2.3 HYDROMODIFICATION

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EXECUTIVE SUMMARY

The following six (6) types of hydromodifications are known to have affected the Green River:

1. Changes in channel type and the total length of mainstem channel;
2. Bank armoring and artificial channel constraints;
3. Reduced size and frequency of in-stream LWD;
4. Changes in the extent of active gravel bars;
5. Loss of off-channel habitats; and
6. Disrupted floodplain connectivity and function.

For the purposes of evaluating the impact of these hydromodifications, the mainstem Green River basin has been broken into four major sub-watersheds and two major tributary sub-watersheds. Within each sub-watershed, river was subdivided into channel types with similar physical characteristics (e.g. gradient, confinement, sinuosity) that might be expected to respond similarly to disturbances and alteration of channel forming processes. Channel types utilized in the assessment of hydromodifications are described in Table HM-1.

KEY FINDINGS

UPPER GREEN RIVER SUB-WATERSHED (RM 64.5 TO 93)

- High sediment supply has transformed portions of the mainstem Floodplain channel type from pool-riffle to braided morphology. Braided channels experience frequent scour of a depth sufficient to damage or destroy chinook redds and have low pool frequencies, reducing the amount of juvenile rearing and adult holding habitat.

- Inundation by Howard Hanson Reservoir has transformed 4.5 miles of former Floodplain channel type (18% of total in Upper Green River sub-watershed) to periodic Lacustrine habitat and has resulted in the loss of 10,000 linear feet of side channel habitat.

- Armoring of channel banks to protect transportation corridors (roads and railroads) has reduced the complexity and quality of rearing habitat in approximately 6.3 miles (26%) of the remaining Floodplain channel type in the Upper Green River sub-watershed.

- Large woody debris (LWD) loadings in the Upper Green River sub-watershed are currently rated as “not properly functioning” or “fair” to “poor” according to criteria developed by the National Marine Fisheries Service (NMFS) (NMFS 1999) and Washington Department of Natural Resources (DNR) (WFPB 1997). LWD that contributes to “fair” rating is generally small and does not include “key” pieces. The low

LWD frequencies correspond with low pool frequencies, indicating that the lack of LWD in Floodplain channels known to be responsive to LWD has degraded rearing and adult holding habitats required by chinook, coho, and steelhead salmonids.

- Large pieces of LWD (up to 90 feet long) were previously mobilized and transported downstream through Floodplain channels in the Upper Green River sub-watershed. Downstream transport of LWD has been interrupted by HHD since 1964.

MIDDLE GREEN RIVER SUB-WATERSHED (RM 32 TO RM 64.5)

- The total length of Floodplain channel type between RM 58 and RM 61 has declined by approximately 0.5 miles (15%) as a result of road/railroad construction and flood control by HHD. This has resulted in a loss of habitat used by adult chinook and steelhead for spawning, rearing, and adult holding. Coho, cutthroat, and probably chum would use this area for rearing and possibly some spawning.

- Bank armoring to protect transportation corridors has reduced the complexity and rearing habitat value over 1.6 miles (26%) of the Large Contained channel between RM 61 and 64.5. Channel constraints in this segment generally affect only one bank, and have not substantially reduced the ability of this channel to form side or off-channel habitats due to the naturally high confinement (valley width <2 times channel width) of this channel type.

- Construction of levees and revetments to prevent bank erosion and control flood levels has reduced the complexity and rearing habitat value over approximately 5.6 miles (40%) of the Middle Green Floodplain segment between RM 31 and RM 45. Levees and revetments generally affect only one bank in this segment, and thus have not altered the overall channel type.

- The length of channel characterized by a braided morphology between RM 31 and RM 45 declined from 10.4 miles to less than 4 miles from 1936 to 1992 (60% reduction). Reduced area of braided morphology represents an improvement in the stability of spawning habitat, as braided channels typically experience extensive scour on an annual basis.

- The area of active gravel bars in Floodplain segments of the Middle Green River has declined as a result of flood control by Howard Hanson Dam. All 10 acres of formerly active bar surface between RM 56 and RM 61 now support riparian forest communities. Bar area in the Floodplain channel segment between RM 31 and RM 45 declined from 236 to 78 acres (67% reduction) between 1936 and 1992. The loss or stabilization of bar surfaces corresponds with a reduction in shallow marginal habitat and suggests that creation of new side channel habitats and riparian forest stands has been slowed or halted.

- LWD is currently scarce in Floodplain channel types known to be responsive to LWD. No LWD was observed in the Floodplain channel segment between RM 58 and RM 61 on aerial photographs from 1953 and 1987. LWD in the Middle Green Floodplain segment (RM 31 to RM 45) currently averages only 32.6 pieces per mile, even with LWD placement undertaken in recent restoration projects. NMFS criteria for “properly functioning habitat require at least 80 pieces per mile. The lack of LWD corresponds with a scarcity in large pools, which numbered less than 0.12 pools per channel width based on evaluation of air photos from 1992 (Fuerstenberg et al. 1996). The scarcity of LWD and pools indicates that the quality and quantity of mainstem rearing and adult holding habitat has declined in Floodplain channel types.

- The length of side channel habitats in the Floodplain segments of the Middle Green River has declined by over 70 percent as the result of the disconnection of 1.7 miles of side channel between RM 58 and RM 61 from 1953 and 1987, and the loss of 13.8 miles of side channels between RM 31 and RM 45 from 1906 to 1992.

- Decreased flood flows, road and railroad construction, and levees and revetments are believed to have reduced the area of floodplain inundated on a regular basis (by 2-year return interval flood). Available data are insufficient to quantify the magnitude of the reduction.

LOWER GREEN RIVER SUB-WATERSHED (RM 11 – RM 32)

- Six miles of Floodplain channel type and 14 miles of Palustrine channel type have been channelized. Both Palustrine and Floodplain channel types typically have complex planforms and dissipate flood energy by overbank flows. Consequently, channelization has presumably resulted in the loss of almost all mainstem winter rearing habitat and a reduction in the quality of summer rearing and adult holding habitat in these segments.

- All 36 acres of gravel bars (100%) in the former Floodplain channel segment (RM 25 to RM 31) have been lost. These sites formerly provided shallow marginal habitat, increased channel complexity, and sites suitable for colonization by riparian hardwood forests.

GREEN/DUWAMISH ESTUARY (RM 0.0 – RM 11.0)

- Diversion of the White and Cedar/Black Rivers from the Green/Duwamish River has reduced the freshwater inflow to the estuary by about two-thirds and has led to profound changes in the nature of the Duwamish River channel and adjacent floodplain.

- Creation of the Duwamish Waterway resulted in replacement of about 9.3 miles of meandering river with 5.3 miles of straightened channel.

- Approximately 98 percent (2.2 mi^2) of the Duwamish River’s historic floodplain marshes and intertidal mudflats have been replaced with fill, overwater structures, commercial and industrial facilities, and other development.

- A large proportion of the shoreline downstream of RM 5.3 and around Elliott Bay has been armored in some way and much of this shoreline also is altered by the presence of overwater piers and wharves.

- Despite the straightening of the river and loss of intertidal habitat, the Duwamish River and Elliott Bay still have some areas of mudflats that provide important estuarine rearing functions for juvenile salmon.

- Recent habitat management policies and restoration projects, as well implementation of requirements for mitigation for any new losses of habitat, have begun to address the degraded conditions along the Duwamish River.

MAJOR TRIBUTARIES

- The lower 0.3 miles of Newaukum Creek have been dredged and straightened by private landowners.

- Stream cleaning and riparian harvest have reduced the frequency of LWD in the lower 1.4 miles of Newaukum Creek to 0.3 pieces per channel width, a level considered “poor” or “not properly functioning”. Pools are also scarce.

OVERVIEW

Euroamerican settlement of the Puget Sound Region resulted in profound physical changes in river systems and aquatic habitats, as federally or locally funded projects and the activities of private citizens resulted in construction of hydroelectric, flood control and irrigation dams, and diking and dredging projects intended to prevent flood damage and facilitate navigation. Much of the direction for the hydromodification of the Green River was systematized by Col. Howard A. Hanson of the U.S. Army Corps of Engineers in his seminal publication, “More Land for Industry” (Hanson, 1957). This document outlined an incremental scheme for the simplification, channelization and dredging of the Duwamish estuary and for ongoing flood containment for the lower Green River valley through a combined program of massive levee construction and the construction of the Howard A. Hanson Dam.

Prior to 1961, the historic agricultural levee system along the Green River was pursued in an orderly fashion by King County through acquisition of easements, design and construction of a vast, cumbrous array of levees and revetments financed by municipal bonds. This construction effort was carried out by King County crews employing draglines to clear and shape the bank, place riprap and remove LWD from the adjoining channel. This program was active from the early 1960s through the mid- to late 1970s. Rigorous suppression of recolonizing riparian plant communities was also performed in compliance with guidelines for eligibility of local levee systems in the federal levee flood damage rehabilitation administered by the Corps under Public Law (PL) 84-99. County compliance with this federal devegetation requirement was informally suspended in 1989, and formally addressed in the 1993 King County Council adopted King County Flood Hazard Reduction Plan (FHRP) Policies FHR-10 and G-7 (King County, 1993). Project by project consideration of these policies with respect to Green River levee maintenance has resulted in incremental establishment of pioneer seral riparian shrub communities on several levee segments within the lower river, and to the formal disqualification of these same segments from eligibility for federal rehabilitation assistance to repair flood damages.

The general effects of hydromodification on salmonid fishes and their habitats are described below. Subsequent sections provide detailed descriptions of the extent of each type of hydromodifications for each of the five sub-watersheds (Upper Green River, Middle Green River, Lower Green River, Green/Duwamish Estuary and Major Tributaries supporting Chinook).

CHANNEL TYPE

Channel morphology is a useful tool for classifying potential fish habitat in streams and rivers because it: 1) dictates habitat conditions and uses by the various life-history stages of salmonid species (Beechie and Sibley 1997); 2) directly influences the productive capacity of each habitat type (Vannote et al. 1980; Naiman et al. 1992; Paustian et al 1992); and 3) varies in terms of sensitivity and response to changes in inputs of water, wood and sediment from natural or anthropgenic disturbances or from restoration activities (Paustian et al. 1992; Montgomery and Buffington 1993; Rosgen 1994).

Straightening formerly sinuous channels reduces the total length of the river, resulting in an overall loss of habitat and habitat complexity. Construction of levees or revetments and rip-rapping banks prevents lateral channel migration and generally confines flood flows to a single channel that is deeper and narrower and than the natural channel (Dunne and Leopold 1978). The result is greater depths and higher velocity flood flows, which increase the sediment transport capacity (Dunne and Dietrich 1978). Because bank erosion is prevented, the increased sediment transport capacity results in increased scour of the streambed, and the channel may degrade. Increased scour can destroy salmonid redds, and may also result in a loss of suitable spawning gravels in the affected reach (Ligon et al. 1995). Sediment stored in the channel may be routed downstream, reducing the area of gravel bars that form secondary channels and the amount of low velocity marginal habitat. Salmonid fry have a particularly narrow tolerance of depth and velocity extremes; juvenile fishes in the Willamette River avoided velocities greater than 11 cm per second and were not found at depth greater than 30 cm (Li and Shreck 1984). The simplified channel margins offer fewer velocity refugia, thus the quantity of available rearing habitat is reduced.

In contrast, if sediment supplies increase dramatically or reduced flood flows are no longer competent to transport coarse sediment, gravel deposition may increase so much that channels which formerly exhibited a pool-riffle morphology become braided. Braided channels reflect a condition of high sediment supply relative to transport capacity (Montgomery and Buffington 1993). The morphology of braided channels is distinguished by the instability of bars and channels, which may vary from day to day during high flows (Morisawa 1985). The excessive scour and constant shifting of braided channels may destroy salmonids redds, reducing the viability of spawning in such reaches (Schuett-Hames and Schuett-Hames 1984).

BANK ARMORING

The primary function of revetment construction is the mechanical armoring of natural riverbank soils against slumping, sloughing, bank scour and erosive transport of failed bank materials from the affected site. This has as its objective the prevention of channel migration, meander incision, avulsion, braiding and similar natural processes which affect the stability of the adjoining lands and the long-term planform of the river. Revetments are frequently constructed in reaches where complex off-channel habitats are common, cutting those areas off from direct connectivity with mainstem flows. Revetments are also frequently constructed where riparian vegetation and/or instream LWD complexes have been severely modified through land clearing, channel dredging, snagging. These activities commonly result in higher rates of bank erosion that has been historically countered with revetment construction.

Although they also frequently result in armored banks, levees differ from revetments in that they include raised fills placed above the adjoining floodplain at or near the riverbank in order to contain flood flows within a highly channelized conveyance corridor. The function of levees is both to prevent migration or widening of the river channel, as is the case with revetments, and to prevent flooding of lands within the former floodplain, thus levees not only disconnect off-channel habitat from mainstem rivers, they also dramatically alter the hydrologic regime of former floodplain habitats.

Channelization and bank armoring transform formerly heterogeneous banks composed of a variety of substrates to steep banks composed of uniform cobble to boulder-sized material. Natural structural features such as exposed tree roots, LWD, and undercut banks are eliminated. Studies indicate that juvenile salmonid densities and species diversity are generally lower near riprap banks than natural banks (Knudsen and Dilley 1987, Peters et al. 1998). Juvenile chinook and coho, and sub-yearling trout abundance is significantly correlated with the amount of wood cover for both natural and hydromodified banks (Beamer and Henderson 1998; Peters et al. 1998). Sub-yearling chum preferred aquatic plants and cobble, cover types that were most common in natural banks (Beamer and Henderson 1998), while yearling and older steelhead trout densities were unaffected or increased at rip-rap stabilized banks (Peters et al. 1998).

Removal of bank vegetation also reduces shade, overhanging cover, LWD recruitment, and inputs of terrestrial insects and fine particulate organic matter. Reduced shade can result in temperatures that equal or exceed the tolerance of salmonid fishes, particularly in small to medium sized (<20 m) streams at low elevations (Sullivan et al. 1990). Terrestrial insects and fine particulate organic matter are important components of the food chain in riverine ecosystems (Vannote et al. 1980).

LARGE WOODY DEBRIS

Large woody debris is critical component of habitat in rivers and streams of the Pacific Northwest. Large woody debris creates low velocity areas that serve as shelter from swift flood flows, provide cover, and create complex habitat preferred by many species of salmonid for summer and winter rearing (Sedell and Froggatt. 1984; Dolloff 1987; Shirvell 1990; Fransen et al. 1993; Peters et al 1993; Fausch and Northcote 1992; Cedarholm et al. 1997). The introduction of large pieces of woody debris also initiates pool formation (Beechie and Sibley 1997), prompts bar, island and side channel formation (Sedell et al.1984; Abbe and Montgomery 1996), stores sediment (Lisle 1986; Keller 1985) and retains organic matter (Bilby and Likens 1980). The role and function of LWD vary by channel type. In small, steep headwater and tributary channels, LWD traps sediment, dissipates erosive energy, and creates a stepped channel profile, often enhancing the depth and complexity of pools (Sullivan et al.1987; Chin 1989; Nakamura and Swanson 1993). In lower gradient, moderate to intermediate size streams, LWD contributes to channel complexity, bank stabilization, and sediment storage, and is of critical importance for forming pools (Montgomery and Buffington 1993). In large, low gradient rivers, LWD often accumulates in jams that contribute to the formation of off channel habitat and increase the cover and complexity of large pools (Abbe and Montgomery 1996; Benner and Sedell 1997). Abundant LWD helps ensure that cover and habitat suitable for salmonids are available over a wide range of flows. The role of LWD in tidal estuaries is poorly studied but widely assumed to include several of the functions provided in upstream areas. In areas with significant tidal exchange, any given piece of LWD is only in the water for a portion of the tidal cycle, however, so the overall importance may be less than in upstream areas.

In-channel LWD and wood recruitment have been diminished compared to historic levels in many Pacific Northwest rivers, including the Green River, due to logging to the stream bank and clearing of floodplain forests for agriculture (Benner and Sedell 1997; Beechie et al. 1994; Williams et al. 1975). Wood was also removed from the Green River to address concerns about flooding, to facilitate navigation, or up until the late 1970s, to eliminate perceived barriers to upstream migration of salmonids (Pence 1946; Krug 1946; Williams et al. 1975). Reduction in instream LWD has been demonstrated to reduce fish population densities (Bryant 1983; Dolloff 1986; Elliot 1986).

GRAVEL BARS

Increased sediment transport capacity, reduced sediment supply, loss of LWD and reduced flood flows can all result in a reduction in the amount of sediment stored in low gradient reaches as gravel bars. Gravel bars are important for providing complexity in large alluvial channels. In rivers such as the Green, gravel and cobbles suitable for salmon spawning tend to accumulate where topographic complexities lead to areas of reduced boundary shear stress, such as in the lee of islands or in side channels (Ligon et al. 1995). Mid-channel bars develop where obstructions such as key size pieces of LWD deposit (Abbe and Montgomery 1996). Diversion of flow around mid-channel bars further reduces shear stress, eventually leading to the formation of stable islands (Abbe and Montgomery 1996; Leopold et. al. 1964).

Controlling flood flows and interrupting the sediment supply may reduce the amount of spawning gravel and off-channel habitats even in reaches that are unaffected by bank armoring. Side-channel habitats are created by long-term processes of alluvial deposition, channel migration and avulsion (Kellerhals and Church 1989; Morisawa 1985). If peak flows are reduced, particularly in combination with a loss of large woody debris, the channel no longer actively cuts against its banks or avulses, thus eliminating recruitment of coarse sediment from alluvial reaches and preventing the formation of new bars or side channels (Ligon et al. 1995). Loss of gravel bars and prevention of lateral channel migration slows the creation of new riparian zones that replace aging stands of riparian species such as cottonwood or willow, species that typically only germinate on recently exposed soils (Niyama 1990; Strahan 1984; Junk et al. 1989). Given the natural gradient of the Green/Duwamish River system, little gravel typically was carried past the lower Green River sub-watershed into the estuary. Gravel is an uncommon substrate type in most large river estuaries in Puget Sound.

OFF-CHANNEL HABITATS

In addition to a reduction in the quality and quantity of mainstem channel habitat, channelization and bank armoring typically disconnect existing off-channel habitats such as side channels, sloughs and wetlands. Flood control structures and reduced flood flows also prevent the formation of new off-channel habitats (Ligon et al. 1984). Development of river bottomlands for urban or agricultural purposes further eliminates off-channel habitats (Benner and Sedell 1997). Many species of salmonids are attracted to off-channel habitats because the channels are often fed by groundwater and have more consistent flow and temperature regimes than mainstem rivers (Lister and Finnegan 1997). Juvenile coho and chinook often utilize these habitats for overwintering or as refuge from high velocity flood flows (Jeanes and Hilgert 2000; Peterson 1982; Cederholm and Scarlett 1982). Chum salmon frequently spawn and rear in side channels (Salo 1991; Coccoli 1996), and chinook salmon have been observed spawning in the outlets of side channels in the Green River (Malcom 1999).

FLOODPLAIN CONNECTIVITY

Finally, the conversion of lands from historic uses to urban and agricultural development, flood control activities and channelization all contribute to a loss of floodplain function. Forested floodplains reduce the energy of floodflows, protects banks from excessive erosion and capture and store sediment, organic matter and nutrients carried by floodwaters (Benner and Sedell 1997). During periodic inundation of the floodplain water slowly seeps into the soil, recharging shallow alluvial aquifers (Bayley 1995; Junk et al 1989). Water stored in alluvial aquifers and wetlands slowly drains toward the river, sustaining baseflows in off-channel habitats and the mainstem river during periods with little precipitation (Naiman et al. 1992). Without periodic inundation, floodplain streams and off-channel habitats dry up earlier in the season and water temperatures may increase (Gore 1995). Reduced floodplain storage may also lower the growth rate and survival of riparian species, leading to a reduction in riparian corridor width and replacement of historic riparian species with species more tolerant of dryer conditions (Smith 1991).

Methods

Descriptions of the nature and extent of hydromodifications were based on existing data and literature where available. Where data was lacking, a preliminary assessment of hydromodifications was conducted using maps, aerial photographs and GIS analysis. To the extent possible, the following discussion presents quantitative data on the extent and effect of hydromodifications in each sub-watershed. However, some of the information presented is of necessity qualitative or speculative, due to the lack of data on certain types of hydromodifications or in certain sub-watersheds. Methods used to quantify the extent of each type of hydromodification considered in this report are presented below.

CHANNEL TYPE

Channel types in the mainstem Green River were identified based on landform, gradient, confinement and channel planform, using a classification system developed by Paustian et al. (1992). The Paustian channel type criteria were modified to conform with channel segments as defined in the Salmon and Steelhead Habitat Inventory and Assessment Project (SSHIAP) database and Washington State Watershed Analysis Process (NWIFC 1999; WFPB 1997). Table HM-1 lists maps, photos and GIS layers used to stratify channel types and conduct the preliminary assessments.

Current channel types in the mainstem Green River were delineated by measuring gradient and confinement on USGS 1:24,000 scale topographic maps, and refined through review of air photos and watershed analyses channel segment maps, based on the criteria presented in Table HM-2. Information used to delineate general channel types miles (e.g. gradient, confinement, average width, dominate substrate) was evaluated at the reach scale over a distance of miles to tens of miles, and thus does not reflect small-scale variations within any given segment. Channel types delineated at the basin scale may therefore include one or more channel types delineated using the SSHIAP method or defined in existing watershed analyses. For historic conditions, channel type was surmised using vegetation and land survey maps, soils information, and descriptions of the valley by early settlers and surveyors. Table HM-2 provides a brief description of common channel types in the Puget Sound Region, and their importance to various salmonid species and life stages.

The length of each channel type under historical (date of earliest map or photo set) and current (data of most recent map or photo set) conditions was estimated to the nearest tenth of a mile. For the purposes of this analysis, River Mile (RM) 0.0 is located 0.75 miles upstream of the entrance of the west waterway, after Williams (1975). The historical channel length in the Green/Duwamish Estuary, Lower Green, and Middle Green sub-watersheds was estimated using a composite GIS layer of the former channel pattern constructed from data digitized by the USACE (1998) and King County (Perkins 1993). RM 0.0 of the historical channel type corresponds with the mean low water line as mapped by Bortelson et al. (1980)

BANK ARMORING

King County and the EPA each maintain GIS data layers depicting publicly funded levees along the mainstem Green River. The GIS data were used to estimate the length of bank bounded by levees or revetments in each sub-watershed. In addition, the Green River has been constrained in numerous places by roads and railroads throughout WRIA 9. The length of channel affected by transportation corridors was estimated using GIS; roads or railroads that ran parallel to the river and were located within 100 feet of the channel were assumed to have resulted in substantial alteration of channel banks through placement of rip-rap or rock ballast to protect the transportation corridor from erosion during high flows. The percentage of a given reach influenced by levees is based on the channel length rather than the total length of bank affected by levees. The distribution of levees (i.e. on both banks or one bank) is described qualitatively. From RM 11 downstream and around Elliott Bay, shoreline types were documented and mapped by field survey teams during low tides in spring and early summer 1999.

GRAVEL BARS

Reports containing data on the frequency and extent of gravel bars in the mainstem Green River covered only parts of the Upper and Middle Green sub-watersheds (O’Connor 1997; Cupp and Metzler 1996; Fuerstenberg 1996). The historic and current extent of gravel bars in the remaining segments of the mainstem was estimated using historic maps that depicted sand and gravel bars (USACE 1907), or aerial photographs taken during low flow conditions (Table HM-1). The resolution of the available photos varied widely, and information collected for sections of the river where the best available photo scale was 1:12,000 or larger are assumed to represent conservative estimates of in channel sediment storage. Gravel bars were identified as features located within the active channel that had mostly exposed mineral surfaces or that supported only annual vegetation. Only mid-channel and point bars were counted for this assessment; linear stream margins exposed at low flow were not considered gravel bars. Bar surface areas were measured from the photographs using a planimeter.

LARGE WOODY DEBRIS (LWD)

Reports containing information on historic or current LWD were available for parts of the mainstem Green River including RM 77 through RM 93 (Fox 1996; Fox and Watson 1997); RM 34 through RM 47 (Fuerstenberg 1996; King County 1999); RM 5 through RM 11 (Pentec 1999); and for RM 0 to RM 1.4 of Newaukum Creek (Boehm 1999; Malcom 1999). Additional data on LWD in the mainstem Green River was obtained by counting pieces visible on two photo sets obtained from the USACE that covered RM 50 to RM 70 and RM 57 to RM 64.5 (Table HM-1). Large woody debris could not be consistently identified on photographs with a scale of 1:12,000 or larger, thus the preliminary assessment did not cover all channel segments where data was lacking.

OFF-CHANNEL HABITATS

Off-channel habitats associated with the mainstem Green River were assessed using a combination of maps depicting the channel planform (USACE 1907; Perkins 1993; Smith and Associates 1994) and small-scale aerial photographs (Table HM-1). For consistency, only off-channel habitats that had a watercourse depicted on a planform map or that was clearly visible on aerial photos (as water or exposed mineral substrate) were counted for this analysis. The length of each off-channel habitat identified was measured to the nearest tenth of an inch using a map wheel. Very small or older off-channel habitats often cannot be clearly delineated except by field surveys, thus original analysis conducted for this report represent a conservative estimate of the amount of off-channel habitat in the Green River system.

Several reports (Fox 1996; Fox and Watson 1997; Wunderlich and Toal 1992; USACE 1998; Fuerstenberg 1996) present the results of detailed field surveys that identified side channel habitats in the Green River. The results of those surveys were used to supplement original analyses conducted for this report or to describe the current availability of off-channel habitat in areas where maps and photographs of a scale suitable for identification of off-channel habitats were not available.

Off-channel habitats identified for this report were classified as one of four types using a modified version of classification system developed by Peterson and Reid (1984) (Figure HM-1). Secondary channels generally transmit a substantial portion of the mainstem flow and often remain wetted even at the lowest flows. Secondary channels are separated from the mainstem by islands or well-developed mid-channel bars, and are most common in Floodplain channel types. Secondary channels provide shallow, low velocity habitat with varying degrees of cover during low flows, but may be deep and swift during high flows. In addition, Secondary channels are often sites where gravels and cobbles of a size suitable for spawning deposit and generally remain stable (Ligon 1995).

Overflow channels are channels located on the top of point bars. These channels are frequently wetted during moderately high flows (recurrence interval less than one year), and generally do not support perennial vegetation. Multiple overflow channels may form across the top of a point bar as a result of lateral accretion of sediment during high flow events. Although salmon may spawn in overflow channels (Cocolli 1996), these channels frequently become dry between high flow events, desiccating redds and potentially trapping or stranding juvenile salmonids that have sought refuge there.

Wall-base channels are groundwater-fed side-channels typically found at the base of a steep sideslope. Wall-base channels may form as seepage that emerges from the base of the slope converges and flows toward the mainstem or they may represent former river channels that have been abandoned. Wall-base channels typically occupy higher portions of the floodplain or terrace outside the influence of active channel processes (Peterson and Reid 1984). Wall-base channels provide relatively stable flows, a moderated temperature regime and in some cases a complex of channel and ponded habitats. Wall-base channels are known to provide particularly stable rearing environments preferred by some species of salmonids such as coho (Lister and Finnegan 1997; Cederholm and Scarlett 1982).

Meander channels are typically formed when a channel avulsion causes the river to move from its former route. Avulsion may be caused by accumulations of LWD that block the former channel, by meander cutoffs, or by gradual erosion into sloughs or oxbows that have a lower elevation than the existing channel. Recently abandoned meander channels generally have sand or gravel beds and little cover. Over time, wetland or terrestrial riparian vegetation communities become established in meander channels, and the side-channels become sloughs. Meander channels may be fed by ground water, overflow of surface water from the mainstem, or both (USACE 1998). The habitat offered by meander channels varies with their age and connectivity to the mainstem.

Floodplain connectivity Although a thorough analysis of the historic and current extent of the area inundated by floods of various return intervals was beyond the scope of this analysis, changes in floodplain function and connectivity are described qualitatively based on the presence of flood control structures and changes in landuse.

RESULTS

UPPER GREEN RIVER SUB-WATERSHED (RM 64.5 TO RM 93)

CHANNEL TYPE

The upper Green River is comprised of three channel types (Figure HM-2). The upper five miles (RM 88 to RM 93) are a High Gradient Contained channel. Historically, the entire lower 23.5 miles of the mainstem (RM 64.5 to RM 88) were a Floodplain channel type. Since construction of Howard Hanson Dam, the lower 4.5 miles of the former Floodplain channel (RM 64.5 to RM 69) are seasonally inundated and periodically transformed into lacustrine habitat.

High Gradient Contained Channel Segment (RM 88 to RM 93)

High gradient contained channel types in the Upper Green River sub-watershed frequently contain bedrock falls and cascades, thus these channels usually coincide with the upstream extent of anadromous fish use (Fox and Watson 1997). Several reports have identified barriers to anadromous fish in this portion of the mainstem Green River (Williams et al. 1975; USACE 1997). However, because fish passage upstream of RM 61 has been precluded since 1913, it is currently unclear whether the identified features are impassable to anadromous fish (see Chapter 2.5). No persistent disturbances to channel segments corresponding with the High Gradient Contained segment of the upper mainstem Green River were identified in the draft Upper Green/Sunday Watershed Analysis (O'Connor 1997), and the length does not appear to have changed since 1944 (Table HM-3). However, habitat within this channel segment is believed to have been impacted by streamside harvest and sediment delivery by debris torrents originating in tributary streams (Fox and Watson 1997).

Floodplain Channel Segment (RM 69 to RM 88)

Between RM 88 and the confluence with Sunday Creek at RM 84, the valley widens and the gradient of the mainstem Green River decreases to less than 2 percent and develops a meandering planform, becoming a Floodplain channel type. This channel segment contains occasional confined reaches (O'Connor 1997). There is no evidence that the total length of this channel segment has changed substantially as compared to historic conditions. However, significant channel migration has occurred as a result of floods and increased delivery of coarse sediment (O'Connor 1997). The dominant channel morphology is currently plane-bed or braided (O'Connor 1997) rather than the pool-riffle morphology typical of undisturbed Floodplain channels.

The Floodplain channel segment continues downstream of the confluence with Sunday Creek. Historic air photos indicate that the entire mainstem from RM 64.5 to RM 84 was best characterized as a Floodplain channel type, although it includes a number of short reaches of Large Contained channel (Cupp and Metzler 1996). The lower 4.5 miles of this Floodplain channel are now periodically inundated by operation of Howard Hanson Dam, which transforms them into lacustrine habitat when the reservoir is filled. Thus, the total length of Floodplain channel type in the Upper Green River sub-watershed has decreased by about 4.5 miles since 1964 (Table HM-3).

Historically, the Floodplain channel segment in the Upper Green River sub-watershed had "a good pool-riffle balance for this size stream, offering a number of very large, deep pools and long, slow-moving glides. The bottom appears to be quite stable, consisting mainly of clear rubble and gravel material" (Williams et al. 1975). The channel width and extent of gravel bars downstream of the confluence with Sunday Creek and at the junctions of tributaries that experienced debris torrents were observed to change frequently between 1958 and 1992 in response to floods and large storm events (Cupp and Metzler 1996). In 1977, the river shifted north between RM 83 and RM 84, eroding a landing strip located adjacent to the north bank

(Cupp and Metzler 1996). As a result of the increased coarse sediment supply and active channel migration, portions of the Floodplain channel segment upstream of Howard Hanson Reservoir currently lack adequate spawning gravel or experience scour to a depth sufficient to cause redd mortality (Fox 1996). Pools and LWD are generally scarce (Fox 1996; Wunderlich and Toal 1992).

Seasonally Inundated Channel Segment (RM 64.5 to RM 69)

Seasonally inundated habitats are characterized by lake-like habitat conditions when water is stored behind Howard Hanson Dam. Seasonally inundated habitats also differ from historic conditions when the reservoir is drawn down. The dominant effects of seasonal inundation on riverine habitats exposed at low flow have been substantial reductions in vegetative cover, bank stability, pool frequency and quality, and an increase in the amount of fines in riffles (Wunderlich and Toal 1992).

BANK ARMORING

High Gradient Contained Channel Segment (RM 88 – RM 93)

No stream adjacent roads, levees or revetments currently influence habitat in the High Gradient Contained channel segment between RM 88 and RM 93 (Figure HM-3A).

Floodplain Channel Segment (RM 69 to 88)

There are no publicly funded flood control levees or revetments upstream of Howard Hanson Reservoir. However, road and railroad right-of-ways tended to follow the valley bottom along the mainstem Green River and major tributaries, and often resulted in the channel being constrained on at least one side by rip-rap installed to protect transportation corridors from erosion (Figure HM-3A). Under current conditions, bank modifications associated with road or railroad lines affect approximately 20 percent of the channel (about 5 miles) between RM 69 and RM 93 (Table HM-4). Hardened banks generally affect only one bank in this channel segment (Figure HM-4).

The winter floods of 1995-1996 eroded approximately 2,200 feet of river bank adjacent to the Burlington Northern rail line along the Green River between about RM 72 and RM 82. Bank armoring and bank protection measures were implemented where necessary to protect the railline from future erosion. Approximately 1,000 feet of mainstem channel was relocated into an abandoned channel. Fish habitat restoration measures including placement of LWD and riparian tree planting were included in the work (Hadley 2000).

Seasonally Inundated Channel Segment (RM 64.5 to RM 69)

The earliest air photos of the Upper Green River sub-watershed examined for this analysis, taken in 1953, indicate that at that time approximately 1.1 miles of the 4.5 miles of mainstem river between RM 64.5 and RM 69 had artificially armored banks protecting stream adjacent roads or railroads on at least one bank. This segment of the river is now seasonally inundated by Howard Hanson Reservoir, and the banks when exposed are typically composed of easily eroded sand and silt deposited in the impoundment at full pool. It is unknown whether rip-rap installed to protect the former road and railroad right-of-ways influences channel margins in this channel segment when Howard Hanson Reservoir is drawn down.

ACTIVE GRAVEL BARS

High Gradient Contained Channel Segment (RM 88 to RM 93)

Dense riparian vegetation precluded an evaluation of the historic extent of gravel bars in the High Gradient Contained channel segment. However, extensive bars do not typically develop in this high-energy channel type. Recent surveys of several reaches in this channel segment conducted in support of watershed analysis described gravel bar development as "few and forced", indicating that deposition of otherwise mobile sediments occurs only in the vicinity of stable obstructions (O'Connor 1997).

Floodplain Channel Segment (RM 69 to RM 88)

Watershed Analyses conducted in the Upper Green River sub-watershed describe "abundant medial (complex bars occupying the center of the channel) and forced gravel bars in the upper Green River (Cupp and Metzler 1996). Seventy percent of the alluvial mainstem channel segment surveyed for the Lester Watershed Analysis was occupied by gravel bars (O'Connor 1997); however, the survey reach covered only about 2 miles of the mainstem Green River upstream of HHD, and may not be representative of the entire channel segment. The width and extent of gravel bars has reportedly changed frequently since 1958, in response to debris torrents delivered from tributary streams, and portions of the mainstem are currently described as braided (O'Connor 1996). Spawning habitat is limited due to the coarse nature of the deposited sediment (Fox 1996). Sediment stored in braided channel segments is frequently unstable during peak flows, and scour to a depth capable of destroying redds has been observed in this portion of the channel (Fox 1996; Fox and Watson 1997).

Seasonally Inundated Channel Segment (RM 64.5 to RM 69)

Prior to construction of Howard Hanson Dam, gravel bars were common in the seasonally inundated channel segment; however the total extent of bars was not measured for this assessment. No information is available on the current extent of gravel bars in this channel segment.

LARGE WOODY DEBRIS

High Gradient Contained Channel Segment (RM 88 to 93)

Little data is available on historic LWD frequency in the upper Green River Watershed; however, LWD is presumed to have been more abundant in channels prior to human disturbance.

Upstream of RM 88, the channel width declines to less than 20 meters (Fox and Watson 1997), thus LWD criteria developed for the DNR Watershed Analysis process are the most appropriate means of evaluating LWD conditions (Table HM 5). Wood counts conducted in two reaches covering a total of approximately 660 feet found LWD loadings of 100 and 133 pieces per mile (1.2 to 1.8 pieces per channel width) (Table HM-5) (Fox and Watson 1997). Based on these samples, LWD is currently abundant enough to result in a “fair” habitat condition rating (equivalent to 1-2 pieces per channel width according to WFPB 1997) for the High Gradient Contained channel segment. However, only one of the pieces inventoried was large enough to qualify as a key piece, defined as a log or rootwads with a volume sufficient to ensure it remains independently stable within the channel (NWIFC 1999). Key pieces are important for sediment storage in small steep channels, or as the initiation site for log-jams in larger unconfined channels (Abbe and Montgomery 1996).

Floodplain Channel Segment (RM 69 to RM 88)

Recent surveys of selected portions of the Floodplain channel segment indicate that LWD is generally small, and is scarce in some reaches (Table HM-5). In 1991, only eight pieces of LWD were noted in a survey of 1.26 miles of the mainstem Green River between approximately RM 69 and RM 70.25 (Wunderlich and Toal 1992). Surveys conducted for the Lester and Upper Green/Sunday Watershed Analyses found an average of 284 pieces per mile (4.5 pieces/CW) in eight reaches of the Floodplain segment between RM 77 and RM 88 (Fox 1996; Fox and Watson 1997). Wood loadings in the surveyed reaches varied from 0 to as high as 2,850 pieces per mile in a single reach that contained a large log jam. However, the minimum size of LWD counted for watershed analysis (4 inches diameter by 7 feet in length) is too small to influence habitat in a channel the size of the mainstem Green River. Large Woody Debris frequencies applied in watershed analysis are applicable only to channels less than 20 meters wide (WFPB 1997), thus the frequency of key pieces or LWD criteria presented by NMFS (1999) are deemed more appropriate the mainstem Green River. Only one of the almost 400 pieces of LWD identified was large enough to qualify as a key piece in a channel as large as the mainstem Green River, and the relatively high LWD frequencies did not necessarily correlate with “good” pool frequency ratings, suggesting that much of the in-channel LWD was not functioning to form pools as would be expected under undisturbed conditions (Fox and Watson 1997).

Seasonally Inundated Channel Segment (RM 64.5 to RM 69)

Large woody debris visible in the channel on the 1953 USACE aerial photographs was counted to develop an estimate of the pre-HHD wood loading and transport capability. It is important to note that hydromodification and harvest of streamside timber had influenced the majority of this reach by 1953, thus the estimated historic LWD loading is not representative of undisturbed habitat condition.

Only the largest pieces of LWD can be positively identified through photo interpretation, thus wood counted for this assessment is assumed to meet the minimum size criteria used by NMFS (>24 inches diameter and longer than 50 feet), but probably under-represents qualifying pieces as defined by Watershed Analysis (4 inches in diameter and about 7 feet long) (NMFS 1999; WFPB 1997). In the reach between RM 64.5 and RM 69, a total of 49 individual pieces and three jams composed of 10 or more logs were identified. This translates to a frequency of 19.8 pieces per mile (0.37 pieces per channel width), well below the level required to be rated as properly functioning habitat based on the NMFS (1999) criteria (Table HM-5). At least 13 of the pieces visible on the photos (15%) were more than 90 feet long, and two of these spanned the channel, which had an average width of approximately 100 feet. Eleven of the pieces (12%) had attached rootwads. Most of the wood (79%), including the large pieces, was located along the channel margin or above the low flow channel, suggesting that even very large pieces of LWD are mobile in the mainstem Green River. The remaining 21 percent of the LWD was contributing to summer rearing habitat.

Wood transported downstream from the Floodplain channel segment is currently stranded above the low flow channel as the pool level declines following a flood event, or collects behind Howard Hanson Dam, and is periodically removed from the reservoir and disposed of. Approximately 100 to 150 tons of wood are collected annually (Olson 1999), although the actual amount of wood collected varies widely since LWD inputs and transport are a function of high flows and are episodic in nature. Wood collected from the reservoir is composed of a mixture large logs and small fragments.

OFF-CHANNEL HABITATS

High Gradient Contained Channel Segment (RM 88 to RM 93)

High Gradient Contained channel types typically do not develop extensive off-channel habitats. Reaches sampled within the High Gradient Contained channel type for the Upper Green/Sunday Watershed Analysis contained no off-channel habitats (Fox and Watson 1996).

Floodplain Channel Segment (RM 69 to RM 88)

Little quantitative data is available describing the current or historic extent of off-channel habitats in the Floodplain channel segment, and aerial photographs with a scale appropriate for the identification of off-channel habitats covered only the downstream-most two miles of this channel segment. Two meander channels with a combined length of almost 3,000 linear feet were identified between RM 69 and RM 71 on the 1953 aerial photo coverage (Figure HM-4). Two secondary channels with a total length of 1,245 feet were identified upstream of the current inundation pool between RM 69 and 70.2 in 1991 (Wunderlich and Toal 1992); however, this survey counted only secondary channels that were wetted at the time of the survey. No information on the number or location of historic off-channel habitats or quantitative data on existing off-channel habitat was provided in watershed analyses conducted to date in the upper Green River basin. However, current off-channel habitats were described as “common”, and were described as providing the majority of winter rearing habitat based on surveys of portions of the Floodplain channel type between RM 77 and RM 88 (Fox 1996; Fox and Watson 1997).

Seasonally Inundated Channel Segment (RM 64.5 to RM 69)

Approximately 10,000 linear feet of off-channel habitats were identified on the 1953 photos between RM 64.5 and RM 69 (Figure HM-4; Table HM-6). Four of the nine off-channel habitats identified were meander channels, three were secondary channels, and one was an overflow channel that remained wetted at low flow. No wetted side channels were identified between RM 67.8 and RM 69 in surveys conducted by the USFWS in 1991 (Wunderlich and Toal 1992). Seasonal inundation by Howard Hanson Reservoir is believed to have obliterated former off-channel habitats or severely reduced their value as salmonid habitat.

FLOODPLAIN CONNECTIVITY

High Gradient Contained Channel Segment (RM 88 to RM 93)

High gradient contained segments typically do not have floodplains.

Floodplain Channel Segment (RM 69 to 88)

Construction of roads, railroads, residences and other structures within the floodplain of the Upper Green River has disconnected off-channel habitats and reduced the area of the floodplain. However, no information is available on the current or former extent of the floodplain. Changes in the hydrologic regime of the Upper Green River sub-watershed have been minimal compared to other WRIA 9 sub-watersheds (Chapter 2.1) and the primary land-use is commercial forestry, thus changes in floodplain connectivity and function are not believed to have been as pronounced as in other Floodplain segments of the mainstem Green River. Timber harvest and transportation corridors have affected riparian communities in the upper watershed, and these effects are discussed later in the chapter.

Seasonally Inundated Channel Segment (RM 64.5 to RM 69)

Seasonal inundation has profoundly modified the former floodplain in this channel segment. Floodplain surfaces that formerly supported coniferous forest vegetation communities are now barren when exposed, or support only limited communities of annual forbs or inundation tolerant vegetation. The floodplain is typically inundated during the main growing season, and has been buried by deposits of fine sediment.

MIDDLE GREEN RIVER SUB-WATERSHED (RM 32 TO RM 64.5)

CHANNEL TYPE

Channel morphology in the Middle Green sub-watershed is variable, alternating between Floodplain channel types and Large Contained channel types (Figure HM-2). Four distinct channel segments were identified: 1) a Large Contained channel segment just downstream of Howard Hanson Dam (RM 61 – RM 64.5); 2) a three-mile stretch of Floodplain channel type near Palmer (RM 58 to RM 61); 3) the Green River gorge (RM 45 – RM 58), classified as a Large Contained channel type; and 4) a second Floodplain channel type, the Middle Green River between Flaming Geyser Park and the city of Auburn (RM 31 to RM 45).

Large Contained Channel Segment (RM 61 to RM 64.5)

The reach between Tacoma's Headworks and HHD is a Large Contained channel type, confined between steep hillslopes. In places the channel is further constrained by transportation corridors that are directly adjacent to the river. Aerial photographs examined for this analysis provided no evidence that the channel type or length of this segment changed since at least 1953.
Floodplain Channel Segment (RM 58 to 61)(H4)

Downstream of Tacoma's Headworks the valley width increases to about 1,000 feet for a distance of three miles, and the channel changes to a Floodplain channel type. Remnant side channels visible of the 1953 aerial photographs provide evidence that this channel segment historically had a more sinuous planform (and thus a lower gradient) than currently exists. Assuming that these former meanders represent the historic channel planform, this channel segment would have been approximately 3.5 miles long, compared to its current length of 3.0 miles (Table HM-3). The reduction in channel length corresponds to an overall loss of aquatic habitat and an increased gradient. In combination with the reduced sediment supply resulting from construction of HHD, these changes are hypothesized to have resulted in a coarsening of the bed and a loss of in-channel sediment storage (Perkins 1999).

Green River Gorge (RM 45 to RM 58)

The Green River gorge begins at approximately RM 58 and extends downstream for about 13 miles, to RM 45. This reach is classified as a Large Contained channel type. The gorge reach is confined between bedrock walls and does not appear to have been directly impacted by development or timber harvest along the river margins. Air photos from 1944 and 1995 examined for this analysis revealed no changes in channel type or length.

Floodplain Channel Segment (RM 32 to RM 45)

Downstream of RM 45, the Green River enters a wide alluvial valley incised through glacial outwash deposits. The channel planform becomes sinuous, and gravel bars and off-channel habitats are common. This section of the river is classified as a Floodplain channel type. While illustrating that the channel planform in this segment has varied considerable over the past 100 years, Perkins (1993) indicated that the overall mainstem length between RM 31 and 45 changed by less than 5 percent between 1906 and 1992; the change actually amounted to an increase of 0.5 miles (Figure HM-5; Table HM3). However, the amount of associated off-channel habitat and complexity of the channel has been greatly reduced since early this century. Extensive gravel bars and a braided morphology formerly characterized an estimated 10.4 miles of this reach in 1892 (Fuerstenberg et al. 1996). In 1994, less than 4 miles of this reach were braided, the length of associated off-channel habitat had decreased substantially and the average channel width between RM 35 and RM 39 had declined by approximately 29 percent (from 277 feet to 195) (Fuerstenberg et al. 1996).

BANK ARMORING

Large Contained Channel Segment (RM 61 to 64.5)

In this segment, the channel is naturally confined between steep hillslopes, thus no levees or revetments have been constructed for flood control purposes. However, the BNSF Railroad and the gravel road to Howard Hanson Dam both parallel the river throughout this reach, and are believed to have altered the natural streambanks through removal of vegetation and placement of rip-rap along approximately 45 percent (1.6 miles) of the channel (Table HM-4). Bank hardening generally affects only one bank of the river in this channel segment.

Floodplain Channel Segment (RM 58 to 61)

No publicly funded levees or revetments have been constructed for flood control purposes in this channel. The BNSF Railroad and the Tacoma Headworks road both run roughly parallel to the river throughout this reach, but impinge upon the channel in only a few locations (Figure HM-3B).

Green River Gorge (RM 45 to 58)

Throughout the Green River gorge, the channel is naturally constrained between steep bedrock walls. There are no roads directly adjacent to the river in this channel segment (Figure HM-3B) and no flood control structures are known to have been constructed in the Green River gorge.

Floodplain Segment (RM 32 to RM 45)

Much of the lower Floodplain segment in the Middle Green River currently has levees or revetments on one or both banks. Armored banks are most common at the downstream end of the Floodplain segment (Figure HM-3B). According to Perkins (1993), 60 percent of the channel between RM 33.8 and RM 37.8 was constrained by levees in 1992; however, less than 30 percent of the banks between RM 37.8 and RM 45 were armored. Overall, approximately 40 percent of this reach has been influenced by bank armoring (Table HM-4). In most cases, levees in the Floodplain segment of the Middle Green River constrain only one side of the river (Figure HM-3B), although in some instances the other side of the river is constrained by steep valley sideslopes.

In recent years, several projects that include setting back or removing levees have been initiated. Large, coniferous logs with rootwads, large woody debris, and riparian revegetation have been incorporated into virtually all levee and revetment repairs on the Green River since 1990 to improve habitat quality. Information gathered on salmonid utilization at one of these sites demonstrates a significant increase in utilization by juvenile and adult salmonids (Peters et al. 1998).

GRAVEL BARS

Large Contained Channel Segment (RM 61-64.5)

The extent of gravel bars in the Large Contained channel segment between RM 61 and 64.5 was assessed using aerial photographs from 1953 and 1987. Sediment stored in in-channel bars large enough to be seen on aerial photos would not be expected in this channel type under natural conditions. No gravel bars were identified within this channel segment on either photo set.

Floodplain Channel Segment (RM 58 – 61)

The extent of gravel bars in the Large Contained channel segment between RM 58 and RM 61 was assessed using aerial photographs from 1953 and 1987. Approximately 7 acres of gravel bars were identified on the 1953 aerial photographs. Three of the four bars present at that time supported some perennial vegetation; however, in no case was more than 50 percent of the bar surface vegetated. By 1987, all of the gravel bars in this channel segment were classified as islands, supporting continuous stands of mature alders. The overall area represented by these islands had increased to 10 acres, largely as the result of the coalescing and stabilization of two formerly active bars near RM 58.5

Green River Gorge (RM 45 – 58)

Gravel bars in the Large Contained channel segment known as the Green River gorge were assessed using aerial photographs from 1944 and 1995. Sediment stored in in-channel bars large enough to be seen on aerial photos would not be expected in this channel type under natural conditions (the scale of the available photos covering the entire gorge segment essentially prevents identification of deposits smaller than about 10,000 ft^2).

No gravel bars were identified within this channel segment on either the 1944 or 1995 photo sets. The 1953 and 1987 photo sets also covered portions of the upstream end of the gorge. Four small gravel bars totaling approximately 3 acres were identified between RM 56 and RM 58 on the 1953 photo set. These bars were still present, but supported continuous perennial vegetation in 1987. The loss of active gravel bar surface is therefore hypothesized to have been influenced more by the reduction in flood flows than by the interruption of the sediment supply caused by construction of Howard Hanson Dam. Although the 1953 photo coverage extended downstream to approximately RM 50, no additional gravel bars were identified, thus in-channel sediment storage within the gorge is believed to have been limited both historically and currently as compared to Floodplain channel types located up and downstream. However, changes in sediment storage are likely to have occurred at the scale of individual habitat units due to the absence of flows greater than 12,000 cfs at Auburn and the reduced supply of sediment and wood from upstream reaches.

Floodplain Channel Segment (RM 32 to 45)

The area of active gravel bars in the Middle Green River system has decreased compared to historic conditions. Fuerstenberg et al. (1996) mapped the change in active gravel bars from 1936 to 1995 in this segment. In 1936, the Floodplain segment of the Middle Green River contained approximately 236 acres of gravel bars; in 1995, the area occupied by gravel bars had decreased to 78 acres, a reduction of almost 70 percent (Fuerstenberg et al. 1996). The lack of floods greater than 12,000 cfs appears to have allowed vegetation to encroach on formerly active bar surfaces. The loss of active gravel bar surfaces may be exacerbated by the reduction in sediment supplied from the Upper Green River sub-watershed, a process that is believed to be contributing to the starvation of in-channel storage areas in the Floodplain reach (Fuerstenberg et al. 1996).

Alluvial rivers may develop a braided morphology in response to large inputs of sediment (Leopold et al. 1964). Braided sections are commonly highly unstable, with the channel location shifting on an annual basis (Knighton 1984). The extensive scour and deposition characteristic of braided reaches may destroy salmonid redds, and prevents the development of new riparian stands that stabilize bars and create rearing habitat for juvenile fish. Portions of the middle Green River Floodplain channel segment have periodically exhibited a braided appearance; braiding was most pronounced in the 1950’s and early 1960s following a period of several large floods (Perkins 1993). These areas subsequently became less braided and developed a predominantly single thread channel after flood control by Howard Hanson Dam began in 1962. The total length of braided channel within the middle Green channel segment has generally declined, from approximately 10 miles in 1892 to around 4 miles in 1992 (Fuerstenberg et al. 1996).

LARGE WOODY DEBRIS

Large Contained Channel Segment (RM 61 to 64.5)

No quantitative field data on LWD in this channel segment was located. No LWD was identified within this channel segment on the 1953 or 1987 aerial photographs.

Floodplain Channel Segment (RM 58 to RM 61)

No quantitative field data on LWD in this channel segment was located. No LWD was identified within this channel segment on the 1953 or 1987 aerial photographs.

Green River Gorge (RM 45 to RM 58)

No information on either the current or historic LWD loading was located for the Green River gorge channel segment. No LWD was observed between RM 50 and RM 58 on the 1953 aerial photographs. Since1964, the lack of recruitment from upstream, high stream power, and removal of logs by private individuals concerned about boater safety in the gorge segment are believed to have combined to keep LWD low in this channel segment.

Floodplain Segment (RM 32 to RM 45)

Although there is no quantitative data on historic LWD loading in the Green River prior to Euroamerican settlement, studies of similar large alluvial rivers suggest that LWD and jams were formerly abundant in low gradient Floodplain channels (Sedell and Froggatt 1984; Beechie et al 1994). Agriculture, rural residential development and flood control measures have all contributed to the reduction in recruitment of LWD between RM 45 and RM 31, and will be described in further detail later in the chapter. Interruption of the downstream transport of LWD past HHD has also reduced inputs of LWD to the middle and lower Green River compared to historic levels.

Fuerstenberg et al. (1996) tallied large pieces of LWD visible on 1994 air photos, and identified a total of 376 pieces of wood between RM 34 and RM 45 (Table HM-5). An additional 80 pieces of LWD were placed in the Floodplain segment on the Middle Green River in 1996 as part of the Hamakami levee restoration project (King County 1999). Because the inventory focused on only the largest pieces of wood, and restoration projects typically utilize large logs or rootwads, these data are believed to represent pieces that are roughly comparable to the NMFS minimum size criteria. However, even recent LWD placement has not sufficiently increased the LWD loading in this segment. The current LWD frequency between RM 34 and RM 45 is approximately 27 pieces/mile as compared to the 80 pieces/mile required to be considered “properly functioning” according to NMFS (Table HM-5). Fuerstenberg et al. (1996) identified fewer than 35 pools in the entire Floodplain channel segment (equivalent to a pool frequency of approximately 0.12 pools per channel width. While there are currently no criteria identifying appropriate pool frequencies in large rivers, the lack of LWD and scarcity of pools in a channel type known to be responsive to LWD suggests that the lack of pools may be related to the scarcity of LWD.

OFF-CHANNEL HABITATS

Large Contained Channel Segment (RM 61 to 64.5)

Off-channel habitats in the Large Contained channel segment between RM 61 and 64.5 were assessed using aerial photographs from 1953 and 1987. No off-channel habitats were observed in this channel segment on either the 1953 or 1987 aerial photographs.

Floodplain Channel Segment (RM 58 to 61)

Approximately 12,340 linear feet of off-channel habitats were visible on the 1953 aerial photos in this channel segment (Figure HM-6; Table HM-6). Approximately 75 percent of off-channel habitat identified consisted of two large meander bends. A former meander on the south side of the valley near RM 59 (Signani Slough) was separated from the river by construction of the Tacoma Headworks Road and Burlington Northern Railroad, presumably around 1911. Salmonids apparently were still able to access Signani Slough in 1953. Signani Slough was filled, channelized and disconnected by the USACE during construction of Howard Hanson dam and re-alignment of the Burlington Northern Railroad Line in 1960 and 1961 (USACE 1998). During construction in 1960-61, over 1,000 adult salmon were trapped in the channel (L. Signani, USACE pers. comm., cited in USACE 1998). Another large meander on the north side of the valley at RM 58 (Brunner Slough) appears to have been abandoned when the channel was originally straightened to cut off Signani Slough. The downstream end of Brunner Slough was still connected to the river at low flow in 1953, and an inlet channel that transmitted flow during floods was present at the upstream end.

By 1987, the amount of off-channel habitat in this channel segment had been reduced by 75 percent, to a total of approximately 3,340 linear feet (Table HM-6). Most of the remaining off-channel habitat in this channel segment consists of short secondary channels (Figure HM 7). Signani Slough still contains wetland and pond habitat that was visible on the 1987 photographs. Brunner Slough is believed to have been isolated from the mainstem because of the reduction in peak flows, and possibly channel incision due to decreased sediment supply. (USACE 1998). No inlet was observed during field surveys of this channel segment in 1996 (Madsen unpublished data), although the outlet reportedly becomes connected at moderate to high flows (Nelson 2000). There are currently plans to reconnect both of these former meanders as part of mitigation and restoration activities to be undertaken in conjunction with the USACE's planned Additional Water Storage Project.

Green River Gorge (RM 45 to 58)

Only four off-channel habitats were identified in the Green River gorge segment, representing a total of approximately 1,850 feet of off-channel habitat. One large secondary channel approximately 800 feet long is located near RM 49.5 and was observed on both the 1944 and 1995 aerial photos. Three additional small overflow channels were identified at the upstream end of the gorge, where the river begins to transition into a Floodplain channel type (Figure HM-6). These channels were all secondary channels associated with active gravel bars that could be seen on the 1953 aerial photos. By 1987, the formerly active gravel bars had stabilized and supported dense terrestrial vegetation, thus the overflow channels were virtually impossible to distinguish even on the 1:400 scale photographs from 1987. However, each of these channels was mapped during field surveys conducted in 1996 (USACE 1998), thus they have been included in this data set. The natural confinement of this portion of the river between high bedrock walls effectively prevents formation of large meander or secondary channels in most of this channel segment.

Floodplain Channel Segment (RM 32 to 45)

Off-channel habitats in the Floodplain reaches of the Middle Green River sub-watershed were assessed using maps of historic channel locations constructed by Perkins (1993), air photos from 1992, and recent FEMA floodplain maps (Smith and Associates 1994). Based on the maps contained in Perkins (1993), there were an estimated 93,852 linear feet of off-channel habitats associated with the Floodplain segment of the middle Green River between RM 31 and RM 45 in 1907. This is believed to be a conservative estimate, because small overflow and wall-base channels or older meander channels may not have been depicted on the maps used to create the channel planform maps. By 1994, the amount of available off-channel habitats had dropped to 20,800 linear feet, a reduction of approximately 78 percent. The majority of off-channel habitat lost was meander channels that were disconnected from the mainstem because of levee construction. However, it is also hypothesized that the prevention of flows greater than 12,000 cfs, combined with the reduction in LWD and sediment delivery from upstream reaches could be isolating several formerly active off-channel habitats upstream of RM 40, leaving them perched above current high flow level.

FLOODPLAIN CONNECTIVITY

Large Contained Channel Segment (RM 61 to 64.5)

There is no floodplain associated with the Large Contained channel segment between RM 61 and RM 64.5.

Floodplain Channel Segment (RM 58 to 61)

Based on the previous extent of meanders in this channel segment, construction of the BNSF Railroad and other transportation corridors appears to have reduced the historic meander belt by as much as 50 percent or more in this channel segment. Although no quantitative data is available depicting the pre- and post Howard Hanson Dam floodplains, the reduction in flood flows has also undoubtedly reduced the floodplain area.

Green River Gorge (RM 45 to 58)

There is no floodplain associated with the Large Contained channel segment known as the Green River gorge.

Floodplain Channel Segment (RM 32 to 45)

While no quantitative data are available to assess the impact of such alterations on the Green River, there has been a reduction in the meander belt width, wetland acreage and in the number of active off-channel habitats. Perkins (1993) conducted a study of channel migration hazards associated with the middle Green River, and found that flood control structures have substantially reduced the meander belt width. In the absence of levees and revetments, the meander belt width between RM 31 and RM 45 ranged from 300 to 1,600 feet in width (Perkins 1993). As a result of constraint by levees, revetments, major roads and developments, areas with a high risk of channel migration in the next 100 years currently range from 30 to 560 feet (Perkins 1993). Assuming that the "constrained meander belt width" can be approximated by applying these distance from each bank of the Green River suggests that flood control has reduced the floodplain by an average of 66 percent since the early 1900s. Such changes are believed to have reduced the channel complexity and floodplain recharge, detrimentally impact salmonid habitat.

LOWER GREEN RIVER SUB-WATERSHED (RM 11 TO RM 32)

CHANNEL TYPE

Prior to the diversion of the White River, the Green River downstream of RM 32 was characterized by two channel types (Table HM-3). Sand and gravel bars were common in the reach between RM 25 and RM 32 (USACE 1907), and the channel was classified a Floodplain channel type based on gradient, confinement, substrate and planform, with morphology and habitat conditions similar to those described for the Floodplain segments of the Middle Green River. The lack of detailed topographic maps and photos depicting channel conditions preclude an accurate identification of the exact downstream extent of the Floodplain channel type; however, the 1907 USACE maps suggest the substrate became finer and bars became less common at a location corresponding approximately to existing RM 25, thus that is the reach break utilized for this analysis.

Between RM 11 and 25, the river is believed to have formerly been a Palustrine channel type, based on gradient, confinement, and descriptions of the valley bottom and soils (Dunne and Dietrich 1978; Mullineaux 1970; Pence 1946). Historically, this reach was gently sinuous, slowly migrating across a swampy floodplain (Dunne and Dietrich 1978). By 1907, levees were already present along much of the lower portion of this segment Palustrine channels generally have organic or fine-grained substrate, lack gravel bars, and are associated with extensive off-channel wetland areas (Paustain et al 1992).

By 1994, virtually the entire Palustrine channel segment and most of the former Floodplain segment had been channelized (Perkins 1993). Today, the entire mainstem Green River in the Lower Green River sub-watershed is classified as a channelized river (Figure HM-2). The total length of mainstem channel in this segment has not changed substantially since 1906 (Table HM-3; Figure HM-5).

BANK ARMORING

Levees and revetments are common in the channelized segment between RM 11 and RM 31. Perkins (1993) indicated that levees and revetments were present along 82 percent of the channel between RM 25.3 and RM 31.7 (Figure HM-3C). Virtually all of the former Palustrine channel between RM 11 and RM 25 is currently confined between levees and/or revetments (Fuerstenberg et al 1996). In the Lower Green River sub-watershed, levees typically line both banks of the river (Figure HM-3C).

LARGE WOODY DEBRIS

There are no data on either historic or existing LWD loading in the mainstem Green River within the Lower Green River sub-watershed.

ACTIVE GRAVEL BARS

The change in active gravel bars in the Lower Green River sub-watershed was estimated by comparing the extent of sand and gravel bars depicted on a historic map from 1907 (USACE 1907) to the current extent of active gravel bars visible in the lower Green River on air photos dating from 1995. Approximately 36 acres of active gravel bars were measured between RM 25 and RM 31 on the 1907 USACE map. For the first one half mile downstream of the confluence with the White River (RM 31), deposition of bedload sediments carried by the White River caused the channel to braid, and double in width as compared to the Green River just upstream (Perkins 1993). By 1960, only six of the bars large enough to have been mapped in 1907 remained (Perkins 1993). Extensive levee construction occurred during the 1960s and 1970s, and by 1992, only one bar remained that was large enough to show at the scale of the 1906 map (Perkins 1993). No active bars were detected on 1:12,000 scale aerial photos from 1995. Channelization and the resulting increased sediment transport capacity are the likely cause of the loss of bars in the Floodplain channel segment (Dunne and Dietrich 1978).

No historic maps depicting former sand or gravels bars between RM 11 and RM 25 are available. Due to the nature of the channel type, sand and gravel bars are expected to be less common in this segment (Paustain et al. 1992). No active bars were observed in this segment during the review of the 1995 aerial photographs.

OFF-CHANNEL HABITATS

The amount of historic off-channel habitat in the Lower Green River sub-watershed (RM 11 to RM 25) is unknown, since channelization and flow diversions had already begun to influence these channel segments at the time of the earliest maps. The migration rate of Palustrine channels is generally low, but there are frequently extensive wetlands, sloughs and beaver ponds associated with such channel types (Paustain et al. 1992). These features were not consistently identified on early maps, but early descriptions(Thomas and Thompson 1936) of the upper portions of this reach suggest such features were abundant:

> *"Prior to 1906, the larger portion [of the White River] flowed closely along the north side of the valley for two miles, when it turned sharply to the north. After flowing north for about a mile, during normal runoff it was divided into two or three channels but in flood time it was divided into a multitude of channels. These channels seemed to wander aimlessly over the valley …."*

This portion of the Green River currently supports little or no off-channel habitat (Malcom 1999), with the exception of those associated with small tributary channels.

FLOODPLAIN CONNECTIVITY

The historic extent and duration of flooding was sufficient to maintain an extensive network of valley bottom wetlands along the lower Green River. Early surveys of the Puget Sound Region are quoted as describing "extensive swamps in the valley of the Stuck, the White, and the Duwamish rivers" (Smalley 1990). Early maps showed wetlands and areas marked as "unmerchantable timber" that were most likely forested wetlands (USGS 1894) Prior to flood control activities, the area subjected to overflow between Auburn and the Black River is estimated to have exceeded 16,000 acres (Shapiro and Associates 1990). Natural levees created slight gradients away from the river so that runoff drained toward the outer margins of the valley, then north to the mainstem through a network of small channels. (Pence 1946).

Diversion of the White River, construction of levees and revetments, and operation of HHD have reduced the area subjected to frequent inundation more in the Lower Green River sub-watershed than in any of the other sub-watersheds discussed in this report. Howard Hanson Dam and the levee system provide flood control, but have not fully eliminated backwatering and ponding of water in the lower watershed. Even though peak flood stages have been reduced by dam operation, the prolonged duration of moderately high flows released from reservoir storage together with confinement of these flows by levees actually raised flood stages and related backwater elevations affecting lower valley tributaries for more minor flood events (Levesque 1999).

Following major inundation of the entire eastern portion of the lower Green River valley in 1965, Congress approved Soil Conservation Service (SCS) plans in 1996 to construct 55 miles of drainage channels to alleviate these conditions (Shapiro and Associates 1990). In anticipation of this initiative, the Green River Flood Control Zone District (GRFCZD) was formed in 1960 to sponsor federal implementation of this flood control scheme. In 1972 the GRFCZD sponsored construction of two pump station facilities within the lower Green River by the Soil Conservation Service (SCS) and limited construction of associated channelization projects. While Renton has continued to participate with SCS (renamed Natural Resource Conservation Service in 1997) in these efforts, Kent has pursued its own major modifications to the original plan on its own initiative. The most recent project elements have included construction of the Oaksdale Avenue culvert improvements in Renton and Kent's conversion of former sewage lagoons to a large scale Mill Creek (Kent) flood storage/wetland habitat/open space complex near RM 19.0 on the Green River. Initial SCS planning on the west side of the Green River has been the topic of extensive restudy resulting in the 1998 Mill Creek (Auburn) Flood Management Plan, which has not yet been implemented.

GREEN/DUWAMISH ESTUARY

CHANNEL TYPE

The large unregulated freshwater outflow of the original Duwamish River (before 1906) built and maintained a large, and likely relatively dynamic estuary in the lower Duwamish valley. This delta was constrained between the hills now occupied by Seattle and West Seattle. Based on early maps, the estuary was characterized by a sinuous main channel and several distributaries. These stream meanders would have been constantly changing as is typical of a low gradient river with substantial periodic sediment-laden flood flows. Because of the influence of the glacially fed White River, the lower estuary would have been subject to high sediment and turbidity levels throughout the summer months, and the turbid freshwater plume would have extended well into Elliott Bay, as it now does in Commencement Bay.

Reduced sediment transport and greatly reduced flood flows and low flows resulting from tributary diversions (Chapter 2.1) by themselves would certainly have greatly reduced the extent of estuarine habitats in the estuary over time. However, beginning as early as 1895, tide flats and saltmarshes along the Duwamish River and the Seattle waterfront were being filled with soil cut from hilly areas to the east and with sediments dredged to create protected harbor areas. These and subsequent actions preempted natural channel changes that might have resulted from the altered hydrology and sediment loading. Filling also created thousands of acres of new uplands along the Duwamish River.

Based on historic maps, Blomberg et al. (1988) determined that the Duwamish Estuary historically included at least three meandering distributary channels, with about 440 acres of deeper (MLLW to approximately –15 ft MLLW) channels downstream of the present location of RM 7. In the early 1900s, the natural estuary was greatly modified by the construction of Harbor Island, the East and West Waterways, and the Duwamish shipping channel. Creation of the waterways resulted in replacement of 9.3 miles of meandering river with the 5.3-mile straightened channel that exists today (measured from the southwestern corner of Harbor Island to the upper turning basin) and the filling of about 2 mi^2 of intertidal area (Blomberg et al. 1988).

To provide flood control and to maintain the channel alignment, dikes or levees were constructed through virtually the entire reach from the confluence of the Black River (RM 112) to the mouth, and banks were hardened with riprap in areas subject to erosion. Commercial, industrial, and residential developments occupy created uplands along both shorelines. Construction of the shipping channel and construction of revetments, levees and dikes focused remaining freshwater flow from the Green River into a single deep channel except for a shallow secondary channel around Kellogg Island and the split waterways around Harbor Island. The ship turning basin at RM 5.3 functions as a settling basin capturing sediments from upstream sources. As a result, the Army Corps of Engineers dredges this basin approximately every three (3) years. Below RM 5.3, the Duwamish River is dredged infrequently (every 10 years or more), to depths ranging from approximately -30 ft MLLW in the lower (Georgetown) reach to -12 ft MLLW in the upper (14^{th} Avenue Bridge) reach, to accommodate commercial navigation (METRO 1989, Harper-Owes 1983). Above the upper turning basin at RM 5.3, the river retains some sinuosity but little of the natural structure and dynamics of a meandering stream.

BANK ARMORING AND OVERWATER STRUCTURES

As noted above, nearly 100 percent of the shorelines of the estuary downstream of RM 11 are modified by dikes, levees, or revetments. From RM 11 to the turning basin (RM 5.3), a 1999 field survey determined that 56 percent of both shorelines had visible riprap armoring and another 3 percent of the shoreline had vertical bulkheads occupying some portion of the intertidal zone (Table HM-7). In many areas, this armoring occupied only the upper intertidal and nearly 60 percent of the shorelines included mud or sand banks and shoals at lower intertidal elevations. Thus, nearly the entire reach has mudbanks and/or shallows on one side or the other. (Figure

HM-8). In the last few years, riprap or revetment repairs needed to protect adjacent properties have included provisions to enhance the habitat values provided. These measures have included placement of boles with attached rootwads projecting from the bank and plantings of riparian vegetation (e.g., willows) along the upper bank. A relatively small proportion of the shoreline in this area is covered by overwater structures, primarily highway or railroad bridges.

Below the turning basin, except in areas that have been actively enhanced or restored, the extent of shoreline armoring is significantly greater than that upstream of the basin.

From RM 5.3 at the turning basin north to RM 0.0 at the southwest corner of Harbor Island, about 65.8percent of the shoreline is riprapped with another 5.3 percent having near vertical bulkheads (Table HM-7). As in the upper reach of the estuary, a substantial portion of the shoreline still has middle to lower intertidal areas that are sand or mudflat. Except where deeper berths have been dredged from the shoreline to the navigation channel, these intertidal sand and mudflats are continuous with the shallow subtidal sand and mud shelf adjacent to the navigation channel.

From the mouth of the estuary (RM 0.0) north to Pier 91, fully 90 percent of the shoreline is riprapped or armored with rubble (Table HM-7); 16.2 percent of the shoreline has vertical bulkheads (some of the shoreline has vertical bulkheads in the upper intertidal zone and riprap in the lower zone). Intertidal sand and mud substrata are found over only about 12.3 percent of the shoreline.

Along much of the industrialized Duwamish Waterway (downstream of about RM 3.5) and along the Seattle waterfront, physically altered shoreline habitats were further modified beginning in the late 1800s by construction of finger piers and marginal wharfs.

In the reach from RM 5.3 to RM 0.0 approximately 15.6 percent of the shoreline is occupied by such structures (Table HM-7). About 12.4 percent of the shoreline also has substantial in-water structures such as floating moorages or extensive pilings.

From the mouth of the estuary (RM 0.0) north to Pier 91, 65.8 percent of the shoreline, including much of the riprapped shore has overwater piers and wharfs. About 14.5 percent of the shoreline also has substantial in-water structures such as floating moorages or extensive pilings.

Until relatively recently, the majority of these structures were constructed of treated wooden piles. Creosote- and metal-treated pilings have the potential to release toxic preservatives into adjacent waters, although the vast majority of releases occurs in the first few weeks of exposure to the aquatic environment (e.g., Weis et al. 1991, Wendt et al. 1995, but see also Bestari et al. 1998). The extent of these overwater structures and the number of treated wood pilings in the estuary and Elliott Bay was probably at its peak in the late 1940s through the 1960s and has declined since. Also, recent agency policies have led to reduced use of treated wood pilings in new construction and in maintenance activity along the river and waterfront.

LARGE WOODY DEBRIS

As noted above, the role off LWD in tidal estuaries is poorly studied but widely assumed to include several of the functions provided in upstream areas. In the upper estuary (e.g., RM 11 to around RM 8) where tidal range is only a few feet, LWD is assumed to function as it does in upstream areas. Lower in the estuary, especially below the Northwind Wier (RM 6.4) where the tidal exchange often exceeds 8 to 10 ft, any given piece of LWD is only in the water for a portion of the tidal cycle, and the overall importance of wood is assumed to be less than in upstream areas.

Woody debris is still removed from the shipping channel between RM 5.3 and RM 0.0 but no formal LWD removal program is in effect above RM 5.3. LWD was inventoried in the reach between RM 11 and RM 5.3 as part of the shoreline habitat survey during May 1999 (Figure HM-8). An average of 9.5 pieces per mile was documented. Some locally generated LWD enters the stream in the form of fallen alders or cottonwoods. A significant number of pieces of LWD were counted in association with bank restoration projects and with shoreline armoring repair projects. The majority of LWD was from relatively large trees and was well weathered. It was thus assumed that much of this wood was from historic upstream sources. The relatively low density of LWD in this reach is probably the result of upstream removal efforts over the last century and by loss of riparian forests in this reach and upstream. Channelization focuses flood flows in a single confined channel and likely reduces the retention of LWD in the area.

ACTIVE GRAVEL BARS

Due to the nature of the channel type and the location in the watershed, gravel bars are expected to be rare in this segment even under natural conditions (Paustain et al. 1992) No historic maps former sand or gravels bars are depicted on early USACE maps (USACE 1907) between RM 11 and RM 0. No gravel bars were identified within this channel segment during May 1999 field surveys. Limited areas of shallow sand bars were scattered between RM 11 and RM 6.

OFF-CHANNEL HABITATS

Only limited areas of off-channel habitat remain in the Duwamish Estuary, primarily in the mouths of small tributary streams and in constructed mitigation or restoration sites. The shallow secondary channel behind Kellogg Island (RM 1.5 to RM 1.0) provides effective off-channel habitat especially during low tide. Across the river and downstream of Kellogg Island (RM 0.8), a drainage ditch near Terminal 105 was rerouted and expanded by the Port of Seattle to create a 0.3-acre tidal slough. At the lower end of the channel west of Kellogg Island the Seaboard Lumber site project is under construction using NRDA settlement funds. When complete, this site will include about 3.5 acres of new intertidal habitat that is partially off-channel. Also in the channel behind Kellogg Island, the Port of Seattle excavated a channel into a small, 0.4-acre, off-channel wetland (the Puget Estuary) at Terminal 107. The site has been planted with wetland plants and the surrounding slopes with upland buffer plants. The Port of Seattle is evaluating the potential for daylighting Puget Creek into this estuary to further improve habitat for anadromous fish.

Farther upstream just north of the 1st Avenue South Bridge, an existing slough or ditch was enlarged and graded to improve access to the river. This project, which was constructed as mitigation for impacts of rebuilding the bridge, included restoration of approximately 1 acre of new aquatic habitat bordered by a large riparian buffer that was created and planted with native vegetation to shield the area from traffic disturbance.

Floodplain Connectivity(H3)

Diking and channelization in the early part of the 20th Century eliminated virtually all the connections between the Duwamish River and its floodplain. Riparian conditions along the Duwamish River are vastly different today from their condition in 1850. In the historic condition, approximately 1,230 acres of freshwater forested wetlands were found along the river (Blomberg et al. 1988). These areas, which were only inundated by flood events, likely included Sitka spruce (*Picea sitchensis*), willow (*Salix* spp.), red alder (*Alnus rubra*), black cottonwood (*Populus trichocarpa*), roses (*Rosa* spp.), and Douglas spirea (*Spirea douglasii*) (Tanner 1991).

Approximately 1,270 acres of tidal marshes occupied areas between +8 ft to +11 ft MLLW (Blomberg 1988). These areas were likely vegetated by bullrush (*Scirpus maritimus* and *S. americanus*) Lyngby's sedge (*Carex lyngbyei*), and sea arrow grass (*Triglochin maritimum*) (Tanner 1991). Vegetation found higher in the marsh probably included tufted hairgrass (*Deschampsia caepitosa*), saltgrass (*Distichlis spicata*), pickleweed (*Salicornia virginica*), Baltic rush (*Juncus balticus*), silverweed (*Potentilla pacifica*), and red fescue (*Festuca rubra*)(Dethier 1990).

Prior to settlement, approximately 1,450 acres of intertidal flats and shallows occupied areas below +6 to +8 MLLW. Although devoid of macrophytes, small patches of eelgrass (*Zostera marina*) or the green alga *Ulva* may have been present (Tanner 1991). The intertidal flats and shallows were concentrated at the mouth of the estuary bordering the south margin of Elliott Bay (Blomberg et al. 1988).

By 1940, filling of low lying areas had virtually eliminated all of the fringing riparian surge plain forested wetland (termed tidal swamps in Blomberg et al. 1988) or isolated it from the river. In addition, Blomberg et al. estimated that 98 percent of the pre-contact tidal marsh, mud flats, and shallows in the floodplain had been eliminated by dredging and filling with most of this loss coming by 1940. The majority of the near-natural estuarine (tidally flooded) habitats that remained were at Kellogg Island, which itself has been altered by disposal of dredged materials (Grette and Salo 1986). Small areas of *Carex*-dominated marsh, generally under 1 acre in size and widely dispersed, and the unvegetated intertidal benches adjacent to the channel or along the river banks, are all that remained. Blomberg et al. (1988) calculated that in 1986 only 45 acres of tidal marshes and mudflats remained.

MAJOR TRIBUTARIES

CHANNEL TYPE

Soos Creek (RM 0.0 to RM 12.0)

Mainstem Soos Creek is characterized by three different channel types (Figure HM-2). The headwaters of Soos Creek originate on a rolling glacial outwash plain. The channel is unconfined, with a gradient of less than 0.1 percent. Stream flows are generally small, with little erosive energy, and the channel is described as alternating between "sections of good gravel and sections of swampy channel splits with mud bottoms" (Williams et al. 1975), characteristic of a Palustrine channel type. At approximately RM 4.75, Soos Creek enters a narrow, steep sided ravine and the channel becomes a Moderate Gradient Mixed Control type, with a gradient of approximately 1.4 percent. Downstream of RM 2, the channel gradient decreases to around 0.5 percent, and Soos Creek becomes a Floodplain channel type that occupies a steep-sided valley.

Newaukum Creek (RM 0.0 to RM 14)

Like Soos Creek, Newaukum Creek was also subdivided into three channel types (Figure HM-2). The headwaters of Newaukum Creek arise in mountainous terrain, and are classified as a High Gradient Contained channel type from RM 14 to RM 9. Between RM 9 and RM 3, Newaukum Creek flows across a low gradient plateau formed by the Osceola Mudflow. The channel is unconfined, with a gradient of about 0.5 percent, and is classified as a Floodplain channel type. At RM 3, Newuakum Creek enters a narrow ravine, and the gradient increases to 2.7 percent (Boehm 1999). The channel is naturally moderately to tightly confined, and is classified as a Moderate Gradient Mixed Control channel type. Unlike Soos Creek, the steep section of Newaukum Creek extends all the way to the confluence with the Green River, with only a short segment of alluvial fan (about 1,500 feet) extending into the Green River valley.

Soos Creek (RM 0.0 to RM 12.0)

The Soos Creek basin plan indicated that "channelization has occurred since the early 1900's in the upper Soos Creek system" (King County 1989). However, no specific information on the extent and location of bank protection structures was located. No levees maintained by King County or the USACE appear in the GIS database.

Newaukum Creek (RM 0.0 to RM 14)

Channelization and bank modifications have altered channel morphology in the short alluvial fan of Newaukum Creek. Between 1984 and 1990, a landowner periodically bulldozed and re-aligned Newaukum Creek between RM 0.1 and RM 0.3, straightening meanders and piling LWD in the old channel to force flows into the newly excavated channel (Boehm 1999). In addition, the riparian zone was cleared and recently riprapped just downstream of RM 0.1 to protect a septic and well system (Boehm 1999). The Moderate Gradient Mixed Control segment of Newaukum Creek (RM 0.3 to RM 4) is essentially unconfined by levees, revetments or riprap (Malcom 1999). No information was located describing current artificial channel constraints upstream of RM 4.0 in Newuakum Creek.

GRAVEL BARS

Soos Creek (RM 0.0 to RM 12.0)

None of the published literature on Soos Creek describing fish habitat and environmental conditions contained information on the extent of gravel bars in mainstem Soos Creek (Williams et al. 1975; Goldstein 1982; King County 1989). Substrate in the Floodplain channel segment was described predominantly gravel (70-80 percent), and "remarkably few areas of problematic erosion or sedimentation were identified" (King County 1989). Aerial photograph coverage of Soos Creek was 1:12,000 scale or larger, and the channel was generally obscured by vegetation, thus no information on either the historic or current extent of gravel bars is available.

Newaukum Creek (RM 0.0 to RM 14)

The lower 400 meters of Newaukum Creek flow across the Floodplain of the lower Green River, forming an alluvial fan composed of cobble and smaller sized sediments. No data on the historic extent or distribution of gravel bars was located. A gravel bar that has built up at the confluence with the Green River currently impairs upstream migration of adult chinook at some flows (Malcom 1999). Information on the existing or historic extent of gravel bars in the remainder of Newaukum Creek is lacking

LARGE WOODY DEBRIS

Soos Creek (RM 0.0 to RM 12.0)

No data or reports describing either historic or current LWD loadings were located for mainstem Soos Creek.

Newaukum Creek (RM 0.0 to RM 14)

There is no quantitative information on the historic abundance of LWD in Newaukum Creek. In the 1950s, LWD was reportedly systematically removed from lower Newaukum Creek to protect a bridge located approximately 1,000 feet upstream of the confluence with the Green River (Boehm 1999).

Separate surveys of lower Newuakum Creek conducted by King County and the MIT both identified low LWD frequencies, although the criteria used to define LWD differed slightly. King County identified a total of 89 pieces of LWD with a minimum diameter of 10 inches and a minimum length of 10 feet, resulting in a LWD frequency of 64 pieces/mile (0.3 pieces/channel width) in the lower 1.4 miles of Newaukum Creek (Boehm 1999). The MIT survey identified 112 pieces of LWD at least 4 inches in diameter and 6.6 feet long, resulting in an LWD frequency of 1.2 pieces per channel width (112 pieces per mile) (Malcom 1999). In each case the low LWD levels correspond with a lack of pools and overwintering habitat (Malcom 1999; Boehm 1999). Boehm (1999) hypothesized that the loss of LWD may have been partly responsible for a change of species composition from predominantly chum and coho to chinook and steelhead.

OFF-CHANNEL HABITATS

Soos Creek (RM 0.0 to RM 12.0)

None of the published literature on Soos Creek describes off-channel habitat either qualitatively or quantitatively (Williams et al. 1975; Goldstein 1982; King County 1989). Available aerial photograph coverage of Soos Creek is 1:12000 scale or larger, and except for the lower reaches, the channel was generally obscured by vegetation, thus no information is currently available to assess either the historic or existing extent or condition of off-channel habitat.

Newaukum Creek (RM 0.0 to RM 14)

There is no available data on the historic frequency of off-channel habitats in Newaukum Creek. Based on channel type, it is expected that off-channel habitats are likely to be present only in the

1,500 foot long reach where the alluvial fan crosses the Green River floodplain or in the Palustrine segment (RM 5 to RM 10) under undisturbed conditions. Off-channel habitats are expected to be rare in the Moderate Gradient Mixed Control segment (RM 0.25 to RM 5) and the High Gradient Contained segment (RM 10 to RM 14) because the confining valley walls effectively limit lateral migration.

Surveys of lower Newaukum Creek conducted in 1998 categorized the area between RM 0 and RM 0.6 as having "few or no backwaters and no off channel ponds" (Malcom 1999) and are assumed to be representative of the entire Moderate Gradient Mixed Control segment. There is no information on the current extent of off-channel habitat available in the Palustrine segment between RM 5 and RM 10.

FLOODPLAIN CONNECTIVITY

Soos Creek (RM 0.0 to RM 12.0)

Only the lower 2.5 miles of Soos Creek downstream of the confluence with Covington Creek have a well-developed floodplain. The channel in this segment is 30 to 40 feet wide (King County 1989) and occupies an alluvial valley that is approximately 500 to 800 feet wide. No information was located describing the current or historic extent of the floodplain in lower Soos Creek, and it is unknown whether bank armoring or disconnection of off-channel habitats have influenced off-channel habitat connectivity. The increased flashiness of the flow regime has most likely increased the frequency at which floodplain surfaces are inundated, but reduced the duration of time that water is present, thus reducing floodplain recharge. Agriculture and rural development are also hypothesized to have impaired floodplain function in portions of this segment, but the extent of these impacts are unknown at this time.

Newaukum Creek (RM 0.0 to RM 14)

Floodplain development is naturally limited in the High and Moderate Gradient Contained channel segment, thus human activities have not substantially altered floodplain connectivity in upper (RM 9 to RM 14) or lower (RM 0 to RM 5) Newaukum Creek. The Floodplain segment of Newaukum Creek (RM 5 to RM 9) is presumably associated with a floodplain that would support inundation tolerant vegetation, contain side and off-channel habitats and serve as a groundwater re-charge zone. The Palustrine channel segment was described as "cutting through pasture and flat farmlands with very little natural growth available to provide shade and protection to the creek" (Williams et al. 1975). Agricultural and rural residential development have continued to influence habitat in the Palustrine segment of Newaukum Creek, and presumably have resulted in altered floodplain function, however no quantitative data on historic or current floodplain connectivity was located.

TABLES

Table HM-1. Map and aerial photo sources used to delineate channel types and conduct a preliminary assessment of hydromodifications WRIA 9.			
Current Conditions			
Source	**Date**	**Scale**	**Area Covered**
Draft Upper Green/Sunday Watershed Analysis Channel Segment Map	O'Connor 1997	1:52,800	RM 84-RM 93
Lester Watershed Analysis Channel Segment Map	Cupp and Metzler 1996	1:52,808	RM 76–RM 84
USFS Watershed Analysis Stream Gradients Map	USFS 1996	1:126,720	RM 64.5-RM 93
USGS topographic maps:		1:24,000	RM 0 – RM 93
Renton	1994		
Auburn	1994		
Black Diamond	1994		
Cumberland	1993		
Eagle Gorge	1993		
Cougar Mountain	1989		
Greenwater	1986		
Nagrom	1986		
Lester	1986		
Aerial photographs	USACE 1987	1:4,800	RM 57-RM 64.5
Aerial photographs	King County 1992	1:7,200	RM 32-RM 45.5
Aerial photographs	DNR 1995	1:12,000	RM 0-RM 93
FEMA floodplain maps	Smith and Associates 1994	1:2,400	RM 34-RM45
Historic Conditions			
Aerial photographs	USACE 1944	1:20,000	RM 0-RM 93
Aerial photographs	USACE 1953	1:7,200	RM 50-RM 70
Map	USACE 1905	1:4800	RM 0-RM 11
Map	USACE 1907	1:4,800	RM 25-RM 35
Map	Bortelson et al. 1980	1:24,000	RM 0 – RM 7
Map	Perkins 1993	1:24,000	RM 25 – RM 45

Table HM-2. Description of natural channel types and relative importance to anadromous salmonids (adapted from Paustain et al. 1992 using TFW Ambient Monitoring Channel Classification criteria).	
Channel Type	**Channel Characteristics and Life-sSage Use**
Estuarine	Intertidal channels that are directly influenced by tidal inundation and saltwater intrusion. These channels are depositional areas with very low stream power. The entire associated estuarine wetland system defines the extent of the riparian zone. Overbank flows are common with significant deposition of fine material on floodplain areas and lateral channel migration during extreme events. Stream bank composition of sand, fine gravel, and silt make this channel type sensitive to bank disturbance and erosion. Large woody debris may provide important habitat features in these channels, however, there is currently little information on natural LWD loadings in this channel type. LWD is provided almost solely from upstream sources, as the dynamic channel planform and extensive associated marsh and wetland habitat generally preclude establishment of mature streamside forests. These channels are always accessible to anadromous salmonids. Very little, if any spawning occurs in this channel type as substrate is generally very fine gravel, sand, silt, clay, and organic material and stream flows are inappropriate as an incubation environment. Adult salmon use this channel type for holding prior to moving into freshwater and as a migration corridor to access upstream spawning areas. Estuarine channels provide young salmon with nursery habitat providing both slow, deep-water areas with high channel complexity, shallow, subtidal refugia and intertidal areas. Additionally, the rich food production of this channel type provides for rapid growth of fry and fingerling. Downstream migrating smolts will reside in these channel types for extended periods using it as a transition area for osmregulation as they move from the freshwater to saltwater environment.
Palustrine	Very low gradient (<1%), unconfined, low velocity channels that typically flow through wetlands or beaver complexes. Stream power is low and high flows frequently over-top the active channel banks, but in-channel depositional features are rare. Riparian area size is highly variable, but may encompass very large wetlands. These channels and the adjacent riparian areas function as sediment and nutrient sinks, and are important buffers against extreme flood flows. Accelerated sediment deposition caused by riparian or upstream disturbance can adversely affect palustrine channel types. Early maps depict nearly all of the land on the Green River floodplain as “cut areas not restocking” suggesting that they had formerly supported timber that would have served as a source of LWD; however, there are also a number of areas classified as “naturally timberless that probably represent frequently inundated lands that are not sufficiently well drained to support timber growth (Shapiro and Associates 1990). Very little, if any spawning occurs in this channel type as substrate is generally very fine gravel, sand, silt, clay, and organic material and stream flows are inappropriate as an incubation environment. This channel type generally consist of deep, off-channel slough areas providing high quality refugia from wintertime high flows. These channels correspond with unconfined Category 1 channels defined using criteria specified in the TFW Ambient Monitoring Stream Segment Identification Module (NWIFC 1999). Palustrine channel types have not been identified in watershed analyses completed to date for the upper Green River basin.
Alluvial Fan	Moderate gradient (2-8 %), depositional channels that occupy the transitional area between steep mountain slopes and valley floodplains. Stream power decreases in the longitudinal direction and deposition results in channels that change course frequently across the body of the fan. High flows are generally not contained within the active channel banks. Channel banks are naturally unstable due to fine textured alluvial bank materials. Riparian vegetation is critical for bank protection and as a source of LWD for bedload retention and sorting and for channel formation. Alluvial fan channels are generally accessible to adult salmon. Spawning areas are generally located in the downstream portions of alluvial fan channels where gradients are lower. Alluvial fan channels are used by chinook, coho, steelhead and bull trout. Overwintering habitat is provided in pools associated with LWD accumulations and near the base of the alluvial fan where the potential for upwelling groundwater to moderate water temperature and inhibit ice formation can occur. Alluvial fan channels are particularly vulnerable to subsurface flows during periods of high sediment supply. These channels generally correspond with unconfined to moderately confined Category 3 and 4 channels defined using criteria specified in the TFW Ambient Monitoring Stream Segment Identification Module (NWIFC 1999). Alluvial fan and incised alluvial fan channels identified in the Lester Watershed analysis (Cupp and Metzler 1996) represent subsets of alluvial fan channels as described here.
Large Contained	Large (>20m bankfull width), low to moderate gradient (1-3%) channels that are moderately to deeply incised within low gradient landforms. High flows are generally contained within the active channel, and stream power is moderate to high, resulting in sporadic and discontinuous depositional features. Bed material is usually dominated by bedrock or boulders. Stream banks in large contained channels are relatively stable compared to alluvial channels due to the high amounts of bedrock and boulder incorporated into them. However, mass wasting of valley side slopes represents an important source of wood and sediment. Although they tend to be less frequent and persist for shorter periods, LWD accumulations can influence on these channels. Large pieces of debris incorporated into the stream bed can have an important function trapping gravel and cobble substrate used for spawning. Smaller or broken pieces of woody debris recruited into this channel type are generally distribute to downstream waters Large contained channels are generally accessible to adult salmonids, however, partial or complete barriers can occur at bedrock knickpoints. Typically these channels contain less suitable spawning area than alluvial channels due to the patchy accumulation of suitable gravel. These channels provide good rearing habitat for juvenile steelhead, and reaches with stable large woody debris and deep-pool habitats may also be used by other species. Large contained channels correspond to confined Category 2 and 3 channels defined using criteria specified in the TFW Ambient Monitoring Stream Segment Identification Module (NWIFC 1999). Large contained channels have been identified as confined mainstem channels in watershed analyses conducted to date in the upper Green River basin (Cupp and Metzler 1996; O’Connor 1997).
Moderate Gradient Mixed Control	Moderate gradient (2-8%) transport dominated channels with moderate stream power. High flows are generally contained within the active channel. Channel banks are frequently composed of boulder or bedrock materials that limit later channel migration and floodplain development. Much of the usable fish habitat in moderate gradient mixed control channels is keyed to large woody debris. For larger channels, where floodplain development has occurred, these channels are highly dependent on riparian vegetation for bank stabilization and LWD recruitment. Large woody debris may significantly influence channel morphology in this channel type including pool/step-pool formation, flow deflection, and gravel storage and sorting. These channel types are generally accessible to adult chinook salmon, but occasionally barriers at bedrock falls do restrict access. Chinook may use the largest and least steep examples of this channel type, however moderate gradient mixed control channels are generally most important for coho, steelhead, bull trout and cutthroat trout. These channels correspond with moderately to highly confined Category 3 and 4 channels defined using criteria specified in the TFW Ambient Monitoring Stream Segment Identification Module (NWIFC 1999). Moderate-gradient mixed control channels have been identified as low to high powered tributaries (O’Connor 1997) and moderate gradient moderate slope or secondary moderate gradient channels channels (Cupp and Metzler 1996) in watershed analyses conducted to date in the upper Green River basin.
High Gradient Contained	Steep, incised channels (>4 percent). Flows are contained within the active channel, and stream power is high, thus sediment is rapidly transported through these channels (Montgomery and Buffington 1993). Wood frequently spans smaller high gradient contained channels, or enters by sliding downslope, and breaks up rapidly (Nakamura and Swanson 1993). However, LWD incorporated into the bed may remain stable for long periods of time if undisturbed by debris torrents, and is important regulating the downstream movement of sediment and dissipating the energy of high flows (Nakamura and Swanson 1993). Associated riparian areas are generally narrow, extending only to the upper stream bank slope break. Steep sideslope areas are sensitive to shallow mass wasting, which provided the majority of sediment recruitment. High gradient contained channels typically supply downstream waters with sediment, large woody debris, nutrients, and aquatic insects. Large (width greater than about 5 meters) high gradient confined channels may be used by steelhead and bull trout, but this channel type generally provides habitat for primarily resident trout. High gradient contained channels correspond to confined Category 4, 5 and 6 channels defined using criteria specified in the TFW Ambient Monitoring Stream Segment Identification Module (NWIFC 1999). High gradient contained channels have been identified as high powered headwater channels (O’Connor 1997) and V-shaped channels (including depositional and moderate to high gradient types) or secondary high gradient channels (Cupp and Metzler 1996) in watershed analyses conducted to date in the upper Green River basin.

Table HM-3. Current and historic channel types of the mainstem Green River, WRIA 9.					
Sub-watershed	**Reach[1]**	**Current Channel Type**	**Current Length (Miles)**	**Historic Channel Type**	**Historic Length (Miles)[2]**
Green/Duwamish Estuary	RM 0-RM 11	Channelized	11.0	Estuarine	14.9
Lower Green River	RM 11-RM 25	Channelized	14.0	Palustrine	14.0
	RM 25-RM 31	Channelized	6.0	Floodplain	6.0
	RM 31-RM 45	Floodplain	13.8	Floodplain	13.3
Middle Green River	RM 45-RM 58	Large Contained	13.0	Large Contained	13.0
	RM 58-RM 61	Floodplain	3.0	Floodplain	3.5
	RM 61-RM 64.5	Large Contained	3.5	Large Contained	3.5
Upper Green River	RM 64.5-RM 69	Lacustrine (seasonally inundated)	4.5	Floodplain	4.5
	RM 69-RM 88	Floodplain	19	Floodplain	19
	RM 88-RM 93	High Gradient Contained	5	High Gradient Contained	5
Major Tribs					
	RM 0-RM 2.5	Floodplain	2.5	Floodplain	Unknown
Soos Creek	RM 2.5-RM 4.75	Moderate Gradient Mixed Control	2.25	Moderate Gradient Mixed Control	Unknown
	RM 4.75-RM 13	Palustrine	8.25	Palustrine	Unknown
Newaukum Creek	RM 0-RM 3	Moderate Gradient Mixed Control	3.0	Moderate Gradient Mixed Control	Unknown
	RM 3-RM 9	Floodplain	6.0	Floodplain	Unknown
	RM 9-RM 14	High Gradient Contained		High Gradient Contained	Unknown

[1]Reaches are designated using current river miles; RM 0 of current channel is located 0.75 miles upstream of the entrance to the West waterway, after Williams (1975).

[2]Historic channel RM 0.0 located at mean low water line within current West waterway, as depicted by Bortelson et al. (1980). Historic channels in lower and Middle Watershed mapped using GIS layers constructed from USACE 1906 and Perkins 1993.

Table HM-4. Approximate current extent of artificial and natural constraints on channel mobility along the mainstem Green River in WRIA 9.

Sub-watershed	Reach	Historic Channel Type	Levees, Revetments, Rip-rap (% of channel length)	Naturally Constrained (% of channel length)
Green/Duwamish Estuary	RM 0-RM 11	Estuarine	98[1]	0[2]
Lower Green River	RM 11-RM 25	Palustrine	95[3]	0[2]
Middle Green R.	RM 25-RM 31[3]	Floodplain	82[4]	2[4]
	RM 31-RM 45	Floodplain	39[4]	10[4]
	RM 45-RM 58	Large Contained	0[2]	100[2]
	RM 58-RM 61	Floodplain	<5[5]	<5[2]
	RM 61-RM 64.5[4]	Large Contained	45[5]	100[5]
Upper Green River	RM 64.5-RM 69	Floodplain	0[5]	0[2]
	RM 69-RM 88[5]	Floodplain	26[2]	<5[2]
	RM 89-RM 93	High Gradient Contained	0[2]	100%
Major Tribs.				
Soos Creek	RM 0-RM 2.5	Floodplain	Unknown	0%[2]
	RM 2.5-RM 4.75	Moderate Gradient Mixed Control	Unknown	40%[2]
	RM 4.75-RM 13	Palustrine	Unknown	0%[2]
Newaukum Creek	RM 0-RM 3	Moderate Gradient Mixed Control	8%[6]	90%[2]
	RM 3-RM 9	Floodplain	Unknown	0%[2]
	RM 9-RM 14	High Gradient Contained	Unknown	100%[2]

[1]Blomberg et al. 1988.
[2]Based on USGS topographic maps
[3]Fuerstenberg et al. 1996
[4]Perkins 1993; 85 percent of the existing levees and revetments are located between RM 25 and RM 38
[5]Estimated from USACE 1953 and 1987 photos
[6] Boehm 1999

Table HM-5. Current LWD loadings of the mainstem Green River, WRIA 9.

Sub-watershed	Reach	Naturally recruited (pieces/mi)	Placed as part of restoration projects[1] (pieces/mi)	Total Loading (pieces/mi) [key pieces/mi]	Relevant Standard[2] (pieces/mi)
Green/Duwamish Estuary	RM 0-RM 11	2.5	3	5.5[3]	80
Lower Green River	RM 11-RM 25	unknown	28.4	unknown	80
	RM 25-RM 31[3]	unknown	7.8	unknown	80
Middle Green River	RM 31-RM 45	28.9	6.2	35.1[4]	80
	RM 45-RM 58	unknown	0	unknown	80
	RM 58-RM 61	unknown	0	unknown	80
	RM 61-RM 64.5	unknown	0	unknown	80
Upper Green River	RM 64.5-RM 69	unknown	0	unknown	80
	RM 69-RM 88	6.4-2,850[5,6]	0	6.4-2,850 [0]	80 [16]
	RM 89-RM 93[7]	100-133	0	100-133 [0-8]	322 [32]
Major Tributaries					
	RM 0-RM 2.5	unknown	unknown	unknown	322
Soos Creek	RM 2.5-RM 4.75	unknown	unknown	unknown	322
	RM 4.75-RM 13	unknown	unknown	unknown	322
Newaukum Creek	RM 0-RM 3	112[8]	0	112 [1.1]	215[9] [22]
	RM 3-RM 9	unknown	unknown	unknown	322
	RM 9-RM 14	unknown	unknown	unknown	322

[1]The number of pieces of LWD input by recent restoration project was obtained from the King County web-site Boaters Page for the Green River, 10/21/99.

[2]For the purposes of this analysis, NMFS standard for "properly functioning" west-side streams of 80 pieces>24 inches diameter and > 50 feet long is used for channels > 20 meters in width (NMFS 1999); Washington Watershed Analysis standard of >2 pieces of LWD greater than 2m in length and 10cm in diameter per channel width for "good" habitat conditions applied for smaller channels (322 pieces/mile for 10 m channel) (WFPB 1997).

[3]Blomberg 1999 (RM 0-RM5); Pentec 1999 (RM 5-RM 12)

[4]Fuerstenberg et al. (1996)

[5]Wunderlich and Toal (1992) RM 69-RM 70.25; Fox (1996). Data from subsamples of two segments totaling 0.6 miles between RM 76 to RM 84; no mention of habitat restoration, so assume all are naturally recruited. Frequency highly variable by reach, ranging from 36 to 236. None of the pieces observed qualified as key pieces.

[6]Fox and Watson (1997); total LWD frequency data from subsample reaches totaling 0.8 miles; no mention of habitat restoration, so assume all are naturally recruited

[7]Fox and Watson 1997; total LWD f frequency data from subsample reaches totaling 0.1 miles; no mention of habitat restoration, so assume all are naturally recruited.

[8]Malcom (1999). Data from RM 0-RM 0.9; no mention of habitat restoration, so assume all are naturally recruited

[9]Average channel width=15 m (Malcom 1999), thus 2 pieces/CW=215 pieces/mile; 0.2 key pieces/CW=22/mile

Table HM-6. Current and historic length of major off-channel habitats associated with the mainstem Green River, WRIA 9.			
Sub-watershed	**Reach**	**Current length (ft)**	**Historic length (ft)**
Green/Duwamish Estuary	RM 0-RM 11	3,500[1]	4,600[2]
Lower Green River	RM 11-RM 25	0[3]	Unknown
	RM 25-RM 31[3]	unknown	unknown
	RM 31-RM 45	20,800 linear ft[4]	93,852 linear feet[5]
Middle Green River	RM 45-RM 58	1,260 linear ft[6]	1,260 linear ft[7]
	RM 58-RM 61	3,340 linear ft[8]	12,340 linear feet[7]
	RM 61-RM 64.5[4]	0	0 linear ft[7]
Upper Green River	RM 64.5-RM 69	0 (inundated by HHD reservoir)	12,940[7]
	RM 69-RM 88[5]	common[9]	unknown
	RM 89-RM 93	0	unknown
Major Tributaries			
	RM 0-RM 2.5	unknown	unknown
Soos Creek	RM 2.5-RM 4.75	unknown	unknown
	RM 4.75-RM 13	unknown	unknown
	RM 0-RM 3	unknown	unknown
Newaukum Creek	RM 3-RM 9	unknown	unknown
	RM 9-RM 14	unknown	unknown

[1]Blomberg 1999
[2]USACE 1906.
[3]Malcom, 1999.
[4]1992 air photos
[5]Perkins 1993.
[6]1995 air photos
[7] USACE 1944 and 1953 air photos.
[8]USACE 1987 air photos
[9]Fox (1996); Fox and Watson (1997)

Table HM- 7. Elliott Bay/Duwamish Estuary habitat/substrate shoreline measurements.

Duwamish Waterway – River Mile 11.0 to River Mile 5.3

Habitat/Substrate	Linear feet	Miles	Percentage of Shoreline (both banks)
Riprap (visible from river)	33,706	6.38	56.0
Bulkhead (near vertical)	1,697	0.32	2.8
Mudbank	29,993	5.68	49.8
Shoal/mudflat (near or below MLLW)	5,342	1.01	8.9
King County levees	13,604	2.58	22.6
Trees*	21,338	4.04	35.4
Shrubs	45,140	8.55	75.0
Grass	3,126	0.59	5.2
LWD (Number per mile)		9.5	

* Includes 33 individual trees each having a 25-ft dripline (total of 850 ft)

Duwamish Waterway – River Mile 5.3 North to Mouth of Duwamish

Habitat/Substrate	Linear feet	Miles	Percentage of Shoreline (both banks)
Riprap (exposed)	40,450	7.66	49.8
Riprap (under dock)	13,000	2.46	16.0
Vertical bulkhead	4,300	0.81	5.3
Exposed sand/mud substrate	45,400	8.60	55.9
Inwater structures (e.g., moorages, extensive piling)	12,300	2.33	15.1
Vegetated shoreline	22,400	4.24	27.6
Rubble shoreline	5,450	1.03	6.7
Overwater structures (e.g., docks and piers)	12,150	2.30	15.3

Elliott Bay – Don Armeni Park to Terminal 91

Habitat/Substrate	Linear feet	Miles	Percentage of Shoreline
Riprap (exposed)	24,850	4.71	35.7
Riprap (under dock)	34,350	6.51	49.3
Vertical bulkhead/concrete sewalls	11,300	2.14	16.2
Exposed sand/mud substrate	11,750	2.23	16.9
Inwater structures (e.g., moorages, extensive piling)	10,250	1.94	14.7
Vegetated shoreline	3,150	0.60	4.5
Rubble shoreline	2,800	0.53	4.0
Overwater structures (e.g., docks and piers)	45,800	8.67	65.8

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Figure HM-4. **Side channels in the Upper Green River Subwatershed, RM 64.5 to RM 70 in 1953, prior to inundation by Howard Hanson Reservoir.**

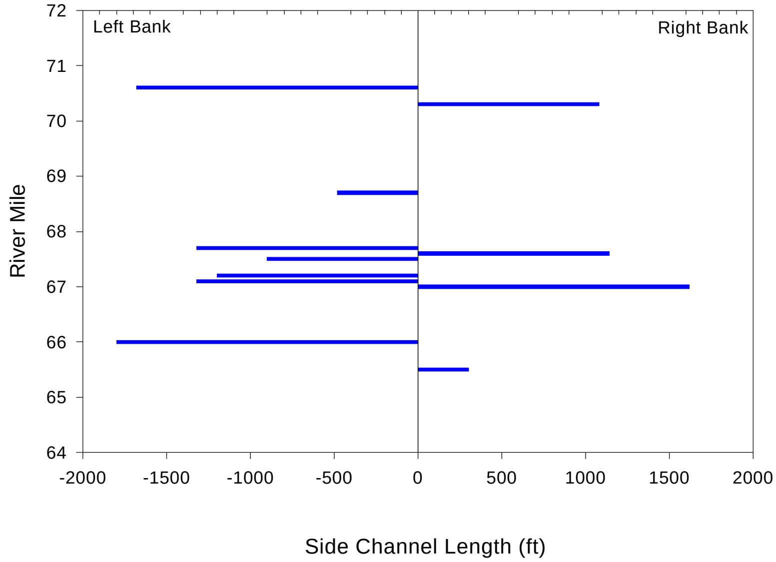


Figure HM-6. Historic length and location of side channels in the Middle Green River Subwatershed, Side channels between RM 31 and RM 45 were identified using maps of the historic channel planform in 1907 from Perkins (1993). Side channels between RM 45 and RM 64.5 were identified using aerial photos from 1944 and 1953.

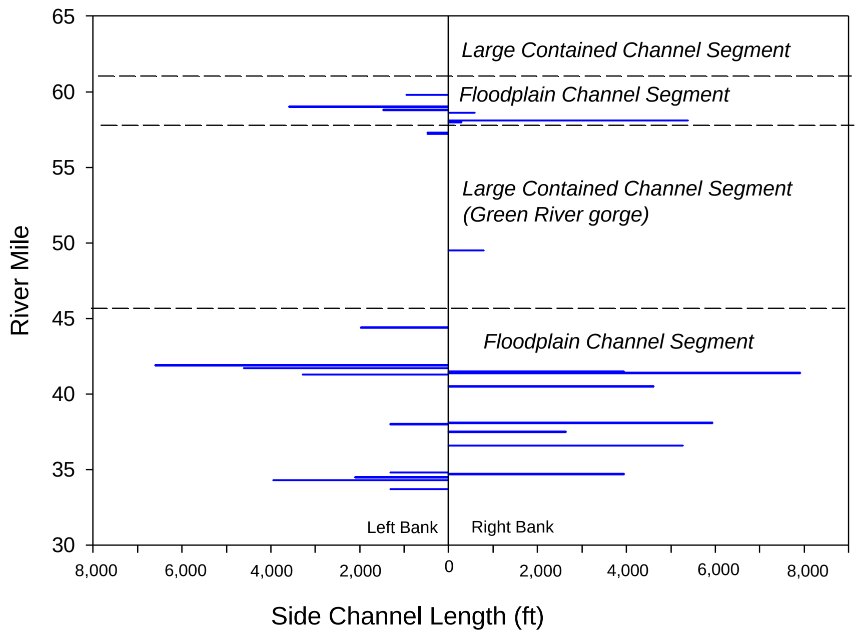
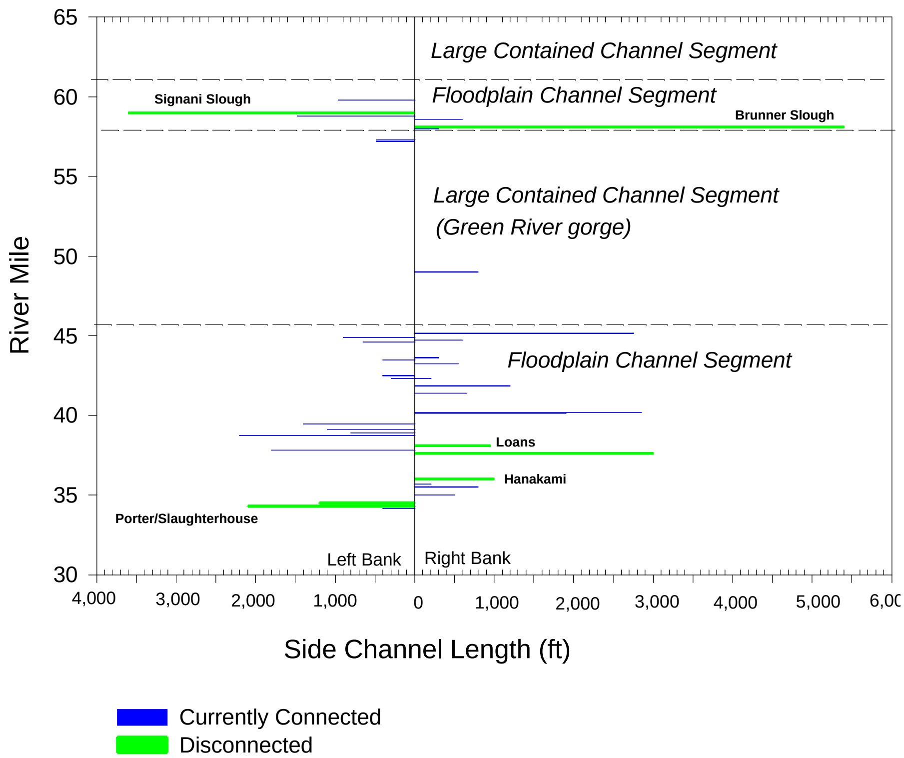


Figure HM-7. **Side channels in the Middle Green River Subwatershed, Side channels between RM 31 and RM 45 were identified using aerial photos from 1992 and detailed floodplain maps (Smith and Associates 1994). Side channels in the Green River gorge were identified using aerial photos from 1995. Side channels between RM 58 and RM 64.5 were identified using aerial photos from 1987.**



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