A Review of the Literature and Assessment of Research Needs in Agricultural Streams in the Pacific Northwest as it Pertains to Freshwater Habitat for Salmonids

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Introduction

As salmonid listings under the Endangered Species Act (ESA) have become more common in the Puget Sound, new sectors of the economy are being affected by the listings. Agricultural lands tend to be concentrated in the lowland areas of Puget Sound and many are in fertile river valleys. This places agricultural land use directly in conflict with salmon use of lowland streams and side channels. Agricultural lands, just as forest lands before them, will be faced with regulations emerging from the Clean Water Act and the Endangered Species Act. Best available science is the keystone to current regulatory policy in Washington and as such, information is needed on the condition of streams in agricultural lands, how those watersheds functioned historically, and ways to improve the ecological functions in streams and riparian areas that lie in agricultural areas.

Few studies have been done in Western Washington on the effects of agriculture on the ecological condition of lowland streams and rivers. This report is the outcome of a project that reviewed the scientific information that is most closely related to King, Snohomish, Skagit and Whatcom county agricultural lands. Using information from the National Marine Fisheries Service (NMFS) on factors affecting essential salmon habitat, various keywords were used in bibliographic searches in combination with agriculture to identify relevant existing literature.

The assumptions behind this report are:

1. Agriculture is a valuable and important industry in the Northwest,
2. Salmon are important ecologically, economically and culturally,
3. Salmon live in and migrate through streams and wetlands surrounded by agricultural lands,
4. Scientific information on the interactions between agricultural land practices in the PNW and salmon is incomplete,
5. All sectors of the economy will need to comply with the ESA and the Clean Water Act.

Farm plans have been or are being developed by western Washington counties. The current, and likely future, listings of salmonid stocks under the ESA affects agricultural operations, especially with respect to buffers, field drainage, and inputs of nutrients and chemicals to the streams. By identifying topics that have limited published information to support current or proposed changes in management, research can be focused to fill these information gaps.

This report investigates many factors that affect salmonid stream habitat, including organic inputs, sediment deposition, stream temperature, woody debris, bank stability, pool formation, and altered hydrology. These factors are all closely linked to each other and reflect the general condition of the riparian ecosystem. The first part of this report presents information on what is known about the functioning of riparian systems in the PNW. Even though much of this information comes from work done on forested lands it still presents a basis for understanding how riparian systems function. Historically, the vast majority of the Puget Sound lowlands consisted of extensive forests and wetlands (Collins pers. commun., see also Beechie at al. 1994). The general ecological processes are the same, no matter what the land-use of the watershed; only the pathways and relative importance of the pathways are altered under different land-uses.

We also present a topic analysis of the agriculturally-related literature to illustrate how the information is distributed across categories such as agricultural management techniques, region and ecosystem in which the research was performed. The papers we identified as having the most agricultural significance are then summarized.

Overview of riparian ecology, fish habitat needs and habitat-forming processes in the Pacific Northwest

The following is a very brief review of basic riparian ecology in the Pacific Northwest. Numerous other documents are available that go into greater detail. The scope of this project did not include an in-depth review of this literature, but we chose to include some background to help put the rest of the report in context.

Sections of the following are taken from Bolton and Shellberg (2001) who prepared a report on ecological issues in floodplains and riparian corridors for the Washington Departments of Ecology (DOE), Transportation (DOT) and Fish and Wildlife (WDFW). The entire report is available on-line on the WDFW webpage, http://www.wa.gov/wdfw/hab/ahg/floodrip.htm. Bolton and Shellberg (2001) focus on the effects of channelization on ecological processes in streams, but the general findings are relevant to any land-use that alters riparian areas and floodplains. Readers are encouraged to look at the full report for ecological information on channels and floodplains. Naiman and Anderson (1997) also summarize current the literature on riparian ecology and management in the PNW.

Review of basic riparian and aquatic ecology in the PNW

The word riparian is defined by Lowrance (1985) as "the complex assemblage of organisms and their environment existing adjacent to and near flowing water." In simpler terms, the riparian zone is the ecosystem adjacent to and including the river. People often underestimate the amount of riparian habitat because they usually visit streams in the dry summer months. Winter rains fill small channels and off-channel habitats that provide critical habitat especially for juvenile fish during high flows. The water quantity and quality in streams reflects the conditions in the watershed including the riparian areas and the upland areas (Naiman et al. 1992). The interactions between the land and water create a diverse and productive habitat for plants and animals. The availability of water, moist rich soils and a variety of plants makes riparian areas attractive to wildlife, livestock and people. These areas are highly productive and diverse.

The size of the riparian area and the extent of interaction between the land and the water varies with the size of the stream (Bilby 1988). In small streams with typically small amounts of stream flow, the forest or other adjacent land use, such as agriculture, dominates the stream. In larger, lowland streams the power of the river exerts considerable force on the adjacent floodplain and periodically creates new habitats.

The major habitat-forming processes in western Washington are sediment, water and wood regimes (Beechie and Bolton 1999). These processes are driven and defined by the source, magnitude, timing, and delivery of these materials to stream systems and adjacent riparian areas (Bisson et al. 1987; Everest et al. 1987; Sullivan et al. 1987). Natural riparian systems develop as a patchwork of forests of different ages with a variety of shrub and tree species. No single area along a river provides the best habitat for all species. This habitat heterogeneity adds diversity and resilience to riparian ecosystems. However, an increase in the number or size of disturbances can overwhelm the system (Ward and Stanford 1989; Stanford and Ward 1992). It is important to understand the historical rate, type, and magnitude of disturbances for any given riparian system (Naiman and Anderson 1997) and to acknowledge that exceedance of the frequency or size of disturbance under which riparian and aquatic organisms have evolved may jeopardize their long-term survival. A watershed view of riparian areas is essential when evaluating the effect of upland management, because human activities, such as mining, grazing, farming, damming and channelization, logging, urbanization, and recreation can alter the processes that deliver water, wood and sediment to riparian areas. Restoration or mitigation of degraded streams that proceeds without recognition of watershed-based processes that created the problem are likely to be ineffective (Kauffman et al. 1997)

Fish habitat needs

The major habitat requirements for salmonids are barrier-free migration, suitable substrate and water quality for spawning, incubation, rearing and migration, food availability, and shelter from extreme flows and predators (Brookes 1988). A diverse set of hydrologically connected habitat types across the landscape provides these major habitat requirements. Anadramous salmonids are vulnerable to freshwater habitat alterations at any life stage from egg to returning adult spawners. If any one habitat type needed for a particular life-stage is degraded, the success of that life-stage and all subsequent development can be affected (e.g., Everest et al. 1987). The freshwater sections of the NMFS documents on essential fish habitat are largely drawn from Gregory and Bisson (1997), and NRC (1996). These references provide an excellent overview of salmonid habitat needs in the PNW and the interested reader is encouraged to consult them for more detailed information.

NMFS (1999) breaks down essential freshwater habitat into water quality, habitat access, stream habitat (biological and physical environment), channel conditions, and hydrologic regime categories. As can been seen in Table 1 (taken from the NMFS report Table 3-2), agriculture and activities associated with agriculture have the potential to affect almost all components of the freshwater habitat of salmonids.

Table 1:
Actions likely to affect salmon habitat and habitat components likely to be altered.
Continued on next page (modified from NMFS 1999 Table 3-2)

ACTIONS LIKELY TO AFFECT SALMON EFH	REMOVAL/ ALTERATION OF RIPARIAN VEGETATION	ALTER AMOUNT OR RATES OF WOODY DEBRIS INPUT	REMOVAL OF WOODY DEBRIS FROM STREAM, LAKES, BAYS	INCREASE / DECREASE IN SEDIMENT DELIVERY	STREAMBANK OR SHORELINE ALTERATION	STREAM BED AND CHANNEL ALTERATION (ALSO BEDS, CHANNELS OF LAKES, BAYS)	WATER REMOVAL/ DIVERSION	WETLAND OR FLOODPLAIN ALTERATION
EXAMPLES OF ACTIVITIES THAT MAY INVOLVE THOSE ACTIONS	forestry, agriculture, ranching, road building, construction, gravel and mineral mining	forestry, fire suppression, flood suppression, road building, dams, beaver removal, agriculture	channel clearing for navigation, rafting, flood or erosion control, wood scavenging, beaver dam removal, agriculture	forestry, agriculture, ranching, road building, construction, sand and gravel extraction, mineral mining, dredging	forestry, agriculture, grazing, urbanization, erosion or flood control, dock construction, habitat restoration	dredging, sand and gravel removal, erosion control, placement of pipelines, habitat restoration	dam/irrigation / municipal/ industrial power facility operation, push up dams, groundwater pumping, desalinization	agriculture, ranching, construction, road building, flood control, dredging, beaver removal, habitat restoration
HABITAT COMPONENTS								
Steam Water Quality:								
Temperature	X		X	X	X	X	X	X
Dissolved Oxygen	X			X	X	X	X	X
Sediment/Turbidity	X	X	X	X	X	X	X	X
Nutrients	X	X	X	X		X	X	X
Contaminants	X			X		X	X	X
Habitat Access:								
Physical Barriers		X	X			X	X	X
Stream Habitat:								
Substrate	X	X	X	X	X	X	X	X
Large Woody Debris	X	X	X		X	X	X	X
Pool Frequency	X	X	X	X	X	X	X	X
Pool Quality	X	X	X	X		X	X	X
Off-Channel Habitat	X	X	X		X	X	X	X
Prey	X	X	X		X	X	X	X
Predators	X	X	X		X	X		X

ACTIONS LIKELY TO EFFECT SALMON EFH	REMOVAL/ ALTERATION OF RIPARIAN VEGETATION	ALTER AMOUNT OR RATES OF WOODY DEBRIS INPUT	REMOVAL OF WOODY DEBRIS FROM STREAM, LAKES, BAYS	INCREASE / DECREASE IN SEDIMENT DELIVERY	STREAMBANK OR SHORELINE ALTERATION	STREAM BED AND CHANNEL ALTERATION (ALSO BEDS, CHANNELS OF LAKES, BAYS)	WATER REMOVAL/ DIVERSION	WETLAND OR FLOODPLAIN ALTERATION
EXAMPLES OF ACTIVITIES THAT MAY INVOLVE THOSE ACTIONS	forestry, agriculture, ranching, road building, construction, gravel and mineral mining	forestry, fire suppression, flood suppression, road building, dams, beaver removal	channel clearing for navigation, rafting, flood or erosion control, wood scavenging, beaver dam removal	forestry, agriculture, ranching, road building, construction, sand and gravel extraction, mineral mining, dredging	forestry, agriculture, grazing, urbanization, erosion or flood control, dock construction, habitat restoration	dredging, sand and gravel removal, erosion control, placement of pipelines, habitat restoration	dam/irrigation / municipal/ industrial power facility operation, push up dams, groundwater pumping, desalinization	agriculture, ranching, construction, road building, flood control, dredging, beaver removal, habitat restoration
HABITAT COMPONENTS								
Channel Condition & Dynamics:								
Streambank/Channel Complexity	X	X	X	X	X	X	X	X
Floodplain Connectivity	X	X	X	X	X	X	X	X
Stream Flow/ Hydrology:								
Change in Peak/Base Flows	X	X	X		X	X	X	X
Increase in Drainage Network	X				X	X	X	X
Estuarine Habitat:								
Extent/cond. of habitat types	X	X	X	X	X	X	X	
Extent/cond. of eel grass beds				X	X	X	X	X
Water quality also disease and contaiminents				X	X	X	X	
Water Quantity/ Timing of fresh water inflow					X		X	X
Prey	X			X	X	X		X
Predators	X			X	X	X		X

Michael Waldichuk (1993) concluded that freshwater habitats are the most vulnerable to human impact and that the success of a year-class of a Pacific salmon species is usually determined by conditions during its freshwater phase. The best chance of improving freshwater habitats in this region will come from restoring habitat-forming processes to the extent that it is physically and economically feasible (Beechie and Bolton 1999). Some of the environmental factors that are known to affect salmonid habitat are described briefly below as we understand their effects in the PNW. The factors include: organic inputs, sediment deposition, stream temperature, woody debris, and bank stability. There are additional factors, as noted in Table 1, that are necessary for high quality freshwater habitat for salmon that we do not discuss below. This reflects time constraints on our part, not lack of importance of the factors.

Organic inputs

Organic inputs to undisturbed streams vary by stream. In small streams organic material comes largely from surrounding vegetation and from subsurface water flows that carry nutrients to the stream. In larger streams, sunlight allows for internal production of organic material via photosynthesis. Larger streams also receive inputs from upstream and from subsurface waters. In general, streams in the PNW have relatively low concentrations of phosphorus and nitrogen but this varies by geology. Thut and Haydu (1971) found primary productivity in streams with underlying volcanic geology were likely to be nitrogen-limited but streams draining glacial or granitic basins were more likely to be phosphorus-limited. Anadromous salmonids carry marine derived nutrients (particularly nitrogen) to freshwater systems when they return to spawn and die (e.g. Bilby et al. 1996; Ben-David et al. 1998; Michael et al. 1998). More work is needed to fully understand nitrogen transformation processes and the relative role of salmon, alders and hyporheic exchanges in providing nitrogen to riparian areas (O'Keefe and Edwards 2001)**.** Evidence from studies on clearcut harvesting have shown a marked increase in stream production when the stream is exposed to sunlight, which increases in-stream photosynthesis (Allan 1995). The switch from external production of organic material to internal production changes the populations in the streams and affects the organization of the food web, which may alter the food resources available to salmon (Wooton et al. 1996).

Sediment inputs

The type, amount, and timing of sediment input influence channel morphology (Sullivan et al. 1987). Unusual amounts of sediment (too much or too little compared to background conditions and stream transport capacity) or a change in the primary sediment source can alter the channel morphology of the stream, changing habitat conditions as well as altering water clarity which can affect fish behavior and the invertebrate community. The effect of sediment introduced into a stream depends on the volume introduced, its grain-size distribution, and the timing of its input, as well as the physical environment of the stream itself (e.g. flow obstructions and meanders) (Everest et al. 1987).

Fine sediments (generally clays, silts and fine sands) can be particularly troublesome for fish and their habitat. The negative effects of fine sediment on the reproductive success of salmonids has been known since 1923 (Harrison 1923). The effect of fine sediments on salmonids depends on many characteristics of the species and river of interest. Thus, species, stock, life history pattern, competition, habitat availability, stream gradient, channel morphology, flow regime, basin lithology and historical and current land use across the watershed all interact to determine the effect of fine sediment on fish (Everest et al. 1987). Field studies on the effects of sediment on eggs and alevin generally show a decrease in survival as the amount of fine sediment increases (Everest et al. 1987:117-118). More recent reviews (e.g. Newcombe and MacDonald 1991; Bash et al. In press) summarize data on the effects of turbidity and suspended sediment on various life-stages of salmonids. Effects on fish include changes in movement rates, feeding rates, predation rates, prey abundance, reaction distance, growth rates, and stress levels.

If salmon populations are large enough, there is some cleaning of the gravels of fine sediment that occurs during spawning (e.g., Burner 1951; Cordone and Kelley 1961). Evolutionarily, this may be effective in natural streams with historic numbers of salmon and historic sediment loading, but is unlikely to have the same success in streams with depressed salmon runs in watersheds altered by human activities.

Stream temperature

Many studies have examined the factors that affect stream temperature in PNW forested systems. Poole and Berman (2001) indicate that climatic drivers (e.g. air temperature, solar radiation, and windspeed), stream morphology, groundwater influences and riparian canopy condition are the most important factors affecting stream temperatures (see also Sullivan and Adams 1988). Removal of vegetation near streams has been shown to increase direct solar radiation, change near-surface air humidity and temperature (Brosofske et al. 1997) as well as alter the flow and temperature of subsurface water (Hanks and Ashcroft 1980). Riparian vegetation reduces near-stream windspeed and traps air against the water surface reducing heat exchange with the atmosphere by decreasing convection and advection of heat energy to the water surface (Naiman et al. 1992). Small shallow streams typically respond more quickly and to greater extremes to increased solar radiation, caused by canopy removal, than deeper streams (Adams and Sullivan 1989). The elevation of streams also contributes to long-term temperature change susceptibility, lowland streams being more vulnerable than mountain streams.

Increased stream temperature has been shown to alter adult migration patterns, accelerate development of eggs and fry emergence, and increase metabolism (Beschta et al. 1987). By influencing the rate at which nutrient cycling and productivity occur, high stream temperatures can increase primary and secondary production in the aquatic environment (Allan 1995). Elevated temperatures can also increase the susceptibility of both juveniles and adults to certain parasites and diseases. Warm water temperatures also reduce the level of dissolved oxygen present (Allan 1995). Brett's (1952) research found that the tolerance of Pacific salmon to different temperatures varied among species and depended on the temperature to which the salmon were acclimated. No species of Pacific salmon could withstand temperatures exceeding 25.1ºC when exposed for one week (Brett 1952). However, high average and peak water temperatures at 20ºC have been shown to cause disease and mortality in most aquatic biota, including salmonids (Brett 1956).

Large woody debris

Large woody debris (LWD) is often defined as wood that is 10 cm or about 4 inches in diameter and more than 2 m long. This definition most likely came from a research program in the 1970s that was concerned with decay of organic matter like leaves, twigs and branches. House and Boehne (1986) noted a relationship between LWD and the health of salmonids. Subsequent studies followed that continued to identify and describe the functions LWD provides to productive streams for salmon and the species upon which they rely (e.g., Benke et al. 1985; Sullivan et al. 1987; Ralph et al. 1994; Montgomery et al. 1995).

Woody debris has both physical and biological effects in stream systems. Channel morphology is affected by the presence of trees, shrubs, and log jams. Pool abundance correlates with overall salmon habitat quality and LWD loading is an important factor in pool formation (Montgomery and Buffington 1993). Sedell et al. (1985) estimated that salmonid production could be increased several times by raising the debris load in streams with low amounts of LWD. LWD and log jams have a major influence on the retention of organic matter including leaves, needles and salmon carcasses in a stream system (Bilby and Ward 1991; Culp et al. 1996). LWD also provides a substrate for microbes and algae that provide part of the food for the grazing guild of macroinvertebrates (Maser and Sedell, 1994). Macroinvertebrates in turn are a valuable food source for salmon.

The functions of LWD in streams include the following:

1. Interrupt the streamflow to trap coarse sediment upstream of the LWD to create bars or islands (Abbe and Montgomery 1996)
2. Modify streamflow to create pool structure/habitat downstream of LWD (Cherry and Beschta 1989)
3. Direct high-water flow to support hydraulic routing (Gippel 1995; Gregory and Bisson 1997)
4. Trap and hold small organic materials (leaves, needles, carcasses, etc.) (Culp et al. 1996)
5. Provide hydraulic roughness to the stream during high flow conditions (Abbe and Montgomery 1996)
6. Provide habitat and perches for aquatic insects, amphibians, birds and riparian mammals (Borchardt 1993)
7. Provide structure and nutrients for microbiological organisms important to the aquatic ecosystem (Bilby and Ward 1989)
8. Provide habitat for aquatic and semi-aquatic plant communities by providing a stable substrate and silt traps within the structure (Maser and Sedell 1994)
9. Provide cover and shade for juvenile and adult salmon (Bisson et al. 1987)

These various functions provide channel complexity by creating a range of flow velocities and depth, providing habitat for components of the aquatic food web and retaining sediment and nutrients for use by in-stream organisms.

Bank stability

If bank stability has been decreased due to changes in flow regime or land-use, bank stabilization has the potential to reduce both the sediment deposition rate and the nutrient levels in receiving waters thus also influencing water clarity, habitat availability and quality for salmonids. Bank stability is largely controlled by the grain size of the bank material, the vegetation cover on the banks, and the amount of bedload carried in the channel (Sullivan et al. 1987). Banks can be strengthened considerably by dense root systems. Therefore, plant species composition (grasses, trees, or shrubs) and vigor of riparian vegetation affect the level of bank stability (Sullivan et al. 1987). Decreased bank stability can cause (and be caused by) loss of riparian vegetation leading to further sediment deposition and perhaps channel incision, which leads to further bank instability. In order to avoid this negative feedback loop, LWD and riparian buffers can be used to protect banks from erosion (Sullivan et al. 1987).

Vegetation may provide bank stability through root reinforcement of the soil (Krogstaad 1995) which increases the soil's resistance to the erosive force of the streamflow. Millar and Quick (1998) demonstrated that the effect of vegetation on bank stability could be expressed as an increase in critical bank shear stress. They estimated that critical shear stress is about three times higher when trees and shrubs are present compared to just grass covered banks. However, there is some evidence that this effect is limited by root density and depth which varies with species and soil types. Rowntree and Dollar (1999) found that willows increased bank stability at flows less than bankfull, but did not appreciably affect long-term shifts in channel position from major floods. Nanson and Hickin (1986) found that outer bank migration in meandering channels was largely a function of river size and grain size in the large sand- and gravel-bed rivers that they studied. Unconfined alluvial channels periodically alter their flow paths and migrate back and forth across the floodplain. This movement delivers sediment and trees to the stream and creates a patchy network of stream and riparian habitat that can increase habitat diversity along the stream network so long as sediment delivery and stream transport capacity are not out of synchrony.

Methods

This project entailed a literature review of published information and organizing and summarizing participant input from individuals and agencies involved in agricultural practice, research and policy in western Washington. The results of this literature review are not intended to be a representation of all the literature available on fish, streams, and agriculture, due to the narrowly-defined scope and three-month duration of this study. The input from participants is not from a representative sample population and may contain unknown biases.

Literature review

A literature review was conducted to assess the status of existing knowledge on salmon habitat needs in agricultural streams and determine the areas where additional research is needed. The results of this literature review were analyzed and summarized according to selected categories. References were located through citations found in the bibliography put together by National Resources Consultant, Inc. for the *Rationale for a*

Managed Agricultural Buffer Zone in Skagit County and from David Correll's annotated bibliography, *Vegetated Stream Riparian Zones: Their Effects on Stream Nutrients, Sediments, and Toxic Substances*, the 9th edition. References were chosen for review from these bibliographies based on wording in the title that indicated topics known to affect salmonids in freshwater streams. Additional literature reviews were performed using on-line databases accessible through the University of Washington library system. The primary database used was Agricola. The largest organized search performed using Agricola was for the key words "Agriculture," "Water," "Temperature". Relevant abstracts were downloaded from the databases and organized using Pro-Cite. A smaller organized search using Agricola was used to find papers specifically related to pasture type agriculture. Agricola was also used to locate abstracts of additional research papers found from cross-bibliographic references. Recommendations of relevant research by other researchers were also included. Full bibliographic references for all articles located in this literature review, including those not included in the analysis, are in Appendix A.

Categories for organizing the literature were chosen based on recurring topics found in the articles and by using the NMFS matrix of pathways (Table 1). The categories were placed under four different criteria designed to summarize the existing research base:

(1) Environmental factors affecting salmonid habitat, otherwise known as limiting factors. These include: organic inputs, sediment deposition, stream temperature, woody debris, bank stability, pool formation, and channel morphology.

(2) Farm practices addressed by the study including: tillage practices, fertilizer application techniques, different fertilizer types, the use of buffers, the use of woody debris, and the effects of hydromodification. (Hydromodification is a catch-all word that includes drains, ditches, and levees).

(3) Region in which the research was conducted. Within the United States these include the following regions: northwest, southwest, high plains, south central, north central, southeast, and northeast. Two locations outside the United States are also included: Europe and New Zealand.

(4) The ecosystem in which the research was conducted, including forested and agricultural.

Using these categories, results are summarized and presented in tables. The tables highlight the areas in which there is a paucity of research and indicate the geographic relevance of the existing information to agricultural related issues in the Northwest ecosystem.

Participant input

In addition to the focused literature review, comments were collected from regional scientists and managers on what they considered to be the most relevant areas of research. The comments were collected in an April 18, 2001 meeting organized by the Center for Streamside Studies (CSS) at the University of Washington. Representatives from Snohomish, Whatcom, Skagit, and King Counties were present. NMFS scientists and other interested parties such as the NRCS, regional consultants, and local farmers also participated. Participants were not selected as a random sample of the population. Therefore, their input may not be generally representative of local opinion and should not be construed otherwise. However, the participants did come from a range of backgrounds and work environments.

At the beginning of the issue identification exercise, each individual was asked to write down three to five research questions which they considered to be the most pressing issues facing the agricultural community. Individuals then took their topic lists and formed groups, which were randomly assigned. Groups were asked to talk about and use their individual comments to develop a single list of three to five research questions that the group as a whole thought were the most pressing. Groups then merged with other groups, and the process continued until all participants were in one group.

The research questions/comments developed using this exercise were summarized into categories chosen by recurrence of topics. The categories include environmental factors that affect salmonids and issues associated with management techniques. Other topics not related to this project also came up, such as policy implementation. The frequency of occurrence of topics was tallied for each level of group formation, individuals, small groups, large groups, and finally the one all-inclusive group. A complete list of the comments is included in Appendix B.

Results

Categorization of agriculturally-related literature

A total of 2001 references were reviewed and of these 123 were selected for the category analysis. Papers were selected for analysis based on whether they were relevant to freshwater agricultural stream ecosystems and if they investigated one or more factors that are known to affect salmonids. Half of the references (~50) were read in full and the other half were categorized based on the abstract alone. An additional twenty-five references were selected from the 930 references in the Natural Resources Consultants Incorporated's report, *Rationale for a Managed Agricultural Buffer Zone in Skagit County*. Twenty-six references were selected from the 715 references contained in David Correll's annotated bibliography. Thirty-one references were collected using the Agricola database available on-line through the University of Washington library system. A search on Agricola for "water + temperature + agriculture" produced 306 references, from which thirty-one were selected. An additional twenty-eight references came from David Shields (pers. commun.). Approximately ten references were dropped from the database after selection because they were not available through the University of Washington library system.

Literature review results are summarized in Tables 2-6. These tables are from the subset of references that we identified as being most relevant to agricultural issues and do not represent all the literature that may exist. Table 2 indicates the number of references found that studied both a particular environmental factor and a particular management type. Some of the articles fit more than one category. The zero entries do not necessarily indicate that there is a lack of research, just that a particular combination of variables may not make logical sense, such as pool formation and fertilizer application techniques. From this table it can be seen that most of the research done on buffers has been in relation to organic inputs and sediment deposition.

Table 3 indicates the number of references found by region and environmental factor. If a region is not included, such as southwest, high plains and south central, then there were no references found from those areas. Table 3 supports the notion that more research on organic inputs has been done in the southeastern region of the United States than has been done in the northwest. Table 5 identifies studies conducted in forestry versus agricultural settings and shows that research on organic inputs has been done more often in agricultural areas than in forestry type settings. In addition, this table also demonstrates that the research on the effects of woody debris and pool formation is primarily forestry-based not agriculturally-based.

Table 2:

Number of articles found covering a particular environmental factor and a particular management type.

	Management type					
	Tillage	Fert. App.	Fert. type	Buffers	Woody debris	Hydro-modification
Organic inputs	6	16	10	37	3	9
Sediment deposition	5	2	3	21	5	6
Temperature	4	2	1	2	0	0
Woody debris	0	0	0	6	---	5
Bank Stability	2	2	0	9	3	6
Pool Formation	0	0	0	2	7	3

Table 3:

Number of articles identified by region and environmental factors.

	Region					
	NW	NC	SE	NE	Europe	New Zealand
Organic inputs	4	4	17	8	9	3
Sediment deposition	1	4	8	4	0	0
Temperature	1	1	0	1	1	0
Woody debris	2	2	0	0	0	0
Bank Stability	3	6	1	3	2	0
Pool Formation	5	1	0	0	0	0
Total	17	11	19	10	10	3

Table 4:

Number of articles identified by region and management type.

	Region					
	NW	NC	SE	NE	Europe	New Zealand
Tillage	2	1	1	3	0	0
Fert. Appl.	1	1	3	2	5	0
Fert. Type	0	0	0	0	1	0
Buffers	11	5	11	6	4	2
Woody Debris	8	1	0	0	0	0
Hydromodification	1	0	0	0	0	0
Total	17	11	19	10	10	2

Table 5:
Number of articles conducted in forestry versus agricultural ecosystems by environmental factors.

		Ecosystem	
		Forestry	Agriculture
	Organic inputs	11	45
	Sediment deposition	3	19
	Temperature	1	6
	Woody debris	5	1
	Bank Stability	1	6
	Pool Formation	2	1
	Total	15	60

Table 6:
Number of studies conducted in forestry versus agricultural ecosystems by management type.

		Ecosystem	
		Forestry	Agriculture
	Tillage	0	8
	Fert. App.	2	12
	Fert. Type	2	9
	Buffers	12	27
	Woody debris	5	1
	Hydromodification	0	8
	Total	15	60

Participant Input

Categories used to summarize comments generated during the CSS workshop are shown in Table 7 (also available at http://depts.washington.edu/cssuw/Research/participant%20feedback.pdf). The list of topics covered in the comments includes both environmental factors and management types in the same way that the literature review does. Unlike the literature review, the comments include topics outside the scope of this project, such as economic concerns of counties and the agricultural community, restoration efforts and outcomes, and policy implementation challenges. An example of a policy question was, “How do we identify the socioeconomic factors that inhibit or stimulate public participation in salmon restoration?” These are relevant questions for the overall discussion about agriculture and salmon, but are not a part of this particular review and will not be discussed further. Prevalent topics are ones that persisted through every group size, from individuals to the final all-inclusive group. Prevalent topics include: limiting factors, hydromodification, agricultural runoff, and general functioning of the agricultural system.

Table 7:
Comments from CSS meeting on April 11th 2001:

Categories	Topic Frequency			
	Individuals	Grouping 1	Grouping 2	Grouping 3
Use by fish	17	2	1	0
Limiting factors	10	4	3	3
Hydromodification	17	6	3	1
Agricultural runoff	5	1	1	1
Monitoring and management	8	2	1	1
Functions of the agricultural system	6	1	1	1
Establishing priorities	3	3	2	1
Water quality	4	0	1	0
Temperature	3	0	0	0
Dissolved oxygen	2	0	0	0
Sediment	2	1	0	0
Large wood debris	1	0	0	0
Invasive species	2	2	0	0
Reed Cannery grass	4	1	1	0
Functions of the riparian zone	4	0	2	0
Buffer width	5	2	0	0
Vegetation type	5	2	1	0
Pests	1	0	0	0
Soil	2	0	0	0
Erosion	1	0	0	0
Nutrient retention	3	1	0	0
Policy implementation logistics	9	2	2	0
Effects on agricultural profitability	9	3	1	0
Farm practices	4	2	1	0

A list of all the comments are included in Appendix B. The three final comments that were generated when the groups in grouping 3 were combined are listed below:

1) “What is the primary limiting habitat attribute for fish?”
2) “Does (increased) nutrient runoff from agriculture increase potential for eutrophication, or provide useful nutrients to salmonids?”
3) “How can natural ecosystem processes, under managed conditions, be best used to protect and restore salmonid stream ecosystems, while allowing farming to continue?”

Discussion of the literature

Environmental factors affecting fish:

Using the information synthesized from the literature review, the effect of agricultural practices on key environmental factors known to affect salmonids are discussed below as they pertain to agricultural streams in the Pacific Northwest. The discussion takes into account information presented in the previous section on Riparian Issues.

Organic inputs

The nature of agricultural practice results in higher probabilities of organic inputs such as nutrients and chemicals being delivered to streams. The application of fertilizers containing high levels of nitrogen and phosphorus, as well as pesticides and herbicides, which contain potentially harmful chemical compounds, is one way agricultural practices can affect salmon habitat. Nutrient runoff, in excess of background levels, constitutes a threat to the quality of receiving waters (McColl 1978). Increased primary and secondary production, as a result of over enrichment of nutrients, can lead to low dissolved oxygen conditions which can cause distress or death due to suffocation of mature, juvenile, and developing fish (Waldichuk 1993). Increased nutrients can alter food web dynamics by changing prey community composition and available habitat for invertebrates and salmonids alike (Kauffman et al. 1997). Increased primary production may lead to increased weight and age for juvenile salmon and can alter migration timing which can affect in-stream and ocean survival. Herbicides and pesticides can reduce survival of eggs, increase physiological stress, and lower disease resistance at various salmonid life stages (NMFS Matrix; see also Solbe et al. 1998; Scholz et al. 2000).

Sediment deposition

Typical agricultural land management practices such as tilling, ditching and dredging can increase the amount of sediment reaching streams (Seta et al. 1993; Shields and Cooper 2000; Moore et al. 2001). To the extent that agricultural land-use leads to increases in fine sediment transport and deposition, one can expect salmonids to be affected in various ways depending on life-stage. Fine sediments generally reduce the permeability of gravels resulting in a decreased intragravel flow, which can decrease dissolved oxygen and waste removal for developing embryos (Everest et al. 1987). Although it is not known to what extent salmonids may use agricultural streams for spawning, studies have shown a direct inverse relationship between fine sediment production and fry survival. Cederholm et al. (1981) found that for every 1% increase in fine sediment there was a decrease in fry survival of up to 3.4%. Sub-lethal effects of suspended sediment on salmonid fry include reduced growth rate, a decreased ability for fry to capture pray and can induce stress symptoms (Everest et al. 1987). Agricultural practices that cause sediment production to exceed processing and transporting capacity of waterways or that alter the normal timing of sediment transport have the greatest potential to damage salmonid populations.

The presence of roughness factors, such as large woody debris and boulders in streams, can set up complex hydraulic patterns that sort sediments, scour pools, and generally maximize the variety of habitat available for salmonids (Coats et al. 1985). To the extent that sediment increases in areas where there is a paucity of structural elements, there is greater potential to negatively impact salmonid survival (Everest et al. 1987).

Stream temperature

As noted earlier, streams at low elevations and with little to no shade tend to have higher temperatures. Agricultural streams may be susceptible to elevated temperatures given that most agricultural areas are in the lowlands and many streams do not have extensive buffers. The published literature on agriculture and temperature explores the effects of soil temperature and nutrient loss (Rudaz et al. 1999) on crop growth. There is very little research on the effects of temperature in agricultural streams as it pertains to the presence or absence of buffers. However, this topic has been researched extensively in forested settings. Baltz and Vondracek (1984) and others found that removing riparian forests increases stream temperatures and that even minor changes in temperature can lead to major changes in fish populations. On small streams, typical of many agricultural settings, shading is likely to be the most important factor in regulating stream temperature (Adams and Sullivan 1989). Additional factors affecting stream temperature are groundwater and hyporheic inflow, channel incision, and other hydrologic and geomorphic processes. Simplified channel complexity, such as straightening, diking, and bank hardening, reduces hyporheic connectivity. Dikes and levees that maintain channel morphology by reducing flood flows decrease subsurface floodwater storage and therefore reduce groundwater discharge (Poole and Berman 2001). An additional factor that can result in a loss of hyporheic potential is the removal of large wood from the channel, which eliminates major structural elements responsible for creating channel heterogeneity. Withdrawals from wells penetrating the groundwater network feeding streams may also reduce flows in stream channels (Poole and Berman 2001). Decreased groundwater discharge can cause streams to be more vulnerable to factors that increase stream temperatures, such as solar radiation.

Woody debris

The amount of large wood in most coastal streams is a small fraction of historical levels (Bilby and Ward 1991; Bisson et al. 1997). Various efforts are underway to increase the amount of wood in streams to provide the ecological benefits mentioned earlier. Protecting riparian areas allows trees to grow larger and provide large wood to the stream and forest floor naturally over time (Beechie et al. 2000). Large woody debris on the forest floor provides habitat for a variety of amphibians and small mammals as well as a surface for seedlings to become established. These nurse logs help conifer seedlings survive and out compete shrubs and hardwoods (Beach 1999). Given the forested nature and frequent flooding of most of the Puget Lowlands historically, wood was likely a common component in streams and floodplains. Woody debris that was present in streams now draining agricultural lands has typically been removed to allow for increased conveyance and more efficient drainage.

Bank stability

Removal of riparian vegetation may have decreased bank stability over historical values. Properly designed and placed bank stabilization applications can reduce bank erosion, stabilize riparian vegetation planting sites, and add to shoreline cover. (However, it must be remembered that streams locations are NOT fixed in space and time in natural systems.) Various studies have addressed the biological effect of specific structures and bank stabilization techniques, such as riprap, spur dikes, and revetments. Hjort et al. (1984) looked at fish and invertebrates along revetments and natural channel areas of the Willamette, River, Oregon and found different numbers and species of fish and invertebrates in natural stream areas compared to banks with riprap. Fewer fish species used riprap areas in high densities than used natural areas. Fish found in revetment areas tended to be ones that fed on algae or diatoms growing on the stones or fed on bottom dwelling invertebrates. The invertebrates found in the revetments were species that preferred a very stable bottom and either clung to the stones or hid in crevices. More fish species were found in areas of natural banks due to the greater diversity of habitat in these areas.

Peters et al. (1998) looked at seasonal fish densities in Washington at sites with various bank stabilization structures. Of all project types surveyed (riprap, riprap with large woody debris, rock deflectors, rock deflectors with large woody debris, and large woody debris), only sites stabilized with large woody debris consistently had higher fish densities in spring, summer, and winter than the control sites without any stabilization structures. Riprap sites consistently had lower densities than control sites. At all sites, fish densities were generally positively correlated with increasing surface of large woody debris and increasing amounts of overhead riparian covering 30 cm of the water surface.

Pool formation

Pools are important resting and hiding places for fish, especially juveniles. Research has shown a decrease in the number and size of pools in the Northwest (Bisson and Sedell 1984). The two main causes for this decrease are: 1) the filling of pools by sediment (Megahan 1982) and 2) the loss of pool-forming structures such as boulders and large woody debris (Bryant 1981; Sullivan et al. 1987; Meehan 1991). Damage by erosion or channelization decreases the number of pools for fish habitat (Shields et al. 2000). Large obstructions, of which woody debris is often the most abundant in small channels, may fully or partly block the flow, thus regulating the scour and deposition of sediment and creating pools and scour holes.

Management in Agricultural areas

Common management techniques in agriculture are discussed below to the extent that they may affect stream habitat.

Tillage

Tillage was originally thought to improve the soil because it loosens and mixes the soil. However, the benefit of tillage has been questioned in the last few decades because of excessive erosion from farmlands after tillage (Seta et al. 1993). There has been an increasing concern for runoff of organic inputs and sediment as a result of tillage practices. Various types of tillage have been studied including conventional tillage, conservation tillage, chisel-plow tillage, and no tillage. Research on the effects that these different practices have on the quality of runoff is not consistent, largely due the role that soil type and subsurface flow patterns play in regulating runoff (Phillips et al. 1980).

There has been an increasing emphasis on the use of conservation tillage practices to reduce chemical losses via surface area runoff and erosion from upland farming areas (Chichester 1976). It has been assumed that because conservation tillage methods reduce runoff and soil erosion they also reduce the potential for water pollution (Phillips et al. 1980). However, it has also been suggested that augmented infiltration resulting from this practice may increase the potential for groundwater pollution (Blevins et al. 1990).

Conservation tillage, when compared with conventional tillage, has been shown to reduce soil losses from agricultural land, decreasing sediment content of runoff, but not necessarily volume of runoff (Blevins et al. 1990). Differences in runoff volume have been attributed to differences in soil surface roughness. The effects of roughness are particularly apparent with chisel-plowing. Andraski et al. (1985) showed that chisel-plowing reduced runoff relative to conventional tillage. No-tillage systems consistently reduce soil sediment losses; however, fertilizer is applied directly on the soil surface which may increase nutrient loss immediately following application (Blevins et al. 1990). The sediment and nutrient losses associated with different tillage practices is dependent on the soil-loss-tolerance-factor (T), which is different for each soil type. Most of the research done on the effects of different tillage systems has been conducted in the southeastern United States where row cropping is the most common form of agricultural production. The extent to which nutrient pollution associated with tillage practices is a problem in northwestern saturated soils is not well documented.

Fertilizer application and types

Nitrogen and phosphorus in runoff leads to the enrichment of surface waters and contributes to algal blooms. Fertilizers are one source of excess nitrogen and phosphorus (Barlow et al. 1999). Application of excess fertilizer can happen when there is no soil monitoring to determine dosages. This is one of the main causes of nitrogen pollution in soils and in waterways, including groundwater. The amount taken up by the crop and therefore not entering the stream is directly related to the quality and quantity of fertilizer available (Omernik et al. 1981). Commercially controlled release fertilizers (CRF) have higher nitrogen-use efficiency because nitrogen is gradually released matching the plants rate of absorption (Omernik et al. 1981). The use of CRFs suggests that it may be possible to control nitrate pollution of soils by rationalization of the fertilizer dosages via soil analyses and using CRF suited to each crop (Diez et al. 1994). It has also been suggested that proper timing of fertilizer application, using a nitrification inhibitor with fertilizer, or in some cases limiting fertilizer application may reduce the levels of excess nutrients reaching streams (Omernik et al. 1981). While it is generally accepted that erosion control will reduce nutrient levels in receiving waters, Frere (1976) notes that effectiveness of management practices for controlling nutrient losses has not reached the same level of understanding as that of controlling runoff and erosion.

Buffers

Riparian buffers are expected to have beneficial effects on water quality for several reasons. Because they are located between aquatic and terrestrial systems, most of the water flowing to a water body must first traverse the riparian area through above or below ground pathways. Effective riparian buffers can provide for sediment removal, plant uptake of nutrients, and denitrification before water originating from diffuse sources enters the stream network (Clausen et al. 1993). Established forested riparian zones have been shown to decrease sediment and nutrients in runoff waters (Schlosser and Karr 1981; Peterjohn and Correll 1984; Lowrance et al. 1986; Cooper et al. 1987). Both denitrification and plant uptake are primarily responsible for nitrate losses from riparian groundwaters (Clausen et al. 1993). However, the process by which the riparian ecosystem removes and retains nutrients is poorly understood, especially in poorly drained landscapes found in the northwest. Most studies on riparian zone function have been done in the eastern United States (e.g. Lowrance et al. 1984; Peterjohn and Correll 1984; for European studies, see also www.qest.demon.co.uk/media/bufferzones_sv.pdf).

The capacity to reduce sediment loading in streams is dependent on the width of the buffer and vegetation type present in the buffer, and on points and channels of concentrated flow (Pearce et al. 1997). Buffers can also reduce sediment levels in streams by reducing the rate of bank erosion, but probably only for streams that are not incising or rapidly widening (Shields et al. 1995). The use of buffers to reduce peak runoff and increase sediment storage is a common management practice in forestry and has been used as a best management practice in agricultural areas primarily in the southeastern United States. The degree to which riparian functions (nutrient uptake, sediment removal, and temperature control) can be enhanced in an agricultural setting by the installation of riparian buffers still remains to be experimentally quantified (Dosskey 2000). The design of riparian buffers, especially width requirements, has received some attention; however, other factors such as vegetation assemblage, layout, slope of adjacent lands, and reach length (how much of the stream needs a buffer) are all key parameters that affect the functional efficiency of the riparian ecosystem (Fisher et al. 2000).

Non-forest buffers, such as grass filter strips, have also been used to reduce sediment and nutrient runoff into streams. As sediment-laden flow comes into contact with a grass filter, its velocity is retarded and its transport capacity reduced. Information on the sedimentation process has largely been done in artificial filter media in efforts to simplify calculations (Barfield et al.1979). Wilson (1967) presented results of a sediment trapping study that delineated distances required for the trapping of sand, silt, and clay on a grass filter with a very flat slope. Grass filter strips have often been used in conjunction with riparian-forested buffer strips, so that runoff first enters the grass filter strip and then flows into the forested buffer. Preliminary data from a study by Wigington (pers. commun.) in the Willamette Valley, Oregon, indicate that grass buffers provided good nitrate uptake but that there was a lot of by-pass flow due to soil saturation. His work noted that riparian forest buffers had lower nitrate treatment effect than grass buffers but the lower treatment may have been compensated for more water passing through the forest buffer.

A summary of the wide range of riparian buffer functions (Malonson 1993; Schueler 1995; Wenger 1999) are listed below:

1. Trapping/ removing sediment from runoff
2. Stabilizing streambanks, and reducing channel erosion, and providing structural and hydraulic diversity
3. Trapping/ removing phosphorus, nitrogen, and other nutrients and retaining them in actively growing riparian vegetation thus reducing eutrophication potential

4. Trapping/ removing other contaminants such as pesticides and herbicides
5. Storing flood waters, thereby decreasing damage to property
6. Maintaining habitat for fish and other aquatic organisms by moderating water temperatures and providing habitat for terrestrial organisms

Woody debris

The functions of woody debris were described above. There are few controlled studies on the before and after effects of vegetation removal from the floodplain or stream channel (Shields and Nunally 1984), but physical effects can be identified by considering the processes affected by vegetation. Streams in western Washington in which logging debris had been removed had fewer pools and longer riffles than streams in old-growth forests (Bisson and Sedell 1984).

Vegetation also protects bank stability by reducing shear stress and by deflecting flows. The use of these properties have been used to prevent bank erosion using felled trees in structures referred to as "tree revetments" or wood debris in "engineered log jams" (Shields and Cooper 2000). The removal of riparian trees and understory vegetation can dramatically alter the stability of streambanks and hillslopes (Simon and Hupp 1992; Simon 1994; Shields 1991; Shields and Gray 1992; Kondolf and Curry 1986), which can lead to slumping, fine sediment input, and unnatural erosion rates. Boulton et al. (1997) note that slumping of hillslopes and streambanks in unvegetated pasture streams lead to the smothering of lateral bars with sediment (especially fines) resulting in narrower channels. Furthermore, in small New Zealand streams, the lack of shading and increased slumping of sediment encouraged the growth of aquatic vegetation and algae. This encroaching vegetation has the potential of trapping fine sediment, which can further smother potential aquatic habitat and allow for the further encroachment of aquatic vegetation. In contrast, a study by Davies-Colley (1997) found that small streams in native forests were wider than those in pasture watersheds. This effect was most noticeable on very small streams (watershed area < 1 sq. km., width < 1 m) and largely disappeared when the watershed area was > 30 sq. km and stream width > 10m.

Efforts are being made to determine ways to develop appropriate wood recruitment conditions (Peterson and Klimas 1996; Beechie et al. 2000) and estimates of "appropriate" wood loading in streams (Fox 2001). The majority of studies on the effects of large woody debris in streams have been done in forested ecosystems rather than in agricultural settings.

Hydromodification

Human activities that alter the timing and quantity of flow, both surface and subsurface, as well as their interactions are considered to be hydromodification. In agricultural areas hydromodification includes, channelization, ditching, dredging, and v-diches. Channelization and other activities occurring over the entire watershed alter the timing, pathway and quantity of runoff delivered to the stream. We did not examine general effects of stream flow modification and regulation, especially as it is affected by watershed land-use, for this report.

One component of the stream system that can be affected by hydromodification is the hyporheic zone. The *hyporheic zone* is a broad term that defines the "saturated interstitial areas beneath the stream bed and stream banks that contain some proportion of channel water or that have been altered by channel water infiltration (advection)" (White 1993). Traditionally, water along river systems has either been defined as surface water or ground water. However, other bodies or zones of water have recently been defined that are ecotones or intermediate in nature (physically, chemically, and biologically) to surface and ground water. Hydrologists have long known that surface water and ground water interact along river systems and research over the last two decades by ecologists and hydrologists has uncovered the functional importance of the hyporheic zone to the physical, chemical, and biological integrity of fluvial ecosystems (e.g. Boulton et al. 1998; Edwards 1998).

The dimensions of the hyporheic zone can vary dramatically depending on the stream size, stream discharge, alluvial porosity and volume, and vertical and lateral exchange rates. In small headwater streams, the hyporheic zone is typically on the order of several meters both vertically and horizontally, or is entirely absent due to lack of alluvium or significant exchanges of water (White 1993). In large montane and lowland alluvial valleys, the hyporheic zone typically is on the scale of several meters below the streambed and up to 100-meters wide. In some highly conductive stream systems (e.g., Flathead River, MT; Yakima River, WA; Methow River, WA), the hyporheic zone can extend over 10 meters deep into alluvium and up to 3 km wide across the floodplain (Stanford et al. 1994; Stanford and Ward 1988; Stanford and Ward 1993; Whiting and Sweeney 1999).

In one of the few studies directly addressing the impacts of land use on hyporheic function and ecology, Boulton et al. (1997) compared the hyporheic ecology of five small streams in New Zealand under different land use: native forest, exotic pine forest and pasture. Both abiotic and biotic differences were observed between the different sites. As expected, the temperatures of hyporheic water at the pasture site were significantly higher than either of the two forested sites. This was attributed to the lack of riparian shading and warmer stream temperatures. Warm water temperatures reduce the levels of dissolved oxygen in the sediments (Allan 1995), which can be a critical control on the presence or absence of certain hyporheic taxa. Boulton et al. (1997) predict that as stream and hyporheic temperatures warm up due to a lack of riparian shading, the hyporheos community structure can dramatically shift towards a community dominated by a few taxa tolerant of low oxygen (hypoxia) and high temperatures.

Boulton et al. (1997) also notes the effects of a lack of a riparian canopy on other physical and ecological processes. They found that the forms of particulate organic matter entering the hyporheic zone differed between sites. Native forests contributed diverse types of leaf materials and woody debris to the hyporheic zone while pasture lands only contributed a few species of grass that decomposed rapidly and contributed less to aquatic production. Boulton et al. (1997) found that pasture streams supported significantly less diverse community of organisms living in the hyporheic zone than the native forest. They largely attributed this to high levels of interstitial fine sediment and the reduction of downwelling oxygen-rich surface water, which promote hypoxic conditions intolerable to some organisms. A change in invertebrate community structure can negatively affect salmon by altering their food source.

Subsurface flow is an area where nitrogen has been found to undergo denitrification (Addy et al. 1999). The nutrient loss pathway provided by subsurface water in the hyporheic zone beneath the riparian area is an essential functional component for nitrogen dispersal in agricultural lands. Subsurface denitrification was the major nitrogen loss pathway identified in various research projects (e.g. Peterjohn and Correll 1984; Jordan et al. 1993; Addy et al. 1999) and was dependent on available dissolved carbon and seasonally saturated anoxic conditions. Maintaining this hydrologic pathway is important for controlling non-point source pollution. Although, it should be noted that this pathway can also deliver non-transformable dissolved substances that may be pollutants to the stream.

The channel processes that determine shape and hydraulic characteristics of streams influenced by agricultural land practices are not completely understood. However, it is known that stream simplification and loss of complexity confine the flow to a single channel and greatly reduce the carrying capacity for young trout (Moore and Gregory 1988; Bisson 1992). Reduced stream habitat complexity has been one of the most pervasive cumulative effects of land-use practices (Bisson et al. 1992) leading to diminished available habitat, reduced species diversity, increased competition, and emigration from the stream. The size and location of salmonid spawning and rearing areas are determined by the hydrologic and hydraulic characteristics of streamflow (Sullivan et al. 1987).

Hydromodification practices, such as drainage ditches, are an integral component of the agricultural production landscape. A network of ditches built to provide field drainage and reduce flooding of cultivated acreage surrounds most agricultural fields. Drainage ditches are often forgotten as links between agricultural fields and aquatic receiving systems, but they play a crucial role in transfer and transformation of contaminants such as nutrients, sediments, and pesticides (Moore et al. 2001).

Gullies and other types of erosion from agricultural lands have been cited as the leading source of sediment in waterways (Pimentel 1987). To avoid formation of tributary gullies, drop pipes have been constructed in riparian zones adjacent to agricultural areas (Shields et al. In press). If left uncontrolled these gullies have the potential to extend into fields generating sediments that pollute downstream waters and degrade aquatic habitat. Damming the gully with a small earthen dam and inserting an L-shaped metal culvert that extends through the embankment is a widely applied practice. The environmental impact of drop pipes is discussed by Shields et al. (In press). They specifically looked at the importance of selected habitat variables on vertebrate taxa in order to extract design and management criteria that will lead to increased levels of vertebrate diversity. They explain that drop pipes retain runoff on the edge of fields, allow sediment deposition at field level where it may be reclaimed, and dissipate excessive runoff energy as flow is conducted down to channel level through the pipe.

In the saturated soils of the northwest, surface ponding of water is a common problem. V-ditches are used to open and remove ponded surface water from cropland, and to covey the water into a drainage ditch. The extent to which V-ditches carry sediment, specifically fine silts and clays, to drainage ditches is largely unexplored. The effectiveness of alternative methods such as cover crops and crop rotation in reducing surface sealing and sediment deposition is also not well documented.

Research needs:

Literature review issues

A majority of the stream and habitat research done in the Northwest has been focused in a forestry setting with some in urban landscapes, but relatively little has focused on lowland agriculture. Much of the research on agriculture and streams has been done in the southeastern United States or in Europe. The full extent to which the research done in different areas is applicable to the northwest agricultural streams is difficult to assess. Research that focuses on ecological processes is transferable although the rates and pathways of the process are likely to be different in the frequently saturated soils typical in agricultural settings in the Northwest.

Prior to initiating new research, there is a need for a comprehensive assessment of stream conditions in agricultural areas of the northwest, including current temperature ranges, nutrient levels, bank stability conditions, channel migration zones, frequency of woody debris and pool occurrence, salmonid and other species presence, and biological community composition. This assessment will provide a description of the ecological conditions of the streams. This information can be combined with historical information to estimate which habitats have suffered the greatest losses. Examples of background information that should be developed are:

1. What are the concentrations and loads of various nutrients and chemicals in agricultural streams in western Washington throughout the year?
2. How do these values compare to similar streams not in agricultural settings?
3. If the nutrients and chemical levels are different in agricultural settings, how are stream food webs (i.e community compositions) affected ?
4. If the aquatic community composition has shifted, how are fish affected?
5. What is the condition of the channels in agricultural lands: are they aggrading, degrading, does that channel have room to migrate, are the banks hardened?
6. What kinds of buffers (e.g. species, width, height, etc.) exist along agricultural streams throughout Western Washington?
7. Does the type of buffer affect its functions?
8. What are the temperatures throught the year in agricultural streams?
9. Are the stream temperatures potential problems either acutely or chronically for salmon?
10. What is the change in amount of stream habitat type in agricultural areas compared to historical conditions? Has this affected some salmon species or some salmon life-stages more than others?
11. What is the source and quantity of flow in agricultural streams throughout the year?
12. What are ‘typical’ agricultural practices and how might they affect the aquatic environment?

After identifying stream and watershed conditions through the assessment, research should begin testing methods used in other regions and new methods suitable to the Northwest to control organic inputs, sediment delivery, stream temperatures and other habitat conditions in Northwest agricultural streams. Specific research will depend on what conditions are found in Western Washington streams.

Based on agricultural research in other areas, the following topics are expected to need to be studied in Western Washington. Local information on the relative importance of salmon, alders, fertlizers and hyporheic exchanges in areas with and without buffer zones to nitrogen transformation processes will be needed. If changes in food webs are found in agricultural streams, research will be needed to identify the effects on the food quantity and quality available to salmonids. If sediment inputs are creating problems in bed composition or channel morphology, ways to prevent the input need to be evaluated. If stream temperature is identified as a factor, then studies on the source of excess heat input need to be done. This will include assessing potential changes in ground water/surface water interactions and shade effects. Identification of the largest loss in historical habitat will point the way to where some of the biggest gains in habitat restoration will be made for salmon production. This will most likely vary from watershed to watershed. In areas where agriculutural inputs to streams are found to be problematic, studies to determine better management practices should be undertaken.

Final comments from participants in the April 2001 meeting

The final comments from the meeting sponsored by CSS in April 2001 are discussed with respect to the literature review findings. Only those final comments that were relevant to scientific research, as opposed to policy and implementation issues, are discussed below.

1) "What is the primary limiting biological habitat [factor] for fish [salmonids]?"

In order to determine the primary limiting factor(s) that affect salmonids, a watershed scale perspective is important. Both the physical and biological factors that affect salmonid habitat conditions must be addressed and both short and long-term analysis must be conducted (see number 7 above). There is a pressing need for research relating fish community composition to habitat characteristics (Bisson et al. 1992). However, given the number of factors that affect salmon through-out their life-cycle and the natural variability in many of these factors, statistically valid results will take many years to collect. It is very difficult to separate changes in fish population due to natural variability and changes due to a specific land use activity. (Brookes 1988). In the meantime, work identifying other stream organisms or characteristics that effectively measure stream ecosystem condition should continue. Various agencies are funding this type of work including the USDA and EPA. The NMFS and USFWS 'Matrix of Pathways' that describe factors affecting salmon identifies critical habitat components for salmon.

2) "Does (increased) nutrient runoff from agriculture increase the potential for eutrophication, or provide useful nutrients to salmonids?"

   It is well documented that increased levels of nutrients leads to increased primary productivity (McColl 1978). Anything that affects the food web that the fish depend on will affect fish. The process of eutrophication is very site specific; some systems are nitrogen limited and therefore will respond rapidly to any increase in nutrients; other systems will respond slowly. Some systems are nitrogen saturated but phosphorus limited and therefore increased primary productivity will only be seen with additions of phosphorus. Identification of the current nutrient state of agricultural streams and the identification of reference sites or other means to assess historical conditions is needed to make decisions about whether agricultural nutrient inputs are a problem for fish. More work is needed to fully understand nitrogen transformation processes and the relative contribution of agriculture, salmon, alders, buffers, ditches, and hyporheic exchanges in providing nitrogen and other nutrients and/or pollutants to riparian areas.

3) "How can natural ecosystem processes, under managed conditions, be best used to protect and restore salmonid stream ecosystems, while allowing farming to continue?"

This question gets at the heart of the issue. Western Washington agriculture is a highly diverse activity ranging from various horticultural crops such as berries and tulips to forage crops for livestock and pasture for dairies. Answers to this question will depend on individual farm crops and practices.

Summary

This report has summarized the existing literature, its relevance to agriculture in the Northwest, and described the effects of various management practices currently in place. Data gaps exist in the current scientific literature pertaining to the degradation of streams in agricultural lands in the northwest. The most pressing areas in which we need a better understanding are:

1) Buffer function: This information is needed so that more efficient and effective buffers can be designed and managed that protect streams from agricultural runoff and sedimentation in the saturated northwestern soils. Specifically what is:
    a) The effect of vegetation type on nutrient and sediment retention in the stream and on the banks?
    b) The appropriate buffer width that allows for natural functioning conditions to be sustained, such as shade, bank stability, organic matter and large woody debris recruitment, and filtration of nutrients?

2) Hydromodification impact:
    a) What is the role of ditches in transforming and transporting nutrients and sediments to streams?
    b) What is the extent to which tillage and V-ditches deliver sediment to streams and how can we evaluate the effectiveness of alternatives such as cover crops and rotation?
    c) What is the role of subsurface flow, as a delivery system to streams, and as an area for denitrification?

d) How has the stream network in the lowlands been changed by ditching and draining and what effect does this change have on stream ecology?

Figures:

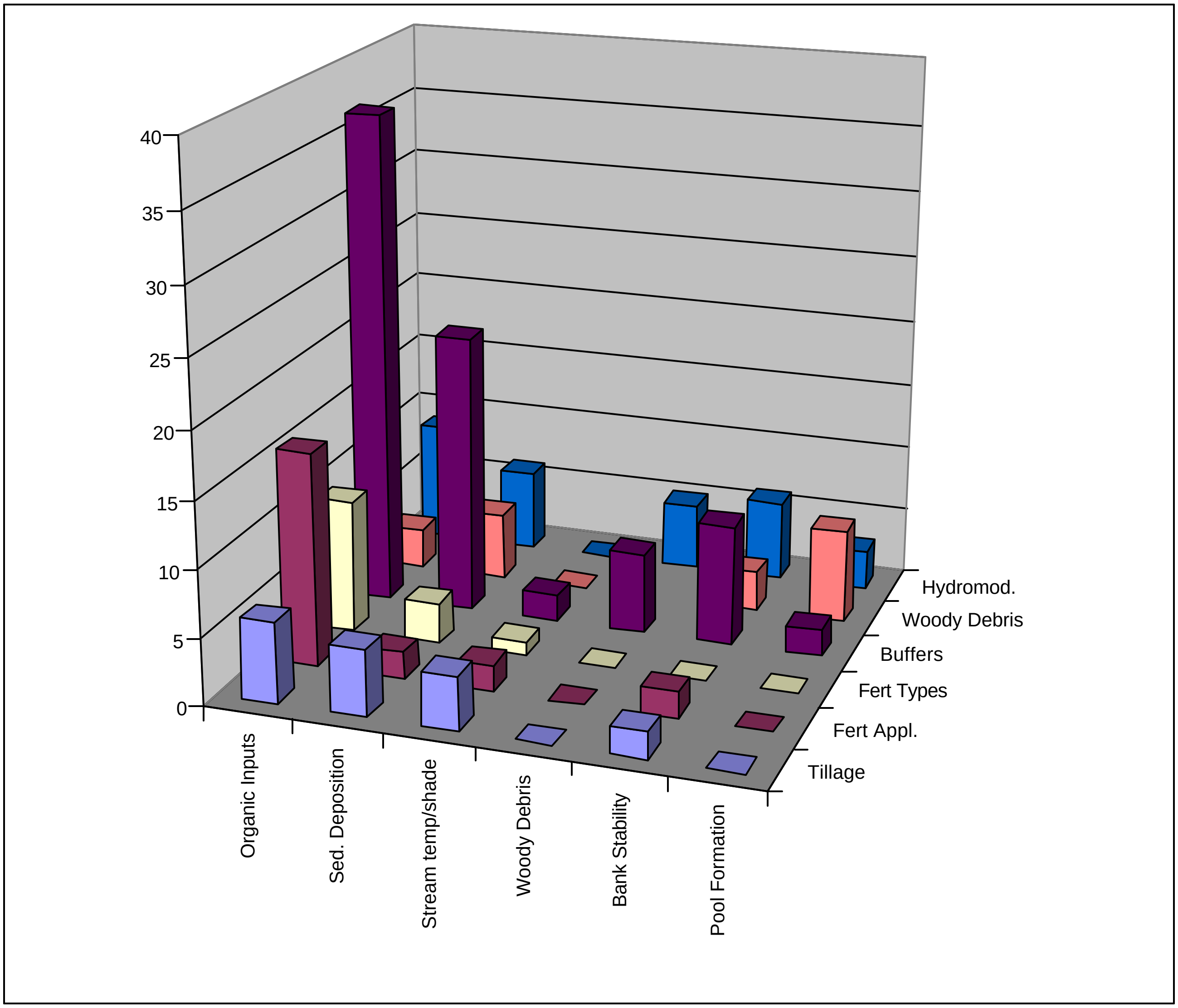

Figure 1: Frequency of occurrence of environmental factors that affect salmonids on the x-axis crossed with management techniques used in agriculture.

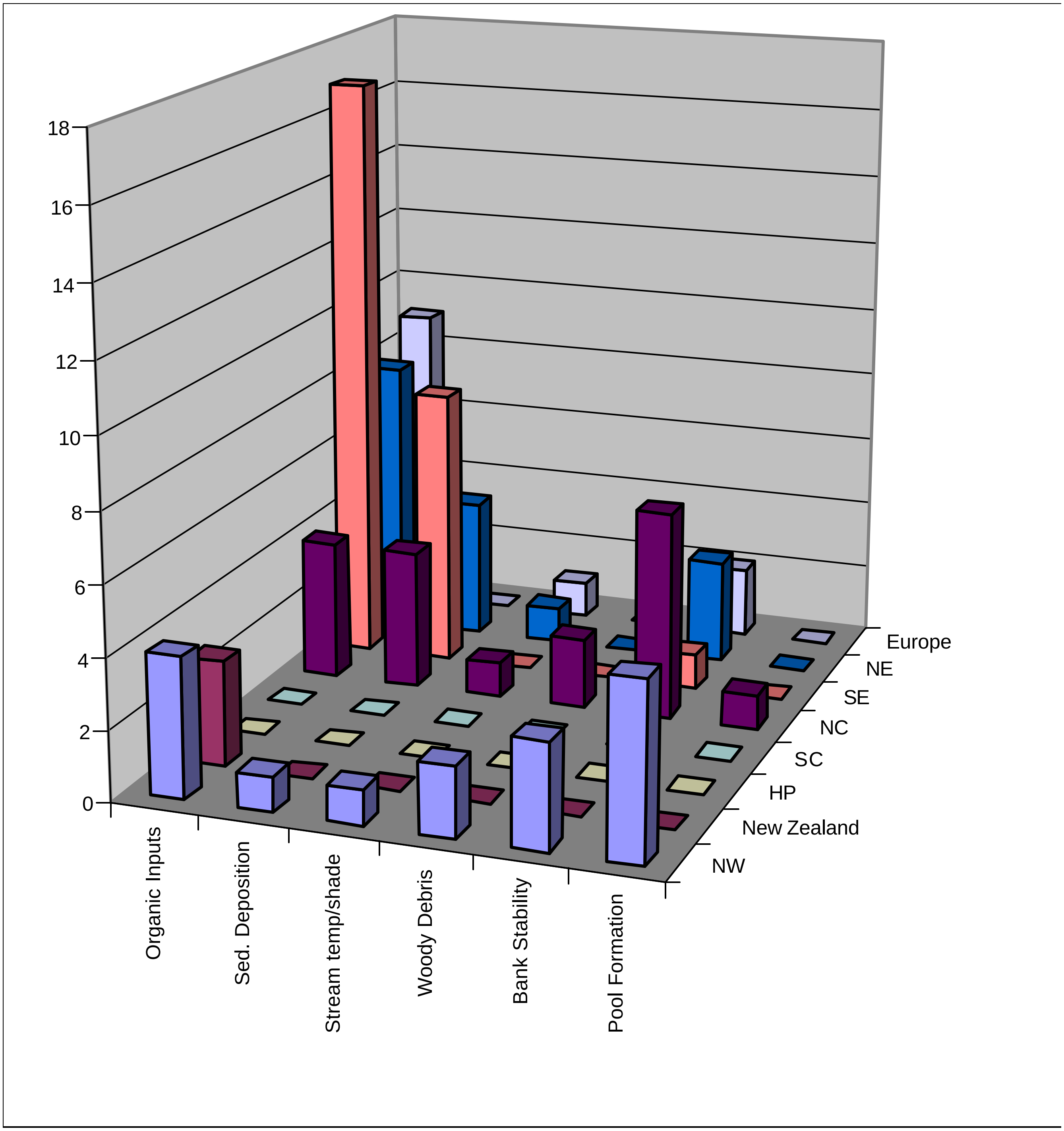

Figure 2: Frequency of occurrence of environmental factors on the x-axis crossed by region.

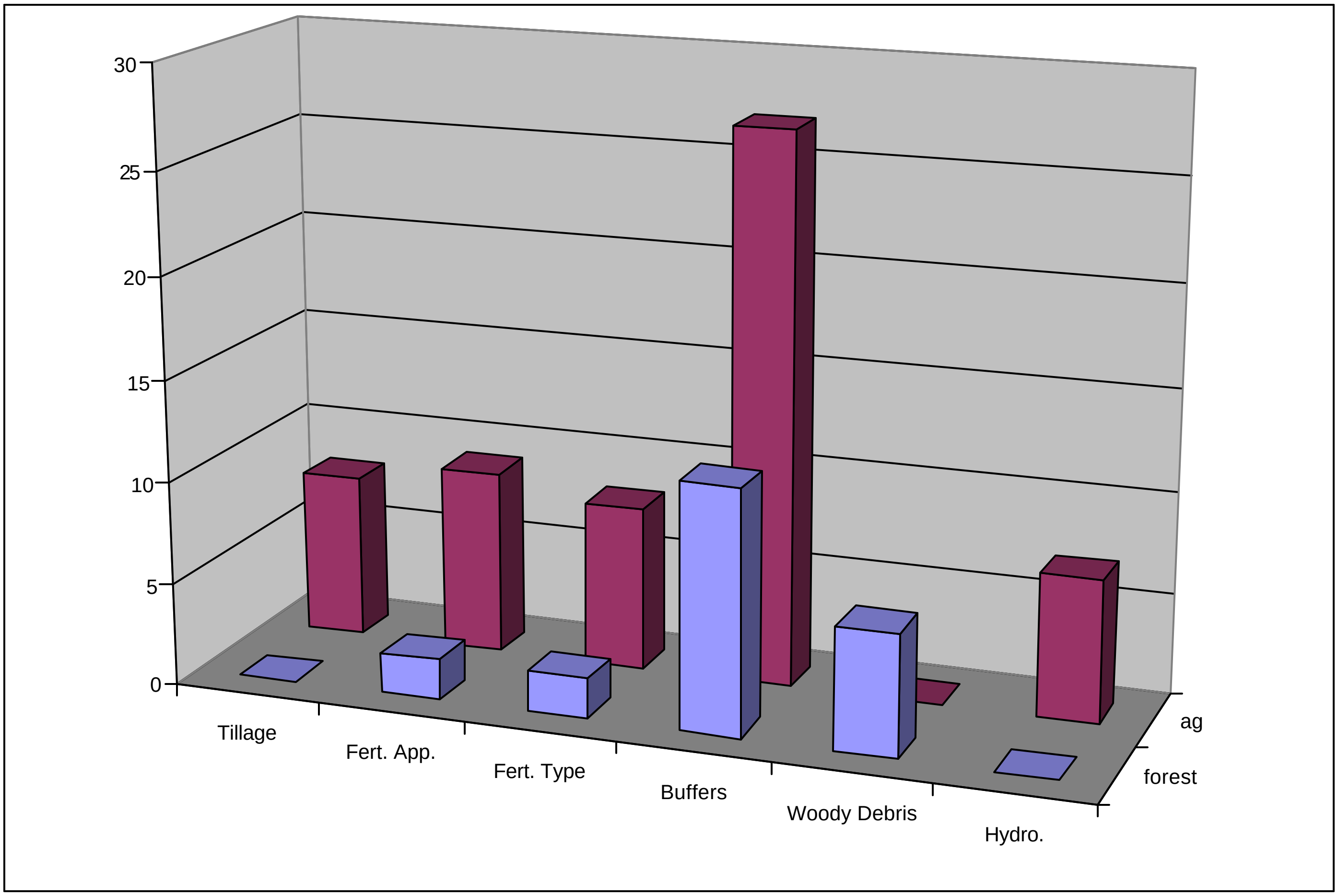

Figure 3: Frequency of occurrence environmental factors on the x-axis crossed with ecosystem.

Appendices:

Appendix A: All References Found in the Search (note that due to variations in databases used to assemble references, the formats and numbering are not consistent, but all information that was available is included)

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Appendix B: Participant input

Participants were requested to identify and list in order of importance 3-5 critical scientific questions that need answers for management of agricultural lands with respect to ESA and CWA.

Individual Comments
1. Use of ag areas by juvenile Chinook – is it an integral part of their life cycle?

2. Causes of decreased dissolved oxygen in ag areas/prevalence of decreased dissolved oxygen in ag areas

3. Habitat value of reed-canary grass for salmonids (prey items, cover)

4. Functions, values of riparian zones for salmonid habitat

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1. Per watershed, what % of historic rearing habitat is needed for restoration to further enable recovery of salmonid population, i.e. chinook – implications to agriculture

2. What is the cumulative impact to receiving waters from poor water quality (increased temperature, decreased DO, fine sediment) from ag lands

3. In flood events, what species and quantities of salmonids are "introduced" behind dikes and pumphouses? What is the expected mortalities?

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1. Biological impact of buffer on agricultural production/profitability to include pest and beneficials associated with buffer plantings.

2. For a given stretch of river/stream/ditch, what role does it play for salmon survival (rearing, spawning, etc) and how does that relate to overall salmon spp survival. What are the population growth limiting factors (see work by Crowder et al on sea turtles for idea)

3. Identifying which life stage parameters of salmon ag can and does ipact and how those factors rank relative to impacts by other land-use options (e.g. forestry, development, etc).

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1. How do agricultural lands and their impacts to listed fish and CWA relate when compared to the entire watershed* (i.e. are ag lands limiting factor, development, forest practices?)

* This question needs to be weighed/evaluated based on importance of floodplains, estuaries, wetlands, etc for fish and clean water, not just overall percentages.

2. How do land uses and zoning regulations limit what can and can not be done to restore riparian functions? Even if farmers are willing (i.e. rights or legal restrictions of drainage districts, corps of engineers rules on dikes and boms?, zoning, regulations, county right of ways and road maintenance issues, etc)

3. If modifications and land use practices in the lower watershed are found to be limiting/primary restriction for recovery of listed fish, there needs to be a recognition of this fact and compensation for farmers.

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1. What proporation of ag lands/streams is required to maintain viable/harvestable fish in a basin?

2. What is the priority of ag related problems (in order of importance) that have the single greatest impact on aquatic ecosystems?

3. How does drainage affect hydrology?

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1. What are the ?? criteria for establishing recovery priorities in ? floodplain landscapes?

2. What is the effect of tiling on floodplain hydrology/???

3. What riparian conditions/plant species best support ?? benthic/?? communities in low gradient sediment substrates in western Washington?

---

1. Define what the real limiting factor is in the productivity of the watershed.

2. What is the impact of harvest on productivity of the watershed (both sport and commercial)?

3. Where are the potential restoration sites that will provide the most cost effective return with minimal reduction in ag activities?

---

1. How is ESA & CWA going to affect the ag community with regards to the salmonid spp?

Many floodplain areas were historically covered in vast wetlands. How can we move beyond restoring ditched channels to restoring wetlands?

How can we provide access and functioning habitat in areas that are isolated by pumpstations?

How can the issue of ditch dredging be addressed?

Reed canary grass – control and management

Drainage, maintenance, and clearing
- How to keep ditches functioning to remove water but yet keep ESA and CWA compliance?
- Sediment downstream

Ditches fill with sediment
- Where does this sediment come from
- How to keep sediment in place
- Options/alternates to keep sediment from getting into

V-ditches
- Study or need for
- Options or alternatives
- Impacts to salmonids and CWA
- Negative slope to fields

Buffers
- Models to determine widths in NW Washington
- One side v. 2-sided
- Continuous v. segments

---

1. If targets for successful riparian function can be established, how can you model stand characteristics over time to determine if a developed stand is on the proper trajectory.

2. With the alterantion of hydrological function that has taken place due to agricultural practices, what is the appropriate mix of tree species that should be established in riparian stands. How would this be determined on a site by site basis?

3. What geomorphic changes and what type of fish use can we expect with the introduction, either through natural or mechanic means, are large wood in low gradient ag streams?

4. What are effective methods of reed canary grass eradication?

5. What is the range of "upstream" movement of juvenile fish in sloughs and streams no longer encumbered by tide gates?

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1. Impact of loss of land base for nutrient management – dairy farms

2. Impact to farming – loss of land, small field <u>not workable</u>
-- shade/competition
3. (Hydromodification) Dredging districts manage of the newly establish riparian buffer so basically drainage v. flood management

---

1. Are the various jurisdictions referencing the same literature and science /data (different data means different policies!)

2. How to best maintain agriculture waterways with safeguards for fish health/habitat?

3. What is the minimum buffer that can achieve an improvement over existing degraded habitat (which in most cases was legally established prior to the fish crisis)?

4. How do we best achieve temperature reductions with regards to maintain productive ag land?

---

1. What are the limiting factors for salmonid habitat in watersheds, sub basins, and river/stream reaches that are adjacent to agricultural lands?

2. How can natural ecosystem processes be protected and restored in areas with agricultural land uses while simultaneously continuing farming?

3. What are some new innovative "fish friendly" and "water quality friendly" farm practices?

How can you mitigate for loss of the channel migration zone or can you mitigate for its loss?

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1. What species (and at what life history) are using ag ditches?

2. What are the habitat requirements of these species – temp, DO, complexity?

3. To what extent are the laws currently on the books being enforced? Are those laws adequate?

4. To what extent are ag rearing habitats inaccessible to salmonids – pumphouses, bad culverts, tide gates?

Riparian forests
1. conversion of ag soils to forest soils

2. silvicultural system design
   managed v. unmanaged
   extent of forest cover
      continuous v. intermitent
   species mix, structural targets/goals and range of functions

3. once established regulatory certainty that these riparian/ag forests will be able to be maintained

Channel dynamics
4. how to reconnect and design where channels should/would be best to migrate

5. design of forest-channel interface to provide periodic supply of large wood

---

What are effects of various agricultural practices? E.g., what are effects of pesticides at occurring levels?

What are the mechanisms responsible for these effects? E.g., how do these effects take place?

Will changing them have a significant impact on salmonid population? E.g., how big a factor are they in salmonid reproduction, survival, behavior?

What are costs associated with changing agricultural practices? E.g., will producers be able to adopt changes? What kind of regulatory/enforcement effort will be required?

---

1. How should BMPs be different in an ag setting v. forested uplands?

2. What indicators can be used to determine success/failure of a buffer? On what time scale?

3. How can wetland restoration be used in ag land to help with drainage issues?

4. We know what needs to be done to help farmers. What is necessary to help fish? How far are we willing to go? Are we willing to hurt farmers in order to preserve fish?

5. What impact do poorly installed drainage tiles have on drainage and the need for dredging?

Assuming we want to keep a healthy/sustainable ag industry, how do we identify opportunities to contribute to recovery of salmonids?
   Constructed refugia v. re-establish cooridors?
   Engineered cover v. walk away?

What contributions/impacts do non-native plants have?
   Reeds canary grass, Himalayan blackberry

What restoration strategies make the "best" economic sense (cost/effectiveness, tradeoffs)?
   eg 5% of land? 10% of land? 50 % of land?

Seral plantings v. climax?

Effects of various plant species composition in riparian buffers on ag (on habitat/fish)

Effect of surrounding ag or re-opened habitats (cost of increased floodplain function on ag)

Trade-offs (economics included)

Differences between ag/fish relationships along mainstem, estuary, small tribs

Effects of upland development on ag effects.

---

1. Do agricultural activities in fact contribute to declining salmon populations? (The implicit assumption from this morning's presentations is that agriculture is bad for fish)

2. What is the key salmon habitat factor that is known, could be altered and have the greatest impact on salmon populations?

3. What are the true costs to farmers and society to make wholesale changes at landscape levels to save/increase salmon populations?

---

1. What is the range of buffer widths needed on the agricultural landscape to provide properly functioning conditions for fish and to meet CWA standards?

2. What is the input rate for sediment, from various agricultural practices, to stream systems?

3. What is the relationship between stream channel width, and/or depth on the size (width) of a riparian buffer to protect properly functioning conditions in the stream?

4. What is the relationship of the channel migration zone (CMZ) to the protection provided to the stream by a riparian buffer?

What are the ecological requirements to enable self-sustaining riparian, wetland and other aquatic resource functions to protect and enhance aquatic biodiversity (and not just listed salmon)?

---

1. Identify sociological factors that a) inhibit and b) stimulate public (ag landowners) participation in salmon restoration.

2. How to compensate landowners for loss of economic value of buffers – tax incentives, etc, to shift cost from property owner to public.

3. Identify factors that contribute to a) success and b) failure of past revegetation efforts and then use this as a beginning to design and conduct further investigation on strategies to improve revegetative success.

Political and Policy
What are reasonable standards of "protection" for salmon and what are we willing to pay, who is willing to pay to meet these standards?

Beyond AG
What are the realtive impacts of exsiting urban aeas on salmon habitat? Political pressure to exempt these areas and focus on politically challenged agricultural areas.

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1. habitat loss – historic/current

2. buffer widths/ beg composition

3. water quality (hydrograph) maintenance (from one - development conditions)

4. water quality (improvement for maintenance of pre-development conditions)

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1. To what extent does shade impact water temperature?

2. What functions important for fish (good and bad) are provided by natural water course meander, and how might they be better provided or mitigated with/by human intervention?

3. What will the economic impact be from removal of ag land from production? How to quantify?

What are the key processes that can alter water quality in an ag riparian setting?

Would created/treatment wetlands be as or more effective than "traditional" upland buffers in improving water quality and in minimizing effects of ag hydromodification techniques?

How can riparian ag soils be modfied/amended to improve tree and shrub growth?

How do we deal with bank erosion that would follow conversion of grassy riparian zone to forested?

What are the limiting factors or key indicators tied to the ESA and CWA for the geographic area of study?

What agricultural practices influence the key indicators?

What indicators are most at risk (i.e., not meeting desired target values)?

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1. How veg. type effects buffer nutrient retention properties?

2. The effect restoration efforts have on re-establishing fish-habitat structure in the long term.

3. How the hydrologic ?? in the buffer affects nutrient retention?

---

1. Nutrient uptake/leaching data is something that has been done to a certain extent, but it seems like there's a gap in the literature in terms of comparing planted to pre-plant sites as well as comparing planted buffers to natural ones. The long-term nature of such a study probably explains why little work has been done on this. Also, this sort of data (combined with turbidity, etc) might be useful in monitoring because the effects might be shorter-term than the return of salmonids to systems.

2. Effects of site prep (e.g. herbicide) on systems

---

1. What are (have been) effects of current (historic) ag practices on salmon habitat (other than diking/draining)?

2. What changes to these practices can help salmon recovery—or must they be discontinued?

3. Do different types of ag activities (e.g. crops, pasture) affect salmon habitat in different ways? If so, how?

Effects of non-native vegetation (weedy species) on flora and fauna of salmon-bearing streams (and sedimentation, etc)

Buffer width requirements (and composition) for active filtration of nutrients and pesticides commonly used in agricultural production.

Controlling vertebrates in buffer areas during riparian buffer establishment.

Long-term effects of fertilizers and pesticides on salmonid behavior.

? for and historical levels of dissolved O_2 in agricultural streams.

Marine-derived nutrients of other nutrient sources – how much is the right amount for salmonids? When and where?

Meanders and channel migration: lower gradient stream energy, sediment budgets, and fish habitat

Stream reach occupation by salmonids: refugia and microhabitats over time w/spp interactions

Low gradient stream heating models: effects of shade, volume, groundwater inflow, hyporheic

Bring back trees, shate, beaver, meanders, temp, blockage, failure of drainage systems (over time) – what to do?

Utility of natural meander/ channel freedom

Buffer composition

Reed canary positives/negatives

Where and why are fish, life history analysis?

Effects of riparian buffer (i.e. insect biology/economics) on adjacent farmland

How do we properly monitor returning fish (given ? catch, natural productions) to assess juvenile survival?

What is the key limiting factor that agriculture creates? This will determine first step.

1st Group
Individuals then formed small groups to combine their lists into one.

Group comments
1. What species are using ag “ditches” (water courses) and at what life history stage?

2. How may the loss of land base affect nutrient balance and adjacent buffer lands – i.e. shading and field size (are we protecting fish at the expense of ag viability?)? Economic implications of buffer requirements.

---

1. Ecological requirements to enable self-sustaining wetland and then aquatic resource function to protect and enhance aquatic biodiversity (not just salmon).

2. Identify sociological/economic factors that inhibit and stimulate public participation in salmon restoration.

3. How to compensate landowners for economic value of buffers?

4. Facotrs that contribute to success and failure of past aquatic ecosystem protection efforts and use as start to design and conduct studies on revegetation success.

---

1. What are the limiting factors for sustainable salmonid populations in ag areas?

2. To what degree does the current indicator/pathway matrix, primarily developed for silvicultural areas, apply to ag areas?

Buffer composition
- What kind of plant species (given hydrology/current conditions)? What is goal?
- Implications economically and practically to adjacent crop

Reed canary grass issues for eradication (and other invasives)

Consistancy of science for policy decision (also across landscapes – e.g. urban)

BMPs – tie more ecological and scientific info now mainly for clean water and not fish. What can we use as indicators of success?

What is the role of wetlands in ag lands and which should be buffered and protected (not all of use to salmon) and what was the historic role of wetlands in ag lands and how can that be incorporated into BMPs and habitat restoration, can we restore wetland processes to ag lands?

---

1. What are economic tradeoffs between restoration strategies?

2. Assuming we want to keep healthy/sustainable ag industry, how do we identify opportunities to contribute to recovery of salmonids (constructed refugia, natural/engineered ?)?

3. What contributions/inputs do non-native plants have on watercourse?

Drainage, maintenance and clearing
- How to maintain function of ditches and yet have fish habitat and meet CWA (dredging effects)

Fish passage issues (pumpstations, tide gate, flood gates, sediment basins)
- How can fish passage issues be addressed?

Buffers
- How can riparian forests be restored in ag areas?
  - Models to determine width
  - One sided v. two sided
  - Width along different ag watercourses – natural, modified natural, constructed
  - Food source from willows, benthic invertebrates

How do dikes and dredging affect the hyporheic zone?

Restoration “triage” – which streams and which reaches (refugia, microhabitat, DO, temp, etc)

Agricultural practices, and cropping systems which are most beneficial/detrimental to salmonids

Effects on non-native vegetation on flora and fauna of salmon-bearing streams

Marine-derived nutrients or other nutrient sources—how much is the right amount for salmonids? When and where?

Do increased nutrients from ag runoff increase the potential for eutrophic conditions (e.g. degreased DO, increased algea production)?

---

1. What are the nutrient uptake differences between vegetation types in riparian buffers?

2. What is the range of buffer widths needed on the agricultural landscape to promote properly functioning conditions for fish to meet CWA standards (e.g. applicability of FEMAT standards to ag streams)?

3. What is the input rate for sediment from various agricultural practices to stream systems?

4. What is the relationship of the channel migration zone to the protection provided to the stream by a riparian buffer?

---

1. What are the desired standards of protection for salmonid habitat and who should pay?

2. What are the limiting factors and standards for salmonid habitat in watersheds and basins and river/stream reaches that are adjacent to agricultural lands?

3. How can natural ecosystem processes be protected and restored in areas with agricultural land uses, while simultaneously allowing farming to continue? (How to balance fish and farms?)

---

1. What role do typical ag land streams/basins play in maintaining aquatic ecosystems that support viable populations of salmonids/fish?

2. What is the effect of drainage/tiling etc. on floodplain functions (i.e. wetlands, water table, salt-water/estuary functions)? Is it still sustainable for agriculture?

3. Step-down process to evaluate limiting factors within the watershed

---

2nd Group

1. Buffer composition – What plant species?

2. How does riparian buffer impact the economics of farming – i.e. adjacent lands lost shade, uneconomical field size, nutrient management?

3. Reed canary grass – How do we deal with invasives in restoration

4. What species are surviving and where do we live and why?

5. Consistancy of policy and regulation across jursidiction and land use for implementation and enforcement

---

1. Are riparian buffers helpful? Ripairan buffers (patches):
   - widths (include 0)
   - species composition
   - degree of active management
   - stand structure
   - "riparian landscape design"

(ag costs, temperature, water quality, habitat types)

2. Wetlands

---

1. Given that floodplain functions (providing areas (tidally influenced) for fish to smoltify) have been drastically altered by land use practices (i.e. rearing habitat, overwintering, migration etc), how do we prioritize and implement recovery projects in these areas (nickel and diming ditches to death may not save fish)?

2. How to maintain the function of ditches and yet have fish habitat and meet the Clean Water Act?

3. How can the altered hydrology of the former estuaries/ floodplains be restored without losing the farm (pun) to development?

4. Buffers – How can riparian functions be restored in ag areas (riparian vegetation) – need to model buffer widths – functions on one side v. both sides regarding temerpature/DO, effects of reed canary, benthic communities?

5. Historical perspective – How much of lower watershed and in what way have things been altered in past 100-150 years – effects on fish habitat and water quality?

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1. Nutrient cycling properties of different vegetation types, including invasive spp. by/in the riparian zone.

2. What is the effect(s) of ag practices and cropping systems to salmonid stream ecosystems?

3. How do we choose how and where to locate restoration activities/efforts to take best advantage of salmonid life stage and habitat needs.

4. To FEMAT or not to FEMAT – That is a research question; do we use SPTH?

5. Does increased nutrient runoff from ag increase potential for eutrophication, or provide useful nutrients to salmonids? When? In which forms? Through which biological pathways?

---

1. How can natural ecosystem processes be protected and restored in areas with agricultural land uses, which simultaneously allowing farming to continue? (How to balance fish and farms?)

2. What are the limiting factors and/or standards for salmonid habitats in watersheds, sub-basins, and river reaches that are adjacent to ag lands?

3. Identify socioeconomic factors that inhibit/stimulate public participation in salmon restoration.

4. Factors that contribute to success and/or failure of past aquatic ecosystem protection efforts and ? to design and conduct future studies

5. To what degree does the current indicator/pathway matrix, primarily developed for silvicultural areas, apply to ag areas?

3rd Group

1. How can natural ecosystem processes, under managed conditions, be best used to protect and restore salmonid stream ecosystems, while allowing farming to continue?

2. How do we choose where to focus our restoration efforts; e.g. what are the limiting factors for salmonid habitats? (Learn from our experience and adaptive management)

3. Identify the socioeconomic factors that inhibit or stimulate public participation in salmon restoration.

4. To what degree does the current indicator/pathway/matrix/FEMAT developed for forestry apply to agricultural areas?

5. Does (increased) nutrient runoff from ag increase potential for eutrophication, or provide useful nutrients to salmonids? When? In which forms? Through which biological pathways?

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1. What is the primary limiting biolgoical habitat for fish? Is it ag lands?

2. Design proper standards to address limiting factors
    buffer composition
    wetlands, flood
    dredging water ways, ditch

Appendix C: Analyzed References on Agriculture and Salmon

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Appendix E: Evaluation of Pilot projects under CTED

An additional deliverable of this project, in agreement with Snohomish County, was an evaluation of pilot projects currently underway that are operating under funding from Washington State Department of Community, Trade, and Economic Development (CTED). We have received information on two pilot projects in Whatcom County and one project in King County.

Whatcom County Projects:
In Snohomish County a graduate student from Western Washington University is working on a two-year study on the effectiveness of different planting strategies to establish buffers in reed canary grass in marginal pasture or agricultural land in the lowland portions of the Nooksack Watershed. A graduate student from Huxley College of Environmental Studies is working on a two-year study on the effects of restoration of meanders to straightened lowland streams in the Nookasack Watershed.

Both students are required to carry out an initial literature reviews specific to their area of focus and to review existing projects in Whatcom County, under the CREP program, Nooksack Salmon Enhancement Association, Lummi Nation Department of Natural resources, Nooksack Tribe of Indians and other governmental agencies and non- governmental organizations. Both students are then asked to proceed in consultation with professionals involved in Riparian Restoration Monitoring Protocols to establish which parameters should be measured.

Complete study designs were not available at the time of this review for either project and the existing documents are vague. Therefore the actual steps being taken to achieve these goals cannot be evaluated. Neither reed canary grass or remeandering of streams through restoration were specifically identified as critical research needs in our review. However, to the extent that these address limiting factors for salmon, are selected based on overall watershed critical areas and have rigorous study designs and measureable objectives, scientific information will be generated. A formal description of current conditions in the Nooksack and identification of limiting factors for species at risk is recommended.

King County Projects:
We received two documents from King County, one titled “A research proposal relating to agricultural drainage maintenance” and one titled “Overview of the monitoring activities for the King County ADAP”. It is not clear if these projects are the same or are two separate projects. The goals of the “Research Proposal” document are general and discuss evaluation, assessment and determination of various items. The methods section of this document is very preliminary and does not have adequate detail for evaluation. The “Research Proposal” document says “the County will analyze the effects of agricultural ditch maintenance and identify means to avoid, minimize or mitigate any negative impacts that may result”. There is insufficient detail for us to evaluate the potential success of this proposal.

The “Overview” document discusses monitoring of maintenance actions on drainage watercourses. The stated ultimate goal is “develop an understanding of the ecosystem in these areas in order to develop mitigation technology which will effectively protect salmonids both directly and indirectly, yet not pose an unacceptable burden to the landowner or the county”. They intend to measure salmonid fitness via an objective measure but do not define what that measure is. The items that are listed as being monitored are outcomes or conditions, not items that will actually be measured. Without knowing what parameters will actually be measured, we cannot evaluate the likely success of the monitoring to meet its stated goals. None of four general areas that will be monitored, salmonids, geomorphology, vegetation and macroinvertebrates, will provide data or information about acceptable or unacceptable burdens on landowners or the county.

The “Overview” study intends to look at the before and after effects of “watercourse maintenance activities”. However, the time period for monitoring before and after maintenance activities is not stated, except that an “appropriate period of time” will be chosen to assess the effectiveness of the required BMPs. Neither are the “required BMPs” described anywhere in the study design. It is not clear if each BMP will be looked at separately or if they will be evaluated together.

Because of the undefined response variables involved in this project as well as a lack of explanation of how sites would be chosen, the scientific validity of this approach cannot be determined at this time. As noted in our main document, it is first essential to determine current conditions of waterways in agricultural lands before determining where to do research. The effects of hydromodification are an essential component to addressing the state of salmonid habitat in agricultural areas, but studies need to be statistically sound and well designed with clear and measurable objectives.

In Conclusion:
All of these pilot projects proceed by first determining environmental conditions before and after their specific treatment. However, the need/ importance of each of these specific pilot studies is not founded on current scientific information on the conditions in agricultural streams in the northwest, because there is no such information available. Therefore, it is preferable that information be collected on the current environmental conditions in agricultural streams prior to determining the specific topics of these pilot projects. However, as they stand today, the pilot projects do focus on valid biological as well as physical factors affecting salmonid habitat conditions. The questions are whether they are the most important variables affecting salmonid habitat, and whether or not they will be carried out in a scientifically rigorous way. The main concerns with respect to scientific validity of these projects are their proposed time line, and the ability to clearly determine and define appropriate response variables.

Appendix F: Description of agricultural lands in counties

Based on information received from county personnel.

Whatcom County

Information requested but none received.

Skagit County

Provided by: Richard Doenges

Skagit County Farmland Legacy Program

Skagit County's agricultural zone is characterized by fertile soil, flat topography and mild climate making it one of the most productive agricultural regions in the nation. Overall, farming produced more than $181 million in gross income in 1996 from a diversified farming system that boasts 70 commercially significant crops and 56 active dairies. Famous for its flower bulbs and flowers, Skagit Valley's Tulip Festival draws one million visitors each spring, generating $65 million in revenue for area businesses. Sharing this agricultural abundance are all five species of salmon and steelhead on the Skagit and Samish Rivers; more than one-third of threatened Puget Sound Chinook return home to the Skagit River. Additionally, large numbers of birds, including bald eagles, other raptors and waterfowl reside or visit the Skagit agro-ecosystem, including 1,300 trumpeter swans, 30,000 snow geese and about half-million ducks. Skagit farmland is a critical resting and feeding area for these migratory waterfowl.

Nearly all of the commercial agricultural land is located in the GMA designated Agricultural-Natural Resource Land (Ag-NRL) designation. The Ag-NRL boundaries closely match the 100-year floodplain of the Skagit and Samish Rivers and include about 92,000 acres of the 1.1 million acre County land base. According to the 1997 USDA Census of Agriculture, there are 73,028 acres of cropland and nearly 10,000 acres of irrigated land. Excessive soil moisture is the limiting factor for farming in this floodplain area. Diking and drainage districts have constructed well-developed systems dikes, levees, drainage ditches, floodgates, tidegates and pump stations designed to move water off cropland located primarily east of Interstate 5. Dikes on the mainstem of the Skagit River also protect the cities of Burlington and Mount Vernon. A GIS analysis of land elevations in the former delta area indicated that approximately 30,000 acres of prime farmland would be inundated during a high tide if all the tidegates and bayfront dikes were removed.

According to DNR hydro data there are approximately 330 miles of shoreline and fish-bearing streams in the Ag-NRL. Additionally, there are about 270 miles of non-fish bearing waters (Types 4 & 5). Under the current Critical Areas Ordinance, nearly 70% of the stream and shorelines are, or will be, subject to riparian buffer requirements. Assuming a 75-foot minimum buffer width, approximately 2,525 acres of farmland will be managed for riparian functions with nearly half of this area already not in agricultural production. A great potential exists for restoration of estuarine habitat for juvenile salmon by converting existing bayfront agriculture if effective drainage for adjacent cropland is not compromised.

King County

Provided by: Ken Carrasco, Senior Ecologist

King County Department of Natural Resources

Water and Land Resources Division

King County has an estimated 325 miles (520 km) of streams of which some 25 miles (40 km) are mainstem rivers and the rest are channelized streams, artificial ditches or natural streams. Most King County streams are relatively low gradient and currently provide either rearing or overwintering habitat. Water quality varies across the county. County farmlands have been placed in one of five agricultural production districts (APDs). Out of a total of around 1,400,000 acres (ha), 40,560 acres (16,414 ha) are in an APD. Agricultural uses in King County range from dairy and horse operations to vegetables, flowers and other horticultural crops.

Table F-1. Percent pasture, crop and forest land in each King County APD

Agricultural Protection District	Enumclaw	Upper Green	Snoqualmie	Lower Green	?	
Pasture	75	33	37	?		
Cropland	<1	16	15	?		
Forest	19	46	16	?		

The Enumclaw APD has many channelized streams and ditches with streambanks degraded by livestock access. There are significant water quality and temperature problems in this district aggravated by poor riparian stand conditions. The Lower Green APD has a moderately well buffered mainstem but there are extensive networks of levees and dikes that affect connectivity of the mainstem and the floodplain. The Snoqualmie APD has a largely unbuffered mainstem with banks historically degraded by livestock. Many of tributaries in this APD have been channelized.

King County has a Farmland Preservation Program in which 31% of the APD lands in the county have entered. Science 1995, a livestock management ordinance regulates animal densities, manure and pasture management, and watercourse fencing. Ditch maintenance rules were implemented in 1997.

Snohomish County

Provided by: Ryan Bartelheimer, P.E.
Snohomish Conservation District

Snohomish County has over 50 active dairies located in areas designated as Riverway Agriculture. In addition to the diary operation, these sites often grow grass and corn as forage feed for the livestock. Many former dairy farms are now heifer raising sites. Some seed and row crops are grown in floodplain areas with appropriate soils and growing conditions. Areas with good conditions include the Tualco Valley south of Monroe , the floodplain of the Stillaguamish west of I-5, the area north of Stanwood and the NE parts of Camano Island. An estimated 62,000 acres of agricultural lands are under GMA protection. More than 90% of these lands are in the floodplain areas of the Snohomish and Stillaguamish Rivers. The lower Snohomish up to Lord’s Hill is heavily diked and drained to maintain suitable growing conditions. Other agricultural areas in Snohomish County may be diked and drained, but to a lesser extent. Issues that are challenges for the Farm Plan process include over-winter manure storage for commercial livestock operations, adequate off-pasture wintering areas, effective handling of manure from non-commercial livestock operations and implementing sustainable farming methods for crop operations.