ASSESSMENT OF CURRENT WATER QUANTITY CONDITIONS IN THE GREEN RIVER BASIN

Prepared for:

WRIA 9 Steering Committee

GREEN/DUWAMISH AND CENTRAL PUGET SOUND WATERSHED

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Prepared by:

Northwest Hydraulics Consultants, Inc.

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Executive Summary

Current water quantity conditions are assessed in the Green River Basin upstream from River Mile 23.8 (RM 23.8) where Mill Creek (Auburn), the last of the basin's major freely-draining tributaries, enters the Green. In the context of the large Green/Duwamish sub-basins described in other reports, this study focuses on the upper Lower Green, the Middle Green, and the Upper Green River sub-watersheds. Water quantity conditions are evaluated in terms of the monthly mean and 7-day low streamflows at selected locations along the main stem channel and on major tributaries. Current conditions are further defined by the status of land use, water withdrawals, and water exports in the watersheds upstream of each location as of approximately Year 2000.

This report identifies and draws upon the many prior studies which have characterized water resources and uses in the study area. An accompanying CD-ROM disk provides copies of recent digitally-published documents including the December 2000 Habitat Limiting Factors and Reconnaissance Assessment Report for the Green/Duwamish Watershed, the July 2001 Tacoma Water Habitat Conservation Plan for the Green River, and the July 2001 Central Puget Sound Regional Water Supply Outlook. The CD-ROM also includes scanned excerpts of other relevant documents which include water supply plans and hydrogeological reports.

Streamflow statistics representing current conditions were determined for six sites on the main-stem Green River from RM 63.6, just below Howard Hanson Dam, to RM 23.8, just below the confluence with Mill Creek (Auburn). The main-stem channel sites correspond to the locations of active USGS stream gages and major tributary inputs. Streamflow statistics for tributary streams were determined for Mill Creek which joins the Green at RM 23.8, Soos Creek at RM 33.8, and Newaukum Creek at RM 40.7, and for Covington and Jenkins Creeks which are tributaries to Soos Creek. These tributaries drain a combined basin area of 106 square miles and account for 56% of the total study area downstream of the Tacoma Diversion.

Streamflow statistics including the 50% and 90% exceedance values for 7-day low flows and mean monthly flows were chosen to reflect the study context of managing water for both fish and people. Statistics that emphasize low-flow conditions are of interest because low flows can be a limiting factor to fish utilization of streams. It is during low flow that competition for water between fish and for people becomes most critical. Average-flow conditions are also of interest because average flows are relevant to a water budget which evaluates water supplies and demands over monthly and annual time frames in a system with reservoir storage. The flow statistics are presented in Chapter 3.

Chinook, chum, coho, pink, and sockeye salmon and steelhead trout are all found within the study area. Chinook salmon in western Washington, including those in the Green River, was listed as a threatened species under the provisions of the Endangered Species Act on 1 November 1999, and is a focus species for water management actions.

Chinook salmon are present within the Green River from the lower end of the study area to RM 61. Anadromous salmon have been prevented from accessing the upper Green River above RM 61 since 1911 when a diversion dam was constructed by the City of Tacoma for its domestic water supply. Howard Hanson Dam, built in 1963 by the US Army Corps of Engineers, is located 3.5 miles upstream from the diversion. Juvenile Chinook salmon are planted above Howard Hanson Dam by the Muckleshoot Indian Tribe to rear in the Upper Green River sub-watershed. The primary spawning areas for summer/fall Chinook salmon in the study area are the mainstem Green River and major tributaries including Big Soos Creek and Newaukum Creek.

The Howard Hanson Dam is operated for Green River flood control and also to provide low flow augmentation through management of a summer conservation pool of approximately 30,000 acre-feet. Low flow augmentation is managed by the Army Corps of Engineers in consultation with the Muckleshoot Indian Tribe, Washington Department of Fish and Wildlife, Tacoma Public Utilities, and several other public and private organizations. Water management coordination meetings occur about twice a month from spring through fall to balance the habitat needs of salmonids while accommodating a variety of competing uses.

From the perspective of resource managers trying to meet water needs for fish in the mainstem Green River, there is rarely enough water to meet all resource needs. Instream flow needs during the early summer through fall conservation pool allocation period include: (1) protection of wild winter steelhead redds through fry emergence, (2) adequate summer low flows for juvenile steelhead and salmon rearing, and (3) sufficient flows for Chinook spawning. In the majority of years, none of these needs can be fully met. Providing enough water for even one of these needs means compromising the others.

The flow regime on the mainstem Green River is expected to change from current (2001-2004) conditions as a result of new procedures associated with the implementation of the City of Tacoma's second diversion water right. The exercising of that water right and initiation of revised practices are expected to begin in late 2005. The revised practices will include increased withdrawals for municipal supply combined with an additional 20,000 acre feet of water storage for summer withdrawals and new instream flow commitments. Exercising the second diversion withdrawals include a guarantee by Tacoma Public Utilities to provide minimum continuous instream flows in the Green River as measured at the Auburn Gage. The minimum flows will vary with weather conditions during the summer months and will range from 350 cfs in average and wet years to a minimum of 225 cfs in a severe drought year.

While storage-based streamflow augmentation is critical to maintaining adequate summer flows in the Green River, reservoir refill operations also present a challenge. The late winter-spring period from late February through May is important for salmon life stages, and the additional water storage project at Howard Hanson Dam will require more aggressive refill rates which may impact habitat and life-stage survival. Additional efforts and management techniques need to be developed to minimize downstream impacts on fish during refill operations, particularly in years with low snow pack or dry spring conditions when refill-period impacts would be most likely to occur.

Fishery resource managers have expressed the view that summer low flows and high water temperatures in the mainstem Green River are a significant issue to habitat quantity and quality, and that protection and restoration of river inflows are essential. The new instream flow guarantee associated with Tacoma's second diversion water right will provide some protection and should prevent recurrences of record low flows as have been experienced in the past. In the low flow month of September, for example, the 7-day low flow in the Green River at Auburn under current conditions has been less than 209 cfs in about 10% of all years. Under the new operating procedures, the 7-day low flow will be guaranteed to not drop below 225 cfs and is expected to be maintained at or above 250 cfs in 90% of all years.

The new instream flow obligations and guarantees do not affect flows in the streams which are tributaries to the Green. They do, however, ensure that future Green River low flows at the Auburn control point will be largely independent of (and unaffected by) changes to the flow regimes of the upstream tributaries. For example, the flow obligations would require additional releases from the storage pool to offset any future reduction in tributary low flows. If the tributary low flows should be increased or improved, there could be a corresponding reduction in flow releases from the storage pool. The current study quantifies the flows in the tributary streams, but does not include fish habitat or biological assessments of the adequacy of those flows. If management actions are taken to improve low flows in the tributary streams, the flow benefits will be limited to the tributary channels and will likely not extend to the mainstem channel.

The new instream flow obligations and guarantees will similarly ensure that future Green River low flows will be largely independent of (and unaffected by) changes to groundwater interactions upstream of the Auburn gage. Prior work has identified two reaches along the Green River with significant, concentrated groundwater inputs. The first is in the vicinity of Auburn, where substantial quantities of groundwater from the adjoining White River basin (WRIA 10) flow to aquifers connected to the Green River. The second reach extends from RM 48 to RM 52, where several large springs flow into the Green River. These springs, which include Icy Creek, Black Diamond and Palmer Springs, are believed to be the discharge points from the adjacent Coal Creek and Deep Creek closed depression basins. Groundwater inputs are perceived by resource managers as being important sources of the cool, clean water which is essential for fish habitat.

Land use activities can have a direct and sometimes dramatic impact on streamflows. An assessment was made of the existing and planned urbanization within the study area to provide an indicator of potential past and future impacts to groundwater recharge and streamflows. The analysis does not specifically quantify the effects of land use activities on streamflows and temperatures but does provide data which are relevant to such an analysis. The lower portion of the study area is already heavily urbanized, with the Soos, Jenkins, and Mill Creek (Auburn) sub-basins all having more than 30% impervious cover. A land use change analysis based on satellite imagery of current conditions and land use zoning to predict future conditions found that 18.5 square miles of new urban-density development is planned for areas that are presently covered with forest, grass or bare soil. Approximately one half of this new development is planned to occur in the Soos Creek basin including its tributaries, Jenkins and Covington Creeks.

Water management activities can also have a direct and sometimes dramatic impact on streamflows. An assessment was made of the total extraction (withdrawals) and the total net water exports from the basin above each flow analysis point. Water extraction in the study area is dominated by several large public water supply systems which include Tacoma Water, Covington Water District, and the Cities of Auburn, Black Diamond, Enumclaw, and Kent. For these and other specific users which were identifiable from Department of Health and Department of Ecology records, actual source-specific monthly withdrawal data were obtained for calendar year 2000 and aggregated by sub-watershed. Withdrawals for self-supplied domestic, irrigation, commercial, and other uses were estimated. Potable water exports (wholesale water sales) between utilities were estimated from differences in each utility's Year 2000 Average Day Demand as reported in the Puget Sound Water Supply Outlook and the reported Year 2000 source withdrawals. Wastewater exports from each of the study basins were estimated from modeling performed by the King County Wastewater Treatment Division.

A comparison of the managed water fluxes to the current condition streamflows found that managed water impacts are discernable in all study basins. The largest impacts occur, expectedly, during low flow conditions. The greatest impacts are in Covington Creek, then in Jenkins Creek, which are both tributaries to Soos Creek which ranks third. On Covington Creek, the analysis suggests that extractions and exports have, in combination, caused the natural-conditions median monthly flow in August and 7-day low flows to be depleted by about 70% and 90% respectively. A net depletion of the flow in the middle and lower Green River is also apparent, with extraction and export amounts ranging from about 10% of the total annual flow in 2000 to about 40% of the 7-day low flows. Of the studied streams, the least affected is Newaukum Creek for which extraction and export amounts are equivalent to about 6% of the mean annual flow in 2000 and about 20% of the 7-day low flows.

Eight alternative management actions are presented to stimulate discussion and consideration of options for improving water quantity conditions for fish. These include: (1) land cover management of impervious surfaces and forest areas, (2) various water supply management techniques, (3) stream morphology hydraulic restoration, (4) stormwater infiltration, (5) drought preparedness planning, (6) preservation of functioning septic systems, (7) use of reclaimed wastewater, and (8) additional agreements with Tacoma Water. These options could be pursued to varying degrees alone or in combination in different geographic areas or sub-basins. No single action will solve the water quantity problems that salmonids face in particular sub-basins or in specific years.

It is hoped that further work will take the next step of identifying specific reaches and time periods for which achievable changes in available water quantity would perceptibly benefit or harm fish populations. Such specificity will facilitate reasonable consideration of potential targeted actions to protect and improve flows at those locations and times, and to cumulatively yield significant benefits for salmonids in the Green River and its tributaries.

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Acknowledgements and Credits

This work was performed by Northwest Hydraulic Consultants (NHC) as a subconsultant to Anchor Environmental. Lorin Reinelt of King County DNRP was the King County project manager and provided technical and administrative liaison with the WRIA 9 Technical Committee. Bill Rozeboom, PE, was the NHC project manager and coordinated the contributions from NHC, King County, Ecology, and sub-consultant staff.

The work presented in this document was accomplished with significant technical contributions from King County and Ecology staff. Contributions by King County staff included background document retrieval and preparation of base maps (Karen Bergeron); retrieval and interpretation of well data plus informed advice on local groundwater issues (Ken Johnson); statistical analysis of flow data for tributary streams (Jeff Burkey); processing and interpretation of wastewater flow model results (Mark Lampard); and preparation of report sections on Normative Flows, and Alternative Management Actions for Water Quantity (Lorin Reinelt). The report section on Fisheries Perspective Assessment of Existing Streamflows was prepared by King County (Karen Bergeron and Lorin Reinelt) in consultation with Fish and Wildlife (Gary Engman). Contributions by Ecology staff included obtaining recent metered water withdrawal data from major water utilities (Arlene Harris), and assessments of non-municipal water rights and exempt wells (Steve Hirschey).

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1 Introduction

This report documents an assessment of current water quantity conditions in the Green River Basin, performed as Task 3.3 of the WRIA 9 Strategic Assessment. The study area for the work is all portions of the Green River Basin which are upstream from River Mile 23.8. That lower boundary was established to be just downstream from where Mill Creek (Auburn), the last of the basin's major freely-draining tributaries, enters the Green. In the context of the large Green/Duwamish sub-basins described in other studies, this study area for this work focuses on the upper Lower Green, the Middle Green, and the Upper Green River sub-watersheds.

Figure 1.1 provides a location map showing the boundaries of the study area and the sub-basins addressed in the analysis.

The assessment focuses on identification and characterization of significant surface and groundwater linkages and inputs to the upper Lower, Middle, and Upper Green River and provides a coarse water budget for people and fish in the study area. The technical work was performed in the broader policy context of identifying opportunities to manage water resources and to limit degradation of important sources of cool, clean water in the Green River.

Conceptual Approach

The conceptual approach for the water quantity assessment is to use best available information to quantify: (1) the streamflows which currently exist at representative points of interest; (2) the geographic extent of surface topography and groundwater basins tributary to those points; (3) the current state of basin land development (basin imperviousness) above those points; and (4) current significant consumptive water withdrawals from those basins. The assessment also compiles best available information to quantify: (5) the currently-authorized basin land use development above each point; and (6) the currently-authorized significant water withdrawals from those same basins. Items (5) and (6) incorporated currently-approved land use zoning and currently-certificated or approved water rights and represent a "do nothing" scenario of future conditions.

The assessment does not attempt to re-create any "natural" flows which would have existed in pristine basins without human intervention. Instead, the focus of the study is on actual streamflows which reflect current conditions, and characterizes those flows using hydrologic statistics which are meaningful to fish utilization and water balance assessments. The study also compiles information to qualitatively assess whether basin buildout to currently-authorized land uses and full utilization of existing water rights/certificates is likely to cause significant changes to the current streamflows. The results of these assessments are used as the foundation for identifying water management opportunities.

Analysis Points and Sub-Basins

Twelve sub-basins and twelve corresponding streamflow analysis points were identified for this study in consultation with the WRIA 9 Technical Committee. The analysis points correspond to the locations of active stream gages on the mainstem Green River, stream gages near the mouths of major tributaries, and the mainstem channel at major tributaries and at some intermediate points. Analysis points are located at the downstream end of each of the study sub-basin areas shown on Figure 1.1. The analysis points are described further in Chapter 3.

Analysis Statistics

The analysis statistics selected for the current work were chosen in the narrow context of managing water for both fish and people. Streamflow statistics that emphasize low-flow conditions were chosen because low flows can be a limiting factor to fish utilization of streams. It is during low flows that competition for water between fish and for people becomes most critical. The statistics also include average-flow conditions because average flows are relevant to a water balance budget in which some storage is available and which evaluates water supplies and demands over monthly and annual time frames. Additional, complex flow statistics are expected to be produced later as a product of the King County Normative Flow Studies project, in progress.

The analysis statistics selected to describe current conditions streamflows for each of the analysis points are listed below.

1. 7-day low flows, by month, long-term medians (50% exceedance).
2. 7-day low flows, by month, 90% exceedance values.
3. Mean monthly flows, long-term medians (50% exceedance).
4. Mean monthly flows, 90% exceedance values.

The analysis statistics selected to describe land use and water extraction conditions in the sub-basins tributary to each point of analysis are listed below.

5. Current-conditions consumptive extraction from wells and diversions.
6. Future-conditions potential cumulative extraction based on outstanding water rights certificates and claims for major urban purveyors.
7. Current conditions effective impervious area, from satellite imagery.
8. Future conditions effective impervious area per approved land-use zoning.

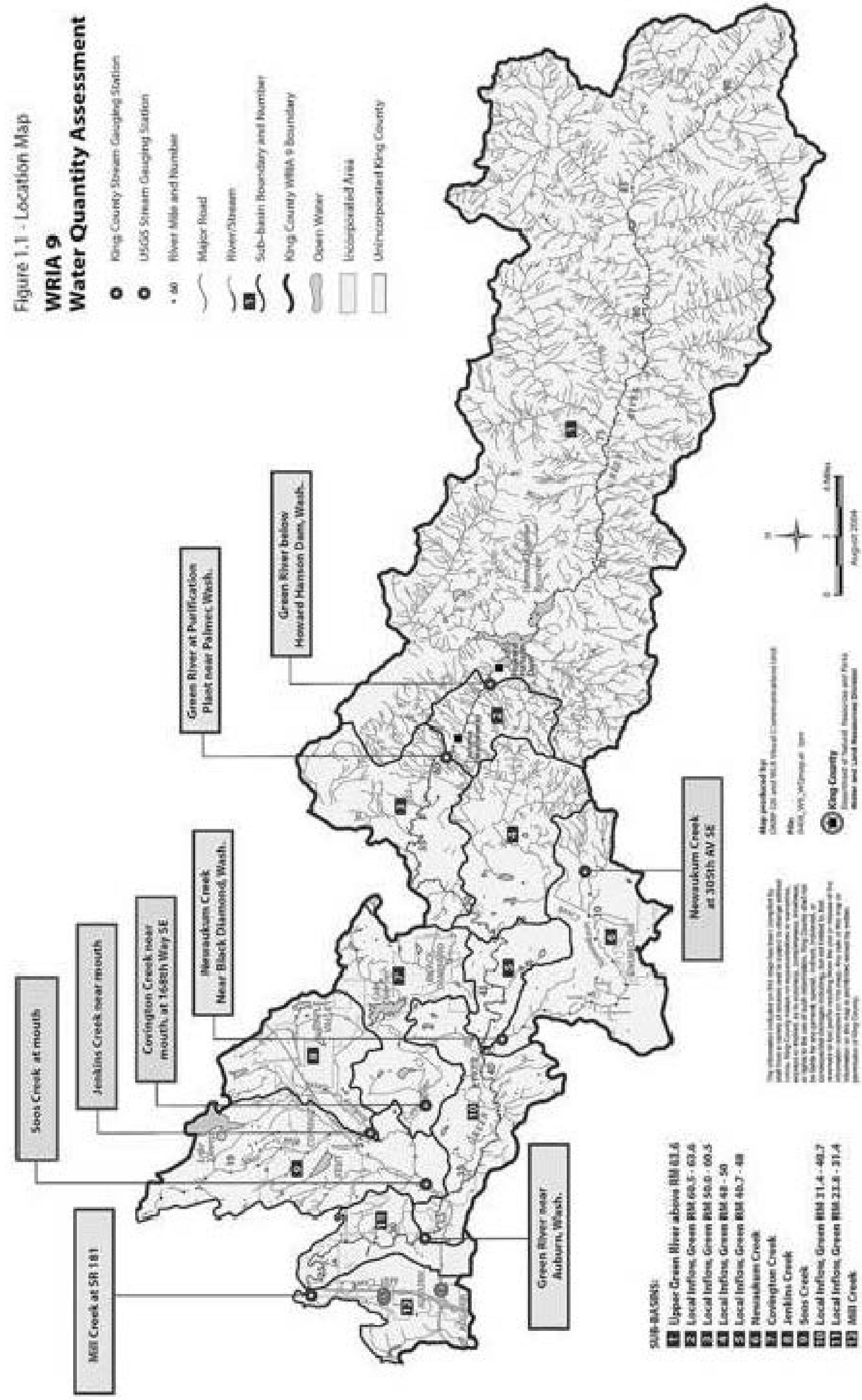

Figure 1.1. Location Map (Placeholder for 11 x 17 color sheet)

2 Summary Inventory of Existing Information

A large body of information exists to describe surface and ground water resources and fish populations in the Green River Study Area. Additional studies by others are currently in progress to expand that body of knowledge. The current work draws from the existing information base and, to the extent possible, is coordinated with other known active studies. The intent is to not re-create (or ignore) relevant information from previous work, and to not duplicate the products of other efforts in progress.

A summary list of active studies, published reports, and sources of data which were obtained for review is provided below. A CD accompanying this report provides digital copies of those reports obtained digitally from internet or agency sources. Most of the older reports, including groundwater studies and water supply plans, are published only in hard-copy format and were obtained for review as loan copies from King County and Ecology libraries.

Information Source	**Date**	**Contents**	**Availability**
Habitat Limiting Factors and Reconnaissance Assessment Report, Green/Duwamish and Central Puget Sound Watersheds, by King County and Washington Conservation Commission	12/2000	Major reference. Provides a current snapshot in time of the existing salmonid species and the habitat conditions that limit the natural production of salmonids in the Green / Duwamish River watershed and other areas within WRIA 9.	Digital (copy included on CD)
Tacoma Water Habitat Conservation Plan Green River Water Supply Operations and Watershed Protection	07/2001	Major reference. Documents current, and proposed upper basin withdrawals, negotiated instream flow guidelines, and discusses operations of Howard Hanson Dam.	Digital (copy included on CD)
2001 Central Puget Sound Regional Water Supply Outlook, by the Central Puget Sound Water Suppliers' Forum	07/2001	Major reference. Assesses the state of municipal water supply and preliminary aquatic habitat instream flow needs in the three-county region of Pierce, Snohomish, and King Counties.	Digital (copy included on CD)
US Geological Survey Continuous Daily Streamflow Data	Annual	Recorded streamflow data at 42 mainstem and tributary sites in the Green-Duwamish basin, various periods of record.	CD includes station list, with links to on-line data.
King County WRIA 9 Streamflow Data	Annual (recent)	Recorded recent streamflow data for many tributary streams.	King County DNR
City of Auburn 1999 Hydrogeologic Characterization Report	1999	Four-volume report includes groundwater modeling and non-USGS streamflow data for sites on the Green and White Rivers in the vicinity of Auburn	Excerpts scanned as PDF file, included on CD.

Information Source	**Date**	**Contents**	**Availability**
Ecology Initial Watershed Assessment, WRIAs 9 & 10	01/1995	Provides an overview of basin hydrology, instream flow regulations, and consumptive use patterns	Digital (copies included on CD)
USGS Water Use Data Summary by Hydrologic Unit	1985, 1990, 1995	Total annual water use, aggregated by groundwater vs surface water source, and type of use,	Digital (1995 data included on CD)
Ecology, Green River Fish Habitat Analysis using the Instream Flow Incremental Methodology	07/1989	Five study sites were analyzed representing approximately 40 miles of the Green River, excluding RM 0 to 12 (tidal influence) and also excluding the gorge from RM 46 to 58.	Digital (copy included on CD)
USGS Water Supply Paper 1852, Water Resources of King County, Washington	1968	Good summary of surface water and groundwater resources, availability, and water use.	Scanned copy included as PDF file on CD
USGS Water Supply Bulletin No. 28, Geology and Ground-Water Resources of Southwestern King County	1969	Good documentation of geology and groundwater. Includes estimates of groundwater flows and summary of known springs.	Excerpts scanned as PDF file, included on CD.
South King County Ground Water Management Plan	04/1991	Includes maps of groundwater flow in shallow aquifer system; analyses of groundwater in Green River Valley and in Covington upland (Soos, Jenkins, Covington Creeks) .	Excerpts scanned as PDF file, included on CD.
USGS Water-Resources Investigations Report 92-4098, Occurrence and Quality of Ground Water in Southwestern King County	1995	Most recent and detailed mapping of aquifers. GIS layers with report's spring locations and major wells obtained for this study from Steve Sumioka (USGS)	Excerpts scanned as PDF file, included on CD.
Directory to Washington State Coal Mine Map Collection	1983	Discusses mining methods, shows areas of know coal mines, but no detail. Mines documented in area of Deep Creek, Coal Creek sub-basins.	Excerpts scanned as PDF file, included on CD
King County Regional Infiltration/Inflow (I/I) Control Program, wet weather monitoring	2001-2002	Data and technical memos. Very large amounts of detailed data focusing on wet-weather, not low flow, periods.	Tech Memos included on CD
City of Kent Water System Plan	1988	Water sources include Clark, Kent, and Armstrong Springs, plus wells and interties to Water District 75 and Tukwila.	Excerpts scanned as PDF file, included on CD.

Information Source	Date	Contents	Availability
Covington Water District Comprehensive Water System Plan	1994	Water sources include wells or well fields at Ravensdale, Lake Sawyer, and Witte Road, with other wells applications pending. Interties with Cedar River Water and Sewer, and Water District No. 111.	Excerpts scanned as PDF file, included on CD.
Soos Creek Water and Sewer District Water Comprehensive Plan	1996	Water is purchased from the City of Seattle. The district uses water diverted from the Cedar River to the Lake Youngs reservoir.	Excerpts scanned as PDF file, included on CD.
City of Auburn Comprehensive Water Plan	2001	Water sources include springs tributary to the White River and several wells in aquifers associated with the White and Green Rivers. Interties to adjacent purveyors	Excerpts scanned as PDF file, included on CD.
City of Enumclaw 1993 Comprehensive Water System Plan	05/1994	Water sources include two wells (one as a standby source) and two springs. An intertie to Tacoma is available for emergency use.	Excerpts scanned as PDF file, included on CD.
City of Black Diamond Final Comprehensive Water System Plan	2000	Water source is a series of four springs: the South Springs, Middle Springs, North Springs, and Palmer Springs. They are located high on the south bank of the Green River and are collectively known as the Black Diamond Springs.	Excerpts scanned as PDF file, included on CD.
Water District No. 111 of King County Water System Comprehensive Plan	1997	Base water supply provided by an intertie to the City of Auburn Lea Hill reservoir. District uses six of its own eight wells to augment supply.	Excerpts scanned as PDF file, included on CD.
Various HSPF models for tributary basins	2004	Models are being developed by King County for a water quality assessment of the Green-Duwamish Basin.	King County DNR
Spreadsheet model of mainstem Green River after diversion and management scenarios	2004	Modeling of the mainstem Green River was performed by CH2M Hill for Tacoma Water's Habitat Conservation Plan	Simulated future flows included on CD
Monthly water use extraction data from major purveyors, by source	recent	Recently monthly water extraction by major municipal users obtained by Ecology.	Included on CD
Water rights certificates, permits, and claims	current	Location information to nearest section. Actual use status unknown	Included on CD

3 Current Condition Streamflows

3.1 Methods and Approach

The approach for the water quantity assessment is to use actual flow data where available to quantify current streamflow conditions at representative points of interest. The focus of this effort is on low flows, which are potentially a limiting factor for fish habitat, and monthly average flows, which reflect total basin runoff and water availability. Current conditions streamflows are intended to represent the flow regimes of about years 2001-2002, corresponding to the most recent basin land use analyses and recorded streamflow data available for assessment. However, because statistical analysis methods require an extended record of flows, the current conditions results are more realistically associated with land use and water extraction practices over the past decade.

The flow regime on the mainstem Green River is expected to significantly change from current (2001-2002) conditions as a result of the forthcoming implementation of the City of Tacoma's[1] second diversion water right. The exercising of that water right is scheduled to begin in the spring of 2005 and will mark the beginning of revised flow management practices for the mainstem Green River. Those revised practices include increased withdrawals combined with additional water storage capacity and new instream flow regulations. To recognize this change in river management procedures, a second set of flows statistics reflecting the anticipated future flow regime is developed for analysis points on the mainstem Green River. These "future" flows may be more representative of near term future flows than those determined for current conditions.

The scope of this study does not include estimation of the flows that would have existed in the basin under a natural condition without human effects. The focus is on current conditions streamflows which can be described with a high level of certainty based on recorded flow data and the results of simulation models calibrated to recorded flow data.

Different methods were used to define current conditions streamflows for the mainstem river versus flows in the major tributaries to the Lower/Middle Green River. Flows in the mainstem are significantly influenced by storage at Howard Hanson Dam (HHD) and by City of Tacoma water supply withdrawals. Flows in the major tributaries to the Lower/Middle Green River are not affected by flood control operations but are significantly influenced by urbanization effects including land cover alteration and water use. Flow regimes in both the main channel and the tributary streams have changed over time, coincident with increasing basin development and evolving water management practices.

The methods used to characterize current conditions are described below.

- Current conditions streamflows for the mainstem Green River were determined by a direct analysis of streamflows recorded by the USGS from 1964 to 2002. This corresponds to the period in which Howard Hanson Dam, a flood control facility operated by the US Army Corps of Engineers, has been in operation. River flow management practices (e.g. reservoir operations, water supply withdrawals, etc.) have evolved over this period, and consideration was given to adjusting the historical data to reflect the most current practices. However, no adjustments were made due to available resources and the need to also assess a flow scenario to incorporate the

[1] Water supply for the City of Tacoma is provided by Tacoma Water. Tacoma Water is one of three operating divisions of Tacoma Public Utilities, owned by the City. In this report, references to Tacoma, Tacoma Water, Tacoma Public Utilities, and to the City of Tacoma are used interchangeably.

anticipated effects of the City of Tacoma's second diversion water withdrawals, scheduled to begin in spring 2005.

- "Future" conditions streamflows for the mainstem Green River were determined using simulated flow data developed for the Environmental Impact Statement and Habitat Conservation Plan for the Tacoma Water second diversion water supply project. The simulated flow data were obtained from CH2M Hill with Tacoma Water authorization and consist of Green River daily flows for the period 1964 through 1995, adjusted for the effects of the second diversion project, the Howard Hanson Dam Additional Water Storage project, and accompanying instream flow commitments from a 1995 agreement between the Muckleshoot Indian Tribe and the City of Tacoma[2].

- Current conditions streamflows for the major Lower/Middle Green River tributaries were initially determined using data generated with HSPF simulation models calibrated to recently-collected streamflow data. The HSPF models were used to simulate continuous flow hydrographs for the 50-year period from 1948 through 1998, based on the model calibration to current conditions. However, due to model emphasis on storm runoff events and relatively poor calibration to low flows, this approach was largely abandoned in favor of a direct evaluation of the available streamflow data recorded since 1988.

Flow characteristics were evaluated for the twelve sites listed in Table 3.1. These include seven sites on the mainstem Green River, and five sites on significant tributaries to the Lower/Middle Green. The tributaries are Mill, Soos, and Newaukum Creeks which discharge to the Green River, and Jenkins and Covington Creeks which are part of the Soos Creek basin. Figure 1.1 shows the basin areas upstream of each of the twelve analysis points.

Table 3.1
Streamflow Analysis Points and Year 2000 Mean Flows

Analysis Point	River Mile	Tributary Basins	Basin Area Sq. Mi.	Year 2000 Mean Flow, cfs
MAINSTEM CHANNEL				
Green River below HHD (USGS Gage 12105900)	63.6	1	222	753 (1)
Green River near Palmer (USGS Gage 12106700)	60.5	1-2	231	687 (1)
Green River in Gorge	50.0	1-3	253	732 (3)
Green River below Icy Creek Springs	48.0	1-4	275	775 (3)
Green River below Newaukum Creek	40.7	1-6	310	847 (3)
Green River near Auburn (USGS Gage 12113000)	31.4	1-10	397	1,021 (1)
Green River below Mill Creek	23.8	1-12	419	1,066 (3)
MAJOR TRIBUTARIES TO LOWER/MIDDLE GREEN				
Newaukum Creek near Black Diamond	0.9	6	27.1	47 (1)
Covington Creek nr Mouth (Soos RM 2.9 tributary)	1.2	7	21.5	25 (2)
Jenkins Creek nr Mouth (Soos RM 4.1 tributary)	0.4	8	15.9	30 (2)
Soos Creek near Mouth	1.1	7-9	66.3	95 (1)
Mill Creek at SR 181 (near Mouth)	0.3	12	12.3	17 (4)

Source of flow data: (1) USGS Gage; (2) King County Gage; (3) Interpolated Value; (4) HSPF Simulation

[2] Details of the instream flow requirements under the 1995 agreement are presented in Section 3.2.2.

3.2 Mainstem Green River

Green River flows have been significantly altered by past and ongoing human activities including major diversions, consumptive withdrawals, and flood control activities. For context, brief summaries of these activities are provided below.[3] Flow statistics are provided following the summaries of major historical alterations and a description of Green River flow management activities by Tacoma Water and the US Army Corps of Engineers.

3.2.1 Chronology of Major Alterations

Significant historical changes to the Green River basin include the events summarized below.

- 1851: European settlement begins in the Duwamish River. Prior to settlement, the Green River was tributary to the White River, and the Duwamish River began at the confluence of the White River and the Black River at Duwamish (Green) River Mile 11.
- 1906-1911: White River is diverted from the Duwamish Basin to the Puyallup River, reducing the Green River watershed area by 30 percent. The original confluence of the White and Green Rivers was near Auburn. Under current conditions some groundwater flow from the White River basin continues to discharge to shallow aquifer of the Green River valley in the vicinity of Auburn (at about RM 35). The groundwater flow is intercepted by the Green River and converted to surface flow along a channel reach extending approximately from upstream of Auburn at RM 35 to the Mill Creek confluence at RM 23.
- 1913: City of Tacoma begins diverting water from the Green River to provide water for homes and industry. Anadromous salmonids blocked from Upper Green River sub-watershed since 1911 when construction for the diversion began.
- 1912-1916: Black and Cedar Rivers are diverted from the Duwamish Basin to Lake Washington to improve navigation, further reducing watershed area by 40 percent from its original size. The original confluence of the Black and Green Rivers was near Renton at Green River RM 11. Under current conditions, Springbrook Creek drains to the remnant Black River channel and thence to the Green River.
- 1962: Howard Hanson Dam is completed for flood control purposes.
- 1895-1980: The Green/Duwamish River is channelized and diked for navigation and flood control.
- 1945-2000: Residential, commercial, and industrial land uses expand, largely replacing farmlands and forests in the western half of the Green-Duwamish Watershed.
- 2005: Tacoma Water (Tacoma Public Utilities, City of Tacoma) plans to first exercise its second diversion water right, triggering new instream flow obligations.

3.2.2 City of Tacoma Withdrawals

Surface water is diverted from the middle Green River basin for municipal supply by the City of Tacoma, which is the principal consumptive user of water from the mainstem Green River. In 1906 and 1908, the City of Tacoma filed water right claims on the Green River for future withdrawals of 400 cfs . In 1911, Tacoma began construction of a water diversion dam at RM 61 on the Green River. In 1913, construction

[3] The summaries provided here draw heavily on direct text excerpts from the 1995 Ecology WRIA 9 Initial Watershed Assessment, the 2000 WRIA 9 Habitat Limiting Factors and Reconnaissance Assessment Report, and the 2001 Tacoma Water Habitat Conservation Plan. Digital copies of those documents in their entirety are included on the CD which accompanies this report.

of a pipeline with a capacity of 65 cfs was completed. By 1952, pipeline capacity had been increased to 113 cfs as the pipeline was upgraded over the years. The existing pipeline is operated under Tacoma's First Diversion Water Right Claim (FDWRC) [4]. Water is continually diverted from the mainstem Green River except at times of excessive turbidity (>5 NTUs), when Tacoma uses groundwater pumped from its North Fork Green River well fields located upstream of Howard Hanson Dam and well fields located in South Tacoma.

In 1985, Tacoma was granted a Second Diversion Water Right (SDWR) to an additional 100 cfs. Water available under the SDWR is scheduled to first be utilized in spring 2005, subject to restrictions described in Tacoma's 2001 Final Habitat Conservation Plan which includes a 1995 agreement between the Muckleshoot Indian Tribe and the City of Tacoma.

Tacoma's FDWRC is not constrained by Washington State minimum instream flow requirements because the asserted water right represented by its claim predates Ecology's adoption of the basin's instream flow rules. However, in recent years, Tacoma has voluntarily cooperated with other agencies and groups to minimize impacts of water withdrawals on fisheries and other instream resources.

Tacoma's Second Diversion Water Right (SDWR) is subject to State-imposed minimum instream flows at the USGS gage at Palmer. Additional constraints come from a 1995 agreement between the Muckleshoot Indian Tribe (MIT) and Tacoma Public Utilities. The agreement with MIT provides that upon first exercising of the SDWR, Tacoma's FDWRC will be constrained by a commitment to support instream flow levels measured at the USGS gage at Auburn.

Instream flow excerpts from the 1995 MIT/TPU agreement are reproduced below. State-imposed regulatory instream flows for the Green River at Auburn and at Palmer were filed in June 1980 and are published in chapter 173-509 Washington Administrative Code (WAC). As a general rule, regulatory instream flows do not represent the flows which are necessarily achieved in the river, but rather establish flow thresholds at which consumptive water withdrawals by junior (interruptible) water right holders must cease. Water rights issued prior to the adoption of instream flow regulations are senior to, and are normally exempt from, the instream flow regulations.

It should be noted that the above MIT/TPU agreement pre-dates and does not address the effects of the joint USACE and Tacoma HHD Additional Water Storage (AWS) project. That project and its effects are discussed in Section 3.2.3 which follows.

[4] In 1971, a water right claim of 400 cfs was filed by Tacoma for this diversion. Under current conditions, Tacoma withdraws up to 113 cfs under its FDWRC. A water right claim on file with the Washington State Department of Ecology (Ecology) cannot be validated until an adjudication occurs. As part of its Habitat Conservation Plan, Tacoma will not pursue adjudication of the full 400 cfs, but will voluntarily cap its FDWRC at 113 cfs

AGREEMENT BETWEEN
THE MUCKLESHOOT INDIAN TRIBE
AND
THE CITY OF TACOMA
REGARDING THE GREEN/DUWAMISH RIVER SYSTEM
1995
(Section 2 presented to describe instream flow commitments.)

SECTION 2. INSTREAM FLOWS

2.1 Guaranteed Minimum Instream Flow Levels That Vary With Annual Conditions

TPU shall provide the following guaranteed minimum continuous instream flows, which will vary with weather conditions during the summer months, in the Green River as measured at the Auburn Gage. For Wet Years the minimum continuous instream flow shall be 350 cfs. For Wet to Average Years[5] the minimum continuous instream flow shall be 300 cfs. For Average to Dry Years the minimum continuous instream flow shall be 250 cfs. For Drought Years, the minimum continuous instream flow shall range from 250 to 225 cfs, depending on the severity of the drought. Before any decision to drop instream flows from 250 cfs to 225 cfs (as measured at the Auburn Gage), consultation among the Resource Agencies, MIT, the Corps of Engineers, and TPU shall explore alternatives to lowering the minimum continuous instream flow, and TPU shall comply with the requirement of Section 2.6[6] of this Agreement.

2.2 Instream Flow Levels for Second Diversion

TPU shall meet the continuous instream flow requirements identified in Sections 2.2.1 and 2.2.2 whenever it is withdrawing water from the Green River with its Second Diversion. TPU shall meet both sets of instream flow requirements before it can withdraw any water with its Second Diversion. To the extent that these instream flow requirements are greater than the State Instream Flows, these instream flow requirements control.

2.2.1 Instream Flow Requirements for Palmer Gage

TPU shall meet the following continuous instream flow requirements, as measured at the Palmer Gage, as a condition of withdrawing water from the Green River with its Second Diversion. From July 15 to September 15 of each year the continuous instream flow level shall be 200 cfs. From September 16 to October 31 of each year the continuous instream flow level shall be 300 cfs. For all other days of the year (November 1 to July 14), the continuous instream flow level shall be 300 cfs, which is the same as the State Instream Flows for those days.

[5] Wet, average, dry, and drought weather conditions are to be determined by conditions within Howard Hanson Reservoir, considering the date and the current volume of water stored within the 24,200-acre-foot block of water for flow augmentation purposes. Details are presented in the Tacoma HCP under Section 5.1.1: Habitat Conservation Measure: HCM 1-01 FDWRC Instream Flow Commitment. The rule curves to determine weather conditions are per HCP Figure 5.1 which is reproduced at the end of this text box.

[6] Section 2.6 is titled "Water Use Curtailment by TPU."

2.2.2 Instream Flow Requirements for Auburn Gage

In addition to the instream flow requirements of Section 2.2.1, from July 15 to September 15 of each year, TPU shall meet the continuous instream flow requirement of 400 cfs, as measured at the Auburn Gage, as a condition of withdrawing water from the Green River with its Second Diversion. TPU specifically understands that if instream flows at the Auburn Gage fall below 400 cfs during the referenced period, the Second Diversion may not be used even if the instream flow requirements in Section 2.2.1 are being met.

Reservoir storage criteria for determining weather conditions: (HCP Figure 5.1)

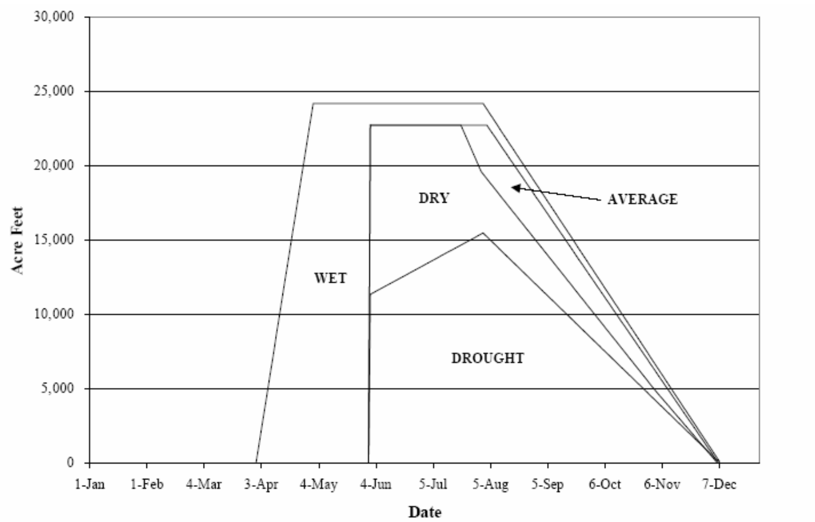

Figure 5-1. Storage reference zones within Howard Hanson Reservoir used to determine minimum flow conditions under yearly wet, average, dry and drought conditions during the period 15 July to 15 September. The storage reference zones pertain to the 24,200-acre-foot block of water stored for flow augmentation purposes.

3.2.3 Flow Management at Howard Hanson Dam

Howard Hanson Dam (HHD) is a federally funded and operated project on the Green River at RM 64.5, authorized by Congress for flood control and conservation storage. The conservation storage is used to augment low summer/fall flows for fisheries enhancement. Dam construction began in February 1959, and reservoir filling began in December 1961. No upstream fish passage facilities were originally incorporated into HHD because it was located approximately 3.5 miles upstream from Tacoma's Headworks Diversion Dam which had blocked upstream fish passage since 1913. Fish utilization of the upper basin is expected to be restored through several measures in the HCP. Those measures include constructing a fish ladder and adult collection and trap-and-haul facility at the Tacoma Diversion to provide passage to adult fish around the Headworks and HHD.

The U. S. Army Corps of Engineers (USACE) operates the dam to prevent flood flows over 12,000 cfs at the Auburn gage and to provide a minimum discharge of 223 cfs from the dam to ensure that 110 cfs passes the Palmer gage after diversion of up to 113 cfs by Tacoma Water. The conservation storage operation of the dam involves capturing late winter and spring runoff and augmenting low flows in July, August, September, and October. The original design and operation of the project provides for 24,200 ac-ft of water storage to augment low flows. The project operation was subsequently modified in the 1990s to provide an additional 5,000 ac-ft of stored water for fisheries benefits, this being one element of a planned Additional Water Storage (AWS) project.

Additional storage and flow management aspects of the AWS project are proposed as Habitat Conservation Measure 2-02 of the Tacoma Water HCP. Under this HCP proposal, authorized uses of HHD will be expanded to provide up to 20,000 ac-ft of additional stored water for municipal and industrial use. The additional storage for the AWS project will be obtained by increasing the reservoir water level during spring and summer months when the space is not required for flood control purposes. Water will be added to the municipal storage pool under Tacoma's Second Diversion Water Right at a maximum rate of 100 cfs, subject to instream flow commitments at the time the water is stored. Water withdrawals from the municipal storage pool will be made when needed by Tacoma Water and will be exempt from further instream flow restrictions at the time of withdrawal.

Reservoir operation at HHD has evolved over time to recognize and address a variety of resource needs. A summary of past operational practices may be found in Chapter 5 of Tacoma Water's HCP. HHD reservoir operation by the USACE currently involves frequent communication with members of the Green River Flow Management Committee. This interagency committee was formed in 1987 and consists of representatives from MIT, State, Federal, and county resource agencies, and other groups. The USACE considers input from the group in an adaptive management strategy to adjust the refill and release regime based on a short-term planning horizon.

Releases from HHD are adjusted to account for changing inflow and weather conditions to provide additional flows to benefit fisheries resources, with consideration for whitewater recreational opportunities and specific community activities[7]. Adjustments in the timing and rate of spring refill represent a compromise between juvenile outmigrant passage through HHD reservoir and downstream fisheries impacts. The refill strategy attempts to provide flows for steelhead spawning and incubation in response to expected weather and runoff conditions.

3.2.4 Flow Statistics

Flow statistics were determined for a total of six sites on the mainstem Green River from River Mile 63.6, just below Howard Hanson Dam, to River Mile 23.8, just below the confluence with Mill Creek (Auburn). The sites were selected to correspond to the locations of active USGS stream gages and major tributary inputs. The downstream end of the studied reach was selected in consultation with the WRIA 9 Technical Committee so as to concentrate the study resources in those reaches of the Lower/Middle Green above the zone of tidal influence and of greatest interest for fish utilization.

The flow statistics are based on historical and simulated flows for USGS gage sites below Howard Hanson Dam (USGS 12105900), at the Purification Plant near Palmer (USGS 12106700), and near Auburn (USGS 12113000). The statistics representing current conditions are based on the daily flow data published by the USGS for these sites for the period January 1964 through September 2002. The statistics representing future conditions are based on daily flow simulation data provided by Tacoma Water for these same sites for the period January 1964 through December 1995. The future flow data represent full exercising of Tacoma's Second Diversion Water Right in combination with the implementation of the Additional Water Storage Project and adherence to all applicable instream flow commitments.

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[7] U.S. Army Corps of Engineers (USACE). 1995. Howard Hanson Dam draft environmental impact statement for operation and maintenance.

Daily flows for other sites were estimated by linear interpolation of same-day flows at the Palmer and Auburn gages, based on basin area. The sites near Palmer and Auburn are significant both for data availability and because they are control points for instream flow regulations. The difference between same-day flows at Palmer and Auburn reflect the combination of local inflows and channel routing effects. Local inflows are the cumulative surface and groundwater inputs from tributary streams and basins (e.g. flows from Icy Creek Springs and Newaukum Creek). Channel routing effects include flow travel time and the volume of water going into and out of channel and floodplain storage during periods of rising and falling stages. The methods used by Tacoma Water to evaluate future flows under the SDWR did not specifically address routing effects. As a simplifying assumption, the SDWR evaluations assumed that the incremental flows between Palmer and Auburn for the simulation period were identical to historical incremental flows except for negative incremental flows which were treated as zero values.

During periods of rapidly rising flow, about 6 days per year on average, daily flows at Auburn are less than those at Palmer because channel routing effects (i.e. water put into storage) are greater than local inflows. By ignoring such negative incremental flows, the future condition modeling slightly exaggerates the total annual volumes of local inflow below Palmer. The modeling also fails to adjust the computed local inflows for the very different channel routing effects which will occur during spring months once the Additional Water Storage project is operational and is storing the spring freshets. These model limitations are noted but should not adversely affect the overall model results. Significant channel routing effects would be most closely associated with flood periods when low streamflows would not limit Tacoma withdrawals.

Tables 3.2 to 3.8 below present the flow statistics computed for the mainstem Green River for current and future conditions. Monthly flow statistics were determined by computing the mean monthly discharge and the 7-day low flow for each month of record and then sorting the data. On average, 50% exceedance (or median) values are exceeded in one half of all years; 90% exceedance values are exceeded in 9 years out of 10. Conversely, flows are equal to or lower than the 90% exceedance values about 1 year in ten. The 7-day low flow amounts were computed as 7-day average flows reported for the last day of the period, such that the 7-day period from October 26 through November 1 is treated as a November value.

The methods used here are different from those used for the Tacoma Water HCP. The methods used for the HCP determined statistics from sorted daily values without first aggregating to average monthly and 7-day values. Methods with and without data aggregation are both commonly used, but produce different results as described below.

- The median (50% exceedance) mean monthly flows presented here are generally larger than the median monthly flows presented in the HCP[8]. Monthly flows in this report are higher because the flow volumes associated with flood events are always included in the monthly average flows. In a daily flow approach used for the HCP, the days with flood events are assigned small exceedance values (typically less than 10%) and are not reflected in the median flows. The methods used in this report to describe monthly flows were selected as being most appropriate in the context of a water balance assessment.

- The 90% exceedance 7-day low flows presented here for each month are generally smaller than the 90% exceedance flows presented for each month in the HCP. Flows reported here are lower because the methods for the HCP considered all flows in a month whereas the methods for the current work considered only the lowest 7-day period in each month. The methods used in this report to describe low flows were selected as being most appropriate in the context of discussing low flows as a limiting factor to fish utilization of the watershed.

[8] Monthly exceedance hydrographs for various scenarios are presented in Chapter 7 of the HCP.

Table 3.2
Green River Flow Statistics
RM 63.6 Below HHD (USGS Gage 12105900)
Basin Area = 221 square miles

Month	Mean Monthly Flows, cfs			
	Current Conditions		Future Conditions	
	50% Exceedance	90% Exceedance	50% Exceedance	90% Exceedance
January	1,538	595	1,432	549
February	1,153	573	1,178	533
March	1,060	721	745	481
April	1,295	756	1,113	523
May	1,222	528	1,299	700
June	640	289	723	370
July	351	237	417	329
August	244	220	363	334
September	290	223	371	323
October	492	221	463	297
November	1,029	412	1,034	372
December	1,373	674	1,430	746

Month	7-Day Low Flows, cfs			
	Current Conditions		Future Conditions	
	50% Exceedance	90% Exceedance	50% Exceedance	90% Exceedance
January	550	366	526	362
February	707	359	693	361
March	684	408	413	390
April	826	566	574	396
May	715	257	828	409
June	371	230	429	288
July	252	222	361	297
August	235	212	339	313
September	232	213	342	307
October	246	202	339	266
November	391	218	443	224
December	585	370	600	359

Table 3.3
Green River Flow Statistics
RM 60.5 Near Palmer (USGS Gage 12106700)
Basin Area = 231 square miles

Month	Mean Monthly Flows, cfs			
	Current Conditions		Future Conditions	
	50% Exceedance	90% Exceedance	50% Exceedance	90% Exceedance
January	1,532	499	1,263	397
February	1,153	490	1,053	407
March	1,024	692	668	394
April	1,280	702	1,030	434
May	1,135	472	1,210	606
June	567	200	533	247
July	244	135	216	143
August	136	116	175	145
September	187	115	177	139
October	434	129	260	134
November	1,015	319	874	255
December	1,345	628	1,260	580

Month	7-Day Low Flows, cfs			
	Current Conditions		Future Conditions	
	50% Exceedance	90% Exceedance	50% Exceedance	90% Exceedance
January	479	293	354	261
February	643	272	557	259
March	641	344	324	300
April	789	469	490	300
May	643	174	689	247
June	275	135	300	185
July	151	115	175	110
August	125	103	150	125
September	133	103	154	121
October	151	106	150	112
November	335	127	290	118
December	507	293	412	258

Table 3.4
Green River Flow Statistics
RM 50.0 In Gorge
Basin Area = 253 square miles

Month	Mean Monthly Flows, cfs			
	Current Conditions		Future Conditions	
	50% Exceedance	90% Exceedance	50% Exceedance	90% Exceedance
January	1,632	569	1,350	430
February	1,240	536	1,147	435
March	1,101	745	746	451
April	1,339	765	1,088	491
May	1,183	499	1,260	635
June	602	220	562	274
July	272	154	241	170
August	155	133	193	165
September	208	135	205	154
October	454	143	282	149
November	1,037	352	906	271
December	1,434	664	1,344	652

Month	7-Day Low Flows, cfs			
	Current Conditions		Future Conditions	
	50% Exceedance	90% Exceedance	50% Exceedance	90% Exceedance
January	539	350	394	305
February	713	321	622	309
March	718	382	430	347
April	857	516	551	354
May	678	204	741	280
June	309	159	333	211
July	173	136	198	131
August	139	122	168	142
September	148	121	171	139
October	165	122	178	130
November	362	144	311	137
December	561	339	471	312

Table 3.5
Green River Flow Statistics
RM 48.0 Below Icy Creek Springs
Basin Area = 275 square miles

Month	Mean Monthly Flows, cfs			
	Current Conditions		Future Conditions	
	50% Exceedance	90% Exceedance	50% Exceedance	90% Exceedance
January	1,732	635	1,476	471
February	1,312	571	1,238	476
March	1,167	791	815	505
April	1,390	826	1,143	546
May	1,229	526	1,308	662
June	635	240	596	300
July	303	171	264	197
August	172	148	210	178
September	226	150	226	169
October	474	157	303	164
November	1,084	383	931	287
December	1,531	699	1,423	684

Month	7-Day Low Flows, cfs			
	Current Conditions		Future Conditions	
	50% Exceedance	90% Exceedance	50% Exceedance	90% Exceedance
January	597	393	461	346
February	797	356	661	358
March	780	428	514	395
April	916	562	615	400
May	720	234	802	312
June	340	177	367	236
July	194	154	220	151
August	156	139	190	159
September	164	137	192	156
October	185	137	198	145
November	383	159	332	150
December	613	369	524	344

Table 3.6
Green River Flow Statistics
RM 40.7 Below Newaukum Creek
Basin Area = 310 square miles

Month	Mean Monthly Flows, cfs			
	Current Conditions		Future Conditions	
	50% Exceedance	90% Exceedance	50% Exceedance	90% Exceedance
January	1,914	747	1,685	556
February	1,466	691	1,379	622
March	1,302	866	924	592
April	1,470	884	1,233	637
May	1,306	570	1,389	706
June	689	276	658	344
July	354	200	299	224
August	204	179	237	200
September	255	175	257	193
October	508	179	338	185
November	1,162	422	976	314
December	1,695	756	1,553	733

Month	7-Day Low Flows, cfs			
	Current Conditions		Future Conditions	
	50% Exceedance	90% Exceedance	50% Exceedance	90% Exceedance
January	715	460	581	405
February	890	433	730	416
March	907	526	637	469
April	1,012	639	706	477
May	798	284	879	364
June	397	208	412	275
July	228	182	256	183
August	182	167	222	187
September	191	160	224	183
October	217	160	228	170
November	416	185	366	173
December	700	420	597	397

Table 3.7
Green River Flow Statistics
RM 31.4 Near Auburn (USGS Gage 12113000)
Basin Area = 397 square miles

Month	Mean Monthly Flows, cfs			
	Current Conditions		Future Conditions	
	50% Exceedance	90% Exceedance	50% Exceedance	90% Exceedance
January	2,335	947	2,191	764
February	1,854	923	1,711	829
March	1,642	1,049	1,253	794
April	1,714	1,044	1,459	857
May	1,462	676	1,541	812
June	825	382	808	449
July	453	283	389	289
August	273	244	305	250
September	326	237	332	250
October	579	237	424	236
November	1,349	497	1,127	379
December	2,090	896	1,898	851

Month	7-Day Low Flows, cfs			
	Current Conditions		Future Conditions	
	50% Exceedance	90% Exceedance	50% Exceedance	90% Exceedance
January	998	589	849	515
February	1,128	619	911	585
March	1,152	764	868	644
April	1,213	825	917	663
May	1,005	403	1,010	491
June	516	309	521	350
July	314	243	344	250
August	249	223	300	250
September	256	209	300	250
October	297	213	300	225
November	513	247	450	229
December	902	523	782	510

Table 3.8
Green River Flow Statistics
RM 23.8 Below Mill Creek (Auburn)
Basin Area = 419 square miles

Month	Mean Monthly Flows, cfs			
	Current Conditions		Future Conditions	
	50% Exceedance	90% Exceedance	50% Exceedance	90% Exceedance
January	2,408	986	2,258	817
February	1,958	981	1,812	878
March	1,707	1,096	1,353	848
April	1,772	1,090	1,533	914
May	1,505	703	1,599	839
June	860	409	846	476
July	478	303	415	306
August	292	260	323	265
September	343	252	351	264
October	597	251	446	249
November	1,398	516	1,165	395
December	2,192	931	1,975	881

Month	7-Day Low Flows, cfs			
	Current Conditions		Future Conditions	
	50% Exceedance	90% Exceedance	50% Exceedance	90% Exceedance
January	1,071	619	912	543
February	1,192	658	958	623
March	1,203	825	1,007	699
April	1,291	872	973	711
May	1,064	436	1,067	524
June	547	335	552	369
July	335	258	364	265
August	266	238	318	263
September	273	224	316	260
October	317	226	317	238
November	535	261	471	243
December	959	541	833	538

3.3 Major Tributaries to Lower/Middle Green River

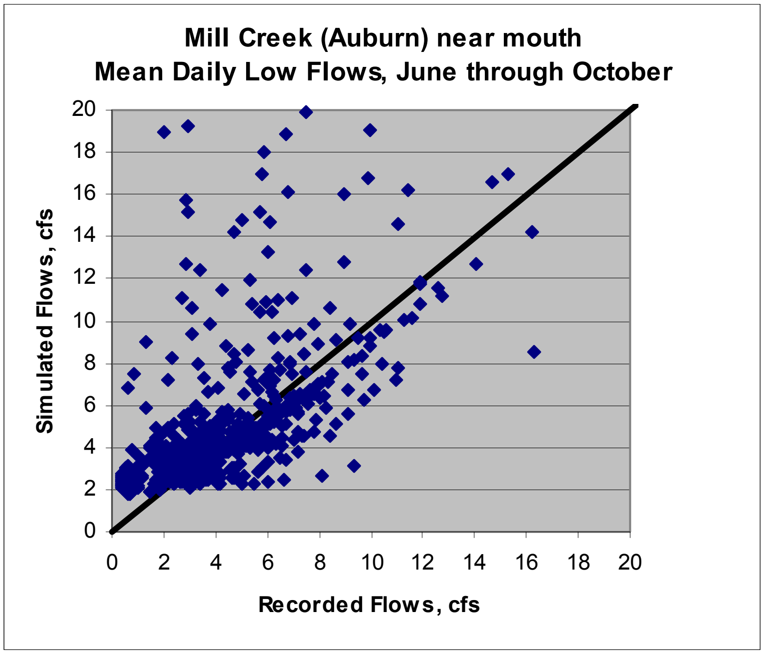
The major tributaries to the study reach of the Lower/Middle Green River are Mill Creek which joins the Green at RM 23.8, Soos Creek at RM 33.8, and Newaukum Creek at RM 40.7. These three tributaries drain a combined basin area of 106 square miles and account for 56% of the total study area downstream of the Tacoma Diversion. Flow statistics were determined for these three creeks plus Covington and Jenkins Creeks which are tributaries to Soos Creek.

The approach originally proposed to develop flow statistics for the tributary streams was to use recently-developed Hydrologic Simulation Program-Fortran (HSPF) models. This approach was proposed to make use of models which had been developed in separate studies to reflect current conditions land use and which had been calibrated to recent (post-1990) streamflow data. The HSPF model for Mill Creek (Auburn) was developed by NHC for a flood control study and, as described below, was adapted for use in the current work. HSPF models for Soos, Covington, Jenkins, and Newaukum Creek were developed by others for King County's Green-Duwamish water quality assessment (in progress).

The HSPF model of Mill Creek (Auburn) was previously developed by NHC for the City of Auburn to provide inflow hydrographs to a separate Full Equations Model (FEQ) hydraulic model of the relatively-flat lower channel. Because the focus of the previous work was on flooding in the Mill Creek valley, the HSPF model was not well calibrated to low flows, except that a constant external input of 2 cfs had been added to the middle Mill Creek basin so that the modeled flows would reasonably match recorded annual flow volumes at 29th Street NW. At the time of the previous study it was speculated that the 2 cfs flow input was associated with regional groundwater inputs originating from the White River.

In the current work, model results were compared to available flow data recorded by King County for Mill Creek at SR 181 (near the mouth of the stream), and a variable groundwater input sequence was developed to improve the model representation of low flows. Figure 3.1 below shows a scatter plot of same-day simulated versus recorded low flows for summer months for the five-year period of stream gage record, 1990 through 1995.

Figure 3.1
HSPF Model Low Flow Validation for Mill Creek (Auburn)



Our interpretation of the low flow validation results is that the model fails to adequately represent flows less than 3 cfs. King County stream gaging records were used to confirm that very low flows of less than 0.5 cfs did occur in the summers of 1994 and 1995. Table 3.9 presents the flow statistics determined from the simulation results. Because the HSPF model was unable to reproduce the very low flows observed in two of the six years of record from 1990 to 1995, the low flow statistics should be used with caution.

HSPF model calibration results for Newaukum, Jenkins, Covington, and Soos Creeks were reviewed and also found to have problems with simulation of the low flows of interest. Because these streams all have active stream gages with relatively long periods of record, it was decided that direct analysis of the recent gage records would provide the most accurate statistics to describe flows under current conditions. The USGS has operated stream gages on Soos Creek (Gage #12112600) since 1960 and on Newaukum Creek (Gage #12108500) since 1944. King County has operated stream gages on Jenkins Creek (Gage 26A) and Covington Creek (Gage 09A) since 1988.

Flow statistics for Newaukum, Jenkins, Covington, and Soos Creeks were determined by an analysis of streamflow data recorded over the 16-year period from January 1988 through May 2004, representing current conditions. Tables 3-10 through 3-13 present the results.

Table 3.9
Tributary Stream Flow Statistics
Mill Creek (Auburn) at SR 181 from HSPF Simulation Data
Basin Area = 12.3 square miles

Month	Mean Monthly Flows, cfs Current Conditions 50% Exceedance	90% Exceedance
January	57	23
February	49	19
March	35	21
April	23	11
May	12	8
June	8	6
July	5	4*
August	5	3*
September	6	3*
October	12	7
November	37	15
December	47	25

Month	7-Day Low Flows, cfs Current Conditions 50% Exceedance	90% Exceedance
January	16	7
February	17	7
March	14	8
April	10	6
May	6	5
June	5	4
July	4	3*
August	3	3*
September	3	2*
October	3	2
November	9	4
December	19	7

*Persistent low flows as small as 0.4 cfs were recorded during the months of July through September 1994. The HSPF simulation model was unable to reproduce those very low flows; 90% exceedance values in summer months are likely smaller than shown in the table above.

Table 3.10
Tributary Stream Flow Statistics from1988-2004 Recorded Data
Newaukum Creek Near Black Diamond, USGS Gage 12108500
Basin Area =27.1 square miles

Month	Mean Monthly Flows, cfs Current Conditions 50% Exceedance	90% Exceedance
January	88	52
February	77	44
March	87	48
April	65	42
May	46	34
June	34	24
July	24	17
August	17	13
September	14	11
October	19	14
November	56	22
December	82	32

Month	7-Day Low Flows, cfs Current Conditions 50% Exceedance	90% Exceedance
January	56	19
February	51	31
March	51	31
April	45	33
May	34	24
June	28	20
July	20	15
August	15	12
September	12	10
October	13	10
November	18	13
December	41	18

Table 3.11
Tributary Stream Flow Statistics from 1988-2004 Recorded Data
Jenkins Creek near Mouth, King County Gage 26A
Basin Area = 15.9 square miles

Month	**Mean Monthly Flows, cfs** Current Conditions 50% Exceedance	Current Conditions 90% Exceedance
January	70	34
February	60	41
March	54	41
April	49	34
May	34	25
June	25	17
July	17	12
August	12	10
September	11	9
October	13	11
November	35	16
December	51	21

Month	**7-Day Low Flows, cfs** Current Conditions 50% Exceedance	Current Conditions 90% Exceedance
January	44	22
February	46	29
March	42	29
April	37	28
May	29	20
June	21	15
July	14	11
August	11	8
September	10	8
October	10	8
November	14	11
December	39	17

Table 3.12
Tributary Stream Flow Statistics from 1988-2004 Recorded Data
Covington Creek near Mouth, King County Gage 09A
Basin Area = 21.5 square miles

Month	**Mean Monthly Flows, cfs** Current Conditions 50% Exceedance	Current Conditions 90% Exceedance
January	56	12
February	61	24
March	59	25
April	40	29
May	24	15
June	13	6
July	6	3
August	3	2
September	2	2
October	3	2
November	13	3
December	47	8

Month	**7-Day Low Flows, cfs** Current Conditions 50% Exceedance	Current Conditions 90% Exceedance
January	29	6
February	44	12
March	49	13
April	29	19
May	18	7
June	10	4
July	4	2
August	3	2
September	2	2
October	2	1
November	3	2
December	32	3

Table 3.13
Tributary Stream Flow Statistics from 1988-2004 Recorded Data
Soos Creek near Mouth, USGS Gage 12112600
Basin Area = 66.3 square miles

Month	Mean Monthly Flows, cfs Current Conditions 50% Exceedance	 Current Conditions 90% Exceedance
January	217	101
February	221	104
March	191	124
April	139	107
May	95	64
June	66	42
July	39	29
August	29	23
September	27	23
October	33	28
November	117	41
December	173	67

Month	7-Day Low Flows, cfs Current Conditions 50% Exceedance	 Current Conditions 90% Exceedance
January	121	61
February	156	70
March	142	78
April	105	81
May	76	46
June	54	33
July	33	26
August	27	21
September	23	20
October	25	22
November	36	30
December	108	46

3.4 Normative Flows

The normative flow discussion presented here is a summary of the early planning stages of work in progress for the mainstem Green River.

In recent years, interest has grown in evaluating the natural flow regime of river systems to gain insight into relationships between flow conditions, physical processes and ecological response. Recent ecological research, including guidance from the National Research Council, NOAA Fisheries and others, has indicated that all aspects of the flow regime have relevance for habitat protection[9,10].This view is summarized in the following statement from a report by Spence et al.[11]: "Protection of salmonid habitats requires stream flows to fluctuate within the natural range of flows for the given location and season." This is in contrast to legal requirements in the State of Washington that rely on establishment of minimum instream flows as the primary flow-related requirement for fish habitat protection.

[9] NRC (National Research Council). 1992. Restoration of aquatic ecosystems: science, technology, and public technology. National Academy Press, Washington, D.C.

[10] Poff, L. N., J. D. Allan, M. B. Bain, J.R. Karr, K. L. Prestegaard, B. D. Richter, R. E. Sparks and J.C. Stromberg. 1997. The natural flow regime: a paradigm for river conservation and restoration. BioScience 47(11) 769-784.

[11] Spence, B.C., G.A Lomnicky, RM. Hughes, R.P. Novitzki. 1996. An ecosystem approach to salmonid conservation. TR-4501-96-6057. ManTech Environmental Research Services Corp., Corvallis, OR.

Research suggests that salmonids evolved with life histories reliant on the entire range of flow variation in a naturally flowing river: the magnitude, frequency, timing, duration, and rates of change of various flow events, annual maxima and minima. The research further suggests that all of these aspects of the flow regime should be evaluated in examining hydrologic factors for salmon production in the Pacific Northwest. Changes in hydrologic parameters become more or less important depending on ecological and geomorphic factors such as gravel regime, wood loading and recruitment, and channel complexity within the river, the life histories of the species of interest, the degree to which various reaches have been altered by channelization and construction of levees and revetments.

As a result of these issues, King County initiated the Normative Flow Studies project to develop a method for evaluating the effects of anthropogenic alteration of flow regimes on aquatic ecosystems, including effects of altered flows on the persistence and recovery of salmonids. The method will be applied in two ways: (1) to assess the effects (and implications for conservation) of existing departures in flow patterns (from a pre-altered condition) in King County streams and rivers, and (2) to evaluate the effects of flow alterations on physical and biological systems. King County selected the Green River as a case study for developing this approach further for larger river systems.

The Middle Green River Flow Investigation was initiated in 2004 as a collaborative effort to identify flow-related research priorities for the middle reach of the Green River and to develop a program to implement studies to address the priorities. The effort includes staff from King County, US Army Corps of Engineers, USGS, American Rivers, Washington Departments of Fish and Wildlife, and Ecology. Current and upcoming work is focused on enhancing our understanding of the relationship between river flow patterns, physical responses, and biological parameters. Three draft “themes” have been developed for consideration as part of the investigation.

- Theme 1: A retrospective study of the Green River comparing channel conditions prior to and after construction of Howard Hanson Dam.
- Theme 2: Macrohabitat analysis and high flow connectivity that includes describing, mapping and summarizing off-channel habitat conditions for high flows.
- Theme 3: The influence of physical processes on aquatic and riparian habitat.

All three of these studies have potential to contribute substantial information to flow-habitat relationships in the Middle Green River that will aid in salmon conservation and recovery.

Theme 1 is the first priority and more detailed scoping has been initiated. The key hypothesis is that closure and operation of Howard Hanson Dam and the modifications in channel structure (e.g., construction of levees and revetments, channel straightening and dredging) for flood control purposes have altered the rates, magnitudes and spatial arrangement of ecosystem processes and functions compared to the pre-dam state. The information learned from addressing this hypothesis will be used to address a follow-up hypothesis: the flow regime during the post-dam period causes geomorphic and habitat variability (in functional, structural and process attributes) sufficient to sustain a viable salmonid population.

The study encompasses the river and its valley from the upper limits of the Green River at approximately river mile 88, downstream to the historic confluence with the now-diverted White River at approximately river mile 31. The time frame covered by this study varies, but generally covers the period from approximately 1856 to the present day. Certain attributes will be examined for a more limited study period from 1936 to present (e.g., hydrologic/gauging data, photographic record), while other attributes may go back to 1856 (e.g., written accounts, anecdotal information).

Theme 2 Hypothesis: Scheduled releases of high flow and selected habitat improvement projects will increase the area and complexity of off-channel habitat for fish in the Middle Reach of the Green River. An increase in habitat area will depend on river stage, secondary channel density, and width of channel migration zone. An increase in usable habitat area will depend on timing of releases and concurrent life stage of fish species.

Study Design and Objectives: Flood storage behind Howard Hanson Dam has reduced high flows downstream. Flows in the Middle Reach of the Green River have not exceeded 12,000 cfs since 1962. Pre-regulation high flows ranged from 12,000 cfs (.50 probability), to 21,000 cfs (.10 probability), to 34,000 cfs (.01 probability)[12]. Flood storage has altered the hydrologic regime of the river and reduced the extent of overbank flows (connectivity) in floodplain and other off-channel areas.

The overall study design is to describe, map, and summarize off-channel habitat conditions at specified high flows on the Middle Reach of the Green River in King County, WA. Habitat assessment areas will include the floodplain at specified flows, historic channel locations, channel migration hazard areas, secondary channels, and associated landforms outside the main channel of the river. Objectives of the study are to define and quantify potential fish habitat benefits of more frequent periods of flows up to 12,000 cfs at Auburn to produce overflows in off-channel areas on the river.

Theme 3 involves the investigation of physical processes on aquatic habitat at the scale of channel forms (e.g., pools, riffles, runs). The results will be used to develop an understanding of how habitat conditions for these general types of channel forms will respond to human manipulations of streamflow, sediment load, channel morphology, and riparian vegetation.

Hypothesis: High flows can be managed to allow ecological functions (e.g., creating and maintaining off-channel habitat, recruitment of large woody debris, patch turnover) without negative consequences including redd scour, depletion of limited sediment supply below Howard Hansen dam, and reducing large woody debris and instream habitat structure. There are a number of important secondary hypotheses related to specific habitat responses. For example, the probability of chinook salmon redd scour increases with streamflow but can be reduced by limiting the frequency and duration of flows exceeding some threshold and managing flows when salmon are selecting spawning sites.

Study Design and Objectives: This study will examine the interactions between streamflow, sediment, and large woody debris (LWD) in the middle Green River. It will require information about channel form and hydraulic conditions at representative sites within the Middle Green River. Hydraulic and sedimentological conditions would be analyzed at the sites to characterize sediment transport regime (e.g., threshold of motion, partial transport, equal mobility of all particles). The sediment transport investigation would include experiments using tracer cobbles in Chinook salmon redd/non-redd locations to assess scour during winter. The investigation of LWD would include a retrospective assessment of in-channel LWD identified from historical aerial photos, US Army Corps of Engineers data on new wood placement, and multispectral aerial imaging. Remote inventorying would be verified and supplemented by field surveys of the location (relative elevation and location in channel) of selected pieces of LWD. The LWD investigation would quantify LWD retention time in selected reaches; quantify streamflow levels for distinct types of interactions (e.g., streamflow that transport key pieces for log jams, transport smaller debris, transport sediment around LWD; or provides cover or pools adjacent to LWD).

[12] King County. 1993. Green River channel migration study. King County Dept. Public Works, Surface Water Management Division. Seattle WA. 45 p.

4 Fisheries-Perspective Assessment of Existing Streamflows

4.1 Salmon Utilization

The following section summarizes information on salmonid species in the Green River study area, including Chinook, chum, coho, pink and sockeye salmon, and steelhead trout. Figure 4.1 shows the distribution of Chinook salmon in the study area. Figure 4.2 shows the distribution of chum, coho, pink and sockeye salmon.

Chinook Salmon

Adult and juvenile Chinook salmon (*Oncorhynchus tshawytsha*) are present within the lower end of the study area to River Mile (RM) 61. Anadromous salmon have been prevented from accessing the upper Green River above RM 61 since 1911 when a diversion dam was constructed by the City of Tacoma for its domestic water supply. Howard Hanson Dam was subsequently built 3.5 miles upstream of the diversion dam (RM 64.5) by the Army Corps of Engineers to provide flood protection and water storage for low-flow augmentation in 1963. Juvenile Chinook salmon are planted above Howard Hanson Dam by the Muckleshoot Indian Tribe to rear in the Upper Green River sub-watershed.

The primary spawning areas for summer/fall Chinook salmon in the study area are the mainstem Green River and major tributaries including Big Soos Creek and Newaukum Creek. Spawning along the mainstem river begins at approximately RM 25, about 1.2 miles upstream from the confluence with Mill Creek (Auburn). The highest concentration of observed spawners is between RM 33.8 and 50.3, based upon analysis of WDFW data by Malcom[13]. Summer/fall Chinook adults have been observed entering the Duwamish River in mid-June and continuing into October. The downstream end of this reach (RM 33.8) corresponds approximately to the confluence with Soos Creek. Spawning in the mainstem Green River occurs from early September to early November[14,15].

[13] Malcom, R. 2002. Annual variation (1997-2000) in the distribution of spawning Chinook in the mainstem Green River (WRIA 09.001), King County, Washington, Draft Report. Ecocline Fisheries Habitat Consulting LTD. Burnaby, BC Canada.

[14] Williams, R., R. Laramie, and J. Ames. 1975. A catalog of Washington streams and salmon utilization, Vol 1, Puget Sound Region. Washington Department of Fisheries, Olympia, Washington.

[15] WDFW Spawning Ground Survey Database

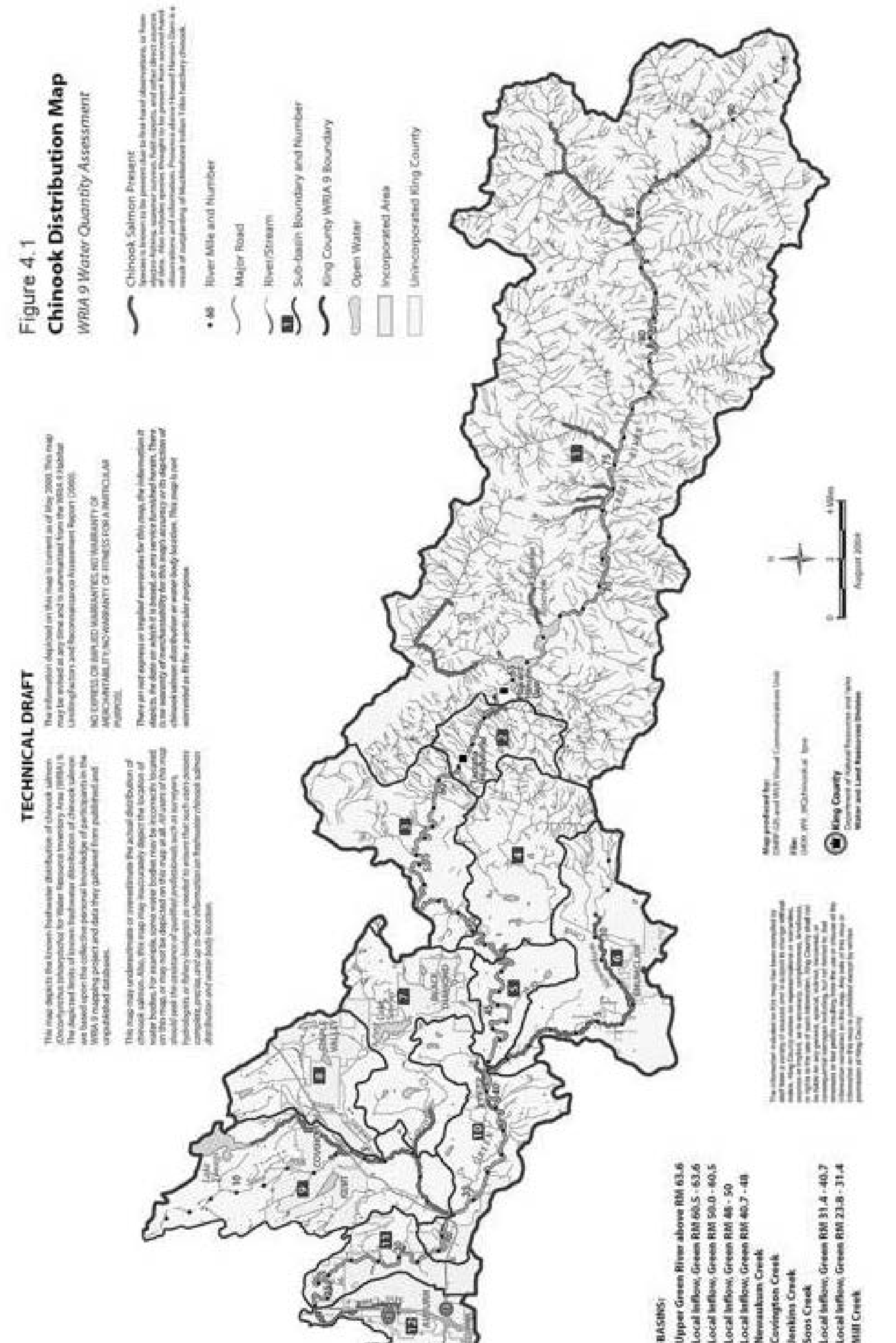


Figure 4.1. Chinook Distribution Map (Placeholder for 11 x 17 color sheet)

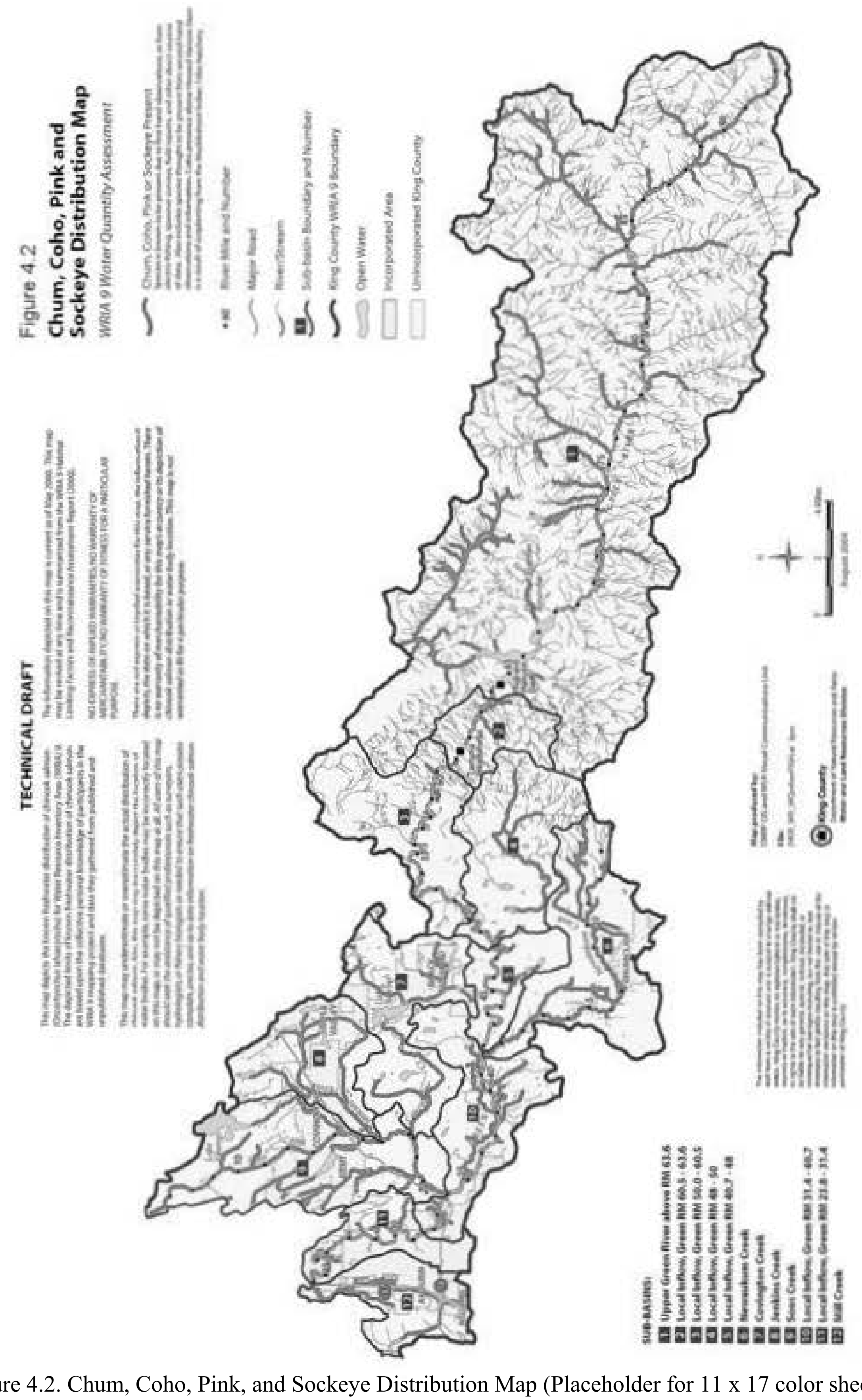


Figure 4.2. Chum, Coho, Pink, and Sockeye Distribution Map (Placeholder for 11 x 17 color sheet)

Juvenile Chinook salmon rearing habitat in the Middle Green is located primarily between RM 33.8 and 60.8[16]. Juvenile Chinook salmon produced in the study area are thought to have at least five life history types. The most common life history types, based upon a recent conceptual model[17] are believed to be:

- *Estuary-Reared Fry*: Fry spend a short time in the study area (several days to several weeks) following emergence, and then migrate quickly downstream to rear in the Duwamish Estuary for two to three months.
- *Marine Direct Fingerlings*: Fingerlings rear near the spawning grounds within the study area for one or two months before migrating relatively quickly through the estuary to Puget Sound.

Historically, both a spring run and summer/fall run of Chinook salmon were believed to be present[18]. Currently, spring Chinook are believed to be locally extirpated in the Green River, although spring Chinook have occasionally been observed in the mainstem river[19]. Spring Chinook are believed to have begun entering the Duwamish River in May and June and remain in the river until spawning in August and September[20]. The Green/Duwamish and Newaukum Creek summer/fall Chinook stock status were rated as healthy in the 1992 Washington State Salmon and Steelhead Inventory[21]. Chinook salmon in western Washington, including those in the Green River, were listed as a threatened species under the provisions of the Endangered Species Act (ESA) in 1999.

Two hatcheries located on tributaries to the Green River currently produce fingerling and yearling size juveniles that are released in May through mid-June. Soos Creek Hatchery, operated by Washington Department of Fish and Wildlife, releases subyearling Chinook in Soos Creek and yearling Chinook in Icy Creek. The Keta Creek Hatchery, located on Crisp Creek, is operated by the Muckleshoot Indian Tribe and produces only fingerlings.

Coho Salmon

Coho salmon (*Oncorhynchus kisutch*) are widely distributed throughout the study area including the mainstem Green River, Newaukum Creek, Soos Creek, Mill Creek, and Springbrook Creek. Adult coho salmon are prevented from migrating above the Tacoma Diversion Dam at RM 61, but juvenile coho

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[16] R2 Resource Consultants, Inc. 2002. Juvenile Salmonid Use of Lateral Stream Habitats Middle Green River, Washington. 2000 Data Report. Prepared for U.S. Army Corps of Engineers, Seattle District. Redmond , WA.

[17] Ruggerone, G. and D. Weitkamp. 2004 WRIA 9 Chinook Salmon Research Framework: Identifying Key Research Questions about Chinook Salmon Life Histories and Habitat Use in the Middle and Lower Green River, Duwamish Waterway, and Marine Nearshore Areas. Prepared for WRIA 9 Steering committee. Prepared by Natural Resource Consultants, Inc., Parmetrix, Inc., and the WRIA 9 Technical Committee. Seattle, WA.

[18] Nehlsen, W., J. Williams, and J. Lichatowich. 1991. Pacific Salmon at the Crossroads: Stocks at Risk from California, Oregon, Idaho, and Washington. Fisheries, Volume 16, No.2

[19] King County Water and Land Resources and WRIA 9. 2004. WRIA 9 Strategic Assessment Report- Scientific Foundation for Salmonid Habitat Conservation. Draft. Prepared for WRIA 9 Steering Committee. Seattle, WA.

[20] Kerwin, J. and T.S. Nelson (Eds.). 2000. Habitat limiting factors and reconnaissance assessment report, Green/Duwamish and Central Puget Sound watersheds (WRIA 9 and Vashon Island). Washington Conservation Commission and King County Department of Natural Resources, Seattle, WA.

[21] Washington Department of Fish and Wildlife (WDFS) and Western Washington Treaty Indian Tribes (WWTIT). 1994. 1992 Washington State salmon and steelhead stock inventory, Appendix 1 Puget Sound stocks. WDFW, Olympia, WA.

salmon are released above Howard Hanson dam by the Muckleshoot Indian Tribe (with approximately 500,000 released in 2004).

The Green River coho population consists of the Green River/Soos and Newaukum Creek stocks[22], which vary greatly in timing. The Green River/Soos stock begins entering the Duwamish between September and early December, with spawning between November and early February[23]. The Newaukum Creek stock migrates later, with spawning into mid-January[24]. Juvenile coho salmon fry emerge in April and May and remain in freshwater for rearing for a year following emergence.

The Green River/Soos Creek stock is listed as healthy in the 1992 Washington State Salmon and Steelhead Inventory[25]. The Newaukum Creek coho stock is rated as depressed in the inventory. Hatchery releases consist of coho yearlings by Washington Department of Fish and Wildlife at the Soos Creek hatchery and coho yearlings by the Muckleshoot Indian Tribe at Crisp Creek.

Chum Salmon

Chum salmon (*Oncorhynchus keta*) are present in the mainstem Green River to RM 60.6, in Newaukum Creek, Crisp Creek, Burns Creek, and Tributary 09.0098[26]. The population consists of two stocks, the Green River fall-run chum and Crisp Creek fall-run chum salmon. The Green River fall-run chum stock is rated as unknown and the Crisp Creek fall chum is considered healthy[27]. The Muckleshoot Indian Tribe releases hatchery raised chum subyearling at Crisp Creek.

Pink Salmon

Pink salmon (*Oncorhynchus gorbusha*) are present in odd years in the study area below the Green River at RM 42 and in Newaukum Creek. The stock status is rated as unknown but presumed depressed[28]. Until recently, pink salmon were believed to be extirpated from the system. However, small numbers of adult pink salmon were observed spawning in the mainstem beginning in the 1990's and juveniles have been captured during sampling[29]. Pink salmon were observed entering the mainstem Green River in

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[22] Ibid.

[23] King County Water and Land Resources and WRIA 9. 2004. WRIA 9 Strategic Assessment Report- Scientific Foundation for Salmonid Habitat Conservation. Draft. Prepared for WRIA 9 Steering Committee. Seattle, WA.

[24] Washington Department of Fish and Wildlife (WDFS) and Western Washington Treaty Indian Tribes (WWTIT). 1994. 1992 Washington State salmon and steelhead stock inventory, Appendix 1 Puget Sound stocks. WDFW, Olympia, WA.

[25] Ibid.

[26] King County Water and Land Resources and WRIA 9. 2004. WRIA 9 Strategic Assessment Report- Scientific Foundation for Salmonid Habitat Conservation. Draft. Prepared for WRIA 9 Steering Committee. Seattle, WA.

[27] Washington Department of Fish and Wildlife (WDFS) and Western Washington Treaty Indian Tribes (WWTIT). 1994. 1992 Washington State salmon and steelhead stock inventory, Appendix 1 Puget Sound stocks. WDFW, Olympia, WA.

[28] Ibid.

[29] King County Water and Land Resources and WRIA 9. 2004. WRIA 9 Strategic Assessment Report- Scientific Foundation for Salmonid Habitat Conservation. Draft. Prepared for WRIA 9 Steering Committee. Seattle, WA.

August with spawning in September and October. Unusually high numbers (300,000) of adult pinks were estimated by WDFW in 2004 on the spawning grounds. The fry are believed to emerge in March and April and rapidly migrate to the estuary.

Sockeye Salmon

A small number of sockeye salmon (*Oncorhynchus nerka*) have been observed in the mainstem Green River within the study area. The Green River sockeye population is documented in the Status Review of Sockeye Salmon in Washington and Oregon[30]. This species is typically associated with lakes but other river-run populations are documented in the Pacific Northwest. Stock status is not rated in the 1992 Washington State Salmon and Steelhead Inventory (SASSI)[31].

Steelhead Trout

There are two winter steelhead (*Oncorhynchus mykiss*) stocks characterized in SASSI in the Green-Duwamish River basin: the native wild spawning population and the early timing hatchery stock. Population trends of Green River wild winter steelhead in the early 1990s began a steady decrease similar to those of many other regional stream systems. From 1978 to 1998, escapement estimates ranged from approximately 960 to 2800 fish. The current hatchery summer steelhead stock in the Green River Basin is a non-native (hatchery introduced) stock with origins from the Washougal and Skykomish Rivers. Hatchery summer steelhead have been released in the Green River since 1965. River entry occurs from April through October with spawning from mid–January through mid-March. They are found in Newaukum Creek, Soos Creek and its larger tributaries, Mill Creek and Springbrook Creek.[32]

4.2 Salmonids and Water Quantity on the Mainstem Green River

The Howard Hanson Dam is operated to accomplish two purposes for the Green River: (1) flood control and (2) low flow augmentation through management of a summer conservation pool that currently is approximately 30,000 acre-feet. Low flow augmentation is managed jointly through real-time flow management in coordination with the Army Corps of Engineers (ACOE). The intent is to meet resource and fisheries needs below Howard Hanson Dam. Coordination is done with the co-managers (Muckleshoot Indian Tribe (MIT) and WDFW) along with other federal, state and local resource agencies and non-governmental organizations including Tacoma Public Utilities (TPU), Washington Department of Ecology, U.S. Fish and Wildlife Service, King County and Friends of the Green River. These water management coordination meetings occur about twice a month from spring through fall to address a range of water resource management needs, including balancing the habitat needs of salmonids while accommodating a variety of other competing uses. The following discussion is taken in part from the perspective of resource managers trying to meet water needs for fish in the Green River[33] with a focus on the mainstem.

[30] NOAA Technical Memorandum NMFS-NWFSC-33 Status Review of Sockeye Salmon from Washington and Oregon, December 1997.

[31] Washington Department of Fish and Wildlife (WDFS) and Western Washington Treaty Indian Tribes (WWTIT). 1994. 1992 Washington State salmon and steelhead stock inventory, Appendix 1 Puget Sound stocks. WDFW, Olympia, WA.

[32] Kerwin, J. and T.S. Nelson (Eds.). 2000. Habitat limiting factors and reconnaissance assessment report, Green/Duwamish and Central Puget Sound watersheds (WRIA 9 and Vashon Island). Washington Conservation Commission and King County Department of Natural Resources, Seattle, WA

[33] Engman, G. personal communication, 2005. and
Coccoli, H., Muckleshoot Indian Tribe Fisheries Division comment letter dated May 2005.

There is rarely enough water to meet all resource needs. Available storage (the 30,000 acre-feet conservation pool) as well as project mandates and rule curve constraints dating from the original project authorization for HHD combine to create resource protection conflicts. Major instream flow needs during the conservation pool allocation period (early summer through fall) include: (1) protection of wild winter steelhead redds through fry emergence, (2) adequate summer low flows for juvenile steelhead and salmon rearing, and (3) sufficient flows for Chinook spawning. In the majority of years, none of these needs can be fully met. Providing enough water for even one of these needs means compromising the others. The annual process of allocating available reservoir storage to instream flows is more a process of distributing impacts in order to achieve the best overall balance for resource protection.

Because all needs cannot be met, priority is given to flows for steelhead incubation and Chinook spawning. Dividing available storage between these two needs, along with other factors that have driven project operations in individual years, means that up to 50 percent of steelhead redds may be dried up before fry have a chance to emerge. If summer-fall precipitation is below normal, Chinook have access to a fraction of available spawning habitat and are forced to spawn in locations vulnerable to streambed scour. Stream flow from about mid-July through most of September is usually not augmented beyond project mandates (110 cfs below the Tacoma Headworks) and relies heavily on local inflows and rainfall. However, both the Tacoma Habitat Conservation Plan and the 1995 Agreement between MIT and the City of Tacoma have provisions to not allow Green River flows to drop below specific thresholds as measured at the USGS gauge at Auburn (see Chapter 2 for more detail). In the past, Tacoma has also helped ensure greater quantities of water were available in the fall to benefit Chinook salmon.

Summer rearing habitat quantity and quality, due to low flow and high water temperatures, are an increasingly significant issue. Protection and, wherever possible, restoration of inflows to the mainstem Green River is essential. A logical solution would appear to be increased storage. The Howard Hanson Dam Additional Water Storage Project Phase 1 (AWSP), authorizing an additional 20,000 acre-feet of storage, will be implemented as early as 2006. That increment, however, is dedicated to municipal supply. Cooperative management for increased resource protection may be possible initially, but as municipal and industrial demand increases this does not appear likely to be a long term solution. Additionally, there may be serious issues in terms of "starving" the Green River below the dam while trying to capture a total of 50,000 acre-feet of storage on an annual basis. Recent occurrences of below normal precipitation and snow pack have made capturing 30,000 acre-feet, in the existing project, challenging. Long term climatic predictions for more of the same will exacerbate these issues. A Phase 2 Project would add another 10,000 acre-feet of storage (60,000 acre-feet total) that would be dedicated to flow augmentation. Benefits of going forward with this further expansion would have to be weighed against even more impacts to storing this volume of water.

While streamflow augmentation is a critical need in the Green River to meet instream flows, it is important to note that reservoir refill operations are also challenging. Reservoir refill begins in late February or early March and extends through May. The late winter-spring refill period is important for salmon life stages in the Green River. The connectivity and availability of side channels and other shallow, low velocity lateral habitats downstream of HHD are significantly reduced during refill. Side channel and lateral habitats are especially important for spawning, incubation, emergence, and early rearing for Chinook, chum, and coho salmon during winter and spring. Chinook fry, after their emergence prior to and during refill, tend to use slow water areas along stream margins and a variety of other edge habitats such as gravel bar pools near vegetative or woody cover. In addition, higher flows that promote less predation and higher survival rates of out-migrating chum and Chinook juveniles are also reduced during spring refill as water is put into storage.

Cooperative efforts, through the water management coordination noted above, help to minimize the effects of storage on downstream habitats and salmon life stages. This has included earlier refill to minimize the proportion of inflow captured in the reservoir (capture rate), and the use of a proportional capture rate as inflows vary. Additional efforts need to be developed in cooperation with the ACOE, TPU, MIT and WDFW to minimize downstream impacts on fish during refill operations. While more reservoir storage may seem like a logical solution to water shortages for fish, it is increasingly apparent that increments in new storage in the reservoir require more aggressive refill rates which may cause further impacts on habitat and life-stage survival. This can be exacerbated in years with low snow pack or dry winter-spring conditions, when it will be challenging to promote the hydraulic connection of side channels and meet other downstream resource needs while achieving additional water storage up to 50,000 acre-feet.

Instream flow regulations and agreements providing for minimum instream flows are an invaluable element of resource protection. The 1995 agreement between MIT and the City of Tacoma provides for development and implementation of a steelhead redd monitoring program (see Section 2.7 – Real-time Monitoring of Steelhead Spawning and Incubation) so that the location of steelhead redds can be included in flow management decision making by the Water Management Coordination Committee. Peak steelhead spawn timing typically occurs in late April to early May and fry emergence typically occurs in late June through early July. Full protection of all steelhead redds is usually not possible, in part due to the need to retain stored water to augment flows during Chinook spawning in the late summer and early fall when inflows to the river are low. Steelhead redd monitoring has provided important information to improve management of summer flows, but it is important to still recognize the limitations of static minimum flows, particularly when flows are higher during steelhead spawning. Providing full-term wild steelhead redd protection through fry emergence is a common example where static minimum flows can fall short. Flows necessary to provide that protection vary greatly from year to year depending on actual flows when spawning takes place. The greater the flow during spawning, the greater the flow must be through emergence. This is an especially acute problem on the Green River where flows during steelhead spawning often vary widely while flows in July, the time of peak emergence, vary little from base levels.

It is important to note that the Green River instream flow requirements or agreements that condition the City of Tacoma Second Diversion Water Right (SDWR) only apply when water is being directly diverted or when water is being placed into storage. They do not apply when previously stored water is being diverted. This means SDWR instream flow provisons do not apply during the critical summer low flow period when SDWR water is being retrieved from Howard Hanson reservoir. However, before withdrawing water under the SDWR, Tacoma Water must adhere to the following seasonal minimum flows at the Palmer and Auburn USGS gauges: July 15 to September 15 – 200 cfs at Palmer and 400 cfs at Auburn; September 16 to July 14 – 300 cfs at Palmer. When these instream flow conditions are met, water can be diverted either directly to the water supply system, or to storage in the reservoir to be used at a later time. At other times, Tacoma will contribute water to the river to ensure that flows do not fall below agreed upon levels at the Auburn USGS gauge committed to by Tacoma as part of the Second Supply project.

Finally, lower flows in the Green River tributaries (Newaukum, Soos, Covington, Jenkins and Mill creeks), particularly during summer months, have had an impact on salmonids. Green River tributaries historically supported more abundant and diverse salmonid populations. WDFW surveys indicate declining numbers of spawners in these tributaries in recent years, especially for steelhead. Declining summer rearing flows and elevated peak flows due to water withdrawals and land development are thought to impact salmonids in these tributaries (see Chapter 9 for more detail on reduction in summer flows).

5 Significant Groundwater Inputs to the Green River

Prior work has identified two reaches along the Green River with significant, concentrated groundwater inputs from external or closed-depression sub-basins. The first is in the vicinity of Auburn, where substantial amounts of groundwater from the adjoining White River basin (WRIA 10) flows to aquifers connected to the Green River. The City of Auburn assessed conditions in the reach from RM 25.5 to RM 35 as part of its 1999 hydrogeologic characterization effort[34]. The second reach extends from RM 48 to 52, where several large springs flow into the Green River. The largest springs are believed to be the discharge points from the adjacent Coal Creek and Deep Creek closed depression basins, which are included in this study as part of Green River Local Inflow Sub-basin 7.

In the two reaches with significant groundwater inputs, Green River flows are expected to increase in the vicinity of the groundwater contributions. In reaches with less pronounced groundwater inputs, the river may gain water from, or lose water to, the underlying groundwater system. These gains and losses may occur within relatively localized areas or along longer reaches of the river, as a discrete event or a long-term condition. Two main factors drive the river-groundwater dynamic: the relationship between water levels in the river and in the underlying (or adjacent) materials, and the permeability of the river bed and bank materials, including bedrock, incised by the river. If river levels are higher than groundwater levels at a given location and the materials are reasonably permeable, water flows from the river into the aquifer[35], a condition known as "losing." On the other hand, if river levels are lower than groundwater levels and the materials are reasonably permeable, water flows into the river from the aquifer—the "gaining" condition.

River-groundwater interactions along the Green River play a crucial role in supporting habitat components for fish and other aquatic species. The dynamic exchange of surface water and groundwater creates unique physical, chemical, and biological conditions. For example, the discharge of cold groundwater into the river can maintain the low water temperatures that fish require, even during the warm summer months. It also maintains habitat features such as wall-based channels and floodplain wetlands that might otherwise dry up in the summer months. Groundwater discharge is influenced not only by conditions along the river but also by the upgradient flow paths that contribute to these conditions. Because of their potential impacts on aquatic habitat, groundwater inputs need to be considered by land use and water resource decision-makers.

The two reaches of significant groundwater inputs to the Green River which are discussed here are not the only sources of groundwater to the river. However, the vast majority of springs and seeps which are the interface from groundwater to surface water are distributed throughout the basin and take on the temperature and water quality characteristics of surface flows before reaching the mainstem Green River. For example, groundwater aquifers are the source of summer base flows in the basin's tributary streams—including Jenkins, Covington, Soos, Newaukum, and Mill Creeks—but those same base flows are regarded as surface water inputs to the Green River. There are numerous groundwater seeps and springs which discharge directly to the Green River along its length, but are typically small and ignored. The areas of groundwater inputs discussed below are of particular interest because of very large and localized flow volumes which are both beneficial to river habitat conditions and attractive as potential sources of water supply.

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[34] Pacific Groundwater Group, 1999. *1999 Hydrogeologic Characterization, City of Aubur*n. Consultants' report prepared for the City of Auburn.

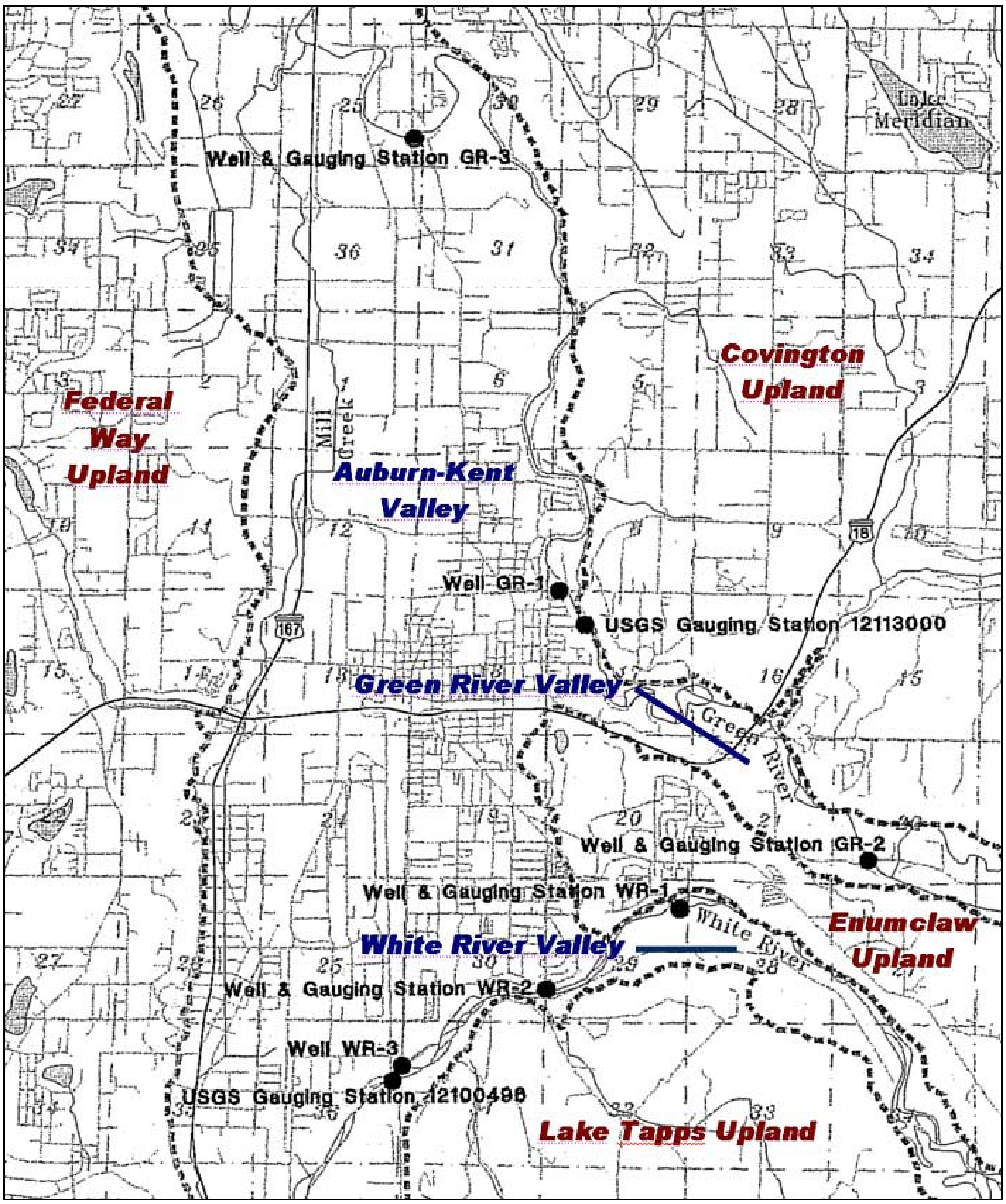
[35] An aquifer is a saturated permeable geologic unit that is capable of transmitting significant quantities of water under ordinary hydraulic gradients. "Significant quantities" is in the context of providing useful amounts of water to springs or wells.

5.1 Groundwater Flows from the White River, WRIA 10

5.1.1 Groundwater Discharge at the Green River near Auburn

In the mid to late 1990s, the City of Auburn installed a network of surface water and groundwater monitoring stations in the Green River vicinity. These stations included wells and nearby stream gauges instrumented with measuring and data logging equipment. Figure 5.1 shows the locations of these monitoring stations. Two stations (GR-1 and GR-3) are located along the Green River in the Auburn Kent-Valley and one (GR-2) is located in the Green River Valley.

Figure 5.1
Geologic Features and Locations of Monitoring Stations



Several factors were characterized to assess the hydraulic connection between the groundwater system and the Green River in these areas: geologic relationships, differences in river and groundwater levels, and river flows.

5.1.1.1 Geologic Relationships

Near its confluence with the Auburn-Kent Valley (at approximately RM 32), the Green River is underlain by an aquifer system composed of two hydrogeologic units—the alluvial deposits (Qal) and the glacial Vashon recessional deposits (Qvrd). Farther upgradient, in the Green River Valley, the aquifer system consists predominantly of Qal. Wells GR-1, GR-2, and GR-3, which lie adjacent to the Green River, locally penetrate silt and fine sand within much of the upper part of the Qal. These relatively fine-grained layers lie at or above river level, likely controlling groundwater flow to the river. These layers have a lower hydraulic conductivity than the surrounding coarser sediments; consequently, groundwater flow through these fine-grained layers has a significant vertical component.

5.1.1.2 River & Groundwater Levels

Groundwater flows down the Qal aquifer beneath the Green River Valley and then enters the Qal/Qvrd in the Auburn-Kent Valley. It then flows northward through the Qal/Qvrd aquifer, roughly following the Green River (Figure 5.1). The river gains flow in some reaches and loses flow in others, as discussed below.

- **RM 35—Well & Gauging Station GR-2**. At this station, which lies 4 miles upstream of the USGS stream gauge #12113000, the river loses flow to the groundwater system. Water levels in the Qal at Well GR-2 are always lower than river stage at SG-GR-2, by about 0.5 to 1 foot.

- **RM 31—Well GR-1 & Stream Gage USGS #12113000, Green River near Auburn.** At this location, the Green River gains flow from the aquifer, as indicated by the relationships between groundwater levels and river stage[36]. The water level difference at the gauge and well is generally small—only 1 foot most of the year. Because gradients are upward, groundwater augments river flows at all times except possibly during extreme, short-term flood peaks. This pattern is consistent with water level contours for the Qal aquifer, which show flow to the river in this area.

- **RM 25.5—Well & Gauging Station GR-3**. At this location, 5.5 miles downstream from the USGS stream gage, the Green River gains flow all year. As at GR-1, water level contours for the Qal show flow from the aquifer to the river; however, the water level differences—and thus the flow gradients toward the river—are much larger here. Water level differences are 1 to 7 feet annually.

5.1.1.3 River Flow Measurements

Gains and losses can be assessed by comparing flow rates at various points along a river. If the flow rate measured at a downstream station is higher than it is at an upstream station, the source of the increase must be groundwater (assuming no tributaries or springs occur along the reach). However, to be statistically valid, the difference between the two measured flows must be higher than the errors associated with measuring them; these measurement-related errors are typically 5 to 10 percent of the

[36] Pacific Groundwater Group, 1999. *1999 Hydrogeologic Characterization, City of Aubur*n. Consultants' report prepared for the City of Auburn.

total river flow using USGS standard methods[37]. Green River flow data evaluated in the PGG study were determined by PGG to have an accuracy of 10% based on ratings by the USGS and PGG subconsultants.

For the City of Auburn study, mean monthly flows for the Green River were compared at three stations between RM 25.5 and 35 that the City of Auburn monitored during Water Years 1997 and 1998[38]. Only results for one month for the upper reach between RM 35 and RM 31, ending at the USGS gauge, were within a confidence interval that could be interpreted as either a gain or loss. Between these two locations, and after adjustment for inflow from Big Soos Creek, which was separately gauged, the Green River gained flow within this reach at an average rate of 53 cfs during September 1997. However, since the reported confidence interval range was ±51 cfs (based on error analysis with upstream flow of 335 cfs and downstream flow of 388 cfs), actual gains were likely to have been anywhere between 2 and 104 cfs. For other periods, the errors significantly exceeded the computed change and no conclusions can be made about gains or losses. Likewise, no conclusions can be made regarding gains or losses for the lower reach between RM 25.5 and RM 31.

5.1.2 Upgradient Groundwater Flow Conditions

The groundwater flowing through the Green River Valley and Auburn-Kent Valley originates from a number of upgradient sources within WRIA 9 and WRIA 10. In the Auburn vicinity, groundwater moves downgradient from the Covington, the Federal Way, and to some degree the Enumclaw Uplands until it reaches the valley, where it may discharge to the Green River. These upland areas include layers of high- and low-permeability sediments that produce horizontal and vertical flow components as groundwater moves downward, toward the Green River. A significant amount of groundwater also originates within the valleys as incident precipitation that infiltrates into the permeable sediments and then flows along a path that roughly parallels the river. Additionally, water from the Green River may discharge to the underlying Qal sediments along losing reaches, recharging the aquifer.

A substantial amount of groundwater flows toward the Green River from the neighboring White River Valley (WRIA 10). The groundwater from the White River Valley flows along a shallow alluvial aquifer (Qal) until it reaches the confluence with the Auburn-Kent Valley (Figure 5.1). It then turns—rather sharply—around the western edge of the Enumclaw Upland and follows the Green River northward through the Auburn-Kent Valley. This groundwater, which originates from the White River and the Lake Tapps and Enumclaw Uplands, follows a path that roughly parallels the ancestral channel of the White River to its historical confluence with the Green River at about RM 32—that is, the pre-1906 channel, before a catastrophic flood diverted most of the river's flow into its southern fork, the Stuck River.

The City of Auburn's *1999 Hydrogeologic Characterization Report* states that water from the White River valley Qal alluvial aquifer (and from the White River) enters the combined Qal and Qvrd aquifer in the Auburn-Kent valley at a rate of 31 to 62 cfs. A substantial portion of this water flows north toward the Green River. While it is not known how much of this water discharges to the Green River, the report states that additional pumping in the Qvrd would reduce groundwater discharge to the Green River. Additional detailed modeling would be required to further address this issue and to quantify the seasonal and annual variability in groundwater flows.

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[37] USGS Office of Surface Water Technical Memorandum No. 93.07, policy statement on stage accuracy dated December 4, 1992, states, "The accuracy of surface water discharge records depends on the accuracy of discharge measurement, the accuracy of rating definition, and the completeness and accuracy of the gage-height record. Accuracies of discharge records for individual days commonly are about 5 to 10 percent.

[38] Pacific Groundwater Group, 1999. *1999 Hydrogeologic Characterization, City of Auburn*. Consultants' report prepared for the City of Auburn.

5.2 Deep & Coal Creek Closed Depression Basins, RM 48-52

The most apparent source of inflow to the Green River along the reach from RM 48–52 is the springs that issue from the upland areas immediately south of the river. Figure 5.2 shows locations of the major springs and assumed recharge areas (the delineated sub-basins). The water level contours on a map presented in a report by Brown & Caldwell map suggest that groundwater flows northwest through a regional aquifer toward the springs[39]. These springs lie along the steep slopes that bound the river valley and discharge into small creeks that eventually join the river. They are located in areas where the steep slopes expose glacial sediments or the interface between relatively unconsolidated glacial sediments and Tertiary bedrock. Four dominant springs flow to the Green River from RM 48–52.

Table 5.1
Major Springs between Green River RM 48 and RM 52

Spring	RM (Approximate)	Flow (cfs) Low	Average	High	Period of Record	Data Source[40]
Icy Creek	48.2	0.9 [1]	23 [2]	78 [3]	1963–68	USGS website
Black Diamond	49.5	5	20	40	---	Penhallegon, 2000[41]
Palmer	49.7	4	10	25	---	Penhallegon, 2000
Resort	51.3	2	---	5	---	Brown and Caldwell, 1989

Notes: 1=mean monthly flow in October 1967; 2=average flow for 1964–1967; 3 = mean monthly flow in February 1965.

5.2.1 Icy Creek

The primary spring that feeds Icy Creek lies at an elevation of about 600 feet, about 0.7 miles upstream of the creek's confluence with the Green River, where WDFW operates a nearby salmon-rearing facility[42]. Seasonal creek flows range widely, according to USGS stream gauge records from the 1960s[43]. Temperatures in the creek range from 6.7°C to 10.6°C degrees seasonally based on King County measurements from July 2001 to August 2002. These seasonal variations in flow and temperature suggest that the creek-spring system is substantially affected by upgradient recharge and local runoff. The recharge area for the Icy Creek spring is suspected to include the adjacent Coal Creek basin, which drains to Fish Lake.

[39] Brown & Caldwell, 1989, *Geohydrology Studies of the Metro Section 16 Silvigrow Project, March 1989*.

[40] The relatively-recent sources listed below may have relied on flow data originally published in Appendix Table 11-records of springs from Luzier, J.E., "*Geology and Ground-Water Resources of Southwestern King County, Washington,*" USGS Water-Supply Bulletin No. 28, 1969.

[41] Penhallegon Associates Consulting Engineering, Inc., 2000, *Year 2000 Final Comprehensive Water System Plan*. Prepared for City of Black Diamond.

[42] Washington State Conservation Commission and King County, *Limiting Factors and Reconnaissance Assessment Report for WRIA 9 and Vashon Island*, December 2000.

[43] U.S. Geological Survey, 2004, Washington NWIS Web Data—USGS 12107300 Icy Creek near Black Diamond, WA. Http://nwis.waterdata.usgs.gov/wa/nwis/nwisman/?site_no=12107300&agency_cd=USGS.

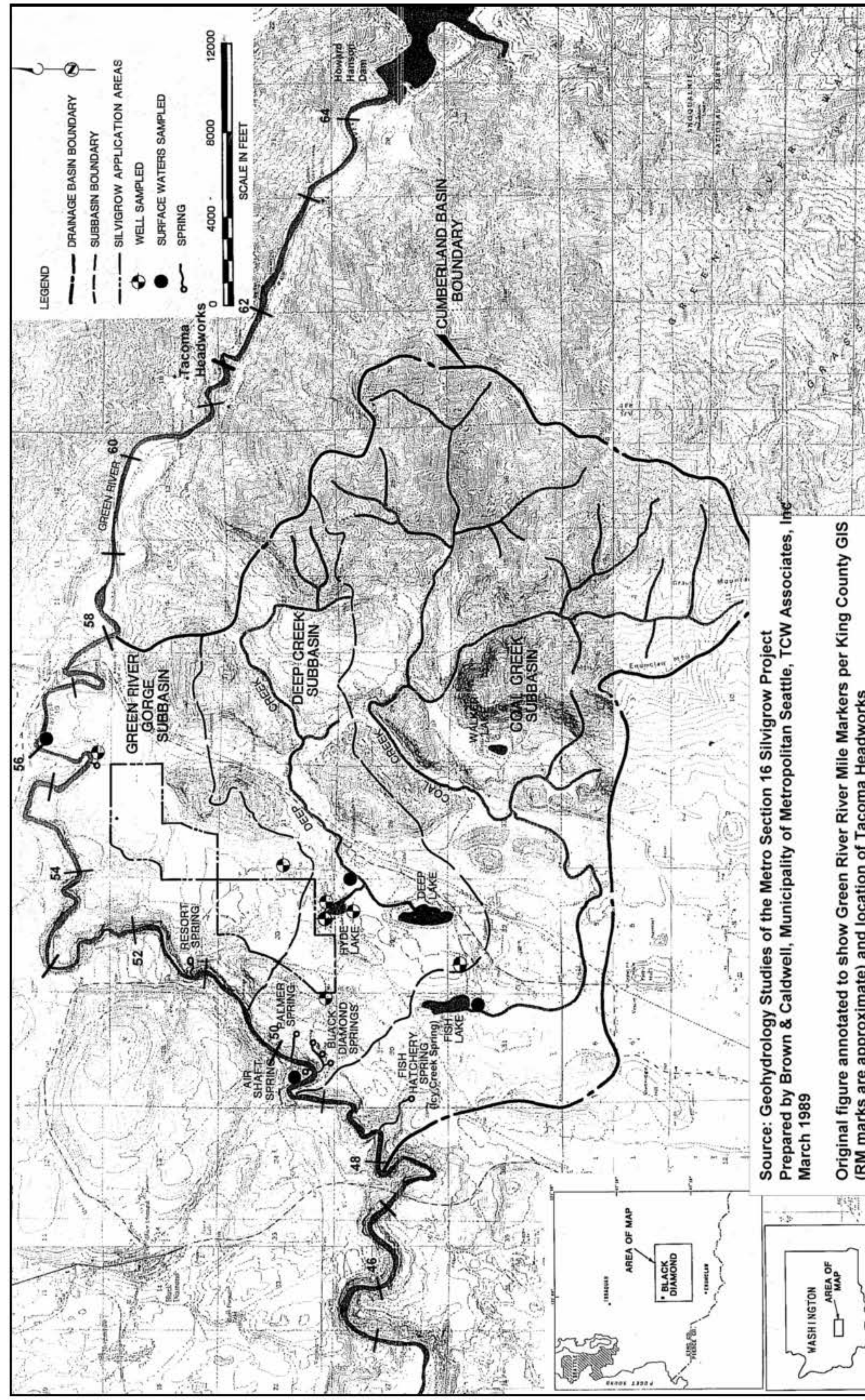

Figure 5.2. Locations of Major Springs

Both local and regional groundwater flow conditions may contribute to Icy Creek spring. Recent drilling on the Franklin Plat above the spring suggests that a highly permeable paleochannel lies in close proximity to the plat, defining a narrow zone of groundwater flow [44]. The site-specific Franklin Plat study reveals how local-scale flow conditions differ substantially from the laterally continuous regional flow conditions of Brown & Caldwell[45]. However, the Franklin Plat study does not address the paleochannel geometry upgradient or downgradient of the plat, nor does it explore the hydraulic connections to the regional flow system.

WDFW uses water from the springs for fish propagation at its salmon-rearing facility. During low-flow periods, the rearing ponds capture all the water flowing from these springs; flow is measured monthly at exit points from the rearing ponds. During seasonal high flows, the piping system into the ponds is incapable of handling the entire spring flows and total flows are estimated. Table 5.2 summarizes recent monthly flows for Icy Creek Springs as reported in the *Limiting Factors Report*[46] which credits the source of these data as S. Mercer (2000) of the Washington Department of Fish and Wildlife. Flows are provided in Table 5.2 in units of both gallons per minute (gpm) and cubic feet per second (cfs). It should be noted that the USGS records of Icy Creek Springs summarized in Table 5.1 suggest monthly flows for Icy Creek Springs which are considerably more variable than the values presented in Table 5.2. As the period of record and frequency of discharge measurements for the Table 5.2 data is unknown; the USGS historical records are considered the more reliable source of data to characterize flows at Icy Creek.

Table 5.2
Recent Monthly Flows in Icy Creek Rearing Ponds and Springs

Month	Low Flow (gpm)	High Flow (gpm)		Low Flow (cfs)	High Flow (cfs)
January	3,700	5,300		8.2	11.8
February	3,700	5,300		8.2	11.8
March	4,000	5,450		8.9	12.1
April	5,300	5,800		11.8	12.9
May	2,800	5,100		6.2	11.4
June	2,800	3,100		6.2	6.9
July	2,500	3,100		5.6	6.9
August	2,600	3,300		5.8	7.3
September	1,100	1,580		2.4	3.5
October	700	915		1.6	2.0
November	1,300	4,500		2.9	10.0
December	3,400	3,900		7.6	8.7

[44] Icicle Creek Engineers, Inc., 2002, *Letter Supplement No. 2, Hydrogeologic Consultation, Proposed Subdivision – Franklin Plat, King County, WA*. King County Application No. L01P001, Letter dated September 12, 2002.

[45] Brown & Caldwell, 1989, *Geohydrology Studies of the Metro Section 16 Silvigrow Project, March 1989.*

[46] Washington State Conservation Commission and King County, *Limiting Factors and Reconnaissance Assessment Report for WRIA 9 and Vashon Island*, December 2000

5.2.2 Black Diamond & Palmer Springs

The Black Diamond Springs actually issue from three locations (south, middle, and north) at an elevation of about 620 feet. The City of Black Diamond operates a collection facility that conveys water from these and the nearby Palmer Springs to its municipal supply system located approximately 2 miles northwest of the Green River. The City has water rights which allow for an instantaneous withdrawal of approximately 8.0 cfs and a mean annual withdrawal of 0.76 cfs from these springs.

5.2.3 Resort Springs

A local community collects a portion of Resort Springs for water supply. No water use data are available for these springs.

5.2.4 Other Springs in vicinity of Green River RM 48-52

An additional source of "spring" water (about 2 cfs) is reported by Brown and Caldwell[47]. This water drains from a coal mine tunnel near Hyde Lake. Another spring—the Air Shaft Spring—discharges from the steep slope on north side of the Green River, approximately at RM 49.6. Other springs undoubtedly flow into creeks that feed the Green River along this reach or they occur as diffuse seepage faces along steep slopes.

[47] Brown & Caldwell, 1989, *Geohydrology Studies of the Metro Section 16 Silvigrow Project, March 1989.*

6 Land Use, Recharge, and Future Land Use Change Analysis

Land use activities have a direct and sometimes dramatic impact on streamflows. In urban areas, the elimination of forest cover, compaction of the surface soils, and placement of impervious surfaces are associated with increased rates and volumes of surface runoff, and with reduced recharge to groundwater. Development activities can also result in increased stream temperatures due to reduced groundwater-derived base flows and to loss of shading along riparian corridors. This chapter provides an assessment of the extent and magnitude of the existing and planned urbanization of the Lower/Middle Green River basin. Also, the findings of recent studies on groundwater recharge in the study area are reviewed. The analysis presented here does not specifically quantify the effects of land use activities on streamflows and temperatures but does provides data which are relevant to such an analysis. The location and magnitude of planned future development is assessed relative to current conditions so as to provide an indicator of potential impacts to groundwater recharge and to streamflows.

6.1 Soils and Land Use Data

All Geographic Information System (GIS) soils and land use datasets used in the land use assessment were obtained from others. The source data sets are summarized below. All datasets obtained from King County used the Washington State Plane-North Zone-NAD1983/HARN coordinate system. Datasets obtained from other sources, which used alternative coordinate systems, were converted to the King County standard.

- Existing land cover was based on 1998 LANDSAT imagery with classifications performed by Hill et al[48]. The dataset is in a raster format with 30-meter pixel size characteristic of the LANDSAT imagery. The land cover classification used seven categories of land cover that were derived for use in urban and urbanizing watersheds. NHC acquired the dataset directly from the author's webpage at the University of Washington Center for Water and Watershed Studies, then re-projected from UTM-zone 10 NAD 1927 coordinate system to the project coordinate system of Washington State Plane-North Zone-NAD 1983/HARN.

- Future land cover was based mainly on land use zoning data compiled in GIS format by the Puget Sound Regional Council (PSRC). The PSRC dataset includes comprehensive plan data for all incorporated and unincorporated areas of Pierce, King, Kitsap and Snohomish Counties. The dataset was acquired from the PSRC in the Washington State Plane-North Zone-NAD 1983 coordinate system and transformed to the NAD 1983/HARN datum.

- Sensitive areas, which are assumed to be protected from future development, were identified from wetland and open water datasets (WETLD and WTRBDY) obtained from King County. County-wide datasets describing other sensitive areas (steep slopes, coal mine hazards, etc.) were not available.

- Groundwater recharge areas were identified primarily from a GIS layer provided by King County (RECHARGE) which characterizes land areas as low to high recharge potential based on the County's analysis of surficial geology, soils and depth to groundwater.

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[48] Hill, Kristina; Botsford, Erik; Booth, Derek. 2000. A Rapid Land Cover Classification Method for Use in Urban Watershed Analysis. Center for Urban Water Resource Management (Now the Center for Water and Watershed Studies) at the University of Washington. October 6th, 2000

- A supplemental source of groundwater recharge information was a dataset titled SURFGEOL, produced by Booth et al.[49] and which characterizes the surficial geology of the entire county. This supplemental information was used for areas of zoned urban development which were beyond the limits of the RECHARGE dataset.

Because the LANDSAT imagery was not available in a shape file format, all data layers were transformed to a common 1-meter grid format for purposes of computations and subsequent displays. The original 30-meter grid from the LANDSAT imagery was felt to be too coarse to use in overlays with watershed boundary and other data layers, and the 1-meter grid was felt to provide appropriate resolution.

Land use classifications from the LANDSAT dataset of future conditions were reclassified to approximate land cover percentages as shown in Table 6.1. Land zoning classifications from the PSRC dataset representing future conditions were aggregated and reclassified to approximate land cover percentages as shown in Table 6.2. Note that High Density Residential land use is defined in this study as all residential densities greater than 4 dwelling units per acre (du/ac), including multi-family densities having more than 7 du/ac. This aggregation was needed because large portions of the urban growth areas in the Green River Study Area are zoned in the PSRC dataset for a residential density of between 4 and 12 du/ac, and does not distinguish between single family and multi-family densities.

The source PSRC dataset of land use zoning included hundreds of discrete zoning classifications. Consolidation of the information into common groupings was performed by looking up the planning data for individual municipalities to decipher planning descriptions. For some areas the planning descriptions do not give any indication of the land cover that may exist in the developed state (i.e. Government, Military, Tribal and Public). In those areas the existing landcover pixels from the LANDSAT classification were incorporated into the PSRC dataset and aggregated using best professional judgment into the categories in Table 6.2.

Table 6.1
1998 LANDSAT Classification Categories and Land Cover*

LANDSAT Classification	Land Cover Percentages				
	Open Water	Trees	Shrubs/Grass	Pavement (TIA)	Bare Earth
Urban Forested (UF)	0	39	23	38	0
Urban Grass Shrub (UG)	1	4	21	73	1
Urban Paved (UP)	1	5	2	92	0
Forested (FOR)	0	96	1	1	2
Grass Shrub Crops (GR)	0	1	94	3	2
Water (WAT)	100	0	0	0	0
Bare Soil (SOIL)	1	2	0	7	90

*Based on orthophoto verification by Hill et al.

[49] Booth, D.B., R.A. Haugerud, and J. Sacket, in review, Geologic map of King County, Washington: U.S. Geological Survey Miscellaneous Investigations Map, scale 1:100,000.

Table 6.2
PSRC Aggregated Zoning Categories and Land Cover

Aggregated Land Use Category based on PSRC Zoning	Land Cover Percentages						
	Forest	Agric/ Pasture	Grass	EIA*	TIA*	Wetland	Open Water
Lakes / Open Water (OW)	0	0	0	0	0	0	100
Designated Wetlands (WET)	0	0	0	0	0	100	0
Industrial Forest (IND FOR): Roaded timber production	99.5	0	0	0.5	1	0	0
Open Grass (OG): Parks and recreational space	0	0	100	0	0	0	0
Mineral Resource Lands: Quarries and mines	0	0	50	50	50	0	0
Agricultural lands (AG)	0	99	0	1	1.3	0	0
Low Density Residential (LDR): < 1 d.u. per acre	0	48	48	4	10	0	0
Medium Density Residential (MDR): 1-3 d.u. per acre	0	0	86	14	25	0	0
High Density Residential (HDR): >4 d.u. per acre	0	0	60	40	53	0	0
Commercial (COM): comer-cial, industrial, road corridors.	0	0	14	86	90	0	0

* EIA is Effective Impervious Area, representing the surface from which runoff is conveyed directly to an improved conveyance system with limited opportunity for infiltration to groundwater. EIA summed with other land covers, excluding TIA, yields 100% of the land area. TIA is Total Impervious Area presented for consistency with the classifications for the current conditions LANDSAT imagery. TIA percentages duplicate other categories and should not be summed with the other future land use components.

Figures 6.1 and 6.2 respectively show the current conditions and the land use zoning. Land use conditions for current and future (zoned) conditions for each of the study area sub-basins were tabulated with a 1-meter grid using ArcView GIS and are summarized in Tables 6.4 and 6.5. Figures showing the current land use of the areas zoned for urban and commercial development, and overlays showing groundwater recharge classifications, are provided as part of the land use change analysis in Section 6.4.

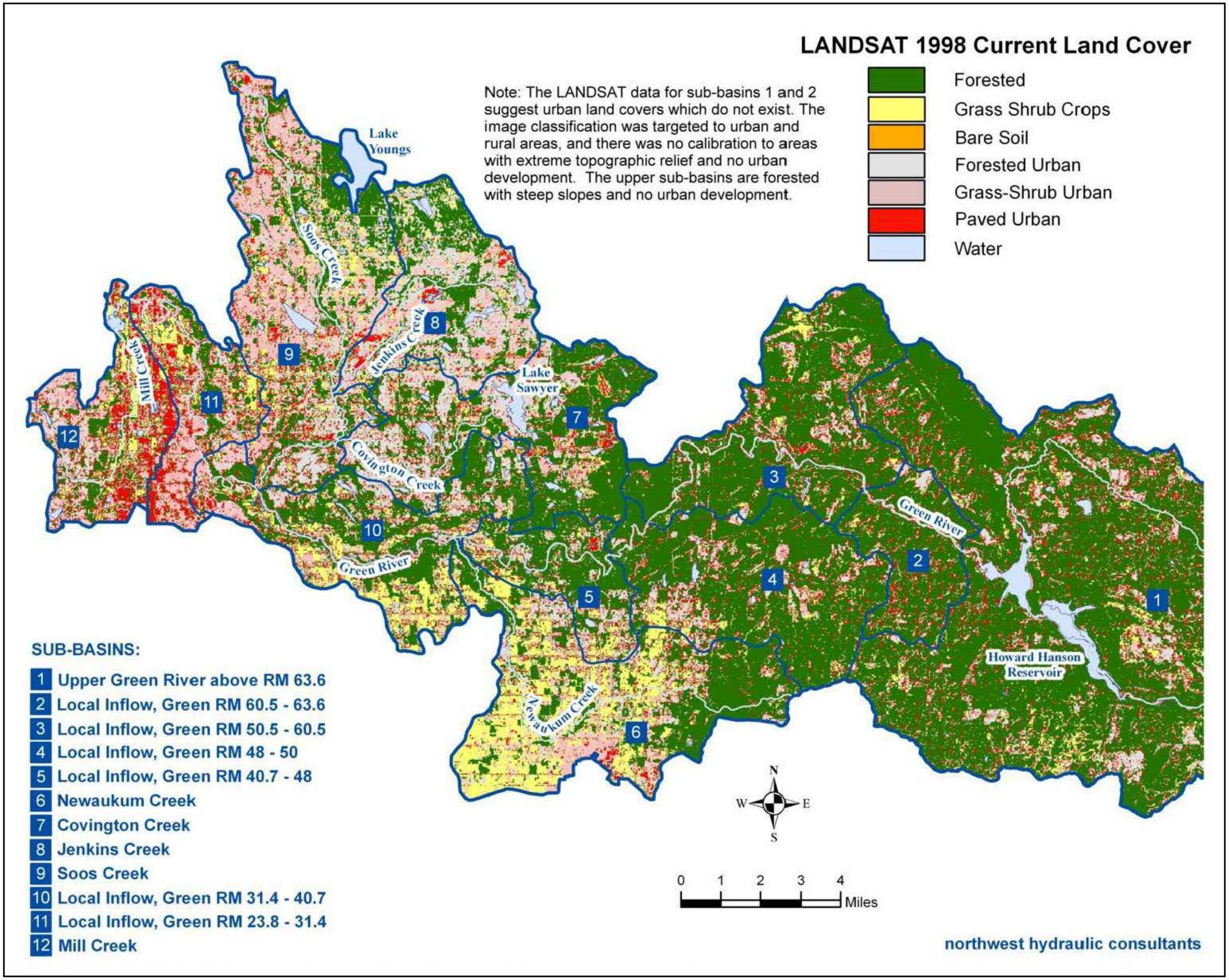

Figure 6.1. Current Land Cover from 1998 Landsat Satellite Image

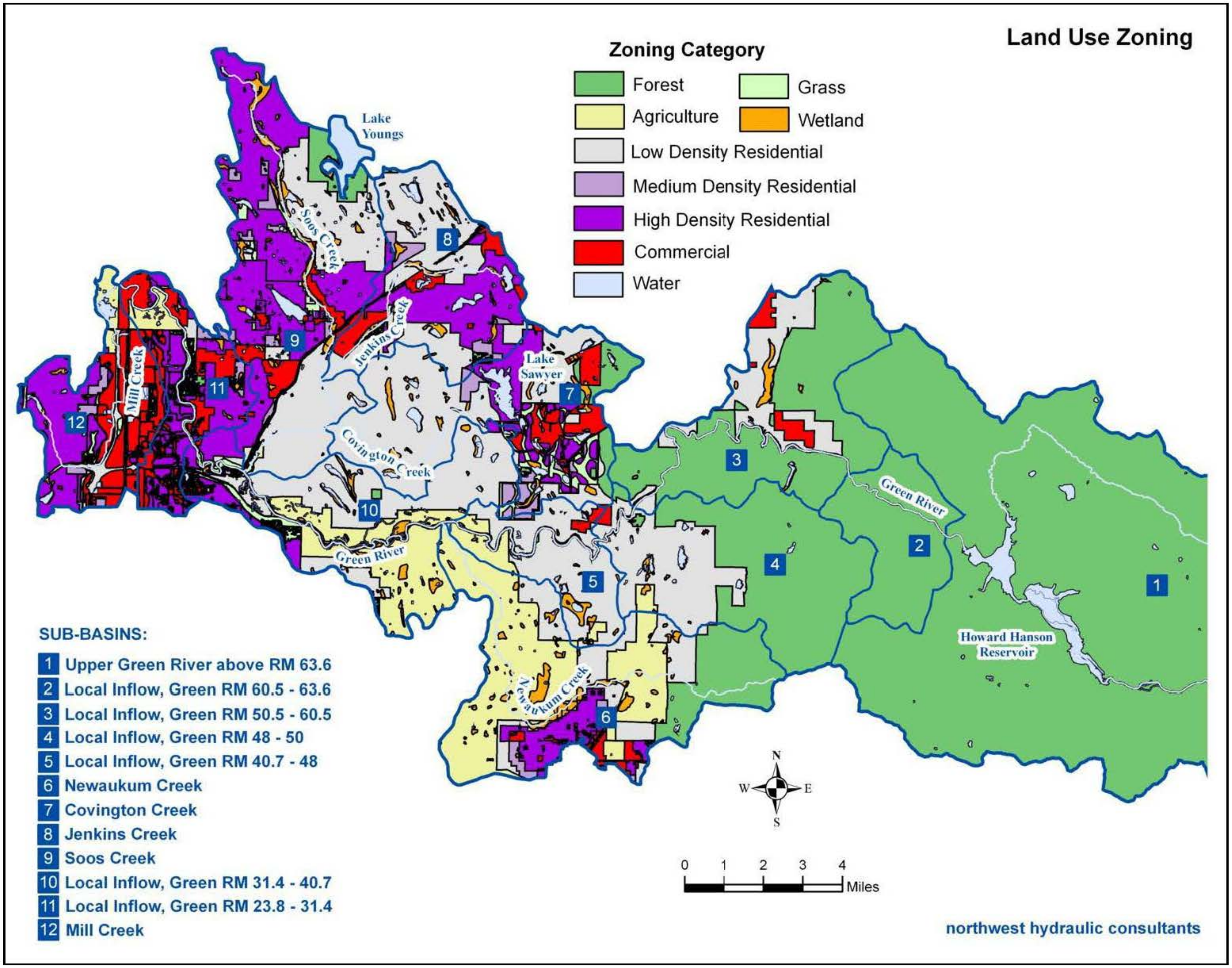

Figure 6.2. Land Use Zoning—Future Land Cover Conditions

Table 6.3
Sub-Basin Current Conditions Land Cover

Sub-Basin		Total Area (sq. mi.)	LANDSAT Classification (%)							TIA:**
ID	Name		Forest Urban	Grass Shrub Urban	Paved Urban	Forest	Grass Shrub Crops	Water	Bare Soil	Total Impervious Area, %
1*	Upper Green River above RM 63.6	222	0	0	0	92	8	0	0	1
2*	Local Inflow, Green RM 60.5 – 63.6	9.4	0	0	0	96	4	0	0	1
3	Local Inflow, Green RM 50.0 – 60.5	22.2	12	3	1	79	5	0	0	8
4	Local Inflow, Green RM 48 – 50	21.5	13	3	0	77	6	0	0	9
5	Local Inflow, Green RM 40.7 – 48	8.6	18	9	2	58	12	0	0	16
6*	Newaukum Creek	27.1	12	5	2	36	45	0	0	11
7	Covington Creek	21.5	25	10	2	52	7	2	1	20
8	Jenkins Creek	15.9	34	20	3	33	8	1	1	31
9	Soos Creek	29.0	24	27	3	31	13	1	1	33
10	Local Inflow, Green RM 31.4 – 40.7	20.2	18	14	2	46	20	0	0	20
11	Local Inflow, Green RM 23.8 – 31.4	10.0	14	32	14	19	20	0	1	42
12	Mill Creek	12.3	17	25	17	17	20	0	3	42

* An initial evaluation of the satellite data identified erroneous results for sub-basins 1, 2, and 6, based on a subsequent comparison to zoning and USGS maps. The following adjustments were made to the data. In sub-basins 1 and 2, which are both forested basins with no urban development, all areas initially categorized from the satellite image as urban forest and urban shrub were respectively reclassified as (non-urban) forest and shrub. In sub-basin 6 which is a predominantly agricultural basin, 2/3 of the area initially categorized from the satellite image as urban shrub was reclassified as (non-urban) shrub/crops. Table 6.3 above presents the values after these adjustments were applied.

** Note that the TIA values presented above are derived from classification methods which were calibrated to urbanized basins. Comparison with the Table 6.4 future TIA values derived from zoning data suggests that the values in Table 6.3 above may be too high in the non-urban basins. Non-urban basins are those with significant forest cover, agricultural land use, and low-density residential development.

Table 6.4
Sub-Basin Zoning: Future Conditions Land Use

Sub-Basin		Total Area (sq. mi.)	Aggregated Land Use from PSRC Zoning (%)									TIA (%)
								RESIDENTIAL				
ID	Name		OW	WET	IND FOR	GR	AG	LD	MD	HD	COM	
1	Upper Green River above RM 63.6	222	1	0	99	0	0	0	0	0	0	1
2	Local Inflow, Green RM 60.5 - 63.6	9.4	1	0	99	0	0	0	0	0	0	1
3	Local Inflow, Green RM 50.0 - 60.5	22.2	1	2	72	0	0	21	0	0	4	6
4	Local Inflow, Green RM 48 – 50	21.5	1	1	65	0	1	31	0	0	1	4
5	Local Inflow, Green RM 40.7 – 48	8.6	3	5	1	1	15	72	1	0	3	10
6	Newaukum Creek	27.1	0	5	18	0	46	17	2	8	2	9
7	Covington Creek	21.5	3	5	8	6	0	53	4	12	9	21
8	Jenkins Creek	15.9	2	6	1	0	0	48	5	31	8	32
9	Soos Creek	29.0	1	6	4	2	0	34	3	43	5	34
10	Local Inflow, Green RM 31.4 - 40.7	20.2	2	5	1	4	33	43	2	8	1	11
11	Local Inflow, Green RM 23.8 - 31.4	10.0	2	2	3	4	7	6	7	42	28	51
12	Mill Creek	12.3	1	3	1	4	6	10	5	36	34	54

Land Use Definitions are per Table 6.2 as follows: OW = Open Water; WET = Designated Wetlands; IND FOR = Industrial Forest with Roads; GR = Grass; AG = Agricultural Lands; LDR = Low Density Residential at < 1 d.u. per acre; MDR = Medium Density Residential at 1-3 d.u. per acre; HDR = High Density Residential at >4 d.u. per acre (including Multi-Family densities); and COM = commercial, industrial, airport, and transportation corridors. TIA is Total Impervious Area.

A land use change analysis, which examines the existing condition of lands zoned for urban and commercial development, is presented in Section 6.3.

6.2 Recharge Analysis

Groundwater quantities are strongly influenced by the recharge process, the mechanism that replenishes groundwater with water derived from precipitation. Factors influencing recharge include precipitation, soil type and surficial geology, and land cover. The highest rates of recharge occur in areas where precipitation is high, soils are coarse, and evapotranspiration rates are low. For example, precipitation falling on coarse soils will recharge at much higher rates than it will in urban areas covered with pavement, which is impervious and facilitates runoff. Recharge may also be higher in higher-elevation areas, which generally receive more precipitation.

For this assessment, the results of two previous regional studies were used to estimate annual volumes of recharge within each sub-basin. Average annual recharge is an important parameter to quantify because it is used in water-budget analyses. The regional recharge studies are discussed in Section 6.2.2; estimates of average annual recharge are presented in Section 6.2.3.

6.2.1 Precipitation and Runoff Amounts

Annual precipitation in the Green River study area ranges from over 90 inches in areas feeding the upper reaches of the Green River to less than 30 inches in the lowlands near Puget Sound, north of White Center. Figure 6.3 shows precipitation contours and basin boundaries. The highest precipitation values occur within the northern portion of the Upper Green River sub-basin and within bordering sub-basins (RM 48–50, RM 50–60.5, and RM 60.5–63.5). These areas generally correspond to higher elevations; precipitation values above Howard Hanson Dam reflect the higher elevations of the uplands and Cascades that rise above the Green River canyon floor. Precipitation values of 40 to 50 inches per year dominate much of the WRIA west of Palmer.

Runoff, or the amount of precipitation that reaches streams, has been coarsely estimated with water balance methods (runoff = precipitation minus evapotranspiration) to range from nearly 80 inches per year in portions of the upper Green River basin to about 25 inches per year in the lower watershed near Auburn. Figure 6.4 adapted from Richardson et al.[50] shows runoff contours for the portions of south King County, including the Green and Cedar River Basins. The runoff amounts combine all components of basin drainage, including both surface runoff and groundwater flows.

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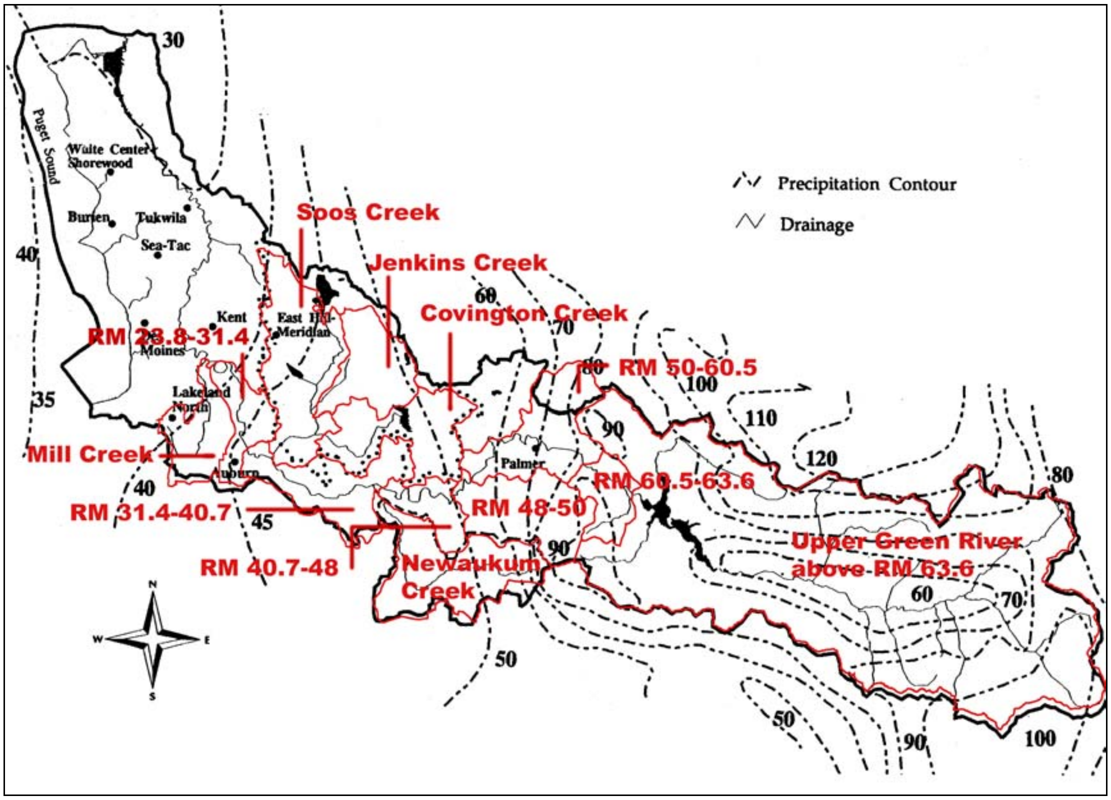
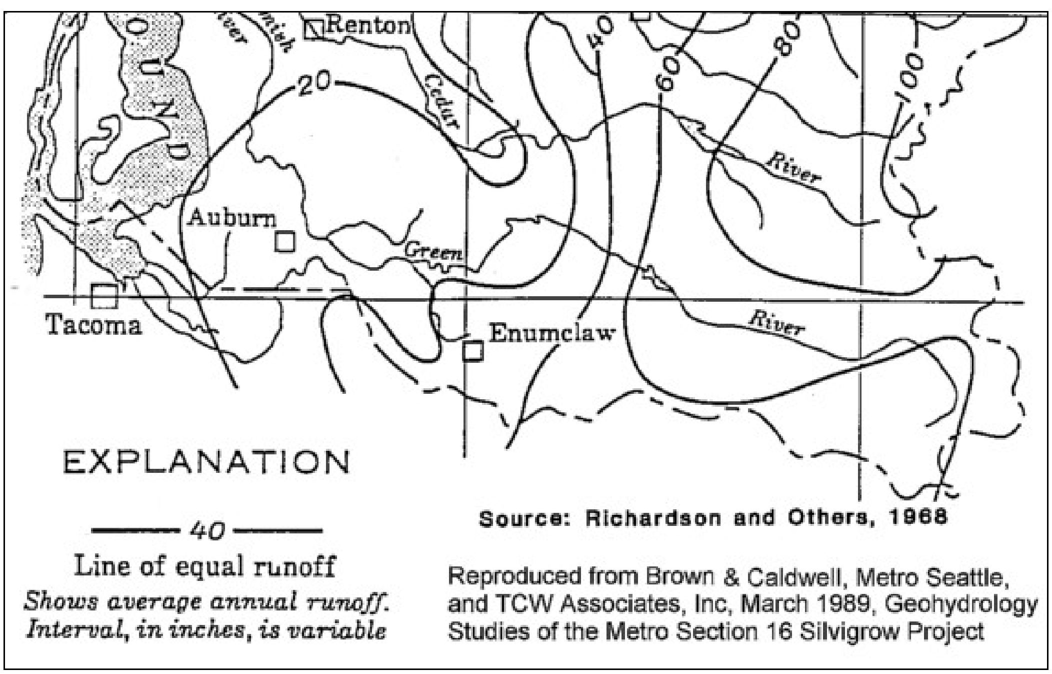
[50] Richardson, D., Bingham, J.W., and Madison, R.J., "*Water Resources of King County, Washington,*" USGS Water-Supply Paper 1852, 1968.

Figure 6.3
Precipitation Contour Map for Green River Study Area



Map modified from a figure in Ecology's 1995 Initial Watershed Assessment for WRIA 9.

Figure 6.4
Runoff Contour Map for Portions of South King County



6.2.2 Recharge Distribution by Gridded Water Balance Models

Two previous studies have assessed the spatial distribution of recharge in the study area. The USGS computed the average annual recharge rate for each quarter-quarter section within King County using a deep percolation model (DPM)[51] and regression equations. These data, which are available in GIS digital format, were used to create Figure 6.5 for this assessment. Data from the City of Auburn was also used; the City's data include annual recharge rates for 400-square-meter grid cells over an area covering parts of WRIA 9 and 10[52]. The Auburn data were not available in GIS format. Instead, a digital PDF version of the color-coded, discretized recharge map from the hard-copy report was used in this analysis. This map was imported into the GIS file; road intersections were then matched to those in the GIS file.

Figure 6.5 shows the extent of data coverage in the study area; in general, recharge rates were calculated only for sub-basins downstream of RM 48 as part of the USGS and Auburn studies. Little or no data are available for four sub-basins—RM 48 to 50, RM 50 to 60.5, RM 60.5 to 63.6, or Upper Green River above RM 63.6—and only the western half of the Newaukum Creek sub-basin was covered.

As described by the USGS[53], the DPM, a grid-based model, computes daily deep percolation below the root zone for each cell within a basin and then accumulates these values to estimate monthly, annual, and long-term average annual values. It simulates the physical processes that control recharge rates, including soil-moisture accumulation, evaporation from bare soil, plant transpiration, surface water runoff, snow accumulation and melt, and the accumulation and evaporation of intercepted precipitation. The DPM also accounts for daily changes in soil moisture, plant interception, and snowpack, as well as deep percolation below the root zone when soil moisture exceeds field capacity. The DPM model was used to simulate recharge only in the Soos Creek basin; recharge in other areas was estimated through simple, two-parameter regression equations

Auburn's recharge analysis by PGG was similar to that of the USGS, but it considered 16 land use types (based on 1995 satellite data), whereas the USGS considered only six. For example, the PGG land use types included "low-intensity development" and "medium-intensity development" which were not used in the USGS analysis. Each land use type requires different coefficients for infiltration, runoff, evapo-transpiration, and other parameters. The City of Auburn modified the USGS equations for some land uses, as described in its 1999 hydrogeologic characterization report[54].

It should be recognized that PGG (for the City of Auburn) and the USGS used different regression equations and different assumptions in developing estimates of recharge. One important difference is in recharge estimates for Group D soils and lakes: PGG assigned a recharge rate of 13.6 inches per year to these features while the USGS assigned a rate of zero.[55]

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[51] Bauer, H.H, and Vaccaro, J.J., 1987. *Documentation of a deep percolation model for estimating ground-water recharge*. U.S. Geological Survey Open-File Report 860536.

[52] Pacific Groundwater Group, 1999. *1999 Hydrogeologic Characterization, City of Aubur*n. Consultants' report prepared for the City of Auburn.

[53] Woodward, D. G., E A. Packard, N. R Dion, and S. S. Sumioka, *Occurrence and Quality of Ground Water in Southwestern King County, Washington,* USGS Water-Resources Investigations Report 92-4098, 1995.

[54] Pacific Groundwater Group, 1999. *1999 Hydrogeologic Characterization, City of Aubur*n. Consultants' report prepared for the City of Auburn.

[55] Ibid.

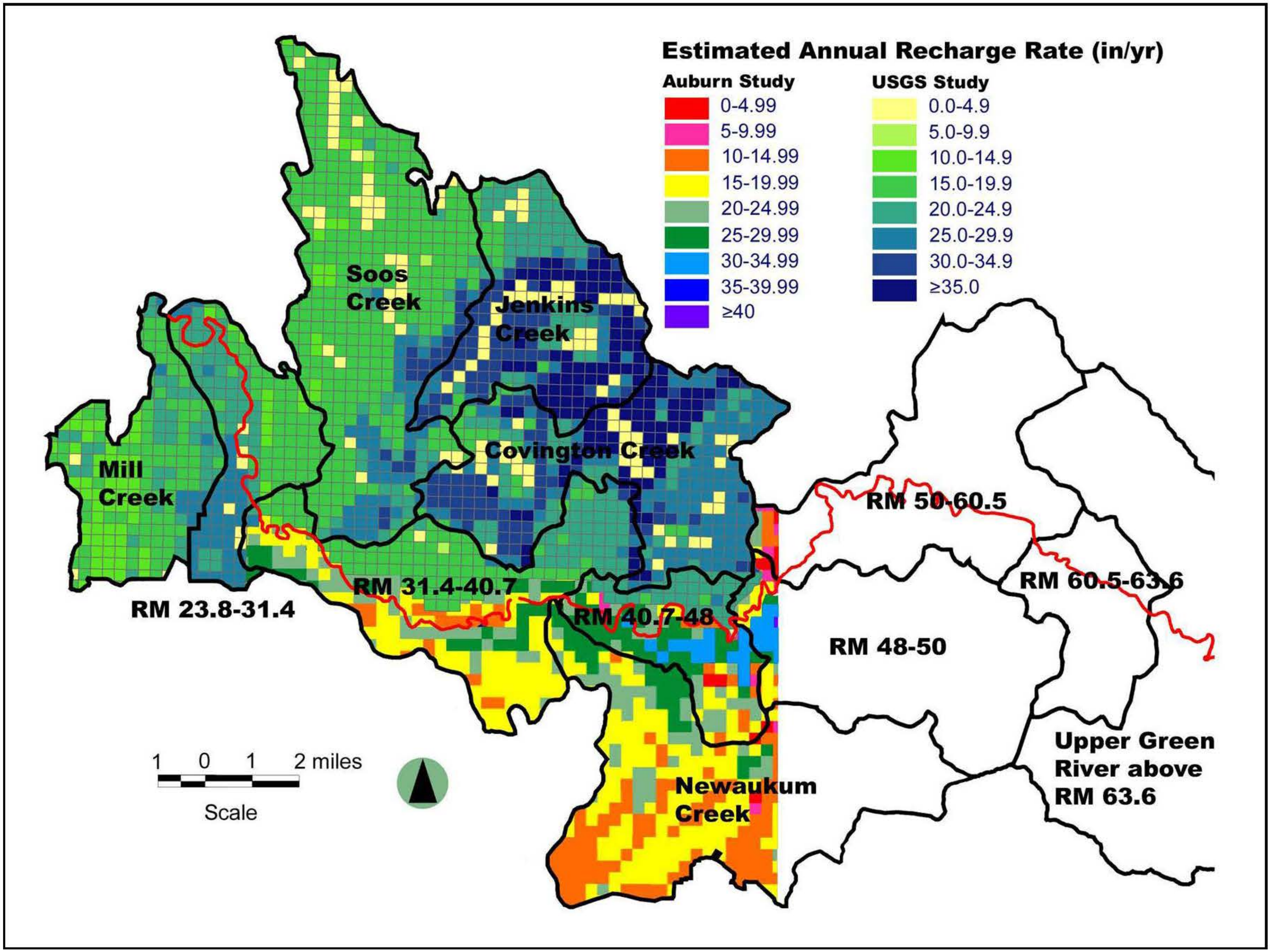


Figure 6.5. Distribution of Average Annual Recharge Rates in Green River Study Area

6.2.3 Average Annual Recharge by Sub-Basin

Table 6.5 summarizes the average annual recharge rate for each sub-basin in the study area. It also shows the percentage of each sub-basin covered under either the Auburn or USGS study. Average recharge was not calculated if either of the two studies covered less than 5 percent of a sub-basin. The values are the best available estimates from published reports of recharge using current analytic techniques.

Table 6.5
Summary of Average Recharge Values by Sub-Basin

ID	Sub-Basin	Average Recharge (in/yr)			Percent of Basin Covered by…	
		USGS	Auburn	Combined	USGS	Auburn
1	Upper Green River above RM 63.6	--	--	--	0	0
2	Local Inflow, Green RM 60.5 - 63.6	--	--	--	0	0
3	Local Inflow, Green RM 50.0 - 60.5	--	--	--	0	<5
4	Local Inflow, Green RM 48 – 50	--	21.5	--	0	9
5	Local Inflow, Green RM 40.7 – 48	21.1	22.7	22.3	23	77
6	Newaukum Creek	--	16.8	--	0	69
7	Covington Creek	26.1	--	--	100	0
8	Jenkins Creek	26.0	--	--	100	0
9	Soos Creek	17.4	--	--	100	0
10	Local Inflow, Green RM 31.4 - 40.7	19.7	17.8	18.6	46	54
11	Local Inflow, Green RM 23.8 - 31.4	20.0	--	--	100	0
12	Mill Creek	18.0	--	--	100	0

Different methods were used to calculate these values, depending on the source data. For the USGS data, a GIS-based approach was used to calculate the average annual recharge rate. After sub-basin boundaries were incorporated into the GIS data, volumetric recharge was calculated for each grid total or partial cell by multiplying rate times area; these volumes were then added and the resulting sum was divided by the area of the entire sub-basin.

GIS coverages were unavailable for the Auburn data. Areas with Auburn recharge data but no USGS data were identified by overlaying the basin boundaries and the USGS recharge coverage on the Auburn recharge map. For each color on the recharge map, cells were counted and an average recharge rate was calculated manually. Although the colors on the Auburn recharge map represented a range of recharge values, the middle value was used for this analysis.

Figure 6.5 and Table 6.5 show that, of the sub-basins covered in this analysis, Jenkins and Covington Creek have the highest recharge rates—greater than 25 in/yr. These sub-basins are characterized by substantial areas of coarse surficial deposits that receive 45 to 65 inches of rain annually (Figure 6.3).

In contrast, the Soos Creek, Mill Creek, and Newaukum Creek sub-basins have the lowest average recharge, all equal or less than 18 inches per year. The Soos and Mill Creek sub-basins feature relatively lower precipitation, low-permeable glacial till, and substantial urban development (impervious surfaces). In the relatively rural Newaukum Creek sub-basin, substantial areas of relatively impermeable mud deposits from the Osceolla mudflow occur at land surface or shallow depths, limiting recharge.

6.3 Land Use Change Analysis

Current land cover conditions were compared to the land use zoning to assess the future land use changes that could occur under the current zoning in the Lower/Middle Green River sub-basins. Sub-basin land use data were presented in Tables 6.3 and 6.4 in Section 6.1. The approach to the land use change analysis assumes that future conversions will be dominated by urban development as allowed under current land use zoning, and that no significant conversions will occur in areas zoned for agricultural or forest use. This approach is superior to a direct comparison of Tables 6.3 and 6.4 because it focuses attention on those areas where significant new impervious cover is likely to occur and can be estimated with a relatively high degree of certainty. As noted previously, the satellite-derived estimates of impervious cover in non-urban portions of the study area were suspiciously high.

Figures 6.6, 6.7, and 6.8 respectively show the extent and current condition of lands which are zoned for urban-density residential, rural residential, and commercial development. Figure 6.6 shows the areas zoned for medium and higher residential development (more than 1 du/ac) including multi-family zones. Figure 6.7 shows the areas zoned for low density (rural) residential with less than one dwelling unit per acre. Figure 6.8 shows the areas zoned for commercial and industrial use. In each case, color coding shows the current condition of the land cover based on the satellite imagery. Areas which are currently developed with urban characteristics are shown in green; areas which are presently in pasture or agricultural uses are shown in pink, and areas which are presently forested are shown in red.

The land use change analysis excludes the green-shaded areas shown on Figures 6.6 through 6.8 because those areas are already developed and any future changes to the land cover are expected to be minor. The red and pink shades show where the new development is planned on currently-pervious lands including forest, open grass, and bare soils, and where the significant land use changes are projected to occur.

Table 6.6 summarizes the results of the land use change analysis.

Table 6.6
Land Use Change Analysis
Forest, Grass, and Bare Soil Areas Zoned for Residential and Commercial Development

Sub-Basin		Pervious Area Zoning area in square miles				Resulting Additional TIA* (sq. mi.)
ID	Name	LDR	MDR	HDR	COM	
1	Upper Green River above RM 63.6	0	0	0	0	0
2	Local Inflow, Green RM 60.5 – 63.6	0	0	0	0	0
3	Local Inflow, Green RM 50.0 – 60.5	3.64	0	0	0.74	1.03
4	Local Inflow, Green RM 48 – 50	5.10	0	0	0.11	0.61
5	Local Inflow, Green RM 40.7 – 48	4.51	0.07	0	0.14	0.59
6	Newaukum Creek	2.76	0.30	0.92	0.24	1.05
7	Covington Creek	6.38	0.56	1.09	1.16	2.40
8	Jenkins Creek	3.87	0.21	1.33	0.35	1.46
9	Soos Creek	5.28	0.35	3.64	0.75	3.22
10	Local Inflow, Green RM 31.4 – 40.7	5.88	0.16	0.54	0.02	0.93
11	Local Inflow, Green RM 23.8 – 31.4	0.23	0.21	1.30	1.10	1.75
12	Mill Creek	0.54	0.36	1.40	1.46	2.20
1-12	Entire Study Area	38.19	2.22	10.22	6.07	15.25

*TIA percentages for LDR, MDR, HDR, and COM are 10, 25, 53, and 90 respectively

The land use change analysis was refined to categorize the areas of new urban development according to groundwater recharge potential. As discussed in Section 6.1, the groundwater recharge dataset from King County classifies the study area into regions of high and lesser recharge rates. Generally, gravelly outwash soils are classified as having a high recharge rate, and fine-grained till soils are classified as having a low recharge rate. From the perspective of urban stormwater management, areas with low infiltration rates and are not suitable for infiltration of urban stormwater runoff.

Table 6.7 summarizes the recharge potential of the areas zoned for new urban development. Figure 6.9 shows the groundwater recharge potential for the areas of new urban development. Green shading is used to designate areas with high infiltration rates and associated high groundwater recharge. Red shading is used to designate areas presumed to have low infiltration rates. As will be discussed later under management options, land use impacts on basin hydrology in the high recharge zones may be mitigated through the use of stormwater infiltration systems and Low Impact Development techniques.

Table 6.7
Groundwater Recharge Potential of
Pervious Areas Zoned for Development

Sub-Basin		Pervious Areas Zoned for Development		
		Total Area	High Recharge Zone	
ID	Name	sq. mi.	sq mi	%
1	Upper Green River above RM 63.6	0	n/a	n/a
2	Local Inflow, Green RM 60.5 - 63.6	0	n/a	n/a
3	Local Inflow, Green RM 50.0 - 60.5	4.4	2.5	58%
4	Local Inflow, Green RM 48 – 50	5.2	4.6	88%
5	Local Inflow, Green RM 40.7 – 48	4.7	2.9	60%
6	Newaukum Creek	4.2	1.4	33%
7	Covington Creek	9.2	3.6	39%
8	Jenkins Creek	5.8	2.4	41%
9	Soos Creek	10.1	3	30%
10	Local Inflow, Green RM 31.4 - 40.7	6.6	3	45%
11	Local Inflow, Green RM 23.8 - 31.4	2.7	1.6	59%
12	Mill Creek	3.7	2.4	67%
1-12	Entire Study Area	56.6	27.4	49%

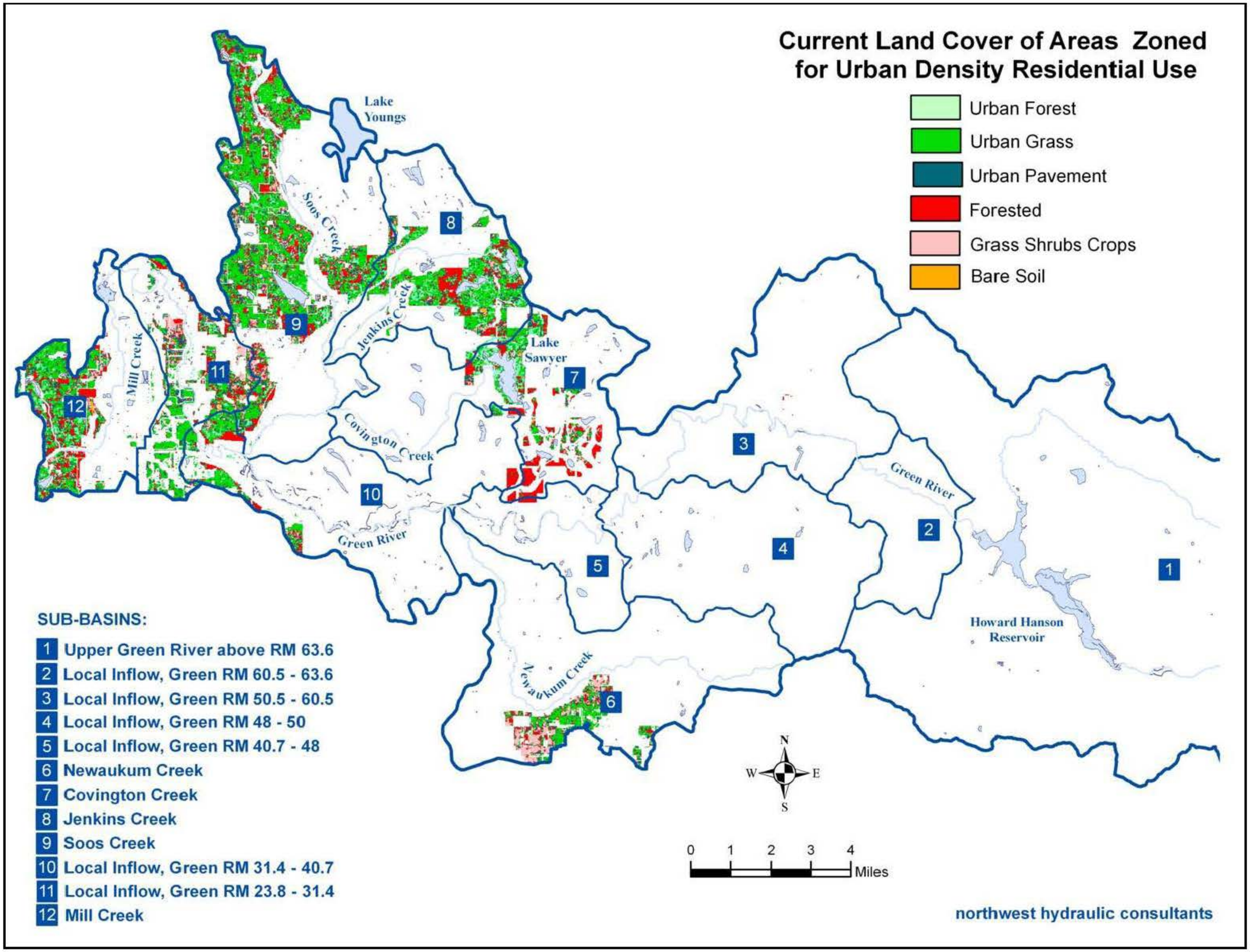


Figure 6.6. Current Land Cover of Areas Zoned for Urban Density Residential Use

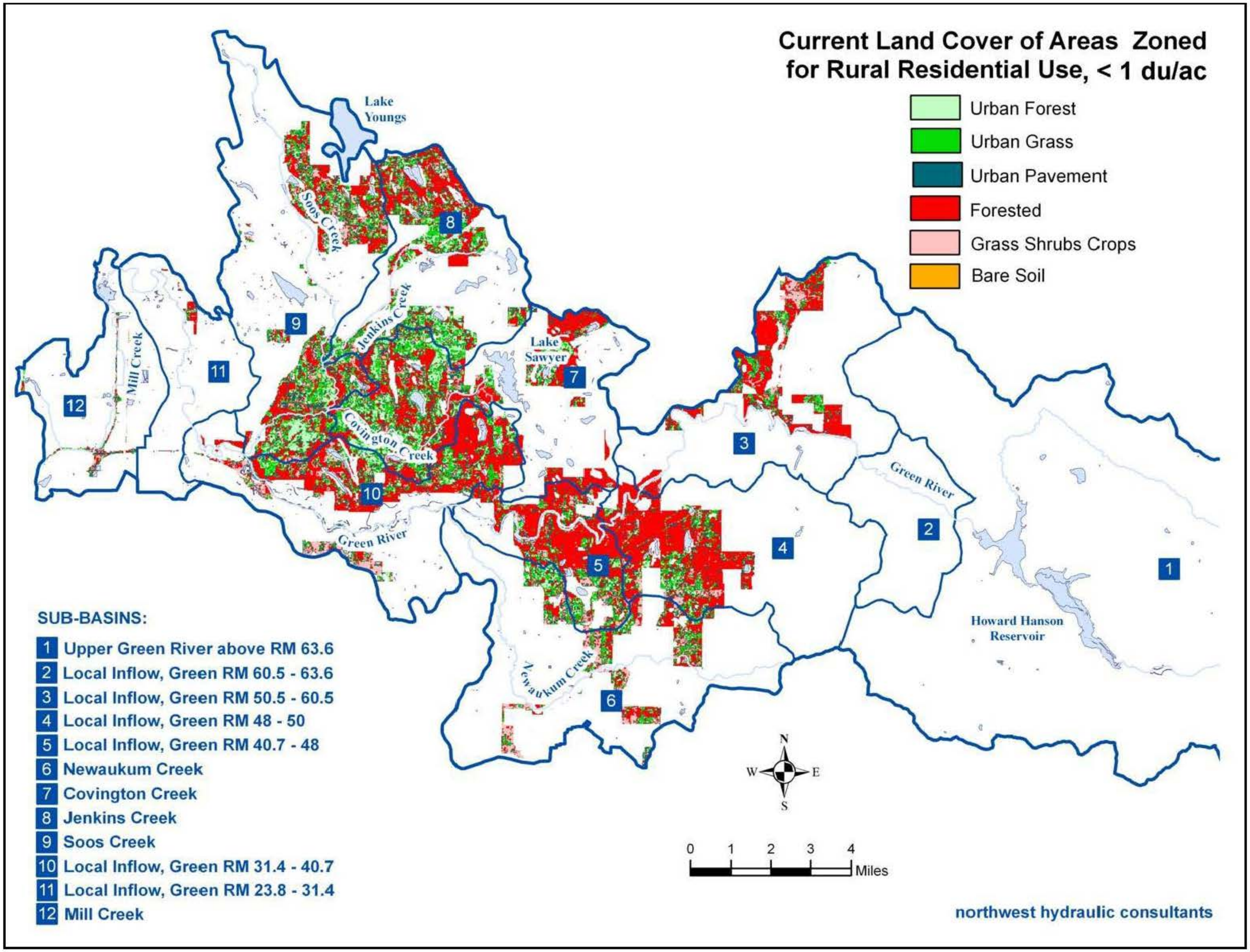


Figure 6.7. Current Land Cover of Areas Zoned for Rural Residential (< 1 du/ac) Land Use

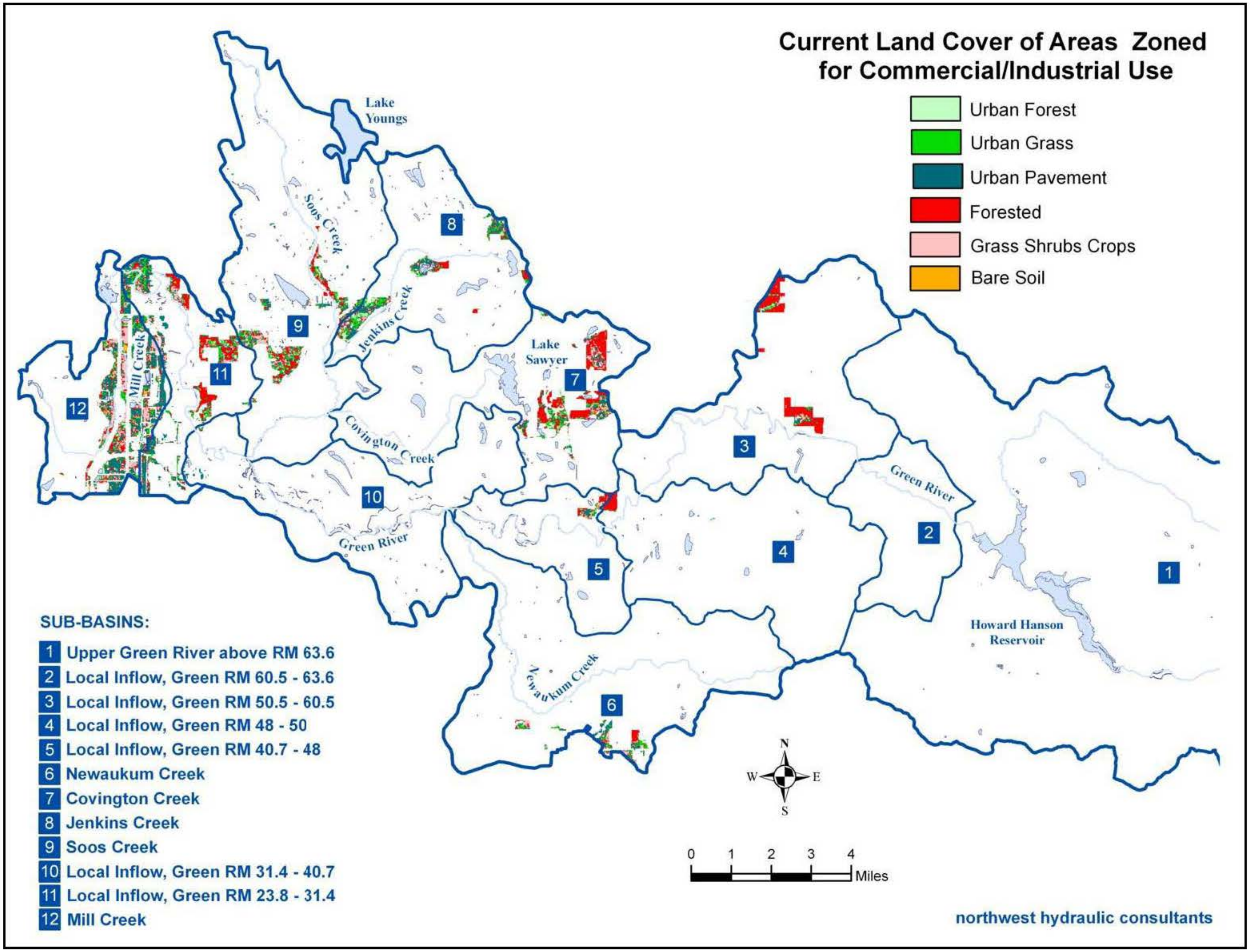


Figure 6.8. Current Land Cover of Areas Zoned for Commercial/Industrial Land Use

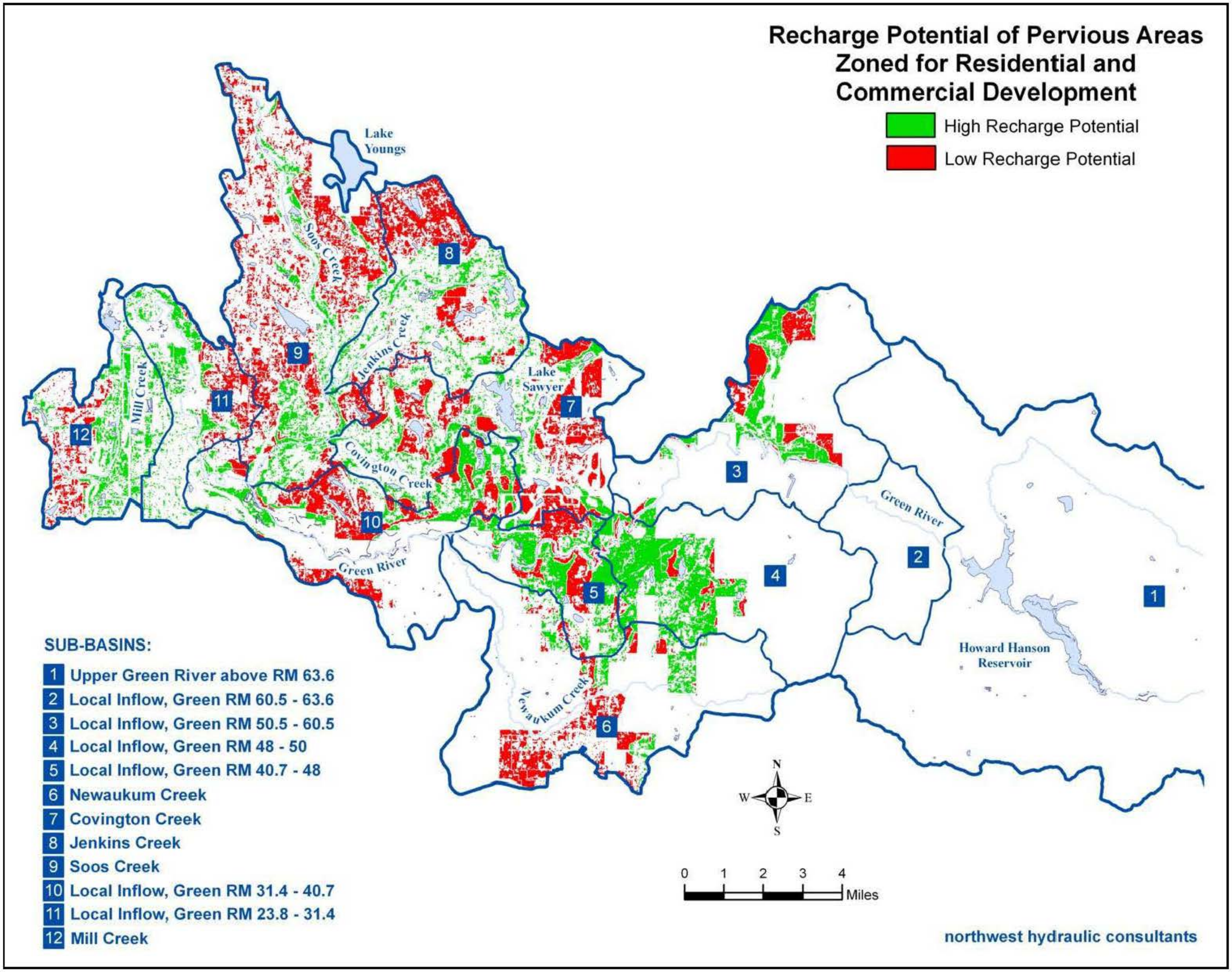


Figure 6.9. Recharge Potential of Pervious Lands Zoned for Development

7 Water Uses from Wells and Diversions

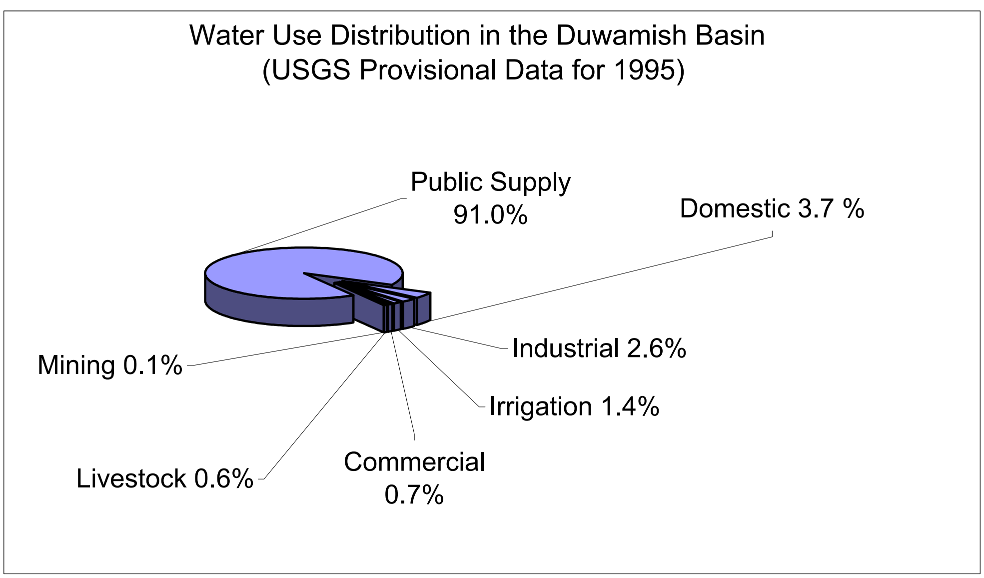
7.1 Overview

Several sources of data were used to identify existing wells and diversions which are currently in use. Primary data sources were State Department of Health records on public water supply systems and Department of Ecology records on water rights claims and certificates. Location information for public water supply wells was obtained from the King County Department of Natural Resources and Parks.

In this discussion, the terms "Group A" and "Group B" systems, and also permit exempt or "exempt wells" are frequently used and deserve explanation. Group A and Group B are identifiers used by the Department of Health to classify and regulate public water supply systems. Group A systems are public water supply systems with 15 or more service connections, plus some transitory and non-community systems[56]. Group B systems are public water supply systems with from 2 to 14 connections. The term "exempt well" is an identifier used by the Department of Ecology to identify relatively small wells which are allowed to withdraw groundwater without a water right permit issued by Ecology. Permit exempt wells are sometimes associated with small subdivision (up to six dwellings) water supplies which would in turn be regulated by the Department of Health as Group B public water supply systems. However, this is just one of the four classes of water permit exemptions which include: (1) stock watering; (2) watering of lawn or non-commercial garden areas not to exceed 1/2 acre in size; (3) domestic uses not exceeding 5,000 gallons a day; and (4) industrial purposes not exceeding 5,000 gallons per day.

Provisional water use data obtained from the US Geological Survey website show that water use in the Duwamish Basin, which includes the study area for this work, is dominated by public water use by systems with 15 or more connections. Figure 7.1 shows the water use breakdown for 1995, for which the USGS data shows the total basin population to be 319,760 persons, the irrigated land to be 600 acres, and the total average daily water use to be 60.1 million gallons per day (MGD). Public water supply plus self-supplied domestic use accounts for 95% of total water use.

Figure 7.1
Basin Water Use Distribution, 1995



[56] See Washington Administrative Code chapter 246-290-020 for a full definition of Group A & B systems.

Figure 7.2 shows the locations of active significant water sources in the study area, categorized by the amount of withdrawal. The figure shows the locations of all Group A and Group B water supply sources, plus irrigation, commercial, and mining sources with annual consumptive withdrawals greater than 10 MG. Figure 7.2 does not show the locations of any of the more than 3,000 single-connection exempt wells estimated from Section 7.2.2.1 to be active in the study area.

7.2 Current Uses

7.2.1 Public Water Supply Systems

Within the study area there are 31 Group A public water supply systems with 15 or more connections and 375 Group B public water supply systems with 2 to 14 connections. Table 7.1 provides population data for the public water supply systems which are active in the study area; the 12 largest Group A systems area listed individually. Figure 7.3 shows the service areas for the major water supply utilities in relation to the watershed basin areas being assessed.

Table 7.1
Public Water Supply Systems in Study Area

Public Water Supply System	Population from Year 2000 Census (or as noted)		
	Entire Service Area	Portion Within Study Area	
Covington Water District	42,845	41,459	97%
City of Auburn	49,349	34,459	70%
Soos Creek Water and Sewer District	54,945	26,969	49%
King County Water District 111	17,517	17,504	100%
Lakehaven Utility District	99,683	12,049	12%
City of Enumclaw	17,621	9,904	56%
City of Kent	55,002	8,079	15%
Cedar River Water and Sewer District	26,176	4,451	17%
Group B Systems (375 combined)*	3,471*	3,471	100%
City of Black Diamond	2,621*	2,545	97%
Other Group A Systems (24 combined)*	2,084	2,084	100%
City of Algona	2,691	467	17%
Muckleshoot Tribe	830	13	2%
Tacoma Water*	301,800*	0	0%
TOTAL		161,370	
* Populations served determined from Department of Health records			

Metered water withdrawals for calendar year 2000 were obtained by the Department of Ecology for all significant Group A public water supply sources in the study area. Data were not obtained on water transfers between utilities, such as for the Soos Creek Water and Sewer District which purchases water from Seattle Public Utilities, or the City of Algona, Water District 111, and Covington Water District which all purchase water from the City of Auburn. For systems such as the City of Kent, City of Auburn, and the City of Enumclaw, which operate independent water sources both within and outside of the study area limits, metered withdrawal data were obtained by Ecology only for those sources within the study area portion of the Green River basin.

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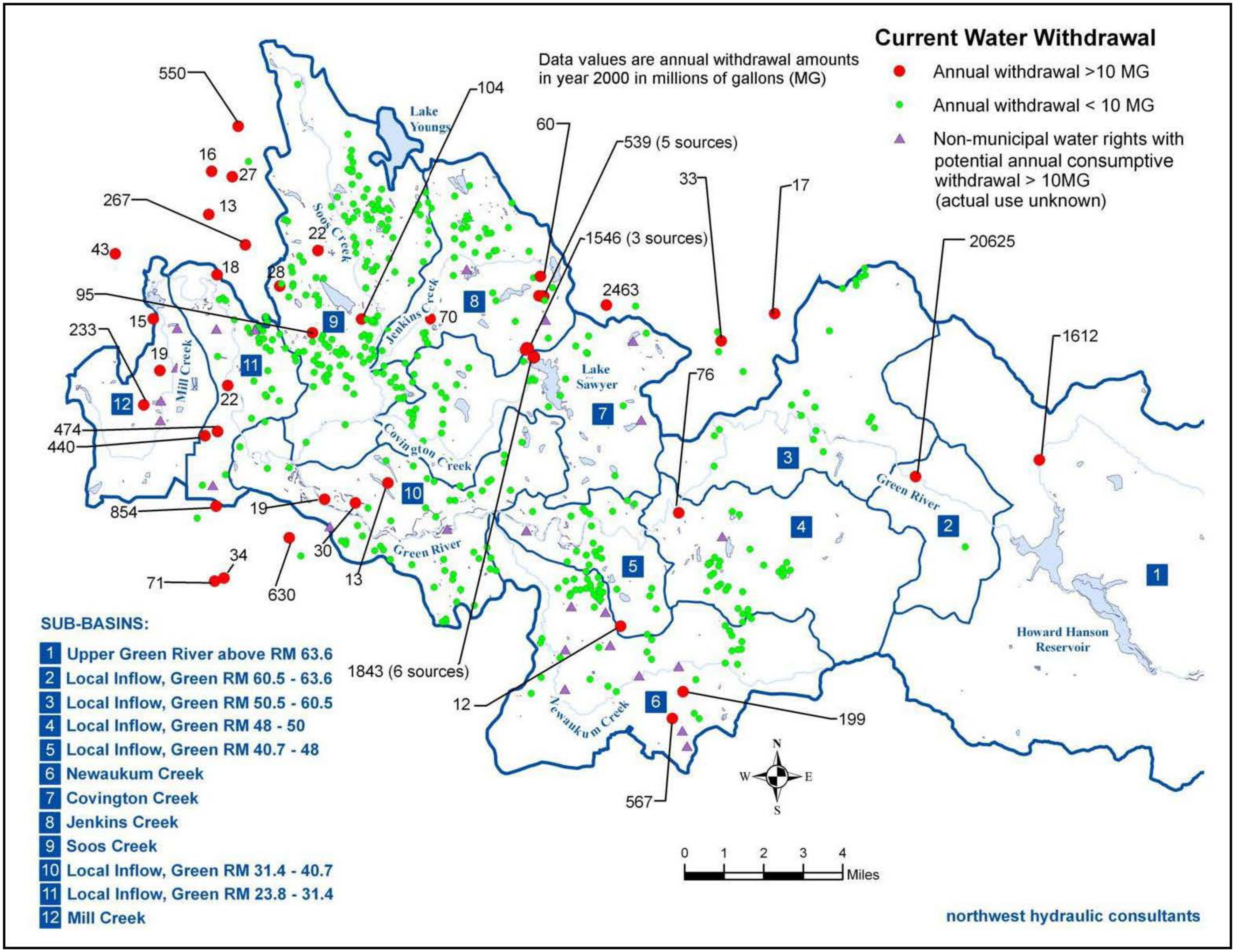


Figure 7.2. Current Water Withdrawals

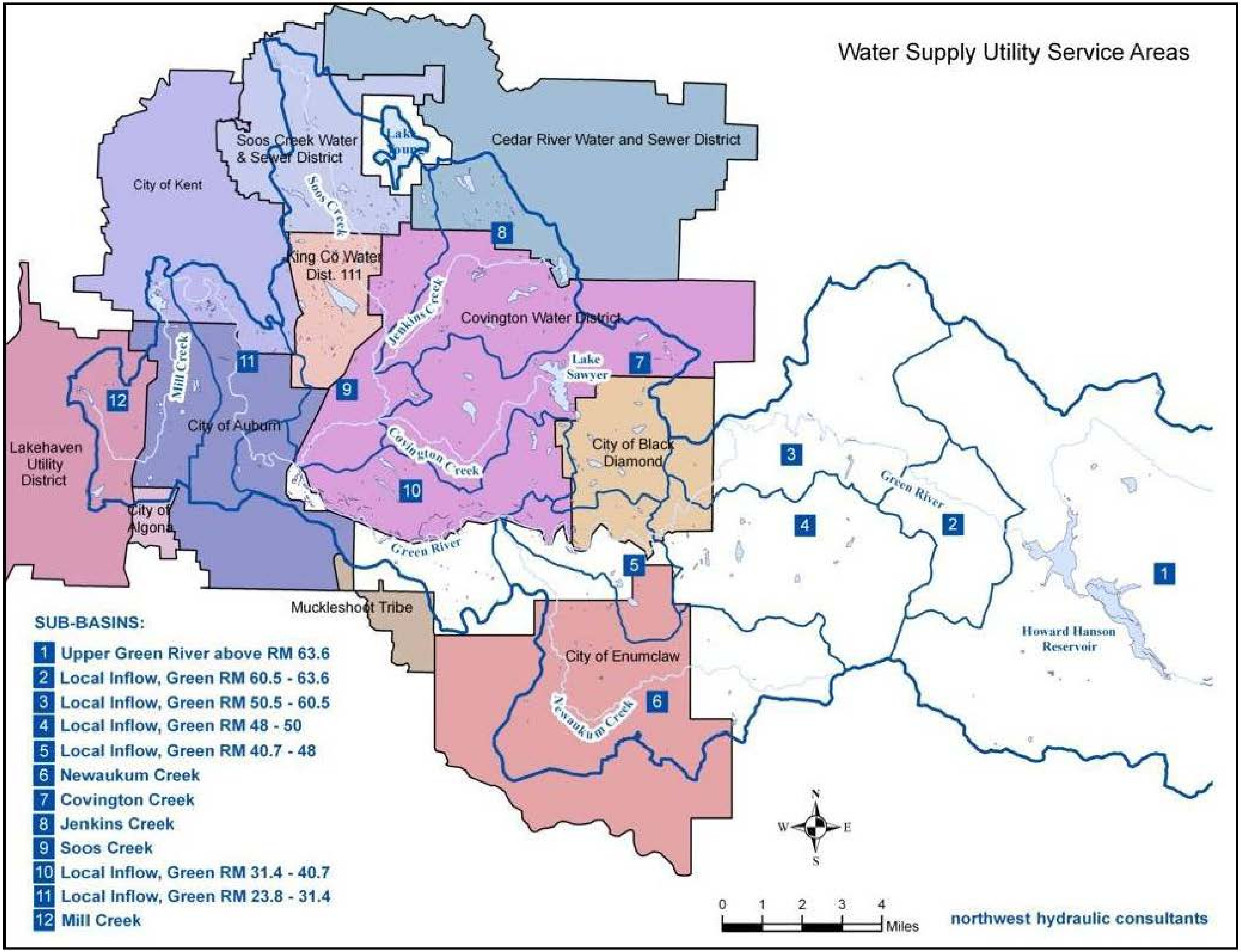


Figure 7.3. Water Utility Service Areas

Metered withdrawal records for the Group B systems and smaller Group A systems are not available. Estimates of the withdrawals were made with the assumption that each system is self-supplied with a source at the location of water use and, on average, withdraws water at the rate of 300 gallons per day per connection. Unit consumption rates for the Group A systems ranged from 237 (Soos Creek Water & Sewer) to more than 600 gallons per day per connection for systems with large industrial and commercial uses. A rate of 300 gallons per day is representative of single family residential consumption

The locations of all significant water withdrawals in the study area are shown in Figure 7.2. These include all study area sources for the Group A systems, the Group B systems, and other commercial and agricultural uses which could be confirmed with reasonable certainty. There are 51 confirmed water sources in and adjacent to the study area with annual withdrawals greater than 10 MG, plotted with a large circle. The locations of 424 confirmed water sources with annual withdrawals less than 10 MG are plotted with a small circle.

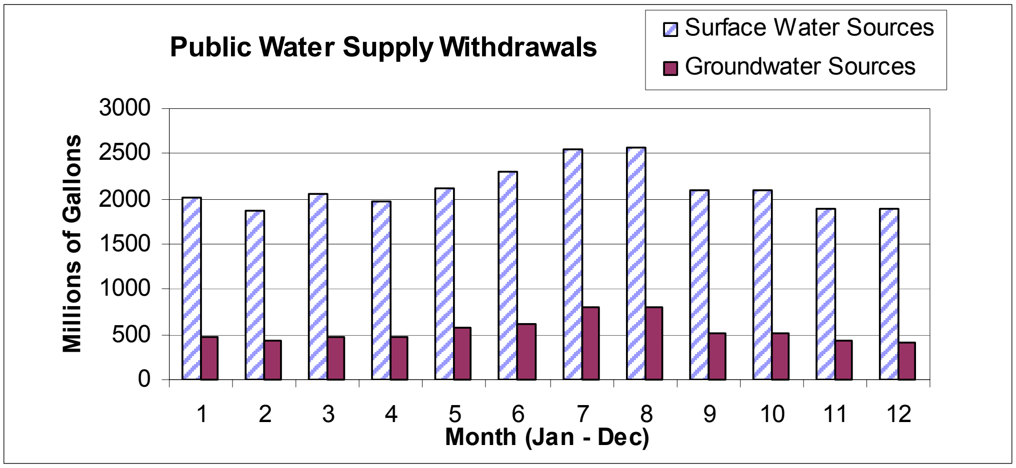
Figure 7.2 does not distinguish between sources for public water supply and for other uses because the overall withdrawals are so dominated by public water supply systems and because of incomplete data to describe the other types of withdrawal. Public water supply systems account for the largest 29 sources (all with annual withdrawals greater than 65 MG) and for one half of the sources with annual withdrawals between 10 and 65 MG. Commercial and industrial sources account for the remaining sources with annual withdrawals between 10 and 65 MG. Public water supply systems account for more than 95% of the sources categorized with less than 10 MG annual withdrawal. Other types of withdrawals, which include self-supplied irrigation, commercial, and domestic uses, are discussed later in this report.

Table 7.2 summarizes the annual public water system withdrawals by the sub-basin in which the source is located. Figure 7.4 shows the monthly distribution of public water system withdrawals for gauged sources, aggregated by surface and groundwater withdrawals. For purposes of Figure 7.4, Tacoma Water withdrawals from its intermittent-use north well field are aggregated with its primary surface diversion and are included in the bar representing surface diversions. Springs are included as surface water sources and spring withdrawals are included in the bar representing surface diversions.

Table 7.2
Public Water System Annual Withdrawals
(Including Group A and Group B Water Systems)

Sub-Basin		Year 2000 Extraction		Largest Purveyor (% of sub-basin withdrawals)
ID	Name	MG	equiv cfs	
1	Upper Green River above RM 63.6	1,612	6.8	Tacoma Water (100%)
2	Green River RM 60.5 – 63.6	20,625	87.4	Tacoma Water (100%)
3	Green River RM 50.0 – 60.5	23	0.1	Green R Gorge Resort (42%)
4	Green River RM 48 – 50	87	0.4	Black Diamond Water Dept (87%)
5	Green River RM 40.7 – 48	26	0.1	Y Bar S Water Co (45%)
6	Newaukum Creek	795	3.4	Enumclaw Water Dept (96%)
7	Covington Creek	1,859	7.9	Covington Water Dept (99%)
8	Jenkins Creek	2,180	9.2	Kent Water Dept (74%)
9	Soos Creek	283	1.2	KC Water Dist 111 (70%)
10	Green River RM 31.4 – 40.7	27	0.1	Diamond Springs Water (26%)
11	Green River RM 23.8 – 31.4	1,328	5.6	Auburn Water Division (97%)
12	Mill Creek	234	1.0	Auburn Water Division (100%)
1 – 12	Entire Study Area	29,080	123.2	Tacoma Water (76%)

Figure 7.4
Monthly Withdrawals by Reporting Public Water Supply Systems



The quantity of water supplied by major public water systems to each of the study sub-basins was estimated by apportioning each system's total supply to the respective sub-basins. Table 7.3 presents the total supply data, which are the Year 2000 Average Day Demand values obtained during preparation of the 2001 Central Puget Sound Regional Water Supply Outlook[57]. For Tacoma Water, which does not have a service district presence in the study area, the values shown are the Year 2000 metered withdrawals from the study area sources. The total supply values include non-revenue water due to system leakage and non-metered uses such as line flushing and fire fighting. Non-revenue water typically accounts for 5 to 15% of total supply for the systems in the study area. The total supply values mostly reflect the consumptive needs internal to each system and exclude wholesale water sales to other utilities, with the exception of data for Auburn which was later found to include 1.76 MGD in wholesale water.

Table 7.3
Major Water Utility Total Supplied Water
(Data give water to entire service area not limited to study boundaries, from all sources of supply)

Utility	Year 2000 Average Day Demand	
	MGD	equiv cfs
Covington Water District	4.1	6.3
City of Auburn	8.2	12.6
Soos Creek Water and Sewer	4.5	7.0
King County Water District 111	1.7	2.6
Lakehaven Utility District	10.5	16.3
City of Enumclaw	3.3	5.1
City of Kent	8.6	13.3
Cedar River Water and Sewer	1.9	2.9
City of Black Diamond	0.2	0.3
City of Algona	0.4	0.6
Tacoma Water*	60.9	94.3

* For Tacoma Water only, values are limited to extraction amounts from WRIA 9 sources.

[57] Average Day Demand data were obtained from RW Beck, co-author of the Water Supply Outlook. The data for some utilities are suspected to be high demands, higher than actual. The demand values are internal to each service area and, except for the City of Auburn, do not include wholesale water sold to other purveyors.

Apportioning of the major systems' total water supply to the study sub-basins was made with a GIS analysis of year 2000 census data and associated Traffic Analysis Zone (TAZ) data[58]. For each utility service area, the numbers of residences, multi-family residences, and employees were determined for the entire service area and for each of the sub-basins being assessed. These base numbers were converted to water use Equivalent Residential Units (ERU) based on approximate unit consumption amounts,[59] converted to ERUs as shown below.

Single-family residential	300 gallons per household per day	(1 residence per ERU)
Multifamily residential	50 gallons per household per day	(6 households per ERU)
Non-residential	45 gallons per employee per day	(6.66 employees per ERU)

Water supplied to each sub-basin, by each major utility named in Table 7.1, was computed as the product of each utility's total supply to all areas and the percentage of total ERUs within each sub-basin. For the smaller public water supply systems not identified in Table 7.1, water uses were assumed to occur within the same sub-basin as the water supply source.

Table 7.4 summarizes the public water supply currently provided in each of the sub-basin areas.

Table 7.4
Public Water System Delivered Water Supply
(Including Group A and Group B Water Systems)

Sub-Basin		Year 2000 Delivered Water Supply		
ID	Name	MG	equiv MGD	Equiv cfs
1	Upper Green River above RM 63.6	0	0.0	0.0
2	Green River RM 60.5 - 63.6	0	0.0	0.0
3	Green River RM 50.0 - 60.5	24	0.1	0.1
4	Green River RM 48 – 50	12	0.0	0.0
5	Green River RM 40.7 – 48	62	0.2	0.3
6	Newaukum Creek	455	1.2	1.9
7	Covington Creek	421	1.2	1.8
8	Jenkins Creek	866	2.4	3.7
9	Soos Creek	1,972	5.4	8.4
10	Green River RM 31.4 - 40.7	499	1.4	2.1
11	Green River RM 23.8 - 31.4	1,371	3.8	5.8
12	Mill Creek	1,086	3.0	4.6
1 - 12	Entire Study Area	6,769	18.5	28.7

[58] TAZ data with employment information were obtained from the Puget Sound Regional Council subject to a confidentiality agreement.
[59] Water use factors were estimated with consideration of values presented in the Water Supply Outlook and guildelines in the Washington Department of Health August 2001 Water System Design Manual. Values presented in the Water Supply Outlook were: single-family residential at 205 gallons per household per day, multifamily residential at 25 gallons per household per day, and non-residential at 42 gallons per employee per day. Current usage is expected to be greater than the Outlook projections which include conservation assumptions.

7.2.2 Withdrawals not for Public Water Supply

The USGS estimates of water use in the Duwamish Basin (see Figure 7.1) show that about 91% of total water use in 1995 was for Group A System public water use. Self-supplied withdrawals for Group B and smaller domestic systems, commercial, industrial, irrigation, livestock, and mining uses account for the remaining 9%. Data to confirm the locations of and current withdrawals from sources not for public water supply were not available in a compiled format and were estimated by other methods.

The data and information sources identified below were used to estimate sources and withdrawals for non-public water supply systems.

- Water withdrawal data from 1986 for the lower portion of the study area, published in USGS Water-Resources Investigations Report 92-4098, "Occurrence and Quality of Ground Water in Southwestern King County, Washington."
- Department of Ecology's Water Rights Tracking System (WRTS) which is a database of water rights claims, certificates, and applications statewide. Department of Ecology staff assisted with the processing, screening, and interpretation of the WRTS data.
- Department of Ecology's databases of water well reports. Department of Ecology staff assisted with the processing, screening, and interpretation of the water well data.
- Personal communication with Tom Beavers, the watershed steward for the Enumclaw Plateau.

Based on the USGS estimates, self-supplied domestic use accounts for about one half of all non-public water supply uses in the Duwamish Basin. Irrigation, industrial, commercial, mining, and livestock uses account for the remainder.

7.2.2.1 Self-Supplied Domestic Use

Self-supplied domestic uses are generally associated with permit exempt wells for which no water right paper work is required by the Department of Ecology. However, exempt wells are tracked by the Department of Ecology via well construction records and those exempt wells with more than one service connection are regulated by the Department of Health as Group B water supply systems. This section presents an evaluation of withdrawals and consumption from self-supplied domestic use for single-connection systems.

For the purposes of the current study, the Department of Ecology evaluated the number of exempt wells in each sub-basin and estimated the withdrawals from active exempt wells not already counted as Group B public water supply systems. Water use from the Group B systems is already included in the public water supply consumption numbers presented in Section 7.2.

Ecology has two databases associated with water wells. The first is the Notice of Intent to Construct a Water Well (NIT, started in 1993) and the second is the Water Well Reports. The NIT database has data on the use of the well, either single domestic, group domestic, or other. The Water Well Reports database started in 1972, but was only populated with water well reports systematically since 1975. In general it took several years for the well drilling community to do water well reports and submit them. In both databases, the well locational data is, at best, ¼, ¼, ¼, of the Section, within a Township and Range.

The Water Well Report database was mined for all records that fall within WRIA 9. Then, Ecology correlated those records (post 1993) with a notice of intent from the Notice of Intent to Construct a Water Well. Those records that had both a water well report and a notice of intent were reviewed to exclude records for group domestic use leaving the single domestic water wells.

The resulting records of water wells were then mapped in GIS to the ¼ of the ¼ of the ¼, of the Section within a Township and Range. The map of water wells was then overlaid with the sub-basin shape files to determine the number of water wells in each sub basin. In many cases when detailed location information was lacking or incomplete, the wells were mapped to the center of the Section.

To estimate the water used by the single connection domestic (exempt) wells on an annual basis, a water duty of 120 gallons per day average was multiplied by the number of wells and then by 345 to calculate the indoor water used in 345 non-peak days. It is assumed that water is also used outside for 20 days a year during the months of July, August, and September. A water duty of 120 gpd multiplied by an Ecology-estimated peaking factor of 2.8 is equal to 336 gpd. The 336 gpd was multiplied by 20 days and added to the indoor water use to arrive at annual water use for each well. This annual water use was multiplied by the number of permit exempt wells in the basin to estimate total basin water use by permit exempt wells.

Table 7.5 summarizes the results of the exempt well analysis

Table 7.5
Estimated Self-Supplied Domestic Use from Exempt Wells

Sub-Basin		# of Single-Connection Wells	Exempt Well Withdrawal	
ID	Name		Annual MG	equiv cfs
1	Upper Green River above RM 63.6	6	0.3	0.00
2	Green River RM 60.5 - 63.6	0	0.0	0
3	Green River RM 50.0 - 60.5	229	11.0	0.05
4	Green River RM 48 - 50	203	9.8	0.04
5	Green River RM 40.7 - 48	215	10.3	0.04
6	Newaukum Creek	381	18.3	0.08
7	Covington Creek	287	13.8	0.06
8	Jenkins Creek	384	18.5	0.08
9	Soos Creek	682	32.8	0.14
10	Green River RM 31.4 - 40.7	457	22.0	0.09
11	Green River RM 23.8 - 31.4	110	5.3	0.02
12	Mill Creek	84	4.0	0.04
1 – 12	Entire Study Area	3,038	146	0.62

7.2.2.2 Irrigation, Commercial, and Other Consumptive Uses

The Department of Ecology water rights records provide a comprehensive dataset of water supply sources. However, the data are in the form of unverified claims and certificates of potential legal use and many of those claimed and certificated sources may presently be inactive or underutilized. The water rights records are insufficient to identify active sources and current water usage.

Confirmed water use data from year 1986 from wells in the lower portion of the study area is available from the 1995 USGS Water-Resources Investigations Report 92-4098. That study identifies source locations and annual withdrawals in 1986 for wells used for irrigation and commercial/industrial uses. The USGS study area encompasses the Soos, Jenkins, Covington, and Mill Creek drainage basins plus areas of local inflow to the Green River below the confluence of Soos Creek and the Green River. The USGS study area did not include either the Newaukum Creek basin or the area of Icy Creek and Black Diamond Springs, and the study did not address surface water withdrawals.

The water use data in the USGS report is felt to provide a reliable source of groundwater withdrawal data that is sufficiently recent to characterize irrigation and commercial uses in the lower portion of the study area. Table 7.6 summarizes the USGS data for the wells located in the sub-basins established in the current work. Commercial water withdrawals in the study area from the USGS data totaled only 1.1 MG from two wells (one each in sub-basins 8 and 11) and are insignificant to basin-scale results. All of the irrigation and commercial water sources from the USGS study are included in the Figure 7.2 plot of the current water withdrawal locations and amounts.

Table 7.6
Irrigation and Commercial Water Withdrawals from USGS-Identified Wells in 1986

Sub-Basin		Non-PWS Withdrawal		Major Use
ID	Name	MG	equiv cfs	
1-5	Green River above RM 40.7	n/a	-	-
6	Newaukum Creek	n/a	-	-
7	Covington Creek	0.3	0.0	Irrigation (2 wells)
8	Jenkins Creek	60.8	0.3	Irrigation (1 well)
9	Soos Creek	32.3	0.1	Irrigation (5 wells)
10	Green River RM 31.4 - 40.7	61.3	0.3	Irrigation (4 wells)
11	Green River RM 23.8 - 31.4	46.0	0.2	Irrigation (6 wells)
12	Mill Creek	18.9	0.1	Irrigation (2 wells)
1 - 12	Study Area covered by USGS	220	0.9	

Assessment of water uses from surface water sources, and water uses outside the USGS study area required use and interpretation of Ecology's water rights records. Ecology staff assisted greatly with this work.

A preliminary screening of water rights certificates in the study area was performed by the Department of Ecology to identify those records representing large, active, consumptive, sources other than for the Group A and B public water supply systems. The screening excluded primarily non-consumptive withdrawals such as for fish hatchery use. The screening was performed by Ecology staff familiar with the study area, and yielded a list of 96 potentially significant "other" water withdrawals. However, the Ecology staff cautioned that the screening process had not confirmed which sources were (and were not) active and was therefore not reliable as a list of active uses.

The preliminary Ecology list was further screened to remove groundwater sources in the lower basin that appeared to duplicate the more reliable information from the USGS study discussed above. This further screening was highly subjective because of poor locational information and a lack of other information to relate the USGS and Ecology data sets.

Table 7.7 below presents a summary of the information derived from the water use certificate data for non-public water supply sources. The estimated annual water use for each of the sources in the Ecology list was estimated to be the lesser of: (1) the annual withdrawal listed by the certificate; or (2) in the case of irrigation uses, an annual amount of 0.3 MG per acre (about 11 inches depth) representing a high estimate of annual consumptive use for irrigated lands in the study area. The locations of significant "other" sources with an estimated annual withdraw of more than 10 MG are shown with a unique (triangle) symbol on Figure 7.2. It should be noted that the actual use associated with these certificates has not been confirmed and that the larger uses are potentially non-consumptive.

Table 7.7
Potential Other Non-Public Water Supply Significant Water Withdrawals and Uses
Estimates from Ecology Water Rights Certificates

Sub-Basin		Estimated Potential Use		Sources (See notes below for additional detail)
ID	Name	Annual MG	equiv cfs	
1	Upper Green R above RM 63.6	-		
2	Green River RM 60.5 - 63.6	-		
3	Green River RM 50.0 - 60.5	7	0.0	1 well
4	Green River RM 48 – 50	10	0.0	1 source - Lake Isabel
5	Green River RM 40.7 – 48	> 40	> 0.2	6 surface water sources
6	Newaukum Creek	70	0.3	21 sources, sw & gw.
7	Covington Creek	> 744	> 3.2	2 wells, 2 lakes
8	Jenkins Creek	104	0.4	3 wells
9	Soos Creek	13	0.1	3 sources, sw & gw
10	Green River RM 31.4 - 40.7	64	0.3	8 sources, sw & gw
11	Green River RM 23.8 - 31.4	364	1.5	20 sources, sw & gw
12	Mill Creek	44	0.2	4 sources - all Mill Creek
1 - 12	Entire Study Area	> 1,460	> 6.2	

Notes

- Sub-basin 5 estimate does not include commercial use withdrawals from Green River by Smith Brothers.

- Sub-basin 6 (Newaukum Creek Basin) water use estimate is based on information from the basin watershed steward that less than 1% of the basin is irrigated, and that the predominant agricultural use is cattle and dairy operations for approximately 2,500 head of cattle. Annual water use is estimated at 0.3 MG per acre for 173 irrigated acres (1% of basin) plus 25 gpd for 2,500 cows. This estimated water use is thought to be more accurate than one based on the water rights certificates which suggest more than 250 MG annual use with irrigation of more than 1,000 acres.

- Sub-basin 7 estimate dominated by 744 MG potential annual withdrawal from Ravensdale Lake by Burlington Northern. Additional (not quantified) mining use withdrawal from Mud Lake by Pacific Coast Coal.

- Sub-basin 8 estimate dominated by 92 MG potential annual withdrawal by Black River Quarry.

- Sub-basin 11 estimate dominated by 290 MG potential annual withdrawal by Miles Co well.

7.3 Authorized Additional Future Uses

Future water demands and sources of supply are evaluated at length in the July 2001 Central Puget Sound Regional Water Supply Outlook. Municipal and domestic water demands are expected to increase in response to a growing population and are estimated in the Outlook based on long-term population, household, and employment forecasts. Non-municipal demands are expected to remain essentially at the same level as current conditions. The Outlook provides demand estimates and various proposals for meeting future municipal demands, including the full use of existing (authorized) water rights, various new water development projects, interbasin transfers, and conservation. The discussion here is limited to existing municipal water rights which are currently under-utilized. Existing water rights are generally insufficient to meet future demands, but discussion and resolution of that larger issue is beyond the scope of this study.

For the present work it is assumed that future growth in water extraction will occur exclusively by the large municipal purveyors already active in the study basins. No significant change is expected to the current levels of self-supplied commercial, agricultural, and other non-municipal water use. The numbers of active exempt wells for domestic supply and smaller public water systems are also assumed to continue unchanged into the future. This same assumption was made in the analysis for the Water Supply Outlook, speculating that there might be an approximate balance between new non-public water supply wells and those which are abandoned after connecting to the larger municipal systems.

The assumptions on active exempt wells are believed to be reasonable in the urban growth areas which are served by public water supply systems, but may under-estimate the future effects of exempt wells in undeveloped areas which are zoned for low-density residential development. However, exempt wells now account for less than 0.3% of total delivered water supply in the study basins and the total effect of new exempt wells in rural areas is likely to be similarly low in comparison with other withdrawals and diversions.

Generally, Ecology is unlikely to approve new water rights applications for consumptive, year around, use of surface or ground water in the study basin. Water right decisions in the study basin are guided, in part, by chapter 173-509 WAC. The WAC is related to instream resource protection and provides little opportunity for new consumptive uses of a year around nature. Most of the tributaries to the Green River are closed to new consumptive uses. The Green River also has established instream flows. Any water rights issued from the Green River would be subject to interruption during those time periods instream flows are not met. In some cases, new water rights may be approved if the project proponent provides mitigation for instream flow impacts. The opportunities for that are also limited. The consequence is that additional extraction in the study area basins will, for the foreseeable future, be limited to exercising inchoate water rights. Inchoate rights are the rights above the current water use and less than or up to the available certificated amount.

Table 7.8 summarizes the water rights and current use data for each of the major public water supply systems which are active in the study area. The data are as reported in the Water Supply Outlook and, with the exception of Tacoma Water, represent each utility's total service area and sources not limited to the study areas for the current work. The Tacoma Water data are limited to withdrawals from the Green River basin. An assessment of source-specific water rights for each major utility, and allocation of available unused amounts to the study sub-basins, could not be determined from the data in the Water Supply Outlook and could not be independently accomplished with the resources available for this study.

The Water Rights Qa and Qi data in Table 7.8 are, respectively, the annual and instantaneous maximum rates of withdrawal available to each utility under existing water rights certificates issued by the Department of Ecology. The timing of Qi relative to Qa is a function of seasonal or sudden (i.e. firefighting) demand and the storage volumes available to each utility. If sufficient storage is available and there are no other constraints, each utility can potentially provide an Average Day Demand water supply equal to its water right Qa amount. Where other known constraints exist, the available Average Day Supply is less than the water right Qa amount. Because of seasonal demand fluctuations, some utilities may already be withdrawing at the maximum Qi amount during summer peak-demand months and have significant reserve capacity to produce additional water only during the winter months.

Table 7.8
Municipal Utilities' Available (Unused) Water Supplies

Water Supply Utility	Water Rights Qa / Qi MGD	Primary Constraint	Available Avg Day Supply MGD	Year 2000 Avg Day Demand MGD	Unused Avail Avg Day Supply	
					MGD	equiv cfs
Cedar R. Water & Sewer	0.05 / 0.17	water rights	0.05	1.86	0	-
City of Algona	purchased water		-	0.36	0	-
City of Auburn	20.8 / 27.0	instream flow	18.28	8.15	10.13	15.7
City of Black Diamond	0.49 / 5.24	water rights	0.49	0.21	0.28	0.43
City of Enumclaw	3.43 / 4.20	water rights	3.43	3.28	0.15	0.23
City of Kent	25.9 / 40.3	aquifer yield	17.0	8.60	8.40	13.0
Covington Water District	5.44 / 7.92	water rights	5.44	4.07	1.37	2.1
King County WD 111	1.97 / 2.77	water rights	1.97	1.66	0.31	0.49
Lakehaven Utility District	18.0 / 42.8	aquifer yield	10.1	10.51	0	-
Soos Ck Water & Sewer	purchased water		-	4.49	0	-
Tacoma Water	n/a	instream flow	137.7	60.92	76.78	118.8

Authorized additional future uses are the unused portion of the available Average Day Supply, computed as the difference between the available Average Day Supply and the current (year 2000) Average Day Demand. Negative values computed for several of the districts indicate that some or all of the water supply for those utilities is currently obtained through wholesale purchases from other purveyors.

The largest authorized additional future use, nearly 120 cfs, is associated with implementation of Tacoma Water's second diversion water right. The impacts of those future withdrawals on Green River flows have been assessed and the resulting post-withdrawal streamflow statistics are included in Section 3.2. The impacts of the other authorized additional uses, including nearly 16 cfs by the City of Auburn, and 13 cfs by the City of Kent, are unknown at this time. Additional work would be required to identify the specific sources for that additional water, and an assessment made of the timing of additional withdrawals and identification of the surface water systems (streams, rivers, lakes, wetlands) most likely to be affected.

8 Interbasin Transfers and Adjustments

8.1 Hydraulic Continuity of Groundwater and Surface Water

A reconnaissance level analysis was made of 420 active wells in the study area to assess whether groundwater withdrawals would impact streamflows in the basin with the well (e.g., the source locations as plotted in Figure 7.2) or in separate, hydraulically-connected, sub-basins. For this study it was assumed that groundwater withdrawals normally result in reduced streamflow; the purpose of the continuity assessment was to assess where those reductions would occur. Withdrawals from surface water sources are assumed to only impact streamflows in the sub-basin where the diversion occurs.

When a well begins pumping, localized hydraulic conditions change. The head (water level) drops in the well, increasing the groundwater gradient—and therefore flow—to the well. Initially, the pumped water is captured from nearby areas in the aquifer. As pumping continues, however, water may be captured from areas that lie increasingly farther from the well. The size of this radial "zone of influence" depends on several factors, including the well's pumping rate and the aquifer properties (transmissivity, confinement, etc.) In areas where surface water and groundwater are hydraulically connected, impacts to lakes, streams, or wetlands increase with proximity to the pumping well. Well withdrawals may affect flow in these features as they capture surface water from them directly or as they intercept groundwater flow to them. Under certain conditions, the pumping wells may intercept groundwater flow to marine waters, changing the position of the freshwater-saltwater interface.

Several steps are required to quantitatively predict the effects of pumping on surface water bodies. First, hydrogeologic conditions must be characterized using data collected in the field. Second, a conceptual model of the surface water-groundwater system must be developed. Finally, a mathematical model must be constructed. Mathematical models vary widely in their complexity, ranging from relatively simple assumptions to complex, distributed-parameter, numerical solutions. Modeling approaches are typically driven by budgets, available data, time, and project goals.

For this project, qualitative assessments were made to estimate the potential effects of pumping from 420 wells that were divided into two groups: (1) wells that produce more than 50 MG annually and (2) wells that produce less than 50 MG. The assessment of wells in these two groups resulted in estimates of the impacts of withdrawals from wells on surface water in the sub-basins.

For the first group, which consisted of 17 Group A public water supply wells, information available from hydrogeologic studies was reviewed and professional judgment was used to assess impacts. The following sub-basin scale information was reviewed for estimating allocations of impact to sub-basins:

- The locations of wells relative to surface water features in the sub-basin
- The aquifers tapped by the wells
- Groundwater flow directions
- Surface water / groundwater relationships, where known

A simpler qualitative approach was used for the second group, which included 31 Group A and 372 Group B public water supply wells. This approach involved calculating the elevation of each well bottom and comparing it to the elevation at the outlet of the well's sub-basin. If the well bottom was higher than the outlet, pumping was assumed to affect streamflow within the sub-basin. If the well bottom was lower, it was compared to outlets of downgradient sub-basins to determine potential effects on them.[60] Table 8.1 summarizes the results of this assessment, and allocates well withdrawals to specific basins. To illustrate how these results are applied, the table shows that Enumclaw Water Department withdrawals from well # 23600_04 in the Newaukum Creek basin would have surface water impacts in Newaukum Creek and also in WRIA 10, which is the White River basin. The total annual withdrawal of 199 MG from this well would be allocated as an annual surface water reduction of 139 MG (computed as 70% of 199) from Newaukum Creek and 60 MG reduction from surface water in WRIA 10.

Table 8.1 shows that each of the 17 public water supply wells producing more than 50 MG annually is estimated to have surface water impacts in the basin where the well is located, and also in at least one other basin. The results indicate that from 5 to 50 percent of the surface water impact for each well occurs in downgradient or adjacent basins. In contrast, 388 of the 403 smaller-capacity wells were estimated to have impacts exclusively in the basin where the well is located, and only 15 wells with surface water impacts in downgradient basins. Note that these qualitative estimates are based on professional judgment; actual impacts may differ substantially. Refining these estimates would require detailed characterization and modeling, which was beyond the scope of this project.

Table 8.2 translates these hydraulic continuity results into net change adjustments that can be added to the source-based public water supply withdrawals in Table 7.2 to estimate potential surface water impacts in each sub-basin. Using the Covington Creek sub-basin for illustration, Table 7.2 shows a total withdrawal of 1,859 MG for public water supply in year 2000, and Table 8.2 shows an adjustment of -108 MG. After adjustment for continuity effects, the water supply withdrawals in year 2000 are thereby estimated to have reduced streamflows in Covington Creek by approximately 1,751 MG (7.4 cfs). This streamflow adjustment is approximate because it does not address return flows to the stream from processes which include septic systems, car washing, and over-watering of lawns. It should be noted also that these adjustments do not account for impacts from wells located outside the study area portion of WRIA 9.

[60] Pumping from a capture point below the basin outlet does not preclude the possibility of surface water impacts within the basin where the pumping occurs. The simpler qualitative approach described above was felt to be appropriate for the current study but may not be applicable in other contexts.

Table 8.1
Wells with Potential Surface Water Impacts in Downgradient and Adjacent Basins

Source Location Basin		System Name	PWSID	Annual MG	Est. % Impact In Basin	Estimated Impact Outside Basin	
ID	Name					%	Basin
***GROUP 1**: Sources with Annual Withdrawal > 50 MG; some non-coincident impacts for all PWS wells assessed*							
6	Newaukum Creek	Enumclaw Water Dept	23600_04	199	70	30	WRIA 10
7	Covington Creek	Covington Water District	41650_13	938	80	20	Jenkins Ck
7	Covington Creek	Covington Water District	41650_10	303	80	20	Jenkins Ck
7	Covington Creek	Covington Water District	41650_12	218	80	20	Jenkins Ck
7	Covington Creek	Covington Water District	41650_09	164	80	20	Jenkins Ck
7	Covington Creek	Covington Water District	41650_07	149	80	20	Jenkins Ck
7	Covington Creek	Covington Water District	41650_01	70	80	20	Jenkins Ck
8	Jenkins Creek	Kent Water Dept	38150_13	508	50	50	Covington Ck
8	Jenkins Creek	Covington Water District	41650_04	269	70	30	WRIA 8
8	Jenkins Creek	Covington Water District	41650_15	107	70	30	WRIA 8
8	Jenkins Creek	Covington Water District	41650_03	72	70	30	WRIA 8
8	Jenkins Creek	Kent Water Dept	38150_08	70	65	25 10	Soos Creek Covington Ck
8	Jenkins Creek	Covington Water District	41650_11	52	70	30	WRIA 8
9	Soos Creek	K.C. Water Dist 111	41900_08	104	50	50	below study limit
9	Soos Creek	K.C. Water Dist 111	41900_07	95	50	50	below study limit
11	Green 23.8-31.4	Auburn Water Division	03350_11	439	75	15 5 5	Mill WRIA 10 below study limit
11	Green 23.8-31.4	Auburn Water Division	03350_04	380	75	15 5 5	Mill WRIA 10 below study limit
***GROUP 2**: Sources with Annual Withdrawal < 50 MG; non-coincident impacts in 15 of 403 sources screened*							
4	Green 48-50	Cunningham, M.	52236	0.3	0	100	below study limit
4	Green 48-50	Strawberry	04552	0.2	0	100	Green 31.4-40.7
5	Green 40.7-48	Flaming Geyser # 3	59314	0.7	0	100	Green 31.4-40.7
8	Jenkins Creek	Underfer, L.	90215	0.8	0	100	Soos Creek
8	Jenkins Creek	Young, G.	99430	0.3	0	100	below study limit
8	Jenkins Creek	Wallis	38301	0.2	0	100	Soos Creek
9	Soos Creek	Lundberg/Dunphy	02234	0.4	0	100	Green 23.8-31.4
9	Soos Creek	Person & Person	43055	0.4	0	100	below study limit
9	Soos Creek	Green R Hatchery	29489	0.3	0	100	below study limit
9	Soos Creek	Hilling	22171	0.3	0	100	below study limit
9	Soos Creek	Kohlmeier/Western	42947	0.2	0	100	below study limit
10	Green 31.4-40.7	O'Well	03621	0.2	0	100	below study limit
10	Green 31.4-40.7	Sargeant's Addition	76350	0.2	0	100	below study limit
10	Green 31.4-40.7	Neely Mansion	04895	0.1	0	100	below study limit
11	Green 23.8-31.4	M. C. Public	01233	0.3	0	100	below study limit

Notes: PWSID= public water system identification.

Table 8.2
Well Withdrawal Adjustments for Non-Coincident Surface Water Impacts

Sub-Basin		Adjustment Amount	
ID	Name	Annual MG	equiv cfs
1	Upper Green R above RM 63.6	n/a	-
2	Green River RM 60.5 - 63.6	n/a	-
3	Green River RM 50.0 - 60.5	n/a	-
4	Green River RM 48 – 50	-1	0.0
5	Green River RM 40.7 – 48	-1	0.0
6	Newaukum Creek	-60	-0.3
7	Covington Creek	-108	-0.5
8	Jenkins Creek	-62	-0.3
9	Soos Creek	-82	-0.3
10	Green River RM 31.4 - 40.7	0	0.0
11	Green River RM 23.8 - 31.4	-205	-0.9
12	Mill Creek	123	0.5
1 - 12	Entire Study Area	-396	-1.7

Note: Adjustments to be added to source-based withdrawals in Table 7.2

8.2 Interbasin Transfers of Public Water Supplies

Interbasin transfers of water of public water supply occur when water is piped from a well or diversion in one basin and exported for use in a different basin. Water transfers are common in the study areas. For example, the Soos Creek Water and Sewer District relies entirely on water purchased from Seattle Public Utilities and which originates in the Cedar River watershed. The City of Kent operates water sources in both the Cedar and Green River watersheds, and the Cities of Auburn and Enumclaw each operate water sources in both the White and Green River watersheds. All of the major water supply utilities shown on Figure 7.3 have service areas which cross the sub-basin limits established for the current work.

Annualized interbasin transfers of public water supplies to and from each of the study sub-basins were estimated by taking the difference between municipal water extraction (Table 7.2) and the water supplied (Table 7.4) in each sub-basin area. The inferred import and export amounts are presented in Table 8.3.

Table 8.3
Public Water System Inferred Imports and Exports
(Difference between Table 7.2 source withdrawal and Table 7.4 delivered supply)

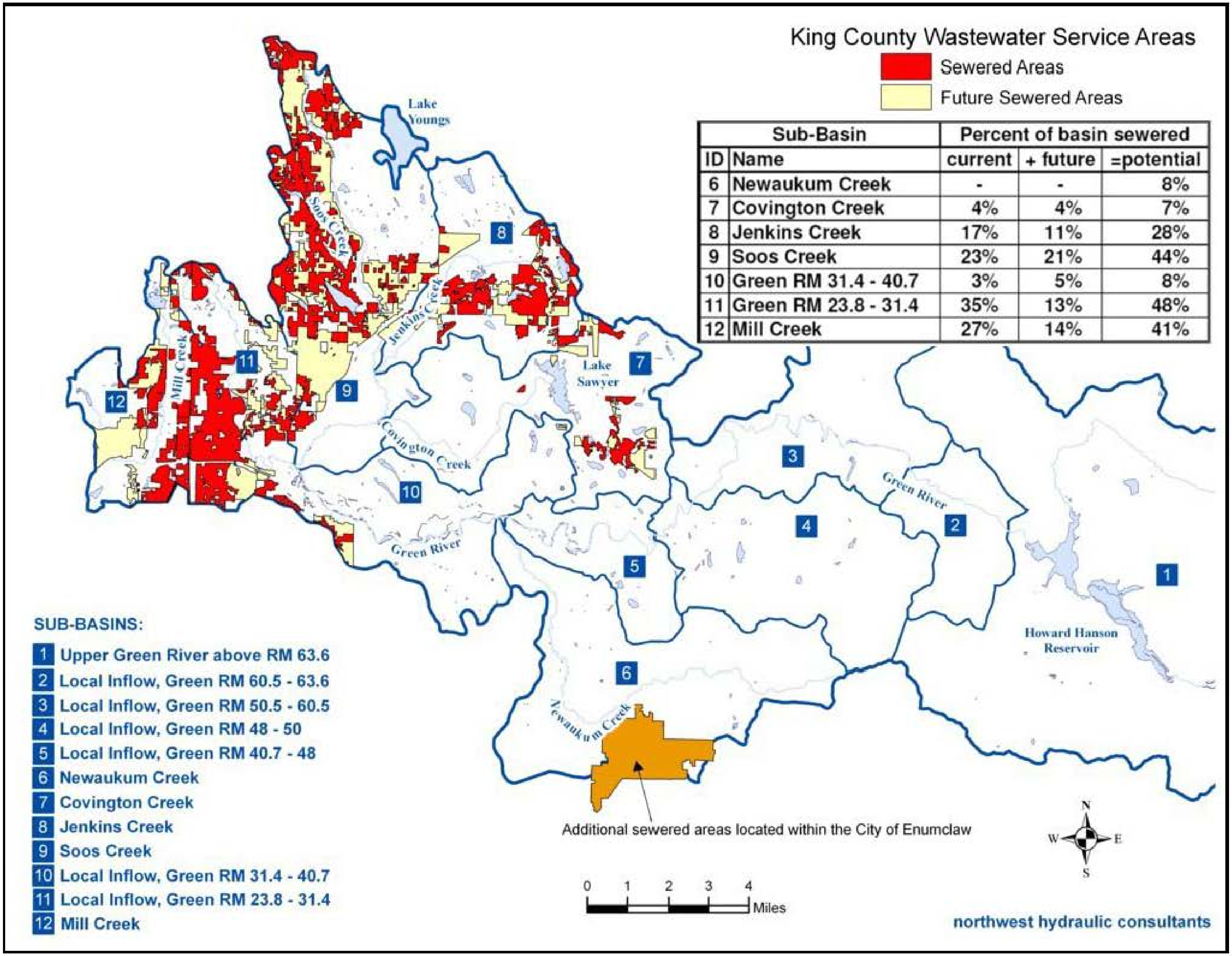
Sub-Basin		Year 2000 Water Import (+) or Export (-)*		
ID	Name	Annual MG	equiv MGD	Equiv cfs
1	Upper Green River above RM 63.6	-1,612	-4.4	-6.8
2	Green River RM 60.5 - 63.6	-20,625	-56.5	-87.4
3	Green River RM 50.0 - 60.5	1	0.0	0.0
4	Green River RM 48 – 50	-75	-0.2	-0.3
5	Green River RM 40.7 – 48	36	0.1	0.2
6	Newaukum Creek	-340	-0.9	-1.4
7	Covington Creek	-1,438	-3.9	-6.1
8	Jenkins Creek	-1,314	-3.6	-5.6
9	Soos Creek	1,689	4.6	7.2
10	Green River RM 31.4 - 40.7	472	1.3	2.0
11	Green River RM 23.8 - 31.4	43	0.1	0.2
12	Mill Creek	852	2.3	3.6
1 - 12	Entire Study Area	-22,311	-61.1	-94.6

* Positive numbers indicate that water supply is met with imports from other sub-basins; negative values indicate that water is being exported.

8.3 Wastewater Exports

King County operates a regional wastewater system that provides treatment for about 1.4 million people in the Puget Sound region. Figure 8.1 shows the extent of the wastewater collection system in the study area; water from this area is treated at the County's South Treatment Plant in Renton and discharged to a deepwater outfall in Puget Sound. The city of Enumclaw operates an independent wastewater system within the city limits, and discharges treated water to the White River. The King County and Enumclaw wastewater systems both result in water exports from the study basins.

Wastewater flows are a combination of base sewage plus additional infiltration and inflow often described as "I and I" or I/I. These components are discussed below.



Sub-Basin		Percent of basin sewered		
ID	Name	current	+ future	=potential
6	Newaukum Creek	-	-	8%
7	Covington Creek	4%	4%	7%
8	Jenkins Creek	17%	11%	28%
9	Soos Creek	23%	21%	44%
10	Green RM 31.4 - 40.7	3%	5%	8%
11	Green RM 23.8 - 31.4	35%	13%	48%
12	Mill Creek	27%	14%	41%

Figure 8.1. Wastewater Treatment Service Areas

Base flow is largely a function of population served by the system. King County Wastewater Treatment Division (KCWTD) staff indicated that base sewage flows can be coarsely estimated from assumptions of 60 gallons per capita per day, 2.5 persons per household, and 4 households per acre, yielding 600 gallons per acre per day, on average, for sewered areas.[61]

I/I is highly variable, and is a function of weather conditions, the physical condition of the system and non-sewage connections. The definition of I/I from the "Joint WEF Manual Of Practice FD2 – ASCE Manual and Report On Engineering Practice No. 62" is: "*Infiltration is water that enters a sewer system from the ground through defective pipes, pipe joints, damaged lateral connections or manhole walls. Inflow is extraneous storm water that enters a sanitary sewer system through roof leaders, cleanouts, foundation drains sump pumps and cellar, yard and area drains.*"

KCWTD is undertaking a major, multi-year assessment of its regional wastewater system and provided this study with considerable detail on the extent of its service area within the study basins, as well as wastewater flow data based on long-term simulation modeling. KCWTD estimates of monthly average sewage flows from the study basins were accompanied by the documentation presented in the following two paragraphs.

> The monthly average volumes are based on 60-year continuous model runs using the first 60 years of the Pierce County Extended Time Series rainfall data set. The average volume was computed by accumulating the monthly volumes of the KCWTD model basins that lie within the Green River Water Quantity study area and dividing the accumulated volume by 60. The KCWTD model basins were calibrated with local measured rainfall to measured sewer flows for the months of November through January, 2000/2001, and 2001/2002. The calibration process involved establishing sewage flow patterns (diurnal flow) based on measured flow data from non-storm time periods and then calibrating the infiltration/inflow (I/I) portion of the model using the local rainfall data in addition to CALAMAR radar rainfall data for the storms. The Model used for the calibration and long-term runs is MOUSE produced by the Danish Hydraulic Institute (DHI).
>
> The KCWTD model basin volumes were apportioned to the Green River Water Quantity study area basins by determining the sewered area of the appropriate KCWTD model basin in each of the study area basins and then multiplying the modeled monthly volume by the ratio of the sewered area within the study area basin relative to the total sewered area of the model basin.

Figure 8.2 shows the monthly average wastewater flows exported from the study area to the King County South Treatment Plant, based on a 60-year simulation model calibrated to current conditions. For analysis purposes, wastewater exports to the Enumclaw treatment facility were estimated on the basis of year 2000 population within the study basin portion of the city[62], a base sewer flow of 60 gallons per capita per day, and I/I contributions equal to the average I/I percentages in the King County system. Table 8.4 summarizes the average annual wastewater exports from each of the study sub-basins.

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[61] This coarse methodology for base flow estimation for wastewater does not distinguish between residential and workplace (employee) flows, and per-capita values are therefore not compatible with potable water supply methodologies which separately estimate each component of total demand.

[62] For Enumclaw, it was determined from city officials that the city provides wastewater treatment for a service area which corresponds closely to the city limits, but not the larger water service area. The population for the study area portion of the city was estimated from year 2000 census data.

Figure 8.2.
Wastewater Exports from Study Area to King County Regional Facility

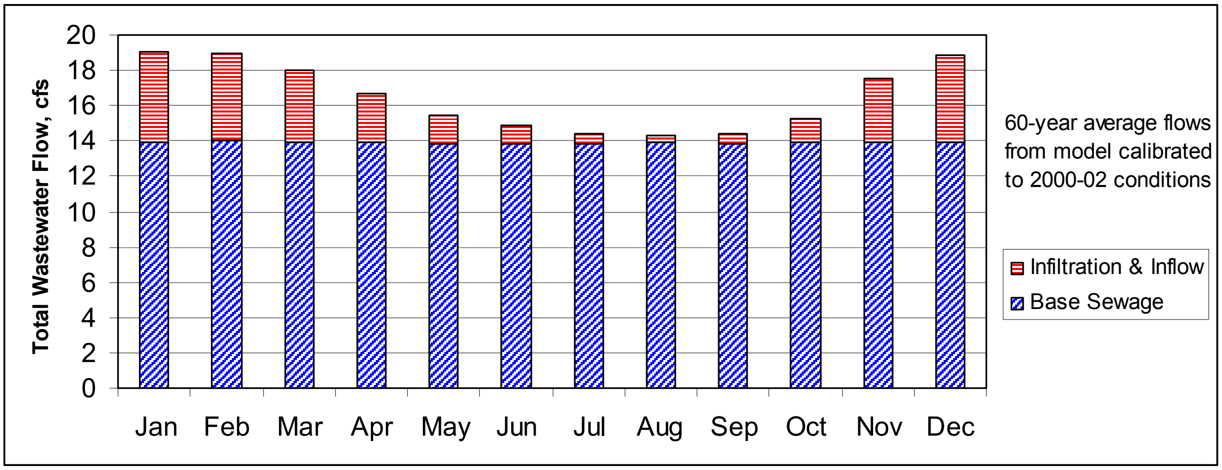

Table 8.4
Average Wastewater Exports under Current Conditions

Sub-Basin		Annual Sewage Flow		I/I as % of Total Sewage Flow		
ID	Name	MG	equiv cfs	Aug (min month)	Dec (max month)	Annual average
1-5	Green River above RM 40.7	0	0.0	-	-	-
6	Newaukum Creek	146*	0.6	-	-	-
7	Covington Creek	118	0.5	10.3%	31.5%	22.4%
8	Jenkins Creek	647	2.7	2.9%	33.5%	20.2%
9	Soos Creek	1,485	6.3	3.5%	28.8%	17.0%
10	Green River RM 31.4 - 40.7	161	0.7	1.5%	20.6%	10.9%
11	Green River RM 23.8 - 31.4	828	3.5	1.4%	22.4%	11.9%
12	Mill Creek	652	2.8	2.8%	23.2%	13.0%
1 - 12	Entire Study Area	3,891	17.1	2.9%	27.1%	15.7%

* Newaukum data are approximate.

9 Water Balance Assessment Summary

In this chapter, the individual water balance components which were assessed in the preceding chapters are aggregated to yield the total managed water fluxes which potentially affect flows at the streamflow analysis points. The fluxes of particular interest are the total extraction (withdrawals) and the total net water exports from the basin above each flow analysis point. These fluxes are compared to the current-condition streamflows to assess the magnitude and significance of managed water effects on streamflows.

Tables 9.1 and 9.2 summarize the water balance components affecting flows at streamflow analysis sites, expressed as mean annual values. Table 9.1 presents data for flow analysis points along the mainstem Green River; Table 9.2 presents data for flow analysis points on the major tributaries. To facilitate comparison, all water balance flux and streamflow values are presented in common units of cubic feet per second.

The data columns in Tables 9.1 and 9.2 correspond to the 12 streamflow analysis points—7 on the mainstem channel and 5 on tributary streams—which are described in Chapter 3. The data rows in Tables 9.1 and 9.2 correspond to the various water balance components which are described at length in Chapters 6, 7, and 8. Each of the data rows includes either a specific reference to the report section where a detailed description may be found, or a numeric formula to show how the data were computed from other values in the table.

Flow conditions in the reference year for which metered municipal withdrawal data were available (calendar year 2000) were slightly lower than average. Year 2000 flows for the Green River at Auburn were 76% of the long-term average since 1963 when Howard Hanson Dam became operational. Year 2000 flows on the gauged tributary streams (Soos, Newaukum, Jenkins, Covington) ranged from 77% to 83% of the 1988-2003 mean annual flows. It is not known how the water withdrawals reported for Year 2000 would compare to water withdrawals in a year of average or wet flows.

Three flow statistics reflecting current conditions are presented in Tables 9.1 and 9.2. These are: (1) mean annual flow for calendar year 2000; (2) the median flow for August; and (3) the 90% exceedance 7-day low flow for whichever month had the lowest flows. The mean annual flow data are from Table 3.1. The August and 7-day low flow statistics were extracted from Tables 3.2 through 3.13.

The most enlightening parts of Tables 9.1 and 9.2 are the final rows which compare water extractions and exports to the reference flow statistics. It should be noted that these comparison ratios are very simply determined and are presented solely to provide a general sense of the magnitude of the managed water fluxes in relation to the existing streamflows. Refinement to develop a more precise monthly accounting of the water budget components and streamflows was not attempted in the present work due to resource constraints and a lack of information to adequately address complexities in hydraulic continuity and time lag effects.

Table 9.1
Green River Flow Analysis Points
Basin Water Budget Components for Current Conditions
Annual Values in cubic feet per second (cfs) unless stated otherwise

Green River Mainstem Channel Analysis Point →	Below HHD	Near Palmer	In Gorge	Below Icy Ck Springs	Below Newau-kum Ck	Near Auburn	Below Mill Ck
River Mile	63.6	60.5	50.0	48.0	40.7	31.4	23.8
Sub-Basins above Analysis Point (Table 3.1)	1	1-2	1-3	1-4	1-6	1-10	1-12
Total Basin Area, square miles (Table 3.1)	222	231	253	275	310	397	419
Total Impervious Area, % of basin (Table 6.3)	1%	1%	2%	2%	3%	8%	10%
Precipitation and Recharge							
Annual Precipitation (Approx, Figure 6.3)	1,226	1,289	1,403	1,514	1,645	1,942	2,013
Annual Groundwater Recharge (Table 6.5)	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Public Water System Extraction and Supply							
A - Year 2000 Extractions (Table 7.2)	6.8	94.2	94.3	94.7	98.2	116.6	123.2
B - Delivered Supply within Basin (Table 7.4)	0.0	0.0	0.1	0.2	2.3	18.3	28.7
Other Water Extraction and Use							
C - Self-Supplied Domestic (Table 7.5)	0.0	0.0	0.0	0.1	0.2	0.6	0.6
D - USGS-Reported Other Use (Table 7.6)	0.0	0.0	0.0	0.0	0.0	0.7	0.9
E - Possible Additional Use (Table 7.7)	0.0	0.0	0.0	0.1	0.5	4.5	6.2
F – Sum of Other Uses (C + D + E)	0.0	0.0	0.1	0.2	0.7	5.7	7.7
Exports and Adjustments							
G - Potable Water Exports (A-B; Table 8.3)	6.8	94.2	94.2	94.6	95.9	98.4	94.6
H - Wastewater Exports (Table 8.4)	0.0	0.0	0.0	0.0	0.6	10.8	17.1
I - Hydraulic Continuity (Table 8.2)	0.0	0.0	0.0	0.0	-0.3	-1.3	-1.7
Major Managed Water Fluxes							
J - Total Extractions (A + F + I)	6.8	94.2	94.4	94.9	98.7	121.0	129.3
K - Total Delivered Supply within Basin (B + F)	0.0	0.0	0.2	0.3	3.1	24.0	36.4
L - Total Net Exports (H + G)	6.8	94.2	94.2	94.6	96.5	109.2	111.7
Current Conditions Streamflows (Chapter 3)							
M - Average Flow in Calendar Year 2000	753	687	732	775	847	1,021	1,066
N - Median Monthly Flow in August	244	136	155	172	204	273	292
O - 90% Exceedance Min Monthly 7-Day Low	202	103	121	137	160	209	224
Total Extractions (J) compared to Current Condition Streamflows							
Extraction as % of Yr 2000 Avg Flow, J /(M+J)	1%	12%	11%	11%	10%	11%	11%
Extraction as % of Aug Median Flow, J /(N+J)	3%	41%	38%	36%	33%	31%	31%
Extraction as % of Min 7-Day Low, J /(O+J)	3%	48%	44%	41%	38%	37%	37%
Total Net Exports (L) compared to Current Conditions Streamflows							
Exports as % of Yr 2000 Avg Flow, L /(M+L)	1%	12%	11%	11%	10%	10%	9%
Exports as % of Aug Median Flow, L /(N+L)	3%	41%	38%	35%	32%	29%	28%
Exports as % of Min 7-Day Low, L / (O+L)	3%	48%	44%	41%	38%	34%	33%

Table 9.2
Tributary Stream Flow Analysis Points
Basin Water Budget Components for Current Conditions
Annual Values in cubic feet per second (cfs) unless stated otherwise

Tributary Stream Analysis Point→	Newaukum Creek nr Black Diamond	Covington Creek nr Mouth	Jenkins Creek nr Mouth	Soos Creek nr Mouth	Mill Creek nr Mouth
River Mile	0.9	1.2	0.4	1.1	0.3
Sub-Basins above Analysis Point (Table 3.1)	6	7	8	7-9	12
Total Basin Area, square miles (Table 3.1)	27.1	21.5	15.9	66.3	12.3
Total Impervious Area, % of basin (Table 6.3)	11%	20%	31%	28%	42%
Precipitation and Recharge					
Annual Precipitation (Approx, Figure 6.3)	100	76	55	227	38
Annual Groundwater Recharge (Table 6.5)	34	41	30	109	16
Public Water System Extraction and Supply					
A - Year 2000 Extractions (Table 7.2)	3.4	7.9	9.2	18.3	1.0
B - Delivered Supply within Basin (Table 7.4)	1.9	1.8	3.7	13.8	4.6
Other Water Extraction and Use					
C - Self-Supplied Domestic (Table 7.5)	0.1	0.1	0.1	0.3	0.0
D - USGS-Reported Other Use (Table 7.6)	0.0	0.0	0.3	0.4	0.1
E - Possible Additional Use (Table 7.7)	0.3	3.2	0.4	3.6	0.2
F - Sum of Other Uses (C + D + E)	0.4	3.2	0.8	4.3	0.3
Exports and Adjustments					
G - Potable Water Exports (A-B; Table 8.3)	1.4	6.1	5.6	4.5	-3.6
H - Wastewater Exports (Table 8.4)	0.6	0.5	2.7	9.5	2.8
I - Hydraulic Continuity (Table 8.2)	-0.3	-0.5	-0.3	-1.1	0.5
Major Managed Water Fluxes					
J - Total Extractions (A + F + I)	3.5	10.6	9.8	21.6	1.8
K - Total Delivered Supply within Basin (B + F)	2.3	5.0	4.4	18.1	4.9
L - Total Net Exports (H + G)	2.1	6.6	8.3	14.0	-0.8
Current Conditions Streamflows (Chapter 3)					
M - Average Flow in Calendar Year 2000	47	25	30	95	17
N - Median Monthly Flow in August	17	3	12	29	5
O – 90% Exceedance Min Monthly 7-Day Low	10	1	8	20	< 2
Total Extractions (J) compared to Current Condition Streamflows					
Extraction as % of Yr 2000 Avg Flow, J / (M+J)	7%	30%	25%	19%	9%
Extraction as % of August Median Flow, J / (N+J)	17%	78%	45%	43%	26%
Extraction as % of Min 7-Day Low, J / (O+J)	26%	91%	55%	52%	> 47%
Total Net Exports (L) compared to Current Conditions Streamflows					
Exports as % of Yr 2000 Avg Flow, L / (M+L)	6%	25%	25%	16%	-5%
Exports as % of August Median Flow, L / (N+L)	11%	69%	41%	33%	-20%
Exports as % of Min 7-Day Low, L / (O+L)	17%	87%	51%	41%	> -74%

The second-to-last block of rows in Tables 9.1 and 9.2 lists extractions (water withdrawals) as a percentage of the total streamflow which would exist before withdrawals if: (1) the extractions are in hydraulic continuity with the stream and result in reduced flows; (2) extractions occur at a constant year-round rate which would eliminate timing or lag effects; and (3) extraction amounts are for fully consumptive use with no flow being returned to the stream. Actual withdrawals match these conditions sufficiently closely to make the extraction-based comparison statistics meaningful as a coarse measure of managed water impacts on the streams.

The last block of rows in Tables 9.1 and 9.2 present net exports (Tacoma Water diversions, King County wastewater exports, etc.) as a percentage of the total streamflow which would exist before exports if: (1) the sources of the exported water are in hydraulic continuity with the stream and result in reduced streamflow; and (2) exports occur at a constant year-round rate which would eliminate timing or lag effects. Except for the Mill Creek basin, for which there are considerable net imports of water into the basin, actual exports match these conditions sufficiently closely to make the export-based comparison statistics meaningful as a coarse measure of managed water impacts on the streams.

The comparison statistics show that managed water impacts are discernable in all the study basins, with the largest impacts occurring, expectedly, during low flow conditions. The greatest impacts are in Covington Creek, then in Jenkins Creek, which are both tributaries to Soos Creek which ranks third. On Covington Creek, the analysis suggests that extractions (with an unknown return flow to the streams) and exports (which are fully consumptive use) have, in combination, caused approximately a 70% depletion of the natural-conditions median monthly flow in August, and approximately a 90% depletion of the 7-day low flows. A net depletion of the flow in the middle and lower Green River is also apparent, with extraction and export amounts ranging from about 10% of the total annual flow in 2000 to about 40% of the 7-day low flows. Of the studied streams, the least affected is Newaukum Creek for which extraction and export amounts are equivalent to about 6% of the mean annual flow in 2000 and about 20% of the 7-day low flows.

10 Alternative Management Actions for Water Quantity

The preceding chapters cover current conditions streamflows, flow sufficiency from a mainstem fishery perspective, land use effects, groundwater influences, and various managed water elements affecting water quantity issues in the Green River and its tributaries. This chapter focuses on alternative management actions to minimize further degradation of, and to improve, current water quantity conditions for habitat and fish.

Due to resource constraints, this study was not able to identify specific reaches and time periods for which modest (achievable) changes in available water would significantly benefit or harm fish populations. Such specificity would have enabled consideration of highly targeted management actions, including but not limited to source exchanges, aquifer recharge, special land use designations in the critical basin areas, and/or channel modifications to improve hydraulic characteristics during low flows. For example, the analysis has quantified the flows which currently exist in Covington Creek, and has concluded that current low flows, due to anthropogenic effects, are dramatically lower than under pristine basin conditions. However, the available resources were insufficient to take the next steps of translating the monthly and low-flow discharge data to channel hydraulic characteristics (depth, width, and velocity) meaningful to fish habitat, and identifying the reaches and time periods when water quantity is most limiting to viable fish populations.

It is apparent from the preceding chapters that there have been significant low flow reductions on the middle and lower Green River, and its major tributaries, due to water withdrawals and exports. Land cover change effects are likely responsible for an additional (but un-quantified) low flow reduction. For the mainstem Green River, the perception from a fish resource perspective is that the quantity of water now available for release to the Green River below the Tacoma diversion is insufficient to meet the needs of the multiple species using the river, and that it is vital to preserve and protect all remaining inflows below the Tacoma diversion. While a fisheries evaluation to specifically address flow sufficiency in the tributary channels has not yet been conducted, low flows have been identified as a limiting factor to fish passage in Soos and Newaukum Creeks.

Because of a lack of specificity in the time and place where improved hydraulic characteristics would be most beneficial to fish populations, our recommendations at this time consist of general Best Management Practices (BMPs) which can be widely applied so as to minimize further hydrologic alterations, and methods which are available to address reach-specific needs once those needs are defined.

The following alternative management actions include a brief description, potential instream flow benefits and potential benefits for fish.

1. Management of impervious surfaces and forest cover (landscape based) – Land cover in a watershed or catchment influences the magnitude, duration and frequency of runoff events and affects the overall water cycle (e.g., surface runoff, evapotranspiration, interflow and groundwater recharge). This is true at both the smaller tributary scale and larger river basin scale. By minimizing impervious surfaces and maximizing forest retention within a watershed, it is possible to minimize the impacts of land-use-related changes on streamflows, aquatic habitat, and salmonids.

Forest conversion to pasture, grass, or impervious surfaces in low-permeability till or clay soils generally results in reduction of evapotranspiration and groundwater recharge. This leads to greater peak flows during wet season rainfall events and reduction in base flows during the dry season and between runoff events. Natural water storage in wetlands and hummocky forested areas, which provide groundwater recharge over prolonged periods, is also reduced.

A somewhat different situation exists in areas of freely draining outwash soils. Provided that forest conversion is accompanied by opportunities for the complete infiltration of stormwater, land cover conversion can enhance recharge and hence water available for stream base flows. However, the potential benefits of this land cover change need to be weighed against the additional water withdrawals (and potential water exports) associated with the land use changes to residential and commercial development.

Minimizing the increase in impervious surfaces and maintaining forest cover where possible helps to maintain existing hydrology by limiting changes to groundwater recharge. Salmonids benefit by limiting changes to the natural flow regime to which they are uniquely adapted. Increases in peak flows can scour redds in spawning areas, increase sedimentation, or flush juvenile fish downstream prematurely. Lower flows can limit salmonid migration, dry up otherwise suitable spawning areas and reduce available rearing habitat. Reduction in groundwater flows can also affect salmonids by increasing water temperatures.

2. Water supply management options to benefit fish – Water withdrawals, whether by surface water diversion or groundwater extraction, have an effect on available water in streams and rivers. With increased awareness of life-cycle needs of salmonids in streams and rivers, it is possible to manage surface and groundwater withdrawals to reduce impacts on fish. This would include managing withdrawals during critical spawning, incubation or rearing periods. Management options include: (1) targeted seasonal reduction in withdrawals, (2) supplementing instream flows with conservation storage (streamflow augmentation), (3) source displacement or source exchange options (in which one source is substituted for another to benefit fish or use water diversions more efficiently), (4) interties (connecting adjacent water systems to allow exchange of water between them to move water where it is needed for both fish and people) or (5) supplementing flows with groundwater, sometimes called "pump and dump."

The effect of surface water diversions and groundwater withdrawals on instream flows can be substantial, particularly during seasonal low flow conditions (see Table 9.2). The estimated water extraction in the five tributaries assessed in the Green River varied from 17 to 78 percent of median August monthly flows. Effects during drier years or localized effects on flow can be even greater. By managing flows using some of the techniques noted above, it would be possible to reduce the effects on dry season low flows. Salmonid benefits would include improved migration, greater access to suitable spawning areas and increased rearing habitat, including mainstem and off-channel areas. Generally, it would be preferable to reduce water withdrawals to enhance instream flows as a first option followed by streamflow augmentation, source displacement, or intertie options because it is more natural and maintains local water conditions. Source displacement, source exchange, and intertie options should be examined carefully on a case-by-case basis to assess the relative benefits and impacts from one system to another.

3. Stream morphometry management to "fit the habitat to the flow" – The Green River flow regime that existed historically has been substantially altered due to flood storage and water diversions. In addition, land use changes and river engineering works (e.g., levees, revetments) have affected floodplains and channel migration. The result of these changes is a river valley, floodplain, and river channel that do not "fit" the current flow regime. This management action could involve lowering the floodplain at select locations, and altering side channel and off-channel areas where feasible to improve connectivity and access for salmonids. This could be applied to the mainstem of the middle and lower Green River and key tributaries.

Prior to construction of Howard Hanson Dam in the early 1960s, peak annual flows exceeded 12,000 cfs as measured at Auburn in more than half of the years between the mid-1930s and early 1960s. Peak flows exceeded 18,000 cfs during five years, with a maximum of 28,000 cfs in 1959. As a result of flood control operations at the dam, peak flows are managed to stay below 12,000 cfs, greatly reducing the area of flooding and access to off-channel habitats. In addition, areas that inundated regularly during higher wet season flows are infrequently inundated under the current flow regime. Through changes to river channel, off-channel and floodplain morphometry, it would be possible to improve habitat conditions for salmonids. This might include expanded spawning area and rearing habitat, and improved connectedness with off-channel or tributary habitats.

4. Infiltration of stormwater – Historically, regular floodplain inundation resulted in groundwater infiltration and support of hyporheic flows to streams and rivers (Hyporheic flow is the percolating flow of water through the sand, gravel, and sediments under and beside a stream channel or floodplain that contributes water to the stream). The alluvial sand and gravel sediments associated with floodplain areas are expected to be permeable and should provide infiltration opportunities. By increasing floodplain infiltration of stormwater, where feasible, it is possible to increase base flow to streams and rivers and improve hydrologic continuity. This could be applied to the mainstem of the middle and lower Green River and key tributaries for new construction or by retrofitting existing stormwater systems. Opportunities for stormwater infiltration should, of course, be pursued wherever suitable conditions exist throughout the watershed. River floodplain areas are of particular interest because they may provide suitable infiltrative soils in protected areas not currently accessible to stormwater engineers.

Typical stormwater management relies on detention of peak flows prior to discharge to surface waters. In addition, areas developed prior to the adoption of adequate stormwater management requirements (before about 1990) often discharge with minimal detention. By harnessing this stormwater resource, it would be possible to improve floodplain and instream hydrologic conditions both seasonally and between rainfall events. Benefits to salmonids could include improved spawning habitat resulting from streambed upwelling, base flow maintenance, and cooler groundwater inflows.

5. Drought preparedness management guidelines – Guidelines could be developed as part of a Drought Response program[63] to protect instream resources (including habitat for salmonids) while addressing water supply needs for out-of-stream uses. Elements could include monitoring of demands, restriction strategies, overall conservation including plumbing upgrades, curtailment of non-essential uses, reduced water withdrawal, and events or actions that will trigger application of drought response programs.[64,65] By properly planning for droughts and anticipating alternative scenarios, it is possible to minimize the potential for extreme impacts on instream resources.

Dry water years and low flow conditions are part of natural conditions, but droughts can be exacerbated by water demands. Instream flows for future water rights in the Green-Duwamish river basin were established in chapter 173-509 WAC, including flows for "critical" water years. By preparing a drought response program, it will be possible to minimize potential effects of low flow on instream resources. Some of the impacts on salmonids likely to result from extreme low flow conditions include limits on

[63] For example, Tacoma Water has a Water Shortage Response Plan, updated in March 2005, that is designed to protect instream resources while addressing municipal water supply needs.

[64] New South Wales. 2004. Best Practice Management of Water Supply and Sewerage Guidelines (Appendix D – Drought Management).

[65] Central Puget Sound Initiative. 2002. Draft Central Puget Sound Regional Water Resources Strategy. October 15, 2002.

adult upstream migration, reduction of available spawning habitat, drying of redds after spawning, water temperature effects, and reduction in area of available rearing habitat. Adequate planning for salmonid needs during drought conditions can help reduce these potential impacts.

6. Maintain functioning septic systems where feasible – Septic systems are usually the wastewater treatment system of choice for lots that are ½-acre or larger. By maintaining functioning septic systems in quasi-suburban and rural areas, it helps protect natural hydrologic conditions. The use of septic systems ensures that water for household purposes gets infiltrated back into the ground locally. When developed areas become served by sewer systems, wastewater is usually exported from the basin, contributing to overall reduction of base flows and groundwater recharge. It is important to note that in some instances, septic systems may result in nutrient enrichment or elevated bacterial levels that should be considered with respect to this potential action.

Benefits of maintaining septic systems include groundwater recharge and base flow supplementation. This helps maintain baseflows year-round and can contribute to dry season low flows. Benefits are cumulative across a larger area from localized infiltration. Salmonid benefits could include improved migration, and support of summer rearing habitats.

7. Develop uses for reclaimed wastewater to reduce water demand –Reclaimed wastewater is water that gets treated to such a high level that it can be used safely and effectively for non-drinking water purposes such as landscape and agricultural irrigation, heating and cooling, and industrial processing. Reclaimed water is available year-round, even during dry summer months or when drought conditions can strain other water resources. King County's Regional Wastewater Services Plan[66] calls for expanding the production and use of reclaimed water as a valuable resource. Reclaimed water could potentially: (1) enhance or maintain fish runs consistent with the region's Endangered Species Act response, (2) supply additional water for the region's non-potable and indirect potable uses, and (3) preserve environmental and aesthetic values.

Greater use of reclaimed wastewater for irrigation and other consumptive uses can reduce the demand on freshwater supplies, particularly during drier low flow periods. This has the potential to leave more water in the streams for instream benefits, including improved adult upstream migration, maximizing available spawning habitat, maintaining flows during incubation of redds, and maximizing access to available rearing habitat.

8. Evaluate options for agreement with Tacoma Water to supply water for fish – Tacoma Water currently diverts up to 113 cfs from the Green River for municipal and industrial purposes as part of its first diversion water right claim. Plans to exercise a second water diversion right up to an additional 100 cfs (known as the Second Supply Project and Additional Water Storage Project at HHD) are nearing completion and will include storage of up to 20,000 additional acre-feet of water at Howard Hanson reservoir for municipal withdrawals[67]. Options for utilizing some of this additional stored water to meet the needs of fish could be pursued through a possible agreement with Tacoma Water. This could involve additional streamflow augmentation when allowed by shortfalls in demand, reduced spring storage to maintain target instream flows, or other arrangements. This effort should be considered in the context of Tacoma's existing agreement with the Muckleshoot Indian Tribe to guarantee instream flow targets at Auburn of 250 cfs in average to dry years and ongoing flow management efforts on the Green River.

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[66] King County. 1999. Regional Wastewater Services Plan.

[67] Tacoma Water. 1999. Tacoma Water Habitat Conservation Plan. Green River Water Supply Operations and Watershed Protection. Public Review Draft.

As noted in Chapter 4, there are challenges in meeting instream flow needs during early summer through fall, including: (1) protection of wild winter steelhead redds through fry emergence, (2) adequate summer low flows for juvenile steelhead and salmon rearing, and (3) sufficient flows for Chinook spawning. Working with Tacoma Water to consider possible options for improved management of instream flows is an additional opportunity that could be pursued. This has the potential to provide more water for fish to improve upstream migration, maximize available spawning and rearing habitat, and maintain flows during incubation of redds. [Note: Tacoma Water has, for years, been actively involved with the Water Management coordination meetings to manage its water withdrawals to augment flow at critical times. Tacoma Water will continue this flexibility in the future within the constraints of meeting public water supply needs.]

The preceding alternative management actions are presented to stimulate discussion and consider options for improving water quantity conditions for fish. Some or all of these options could be pursued to varying degrees or in different geographic areas or sub-basins. No single action will solve the water quantity problem that salmonids face in particular sub-basins or specific years. However, if creative options are considered and implemented where feasible, it will be possible to cumulatively make a significant difference for salmonids in the Green River and its tributaries.