EFFECT OF RIPARIAN AREAS ON THE ECOLOGICAL CONDITION OF SMALL, PERENNIAL STREAMS IN AGRICULTURAL LANDSCAPES OF THE WILLAMETTE VALLEY. RESEARCH PLAN, JUNE 1997

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Research Plan

June 1997

United States Environmental Protection Agency
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National Health and Environmental Effects Laboratory
Western Ecology Division, Corvallis, OR

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16. Abstract:
Despite their limited areal proportion in a watershed, riparian areas, particularly streamside plant communities, are widely considered critical for maintaining stream ecological condition. Riparian vegetation functions important to stream ecological condition include: 1) contributions of large woody debris, 2) supply of fine organic matter, 3) stabilization of streambanks, 4) provision of stream shading, and 5) regulating the flux of upland-derived sediments, nutrients, and other chemicals. Little research has been directed toward determining the status and ecological role of riparian areas in agricultural landscapes of the Willamette Valley, Oregon. Additional knowledge about the relationships among riparian attributes, agricultural land use, and stream ecological condition is needed to improve the ecological basis for evaluating the consequences of alternative future scenarios of human land use and ecosystem management alternatives. A research project has been designed to contribute to the development and evaluation of alternative future scenarios and to improve the basic understanding of the role of riparian areas on the ecological condition of small, perennial streams in agricultural landscapes of the Willamette Valley. The objectives of the research are: 1) to quantify relationships between riparian attributes at varying spatial scales and stream ecological condition, and 2) to estimate the influence of selected riparian area-agricultural configurations on the indicators of stream ecological condition. To address these objectives, remotely-sensed imagery (aerial photography and thematic mapper satellite imagery) will be used to quantify land cover at multiple spatial scales (i.e., stream reach, stream network, watershed), from which riparian vegetation function, land use stressor, and stream network structure indicators (i.e., potential explanatory variables) will be derived for 41 study watersheds. At the base of each study watershed, field sampling will be conducted in a single stream reach to measure in-channel physical habitat, as well as to collect fish, macroinvertebrate, and water samples, from which indicators (i.e., response variables) of the ecological condition of the stream reach will be derived. Multiple regression will be used to relate stream reach response variables to stream-reach-, stream network-, and watershed-scale explanatory variables.

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EXECUTIVE SUMMARY

THE EFFECT OF RIPARIAN AREAS ON THE ECOLOGICAL CONDITION OF SMALL, PERENNIAL STREAMS IN AGRICULTURAL LANDSCAPES OF THE WILLAMETTE VALLEY

This project is a component of EPA's Pacific Northwest Research Program which was created to conduct ecological research in western Oregon and Washington as part of the follow-up to the President's Forest Conference. A central organizing framework for much of EPA's ecological research in the Pacific Northwest is the development and evaluation of the ecological consequences of alternative future scenarios of human development and ecosystem change. The Willamette River Basin will be the first case study area in the Pacific Northwest for which alternative scenarios are produced.

This research will be confined to the Willamette Valley ecoregion of Oregon, a predominantly agricultural landscape, with substantial amounts of upland forest and urban areas. Due to a temperate climate, level topography, and productive soils, the Willamette Valley has one of the largest concentrations of diversified agriculture in the Pacific Northwest. A wide range of stream types and sizes can be found in the Willamette Valley floor and adjoining foothills. A large number of small, perennial and intermittent streams occur throughout the Valley. Most of the riparian vegetation in the Willamette Valley exists as fragmented, gallery forests along the Willamette River and its major tributaries, and as fragmented woodland and shrub/scrub corridors along smaller dendritic networks within a mosaic of agricultural fields, pasturelands, and forest patches. Patches of herbaceous riparian vegetation also are common along Willamette Valley streams.

Little research has been directed toward determining the status and ecological role of riparian areas in agricultural landscapes of the Willamette Valley. Additional knowledge about the relationships between riparian area attributes and stream ecological conditions in agricultural landscapes is needed to improve the ecological basis of alternative scenario evaluations and to contribute to the understanding of agricultural-riparian complexes in areas with similar settings in
the Pacific Northwest and throughout the United States. Therefore, this project has been
designed to contribute to the development and evaluation of alternative future scenarios and to
improve the basic understanding of the role of riparian areas on the ecological condition of small,
perennial streams in agricultural landscapes of the Willamette Valley.

The major *scientific question* being addressed in this study is:

- To what extent do riparian area attributes affect the ecological condition of small, perennial
  streams in agricultural landscapes of the Willamette Valley?

Based on a conceptual understanding of agriculture-riparian-stream relationships, the following
*hypotheses* will be evaluated during the course of this research:

- The ecological condition of streams in agricultural landscapes is positively related to the width
  and longitudinal extent of woody riparian vegetation along streams. Woody riparian vegetation
  classes are ranked as follows for their association with good ecological condition: closed canopy
  forest > open canopy forest > shrub/scrub.

- The ecological condition of streams in agricultural landscapes is negatively related to the
  proportion of the entire watershed in agriculture. Good ecological condition in streams is more
  likely to be associated with low-intensity, rather than high-intensity agriculture.

- The degree of influence of riparian areas and uplands on stream ecological condition varies
  with spatial scale (e.g., stream reach, nearest 25% of stream network) within watersheds.

- Stream channel disturbances and attributes can modify or dominate riparian and agricultural
  land use effects on the ecological condition of streams.

The *objectives* of the research are:

- To quantify relationships between riparian area attributes at varying spatial scales and stream
  ecological condition. Stream ecological condition indicators are: fish assemblages,
  macroinvertebrate assemblages, water chemistry (nitrogen and phosphorus), and physical habitat.

- To estimate the influence of selected riparian area-agricultural configurations on the indicators
  of stream ecological condition.

To address the objectives and evaluate the hypotheses stated above, we have designed an *approach*
that incorporates multiple spatial scales and builds on research conducted in the Willamette Valley by
the Riparian Areas Project and the Environmental Monitoring and Assessment Program's Surface Waters Project (EMAP-SW).

Because methods to characterize riparian areas at a landscape scale are poorly developed, we conducted a pilot study in the Pudding River drainage, an agriculturally diverse area in the north-central Willamette River Basin. Our goal was to develop sampling methods and assessment techniques for characterizing riparian-agricultural complexes along streams using medium-scale aerial photography and geographic information system (GIS) technology. The methods developed can be used to estimate riparian and stream network characteristics for particular segments of a stream network or can be used as part of a sampling approach to estimate riparian characteristics across a region or large river basin.

The next step in understanding the role that riparian areas play in controlling stream ecological condition is to quantitatively relate riparian area attributes to actual stream ecological conditions. This research is based on collaboration with EMAP-SW investigations in the Pacific Northwest. EMAP-SW includes a probability-based sampling approach designed to develop indicators of the ecological condition for streams and to estimate the extent and magnitude of surface water degradation at regional scales. We will combine the remote sensing and GIS techniques developed in the Pilot Study with EMAP-SW stream reach field approaches to quantify relationships between riparian area attributes and stream ecological condition.

In this study, we will focus on small, perennial streams with watersheds ranging from 15 to 80 km² in area that are predominantly in the Willamette Valley floor or foothills. Within this range of stream-watershed size, aquatic communities are well developed and have resident fish populations. Streams of this size are more closely influenced by local riparian conditions, land uses, and disturbances than are larger streams originating in the surrounding mountains. There is also is a practical consideration for focusing on small, perennial streams. For the indicators of stream ecological condition that we have adopted for this study, EMAP-SW has well-established field sampling and measurement protocols for wadeable streams, but are just now developing protocols for larger streams. Also, the remote sensing techniques developed in the Pilot Study can be applied with a reasonable level of effort to the networks and associated watersheds of small, perennial streams.
Using 1:150,000 scale topographic maps and thematic mapper (TM) images, we have identified 41 streams with no major impoundments that drain predominantly agricultural watersheds ranging in area from 15 to 80 km², and have no major urban areas. This is the entire population of streams in the Willamette Valley floor or foothills that meet these criteria. Fortunately, there is a wide range of riparian vegetation configurations (e.g., width, connectivity) among the stream networks of the 41 study watersheds.

For the upcoming field season (1997), we will select 25 of the 41 study watersheds across the range of riparian configurations found along small, perennial streams of the Willamette Valley floor or foothills. We will identify a single sampling stream reach at the base of each watershed where we will conduct field measurements of in-channel physical habitat, as well as collect fish, macroinvertebrate, and water samples to calculate indicators of the ecological condition in the stream reach. Remotely-sensed imagery (aerial photographs and TM images) and GIS technology will be used to measure land cover and land use characteristics adjacent to each sampling stream reach, as well as throughout the riparian area and watershed upstream of each sampling stream reach. We will use color-infrared aerial photography to classify riparian vegetation and agricultural land uses within 150-m bands adjacent to and along both sides of the entire stream network for each of the 25 watersheds. We will summarize riparian vegetation attributes, agricultural land uses, and stream network characteristics at the stream-reach scale and at different proportions of the stream network. In addition, classified TM imagery will be used to derive generalized land cover data for each watershed. The reach-level indicators of stream ecological condition will be related to riparian area characteristics and watershed land use immediately adjacent to the stream reach, as well as throughout the entire upstream watershed. Exploratory multivariate methods will be used to screen potential explanatory variables (i.e., independent variables) describing riparian vegetation configuration and watershed land cover/land use for their associations with stream ecological condition indicators (i.e., response variables, dependent variables). Multiple regression will then be used to relate sampling stream reach response variables to reduced sets of stream reach-, stream network-, and watershed-scale explanatory variables.
During the second field season (1998), we will make field and remote sensing measurements for the remaining 16 study watersheds. These data will be used to test the empirical models developed from the first 25 watersheds. Once the evaluation of the models has been completed, the data for all 41 watersheds will be pooled and final models developed. The final models will then be used to estimate responses of our stream ecological indicators to varying riparian vegetation configurations. The models will be available for use in the evaluation of alternative scenarios for the Willamette River Basin case study.
1.0 INTRODUCTION

1.1 Research Context

The research described in this document is part of EPA's Pacific Northwest (PNW) Research Program and will be conducted by scientists at EPA's Western Ecology Division (WED) of the National Health and Environmental Effects Research Laboratory. The PNW Research Program was created to conduct ecological research in western Oregon and Washington as part of the follow-up to the President's Forest Conference (Baker et al. 1995). A major component of the PNW Research Program is the Pacific Northwest Ecosystem Research Consortium (PNW-ERC). The PNW-ERC is a regional, multidisciplinary research program effort by Oregon State University, University of Oregon, University of Washington, and the WED (Gregory et al. 1996).

The PNW-ERC research is designed to: 1) create a regional landscape context for interpreting trajectories of regional ecosystem change, 2) identify and understand critical processes, and 3) develop approaches for evaluating outcomes of alternative future land use, management, and policy. Focused in two case study areas, the Willamette River Basin of Oregon and the Southwest Washington Coastal Ecoregion, an important thrust of the PNW research is the study of ecological and social consequences of alternative future scenarios for human development and ecosystem change, both natural and anthropogenic.

In addition to contributing to the PNW-ERC, research scientists at the WED are conducting riparian research as part of the overall PNW research program. Historically, most riparian research in western Oregon and Washington has examined riparian areas in forested landscapes, and little is known about the status and ecological role of riparian systems in agricultural settings (Van Deventer 1990). Most agricultural riparian research has occurred in the East or Midwest under conditions quite different from agricultural lands common in western Oregon and Washington. Many of the agricultural lands of western Oregon and Washington have level topography and poorly drained soils. In many areas, agricultural fields are located in what were historically riparian or palustrine wetlands (Tsutsui 1979, Titus et al. 1996). For these reasons, research examining the ecological function of riparian areas in agricultural settings has been an important area of emphasis in the PNW research program (Baker et al. 1995).
One research project especially relevant to the research proposed is a pilot study that was recently conducted by WED scientists in the Pudding River drainage, an agriculturally diverse landscape in the north-central Willamette River Basin. The goal of the pilot study was to develop sampling methods and assessment techniques for characterizing riparian-agricultural complexes using medium-scale aerial photography and geographic information system (GIS) technology. Methods developed in the pilot study will be important to the research described herein. A brief summary of the Pilot Study is presented in Appendix A.

The development and evaluation of the ecological consequences of alternative future scenarios of human development and ecosystem change is a central organizing framework for much of EPA's ecological research in the Pacific Northwest. The Willamette River Basin will be the first case study for which alternative scenarios are produced (Gregory et al. 1996). Additional knowledge about the relationships among riparian attributes, agricultural land use, and stream ecological condition are needed to improve the ecological basis of alternative scenario evaluations. The research described in this plan is explicitly designed to contribute to the ecological understanding needed for these evaluations. Furthermore, this research will contribute to the understanding of agricultural-riparian complexes in areas with low topography and poorly drained soils throughout the United States.

This research also presents an excellent opportunity for collaboration with the Environmental Monitoring and Assessment Program-Surface Waters (EMAP-SW) investigations in the Pacific Northwest. EMAP-SW includes a probability-based sampling approach designed to develop indicators of the ecological condition for streams and to estimate the extent and magnitude of surface water degradation at regional scales (Whittier and Paulsen 1992, Herlihy et al. 1997). In this proposal, we combine the remote sensing and GIS techniques developed in the Pudding River Drainage Pilot Study with EMAP-SW stream reach field approaches to evaluate relationships between riparian area attributes and the ecological condition of streams in agricultural landscapes of the Willamette Valley.
1.2 Rationale

Oregon is experiencing a rapid growth in human population. The predominantly agricultural landscape of the Willamette Valley, home to approximately 70% of the State's population, is projected to absorb much of the future growth in Oregon's human population (PSU 1993, ODAS 1997). Alternative future scenarios represent possible trajectories in land use that are based on assumptions of the projected rate of growth in human population over the next 30 years, as well as assumptions regarding land use planning, management, and policy. In short, future scenarios are tools which can aid the public and decision-makers in visualizing a set of possible land use and ecosystem management alternatives. They include descriptions (i.e., maps, figures, tables, narrative) of possible combinations in the composition and pattern of land cover and land use in a specified watershed or basin, and the likely ecological and socioeconomic consequences, both positive and negative, resulting from each combination. With this information, decision-makers and the public can evaluate ecological and socioeconomic trade-offs, reach informed decisions, and plan effective management strategies for the choices selected.

Historic, human-imposed disturbances, such as agriculture, urbanization, and silviculture have altered the Willamette Valley landscape. Much of the native vegetation has been removed, streams have been dammed and channelized, and hydric soils have been drained (Johannessen et al. 1970, Tsutsui 1979, Sedell and Luchessa 1981, Towle 1982, Sedell and Frogatt 1984, Sedell et al. 1990). These alterations, directly or indirectly, have influenced the ecological condition of Willamette Valley streams by disturbing the biological, physical, and chemical processes of watersheds, particularly those that are critical to aquatic habitat functions provided by riparian areas along stream networks.

Natural resource managers and land use planners face major challenges in managing human-dominated landscapes, such as the Willamette Valley, where a mosaic of multiple, natural resources have simultaneous and often opposing values. To maintain or improve the ecological condition of streams in the Willamette Valley requires the management of landscapes or watersheds. Because of the important aquatic habitat functions provided by riparian areas, landscape or watershed management plans must include provisions for the protection and
restoration of riparian vegetation along stream networks.

Little ecological research has been directed towards determining the status and ecological role of riparian systems in maintaining stream ecological condition in agricultural landscapes of the Willamette Valley (Van Deventer 1990). We don't know the degree to which riparian aquatic habitat functions are currently being realized in the Willamette Valley. We don't know whether current riparian vegetation significantly affects the condition of aquatic habitat, or whether riparian functions are circumvented or overwhelmed by agricultural land uses and associated management practices. We also don't know what riparian vegetation community composition or configurations (i.e., width, longitudinal extent, connectivity, evenness) along stream networks in agricultural landscapes of the Willamette Valley are most beneficial to stream ecological condition, as defined by fish and macroinvertebrate assemblages, water chemistry, and stream physical habitat. Additional knowledge about the relationships between riparian attributes and stream ecological conditions in agricultural landscapes is required to improve the ecological basis of alternative scenario evaluations.

In a broader context, this research will provide an important contribution to landscape ecological research. The research will address fundamental questions about the relationships between landscape structure, function, and scale, all of which are important monitoring and assessment issues in many areas outside the Willamette Valley. The empirical relationships we find among riparian attributes, land use stressors, and stream ecological condition, at varying spatial scales, will further the understanding of landscape structural-functional relationships. In addition, our detailed evaluation of land cover/land use classes will provide guidance in devising relevant classification schemes. Finally, the sampling methods and assessment techniques developed during the course of this research will be transferable to other regions.

1.3 Major Scientific Question, Hypotheses, and Objectives

The major scientific question being addressed in this study is:

- To what extent do riparian area attributes affect the ecological condition of small, perennial streams in agricultural landscapes of the Willamette Valley?
The following hypotheses will be evaluated during the course of this research:

- The ecological condition of streams in agricultural landscapes is positively related to the width and longitudinal extent of woody riparian vegetation along streams. Woody riparian vegetation classes are ranked as follows for their association with good ecological condition: closed canopy forest > open canopy forest > shrub/scrub.

- The ecological condition of streams in agricultural landscapes is negatively related to the proportion of the entire watershed in agriculture. Good ecological condition in streams is more likely to be associated with low-intensity, rather than high-intensity agriculture.

- The degree of influence of riparian areas and uplands on stream ecological condition varies with spatial scale (e.g., stream reach, nearest 25% of stream network) within watersheds.

- Stream channel disturbances and attributes can modify or dominate riparian and agricultural land use effects on the ecological condition of streams.

The objectives of the proposed research are two-fold:

- To quantify relationships between riparian area attributes at varying spatial scales and stream ecological condition. Stream ecological condition indicators are: fish assemblages, macroinvertebrate assemblages, water chemistry (nitrogen and phosphorus), and physical habitat.

- To estimate the influence of selected riparian area - agricultural configurations on indicators of stream ecological condition.

To address our research objectives and hypotheses, we have designed a two-phased research approach that incorporates multiple spatial scales and a field component for determining the relationships between riparian area attributes and stream ecological condition. This study builds on research conducted in the Willamette Valley by the Riparian Areas Project and EMAP-SW. The research will be conducted over a three-year period.

Using 1:150,000 scale topographic maps and thematic mapper (TM) images, we have identified 41 streams with no major impoundments that drain predominantly agricultural watersheds ranging in area from 15 to 80 km², and have no major urban areas. This is the entire population of streams in the Willamette Valley floor or foothills that meet these criteria. Fortunately, there is
a wide range of riparian vegetation configurations (e.g., width, connectivity) among the stream networks of the 41 study watersheds.

During the first phase of the research, we will select 25 of the 41 study watersheds across the range of riparian configurations found along small, perennial streams of the Willamette Valley floor or foothills. We will identify a single sampling stream reach at the base of each watershed where we will conduct field measurements of in-channel physical habitat, as well as collect fish, macroinvertebrate, and water samples to calculate indicators of the ecological condition in the stream reach. Remotely-sensed imagery (aerial photographs and TM images) and GIS technology will be used to measure land cover and land use characteristics adjacent to each sampling stream reach, as well as throughout the riparian area and watershed upstream of each sampling stream reach. We will use color-infrared aerial photography to classify riparian vegetation and agricultural land uses within 150-m bands adjacent to and along both sides of the entire stream network for each of the 25 watersheds. We will summarize riparian vegetation attributes, agricultural land uses, and stream network characteristics at the stream-reach scale and at different proportions of the stream network. In addition, classified TM imagery will be used to derive generalized land cover data for each watershed. The reach-level indicators of stream ecological condition will be related to riparian area characteristics and watershed land use immediately adjacent to the stream reach, as well as throughout the entire upstream watershed. Exploratory multivariate methods will be used to screen potential explanatory variables (i.e., independent variables) describing riparian vegetation configuration and watershed land cover/land use for their associations with stream ecological condition indicators (i.e., response variables, dependent variables). Multiple regression will then be used to relate sampling stream reach response variables to reduced sets of stream reach-, stream network-, and watershed-scale explanatory variables.

During the second phase of the research, we will make field and remote sensing measurements for the remaining 16 study watersheds. These data will be used to test the empirical models developed from the first 25 watersheds. Once the evaluation of the models has been completed, the data for all 41 watersheds will be pooled and final models developed. The final models will then be used to estimate responses of our stream ecological indicators to varying riparian
vegetation configurations. The models will be available for use in the evaluation of alternative scenarios for the Willamette River Basin case study.

2.0 STUDY AREA

The study area will be confined to the Willamette Valley ecoregion (EPA 1997) of Oregon, a 13,165 km² structural depression oriented north-south and lying between the Coast Ranges on the west and the Cascade Range on the east (Figure 1). Topographically, the Willamette Valley consists of broad, alluvial flats and terraces, interrupted by low basalt hills, and a transitional zone of rolling basalt/marine sandstone foothills between the valley floor and the Coast and Cascade Ranges (Franklin and Dyrness 1973). As shown in Figure 2 and described below, the Willamette Valley ecoregion is further subdivided into four subecoregions (EPA 1997):

- **Valley Foothills** -- This subecoregion is an agricultural/forest transitional zone between the Willamette Valley and the Coast Ranges and Cascade Range. The common land uses include pastureland, tree farms, vineyards, orchards and rural residential development. This area also includes fragmented patches of coniferous and deciduous woodlands.

- **Prairie Terraces** -- This subecoregion is dissected by low-gradient, meandering streams and rivers. The common land uses include grass seed and grain crop farming, and rural residential development.

- **Willamette River and Tributaries Gallery Forest** -- This subecoregion is composed of meandering, low-gradient channels and oxbow lakes that are incised into broad floodplains. The common land uses include vegetable and fruit farming, pastureland, urban, suburban, and rural residential development. These land uses have largely replaced deciduous riparian forests that once grew on its fertile, alluvial soils.

- **Portland/Vancouver Basin** -- This subecoregion is composed of undulating terraces and floodplains with numerous wetlands, oxbow lakes, and ponds. The common land uses include urban, suburban, rural residential, industrial, pastureland, and nursery crops.

The Willamette Valley is predominantly an agricultural landscape, with substantial amounts of upland forest and urban areas and lesser amounts of riparian forest and brush/grassland areas (Figure 1, Table 1). Due to a temperate climate, productive soils, and level topography, the Willamette Valley represents one of the largest concentrations of diversified agriculture in the Pacific Northwest (Jackson 1993, USBC 1994), although pastureland and grass seed cropping systems represent approximately 60% of the agricultural acreage in the Valley (Figure 3).
Figure 1. Map of the Willamette Valley ecoregion and its major land use and land cover classes.
Figure 2. Distribution of first to third Strahler order streams by subecoregion within the Willamette Valley ecoregion.
Table 1. Land cover and land use (km²) for the Willamette Valley subecoregions.

<table>
<thead>
<tr>
<th>Land Cover/Land Use</th>
<th>Valley Foothills</th>
<th>Prairie Terraces</th>
<th>Willamette River &amp; Tributaries Gallery Forest</th>
<th>Portland &amp; Vancouver Basin</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>1,173</td>
<td>3,806</td>
<td>983</td>
<td>110</td>
<td>6,072</td>
</tr>
<tr>
<td>Upland Forest</td>
<td>4,065</td>
<td>576</td>
<td>189</td>
<td>48</td>
<td>4,878</td>
</tr>
<tr>
<td>Urban</td>
<td>230</td>
<td>612</td>
<td>226</td>
<td>329</td>
<td>1,397</td>
</tr>
<tr>
<td>Riparian Forest</td>
<td>89</td>
<td>72</td>
<td>324</td>
<td>71</td>
<td>556</td>
</tr>
<tr>
<td>Brush/Grassland</td>
<td>109</td>
<td>5</td>
<td>25</td>
<td>1</td>
<td>140</td>
</tr>
<tr>
<td>Water</td>
<td>32</td>
<td>31</td>
<td>1</td>
<td>58</td>
<td>122</td>
</tr>
<tr>
<td>Total</td>
<td>5,698</td>
<td>5,102</td>
<td>1,748</td>
<td>617</td>
<td>13,165</td>
</tr>
</tbody>
</table>

(Source: EPA 1997)
Figure 3. Distribution of 1992 agricultural acreage in the Willamette Valley ecoregion.
A wide range of stream types and sizes can be found in the Willamette Valley floor and adjoining foothills. Large streams such as the mainstem of the Willamette or the Santiam River drain from large mountain watersheds before descending to the valley. A large number of small, perennial and intermittent streams occur throughout the Valley. Most of the riparian vegetation in the Valley exists as fragmented, gallery forests along the Willamette River and its major tributaries, and as fragmented woodland and shrub/scrub corridors intermixed with herbaceous vegetation along smaller, dendritic stream networks within a mosaic of agricultural fields, pastureland, and forest patches. Because our research will address small, perennial streams draining agricultural landscapes, it is the latter riparian-stream networks where we will conduct the research. Therefore, our study area will be restricted primarily to two of the four Willamette Valley subecoregions, namely the prairie terraces and valley foothills (Figure 2). These subecoregions contain approximately 82% of the agricultural lands in the Willamette Valley; however, riparian forests occupy less than 2% of the area in each of these subecoregions (Table 1).

3.0 CONCEPTUAL FRAMEWORK

3.1 Relationships Between Riparian Areas and Streams

The ecological condition of streams is affected by complex interactions among numerous physical, chemical, and biological processes operating at various spatial and temporal scales. Naiman et al. (1992) states that stream characteristics are the best indicators of watershed vitality, with the routing and delivery of water, sediment, and woody debris to streams as the key processes regulating the vitality of the watershed. Stanford and Ward (1992) described streams within a watershed as four-dimensional ecosystems that are connected by biophysical processes operating longitudinally (upstream-downstream), laterally (riparian-uplands), vertically (channel-groundwater), and temporally (dynamic over time). The ecological condition of streams is dependent upon the longitudinal, lateral, and vertical connectivity of these biophysical processes among five stream corridor components -- basin geomorphology, hydrologic patterns, water quality, riparian vegetation characteristics, and habitat characteristics (Naiman et al. 1992), as well as the frequency, duration, and magnitude of disturbance events that alter biophysical processes (Stanford and Ward 1992).
Riparian areas are one of the most dynamic parts of the landscape (Swanson et al. 1988). They are critically important interfaces between terrestrial and aquatic ecosystems, having profound effects on the biological, chemical and physical characteristics of streams. They are major hydrologic source areas for stream flow (Hewlett and Hibbert 1967, Dunne et al. 1975), exert a strong influence on the quality of stream environments (Karr and Schlosser 1978, Decamps 1993, Phillips et al. 1993), have diverse plant communities (Nilsson et al. 1989, Gregory et al. 1991), and are important for a large number of terrestrial animal species (Brinson et al. 1981, Naiman et al. 1993).

Gregory et al. (1991) define riparian areas as three-dimensional zones of direct interaction between terrestrial and aquatic ecosystems. The boundaries of riparian areas extend outward to the limits of flooding and upward into the canopy of streamside vegetation. The size of the zone of influence for a specific ecological process or function is determined by the unique spatial patterns and temporal dynamics of each process or function. Spatial and temporal variance of hydrologic and geomorphic processes, terrestrial plant succession, and the nature of adjacent aquatic ecosystems define the attributes of riparian areas. Geomorphic processes create a mosaic of stream channels and floodplains within the valley floor, which in turn provides a physical template for the development of riparian plant communities (Gregory et al. 1991). Valley landforms and associated riparian vegetation create the array of physical habitats within the active channels and floodplains.

Although processes occurring throughout the watershed can affect stream ecological condition, the importance of riparian areas far exceeds their limited areal proportion in a watershed because of the critical processes occurring in this important interface between uplands and stream networks (Gregory et al. 1991). Streamside plant communities are widely considered critical for maintaining stream ecological condition (Brinson 1981, Gregory et al. 1991, Naiman 1992). Table 2 provides a summary of the functions of riparian vegetation as they relate to the ecological condition of streams. These functions include: 1) contributions of large woody debris, 2) supply of fine organic matter, 3) stabilization of streambanks, 4) provision of stream shading, and 5) regulating the flux of upland-derived sediments, nutrients, and other chemicals.
Table 2. Summary of the functions provided by riparian vegetation that are essential to stream ecological condition and the important attributes of riparian vegetation responsible for each function.

<table>
<thead>
<tr>
<th>Riparian Vegetation Functions</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Large Woody Debris (LWD) Supply</strong>: Large woody debris <em>(trees and tree branches)</em> enters stream channels as a result of toppling of dead trees, undercutting of streambanks, mass bank movement, and windthrow. LWD provides structural diversity to stream channels resulting in increased aquatic habitat diversity and complexity -- forms pools and riffles; affects routing and velocity of water, channel width and depth; provides refugia for fish; retains gravel for spawning habitat, provides long-term nutrient storage; contributes to aquatic food webs through decomposition and provision of macroinvertebrate habitat.</td>
<td>Swanson et al. 1976&lt;br&gt;Brinson et al. 1981&lt;br&gt;Bisson et al. 1987&lt;br&gt;McDade et al. 1990&lt;br&gt;O'Connor 1991&lt;br&gt;Borchardt 1993&lt;br&gt;Trotter 1990&lt;br&gt;Van Sickle and Gregory 1990&lt;br&gt;Bilby and Likens 1980&lt;br&gt;FEMAT 1993&lt;br&gt;Malanson 1993&lt;br&gt;Spence et al. 1996</td>
</tr>
<tr>
<td>Important Vegetation Attributes: composition, width, longitudinal extent</td>
<td></td>
</tr>
<tr>
<td>Other Important Attributes: riparian area slope, soil type, hydrology.</td>
<td></td>
</tr>
<tr>
<td>Important Vegetation Attributes: composition, width, longitudinal extent</td>
<td></td>
</tr>
<tr>
<td>Other Important Attributes: stream width, orientation, and sinuosity, riparian area slope</td>
<td></td>
</tr>
<tr>
<td>Important Vegetation Attributes: composition, width, longitudinal extent</td>
<td></td>
</tr>
<tr>
<td>Other Important Attributes: stream sinuosity</td>
<td></td>
</tr>
</tbody>
</table>
Table 2. (Continued).

<table>
<thead>
<tr>
<th>Riparian Vegetation Functions</th>
<th>References</th>
</tr>
</thead>
</table>
| **Shading**: The canopy of riparian vegetation controls the amount and quality of incident solar radiation reaching the stream channel in the summer and provides insolation from radiative and convective heat losses from stream during winter. Shading moderates seasonal and diurnal fluctuations of stream channel temperature, preventing deleterious effects of high water temperatures (with accompanying reductions in dissolved oxygen) on fish and other aquatic organisms; insulates radiative and convective heat losses from stream channel, reducing anchor-ice formation; controls algal growth and eutrophication, maintaining water clarity, dissolved oxygen level, and aquatic community structure. | Karr and Schlosser 1978  
Brinson et al. 1981  
Hawkins et al. 1982  
Theurer et al. 1985  
Beschta et al. 1987  
King and Cummins 1989  
Murphy and Meehan 1991  
FEMAT 1993  
Malanson 1993  
Spence et al. 1996 |
| Important Vegetation Attributes: composition, canopy cover over stream, width, longitudinal extent.  
Other Important Attributes: channel width and orientation, riparian area topography. | |

| Sediment and Nutrient Regulation: Sediment-laden overland flow from uplands is slowed and dispersed in vegetated riparian areas, where it encounters several obstructions (e.g., boles, herbaceous vegetation, fallen wood, leaf litter, porous soils) while moving toward stream channels. This tends to increase infiltration of runoff water and storage of sediment in riparian areas instead of stream channels. Nutrients and chemicals are also reduced by plant uptake, microbial processes, and chemical processes as water moves in the subsurface from agricultural uplands, through riparian areas and into streams. Regulation of upland-derived sediments prevents burial of fish and macroinvertebrate habitat, reduces water turbidity, and increases water quality. Regulation of upland-derived nutrients and other chemicals maintains water quality and prevents stream eutrophication, thereby maintaining diversity of aquatic communities. | Karr and Schlosser 1978  
Thompson et al. 1978  
Young et al. 1980  
Schlosser and Karr 1981a, b  
Brinson et al. 1981  
Lowrance et al. 1984a, b  
Peterjohn and Correll 1984  
Jacobs and Gilliam 1985  
Theurer et al. 1985  
Cooper et al. 1987  
Fail et al. 1988  
Osborne and Wiley 1988  
Dillaha et al. 1989  
Muscutt et al. 1993  
Jordan et al. 1993  
Castelle et al. 1994  
Vought et al. 1994  
Spence et al. 1996 |
| Important Vegetation Attributes: composition, width, longitudinal extent  
Other Important Attributes: upland and riparian area slope and soil type, upland source dynamics (e.g., chemical use, tillage), drainage patterns. | |
The quality of stream habitat for fish and macroinvertebrates varies naturally along the longitudinal dimension of streams in response to differences in topography, hydrology, sediment load, and riparian vegetation. Water quality requirements for fish include cool temperatures, high dissolved oxygen concentrations, natural nutrient concentrations, and low levels of pollutants. Physical habitat requirements for fish include a variety of structural channel features, such as pools, riffles, undercut banks and overhanging vegetation for cover, and coarse substrate. Channel complexity is enhanced by the presence of large woody debris, which retains coarse sediments and creates hydraulic heterogeneity, pools, side channels, and habitat for macroinvertebrates. As discussed below, human land uses can dramatically alter the chemical and physical habitat requirements of fish and macroinvertebrates.

3.2 Land Uses and Potential Stressors of Stream Ecological Condition

Lowrance and Vellidis (1995) and Spence et al. (1996) discuss several mechanisms by which human land use practices, directly or indirectly affect the ecological condition of streams. Most human-related effects on watershed processes result from alterations in vegetation and soil characteristics in uplands and riparian areas, which subsequently affect the rate of delivery of water, sediments, and nutrients to stream networks. Converting lands in riparian areas for human uses can affect the ecological condition of streams by altering the riparian functions, resulting in increases in the amount of solar radiation reaching the stream channel, reduction of large woody debris and fine organic matter inputs to streams, and modification of fluvial processes that affect streambank stability and the capacity of riparian areas to regulate sediment and nutrient loads to streams.

In the Willamette Valley, agriculture is the predominant land use (Table 1). Agricultural practices associated with cropping systems generally involve repeated tillage, fertilizer and pesticide application, and annual harvesting of cropped acreage, as well as artificial drainage of hydric soils in lowland areas. These practices alter physical soil characteristics, often resulting in lower infiltration rates, increased runoff and soil erosion, and ultimately greater sediment,
nutrient, and chemical loads to streams (Spence et al. 1996). The above- and below-ground transport of residual nutrients and pesticides from uplands are additional potential stressors to stream systems in agricultural landscapes (Waddell and Bower 1988, Lowrance et al. 1985, Lowrance and Vellidis 1995). Agricultural practices commonly include stream channelization, which decreases the retention of nutrients and sediments through a complex series of physical trapping, chemical exchange, and biological uptake mechanisms (Speaker et al. 1984, Malanson 1993). The withdrawal of water from small streams for irrigation can adversely affect fish and macroinvertebrates by reducing summer water levels and flows, increasing water temperature and turbidity, and decreasing dissolved oxygen concentrations in streams (Spence et al. 1996).

Although the Willamette Valley is a diverse agricultural area, the kinds and diversity of agriculture in specific areas of the Valley are dependent on several factors, including soil drainage, slope, irrigation rights, and availability of processing contracts. Because management practices (e.g., fertilizer and pesticide inputs, irrigation, tillage) are not the same for all agricultural systems, there tends to be a continuum of management intensity that ranges from high to low levels of human inputs (Krummel and Dyer 1984). The diverse and high intensity agricultural cropping areas in the Valley may be greater potential sources of sediment and agricultural chemicals to stream systems than less diverse and low intensity agricultural cropping areas. Pastureland occupies the greatest proportion of agricultural lands in the Willamette Valley. Permanent pastureland is usually restricted to areas unsuitable for cultivated crops (e.g., very poorly drained soils, low fertility soils, and/or steep slopes). Grazing stresses to stream systems include riparian vegetation removal, trampling, and defoliation, reduced bank stability, plant community alteration, soil compaction, reduced evapotranspiration and infiltration, increased surface runoff, and organic waste inputs to streams.
3.3 Conceptual Model and Potential Indicators of Stream Ecological Condition

The above discussion summarized the interrelationships among streams, riparian areas, and land use stressors in terms of their influences on stream ecological condition. Figure 4 is a simple, conceptual representation of the interrelationships among structural properties and functions of three watershed systems -- streams, riparian areas, and uplands. The diagram illustrates the spatial arrangement of these systems, where each system exerts some degree of influence on other systems, with all systems affecting the biological, chemical, and physical attributes of streams. At the watershed scale, the structural properties and processes of these systems are shaped and influenced by pervasive, long-term, climatic, geomorphic, and topographic factors. These factors control soil formation, potential natural and cultivated vegetation, hydrology, and nutrient cycling, as well as influencing the flows of water and materials from uplands to stream channels. Disturbance events, natural and anthropogenic, alter the structural and functional connectivity of streams, with the severity of the alteration dependent upon the location of the disturbance and the frequency, duration, and magnitude of the disturbance.

The ecological condition of streams is affected by complex interactions among numerous physical, chemical, and biological components and processes. Due to this inherent complexity, there is no one single indicator (i.e., measurable attribute) that will serve as a satisfactory gauge of overall ecological condition. Because we intend to assess the ecological condition of small, perennial streams, we will develop and evaluate multiple indicators: fish assemblages, macroinvertebrate assemblages, water chemistry, and stream physical habitat. Currently, we lack the quantitative and functional knowledge to predict stream ecological condition based on ecosystem process models, particularly over large spatial scales with multiple land cover and land use configurations. Therefore, we will develop riparian vegetation function indicators, land use stressor indicators, and stream network structure indicators, and use these as explanatory variables in developing empirical relationships with stream ecological condition indicators (i.e., response variables). Our indicator development process will initially focus on a small set of structural indicators representing riparian vegetation functions, land use stressors, and stream
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Figure 4. Conceptual representation of the interrelationships among uplands, riparian areas, and stream channels within a watershed.
The indicators that we will develop and use as explanatory variables of stream ecological condition fall into the following three categories: 1) riparian vegetation function indicators, 2) land use stressor indicators, and 3) stream network structure indicators. As illustrated in Figure 5, the spatial scales that will be considered in the study include the watershed, the stream network (and various proportions of the stream network), and the stream reach. Table 3 provides the anticipated ranges in total stream length and total land area for each spatial scale, as well as their respective indicator category(ies) and data sources. Table 4 lists the indicator categories and their respective indicators across the spatial scales.

3.3.1 Stream Ecological Condition Indicators

Stream ecological condition indicators are defined as measurable, in-channel attributes that reflect the biological, chemical, or physical condition of a stream reach. Field measurements of fish and macroinvertebrate assemblages, water chemistry, and physical habitat within stream reaches will be used to calculate indicators of stream ecological condition. In the development of empirical models, the water chemistry and physical habitat indicators will be used as both explanatory variables (i.e., independent variables) of the biological status of stream reaches and as response variables (i.e., dependent variables) of stream ecological condition.

EMAP-SW has been conducting research on how best to measure, express, and interpret stream ecological condition (Paulsen et al. 1991, Whittier and Paulsen 1992, Herlihy et al. 1997). Indicators of the ecological condition of streams that have been developed by EMAP-SW are: 1) biologically relevant, 2) implementable on regional and national scales, 3) repeatable and quantitative, and 4) sensitive to anthropogenic disturbance (Herlihy et al. 1997). The indicators proposed here are based on EMAP-SW research, particularly the results from the 1992-1996 stream pilot study conducted on perennial, wadeable streams in the Willamette River Basin (Herlihy et al. 1997). We will use EMAP-SW indicators of stream ecological condition, including fish and macroinvertebrate assemblages, water chemistry, and stream physical habitat (see Table 4 and Appendix B).
network structure that are conceptually linked to stream ecological condition, as discussed in Sections 3.1 and 3.2.

A critical consideration in designing a study to estimate stream ecological condition through the use of spatial data (i.e., composition and pattern of land cover/land use in riparian areas and uplands) is the effect of spatial scale on the phenomenon being investigated (Forman and Godron 1986, Roth et al. 1996). The ability to detect empirical relationships among riparian vegetation function indicators and land use stressor indicators and stream ecological condition indicators is a function of scale, as well as the level of classification used to describe the landscape elements. In forest/urban watersheds of southern Ontario, Steedman (1988) reported that the index of biotic integrity (IBI) for streams was mostly a function of the proportion of the watershed in urban land use and the proportion of lower order streams with intact riparian forest vegetation. Steedman also proposed that predictive models would likely improve for rural streams in southern Ontario if greater detail was obtained on agricultural land use and streamside vegetation. In another southern Ontario study, Barton et al. (1985) reported that riparian forest within approximately 1 km of a site was most important in predicting maximum stream temperature and trout distribution. In an agricultural and urbanizing landscape of southern Michigan, Roth et al. (1996) reported that the proportion of the watershed in agricultural land use was the primary determinant of stream biotic integrity as assessed by IBI and habitat index scores. These researchers also reported that regressions of land use and riparian vegetation variables against IBI showed land uses at larger scales, whether the entire catchment upstream of a site or the entire riparian corridor upstream of a site, were more effective predictors of IBI scores than land use or riparian vegetation at local scales.

Because we anticipate that the degree of influence of riparian area attributes and agricultural land use on stream ecological condition is a function of spatial scale, we have designed our study to specifically address the effect of spatial scale. As defined and discussed in the following subsections, we will develop indicators from remote sensing data at several spatial scales and use these indicators as explanatory variables of stream ecological condition. Stream ecological condition indicators have been developed from previous EMAP-SW research (see Section 3.3.1), and we will calculate these indicators from stream reach field data.
Figure 5. Representation of the watershed, stream network, and stream reach spatial scales, with 150-m banding on each side of the stream network and stream reach.
Table 3. Expected ranges in total stream length and total land area for the spatial scales to be considered in this study, and the indicator category(ies) for each spatial scale and their respective data sources.

<table>
<thead>
<tr>
<th>Spatial Scale</th>
<th>Expected Range in Stream Length</th>
<th>Expected Range in Land Area</th>
<th>Indicator Category (Source of Data)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stream Reach (11 transects across stream channel)</td>
<td>150 - 300 m</td>
<td>Not Applicable</td>
<td>Stream Ecological Condition Indicators (In-Channel Field Measurements)</td>
</tr>
<tr>
<td>Stream Reach (11, 10 m x 10 m plots on each side of stream)</td>
<td>150 - 306 m</td>
<td>0.002 km²</td>
<td>Riparian Vegetation Function &amp; Land Use Stressor Indicators (Near-Channel Field Measurements)</td>
</tr>
<tr>
<td>Stream Reach (150-m band on each side of the stream)</td>
<td>150 - 300 m</td>
<td>0.04 - 0.09 km²</td>
<td>Riparian Vegetation Function, Land Use Stressor, &amp; Stream Network Structure Indicators (Aerial Photographs)</td>
</tr>
<tr>
<td>Stream Network (150-m band on each side of the stream)</td>
<td>2,000 - 19,000 m</td>
<td>0.6 - 5.7 km²</td>
<td>Riparian Vegetation Function, Land Use Stressor, &amp; Stream Network Structure Indicators (Aerial Photographs)</td>
</tr>
<tr>
<td>25% of banded network</td>
<td>4,000 - 38,000 m</td>
<td>1.2 - 11.4 km²</td>
<td></td>
</tr>
<tr>
<td>50% of banded network</td>
<td>8,000 - 76,000 m</td>
<td>2.4 - 22.8 km²</td>
<td></td>
</tr>
<tr>
<td>Watershed</td>
<td>8,000 - 76,000 m</td>
<td>15 - 80 km²</td>
<td>Riparian Vegetation Function, Land Use Stressor, &amp; Stream Network Structure Indicators (Thematic Mapper Images)</td>
</tr>
</tbody>
</table>
Table 4. Indicators by indicator category and spatial scale.

<table>
<thead>
<tr>
<th>Indicator Category</th>
<th>Spatial Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fish Assemblages</td>
<td>Stream Reach (In Channel Field Data)</td>
</tr>
<tr>
<td>- Index of biotic integrity</td>
<td></td>
</tr>
<tr>
<td>- Richness &amp; evenness</td>
<td></td>
</tr>
<tr>
<td>- Assemblage composition</td>
<td></td>
</tr>
<tr>
<td>Macroinvertebrate Assemblages</td>
<td></td>
</tr>
<tr>
<td>- Assemblage composition</td>
<td></td>
</tr>
<tr>
<td>- Richness &amp; evenness</td>
<td></td>
</tr>
<tr>
<td>- Functional feeding classes</td>
<td></td>
</tr>
<tr>
<td>Water Chemistry</td>
<td></td>
</tr>
<tr>
<td>- Nutrient status (N &amp; P)</td>
<td></td>
</tr>
<tr>
<td>Physical Habitat</td>
<td></td>
</tr>
<tr>
<td>- Habitat complexity index</td>
<td></td>
</tr>
<tr>
<td>- Habitat quality index</td>
<td></td>
</tr>
<tr>
<td>- Percent of reach shaded</td>
<td></td>
</tr>
<tr>
<td>Stream Condition</td>
<td>Riparian Canopy</td>
</tr>
<tr>
<td>- Percent canopy cover</td>
<td></td>
</tr>
<tr>
<td>Riparian Vegetation Structure</td>
<td></td>
</tr>
<tr>
<td>- Habitat complexity index</td>
<td></td>
</tr>
<tr>
<td>Composition &amp; Pattern</td>
<td></td>
</tr>
<tr>
<td>- Proportion of area in woody vegetation (by class)</td>
<td></td>
</tr>
<tr>
<td>- Percent of streambank with forest of x m width</td>
<td></td>
</tr>
<tr>
<td>- Percent of streambank with woody vegetation of x m width</td>
<td></td>
</tr>
<tr>
<td>- Number &amp; length of breaks in forest per streambank km</td>
<td></td>
</tr>
<tr>
<td>Composition &amp; Pattern</td>
<td></td>
</tr>
<tr>
<td>- Proportion of area in woody vegetation (by class)</td>
<td></td>
</tr>
<tr>
<td>- Percent of streambank with forest of x m width</td>
<td></td>
</tr>
<tr>
<td>- Percent of streambank with woody vegetation of x m width</td>
<td></td>
</tr>
<tr>
<td>- Number &amp; length of breaks in forest per streambank km</td>
<td></td>
</tr>
<tr>
<td>Composition</td>
<td></td>
</tr>
<tr>
<td>- Proportion of area in woody vegetation</td>
<td></td>
</tr>
<tr>
<td>- Proportion of area in forest</td>
<td></td>
</tr>
<tr>
<td>Riparian Vegetation Functions</td>
<td></td>
</tr>
<tr>
<td>Riparian Vegetation Structure</td>
<td></td>
</tr>
<tr>
<td>- Habitat complexity index</td>
<td></td>
</tr>
<tr>
<td>Human Disturbance</td>
<td></td>
</tr>
<tr>
<td>- Proximity-weighted disturbance index</td>
<td></td>
</tr>
<tr>
<td>Composition</td>
<td></td>
</tr>
<tr>
<td>- Proportion of area in agriculture (by class)</td>
<td></td>
</tr>
<tr>
<td>- Proportion of area in built-up (by class)</td>
<td></td>
</tr>
<tr>
<td>- Ratio of agriculture (by class) to riparian woody vegetation (by class)</td>
<td></td>
</tr>
<tr>
<td>- Proportion of 10-m band in agriculture (by class)</td>
<td></td>
</tr>
<tr>
<td>Composition</td>
<td></td>
</tr>
<tr>
<td>- Proportion of area in agriculture (by class)</td>
<td></td>
</tr>
<tr>
<td>- Proportion of area in built-up (by class)</td>
<td></td>
</tr>
<tr>
<td>- Ratio of agriculture (by class) to riparian woody vegetation (by class)</td>
<td></td>
</tr>
<tr>
<td>- Proportion of 10-m band in agriculture (by class)</td>
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<td>Composition</td>
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<td>- Ratio of agriculture to forest</td>
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<td>Stream Network Structure</td>
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Fish and benthic macroinvertebrates are important integrative indicators of stream ecological condition, as they reflect the condition of the chemical and physical habitat of the stream and the vitality of the watershed. Fish assemblages are usually relatively stable during the mid to late summer sampling period and interannually (Matthews 1986, Ross et al. 1985, Karr et al. 1986). We will use EMAP-SW fish assemblage indicators, including an IBI, species richness and evenness, and assemblage composition (Table 4). The overall fish assemblage structure (e.g., number of species, abundances, length, and condition of individuals) will be used to calculate an IBI. Various IBI's have proven useful in assessing the ecological condition of streams in several regions of the United States and Canada (Karr et al. 1986, Miller et al. 1988, Steedman 1988, Roth et al. 1996, Hughes et al. 1997). Benthic macroinvertebrates play a significant role in the aquatic food web, between primary producers and fish (Cummins 1974). Macroinvertebrate assemblage structure has been used extensively for the evaluation of ecological conditions of aquatic habitats (Plafkin et al. 1989, Fisk 1988, Metcalf 1989, Merritt, et al. 1996). We will use EMAP-SW macroinvertebrate assemblage indicators, including richness and proportions of various taxonomic groups (e.g., Ephemeroptera, Plecoptera, Trichoptera [EPT], Chironomidae), taxa richness and evenness, and richness and proportions of functional feeding classes (Table 4).

Physical habitat and water chemistry indicators are normally used as diagnostic tools when measured in conjunction with fish and macroinvertebrate assemblage indicators. We intend to use water chemistry and physical habitat indicators as both dependent and independent variables in evaluating empirical relationships. Physical habitat quality -- the size, shape, structure, and hydrology of the stream channel -- characterizes the physical conditions that provide the setting for different natural biological and chemical conditions. EMAP-SW measures several components of in-channel physical habitat (see Appendix B). We will use these data to calculate habitat complexity and habitat quality indicators (Table 4). Water chemistry indicators reflect the general chemical environment surrounding aquatic organisms and the possible water column stresses on the biota (Hynes 1974, Warren 1974). Much of the variability in aquatic species composition and abundance not explained by physical habitat is likely to be associated with differences in water quality (Paulsen et al. 1991). Although EMAP-SW collects a range of chemical data (see Appendix B), our study will focus primarily on the nutrient status (nitrate,
total nitrogen and phosphorus) of stream reaches (Table 4).

3.3.2 Riparian Vegetation Function Indicators

Riparian vegetation function indicators are defined as measurable structural attributes of riparian areas that can be used as surrogates of riparian ecological functions important for maintaining stream ecological condition. In this study, riparian vegetation function indicators will be developed from both field measurements and remotely sensed imagery. Field measurements of riparian vegetation composition and vertical cover will be obtained from 10-m x 10-m plots placed in the near-channel riparian areas along stream reaches and will adhere to EMAP-SW protocols (Klemm and Lazorchak 1995, see Appendix B). These indicators, although based on semi-quantitative measurements, provide detail not easily achieved using remotely sensed imagery; and, therefore may be important at a local level (i.e., stream reach). Aerial photography will be used to characterize the composition and pattern of riparian vegetation, specifically woody vegetation (i.e., forest and shrub/scrub classes), in 10-m increments within a 150-m band on both sides of the stream at the stream reach and stream network scales (Figure 5). The 150-m banding on each side of the stream is based on results from the Pudding River Drainage Pilot Study showing the distribution of woody riparian vegetation and agricultural land use as a function of distance from the stream network (see Appendix A), as well as literature sources reporting that the influence of woody riparian vegetation on aquatic habitat decreases with distance from the stream (Johnson and Ryba 1993, WDFW 1995). In addition to providing overall land use and land cover composition for the entire watershed, coarser resolution data from TM images will also be used to characterize the areal extent of woody riparian vegetation within the 150-m bands at the stream reach and stream network scales.

As discussed in Section 3.1 and summarized in Table 2, riparian vegetation fulfills a vital role in maintaining the ecological condition of streams. We are primarily interested in developing riparian indicators that are linked to: 1) riparian area functions that affect stream ecological condition, such as contributions of large woody debris and leaf litter, shading for moderation of extreme channel temperatures, and stabilization of streambanks; and 2) riparian area functions that moderate the influence of land use stressors on stream ecological condition, such as
controlling and regulating the delivery of upland-derived sediments, nutrients, and other chemicals to streams. Although streambank stabilization and regulation of sediments and nutrients are influenced by non-cultivated, herbaceous vegetation inhabiting riparian areas (Vought et al. 1994), the resolution of the remote sensing imagery to be used in this study will not allow us to consistently discriminate between non-cultivated herbaceous vegetation and cultivated grass seed and grain crops commonly grown in the Willamette Valley.

Petersen (1992) describes a Riparian, Channel, and Environmental (RCE) Inventory method for field assessments of the biological and physical condition of small streams in lowland, agricultural landscapes. Of the 16 characteristics included in this method, Petersen stated that the most important determinants of total stream condition are, in order: 1) land use composition beyond the immediate riparian zone; 2) width of woody riparian vegetation; 3) completeness (i.e., connectivity) of the riparian vegetation along the stream; and 4) composition of riparian vegetation within 10 m of the stream. The first characteristic is related to the potential effects of land use stressors on stream ecological condition as discussed in Section 3.2; while the latter three characteristics are related to riparian vegetation functions, as discussed in Section 3.1. For an individual stream reach, the woody riparian vegetation characteristics of width, connectivity, and composition will influence aquatic habitat by providing shade, contributing large woody debris and fine organic matter, stabilizing streambanks, and regulating local inputs of sediments, nutrients, and chemicals to streams. However, these same riparian vegetation characteristics, considered over the length of a stream network, should be of greater importance to overall water temperature, allochthonous inputs, and regulation of sediment, nutrient, and chemical loads to streams.

There are several commonalities among the five selected riparian area functions and riparian vegetation attributes, particularly woody vegetation. These common attributes include woody riparian vegetation composition, width, longitudinal extent, and connectivity along the stream network (Table 2). At the stream reach and stream network spatial scales, the width, longitudinal extent, and connectivity of woody riparian vegetation classes (e.g., deciduous, closed canopy) will be developed as potential indicators of stream ecological condition (Table 4), and be included as independent variables in developing empirical models. As discussed above, aerial
photointerpretation of land cover within 150 m on both sides of the stream, with summarization of the data in 10-m increments (see Appendix A), will be used in developing riparian vegetation function indicators.

3.3.3 Land Use Stressor Indicators

Land use stressor indicators are defined as measurable structural attributes of human land uses that can be used as surrogates of anthropogenic stressors on stream ecological condition. In this study, land use stressor indicators will be developed from both field measurements and remotely sensed imagery. Field measurements of human land uses will be restricted to near-channel riparian habitat along stream reaches and will adhere to EMAP-SW protocols (Klemm and Lazorchak 1995, see Appendix B). Aerial photography will be used to characterize the composition, extent, and proximity of human land uses, with emphasis on agricultural land uses, in 10-m increments within a 150-m band on both sides of the stream at the stream reach and stream network scales (Figure 5). Coarser resolution data from TM images will also be used to characterize the areal extent of human land uses within the 150-m bands at the stream reach and stream network scales. In addition, TM imagery will be used to characterize land use and land cover composition and areal extent for the entire area of each study watershed. Land use stressor indicators will be included as covariates in our development of empirical models.

As discussed in Section 3.2, agricultural land uses affect the quantity and routing of water, sediments, nutrients and other chemicals transported to streams. It is not unreasonable to assume that Willamette Valley watersheds with greater proportions of area in agriculture and/or built-up land uses are potentially greater sources of sediments, nutrients, and other chemicals than watersheds with lesser proportional areas in human land uses. Therefore, land use composition and areal extent, particularly agricultural land use, will be our primary stressor indicators. Because high intensity agricultural cropping systems are greater sources of potential stressors on stream habitat than low intensity agriculture, the composition of different agricultural classes at the stream reach and stream network scales will be evaluated as indicators of stream ecological condition. Human land use activities are not totally restricted to upland areas. In the Willamette Valley, agricultural land uses are often closely associated with streams, particularly lower order
streams (see Appendix A, Boxes A-3, A-4, and A-5). Because there may be a relationship between the proximity of agricultural land uses and stream ecological condition, we will also develop land use proximity indicators by use of an incremental banding approach developed in the Pudding River Drainage Pilot Study (see Appendix A, Boxes A-3 and A-4).

3.3.4 Stream Network Structure Indicators

Stream network structure indicators are defined as measurable structural characteristics of the stream network that can be used as surrogates of stream channelization or as surrogates of the potential extent of riparian vegetation within a watershed. Stream network data interpreted from aerial photography will be used to develop stream network structure indicators. Table 4 lists the stream network structure indicators that we intend to develop at the stream reach, stream network, and watershed scales. These indicators will be included as covariates in our development of empirical models.

Stream network characteristics, such as sinuosity, stream density, and stream frequency are important factors at a watershed scale. These characteristics not only establish the potential lateral and longitudinal extent of riparian areas within a watershed, they also influence hydraulic heterogeneity (Karr and Schlosser 1978, Naiman et al. 1992), flooding and nutrient delivery to riparian areas (Malanson 1993), and the creation and maintenance of off-channel habitats, such as oxbow lakes, sloughs, and ponds.

4.0 APPROACH

The project has been designed to contribute to the development and evaluation of alternative future scenarios by the PNW-ERC and to improve the basic understanding of the role of riparian areas on the ecological condition of small, perennial streams in agricultural landscapes of the Willamette Valley. We seek to develop empirical relationships between measurable riparian area attributes and the ecological condition of small, perennial streams in agricultural landscapes of the Willamette Valley.
Because our research focus is on small streams draining agricultural landscapes, we have defined our study area as primarily being restricted to two of the four Willamette Valley subecoregions, namely the prairie terraces and valley foothills (Figure 2). Within these subecoregions we will restrict our attention to perennial streams draining predominantly agricultural watersheds of approximately 15 to 80 km². We define predominantly agricultural watersheds as those with greater than 50% of their area in agriculture and with no urban development. Although some built-up areas (e.g., roads, rural residential) are likely to be present in most of the watersheds of our target population size range, only watersheds with less than 10% built-up areas will be considered for inclusion in the study. We will also consider only streams having no major impoundments.

Perennial streams draining 15 to 80 km² watersheds were chosen because they are of sufficient size to have well developed aquatic communities with resident fish populations. These streams range from 3 to 7 m wide, with a mean maximum thalweg depth of 20 to 70 cm (Herlihy et al. 1997). In addition, they drain a greater proportion of the agricultural landscape and are more closely influenced by local riparian conditions, land uses, and disturbances than are larger streams originating in the surrounding mountains (Naiman et al. 1992). Finally, these streams are spatially well distributed among the subecoregions and major land uses of the Willamette Valley (see Figures 2 and 6).

There is also is a practical consideration regarding the size of streams selected. First, WED scientists have developed remote image analysis methods that can be applied with a reasonable level of effort to quantify riparian and land use characteristics in watersheds of our target size (i.e., 15 - 80 km²). Second, established and reliable field sampling and measurement protocols are currently available for wadeable streams (Klemm and Lazorchek 1995; see Appendix B). Although field methods are currently under development for larger streams, they will not be tested and available within the time frame of our study.
Figure 6. Distribution of first to third Strahler order streams by major land use and land cover classes within the Willamette Valley ecoregion.
A two-phased approach will be used to address the research objectives. Phase I will feature the evaluation of hypotheses (see Section 1.3) and the development of empirical models to identify important relationships between indicators of stream ecological condition (i.e., dependent variables) and indicators of riparian, vegetation function (i.e., independent variables) as well as indicators of land use stressors and stream network structure (i.e., covariates) at varying spatial scales. Phase I will also evaluate the appropriate spatial scales and land cover classifications at which to best measure and generate indicators of riparian attributes and land use characteristics. In Phase II, we will test and refine the empirical models developed in Phase I.

4.1 Phase I

Phase I is designed to accomplish our first research objective:

- To quantify relationships between riparian area attributes at varying spatial scales and stream ecological condition. Stream ecological condition indicators are: fish assemblages, macroinvertebrate assemblages, water chemistry (nitrogen and phosphorus), and physical habitat.

4.1.1 Selection of Study Streams

A first step toward accomplishing this objective is the selection of streams which meet the criteria of our defined target population (see Section 4.0). Using topographic maps (1:150,000) and TM imagery (30 m x 30 m pixel resolution), we have identified 41 streams (and associated watersheds) that meet our criteria. These 41 streams are the entire population of streams that meet the criteria, and their associated watersheds are well distributed within our study area (Figure 7). Because the focus of this study is on the role of riparian areas on stream ecological condition in agricultural landscapes, we want to capture a range in the configuration (i.e., width, longitudinal extent, connectivity) of woody riparian vegetation along the stream networks. Using topographic maps and TM imagery, we found that there is a wide range of riparian vegetation configurations among the stream networks of the 41 watersheds. For example, the percentage of total stream network length having woody riparian vegetation ranges from almost 0% to approximately 90% within the agricultural portions of the 41 watersheds.
Figure 7. Distribution of the population of streams and their associated watersheds within the study area that meet our criteria.
Prior to Phase I, we will survey all 41 watersheds to obtain coarse estimates of the extent and configuration of riparian vegetation cover along the stream networks. The survey will be based on remote image analysis. The survey information will allow us to identify a gradient in riparian vegetation cover among the watersheds, along which a total of 25 watersheds will be selected for Phase I sampling and modeling. The remaining 16 watersheds will be set aside for Phase II sampling.

4.1.2 Stream Field Measurements and Sample Collection

We will use 7.5-minute topographic maps to identify a potential stream reach point near the base of each watershed. The identification of the potential stream reach point will be made upon evaluation of the topographic profile in order to eliminate or substantially reduce the influence of backup flood waters on the lower portions of the stream network for each of the watersheds. If access to the potential stream reach point is granted by the landowner, then, a stream reach, as defined below, will be sampled. If access to the identified point is denied, we will seek access permission from the nearest upstream landowner. This process will be repeated until access by a landowner is granted. If during this process the total watershed area drops below 15 km² or if the proportion of agricultural land use in the watershed becomes less than 50%, the watershed will be rejected.

Once the stream reaches have been determined, we will conduct field measurements of in-channel and near-channel physical habitat, and will collect fish, macroinvertebrate, and water samples required to calculate indicators of stream ecological condition -- fish assemblages, macroinvertebrate assemblages, physical habitat, and water chemistry (see Table 4). Field measurements and sample collection will be conducted during low-flow stream conditions (July to September), and according to standard EMAP-SW protocols within a stream reach. For this project, we define the term stream reach as the section of stream that will be sampled in the field for stream biota and physico-chemical habitat. Past experience in the Willamette River Basin has shown that a stream reach that is 40 times the mean baseflow wetted channel width is sufficient to overcome small scale spatial variability in quantifying fish, benthos, and physical habitat condition metrics (Herlihy et al. 1997).
4.1.3 Remote Sensing Measurements of Riparian and Upland Land Cover

This study will encompass the interpretation of remote sensing imagery at three general scales: stream reach, stream network, and watershed (see Figure 5 and Table 3). Generalized land cover maps for each watershed will be derived from land cover data based on classified TM imagery. A land cover map, being compiled by the PNW-ERC using a time series of TM satellite images, should be available by December 1997. We will generalize these data in a minimum mapping unit of about 0.5 ha from the original resolution of 900 m² pixels. We will collapse the classification into the first hierarchy of the land cover classification used in our pilot study (Table 5). The categories for the watershed characterization will include forest, shrub/scrub, grass/forb, agriculture, built-up, barren land, water, and other. This approach will allow for gross evaluation of woody riparian vegetation, as well as the areal extent of agricultural lands, built-up areas, forests, and other land covers for each watershed. Also, we be able to evaluate the utility of TM imagery in resolving relatively narrow bands of woody riparian vegetation along stream networks by comparing TM imagery land cover results with the first hierarchy of land cover results from aerial photo interpretation.

Thorough evaluation of the riparian vegetation attributes for each study stream requires higher resolution data than will be possible from the interpretation of TM imagery. Color-infrared, aerial photographs at a scale of 1:31,680 will be flown during the summer of 1997 for each watershed from which digital orthophotos will be constructed. We will delineate perennial and intermittent streams directly on the digital orthophotos to create a GIS coverage for the stream network of each watershed. We will use the aerial photography and digital orthophotos to classify and digitize land cover and land use (Table 5) at a minimum mapping unit of 0.1 ha within 150-m bands on each side of the streams at the stream reach and stream network scales. GIS functions will be used to create the 150-m bands, as well as the 10-m incremental banding, along the stream reach and stream network for each study watershed. The incremental banding approach, developed from the Pudding River Drainage Pilot Study (see Appendix A), will provide an effective mechanism for addressing specific riparian vegetation attributes, such as the width and connectivity of woody riparian vegetation along stream networks, as well as a method to explore the sensitivity of riparian vegetation indicators as a function distance from the stream. In addition, the proximity of land uses to the stream can be effectively addressed using this approach.
Table 5. Hierarchical classification scheme to be used for Phase I aerial photointerpretation of land cover and land use within the 150-m band on each side of streams at the stream reach and stream network scales.

I. Forest
1. Coniferous Forest
   a. Coniferous Forest (closed canopy) = 70% to 100% aerial canopy cover
   b. Coniferous Forest (partially closed canopy) = 40% to 69% aerial canopy cover
   c. Coniferous Forest (open canopy) = 10% to 39% aerial canopy cover
2. Deciduous Forest
   a. Deciduous Forest (closed canopy) = 70% to 100% aerial canopy cover
   b. Deciduous Forest (partially closed canopy) = 40% to 69% aerial canopy cover
   c. Deciduous Forest (open canopy) = 10% to 39% aerial canopy cover
3. Mixed Forest
   a. Mixed Forest (closed canopy) = 70% to 100% aerial canopy cover
   b. Mixed Forest (partially closed canopy) = 40% to 69% aerial canopy cover
   c. Mixed Forest (open canopy) = 10% to 39% aerial canopy cover
4. Clear Cut
5. Tree Farm

II. Shrub/Scrub = land dominated by woody shrubs (greater than 50% shrub/scrub cover), with less than 10% aerial tree canopy cover

III. Grass/Forb (includes grassed pastureland) = land dominated by grass and forbs (greater than 50% grass/forb cover), with less than 10% aerial tree canopy cover

IV. Agriculture
1. Cropland
   a. Field Crops (e.g., grass and legumes grown for seed, small grains)
   b. Row Crops (e.g., vegetables, low growing berry crops)
   c. Orchards (e.g., tree fruits and nuts, hops, vineyards, canebberries)
2. Christmas Tree Farms
3. Confined Animal Feeding Operations
4. Nurseries
5. Farmsteads
6. Other Agricultural Land (farm wasteland)

V. Built-up
1. Residential
2. Industrial and Commercial
3. Roads, Freeways and Railroads
4. Other (cemeteries, golf courses, parks)

VI. Barren Land (land of limited ability to support vegetation)

VII. Water
1. Rivers (greater than 10 meters in width)
2. Lakes, Ponds, and Reservoirs

VII. Other (lands not included in the other classes)
Final land cover classes will be assigned following field verification. We will then summarize woody riparian vegetation, agriculture, built-up, forest, and other land covers, as well as stream network characteristics at different spatial scales. These scales will include the stream reach and different proportions of the banded stream network, such 25%, 50%, and 100% of the total stream network (Figure 5). This longitudinal analysis will allow us to determine if indicators generated within a smaller extent of the stream network are as effective in estimating stream ecological condition as the entire banded stream network of a watershed, as well as a method for evaluating the importance of upstream riparian vegetation configurations on downstream sampling reaches.

4.1.4 Development of Empirical Models

We will use exploratory multivariate methods such as ordinations and similarity analyses to screen out non-influential watershed and riparian potential explanatory variables. Prior to model building, sensitivity analyses will be performed for the change in riparian vegetation and watershed land use/land cover variables with aggregation scale. Separate multiple regression models will be developed for each reach-scale stream condition indicator, with watershed and riparian land cover/land use estimates at various spatial scales (e.g., 25%, 50%, 100% of the total stream network of the watershed) as potential explanatory variables. Model residuals will be mapped to check for spatial dependence of neighboring watersheds, and also to check for large scale spatial trends. We will also investigate whether existing, coarse resolution, digital soils and surficial geology data help explain any spatial patterns seen in the empirical model residuals.

An example of the type of relationships that we hope to develop can be found in Steedman (1988). For a series of study streams in southern Ontario, Steedman was able to establish a multiple regression model that related fish IBI to the proportion of stream channels with intact riparian forest and with the proportion of the watershed in urban land use. A nomograph then depicted IBI class (i.e., excellent, good, fair, and poor) to percent of riparian forest cover and percent of urban lands (Figure 8). In essence, Steedman (1988) used the results of this regression analysis to develop and hypothesize about the relationship between watershed and riparian conditions and IBI. Unfortunately, Steedman (1988) was unable to test and model (or classification system) on an independent set of watersheds.
Figure 8. Contour plot of qualitative IBI ratings as a function of urbanization and riparian forest, calculated from the equation, IBI = 29.47 - 19.35 URB + 14.21 RIP ($r^2 = 0.68$, $n = 18$) (Adapted from Steedman 1988).
4.2 Phase II

Phase II is designed to accomplish our second research objective:

- To estimate the influence of selected riparian area - agriculture configurations on indicators of stream ecological condition.

In Phase II, we will sample and characterize the remaining 16 targeted watersheds as described earlier or as modified based on Phase I results. Phase II data will be used to test the Phase I empirical models. Once the evaluation of the models has been completed, the data for all 41 study watersheds will be pooled and final models will be developed for each of the indicators of stream ecological condition. These models will then be used to estimate the responses of stream condition indicators to varying riparian vegetation configurations. These models will also be made available in the evaluation of alternative future scenarios for the Willamette River Basin case study.

5.0 QUALITY ASSURANCE

We will employ quality assurance/quality control (QA/QC) checks throughout both research phases to assess the quality of existing data and to control error during digitizing, information processing, and map production. We will develop and implement protocols for data storage/retrieval, digitizing, interpretation of remotely sensed imagery, field data collection, classification accuracy, and data documentation. Data and spatial information used in the project will be maintained under project directories on the EPA NHEERL-WED (Corvallis) distributed network.

A separate Quality Assurance Project Plan has been prepared in support of this research plan.
6.0 SCHEDULE AND PRODUCTS

The schedule and anticipated products are listed below by research phase.

**Phase I**
- May 1997 -- Identify Stream Reach Sample Points
- May 1997-June 1997 -- Determine Ownership and Obtain Access Permission
- May 1997 -- Arrange for Summer Aerial Photography of 25 Study Stream Networks
- July 1997-September 1997 -- Collect Stream Reach Field Data
- July 1997 -- Obtain Aerial Photography and Orthophotos for 25 Study Stream Networks
- July 1997-January 1998 -- Interpret and Digitize Land Cover
- August 1997-February 1998 -- Enter and Summarize Field Data
- August 1998 -- Interim Report
- December 1998 -- Journal Manuscript

**Phase II**
- May 1998 -- Identify Stream Reach Sample Points
- May 1998 -- Arrange for Summer Aerial Photography of 16 Study Stream Networks
- July 1998-September 1998 -- Collect Stream Reach Field Data
- July 1998 -- Obtain Aerial Photography and Orthophotos for 16 Study Stream Networks
- July 1998-December 1998 -- Interpret and Digitize Land Cover
- August 1998-February 1999 -- Enter and Summarize Field Data
- August 1998-February 1999 -- Summarize Remote Sensing Data
- February 1999-June 1999 -- Test Phase I Empirical Models and Refine Models
- September 1999 -- Final Report
- December 1999 -- Journal Manuscript
7.0 REFERENCES


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APPENDIX A. Summary of Methods and Results from the Pudding River Drainage Pilot Study that were presented at the 12th Annual U.S. Landscape Ecology Symposium (March 1997, Durham, NC).

Development of Sampling Methods for Assessing Riparian-Stream Networks in Agricultural Landscapes

Introduction

Riparian areas along stream networks affect the quality of aquatic habitat. Little is known about the composition, pattern, and ecological condition of riparian areas along stream networks in agricultural landscapes in the Pacific Northwest. It is often not feasible to inventory riparian-stream networks and associated uplands at basin or regional scales with the desirable resolution for developing landscape indicators and metrics for assessing riparian functions, such as the aquatic habitat function. Sampling approaches can provide an attractive option by providing a mechanism for making inferences about riparian-stream networks at the desired scale. An important sampling design consideration is the size of the individual sample areas (SA) in relation to the scale of the phenomenon being investigated. We describe a pilot study being conducted in a 1,000 km² area which encompasses most of the Pudding River drainage, an agriculturally-diverse landscape of Oregon's north-central Willamette River Basin (Figure A-1). Our goal is to develop sampling methods and assessment techniques for evaluating the aquatic habitat function of riparian areas, using medium-scale aerial photography and geographic information system (GIS) technology.

Operational Definitions

Sample Area (SA): the neighborhood surrounding the stream sampling point in which land cover is characterized and landscape indicators are measured for evaluating the aquatic habitat function of riparian areas.

Adjacent woody vegetation: forest or shrub/scrub patches juxtaposed to a perennial or intermittent stream at some point along the stream network within the SA. Tree plantations and clearcuts were not included as adjacent woody vegetation.

Landscape indicator: a measurable characteristic of the landscape that is used to represent an
ecological attribute of the aquatic habitat function of riparian areas or a potential stressor of an ecological attribute. The connectivity of woody vegetation directly adjacent to a stream network is an example of a landscape indicator.

**Indicator metric:** a specific measure for a landscape indicator which allows quantitative assessments of the aquatic habitat functions of riparian areas. The number of breaks in adjacent woody vegetation on streambanks is an example of a metric for connectivity.

**Objectives**

- Develop an empirical approach for determining an optimal SA for characterizing riparian-stream networks and their spatial relationships with uplands, particularly agriculture, at a basin or regional scale.

- Develop cost-effective and efficient land cover interpretation and digitizing methods for generating GIS data layers for detailed spatial analysis of the SAs.

- Develop methods for characterizing the spatial distribution of land cover composition and pattern along stream networks, with specific emphasis on landscape indicator metrics which allow for quantitative assessments of the aquatic habitat function of riparian areas.

**Conceptual Model**

The ecological condition of riparian areas can be assessed according to their ability to provide aquatic and terrestrial habitat functions. These functions are dependent upon long-term climatic, geomorphic, and hydrological processes. They are further modified by structural (i.e., composition and pattern) attributes, ecological processes, and disturbance regimes of uplands, riparian areas, and stream networks; and, the complex interactions occurring among these systems. The conceptual model depicted in Figure A-2 is a simplified representation of these interactions, focusing specifically on the attributes of the aquatic habitat function of riparian areas. It is intended as a general framework for guiding the selection of indicators and developing specific metrics and indices for conducting assessments of the aquatic habitat function of riparian areas. Indicators are used to represent specific attributes within the SA, and are limited in this study to characteristics that can be measured from aerial photographs or obtained from existing databases.
Methods

The methodology was developed in three phases. In Phase 1 we determined an optimal SA (Box A-1). In Phase 2 we interpreted, digitized, and classified land cover from aerial photography for the SAs (Box A-2). Finally, in Phase 3 we developed methods to characterize the SA land cover using incremental buffering (Box A-3).

Results

Buffering stream networks in 10-m increments provides a framework for developing landscape indicator metrics for estimating basin-scale or regional-scale information, such as composition and pattern of riparian land covers (Box A-4). Incremental buffering of the stream network can be used to visualize the differences in landscape composition among the SAs, as well as the patterns of change in land cover with increasing distance from the stream network (Box A-5). The width and connectivity of adjacent woody vegetation along stream networks are potentially important indicators of the condition of riparian areas. We are exploring methods for generating landscape pattern metrics for these, as well as other indicators (Box A-6).

Conclusions

- The empirically-derived SA, encompassing a 300-m buffer around perennial and intermittent streams within a 10 km² circular area, adequately represented stream network structure and land cover for making inferences about riparian-stream networks in agricultural landscapes of the Willamette River Basin.

- The ability to interactively interpret and digitize landscape elements from aerial photos, proved to be a cost-effective and efficient method for creating detailed GIS layers.

- The buffering of stream networks in 10-m increments is an effective method for characterizing the composition and pattern of land cover as a function of distance from the stream network, and shows promise for ongoing research to develop landscape indicator metrics for assessing the aquatic habitat function of riparian areas.
Figure A-1. Study Area Location

Willamette River Basin

Box A-1. Phase 1 - Determination of an Optimal Sample Area (5a)

Area within a 500-m outer circle all contained perennial and intermittent streams lying within 10-km circle centered on a stream sample point (d).
Box A.2: Phase 2 - Interpretation and classification of sample area land cover
Box A.3 Phase 2 - Characterization of Sample Area Land Cover Using Incremental Buffering
Box A-4. Measuring Landscape Metrics as a Function of Distance from the Stream Network

composition and pattern of land cover influences at selected buffer widths, depending on the focus of the research. Depending on the focus of the research, the accuracy of the analysis will vary. Buffering stream networks can also be used to derive metrics for assessing the accuracy of the analysis. The left graph shows the mean landscape metrics for each buffer width, while the right graph shows the mean landscape metrics for the entire stream network. The graphs show the distribution of metrics as a function of distance from the stream network. The graphs also show the mean and standard deviation of the metrics for each buffer width.
Box A-5: Landscape Composition Metrics

Proportional increase with distance from the stream network.

A general pattern of cropping showing a substantial agricultural class is in both the 50-m and 300-m buffers. In addition, there is a general pattern of cropping that is more substantial in the 300-m buffer. The graphs below reveal the differences in land use composition among the 5A5 as well as the patterns of change in land use with increasing distance from the stream network.
Vegetation patches are closely associated with the streambanks by the vegetation pattern. A break adjacent to the streambank, the number of non-woody vegetation patches was calculated by dividing the number of non-woody vegetation patches per km of streambank by the number of breaks. The length of these breaks adjacent to the streambank was calculated by averaging the length of all non-woody vegetation patches between breaks adjacent to the streambank. Two methods were developed to estimate connectivity: 1) the mean length of breaks between adjacent woody vegetation patterns along streambanks and 2) the number of breaks within a specific buffer. Two methods were used to estimate the mean width of adjacent woody vegetation with a buffer width of 10 m. The average vegetation was measured per km of streambank and the adjacent woody vegetation was measured per km of stream. Method #1 is an alternative for estimating vegetation width, which can be quickly calculated from our existing GIS data.

**Box A-6: Landscape Pattern Metrics**

*The width and connectivity of adjacent woody vegetation along stream networks are potentially important indicators of the condition of riparian areas. As described below, we are exploring methods for generating landscape pattern metrics for these, as well as other indicators.*
APPENDIX B. In-Channel & Near-Channel Field Measurements Conducted by EMAP-SW.

In-channel and near-channel field measurements of biological, chemical, and physical attributes of stream reaches will be made according to established protocols developed by Oregon State University and EMAP-SW. These protocols are described in detail in a field operations and methods manual (Klemm and Lazorchak 1995). The EMAP-SW protocols were developed for evaluating perennial, wadeable streams and the immediate riparian area during low flow conditions and during times when terrestrial vegetation is active. The protocols are designed for monitoring applications where robust, quantitative descriptions of reach-scale habitat can be achieved by a three-member field crew during a single, one-day sampling period. The protocols define the length of each sampling reach proportional to stream width and then systematically place measurements to statistically represent the entire reach. The in-channel and near-channel measurements are summarized below.

**In-Channel Measurements**

The ecological condition of perennial, wadeable streams in the Willamette Valley will be evaluated by taking in-channel measurements of fish assemblages, macroinvertebrate assemblages, water chemistry, and physical habitat. The measurements will be collected over stream reaches with lengths 40 times their mean wetted width (minimum of 150 m) during summer, low flow conditions (July - September), where all measurements on an individual stream reach are collected in one day.

**Fish Assemblages:** The objective of the fish assemblage protocol is to collect a representative sample of the fish assemblage. A representative sample of the stream reach fish assemblage will be obtained via a one pass electroshocking protocol. The captured fish will be identified to species and the number of fish per species will be recorded. Sport fish and very large specimens will be identified, measured (i.e., standard length, total length, body depth), examined for external anomalies, and then released. For other species, the largest and smallest individual per species will be measured (i.e., standard length, total length). In addition, the proportion and type of
external anomalies by fish species will be recorded. Voucher specimens, with the exception of large individuals of easily identified species, will be collected.

**Macroinvertebrate Assemblages:** Benthic macroinvertebrates inhabit the sediment and bottom substrates of streams. The benthic macroinvertebrate assemblages in streams reflect the overall biological integrity of the benthic community. The objective of the macroinvertebrate assemblage protocol is to collect a representative sample of the benthic macroinvertebrate assemblage. A representative sample of the macroinvertebrate assemblage within stream reaches will be collected at 11 equidistant transects along the reaches using a surber sampler. Each sample will be placed in a separate whirl-bag and preserved with ethanol. Identification and enumeration will be done by a designated taxonomist.

**Water Chemistry and Temperature:** The chemical and thermal status of streams affects the condition of fish and macroinvertebrate assemblages. There are two components to the water chemistry and temperature protocol for stream reaches: (1) collecting samples of stream water to ship to the analytical laboratory, and (2) *in situ* stream measurements of specific conductance, dissolved oxygen, and temperature. The water samples and *in situ* stream measurements will be obtained from the middle of the wetted channel at the downstream end of the reach. The water samples will be kept on ice in a cooler while in the field and taken to the WED analytical laboratory upon completion of the day's sampling. Stream water will be analyzed for the major cations and anions, nutrients (i.e., nitrate, total nitrogen and phosphorus), dissolved organic carbon, turbidity, and pH. Quality assurance for water samples and *in situ* stream measurements are discussed in detail in Klemm and Lazorchak (1995).

**Physical Habitat:** The objective of the in-channel, physical habitat protocol is to assess those physical attributes that influence or provide sustenance to organisms in the stream. Kaufmann (1993) identified several in-channel, physical habitat attributes important in influencing stream ecology. A descriptive summary of these attributes and their measurements, as conducted by EMAP-SW (Klemm and Lazorchak 1995), is provided in Table B-1.
Near-Channel Measurements

In addition to in-channel measurements, visual estimates of riparian vegetation and human disturbance will be recorded within the immediate vicinity of the stream reach. Measurements will include the recording of riparian vegetation type and cover for the canopy, understory and ground layers, and the presence and proximity of 11 categories of human influences. These measurements are collected from 22, 10 m x 10 m transect plots located on the right and left banks at 11 equally-spaced cross-sectional transects along the stream reach. A summary of the measurements collected is provided in Table B-2.
Table B-1. Components and description of in-channel physical habitat measurements.

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thalweg Profile</td>
<td>Longitudinal survey of the maximum depth, habitat class (i.e., pool types, glide, riffle, rapid, cascade, falls), and presence/absence of soft/fine sediments at 10 to 15 equally spaced intervals between each of 11 channel cross-sectional transects equally spaced along the centerline between the two ends of the stream reach (total of 100 to 150 measurements for the stream reach).</td>
</tr>
<tr>
<td>Woody Debris</td>
<td>Continuous tally of large woody debris by size class and location (i.e., at least partially in bankfull channel or spanning above bankfull channel) between each of the equally-spaced, 11 channel cross-sectional transects for the entire length of the stream reach. Large woody debris is defined here as woody material with small end diameter of 10 cm and length of at least 1.5 m.</td>
</tr>
<tr>
<td>Channel Cross-Section Dimensions, Channel Gradient and Sinuosity, Substrate, Fish Cover, Bank Characteristics, and Riparian Canopy Cover</td>
<td>Measures of channel width, depth, bank angle, incision and undercut (with rod and clinometer), gradient (clinometer), sinuosity (compass backsite), and riparian canopy cover of stream (densiometer) at each of the 11 equally-spaced cross-sectional transects along the length of the stream reach. Five equally-spaced depth measurements are made at each of the 11 cross-sectional transects as determined by the channel width at each transect. Substrate size class (i.e., bedrock smooth or rough, boulders, cobbles, gravel coarse or fine, sand, fines, and wood) and embeddedness (0-100%) are made at each of the 5 depth measurement points for each of the 11 cross-sectional transects.</td>
</tr>
<tr>
<td>Discharge</td>
<td>Measure of instantaneous stream velocity (at 0.6 of stream depth from surface using electromagnetic or impeller-type flow meter) at 15 to 20 equally-spaced intervals across one optimally chosen channel cross section on the stream reach.</td>
</tr>
</tbody>
</table>
Table B-2. Components and description of near-channel riparian habitat measurements.

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Riparian Vegetation Type</td>
<td>Visual estimates of forested vegetation composition (i.e., deciduous, coniferous, and mixed) in 10 m x 10 m plots on each side of the stream at 11 equally-spaced cross-sectional transects along the stream reach.</td>
</tr>
<tr>
<td>Riparian Vegetation Cover</td>
<td>Visual estimates of vegetation areal cover for the canopy, understory, and ground layers in 10 m x 10 m plots on each side of the stream at 11 equally-spaced cross-sectional transects along the stream reach.</td>
</tr>
<tr>
<td>Human Disturbance</td>
<td>Visual estimates of the presence and proximity of 11 categories of human land use activities (i.e., buildings, lawns/parks, pastureland, cropland, roads/railroads, pavement, landfill/trash, mining operations, logging operations, influent/effluent pipes, and bank revetments) in 10 m x 10 m plots on each side of the stream at 11 equally-spaced cross-sectional transects along the stream reach.</td>
</tr>
</tbody>
</table>
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