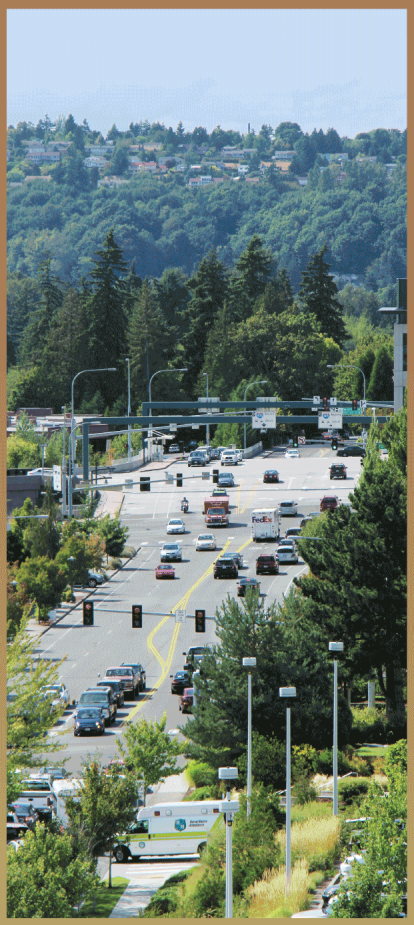
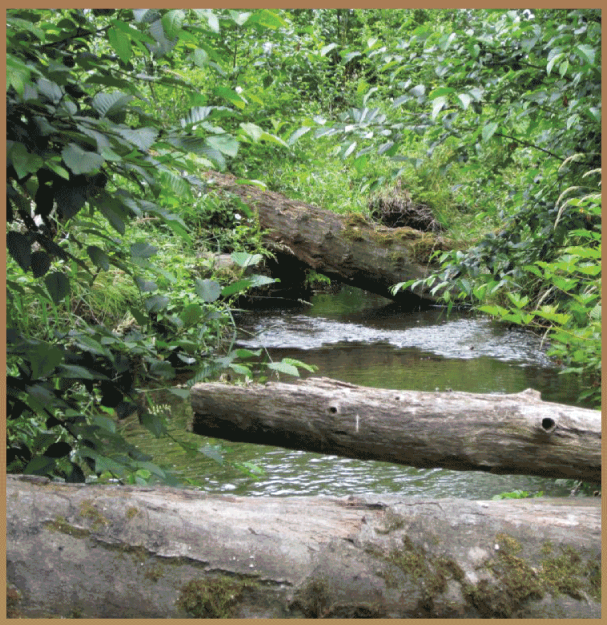
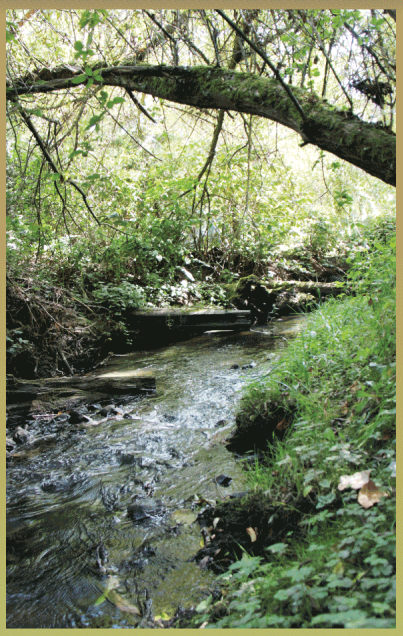




Stormwater Retrofit Analysis and Recommendations for Juanita Creek Basin in the Lake Washington Watershed



AUGUST 2012

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

DEPARTMENT OF ECOLOGY
State of Washington

CITY OF KIRKLAND WASHINGTON

Washington State
Department of Transportation

"A society grows great when its elders plant trees whose shade they know they shall never sit in."

Greek Proverb

Stormwater Retrofit Analysis and Recommendations for Juanita Creek Basin in the Lake Washington Watershed

Ecology Grant: G0800618

August 2012

King County

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Table of Contents

Abstract ix
Executive Summary xi
1.0. Introduction 1
1.1 Project Area 1
1.2 Background 3
1.3 Project Management 4
2.0. Methods 5
2.1 Water Quality and Quantity Monitoring 5
2.2 Geomorphology Assessment 5
2.3 Stream Reconnaissance 5
2.4 Stormwater Mapping 6
2.5 Watershed Modeling 7
2.5.1 Model Accuracy 8
2.6 Defined Removal Efficiencies for Facilities 10
2.7 Basin Metrics 11
2.7.1 Biotic Metrics 12
2.7.2 Hydrologic Metrics and BIBI 13
2.7.3 Water Quality Metrics 18
2.7.4 Geomorphologic Metrics 19
2.8 Mitigation Unit Costs 21
2.8.1 Dry and Wet/Dry Ponds 22
2.8.2 Low Impact Development (Rain Gardens and Cisterns) 22
2.9 Target Definitions 24
2.9.1 Beneficial Uses 24
2.9.2 Biological Targets 25
2.9.3 Washington State Water Quality Standards (WAC) 25
2.9.4 Gravel Disturbance 27
2.10 Scenario Descriptions 27
2.10.1 Scenario—Benchmark Benchmark Forested Basin (FORESTED) 28
2.10.2 Scenario—Alternative Baseline 65/10 (65/10) 28

2.10.3 Scenario—1977 Land Use (LU1977) 29
2.10.4 Scenario—Existing Conditions (LU2002) 29
2.10.5 Scenario—Future Land Use Unmitigated (FUTURE) 29
2.10.6 Scenario—Level 2 Stormwater Dry Ponds (LEVEL2) 29
2.10.7 Scenario—LID 40% Mitigation (LID40) 29
2.10.8 Scenario—LID 80% Mitigation (LID80) 29
2.10.9 Scenario—Ecology 8% Proposed Standard (ECY08) 30
2.10.10 Scenario—LID 40% w/three regional ponds (LID40+) 30
2.10.11 Scenario—Level 2 with Wet Ponds (LVL2WET) 30
2.10.12 Scenario—Residential Cisterns (CISTERNS) 30
3.0. Results Summary 31
3.1 Water Quality and Quantity Monitoring 31
3.1.1 Precipitation and Stream Flows 31
3.1.2 Dissolved Oxygen 34
3.1.3 Water Temperature 34
3.1.4 pH 34
3.1.5 Fecal Coliforms 34
3.1.6 Dissolved Copper 35
3.1.7 Dissolved Zinc 35
3.2 Stream Reconnaissance 35
3.3 Geomorphology Assessment 37
3.4 Model Accuracy 38
3.4.1 Stream Flows 38
3.4.2 Hydrologic Flashiness Metrics 40
3.4.3 Simulated BIBI 41
3.4.4 Water Quality 41
3.5 Model Limitations 43
3.6 Benchmark Scenario Simulation Results 44
3.6.1 Forested Condition Benchmark (FORESTED) 45
3.6.2 Limited Development Benchmark (65/10) 45
3.6.3 1977 Land Use Benchmark (LU1977) 45
3.7 Mitigation Scenario Simulation Results 45

3.7.1 Simulated BIBI Results 45
3.7.2 Simulated Water Quality Results 50
3.7.3 Simulated Gravel Disturbances and LWD Densities 56
3.7.4 Mitigation Costs 59
3.7.5 Mitigation Cost Effectiveness 60
4.0. Discussion 77
5.0. Recommendations 79
6.0. References 80

Figures

Figure 1 Location of Juanita Creek drainage basin. 3

Figure 2 Map of stormwater infrastructure (City of Kirkland, 2010) 7

Figure 3 Removal efficiency curve for rain gardens and regional wet ponds. Further detail can found in Appendix D—Section 5. 11

Figure 4 Scatter plots with regressions lines for LPC, LPD, HPC, HPD, HPR, and QR. 17

Figure 5 Scatter plots with regression lines for TQmean, RBI, and PK2YR. 18

Figure 6 Location of catchments, modeled stream reaches, and specific assessment stream segments for assessment of gravel disturbances. 21

Figure 7 Summary of daily accumulated precipitation, 15-minute flow rates, and sample event dates. 33

Figure 8 Measured BIBI scores in Juanita Creek for 2008 (Berge and Burkey 2009) and Historical (King County 2009) monitoring. Numbers in the symbols represent locator numbers listed in Table 12 and Table 13. 37

Figure 9 Scatter plots comparing observed to simulated for mean daily flow rates 40

Figure 10 Mainstem simulated and observed dissolved copper during the monitoring period of this study (water year 2009). 42

Figure 11 Mainstem simulated and observed fecal coliforms during the monitoring period of this study (water year 2009). 43

Figure 12 Simulated basin-wide average of BIBI scores per scenario. 48

Figure 13 Simulated basin-wide average percent of potential maximum BIBI per scenario. 49

Figure 14 Unit area loading rates by land use for fecal coliforms. Blue symbols are simulated, red are from literature and previous studies. 53

Figure 15 Simulated moving 30-day geometric means of fecal coliforms for forested (FOREST) conditions. 53

Figure 16 Estimated present value costs for full retrofit mitigation strategies. 60

Figure 17 Cost effectiveness for basinwide average BIBI score. (LEVEL2 ≈ LVL2WET, LID40 ≈ LID40+) 62

Figure 18 Cost effectiveness for reducing dissolved copper exceedances (LEVEL2 not assessed for removal efficiencies). 63

Figure 19 Cost effectiveness for reducing dissolved oxygen exceedances. 64

Figure 20 Cost effectiveness for reducing water temperature exceedances 65

Figure 21 Cost effectiveness for reducing fecal coliform exceedances. 66

Figure 22 Cost effectiveness for reducing annual loads of TSS (LID40 ≈ LID40+). 67

Figure 23 Cost effectiveness of reducing annual loads for total copper (LID40 ≈ LID40+). 68

Figure 24 Cost effectiveness of reducing annual loads for ammonia-n (LID40 ≈ LID40+)... 69

Figure 25 Cost effectiveness of reducing annual loads for nitrates (LID40 ≈ LID40+). 70

Figure 26 Cost effectiveness of reducing annual loads for total nitrogen (LID40 ≈ LID40+). 71

Figure 27 Cost effectiveness of reducing annual loads for orthophosphate (LID40 ≈ LID40+). 72

Figure 28 Cost effectiveness of reducing annual loads for total phosphorus (LID40 ≈ LID40+). 73

Figure 29 Cost effectiveness for gravel disturbances for lower Juanita, site 107, LID40 ≈ LID40+. 74

Figure 30 Cost effectiveness for gravel disturbances for middle Juanita, site 105, LID40 ≈ LID40+. 75

Figure 31 Cost effectiveness for gravel disturbances for upper Juanita, site 203, ECY08 had zero disturbances, set to 0.01 for display purposes, and LID40 was similar to LID40+ with 0.8 disturbances per year..... 76

Tables

Table 1. Estimated 2002 land use for study area (Alberti, et al., 2004). 2

Table 2 List of statistics used for assessing model accuracy based on simulated hourly timesteps..... 8

Table 3 Assumed percent removal efficiencies for rain gardens and regional wet ponds.... 10

Table 4 Five qualitative categories of biological condition from Karr et al. (1986) as included in Morley (2000). 12

Table 5 Summary of hydrologic metrics used in this study 14

Table 6 Regression coefficients (a,b) for predicting BIBI ($\boldsymbol{y}$) from hydrologic flashiness metrics ($\boldsymbol{x}$). 15

Table 7 List of water quality metrics..... 19

Table 8 Elements used for defining costs for the mitigation strategies. 23

Table 9 Modeled pollutants and target metrics 26

Table 10 Summary of Scenarios..... 27

Table 11 Percent of Time stream temperatures were above state criterion..... 34

Table 12 Averaged BIBI scores measured for 2008 monitoring. 36

Table 13 Measured BIBI scores from 2002 to 2011. Green shaded cells used for model verification. 36

Table 14 Summary of simulated and observed flow rates. 39

Table 15 Summary statistics of model accuracy for stream flows based on hourly time increments 39

Table 16 Summary of accuracy for simulated hydrologic metrics. 40

Table 17 Simulated versus observed BIBI scores. 41

Table 18 Summary statistics of model accuracy for total suspended solids, total copper, dissolved copper, fecal coliforms, and water temperature for mainstem Juanita Creek. 42

Table 19 Summary of Mann-Whitney U-test for N, NH_4, PO_4, and TP for the mainstem..... 43

Table 20 Summary of benchmark simulation results per metric 44

Table 21 Summary of simulated BIBI scores by catchment. 47

Table 22 Simulated BIBI responses by NFP metric and by scenario. 50

Table 23 Benchmark scenario values for annual exceedances (acute and chronic combined) for dissolved copper, water temperature, dissolved oxygen, and fecal coliforms. 51

Table 24 Simulated average annual exceedances for dissolved copper..... 51

Table 25 Simulated average annual exceedances for water temperature, dissolved oxygen, and fecal coliforms. 52

Table 26 Simulated average annual exceedances for fecal coliforms. 53

Table 27 Simulated mitigation scenarios meeting forested conditions targets for dissolved copper, water temperature, dissolved oxygen, and fecal coliforms. 54

Table 28 Simulated mitigation scenarios meeting 65/10 conditions targets for dissolved copper, water temperature, dissolved oxygen, and fecal coliforms. 54

Table 29 Simulated mitigation scenarios meeting 1977 conditions targets for dissolved copper, water temperature, dissolved oxygen, and fecal coliforms. 54

Table 30 Simulated average annual loads. 55

Table 31 Simulated annual loads meeting benchmarks. 56

Table 32 Estimated gravel disturbances and LWD placement density for Site 107 (near the mouth). Yellow cells indicate the flow rate used for analysis. 57

Table 33 Estimated gravel disturbances and LWD placement density for Site 105 (mid-basin mainstem). Yellow cells indicate the flow rate used for analysis. 58

Table 34 Estimated gravel disturbances and LWD placement density for Site 203 (north branch headwater tributary). Yellow cells indicate the flow rate used for analysis, green cells indicate achieved targets. 58

Table 35 Net present value costs per scenario, based on 40 year lifespan. 59

Table 36 Summary of cost effectiveness responses for the mitigation scenarios. 60

Appendices

Appendix A. Water Quality Monitoring Report A-1

Appendix B. Geomorphologic Reports B-1

Appendix C. Juanita Creek Reconnaissance and BIBI Report C-1

Appendix D. Juanita Creek BMP Pollutant Removal Efficiences D-1

Appendix E. Watershed Model Calibration Report E-1

Appendix F. Detailed Cost Estimate Worksheets F-1

ABSTRACT

Untreated stormwater runoff delivers high flow and pollutants (bacteria, petroleum based products, soil, etc.) that impair ecological functions in natural systems and contribute to localized flooding. In response, local governments have made large investments in constructing stormwater mitigation features (e.g., ponds and bio-swales) to ameliorate these impacts. In the heavily developed Juanita Creek basin, stormwater facilities are critically lacking and undersized relative to current standards (Washington State Department of Ecology 2005 Stormwater Management Manual for Western Washington—Ecology 2005 SMMWW). This is a consequence of the development regulations in effect during the middle to late 20th century when the majority of development was occurring in the basin. The effectiveness of seven potential stormwater mitigation scenarios was evaluated using a calibrated Hydrological Simulation Program-Fortran (HSPF) model. The objective of the evaluation was to identify a retrofit strategy or strategies that, if implemented, would achieve the goal of improved flow and water quality conditions supportive of aquatic beneficial uses (e.g., fish use) within the Juanita Creek stream system. A 'multiple lines of evidence' approach was used to evaluate the effectiveness of each mitigation scenario, using metrics that included a biological indicator (Benthic Index of Biotic Integrity–BIBI) estimated from regression relationships with hydrologic metrics, frequency of gravel disturbance, water-quality exceedances relative to Washington State standards (e.g., dissolved copper) and reductions in pollutant loads for water quality parameters with no regulatory thresholds (e.g., total suspended solids). The best performing mitigation scenario combined the flow control standards for low-flow (low impact development (LID) performance standard) and high-flow (standard requirement) proposed by Ecology in the draft Phase 1 Municipal National Pollutant Discharge Elimination System (NPDES) permit with effective date of August 1, 2013. To meet the standard requires not only LID best management practices applied to most impervious surfaces, but also conventional end-of-pipe flow control and treatment facilities. The modeling results indicate that this scenario, if implemented, would achieve the stated project goal. All other scenarios evaluated, including the scenario representing flow control standards from Ecology's 2005 SMMWW targeting high-flows only, were less effective and failed to achieve flow and water quality conditions supportive of aquatic beneficial uses. The estimated cost in current (2011) dollars to retrofit Juanita Creek basin to the best performing mitigation scenario is approximately $1.4 billion ($200 million per square mile).

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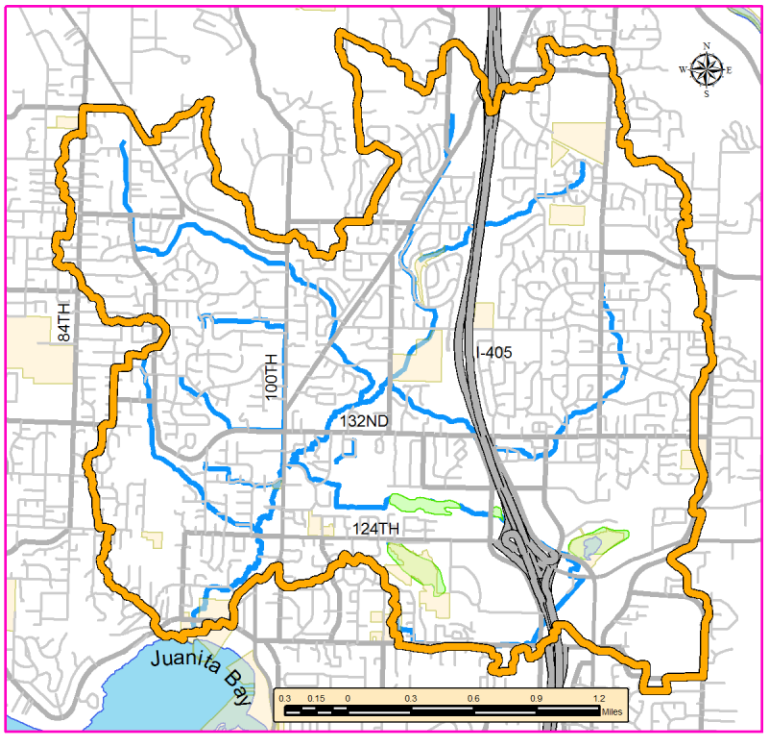
EXECUTIVE SUMMARY

Located northeast of Juanita Bay in the City of Kirkland, the Juanita Creek basin is comprised of an area of approximately 6.8 square miles that includes 15.7 miles of stream. The basin is heavily developed with impervious surfaces (pavement, roofs, etc.) covering approximately 68% of the land area. The primary land use is residential with some commercial development. Underlying soils in the basin are a mix of permeable outwash (45%) and less permeable till soils (55%). Facilities for detaining and treating stormwater are critically lacking and undersized relative to current stormwater standards, a consequence of the mid- and late 20th century development standards in effect when most development was occurring.



Map of Juanita Creek Basin

Runoff patterns and water quality in the Juanita Creek basin have changed dramatically as a result of development that occurred over many decades with ineffective or no stormwater controls. Consequently, the Juanita Creek stream system, whose designated/ beneficial use for aquatic life is core rearing and spawning habitat for coho salmon *Oncorhynchus kisutch*, has been severely degraded. Studies describe the Juanita Creek basin stream system as one where bank instability is a pervasive problem, habitat complexity is low, excessive fine sediments limit salmon spawning areas, frequency of large wood is critically low, and biological conditions are generally poor. Additionally, Juanita Creek is listed on the Washington State Department of Ecology (Ecology) 303(d) list of impaired water bodies for fecal coliform bacteria, dissolved oxygen and temperature.

To address the creek system's problems, King County (KC) partnered with Ecology, the City of Kirkland (COK) and the Washington State Department of Transportation (WSDOT) to recommend a plan of action for making significant systematic and cost-effective improvements in water quality and hydrologic conditions that would be supportive of designated beneficial uses for aquatic life specified as part of the state water quality standards (173-201A WAC).

Funding for the project was provided by Ecology Grant #G0800618 with matching funds and labor provided by KC Department of Natural Resources and Parks, COK, and WSDOT. The Ecology funding source was the Stormwater Management Implementation Grant Program, FY2008, 2007-09 Biennial Capital Budget. Total estimated project cost was $922,389; total eligible cost was $805,479; and the Ecology share was $604,109. The grant agreement had an effective start date of January 31, 2008 and an expiration date of April 15, 2012.

Methods

Although focus was on the Juanita Creek basin, this project demonstrates a quantitative, analytical approach to the development of stormwater retrofit strategies for other urbanized Puget Sound basins. It included extensive stormwater infrastructure mapping, flow gauging, habitat assessment, and water-quality testing, as well as the development of a Hydrological Simulation Program-Fortran (HSPF) model characterizing hydrology and water quality. Stormwater mitigation scenarios were evaluated to determine their effectiveness in achieving the project goal of restoring beneficial use. The scenarios modeled basin retrofits using various combinations and intensities of low-impact development techniques (e.g., rain gardens) and conventional stormwater ponds. For comparison purposes, benchmark scenarios were modeled for conditions including fully forested, 1977 land use, existing land use, future land use, and a hypothetical build-out land use. Cost estimates were prepared for each mitigation scenario in present (2011) dollars.

A calibrated hydrologic model (HSPF) was used to predict metric scores resulting from the benchmark and mitigation scenarios. Multiple metrics were used for evaluating the effectiveness of the mitigation scenarios to provide additional confidence in the predicted outcomes by acknowledging the uncertainty in any single metric's prediction. Metrics included BIBI (Biological Index of Benthic Integrity) based on correlations with hydrologic metrics, frequency of gravel disturbances, water-quality exceedances relative to Washington State standards (e.g., dissolved copper) and reductions in pollutant loads for water quality parameters with no regulatory thresholds (e.g., total suspended solids). The effectiveness of the mitigation scenarios was gauged on the degree to which identified targets for the selected metrics were achieved and also relative to simulated benchmark values.

For targeting, a BIBI of 35 was identified as a critical level based on "EPA's Review of Washington's Water Quality Criteria: An Evaluation of Whether Washington's Criteria

Proposal Protects Stream Health and Designated Uses (Karr et al., 2003[1]),” which found that this is a score below which salmonid viability typically drops precipitously. In addition to determining whether a given scenario produced a predicted BIBI equal to or exceeding this critical score, scenarios were evaluated on a comparison of predicted BIBI scores with those of benchmark scenarios for forested, hypothetical build-out, and 1977 land use conditions.

The target range selected for gravel disturbances was 1 to 3 runoff events per year. Doyle (et al., 2000) found stable channel conditions in perennial, humid region streams commonly experience on average this number of events per year large enough to mobilize stream bed gravels.

Water quality targets were taken from WAC 173-201A, except for pollutants for which there are no surface water quality standards, in which case pollutant load reduction was used as a comparative metric. Pollutants evaluated with respect to water quality standards included dissolved copper, fecal coliform, water temperature, and dissolved oxygen. Pollutants evaluated with respect to load reduction included total suspended solids, dissolved copper, total copper, orthophosphate, total phosphorus, nitrate plus nitrite, ammonia, and total nitrogen.

Seven stormwater mitigation scenarios were evaluated, ranging from limited green infrastructure with rain gardens designed to infiltrate, detain, and treat 40% of the impervious surfaces in the basin (LID40), to an extensive retrofit where 80% of the impervious area was routed to rain gardens in combination with regional detention and water quality ponds (ECY08).

Mitigation Scenario Effectiveness

The ECY08 mitigation scenario, representing a combination of the flow control standards for low-flow (low impact development (LID) performance standard) and high-flow (standard requirement) proposed by Ecology in the draft Phase 1 Municipal National Pollutant Discharge Elimination System (NPDES) permit with effective date of August 1, 2013, was the best performing mitigation scenario of the seven evaluated, and the only one that achieved the goal of restoring flow and water quality conditions supportive of restored aquatic beneficial uses. The average predicted BIBI resulting from this scenario was 36—just above the identified critical level and at the high end of “Fair” on the narrative BIBI scale which assigns descriptors of “Very Poor, Poor, Fair, Good, and Excellent” for BIBI score ranges of 10-16, 17-26, 27-36, 37-44, and 45-50, respectively.

With the exception of the LID80 scenario (80% of impervious surface routed to rain gardens), which scored in the low end of the “Fair” range with a predicted BIBI of 28, the remainder of the scenarios had predicted scores in the “Poor” category, with BIBI scores ranging from 17 to 24. This includes the LVL2WET mitigation scenario, representing the

[1] Karr, J.R., R.R. Horner, and C.R. Horner. 2003. EPA's review of Washington's water quality criteria: an evaluation of whether Washington's criteria proposal protects stream health and designated uses. National Wildlife Federation, Seattle. 25 p.

flow control and water quality standards from Ecology's 2005 Stormwater Management Manual for Western Washington (SMMWW), which had a predicted BIBI score of 24.

The mitigation scenarios were generally effective in reducing the number of gravel disturbances from those calculated for existing (2002) conditions for the three sites evaluated. However, to achieve the target range of 1 to 3 disturbances per year, nearly all would require additional actions. Stream roughening measures such as large wood placement would be necessary where reduction of gravel disturbances is required to meet the target range. The amount of added large wood required to sufficiently roughen the channels ranged among the mitigation scenarios from 3 to 9 pieces per 1000 ft of stream. Channel modifications to increase the number of gravel disturbances may be beneficial where results indicate disturbances occur less than once per year.

The ECY08 and LID80 scenarios were the best performers for water quality metrics, although neither could completely match results from the forested condition benchmark. ECY08 resulted in water quality exceedances equal to or below those for the modeled forest condition benchmark for dissolved copper and water temperature, while failing to do so for dissolved oxygen and fecal coliform bacteria. LID80 simulated exceedances were equal to or below forested benchmark levels for water temperature and dissolved oxygen, but failed for dissolved copper and fecal coliform bacteria. When using the 1977 benchmark scenario as a comparison, both scenarios were successful in producing results at or below the target exceedances for all four pollutants. Simulated annual loadings results for ECY08 and LID80 told a similar story: forested benchmark loadings could not be met, but significant reductions compared to the 1977 benchmark were predicted for all eight measured pollutants—with the exception of ammonia for the ECY08 scenario.

The remainder of the mitigation scenarios was less effective in improving water quality—none achieved exceedance targets for all four pollutants when compared to the 1977 benchmark scenario. Only two scenarios (CISTERNS and LID40+) achieved targets relative to the forested condition benchmark and for only one parameter—temperature. Simulated annual loadings results, when using the 1977 benchmark scenario for comparison, indicate that the LID40 and LID40+ scenarios were moderately effective meeting targets for 5 of 8 measured pollutants while LVL2WET and CISTERNS did so for only 3 pollutants.

Cost Estimates

Estimated costs in present (2011) dollars to achieve the mitigation scenarios ranged from $200 million to $1.4 billion dollars, equating to a range of $30 to $200 million per square mile. The most effective scenario, ECY08, was also the most expensive at $1.4 billion. LID80 was the second most effective scenario and second in projected cost at $ 1.2 billion. The remaining mitigation scenarios had lower costs along with generally low overall levels of effectiveness. LID40 and LID40+ had nearly identical costs of approximately $600 million; the difference being three added stormwater ponds in LID40+. The cistern scenario (CISTERNS) that captures rooftop runoff had a cost of $257 million, while the "gray" infrastructure scenarios LEVEL2 and LVL2WET were priced at $210 and $215 million, respectively. Cost estimates included all significant costs required to implement each mitigation scenario, including land purchases using prices specific to the Juanita Creek

basin, construction costs, and operation and maintenance costs accrued over an assumed 40 year life cycle.

Caveats

Several caveats must accompany any interpretation or use of this study's findings. Predicted BIBI scores in the study are based on statistical correlations derived from limited paired hydrology and BIBI data observed over a range of development in stream basins in King County. This study makes the untested assumption that absent other limiting factors prohibiting restoration of healthy stream conditions, improvement in the selected hydrologic metrics will result in improvements in BIBI scores of the order estimated from the derived statistical correlations. In addition, the correlations to hydrologic metrics used to predict BIBI scores portray an *average* response and therefore, for this study, simulated BIBI scores assume that Juanita Creek will similarly respond like an *average* basin.

Conclusions and Next Steps

Of the seven mitigation scenarios evaluated, only the ECY08 scenario successfully met the goal of restoring flow and water quality conditions supportive of aquatic beneficial uses.

Infiltration of stormwater runoff was instrumental in meeting the ECY08 scenario performance standard. In combination with conventional pond facilities, the scenario employed low impact development BMPs (i.e., rain gardens) to treat and infiltrate stormwater runoff from the majority (80%) of the impervious surfaces in the Juanita Creek basin where the mapped distribution of soil types is split nearly equally between those derived from glacial outwash (high permeability) and till (low permeability). The high rates of infiltration assumed for modeling rain gardens in outwash areas was critical in meeting the desired performance. To achieve the same performance in basins dominated by low-permeability soils, extensive use of soil amendments or greater reliance on conventional facilities (ponds) would be necessary.

In addition to being the best performing scenario, ECY08 was easily the most expensive at an estimated $1.4 billion—largely driven by the expenses associated with constructing and maintaining many small, individual rain gardens spread across the landscape. Operations and maintenance costs of the rain gardens account for nearly 60% of the total scenario costs and are expected to mainly be borne by private property owners. However, reliance on the performance of rain gardens (and other small scale BMPs such as soil amendments, etc.) located on private properties and maintained by homeowners may be a concern given that the long-term functionality, inspection, and maintenance requirements of these facility types are not yet well understood. Implementation strategies for the ECY08 scenario should evaluate whether regional infiltration facilities are practicable as these could provide the required infiltration performance at reduced costs, due to a presumptive economy of scale realized in construction and maintenance of fewer, larger facilities. This suggestion, however, includes the caveat that potential cost savings resulting from a regional facility approach will come at the price of allowing impacts from untreated stormwater to occur at all locations upstream of the regional facilities.

Results from the study indicate that the Juanita Creek basin, even if fully restored to the desired hydrologic conditions with amended gravel supportive of coho salmon, will likely require channel modifications to achieve target gravel disturbances of on average 1 to 3

per year. The reduced stream energy from hydrologic mitigation hinders mobilization of median gravel sizes (i.e., they would typically be immobile in most years) because the existing channels have widened due to stream bank erosion over time. This issue may be further compounded by the likely necessary addition of large wood (LWD) to the system to improve overall habitat diversity. In general, LWD will increase hydraulic resistance, lower reach average velocity and grain shear, which would further reduce the likelihood of gravel movement. However, judicious placement of LWD can actually accelerate flow in the middle of the channel and promote channel narrowing over time as sediment builds up near the banks. Thus, it is possible that the stream channels would return to a more natural balance between restored hydrologic regime, channel geometry, and gravel disturbance frequency over time. Further modeling of alternative permutations of LID BMP's (e.g., rain gardens) and detention that result in a hydrologic response comparable to the ECY08 scenario, which matches post-developed flows to forest condition flows for runoff events ranging from 8% of the 2 year storm to the 50 year runoff event, is recommended. Some such alternatives may be even more cost-effective and/or practical to achieve the predicted responses in some settings, depending upon factors such as land cost, public acceptance of LID, etc. Based on our results, however, it is virtually certain that any pond-only mitigation scenario will not effectively meet any credible performance goals.

For the Juanita Creek basin, achievement of the goal to improve flow and water quality conditions to levels identified as critical for supporting aquatic beneficial uses (e.g. fish use) will require stormwater performance that at minimum matches that of the ECY08 mitigation scenario evaluated in this report. Achieving this performance level may be accomplished through stormwater regulations applied to new and redevelopment projects as well as retrofitting existing development. Without an aggressive capital retrofit program, however, it could take many decades for the full benefits to be realized given the slow rates of new and redevelopment occurring in the basin.

Next steps towards implementing the study recommendation for the Juanita Creek basin are detailed in section 5 of the report. These include preparing an implementation plan, selecting a pilot sub-basin to construct and measure the results of the mitigation strategy, and determining required large wood densities to achieve target gravel disturbance metrics in the remaining stream reaches.

Although the study was limited to the goal of evaluating stormwater mitigations to improve flow and water quality conditions for supporting aquatic beneficial uses, a comprehensive approach to stream restoration would include other elements—likely a combination of riparian buffer restoration to provide improvement in stream shading as a strategy to address water quality (temperature) issues in the stream system, bank stabilization projects to improve water quality and reduce fine sediments that impact salmon spawning habitat, and addition of LWD to achieve densities within the range typical for a natural stream system to improve rearing habitat for juvenile salmonids.

1.0. INTRODUCTION

The Juanita Creek basin has been heavily impacted by changes in stormwater, a result of development that occurred over many decades with ineffective or no stormwater controls. Consequently, the Juanita Creek stream system, whose designated beneficial use for aquatic life is core summer spawning habitat for coho salmon, has been severely degraded.

To address the creek system's problems, King County (KC) partnered with the Washington State Department of Ecology (Ecology), the City of Kirkland (COK) and the Washington State Department of Transportation (WSDOT) to recommend a plan of action for making significant systematic and cost-effective improvements in water quality and hydrologic conditions that would be supportive of aquatic life. The project included extensive mapping, gauging, and water-quality testing, as well as the development of hydrologic and water-quality models characterizing the hydrologic regime of the basin. These models were then used to evaluate a range of stormwater mitigation scenarios that included varying combinations of green (i.e., low-impact development) and gray (i.e., detention ponds and wet ponds) infrastructure.

Funding for the project was provided by Ecology Grant #G0800618 with matching funds and labor provided by KC Department of Natural Resources and Parks, COK, and WSDOT. The Ecology funding source was the Stormwater Management Implementation Grant Program, FY2008, 2007-09 Biennial Capital Budget. Total estimated project cost was $922,389; total eligible cost was $805,479; and the Ecology share was $604,109. The grant agreement had an effective date of January 31, 2008 with an expiration date of April 15, 2012.

1.1 Project Area

Juanita Creek is located on the northeastern shore of Lake Washington (Figure 1). Land use in the basin is composed of mostly residential and commercial developments (including a major interstate freeway corridor, I-405), two large forested wetlands, and one small lake that receives stormwater runoff from a large portion of the commercial development in the eastern headwaters of the basin.

The drainage area is estimated to be 6.8 square miles, with approximately 15.7 miles of stream channel. Based on 2002 satellite data, approximately 65 percent of the basin is developed, mostly in residential land uses with smaller amounts of commercial use (Table 1). Two dominant soil types are found in the basin, one derived from low permeability glacial till (till soils) and the other derived from high permeability glacial outwash (outwash soils). Outwash soils generally occur at low gradient within stream valleys while till soils are found on steeper hill sides and ridges along the basin-perimeter. For the entire study area, till soils are more common making up 55 percent of the basin compared to 45 percent for outwash soils.

Table 1. Estimated 2002 land use for study area (Alberti, et al., 2004).

Land Use	2002 Land Use Acres	Percent
High-Intensity Development	801	18.5%
Medium and Low-Intensity Development	1,996	46.0%
Bare Ground	19	0.4%
Dry Ground	22	0.5%
Grass/shrub	139	3.2%
Forest	1,313	30.2%
Wetlands	46	1.1%
Open Water	6	0.1%
Total	4,342	acres

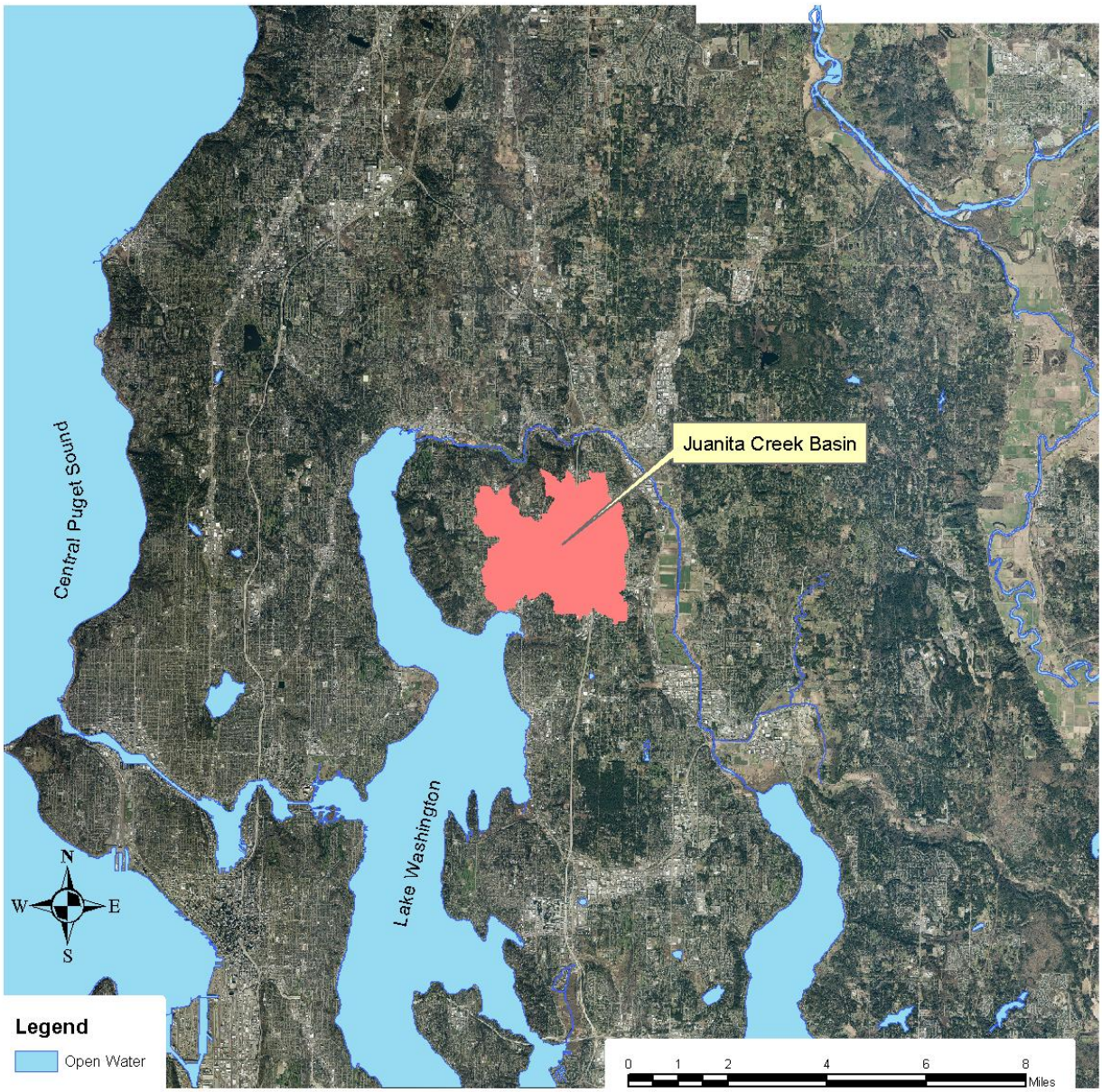


Figure 1 Location of Juanita Creek drainage basin.

1.2 Background

The Juanita Creek basin is a prime example of an area that was developed during the mid-20th century with few or no stormwater controls. Impervious area covers approximately 68 percent of the basin, and the equivalent volume of current stormwater storage is negligible. The vast majority of the stormwater detention facilities in the basin were designed to standards that are now understood to be ineffective with regard to protecting streams from erosive, channel-deforming flows and are only a fraction of the size that would be required under current stormwater standards (i.e., the 2009 King County Surface

Water Design Manual (KCSWDM) and Ecology's 2005 Stormwater Management Manual for Western Washington (SMMWW)).

Juanita Creek is on Ecology's 303(d) list of impaired water bodies for the following water quality parameters: fecal coliform bacteria, dissolved oxygen and temperature (Appendix A). Much of the basin was developed before requirements for water quality treatment of stormwater were implemented by King County via the 1990 KCSWDM. King County's Habitat Inventory and Assessment of Juanita Creek in 2000 (Rush et al., 2002), Otak's Juanita Creek Basin Stabilization Study (2000), and Northwest Hydraulic Consultants' Juanita Creek Basin Geomorphic Analysis (Appendix B) paint a picture of the Juanita Creek basin stream system where bank stability is a pervasive problem, habitat complexity is poor, excessive fine sediments limit salmon spawning areas, and the frequency of large wood in the channel is critically low. Recent BIBI analysis within the Juanita Creek basin by King County have found that biological conditions are generally poor (Appendix C).

The over-arching goal of the project was to inform the restoration and protection of the aquatic life beneficial uses of the Juanita Creek basin stream system that are affected by stormwater. The specific objectives proposed and accomplished by this project in support of this goal included: identifying a stormwater management mitigation strategy that, if implemented, would be supportive of restoring the beneficial use of the Juanita Creek basin stream system and developing cost effectiveness curves for various mitigation scenarios that can be applied to Juanita Creek basin. Additional objectives that apply more broadly to other urbanized areas of the Puget Sound included: developing analytic methods to support future basin retrofitting projects, and developing a template "cost and effectiveness" method for identifying retrofit projects with improved chances of restoring salmon habitat.

1.3 Project Management

Active management of the project was provided by King County. Quarterly reports were provided to Ecology detailing financial expenditures and project progress.

The project was implemented by two main teams:

King County Internal Design Team: Curt Crawford, Jeff Burkey, Dale Nelson, David Batts, Hans Berge, Mark Wilgus, and Steve Foley, supported by Northwest Hydraulic Consultants (NHC) and Stillwater Sciences.

Project Management Team: Ed O'Brien and Anne Dettelbach from Ecology; Curt Crawford, Mark Wilgus, Steve Foley, and Jeff Burkey from King County; Jenny Gaus from COK; and Bill Jordan from WSDOT.

2.0. METHODS

Multiple types of data were collected to support the goals and objectives of this study, either for model development and/or characterization of existing conditions. Much of the data-collection effort has been previously documented in reports and technical memorandums, which are included in the appendices for reference. The sections below are brief summaries of those documents where they exist.

2.1 Water Quality and Quantity Monitoring

Water quality monitoring stations were set at eight locations (Appendix A—Figure 2) within Juanita Creek: one near the mouth on the mainstem, one at each of the four major tributaries, one upstream and one downstream of a large regional wetland, and one at the mouth of Billy Creek. Water quality samples were collected during three base flow and seven storm flow conditions, over a period of 14 months (October 2008 through November 2009). Base flows were sampled twice per day (one AM and one PM) to better understand diurnal conditions at the sampling stations. Storm sampling included taking three samples 8 hours apart at each monitoring station. Laboratory analyses of the samples included: total suspended solids, copper and zinc (dissolved and total), nutrients, and biochemical oxygen demand. Parameters measured in the field included water temperature, dissolved oxygen, pH, and conductivity.

Continuous stream flows were measured at six of the eight locations (excluding inflows and outflows to the regional wetland). For further detail, see Appendix A.

2.2 Geomorphology Assessment

Northwest Hydraulic Consultants, Inc. (NHC) performed hydraulic and geomorphic analysis on Juanita Creek and several of its major tributaries. Stillwater Sciences (Stillwater) served as a subconsultant to NHC for geomorphology and biological issues. NHC analyzed geomorphic parameters for 39 assessment reaches on the Juanita Creek mainstem and nine tributaries. The parameters included: bank stability, substrate size and distribution, local slope, bankfull channel dimensions on priority reaches, and large woody debris (LWD) and large pool frequency. Nearly 3,800 feet of channel was included in the assessment of the seven parameters above, and an additional 4,800 feet of channel length was surveyed for LWD and pool frequency. Substrate fines were assessed over a total of 14,600 feet of channel length (30% of the open channel network in the entire basin and near 50% of the Juanita Creek mainstem). Juanita Creek Basin Geomorphic Analysis (2010) by NHC is included as Appendix B. The NHC assessment reviews complement and expand upon two previous studies, King County's Habitat Inventory and Assessment of Juanita Creek in 2000 (Rush et al., 2002) and Otak's Juanita Creek Basin Stabilization Study (Otak 2000).

2.3 Stream Reconnaissance

A rapid assessment of basin streams was conducted using readily available points of access (road crossings and publicly held lands) to investigate relative habitat quality throughout

the watershed and any opportunities for habitat restoration. Observed channel characteristics were: cross-section geometry, wetted width and depth, riparian vegetation, and presence or absence of woody debris. Further detail can be found in Appendix C.

In September 2008, macroinvertebrate samples were collected from seven sites (Appendix C, Figure 1) in Juanita Creek following the protocols of Karr and Chu (1999). The purpose of macroinvertebrate sampling was to assess the benthic index of biotic integrity (BIBI) of Juanita Creek for comparison with other Puget lowland streams. We compared these data to those collected by the City of Kirkland using the same methods (2001 through 2008) at three sites in the same vicinity as our collections in 2008, which were subsequently used as part of the evaluation of a watershed model's ability to predict BIBI scores (Section 3.4).

2.4 Stormwater Mapping

Detailed mapping of the stormwater infrastructure was conducted by City of Kirkland. The mapping identified alignments and directions of flow for the network of pipes, vaults, ponds, etc. (Figure 2). This level of detail was used to refine catchment delineations that were topographically driven with storm pipe interceptions. Additionally, a rough estimate of transient storage in the pipe network was integrated into the watershed hydraulic routing schema. These data can be obtained from the City of Kirkland Public Works Department.

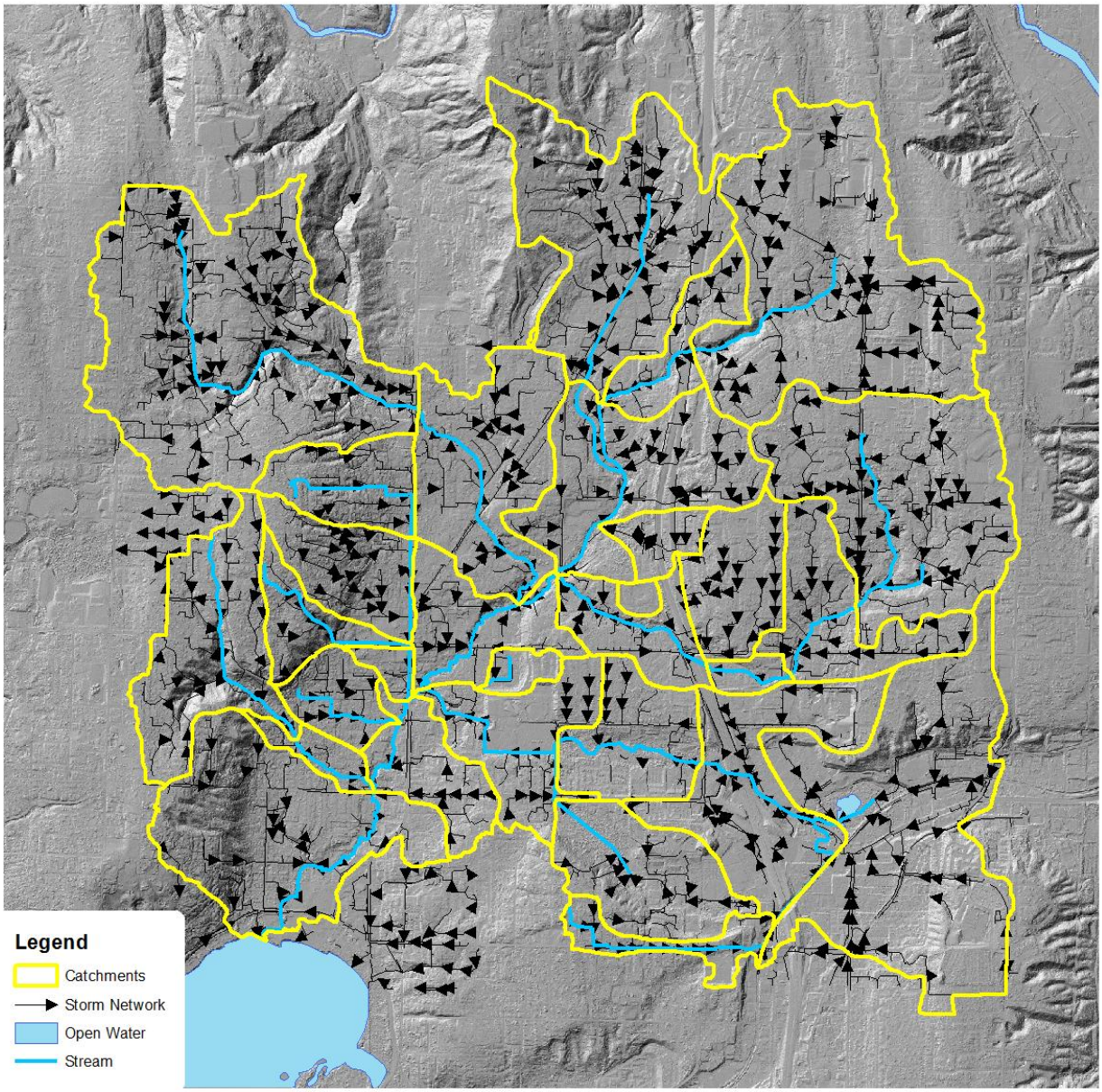


Figure 2 Map of stormwater infrastructure (City of Kirkland, 2010)

2.5 Watershed Modeling

In this study, EPA's watershed model, Hydrologic Simulation Program FORTRAN (HSPF v12), was used to simulate continuous stream flow, pollutant concentrations, and loads resulting from various mitigation scenarios. These outputs were post-processed to generate the metrics which characterize the relative effectiveness of each of the strategies.

The model was segmented into 30 catchments (Figure 2) averaging 145 acres and ranging in size from 9 to 484 acres. Internal model time steps were in 15-minute increments. Model outputs at either hourly or daily intervals were used in post processing depending

on the metric of interest. Calibration of the model was based on data collected from October 2008 to December 2009 at the eight monitoring locations detailed in Section 2.1, as well as data from an earlier period (1995 – 2010) from a site near the mouth of the creek where King County has been monitoring for other purposes.

More detailed discussions of model development, calibration, and model limitations, are provided in sections 3.4 and 3.5, and Appendix E.

2.5.1 Model Accuracy

Model accuracy was evaluated by comparing simulated to observed values for three elements: 1) stream flow rates, 2) water quality concentrations, and 3) hydrologic metrics used for predicting BIBI scores.

Flow rates, the basis of all of this study's model predictions, were scrutinized the most by applying a comprehensive suite of statistics quantifying (thus identifying) the model's strengths and weaknesses. The model accuracy was evaluated considering durations, cancelation of errors, compounding of errors, and the model's ability to predict given the observed variability in the data. Dependent on this accuracy of predicted stream flows is the model's ability to simulate instantaneous water quality concentrations used for evaluating impacts sensitive to short and long duration exposures. The amount of data available for water quality is substantially less than continuously monitored stream flows. Consequently, a subset of the stream flow statistics is applied to water quality concentrations focusing on model correlations and predictiveness.

With much of this study's emphasis on biotic measures in the stream system (section 2.7.1), a non-parametric equivalency test (Mann-Whitney *U*-test) comparing hydrologic flashiness between simulated and observed conditions (section 2.7.2) was performed providing additional validation of the model's predictiveness. A list of statistics used is summarized in Table 2 below, and a complete list of model accuracy is in the watershed calibration report (Appendix E).

Table 2 List of statistics used for assessing model accuracy based on simulated hourly timesteps.

Statistic	Description	Applied to:
Model Biases		Flow Rates
Mean Error	Overall difference allowing for cancelation of errors.	
Mean Absolute Error	Overall difference not allowing for cancelation of errors	
RMSE	Square root of the square of the mean error	
Mean (RPD)	Relative difference in mean error between simulated and observed	
Model Predictions		
Pearson Coefficient	Measure of correlation	
r-square	Measure of variance explained	

Statistic	Description	Applied to:
Nash-Sutcliffe	Measure of correlation taking into account data variability	
Skill Score	Similar to Nash-Sutcliffe, measuring the models predictive capability	
Distribution Shifts (RPD)		
90-Percentile 75-Percentile 50-Percentile 25-Percentile 10-Percentile	Relative difference of simulated minus observed at each of the quantiles ranges.	
Other statistics		
Annual 7-Day Low Flow	(mean difference)	
	(RPD)	
Instantaneous Daily Maximums	(mean difference)	
	(RPD)	
Instantaneous Annual Maximums	(mean difference)	
	(RPD)	
RMSE	see above	Water Quality
Mean Error		
Relative Percent Difference (RPD)		
r-square		
Mann-Whitney U-Test	A non-parametric test comparing distributions	
Mann-Whitney U-Test	see above	Hydrologic Metrics

Equation 1 Mean error (cfs)

$$\sum (Q_{sim} - Q_{obs})$$

Equation 2 Mean absolute error

$$\sum |Q_{sim} - Q_{obs}|$$

Equation 3 Relative percent difference (RPD)

$$\left(\sum \frac{(Q_{sim} - Q_{obs})}{Q_{obs}}\right) \times 100$$

Equation 4 Root mean square error (RMSE)

$$\sqrt{\frac{\sum (Q_{sim} - Q_{obs})^2}{n}}$$

Equation 5 Skill Score

$$1 - \frac{RMSE}{\sqrt{\frac{\sum\left(Q_{obs} - \overline{Q}_{obs}\right)^2}{n}}}$$

2.6 Defined Removal Efficiencies for Facilities

The HSPF model developed for this study requires (among other inputs) pollutant-removal efficiency values for several pollutants for two types of water-quality treatment facilities—rain gardens and regional wet ponds. Removal efficiency estimates for pollutants considered in this study were based on a literature review with the exception of total suspended solids which used an assumed 80% removal efficiency for both types of treatment as specified in the 2009 King County Surface Water Design Manual (King County, 2009). During the course of this study, removal efficiencies continued to be under study and final values (Appendix D) are slightly different from those used in modeling. See Table 3 for the complete list of assumed removal efficiencies.

Table 3 Assumed percent removal efficiencies for rain gardens and regional wet ponds.

Parameter	Maximum Percent Removal Efficiencies	
	Rain Gardens	Regional Ponds
Total suspended solids (TSS)	80	80
Copper – particulate (Cu)	80	80
Copper – dissolved (DCu)	20	20
Phosphorus – total (TP)	50	40
Phosphorus – SRP (PO_4)	0	0
Nitrate (NO_3)	30	30
Ammonia/ammonium (NH_3)	0	0
Total Nitrogen (TKN)	10	10
Fecal coliform bacteria (FC)	0	0

Facility pollutant-removal efficiencies are inherently inexact because they depend in part on flow rates and influent pollutant concentrations, which may be highly variable. There is also variability in facility design which stems from a lack of accepted standards for design, configuration, implementation, and performance monitoring.

To characterize the variable removal efficiencies of the mitigation facilities, an empirical relationship was developed. As a result of longer residence times, ponds with larger volumes in relation to the volume of storm runoff directed to them are more effective at removing pollutants (Figure 3). A maximum limiting rate is assumed to occur when pond volumes (VB) exceeded three times the volume of the mean annual storm (VR)--defined as the annual rainfall divided by the number of storms per year. To illustrate how different

maximum rates were assigned in the model for different water-quality parameters, four alternative y-axes are included to represent effectiveness by parameter.

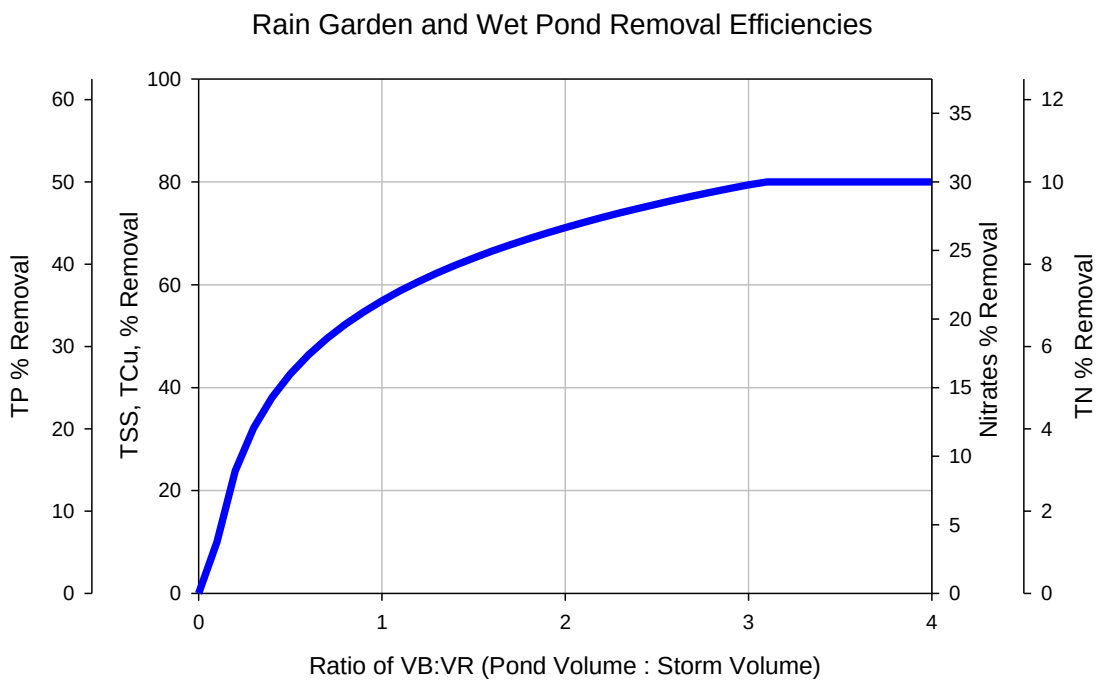


Figure 3 Removal efficiency curve for rain gardens and regional wet ponds. Further detail can found in Appendix D—Section 5.

2.7 Basin Metrics

Multiple metrics were utilized to judge the effectiveness of proposed mitigation strategies to create conditions supportive of the aquatic life beneficial use in Juanita Creek. These metrics were selected to reflect hydrologic, geomorphologic, biologic, and water quality conditions. The reasoning behind using multiple metrics is that for any given predicted outcome, there may be a limiting factor not accounted for in any individual metric (Konrad et al. 2008). Thus, this multiple metric approach was adopted to increase the robustness of mitigation strategies suggested by study results and reduce the possibility of overestimating beneficial outcomes. Furthermore, it was considered advisable that mitigation strategies be required to show improvement across all metrics to be judged adequate in meeting basin management goals. Mitigation strategies exhibiting weaker improvements for some metrics suggest that additional work would be required before adoption, either by bolstering its prescriptions if its deficiencies are sufficiently understood, or possibly by further study to determine how it could be strengthened.

These four categories of metrics (hydrologic, geomorphologic, biologic, and water quality) are not meant to be comprehensive in predicting success. Indeed, there are many other facets to stream health not accounted for in this study that can be equally limiting to the

achievement of a sustainable beneficial use. As an example, a predicted hydrologic regime may be similar to the goal of a forested condition, but without riparian habitat and adequate water quality, the predicted outcome likely would not be achieved as a consequence of other limiting conditions. However, these four metric categories have been used in previous research describing stream health in quantitative measures and are considered strong indicators of effectiveness for this study (e.g. King County 1993).

2.7.1 Biotic Metrics

In lotic systems, benthic macroinvertebrates constitute the biomass of primary consumers, process allocthonous energy sources, serve as detritivores, and filter organic matter carried in the water column (Hynes 1970). Invertebrate assemblages are sensitive to perturbations in water quality (Rosenberg and Resh 1993; Nelson and Roline 1996), hydrology (Booth et al. 2004; DeGasperi et al. 2009), and channel hydraulics (Minshall 1984; Hilderbrand et al. 1997; Pastuchova et al. 2008). Because of their sensitivity to multiple stressors in streams, macroinvertebrates have been shown to be effective ecological indicators of overall water quality and are particularly sensitive to activities such as logging, agricultural runoff, urban runoff, road crossings, herbicide application, and mining (Rosenberg and Resh 1993; Holt and Miller 2011).

The Benthic Index of Biotic Integrity (BIBI) was developed as a mulitmetric index to quantify the ecological condition of streams in the Pacific Northwest (Kleindl 1995, Karr and Chu 1999). It is based on ten metrics that represent the presence of important taxa at the sampling location. Metrics include total taxa richness, ephemeroptera richness, plecoptera richness, trichoptera richness, intolerant taxa richness, clinger taxa richness, long-lived taxa richness, percent tolerant, percent predator, and percent dominance. Each metric is assigned a score between 1 and 5, and the individual metric scores are summed to calculate a score for a given site, between 10 and 50. Total scores are binned and assign qualitative descriptions of condition (Table 4).

Table 4 Five qualitative categories of biological condition from Karr et al. (1986) as included in Morley (2000).

Condition	General Description	BIBI Range
Excellent	Comparable to least disturbed reference condition; overall high taxa diversity, particularly of mayflies, stoneflies, caddis flies, long-lived, clinger, and intolerant taxa. Relative abundance of predators high.	46-50
Good	Slightly divergent from least disturbed condition; absence of some long-lived and intolerant taxa; slight decline in richness of mayflies, stoneflies, and caddis flies; proportion of tolerant taxa increases.	38-45
Fair	Total taxa richness reduced – particularly intolerant, long-lived, stonefly, and clinger taxa; relative abundance of predators declines; proportion of tolerant taxa continues to increase.	28-37
Poor	Overall taxa diversity depressed; proportion of predators greatly reduced as is long-lived taxa richness; few stoneflies or intolerant taxa	18-27

Condition	General Description	BIBI Range
	present; dominance by three most abundant taxa often very high.	
Very Poor	Overall taxa diversity very low and dominated by a few highly tolerant taxa; mayfly, stonefly, caddis fly, clinger, long-lived, and intolerant taxa largely absent; relative abundance of predators very low.	10-17

In the Puget Sound region, the BIBI has been used extensively as an indicator of stream health by federal, state, and local agencies (Morley and Karr 2002). The BIBI has proved useful in understanding thresholds at which flow, habitat degradation, and water quality degrade stream health.

2.7.2 Hydrologic Metrics and BIBI

Alterations in hydrology have been measured using dozens of flow-rate metrics that numerically characterize the hydrologic regime into five broad categories: magnitude, timing, duration, frequency and rate of change (e.g. Richter et al 1996, Poff et al 1997). These categories are qualitatively related to channel habitat on larger stream and river ecosystems. More recent studies (Cooper 1996, Booth et al. 2004, Cassin et al. 2005, and DeGasperi et al. 2009) have focused on smaller stream systems local to the Puget Sound and begin to quantify the quality of channel habitat using biological indicators (see section 2.7.1 above), yielding a more direct linkage to measured stream health and hydrology.

Fundamentally, the metrics with the best identified correlations to BIBI measure flashiness in the system. These metrics are associated with a range of conditions beyond those normally included in routine flow assessments which normally focus on peak annual frequencies (e.g., half the 2-year through 50-year flood frequencies). In addition to eight metrics identified in DeGasperi et al. (2009), a ninth metric was included in this study based on the work of Cooper (1996). These nine hydrologic metrics, summarized in Table 5, were used to estimate responses in BIBI scores using predicted changes in hydrology under various benchmark and mitigation scenarios. For this study, catchment level BIBI scores are calculated by averaging the responses derived from each of the nine metrics. The catchment level scores are then averaged over all catchments to produce a basin level response—further referred to as the basin-wide average.

Table 5 Summary of hydrologic metrics used in this study

Metric	Name	Description
LPC	Low Pulse Count	Number of times each calendar year that discrete low flow pulses occurred
LPD	Low Pulse Duration	Annual average duration of low flow pulses during a calendar year
HPC	High Pulse Count	Number of days each water year that discrete high flow pulses occur
HPD	High Pulse Duration	Annual average duration of high flow pulses during a water year
HPR	High Pulse Range	Range in days between the start of the first high flow pulse and the end of the last high flow pulse during a water year
FR	Flow Reversals	The number of times that the flow rate changed from an increase to a decrease or vice versa during a water year. Flow changes of less than 2% are not considered
TQmean	TQ_{mean}	The fraction of time during a water year that the daily average flow rate is greater than the annual average flow rate of that year
RBI	R-B Index	Richards-Baker Index – A dimensionless index of flow oscillations relative to total flow, based on daily average discharge measured during a water year
PK2YR[1]	Peak 2-yr:Winter Baseflow	Ratio of the estimated 2-year peak flow to winter baseflow (i.e., mean flow for October through April)

[1]Relationship between metric and BIBI still in development as part of EPA WRIA 9 grant.

The responses in BIBI are derived from observed relationships between the metrics listed above and BIBI scores. Using the BIBI data from the DeGasperi (et al.) and Cooper studies, these relationships were quantified as regressions defined either as log-linear (Equation 6), linear (Equation 7), or as exponential (Equation 8) to achieve a *best fit* among the data. In addition to the listing of the coefficients for the regressions in Table 6 below, the r-square for each is also given providing context to the accuracy of these regressions predicting BIBI scores. As shown in the table, the high pulse metrics have the best correlations to the regressions with an R^2 greater than 0.63. The ratio of 2-year peak flow to winter base flow (PK2YR) had the least predictive skill with an R^2 equal to 0.22, however this metric's regression is being refined in another study and will likely change. The PK2YR regression is based on 56 data points, while the other eight metric regressions used 16.

Equation 6 Regression used for LPC, LPD, HPC, and HPD.

$$y = a + b \log_{10} x$$

Equation 7 Regression used for HPR, QR, TQmean, and RBI

$$y = a + bx$$

Equation 8 Regression used for PK2YR.

$$y = ax^b$$

Table 6 Regression coefficients (a,b) for predicting BIBI (y) from hydrologic flashiness metrics (x).

Metric (x)	Equation Used	a	b	R^2
LPC	1	45.331	-22.466	0.44
LPD	1	-5.1273	23.214	0.59
HPC	1	53.05	-30.106	0.71
HPD	1	8.9753	23.498	0.64
HPR	2	44.167	-0.1148	0.73
FR	2	66.994	-0.7664	0.42
TQ_{mean}	2	-21.493	147.3	0.47
RBI	2	38.616	-51.851	0.49
P2YR	3	57.277	-0.311	0.22

When applying this method, model results should be interpreted with an awareness of a several key assumptions and caveats. The regressions predict an *average* response—the actual responses in BIBI scores from the simulated scenarios could be lower or higher for any given basin. Further illustrating this are scatter plots of the observed data used for developing the regressions showing that drainage basins with similar hydrologic metric values might range several points in BIBI score, possibly even spanning qualitative categories as described in Table 4. For this study, we are assuming Juanita Creek will respond like an average basin vis-à-vis the regressions; and if this method is applied over a broad area, the predicted responses from mitigation strategies on average should be achieved.

The responses in stream health predicted by the scenarios also assume the absence of other limiting environmental conditions (e.g., lack of riparian vegetation, poor water quality, scarcity of large wood, bank instability, etc.) that may suppress BIBI scores. It is likely, however, that such limiting conditions were present within even the least disturbed watersheds used for developing the relationships between BIBI and hydrology. This possibility is reinforced by the fact that only one of all observed basins met the criteria describing a stream system in (near) *excellent* condition (Figure 4 and Figure 5). This suggests that predicted BIBI responses from the mitigation strategies may potentially be conservative (i.e., under-predicting scores) when considering strategies that address limiting factors either explicitly (within the ascribed mitigation itself) or when used in concert with other restoration efforts.

Moreover, it is worth noting that there are no known studies testing the hypothesis that a watershed can be fully restored (as measured using BIBI) to a healthy stream system supportive of sustainable beneficial uses. This uncertainty in competency restoring a stream system is ameliorated in this study with a multiple lines of evidence approach that

uses various indicators (hydrology, biology, water quality, and geomorphology) to evaluate the effectiveness of the mitigation scenarios.

Lastly, it is not known if any one or more of the nine hydrologic metrics are better indicators for predicting BIBI. It is possible that a low predicted BIBI for a given individual metric may indicate an actual condition limiting aquatic health which might not be recognized if only the ensemble average is evaluated.

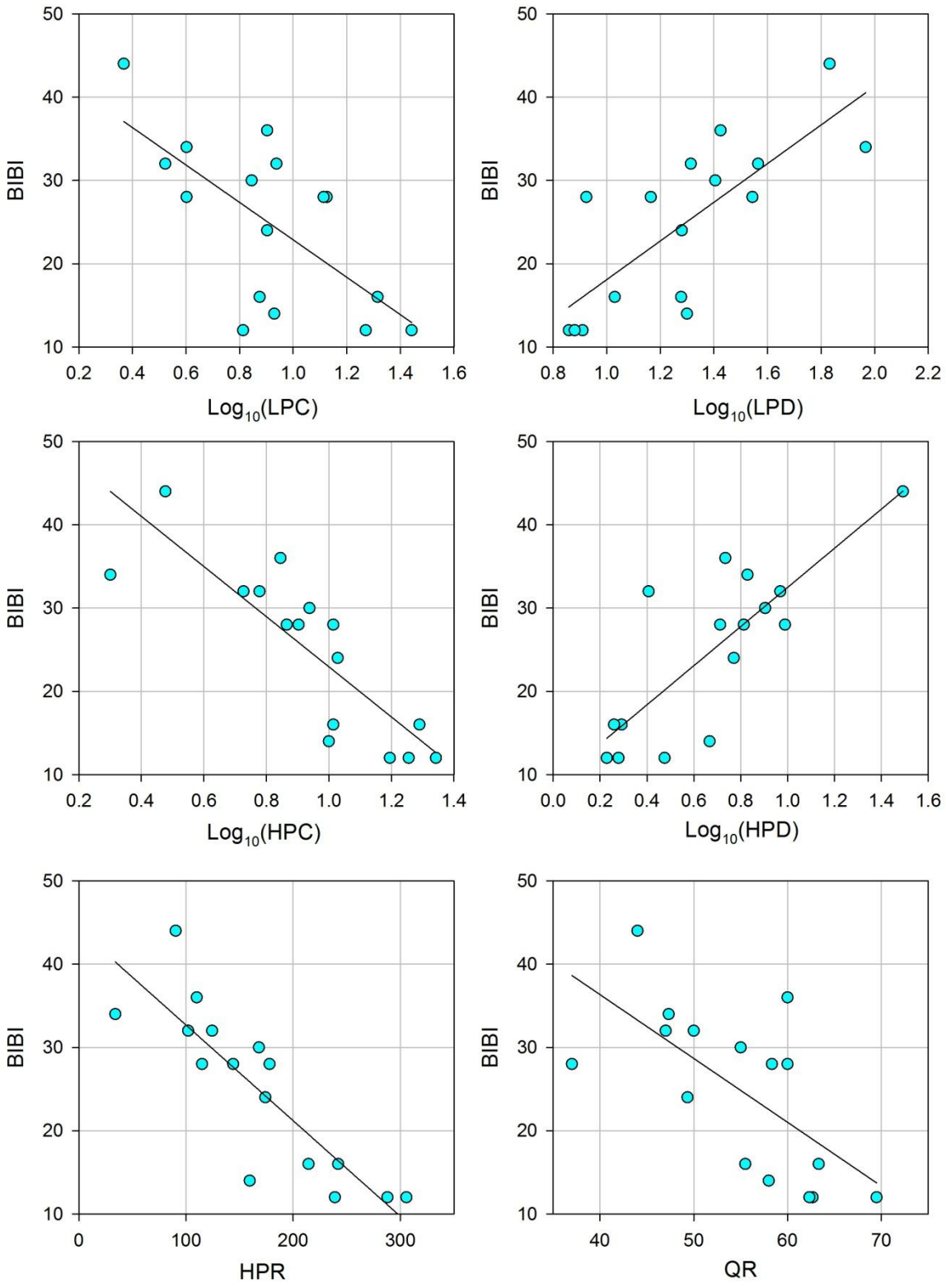


Figure 4 Scatter plots with regressions lines for LPC, LPD, HPC, HPD, HPR, and QR.

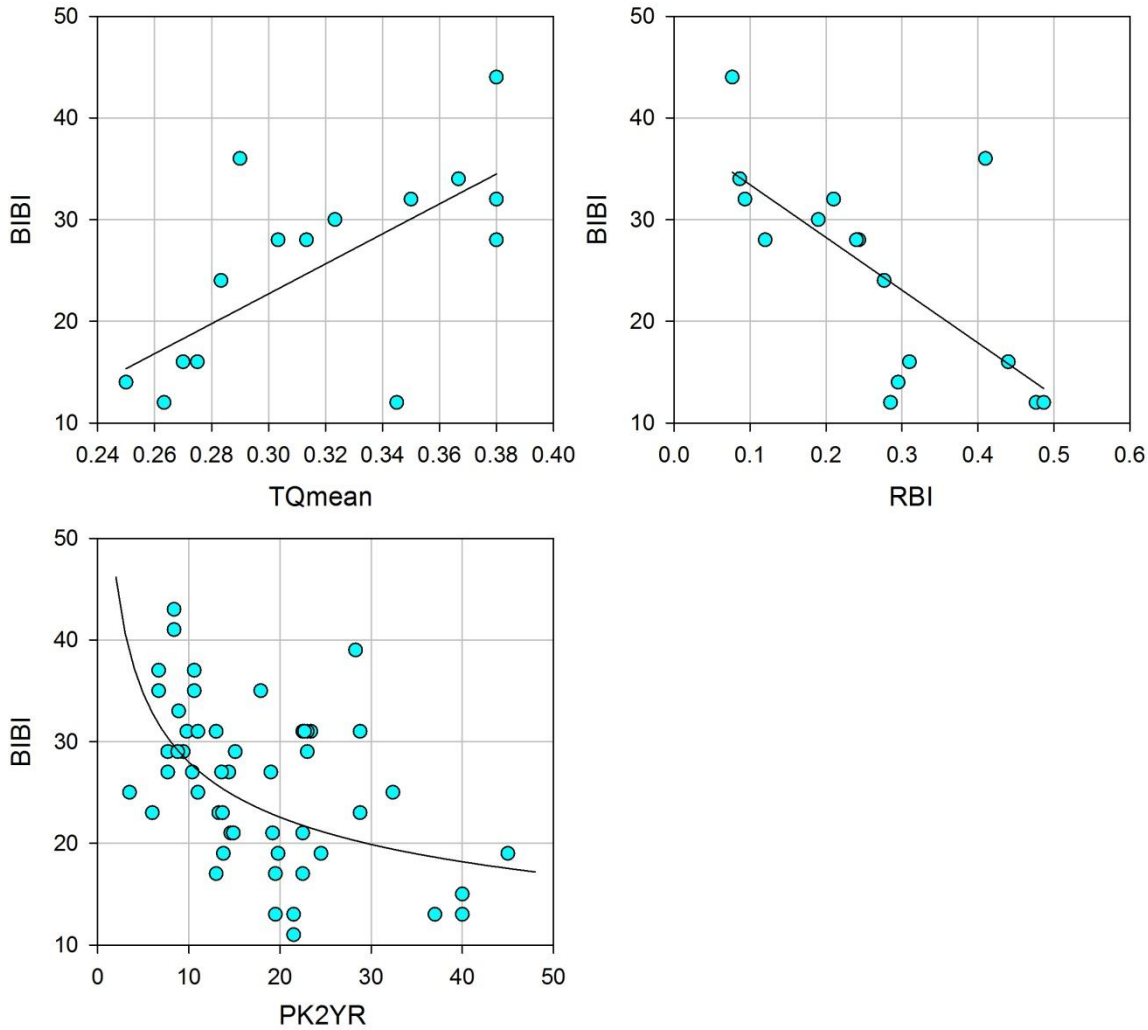


Figure 5 Scatter plots with regression lines for TQmean, RBI, and PK2YR

2.7.3 Water Quality Metrics

Water quality metrics are grouped into two types, concentrations and mass loadings. For water quality constituents with established concentration standards, the total number of simulated exceedances of water quality standards (173-201A WAC) by the HSPF model were divided by the by the number of years of simulation to compute the average number of violations per year. Where criteria (standards) do not exist, average annual loadings rates were computed (Table 7).

Parameters evaluated as concentrations include dissolved copper (**DCu**), fecal coliforms (**FC**), water temperature (**Temp**), and dissolved oxygen (**DO**). Each of the concentrations is aggregated differently; depending on the method prescribed in the state standards, and are listed below.

- Dissolved copper concentrations are calculated at hourly time increments and adjusted for hardness. In addition to hourly concentrations, a moving 4-day average is also computed for evaluating chronic conditions.
- Fecal coliforms concentrations are calculated as moving 30-day geometric means.
- Water temperatures are calculated as a moving 7-day average.
- Dissolved oxygen is evaluated using daily minimum concentrations.

Annual loading rates were computed for: total suspended solids, total copper (**TCu**), soluble reactive phosphorus modeled as ortho-phosphate (**PO_4**), total phosphorus (**TP**), nitrates plus nitrite (**NO_3**), ammonia-N (**NH_3**), and total nitrogen (**TN**).

Table 7 List of water quality metrics

Parameter	Exceedances	Loading Rates
Total Suspended Solids		mt[1]/year
Dissolved Copper	# exceedances / year (µg/L)	
Total Copper		kg/year
Orho-phosphate		kg/year
Total Phosphorus		kg/year
Nitrate		kg/year
Ammonia		kg/year
Total Nitrogen		kg/year
Fecal Coliform	# exceedances / year (50/10%/200 cfu/100ml)	
Water Temperature	# exceedances / year 55.4°F, 60.8°F	
Dissolved Oxygen	# exceedances / year (8.0, 9.5, -0.2 mg/L)[2]	

[1]Metric ton (mt) equivalent to 1000 kilograms
[2]Dissovled oxygen concentrations are seasonally specified: none summer, summer, and amount concentrations can drop below background conditions.

2.7.4 Geomorphologic Metrics

A healthy stream that is supportive of aquatic life requires gravel mobilizing events (disturbances) to maintain clean gravels, recruit large woody debris, and engage other natural channel-forming processes. In channels where disturbances occur too frequently, however, it is difficult for long- lived taxa to persist and for those biologic communities to

reach any type of equilibrium. Likewise, channels where disturbances occur too infrequently can become hardened and relatively devoid of complexity and the nutrients necessary for supporting beneficial uses (Doyle et al. 2000).

Average annual frequency of gravel disturbances was selected as a geomorphologic metric to define a target that represents a condition of sustainable beneficial uses. Gravel disturbances are defined as discrete events (of variable duration) where flow rates reach levels capable of mobilizing the median gravel size (D50) in the channel and then recede back below the same flow threshold. Magnitude and duration of the events are not considered as part of this metric—a catastrophic single event that may destabilize a system is given the same weight as a more typical event that would not do so.

The threshold of gravel mobilization is a parameter that is likely unique to every reach in the system and depends on gravel size, gravel density, channel roughness, and flow velocity.

Shear stress values at which target gravels are mobilized were calculated using identified methods of incipient motion detailed in Appendix B. A HEC- RAS model (HEC 2010) was then used to identify flow rates associated with those shear stresses at three stream reaches (Sites 203, 105, and 107) shown on Figure 6. Flow rate thresholds were calculated at each location for existing gravel sizes and a gravel size (D50 = 16.5mm) considered supportive of coho spawning habitat (Kondolf and Wolman 1993)—the target salmonid species for restoring beneficial uses in Juanita Creek.

HSPF was used to calculate the average annual number of gravel disturbances using 60 years of simulation for each benchmark (assuming existing gravel sizes) and mitigation scenario (assuming D50 = 16.5mm).

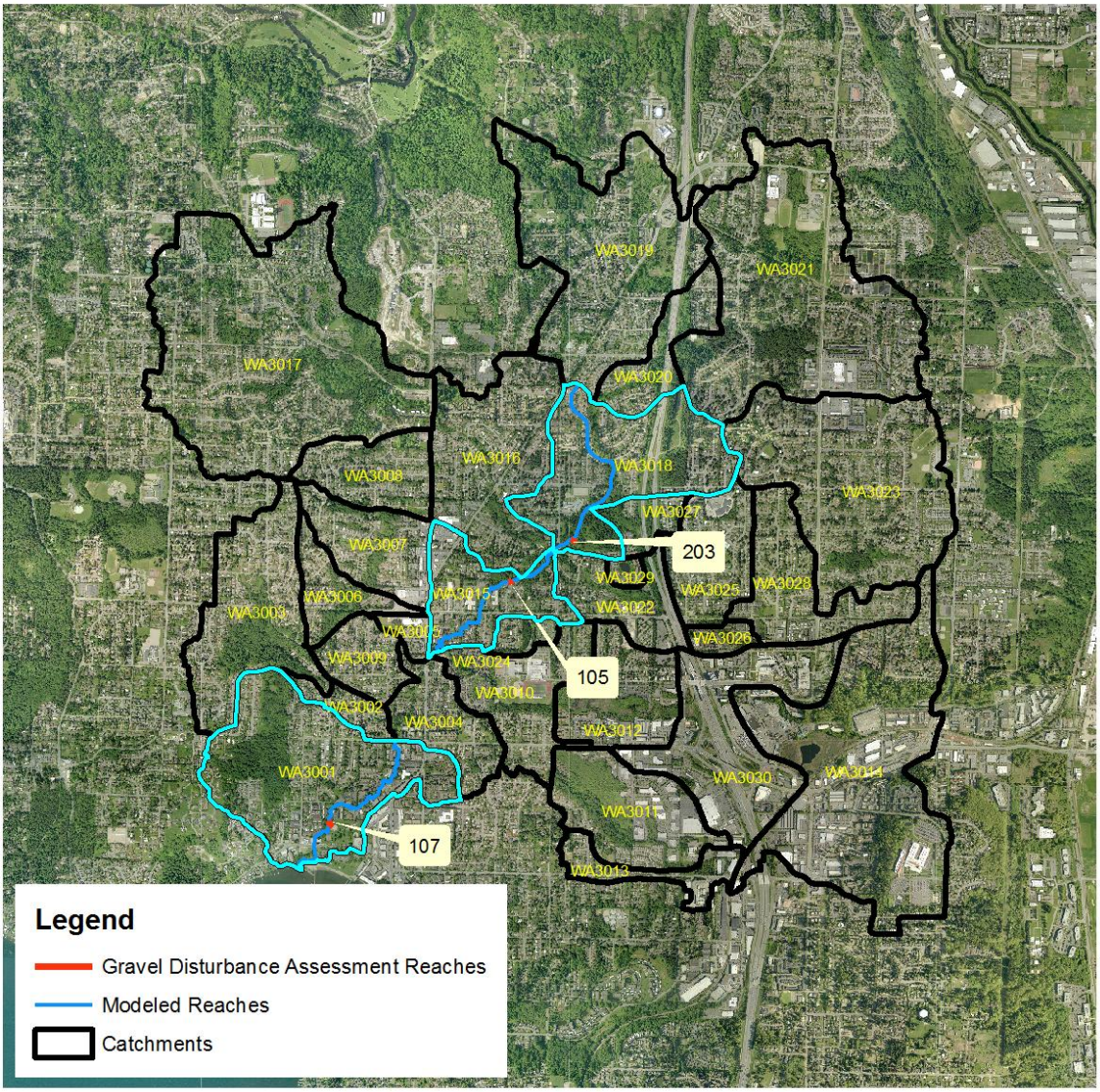


Figure 6 Location of catchments, modeled stream reaches, and specific assessment stream segments for assessment of gravel disturbances.

2.8 Mitigation Unit Costs

To create the cost mitigation curves (section 3.7.5), which plot cost (as net present value) versus performance metrics (BIBI, water quality excursions, and gravel disturbances), unit costs were developed for the construction, maintenance, and land-acquisition components required to implement each scenario. Net present value over a 40-year life cycle with an assumed four- percent inflation rate was calculated for each mitigation scenario (section 3.7.4). Table 8 is organized by facility type and includes the unit costs used for each scenario as well as the source of the unit cost data. Spreadsheets included in Appendix F of

this report contain the detailed calculations of net present value and supporting information.

2.8.1 Dry and Wet/Dry Ponds

Scenarios with wet ponds and wet/dry ponds assume that these will be public facilities that require purchase of land and ongoing public operations and maintenance. Costs for manholes, flow restrictors, and stormwater conveyance were not included in the unit costs and are likely small relative to the overall costs of regional facilities. The land costs were determined by choosing a random sample of ten residential properties from each catchment. The value of the properties was determined by researching the value of the land and the improvements from the tax assessor's records in 2011 dollars. The average cost of the land and improvements from the 30 catchments was averaged to obtain a cost per acre for the land required to site the ponds in the basin.

Soft costs include design, permitting, administrative, real-estate transaction fees, etc. and are estimated as 35% of construction costs for wet ponds and dry ponds.

The unit cost for construction is based on WSDOT bid tabulation data with the caveat that costs for any given site will be highly variable with facility size and site parameters.

The use of underground vaults for detention and water-quality treatment could be part of an implemented urban basin-wide retrofit but was not factored into any of the scenarios or associated costs. Underground vaults offer the benefits of being built within the right-of-way with reduced or no acquisition costs, reduced water temperatures as compared to large open-water facilities, and come without the limitations that may hamper large land acquisitions necessary for regional pond construction, such as waiting for properties to be available for purchase or initiating condemnation procedures. However, based upon personal discussion with sales staff from the Utility Vault Company, a typical planning estimate delivered unit cost ($10 per cubic foot displacement/storage) for a prefabricated vault (not including construction) is nearly triple the estimated combined unit cost ($3.4 per cubic foot) of the construction and land acquisition components for a regional open air pond on average.

2.8.2 Low Impact Development (Rain Gardens and Cisterns)

Scenarios that include low impact development (LID) assumed that rain gardens and cisterns (for the stand-alone cistern scenario) will be located on private properties and include a public inspection cost. Maintenance costs are considered to be private but are included in the total cost of the associated scenario. Note that standards for maintenance and operation of disparate small rain garden and cistern facilities located on private properties, and the effectiveness of such maintenance, is not yet well understood. Soft costs for rain gardens and cisterns are included in the unit cost for construction—sourced from and based on discussion with City of Seattle Rainwise Program staff.

Table 8 Elements used for defining costs for the mitigation strategies.

Facility Type and Cost Source	Land Acquisition	Construction	Soft Costs	Maintenance and Operations (Public)	Maintenance and Operations (Private)
Wet/Dry Ponds Cost Source	$1.3 million/acre Average KC Tax assessments	$6/cubic yard WSDOT Bid Tabs for excavation and haul	35% of construction (includes design, permitting, and administrative) King County standard multiplier	$0.004/cubic foot-year King County records averaged	N/A
Rain gardens Cost Source	N/A-placed on private property	$20/square foot of rain garden footprint Seattle Rainwise Program reimbursement plus 25% for program admin/soft costs	Included in construction	$0.36/cubic foot-year King County estimate (See Appendix F)	$1.86/cubic foot-year King County estimate (See Appendix F)
Cistern Cost Source	N/A-placed on private property	$4/square foot of tributary area Seattle Rainwise Program reimbursement	Included in construction	$90.36/each cistern-year King County estimate (See Appendix F)	N/A

2.9 Target Definitions

Using the metrics previously described, a set of targets were defined either with values identified independent of the modeling or derived from model simulated outputs characterizing a set of benchmark conditions.

Targets with values identified independent of the modeling include a BIBI level cited as supportive of sustainable healthy stream systems, water quality parameters sourced from the Washington State Administrative Code (WAC), and a range of annual gravel disturbance events associated with stable, habitat- diverse streams.

Simulated outputs for BIBI, water quality, and gravel disturbance metrics used for targets were produced for three benchmark conditions that represent various levels of disturbance in the basin.

The forested condition benchmark (Forested) represents undisturbed, pristine conditions and is used as the goal for fully restoring streams to their beneficial uses. For any given location, the metric values produced by the model for the forested benchmark are assumed to be the best that can be achieved at that location. Logic suggests that the targets identified independent of the model for BIBI, water quality, and gravel disturbances would be met in Juanita Creek and most other basins under the forested benchmark.

The limited development (65/10) benchmark is based on and referenced in early King County basin planning work which identified a disturbance with a minimum of 65 percent forest retention and a maximum of 10 percent effective impervious area (EIA) as a functional threshold marking the transition to unstable channels and resultant degraded stream conditions (Booth and Jackson, 1997). As a means of defining a 65/10 benchmark that shifts a basin and its stream channel away from the "threshold" toward stable, un-degraded conditions, the 10 percent impervious was assumed to be total impervious area (TIA) in this study, resulting in EIA of 5% being routed to the streams.

The third benchmark (LU1977) represents a level of disturbance that was in existence in 1977, used in this study as a proxy for conditions existing in 1975 when the Clean Water Act was implemented for maintaining the chemical, physical and biological integrity of the Nation's waters.

The effectiveness of the mitigation scenarios was evaluated on whether model-independent targets identified for BIBI, water quality, and gravel disturbances were achieved and by comparing mitigation scenario results to those simulated for the benchmarks. No definitive condition (i.e., Forested, 65/10, or LU1977) for establishing targets for Juanita Creek has been identified at this time.

2.9.1 Beneficial Uses

A primary goal of the project is to identify mitigation strategies that will result in stream flow and water quality conditions necessary for restoring beneficial uses and complying with state water quality standards in Juanita Creek. 'Beneficial uses' are typically referred to as 'designated uses' in the WAC (Washington Administrative Code) and include public water supply, protection for fish, shellfish, and wildlife, as well as recreational, agricultural,

industrial, navigational and aesthetic purposes. Water quality criteria are designed to protect the designated uses and are used to assess the general health of Washington surface waters and set permit limits. Aquatic life uses and the accompanying criteria are those that are considered in this project since they are the most stringent and directly related to the mitigation strategies being considered. Per WAC 173-201A-600, Juanita Creek and its tributaries have a designated aquatic life use of "Core Summer Habitat" for salmonids. The details of the Washington State Water Quality Standards are included in Section 2.9.3 of this report.

2.9.2 Biological Targets

BIBI targets used for evaluating the effectiveness of the mitigation scenarios include a cited value defined independently of benchmark conditions and the predicted BIBI scores of the benchmarks (forested, limited development (65/10), and 1977 land use). A BIBI score of 35 was defined as a target based on *EPA's Review of Washington's Water Quality Criteria: An Evaluation of Whether Washington's Criteria Proposal Protects Stream Health and Designated Uses* (Karr et al., 2003), which found that scores below this value and salmonid viability typically drops precipitously. Although Karr et al. (2003) suggests that a BIBI score of 35 sets a reasonable lower limit, further study of the relationship between salmon population viability and BIBI levels seem warranted.

Of the three benchmark conditions used for evaluating mitigation scenario results, the forested condition is given special consideration. Since it represents pristine, undisturbed conditions which are assumed to result in predicted BIBI scores that are 'the best that you can get' at a given location, it is instructive to measure the effectiveness of each scenario by normalizing their results against the maximum result produced by the forested condition. This is accomplished by dividing the basin-wide average BIBI scores predicted for each scenario by the basin-wide average predicted for the forested condition and reporting as *percent of potential maximum*.

2.9.3 Washington State Water Quality Standards (WAC)

Modeled water quality parameter targets are based on the Washington state surface water quality criteria given in WAC 173-201a, except for pollutants for which there are no surface water quality standards, in which case pollutant load reduction is the metric. Target load reductions are modeled from literature percent removal values which are almost all based on difference between treatment influent and effluent concentrations, with no flow measure given. The following table gives modeled parameters and targets.

Table 9 Modeled pollutants and target metrics

Pollutant	Comparison Metric: Surface WQS WAC 173-201a	Comparison Metric: Load Reduction	Comparison Metric: Other Considerations
Total suspended solids (TSS)	---	X	
Copper – dissolved (DCu)	Two WQS criteria: acute and chronic Basis is hardness, which is variable	---	e.g. hardness mg/L; Cu-diss criteria ug/L chronic / acute 25: 3.5 / 4.6 37.5: 4.9 / 6.8 50: 6.3 / 8.9
Copper – solid (TCu)	---	X	.
Phosphorus - orthophosphate (PO_4))	---	X	
Phosphorus – total (TP)	See *Other Considerations*	X	There are total phosphorus criteria for lakes, but not for surface water streams or groundwater.
Nitrate plus Nitrite (NO_3) as N	---	X	
Ammonia (NH_3)	WQS is for ammonia, and is pH dependent	X	The ratio of NH_3/NH_4 at pH 7 is 0.0057. At pH 6 the ratio is $5.7*10^{-4}$.
Total Nitrogen (TN)	---	X	
Fecal coliform bacteria (FC)[1]	GMV[2] ≤ 50cfu/100 mL ≤ 10% of all samples (or any single sample when < 10 samples exist) obtained for calculating GMV exceeding 100 cfu/100 mL.	---	SWQS is a two-part standard. If either criterion is exceeded, the WQS is exceeded.
Total coliform bacteria	---		*Not being modeled, but should mindful with regard to potential for bacteria to migrate through soil to groundwater, as this is a hydraulic pathway in the model.*

[1] WAC 173-201a-600(a)(ii).
[2] geometric mean value

2.9.4 Gravel Disturbance

A target range of 1 to 3 gravel disturbances per year was selected to represent a condition of sustainable beneficial uses based upon Doyle et al. (2000) which found this to be a range typical of stable, perennial streams in humid-regions.

2.9.4.1 Large Woody Debris

Further adjustments in estimated disturbances will result from an adjustment in assumed channel roughness. As part of this study, rating curves were developed to characterize the effective roughness in a channel with the presumed placement of large woody debris in the stream channel. Roughness increases as more LWD installations are placed per unit length (Appendix B). Additionally, orientation of LWD placement was also considered in quantifying roughness estimates. For a given retrofit strategy that did not meet the target of 1 to 3 disturbances per year, LWD densities were adjusted until targeted conditions were met.

2.10 Scenario Descriptions

Modeled scenarios for this study characterize three types of conditions: 1) benchmark, 2) existing, and 3) future. Benchmark scenarios include: 1) undisturbed fully forested, 2) assumed limited disturbance with 65 percent forest retention and 10 percent impervious surfaces, and 3) moderately developed based on 1977 land use conditions.

Existing conditions were defined based on land use interpretations from 2002 satellite imagery, with the inclusion of three existing regional stormwater facilities.

Future conditions assume full potential build-out to the most intensive land use allowed by current (circa 2010) zoning. Seven stormwater mitigation scenarios were developed that include gray and green infrastructures represented using ponds, cisterns, and rain gardens with various levels of retention and detention. One future scenario was developed with no mitigating strategies to evaluate maximum potential impacts forecasted with the models. In total, twelve scenarios were evaluated and are listed in Table 10 below.

Table 10 Summary of Scenarios

Scenario	Category	Description
Forested	Benchmark	Basin is assumed fully forested, pristine conditions
LU1977		Land use derived from 1977 aerial imagery
65/10		Basin is assumed to have evolved under early watershed planning threshold of stream stability with forest retention and limited impervious surfaces
LU2002	Existing	Existing conditions as defined with 2002 satellite imagery.

Scenario	Category	Description
FUTURE	Future	Full build-out of potential land use based on current zoning, no mitigation.
LEVEL2		Future land use with King County Level 2 stormwater ponds applied basin-wide.
LID40		Future land use with 40% TIA captured by rain gardens
LID80		Future land use with 80% TIA captured by rain gardens
ECY08		Ecology-proposed matching durations to 8% of the 2-year forested to the 50-year forested, using a combination LID80 and stormwater detention ponds stacked on basic wetponds applied basin-wide.
LID40+		Combination of LID40 throughout the basin and King County Level 2 stormwater detention ponds stacked on basic wetponds in three catchments
LVL2WET		Future land use with King County Level 2 stormwater detention ponds stacked on basic wetponds applied basin-wide.
CISTERNS		Future land use where roof area runoff from a mild wet season of rainfall is captured then released July-Sept each calendar year at a constant rate.

2.10.1 Scenario—Benchmark Benchmark Forested Basin (FORESTED)

Characteristics of a theoretical fully forested landscape are assumed to be representative of pristine conditions prior to any anthropogenic disturbances. For any given location, the hydrologic, biologic, geomorphologic, and water quality conditions produced by the fully forested benchmark are assumed to be the best achievable.

2.10.2 Scenario—Alternative Baseline 65/10 (65/10)

This scenario assumes development would occur while maintaining 65% forest retention, no more than 10% total impervious surfaces, and with the remaining landscape in grass. Grass and forest land cover were segregated into high (outwash) and low (till) permeability soils based on the existing underlying surficial geology (Booth and Sackett 2006) with existing wetland areas modeled as saturated soils in this and all other scenarios. There is no assumed spatial distribution (i.e., no clustering) of where and how development might occur. The 65/10 land use threshold is referenced in early King County basin planning work as marking the transition to severely degraded stream conditions in

regards to channel stability (Booth et al., 2002), albeit with the use of effective impervious area as the metric.

2.10.3 Scenario—1977 Land Use (LU1977)

Congruent with the implementation of the Clear Water Act in 1975, this benchmark is based on land use composition near that same period. Ortho-rectified photography was available from 1977 and was assumed to be sufficiently representative of 1975 conditions. The level of existing development is more similar to existing conditions (2002) than the restricted development benchmark (65/10), and significantly more disturbed than pristine forested conditions.

2.10.4 Scenario—Existing Conditions (LU2002)

This scenario modeled approximate existing land use based on 2002 land cover developed by University of Washington UERL (Alberti et al., 2004).

2.10.5 Scenario—Future Land Use Unmitigated (FUTURE)

This scenario modeled land use based upon predicted/simulated future development in absence of stormwater controls applied to the new development. It is included as a useful comparison tool (or bookend) for a worst case condition. Future conditions are assumed to be fully built-out to maximum potential development based on current zonings.

2.10.6 Scenario—Level 2 Stormwater Dry Ponds (LEVEL2)

This scenario modeled future land use with a basin-wide retrofit utilizing detention ponds sized to the 2009 King County Surface Water Design Manual (KCSWDM) Level 2 standard applied to all drainage areas. The Level 2 standard requires developed flows to be released at predeveloped rates and durations for the range of flows from 50% of the 2 year storm to the 50 year storm where pre-developed conditions are modeled as forested.

2.10.7 Scenario—LID 40% Mitigation (LID40)

This scenario modeled future land use with a basin-wide retrofit utilizing rain gardens sized per 2009 KCSWDM methodology applied to 40% of the total impervious area of the basin. Three inches of storage is provided for treated tributary impervious area and rain garden facility footprints are consistent with 1 foot of dead storage. Rain gardens were modeled with infiltration rates of 0.2 inches/hour in areas mapped as till soil and 3 inches/hour in areas mapped as outwash soil. The outwash soil rain garden infiltration rate is a long-term estimate based upon providing a compost/soil blend treatment liner between these facilities and the native outwash soils.

2.10.8 Scenario—LID 80% Mitigation (LID80)

This scenario used the same mitigation design as LID40, but applied to 80% of the total impervious area of the basin.

2.10.9 Scenario—Ecology 8% Proposed Standard (ECY08)

This scenario modeled future land use with a basin-wide retrofit utilizing a combination of rain gardens sized per 2009 KCSWDM methodology applied to 80% of the total impervious area of the basin and combined detention/wet ponds applied to all modeled overflows from the rain gardens as well as all other unmitigated surfaces in the basin. The rain garden and detention pond combination were used to achieve the Washington State Department of Ecology (Ecology) proposed 8% standard which matches post-developed flows to pre-developed flows for runoff events ranging from 8% of the 2 year storm to the 50 year runoff event assuming the predeveloped condition as forested. The wet pond volume component of the combination pond was sized per 2009 KCSWDM methodology for "Basic Wet pond" with a treatment goal of removing 80% of total suspended solids (TSS).

2.10.10 Scenario—LID 40% w/three regional ponds (LID40+)

This scenario modeled future land use with a basin-wide retrofit utilizing a combination of rain gardens sized per 2009 KCSWDM methodology applied to 40% of the total impervious area of the basin and three Level 2 combination detention/wet ponds each located in a separate catchment. The three sites were chosen based on availability of a sufficiently large tract of currently undeveloped land at a location low enough in the given catchments to treat a meaningful percentage of drain area. The identified parcels are classified currently as open space. The wet pond volume component of the combination pond was sized per 2009 KCSWDM methodology for "Basic Wet pond" with a treatment goal of removing 80% of total suspended solids (TSS).

2.10.11 Scenario—Level 2 with Wet Ponds (LVL2WET)

This scenario modeled future land use with a basin-wide retrofit utilizing combination detention/wet ponds sized to the 2009 King County Surface Water Design Manual (KCSWDM) Level 2 flow control standard applied to all drainage areas. The Level 2 flow control standard requires maintaining the durations of flows at their predevelopment levels for all flows greater than 50% of the 2- year peak flow up to the 50-year peak flow. The predeveloped condition is modeled as historic (forested) condition. The wet pond volume component of the combination pond was sized per 2009 KCSWDM methodology for "Basic Wet pond" with a treatment goal of removing 80% of total suspended solids (TSS).

2.10.12 Scenario—Residential Cisterns (CISTERNS)

This scenario modeled future land use with a basin-wide retrofit utilizing cisterns designed per the 2009 KCSWDM Appendix C methodology applied to an estimate of residential and commercial roof areas in the basin. Cisterns were sized to provide 2.5 ft. depth of storage over the treated tributary impervious area. The cisterns are modeled to completely drain the accumulated rainfall at a constant release rate during the months of July through September each calendar year. Winter rainfall that exceeds 2.5 feet (typical annual rainfall equals 3.25 ft.) overtops the available cistern storage and is routed in the model to the stream system.

3.0. RESULTS SUMMARY

This section represents a summary of field data collection and watershed model simulation results. Details of study components are presented as separate reports in the appendices. The presentation of water quality modeling results focused on the mainstem stream reaches, where the calibrated model exhibited the best fit to the available data. Simulated BIBI results are presented both as a basin-wide average response and at the tributary catchment scale (with model limitations noted where appropriate) to allow a broader spatial comparison among of the scenarios. Gravel disturbances results are focused on three specific stream reaches.

3.1 Water Quality and Quantity Monitoring

Water quality and quantity monitoring was performed as described in section 2.1 and includes data collected for stream flows, dissolved oxygen, water temperature, pH, fecal coliforms, dissolved copper, and dissolved zinc. Results[1] are summarized in the following sections and detailed in the monitoring report (appendix A).

3.1.1 Precipitation and Stream Flows

Rainfall measured at National Weather Service Sea-Tac monitoring station during water year 2009 was slightly less (34.0 inches) than average (38.2 inches) when comparing to the historical period of record. Annual volume measured at Juanita Creek (KC 27u) was similar to Sea-Tac totaling 34.4 inches. The number and volume of storms were also similar to historical averages with Juanita creek experiencing 63 storm events[2] that average 0.47 inches in volume, compared to Sea-Tac's 52 storms for the same year with an average volume of 0.56 inches. Sea-Tac's historical average is 61 events with an average volume of 0.55 inches.

Stream flows in Juanita Creek respond quickly to rainfall with rising hydrographs observed near the mouth (KC 27a) lagging an hour or less and even shorter durations occurring in the tributaries. Not accounting for attenuation of storm peaks being routed downstream, the five tributaries monitored produce approximately 60 to 70 percent of the storm peaks observed near the mouth during the wet season and more than 90 percent during the dry season. The peak runoff event during WY 2009 was approximately 190 cfs near the mouth, and a maximum 350 cfs was recorded in October 2010. Except for Billy Creek (KC 27i), the lateral tributaries respond with similar magnitudes (including Totem Lake) ranging from about 10 to 20 percent of observed near the mouth. Billy Creek has a smaller drainage area accounting for less than 10 percent.

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[1] As part of a County wide monitoring program, two of the monitoring stations in that program are within Juanita Creek. As a result, more recent data are available then reported as part of this study (King County 2012).

[2] Event must be greater than 0.15-inches in volume and a minimum of 6-hours with no measurable rainfall prior to the event.

Each of the stream gauges and precipitation gauge are plotted as time series to facilitate how Juanita Creek and its tributaries behaved during the monitoring period of this study (Figure 7).

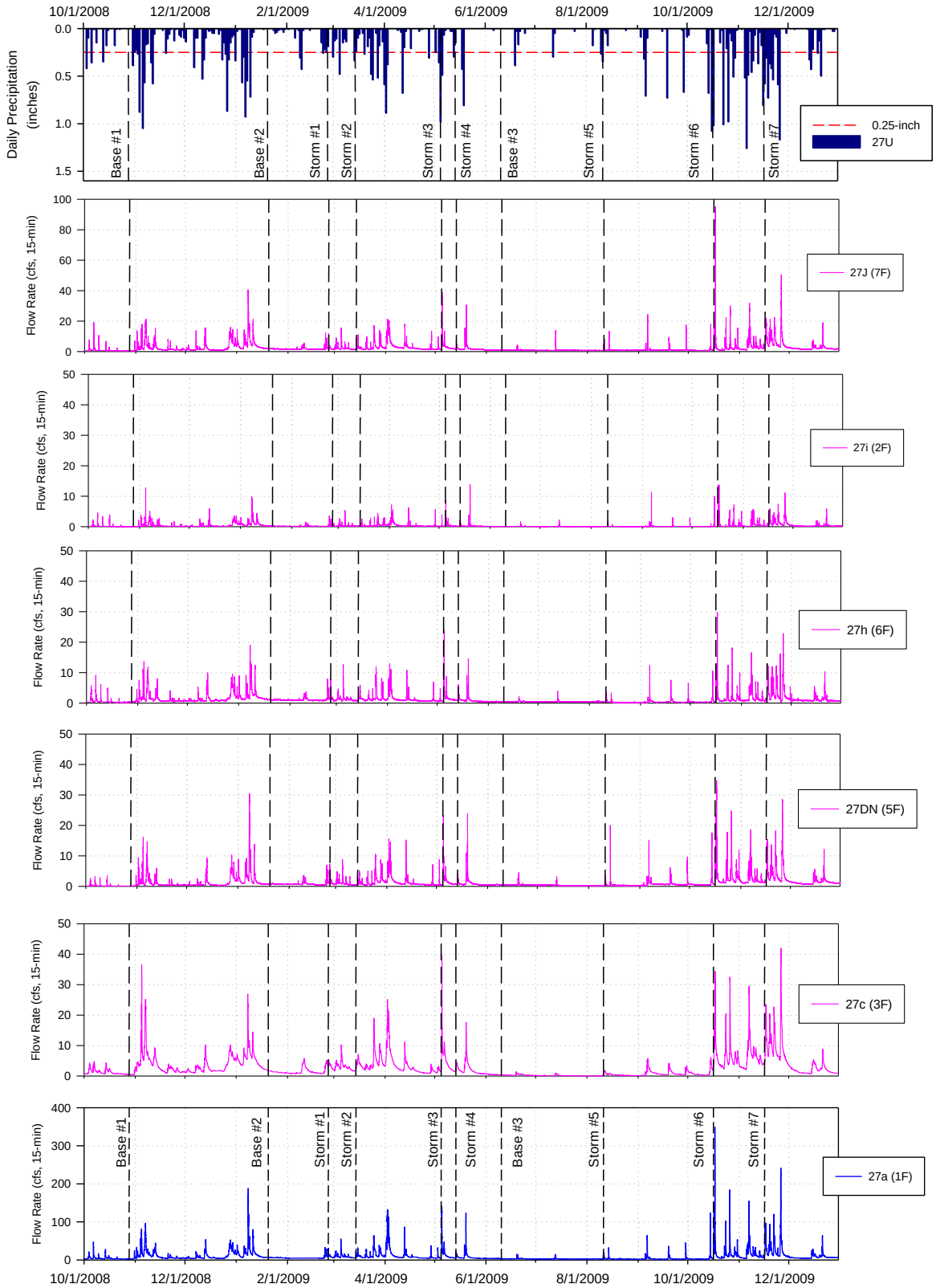

Figure 7 Summary of daily accumulated precipitation, 15-minute flow rates, and sample event dates.

3.1.2 Dissolved Oxygen

The dissolved oxygen (DO) concentrations were below the state criteria of 9.5 mg/L during both base and runoff events at all the locations, during at least one or more events. In particular, wetland inflows (4GI) had the lowest DO concentrations during baseflow events. One storm in particular (10/16-17/2009) had anoxic DO concentrations ranging from 0.7 to 3.8 mg/L. Samples taken at the inlet to the wetland (4GI) are taken in backwater conditions, which likely further suppress observations recorded.

3.1.3 Water Temperature

All continuous temperature sites had results exceeding the criterion (16°Celsius) intended to protect salmonid rearing and migration for durations ranging from 10 to 35 percent of the year, depending on the location (Table 11).

Table 11 Percent of Time stream temperatures were above state criterion.

Subbasin	Gauge Site	Percent of Time above Criterion
Mainstem	27a (1G)	24%
West Branch	27dn (5G)	10%
North Branch	27h (6G)	35%
East Branch	27j (7G)	11%

3.1.4 pH

With the exception of five samples, the pH data for all baseflow and runoff events were within the state criteria of greater than 6.5 and less than 8.5. Three samples were below pH 6.5 (~ 6.3) at the west branch (5GF) site and two samples were just under 6.5 (~ 6.47) at the inflow to the wetland (4GI) downstream of Totem Lake.

3.1.5 Fecal Coliforms

Fecal coliform were detected in all samples from baseflow and runoff events. The geometric mean of all baseflow event samples was 64 CFU/100 ml while the geometric mean of all runoff event samples was 765 CFU/100 ml, approximately an order of magnitude greater during runoff events. Both of these results are above the Extraordinary Primary Contact Recreation criterion of 50 CFU/100 ml. Storm 5 (08/10-11/2009) had the highest geometric mean of all runoff events with 3,823 CFU/100 ml in the east branch tributary (6G) with a geometric mean average for all sites of 2,479 CFU/100 ml. For the baseflow events, event #3 (06/20/2009) had the highest geometric mean value with 622 CFU/100 ml again in the east branch tributary site (6G) with a geometric mean of all sites equal to 204 CFU/100 ml. These elevated concentrations of bacteria were consistent with another study that conducted a comprehensive monitoring program tracing sources of contamination back to its sources (City of Kirkland 2009).

3.1.6 Dissolved Copper

For dissolved copper, base flow event samples did not exceed either the acute or chronic criteria. However, two of the 142 samples did exceed the acute criterion. These samples were from Storm 5 (08/20/2009) and occurred at inflows into the wetland downstream of Totem Lake (4GI) and flows from west branch tributary (5G). The chronic criterion was exceeded in 12 samples; with Storm 5 producing nine exceedances at a couple locations and site 4GI having six samples exceed criteria during a few storms. Storm 3 had two samples with values over the chronic criterion while Storm 7 had one. The other sites with sample values over the chronic criterion included east and west branch tributaries (5GF and 6G) with two samples each and near the mouth of the mainstem and Billy Creek (1G and 2G) with one sample each.

3.1.7 Dissolved Zinc

For dissolved zinc, six of the 142 storm samples exceeded the chronic and acute criterion. The location of these exceedances is different than those for dissolved copper. Storm 2 near the mouth of the mainstem (1G) had all three samples over the criteria. Storm 5 had two samples with values over the chronic criterion while Storm 7 only had one. The other sites with sample values over the chronic criterion included inflow and outflows of the wetland (4GI and 4GO) and the west branch tributary (5GF) with one sample each.

3.2 Stream Reconnaissance

The stream habitat assessment and BIBI scores observed in Juanita Creek (Appendix C) reinforce the work of Rush et al. (2002), which reported habitat conditions were degraded from "properly functioning conditions." BIBI scores in Juanita Creek in 2008 ranged from 19 to 35, or from "poor" to "fair" (Table 12), with higher scores in the headwaters and lower scores lower in the system (as shown in Figure 8 with square symbols). Observed BIBI scores used (King County 2009b) as part of the model accuracy assessment (plus four additional sites added in 2010/2011) reflect consistently poor conditions (i.e. *Very Poor* to *Poor*) with scores ranging 11 to 20. These "historical" sites are shown in Figure 8 as circular symbols.

Like other urban streams in the Puget Sound lowlands, Juanita Creek lacks suitable large wood densities (LWD). In Juanita Creek, LWD is found in much lower densities than even the low end ranges for natural conditions in the Pacific Northwest (Rush et al. 2002). Approximately 150 to 670 pieces of LWD per km are needed for properly functioning conditions, and none of the reaches sampled in Juanita Creek met that criteria (Rush et al. 2002).

Table 12 Averaged BIBI scores measured for 2008 monitoring.

Location	B-IBI Score (10 - 50)
Site 1	18. 7
Site 2	26.3
Site 3	21.3
Site 4	26
Site 5	25
Site 6	30
Site 7	35.3

Table 13 Measured BIBI scores from 2002 to 2011. Green shaded cells used for model verification.

Location	Description	2002	2003	2005	2006	2007	2008	2009	2010	2011	Avg.
1	BillyKirk1									14	14.0
2	E1186									14	14.0
3	JuanitaKirk1	12.7		12.7	15	15.3	16	17.3	19.3	16	15.5
4	JuanitaKirk2			12	13.3	14.7	16	14.7	15.3	20	15.1
5	JuanitaKirk3	14.7		10.7	12.7	12.7	14.7	19.3	17.3	18	15.0
6	JuanitaKirk4	16	14.7	13.3	15.3	14	17.3	16	18	18	15.8
7	KingsgateKirk1									16	16.0
8	WAM06600-083959								14	20	17.0
9	E1186				12	12	20	18	16		15.6

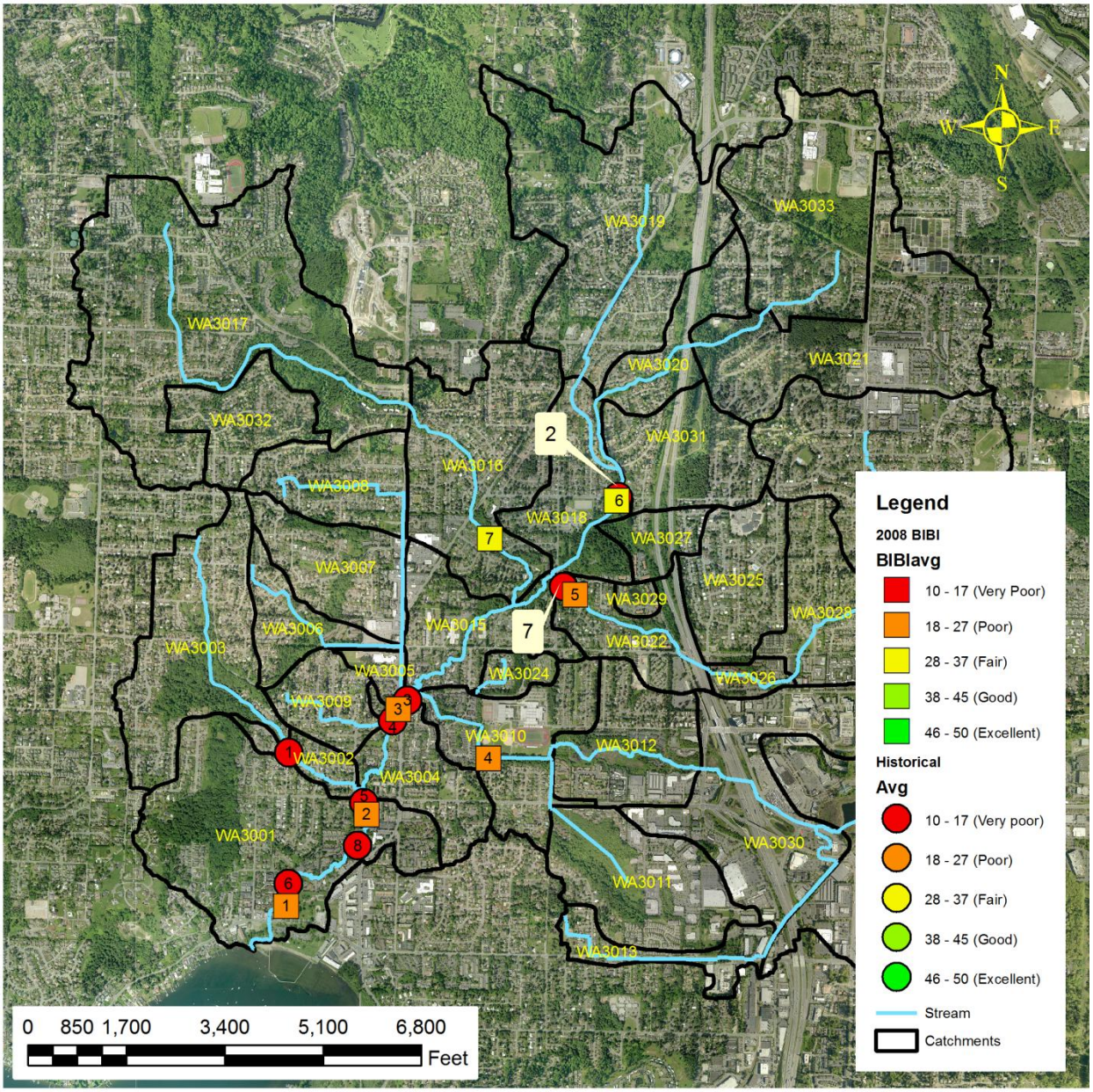

Figure 8 Measured BIBI scores in Juanita Creek for 2008 (Berge and Burkey 2009) and Historical (King County 2009) monitoring. Numbers in the symbols represent locator numbers listed in Table 12 and Table 13.

3.3 Geomorphology Assessment

As detailed in Appendix B, bank instability is pervasive throughout most of the Juanita Creek Basin watershed and is associated with areas of high discharge and, in many cases, more erodible substrates. Observed amounts of fine sediment in the system reflect substantial degradation of aquatic habitat. Bank erosion is occurring nearly everywhere in the basin with no obvious discrete point sources in terms of fine sediment source locations. It is postulated that reaches in erosive geologic substrate have the highest potential for continued erosion pointing to Billy Creek, the upper reaches of Cedar Creek, the upper

mainstem, and potentially the Juanita-Woodinville Way tributary as areas of particular concern.

Backwater effects from various culverts limit downstream sediment transport, especially gravels. Replacing culverts in this basin needs to be done with caution to avoid unintended consequences from increased downstream sediment loads, loss of gravels, and potentially bed incision in addition to already- occurring channel widening.

Visual estimates of the spatial extent of sand and fines that cover the stream bed strongly suggest that spawning habitat is limited and is a significant factor in limiting the productivity of native fish populations. When spawning gravels are embedded with fine sediment and sand, it is difficult for native fishes (especially salmonids) to construct redds. In addition, fine sediment reduces the success of incubating embryos by preventing adequate oxygen delivery and removing metabolic waste from egg pockets in redds (Everest et al. 1987; Reiser and White 1988).

Tables 7 and 8 of the Juanita Creek Basin Geomorphic Analysis in Appendix B identify specific critical reaches/locations that data suggests may be significant problem areas or those that may have the most potential for improvement. Problem types including hydrology, bank instability, fine sediment, sediment transport, and habitat are listed with corresponding locations.

3.4 Model Accuracy

As previously defined in section 2.5.1, statistics used for assessing model accuracy were applied to stream flows, water quality concentrations, and the hydrologic flashiness metrics. A comprehensive assessment of model accuracy can be found in the calibration report in appendix E.

3.4.1 Stream Flows

Model accuracy was variable depending on the simulated parameter and location, but generally calibrated well for stream flows at all six monitoring stations (Table 14 and Table 15) with mean errors ranging from -2% to +18% and root-mean-square-error (RMSE) ranging from 0.45 to 2.0 cfs for the tributaries and 8.1 cfs for the mainstem. Other than Totem Lake (27c) and East Branch (27h) tributaries being poorly calibrated for summer low flow conditions, statistics summarized in Table 14 and Table 15 and an example of scatter plots shown in Figure 9 reflect a well calibrated model and are similar in accuracy with other modeling efforts conducted in King County (e.g., King County 2003).

Table 14 Summary of simulated and observed flow rates.

Statistic	Data Source	Mainstem (27a)	Billy Creek (27i)	Totem Lake Trib. (27c)	West Branch (27dn)	East Branch (27h)	North Branch (27j)
Mean Annual Flow Rate	Obs	11.0	0.3	2.4	1.2	1.2	2.3
	Sim	10.8	0.4	2.7	1.3	1.3	2.5
Mean Peak Annual Flow Rate	Obs	184	6.8	32.5	19.7	16.4	42.0
	Sim	186	6.2	33.9	15.9	18.2	34.6
Mean 7-Day Average Daily Minimum Flow Rates	Obs	3.97	0.18	0.88	0.68	0.57	1.33
	Sim	3.91	0.22	1.67	0.74	0.88	1.56
Mean Daily Maximum Flow Rate	Obs	17.3	0.9	3.4	2.5	2.5	4.4
	Sim	19.2	0.9	4.2	2.6	2.8	5.0
Mean Annual	RPD	-2%	18%	13%	6%	8%	10%
Mean Peak Annual		1%	-8%	4%	-19%	11%	-18%
Mean 7DADM		-1%	26%	90%	9%	55%	17%
Mean Daily Maximum		11%	3%	24%	1%	12%	16%

Table 15 Summary statistics of model accuracy for stream flows based on hourly time increments

Statistic	Mainstem (27a)	Billy Creek (27i)	Totem Lake Trib. (27c)	West Branch (27dn)	East Branch (27h)	North Branch (27j)
Model Biases						
Mean Error (cfs)	-0.2	0.06	0.31	0.08	0.1	0.23
Mean Absolute Error (cfs)	4.19	0.2	1.05	0.64	0.34	0.69
RMSE (cfs)	8.1	0.45	1.99	1.35	0.74	1.49
Model Predictions						
Pearson Coefficient	0.86	0.76	0.88	0.80	0.91	0.91
r-square	0.74	0.58	0.78	0.64	0.83	0.82
Nash-Sutcliffe	0.69	0.44	0.61	0.52	0.81	0.75
Skill Score	0.45	0.25	0.37	0.31	0.56	0.50
Distribution shifts (RPD)						
90-Percentile	5%	22%	11%	27%	-2%	26%
75-Percentile	-2%	12%	-15%	-8%	3%	10%
50-Percentile	-19%	26%	-2%	-14%	20%	-5%
25-Percentile	-23%	-3%	38%	-35%	32%	-8%
10-Percentile	-13%	2%	187%	-13%	25%	-26%

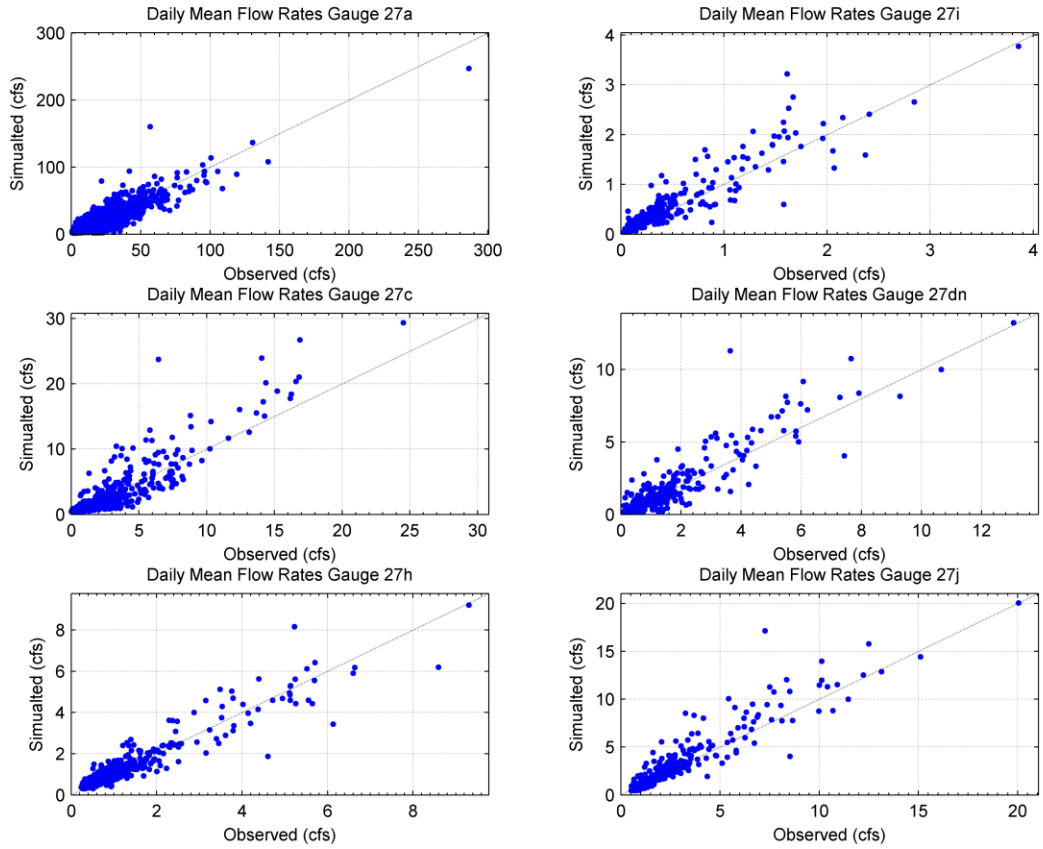

Figure 9 Scatter plots comparing observed to simulated for mean daily flow rates

3.4.2 Hydrologic Flashiness Metrics

With too few of data points on the tributaries (i.e. one data point), comparing simulated hydrologic flashiness metrics to observed was limited to the mainstem of Juanita Creek. As previously described in section 2.7.2, the Mann-Whitney *U*-test was used to compare distributions for equivalency between simulated and observed. Two of the metrics (HPC and RBI) fail the test individually with p-values less than 0.05; however, combining all of the distributions passes the test (Table 16). Accuracy of the P2YR requires a minimum of ten years of data to compute a peak 2-year return period. With insufficient data for the mainstem, accuracy is based on comparing components of the metric as a surrogate. Simulated annual peaks are approximately one percent larger than observed (Table 14) and seasonal winter flow rates were over simulated by 12 percent. These error rates seem reasonable to assume this metric "passes" the accuracy test.

Table 16 Summary of accuracy for simulated hydrologic metrics.

Metric	Description	27a *p*	Mann-Whitney
LPC	Low Pulse Count	0.08	Pass
LPD	Low Pulse Duration	0.70	Pass

Metric	Description	27a *p*	Mann-Whitney
HPC	High Pulse Count	0.03	Fail
HPD	High Pulse Duration	0.39	Pass
HPR	High Pulse Range	0.12	Pass
FR	Flow Reversals	0.09	Pass
TQ	TQmean	0.54	Pass
RBI	RBI Index	0.00	Fail
P2YR	2yr:winter	n/a	n/a
All above		0.70	Pass

3.4.3 Simulated BIBI

The relationships defined between the hydrologic metrics and BIBI scores (section 2.7.2) were further evaluated for Juanita Creek by comparing observed BIBI scores (section 3.2) measured at five locations to the predicted BIBI scores for the same approximate locations. Simulated scores (BIBI = 17) averaged three points higher than observed (BIBI ≈ 14) over a similar time period (Table 17). This level of accuracy is far greater than the identified accuracy among the defined relationships (section 2.7.2), thus predicting existing conditions to within a few BIBI points establishes a reasonable accuracy for further applications in this study.

Table 17 Simulated versus observed BIBI scores.

Site Code	Mean BIBI	
	Observed	Simulated
JuanitaKirk1	14	16
JuanitaKirk2	14	16
JuanitaKirk3	13	18
JuanitaKirk4	15	18
E1186	16	17

3.4.4 Water Quality

Accuracy in simulated water quality parameters resulted in limiting the focus of responses from the mitigation strategies to the mainstem when evaluating instantaneous concentrations. The r-square values for simulating instantaneous concentrations over a five-year period (2005 – 2009) were adequate, ranging from 0.45 to 0.95 for total suspended solids, total copper, dissolved oxygen, and water temperature, and with lower r-square values (< 0.2) for dissolved copper and fecal coliforms (Table 18).

The model "predictiveness" for dissolved copper and fecals would improve by removing one event (August 2009) from the observations, but for completeness there was no censorship and all data points were used in the accuracy assessment. This is evident by

plotting the simulated hourly time series and observed data collected during this study, which illustrates the closeness between simulated and observed throughout the year for base flows and runoff events (Figure 10 and Figure 11).

Table 18 Summary statistics of model accuracy for total suspended solids, total copper, dissolved copper, fecal coliforms, and water temperature for mainstem Juanita Creek.

Statistic	TSS (mg/L)	T.Cu (ug/L)	D.Cu (ug/L)	Fecals (cfu/100ml)	DO (mg/L)	Temperature (deg-F)
RMSE	67.95	10.18	2.03	1499	0.82	3.31
Mean Error	-24.87	0.00	0.81	-402	-0.45	-2.78
Mean Error (RPD)	-43%	0%	39%	-49%	-4%	-5%
r-square	0.66	0.45	0.15	0.18	0.69	0.95

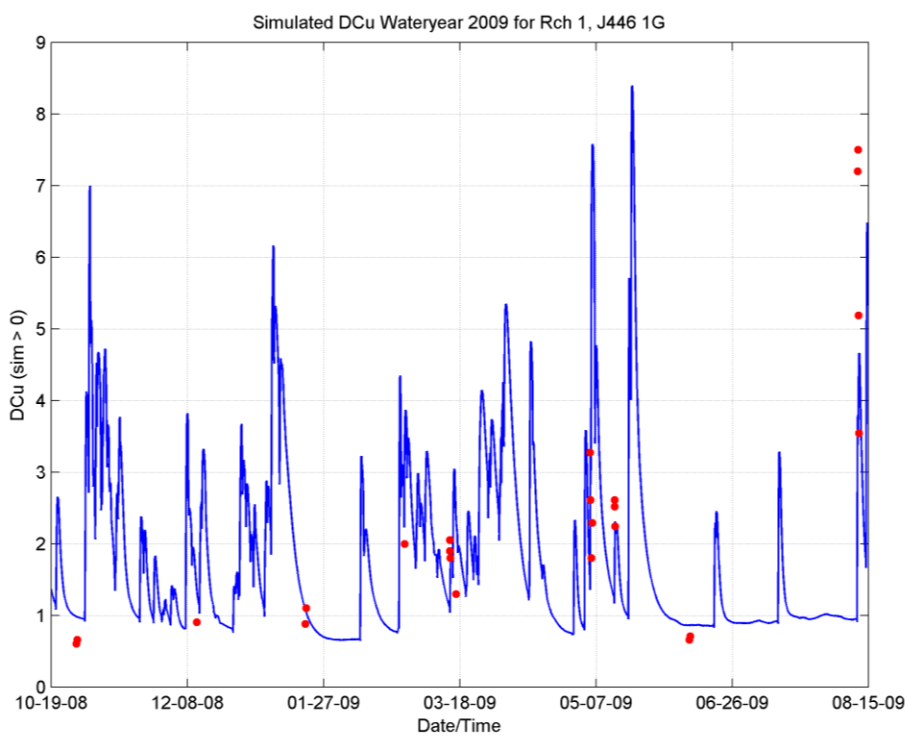

Figure 10 Mainstem simulated and observed dissolved copper during the monitoring period of this study (water year 2009).

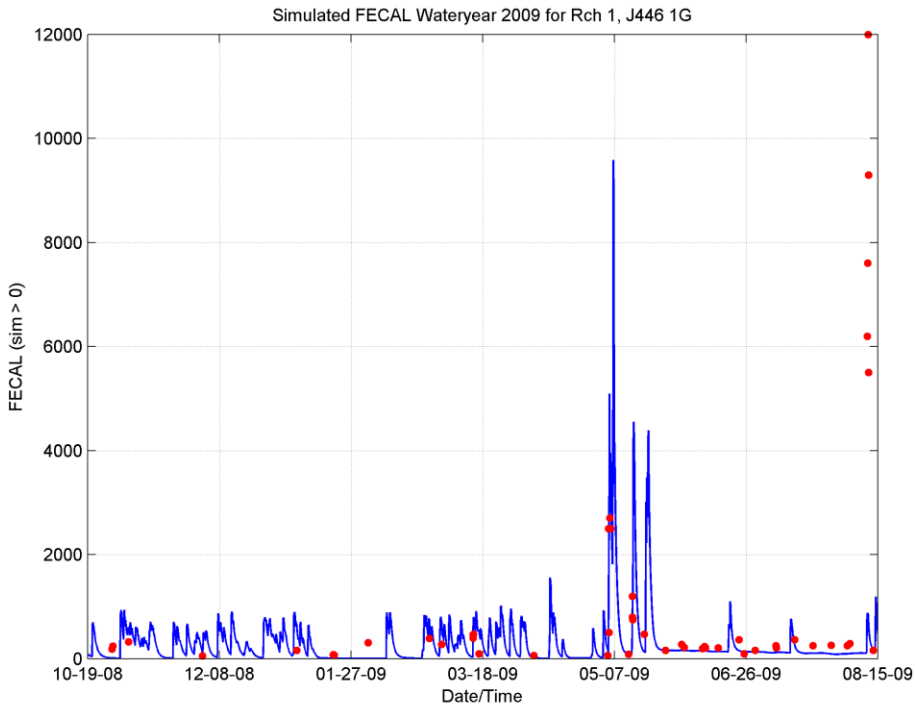

Figure 11 Mainstem simulated and observed fecal coliforms during the monitoring period of this study (water year 2009).

Mann-Whitney *U*-test on annual loading metrics (i.e. nutrients) result in three of the four parameters validating simulated distributions are equivalent to observed (Table 19). However, nitrates for this study are secondary in priority, and failing this test does not adversely affect possible outcomes from this study. Further detail on model accuracy can be found in Appendix E.

Table 19 Summary of Mann-Whitney U-test for N, NH_4, PO_4, and TP for the mainstem.

Mann-Whitney *U*-test		
Parameter	*p*	Test
Nitrates	0.01	Fail*
Ammonia-N	0.24	Pass
Orthophosphorus	0.41	Pass
Total Phosphorus	0.31	Pass

*Passes all headwater tributaries
(West = .75, North = .57, East = .08)

3.5 Model Limitations

Accuracy of the water quality simulation was inconsistent among the tributaries and the parameters. Thus, outcomes from simulated scenarios were limited to the mainstem of Juanita Creek.

Simulated flow rates at the six monitoring locations were good to exceptionally accurate (see section 3.4 and Appendix E) over the entire hydrologic regime, based on continuous hourly data over more than a year at the tributaries, and multiple years for the mainstem. What further substantiates the distributed accuracy beyond the points of measure is in the method of calibration performed for stream flows and water quality. With not enough identified differences in the landscape to warrant unique parameter adjustments (i.e. multiple calibrated sub-models) for each of the calibration points, adjustment made affected all catchments and subbasins.

Gravel disturbance analyses were limited to three locations within the study basin. True hydraulic characteristics will be unique for any given site in the basin and can be highly variable. Thus, these three locations are surrogates for what is assumed typical in the basin, but true basin wide responses to the various mitigation strategies are unknown and should be evaluated as such.

BIBI limitations in application for forecasted responses have been previously articulated and can be found in section 2.7.2.

3.6 Benchmark Scenario Simulation Results

Results for three benchmark scenarios representing different levels of disturbance in the basin (Table 20) were calculated for comparison with the proposed mitigation scenarios and discussed in the sub-sections that follow.

Table 20 Summary of benchmark simulation results per metric

Metric	Units / Description	Benchmark Results		
		FORESTED	65/10	LU1977
Total Suspended Solids	mt/year	0.1	0.6	4.4
Dissolved Copper	# exceedances / year	0.0	1.0	13.4
Total Copper	kg/year	0.1	0.4	1.3
Soluble Reactive Phosphorus	kg/year	1.9	3.6	8.4
Total Phosphorus	kg/year	7.7	11.2	17.8
Nitrates	kg/year	35.4	45.3	281
Ammonia	kg/year	5.0	4.8	7.5
Total Nitrogen	kg/year	101	129	386
Fecal Coliforms	# exceedances / year 50/10/200 cfu/100ml	101	163	332
Water Temperature	# exceedances / year 55.4°F, 60.8°F	46	50	60
Dissolved Oxygen	# exceedances / year 8.0, 9.5, -0.2 mg/L	0	60	68
Gravel Disturbance (D_{50} = 16.5 mm)	(# / year) at sites 107, 105, and 203 respectively	0.5, 0, 0	5, 0, 0	30, 8, 3
BIBI	Numerical Score	38	29	19
	Stream Health Description	Good	Fair	Poor

3.6.1 Forested Condition Benchmark (FORESTED)

Metric values calculated for the forest condition benchmark are generally consistent with the paradigm of pristine conditions. This scenario resulted in low pollutant loadings and water quality exceedances for two of the four measured parameters—fecal coliform bacteria and water temperature. A modest average riparian shading of 60% was used in the calibrated model and may partially explain the water temperature exceedances since a fully forested basin would likely have shading of 90% (King County 2005, Ecology 2011). Simulated BIBI scores at the sub-catchment level ranged from 33 to 43 with a resultant basin average of 38--equating to a category of "Good" ("Excellent" ranges from 46– 50) and exceeding the model-independent target score of 35. Gravel disturbances under the forested condition were less frequent than the target of 1-3 disturbances per year. This is most likely a result of using the modern-day channel geometry instead of the likely narrower channel that would have been present in a fully forested watershed. This emphasizes the likelihood that restoring hydrology to forested conditions would also require modifying channel geometry or allowing for an extended period of natural re-equilibration.

3.6.2 Limited Development Benchmark (65/10)

The 65/10 benchmark results failed to meet State water quality standards for all four metrics with defined values: dissolved copper, fecal coliform bacteria, dissolved oxygen, and water temperature. Pollutant loading rates are significantly elevated as compared the forested condition for most metrics. The simulated basin average BIBI score is 29 (i.e., "Fair").

3.6.3 1977 Land Use Benchmark (LU1977)

Similar to the 65/10 benchmark, the LU1977 benchmark results failed to meet water quality standards for all metrics. Pollutant loadings are multiples greater than forested conditions and simulated BIBI scores are reflective of a highly disturbed stream system with a basin average score of 19 (i.e., "Poor"). These simulated conditions suggest beneficial uses are not achievable.

3.7 Mitigation Scenario Simulation Results

Results for the seven mitigation scenarios are summarized in the following sub-sections by metric: BIBI, water quality exceedances and loadings, and gravel disturbances. Benchmark scenario results are also included for convenience and comparison.

3.7.1 Simulated BIBI Results

Simulated BIBI scores indicating stream health were calculated from hydrologic statistics derived from simulated discharges at each catchment outlet. Table 21 provides a summary of the simulated scores by catchment for benchmark and mitigation scenarios. For this study, the maximum basin-wide average BIBI score (38) was generated from the fully

forested scenario, while the lowest scores (16 and 17) were generated from the future unmitigated and existing condition scenarios, respectively.

Simulated BIBI scores for any given scenario are generally similar among the numerous catchments with the worst scores located in pipe-dominated conveyances (i.e., catchments WA3008 and WA3027) and better than average scores found in the Totem Lake tributary basin (catchments WA3010, WA3011, WA3012, and WA3014) which has significant amounts of natural storage. The standard deviation among the catchments for each scenario ranged from 2.2 to 4.6—the best catchment level scores were generally 7 points above the basin-wide average and the worst scores 6 points below the basin-wide average.

Table 21 Summary of simulated BIBI scores by catchment.

Catchment	FORESTED	65/10	LU1977	LU2002	FUTURE	LEVEL2	LID40	ECY08	LID40+	LID80	LVL2WET	CISTERNS
WA3001	39.8	30.6	21.1	18.7	17.1	24.2	21.4	36.2	22.1	29.7	24.6	18.7
WA3002	31.3	23.2	16.0	14.4	13.6	19.1	18.1	31.8	18.1	26.0	20.0	15.2
WA3003	31.4	24.2	16.6	14.7	13.7	19.8	18.0	35.0	18.0	26.1	20.1	15.4
WA3004	40.2	30.6	21.0	18.8	17.0	24.2	21.4	36.7	22.4	29.6	24.9	18.9
WA3005	35.4	25.6	14.9	14.1	13.6	19.4	18.3	30.2	18.3	26.3	20.4	15.2
WA3006	37.2	28.1	16.1	15.7	14.9	21.9	18.6	29.3	18.6	26.9	22.7	15.6
WA3007	34.7	24.3	14.6	13.8	13.6	18.3	18.4	30.6	18.4	26.6	19.2	15.2
WA3008	32.3	21.6	13.6	13.1	12.9	16.0	18.0	26.6	18.0	26.6	17.2	15.6
WA3009	38.0	28.4	17.1	15.2	14.7	18.3	19.1	29.6	19.1	27.2	19.9	15.6
WA3010	40.3	35.2	29.0	24.1	22.2	29.4	26.4	39.8	26.4	34.6	29.8	23.7
WA3011	40.3	29.7	26.8	15.7	14.6	23.1	18.4	35.2	18.4	27.8	23.7	16.2
WA3012	40.1	36.2	29.4	24.8	23.3	30.4	27.4	41.7	27.4	35.6	30.6	24.8
WA3013	39.4	30.6	19.1	15.9	15.4	26.3	19.6	36.9	19.6	28.3	27.2	17.0
WA3014	41.1	31.4	22.6	16.8	15.8	25.8	20.0	41.0	20.0	28.7	25.9	18.1
WA3015	40.3	29.6	19.1	17.0	15.8	22.9	19.4	36.1	20.9	28.3	23.3	17.2
WA3016	39.0	26.2	19.0	16.2	15.4	19.7	19.9	35.7	21.4	29.1	20.4	18.1
WA3017	40.6	27.8	21.1	16.3	15.4	20.8	19.1	38.9	21.0	28.2	21.2	17.2
WA3018	40.3	29.9	18.3	17.4	15.9	23.0	19.4	35.1	21.7	28.2	23.4	17.2
WA3019	38.8	29.2	18.9	16.6	15.0	22.6	19.6	32.7	19.6	27.6	22.9	16.0
WA3020	41.1	30.7	18.9	18.6	16.2	24.3	20.0	39.1	23.0	29.3	24.4	18.3
WA3021	41.0	30.8	19.3	18.9	16.3	24.4	20.4	40.8	23.8	29.7	24.7	18.7
WA3022	38.7	28.1	17.3	15.7	15.1	23.9	19.7	37.0	19.7	27.6	24.3	16.6
WA3023	40.4	27.7	17.1	15.9	15.3	24.0	19.3	40.4	19.3	27.4	24.7	16.4
WA3024	41.4	30.1	17.6	18.3	14.9	22.2	18.8	31.3	18.8	26.6	24.0	18.0
WA3025	40.2	27.4	16.3	15.2	14.8	24.0	19.1	36.3	19.1	27.2	24.7	16.1
WA3026	39.8	29.1	18.6	16.6	15.9	24.8	20.1	40.3	20.1	28.1	25.1	17.2
WA3027	35.3	26.3	14.4	14.1	12.4	22.7	16.3	26.4	16.3	24.7	22.9	12.8
WA3028	39.9	29.2	18.7	16.6	16.0	24.8	20.4	40.9	20.4	28.4	25.0	17.4
WA3029	30.0	27.3	29.8	21.9	21.2	27.6	24.0	31.1	24.0	28.8	29.6	23.4
WA3030	40.8	31.0	19.8	16.1	15.2	25.6	19.6	41.1	19.6	28.1	25.9	16.7
Average	38.3	28.7	19.4	16.9	15.8	23.1	20.0	35.5	20.5	28.2	23.8	17.4

Category	Very poor	10-17	Poor	18-27	Fair	28-37	Good	38-45	Excellent	46-50

Basin-wide average BIBI scores for the mitigation scenarios grouped mostly into one category of stream health—poor. Two of the scenarios showed marked improvements above the existing conditions category of very poor/poor by elevating stream health either to the low end of fair (LID80) or to the high end of fair (ECY08). Only the ECY08 mitigation scenario elevates the basin-wide average BIBI to a score above the identified target of 35—a threshold level indicated to be necessary for sustainable healthy stream systems (Karr et al., 2003). The LEVEL2 and LVL2WET scenarios produced similar results with simulated BIBI scores of 23 and 24, respectively. Although BIBI levels are raised by nearly 7 points from existing conditions, the poor category of stream health resulting from the LVL2WET scenario is notable given this scenario represents current (2005 SMMWW) stormwater standards. The LID40 and LID40+ scenarios resulted in nearly identical BIBI scores near 20, while the CISTERN scenario showed the least improvements by maintaining poor existing conditions into the future (Figure 12).

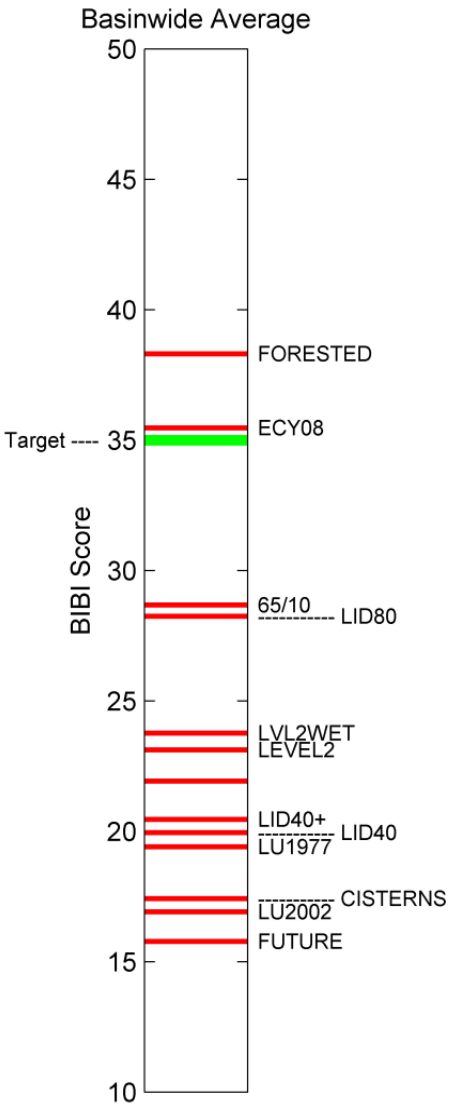

Figure 12 Simulated basin-wide average of BIBI scores per scenario.

3.7.1.1 Percent of Potential Maximum

As detailed in the methods section 2.9.2, 'percent of potential maximum' is used to measure the effectiveness of each mitigation scenario by normalizing their simulated BIBI results against the maximum result produced by the forested condition (Figure 13). The results show that the best performing scenario (ECY08) is impressively effective (93%), as might be expected given that this scenario is designed to match peaks and durations produced under forested conditions for a broad range of runoff events beginning at 8% of the 2-year storm.

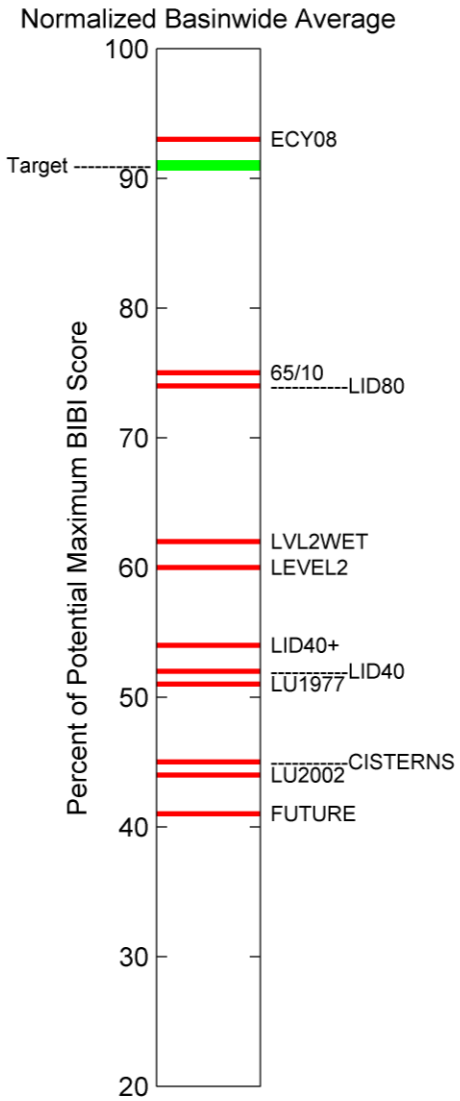

Figure 13 Simulated basin-wide average percent of potential maximum BIBI per scenario.

3.7.1.2 Simulated BIBI Results per Individual Hydrologic Metric

In addition to using catchment and basin-wide averages of BIBI scores that are based on averaging the BIBI values determined for each of the nine hydrologic metrics together, it is also instructive to evaluate how the individual metrics respond to the mitigation scenarios at a basin-wide scale. It is possible that a low outlier among the nine hydrologic metrics could indicate an actual condition limiting aquatic health and this might not be recognized if only the ensemble average is evaluated. Among the nine metrics, two of them (High Pulse Count and High Pulse Range) were consistently projecting lower BIBI scores than the other seven. In fact, simulated BIBI scores for High Pulse Range are categorized as very poor for all scenarios except for ECY08, Forested, and 65/10 (Table 22).

Table 22 Simulated BIBI responses by NFP metric and by scenario.

Metric	FOREST	65/10	LU1977	LU2002	FUTURE	LEVEL2	LID40	ECY08	LID40+	LID80	LVL2WET	CISTERN
LPC – Low Pulse Count	35	24	20	19	17	20	26	37	29	36	20	19
LPD – Low Pulse Duration	33	19	18	17	17	19	17	23	16	17	19	13
HPC – High Pulse Count	43	27	13	11	11	17	12	33	12	21	17	11
HPD – High Pulse Duration	35	27	20	19	19	28	21	44	22	33	29	19
HPR – High Pulse Range	38	28	12	10	10	10	10	24	10	15	10	10
FR – Flow Reversals	43	29	25	24	23	27	26	41	26	30	28	25
TQ - TQ_{mean}	39	38	27	20	17	32	26	44	27	40	33	28
RBI – R-B Index	36	32	17	12	11	24	18	35	19	31	25	13
P2YR – 2yr:Winter	42	33	22	19	17	30	23	38	23	32	31	18
Average	38	29	19	17	16	23	20	35	20	28	24	17

Category	Very poor 10-17	Poor 18-27	Fair 28-37	Good 38-45	Excellent 46-50

3.7.2 Simulated Water Quality Results

Simulated water quality results are evaluated using two methods, 1) the number of exceedances in chronic and/or acute concentrations per year, and 2) the annual loading rates. Both methods average 60 years of continuous simulations and are compared to modeled conditions for the three benchmark scenarios: FOREST, 65/10, and LU1977 for the mainstem of Juanita Creek with the exception of LEVEL2. Dry ponds are assumed to have no water quality benefit, thus LEVEL2 is omitted for this part of the reporting. Dissolved copper acute exceedances are based on hourly intervals, whereas chronic exceedances are four-day intervals. Thus every hour concentrations are above the acute criteria is an exceedance and every four days the concentration is above the chronic concentration is an exceedance. Water temperature, dissolved oxygen, and fecal coliforms are all based on daily intervals.

3.7.2.1 Exceedances

The forested benchmark scenario had no exceedances of dissolved copper, 65/10 had three events with enough hours of acute to average one hour of exceedances per year, and LU1977 had on average 13 per year consisting mainly short durations exceeding acute criteria. Simulated water temperature and fecal coliforms consistently exceeded criteria each year for all three benchmarks, with increasing exceedances with increasing development (Table 23). Exceedances in dissolved oxygen occurred in both the 65/10 and LU1977 benchmark scenarios, while FOREST produced none. The 65/10 scenario had exceedances with 1-day minimum concentrations that were a result of daily differences slightly greater than (-) 0.2 mg/L which is part of the criteria defining an exceedance.

Table 23 Benchmark scenario values for annual exceedances (acute and chronic combined) for dissolved copper, water temperature, dissolved oxygen, and fecal coliforms.

Parameter	Avg. # exceedances per year		
	FORESTED	65/10	LU1977
Dissolved Copper	0.0	1.0	13.4
Water Temperature[1]	46	50	60
Dissolved Oxygen	0.0	60	68
Fecal Coliforms	101	163	332

[1]Riparian shading kept constant among scenarios

<u>Dissolved Copper</u>

All mitigation scenarios reduced the number of exceedances in dissolved copper concentrations by 60% or more when compared to unmitigated future conditions with the exception of the CISTERN scenario which resulted in a slight increase (Table 24). This increase is likely a result of long detention times and no effective removal of solids allowing for desorption of copper in the sediments to dissolve back into solution before being released in the summer months. This return of copper to solution also occurs in the LVL2WET scenario but is compensated by the scenario's removal efficiency of solids and the copper attached to the solids. Only the ECY08 scenario combining dry ponds, wet ponds, and rain gardens fully mitigated all concentrations reducing the number of exceedances to zero (i.e. equivalent to forested conditions). Commensurate with the amount of impervious surfaces captured, the two scenarios utilizing rain gardens for mitigation (LID40 and LID80) reduce dissolved copper concentrations exceedances by 63% and 87%, respectively.

Table 24 Simulated average annual exceedances for dissolved copper.

Parameter	Average # of Exceedances per year							
	LU2002	FUTURE	LID40	ECY08	LID40+	LID80	LVL2WET	CISTERN
Dissolved Copper	92	99	37	0.0	33	13	3.8	105

The number of exceedances per year mostly is comprised of hourly acute exceedances, not days. Thus, one event can be comprised of multiple acute exceedances but is not

differentiated in the results. As an example, an average annual number of exceedances for LID40 is 37, but that could result from 2 to 3 events during the year.

Water Temperature

As previously reported from the monitoring conducted during this study, water temperatures in the various stream segments were above defined criteria for one or more months during the year. However, air temperatures during that summer (2009) were above normal, with record breaking days observed at Sea-Tac and other locations in the state which resulted in approximately 87 exceedances for that year (approximately 25% of the time). The simulated frequency of long-term temperature exceedances for current (LU2002) and future unmitigated conditions (FUTURE) is lower and estimated to occur approximately 17% of the time assuming current riparian shading conditions (Table 25).

Mitigation scenarios do not include any changes to riparian shading. Any effects seen can be attributed to either increasing base flows, and/or heating of large open bodies of water in ponds. The CISTERN scenario assumes no direct solar radiation reaches water surfaces but allows for heat transfer due to ambient air temperature. The mitigation scenarios with larger amounts of infiltration (ECY08 and LID80) reduce frequency of exceedances by more than 50 percent from future conditions. For the LVL2WET scenario, stream temperatures increase as a result of stagnate, large open bodies of water comprising the wetponds.

The intent of the modeling was to evaluate the effect of the mitigation scenarios without any changes to riparian buffers. Assuming an effective shade of 90 percent would most likely mitigate all exceedances for a stream system of this type (i.e. restoration of base flow, steeper gradient, faster travel times and lower potential of thermal inputs), but was not verified in this study.

Table 25 Simulated average annual exceedances for water temperature, dissolved oxygen, and fecal coliforms.

Parameter	Average # of Exceedances per year							
	LU2002	FUTURE	LID40	ECY08	LID40+	LID80	LVL2WET	CISTERN
Water Temperature[1]	63	69	44	29	28	20	74	30
Dissolved Oxygen	2.2	12	0.9	0.1	0.1	0.0	95	6.0
Fecal Coliforms	327	336	289	167	276	196	259	324

[1]Riparian shading kept constant among scenarios

Dissolved Oxygen

Dissolved oxygen will be near saturation and driven by air temperature for this type of stream system. However, mitigation scenarios with significant residence time will be additionally influenced by algae growth and respiration, organic decay, etc. In the simulated wetponds, 1-day minimum dissolved oxygen concentrations would routinely drop to 2 mg/L during summer months—affecting most, the LVL2WET scenario which features large wet ponds. The CISTERN scenario essentially had no algae growth (no light penetration), which would also suppress oxygen levels, but not nearly as much as stagnant wet ponds.

Fecal coliforms

As defined in section 2.6 describing removal efficiency, removals of fecal coliforms in the model are based solely the on the decay rate defined during calibration for the stream system and applied to the flow control facilities. In addition, large open bodies of water likely will be an attraction for wildlife and become fecal sources which are undifferentiated between human and animal in this study. Simulated unit area loading rates from forested conditions are lower than literature values (Figure 14) but still exceed defined thresholds (Figure 15).

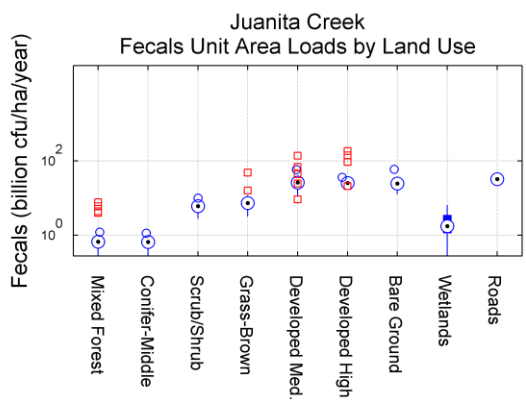

Figure 14 Unit area loading rates by land use for fecal coliforms. Blue symbols are simulated, red are from literature and previous studies.

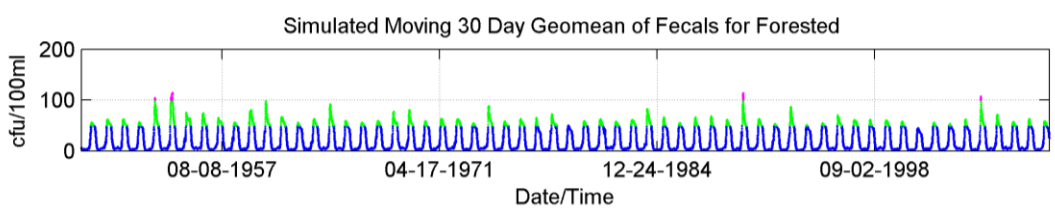

Figure 15 Simulated moving 30-day geometric means of fecal coliforms for forested (FOREST) conditions.

All mitigation scenarios produced exceedances of fecal coliform standards (Table 26). The ECY08 scenario showed the greatest reduction in the number of exceedances when compared to future unmitigated conditions (Future) with the LID80 scenario nearly as effective. The remaining scenarios reduced exceedances from 5 to 23 percent depending on the amount of flow control applied.

Table 26 Simulated average annual exceedances for fecal coliforms.

Parameter	Average # of Exceedances per year							
	LU2002	FUTURE	LID40	ECY08	LID40+	LID80	LVL2WET	CISTERN
Fecal Coliforms	327	336	289	167	276	196	259	324

The following three tables summarize how well the various mitigation scenarios meet the three benchmarks of forested (Table 27), 65/10 (Table 28), and LU1977 (Table 29). Cells filled with "Yes" are equal to or below the target scenario exceedances, and highlighted in green. Cells filled with "No" signify a scenario that does not achieve exceedance levels, and

are highlighted in red. Cells filled with "No*" do not meet target levels but are reduced from projected future conditions, and are also highlighted in green. The more relaxed the standard, the more targets are achieved with the exception of dissolved oxygen targets for 65/10. As the number of exceedances increase among the benchmarks, the relative comparison of the mitigation scenarios become more favorable. With the exception of LVL2WET and CISTERN, all mitigation scenarios had less exceedances then compared to LU1977 benchmark conditions.

Table 27 Simulated mitigation scenarios meeting forested conditions targets for dissolved copper, water temperature, dissolved oxygen, and fecal coliforms.

Parameter	Meet Forested Conditions Benchmark							
	LU2002	FUTURE	LID40	ECY08	LID40+	LID80	LVL2WET	CISTERN
Dissolved Copper	No	No	No*	Yes	No*	No*	No*	No
Water Temperature	No	No	No	Yes	Yes	Yes	No	Yes
Dissolved Oxygen	No	No	No	No	No	Yes	No	No
Fecal Coliforms	No	No	No	No	No	No	No	No

*Annual exceedances are significantly reduced from projected future conditions.

Table 28 Simulated mitigation scenarios meeting 65/10 conditions targets for dissolved copper, water temperature, dissolved oxygen, and fecal coliforms.

Parameter	Meets 65/10 Conditions Benchmark							
	LU2002	FUTURE	LID40	ECY08	LID40+	LID80	LVL2WET	CISTERN
Dissolved Copper	No	No	No*	Yes	No*	No*	No*	No
Water Temperature	No	No	No	Yes	Yes	Yes	No	Yes
Dissolved Oxygen	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
Fecal Coliforms	No	No	No	No	No	No	No	No

*Annual exceedances are significantly reduced from projected future conditions.

Table 29 Simulated mitigation scenarios meeting 1977 conditions targets for dissolved copper, water temperature, dissolved oxygen, and fecal coliforms.

Parameter	Meet 1977 Conditions Benchmark							
	LU2002	FUTURE	LID40	ECY08	LID40+	LID80	LVL2WET	CISTERN
Dissolved Copper	No	No	No*	Yes	No*	Yes	Yes	No
Water Temperature	No	No	Yes	Yes	Yes	Yes	No	Yes
Dissolved Oxygen	No	No	Yes	Yes	Yes	Yes	No	No
Fecal Coliforms	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes

*Annual exceedances are significantly reduced from projected future conditions.

3.7.2.2 Annual Loadings

In absence of mitigation, the projected largest increase in loadings is a near doubling of solids (i.e. TSS) from existing (LU2002) to future unmitigated (FUTURE) conditions. All other parameter loading rates remain similar between current and future conditions. The most effective mitigation scenarios for solids and metals were the LID80 scenario with rain gardens capturing 80 percent impervious surfaces and the ECY08 scenario which is a combination of rain gardens and dry/wet ponds (Table 30). However, the scenarios that include wet ponds (ECY08 and LVL2WET) increase ammonia loads as a result of simulated organic matter decaying into inorganic nitrogen and phosphorus species and the nitrate reduction via denitrification processes with low oxygen levels. Removal efficiencies are assumed zero for cisterns because of the absence of any algae growth or organic sediment. Any simulated reductions are a consequence of fate and transport processes simulated in the stream system occurring during the summer month releases.

Table 30 Simulated average annual loads.

Scenario		Solids[1]	Metals[2]		Nitrogen[2]			Phosphorous[2]	
		TSS	DCu	TCu	NH_4	NN	TN	PO_4	TP
Targets	FORESTED	0.1	0.1	0.1	5.0	35.4	100.8	1.9	7.7
	65/10	0.6	0.3	0.4	4.8	45.3	129.2	3.6	11.2
	LU1977	4.4	0.7	1.3	7.5	280.5	386.0	8.4	17.8
Unmitigated	LU2002	9.8	1.3	2.6	8.3	155.4	274.5	10.2	21.2
	FUTURE	17.8	1.4	3.3	8.4	138.0	258.2	11.0	22.4
Mitigations	LID40	5.1	0.9	1.7	7.1	116.7	203.0	7.5	15.5
	ECY08	0.7	0.5	0.5	11.2	78.3	129.3	5.9	9.2
	LID40+	5.2	0.9	1.7	7.4	116.7	203.9	7.5	15.5
	LID80	1.5	0.5	0.8	6.7	108.8	185.7	4.6	11.1
	LVL2WET	3.9	1.3	2.1	9.8	123.4	194.5	12.6	18.8
	CISTERN	10.7	1.5	3.0	7.1	134.7	246.3	11.0	21.5

[1]Loads are in metric tons per year (mt/yr)

[2]Loads are in kilograms per year (kg/yr)

<u>Annual Loading Targets</u>

None of the mitigation strategies reduce annual loadings to those modeled under hypothetical forested or 65/10 benchmarks, with the exception of total phosphorus which is reduced to below 65/10 levels applying the ECY08 and LID80 scenarios. Estimated annual loadings are less than those estimated under the LU1977 benchmark scenario for at least two parameters for every mitigation scenario (Table 31). The LID80 scenario had lower loadings for all parameters. It is worth noting that the simulated nitrate and total nitrogen loading rates for LU1977 are significantly higher than all other scenarios. This is a result of large portions of the basin assumed to have active pasture lands (based on photo interpretation done generating the 1977 land use scenario) with sources higher in nitrogen.

Table 31 Simulated annual loads meeting benchmarks.

Target Scenario	Scenario	Solids	Metals		Nitrogen			Phosphorous	
		TSS	DCu	TCu	NH_4	NN	TN	PO_4	TP
Forested	LU2002	No	No	No	No	No	No	No	No
	FUTURE	No	No	No	No	No	No	No	No
	LID40	No	No	No	No	No	No	No*	No
	ECY08	No*	No*	No*	No	No	No	No*	No*
	LID40+	No	No	No	No	No	No	No*	No
	LID80	No*	No*	No*	No	No	No	No*	No*
	LVL2Wet	No*	No	No	No	No	No	No	No
	CISTERNS	No	No	No	No	No	No	No	No
65/10	LU2002	No	No	No	No	No	No	No	No
	FUTURE	No	No	No	No	No	No	No	No
	LID40	No	No	No	No	No	No	No*	No
	ECY08	No*	No*	No*	No	No	No	No*	Yes
	LID40+	No	No	No	No	No	No	No*	No
	LID80	No*	No*	No*	No	No	No	No*	Yes
	LVL2Wet	No*	No	No	No	No	No	No	No
	CISTERNS	No	No	No	No	No	No	No	No
LU1977	LU2002	No	No	No	No	Yes	Yes	No	No
	FUTURE	No	No	No	No	Yes	Yes	No	No
	LID40	No	No	No	Yes	Yes	Yes	Yes	Yes
	ECY08	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
	LID40+	No	No	No	Yes	Yes	Yes	Yes	Yes
	LID80	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	LVL2Wet	Yes	No	No	No	Yes	Yes	No	No
	CISTERNS	No	No	No	Yes	Yes	Yes	No	No

*Does not meet targets, but annual loads are significantly reduced.

3.7.3 Simulated Gravel Disturbances and LWD Densities

Using the methods described in section 2.7.4, average annual gravel disturbances were determined for mitigation and benchmark scenarios for three selected stream reaches (Sites 107, 105, and 203). Actual flow rates competent to mobilize gravels at each of the three sites varied to a minor degree around a typical value of 30 cfs. The number of disturbances, with an assumed D_{50} equal to 16.5 mm, range from near zero in the headwater reach to an average disturbance greater than 30 times per year near the mouth for half of the scenarios (LID40, LID40+, and CISTERN). Several scenarios for the mid-basin and upper tributary site produced conditions closer to target ranges, while the most aggressive mitigation scenarios over-shot the target causing disturbances less than 1 per

year. Except for near the mouth (Site 107), the fully forested (FOREST) scenario does not produce high enough flow rates to mobilize gravels using existing channel geometries with ideal gravel sizes. In addition, the 65/10 scenario will not move gravels in the upper site (site 203), moves gravels only marginally in the mid-basin site (site 105), and over-produces disturbances in the lower site (site 107) near the mouth. Average annual gravel disturbances are summarized in Table 32, Table 33, and Table 34 below, with green cells highlighting where the target range of 1 to 3 per year is met. Also included in the tables are flow rates associated with average frequencies of 1 per year (Upper Q) and 3 per year (Lower Q), respectively.

Scenarios that project the number of disturbances greater than three per year are further evaluated by augmenting stream channel roughness with large wood (LWD). Using estimated equivalencies of average channel roughness (Manning's n) to linear densities of placement for LWD, a channel roughness capable of reducing the number of disturbances back to the target range of 1 to 3 per year is estimated. The greater the number of disturbances per year, the more pieces of LWD per 1000 feet is necessary. Existing channel roughness at the three sites is estimated as n= 0.036, .035, and .035. The modified channel n-values required to achieve the target disturbance range and the density of LWD placements necessary to achieve those roughnesses are listed in Table 32, Table 33, and Table 34.

For comparative purposes only, gravel disturbances and LWD densities are included for unmitigated existing (LU2002) and future (FUTURE) conditions.

Table 32 Estimated gravel disturbances and LWD placement density for Site 107 (near the mouth). Yellow cells indicate the flow rate used for analysis.

Scenario	Site 107 Gravel Disturbance				
				Using modified Wilcock	
	Lower Q (cfs)	Upper Q (cfs)	# of Disturbances	LWD Density* (# / 1000 ft)	Modified channel-n (n_{exist} 0.036)
FORESTED	14.3	23.3	0.5	--	< 0.036
65/10	34.6	43.9	5.4	3	0.040
LU1977	103.9	144.9	30.1	9	0.045
LU2002	141.1	199.3	33.2	8	0.044
FUTURE	189.0	260.7	34.2	6	0.042
LID40	107.3	145.8	30.8	9	0.045
ECY08	40.0	51.7	6.3	3	0.040
LID40+	108.2	147.0	31.1	9	0.045
LID80	55.7	71.3	17.2	6	0.042
LVL2WET	43.1	53.1	8.8	3	0.040
CISTERN	136.2	197.2	33.0	9	0.045

*Represents density necessary to achieve 1 to 3 disturbances per year

Table 33 Estimated gravel disturbances and LWD placement density for Site 105 (mid-basin mainstem). Yellow cells indicate the flow rate used for analysis.

Scenario	Site 105 Gravel Disturbance				
			Using standard Shields		
	Lower Q (cfs)	Upper Q (cfs)	# of Disturbances	LWD Density* (# / 1000 ft)	Modified channel-n (n_{exist} 0.035)
Forest	5.7	12.6	0.0	--	< 0.035
65/10	20.5	26.9	0.1	--	< 0.035
LU1977	68.1	97.7	8.1	2	0.040
LU2002	88.8	127.4	13.8	7	0.044
FUTURE	123.5	167.3	19.7	21	0.050
LID40	65.2	88.4	7.3	2	0.040
ECY08	21.4	28.9	0.1	--	< 0.035
LID40+	66.5	89.6	7.8	5	0.042
LID80	34.0	43.6	0.6	--	< 0.035
LVL2WET	25.1	31.0	0.2	--	< 0.035
CISTERN	87.7	130.4	13.1	7	0.044

*Represents density necessary to achieve 1 to 3 disturbances per year

Table 34 Estimated gravel disturbances and LWD placement density for Site 203 (north branch headwater tributary). Yellow cells indicate the flow rate used for analysis, green cells indicate achieved targets.

Scenario	Site 203 Gravel Disturbance				
			Using standard Shields		
	Lower Q (cfs)	Upper Q (cfs)	# of Disturbances	LWD Density* (# / 1000 ft)	Modified channel-n (n_{exist} 0.035)
FORESTED	1.6	4.9	0.0	--	< 0.035
65/10	7.8	9.9	0.0	--	< 0.035
LU1977	29.5	46.6	2.9	0	0.035
LU2002	33.9	55.1	4.2	3	0.040
FUTURE	56.9	76.6	10.0	18	0.049
LID40	21.0	29.0	0.8	1	0.037
ECY08	9.8	12.6	0.0	--	< 0.035
LID40+	21.8	29.9	1.0	0	0.035
LID80	12.6	16.5	0.1	--	< 0.035
LVL2WET	9.8	12.4	0.1	--	< 0.035
CISTERN	36.8	61.0	5.0	3	0.040

*Represents density necessary to achieve 1 to 3 disturbances per year

3.7.4 Mitigation Costs

As detailed in the methods section 2.8, this cost analysis includes all significant costs required to implement each mitigation scenario, including land purchases using prices specific to the Juanita Creek basin, construction costs, and operation and maintenance costs accrued over an assumed 40 year life cycle. Methods used to size the dry ponds in the regulatory ECY08 scenario were not fully optimized to reduce footprints and volumes of the facilities.

The estimated total net present (2011) value for the seven scenarios (Table 35 and Figure 16) evaluated ranged from $200 million to $1.4 billion dollars, which equates to $30 to $200 million per square mile or $5 to $35 million per year (over a 40 year time span).

Two scenarios, ECY08 and LID80, far surpass the others in terms of cost. In both cases, the primary cost driver is the installation and maintenance of many small rain gardens across the landscape necessary to achieve the required performance. In particular, operations and maintenance costs attributed to private homeowners for rain gardens comprise approximately 50% of the total costs for these two scenarios. Both scenarios utilize rain gardens to treat the majority (80%) of impervious surfaces in the basin (ECY08 utilizes conventional ponds as well).

The LID40 and LID40+ scenarios have nearly identical costs-- again mostly driven by the rain gardens, which for these scenarios treat 40% of the total basin impervious surfaces.

A common theme among the least expensive scenarios was low operations and maintenance costs. These include LEVEL2, LVL2WET, and CISTERN scenarios.

Table 35 Net present value costs per scenario, based on 40 year lifespan.

		O & M[3]		
Scenario	Capital[3]	Private[1]	Public[2]	Total[3]
LEVEL2	$207.52	$0.00	$2.98	$210.50
LID40	$184.57	$339.74	$65.76	$590.06
ECY08	$559.00	$679.48	$134.45	$1,372.93
LID40+	$185.32	$339.74	$65.95	$591.01
LID80	$369.13	$679.48	$131.51	$1,180.12
LVL2WET	$210.92	$0.00	$3.87	$214.79
CISTERN	$177.71	$0.00	$79.46	$257.17

[1]Private costs are burdens on the private citizens
[2]Public costs are burdens on the government jurisdictions
[3]Estimated costs are in millions of dollars

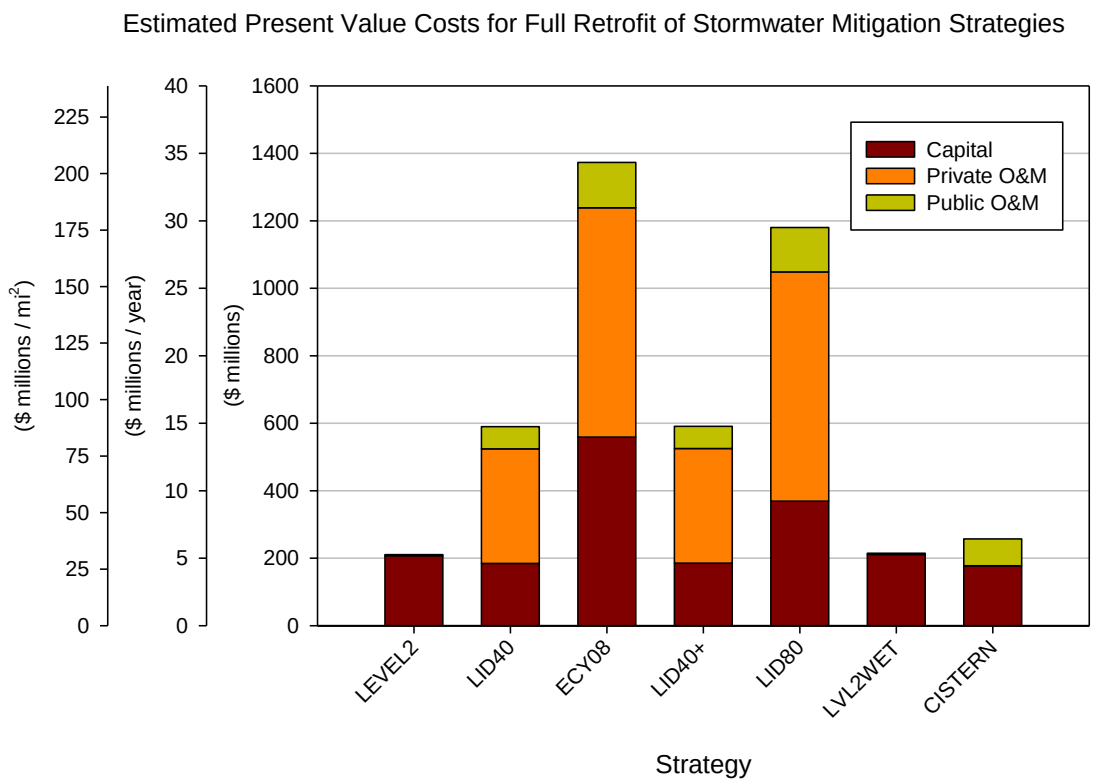

Figure 16 Estimated present value costs for full retrofit mitigation strategies.

3.7.5 Mitigation Cost Effectiveness

Of the seven mitigation scenarios evaluated, the two most expensive scenarios, LID80 and ECY08, routinely stand out as the most generally effective. The remaining mitigation scenarios had lower overall levels of effectiveness. Interestingly, the LVL2WET scenario appears to be a 'best bang for the buck' scenario even though its overall level effectiveness is deemed poor.

Cost effectiveness is summarized by metric in Table 36 below. Further detail is provided in the following Figure 17 through Figure 31.

Table 36 Summary of cost effectiveness responses for the mitigation scenarios.

Metric	Effectiveness	Figure
BIBI	ECY08 and LID80 best mitigate altered hydrology degrading projected biotic responses, but only ECY08 projects a BIBI score of 35- identified as one element necessary for achieving restoration of full beneficial uses.	Figure 17
Dissolved Copper	ECY08 and LID80 are most effective, but LVL2Wet highly effective and considerably less expensive.	Figure 18

Metric	Effectiveness	Figure
DO	All scenarios are similarly effective with the exception of wet ponds that experience low oxygen levels during warmer months.	Figure 19
Temperature	All scenarios are similarly effective with the exception of wet ponds that act as shallow lakes more sensitive to air temperatures and solar radiation. None of the mitigation strategies evaluated riparian buffer shading.	Figure 20
Fecal	ECY08 and LID80 are most effective and most expensive. Reducing fecal concentrations are a result of flow controls via infiltration pathways.	Figure 21
TSS	Similar to dissolved copper, ECY08 and LID80 are most effective, but LVL2Wet highly effective and considerably less expensive.	Figure 22
Total Copper	ECY08 and LID80 most effective and most costly	Figure 23
Nitrogen	ECY08 shows to be the most effective for nitrates and total nitrogen, but true responses are more unknown given the variable dynamics in nutrient uptake for the wet ponds.	Figure 24 Figure 25 Figure 26
Phosphorus	ECY08 and LID80 are most effective, but like nitrogen, true responses are more unknown given the variable dynamics in nutrient uptake for the wet ponds.	Figure 27 Figure 28
Gravel Disturbances	Any scenario not effective is mostly due to over-mitigation by reducing stream energies below levels capable of mobilizing gravels. This is more prevalent in headwater study reach (Site 203).	Figure 29 Figure 30 Figure 31

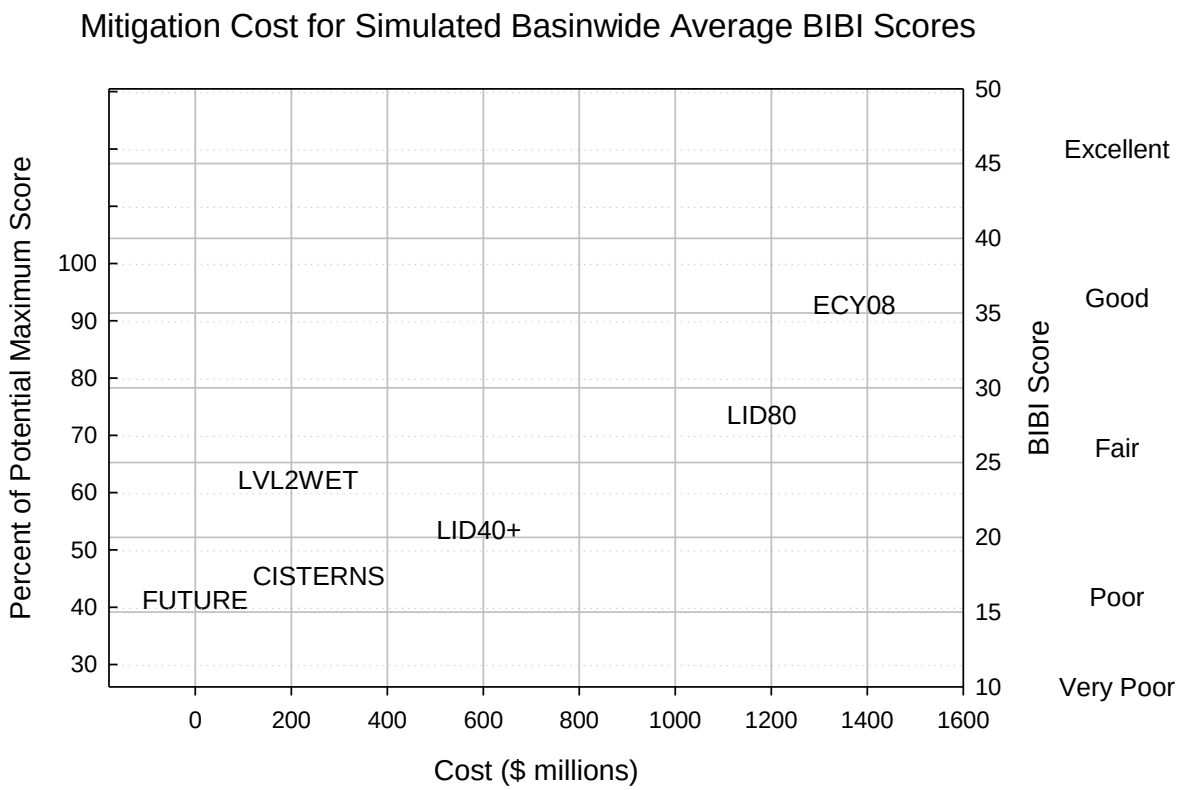

Figure 17 Cost effectiveness for basinwide average BIBI score. (LEVEL2 ≈ LVL2WET, LID40 ≈ LID40+)

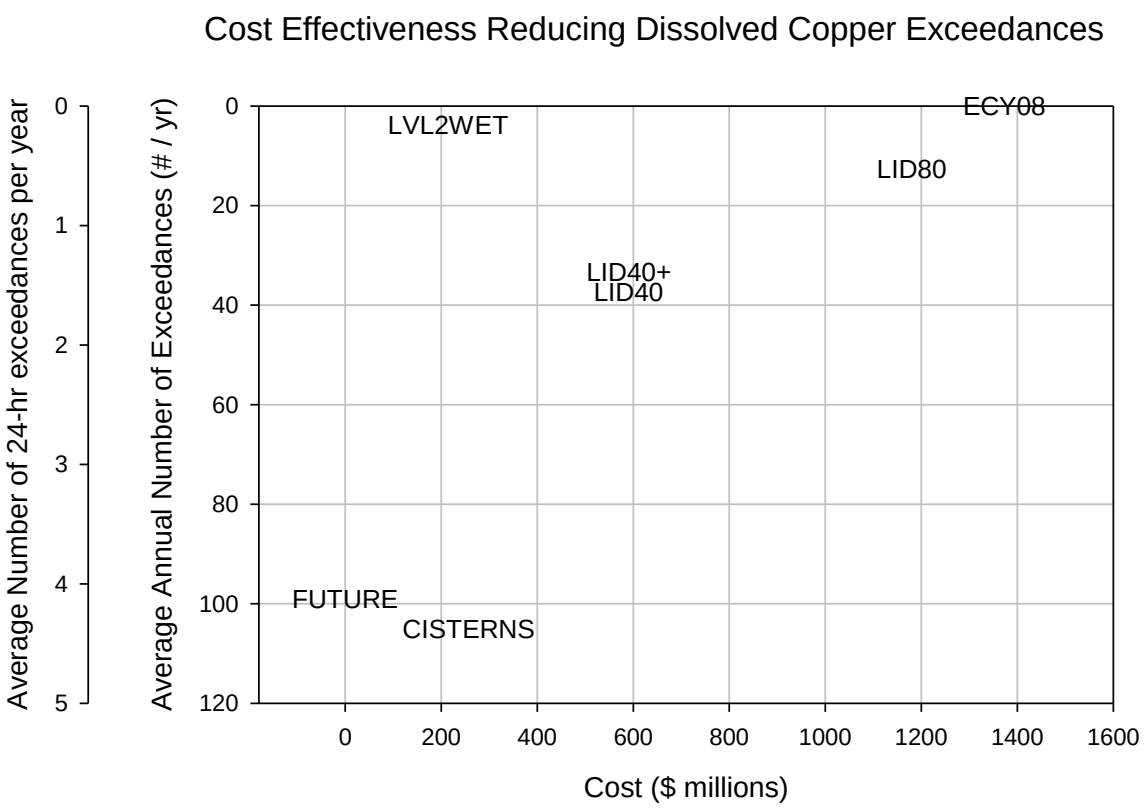

Figure 18 Cost effectiveness for reducing dissolved copper exceedances (LEVEL2 not assessed for removal efficiencies).

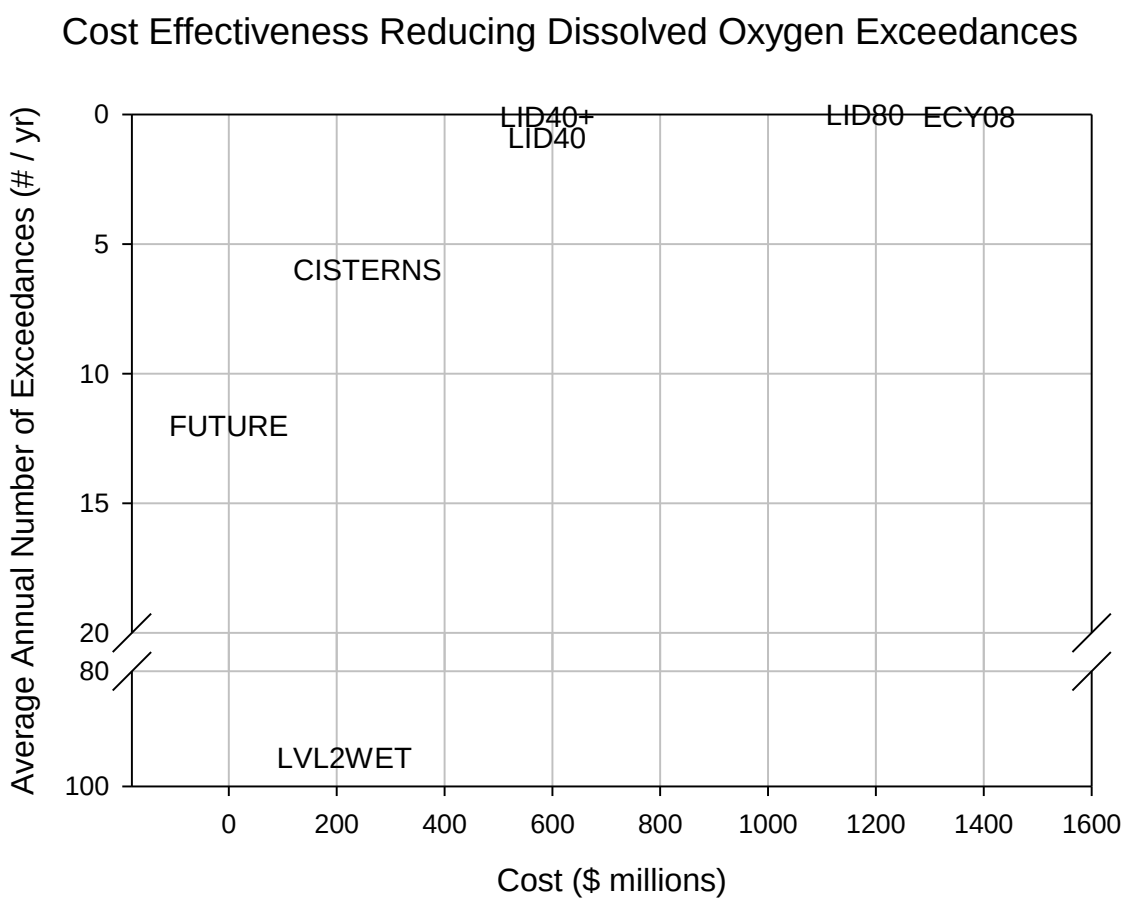

Figure 19 Cost effectiveness for reducing dissolved oxygen exceedances.

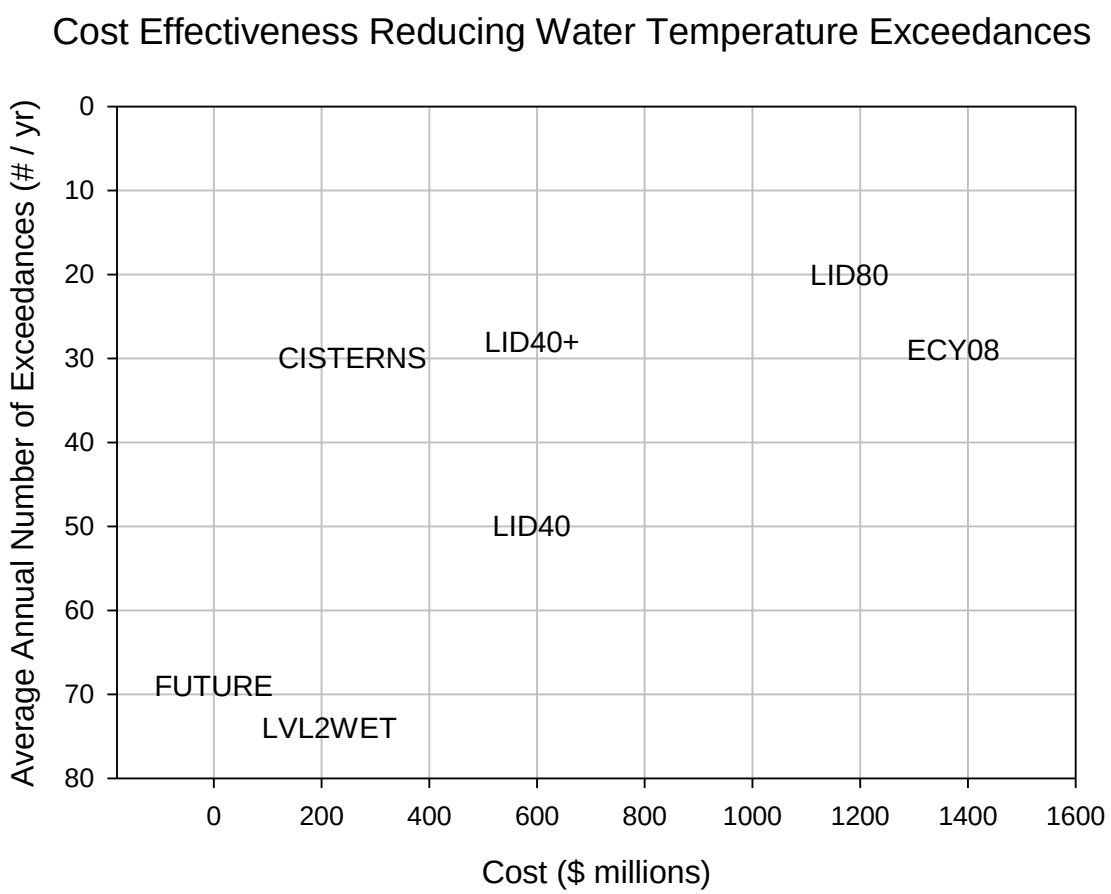

Figure 20 Cost effectiveness for reducing water temperature exceedances

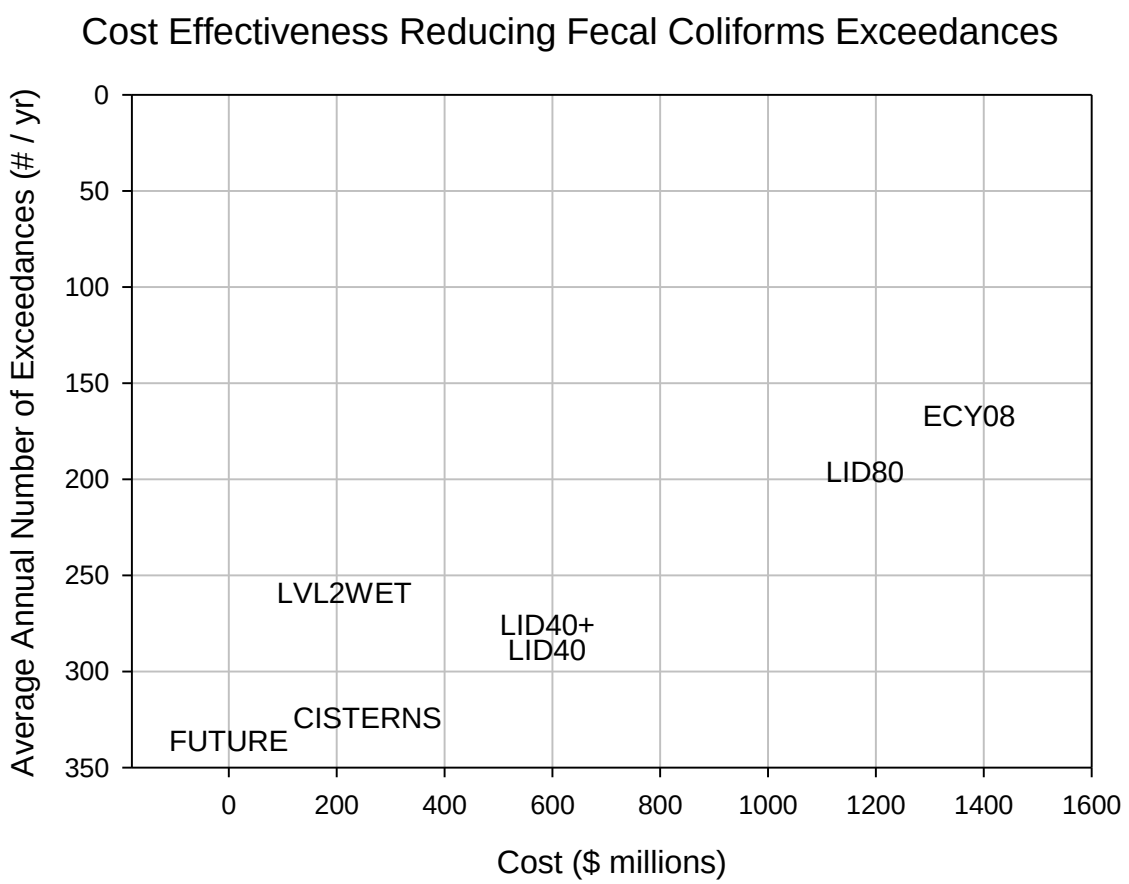

Figure 21 Cost effectiveness for reducing fecal coliform exceedances.

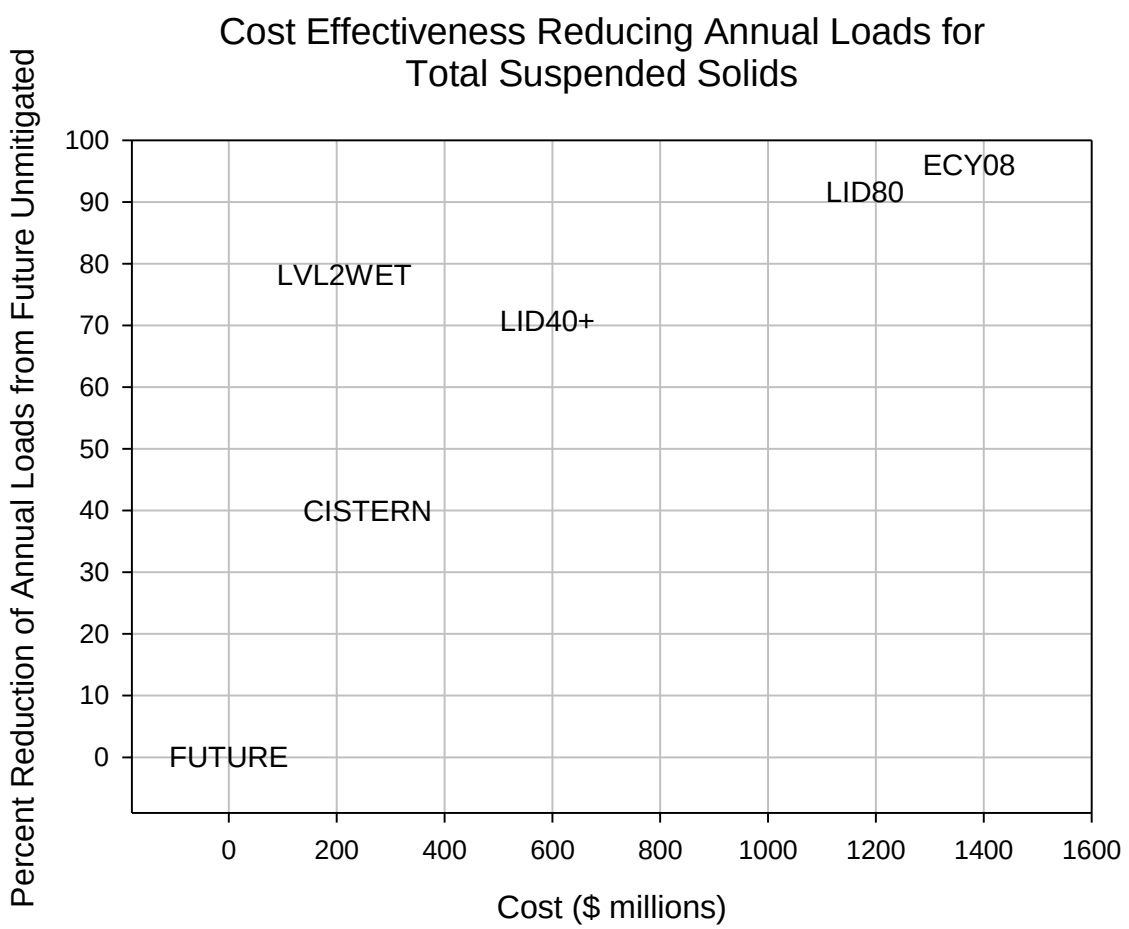

Figure 22 Cost effectiveness for reducing annual loads of TSS (LID40 ≈ LID40+).

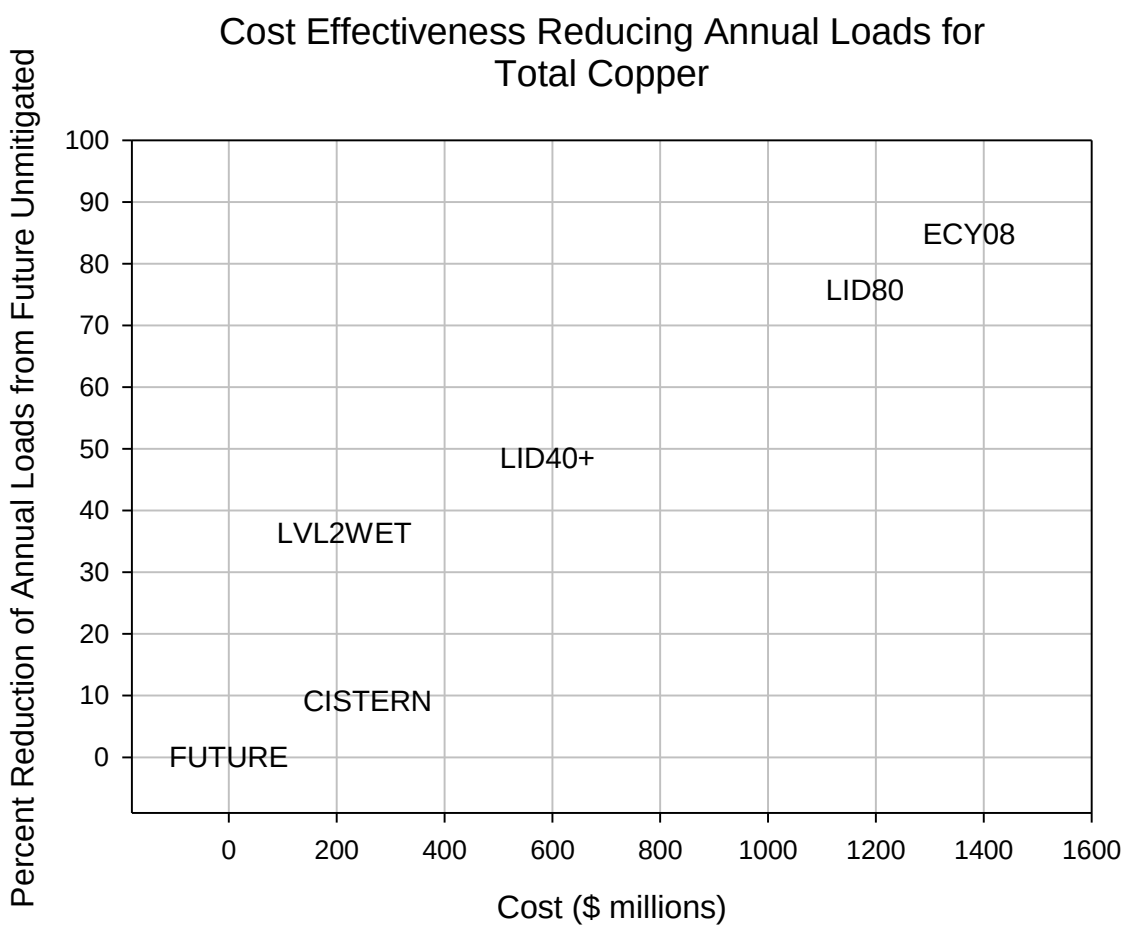

Figure 23 Cost effectiveness of reducing annual loads for total copper (LID40 ≈ LID40+).

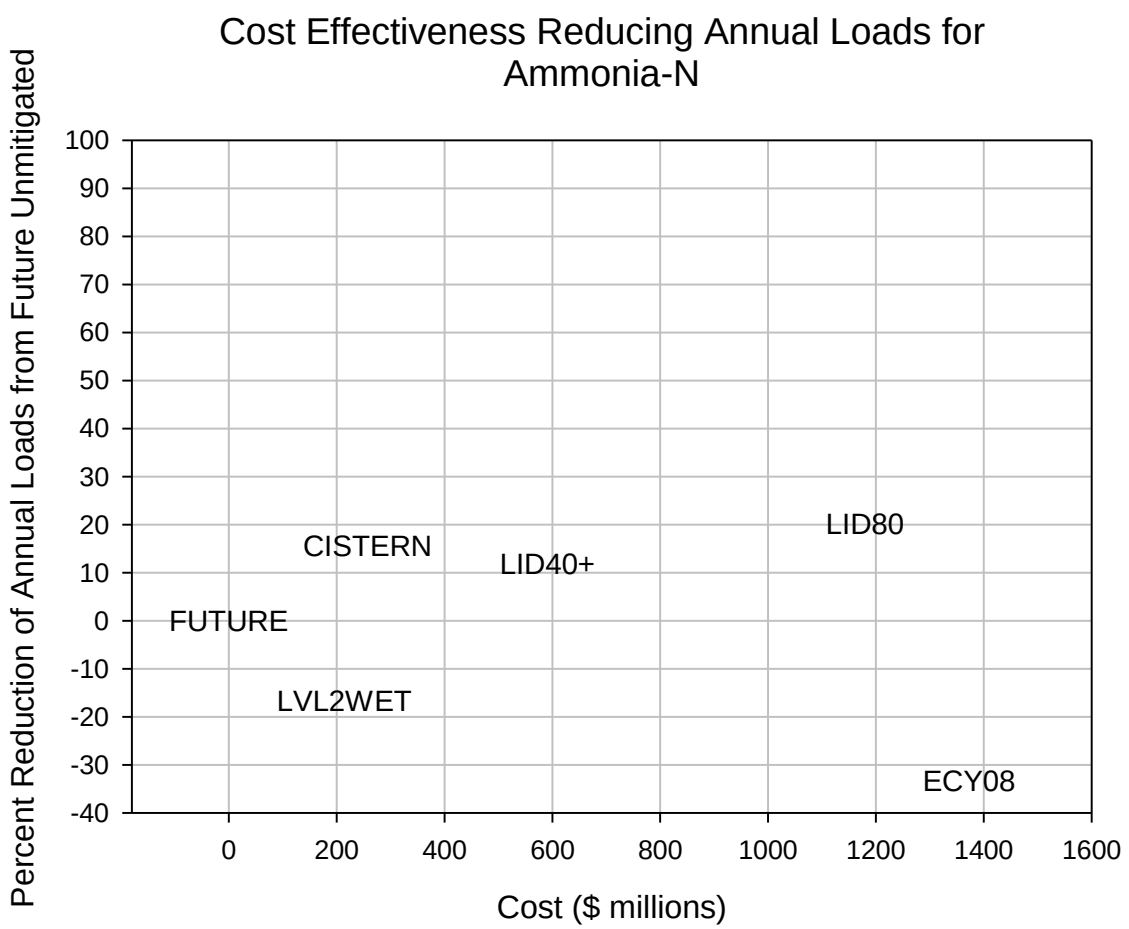

Figure 24 Cost effectiveness of reducing annual loads for ammonia-n (LID40 ≈ LID40+).

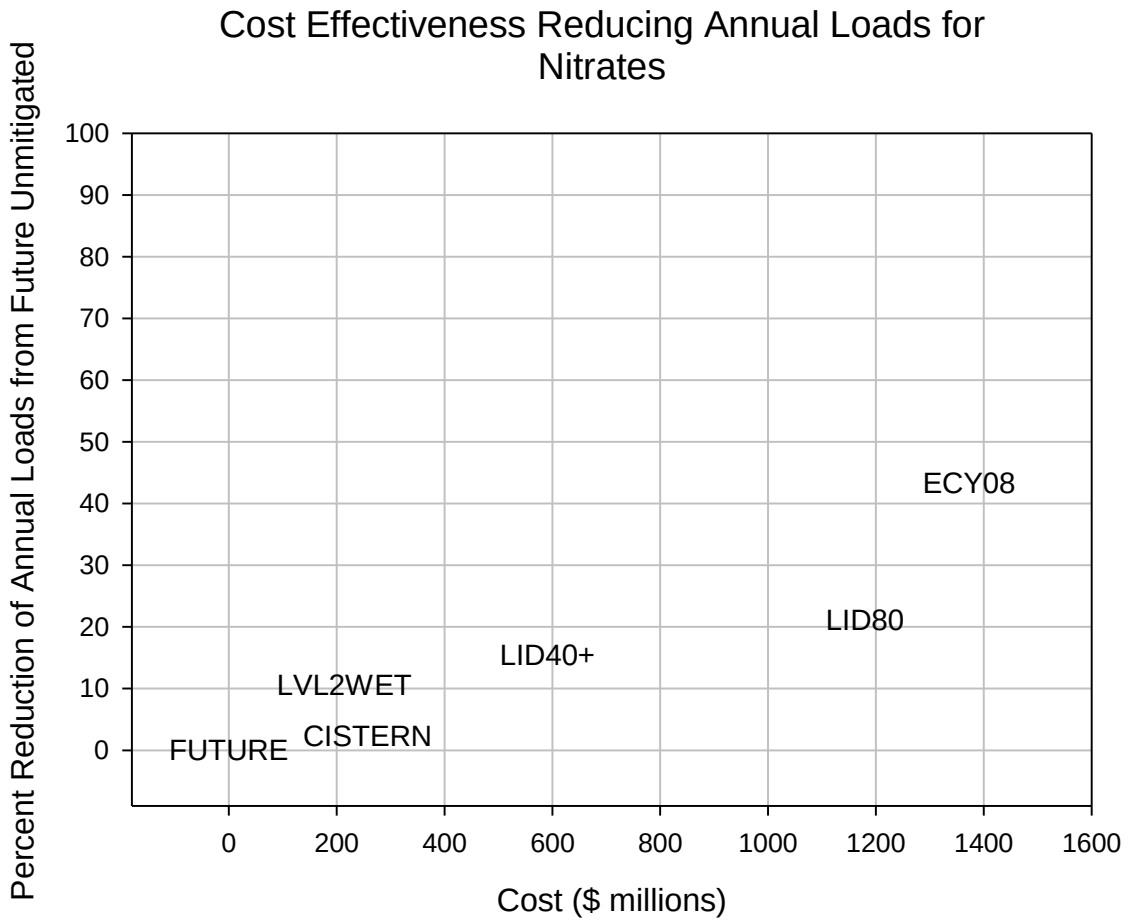

Figure 25 Cost effectiveness of reducing annual loads for nitrates (LID40 ≈ LID40+).

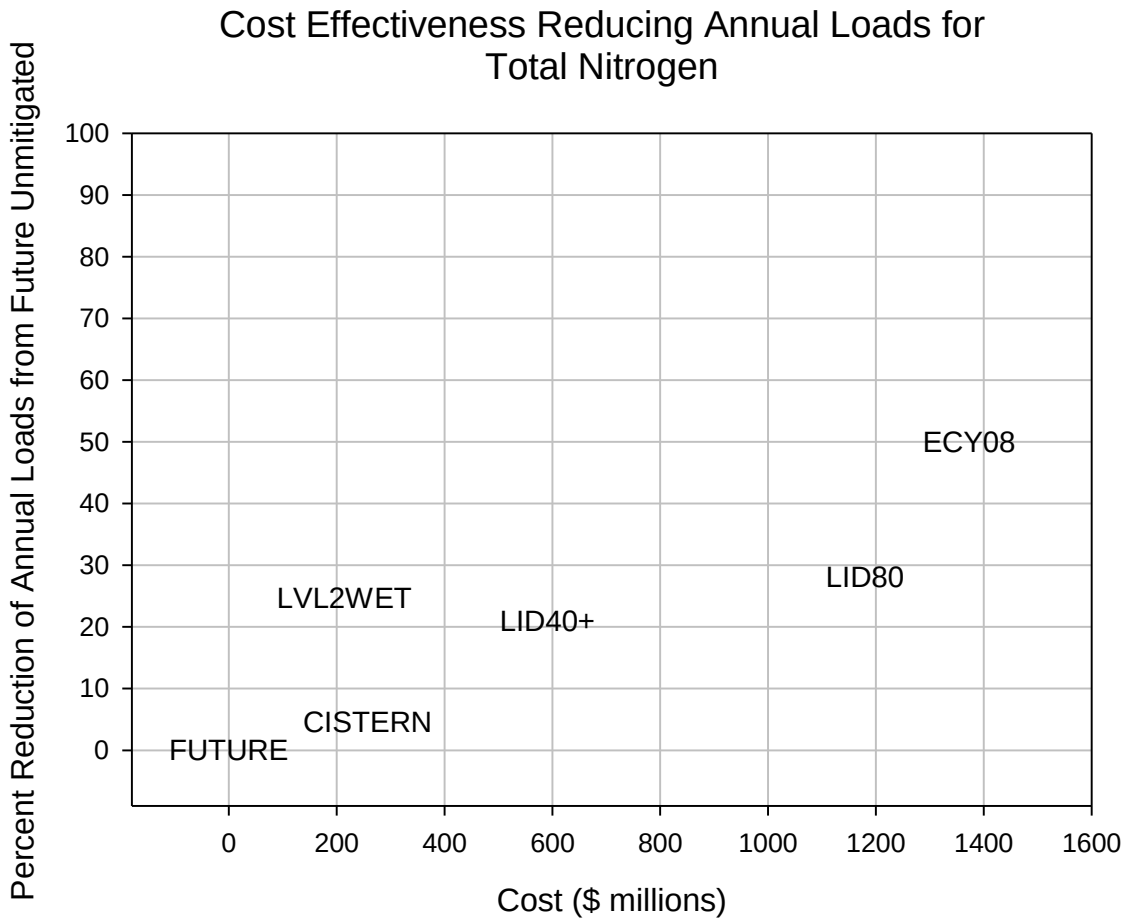

Figure 26 Cost effectiveness of reducing annual loads for total nitrogen (LID40 ≈ LID40+).

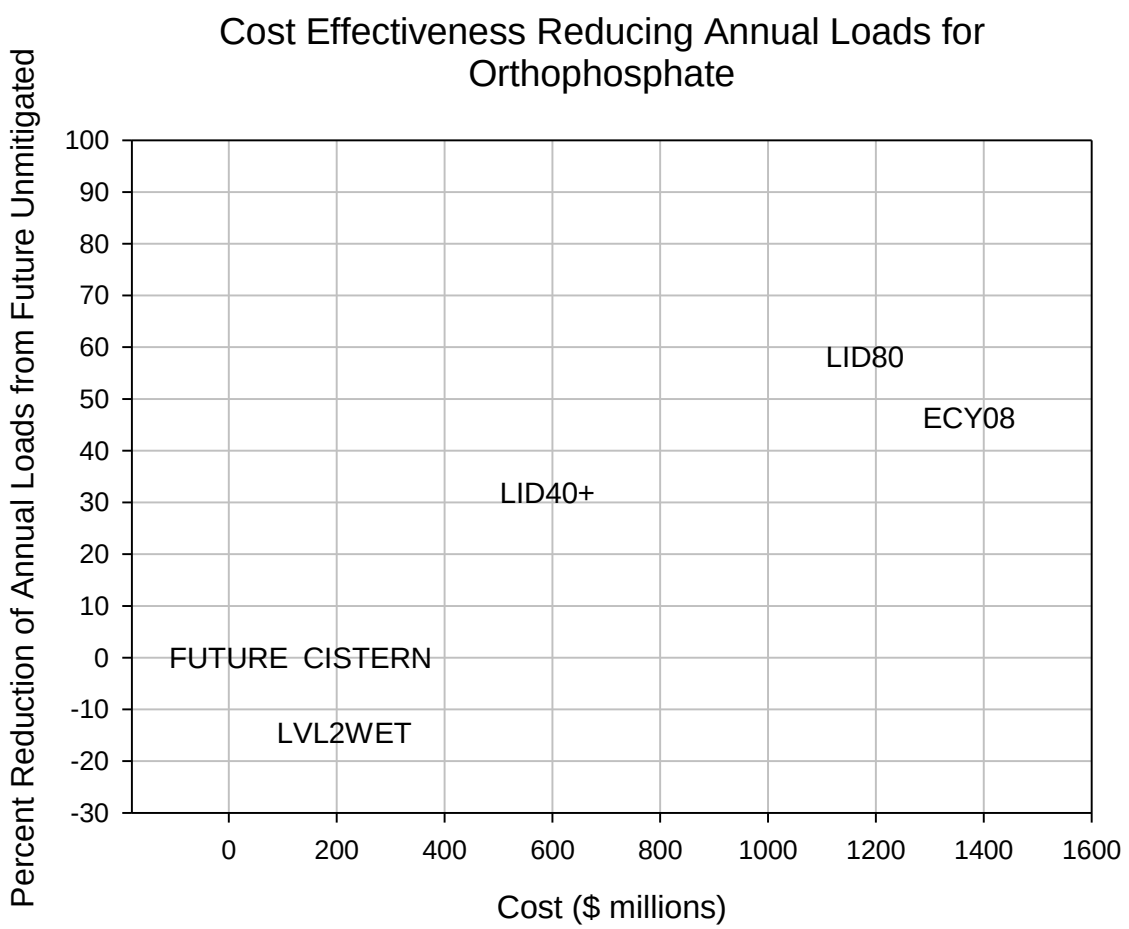

Figure 27 Cost effectiveness of reducing annual loads for orthophosphate (LID40 ≈ LID40+).

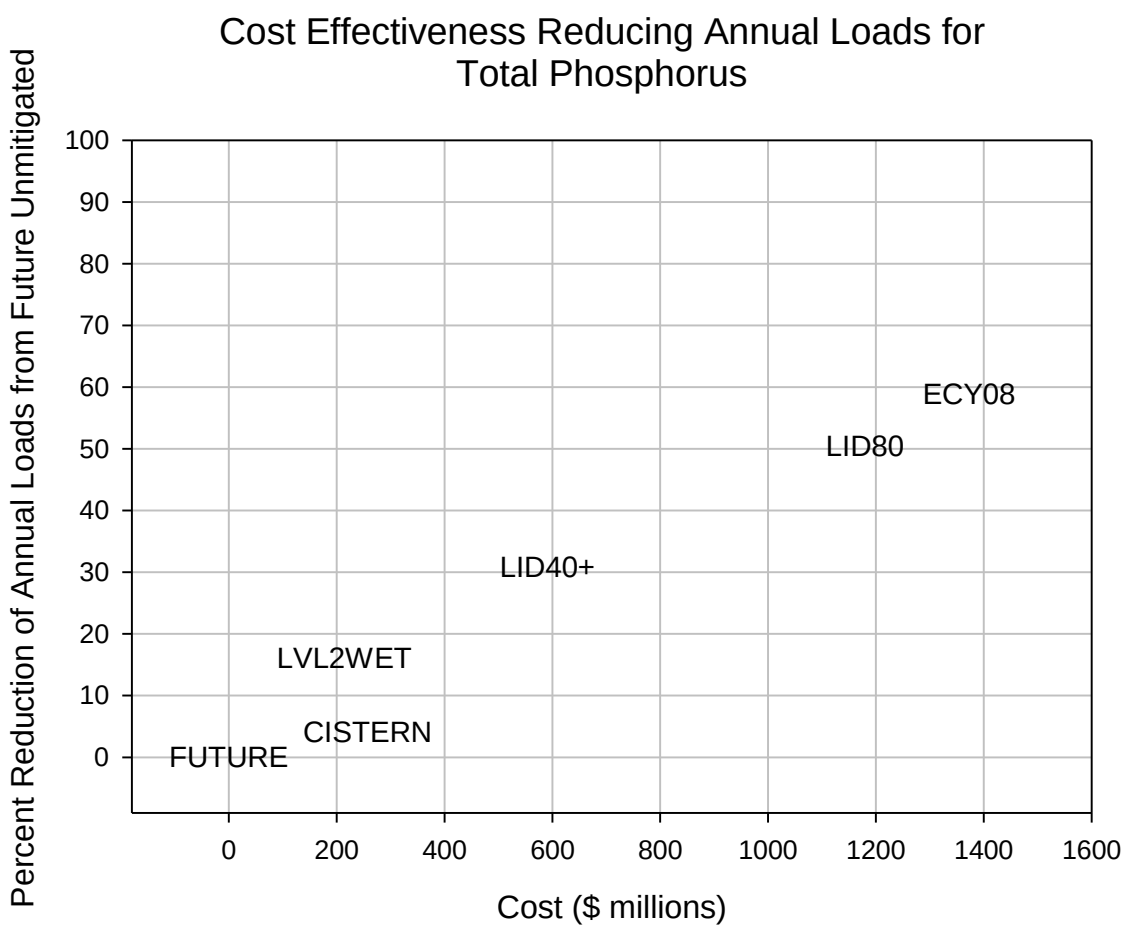

Figure 28 Cost effectiveness of reducing annual loads for total phosphorus (LID40 ≈ LID40+).

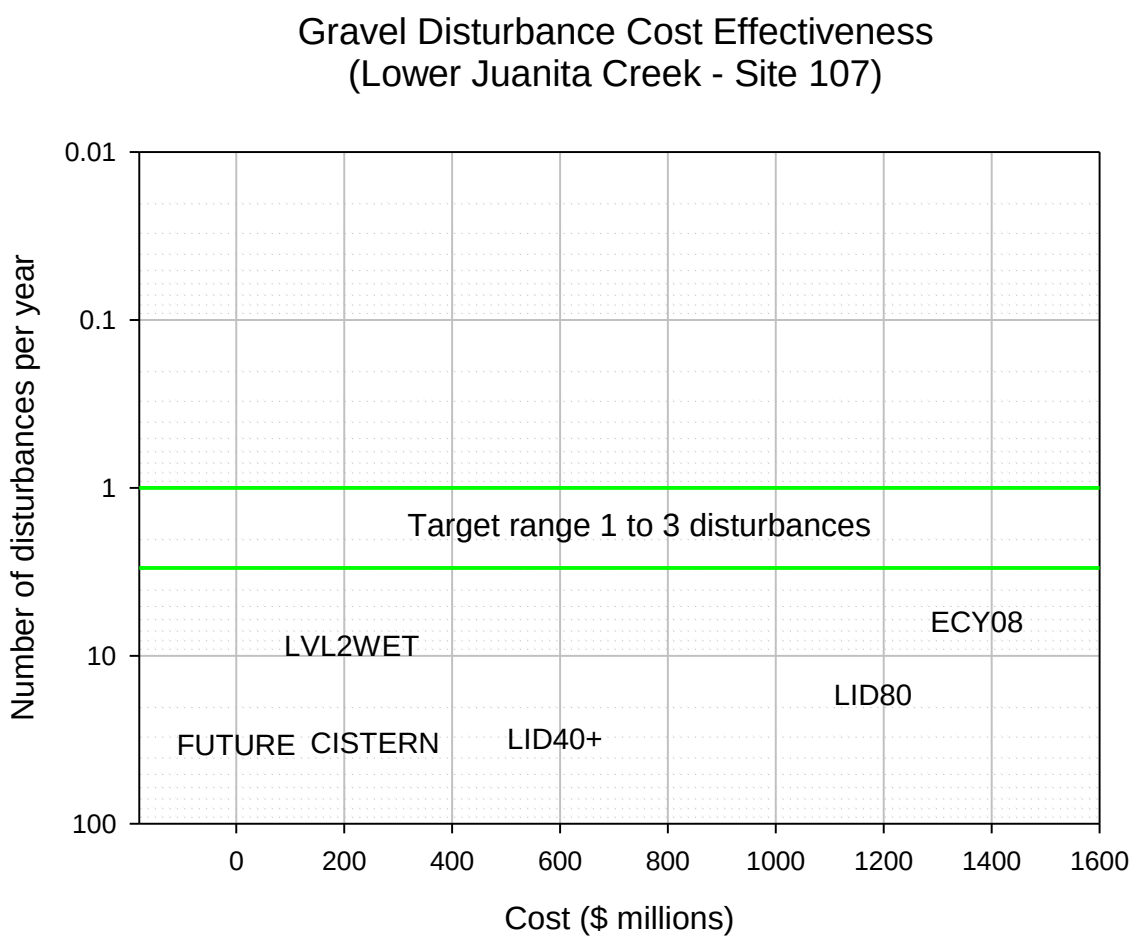

Figure 29 Cost effectiveness for gravel disturbances for lower Juanita, site 107, LID40 ≈ LID40+.

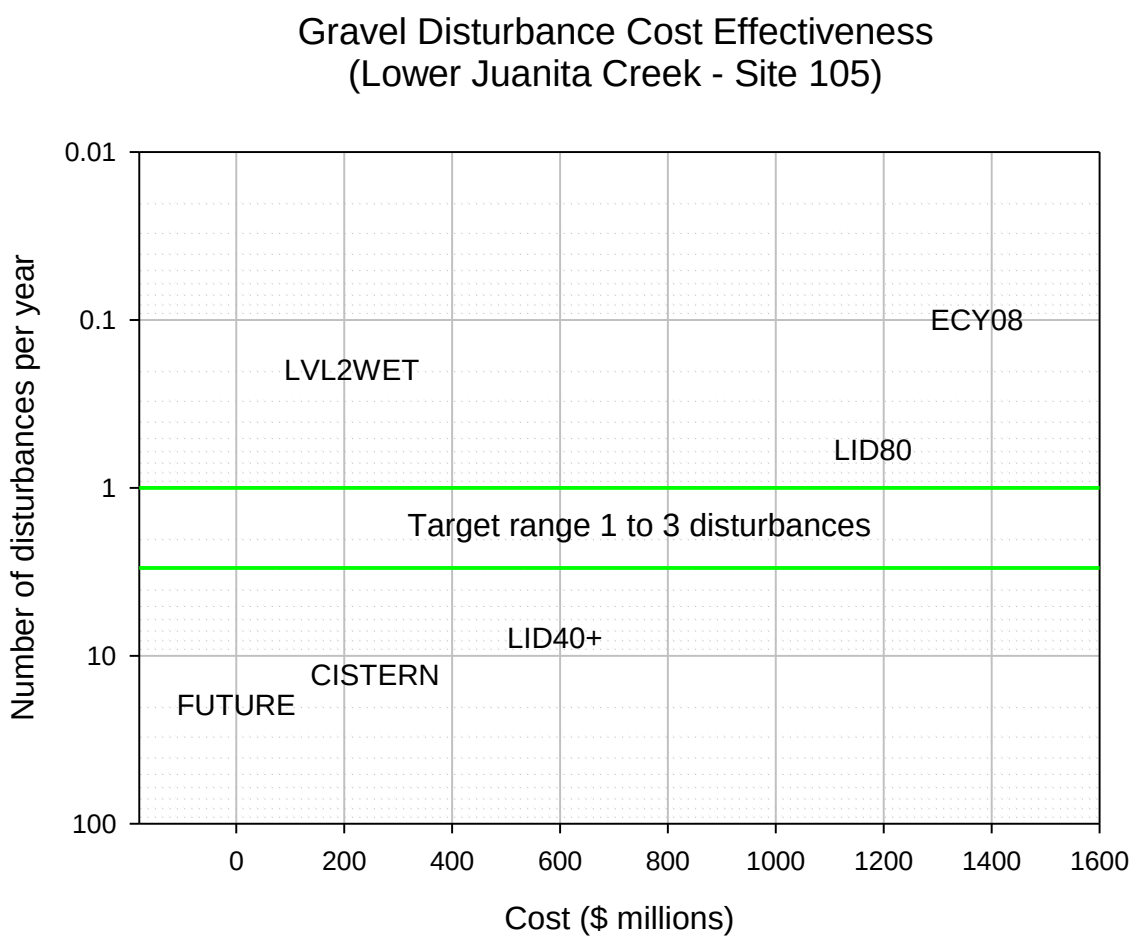

Figure 30 Cost effectiveness for gravel disturbances for middle Juanita, site 105, LID40 ≈ LID40+.

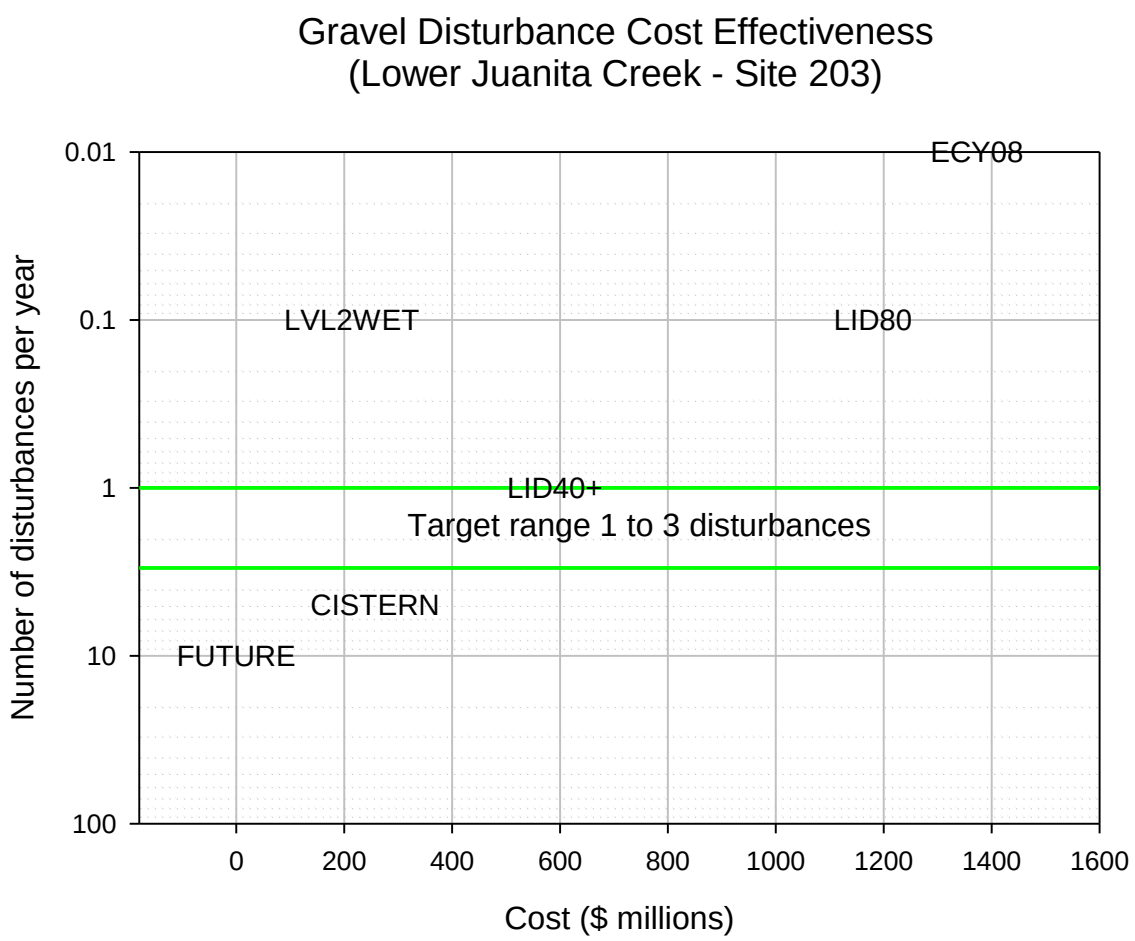

Figure 31 Cost effectiveness for gravel disturbances for upper Juanita, site 203, ECY08 had zero disturbances, set to 0.01 for display purposes, and LID40 was similar to LID40+ with 0.8 disturbances per year.

4.0. DISCUSSION

Hydrologic conditions are the key driver determining and setting the foundation for the health of stream systems (e.g., Poff et al. 1997, Richter 1996, Instream Flow Council 2002). Modified hydrology that results from urbanization can be seen in the exacerbation of the flashiness of stream flows---with corresponding deleterious effects on overall stream health. These effects can be observed (and measured) in lower BIBI scores, degraded water chemistry, and increases in frequency of stream bed mobilization.

In the Juanita Creek stream system, this study found that a basin-wide retrofit to the current stormwater standards required by King County and Ecology (LVL2WET) fails to achieve flow and water quality conditions supportive of beneficial uses. In fact, of seven mitigation scenarios evaluated, we feel confident in asserting that only one, ECY08, meets the stormwater restoration goal. Along with significant improvements made to water quality, the ECY08 scenario was unique among the scenarios evaluated in exceeding the targeted BIBI score of 35—a suggested lower threshold for salmon population viability. In addition, ECY08's predicted BIBI (36) was nearly equal to that generated under fully forested conditions (38)—achieving 93% of this potential maximum score.

It is possible that the predicted BIBI scores for ECY08 (and other scenarios) are conservative (under- predicting BIBI) when other limiting factors are addressed as part of the mitigation or through other restoration efforts. This is suggested by the observation that the original paired BIBI/hydrology data used for creating the predictive regressions likely included suppressing factors (e.g., degraded water quality, lack of riparian buffer, scarcity of large wood, bank instability, etc.) not accounted for in the regression relationships.

Infiltration of stormwater runoff was instrumental in meeting the ECY08 scenario performance standard. In concert with conventional pond facilities, the scenario employed low impact development BMPs (i.e., rain gardens) to treat and infiltrate stormwater runoff from the majority (80%) of the impervious surfaces in the Juanita Creek basin—which has a roughly even split of outwash and till underlying soil types. High infiltration rates assumed in the rain gardens in outwash soil areas was critical in meeting the desired performance. To achieve the same performance in basins dominated by low permeability soils, extensive use of soil amendments or greater reliance on conventional facilities (i.e., ponds) would be necessary.

In addition to being the best performing scenario, ECY08 was also the most expensive, mostly a result of the costs associated with the aforementioned LID BMPs. In particular, the costs for this scenario were driven by the operations and maintenance needs of thousands of individual rain gardens distributed across the landscape—the majority of which will likely be located on private properties. While the assumption that most of these costs will be shouldered by individual property owners may suggest this strategy as being more 'affordable' to public agencies, it comes with a corresponding caution regarding how much reliance should be placed on the performance of privately maintained small scale BMPs -- whose long term functionality, inspection, and maintenance requirements are not yet well understood.

Implementation strategies should evaluate whether publicly maintained regional infiltration facilities are practicable as these could provide the required infiltration performance at reduced costs, due to a presumptive economy of scale realized in construction and maintenance of fewer, larger facilities. This suggestion, however, includes the caveat that potential cost savings resulting from a regional facility approach will come at the price of allowing impacts from untreated stormwater to occur at all locations upstream of the regional facilities.

An interesting result of the gravel disturbance analysis was that highly mitigative scenarios including ECY08, LID80, and LVL2WET produced disturbances below the targeted range of 1 to 3 per year at two of the three sites studied. This suggests that a basin fully restored to the desired hydrologic conditions with amended gravel supportive of Coho salmonids will likely require channel modifications (e.g. benched channels with narrower inner channels where gravels can be mobilized by smaller events and upper benches to pass less frequent, larger peaks) to achieve gravel disturbances within the target range. The available flow energy per unit width under these mitigation scenarios is insufficient to mobilize median D_{50} gravels frequently enough in the existing widened, altered channels. This issue is further compounded by the likely necessary addition of large wood to the system, which presently is sorely lacking (NHC 2010). Any such addition would further reduce the energy in the system available to move gravels. It is possible that the stream channels would 'heal' and narrow over time as the hydrologic regime is gradually restored in response to the gradual implementation of mitigation projects.

Despite the fact that hydrologic mitigation is necessarily the foundation of any restoration effort, a comprehensive approach to stream restoration would include: implementing programs to recover buffer and restore stream shading as a strategy to address temperature issues in the stream system, water quality treatment of developed surfaces, bank stabilization projects to improve water quality and reduce fine sediments that impact salmonid spawning habitat, addition of large wood to achieve densities within the range typical for a natural stream system to improve habitat, and channel modifications in response to the mitigated hydrology.

If communities accept restoration of beneficial uses in streams in the urbanized Puget Sound region as an important goal, large-scale retrofitting efforts are critical in order to mitigate the hydrologic impacts caused by existing development. Updated stormwater regulations, like the ECY08 standard described in this study, applied to new and re-development projects may ultimately succeed in accomplishing this goal, but without aggressive retrofitting, this approach could take decades or longer.

This study advances a new paradigm with regard to the analytic methods used for evaluating stormwater impacts and measuring the effectiveness of mitigation strategies. The study provides an effective quantitative template for examining retrofit options in the Puget Sound region and beyond.

5.0. RECOMMENDATIONS

Based upon the results of the study, the following recommendation is provided to improve flow and water quality conditions to levels identified as critical for supporting aquatic beneficial uses (e.g. fish use) within the Juanita Creek basin stream system:

> Adopt a stormwater performance standard that, at minimum, matches that of the ECY08 mitigation scenario evaluated in this report. Achieving this standard may be accomplished through stormwater regulations applied to new and re-development projects as well as retrofitting existing development. Without an aggressive capital retrofit program, however, it could take many decades for a full retrofit to be accomplished given the slow rates of new and redevelopment occurring in the basin.

<u>Recommended Next Steps:</u>

1. Prepare a detailed plan that includes a time bound implementation strategy and performance targets; and that identifies specific capital projects. Use this report and appendices as a resource for the plan. Consider using a test sub-basin to study the efficacy of the proposed ECY08 mitigation scenario before implementing capital retrofit projects basin-wide. Use the results of the study to inform how to adapt a basin-wide mitigation strategy. Selection criteria for the test sub- basin should include: size (i.e., pick a drainage area that both supports a perennial stream where BIBI and flow can be measured while minimizing other potential limiting factors such as water temperature, dissolved oxygen, etc.); existing BIBI score (i.e. pick an impacted area that the model predicts could be improved significantly); and land availability and cost for the required new stormwater infrastructure (green and gray).

2. Using hydraulic modeling, determine the amount of LWD that could be placed in the stream system considering the limitations of flooding or other local hydraulic constraints.

3. Determine the amount of LWD necessary to achieve the target gravel disturbance metric in the remaining stream reaches (beyond the three modeled in the study) under future conditions with proposed mitigated hydrology and amended gravel size.

4. Determine alternative permutations of LID BMP's (e.g. rain gardens) and detention that result in a hydrologic response comparable to the ECY08 scenario. These alternatives may be more cost effective and/or practicable to achieve the predicted responses in some settings depending upon factors such as land cost, public acceptance of LID, etc.

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