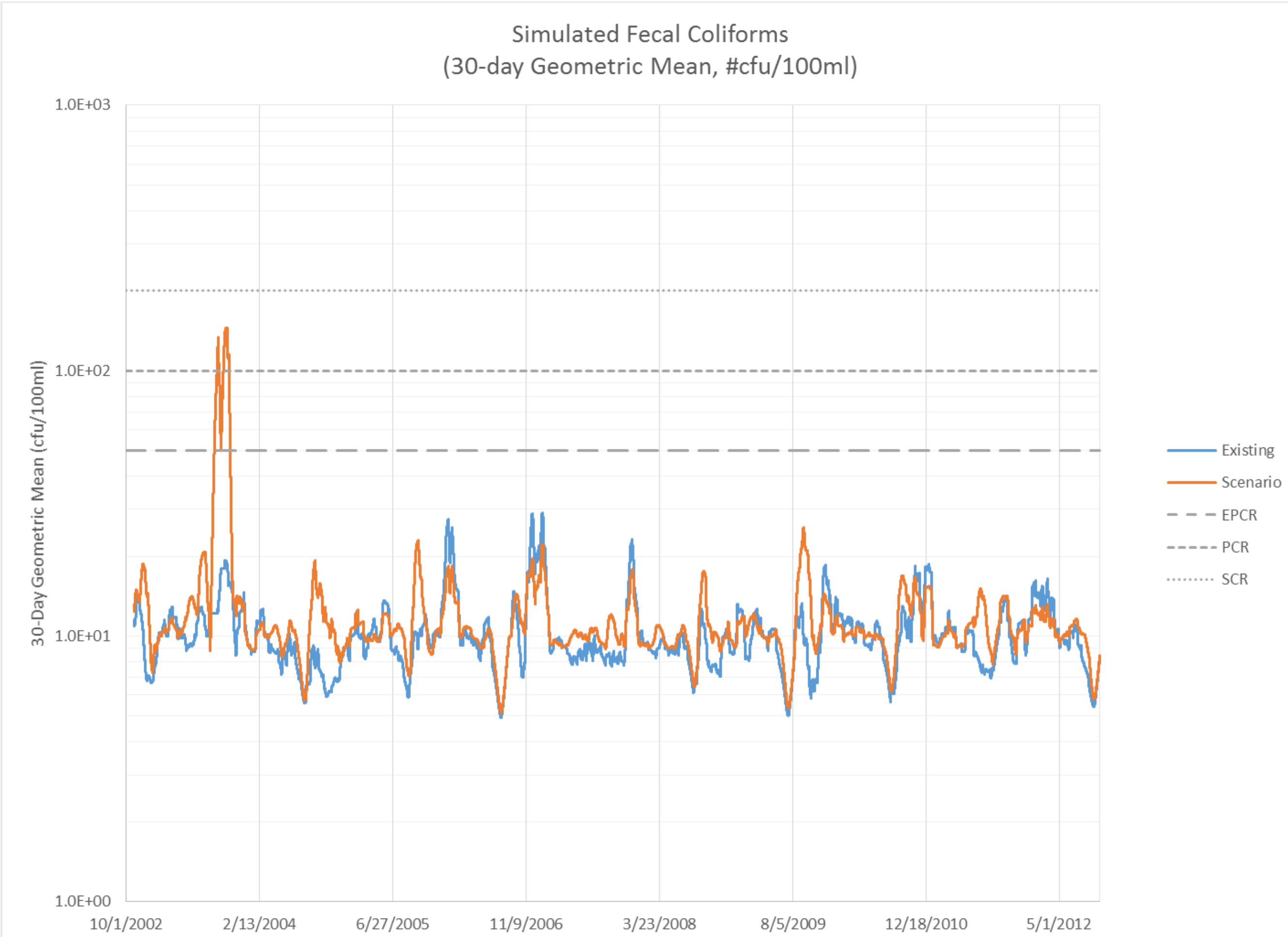

Figure 205 BEA270 simulated 30-day geometric mean concentrations of fecal coliforms per 100ml.

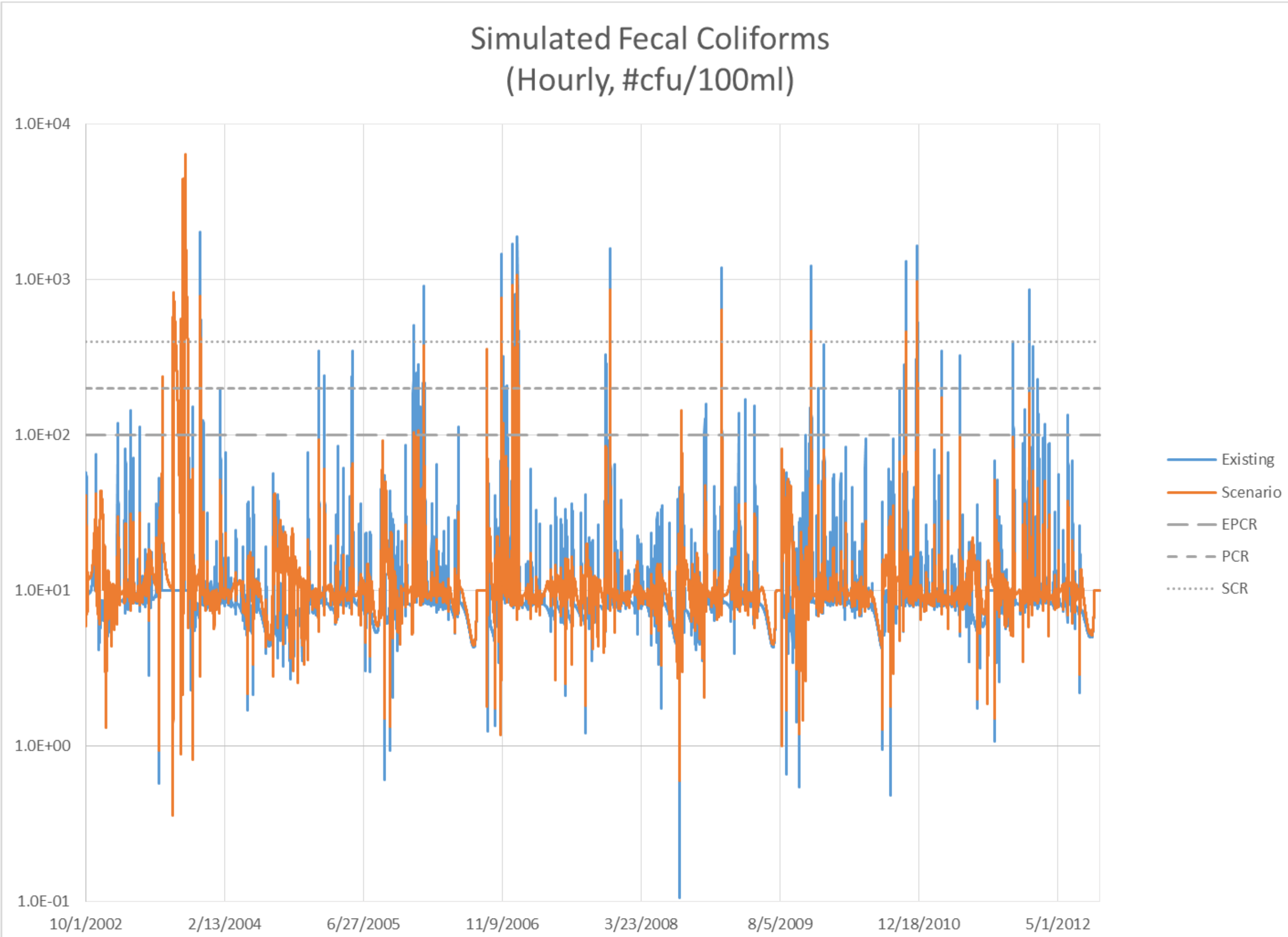

Figure 206 BEA270 simulated hourly concentrations of fecal coliforms per 100ml.

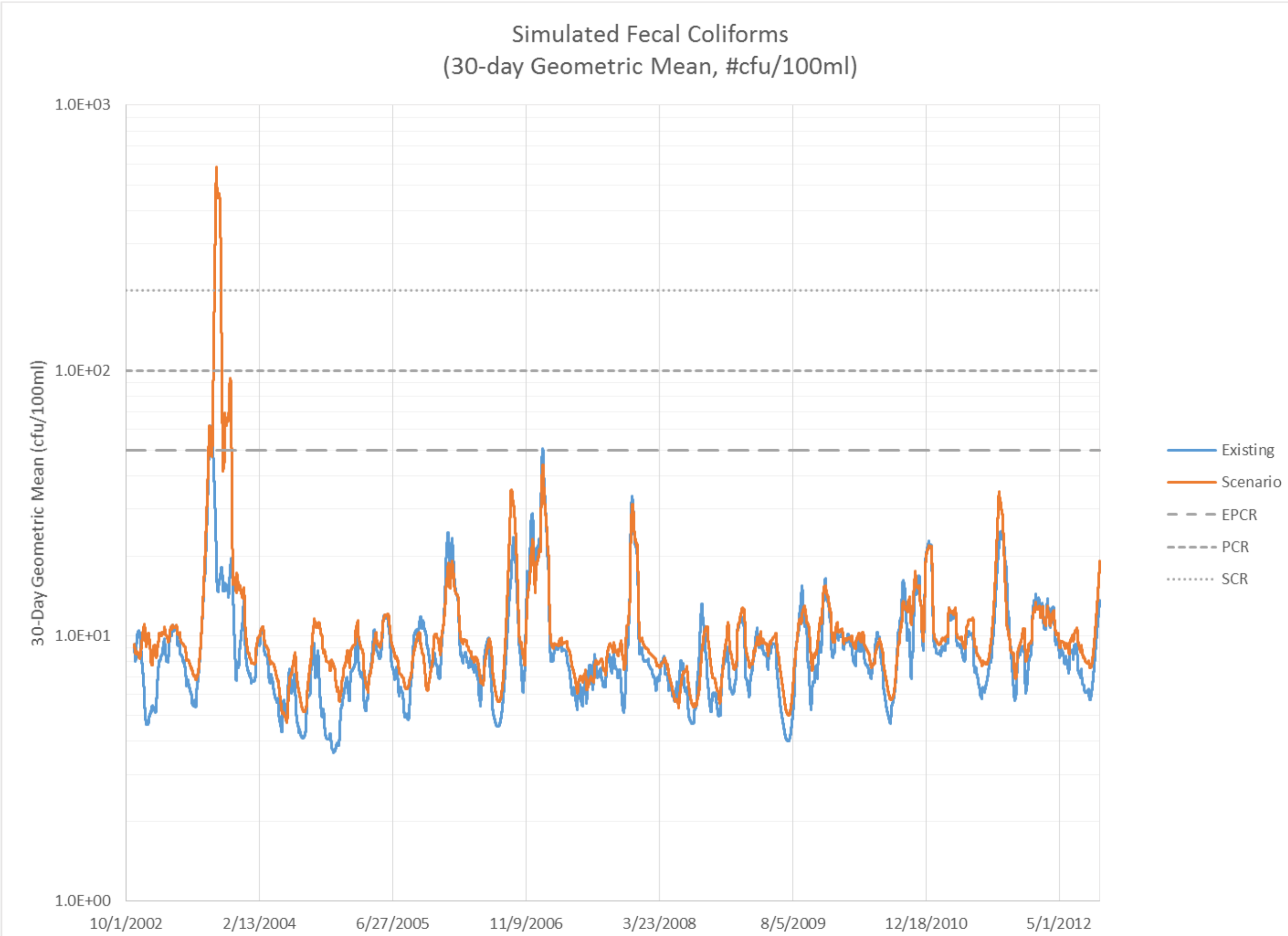

Figure 207 BEA280 simulated 30-day geometric mean concentrations of fecal coliforms per 100ml.

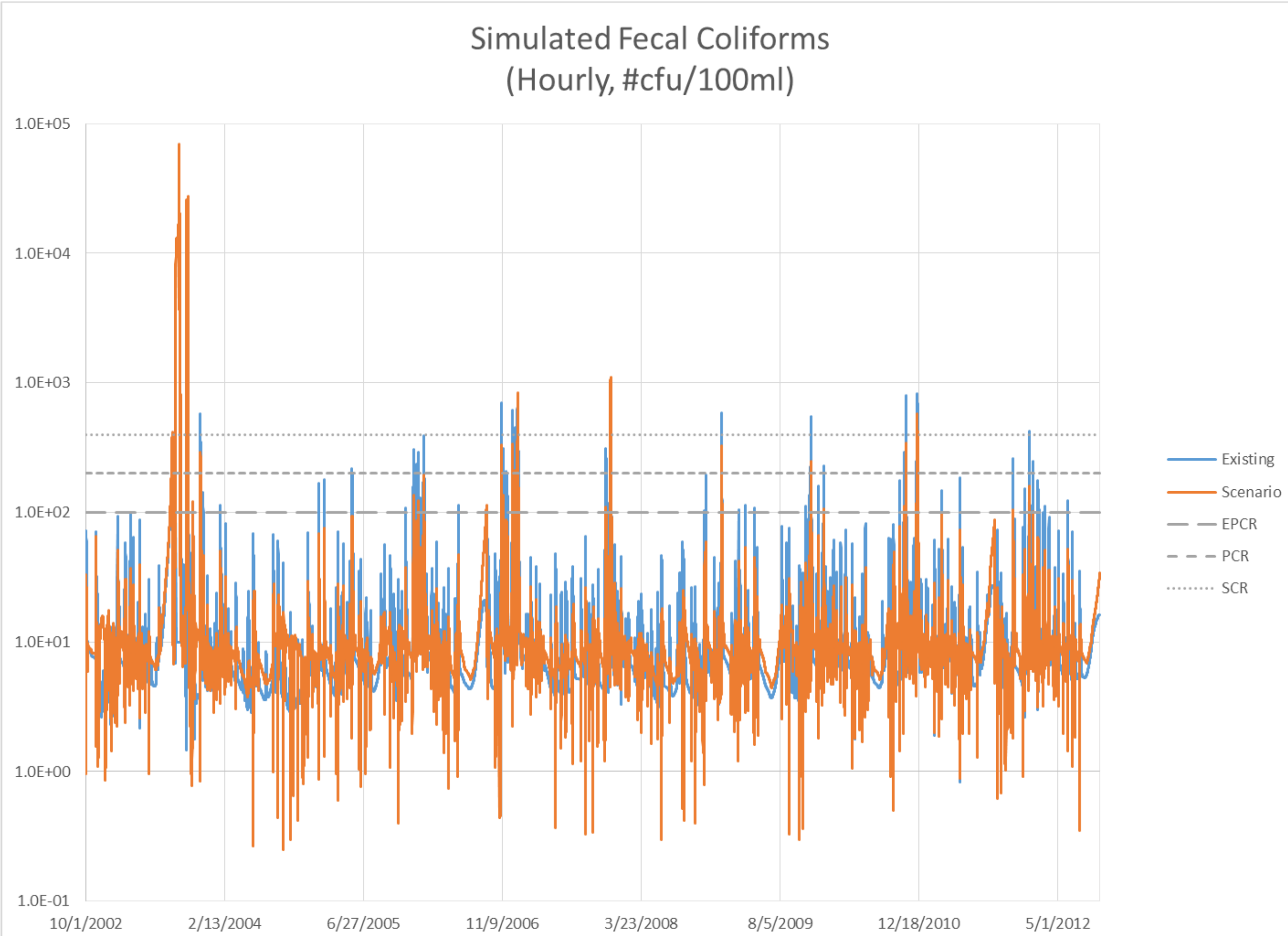

Figure 208 BEA280 simulated hourly concentrations of fecal coliforms per 100ml.

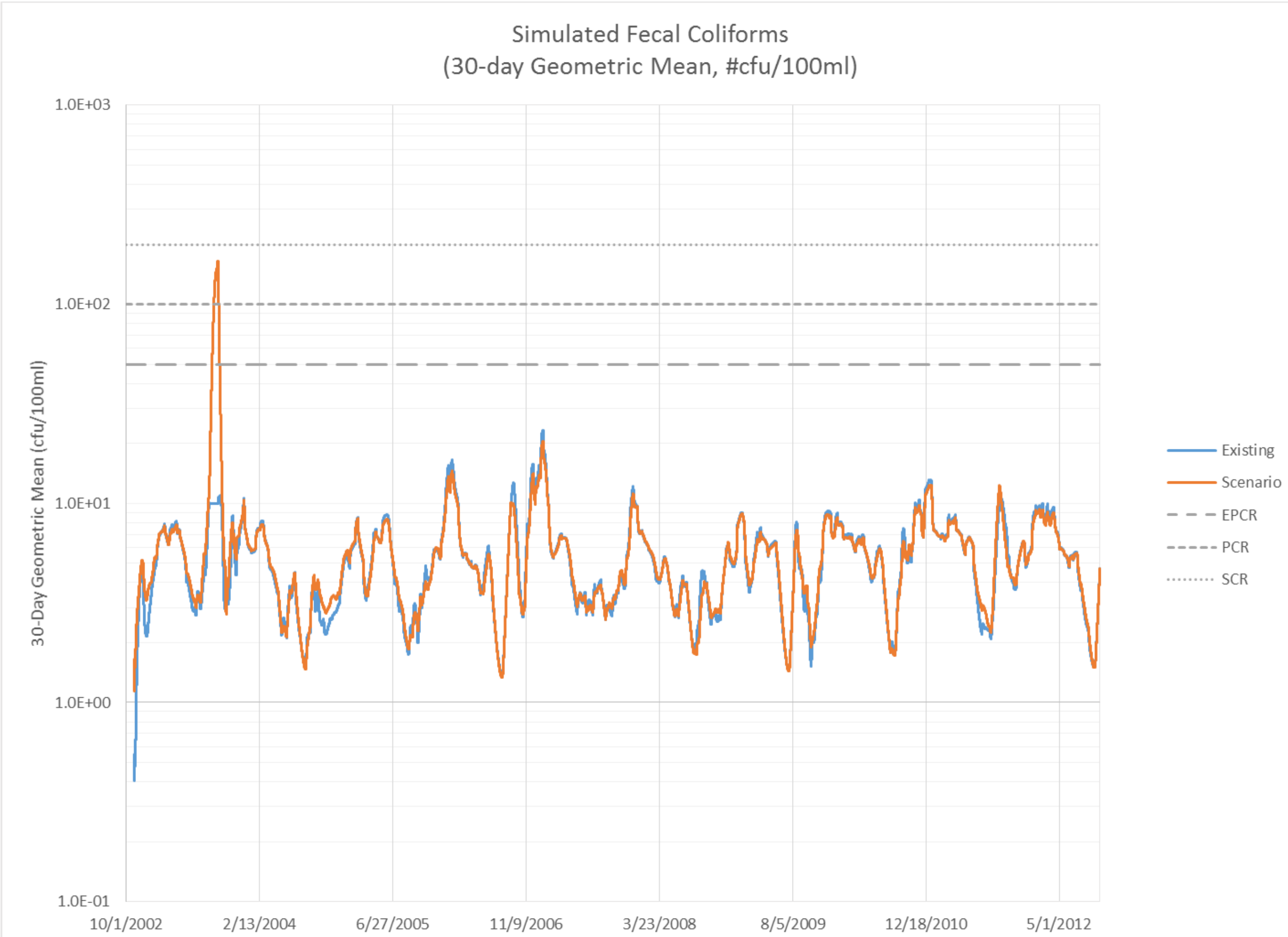

Figure 209 BEA310 simulated 30-day geometric mean concentrations of fecal coliforms per 100ml.

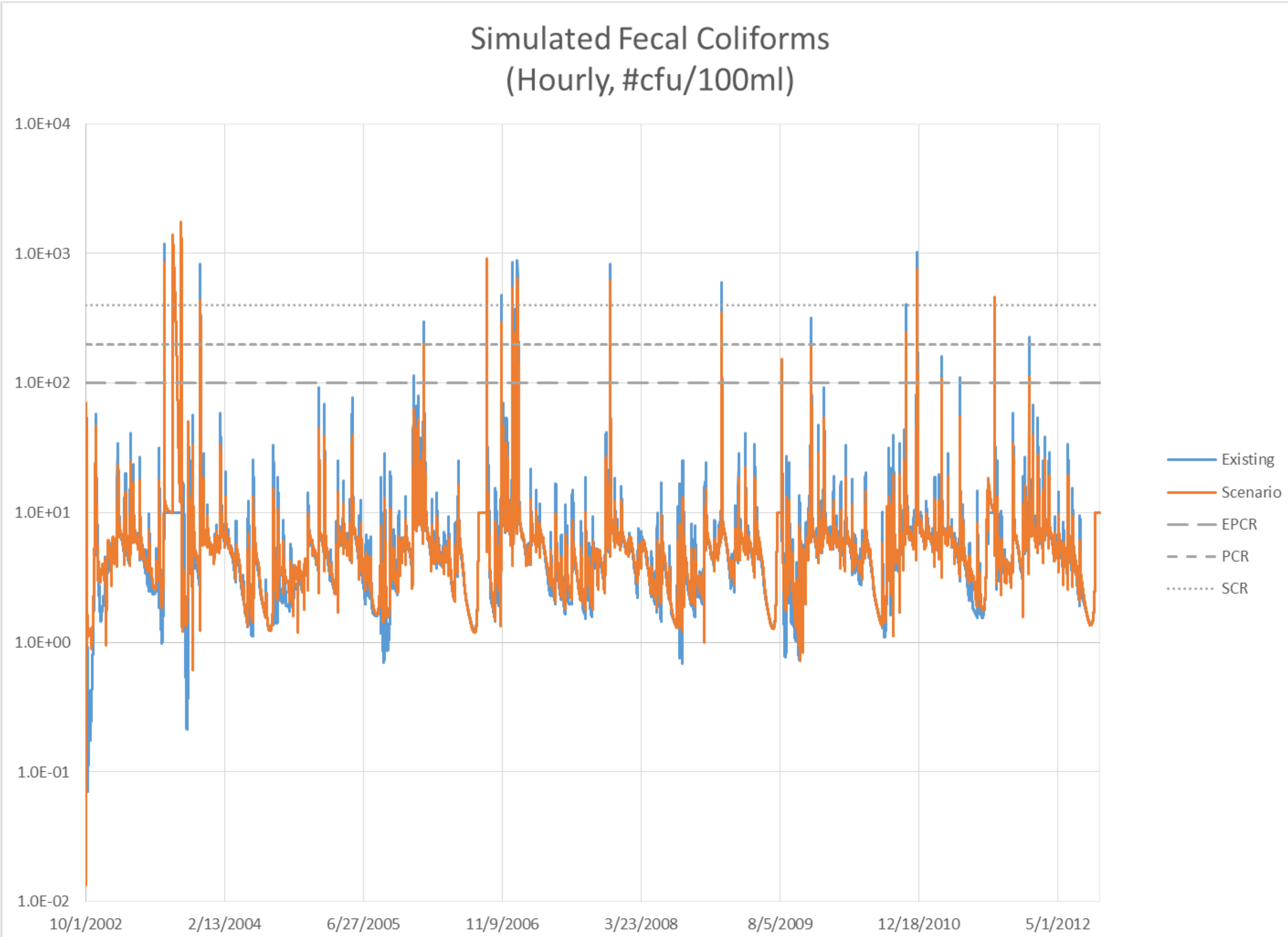

Figure 210 BEA310 simulated hourly concentrations of fecal coliforms per 100ml.

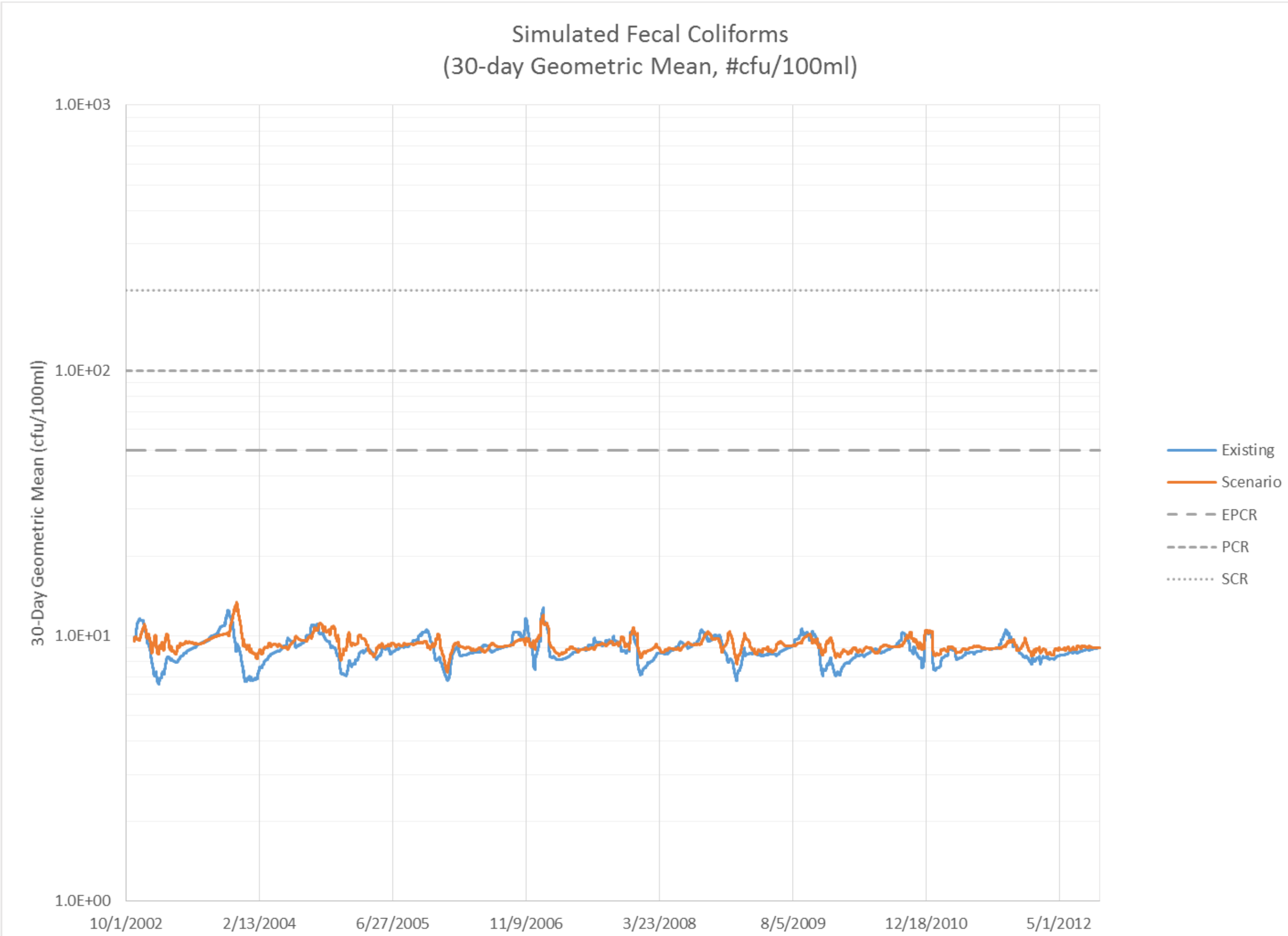

Figure 211 BEA370 simulated 30-day geometric mean concentrations of fecal coliforms per 100ml.

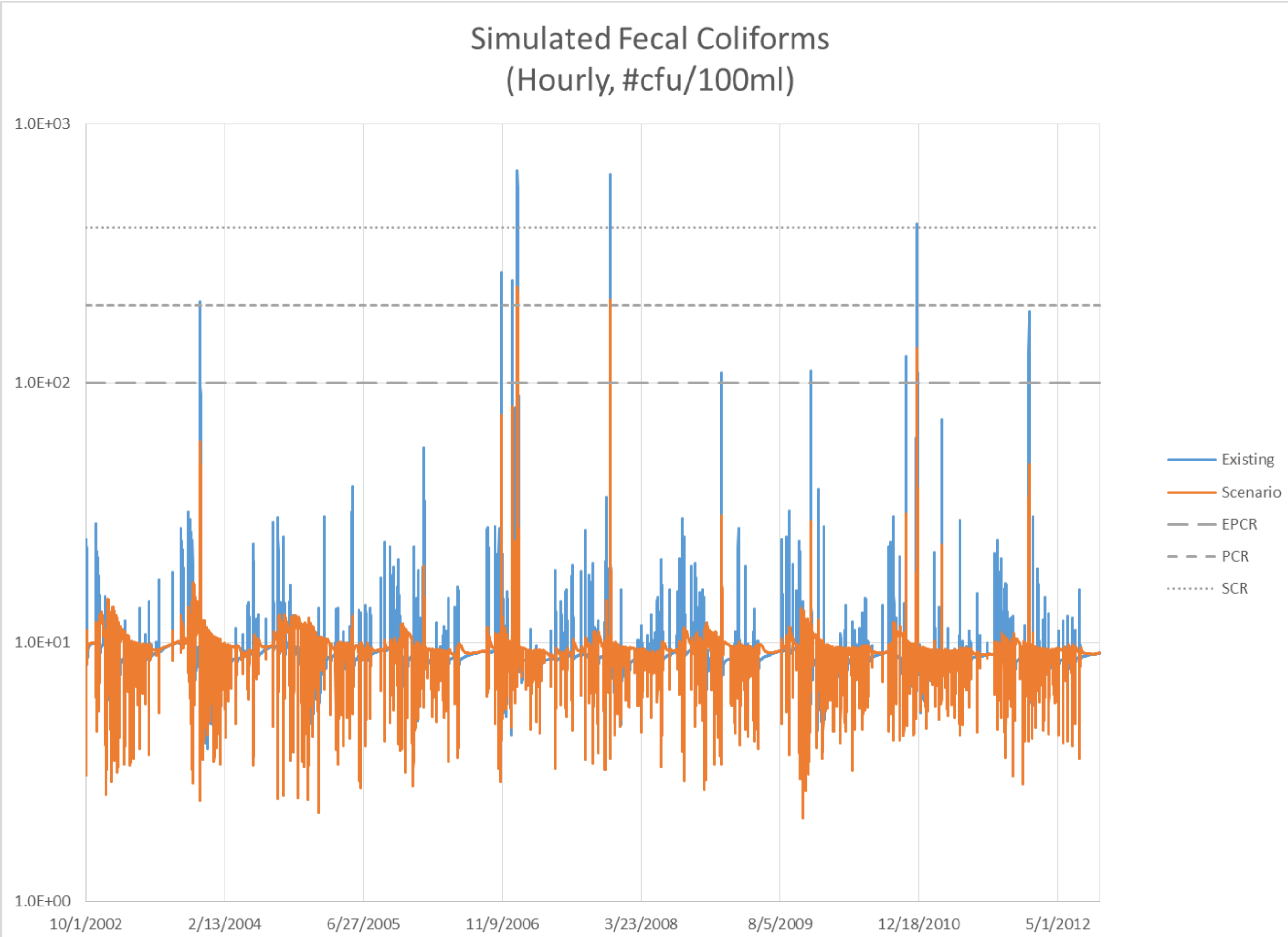

Figure 212 BEA370 simulated hourly concentrations of fecal coliforms per 100ml.

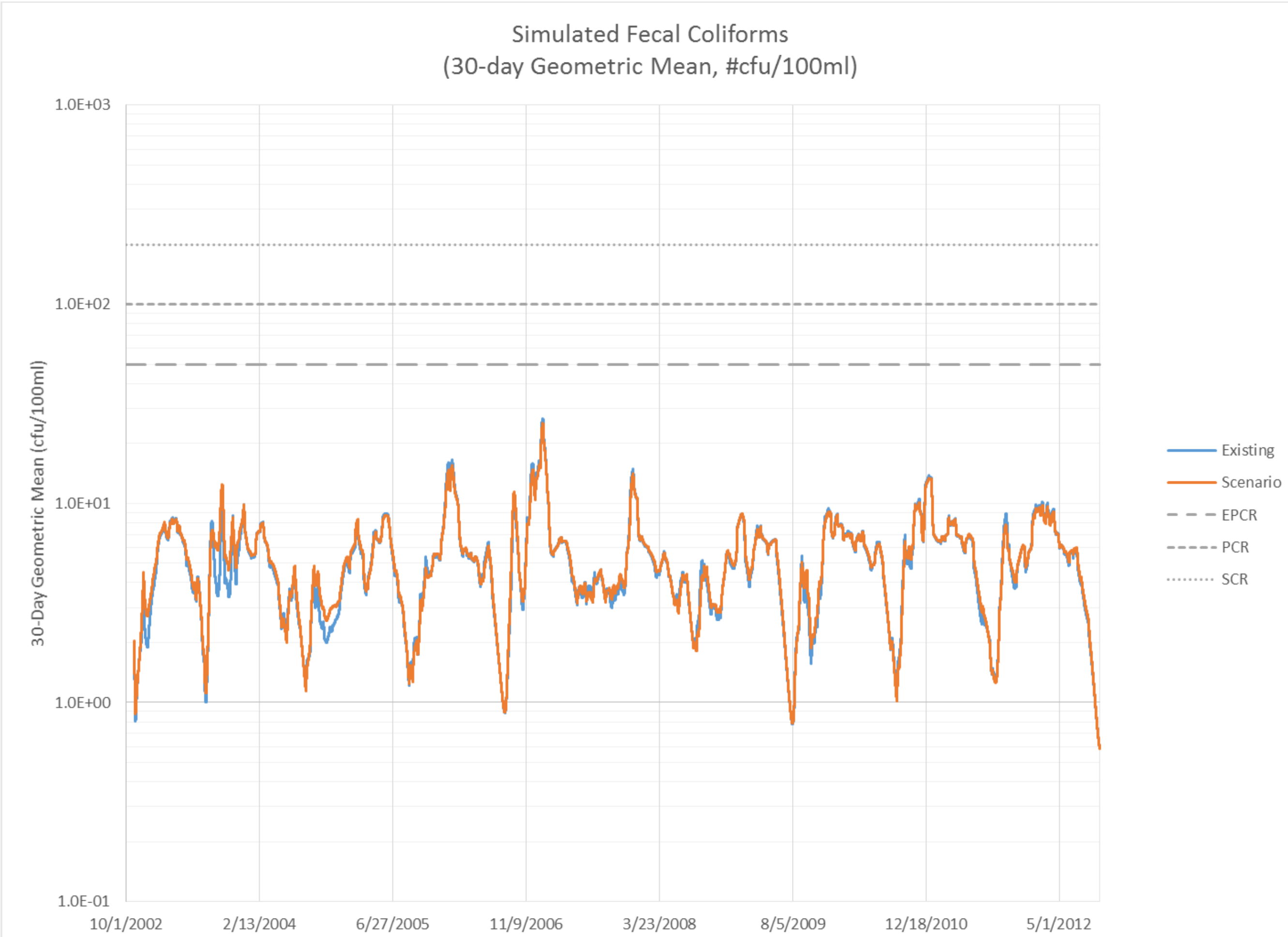

Figure 213 BEA410 simulated 30-day geometric mean concentrations of fecal coliforms per 100ml.

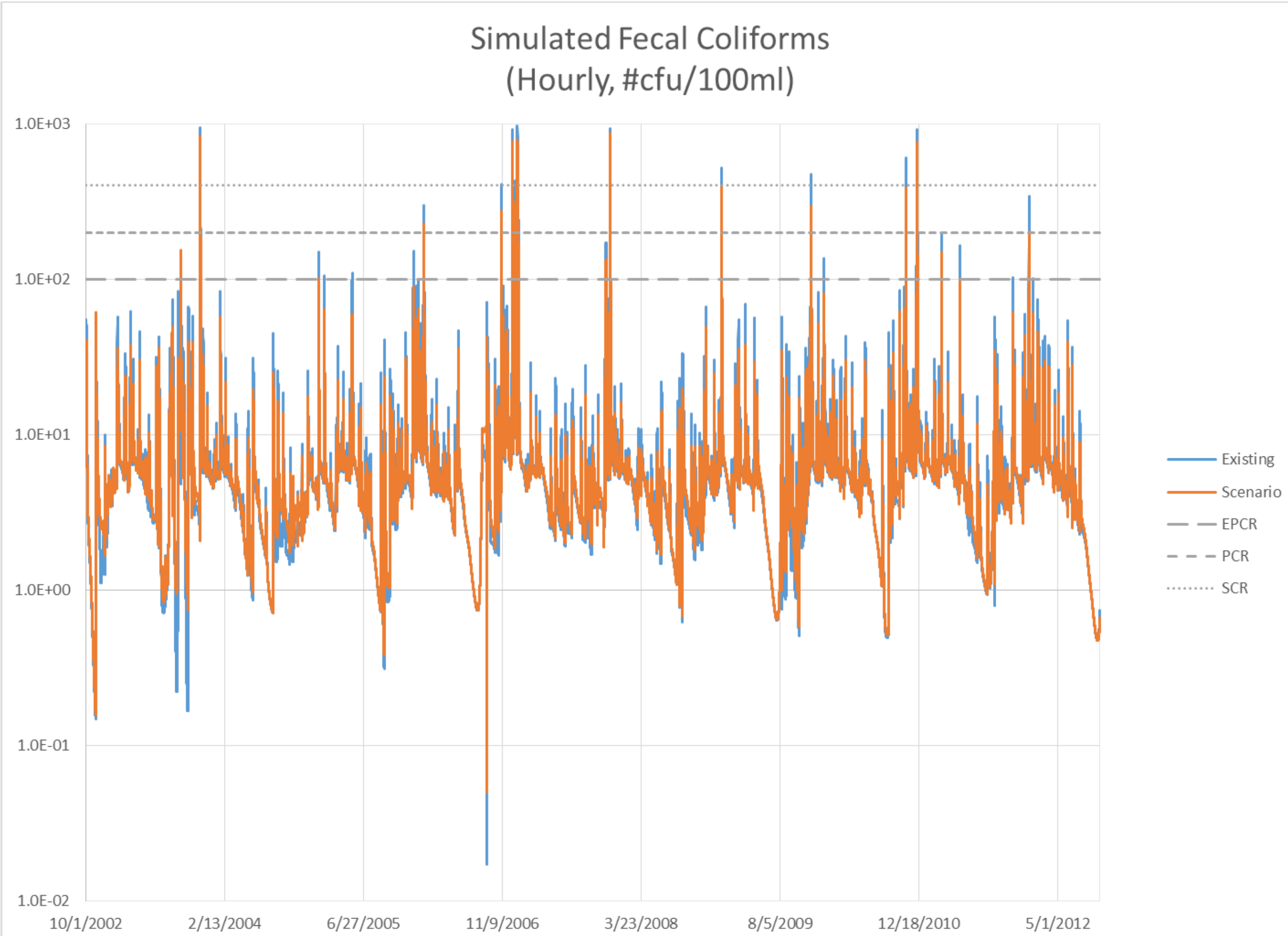

Figure 214 BEA410 simulated hourly concentrations of fecal coliforms per 100ml.

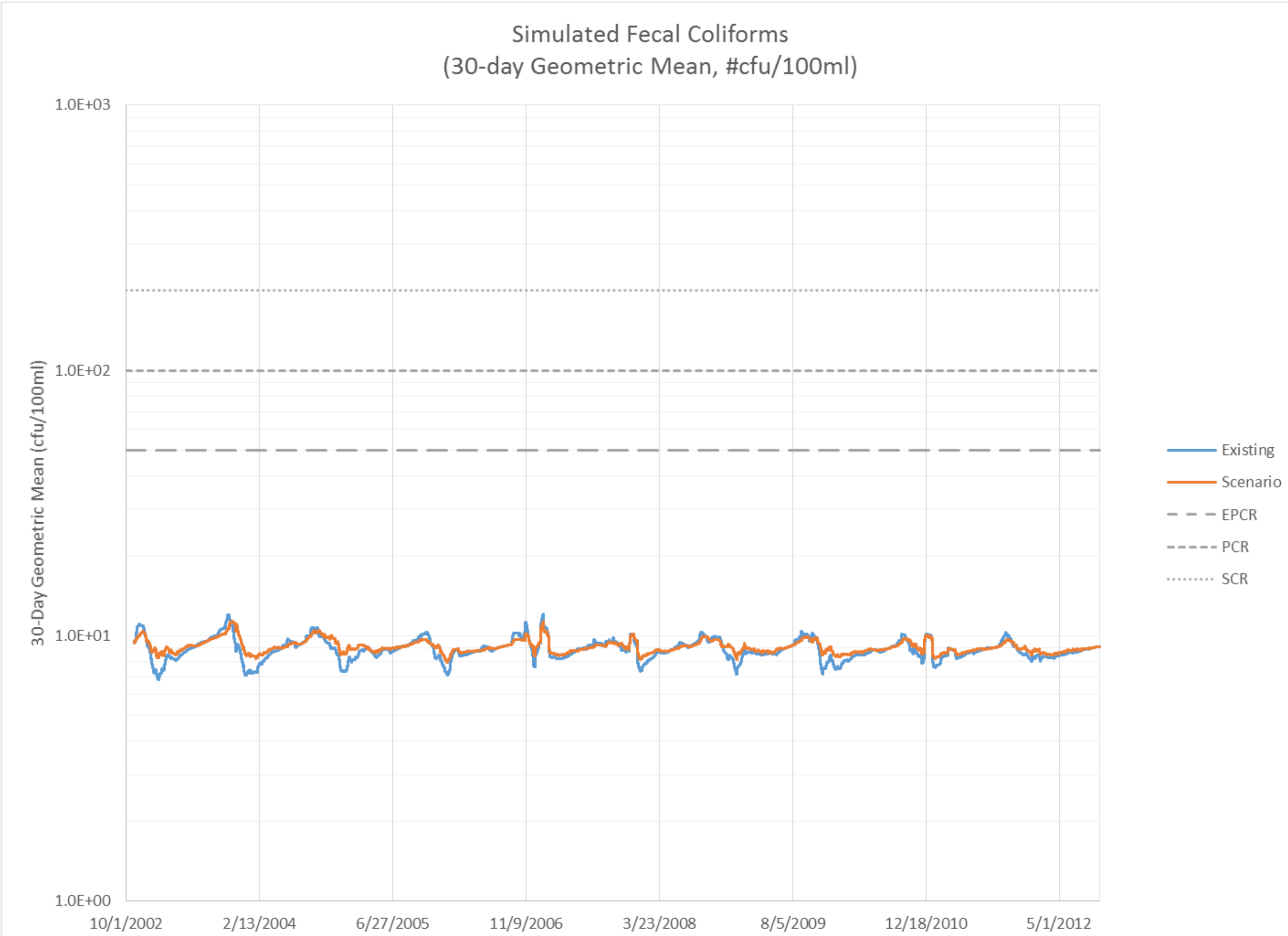

Figure 215 BEA590 simulated 30-day geometric mean concentrations of fecal coliforms per 100ml.

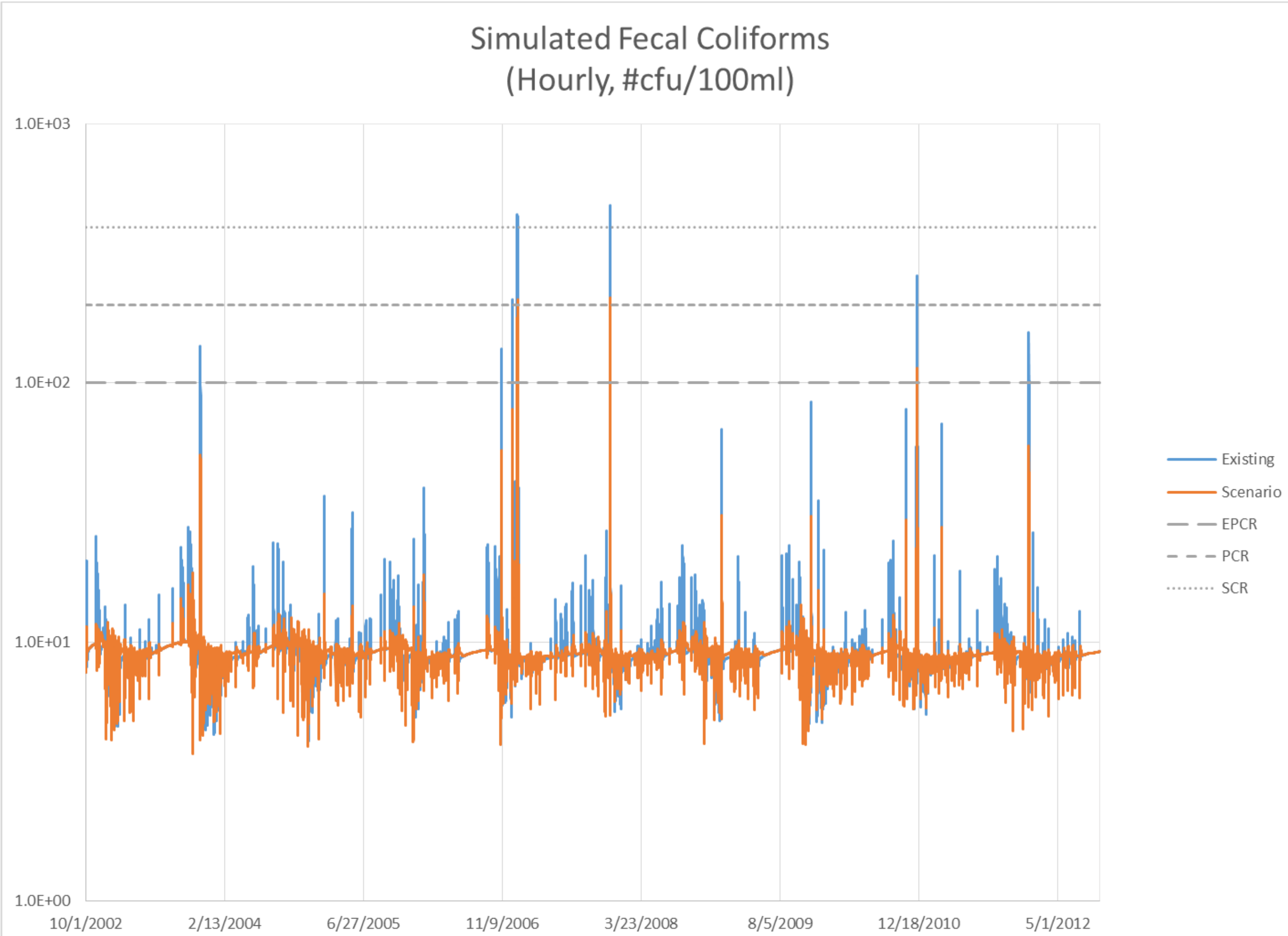

Figure 216 BEA590 simulated hourly concentrations of fecal coliforms per 100ml.

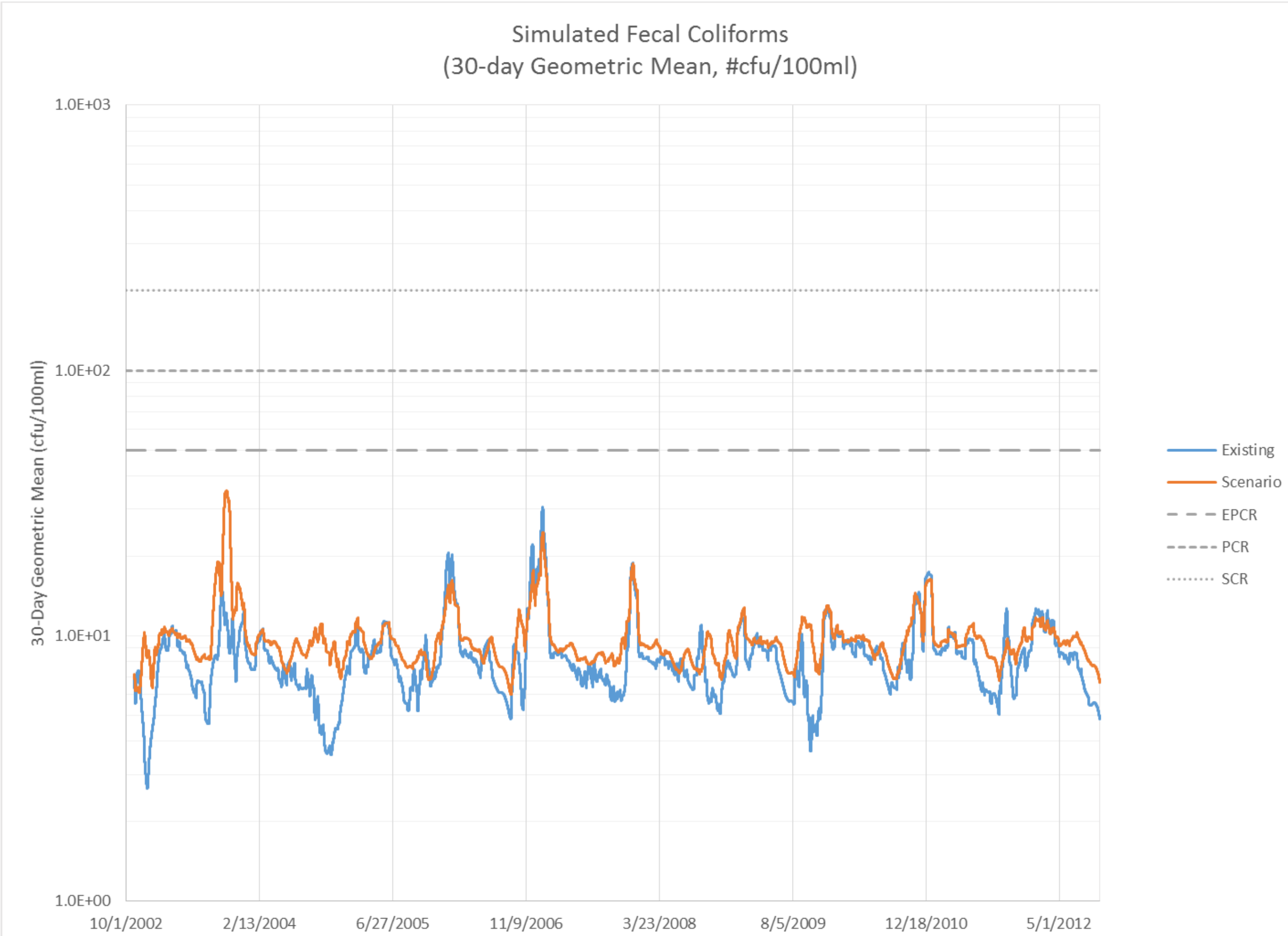

Figure 217 BEA800 simulated 30-day geometric mean concentrations of fecal coliforms per 100ml.

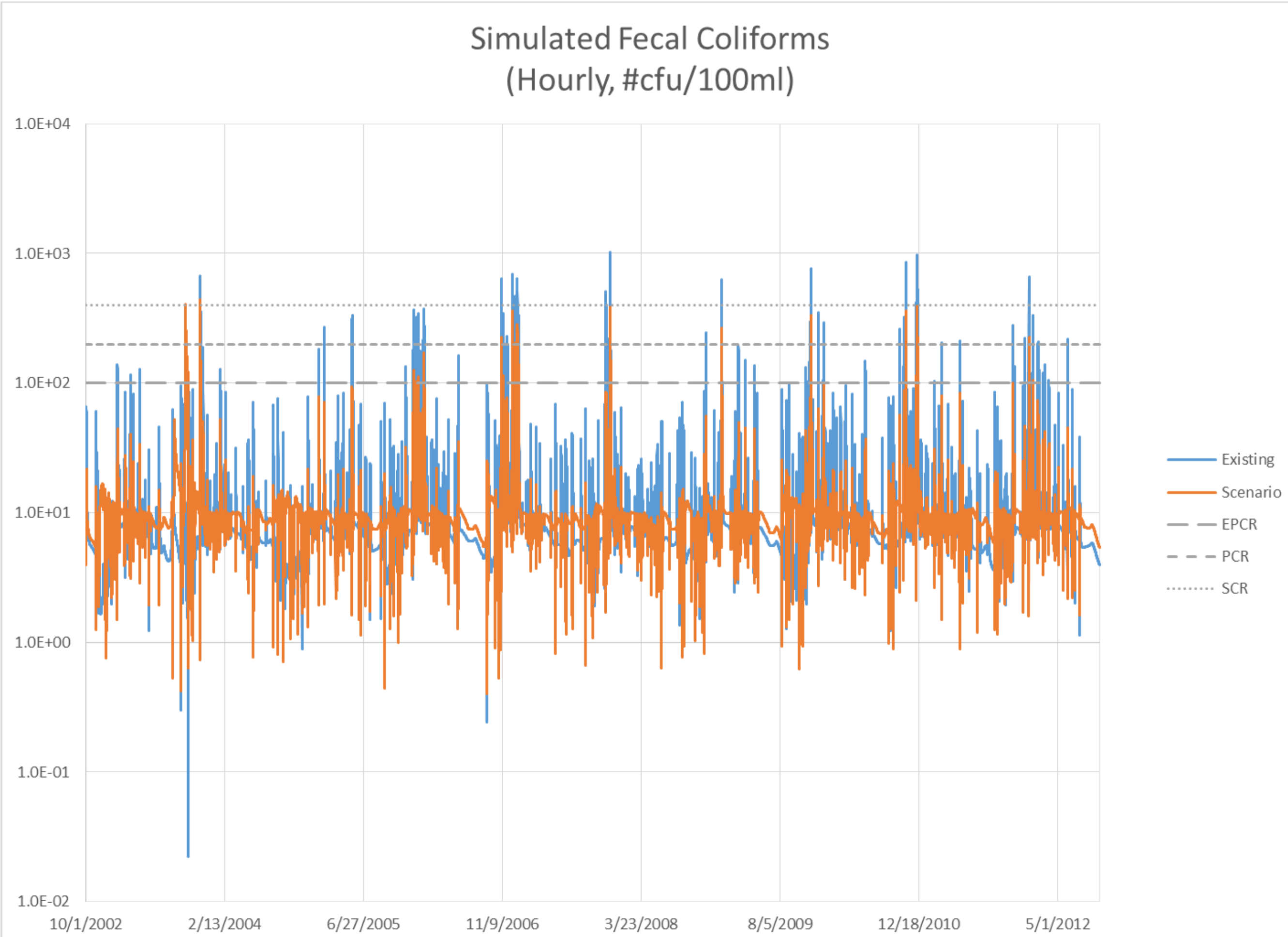

Figure 218 BEA800 simulated hourly concentrations of fecal coliforms per 100ml.

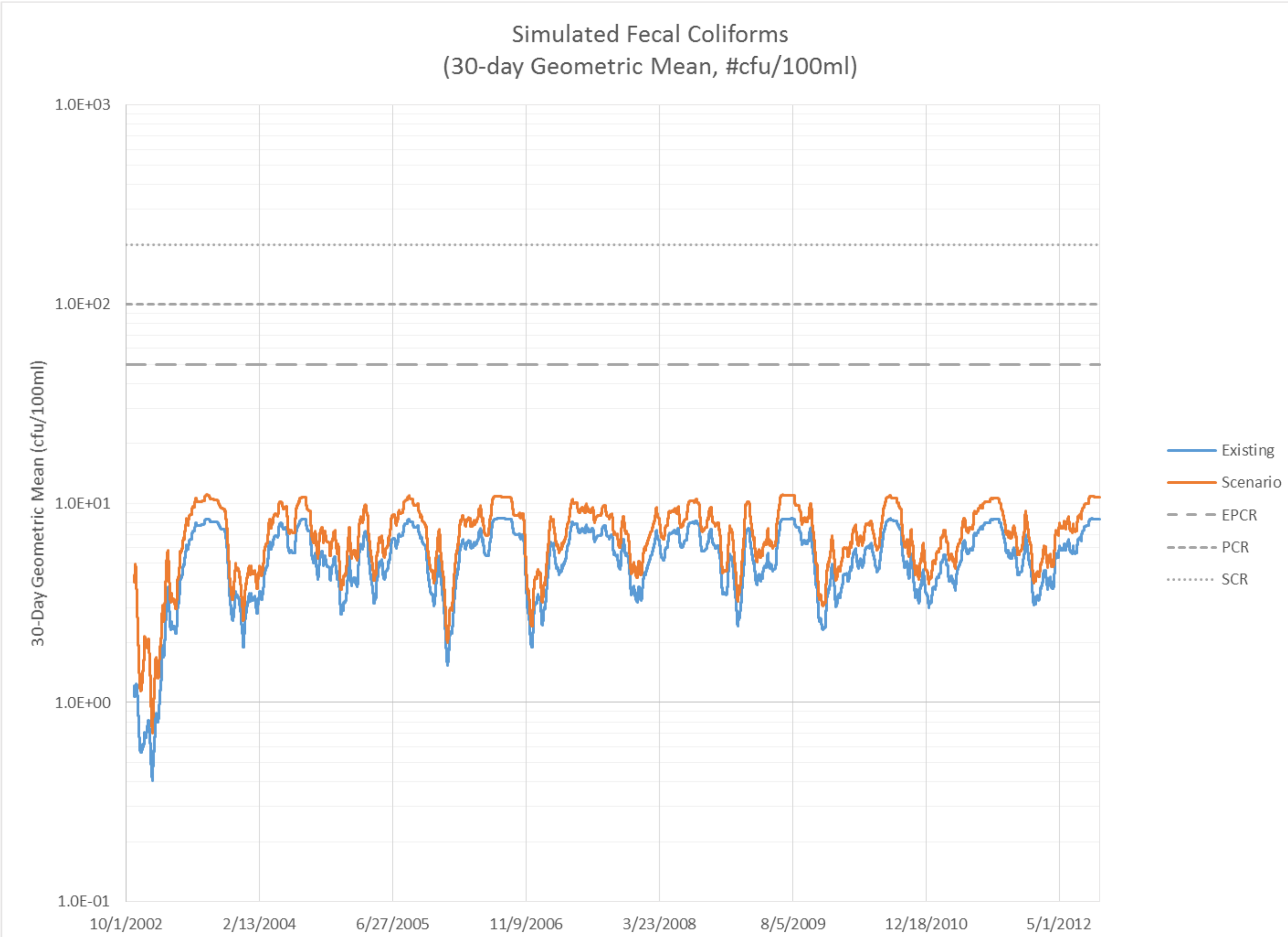

Figure 219 MON030 simulated 30-day geometric mean concentrations of fecal coliforms per 100ml.

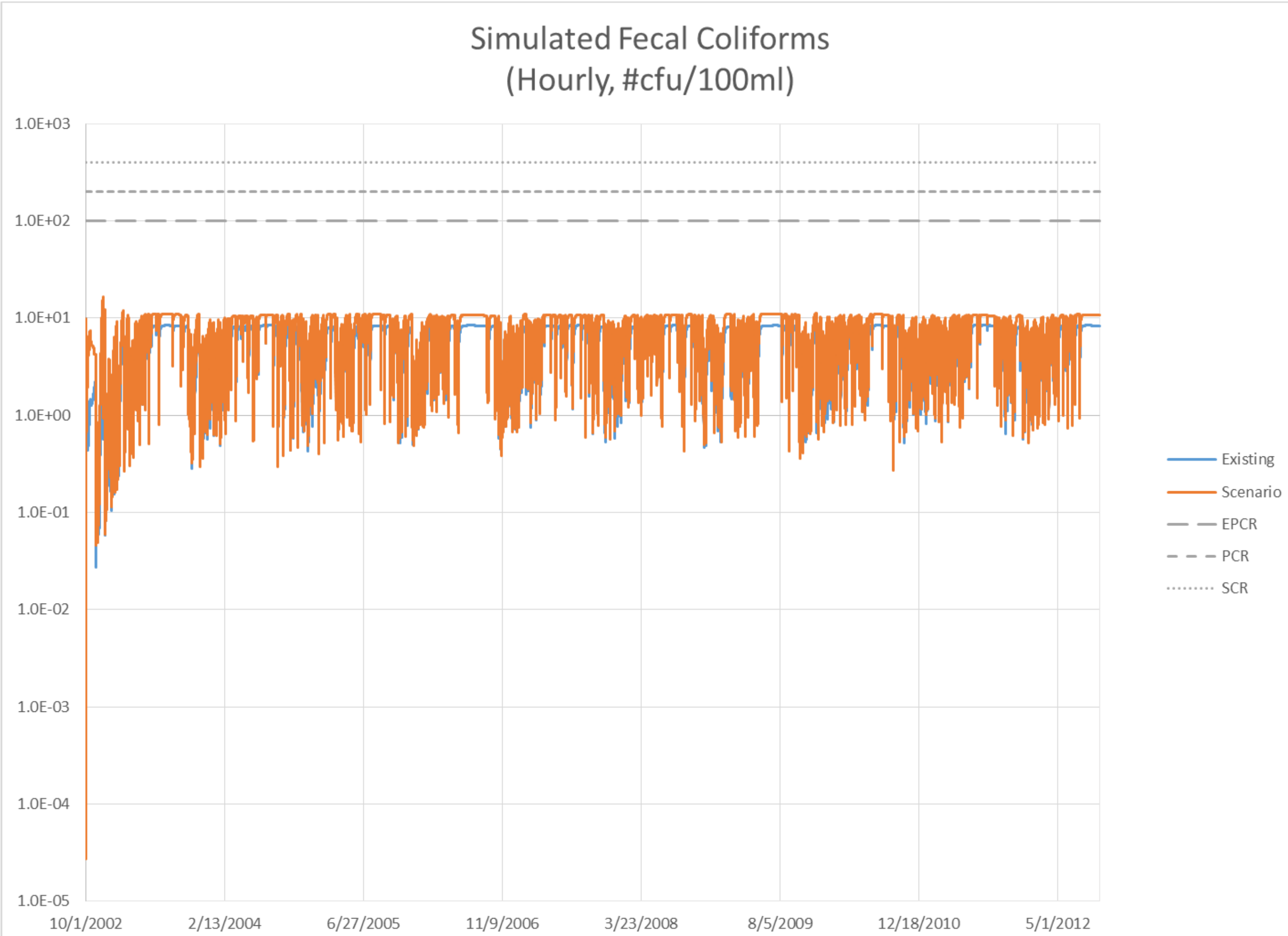

Figure 220 MON030 simulated hourly concentrations of fecal coliforms per 100ml.

This page intentionally left blank.

APPENDIX L: Simulated Total Suspended Sediments

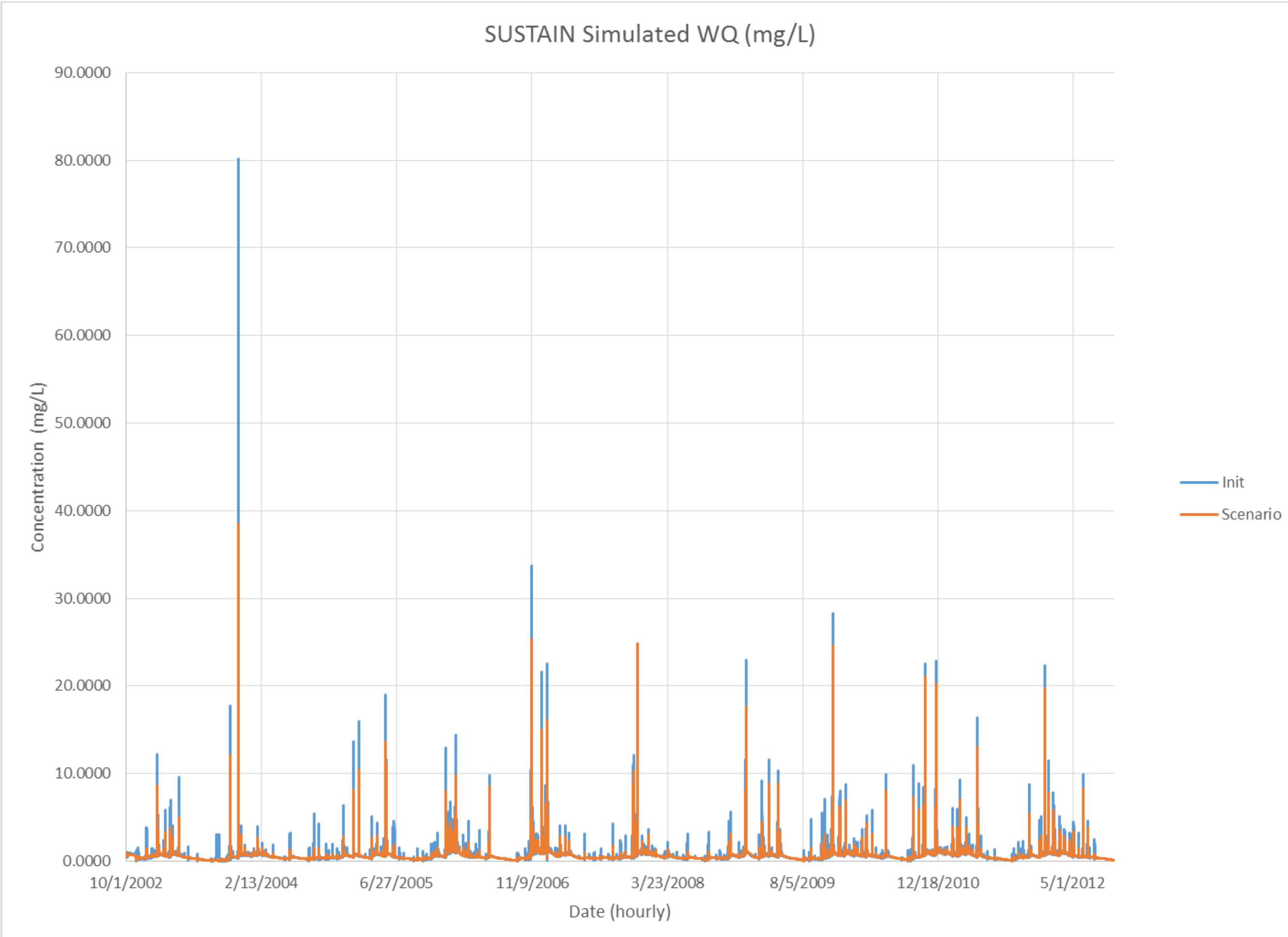

Figure 221 BEA020 simulated concentrations of Total Suspended Sediments (TSS)

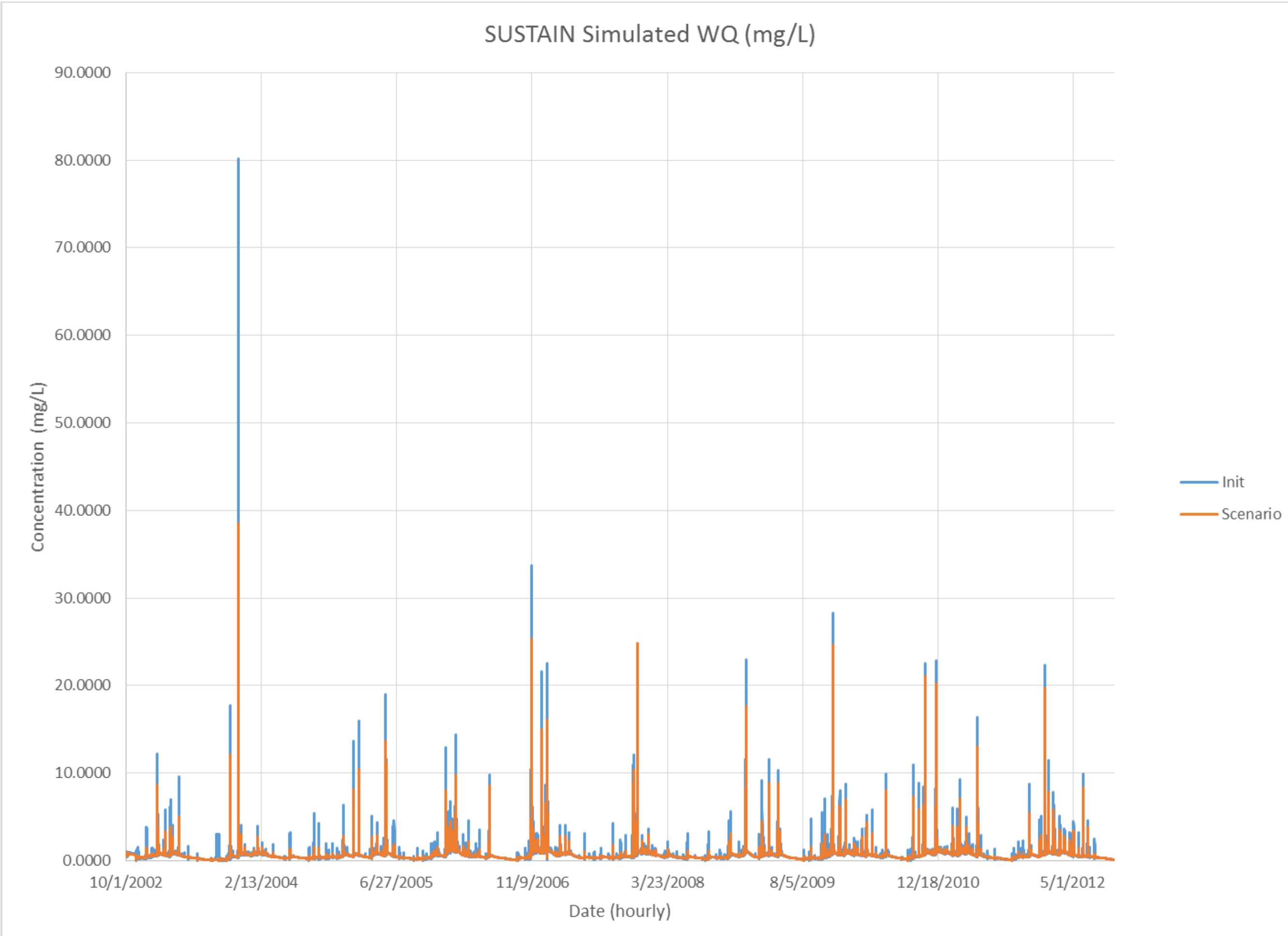

Figure 222 BEA020 simulated concentrations of Total Suspended Sediments (TSS)

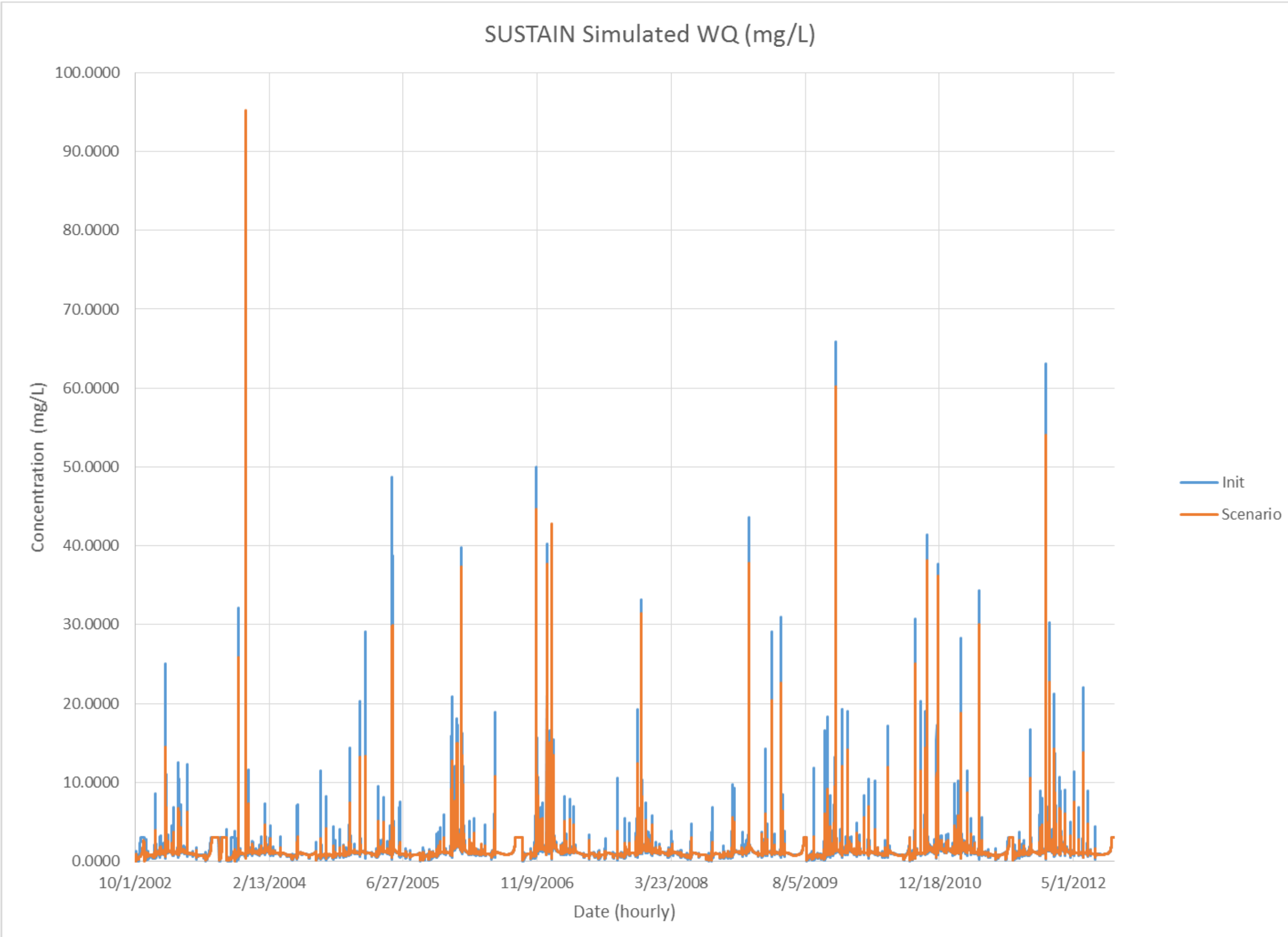

Figure 223 BEA120 simulated concentrations of Total Suspended Sediments (TSS)

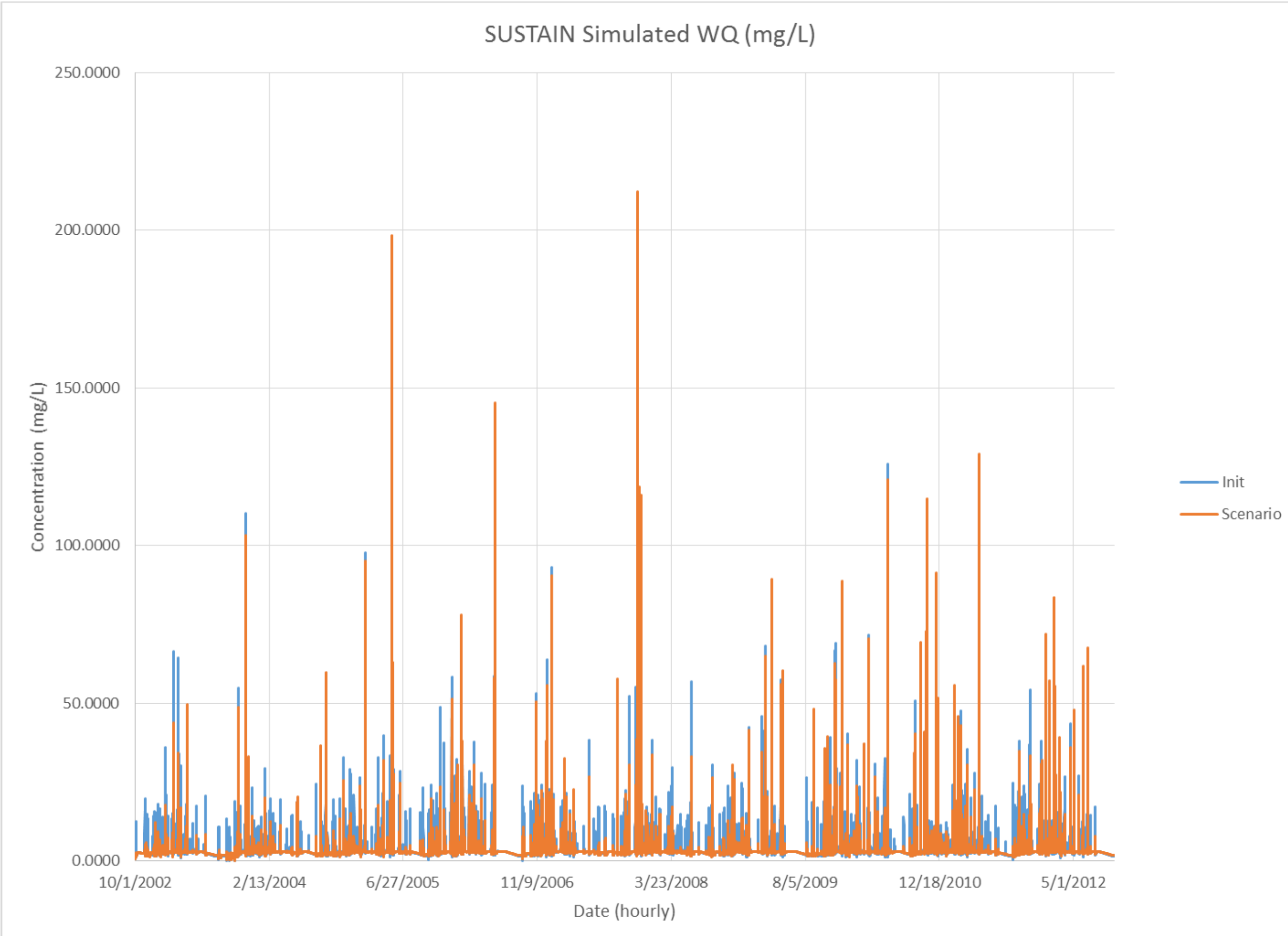

Figure 224 BEA210 simulated concentrations of Total Suspended Sediments (TSS)

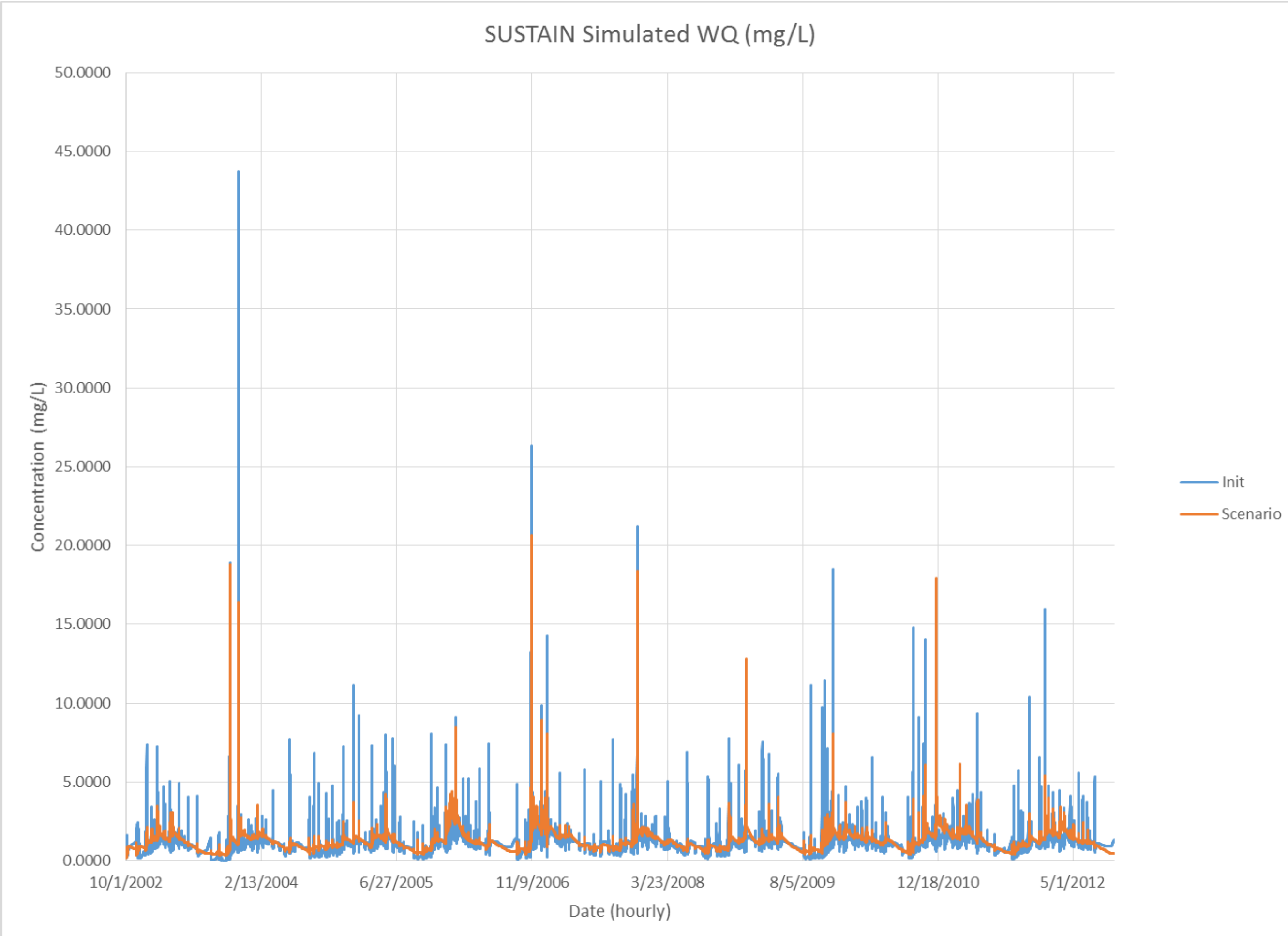

Figure 225 BEA240 simulated concentrations of Total Suspended Sediments (TSS)

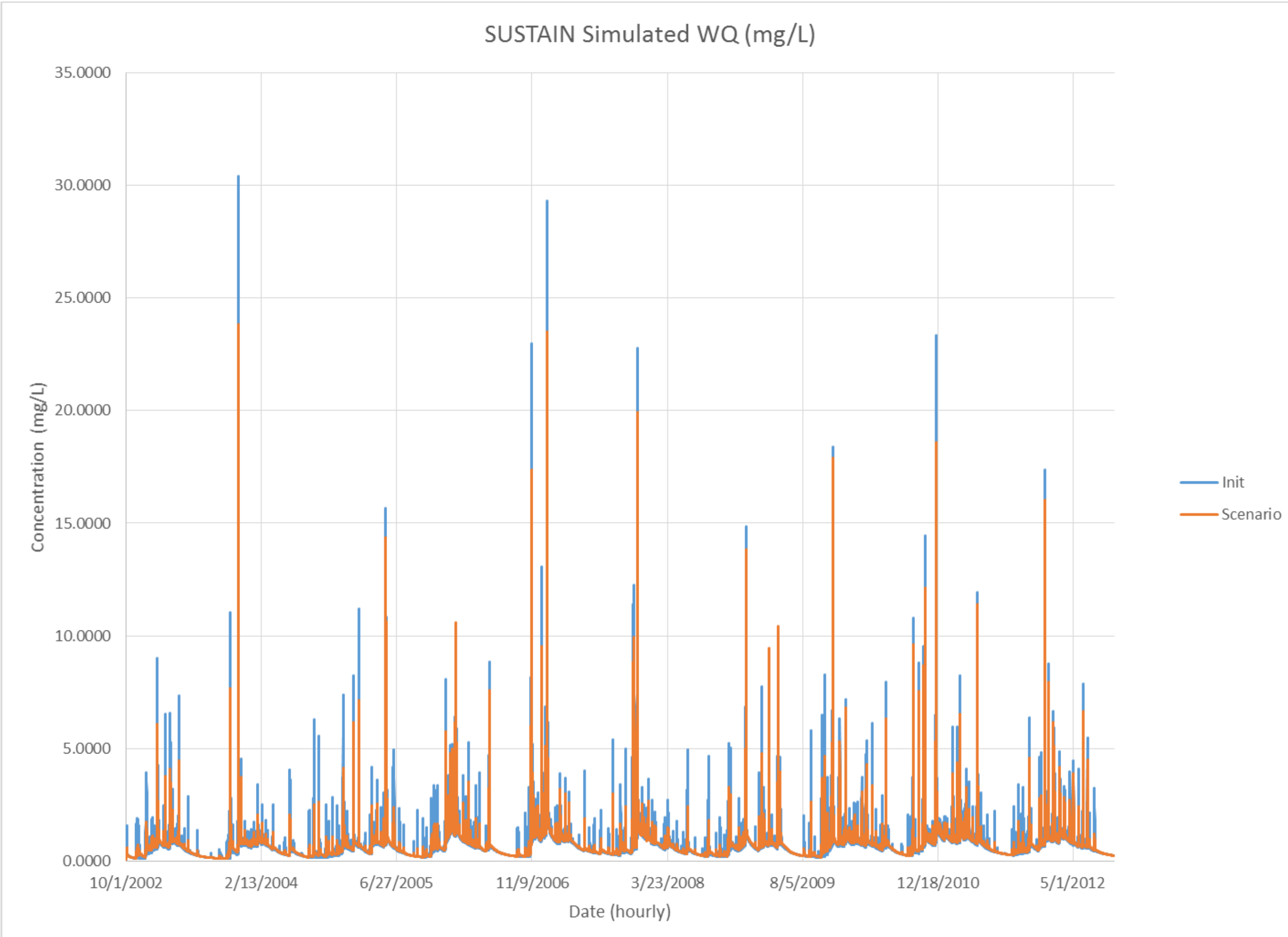

Figure 226 BEA260 simulated concentrations of Total Suspended Sediments (TSS)

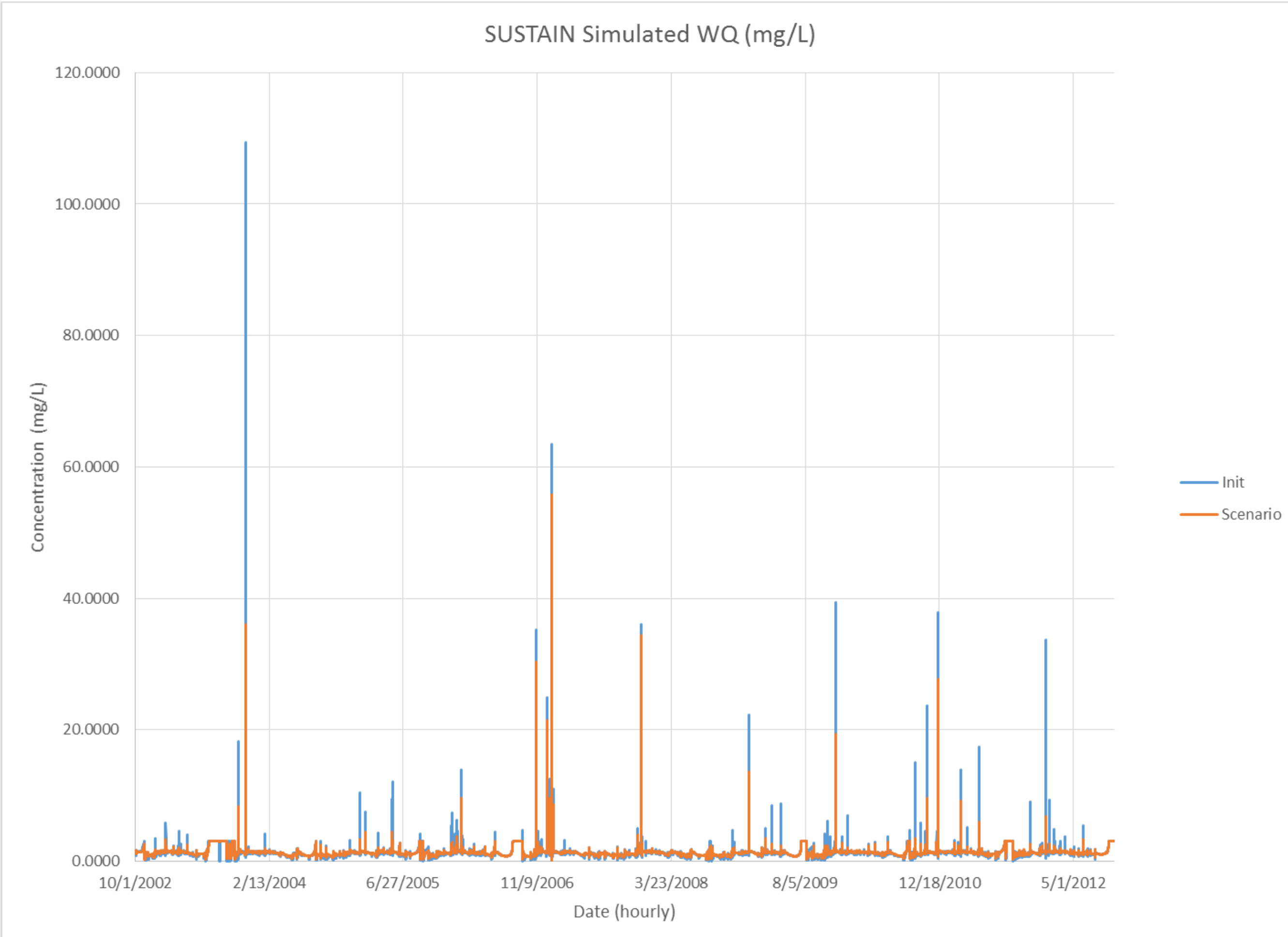

Figure 227 BEA270 simulated concentrations of Total Suspended Sediments (TSS)

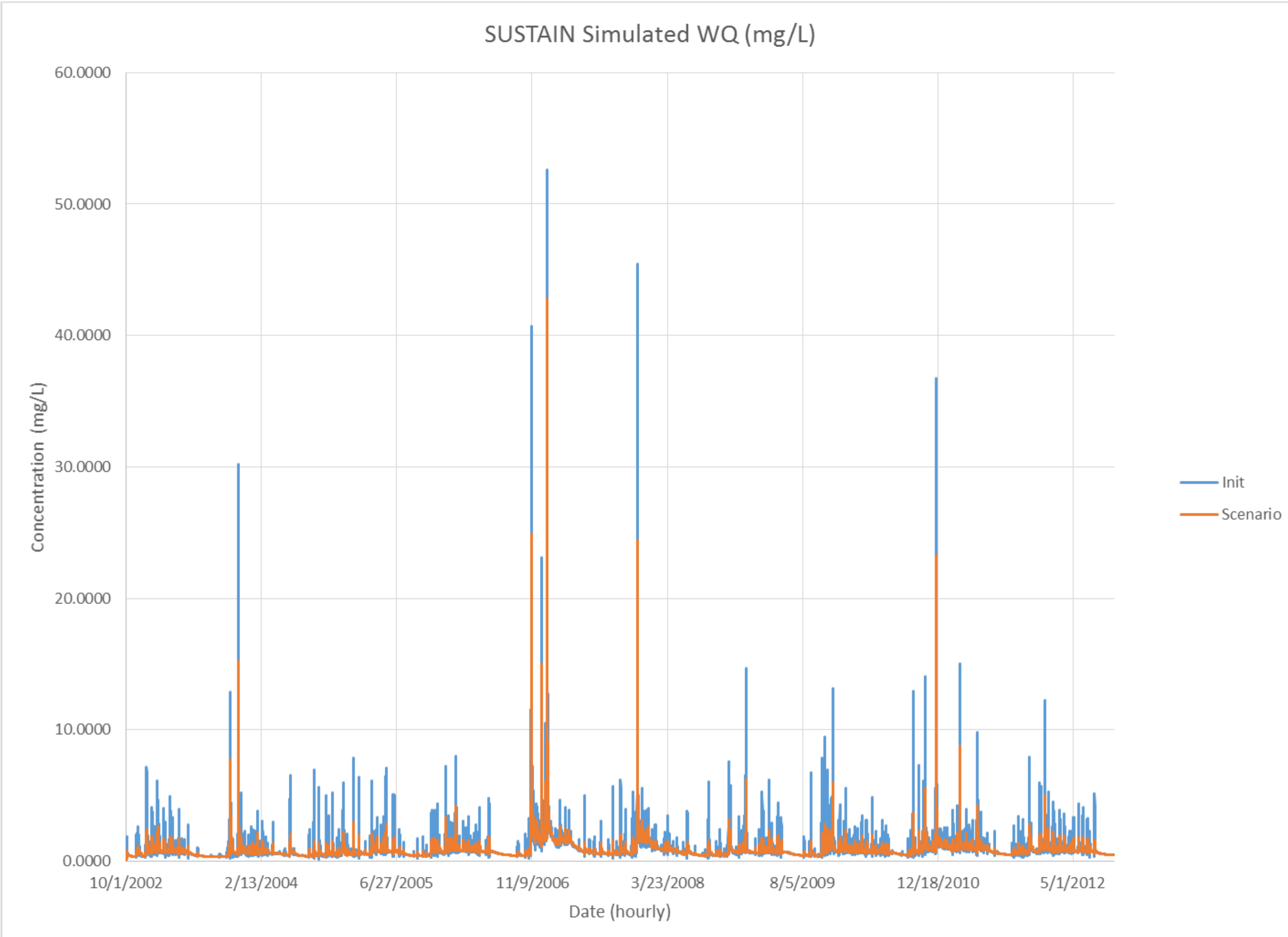

Figure 228 BEA280 simulated concentrations of Total Suspended Sediments (TSS)

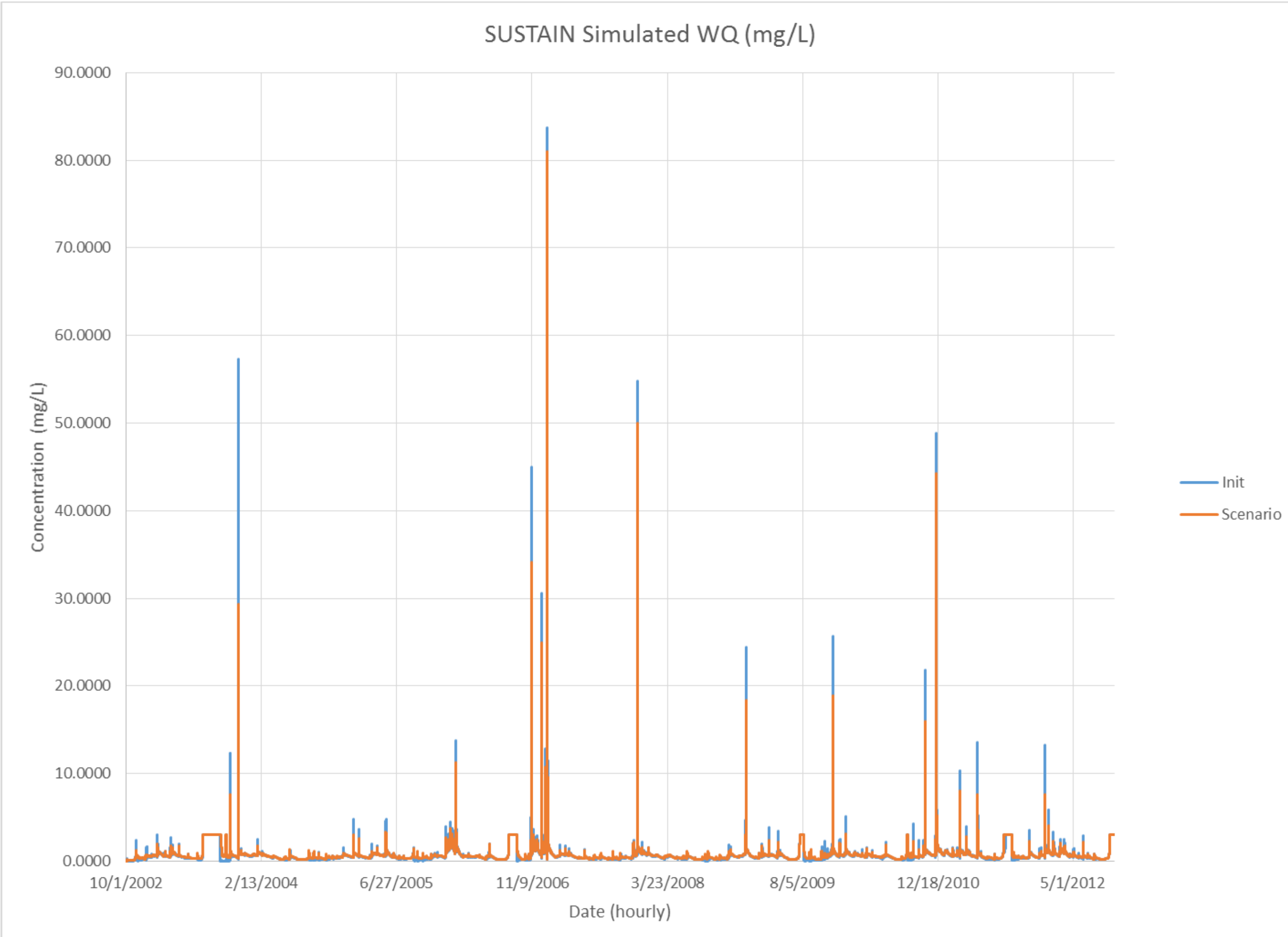

Figure 229 BEA310 simulated concentrations of Total Suspended Sediments (TSS)

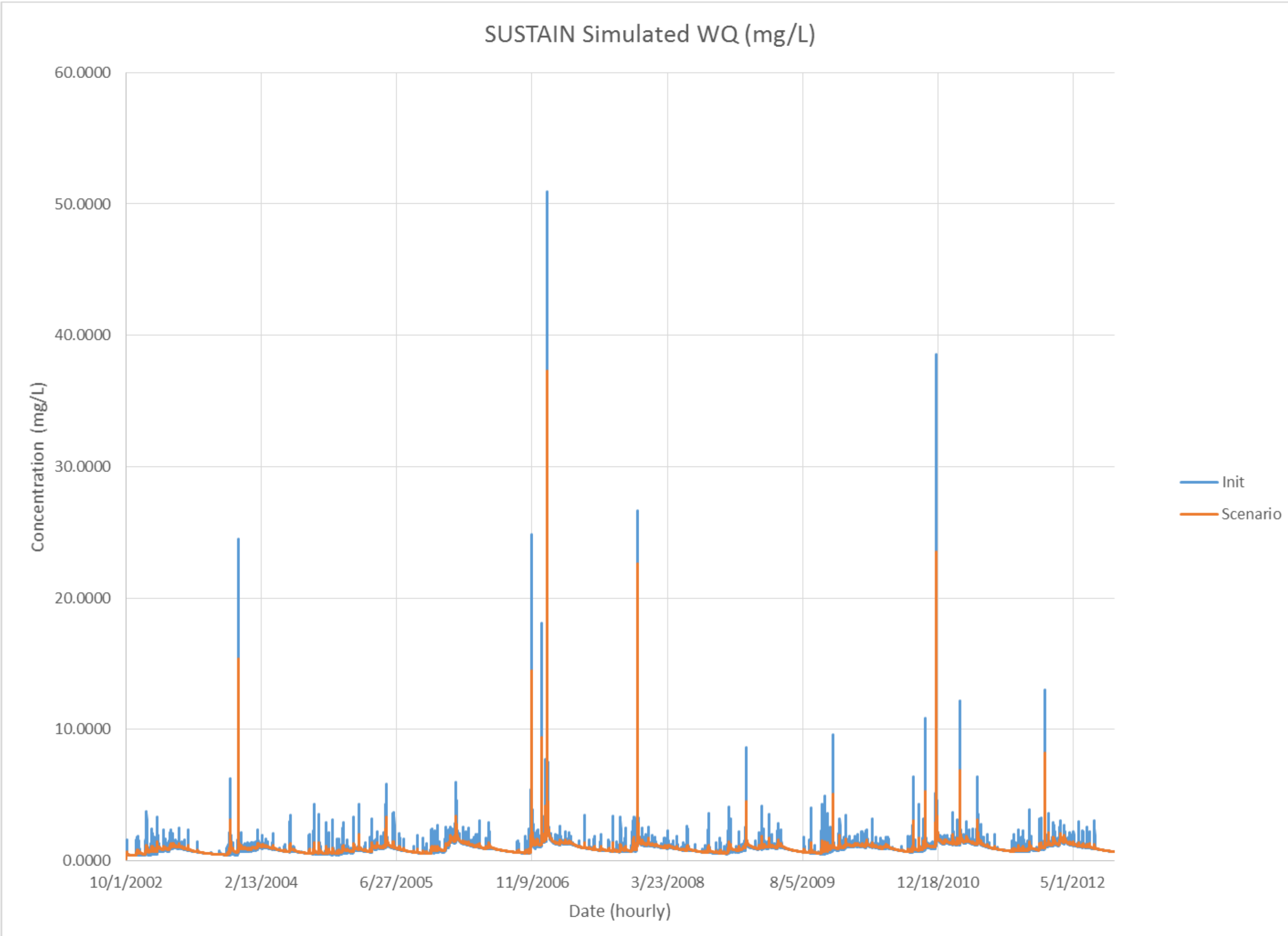

Figure 230 BEA370 simulated concentrations of Total Suspended Sediments (TSS)

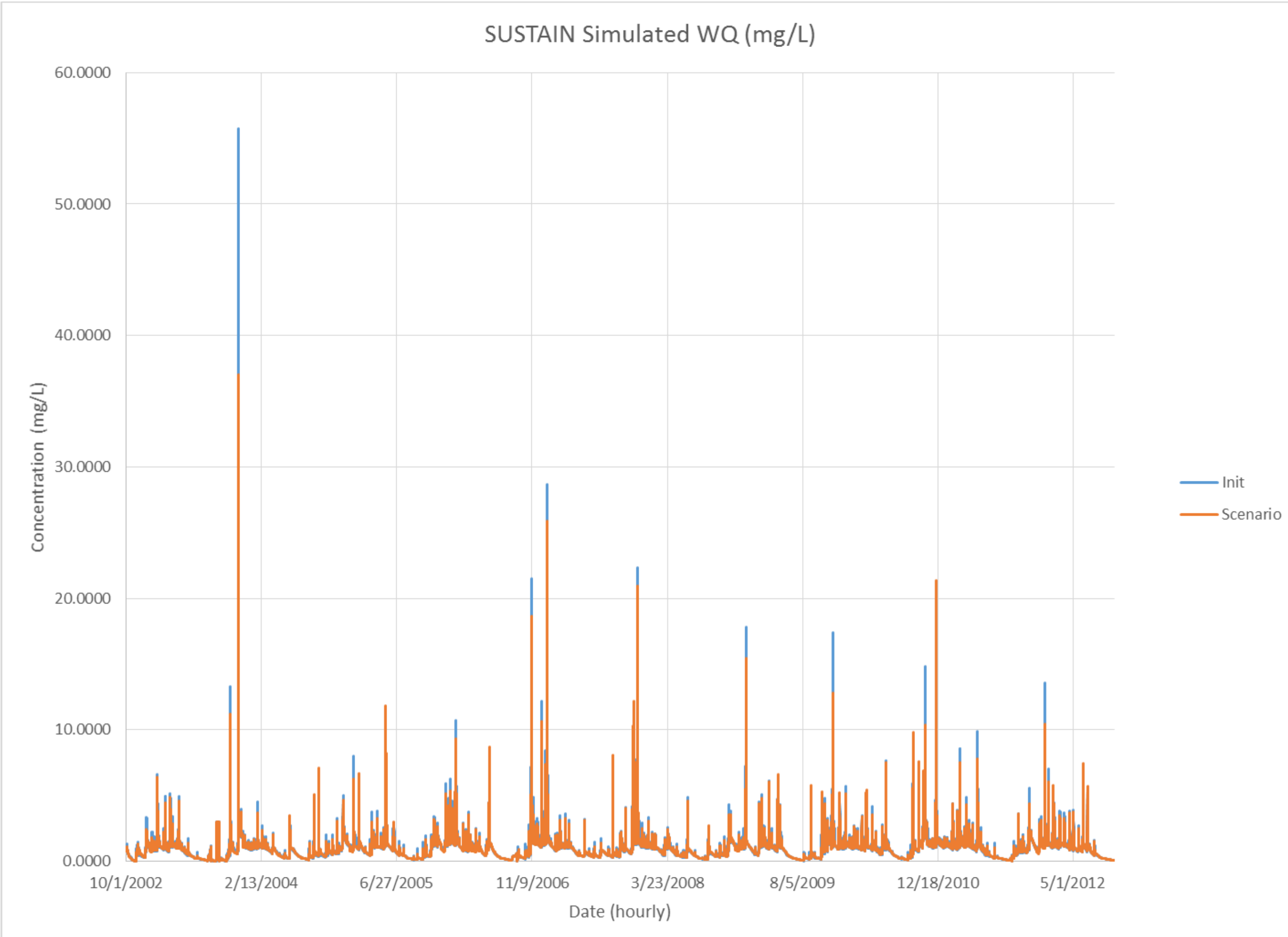

Figure 231 BEA410 simulated concentrations of Total Suspended Sediments (TSS)

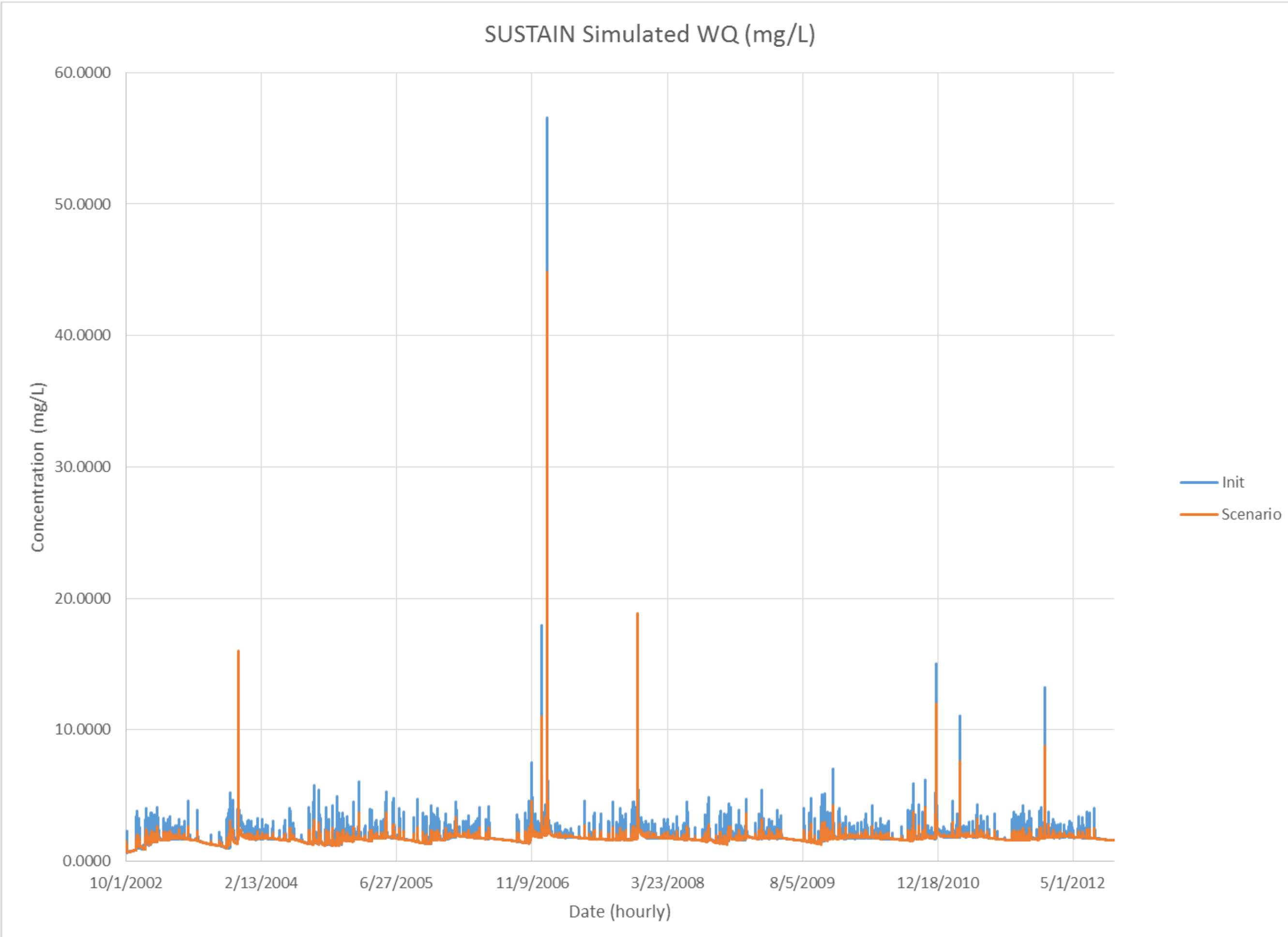

Figure 232 BEA590 simulated concentrations of Total Suspended Sediments (TSS)

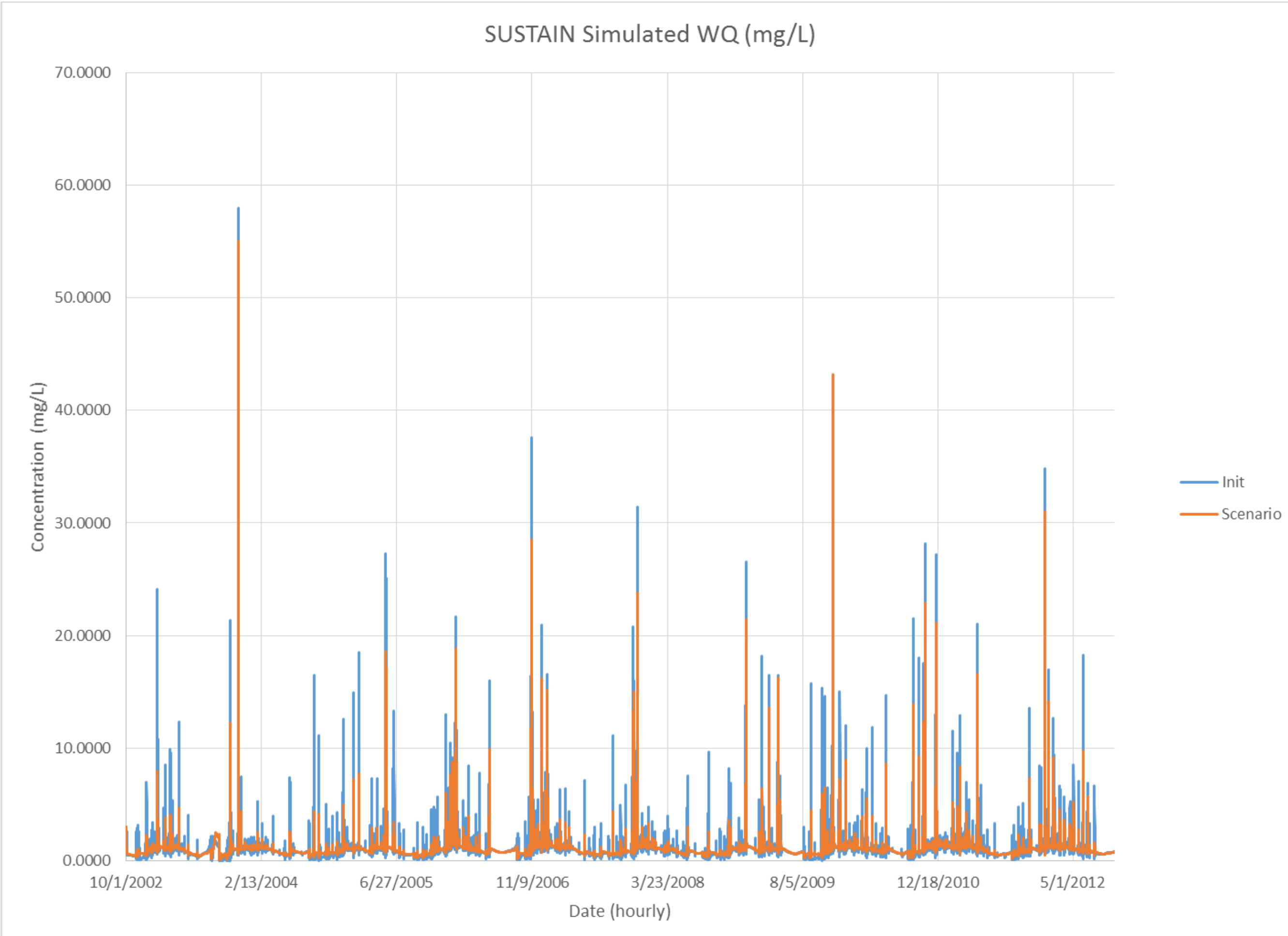

Figure 233 BEA800 simulated concentrations of Total Suspended Sediments (TSS)

APPENDIX M: Simulated Copper

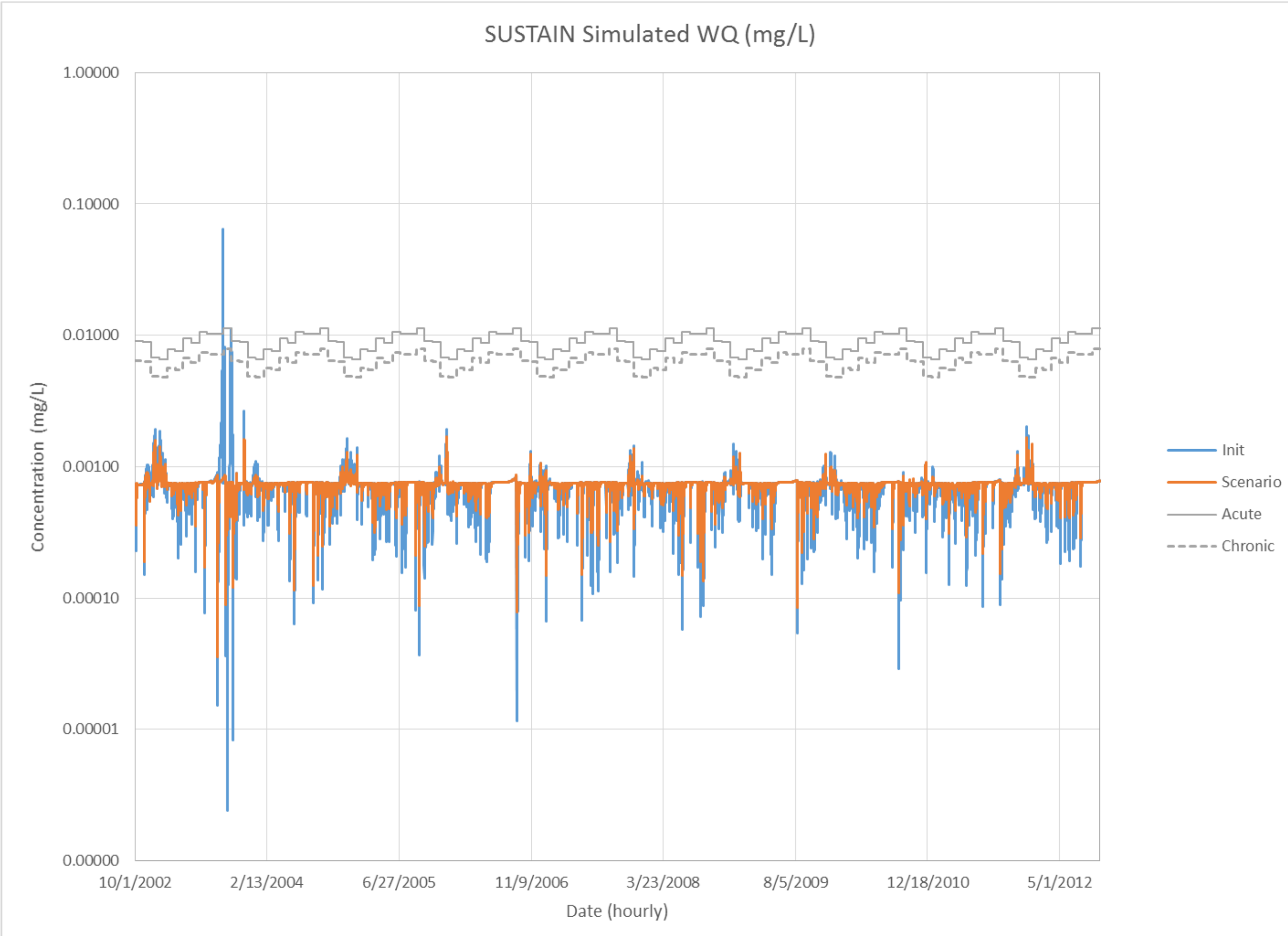

Figure 234 BEA020 simulated concentrations of dissolved copper

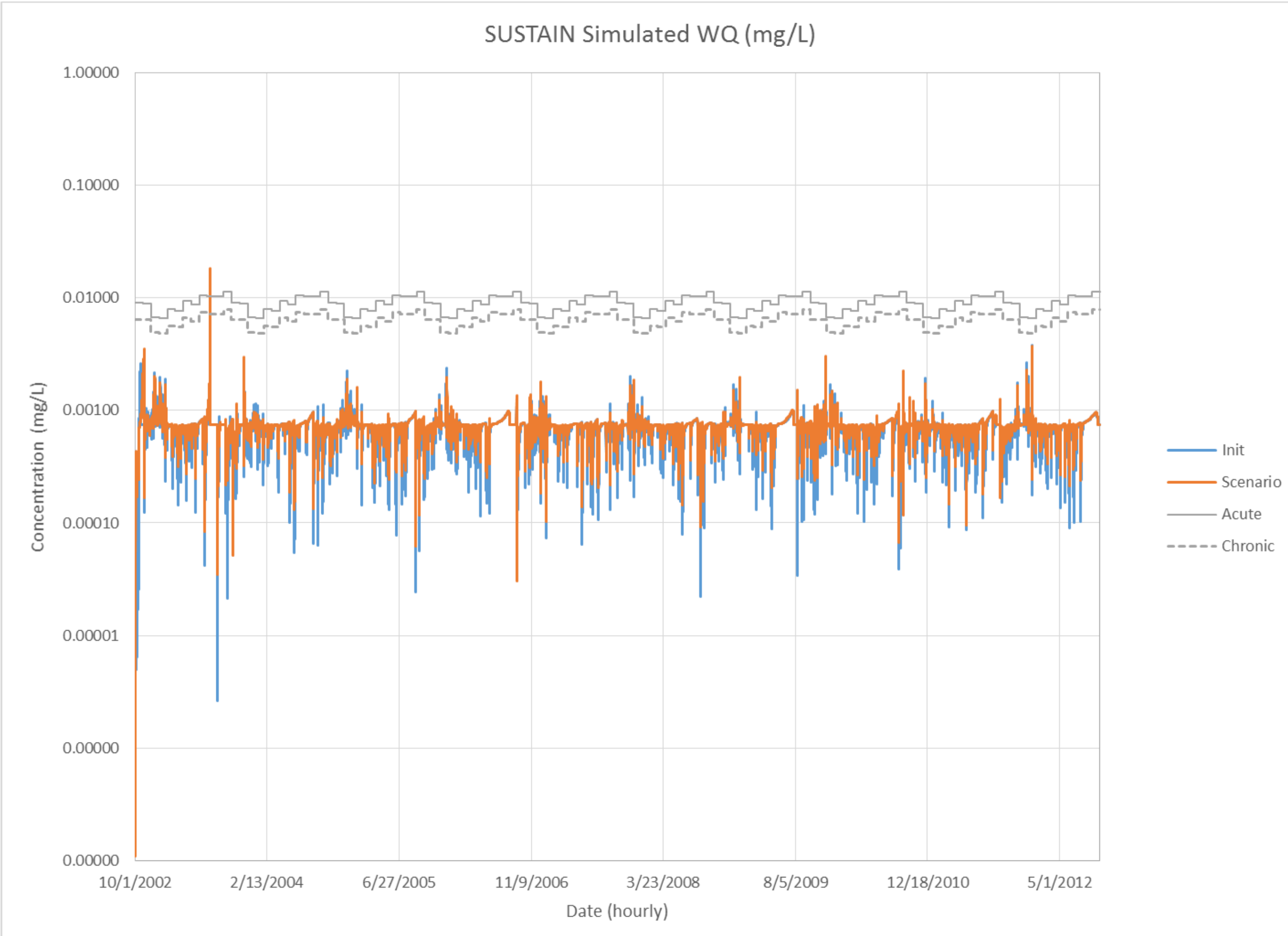

Figure 235 BEA120 simulated concentrations of dissolved copper

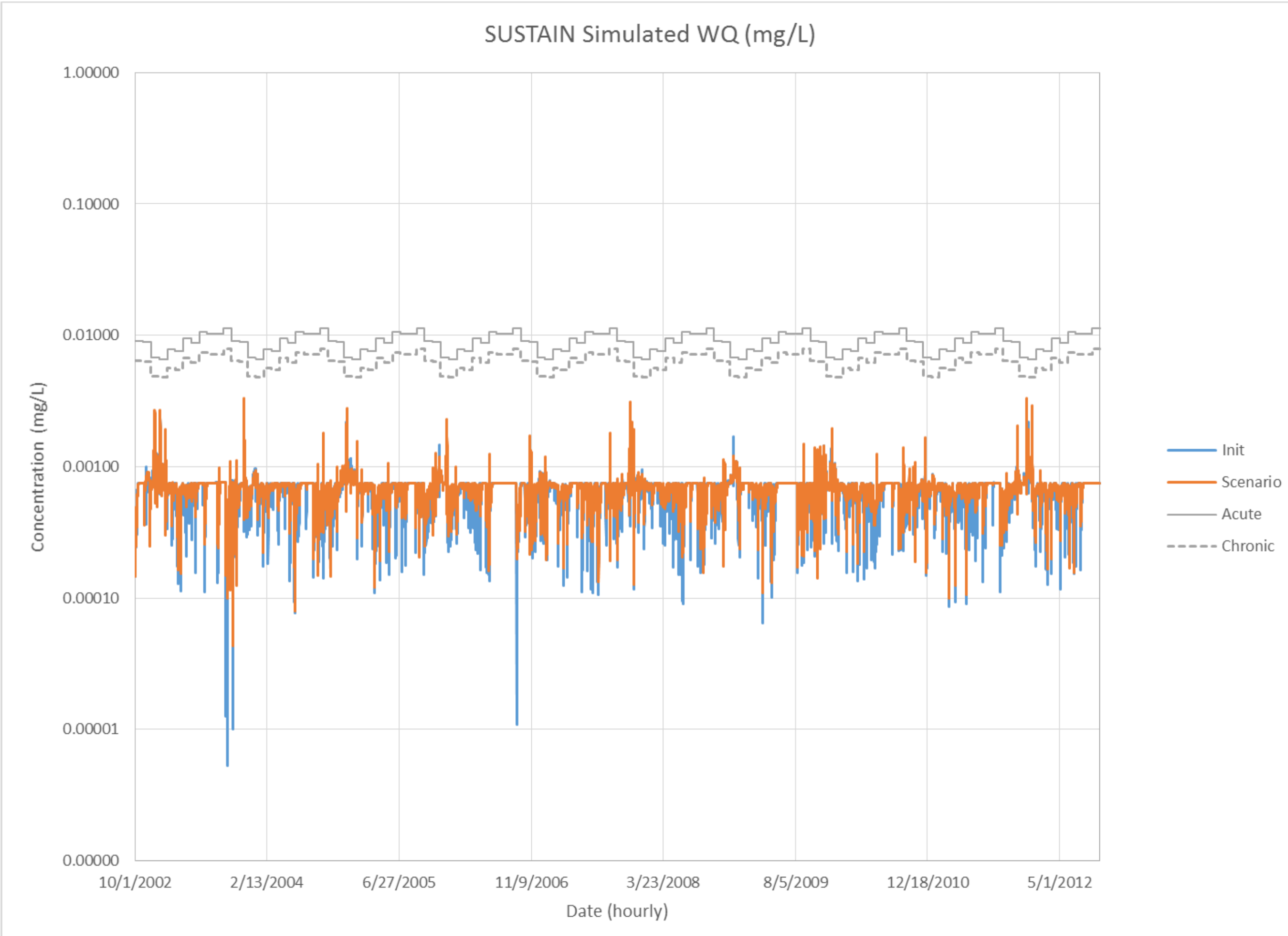

Figure 236 BEA210 simulated concentrations of dissolved copper

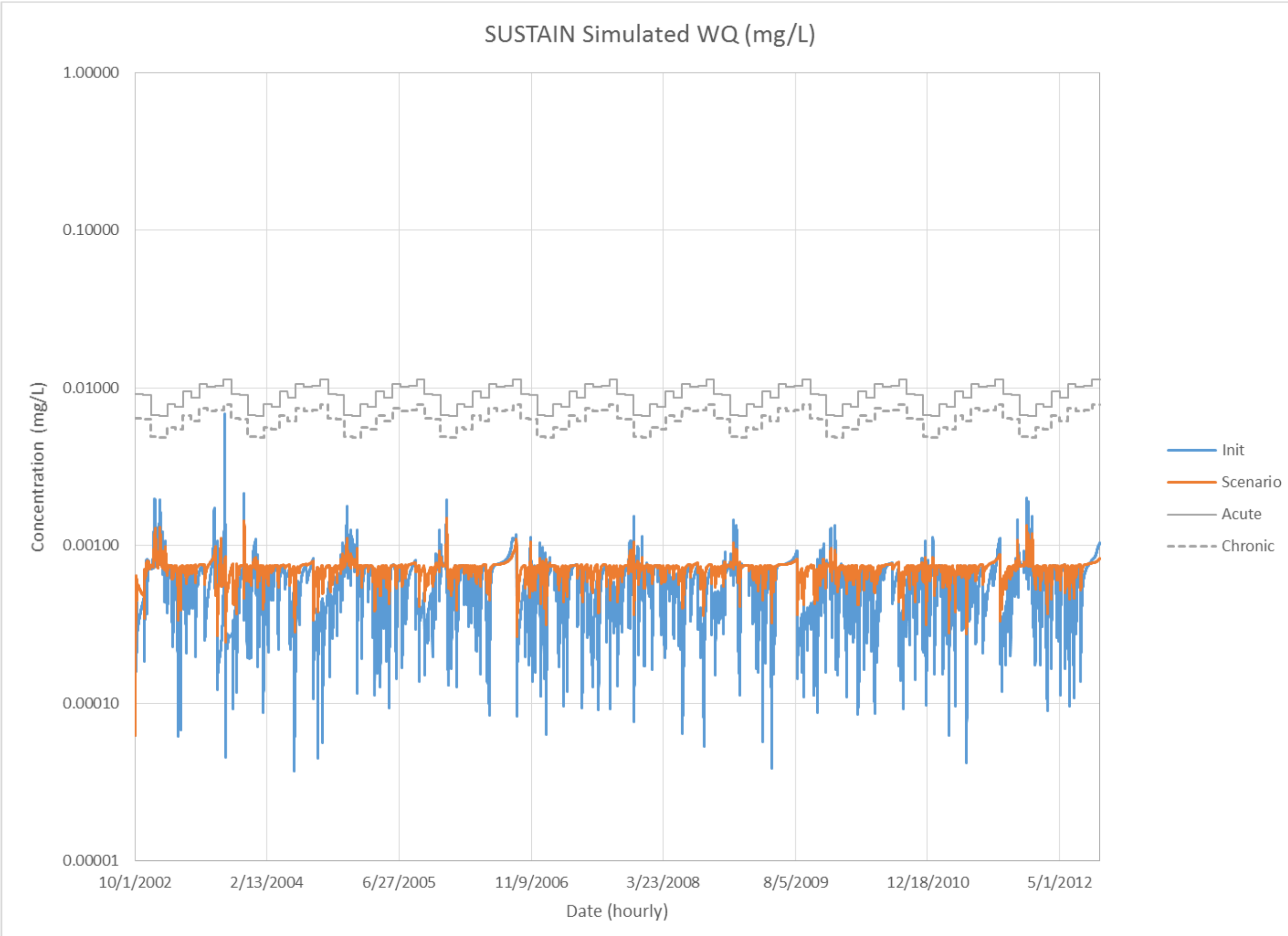

Figure 237 BEA240 simulated concentrations of dissolved copper

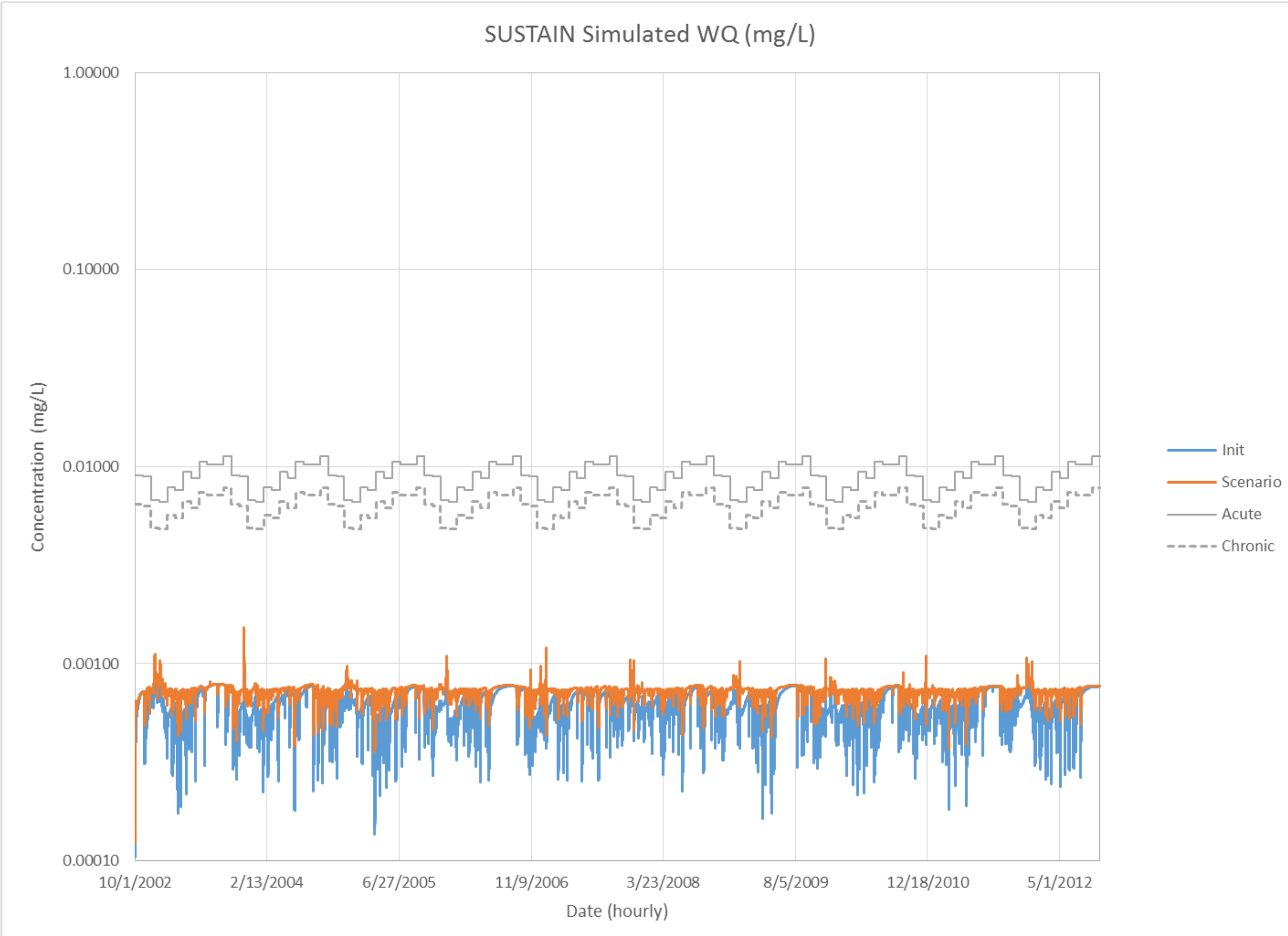

Figure 238 BEA260 simulated concentrations of dissolved copper

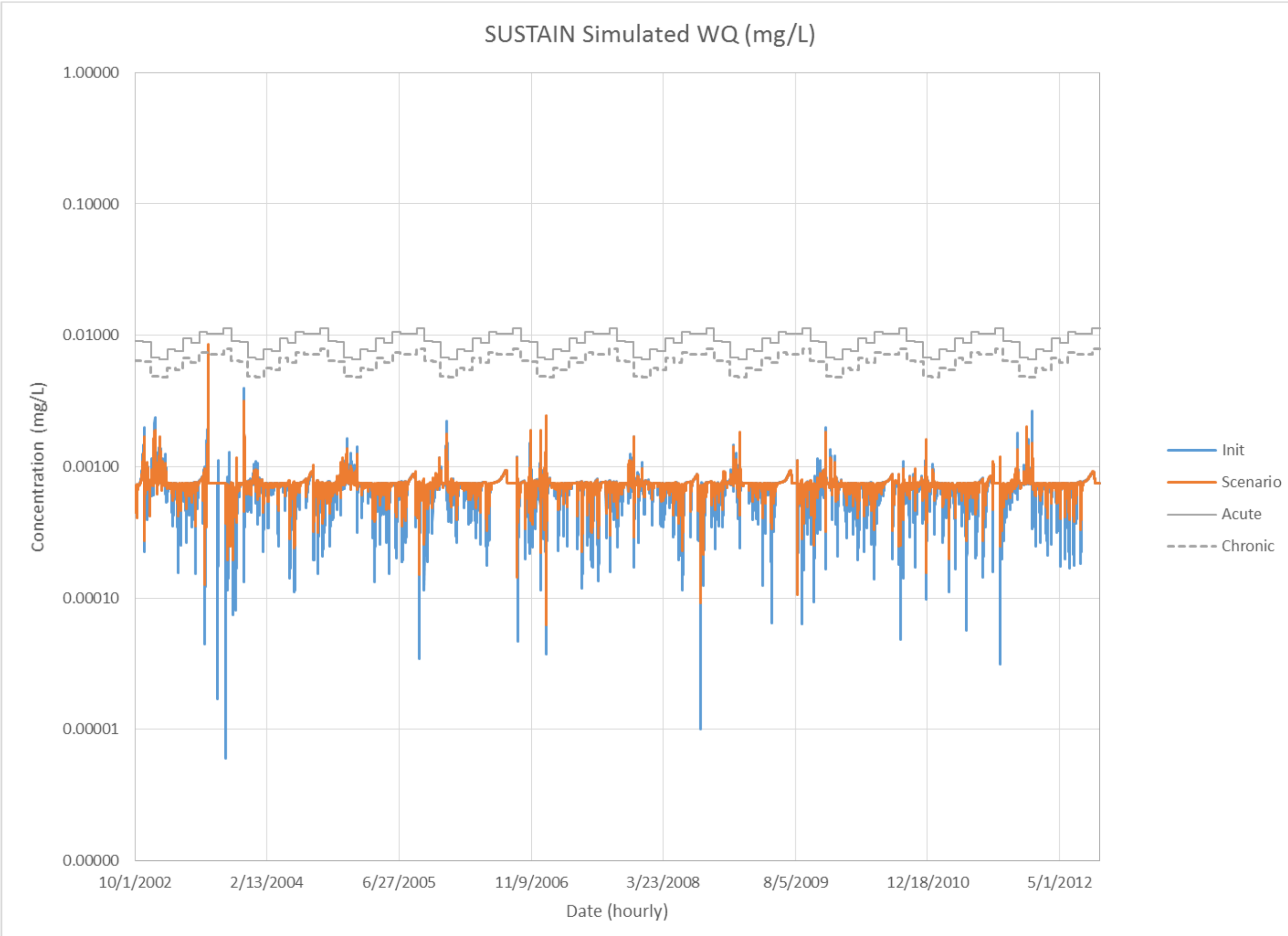

Figure 239 BEA270 simulated concentrations of dissolved copper

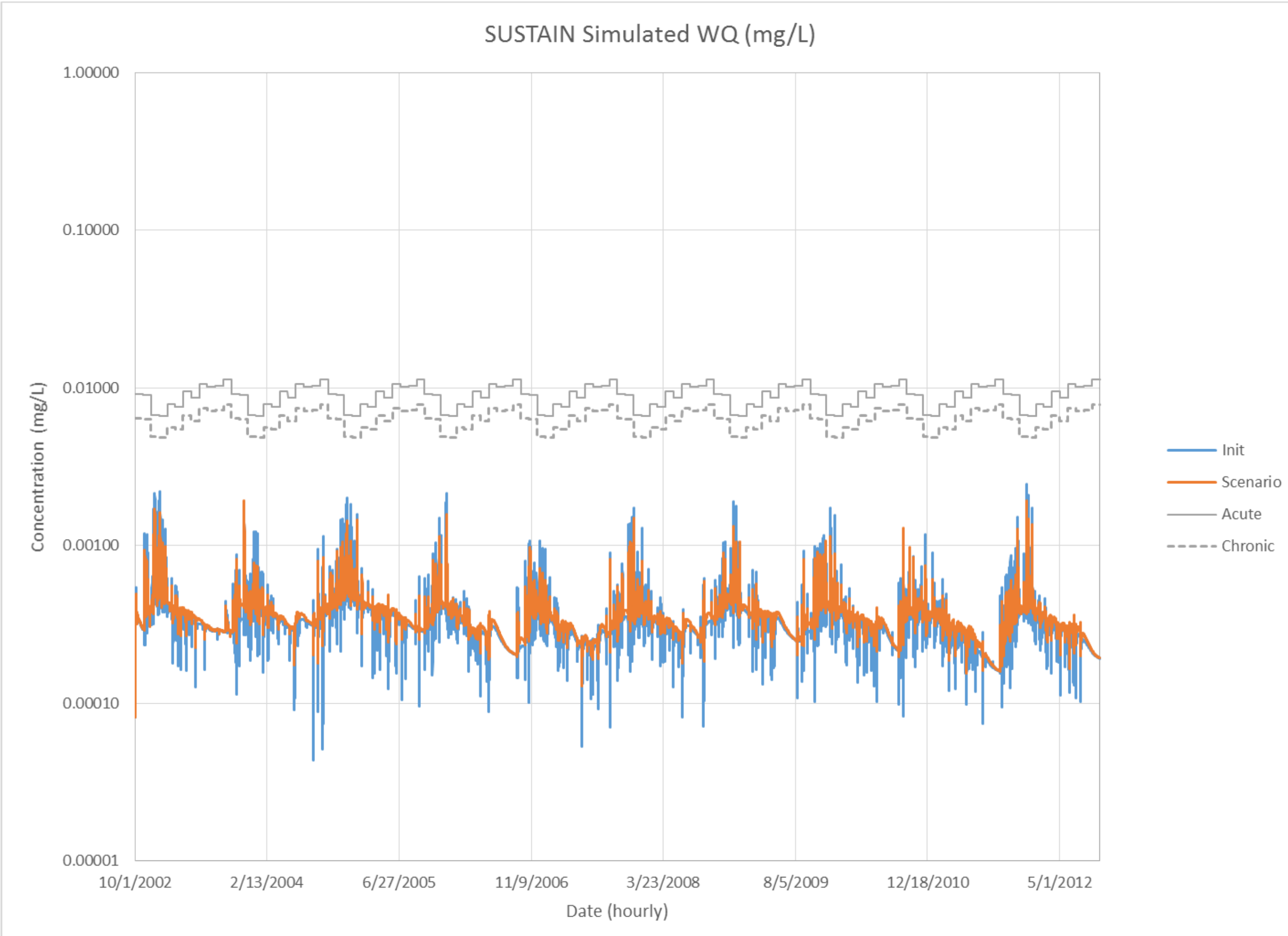

Figure 240 BEA280 simulated concentrations of dissolved copper

Figure 241 BEA310 simulated concentrations of dissolved copper

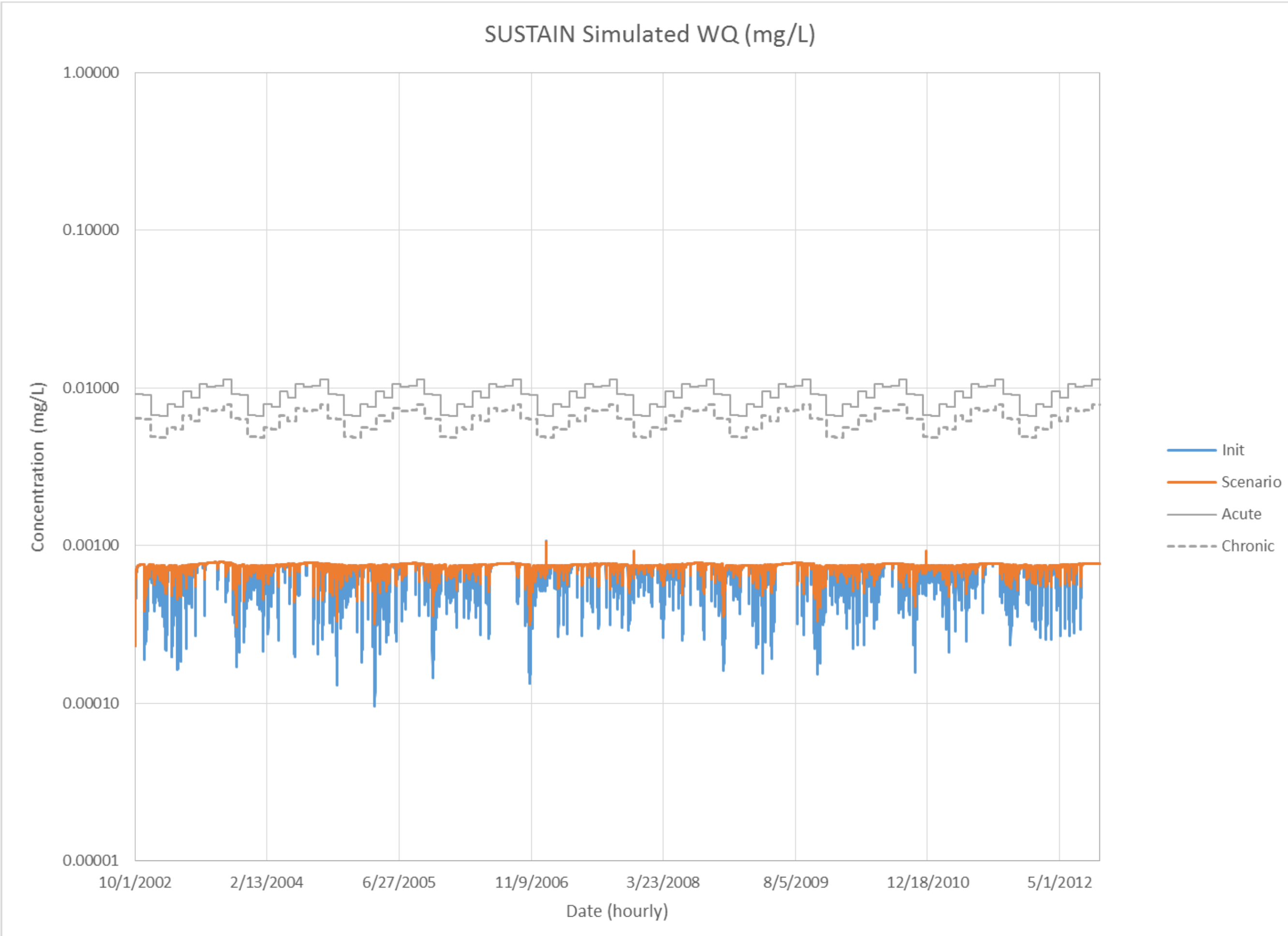

Figure 242 BEA370 simulated concentrations of dissolved copper

Figure 243 BEA410 simulated concentrations of dissolved copper

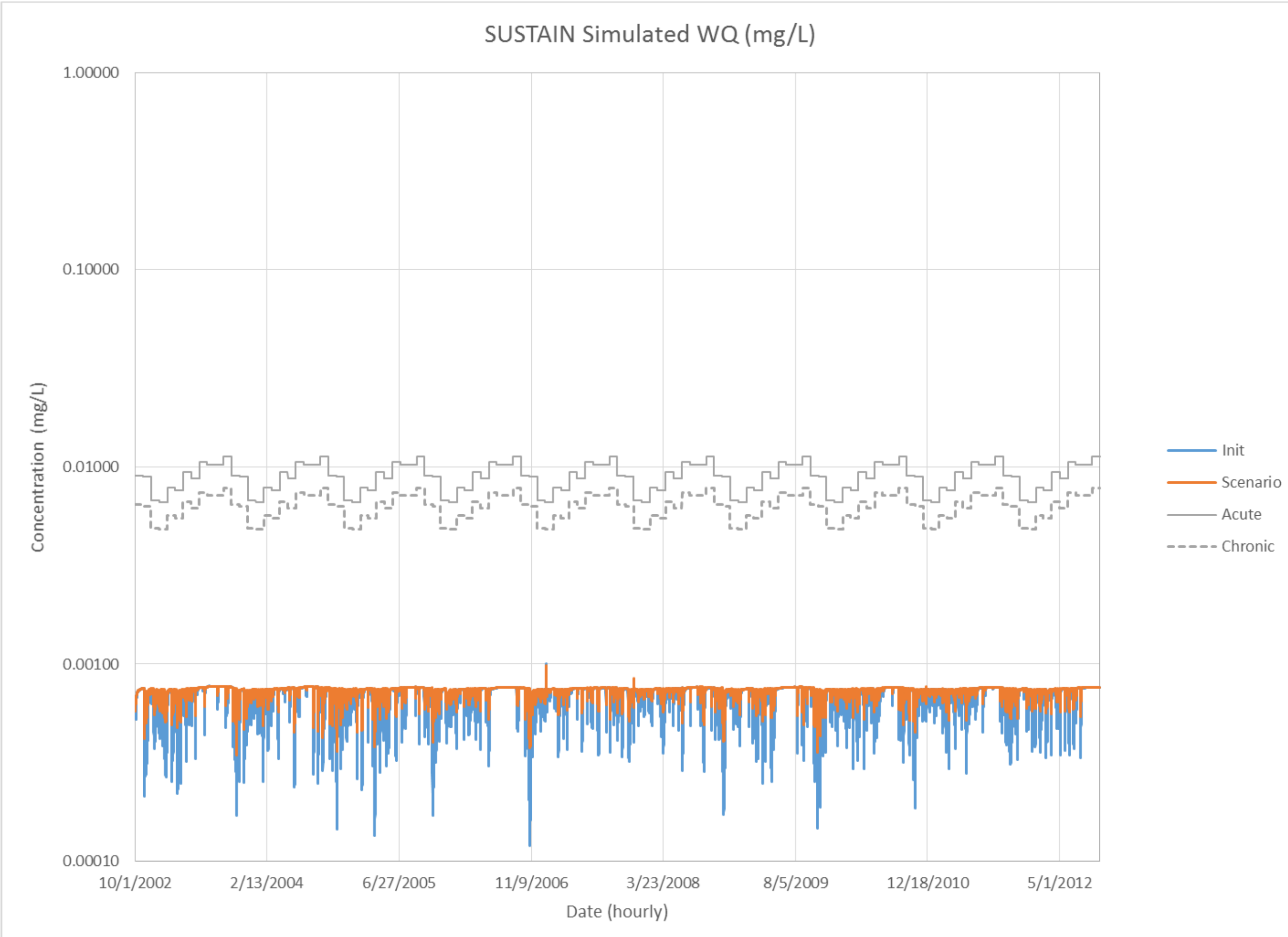

Figure 244 BEA590 simulated concentrations of dissolved copper

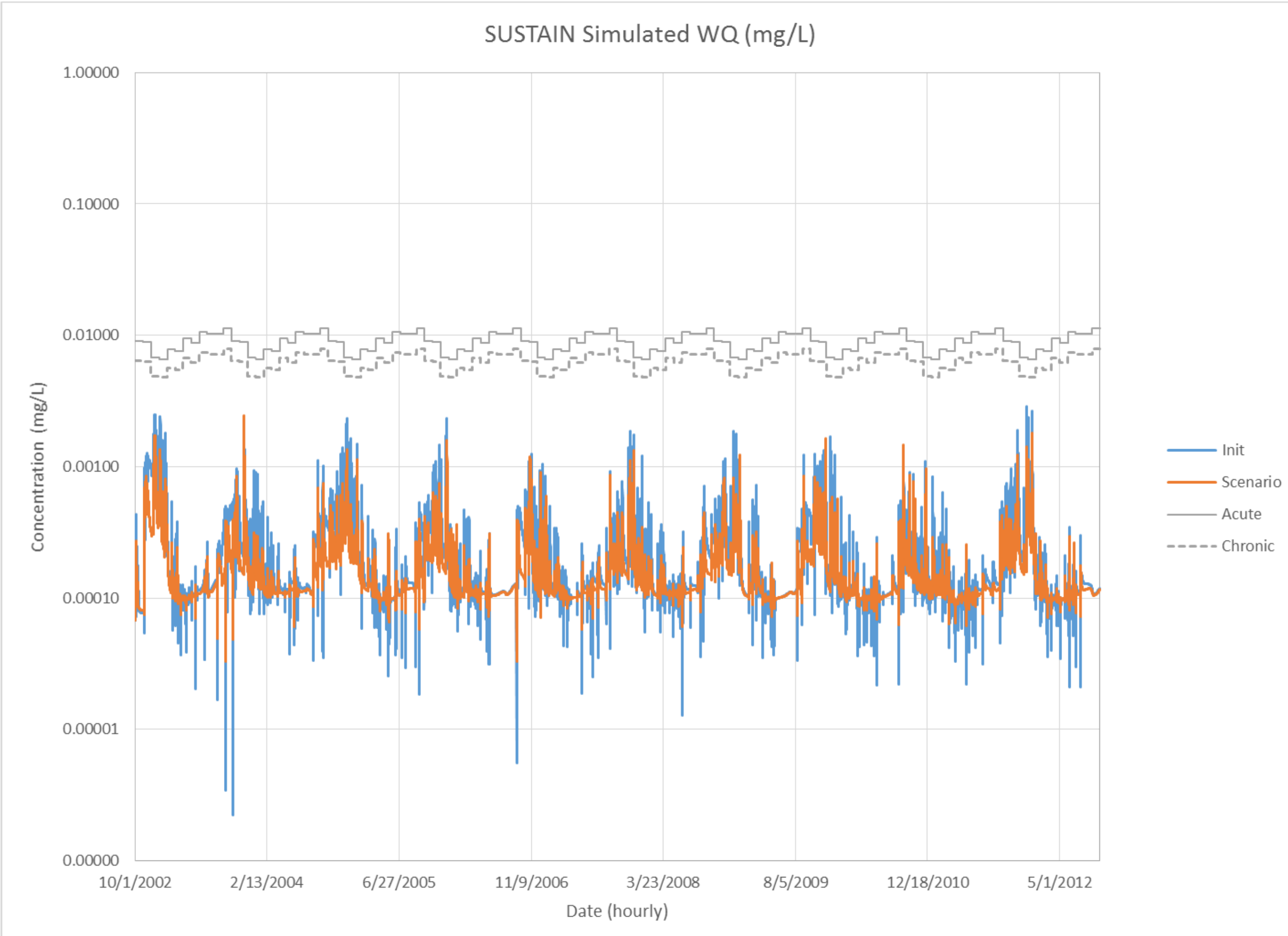

Figure 245 BEA800 simulated concentrations of dissolved copper

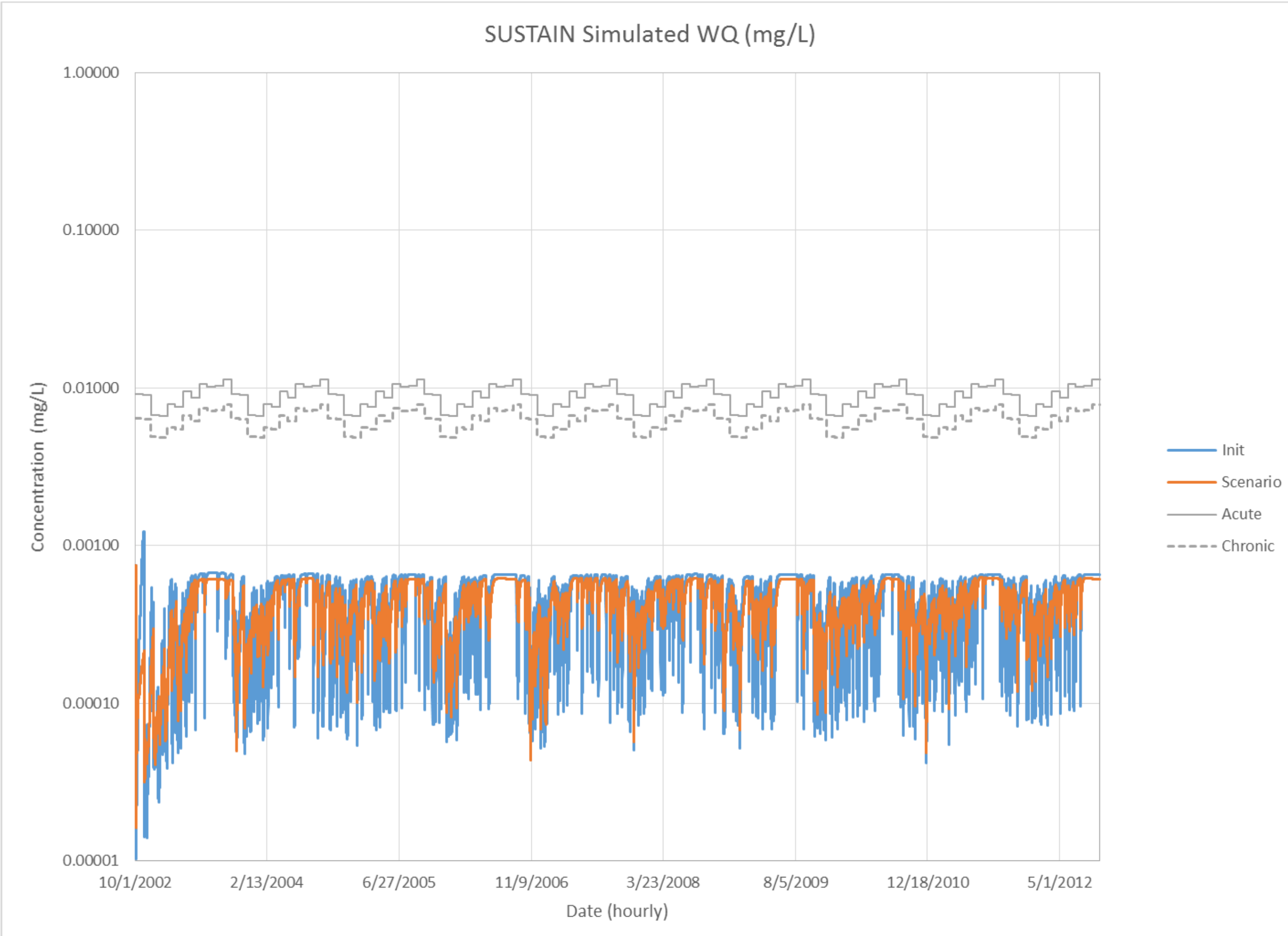

Figure 246 MON030 simulated concentrations of dissolved copper.

APPENDIX N: Simulated Zinc

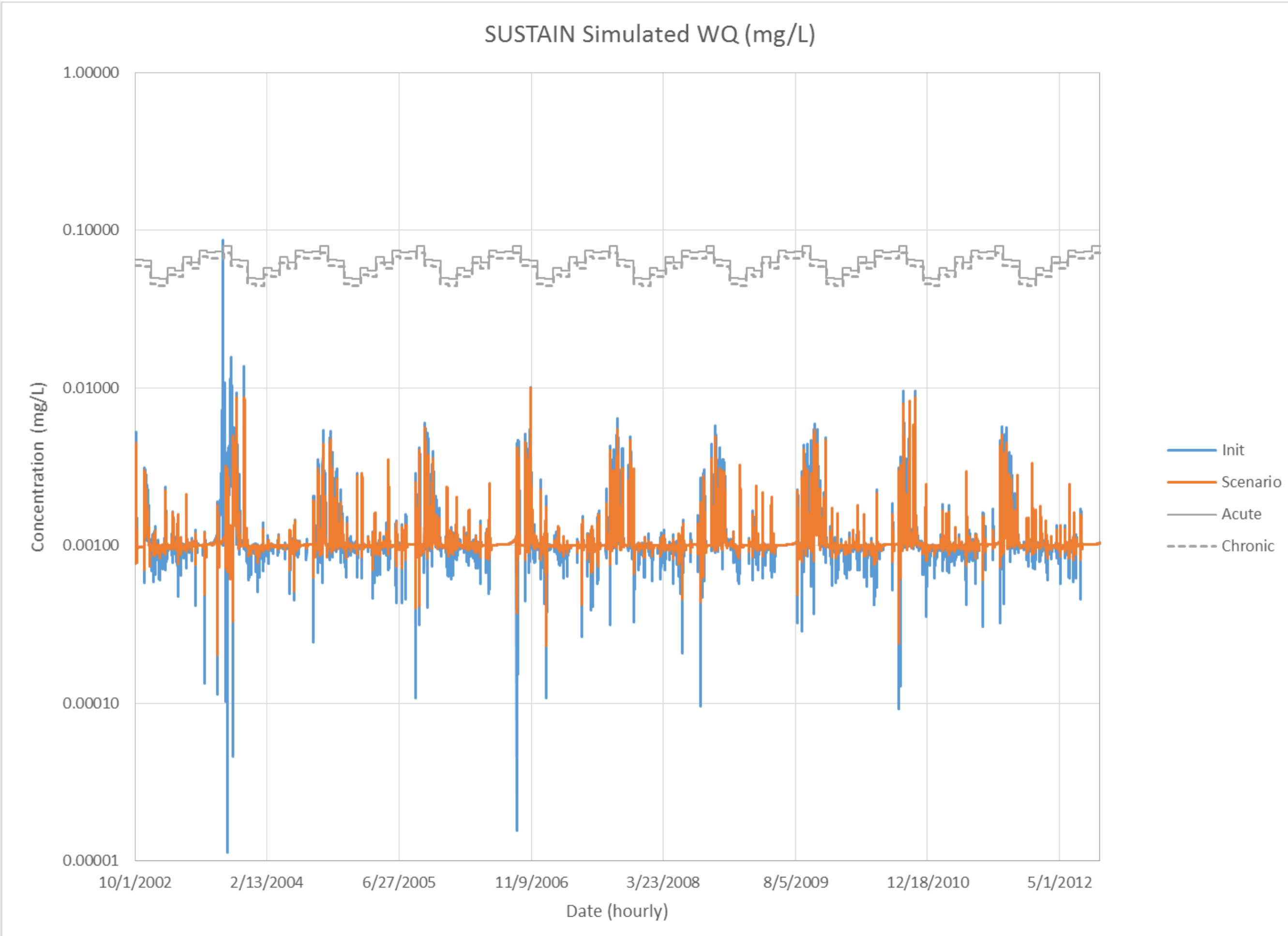

Figure 247 BEA020 simulated concentrations of dissolved zinc.

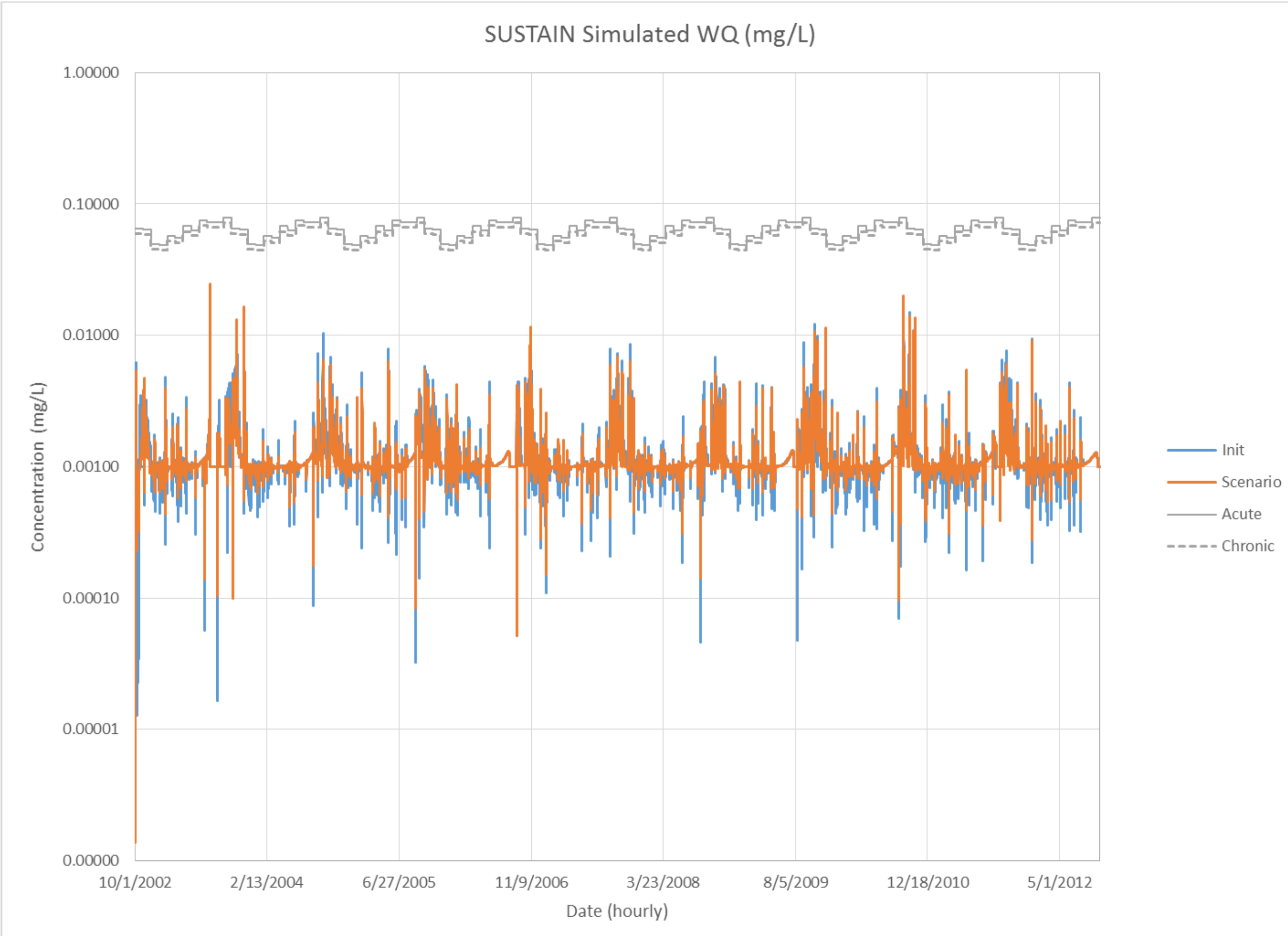

Figure 248 BEA120 simulated concentrations of dissolved zinc.

Figure 249 BEA210 simulated concentrations of dissolved zinc.

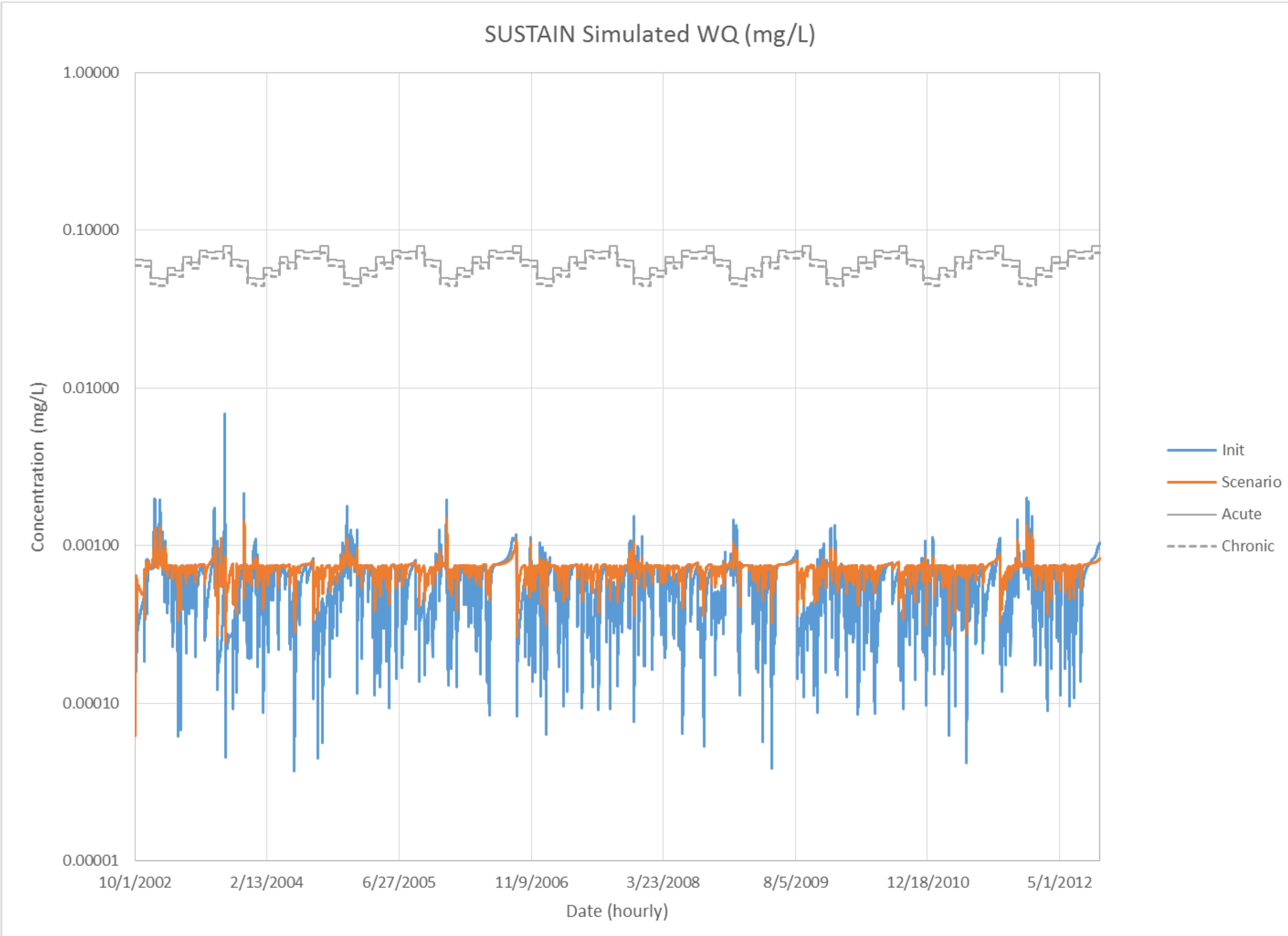

Figure 250 BEA240 simulated concentrations of dissolved zinc.

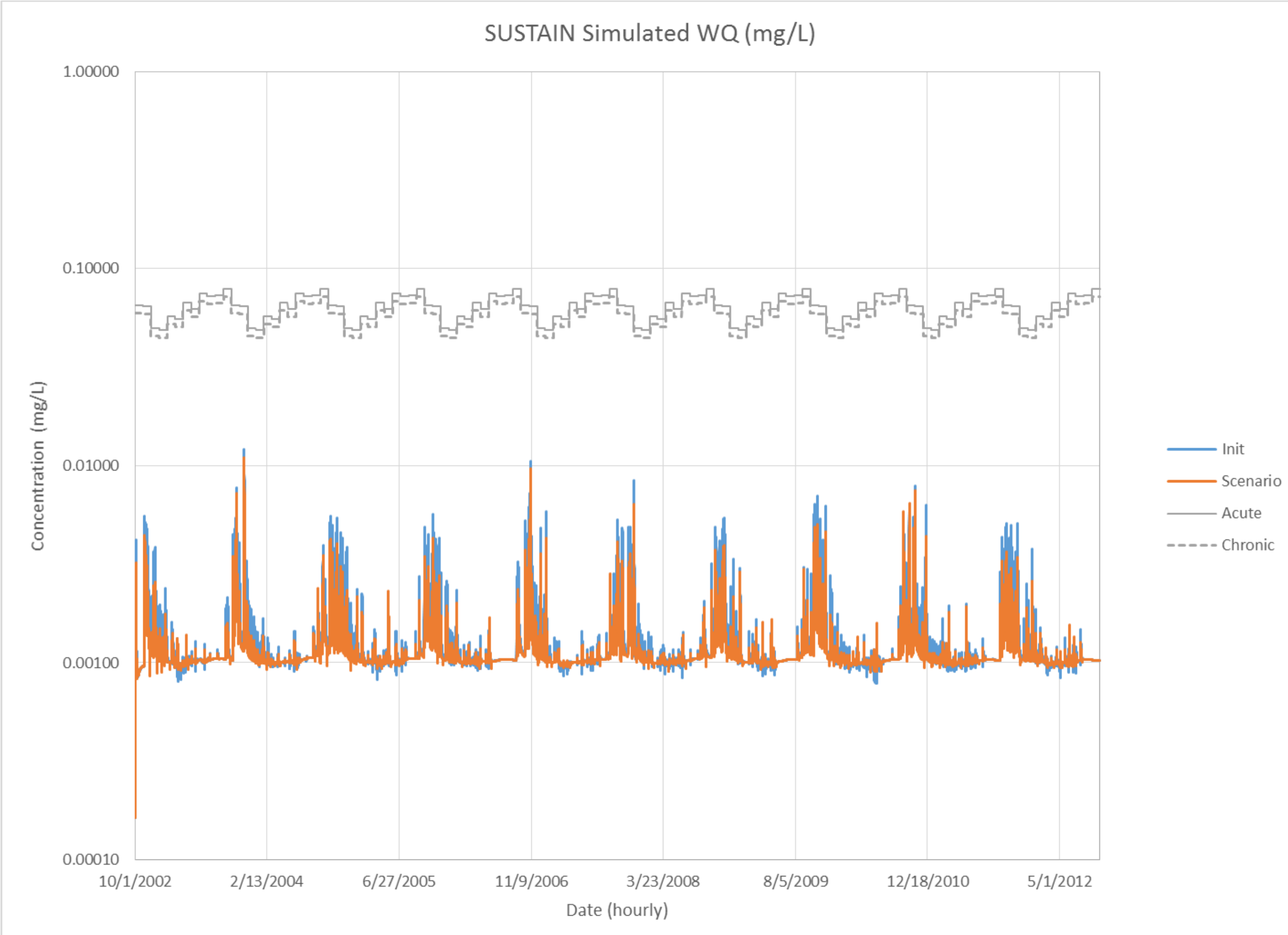

Figure 251 BEA260 simulated concentrations of dissolved zinc.

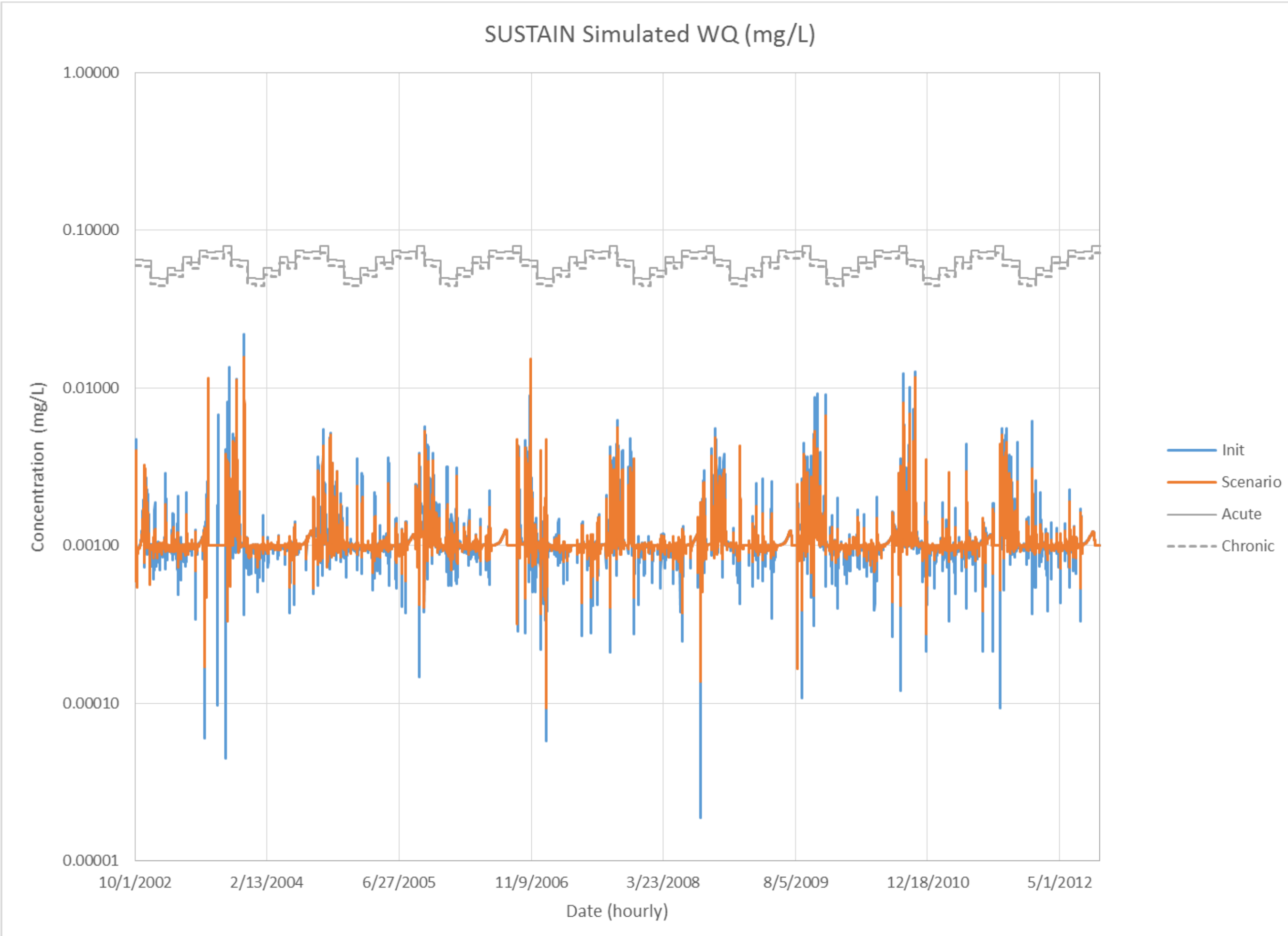

Figure 252 BEA270 simulated concentrations of dissolved zinc.

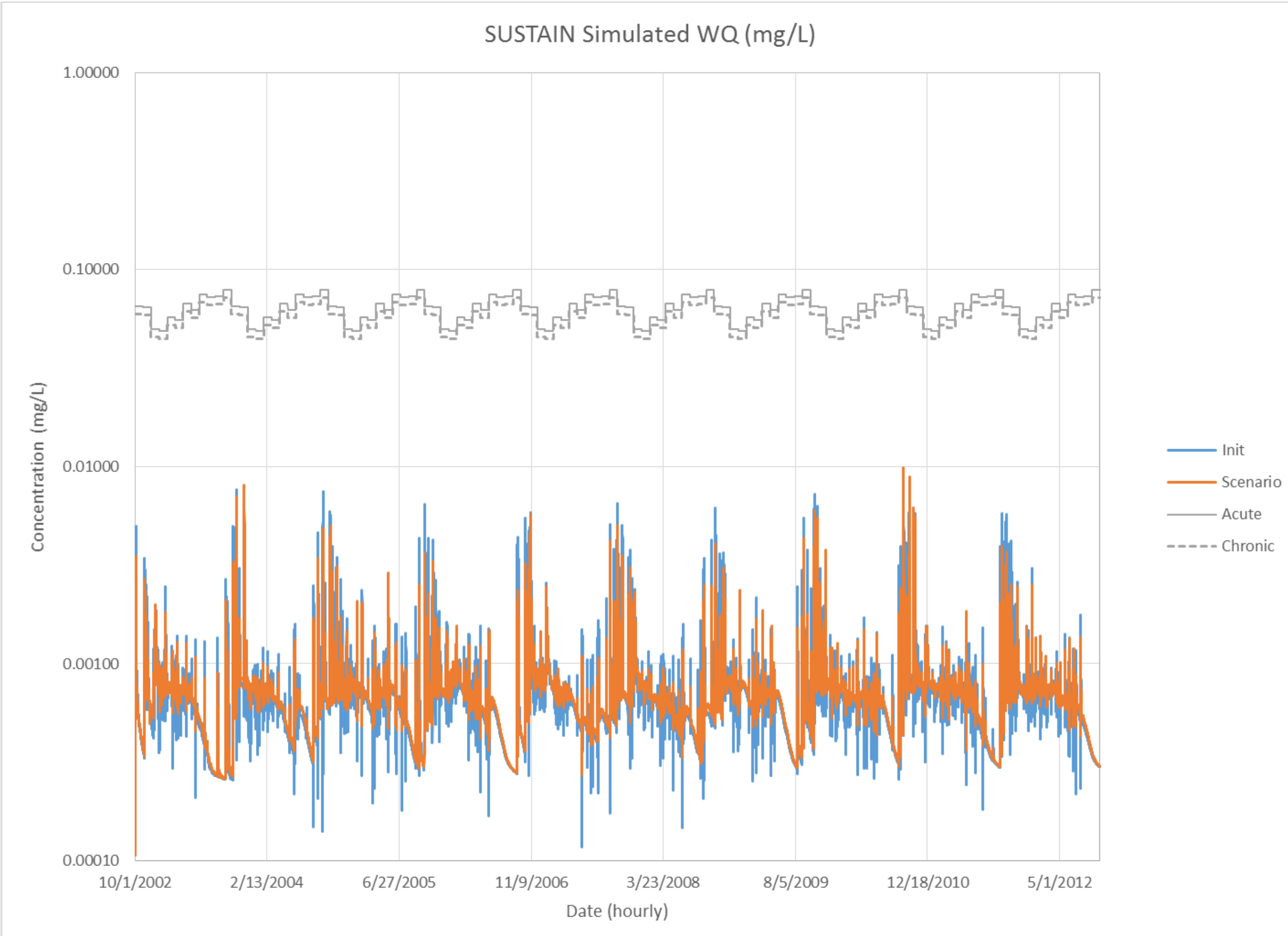

Figure 253 BEA280 simulated concentrations of dissolved zinc.

Figure 254 BEA310 simulated concentrations of dissolved zinc.

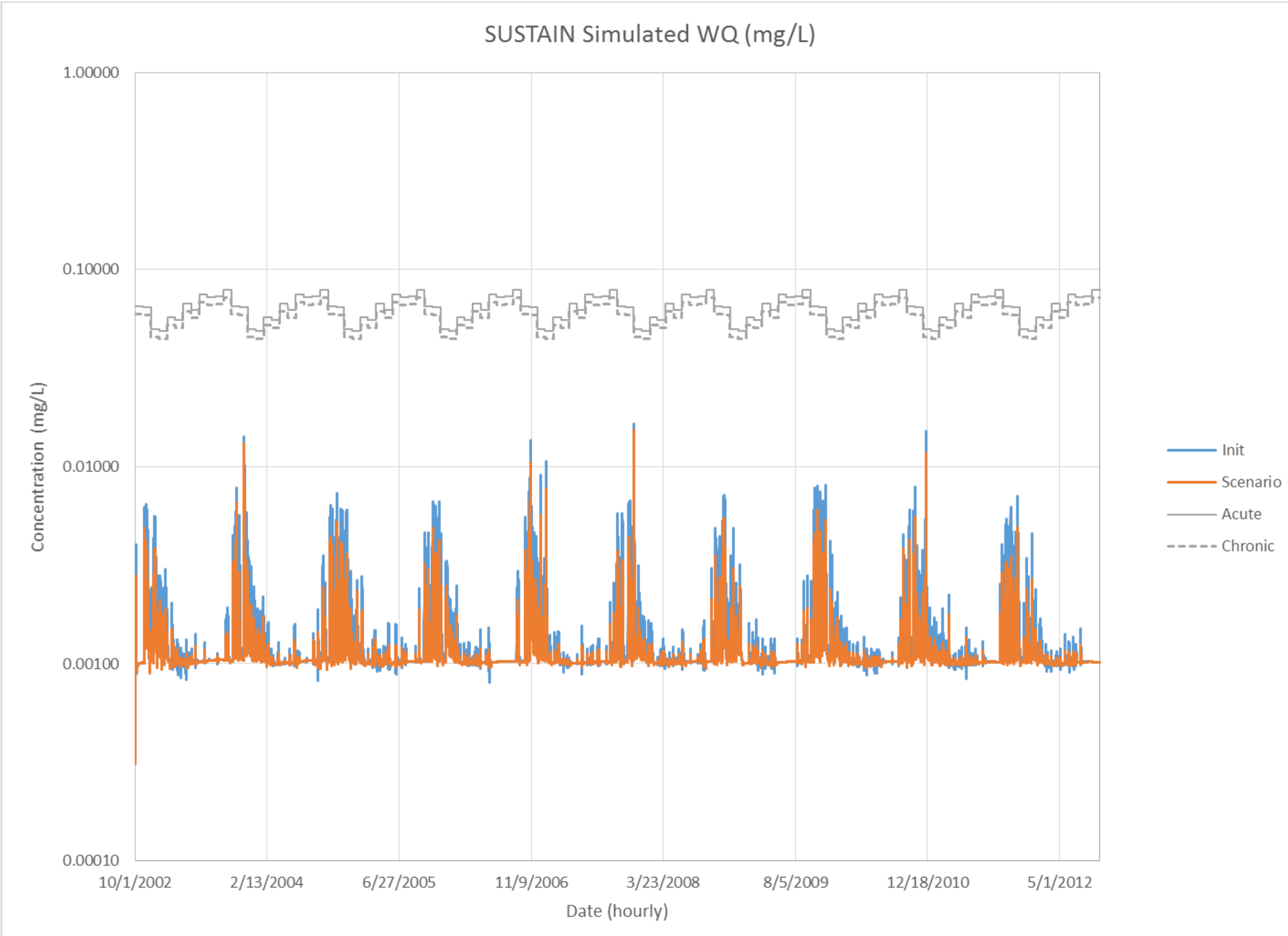

Figure 255 BEA370 simulated concentrations of dissolved zinc.

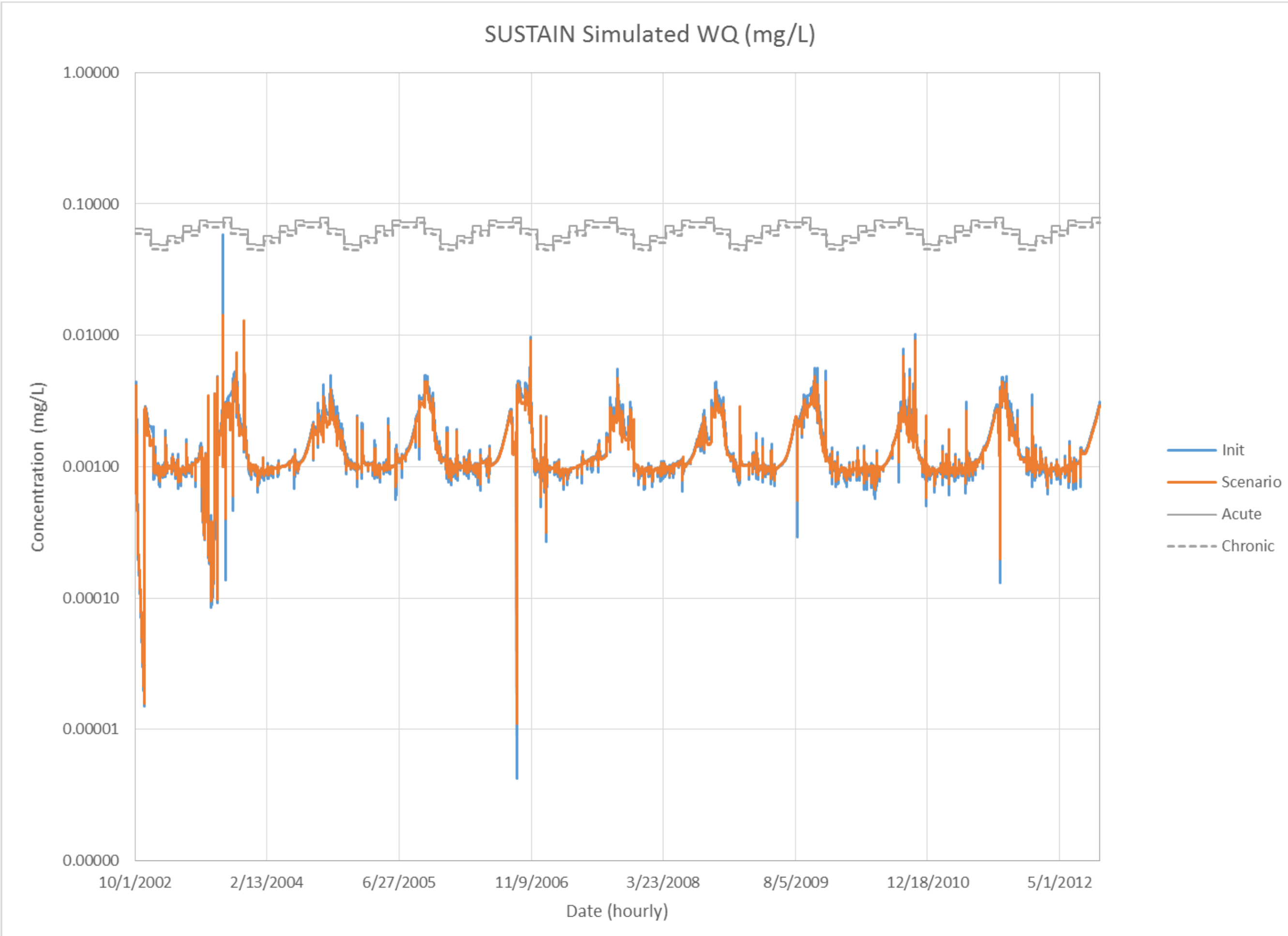

Figure 256 BEA410 simulated concentrations of dissolved zinc.

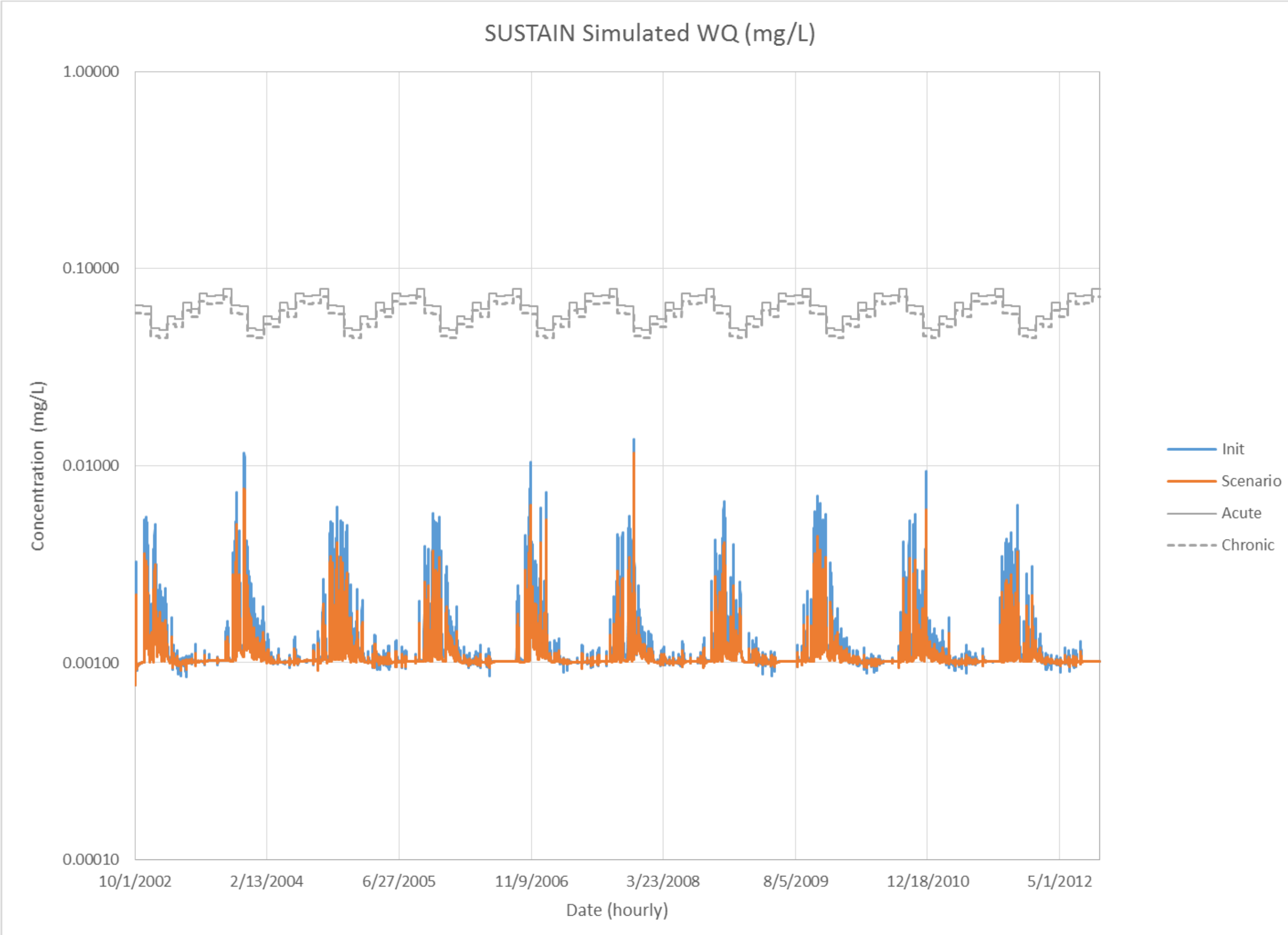

Figure 257 BEA590 simulated concentrations of dissolved zinc.

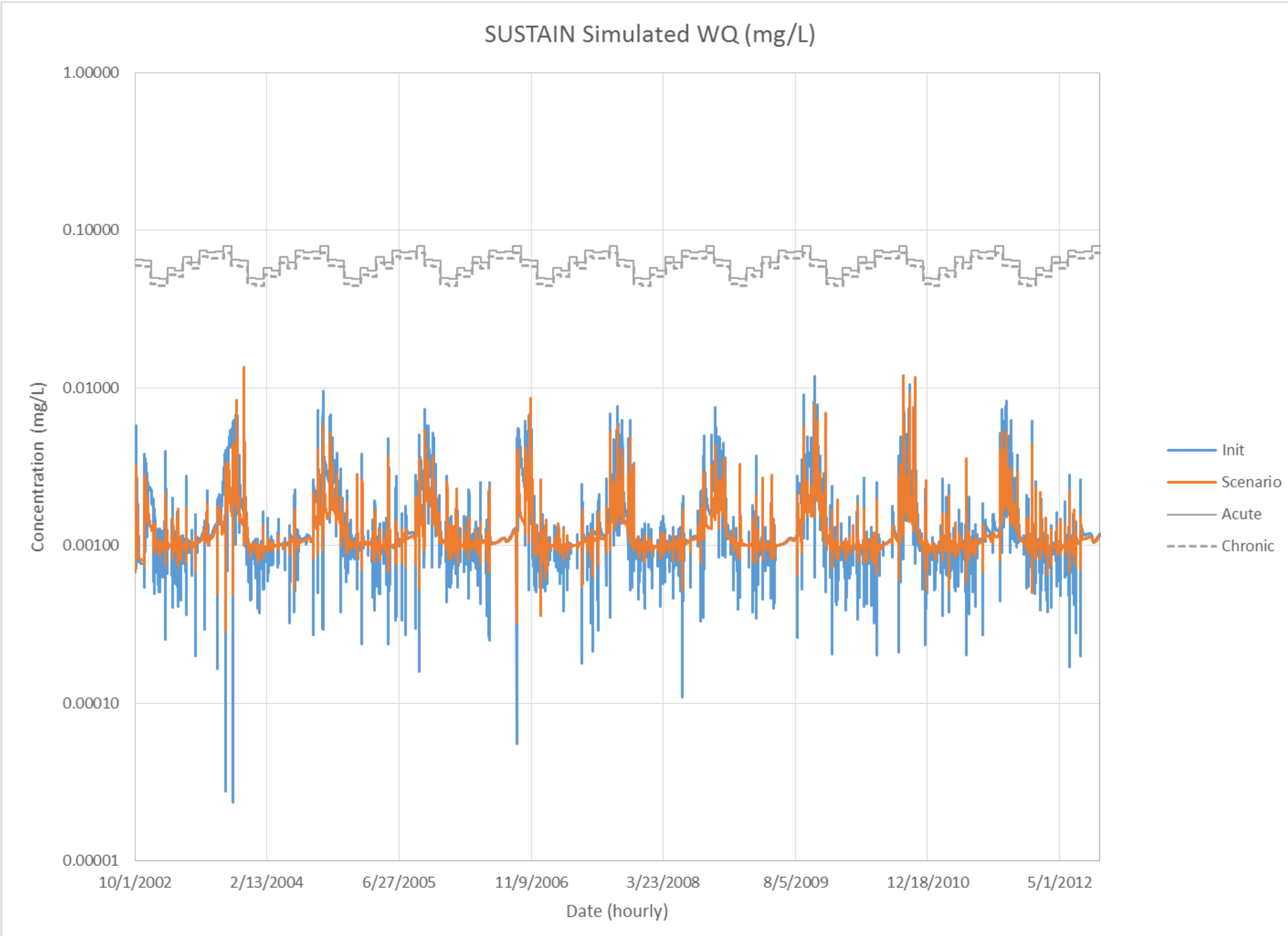

Figure 258 BEA800 simulated concentrations of dissolved zinc.

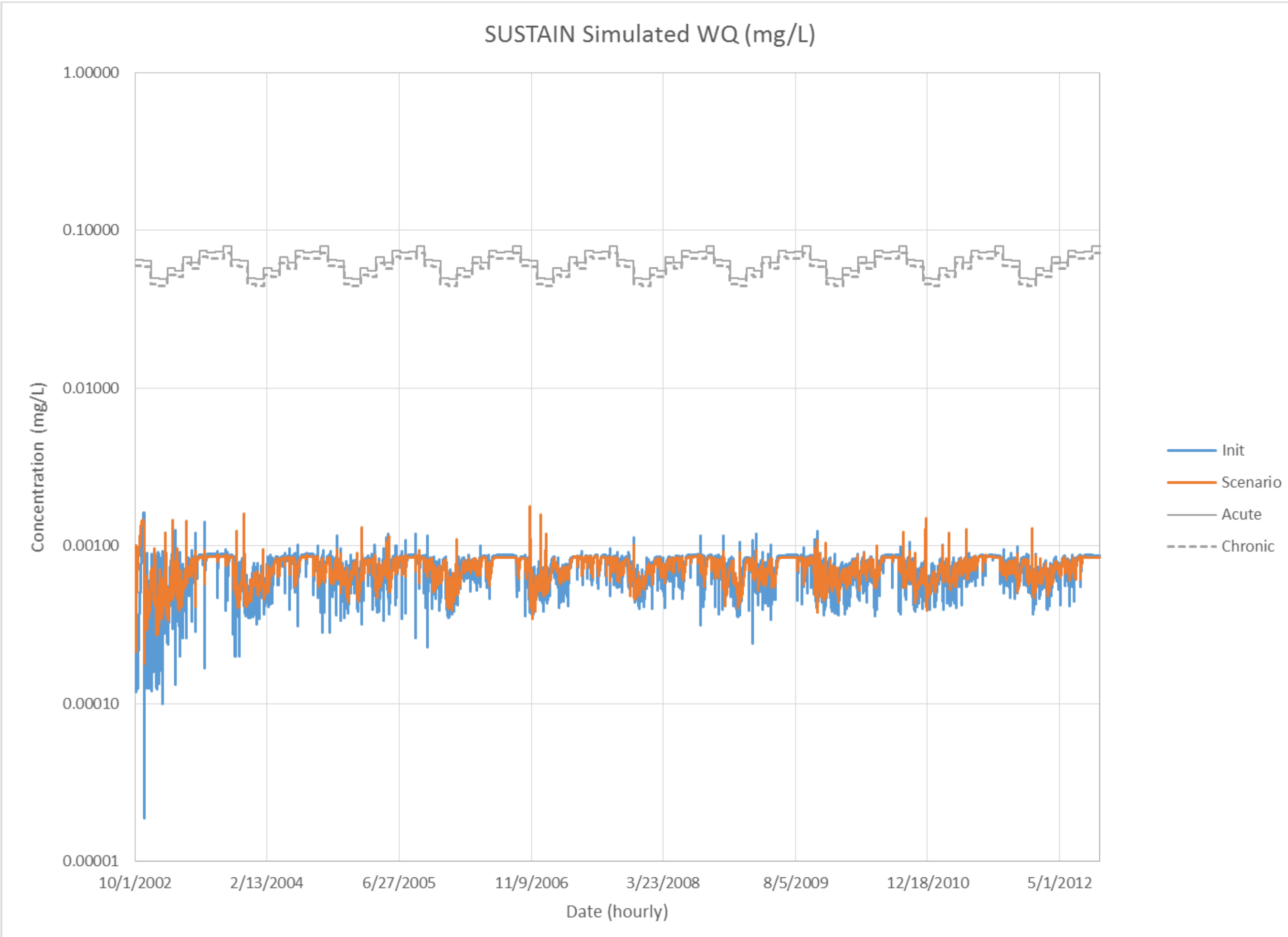

Figure 259 MON030 simulated concentrations of dissolved zinc.

APPENDIX O: Simulated B-IBI Scores

Table 65 HSPF simulated forested conditions B-IBI Scores.

KC_ID	Simulated WY1950-2012			Simulated B-IBI Forested Conditions						
	High Pulse Counts			(0-100)				(10-50)		
	Forested	Existing	Future	WRIA 8	PSB	Juanita Creek	WRIA9	WRIA 8	PSB	Juanita Creek
BEA010	4.2	9.1	12	74.3	59.1	56.2	68	36.8	30.6	33.7
BEA020	2.9	10.7	13.1	78.2	60.9	61.1	74.2	38	31.1	35.7
BEA030	3	12.1	15.1	77.9	60.7	60.7	73.7	37.9	31.1	35.5
BEA040	3.1	20.7	22.5	77.8	60.7	60.6	73.5	37.9	31	35.4
BEA050	3.1	15.2	17.2	77.6	60.6	60.4	73.3	37.9	31	35.4
BEA060	4.2	9.1	12	74.5	59.2	56.4	68.3	36.9	30.7	33.8
BEA070	2	5.1	6.2	80.9	62.1	64.5	78.9	38.9	31.4	37
BEA080	2.7	24.1	31.1	78.7	61.1	61.8	75.1	38.2	31.2	35.9
BEA100	4.2	9	11.9	74.5	59.2	56.4	68.3	36.9	30.7	33.8
BEA110	3.1	23.7	30.9	77.7	60.7	60.5	73.4	37.9	31	35.4
BEA120	2.9	11.1	15.9	78.2	60.9	61.2	74.3	38	31.1	35.7
BEA121	2.9	11.1	15.9	78.2	60.9	61.2	74.3	38	31.1	35.7
BEA130	2.4	11.1	14.6	79.7	61.6	63	76.8	38.5	31.3	36.4
BEA131	2.9	11.1	15.9	78.2	60.9	61.2	74.3	38	31.1	35.7
BEA140	3.1	13.1	17.2	77.7	60.7	60.5	73.5	37.9	31	35.4
BEA141	3.1	13.1	17.2	77.7	60.7	60.5	73.5	37.9	31	35.4
BEA150	3	13.2	16.7	78	60.8	60.9	73.9	38	31.1	35.6
BEA151	3	13.2	16.7	78	60.8	60.9	73.9	38	31.1	35.6
BEA155	3.1	15.2	17.2	77.6	60.6	60.4	73.3	37.9	31	35.4
BEA160	2.8	18.9	19.7	78.5	61	61.5	74.7	38.1	31.1	35.8
BEA170	3.1	22.7	23.1	77.8	60.7	60.6	73.5	37.9	31	35.4
BEA180	3	5.8	9.5	77.9	60.8	60.8	73.8	37.9	31.1	35.5
BEA190	3.1	22.5	30.1	77.5	60.6	60.3	73.1	37.8	31	35.3
BEA200	4.2	8.7	11.3	74.5	59.2	56.4	68.3	36.9	30.7	33.8
BEA210	2.8	8.5	14.7	78.7	61.1	61.7	75	38.2	31.2	35.9
BEA220	2.7	8.6	14.3	78.9	61.2	62	75.4	38.2	31.2	36
BEA230	3.8	8.3	10.9	75.7	59.8	58	70.2	37.3	30.8	34.4
BEA235	2.7	14.4	22.7	78.8	61.2	61.9	75.3	38.2	31.2	36
BEA240	2.2	11.1	18.1	80.3	61.9	63.8	77.8	38.7	31.3	36.7
BEA245	2.8	14.9	23.3	78.6	61.1	61.6	74.9	38.1	31.1	35.8
BEA250	2.8	16.4	24.7	78.6	61.1	61.7	75	38.2	31.1	35.9

KC_ID	Simulated WY1950-2012			Simulated B-IBI Forested Conditions						
	High Pulse Counts			(0-100)				(10-50)		
	Forested	Existing	Future	WRIA 8	PSB	Juanita Creek	WRIA9	WRIA 8	PSB	Juanita Creek
BEA260	4.7	8.1	9.9	73	58.6	54.6	66.2	36.5	30.5	33.1
BEA270	2.7	8	11.7	78.8	61.2	61.9	75.3	38.2	31.2	36
BEA275	3.1	9	13.8	77.6	60.6	60.3	73.2	37.8	31	35.3
BEA280	1.9	8.6	10.7	81.3	62.3	65	79.5	39	31.5	37.2
BEA290	2.8	13.1	19.2	78.4	61	61.4	74.6	38.1	31.1	35.8
BEA300	4.6	8.1	9.9	73.1	58.6	54.7	66.3	36.5	30.5	33.1
BEA310	6.3	7.1	9	68.1	56.3	48.3	59.2	34.9	29.9	30.6
BEA315	6.1	6.5	7.9	68.8	56.6	49.3	60.2	35.2	30	31
BEA320	5.9	6	7	69.4	56.9	50	61	35.3	30.1	31.3
BEA325	6.5	6.4	7.4	67.8	56.2	47.9	58.8	34.8	29.9	30.5
BEA330	7.2	12.1	13.8	65.7	55.2	45.3	56.1	34.2	29.6	29.4
BEA335	6.5	10.5	11.9	67.8	56.2	47.9	58.8	34.8	29.9	30.5
BEA350	4.5	8.1	9.9	73.6	58.8	55.3	67	36.6	30.6	33.4
BEA360	6	15.4	20.4	68.9	56.7	49.4	60.4	35.2	30	31
BEA370	4	7.4	9.3	75	59.4	57	69.1	37	30.7	34
BEA380	6.6	14.8	17.7	67.4	56	47.4	58.3	34.7	29.8	30.3
BEA390	6.3	12.3	16.2	68.1	56.3	48.4	59.3	35	29.9	30.6
BEA400	1	14.7	18.2	83.9	63.5	68.3	84.3	39.8	31.8	38.5
BEA410	5	7.7	9.8	72.2	58.2	53.5	64.9	36.2	30.4	32.7
BEA420	4.5	6.9	8.7	73.6	58.8	55.3	67	36.6	30.6	33.4
BEA430	4.5	6.7	8.6	73.7	58.8	55.4	67.1	36.6	30.6	33.4
BEA450	4.9	6.7	9	72.3	58.2	53.7	65.1	36.2	30.4	32.7
BEA460	5	7.8	10.5	72	58.1	53.3	64.6	36.1	30.4	32.6
BEA480	6.3	10.7	13.5	68.3	56.4	48.6	59.6	35	29.9	30.7
BEA490	6.2	10.7	13.4	68.4	56.4	48.7	59.6	35	29.9	30.8
BEA500	4	7	8.8	75.1	59.5	57.2	69.3	37.1	30.7	34.1
BEA510	4.9	12.7	14.4	72.3	58.2	53.6	65.1	36.2	30.4	32.7
BEA525	4.1	9.4	11.6	74.8	59.3	56.8	68.8	37	30.7	33.9
BEA530	3	7.5	8.9	77.9	60.8	60.8	73.8	37.9	31.1	35.5
BEA540	5	11.6	15.5	72.2	58.2	53.5	64.9	36.2	30.4	32.7
BEA550	5.2	13.4	17.9	71.6	57.9	52.7	64	36	30.3	32.4
BEA570	4	6.7	8.3	75.1	59.5	57.2	69.3	37.1	30.7	34.1
BEA580	4.8	11.7	15.4	72.6	58.4	54.1	65.5	36.3	30.4	32.9
BEA590	4	6.7	8.2	75.1	59.5	57.3	69.4	37.1	30.7	34.1
BEA600	3.8	9.8	12	75.5	59.7	57.7	69.9	37.2	30.8	34.3
BEA610	3.9	6.6	8	75.2	59.5	57.3	69.4	37.1	30.7	34.2
BEA620	4.7	9.5	12	72.8	58.5	54.3	65.8	36.4	30.5	33

KC_ID	Simulated WY1950-2012			Simulated B-IBI Forested Conditions						
	High Pulse Counts			(0-100)				(10-50)		
	Forested	Existing	Future	WRIA 8	PSB	Juanita Creek	WRIA9	WRIA 8	PSB	Juanita Creek
BEA625	4.6	10.4	15.6	73.2	58.6	54.9	66.5	36.5	30.5	33.2
BEA630	4.5	12.6	17.9	73.5	58.8	55.2	66.8	36.6	30.5	33.3
BEA640	4.6	7.2	8.7	73.2	58.6	54.8	66.4	36.5	30.5	33.2
BEA650	5.2	7.6	12.5	71.5	57.8	52.6	63.9	36	30.3	32.3
BEA660	4.7	7.3	8.6	73	58.5	54.6	66.1	36.4	30.5	33.1
BEA665	4	6.7	9.6	75.1	59.5	57.1	69.2	37.1	30.7	34.1
BEA670	3.6	5.6	6.9	76.3	60	58.7	71.1	37.4	30.9	34.7
BEA690	4.4	10.1	13.3	73.8	58.9	55.5	67.2	36.7	30.6	33.4
BEA700	1.8	8.2	10.3	81.4	62.4	65.2	79.8	39	31.5	37.3
BEA710	1.8	8.1	10.2	81.4	62.4	65.2	79.8	39	31.5	37.3
BEA720	1.8	7.4	9.3	81.4	62.3	65.2	79.7	39	31.5	37.2
BEA725	2.1	14.3	18.4	80.7	62	64.2	78.5	38.8	31.4	36.9
BEA730	2.1	14.3	18.6	80.5	62	64.1	78.2	38.7	31.4	36.8
BEA740	1.2	23.2	25.6	83.3	63.2	67.5	83.1	39.6	31.7	38.2
BEA750	1.6	22.9	27.8	82.1	62.7	66.1	81	39.2	31.6	37.6
BEA760	1.8	7.1	8.9	81.4	62.3	65.2	79.7	39	31.5	37.2
BEA770	2.3	18.9	26.5	80.2	61.8	63.6	77.6	38.6	31.3	36.6
BEA780	1.9	6.5	7.5	81.3	62.3	65	79.6	39	31.5	37.2
BEA800	1.7	11.6	15.1	81.8	62.5	65.6	80.4	39.1	31.5	37.4
BEA820	1.9	9.3	11.4	81.2	62.2	64.9	79.3	38.9	31.4	37.1
BEA830	1.8	12.4	15.7	81.5	62.4	65.3	79.9	39	31.5	37.3
BEA840	1.6	19.9	24.4	82.1	62.7	66.1	81	39.2	31.6	37.6
BEA850	2	11.7	12.8	80.9	62.1	64.5	78.9	38.9	31.4	37
BEA860	1.8	19.8	21.1	81.4	62.3	65.2	79.7	39	31.5	37.2
BEA900	2	6	5.9	81.1	62.2	64.7	79.1	38.9	31.4	37.1
BEA910	2.1	10.2	10.1	80.7	62	64.2	78.5	38.8	31.4	36.9
BEA920	2	9.1	9	80.9	62.1	64.5	78.9	38.9	31.4	37
BEA940	3.4	11	10.9	76.9	60.3	59.5	72.1	37.6	30.9	35
BEA950	3.5	10.7	10.5	76.6	60.2	59.1	71.6	37.5	30.9	34.8
BEA960	3.9	10.9	10.7	75.2	59.5	57.3	69.4	37.1	30.7	34.2
BEA970	1.6	24.8	23	82.1	62.7	66.1	81	39.2	31.6	37.6
BEA990	1.5	14.3	14.2	82.3	62.7	66.2	81.3	39.3	31.6	37.7
MON001	3.2	19.3	26	77.3	60.5	60	72.8	37.8	31	35.2
MON002	3.4	21.3	26.5	76.9	60.3	59.4	72.1	37.6	30.9	35
MON003	3.9	23.5	24.7	75.3	59.6	57.4	69.6	37.1	30.8	34.2
MON004	3.1	18.5	19	77.5	60.6	60.3	73.1	37.8	31	35.3
MON005	3.6	13.6	14.7	76.1	60	58.5	70.9	37.4	30.9	34.6

KC_ID	Simulated WY1950-2012			Simulated B-IBI Forested Conditions						
	High Pulse Counts			(0-100)				(10-50)		
	Forested	Existing	Future	WRIA 8	PSB	Juanita Creek	WRIA9	WRIA 8	PSB	Juanita Creek
MON006	2.7	16	20.2	78.8	61.2	61.8	75.2	38.2	31.2	35.9
MON007	2.9	16.5	17.2	78.3	61	61.3	74.5	38.1	31.1	35.7
MON008	4.3	10.8	27.8	74.1	59	55.9	67.7	36.8	30.6	33.6
MON009	3	9.9	10.3	78	60.8	60.8	73.8	38	31.1	35.5
MON010	3.5	7.5	8.6	76.5	60.1	58.9	71.5	37.5	30.9	34.8
MON011	3.1	23.7	22.6	77.6	60.6	60.3	73.2	37.8	31	35.3
MON012	2.9	18.2	19	78.2	60.9	61.1	74.2	38	31.1	35.7
MON013	3.3	13.8	19.7	77.2	60.4	59.8	72.5	37.7	31	35.1
MON014	3.1	19.4	20.5	77.6	60.6	60.4	73.3	37.9	31	35.4
MON015	2.8	16.7	18.8	78.6	61.1	61.6	74.9	38.1	31.1	35.8
MON016	3.4	8	7.9	76.8	60.2	59.3	71.9	37.6	30.9	34.9
MON017	3	32.5	28.3	78	60.8	60.9	73.9	38	31.1	35.6
MON019	2.9	12.8	23.8	78.2	60.9	61.2	74.3	38	31.1	35.7
MON020	3	26	26.6	77.9	60.7	60.7	73.7	37.9	31.1	35.5
MON021	2.9	34.3	34.3	78.2	60.9	61.1	74.2	38	31.1	35.6
MON022	3	33.2	33.4	78.1	60.9	61	74.1	38	31.1	35.6
MON023	2.8	15	15.2	78.6	61.1	61.7	75	38.2	31.1	35.9
MON024	3.4	22.9	29	76.9	60.3	59.4	72.1	37.6	30.9	35
MON025	3.3	17.3	23	77.2	60.4	59.9	72.6	37.7	31	35.2
MON026	3.3	16.6	23.6	77.1	60.4	59.7	72.4	37.7	31	35.1
MON027	3.4	15.6	21.5	76.8	60.2	59.3	71.9	37.6	30.9	34.9
MON028	3	29.8	26.1	77.9	60.7	60.7	73.7	37.9	31.1	35.5
MON029	3.2	14.9	20.2	77.2	60.5	59.9	72.7	37.7	31	35.2
MON030	3.3	15.2	20.4	77.2	60.4	59.8	72.5	37.7	31	35.1
MON031	3.9	20.2	21.6	75.2	59.6	57.4	69.5	37.1	30.7	34.2
MON032	3.4	15.8	22.3	76.9	60.3	59.5	72.1	37.6	30.9	35
MON033	3.4	14.1	20	76.9	60.3	59.5	72.1	37.6	30.9	35
MON034	3.2	23.4	22.8	77.4	60.6	60.2	73	37.8	31	35.3
MON035	3.4	22.9	28.3	76.9	60.3	59.5	72.1	37.6	30.9	35
MON036	3.4	5.6	27.8	76.8	60.2	59.3	71.9	37.6	30.9	34.9
MON037	2.8	7.9	8.3	78.7	61.1	61.7	75	38.2	31.2	35.9
MON038	3.8	17.6	19.1	75.6	59.7	57.8	70	37.2	30.8	34.3
MON039	3.3	12	19.8	77.2	60.4	59.8	72.5	37.7	31	35.1
MON040	2.4	8.3	10.2	79.7	61.6	63	76.8	38.5	31.3	36.4
MON041	2.8	9.5	10.1	78.5	61	61.5	74.8	38.1	31.1	35.8
MON042	3.5	16.5	27.8	76.5	60.1	59	71.5	37.5	30.9	34.8
MON043	3.2	15.2	28	77.3	60.5	60	72.8	37.8	31	35.2

KC_ID	Simulated WY1950-2012			Simulated B-IBI Forested Conditions						
	High Pulse Counts			(0-100)				(10-50)		
	Forested	Existing	Future	WRIA 8	PSB	Juanita Creek	WRIA9	WRIA 8	PSB	Juanita Creek
MON044	2.8	18.1	20.4	78.7	61.1	61.7	75	38.2	31.2	35.9
MON045	2.7	7.8	8.5	78.8	61.2	61.8	75.2	38.2	31.2	35.9
MON046	4.6	8.6	9.3	73.2	58.6	54.9	66.5	36.5	30.5	33.2
MON047	4.1	27.2	27.5	74.8	59.3	56.8	68.8	37	30.7	33.9
MON048	2.9	20.9	21	78.3	60.9	61.2	74.4	38.1	31.1	35.7
MON049	3	16	16.9	78	60.8	60.8	73.8	38	31.1	35.5
MON110	3.9	11.7	26.1	75.3	59.6	57.5	69.6	37.2	30.8	34.2
MON128	3.2	29.9	28	77.5	60.6	60.2	73.1	37.8	31	35.3
MON139	3.3	11.9	19.5	77	60.3	59.6	72.2	37.7	31	35
MON146	3.4	20.9	21.7	76.7	60.2	59.2	71.8	37.6	30.9	34.9
MON147	3.5	20.1	20.9	76.5	60.1	58.9	71.5	37.5	30.9	34.8

Table 66 HSPF simulated existing conditions B-IBI scores.

KC_ID	Simulated B-IBI Existing Conditions						
	(0-100)				(10-50)		
	WRIA 8	PSB	Juanita Creek	WRIA9	WRIA 8	PSB	Juanita Creek
BEA010	59.8	52.5	37.9	49.2	32.4	28.9	26.5
BEA020	55.2	50.5	32.1	44.4	31	28.4	24.2
BEA030	51	48.5	26.7	40.4	29.7	27.9	22.1
BEA040	25.8	37.1	0	23	22	24.9	10
BEA050	42	44.5	15.4	33.1	27	26.8	17.6
BEA060	60	52.7	38.2	49.5	32.5	29	26.6
BEA070	71.9	58	53.1	64.4	36.1	30.3	32.5
BEA080	15.6	32.5	0	18.4	19	23.7	10
BEA100	60.2	52.7	38.4	49.6	32.5	29	26.7
BEA110	16.8	33	0	18.8	19.3	23.9	10
BEA120	54.1	49.9	30.6	43.3	30.7	28.3	23.6
BEA121	54.1	49.9	30.6	43.3	30.7	28.3	23.6
BEA130	53.9	49.9	30.5	43.2	30.6	28.2	23.6
BEA131	54.1	49.9	30.6	43.3	30.7	28.3	23.6
BEA140	48.1	47.2	23.1	37.9	28.8	27.5	20.6
BEA141	48.1	47.2	23.1	37.9	28.8	27.5	20.6
BEA150	47.9	47.1	22.8	37.7	28.8	27.5	20.5
BEA151	47.9	47.1	22.8	37.7	28.8	27.5	20.5
BEA155	42	44.5	15.4	33.1	27	26.8	17.6

KC_ID	Simulated B-IBI Existing Conditions						
	(0-100)				(10-50)		
	WRIA 8	PSB	Juanita Creek	WRIA9	WRIA 8	PSB	Juanita Creek
BEA160	30.9	39.4	1.4	25.8	23.6	25.5	12.1
BEA170	19.9	34.4	0	20.2	20.2	24.2	10
BEA180	69.7	57.1	50.4	61.5	35.5	30.1	31.4
BEA190	20.3	34.6	0	20.4	20.4	24.3	10
BEA200	61	53.1	39.4	50.5	32.8	29.1	27.1
BEA210	61.8	53.5	40.4	51.5	33	29.2	27.5
BEA220	61.3	53.2	39.8	50.9	32.9	29.1	27.2
BEA230	62.2	53.6	40.9	51.9	33.2	29.2	27.7
BEA235	44.3	45.5	18.3	34.8	27.7	27.1	18.7
BEA240	54	49.9	30.6	43.3	30.7	28.2	23.6
BEA245	42.7	44.8	16.3	33.6	27.2	26.9	18
BEA250	38.4	42.8	10.8	30.5	25.9	26.4	15.8
BEA260	63	54	41.9	52.9	33.4	29.3	28.1
BEA270	63.1	54.1	42.1	53	33.4	29.3	28.1
BEA275	60.1	52.7	38.3	49.6	32.5	29	26.7
BEA280	61.4	53.3	39.9	51	32.9	29.1	27.3
BEA290	48.2	47.3	23.2	38	28.9	27.6	20.7
BEA300	62.8	53.9	41.7	52.6	33.3	29.3	28
BEA310	65.8	55.3	45.4	56.2	34.2	29.6	29.5
BEA315	67.7	56.1	47.9	58.8	34.8	29.9	30.4
BEA320	69.1	56.8	49.7	60.6	35.3	30	31.1
BEA325	67.8	56.2	48	58.8	34.9	29.9	30.5
BEA330	51.2	48.6	27	40.6	29.8	27.9	22.2
BEA335	55.9	50.8	33	45.1	31.2	28.5	24.5
BEA350	62.8	53.9	41.7	52.6	33.3	29.3	28
BEA360	41.2	44.1	14.3	32.5	26.7	26.7	17.2
BEA370	65	54.9	44.5	55.3	34	29.5	29.1
BEA380	43	44.9	16.7	33.8	27.3	26.9	18.1
BEA390	50.4	48.3	26	39.9	29.6	27.8	21.8
BEA400	43.3	45.1	17.1	34.1	27.4	27	18.3
BEA410	64.1	54.5	43.3	54.2	33.7	29.4	28.6
BEA420	66.4	55.5	46.2	57	34.4	29.7	29.8
BEA430	67.2	55.9	47.2	58	34.7	29.8	30.2
BEA450	66.9	55.8	46.8	57.7	34.6	29.8	30
BEA460	63.8	54.4	42.9	53.8	33.6	29.4	28.5
BEA480	55.2	50.4	32	44.4	31	28.4	24.2
BEA490	55.2	50.5	32.1	44.4	31	28.4	24.2

KC_ID	Simulated B-IBI Existing Conditions						
	(0-100)				(10-50)		
	WRIA 8	PSB	Juanita Creek	WRIA9	WRIA 8	PSB	Juanita Creek
BEA500	66.1	55.4	45.8	56.7	34.3	29.7	29.6
BEA510	49.3	47.8	24.7	39	29.2	27.7	21.3
BEA525	59	52.2	36.8	48.3	32.2	28.8	26.1
BEA530	64.5	54.7	43.9	54.7	33.9	29.5	28.8
BEA540	52.7	49.3	28.9	42	30.2	28.1	22.9
BEA550	47.2	46.8	21.9	37.1	28.6	27.4	20.2
BEA570	67.2	55.9	47.2	58	34.7	29.8	30.2
BEA580	52.2	49.1	28.3	41.6	30.1	28	22.7
BEA590	67.2	55.9	47.2	58	34.7	29.8	30.2
BEA600	58	51.7	35.6	47.3	31.9	28.7	25.6
BEA610	67.2	55.9	47.2	58.1	34.7	29.8	30.2
BEA620	58.8	52.1	36.6	48.1	32.1	28.8	26
BEA625	56	50.8	33.1	45.2	31.3	28.5	24.6
BEA630	49.7	48	25.1	39.3	29.3	27.7	21.5
BEA640	65.6	55.2	45.2	56	34.2	29.6	29.4
BEA650	64.3	54.6	43.5	54.4	33.8	29.5	28.7
BEA660	65.3	55	44.8	55.7	34.1	29.6	29.2
BEA665	67	55.8	46.9	57.8	34.6	29.8	30.1
BEA670	70.3	57.3	51.1	62.2	35.6	30.2	31.7
BEA690	56.9	51.2	34.3	46.2	31.5	28.6	25.1
BEA700	62.5	53.8	41.3	52.3	33.3	29.2	27.8
BEA710	63	54	41.9	52.9	33.4	29.3	28.1
BEA720	64.8	54.8	44.2	55.1	34	29.5	29
BEA725	44.5	45.6	18.5	35	27.7	27.1	18.8
BEA730	44.5	45.6	18.6	35	27.8	27.1	18.9
BEA740	18.3	33.7	0	19.5	19.8	24	10
BEA750	19.2	34.1	0	19.9	20	24.1	10
BEA760	65.7	55.2	45.3	56.2	34.2	29.6	29.4
BEA770	31	39.5	1.5	25.9	23.7	25.5	12.2
BEA780	67.7	56.1	47.8	58.7	34.8	29.9	30.4
BEA800	52.4	49.2	28.6	41.8	30.2	28.1	22.8
BEA820	59.4	52.4	37.4	48.8	32.3	28.9	26.3
BEA830	50.1	48.1	25.6	39.6	29.5	27.8	21.6
BEA840	28.1	38.2	0	24.3	22.8	25.2	10.7
BEA850	52.3	49.2	28.5	41.7	30.1	28	22.8
BEA860	28.3	38.2	0	24.4	22.8	25.2	10.8
BEA900	69.2	56.8	49.7	60.7	35.3	30	31.2

KC_ID	Simulated B-IBI Existing Conditions						
	(0-100)				(10-50)		
	WRIA 8	PSB	Juanita Creek	WRIA9	WRIA 8	PSB	Juanita Creek
BEA910	56.6	51.1	33.8	45.8	31.4	28.5	24.9
BEA920	60	52.6	38.1	49.4	32.5	29	26.6
BEA940	54.2	50	30.8	43.5	30.7	28.3	23.7
BEA950	55.3	50.5	32.2	44.5	31	28.4	24.2
BEA960	54.5	50.1	31.2	43.7	30.8	28.3	23.8
BEA970	13.5	31.5	0	17.5	18.3	23.5	10
BEA990	44.5	45.6	18.6	35	27.8	27.1	18.9
MON001	29.7	38.9	0	25.1	23.2	25.4	11.5
MON002	24	36.3	0	22.1	21.5	24.7	10
MON003	17.3	33.3	0	19.1	19.5	23.9	10
MON004	32.2	40	3	26.6	24	25.7	12.7
MON005	46.7	46.6	21.4	36.8	28.4	27.4	20
MON006	39.7	43.4	12.5	31.4	26.3	26.6	16.5
MON007	38.2	42.7	10.6	30.4	25.8	26.4	15.7
MON008	54.9	50.3	31.7	44.2	30.9	28.4	24.1
MON009	57.5	51.5	35	46.8	31.7	28.7	25.3
MON010	64.6	54.7	44	54.8	33.9	29.5	28.9
MON011	16.9	33.1	0	18.9	19.3	23.9	10
MON012	33	40.4	4	27.1	24.2	25.8	13.1
MON013	46	46.3	20.5	36.2	28.2	27.3	19.6
MON014	29.4	38.7	0	25	23.1	25.3	11.3
MON015	37.5	42.4	9.7	29.9	25.6	26.3	15.4
MON016	63.1	54	42	53	33.4	29.3	28.1
MON017	0	21.2	0	10.5	11.3	20.8	10
MON019	49	47.7	24.3	38.7	29.1	27.7	21.1
MON020	10	29.9	0	16.2	17.2	23.1	10
MON021	0	18.8	0	9.4	9.7	20.2	10
MON022	0	20.2	0	10	10.7	20.5	10
MON023	42.4	44.6	15.9	33.4	27.1	26.9	17.8
MON024	19.3	34.1	0	19.9	20.1	24.1	10
MON025	35.7	41.6	7.4	28.7	25.1	26.1	14.5
MON026	37.8	42.6	10.1	30.1	25.7	26.3	15.5
MON027	40.6	43.8	13.7	32.1	26.6	26.7	16.9
MON028	0	24.8	0	12.6	13.8	21.7	10
MON029	42.7	44.8	16.2	33.6	27.2	26.9	18
MON030	41.8	44.4	15.2	33	26.9	26.8	17.5
MON031	27	37.7	0	23.7	22.4	25.1	10.2

KC_ID	Simulated B-IBI Existing Conditions						
	(0-100)				(10-50)		
	WRIA 8	PSB	Juanita Creek	WRIA9	WRIA 8	PSB	Juanita Creek
MON032	40.1	43.6	13.1	31.7	26.4	26.6	16.7
MON033	45.1	45.9	19.3	35.4	27.9	27.2	19.1
MON034	17.8	33.5	0	19.3	19.6	24	10
MON035	19.3	34.1	0	19.9	20.1	24.1	10
MON036	70.4	57.3	51.2	62.3	35.6	30.2	31.8
MON037	63.6	54.3	42.7	53.6	33.6	29.4	28.4
MON038	34.9	41.2	6.4	28.2	24.8	26	14.1
MON039	51.4	48.8	27.3	40.9	29.9	27.9	22.3
MON040	62.2	53.6	40.9	52	33.2	29.2	27.7
MON041	58.8	52.1	36.7	48.2	32.1	28.8	26
MON042	37.9	42.6	10.3	30.2	25.8	26.4	15.6
MON043	42	44.4	15.3	33.1	27	26.8	17.6
MON044	33.4	40.6	4.6	27.3	24.4	25.8	13.3
MON045	63.7	54.3	42.9	53.8	33.6	29.4	28.5
MON046	61.4	53.3	39.9	51	32.9	29.1	27.3
MON047	6.4	28.3	0	14.9	16.1	22.6	10
MON048	25	36.8	0	22.7	21.8	24.8	10
MON049	39.4	43.3	12.2	31.2	26.2	26.5	16.3
MON110	52.2	49.1	28.2	41.5	30.1	28	22.7
MON128	0	24.6	0	12.5	13.7	21.7	10
MON139	51.7	48.9	27.6	41.1	29.9	28	22.4
MON146	25.2	36.8	0	22.7	21.9	24.8	10
MON147	27.3	37.8	0	23.8	22.5	25.1	10.3

Table 67 HSPF simulated future condition B-IBI scores.

KC_ID	Simulated B-IBI Future Conditions						
	(0-100)				(10-50)		
	WRIA 8	PSB	Juanita Creek	WRIA9	WRIA 8	PSB	Juanita Creek
BEA010	51.2	48.6	27	40.6	29.8	27.9	22.2
BEA020	48.2	47.3	23.2	38	28.9	27.6	20.7
BEA030	42.2	44.5	15.6	33.2	27	26.8	17.7
BEA040	20.2	34.6	0	20.3	20.3	24.3	10
BEA050	36	41.7	7.8	28.9	25.2	26.1	14.6
BEA060	51.3	48.7	27.1	40.7	29.8	27.9	22.2
BEA070	68.6	56.5	49	59.9	35.1	30	30.9
BEA080	0	23.1	0	11.6	12.6	21.3	10
BEA100	51.7	48.9	27.7	41.1	30	28	22.5
BEA110	0	23.3	0	11.7	12.8	21.3	10
BEA120	39.8	43.5	12.6	31.5	26.3	26.6	16.5
BEA121	39.8	43.5	12.6	31.5	26.3	26.6	16.5
BEA130	43.7	45.2	17.5	34.3	27.5	27	18.4
BEA131	39.8	43.5	12.6	31.5	26.3	26.6	16.5
BEA140	36	41.7	7.8	28.9	25.2	26.1	14.6
BEA141	36	41.7	7.8	28.9	25.2	26.1	14.6
BEA150	37.3	42.3	9.5	29.8	25.6	26.3	15.3
BEA151	37.3	42.3	9.5	29.8	25.6	26.3	15.3
BEA155	36	41.7	7.8	28.9	25.2	26.1	14.6
BEA160	28.5	38.3	0	24.5	22.9	25.2	10.9
BEA170	18.6	33.9	0	19.6	19.9	24.1	10
BEA180	58.6	52	36.4	48	32.1	28.8	25.9
BEA190	0	24.5	0	12.4	13.6	21.6	10
BEA200	53.3	49.6	29.6	42.6	30.4	28.2	23.2
BEA210	43.3	45	17	34	27.4	27	18.3
BEA220	44.7	45.7	18.8	35.1	27.8	27.1	19
BEA230	54.6	50.2	31.3	43.8	30.8	28.3	23.9
BEA235	19.6	34.3	0	20.1	20.2	24.2	10
BEA240	33.4	40.6	4.6	27.3	24.4	25.8	13.3
BEA245	17.8	33.5	0	19.3	19.6	24	10
BEA250	13.7	31.6	0	17.6	18.4	23.5	10
BEA260	57.5	51.5	35	46.8	31.7	28.7	25.4
BEA270	52.4	49.2	28.5	41.7	30.2	28.1	22.8
BEA275	46	46.3	20.5	36.2	28.2	27.3	19.6
BEA280	55.1	50.4	31.9	44.3	31	28.4	24.1

KC_ID	Simulated B-IBI Future Conditions						
	(0-100)				(10-50)		
	WRIA 8	PSB	Juanita Creek	WRIA9	WRIA 8	PSB	Juanita Creek
BEA290	30.1	39.1	0.4	25.4	23.4	25.4	11.7
BEA300	57.5	51.5	35	46.8	31.7	28.7	25.4
BEA310	60.3	52.8	38.5	49.8	32.6	29	26.7
BEA315	63.4	54.2	42.4	53.3	33.5	29.3	28.3
BEA320	66	55.4	45.7	56.5	34.3	29.7	29.6
BEA325	64.9	54.8	44.3	55.1	34	29.5	29
BEA330	46.1	46.3	20.6	36.3	28.3	27.3	19.7
BEA335	51.6	48.8	27.5	41	29.9	28	22.4
BEA350	57.6	51.6	35.2	46.9	31.8	28.7	25.4
BEA360	26.4	37.4	0	23.4	22.2	25	10
BEA370	59.5	52.4	37.5	48.9	32.3	28.9	26.3
BEA380	34.5	41	5.9	28	24.7	25.9	13.9
BEA390	38.8	43	11.4	30.8	26	26.5	16
BEA400	32.9	40.3	3.9	27	24.2	25.8	13.1
BEA410	57.7	51.6	35.3	47	31.8	28.7	25.5
BEA420	61.2	53.2	39.7	50.8	32.9	29.1	27.2
BEA430	61.5	53.3	40	51.1	32.9	29.1	27.3
BEA450	60.2	52.7	38.4	49.7	32.5	29	26.7
BEA460	55.8	50.7	32.8	45	31.2	28.5	24.5
BEA480	47	46.7	21.7	37	28.5	27.4	20.1
BEA490	47.2	46.8	21.9	37.1	28.6	27.4	20.2
BEA500	60.7	53	39	50.2	32.7	29	26.9
BEA510	44.3	45.5	18.3	34.8	27.7	27.1	18.8
BEA525	52.5	49.2	28.7	41.9	30.2	28.1	22.9
BEA530	60.5	52.8	38.7	50	32.6	29	26.8
BEA540	41.1	44	14.2	32.4	26.7	26.7	17.2
BEA550	34	40.8	5.3	27.7	24.6	25.9	13.6
BEA570	62.4	53.7	41.2	52.2	33.2	29.2	27.8
BEA580	41.3	44.1	14.5	32.5	26.8	26.7	17.2
BEA590	62.6	53.8	41.4	52.4	33.3	29.3	27.9
BEA600	51.3	48.7	27.1	40.7	29.8	27.9	22.2
BEA610	63.2	54.1	42.2	53.1	33.5	29.3	28.2
BEA620	51.4	48.8	27.3	40.9	29.9	27.9	22.3
BEA625	40.8	43.9	13.9	32.2	26.6	26.7	17
BEA630	34	40.8	5.3	27.7	24.6	25.9	13.6
BEA640	61	53.1	39.4	50.5	32.8	29.1	27.1
BEA650	50	48.1	25.5	39.6	29.4	27.8	21.6

KC_ID	Simulated B-IBI Future Conditions						
	(0-100)				(10-50)		
	WRIA 8	PSB	Juanita Creek	WRIA9	WRIA 8	PSB	Juanita Creek
BEA660	61.5	53.3	40	51.1	32.9	29.1	27.3
BEA665	58.5	51.9	36.2	47.8	32	28.8	25.8
BEA670	66.4	55.5	46.2	57	34.4	29.7	29.8
BEA690	47.5	46.9	22.3	37.4	28.7	27.5	20.3
BEA700	56.3	50.9	33.4	45.5	31.3	28.5	24.7
BEA710	56.8	51.2	34.1	46	31.5	28.6	25
BEA720	59.4	52.4	37.4	48.8	32.3	28.9	26.3
BEA725	32.5	40.1	3.4	26.8	24.1	25.7	12.9
BEA730	31.8	39.8	2.6	26.4	23.9	25.6	12.5
BEA740	11	30.4	0	16.6	17.6	23.2	10
BEA750	4.7	27.5	0	14.4	15.6	22.4	10
BEA760	60.6	52.9	38.9	50.2	32.7	29	26.9
BEA770	8.5	29.3	0	15.7	16.8	22.9	10
BEA780	64.7	54.8	44	54.9	33.9	29.5	28.9
BEA800	42.3	44.6	15.8	33.3	27.1	26.9	17.8
BEA820	53.2	49.6	29.6	42.5	30.4	28.2	23.2
BEA830	40.3	43.7	13.3	31.9	26.5	26.6	16.8
BEA840	14.7	32.1	0	18	18.7	23.6	10
BEA850	48.9	47.6	24.1	38.6	29.1	27.6	21
BEA860	24.4	36.5	0	22.3	21.6	24.8	10
BEA900	69.5	56.9	50.1	61.1	35.4	30.1	31.3
BEA910	57	51.3	34.3	46.2	31.6	28.6	25.1
BEA920	60.2	52.7	38.4	49.7	32.5	29	26.7
BEA940	54.6	50.2	31.3	43.8	30.8	28.3	23.9
BEA950	55.9	50.8	33	45.1	31.2	28.5	24.5
BEA960	55.3	50.5	32.2	44.5	31	28.4	24.2
BEA970	18.9	34	0	19.7	19.9	24.1	10
BEA990	44.9	45.8	19.1	35.3	27.9	27.2	19.1
MON001	10	29.9	0	16.2	17.2	23.1	10
MON002	8.5	29.3	0	15.7	16.8	22.9	10
MON003	13.8	31.7	0	17.6	18.4	23.5	10
MON004	30.5	39.3	0.9	25.6	23.5	25.5	11.9
MON005	43.3	45.1	17.1	34.1	27.4	27	18.3
MON006	27	37.7	0	23.7	22.4	25.1	10.2
MON007	36.1	41.8	7.9	29	25.2	26.1	14.7
MON008	4.7	27.5	0	14.4	15.6	22.4	10
MON009	56.4	51	33.6	45.7	31.4	28.5	24.8

KC_ID	Simulated B-IBI Future Conditions						
	(0-100)				(10-50)		
	WRIA 8	PSB	Juanita Creek	WRIA9	WRIA 8	PSB	Juanita Creek
MON010	61.4	53.3	40	51.1	32.9	29.1	27.3
MON011	20.1	34.5	0	20.3	20.3	24.3	10
MON012	30.7	39.4	1.2	25.7	23.6	25.5	12
MON013	28.4	38.3	0	24.5	22.9	25.2	10.9
MON014	26.1	37.2	0	23.2	22.1	25	10
MON015	31.3	39.6	1.9	26.1	23.7	25.6	12.3
MON016	63.6	54.2	42.6	53.5	33.6	29.4	28.4
MON017	3	26.8	0	13.9	15.1	22.2	10
MON019	16.4	32.8	0	18.7	19.2	23.8	10
MON020	8.1	29.1	0	15.5	16.7	22.8	10
MON021	0	18.8	0	9.4	9.8	20.2	10
MON022	0	20	0	10	10.6	20.5	10
MON023	42	44.5	15.4	33.1	27	26.8	17.6
MON024	1.2	26	0	13.3	14.6	22	10
MON025	18.8	33.9	0	19.7	19.9	24.1	10
MON026	17.1	33.2	0	19	19.4	23.9	10
MON027	23.2	36	0	21.8	21.3	24.6	10
MON028	9.8	29.8	0	16.1	17.2	23	10
MON029	27.2	37.8	0	23.8	22.5	25.1	10.3
MON030	26.6	37.5	0	23.4	22.3	25	10
MON031	22.9	35.8	0	21.6	21.2	24.6	10
MON032	20.8	34.9	0	20.6	20.5	24.3	10
MON033	27.7	38	0	24	22.6	25.1	10.5
MON034	19.5	34.2	0	20	20.1	24.2	10
MON035	3.2	26.9	0	13.9	15.2	22.3	10
MON036	4.5	27.5	0	14.3	15.6	22.4	10
MON037	62.2	53.7	41	52	33.2	29.2	27.7
MON038	30.3	39.1	0.6	25.5	23.4	25.4	11.8
MON039	28.4	38.3	0	24.4	22.8	25.2	10.8
MON040	56.6	51.1	33.8	45.8	31.4	28.6	24.9
MON041	56.8	51.2	34.1	46.1	31.5	28.6	25
MON042	4.6	27.5	0	14.3	15.6	22.4	10
MON043	3.9	27.2	0	14.2	15.4	22.3	10
MON044	26.4	37.4	0	23.4	22.2	25	10
MON045	61.6	53.4	40.1	51.2	33	29.1	27.4
MON046	59.2	52.3	37.2	48.6	32.2	28.9	26.2
MON047	5.4	27.9	0	14.6	15.8	22.5	10

KC_ID	Simulated B-IBI Future Conditions						
	(0-100)				(10-50)		
	WRIA 8	PSB	Juanita Creek	WRIA9	WRIA 8	PSB	Juanita Creek
MON048	24.9	36.7	0	22.6	21.8	24.8	10
MON049	36.9	42.1	9	29.5	25.4	26.2	15.1
MON110	9.8	29.8	0	16.1	17.2	23	10
MON128	4	27.2	0	14.2	15.4	22.4	10
MON139	29.1	38.6	0	24.8	23	25.3	11.2
MON146	22.7	35.7	0	21.5	21.1	24.6	10
MON147	25	36.8	0	22.7	21.8	24.8	10