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**Working Draft**

**Preliminary Estimates of  
Summer Environmental  
Restoration Flow Targets in  
Streams Identified as Likely to  
Benefit from Additional Water  
Inputs**

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September 2009



**King County**

Department of  
Natural Resources and Parks  
**Wastewater Treatment Division**

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# **Preliminary Estimates of Summer Environmental Flow Targets in Streams Identified as Likely to Benefit from Additional Water Inputs**

September 2009

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**King County**

Department of  
Natural Resources and Parks  
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# EXECUTIVE SUMMARY

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This report provides estimates of summer (defined here as July-October) base flow prior to significant modern human influence (referred to as the *natural summer base flow* in this report) and planning level environmental flow restoration targets in 12 basins in King County. Fifteen basins were initially selected for analysis, but natural summer base flow and environmental flow restoration targets could not be developed for three basins due to lack of estimates of water management impacts in these basins.

Environmental flow restoration targets are an estimate of the amount of water needed to restore stream base flow to a level that is more consistent with historical levels. These estimates are based on current average base flow conditions using long-term gauge records, estimates of consumptive water use and water imports/exports by basin from published reports, and modeled effects of basin land cover change on summer base flow.

This report is intended to provide information for consideration during King County's reclaimed water planning process. The information provided consists of estimates of the:

- Summer (July-October) base flow based on available continuous stream gauging records for 15 streams;
- Potential effect of land cover change on observed base flows using the approach outlined in King County (2001) conducted for 15 streams; and
- Potential effect of water management activities (surface and groundwater withdrawals, wastewater exports, potable water imports/exports) on observed base flows available for 12 of the 15 basins considered.

Of the 12 basins for which natural summer base flow estimates could be developed, all appear to have current summer base flows that are less than natural base flow conditions. Based on the data and methods described in this report, the estimated environmental summer flow restoration targets for the basins evaluated ranged from 0.9 to 24.3 cfs (0.6 to 15.7 MGD). The range in these estimates not only reflects the degree of land use and water management impacts on summer base flow, but also the range in size of the basins evaluated. The estimated percent loss in summer base flow relative to pre-development conditions ranged from 14 to 82 percent for Newaukum Creek and North Fork Issaquah Creek, respectively. The total estimated environmental base flow restoration target for the 12 basins for which this estimate was derived was 83 cfs (54 MGD).

These results provide planning-level environmental flow restoration targets for twelve basins in King County. 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 pre-development, 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 through October. Depending on how additional water is provided to the stream, benefits to wetlands and groundwater may also be realized.

## 1.0 INTRODUCTION

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This report provides estimates of summer base flow prior to significant human influence (hereafter referred to as the *natural summer base flow*) and planning level environmental flow restoration targets in 12 watersheds in King County. Environmental flow restoration targets are an estimate of the amount of water needed to restore stream base flow to a level that is more consistent with historical levels. These estimates are based on current average base flow conditions using long-term gauge records, estimates of consumptive water use and water imports/exports from published reports, and modeled effects of land cover change on summer base flow. The estimate of natural summer base flow is derived from the sum of current base flow, basin-level estimates of the net loss (or gain) of water due to water management<sup>1</sup> activities, and the effect of land cover change on ground water recharge and basin-scale stream base flow<sup>2</sup>. The estimated flow restoration target can be derived from the difference between historical and current base flow. Detailed documentation of the data and methods used and the results are provided in the remainder of this report.

Current summer base flow is based on average summer (July-October) base flow observed over the period 1993-2007 in stream basins with sufficient<sup>3</sup> stream gauging data that allows for the estimation of relatively long-term average base flow. Basin-level estimates of the net loss (or gain) of water due to water management activities such as surface and groundwater withdrawals, water supply export and import, and regional wastewater system export have been 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 due to the conversion of forest to effective impervious cover, on ground water recharge and basin-scale stream base flow was also adapted for use in this study.

Environmental flow targets as defined in this report are based on the *natural flow regime* concept (Poff et al., 1997). In general, this concept is 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. In this report focus is on the summer base flow period (July-October), when stream flows are typically lowest in this region and because of the greater potential for natural flows to be reduced by human activities

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<sup>1</sup> Water management activities refers to basin estimates of surface and ground water extractions, export, import, and consumptive use of water and of wastewater management activities.

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

<sup>3</sup> “Sufficient” was defined in the King County (2009a) study as: The station should have a minimum of 15 years of usable data collected between 1990 and 2007 (with an allowance of 3 missing years over this period).

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 stream flow and water temperature, and thus on habitat and aquatic life.

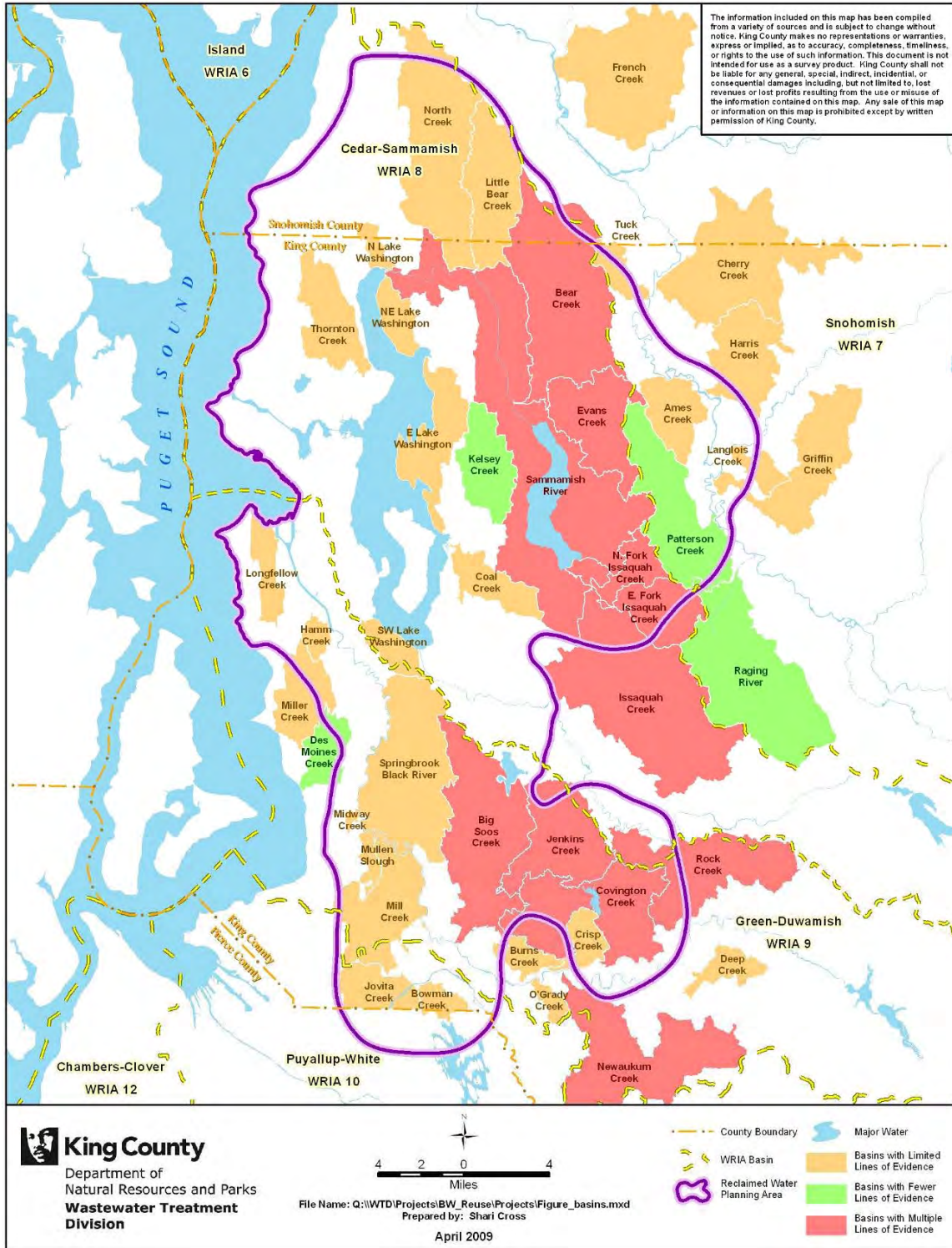
Adding water to low flows under a natural flow regime approach may not be the only restoration measure necessary if other aspects of the flow regime have been significantly altered. For example, in highly developed areas in and near cities, significant alteration of high flows may have occurred as a 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 focus of this study is on the 15 basins identified in King County (2009a) as having more than two lines of evidence that stream flow is lower today than historically due to land cover change and water management activities (Figure 1 and Table 1). However, environmental flow restoration targets could only be made for 12 of the 15 basins due to lack of estimates of water management impacts for three of the basins. The three basins were either outside of the WRIsAs 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 its 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).

This report is intended to provide information for consideration during King County's reclaimed water planning process. The information provided consists of estimates of the:

- Summer (July-October) base flow based on available continuous stream gauging records for 15 streams;
- Potential effect of land cover change on observed base flows using the approach outlined in King County (2001) conducted for 15 streams; and
- Potential effect of water management activities (surface and groundwater withdrawals, wastewater exports, potable water imports/exports) on observed base flows using the data provided by King County (2001) and Northwest Hydraulic Consultants (2005) available for 12 of the 15 basins considered.

These planning level estimates 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.



**Figure 1. Locations of Basins Identified in King County (2009a) that Might Benefit from Additional Water During Summer Low Flow.**

**Note:** Basins identified in Red and Green have more than limited lines of evidence (i.e., more than 2 lines of evidence) of low flow problems.

**Table 1. List of 15 basins selected for analysis in this study**

<b>Basin</b>	<b>Representative flow gauge</b>
<b>WRIA 7 – Snohomish Watershed</b>	
Patterson Creek	12145500
Raging River	48a
<b>WRIA 8 – Cedar-Sammamish Watershed</b>	
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
<b>WRIA 9 – Puyallup-White Watershed</b>	
Big Soos Creek	12112600
Covington Creek	09a
Jenkins Creek	26a
Des Moines Creek	11d
Newaukum Creek	12108500

## 2.0 METHODS

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The historical summer base flow in each basin is estimated in this report using the following equation:

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

The environmental flow restoration target in each basin as estimated in this report is based on difference between the natural summer base flow and the current summer base flow:

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

Where the variables in the two equations above are defined as follows,

$Q_{\text{Current Base Flow}}$  = Current July-October base flow based on available gauging data

$Q_{\text{Effect of Land Cover Change}}$  = Change in July-October base flow based on HSPF model and land cover data (here a positive change indicates a loss of base flow)

$Q_{\text{Effect of Water Management}}$  = Change in July-October base flow based on published estimates of net water imports/exports and consumptive water use (here a positive change indicates a loss of base flow)

$Q_{\text{Environmental Restoration Flow}}$  = Estimate of additional water needed to restore average base flow to pre-development<sup>4</sup> levels

The result ( $Q_{\text{Environmental Restoration Flow}}$ ) is the estimate of additional flow that would restore average stream base flow conditions to a level that would occur in the absence of land cover change (i.e., historical forest cover) and water management activities (i.e., 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.

### **Summer Base Flow**

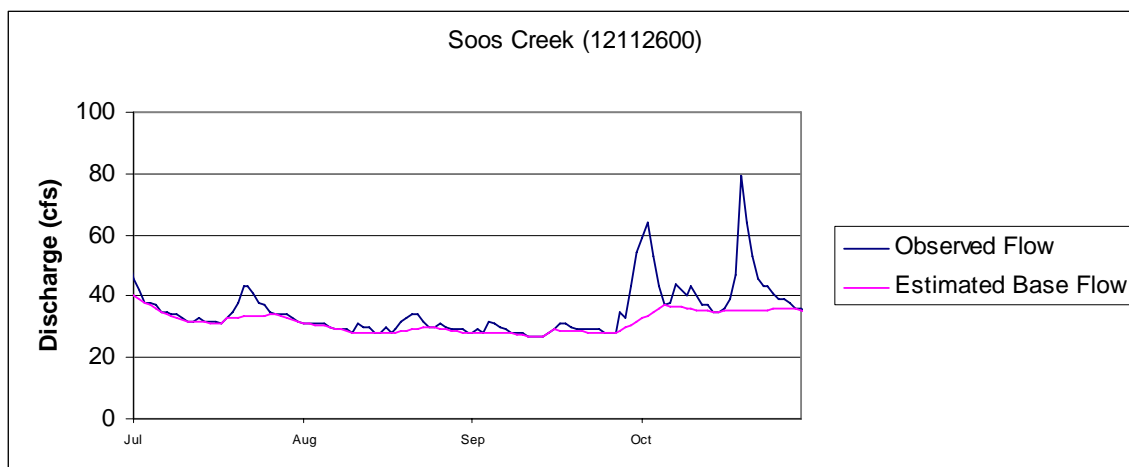
The methods used in this study rely on relatively long-term continuous gauging records collected by King County and the U.S. Geological Survey (USGS). King County (2009a) identified basins with sufficient historical stream gauging data to perform trend analyses on the annual minimum 7-day low flow and annual mean flow. The same stream gauging data is used in this study to estimate summer base flow in the selected study stream basins. Even in the least developed of these basins, summer rain events result in storm flow peaks that influence the magnitude of

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<sup>4</sup> Pre-development: prior to significant human development of the landscape and management (extraction, import/export, consumption) of basin water resources.

observed daily discharge (DeGasperi et al., 2009). Therefore, a technique is used in this study to separate storm flow from base flow. There are a number of tested and published computerized approaches to separating daily flow records into storm and base flow components. These programs include HYSEP (Sloto and Crouse, 1996), BFlow (Arnold and Allen, 1999), and BFI (Wahl and Wahl, 1988). These three programs were evaluated in this study and the BFI program was selected because of its ease of use and the reasonableness of results generated using the default input parameters.

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 the period July-October period for 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 base flow separation program for Soos Creek, July-October 2007.**

### ***Regional Base Flow 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 pre-development flow observations, carefully constructed models have been developed to provide estimates of summer base flow conditions prior to significant human alteration of a basin’s summer base flow. This model was developed by King County (2001) based on the initial development and testing by the USGS (Dinicola, 1990; Dinicola, 2001) and subsequent King County experience applying the Hydrologic Simulation Program-FORTRAN (HSPF) in basin planning efforts (e.g., King County, 1991). The model is based on spatially explicit information in each basin on surficial geology and current land cover (including forest and impervious surface cover). Pre-development 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, 2001). These HRUs and regionally tested HSPF model parameters are described and defined in Appendix A.

Conceptually, the model HRUs represent the intersection of 2 surficial geological characteristics (Till or Outwash) representing relatively better (Outwash) or poorer (Till) rain infiltration rates with 2 vegetation cover types [Undisturbed (“Forest”) and Disturbed (“Grass”)] with differing rain interception, infiltration, and evapotranspiration characteristics. The remaining hydrologic response units in the model are effective impervious area (EIA)<sup>5</sup>, 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 storm water 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 base flow (in cubic feet per second per square mile – cfs mi<sup>-2</sup>) from each of the conceptual HSPF hydrologic response units and the regional model parameters validated by Dinicola (2001) for each of these units (see Appendix A). Data sets 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 record based on reference grass PET reported at the Washington State University’s Experiment Station in Puyallup<sup>6</sup> as inputs to the model. These data sets provide the most reliable long-term records for the region of interest and currently span October 1948 through September 2008 (Figure 3 and Figure 4).

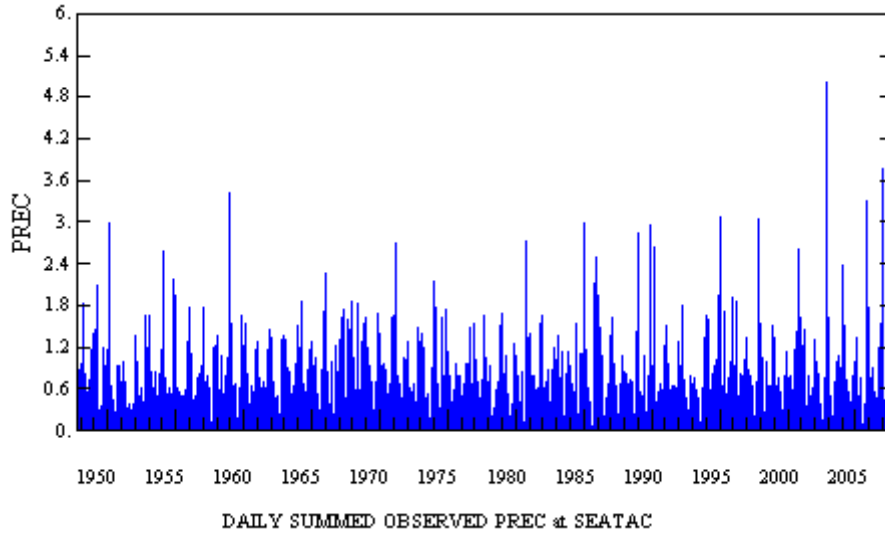
Output from the model includes predictions of unit area surface (SURO), interflow (IFWO), and active groundwater (AGWO) outflow from each HRU. Consistent with Vaccaro et al. (1998), this study used the HSPF-predicted active groundwater outflow (excluding direct surface runoff and interflow) to calculate average unit area base flow from each HRU. The July through October period of 1993 through 2007 was selected to represent summer base flow conditions under recent climate conditions. Although the HRUs of Dinicola (2001) also include categories for land slope, this study does not consider slope explicitly. Instead, the predictions for HRUs with the same surficial geology and land cover were averaged over the 3 slope classes to generate a regional unit area base flow factor for each surficial geology/land use classification (Table 2).

Once the basin area covered by each of these hydrologic response units is determined, the unit area base flow predicted by the HSPF model can be used to estimate the impact of land cover change (i.e., the effect of converting forest to grass and EIA) using the following formula:

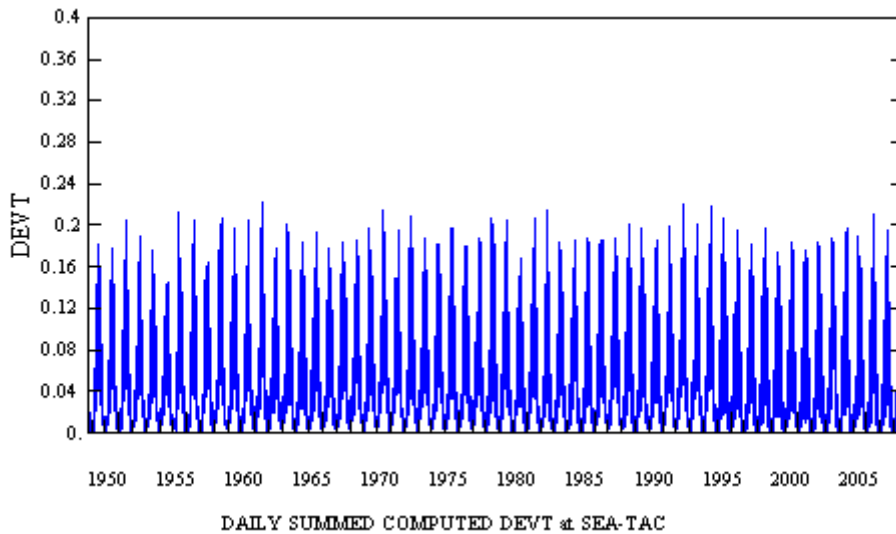
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<sup>5</sup> Effective impervious area is the portion of total impervious area that conveys runoff directly into receiving waters. This concept recognizes that some forms of impervious land cover direct runoff to adjacent forested or grassed areas that would permit some infiltration and attenuation of direct runoff to receiving waters.

<sup>6</sup> Reliable reference PET records at the WSU Puyallup Experiment Station do not extend back before 1995. Therefore, an empirical model (Jensen-Haise) was calibrated to the WSU 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 WSU Experiment Station in Puyallup, October 1948-September 2008.**

**Table 2. HSPF model unit area flow predictions for each flow component (surface, interflow, and active groundwater) and base flow for each conceptual hydrologic response unit.**

	Surface Runoff (SURO) cfs mi <sup>-2</sup>	Interflow (IFWO) cfs mi <sup>-2</sup>	Active Ground Water Flow (AGWO) cfs mi <sup>-2</sup>
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 Avg.			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 Avg.			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 Imp. 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 base flow from these hydrologic response units.

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

where,

*Historical Baseflow* =

$$BFF_{TF} (TF + TG) + BFF_{OF} (OF + OG) + BFF_{SAT} (SAT + OW) + BFF_{TF} EIA f_{Till} + BFF_{OF} EIA f_{Outwash}$$

and

*Developed Condition Baseflow* =

$$BFF_{TF} TF + BFF_{TG} TG + BFF_{OF} OF + BFF_{OG} OG + BFF_{SAT} (SAT + OW)$$

where,

$BFF_{TF}$	=	Base flow factor for Till/Forest (cfs mi <sup>-2</sup> )
$BFF_{TG}$	=	Base flow factor for Till/Grass (cfs mi <sup>-2</sup> )
$BFF_{OF}$	=	Base flow factor for Outwash/Forest (cfs mi <sup>-2</sup> )
$BFF_{OG}$	=	Base flow factor for Outwash/Grass (cfs mi <sup>-2</sup> )
$BFF_{SAT}$	=	Base flow factor for Saturated Soils (cfs mi <sup>-2</sup> )
$TF$	=	Area of basin covered in Till/Forest (mi <sup>2</sup> )
$TG$	=	Area of basin covered in Till/Grass (mi <sup>2</sup> )
$OF$	=	Area of basin covered in Outwash/Forest (mi <sup>2</sup> )
$OG$	=	Area of basin covered in Outwash Grass (mi <sup>2</sup> )
$SAT$	=	Area of basin covered in Saturated Soils/Wetlands (mi <sup>2</sup> )
$OW$	=	Area of basin covered in Open Water (mi <sup>2</sup> )
$EIA$	=	Area of basin covered in Effective Impervious Cover (mi <sup>2</sup> )
$f_{Till}$	=	Fraction of basin with till soils (unitless)
$f_{Outwash}$	=	Fraction of basin with outwash soils (unitless)

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

### **Hydrologic Response Units**

The estimates of the area covered by each of the hydrologic response units 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 data set 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)<sup>7</sup> for each developed land use category is needed.

Although the relationship between EIA and TIA would seem to logically be non-linear – 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 – an analysis performed on a 1.85 km<sup>-2</sup> 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:

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

A number of land use/cover data sets 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\_01Indc2) was selected as the most recent data set available with additional data sets 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 hydrologic response unit 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 (i.e., poor infiltration capacity) in the HSPF model.

### **Water Management Data**

The net amount of water extracted from each study basin as a result of basin water management activities in cfs 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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<sup>7</sup> Total impervious area includes paved areas, rooftops, parking lots, roads, etc. that do not allow rain to infiltrate directly into the ground. Runoff from some of impervious areas may direct runoff 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 RESULTS

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Based on the data and methods described above, the estimated environmental summer flow restoration targets for the basins evaluated ranged from 0.9 to 24.3 cfs (0.6 to 15.7 MGD) (Table 3). The range in these estimates not only reflects the degree of land use and water management impacts on summer base flow, but also the range in size of the basins evaluated. The estimated percent loss in summer base flow relative to pre-development conditions ranged from 14 to 82 percent for Newaukum Creek and North Fork Issaquah Creek, respectively. The total estimated environmental base flow restoration target for the 12 basins for which this estimate was derived was 83 cfs (54 MGD).

These results provide planning-level environmental flow restoration targets for twelve 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 pre-development, 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 through October. Depending on how additional water is provided to the stream, benefits to wetlands and groundwater may also be realized.

In general, the effect of land use change on base flow was estimated to be relatively small compared to the effect of water management exports and ranged from a net reduction in base flow under current conditions in most basins and a net increase in some less developed basins. This result is not unexpected since there is a tradeoff in a basin's water balance between the replacement of forest cover that reduces direct storm water 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, 2009b).

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

Basin No.	Basin Name	Flow Gauge Station ID	Effective Impervious Area	[A] Summer Base Flow (Jul-Oct) 1993-2007	[B] Effect of Land Use on Base Flow Recharge (+loss/-increase)	[C] Total Net Water Exports (+loss/-increase)	[D = A + B + C] Estimate of Natural Summer Base Flow	[E = D - A] Estimate of Summer Base Flow Environmental Restoration Target		[F = (E / D)*100] Potential Base Flow Loss as % of Natural Stream Flow
			%	Cubic Feet per Second (cfs)			cfs	MGD	%	
<b>WRIA 7</b>										
1	Raging River	12145500	1%	17.6	0.3	unavailable	-	-	-	-
2	Patterson Creek	48a	2%	6.0	-0.2	unavailable	-	-	-	-
<b>WRIA 8</b>										
3	North Fork Issaquah Creek	46a	9%	0.9	0.1	4.0	5.0	4.1	2.7	82%
4	East Fork Issaquah Creek	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%
<b>WRIA 9</b>										
10	Covington Creek	09a	4%	3.4	-0.3	6.6	9.7	6.3	4.1	65%
11	Jenkins Creek	26a	11%	12.9	0.5	8.3	21.7	8.8	5.7	40%
12	Soos Creek	-	12%	-	1.9	-	-	-	-	-
	Big Soos Basin	12112600	9%	31.5	2.1	14.0	47.6	16.1	10.4	34%
13	Newaukum Creek	12108500	4%	16.6	0.6	2.1	19.3	2.7	1.8	14%
14	Des Moines Creek	11d	40%	1.3	1.2	unavailable	-	-	-	-
15	Rock Creek	12118500 / 31L	1%	2.7	-0.7	6.1	8.1	5.4	3.5	67%

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## 4.0 REFERENCES

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# Appendix A

## Regional HSPF Model Parameters

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

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



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

Land segment	Model Parameter																
	LZSN	INFILT	LSUR	SLSUR	KVARY	AGWRC	INFEXP	INFILD	BASETP	AGWETP	CEPSC	UZSN	NSUR	INTFW	IRC	LZETP	RETSC
	(in)	(in hr <sup>-1</sup> )	(ft)		(in <sup>-1</sup> )	(day <sup>-1</sup> )						(in)			(day <sup>-1</sup> )		(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**

<b>Parameter</b>	<b>Definition and description</b>
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)