Working Draft

Preliminary Estimates of Summer Environmental Restoration Flow Targets for Basins in King County with Declines in Summer Low Flows

Revised April 2010

King County

Department of
Natural Resources and Parks
Wastewater Treatment Division

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Prepared for:

Planning and Asset Management Unit
Wastewater Treatment Division
Department of Natural Resources and Parks

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King County
Department of
Natural Resources and Parks
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EXECUTIVE SUMMARY

King County conducted a preliminary assessment of water resource conditions to support the preparation of a reclaimed water comprehensive plan. The assessment focused on identifying streams and rivers with summer low flows that are lower than historical summer low flows, wetland areas that are not classified as bogs or forested coniferous wetlands and that are likely to have altered hydrology, and groundwater resources that are reported to have lower groundwater levels. The assessment is intended to provide preliminary information on water resources that might potentially benefit from additional water inputs, with an understanding that further investigation may be needed to understand if, or how, these water resources might benefit from additional water. The planning area includes the county's wastewater service area and areas immediately surrounding the service area.

The streamflow portion of the preliminary water resource assessment identified 15 basins in the reclaimed water planning area as having "multiple" or "fewer" lines of evidence for declining summer low flows.[1] Starting with these 15 basins, King County estimated summer baseflows prior to significant modern human influence (referred to as the natural summer baseflow) and developed planning-level environmental flow restoration targets for 12 of the 15 basins. Restoration targets could be established for only 12 of the basins because all three sources of information (described below) required for estimating targets were available for these basins only.

Environmental flow restoration targets are an estimate of the amount of water needed to restore stream baseflow to a level that is more consistent with historical levels. These estimates are made based on the difference between natural summer baseflow and current summer baseflow. The estimate of natural summer baseflow is derived from the sum of current summer baseflow, basin-level estimates of the net loss (or gain) of water resulting from water management activities, and the effect of land cover change on groundwater recharge and basin-scale stream baseflow.[2] These factors were derived from the following sources:

- **Current average baseflow conditions.** For all 15 stream basins, long-term average baseflows were estimated based on average summer (July–October) baseflows observed over the period 1993–2007.
- **Modeled effects of basin land cover change on summer baseflows.** For all 15 basins, the approach described in King County (2001) was used to incorporate the effect of land cover change on groundwater recharge and basin-level baseflows. [3,]

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[1] King County. 2010. *Working Draft: Identification of Streams with Declines in Summer Low Flows.* Prepared by Curtis DeGasperi and Jeff Burkey.

[2] The effect of land cover change from forest to impervious cover has the potential to increase baseflow by reducing the loss of water through forest evapotranspiration and can potentially reduce baseflow by reducing the amount of rainfall infiltration if impervious cover routes rainfall directly to a stream and out of the basin.

[3] King County. 2001. *Screening Level Analysis of 3rd Order and Higher WRIA 8 Streams for Change in Hydrologic Regime*. Draft report prepared by David Hartley for the WRIA 8 Technical Subcommittee on Flow Regime.

- **Effects of water management activities.** For 12 of the 15 basins, basin-level estimates of the net loss (or gain) of water resulting from water management activities (surface water and groundwater withdrawals, wastewater exports, potable water imports and exports) were taken from studies by King County (2001) for the Cedar-Sammamish basin in Watershed Resource Inventory Area (WRIA) 8 and by Northwest Hydraulic Consultants (2005) for portions of the Green River basin in WRIA 9.[4]

All 12 basins appear to have current summer baseflows that are less than natural baseflow conditions. The estimated environmental summer flow restoration targets for these basins range from 0.9 to 24.3 cfs (0.6 to 15.7 mgd). The range in these estimates reflects not only the degree of land use and water management impacts on summer baseflow but also the range in size of the basins evaluated. The estimated percent loss in summer baseflow relative to predevelopment conditions ranges from 14 percent for Newaukum Creek to 82 percent for North Fork Issaquah Creek. The total estimated environmental baseflow restoration target aggregated for the 12 basins is 83 cfs (54 mgd).

The planning-level environmental flow restoration targets refer to the estimated amount of additional flow (averaged from July–October) desired for a particular stream to achieve conditions that would be considered natural under current climate, but predevelopment, conditions. The amount and timing for specific water quantities in any flow restoration scheme would depend on the method chosen to deliver this amount of water during the summer low-flow period. In general, depending on how water is added to the stream, benefits to wetlands and groundwater may also be realized.

[4] Northwest Hydraulic Consultants, Inc. 2005. *Assessment of current water quantity conditions in the Green River basin*. Prepared for WRIA 9 Steering Committee.

1.0 INTRODUCTION

King County conducted a preliminary assessment of water resource conditions to support the preparation of a reclaimed water comprehensive plan. The assessment focused on identifying streams and rivers with summer low flows that are lower than historical summer low flows, wetland areas that are not classified as bogs or forested coniferous wetlands and that are likely to have altered hydrology, and groundwater resources that are reported to have lower groundwater levels. The assessment is intended to provide preliminary information on water resources that might potentially benefit from additional water inputs, with an understanding that further investigation may be needed to understand if, or how, these water resources might benefit from additional water. The planning area includes the county's wastewater service area and areas immediately surrounding the service area (Figure 1).

The streamflow portion of the preliminary water resource assessment identified 15 basins in the reclaimed water planning area as having "multiple" or "fewer" lines of evidence for declining summer low flows (King County, 2010). Starting with these 15 basins, King County estimated summer baseflows prior to significant modern human influence (referred to as the natural summer baseflow) and developed planning-level environmental flow restoration targets for 12 of the 15 basins. Restoration targets could be established for only 12 of the basins because all three sources of information (described below) necessary for estimating targets were available for these basins only.

Environmental flow restoration targets are an estimate of the amount of water needed to restore stream baseflow to a level that is more consistent with historical levels. These estimates are made based on the difference between natural summer baseflow and current summer baseflow. The estimate of natural summer baseflow is derived from the sum of current summer baseflow, basin-level estimates of the net loss (or gain) of water resulting from water management activities, and the effect of land cover change on groundwater recharge and basin-scale stream baseflow.[5]

Current summer baseflow is based on average summer (July–October) baseflow observed over the period 1993–2007 in stream basins with sufficient[6] stream gauging data that allow for estimating relatively long-term average baseflow. Basin-level estimates of the net loss (or gain) of water from water management activities such as surface and groundwater withdrawals, water supply export and import, and regional wastewater system export, were provided in previous studies by King County (2001) for the Cedar-Sammamish basin in Watershed Resource Inventory Area (WRIA) 8 and by Northwest Hydraulic Consultants (2005) for portions of the Green River basin in WRIA 9. An approach described in King County (2001) to incorporate the effect of land cover change, primarily from the conversion of forest to effective impervious cover, on groundwater recharge and basin-scale stream baseflow was adapted for use in this

[5] The effect of land cover change from forest to impervious cover has the potential to increase baseflow by reducing the loss of water through forest evapotranspiration and can potentially reduce baseflow by reducing the amount of rainfall infiltration if impervious cover routes rainfall directly to a stream and out of the basin.

[6] "Sufficient" was defined in the King County (2010) as having a minimum of 15 years of usable data collected between 1990 and 2007 (with an allowance of 3 missing years over this period).

study.[7] Detailed documentation of the data and methods used and the results are provided in the remainder of this report.

The three basins for which environmental restoration targets could not be estimated were either outside of the WRIAs considered in the King County (2001) or Northwest Hydraulic Consultants (2005) studies (Patterson Creek and Raging River in WRIA 7) or, in the case of Des Moines Creek, were not evaluated in the Northwest Hydraulic Consultants (2005) study because of the study's focus on the Green-Duwamish basin rather than the entirety of WRIA 9. (Des Moines Creek, while in WRIA 9, is a Puget Sound tributary.)

Environmental flow targets as defined in this report are based on the natural flow regime concept (Poff et al., 1997). In general, this concept maintains that native fish and other native aquatic life have adapted to the natural flow regime—the flow regime typical of the many thousands of years prior to significant human alteration of the landscape. This regime includes many aspects of flow that historically have varied over time, including flow magnitude, frequency, duration, timing, and rate of change. Significant changes beyond the natural range in any or all of these flow characteristics are expected to result in adverse biological responses. This report focused on the summer baseflow period when streamflows are typically lowest in this region and when there is greater potential for natural flows to be reduced by human activities such as increased demand for surface water and groundwater sources for irrigation. The summer low-flow period is also the time of year when addition of water from supplemental sources might have the greatest effect on streamflow and water temperature, and thus on habitat and aquatic life.

Adding water to low flows under a natural flow regime approach may not be the only restoration measure necessary if other aspects of the flow regime have been significantly altered. For example, in highly developed areas in and near cities, significant alteration of high flows may have occurred as a result of rapid runoff and transfer of rainfall from streets, rooftops, and parking lots to streams and rivers (DeGasperi et al., 2009). Other critical aspects of the environment may also require restoration if the full biological benefit of flow restoration is to be realized. At a minimum, this would include attention to riparian vegetation cover, sediment transport, water quality, and instream woody debris in any stream initially targeted for inputs of additional water (Lombard and Somers, 2004; Tributary Streamflow Technical Committee, 2006).

The planning-level flow restoration target estimates in this report are for additional water provided to these basins without any consideration of the method or location of delivery. In general, depending on how additional water is provided to the stream, benefits to wetlands and groundwater may also be realized.

[7] Effective impervious area is the portion of total impervious area that conveys runoff directly into receiving waters. This concept recognizes that some forms of impervious land cover direct runoff to adjacent forested or grassed areas that would permit some infiltration and attenuation of direct runoff to receiving waters.

Table 1. Fifteen Basins Identified in King County (2010) with Declines In Summer Low Flows

Basin	Flow Gauge
WRIA 7 – Snohomish Watershed	
Patterson Creek	12145500
Raging River	48a
WRIA 8 – Cedar-Sammamish Watershed	
Big Bear Creek	02a
Evans Creek	18a
Issaquah Creek	12121600
East Fork Issaquah Creek	14a
Mercer (Kelsey) Creek	12120000
North Fork Issaquah Creek	46a
Rock Creek	12118500 / 31L
Sammamish River	12125200 / 51T
WRIA 9 – Green-Duwamish Watershed	
Big Soos Creek	12112600
Covington Creek	09a
Jenkins Creek	26a
Des Moines Creek	11d
Newaukum Creek	12108500

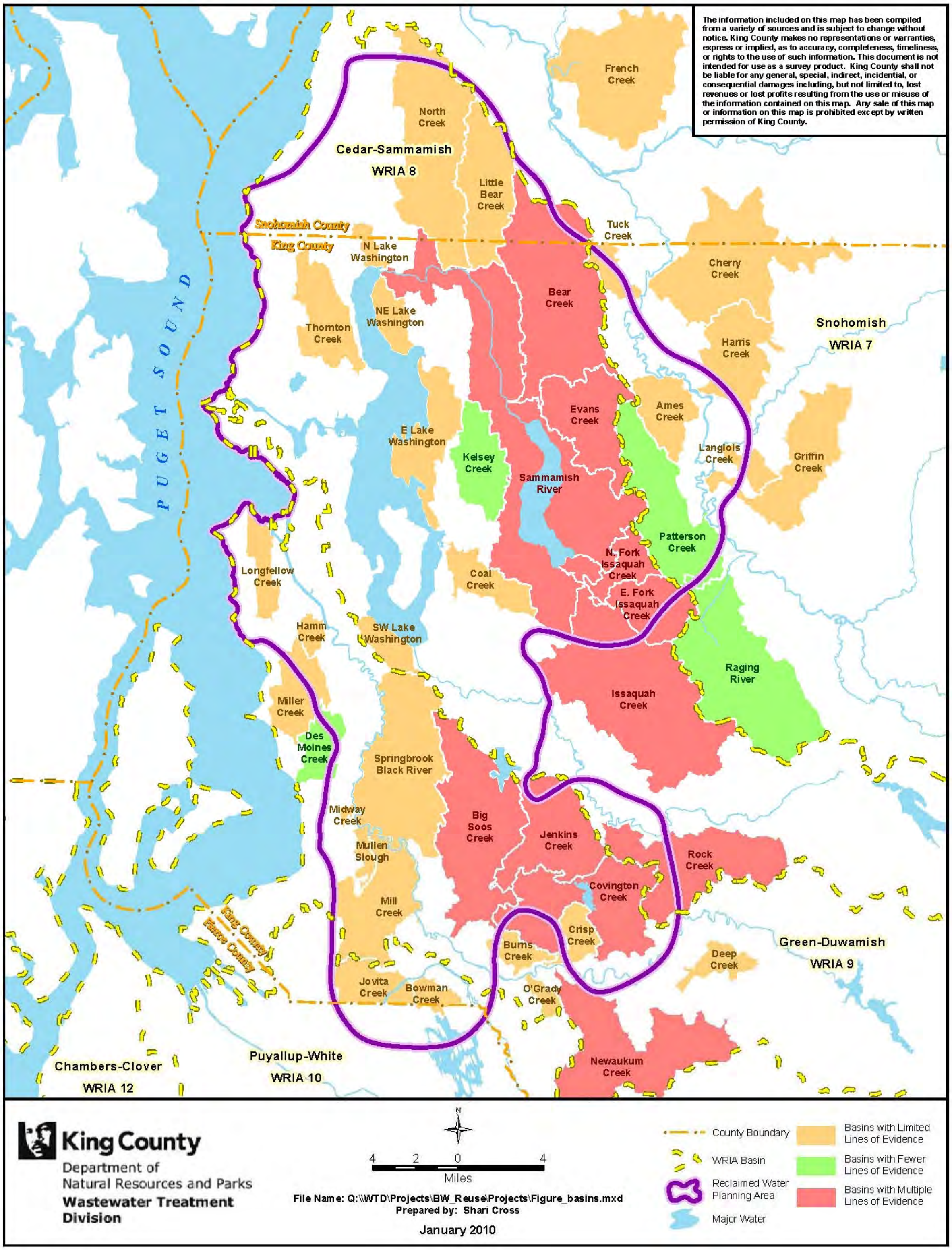

Figure 1. Locations of Basins Identified in King County (2010) with Declines in Summer Low Flows

(Note: Basins identified in red and green have more than limited lines of evidence (more than 2 lines of evidence) of low-flow problems.)

2.0 METHODS

The natural summer baseflow in each basin was estimated using the following equation:

$$Q_{Natural\ Summer\ Base\ Flow} = Q_{Current\ Base\ Flow} + Q_{Effect\ of\ Land\ Cover\ Change} + Q_{Effect\ of\ Water\ Management}$$

The environmental flow restoration target in each basin was estimated based on the difference between the natural summer baseflow and the current summer baseflow:

$$Q_{Environmental\ Restoration\ Flow} = Q_{Natural\ Summer\ Base\ Flow} - Q_{Current\ Base\ Flow}$$

The variables in the two equations above are defined as follows:

$Q_{Current\ Base\ Flow}$	= Current July–October baseflow based on available gauging data
$Q_{Effect\ of\ Land\ Cover\ Change}$	= Change in July–October baseflow based on HSPF model and land cover data (here a positive change indicates a loss of baseflow)
$Q_{Effect\ of\ Water\ Management}$	= Change in July–October baseflow based on published estimates of net water imports/exports and consumptive water use (here a positive change indicates a loss of baseflow)
$Q_{Environmental\ Restoration\ Flow}$	= Estimate of additional water needed to restore average baseflow to predevelopment levels[8]

The result ($Q_{Environmental\ Restoration\ Flow}$) is the estimate of additional flow that would restore average stream baseflow conditions to a level that would occur in the absence of land cover change (historical forest cover) and water management activities (no consumptive groundwater/surface water extraction or water import/export) under recent climate conditions.

The methods and sources of data used to estimate summer environmental flow restoration targets are described below.

2.1 Current Summer Baseflow

The methods used in this study rely on relatively long-term continuous gauging records collected by King County and the U.S. Geological Survey (USGS). King County (2010) identified basins with sufficient historical stream gauging data to perform trend analyses on the annual minimum 7-day low flow and annual mean flow. The same stream gauging data are used in this study to estimate summer baseflow in the 12 stream basins. Even in the least developed of these basins, summer rain events result in storm flow peaks that influence the magnitude of observed daily discharge (DeGasperi et al., 2009). Therefore, this study uses a technique to separate storm flow from baseflow. There are a number of tested and published computerized approaches to separating daily flow records into storm flow and baseflow components. These programs include HYSEP (Sloto and Crouse, 1996), BFlow (Arnold and Allen, 1999), and BFI (Wahl and Wahl, 1988). After evaluating the three programs, King County selected the BFI program because of its ease of use and the reasonableness of results generated using the default input parameters.

[8] Predevelopment: prior to significant human development of the landscape and management (extraction, import/export, consumption) of basin water resources.

Data were downloaded from the USGS or King County discharge monitoring database and formatted for input to the BFI program. The output from the program was imported to an Access database, and an average was calculated for July–October for the period 1993–2007. Only one station did not have complete data for this period: King County's East Fork Issaquah Creek records ended in 2002. An example result from the BFI program for Soos Creek (USGS gauge 12112600) is shown in Figure 2.

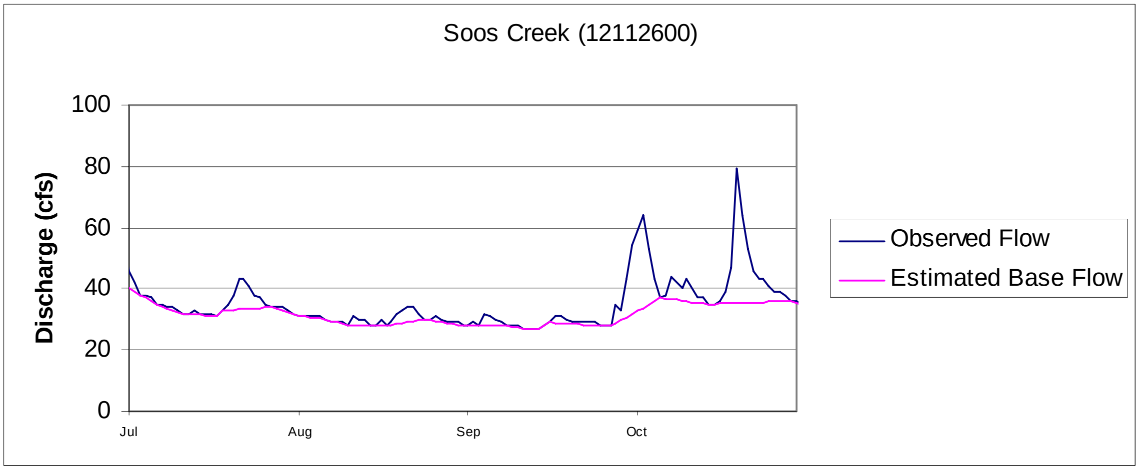

Figure 2. Example Output from the BFI Baseflow Separation Program for Soos Creek, July–October 2007

2.2 Effect of Land Cover Change

2.2.1 Regional Baseflow Model

Unfortunately, even the longest flow records in this region do not extend to a period prior to development of the landscape and water management infrastructure of the basin. In the absence of direct predevelopment flow observations, a carefully constructed model wase developed to provide estimates of summer baseflow conditions prior to significant human alteration of a basin's summer baseflow (King County, 2001). This model is based on initial development and testing by USGS (Dinicola, 1990 and 2001) and subsequent King County experience applying the Hydrologic Simulation Program-FORTRAN (HSPF) in basin planning efforts (for example, King County, 1991). The model relies on spatially explicit information in each basin on surficial geology and current land cover (including forest and impervious surface cover). Predevelopment conditions in the model are estimated by assuming all currently developed land cover was historically covered by forest. This information is then processed to determine the areal extent in each study basin of HSPF-specific conceptual hydrologic response units (HRUs). These HRUs were developed from hydrologic conceptual model and tested for the King County Puget Lowland region by Dinicola (1990 and 2001). These HRUs and regionally tested HSPF model parameters are described and defined in Appendix A.

Conceptually, the model HRUs represent the intersection of two surficial geological characteristics (till or outwash) representing relatively better (outwash) or poorer (till) rain infiltration rates with two vegetation cover types (undisturbed ["forest"] and disturbed ["grass"]) with differing rain interception, infiltration, and evapotranspiration characteristics. The remaining HRUs in the model are effective impervious area (EIA),[9] open water, and saturated soil areas sometimes referred to as wetlands. EIA represents rooftops and paved areas with no infiltration capacity that are connected to a stormwater conveyance network that quickly directs rainfall into the stream channel. Saturated soil and open water areas in the model have the potential to infiltrate water, but they also evaporate water back into the atmosphere.

For this study, an HSPF model was set up that represented unit area runoff and baseflow (in cubic feet per second per square mile [cfs mi^{-2}]) from each of the conceptual HSPF HRUs and the regional model parameters validated by Dinicola (2001) for each of these units (see Appendix A). Datasets representing regional long-term daily rainfall and potential evapotranspiration (PET) are also required inputs to the model. For this study, a long-term hourly precipitation record for Sea-Tac International Airport was used along with a long-term daily PET records based on reference grass PET reported at the Washington State University's Experiment Station in Puyallup as inputs to the model. [10] These datasets provide the most reliable long-term records for the region and currently span October 1948 through September 2008 (Figure 3 and Figure 4).

Output from the model includes predictions of unit area surface runoff (SURO), interflow (IFWO), and active groundwater (AGWO) outflow from each HRU. Consistent with Vaccaro et al. (1998), this study used the HSPF-predicted active groundwater outflow (excluding direct surface runoff and interflow) to calculate average unit area baseflow from each HRU. The July–October period of 1993 through 2007 was selected to represent summer baseflow conditions under recent climate conditions. Although the HRUs of Dinicola (2001) also include categories for land slope, this study did not explicitly consider slope. Instead, the predictions for HRUs with the same surficial geology and land cover were averaged over the three slope classes to generate a regional unit area baseflow factor for each surficial geology/land use classification (Table 2).

[9] Effective impervious area is the portion of total impervious area that conveys runoff directly into receiving waters. This concept recognizes that some forms of impervious land cover direct runoff to adjacent forested or grassed areas that would permit some infiltration and attenuation of direct runoff to receiving waters.

[10] Reliable reference PET records at the Washington State University Experiment Station in Puyallup do not extend back before 1995. Therefore, an empirical model (Jensen-Haise) was calibrated to the Puyallup Experiment Station using daily minimum and maximum air temperature reported at Sea-Tac International Airport as input was used to develop a long-term continuous time series for regional PET.

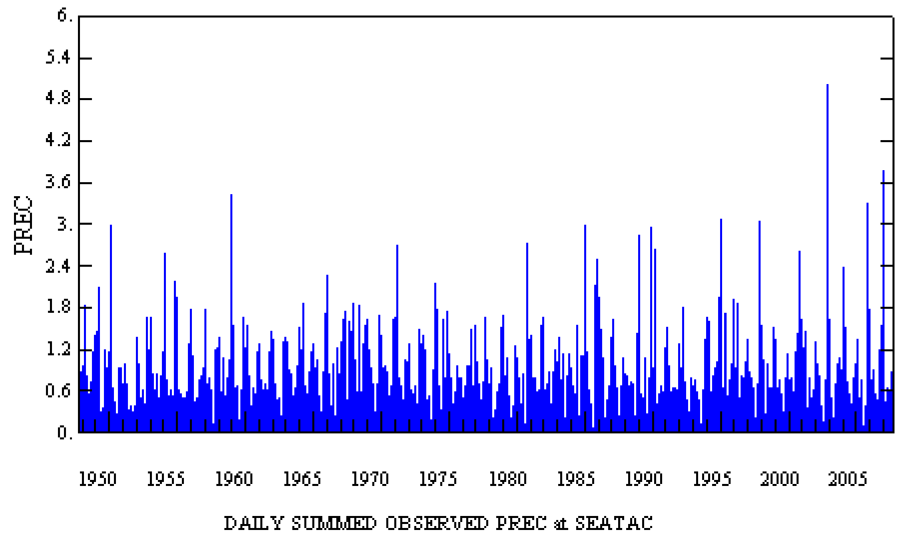

Figure 3. Time Series of Daily Precipitation in Inches Recorded at Sea-Tac International Airport, October 1948–September 2008

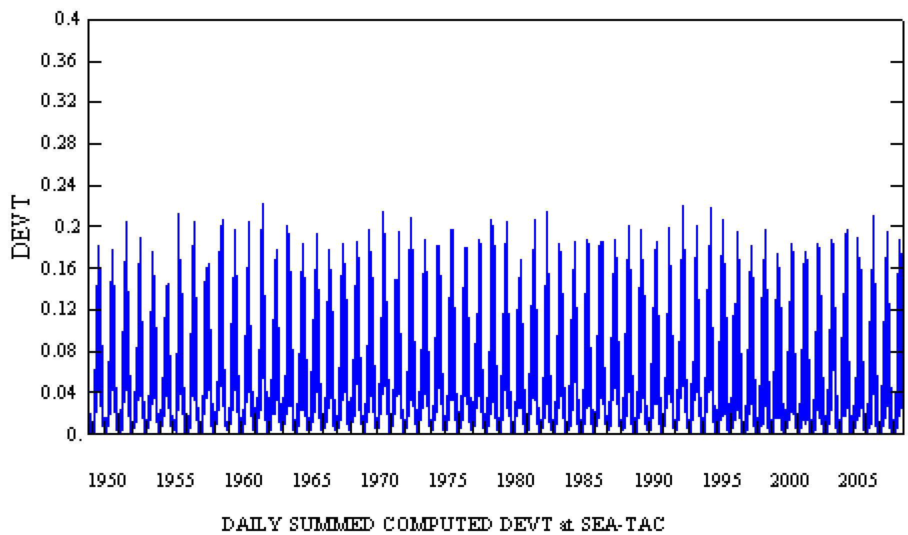

Figure 4. Time Series of Daily Potential Evapotranspiration (PET) in Inches Referenced to Grass PET Reported at the Washington State University Experiment Station in Puyallup, October 1948–September 2008

Table 2. HSPF Model Unit Area Flow Predictions for Each Flow Component (Surface Runoff, Interflow, and Active Groundwater) and Baseflow for Each Conceptual Hydrologic Response Unit

	Surface Runoff (SURO) (cfs mi^{-2})	Interflow (IFWO) (cfs mi^{-2})	Active Groundwater Flow (AGWO) (cfs mi^{-2})
Till Forest Flat	0.00	0.01	0.45
Till Forest Mod.	0.00	0.02	0.49
Till Forest Steep	0.00	0.04	0.50
Till Forest Average			0.48‡
Till Grass Flat	0.03	0.16	0.37
Till Grass Mod.	0.01	0.26	0.41
Till Grass Steep	0.02	0.32	0.42
Till Grass Average			0.40‡
Outwash Forest	0.00	0.00	0.79
Outwash Grass	0.00	0.00	1.02
Saturated	0.01	0.03	0.22
Effective Impervious Area	1.16	0.00	0.00

‡The average of the model-predicted active groundwater flow from the three slope categories for till/forest and till/grass were used to estimate unit area baseflow from these hydrologic response units.

Once the basin area covered by each of these HRUs was determined, the unit area baseflow predicted by the HSPF model was used to estimate the impact of land cover change (the effect of converting forest to grass and EIA) using the following formula:

$$Q_{Effect\ of\ Land\ Cover\ Change} = Historical\ Base\ Flow - Developed\ Condition\ Base\ Flow$$

where,

$$Historical\ Baseflow =$$
$$BFF_{TF}\ (TF + TG) + BFF_{OF}\ (OF + OG) + BFF_{SAT}\ (SAT + OW) + BFF_{TF}\ EIA\ fTill + BFF_{OF}\ EIA\ fOutwash$$

and

$$Developed\ Condition\ Baseflow =$$
$$BFF_{TF}\ TF + BFF_{TG}\ TG + BFF_{OF}\ OF + BFF_{OG}\ OG + BFF_{SAT}\ (SAT + OW)$$

where,

BFF_{TF}	=	Baseflow factor for till/forest (cfs mi^{-2})
BFF_{TG}	=	Baseflow factor for till/grass (cfs mi^{-2})
BFF_{OF}	=	Baseflow factor for outwash/forest (cfs mi^{-2})
BFF_{OG}	=	Baseflow factor for outwash/grass (cfs mi^{-2})
BFF_{SAT}	=	Baseflow factor for saturated soils (cfs mi^{-2})
TF	=	Area of basin covered in till/forest (mi^2)
TG	=	Area of basin covered in till/grass (mi^2)
OF	=	Area of basin covered in outwash/forest (mi^2)
OG	=	Area of basin covered in outwash grass (mi^2)
SAT	=	Area of basin covered in saturated soils/wetlands (mi^2)
OW	=	Area of basin covered in open water (mi^2)
EIA	=	Area of basin covered in effective impervious cover (mi^2)
fTill	=	Fraction of basin with till soils (unitless)
fOutwash	=	Fraction of basin with outwash soils (unitless)

Historical Baseflow (in cfs) represents summer baseflow prior to extensive land cover change and *Developed Condition Baseflow* (in cfs) represents summer baseflow under current land cover conditions without consideration of the effects of water management activities.

2.2.2 Areas Covered by Hydrologic Response Units

The estimates of the area covered by each of the HRUs in any particular basin are generally developed using desktop computer GIS tools to intersect cover/land use and surficial geology data. Estimates of the percent impervious and forest cover of developed land use categories in the dataset are also needed. In addition to these data sources, a method of estimating the amount of EIA from the amount of total impervious area (TIA) for each developed land use category is needed. [11]

The relationship between EIA and TIA would seem to be nonlinear—the more TIA, the less unlikely that new impervious surface added to the basin would not be directly connected to the stormwater conveyance system discharging to a nearby stream channel. However, an analysis performed on a 1.85 km^{-2} basin in Ohio using the 2001 National Land Cover Database (Roy and Shuster, 2009) suggested a linear relationship:

$$EIA = (1.046\,TIA) - 6.23\% \quad r^2 = 0.98$$

A similar analysis performed for the Puget Sound region also found a linear relationship between EIA and TIA (Elmer, 2001). Elmer's relationship is very similar to that found by Roy and Shuster (2009) and was chosen for use in this study. The equation is as follows:

$$EIA = (1.0428\,TIA) - 11.28\% \quad r^2 = 0.85$$

A number of land use/cover datasets readily available on the King County GIS data server were evaluated for use in this study. Of the available data, the 2001 National Land Cover Database (NLCD) for the Puget Sound region (reg_01lndc2) was selected as the most recent dataset available with additional datasets on impervious cover (NLCD percent impervious cover [reg_pimp]) and forest cover (NLCD percent forest canopy cover [reg_forcan098]) that would facilitate the conversion of the land use/cover data to estimates of the area of each HRU within a basin. The 2002 USGS surficial geology cover (ngs_surfgeol) was used to estimate the spatially explicit distribution of surficial till, outwash, and bedrock in the study basins. Bedrock is currently assumed to behave like till (poor infiltration capacity) in the HSPF model.

2.3 Effect of Water Management

The net amount of water (in cfs) extracted from each study basin as a result of basin water management activities were taken from Appendix I (Column H – Base Q Loss-Water MGMT) in King County (2001) for WRIA 8 basins and Table 9.2 (Line L – Total Net Exports) Northwest Hydraulic Consultants (2005) for WRIA 9 basins. More detail on how these estimates were derived can be found in the referenced reports.

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[11] Total impervious area (TIA) includes paved areas, rooftops, parking lots, roads, and other surfaces that do not allow rain to infiltrate directly into the ground. Runoff from some of impervious areas may direct run off to adjacent forested or grassed areas that would permit some infiltration and attenuation of direct runoff to receiving waters. The portion of the total that directs runoff directly to streams is considered effective impervious area.

3.0 FINDINGS

The estimated environmental summer flow restoration targets for the 12 basins evaluated range from 0.9 to 24.3 cfs (0.6 to 15.7 mgd) (Table 3). The range in these estimates reflects not only the degree of land use and water management impacts on summer baseflow but also the range in size of the basins evaluated. The estimated percent loss in summer baseflow relative to predevelopment conditions ranges from 14 percent for Newaukum Creek to 82 percent for North Fork Issaquah Creek. The total estimated environmental baseflow restoration target aggregated for the 12 basins is 83 cfs (54 mgd).

These results provide planning-level environmental flow restoration targets for 12 basins in the planning area. These targets refer to the estimated amount of additional flow (averaged from July–October) desired for a particular stream to achieve conditions that would be considered natural under current climate, but predevelopment, conditions. The amount and timing of any flow restoration scheme would depend on the method chosen to deliver this amount of water during the summer low-flow period of July–October. Depending on how water is added to the stream, benefits to wetlands and groundwater may also be realized.

In general, the effect of land use change on baseflow was estimated to be relatively small compared to the effect of water management exports, ranging from a net reduction in baseflow under current conditions in most basins and a net increase in some less developed basins. This result was not unexpected because there is a tradeoff in a basin's water balance between the replacement of forest cover that reduces direct stormwater runoff—but also evaporates and transpires water back into the atmosphere—and effective impervious area that does not allow any infiltration of water into the ground but does not actively transpire soil moisture back into the atmosphere during the summer (Cuo et al., 2008; King County, 2009).

Table 3. Summary of Analysis of Summer Baseflow in Selected King County Basins and Estimated Summer Baseflow Environmental Targets

Basin	Flow Gauge Station ID	Effective Impervious Area (%)	[A] Summer Baseflow (July–Oct) 1993–2007	[B] Effect of Land Use on Baseflow Recharge (+loss/–increase) (cfs)	[C] Total Net Water Exports (+loss/–increase) (cfs)	[D = A + B + C] Estimate of Natural Summer Baseflow (cfs)	[E = D – A] Estimate of Summer Baseflow Environmental Restoration Target		[F = (E / D)*100) Potential Baseflow Loss as % of Natural Streamflow (%)
							cfs	mgd	
WRIA 7									
1. Raging River	12145500	1	17.6	0.3	Unavailable	-	-	-	-
2. Patterson Creek	48a	2	6.0	-0.2	Unavailable	-	-	-	-
WRIA 8									
3. North Fork Issaquah	46a	9	0.9	0.1	4.0	5.0	4.1	2.7	82
4. East Fork Issaquah	14a	2	3.4	0.0	0.9	4.3	0.9	0.6	21
5. Issaquah Creek	-	2	-	-0.1	-	-	-	-	-
(Issaquah Basin)	121216000	3	26.8	0.1	6.4	33.3	6.5	4.2	19
6. Evans Creek	18a	5	5.5	0.1	5.9	11.5	6.0	3.8	52
7. Bear Creek	-	6	-	0.9	-	-	-	-	-
(Big Bear Basin)	02a	6	21.7	0.9	8.9	31.5	9.8	6.4	31
8. Sammamish River	-	16	-	3.9	-	-	-	-	-
(Sammamish Basin)	12125200 / 51T	8	74.8	4.0	20.3	99.1	24.3	15.7	25
9. Kelsey Creek	12120000	29	6.8	1.5	0.7	9.0	2.2	1.4	25
10. Rock Creek	12118500 / 31L	1	2.7	-0.7	6.1	8.1	5.4	3.5	67
WRIA 9									
11. Covington Creek	09a	4	3.4	-0.3	6.6	9.7	6.3	4.1	65
12. Jenkins Creek	26a	11	12.9	0.5	8.3	21.7	8.8	5.7	40
13. Soos Creek	-	12	-	1.9	-	-	-	-	-
(Big Soos Basin)	12112600	9	31.5	2.1	14.0	47.6	16.1	10.4	34
14. Newaukum Creek	12108500	4	16.6	0.6	2.1	19.3	2.7	1.8	14
15. Des Moines Creek	11d	40	1.3	1.2	Unavailable	-	-	-	-

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Appendix A
Regional HSPF Model Parameters

Table 1A. Regional HSPF model parameters from Dinicola (2001)

	Model Parameter																
	LZSN	INFILT	LSUR	SLSUR	KVARY	AGWRC	INFEXP	INFILD	BASETP	AGWETP	CEPSC	UZSN	NSUR	INTFW	IRC	LZETP	RETSC
Land segment	(in)	(in hr^{-1})	(ft)		(in^{-1})	(day^{-1})					(in)				(day^{-1})		(in)
TFF	4.5	0.08	400	0.05	0.5	0.996	3.5	2.0	0.0	0.0	0.2	1.0	0.35	3.0	0.7	0.7	na
TFM	4.5	0.08	400	0.10	0.5	0.996	2.0	2.0	0.0	0.0	0.2	0.5	0.35	6.0	0.5	0.7	na
TFS	4.5	0.08	200	0.20	0.5	0.996	1.5	2.0	0.0	0.0	0.2	0.3	0.35	7.0	0.3	0.7	na
TGF	4.5	0.03	400	0.05	0.5	0.996	3.5	2.0	0.0	0.0	0.1	0.5	0.25	3.0	0.7	0.25	na
TGM	4.5	0.03	400	0.10	0.5	0.996	2.0	2.0	0.0	0.0	0.1	0.25	0.25	6.0	0.5	0.25	na
TGS	4.5	0.03	200	0.20	0.5	0.996	1.5	2.0	0.0	0.0	0.1	0.15	0.25	7.0	0.3	0.25	na
OF	5.0	2.00	400	0.05	0.3	0.996	2.0	2.0	0.0	0.0	0.2	0.5	0.35	0.0	0.7	0.7	na
OG	5.0	0.8	400	0.05	0.3	0.996	2.0	2.0	0.0	0.0	0.1	0.5	0.25	0.0	0.7	0.25	na
SA	4.0	2.00	100	0.001	0.5	0.996	10.0	2.0	0.0	0.7	0.1	3.0	0.50	1.0	0.7	0.8	na
EIA	na	na	500	0.01	na	na	na	na	na	na	na	na	0.10	na	na	na	0.10

na = not applicable

Notes: Adapted from Dinicola (2001). [Units, are printed below parameter name; where units are not listed, the parameter has no units. Land-segment definitions: TFF = till soils, forest cover, flat slopes; TFM = till soils, forest cover, moderate slopes; TFS = till soils, forest cover, TGF = till soils, non-forest cover, flat slope; TGM = till soils, non-forest cover, moderate slopes; TGS = till soils, non-forest cover, steep slopes; OF = outwash soils, forest cover, all slopes; OG = outwash soils, non-forest cover, all slopes; SA = saturated soils, all covers, all slopes; EIA = effective impervious areas, all slopes. LZN = lower-zone normal storage; INFILT = infiltration index; LSUR = average length of the overland flow plane; SLSUR = average slope of the overland flow plane; KVARY = ground-water outflow modifier; AGWRC = ground-water recession parameter; INFEXP = infiltration equation exponent; INFILD = ratio of the maximum to mean infiltration rate of a pervious area; BASETP = fraction of available-Potential Evapotranspiration (PET) demand that can be met with ground-water outflow; AGWETP = fraction of available-PET demand that can be met with stored ground water; CEPSC = interception storage capacity of plants; UZSN = upper-zone nominal storage; NSUR = average roughness of the overland flow plane; INTFW = interflow index; IRC = interflow recession parameter; LZETP = lower-zone Evapotranspiration (ET) index; RETSC = retention storage capacity of impervious areas.

Table 2A. Detailed definition and description of regional HSPF parameters in Table 1A

Parameter	Definition and description
LZSN	Lower-zone storage – nominal; represents the soil-moisture storage ability of the lower soil zone.
INFILT	Infiltration index; governs the partitioning of water incident on the soil surface into either potential direct runoff (including interflow and overland flow), or lower-zone soil-moisture.
LSUR	Length of surface overland-flow plane; represents the average length of the overland flow plane for a land segment.
SLSUR	Slope of the surface overland-flow plane; represents the average slope of the overland flow plane for a land segment.
KVARY	"K" variation; governs, in combination with AGWRC, the rate at which active ground-water is discharged from a land segment over time. It affects this discharge when there is inflow to active ground-water storage.
AGWRC	Active ground-water recession coefficient; governs the rate at which active ground water is discharged from a land segment over time. When there is no inflow to the active ground-water storage, it is equal to the ratio of the rate of discharge 'today' to the rate of discharge 'yesterday'.
INFEXP	Infiltration equation exponent; it is the exponent in the infiltration equation that governs the rate of decrease of infiltration with increasing soil-moisture in the lower zone.
INFILD	Infiltration difference; it is the ratio of the maximum to the mean infiltration rate within a land-segment. It is used to represent the amount of variation in soil properties within a land-segment type.
BASETP	Baseflow evapotranspiration index; represents the maximum amount of intercepted precipitation that can be stored on vegetation.
AGWETP	Active ground-water evapotranspiration (ET) index; represents the fraction of available PET that can be met from active ground-water storage, (active ground-water storage is the portion of ground water than can discharge to the surface). It represents ET by plants that have roots in the saturated zone.
CEPSC	Interception storage capacity; represents the maximum amount of intercepted precipitation that can be stored on vegetation.
UZSN	Upper-zone storage – nominal; represents the storage ability in depressions and surface layers of a pervious land segment.
NSUR	"N" value of the surface overland-flow plane; represents the average Manning's roughness coefficient of the overland flow plane for a segment.
INTFW	Interflow index; governs the portioning of potential direct runoff into either interflow (shallow-subsurface flow), overland flow, or upper-zone soil moisture storage.
IRC	Interflow recession coefficient; governs the rate at which interflow is discharged from a land-segment over time.
LZETP	Lower-zone evapotranspiration; represents the depth and density of plant roots in the lower soil zone and, thus, governs transpiration from that zone.
RETSC	Retention storage capacity; represents the maximum amount of water that can be retained on impervious land segments.

Source: Adapted from Dinicola (2001).