# Appendix A:

# THE EFFECTS OF AGRICULTURAL OPERATIONS ON CRITICAL AREAS

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The effects of agriculture in general and of particular agricultural operations and activities on fish and wildlife and their habitats have been well documented in various publications over many years. This appendix summarizes these effects as they pertain to the agricultural activities and critical areas in King County.

**Section A.1** of this appendix addresses landscape and local effects of agricultural activities in King County generally. Effects that are the result of historic (and present) changes in land cover and use across large areas of land are termed landscape effects. Landscape effects include several processes: fragmentation, substitution, and isolation. Among them local effects include both physical alterations to critical areas and pollution effects from agricultural operations. These are mainly site-specific and are most often the target of regulations and performance standards. The effects on specific critical areas are considered from both the landscape and local perspective. **Section A.2** of this appendix considers best management practices that are intended to control impacts from agricultural activities on critical areas and evaluates the efficacy of two best management practices in particular. **Section A.3** discusses the potential risks to the functions and values of critical areas given King County-proposed protection requirements on agricultural lands. **Section A.4** of this appendix presents major conclusions and **Section A.5** is a bibliography of literature reviewed.

## A.1 LANDSCAPE AND LOCAL EFFECTS OF AGRICULTURAL ACTIVITIES ON CRITICAL AREAS

### A.1.1 Landscape Effects of Agriculture

As land is altered from native cover to human uses for agriculture, both the area and continuity of native vegetation is modified and transformed from the original composition and arrangement to an alternative structure and function (see Best Available Science [BAS], Volume I, Chapter 2 Scientific Framework, for a general discussion of landscape effects). There are several processes associated with land transformation that have serious implications for wildlife and their habitats (Forman 1995). These processes generally represent stages in the transformation process from one type of landscape or patch to another. The process usually begins with *perforation*—the creation of "holes" in an otherwise homogeneous land or habitat area. This may result from carving out a small portion within the original landscape for a homestead or farm, or it may be the result of a blowdown or fire within a larger forested landscape. D*issection* may occur simultaneously as a road or rail line splits the landscape into sections and *fragmentation* occurs as the original landscape is further broken into unconnected pieces. *Shrinkage* is the decrease in size of any habitat or patch; *attrition* is the disappearance of habitat or patch types and leads, ultimately, to the *substitution* of a new landscape for the original one. The first three processes are largely the result of transformations that began in the mid-19th century in King County and reached their zenith around the turn of the century in most of our present agricultural areas. These transformation processes have continued through the 20th century and into the present as forested landscapes continue to be transformed to agricultural, suburban, and urban land uses.

Each of the spatial processes described above has distinctive attributes, and each exerts significant effects on a range of ecological characteristics from habitat structure to biodiversity to erosion to water chemistry. Perforation, dissection, and fragmentation may affect the whole landscape or a patch within it; shrinkage and attrition apply mainly to a patch or corridor within the larger landscape. Substitution, the ultimate result of attrition, results in conversion from the original condition to a wholly new one, and applies mainly to the landscape but is sometimes said of a habitat or patch as well.

## Agriculture Effects on Wildlife Habitat at the Landscape Level

Table A-1 presents the effects of spatial processes on four landscape attributes important to wildlife survival. As each attribute of the landscape is altered, the relationship among habitats and the species that occupy them is likewise altered. Migration patterns, reproductive success, exposure to invading species and predators, are modified as populations are split and isolated. As habitats shrink, they are no longer capable of supporting populations large enough to maintain themselves; many populations are locally extirpated even though some attributes of the habitat remain. Reviews by Capel et al. (1993) and Berner (1988) attest to agricultural effects on nesting bird populations at this large scale.

**Table A-1. Effects of land transformation on wildlife. Major processes are listed in the first column and their effects on landscape attributes important to wildlife follow. A + = increase; A - = decrease; and a 0 = no change.**

| ***Spatial Process*** | Patch Size | Connectivity | Habitat Loss | Isolation |
|---|---|---|---|---|
| Perforation | - | 0 | + | + |
| Dissection | - | - | + | + |
| Fragmentation | - | - | + | + |
| Shrinkage | - | 0 | + | + |
| Attrition | + | 0 | + | + |
| Substitution | +/-/0 | - | + | 0 |

According to Edge (2001), agricultural habitats in Oregon and Washington support 342 species of wildlife—more than any other habitat. This high diversity is the result of the broad distribution of agricultural areas and the wide variety of habitat conditions, land uses, and crops (both as food sources and habitats) that are grown in agricultural areas. These habitats are largely anthropogenic, the result of a human remaking of the native landscape and are often home to a wide variety of non-native species. Opossum and bullfrogs are common along rivers on the westside of both states; rock doves, European starlings, house sparrows, ring-necked pheasants, and California quail are also associated with agricultural landscapes in King County (the last two species have been introduced to King County as gamebirds in an attempt to offset losses of native game species). Because of the non-natural character of agricultural landscapes, the habitats found there are not typically critical for threatened or endangered species, even many sensitive species are no longer found in these areas. This is an historic artifact of the conversion of native landscapes to agriculture that has caused the decline of many native ecosystems that once supported these sensitive species.

Most wildlife that uses agricultural habitats are either seasonal migrants or make use of the habitats on an intermittent basis, in conjunction with other habitats (Edge 2001). Many, if not most, are ecological generalists who can forage in a variety of areas and can be found in other habitats as well. Most of the activity in agricultural areas occurs in remnant habitat patches or elements such as windbreaks and shelterbelts, fence rows, and field borders rather than in crop fields (there are some cropland breeders but feeding is the dominant activity there). Some species that are closely associated with pasturelands, either for breeding or feeding, appear to do so because the fields resemble sufficiently the native grassland habitats that they replaced (Best et al. 1995).

### Agriculture Effects on Aquatic Areas at the Landscape Level

For native fishes, particularly salmonids, agricultural areas present a special case. Western Washington does not support a large fish fauna—only 23 species are native to the streams and rivers of this side of the mountains. Salmonids can be found throughout the river systems of King County, from the largest rivers to very small streams. Habitat differentiation has served the species well, reduced competition for food and space, and has resulted in populations that have become adapted to the local conditions of watersheds and stream systems. See BAS, Volume I, Chapter 7, Aquatic Areas for additional general information on aquatic areas and fish habitat.

Unlike the wildlife generalists that often thrive in agricultural habitats, salmonids are specialists and require relatively exacting conditions to successfully carry out their life cycle. Small, persistent changes in water quality, temperature, habitat structure, or even distribution within a watershed can have severe consequences for survival, even under natural conditions. In the agricultural landscape of modified streams and drainageways, salmonids do not generally encounter the habitat quality that supports survival. Nevertheless, salmonids continue to be found in stream remnants and even in greatly altered habitats although their survival in these places is uncertain.

## A.1.2 Local Effects of Agriculture

Table 2 summarizes the effects of agricultural activity on selected attributes and functions of critical areas. The discussion that follows is intended to provide the reader with information about the effects of agricultural operations at the local level. The discussion in the table is a summary of Spence et al. (1996); Smith (1971), Cross and Collins (1975), Gammon (1977) and Menzel et al. (1984); Capel et al. (1993); the National Research Council (1982); National Academy of Sciences (1990); Morgan (1995); and Johnson and O'Neill (2001).

## Table A-2. The Effects of Agriculture on Selected Attributes and Functions of Critical Areas

<table>
<tr><td>Vegetation/land cover</td><td colspan="3">Woodlands and wetlands have been modified to produce domestic crops and graze livestock; non-native plants invade disturbed soils; habitat patches have been reduced in size and are generally isolated from other like habitats; corridors are generally narrow and truncated. Riparian vegetation generally cleared with concomitant reductions in woody debris input, leaf litter, shading, bank stability (Spence et al. 1996).</td></tr>
<tr><td>Soils/erosion[1]</td><td colspan="3">Repeated tillage alters physical structure and soil microorganisms by mixing, aerating and reducing soil tilth; compaction of fine soils immediately below depth of tilling; compaction of heavily grazed areas; exposure of bare soils to rainfall increases erosion rates (Morgan 1995).</td></tr>
<tr><td>Hydrology</td><td colspan="3">Soil compaction reduces infiltration rates and increases both volume and rate of runoff (Auten 1933); loss of vegetation also increases runoff (Hornbeck et al. 1970); irrigation and diversions reduce water volumes in streams and rivers; channelization of streams and waterways alters concentration time and volume of runoff.</td></tr>
<tr><td>Sediment transport</td><td colspan="3">Cropped lands contribute considerable sediment to streams through surface erosion (SCS 1984), bank sloughing (Sekely et al. 2002), and ditching and dredging activities.</td></tr>
<tr><td>Nutrient/solute transport[2]</td><td colspan="3">Virtually all streams and rivers tested for nitrate and phosphorus within agricultural areas show concentrations well beyond streams draining forested areas; Increases in chlorine, sodium, N and P are characteristic of catchments draining pasture lands (Omernik 1977).</td></tr>
<tr><td>Pesticides and herbicides[3]</td><td colspan="3">Atrazine is commonly found in streams draining both agricultural and urban catchments in King County. This may be representative of other herbicides and pesticides that have not yet been documented.</td></tr>
<tr><td>Physical habitat structure</td><td colspan="3">Channelization and dredging of streams, removal of woody debris, construction of revetments, and removal of riparian vegetation all contribute to reductions in habitat quality and complexity of streams and riparian habitats; draining and farming of wetlands reduces habitat volume and function, and conversion of woodlots to pasture and crop uses reduces habitat volume and eliminates perches, nesting sites, and cover for wildlife (Spence et al. 1996).</td></tr>
<tr><td>Effects on biota[4]</td><td colspan="3">Fish and invertebrate biomass decline in channelized waterways; diversity declines in channelized reaches of agricultural waterways (Gorman and Karr 1978, Shields et al. 1994); sediment, nutrient and pesticide loadings reduce invertebrate diversity and productivity (Maxted 1994); habitat loss reduces bird diversity and reproductive success (Askins, 2000). Loss and fragmentation of habitat types eliminates sub-populations of birds and amphibians and reduces migration rates.</td></tr>
<tr><td>[1] Little information is available about erosion rates from King County agricultural activities. Rates are thought to be relatively low due to soil characteristics and slopes on which these activities take place.</td><td>[2]. Omernik (1977) in a nationwide study of streams draining 925 catchments, found concentratins of N and P from agricultural catchments to be 900 percent greater than in streams draining forested catchments.</td><td>[3]. When applied according to recommended rates, very little of these pesticides run off the land surface. Horticultural operations often use more pesticides per acre than commercial row crop farms, however.</td><td>[4] Askins (2000) among many authors has documented severe declines in bird populations in agricultural areas. Remnant patches of habitats often act as sinks for populations, hastening their decline.</td></tr>
</table>

Table A-3 provides a summary of changes in performance of some structural and functional attributes of streams, wetlands and fish and wildlife habitat conservation areas as a result of agricultural activities.

This summary is based on Spence et al. 1996; Ritter and Shirmohammadi 2001, 1995; Mitsch and Gosselink, 1992.

**Table A-3. Local changes in performance of selected attributes of aquatic areas, wetlands and wildlife habitat.**

| Aquatic Areas | | Wetlands | | Wildlife Habitat | |
|---|---|---|---|---|---|
| Function/ Attribute | Performance | Function/ Attribute | Performance | Function/ Attribute | Performance |
| HC | – | HC | 0/– | HC | 0/– |
| SD | – | SD | – | SD | – |
| PP | +/0 | PP | + | PP | 0 |
| PS | – | PS | – | PS | – |
| HD | – | HD | –/0 | HD | 0 |
| S | – | Sp | – | C | – |

Key:

HC = Habitat complexity; SD = Species diversity; PP = Primary Productivity; PS = Population support; HD = Hydrologic damping; SS = Salmonid support; Sp = Spatial diversity (wetland complexes); C = Connectivity

Performance codes: + = increase; - = decrease; 0 = no change

For most of the functions and attributes listed in Table A-3, agricultural activities cause a decline in function and a loss of structure. For primary productivity (PP), however, nutrient loading to aquatic systems may stimulate growth of algae and aquatic plants, increasing the net productivity of the system. In other cases, productivity of the habitat is unaffected, as in forested areas or grasslands. In the case of hydrologic damping (HD), the loss of channel complexity in streams (due to channelization and removal of woody debris) results in faster concentration times, less in-channel storage, and generally greater flooding frequencies downstream. As wetland habitats are modified through filling or draining, the loss of wetland storage also contributes to increases in runoff volumes.

For population support (PS) and species diversity (SD), single wetlands, forest or grassland patches, even small streams do not function in isolation but are parts of larger ecosystem units. Alone, habitat patches do not support much diversity or even whole populations (except in the case of endemic plants and animals that generally occupy very rare habitats); combined with other habitat patches or streams, a mosaic pattern of diversity and abundance begins to emerge across the landscape. It is the mosaic of habitats—some occupied, others unoccupied—that supports this diversity and abundance and is the proper landscape unit for assessing population effects. That is not to say the habitat patch is unimportant for, as patches are lost due to land transformation, the range of a population must necessarily shrink to those patches that remain. Isolation and shrinkage of these habitats means less support for abundance and diversity across the agricultural landscape (Forman 1995).

The local effects of agriculture and agricultural operations on each critical area of King County are discussed below.

## Wildlife Habitat

The habitats in agricultural landscapes are artificial in the sense that they are mainly human-built or certainly human-modified. Remaining natural habitats tend to be fragmented or are remnants of once more extensive native habitats (Edge 2001). At a habitat scale, agricultural areas can show high habitat diversity due to the variety of crop types and the proliferation of edges that are the result of management activities. In fact, some 342 species of wildlife can be found on agricultural landscapes throughout the state. Even as diversity of types increases, complexity—the combination of diversity and spatial extent—may decrease over large areas as the patterns of agricultural use come to dominate the landscape (Forman 1995).

The many habitat types and the extent of agricultural land helps to explain the high observed species diversity in these areas. However, these species are typically seasonal migrants, intermittent habitat users, and tend to be generalists rather than specialists—agricultural habitats do not often support sensitive species but rather those tolerant of regular disturbance.

For some species, particularly those that are generalists, agricultural areas, with their ample supply of food sources, provide excellent population support. Unfortunately, many of these favored species are non-natives and have invaded regions as agricultural practices produce conditions favorable to their survival. Starlings, cowbirds, and California quail are examples; some natives have exploded into agricultural areas as well, their numbers increasing dramatically over the last decades. The corvids—crows and their relatives—are examples. For specialist species, those that require particular habitat types or areas or respond poorly to disturbances, agricultural operations have tended to have a negative effect. This is not surprising given the replacement of their native habitats with new ones.

As the landscape is altered by agricultural operations, fragmentation and isolation increases dramatically (see again the introduction) and connectivity among habitats is reduced as the number of fields, structures, and roadways, and the distance between habitats, increases. More recently, the advent of “clean farming” has eliminated the remnant corridors that once existed along fence rows and roadsides, and could be found in hedgerows, windbreaks and shelterbelts, and in “banked” areas where no cultivation occurred.

## Aquatic Areas

### *Streams*

Spence et al. (1996) provides a useful review of the effects of agriculture in general on stream ecosystems. Most, if not all, of the effects discussed are apparent in streams flowing through the agricultural areas of King County. The effects relevant to streams include hydrologic effects, changes in sediment transport, energy transfer, nutrient and solute transport, effects on physical habitat structure, and direct effects on stream biota.

Changes in soil structure and vegetation on agricultural lands typically result in lower infiltration rates, which generate greater runoff. Auten (1933) suggested that forested areas might absorb up to 50 times more water than do agricultural areas; Hornbeck et al. (1970) describe increased runoff effects from vegetation loss and soil compaction. This increase in runoff rates (rather than infiltration) may affect the water table in some areas where infiltration rates are typically low. This can, in turn, affect streamflows, particularly in small streams in late summer when streams depend on base flow. This effect can be quite pronounced in drought years and can result in fewer perennial streams (Gorman and Karr 1978; Griswold et al. 1978).

Because of the intensity of land use, agricultural lands contribute considerable quantities of (mostly fine) sediment to streams. Loss of permanent vegetation, regular tilling of the soil, and sloughing of ditch and channelized stream banks all contribute to sedimentation (see the discussion of the Universal Soil Loss Equation for background).

Removal of riparian forests and shrubs eliminates stream shading and increases exposure to wind. This combination can cause increases in water temperatures as streams pass through agricultural lands. Moreover, bare soils retain greater heat than vegetated soils which can increase conductive transfer of heat to water that flows overland to streams. This effect can be exacerbated by irrigation return flow to streams (Dauble 1994).

Historic (and some present) agricultural practices included stream channelization (see Ecological Traps), large woody debris removal, the construction of revetments or armoring, and the removal of riparian vegetation. Each activity contributes to a reduction in habitat complexity, tends to decrease channel stability, and modifies the trophic structure of the stream (Karr and Schlosser (1978). Natural channels in easily eroded soils and with low gradients (floodplains, for example) tend to meander and often braid, creating considerable channel complexity. Channelization lowers the base level of streams, increases the local slope of the stream, and stimulates channel erosion (Nunnally and Keller 1979). The channelized reach tends to become wider and shallower. If the reach is revetted (armored), the erosive force tends to result in downcutting, which leads to a renewed cycle of erosion. Richards and Host (1994) reported significant correlation between increased agriculture at the catchment level and increased stream downcutting.

The physical and chemical changes in streams in agricultural areas are reflected in changes in the biota. In two states with extensive agricultural development (Ohio and Delaware), instream biological criteria were not met in 85 percent of the sites tested (Ohio EPA 1990: and Maxted et al. 1994). While Washington has no instream biotic criteria similar to these states, measures of biologic integrity (mainly B-IBI scores) in agricultural streams are typically much lower than those from forested areas. Modification of physical habitat structure has been linked to a number of biotic effects. Marzolf (1978) estimated that 90 percent of invertebrate biomass was attached to in-channel debris; Hickman (1975) found that snags (in water) were associated with 25 percent higher standing crops for all fish and 51 percent higher standing crop for catchable fish. Fish biomass was 4.8 to 9.4 times greater along a streamside with in-stream cover than along a side that had been cleared of all cover (Angermeier and Karr 1984). Shields et al. (1994) found that incised channels in agricultural lands supported smaller and fewer fish than did an equal area of unaffected channel. On a larger scale, habitat and reach diversity and abundance must be great enough to provide refugia for fishes during extremes of temperature, drought, or flood (Matthews and Heins 1987). If refugia are present, fishes in agricultural streams can rapidly re-colonize disturbed habitats and reaches.

## Channel Migration Zones

Channel migration zones represent the area along rivers and streams where the channel may be expected to move laterally over time. Stream and river channels, especially those in low gradient, alluvial, or easily erodible deposits, tend to meander laterally across their floodplains in response to floods (avulsions) or more slowly as banks are eroded on outside bends and sediment are deposited as point bars (see BAS, Volume I, Chapter 4, Channel Migration Zones). CMZs are those areas where public safety is of prime concern due to this tendency to migrate. Agricultural operations have had important effects on this process, especially along our larger rivers and streams. Agricultural lands in each of our major river valleys—the White, the Green, the Cedar, and the Snoqualmie—have a long history of protection from channel changes and floodwaters.

As land is brought under cultivation, the tendency of rivers to erode banks and cropland becomes less tolerable. Fields can be threatened, structures put at risk, and occasionally, property lines can (and do) shift with the river channel. This situation compelled many farmers to armor eroding banks with stone, concrete, or other resistant material in order to stem the movement of the channel. Many of these individual efforts were failures for a variety of reasons: the protection was not extensive enough; the material was insubstantial in the face of erosive forces; and floods would alter the river form at scales larger than individuals were capable of dealing with (Mount 1995). Moreover, the river, with no change in the relationship between discharge and sediment supply, would respond to the attempted channelization by seeking a new equilibrium, often at the expense of the solution itself. Nevertheless, many agencies were enlisted in the effort, including the Corps of Engineers and King County, and many “river improvement projects” were undertaken throughout the 1960s, 1970s, and 1980s to protect property from river bank erosion. Revetments were built, riprap (large angular rock) installed at eroding bends, and channels were straightened, all in an attempt to control the lateral movement of the river channel. The Army Corps of Engineers, once a minor player in river modification early in the 20th century, became actively involved in river engineering after the devastating floods of the early 1920s on the Mississippi. Following Congressional mandates, the ACOE and local agencies—mainly counties but some flood control districts also—began in earnest to erect levees, dikes and revetments to control both floodwaters and river migration. In King County, this activity reached its zenith in the late 1960s and early 1970s along our major rivers.

Coupled with flood control facilities on some rivers (notably the Green), the program has been largely successful and King County now maintains many miles of levees and revetments on our waterways. These facilities generally constrain the ability of the river to move laterally where structures or public safety are threatened. In other areas, the river remains unconstrained and subject to lateral movement across the floodplain (once again, see the CMZ section in the BAS Volume I). It is in these unconstrained areas, that the Channel Migration Zones apply.

## Riparian Zones

Riparian zones are considered ecosystems in themselves (Smith and Hellmund 1993). As such, they have functional connections with neighboring ecosystems, are elements of the landscape, and are comprised of smaller ecosystems and habitats. In particular, riparian ecosystems are intimately connected with the adjacent aquatic feature, whether river, stream, lake or wetland, even estuary. In current scientific thought, riparian zones are viewed as inseparable from the aquatic feature they border; the river and its riparian zone are usefully considered as an ecological unit. Defining the extent of the riparian zone is not an easy task. At the least, the riparian zone extends from the river (in this example) across its floodplain, up the banks of the floodplain where it grades into the terrestrial plant community—the transitional zone between aquatic-dominated and terrestrially dominated landscapes. According to Ewel (1978) riparian ecosystems have two essential characteristics: laterally flowing water that rises and falls at least once within a growing season and a high degree of connectedness with aquatic and upland ecosystems. The litter and soil characteristics associated with riparian areas act as a sponge to hold water for slow release, creating more stable water supply for the aquatic environment. The riparian vegetation retards the flow of floodwaters and increases the rate of infiltration. This process moderates both floods and droughts and in critical in arid areas and during extremely dry periods when base flow may depend completely on water stored in the soil profile (Lowrance 1985).

Riparian zones perform several functions essential to the ecological integrity of the adjacent aquatic ecosystem. Tables A-4 and A-5 summarize the importance of riparian zone functions for fish and wildlife and identify the effects of agriculture on riparian zones at the local level.

Riparian vegetation often filters out upland sediment as it travels downslope to streams; the amount can be substantial. Upland erosion occurs naturally but when upland disturbances cause an excessive amount of material to enter a stream network, sediment can carry excess nutrients into the waterway and sediment can smother gravelly streambeds harming habitats for salmon and aquatic insects. Sediment deposited in lakes and wetlands reduces storage capacity and degrades water quality. As a sediment sink, riparian zones can be effective for a very long time. In a watershed on the coastal plain of Georgia, the riparian zone has trapped all the sediment eroded from adjacent agricultural fields, plus additional sediment from upstream areas, since 1880 (Lowrance et al. 1986).

Filtration efficiency increases with greater width and decreased slope of the vegetated corridor, with greater density of vegetation and litter cover, and with larger size and greater concentration of particles in suspension (Karr and Schlosser 1978). The overland distance required for particles to settle out of runoff varies according to the particle-size distribution and with the type of vegetation.

Nutrients occur in both particulate and dissolved forms. Inorganic silt and clay particles have large surface areas on which nutrient molecules attach and water is a strong solvent for many nutrient compounds. Nutrients can enter streams directly, accumulate in the soil to be flushed into the lake or stream later, or be incorporated into riparian vegetation as biomass. Riparian zones can be quite effective in nutrient removal (see also the discussion on filter strips that follow). Vegetation and soil can filter as much as 99 percent of total phosphorus mass and upwards of 60 percent of total nitrogen (Karr and Schlosser 1977). Denitrification is also an important mechanism for nutrient filtering that can substantially reduce the amount of nitrogen in ground water (Lowrance 1985). This process requires anaerobic conditions and occurs most efficiently in soils that undergo periodic flooding and drying, such as in riparian areas (Patrick and Reddy 1976).

The vegetation in riparian zones—especially tall trees—prevents temperature extremes by shading the water surface in summer and by creating a microclimate within the “tunnel” of overhanging vegetation. This reduces both solar heating and convection heating from surrounding warmer air. Moreover, the water stored in the riparian soils seeps into the stream moderating water temperatures directly Budd et al. 1987).

Streamside vegetation is essential to aquatic life because, in addition to the earlier functions, it stabilizes and contributes to the diversity of habitat and trophic dynamics of the stream (see also the aquatic areas discussion in this document). Fallen trees (Large woody debris), branches and root masses from the riparian zone that come in contact with flowing water establish local hydraulic diversity in the form of dammed pools, riffles, eddies and backwaters (Budd et al. 1987). These diverse habitats give rise to greater diversity of aquatic organisms (Benke et al. 1984; Angermeier and Karr 1984). In forested watersheds, over 99 percent of the energy in the stream food web may originate in the forest adjacent to the stream (Budd et al. 1987; Likens et al. 1970; Bormann and Likens 1969). In headwater streams, riparian vegetation is especially critical as an energy source. In King County rivers and streams, salmon carcasses are a major source of energy for the stream food web (Cederholm 2000; Naiman et al. 2001) and may account for 35 percent of the energy that sustains the stream ecosystem.

## Wetlands

Agricultural operations affect wetlands in much the same manner as they affect streams. Water quality is degraded, physical structure altered, and the diversity of wetland biota is reduced as a result. From a functional standpoint, several attributes tend to decline over time as a result of agricultural activities. Habitat complexity, species diversity, population support, hydrologic damping, and spatial diversity and connectivity all tend to decline in wetlands surrounded by agricultural landscapes (see Table A-3). One function, that of primary productivity, tends to increase as a result of an influx of nutrients from tilled soils and applications of fertilizers and nutrients.

**Table A-4. Importance of Riparian Areas to Fish and Wildlife**

| Function / Attribute | Notes |
|---|---|
| Maintenance of streamflow and wetland water levels | Riparian vegetation promotes the infiltration and storage of runoff and floodwaters adjacent to streams and wetlands. These reserves support base flow and water levels. |
| Sediment/pollutant filtration | Riparian vegetation filters sediment and dissolved materials from uplands and land management activities adjacent to aquatic areas. |
| Nutrients and nutrient transformation | Riparian vegetation provides food for birds, leaf litter to streams to support insects, terrestrial insects for birds and stream fishes; and, because of the soil\water interactions, is the site of nutrient transformations critical to stream and wetland health. |
| Shade/Cover | Shade from riparian vegetation reduces solar heating and affords cryptic protection for juvenile fishes; vegetation provides cover for small mammals, birds, and protection for spawning salmonids. |
| Habitat, travel corridors and migration rest-stops | Of the approximately 480 species of wildlife in the terrestrial and shoreline habitats of Washington, 60 percent are found in wooded riparian habitats (RHTC 1985). Small mammals and bats are more common in riparian zones than in upland habitats (Cross 1988); Local movement of birds and mammals often follows riparian corridors; Neo-tropical migratory songbirds rely almost exclusively on riparian habitats as rest stops during their migrations between northern forests and tropical wintering areas–old cottonwood forests, in particular. |
| Nesting and Perching and feeding | Raptors show a strong affinity for riparian habitats in western Washington; eagles, osprey, harriers are examples (Knight 1988). |
| Bank stability | Deeply rooted vegetation holds soils in place (Swanson et al. 1982); vegetation slows water and “combs” sediment from floodwaters to build banks (Elmore 1992). |
| Microclimate | Local humidity, air temperature, wind speed, and soil temperatures are greatly influenced by the composition and extent of riparian vegetation Spence et al. 1996). |

**Table A-5. Effects of Agricultural Activities on Riparian Areas**

| Function / Attribute | Notes |
|---|---|
| Overgrazing | Decrease plant vigor; reduces productivity; allows weeds and exotics to invade. |
| Trampling | Expose streambanks to erosion; compact soil and reduce infiltration; increases bank sheer and sloughing. |
| Browsing of trees and shrubs | Reduces vigor and eventually eliminates them. |
| Livestock manure | Contaminate water with bacteria and disease-causing organisms; promote excessive algae growth. |
| Cultivation | Removes riparian vegetation; increases edge effects and alters boundary conditions for wildlife. |
| Field Erosion | Deposited in riparian zone, excessive sedimentation can smother plants, reduce infiltration. |
| Fertilizers and pesticides | Residues carried into riparian zones can stimulate growth of weedy species and eliminate native vegetation. |
| Clearing | Removal of riparian vegetation adjacent to crop fields can lower water tables and increase soil salinity. |

In most wetlands of this area, regular, seasonal pulses of water (via surface flow or shallow groundwater) to the wetland tend to create diverse conditions of water depth and area that lead to various plant communities and thus to habitat complexity. These relatively regular pulses serve to interrupt successional patterns and maintain the wetland structure. When hydrologic patterns are modified, either through wetland draining or by sending more water to the wetland, the pulsed effect is lost or greatly modified and the wetland communities shift in response. In agricultural areas, these hydrologic modifications tend to favor non-native species such as Reed Canary Grass or create mono-typical stands of vegetation such as cattails.

This alteration in habitat complexity toward fewer vegetation communities leads to a decrease in species diversity among the fauna of wetlands (Mitsch and Gosselink (1992). Amphibians and birds are particularly susceptible to hydrologic alteration and the consequent shift in vegetation communities. A change of only a few centimeters in water surface elevation or of a few hours in exposure is sufficient to reduce survival of eggs laid by amphibians and thus reduce their survival.

Primary productivity is one function that tends to increase in wetlands found in agricultural areas. As nutrients find their way into the wetland through surface or ground water, plant growth increases and the biomass of certain opportunistic plants can rise rapidly. This phenomenon is similar to eutrophication in lake environments and can accelerate successional paths from emergent vegetation to woody vegetation, with a concomitant change in fauna diversity.

As species are lost from modified wetlands, the local breeding populations they represent decline in number and their range decreases. As this occurs, the support that any particular wetland provides as a hedge against local extinction is reduced also. The spatial distribution of the overall population may be reduced as fewer and fewer groups are represented across the landscape. This imposes a greater risk to the population from random changes in the remaining habitats and from disturbances that would otherwise be tolerable. Moreover, movement across the landscape from wetland to wetland is impeded as wetlands are modified or barriers imposed by road networks or fields. Eventually, a population may crash and a local extinction occurs; it may take decades to recolonize the area even if suitable habitats are present.

Hydrologic damping is a function of the ability of wetlands to store water during times of flood and meter it out gradually to streams, rivers, or to groundwater. In the recent past, agriculture was responsible for the majority of wetland losses in the U.S., especially in the Midwest and southeast. In King County, agriculture was responsible for wetland losses mainly in the floodplains of our major rivers through draining and diking; in other areas of the county, fills of shallow wetlands accounted for the majority of loss. The effect is felt in downstream reaches as loss of storage increased both peak flows and the frequency of large flows (Soos Creek Conditions Report 1989; East Lake Sammamish Conditions Report 1994).

## Ecological Traps

The habitats found in agricultural landscapes have the potential to become ecological traps for many species (Edge 2001). The operations carried out on farms, from seedbed preparation to cultivation to harvest, and the often small and modified habitat remnants that remain in agricultural landscapes, may result in areas that appear suitable for breeding and rearing but, in fact, act as population sinks rather than sources for the species that use these sites (Best 1986; Gates and Gysel 1978). These areas—generally human-made—are called ecological traps and may include ditches and channelized streams, remnant woodlots, isolated wetlands, remnant grasslands, pastures, even rowcrops and hayfields. In many ecological traps, breeding or rearing is interrupted by field operations; in others, nesting or rearing success is reduced by the effects of edge and competition with non-native species; still others are the result of conversion of one field or crop type to another (Best 1986; Yahner 1988; Edge 2001).

Field operations trap wildlife—particularly ground nesting birds but small mammals also—by initially providing conditions that are attractive to breeding and feeding then disrupting the life cycle by altering these conditions or by direct destruction of nests. Most agricultural (horticultural) activities in western Washington require at least four field operations and some as many as 10 during the growing season. The number and character of operations is somewhat dependent on the tillage method- no-till or reduced till methods reduce cultivation but may substitute further herbicide application (Edge 2001). Best (1986) suggests that the severity of disturbance due to field operations depends on five characteristics of the breeding behavior of the species: (1) timing of the breeding season; (2) length of the breeding season; (3) length of the breeding cycle; (4) the probability of re-nesting after disturbance; and (5) position of the nest in relation to the operation;. If breeding coincides with field operations such as plowing and cultivation, a species is unlikely to build a successful nest or even establish a nesting territory. For example, the breeding timing of mourning dove and savannah sparrows coincides with early field operations while that of killdeer precedes most field operations by a month or more. This would make the former species more vulnerable to disturbance and would probably result in a decline in local population. Some small mammals are also subject to ecological entrapment; Edge et al. (1996) reported a near 50 percent decline in gray-tailed vole populations due to mowing of alfalfa.

The length of the breeding season is another factor in determining a species' vulnerability to agricultural disturbances. Breeding seasons that extend beyond the duration of agricultural disturbances reduce this vulnerability since some nesters will not be subject to disruption and will be successful in breeding young; mourning doves, despite the timing of their nesting onset, have a breeding season that extends well beyond many agricultural operations. Still, their numbers steadily declined in King County until recently. Their range seems to be expanding as the species makes use of recently harvested forest areas.

If the breeding cycle of a species is short, its exposure to disturbance will be reduced when compared to other species. The longer the time from egg-laying to fledging, the greater the opportunity for a species to be disrupted by agricultural operations. A species with a short cycle may escape disruption since it can complete the breeding and rearing between operations. Some species of birds may renest after a disturbance while others (typically those with a long nesting cycle) will raise only a single brood each year. Re-nesters have a clear advantage in agricultural landscapes since they can survive disturbances that would cause a brood year failure in single nesters. The position of nests relative to the disturbance is another factor in the nesting success of birds in agricultural landscapes. Field operations can destroy nests directly if they are in the path of wheels, plows, or cultivators. Between-row nesters such as killdeer and pheasants are particularly vulnerable while within-row nesters such as mourning doves and vesper sparrows (rare in King County) suffer somewhat less.

Best (1986) also points out another form of ecological trap that can result from attempts to reduce soil erosion through the implementation of conservation tillage practices. The conversion of pastures and hay fields to no-till row crops can “fool” some philopatric species (species who return to the same area to nest) into nesting on the converted sites. Later in the nesting season, the eggs or young become subject to predation or the vagaries of weather and the brood fails. Many of these species are unlikely to establish new territories elsewhere when the breeding fails.

Two other kinds of ecological traps occur for wildlife species: the amount and distribution of edge habitats and the amount and distribution of various habitat elements that were, in the past, important components of agricultural landscapes. Edges have been the focus of considerable study in ecology and the descriptions of “edge effects” are well known among ecologists (Reese and Ratti 1988; and Yahner 1988). Although much of the work focuses on forest edges, there are some implications for agricultural landscapes. Where forest and shrub habitats are interspersed with farmlands, cowbird nest parasitism is pronounced (Mayfield 1965), probably due to the cowbird’s practice of partitioning it’s breeding and feeding activities. Cowbirds typically nest in edge habitats between forests and meadows, in sparse forests and woodlots, and in riparian areas; they feed in open fields, livestock facilities, and corrals. Cowbird nest parasitism has been implicated in the local decline of willow flycatchers, vireos, and yellow warblers (USFWS 1982).

The advent of “clean farming” in the 1960’s has led to the decline in the diversity and abundance of habitats that once supported many species. The loss of field borders, hedgerows, windbreaks and shelterbelts, and roadsides to management for pests and invasive weeds has reduced the area for many species and left the remaining habitats fragmented and isolated. Similar to an edge effect, these habitats are favored by generalist species and many omnivorous predators such as corvids, gulls, raccoons, opossums, and rodents (Schmitz and Clark 1999). This effect has been exacerbated by increased roadside management by road crews in the form of mowing and weed spraying. Both sets of practices have contributed to the elimination of roadsides as travel corridors and habitats.

Ecological traps are also a concern for fish species, especially for salmonids that seek small streams for rearing and feeding during their juvenile life phase. Two kinds of traps occur in agricultural areas: streams that have been modified—often channelized and straightened—for ease of field layout and management; and ditches constructed for field drainage that resemble stream habitats sufficiently to attract juvenile salmonids. In the first case, many small streams, particularly those that cross large river floodplains and small headwater streams, have been channelized along section or property lines to create easy pathways for cultivation or to create large contiguous blocks for fields. This channelization also aided field drainage by eliminating the flooding effects from the stream. As a result of channelization, the habitat structure of the stream is dramatically changed—meanders are eliminated, local slope is increased, and the cross section of the channel is altered, mainly widened, and smoothed. Riparian habitats were eliminated and associated floodplain features such as wetlands, side channels, and back eddies were lost. During portions of the year, however, these streams remain attractive to juveniles as they seek food or refuge from floodwaters. For some species and life stages, the use is intermittent (as in floodwater refuge) and the animals exit the stream as soon as the critical period passes. For some species with longer stream residence times, modified streams may act as population sinks—individuals enter during relatively benign conditions only to encounter conditions later in the season that are not conducive to survival—rapid temperature increases, great variations in dissolved oxygen content, or declines in water quality. Such conditions may effectively trap juveniles in these streams and cause high mortality in the population.

Drainage ditches can act in a similar fashion to trap juvenile fishes; the ditches, when they flow in the spring are “strong attractors” for juvenile salmonids seeking small streams for seasonal feeding and escape from large river predators. The intermittent nature of these features suggests that they may provide significant habitat for a short period of time but do not support the necessary functions over the life cycle required by the animals. Thus, while juveniles are found in these systems, this does not indicate long term survival. Not all modified streams and ditches in agricultural areas are traps, however. Evidence suggests that some systems may offer refuge and feeding conditions that can support juveniles throughout their occupancy. This is probably the case in larger streams and ditches with long periods of flow that allow native behaviors to be expressed.

## A.2 BEST MANAGEMENT PRACTICES TO CONTROL THE EFFECTS OF AGRICULTURAL ACTIVITIES ON CRITICAL AREAS

Using information from the U.S. Natural Resources Conservation Service (NRCS) and the current scientific literature, this review considers best management practices and their effectiveness at controlling the effects of agriculture on critical areas. The effectiveness is examined here for three management practices in particular: vegetated filter strips, cover crops, and livestock fencing and exclusions. Then, the need for combined application of best management practices is discussed.

The background for analysis of vegetated filter strips and cover crops is derived from the assumptions of the Revised Universal Soil Loss Equation. This equation is the standard and accepted approach to estimating soil erosion worldwide and, while imperfect, it is an appropriate basis against which to compare theory and approach for scientific robustness. A brief explanation of the RUSLE is instructive for assessing VFS methods and standards. The RUSLE has a deceptively simple form:

$$E = R.K.L.S.C.P$$

Where E is the mean annual soil loss; R is the rainfall erosivity index; K is the soil erodibility index; L is the slope length; S is the slope steepness; C is a cropping factor which represents the ratio of soil loss under a given crop to soil loss with bare soil; and P represents the effect of cropping practices such as contouring and strip-cropping.

The relationship among these factors is complex and useful approximations of E are often difficult to obtain, especially since C and P are largely management activities that are socio-culturally driven.

Without factoring in the effects of management activities, soil erosion is related to four factors: erosivity of rainfall, erodibility of the soil, slope length, and steepness, and the nature of the plant cover.

Erosivity is a measure of the power of an eroding agent—rainfall, flowing water, or wind—to cause soil loss. Soil loss is closely related to rainfall through the detachment of soil particles as rain drops strike the soil surface and through the contribution of rain to runoff.

The effect of rainfall intensity is illustrated by observations which show that average soil loss per rainfall event increases with storm intensity (Fournier 1972). The response of soil to rainfall is sometimes determined by previous conditions of soil saturation. In a study in Ohio in 1940, intense rain falling on dry ground produced little runoff, most of the precipitation soaking into the soil. In a subsequent storm, however, over 60 percent of the rain ran off and soil loss almost tripled over the first event. The closeness of the soil to saturation was the determining factor in this case. The most useful expression of rainfall erosivity is an index based upon the kinetic energy of the rain.

Erodibility defines the resistance of soil to detachment and transport. A soil's resistance to erosion depends somewhat on topographic position, slope steepness, and the amount of disturbance (during tillage, for example) but is mainly dependent on the properties of the soil itself. Erodibility varies with texture, stability, cohesiveness, infiltration capacity, and organic content and chemical composition of the soil. In general, large particles are resistant to erosion because of the greater force required to entrain them whereas fine particles are resistant to detachment because of their cohesiveness. The least resistant particles are silts and fine sands; thus, soils with high silt content are highly erodible.

Soils that form aggregates of clay particles and organic matter are also more resistant to erosion as are soils that are strongly cohesive (until they are wetted). Organic content is important because of its influence on aggregate formation. According to Evans (1980), soils with less than 2 percent organic content can be considered erodible.

An increase in slope steepness and slope length would normally be expected to cause an increase in erosion due to increases in runoff velocity and volume. While this is generally the case, especially for slopes with average steepness less than about 8-10 degrees, the shape of the slope exerts an influence also: convex slopes show greater soil loss than concave slopes of the same length. Moreover, erosion has been shown to decrease as slopes lengthen and the depth of overland flow downslope increases, protecting the soil from raindrop impact. Erosion becomes limited by the rate of detachment, which is decreasing with slope length. This is not often the case where rills and gullies form. Here, erosion increases rapidly downslope due to the energy of flow as velocity and volume increase. Suffice to say that the relationship between slope and erosion is more complex than expected.

Vegetation acts as a protective layer between the rainfall and the soil. Above ground components absorb much of the energy from falling rain before it strikes the soil, and the root system contributes mechanical strength to the soil. The importance of plant cover to reducing soil erosion has been demonstrated often and depends on three factors: the density of the vegetative cover, the height of the vegetation above the soil surface, and the continuity of the cover. Generally, the greater the density of the cover, the lower the cover is to the soil surface, and the more continuous or "closed" the vegetative cover is, the more protection is afforded to the soil surface. However, in many horticultural activities, particularly in row crop production, the discontinuity of the vegetation cover may serve to concentrate rainfall and exacerbate soil erosion to levels much greater than would be expected from even bare ground (Morgan 1995). This unexpected result is caused by the concentration of rain between the plant rows as rainfall flows across plant surfaces and onto the soil.

Since many agriculturally based water quality effects are related to soil erosion and to the adsorption of various agricultural chemicals and fertilizers to soil particles, filter strips may reduce or prevent the delivery of these chemicals and nutrients to the aquatic system (Dillaha et al. 1989; Morgan, R.P.C. 1995; Leeds, R. et al. 1994).

## A.2.1 Vegetated Filter Strips

### Effectiveness of Vegetated Filter Strips

Both forested and grass vegetated filter strips (VFS) have been shown to be effective in the removal of sediment from cropland runoff. In virtually all field and experimental studies, even VFSs with flow paths as short as 10 feet removed sediment from runoff water at relatively high efficiencies (54-88 percent; see Table A-1). In Blacksburg, Virginia, researchers found that orchard grass strips 30 feet wide removed 84 percent of the sediment from surface runoff (Dillaha et al. 1989); in Maryland, tall fescue filter strips 15 feet wide reduced sediment losses from cropland by 66 percent (Magette et al. 1989). An increase in flow length of the VFS resulted in a marked gain in removal efficiency (Tables A6 and A7) but doubling of the filter width did not result in a doubling of the removal effectiveness. It should be noted that the greatest efficiencies were observed when runoff entering the filter strips occurred as shallow sheet flow, a condition difficult to achieve in field applications.

**Table A-6. Vegetated filter strip effectiveness for constituents of agricultural runoff adsorbed to soil particles (Leeds et al. Aex-467-94).**

| Location | Soil Texture | Slope | Filter Strip width | Sediment Removal percent | Nitrogen Removal percent | Phosphorous Removal percent |
|---|---|---|---|---|---|---|
| Indiana 1979 | Silt loam | <5 percent | 15 feet<br>30 feet | 70<br>84 | 54<br>73 | 61<br>79 |
| Virginia 1989 | Silt loam | 11-16 percent | 15 feet<br>30 feet | 83<br>93 | 83<br>82 | 85<br>87 |
| Maryland 1989 | Sandy Loam | 3-4 percent | 15 feet<br>30 feet | 66<br>83 | 0<br>48 | 27<br>46 |
| Iowa 1991 | Silt loam | 7 percent | 10 feet<br>20 feet<br>30 feet | 72<br>83<br>97 | ND | ND |
| Iowa 1991 | Silt loam | 12 percent | 10 feet<br>20 feet<br>30 feet | 88<br>90<br>96 | ND | ND |

**Table A-7. General results from several studies on the removal of Nitrate-N and P from surface and sub-surface waters in agricultural areas by vegetated (forested and grass) filter strips (Osborne and Kovacic 1993).**

| Width (m) | Parameter | Percent Reduction | VBS Type | Reference |
|---|---|---|---|---|
| Subsurface flow | | | | |
| 10 | N | 60-98 | Forest | James, et al. 1994 |
| 19 | N | 40-90 | Forest | Schnabel 1986 |
| 25 | N | 68 | Forest | Lowrance et al. 1984 |
| 30 | N | 100 | Forest | Pinay & DeCamps 1988 |
| 27 | N | 10-60 | Grass | Schnabel 1986 |
| 19 | P | 33 | Forest | Peterjohn & Correll 1984 |
| 50 | P | -114 | Forest | Peterjohn & Correll 1984 |
| Surface flow | | | | |
| 30 | N | 98 | Forest | Doyle, Stanton et al. 1977 |
| 9 | N | 73 | Grass | Dillaha et al. 1989 |
| 5 | N | 54 | Grass | Dillaha et al. 1989 |
| 27 | N | 84 | Grass | Young et al. 1980 |
| 16 | P | 50 | Forest | Cooper & Gilliam 1987 |
| 19 | P | 74 | Forest | Peterjohn & Correll 1984 |
| 50 | P | 85 | Forest | Peterjohn & Correll 1984 |
| 9 | P | 79 | Grass | Dillaha et al. 1989 |
| 27 | P | 83 | Grass | Dillaha et al. 1989 |

Many researchers caution that the effectiveness of grass filter strips may decrease as the strip becomes inundated with sediment or as the ground becomes flooded or saturated (Klapproth ammonium was actually lost from the filter. Work in Illinois, Georgia (15 year study), and elsewhere has 2000). In an experiment at Virginia Tech in 1989, Dillaha et al. found that a filter strip which initially removed 90 percent of delivered sediment was removing only 5 percent after six trials. This clearly emphasizes the necessity of regular maintenance if high efficiencies are to be sustained. VFSs are probably more efficient at removing large soil particles than fine ones—especially clays. In Arizona, using Bermudagrass filter strips, sand particles settled out within 10 feet while the removal of silts required 50 feet (Wilson 1967). Experimenters in Minnesota suggest that VFSs of 300 feet may be required to remove clay particles.

Clearly, many factors influence the ability of VFS to remove sediment from land runoff. Gough (1988) argued that attempts to craft singular, generic standards for VFS widths are inappropriate since they are based on over-simplifications of complex physical processes. Factors other than width and sediment load that are important for determining the efficiency of VFS are field relief, slope, vegetation type and density (which dictates hydraulic resistance), surface litter characteristics, soil structure, and the timing, frequency and force of rainfall events (Osborne and Kovacic 1993). Riparian VFS must be properly constructed and regularly maintained if they are to remain effective; perhaps the most important consideration is the maintenance of shallow sheet flow into and across the VFS. When flow paths begin to form or when deep sediments accumulate, the efficiency of VFS drops dramatically.

Nutrients can enter surface waters in surface flows adsorbed to soil particles or in subsurface flows in dissolved forms. Phosphorus, for example, mainly enters streams and other waters adsorbed onto soil particles or organic material while nitrate is most commonly transported in soluble form through shallow groundwater (Klapproth 2000).

The primary mechanism for phosphorus removal by VFS is the deposition of P associated with settling of sediments (Brinson et al. 1984). Removal efficiencies should be correlated somewhat with sediment removal efficiencies. There is, however, no consistent general pattern to removal despite generally high removal rates. Researchers in Illinois compared the effectiveness of a mixed hardwood riparian forest and a grass filter strip to reduce P loads from agricultural lands. While the forest buffer removed more P initially, the forest also released more P during the dormant season. On an annual basis, the grass filter was a more efficient sink for P than the forest. However, grass buffers may only trap particulate P temporarily, releasing it during later storms. Removal efficiencies are complicated by this cycle of entrapment and release. Never the less, with careful attention to sediment removal and biomass harvesting, removal efficiencies of both grass and forest filter strips may be kept relatively high.

Many pollutants, however, occur in soluble form and are unlikely to be removed effectively with certain types of VFSs. However, the removal of soluble nutrients and other pollutants is much more variable. A limited number of studies have evaluated VFS trapping of nitrogen, phosphorous and some pesticides, particularly those in soluble form.

Riparian forests have been reported by many researchers to effectively remove nitrogen from agricultural runoff. For example: On Chesapeake Bay in Maryland, scientists estimated that a forested riparian buffer removed approximately 89 percent of the nitrogen from field runoff, predominantly in the first 62 feet of the buffer (Peterjohn & Correll 1984). In a Virginia study that evaluated nitrate and ammonium trapping, nitrate removal ranged from 46 to 75 percent, but documented a 10 percent to 90 percent reduction in nitrate concentration for forested and grass filter strips, and a range of —114 percent to 85 percent reduction in phosphorous concentrations (the negative value indicates a net release from the filter). A corroborating study in Maryland suggests that this release is due to previously trapped P to be released as soluble phosphorous (Pts).

Grass VFSs may also reduce nitrogen levels from agricultural runoff. In North Carolina, grass and grass/forest filter strips reduced total nitrogen by 50 percent (Daniels and Gilliam 1996); on experimental plots in Virginia, orchardgrass VFSs 30 feet wide reduced total nitrogen by 76 percent (Dillaha et al. 1989). Even so, forested buffers may be more efficient at nitrogen removal than grass (Haycock and Pinay 1993), probably due to the larger amount of carbon available in the forested buffers year-round. (Carbon has been found to aid denitrification but inhibit dissolved Phosphorus removal, which occurs mainly in mineral soils). The most important factor for removing dissolved nutrients from runoff seems to be the infiltration capacity of the soil.

The fate of other pathogens and toxins in riparian zones and VFSs is not well understood. Limited research suggests that riparian buffers may help reduce pesticides and metals from runoff (Klapproth 2000). Although pesticides have the potential to cause significant damage to aquatic communities, losses from farm fields are generally very low—less than 5 percent of applied pesticides—and pesticide levels in surface waters are considered extremely low in many parts of the nation. (Klapproth 2000). However, contamination of surface waters by a variety of pesticides can and does occur throughout the U.S. and Washington State. Twenty-three different pesticides were detected in Puget Sound streams by the U.S. Geological Survey during a water quality survey throughout the Puget Sound Basin. Most of the streams drained urban or suburban areas and probably reflect misuse of chemical pesticides by homeowners; certain of the streams occur in rural and agricultural areas, however, and probably reflect crop-based pesticide use there (Bortleson and Davis. 1997).

Several studies have examined the effectiveness of grass VFS to reduce pesticide levels in agricultural runoff. In southern Georgia, filter strips of grass successfully removed from 86 to 96 percent of the herbicide trifluralin from runoff (Rhodes et al. 1980); studies on the effectiveness of bromegrass filter strips on atrazine, cyanzine, and metolachlor suggested that the filter only removed 10 to 40 percent of the herbicides entering the VFS (Hatfield et al. 1995). A more recent study in Iowa indicated a 28 to 35 percent removal rate of the pesticide atrazine for a 15-foot-wide filter and a 51 to 60 percent removal rate for a 30-foot filter. Adsorption was greatest in soils with high organic content; half the atrazine became irreversibly bound to soil particles while about 15 percent was broken down by soil microorganisms (Moorman et al. 1995).

## Factors for Determining Appropriate Widths and Composition of Vegetated Filter Strips

The VFS must address four types of pollutants in agricultural runoff: sediment, sediment-adsorbed pollutants in surface runoff, dissolved pollutants in surface runoff, and dissolved pollutants in groundwater. The effectiveness of VFS to remove these various pollutants from agricultural runoff depends on many factors: pollutant type and load, field shape and slope, type and density of vegetation in the VFS, soil structure within the VFS (especially infiltrative capacity), subsurface drainage patterns, and climatic conditions. The design of VFSs—whether grass or forest—to improve water quality must take these factors into account.

It is oftentimes difficult to translate controlled experiments into practical applications. Still, much field research supports the use of filter widths in the range of 10 to 40 feet. These distances depend on field to VFS ratios of no more than 50:1 (area:area) and assume shallow uniform flow through the VFS. Most authors stress that these values are minimums and recent work suggests VFS of greater widths may be necessary to remove pollutants (see Table A-8). Palone and Todd (1997) suggest VFS widths from 50 to

100 feet to effectively trap sediments. As a rule of thumb, the filter should expand 5 feet for every 1 percent increase in slope. The same authors suggest VFS widths from 35 to 125 feet may be required to effectively remove dissolved pollutants. Values in the FWHCA are consistent with these data and recommendations but lie near the lower values of the range.

**Table A-8. Suggested VFS widths Based on Percent Slope.**

| Land Slope percent | VFS Width in Feet |
|---|---|
| 0-5 | 20 |
| 5-6 | 30 |
| 6-9 | 40 |
| 9-13 | 50 |
| 13-18 | 60 |
| Widths are for grass and legumes only and are not intended for shrub and tree species | Adapted from USDA-NRCS (Indiana) |

The method used to determine filter strip width for the FWHCA is based on this literature review and uses multiple factors to determine the appropriate width of the VFS. This approach is generally consistent with recent NRCS methods and applications in other states and in Europe although it produces VFS widths somewhat larger than the NRCS method (see Figure A-1). The NRCS recommendations are based on considerable research into the effectiveness of filter strips and provide guidance for proper design and implementation of VFSs in many situations. The recommendations of the NRCS are quite general, however, and should be considered minimums. Other slope-based methods yield slightly different values depending on conditions.

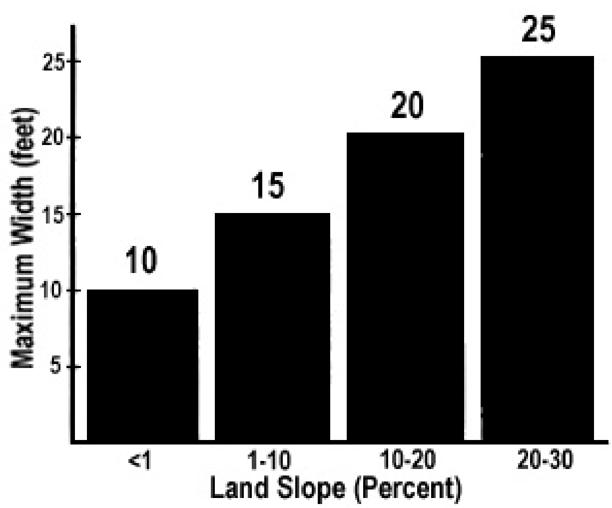


**Figure A.1.NRCS recommended filter strip minimum widths based on percent slope.**

However compelling slope may be as criteria for determining filter strip width, virtually all authors caution against using slope as the only criteria for establishing a vegetated filter strip. Eck (2000) is representative of most when he discusses effectiveness of VFSs. He groups the factors that influence VFS effectiveness into 5 categories.

*The amount of sediment reaching the VFS from surrounding fields.* This is affected by field slope, slope length, rainfall intensity, length of rainfall, and the type of tillage above the filter;

*The retention time of the water in the VFS.* VFS width, type of cover, and the condition of the cover affect this.

*The infiltration rate of the soil.* Soils with higher infiltration rates trap and hold more dissolved nutrients and pesticides than less infiltrative soils.

*Surface uniformity of the VFS.* Even small rolls, rills, and depressions can concentrate flow and reduce the effectiveness of the VFS.

*Maintenance of the VFS.* Upkeep of vegetation stands, removal of previously trapped sediments and debris, and regular repair and replanting of damaged areas of the VFS are critical to proper function.

Other authors describe similar factors. Franti (1997) adds shape and area of the field to the factors; Leeds et al. (1994) emphasizes soil characteristics, field shape, and area of the field as important factors to be considered in evaluating the effectiveness of VFSs. Since filter-strip width is also affected by soil characteristics, the shape and size of the land draining to the filter, and other attributes, the values in Figure A.1 should be adjusted upward depending on particle size, the nature of pollutants in the runoff, and, according to most authors, the ratio of field drainage area to filter area (Leeds et al. 1994). Many authors (Franti 1997, for example) suggest that the ratio be no greater than 30:1; the width of the VFS increasing as the ratio increases. Preferably, the ratio should be in the range of 3:1 to 8:1 (area to area). Based on a survey of over 2,700 sites in the U.S., the ratio of drainage area to filter strip area averaged about 3:1 (Leeds et al. 1994)

In Code 393 of the NRCS Conservation Practices (1999), The agency uses compound criteria to determine the minimum VFS widths as follows:

To reduce sediment, particulate organics, and sediment-adsorbed contaminants in runoff, the minimum flow length is 20 feet. This applies where the field slope is between 1 and 10 percent, where the ratio of drainage area to filter area is less than 50:1, and where the rate of sheet and rill erosion is less than 10 tons/year.

To reduce dissolved contaminants in runoff, an additional minimum of 30 feet is required based on the contaminants of concern, the volume of runoff, and the infiltration capacity of the soil.

Use of this method suggests that in many cases, the successful treatment of agricultural runoff requires a VFS width of approximately 50 feet if both particulate and dissolved pollutants are present in the runoff. Once again, the FWCHA values are close but somewhat less than this recommendation.

Departures from these methods and standards are typically made in response to variations in local conditions or in local objectives for water quality protection. In general, the departures from methods—the simplification of criteria or the omission of criteria—should reflect relatively homogeneous conditions in one or more of the controlling parameters of the method. If all soil types or rainfall patterns are similar, or if drainage areas all lie within a few percent difference, it would be possible (and even advisable) to omit or simplify these factors to avoid unnecessary complexity. Even so, the rationale for these departures and simplifications must be explained and justified. The same can be said of specific thresholds and criteria for establishing VFSs. Whether defining slope categories, resource sensitivities, or soil groups, it is necessary to provide a rationale for choices between defined units. Where no empirical pattern or division can be found, expert judgment can be substituted if its basis can be determined.

## Sensitivity of Receiving Waters and Target Organisms

Virtually no authors considered the degree of sensitivity of the receiving waters or the sensitivity of biota in the aquatic system in establishing the VFS widths or in evaluating their effectiveness. The methods above are identical in that they are “source-sensitive” and seek to reduce to the maximum extent practicable the pollutant loads to receiving waters. While that is a desirable goal, they are not “target-sensitive” in that no standards are established for pollutant reductions based on the sensitivity of receiving waters or on the tolerance of biota inhabiting the waters. Without such a criterion, it is not possible to judge the outcome of even a large reduction in pollutant loading. Thus, an 80 percent reduction in a pollutant may still fail to reduce the pollutant to tolerable levels for particularly sensitive organisms.

An attempt has been made, however, in the FWHCA to consider sensitivities of salmonids as a criterion for increasing VFS widths. Rationale for the increase is assumed to be based on protection of embryos as the most sensitive developmental stage of all possible life stages inhabiting agricultural waterways (as evidenced by the gravel-bedded indicator in the rule). A review of the current literature (which is a bit sparse) suggests that such a distinction may be appropriate. The effects of sediment on salmonid embryos are well studied and have been shown to cause high mortalities in both eggs and alevins incubating in the gravel (Cooper 1965; Koski 1972; Phillips 1971; Sear 1993; Chapman 1988). Cook et al. (1997) found that various forms of the pesticide TCDD (tetrachlorodibenzo-dioxin) produced acute toxic effects at much lower dosages in embryos of lake trout than in juveniles. Guillette et al. (1995) suggest that embryonic stages of fish and wildlife are generally the most susceptible to environmental pollutants.

However, there are a host of sub-lethal effects associated with pesticides that affect all life stages of salmonids. In fact, juvenile stages of salmonids, from early emergent fry to out-river migrants, exhibit considerable sensitivity to many pollutants, most particularly herbicides and pesticides. These effects range from outright lethality to impaired swimming ability, changes in schooling behavior, interruption of smoltification, inhibition of normal migratory behavior, and immunosuppression (Bennett and Wolke 1987; Birge et al. 1993; Dodson and Mayfield 1979; Elson et al. 1972 and many others). Recent work at the Northwest Fisheries Science Center of the National Marine Fisheries Service in Seattle suggests that certain pesticides can inhibit homing of adults by interfering with olfactory receptors in adults (Scholz, N. 2001).

These sub-lethal effects may ultimately be as damaging to salmonid survival as direct lethality. A precautionary approach would suggest that if this is so, the level of protection afforded juvenile salmon should probably not vary by life stage.

Little research has been done to suggest appropriate VFS widths to remove pesticides and herbicides from agricultural runoff. Work by Correll et al. (1978), Rhode et al. (1980), and Schultz et al. (1994) suggests that VFS with subsurface flow paths of at least 10 meters may be necessary to achieve a 50 percent reduction. A Minnesota study suggested a flow path closer to 30 meters to achieve a substantial reduction of 80 percent in atrazine. In all cases, the proper distance will depend on the infiltrative capacity of the soil beneath the VFS since pesticide removal depends on adsorption to soil particles and decomposition by soil microorganisms.

## A.2.2 Cover Crops

### Effectiveness of Vegetated Cover Crops

Cover crops are a source reduction management practice. They are defined as crops grown during the time period between harvest and planting of the primary crop (NRCS 1998). The main purpose of cover crops is to provide soil cover and protection against soil erosion. Cover crops may also sequester nutrients over the winter.

- Cover crops are an effective management practice to reduce soil loss from both wind and water erosion;
- Cover crops can also be effective in filtering sediment from shallow floodwaters that pass through the cover crop;
- Rapid establishment and high density of vegetation is key to effective erosion prevention;
- Fields in King County are generally flat and soils are not as erodible as the loess soils of SE Washington or the Piedmont region where cover crops are in general use.

The cover of vegetation on the land acts as a protective layer between the soil and the atmosphere; above ground components such as stems, leaves, or branches absorb some of the energy of raindrops, runoff, or wind thereby reducing the effect on the soil below. The roots of the vegetation add to the mechanical strength of the soil. The effect of vegetation cover was demonstrated in a most elegant experiment carried out by Hudson and Jackson (1959) using mosquito gauze in place of plants as a soil cover. Soil loss was compared from identical bare plots on clay loam, one plot covered by the gauze suspended just above the soil, the other remained bare. The gauze had the effect of breaking the force of the falling raindrops by absorbing their impact and causing the water to fall to the soil surface as a fine spray. Over the 10-year period of the experiment, mean annual soil loss for the bare (uncovered) plot was 126.6 tons/hectare (ha) and only 0.9 t/ha for the gauze-covered plot. Similar results were obtained in a similar experiment carried out in Italy by Zanchi (1983): 43 t/ha for an uncovered clay soil plot and 3.8 t/ha for a covered one.

The effectiveness of the plant cover in protecting the soil from rainfall depends on the height, density, and continuity of the cover (Morgan 1995). If the canopy is high—7 meters or greater—water drops may regain 90 percent of their energy. Even for low-growing plants such as soybeans, concentration of leaf runoff between the rows resulted in a soil detachment rate that was still 94 percent of that on open ground (Armstrong and Mitchell 1987). The greatest reduction in kinetic energy of rainfall occurs with dense, spatially uniform vegetation; clumpy, tussocky vegetation and row crops are less effective and may even lead to locally high detachment intensities and runoff velocities between clumps and rows (Morgan 1995). These and other examples can be found in Morgan (1995), Soil Erosion and Conservation.

The importance of the continuity and density of the ground cover in reducing soil loss is clearly demonstrated in tests carried out over several years by North Carolina State University on the highly erodible soils of the piedmont region. Table A-9 shows the results of several years of plot experiments on these soils. In this case, a mixture of grasses was used as the cover over the fine, sandy soils.

**Table A-9. Effectiveness of Ground Cover on Reducing Soil Loss: Soil loss in tons/acre/year.**

| Slope in percent | Continuity of Ground Cover | | |
|---|---|---|---|
| | 30 percent | 60 percent | 90 percent |
| 3 | 3.7 | 2.7 | 0.4 |
| 6 | 10.0 | 7.7 | 6.0 |
| 9 | 17.2 | 13.2 | 10.5 |

In agricultural applications, this vegetation cover is achieved by planting a second, usually grass-like cover crop, immediately after harvest of the primary crop. Cover crops are generally grown as a conservation measure during the off-season or as ground protection under orchard and nursery trees, and increasingly, in the rows between grapevines throughout the wine growing regions of California and France. In the U.S., cover crops are more widely used in the southeastern and Mid-Atlantic states than in other areas of the country.

In the Northwest, cover crops are generally grown as winter annuals to be harvested and the residue ploughed under in the spring as a green manure. In eastern Washington's Palouse region, cover crops are sown to prevent wind erosion during the winter (STEEP 1995); in other areas of the U.S. such as the southeast and Pacific northwest, cover crops may provide considerable protection from splash erosion and can even act as a physical filter for sediment-laden runoff (and thus for pollutants bound to that sediment). Moreover, cover crops may act to increase soil porosity thus aiding infiltration and reducing runoff (Table A-10). In some cases, cover crops were found to be scavengers of excess nitrogen left after harvesting the main crop (Mostaghimi et al. 1992) and are shown to reduce nitrogen leaching to groundwater in parts of North America and Europe (Ritter and Shirmohammadi 2001). Non-leguminous crops were more effective than legumes at this reduction. The study by Mostaghimi et al. (1992) also revealed the *loss* of nitrogen from experimental plots where residue levels from the incorporated cover crop exceeded 1500 kg/ha. A similar result was found for phosphorus (Mostaghimi et al. 1988). Never the less, cover crops as part of rotations are widely used to control soil erosion from both wind and water.

**Table A-10.Functions of Cover Crops in Relation to Erosion and Runoff Reduction**

| Function of Cover | Result relative to erosion and runoff |
|---|---|
| Rainfall Interception | Reduce splash detachment |
| Enhance soil structure and reduce compaction | Improve infiltration, water retention, reduce runoff volume |
| Nutrient uptake | Reduce Nitrogen leaching |
| Flow interception | Slow runoff, increase retention time, trap sediment and sediment-bound pollutants |
| Mechanical stability | Reduce soil detachment |

To be effective at these functions and be useful as a soil conservation measure, cover crops must possess four attributes (Morgan 1995):

- **Quick to establish**. In King County, establishment must occur within a relatively short period after the growing season. However, mild autumn temperatures can provide a somewhat longer window for this establishment in some years;

- **Provide an early, dense cover.** As growth rates decline in the autumn, any cover crop should be well established with a dense cover prior to the onset of winter rains in November;
- **Be aggressive enough to suppress weeds**. To be effective as an erosion preventative cover, and useful as a spring manure, the crop must take root rapidly and grow quickly, out competing weedy species that may invade the field.
- **Possess a deep root system**. This attribute increases the macroporosity of the soil and aids infiltration of rainfall. It also increases the binding strength of the cover and it's ability to hold soil in place.

Cover crops function by resisting soil detachment by wind or by raindrop splash (Morgan 1995) and have been found to be effective in many horticultural situations. Use of a permanent cover in vineyards of the Beaujolais region of France reduced erosion to less than 7 percent of that found in vineyards with bare soil (Gril, Canler and Carsoulle 1989). The cover was managed by mowing and did not compete with the vines for water, even during the dry parts of the summer. The authors suggested that the increased infiltration promoted by the grass limited water loss during storms and thus helped to counterbalance the water deficit. The storm patterns in this region of France are considerably different from our in King County but an increase in soil porosity and retention capacity of many horticultural soils in our area could prove beneficial for both water retention and pollutant—especially nutrient—uptake and removal. In another example from vineyards in the Ruwer Valley of Germany, a grass cover reduced annual soil loss to 0.31 tons per hectare (ha) compared to 2.77 t/ha without such a cover (Bamberger 1991). In a study of small grain cover crops following corn harvest, Kaspar et al. (2001) found that both oat and rye cover crops decreased rill erosion when compared to the control. In 1997 and 1998, the rye cover crop decreased rill erosion 93 percent and 86 percent, respectively. In comparison, the oat cover crop decreased rill erosion by 64 percent in 1997 and 42 percent in 1998.

A simulation study (using the Annualized Agricultural Non-point Source loading model) compared the effectiveness of BMPs in different cropping systems (conventional till, no-till, and reduced till) in Mississippi (Yuan et al. 2002). The study found that cover crops reduced sediment yield by 32 percent in the conventional till system, by 41 percent in the reduced till system, and by 32 percent in the no-till system. Absolute reductions in sediment yield were highest for conventional till since erosion rates were considerably higher to begin with (in tons per acre per year). Cover crops were of particular value in reduced till systems where residue created during winter growth was retained on the surface during the summer.

The contribution of cover crops to soil structure depends mainly on their incorporation into the soil horizon when they are tilled into the field. This incorporation accelerates the formation of soil aggregates via microbial decomposition processes that "glue" soil particles together with polysaccharide gums forming stable aggregates (Burns and Davies 1986). These aggregations, along with the channels formed by decayed roots are the principle factors responsible for increased infiltration capacity (Lal et al. 1991).

Nutrient uptake by cover crops can substantially reduce nitrate leaching to shallow and even deeper groundwater. In many parts of the U.S., nitrate contamination of aquifers has become a significant problem. A 1984 study found that over 6 percent of the wells throughout the U.S. for which data were available exceeded the EPA drinking water standard for nitrate (Madison and Brunett, 1984). A survey of 168 wells in the Willamette Valley of western Oregon found that 20 percent exceeded that limit (CAST, 1985). In a study by Sattell et al. (1999) of Oregon State University during 1992 to 1995, a cereal rye cover crop reduced nitrate leaching by 32 to 42 percent as compared to leaching under fallow conditions. In another western Oregon study of nitrate movement in the soil following harvest of a broccoli crop, Hemphill and Hart (1991) demonstrated the effectiveness of a fall-planted rye cover crop introducing movement of nitrate into the deeper soil profile. Areas with the rye cover crop contained 0.18 ppm (parts per million) nitrate at 30-40 inches of soil depth compared to 5.38 ppm nitrate at the same depth in areas with no cover crop. No measure of nitrate concentrations in groundwater were made during this study, however, but the implications for nitrate capture by the cover crop seems clear.

There is considerable evidence that cover crops can perform various erosion prevention and pollutant prevention and sequestering functions. One overlooked function that arises from the proposed location of cover crops on floodplain fields is that of sediment removal and entrainment from sediment-laden floodwaters. The filtering function of grassed waterways and vegetated filter strips is well known (Ritter and Shirmohammadi 2001; see also the discussion of VFS above) and cover crops may perform a similar function provided flow depths and velocities are not so great that the cover crop is flattened or occupies a very small portion of the water column. Even in these cases, however, some filtration may still occur. In a study by Wilson (1967) in Arizona of sediment removal from floodwaters, plots of Bermudagrass, alfalfa, and Panicum were tested for their ability to filter sediment and clarify sediment-laden overflow water. Between 95 percent and 99 percent of the sediment in test water was filtered by Bermudagrass; fescue and Panicum each removed about 96 percent; and a smaller variety of Panicum about 94 percent. In a particularly dramatic test of the filtration ability of coastal Bermudagrass, the turbidity of test water declined from 5,000 ppm to 45 ppm in a distance of 700 feet. While these were strictly controlled tests, the evidence suggests that cover crops may provide some filtration function during low frequency flood events, provided the vegetation is dense and well-established, and floods do not repeat too quickly.

Using cover crops in horticultural production systems provides multiple benefits to soil quality, soil conservation and water quality. Other benefits include enhanced nutrient cycling and pest management. But there can be deleterious effects as well. In situations where soils are cool and wet during the winter, planting can be delayed; some nutrients can be immobilized while others can be released ($PO_4$); in some cases, the cover crop is killed with a herbicide prior to tilling the field for planting, thus increasing the use of herbicides in the operation (Luna 1998; Curran et al. 1996).

## Application of Cover Crops in King County

The use of cover crops in the U.S. for erosion protection has been typically restricted to highly erosive soils in the southeast, south, and intermountain west—particularly in southeast Washington (the Palouse Hills) and northeast Oregon, both regions of light, fine sandy loess soils. Cover crops have been used mainly as a technique to avoid wind erosion but their use for the control of water erosion is rapidly gaining favor. Unlike the loess soils of eastern Washington or the piedmont soils of the Southeast, the soils of King County are not considered highly erosive; rather, they belong to the lowermost erosion class established by the National Resource Conservation Service. The reasons for this low erosion rate is two-fold: most agriculture in King County is carried out on relatively flat ground (compared to the wheat fields of eastern Washington where tilled slopes often exceed 25 percent), and our soils are relatively coarse when compared to loess soils or piedmont soils. The most erosive soils contain high percentages of silts and fine sands and are generally found on our large river floodplains, and on the Enumclaw Plateau where fine, ash-laden material is a large component of the soil (King County Soil Survey). These are the same areas where most of the County's large-scale agriculture is concentrated and, combined with the erosive characteristics of the soils, these areas are most prone to winter erosion if soils are left exposed.

### *Livestock Fencing and Exclusions*

Fencing or other use-exclusion BMPs are structural practices that focus on source reduction and recovery of damaged habitats (Ritter and Shirmohammadi 2001). When livestock have access to streambanks or riparian areas surrounding streams and wetlands, they may defecate directly into the stream, stir up sediment from the stream bottom, or break down the banks of the stream as they clamber up and down seeking water. The stream banks may already be destabilized by grazing or animal traffic through the riparian area and bank sloughing may be apparent. Streambank failure has been shown to be a significant source of sediment and phosphorus in the mid-west (Sekely et al. 2002) and livestock access can exacerbate this process (Elmore 1992, and Platts 1991). In fact, grazing, mainly in the more arid parts of the West, is largely responsible for the extremely poor condition of riparian areas throughout the region (Fleischner 1994).

The health of aquatic systems is closely tied to the integrity of riparian zone (Gregory et al. 1991; Naiman et al. 1992) and appropriate management to ensure that integrity is vital. Riparian zones perform a number of functions critical to the quality of aquatic habitats: shade, bank stabilization, sediment control and nutrient filtration, large woody debris, organic litter, nutrient transformations, and microclimate (humidity, soil moisture, wind speed, and air temperature) control. In addition, even though riparian zones constitute only a small percentage of the total land area in a watershed, they are extraordinarily important for wildlife. Brown (1985) reports that 87 percent of wildlife species in western Oregon and western Washington use wetlands or riparian areas during some or all of their life cycle. Bury (1988) reported that 8 of 11 species of amphibians and 5 of 6 species of reptiles in Oregon either live or breed in riparian and aquatic habitats. Beschta et al. (1995) reported that 55 Oregon bird species depend on or exhibit preferences for the riparian zone.

Fencing and exclusions have been used throughout the West to reduce livestock effects on these sensitive habitats. In an evaluation of grazing strategies for their effects on riparian zones, Platts (1991) found fencing to be one of two strategies that afforded the most protection from livestock. The GAO (1988) and Chaney et al. (1990) reviewed riparian restoration efforts on BLM and Forest Service land and reported substantial improvements in riparian and stream condition in many cases. Riparian fencing and reductions in stocking rates generally proved to be the most effective measures.

Fencing in the Snoqualmie floodplain for riparian and streambank protection is consistent with results from several studies and with recommendations from the BLM and Forest Service where livestock grazing is allowed on their lands.

One note of caution, however: fences in any river floodplain would necessarily be either very strong to resist flow pressure during flood events, or be very weak to easily break away (and be easily repaired). If the fence were very strong and ran perpendicular to the flow, floodwaters could conceivably be delayed or diverted by them if they accumulated abundant debris. Perhaps a more portable fence could be used that could be removed prior to flooding. Such fences are in use in eastern Washington to delineate paddocks for livestock and consist of single or double strand electric that can be wound on reels for portability.

### *Combined Application of Best Management Practices*

No single best management practice (BMP) can be expected to be useful in all circumstances. Table A-11 lists best management practices and pollutants treated by them, including vegetated filter strips, cover crops and livestock fencing and exclusions. Combinations of soil, slope, area, and management are simply too complex for confident application of any one BMP. A sound scientifically-defensible approach to alleviating agricultural effects on aquatic areas must recognize the attributes of the farmed landscape—soils, slopes, crop types, the management practices employed on the farm, and the sensitivity of the feature to be protected or conserved. In this way, context-sensitive solutions can be adopted that prevent many of the effects associated with agricultural operations. This strategy of preventive management is far superior to any simple treatment strategy both for the sensitive feature or habitat and for the health of the farmed landscape (Altieri 1995). Moreover, as the context of an agricultural operation is altered in response to changing market conditions, changes in ownership, or simple preferences, the solutions must be adaptable as well.

**Table A-11. Best Management Practices (BMPs) for Sediment and Non-Point Pollution Reduction. Adapted from Ritter and Shirmohammadi (2001).**

| BMP | Type | Pollutants Treated |
|---|---|---|
| Conservation tillage | Source reduction; managerial | Sediment and sediment- bound pollutants |
| Contour farming | Source reduction; managerial | Sediment and sediment- bound pollutants |
| Contour strip cropping | Source reduction; managerial | Sediment and sediment- bound pollutants |
| Field strip cropping | Source reduction; managerial | Sediment and sediment-bound pollutants |
| Vegetated filter strips | Transport interruption; structural | Sediment, sediment-bound, biological and some soluble pollutants |
| Riparian buffers | Transport interruption; structural | Sediment, sediment-bound, and some soluble pollutants |
| Cover crop | Source reduction; managerial | Sediment, sediment-bound and soluble pollutants |
| Conservation crop rotation | Source reduction; managerial | Sediment, sediment-bound and soluble pollutants |
| Nutrient management | Source reduction; managerial | Sediment, sediment-bound, biological, and soluble pollutants |
| Manure storage facilities | Source reduction; structural | Sediment, sediment-bound, biological, and soluble pollutants |
| Precision farming | Source reduction; managerial | Sediment, sediment-bound, and soluble pollutants |
| Grass waterways | Source reduction or transport interruption; structural | Sediment, ssediment-bound pollutants |
| Constructed wetland | Transport interruption; structural | Sediment, sediment-bound, biological and soluble pollutants |
| Sediment detention basin | Transport interruption; structural | Sediment and sediment-bound pollutants |
| Fencing and exclusions | Source reduction; structural | Sediment, sediment-bound, biological, and soluble pollutants |
| Off-stream watering | Source reduction; structural | Sediment, sediment-bound, biological and soluble pollutants |
| Rotational grazing | Source reduction; managerial | Sediment, sediment-bound, biological and soluble pollutants |
| Integrated Pest Management | Source reduction; managerial | Sediment, sediment-bound and soluble pollutants |

# A.3 POTENTIAL RISKS TO THE FUNCTIONS AND VALUES OF CRITICAL AREAS GIVEN PROPOSED AGRICULTURAL STANDARDS

The present proposal for regulating agricultural operations in the Critical Areas Ordinance (CAO) addresses four types of agricultural activities separately, including:

- Existing agriculture (no new clearing, structures or field access drives in critical areas or buffers);
- New or expanded agriculture on non-forested areas;
- New agriculture or expanded agriculture on forested areas; and
- Maintenance of agricultural ditches.

Each activity has a set of rules or standards associated with it that constrain activities within the element. This section evaluates the elements of the CAO proposal, lists and briefly discusses departures from the accepted scientific approach and standards, and assesses the risk to functions of aquatic areas (including a discussion of channel migration zones), wetlands and wildlife habitat. It should be noted that risk, as it is used here, means the probability of a harmful departure from a "no net loss" standard of function or value for the critical area. The greater the probability of the harmful departure from that standard, the higher the risk to the critical area or function. The functions assessed for each critical area are listed in Section A.1.2 of this appendix.

Three categories of risk are established for this analysis. **Low** indicates no decline in the performance of the function or value is discernible; the range of variation of the function remains unchanged. **Moderate** indicates there is a decline in the performance of the function or value, the rate of decline is accelerated, or the range of performance is changed. **High** indicates there is a decline in performance that is likely to lead to complete loss of function within a specified time frame, for a species. This decline is likely to lead to endangerment; or the range of variation around the performance is grossly altered.

## A.3.1 Major Elements of the CAO Proposal

### Existing agriculture regulation includes:

- Ongoing activities are allowed in critical areas and their buffers;
- Compliance with amended livestock ordinance required;
- Water quality violation addressed through KC water quality ordinance and farm planning; and
- Farm management plans encouraged.

### New or expanded agriculture on non-forested areas regulation includes:

- Farm management plan required, including best management practices, site planning and long term commitment to agriculture;
- New farm buildings and access drives allowed in CAO buffers and in grazed wet meadows according to approved farm plan;

- New residences not allowed in CAO buffers;
- New residences are allowed in grazed wet meadows according to approved farm plan; and
- Compliance with amended livestock ordinance required;
- 35 percent clearing restriction does not apply.

### New agriculture or expansion of existing agriculture in forested areas regulation includes:

- CAO fixed regulations, including critical area buffers, apply;
- Compliance with amended livestock ordinance required; and
- 35 percent clearing restriction applies.

### Agricultural ditch maintenance regulation includes:

- Farm plan must include ditch maintenance BMPs; and
- State Hydraulic Project Approval Permit may be required.

## A.3.2 Risk Analysis

Table A-12 is a summary of the risk analysis done for the agricultural rule. Since there is uncertainty associated with any risk estimate, the table examines the risk *relative* to a fully functional critical area or to an unimpaired function or value. The relative risk is estimated for Current conditions, conditions 5 years after CAO implementation and 25 years after implementation. The greater the time frame, the greater the possibility that there is an error in risk estimation.

### Assumptions of risk analysis include:

- Farm management plans are developed and implemented within 5 to 10 years;
- Farm management plans include fish and wildlife conservation BMPs;
- No compensatory flood storage required for residences and buildings;
- Existing forest cover is not presently designed to meet wildlife objectives; and
- Farm plans and best management practices are revised as agricultural activities change through adaptive management.

As previously discussed, the present condition of the agricultural landscape in King County imposes considerable risk on most of the functions and values associated with the critical areas found in those landscapes. The transformation of native ecosystems to human-built ones over the last 100 years, coupled with the regular disruptions caused by agricultural operations, has led to native species loss and non-native species invasions. In some cases, these effects are historical artifacts that cannot be quickly undone and the level of risk will persist for many years. However, many of these effects can be remedied and possibly even reversed given enough time and effort. The fundamental base for ecosystem development—the land—remains intact though greatly changed. So we begin with a landscape that is high risk for most functions but has the capability for some recovery.

## *Wildlife Habitat*

Risk from the current landscape is high; in virtually all cases except for species diversity and spatial diversity in forestland to agriculture conversions, the current level of risk can be reduced through the use of farm planning. Among the BMPs used for this work are several wildlife-related habitat management practices that purport to manage habitats for wildlife survival. These BMPs include upland management, wetland management, early successional habitat management, etc. and are focused on maintaining and, in some cases, recovering native habitats. Areas of concern are population support, spatial diversity and habitat complexity under both the new or expanded agriculture and the conversion of forested areas to agriculture. The risk remains high in the expanded agriculture as areas now banked are once again brought under cultivation. The conversion of forest to farmland will decrease habitat complexity as edge is created and core habitats decline; native species diversity will likely follow, especially for sensitive species and spatial diversity will decline as the remnants of forest become isolated and disconnected. The risk moves from low to moderate for these species diversity and spatial diversity, remains at moderate for population support and connectivity, and actually increases in the short-term for sensitive species support as the conversion occurs. As the conversion settles in, the risk may drop back to slightly less than high provided the remainder of forest can be aggregated with adjacent patches of forestland.

## *Aquatic Areas*

Seven functions were evaluated for risk in this critical area (refer to Table A-12). All have a current relative risk of “High.” Few change dramatically over the short term (5 years) and only two over the long term (25 years). Habitat complexity is the result of in-channel habitat diversity, connectivity with the surrounding floodplain and riparian zone, and variation in function over time. In most agricultural areas, streams have been channelized or riparian areas degraded or both. Current risk is high. Under the proposed ordinance, risk remains high for the short term despite management changes because streams require considerable time to respond to most management actions. This lag is measured in tens of years. Only under the rules that require farm plans does the risk begin to decline; the plans allow integration of management activities that can affect multiple habitats and operations that cause declines. The same is true for species diversity—this should track habitat complexity to some degree although this function is the result of larger (than a single field) than a single stream.

The risk to primary productivity declines mainly as a result of sediment and nutrient BMPs and closer attention to fertilizer application. This trend should accelerate as practices become acculturated and the lags in response of streams (and wetlands) are overcome. Sediment and water quality values track this phenomenon directly since the materials carried in runoff and groundwater are responsible for eutrophication. Only in new agriculture on forested areas does the risk increase; this is due to clearing and the loss of nutrients from the forest floor as it is converted to agriculture. With appropriate BMPs, the sediment loss should return almost to normal and the risk drop back to low.

Hydrologic damping, the function to store water or to at least decrease concentration times, remains at high risk under the ordinance. However, reductions in risk are seen from ditch maintenance as mitigation efforts create channel complexity and management plans establish standards and schedules for maintenance.

The risk to salmonid support should decline over time as water quality improves and sediment loss declines, and maintenance schedules reflect biological criteria in management plans.

Although channel migration zones provide ancillary functions such as habitat complexity, connectivity, and salmonid support, the primary objective for regulating land use in channel migration zones is to protect the public from meandering rivers. Agricultural uses may compromise public safety if new structures are permitted on grazed wet meadows that lie in channel migration zones. It is predicted that risk would rise slightly over time, from moderate to slightly greater than moderate, as a result of agricultural development.

### *Wetlands*

Added to the functions for wetland assessment is spatial diversity—the variation in wetlands across the landscape; salmonid support is not evaluated. The current condition of agricultural landscapes imposes a high risk on all functions save hydrologic damping. In this case, floodplain wetlands and grazed wet meadows remain available to store floodwaters and rainfall even though their numbers have declined markedly.

Reductions in risk from the current status are primarily due to the development and implementation of farm management plans. This is reflected in the estimated risk for population support and species diversity, which would benefit from farm planning if conservation BMPs are used. Using the BMPs from the public rule, practices for wetland management and protection can be implemented for any operation. This effort can reduce the risk one category and could reduce risk associated with water quality and sedimentation to low within 25 years. This would bring the risk to primary productivity to low also except in the newly created farmland in now forested areas. In this case, an existing low risk would probably rise to moderate as the nutrients now sequestered in forestland are released into the environment and nutrients from the farm operation enter the system. In this same area, risk to species diversity would rise as wetlands become isolated despite CAO buffers. Spatial diversity of wetlands—the diversity of wetland types across the landscape—would also decline as landscapes are converted to agricultural uses.

Risk would also rise for hydrologic damping as storage volume in grazed wet meadows is taken up for buildings and residences. Although this practice may not be widespread, it could be locally severe and raise the risk in existing farmlands and in expansions from moderate to high. In all cases, the risk rises as wetlands—including grazed wet meadows—are isolated and converted to building areas.

**Table A-12. Relative Risk to critical area functions under current Agricultural Proposal.**

| Critical Area/Function | Existing agriculture<br>Current > 5yr > 25yr | New or expanded Agriculture<br>Current > 5yr > 25yr | New or expanded agriculture on forested areas<br>Current > 5yr > 25yr | Agricultural Ditch Maintenance<br>Current > 5yr > 25yr | Notes and Comments<br>Current > 5yr > 25yr |
|---|---|---|---|---|---|
| Aquatic Areas<br>Habitat Complexity | (H) > H >M | (H) > H > M | (M) > M >M | (H) > M | Risk in all categories could drop significantly with farm management plans, particularly if the FMP includes integrated components for conservation of existing fish and wildlife habitats and provisions for active management of newly created habitats.<br><br>Careful positioning of the 65/10 forest cover would tend to mitigate somewhat for the conversion of forest to agricultural uses.<br><br>Also, farm plans are adaptively managed as uses change on the farm. |
| Species Diversity | (H) > H | (H) > H > M | (M) > M > M | (H) > M | |
| Primary Productivity | (H) > M | (H) > M > L | (L) > M > M | NA | |
| Population Support | (H) > M | (H) > M | (M) > M > M | (H) > M | |
| Hydrologic Damping | (H) > H | (H) > H > H | (L) >M > M | (H) > M | |
| Sediment/Water Quality | (H) > M > L | (H) > L | (L) > M > L | (H) > L | |
| Salmonid Support | (H) >H > M | (H) > M > M | (M) > M > M | (H) > M | |
| Wetlands<br>Habitat Complexity | (H) > H | (M) > H > M<br>Change due to FMP | (M) > M > H | | |
| Species Diversity | (H) >H > M | (H) > H > M | (M) > H Potential loss of core habitats and increase in edge | | |
| Primary Productivity | (H) > M > L | (H) > M- > L | (L) > M > M | | |

Table A-12, continued

| Critical Area/Function | Existing agriculture<br><br>Current > 5yr > 25yr | New or expanded Agriculture<br><br>Current > 5yr > 25yr | New or expanded agriculture on forested areas<br>Current > 5yr > 25yr | Agricultural Ditch Maintenance<br><br>Current > 5yr > 25yr | Notes and Comments<br><br>Current > 5yr > 25yr |
|---|---|---|---|---|---|
| Population Support | (H) > H > M | (H) > H > M | (L) > M > M | | |
| Hydrologic Damping | (M) > M+ > H | (M) > H > H | (L) > M > M | | |
| Sediment/Water Quality | (H) > M > L | (H) > L > L | (L) > M > M | | |
| Spatial Diversity | (H) > H > M | (H) > H > H | (M) > M > H<br>Increased fragmentation and isolation of wetlands possible | | |
| Wildlife Habitat<br><br>Habitat Complexity | (H) > H > M | (H) > H > M | (L) > L > M | | |
| Species Diversity | (H) > M | (H) > H > M | (L) > M > M | | |
| Spatial diversity | (H) > M | (H) > H > M | (L) > M > M | | |
| Population Support | (H) > H > M | (H) > H > H | (M) > M+ > M+ | | |
| Connectivity | (H) > M > M | (H) > H > M | (M) > M > M+ | | |
| Sensitive species | (H) > H > M | (H) > H > M | (M) > H > M+ | | |

# A.4 CONCLUSIONS

No single best management practice (BMP) can be expected to be useful in all circumstances to control the impacts of agricultural operations. Combinations of soil, slope, area, and management are simply too complex for confident application of any one BMP. A sound scientifically-defensible approach to alleviating agricultural effects on aquatic areas must recognize the attributes of the farmed landscape—soils, slopes, crop types, the management practices employed on the farm, and the sensitivity of the feature to be protected or conserved. As the context of an agricultural operation is altered in response to changing market conditions, changes in ownership, or simple preferences, the solutions must be adaptable as well.

In general, scientific literature supports the use of protective buffers that shield critical areas from intrusion by development and other human activity (see BAS, Volume I, Chapters 7 and 9, Aquatic Areas and Wetlands). The provisions to allow development of agricultural or residential structures in critical areas or their buffers contradicts the scientific evidence for buffer integrity as a necessary condition of aquatic system integrity.

Two major conclusions can be drawn from this analysis regarding risks to critical areas given proposed King County agricultural regulations:

Despite the rules of the CAO, the farmed landscape is so altered from its native condition, and imposes so too many disturbances on the functions of critical areas, that the effects of agricultural activities cannot be considered “low” risk. There are historic changes in landscape structure that isolate and fragment habitats of all kinds; native systems (to which native species are adapted) have been replaced with mainly anthropogenic habitats; operations disrupt normative processes such as nesting or spawning too frequently.

In general, the King County landscape remains largely intact and considerable progress can be made in reducing the effects of agricultural operations and gaining improvements in the ecological functions of critical areas. This will come as a result mainly of the farm management planning efforts using BMPs tailored to conditions prevailing on individual farms, aggregating them across larger landscapes or watersheds, and adapting the plans as operations change on the farm.

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