Ecological Functions of Off-Channel Habitat, Willamette River, Oregon

Final Research Plan

United States Environmental Protection Agency, Research and Development

National Health and Environmental Effects Laboratory, Western Ecology Division, Corvallis, OR

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Introduction

Off-channel features such as alcoves and side channels can have important ecological functions for large rivers such as the Willamette River. Some species and age classes of fish may select these features instead of the main channel to feed, avoid predation by other fish, escape fast water, or seek out cool water in the summer. Other organisms such as amphibians, mussels, and birds may also be attracted to alcoves and side channels because of unique physical and water quality characteristics.

Off-channel features are portions of the river and its flood plain that have surface water but are separate from the main channel for at least part of the year. Alcoves are off-channel features that have no surface water flowing into the upstream end during at least some part of the year and are open to the main channel at the downstream end (Figure 1). Side channels are off-channel features that have surface flow at both ends, are significantly narrower than the main channel, and are separated from the main channel by land for at least for part of the year. In this document, off-channel habitat refers to habitat for organisms using these features.

The Willamette River, like many other western rivers, has been channelized and manipulated in other ways over the last century, thereby reducing the number of alcoves and side channels (Froogart and Sedell 1984). Also, waste discharges from municipal and industrial sources may be reducing overall river water quality, potentially making remaining off-channel habitat less useful to aquatic organisms (Tetra Tech 1992b). A reduction in the extent of riparian forest may have diminished the supply of large woody debris and litter that falls into off-channel features or floats into them during high flows. This organic material can play a role in providing cover for fish or become a part of the food web (Gregory et al. 1991). The introduction of exotic fish may also be disrupting the use of off-channel features by native species through predation and competition (Li et al. 1987). Exotic aquatic plants may be displacing native aquatic plants or occupying large portions of off-channel features and changing dissolved oxygen dynamics, thereby altering habitat for fish. In contrast, the release of cool water from upstream reservoirs during the summer may be helping to maintain habitat quality in both off-channel features and the main channel (Hines et al. 1977).

This proposal describes research to evaluate the functions of alcoves and side channels in a large river ecosystem, determine factors that currently affect their ecological functions, and identify future management actions that could be taken to improve these functions. In addition, we intend to relate the processes occurring within alcoves and side channels to processes occurring in the main channel, in adjacent ground water, and the riparian vegetative community.

Willamette River - setting and history

The Willamette River is in western Oregon and drains nearly 30,000 square km. Eleven impoundments have been built in the watershed during the last 55 years to regulate flood flows and store water for release in the summer. Over two-thirds of the basin is forested hills and mountains (Figure 2). Twenty percent of the watershed is farm fields which are, for the most part, in the broad valley floor. Urbanized areas make up 4% of the basin and this is where the majority of Oregon’s population reside.
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Figure 1. Diagram of an alcove and a side channel
Figure 2. Willamette River Basin and major land uses. Project area extends from the Yamhill River to Eugene.
Since at least the turn of the century, portions of the Willamette River basin have experienced serious water pollution problems. Organic waste and ammonium contained in industrial and municipal effluents once caused severe dissolved oxygen deficits, algal blooms, and fish kills during summer months (Rogers et al. 1930; Gleeson 1972; Hines et al. 1977; Tetra Tech 1995a). Upon completing a comprehensive fish survey of the Willamette River in the early 1940's, Dimick and Merryfield (1945) concluded:

“Pollution in the Willamette River system is a State shame... this magnificent river is at present in part an open sewer in which tremendous quantities of untreated human sewage and industrial wastes are disposed... Pollution in Oregon’s great river, along with other detrimental activities, has depleted a world-famous commercial and game fish fauna.”

By the early 1970's basin-wide secondary waste water treatment, reductions in ammonium releases, and augmentation of summer streamflow through reservoir releases had resulted in marked improvements in dissolved oxygen levels (Hines et al. 1977). Fish are now able to live in portions of the basin where summer dissolved oxygen levels had previously been too low for them to survive.

Nevertheless, portions of the Willamette basin still experience dissolved oxygen deficits that drop levels below state water quality standards and potentially affect the composition and abundance of fish communities. Dissolved oxygen is lowest in the smaller Willamette valley rivers that have no summer flow augmentation, within side channels and alcoves connected to the main channel, and where industrial or municipal influences are high (Tetra Tech 1992a). However, low dissolved oxygen may also be a natural phenomena for some portions of the river due to hyporheic and other subsurface sources of water that are low in oxygen (Matthews and Berg 1997). Hyporheic flow is subsurface water that travels beneath or next to a river and roughly in the same direction as the river but usually at a much slower rate (Stanford and Ward 1992).

The geometry of the river was also altered after European settlement. Rivers flowing through the Willamette valley floor once contained numerous alcoves and side channels. Over time, these rivers were engineered into what are now predominantly single channels (Froogart and Sedell 1984; Figure 3). Large woody debris was removed, channels were dredged and straightened for navigation, side channels and sloughs were filled to promote farming of land near the river, and river banks were lined with revetments to restrict future channel encroachment upon farm land and towns. In addition, much of the riparian forest which had been a source of large woody debris, shade, and carbon was removed so that the fertile soils nearest the river could be farmed.

Channel simplification combined with summer reservoir releases has actually allowed for efficient processing of wastes discharged into the river. The channelized river with augmented flow quickly transports waste loads downstream. Reservoir releases now boost August flows by 80 percent over natural flow levels (measured at Salem). The time it takes main channel water to travel the 215 km from Eugene to Newburg during the summer is only 3 days (Harris 1968). As a result, this upper portion of the Willamette River is able to export (or assimilate) current levels of waste without experiencing significant declines in main channel dissolved oxygen (Pogue and Anderson 1995) and without growing much nuisance algae (Gregory 1993). In August 1991 it was estimated that the combined biological oxygen demand of effluent discharged by major NPDES permittees was 1658 kg/day from sources upstream of the McKenzie River confluence (downstream of Eugene a few kilometers). An additional 2158 kg/day entered from the McKenzie River confluence to Newburg. Of the total biological oxygen demand entering upstream of Newburg, about 70 percent came from
Figure 3. Changes in Willamette River channel density and connectivity from 1854 to 1967 for a reach that extends from Harrisburg to Eugene.
pulp and paper mills and the remainder from sewer treatment plants (Tetra Tech 1992b).

Alcoves and side channels increase the transit time for a portion of the river flow, giving aquatic organisms more opportunity to assimilate nutrients and carbon that collect within these features. Consequently, greater diurnal flux in dissolved oxygen should occur. Low dissolved oxygen levels at night resulting from biological breakdown of organic materials and growth of nuisance algae may be more prevalent in these off-channel features than in the main channel. Low dissolved oxygen in alcoves and side channels may also result from the inflow of groundwater that is naturally low in dissolved oxygen. Fish use of alcoves and side channels during summer months is likely tied to the quality of water as well as other habitat features.

Little is known about how multiple off-channel features affect a river’s overall water quality and the composition of its fish community. What work that has been reported has typically focused on small rivers that flow through forest land (Peterson and Reid 1984; Swales and Levings 1989). The ability to even address this issue is hampered by today’s scarcity of off-channel features along large rivers. The remaining off-channel features along the upper Willamette River are perhaps numerous enough that they can provide insight into ecological processes that have now mostly faded within other large rivers that have been channelized severely.

Social and biological constraints

There have been proposals and attempts to reconnect historic alcoves and side channels to the main channel of the Willamette River (Oregon Division of State Lands, personal communication). It has been suggested that the lack of habitat provided by off-channel areas can interfere with fish reproductive success and fish species diversity in a river (Copp et al. 1994; Poizat and Pont 1996). Yet, because exotic species of fish are present in the Willamette River the ability to approach historic conditions may be limited. Without an understanding of the dissolved oxygen, water temperature, and other needs of native fish and to fish community dynamics, attempts to alter habitat by improving or constructing new off-channel features may benefit only harder exotic fish species (Baltz et al. 1987; Cech et al. 1990; Kramer 1987). The Oregon Department of Fish and Wildlife has adopted a philosophy of managing for native fish rather than exotics in rivers such as the Willamette in order to prevent drastic declines in individual native species and to preserve the integrity of the native fish community.

Evaluating the combined effects of waste loads, summer water withdrawals, reservoir releases, and channel geometry on water quality and related fish habitat can be exceedingly complex. Interactions between water quality and fish habitat are likely to differ longitudinally in upstream portions of the river where water is cooler, faster, waste loads less, and establishment of exotic species less entrenched than in downstream portions of the river. The problem also takes on an element of time since human population growth, related waste loads, and water withdrawals will be occurring at different rates throughout the Willamette basin. High flows, which are linked to reservoir management, make the system even more dynamic by creating, rearranging, and filling in alcoves and side channels through annual flood disturbance cycles.

The spatial and temporal dimensions of these processes provide an additional challenge in evaluating the river system. For example, the processes occurring within an individual off-channel feature may have great bearing on the fish using that feature, yet it is the combined influence of many off-channel features having varying characteristics that probably define the structure of the overall fish
community. Similarly, the way in which off-channel features provide habitat for fish may vary widely depending on the season and, on a larger time scale, the period since an unusually high flow has occurred.

Figure 4 illustrates factors that may influence habitat quality for native fishes that use alcoves and side channels for all or portions of their life. Many of these factors involve basin-wide processes. Dissolved oxygen levels can be influenced by groundwater and waste water discharges throughout the basin. Reservoir releases in upper portions of the basin can directly influence downstream fish habitat by keeping water levels high within alcoves and side channels during the summer and by diluting waste loads that can cause dissolved oxygen deficits. Reservoir releases can also create, to some extent, downstream water temperature reductions. The water temperature and dissolved oxygen level, in turn, can influence the level of competition from exotic species of fish, since introduced species such as largemouth bass can often withstand lower dissolved oxygen and higher water temperature than native species such as cutthroat trout (Doudoroff and Shumway 1970). Basin-wide processes can be either magnified or muted by site conditions at an alcove or side channel. Consequently, it is the combination of basin-wide and site conditions that controls habitat quality within any given alcove or side channel.

The future management of reservoirs and the magnitude of waste loads in the Willamette River are linked to population growth and the choices made on how to allocate reservoir water, how much money to spend on treating waste water, and how to manage non-point sources of nutrients. Population increases can also create pressures to further channelize or riprap the river as more homes are built near the river in areas where localized flooding or channel migration occur. Accelerated population growth that began in the Portland area a decade ago is now occurring further upstream in the Willamette Valley. Counties in the mid-Willamette area (Yamhill, Polk, and Marion) grew at a rate of 2.6 percent per year from 1990 to 1995 (Wineberg 1996). While the tri-county area of Benton, Linn, and Lane Counties grew at only a 1.3 % annual rate from 1990 to 1995, some towns in this upper-Willamette area are also beginning to grow rapidly. Springfield, for example, grew at a 2.6 percent rate from 1994 to 1995.

A number of entities have recently been involved in evaluating the Willamette River's condition and planning for its future. In the 1990's the Oregon Department of Environmental Quality commissioned various studies on water quality and biota so they would have quantitative tools to assist with making management decisions about the river (Tetra Tech 1995a). About the same time, the Willamette River basin was selected by the U.S. Geological Survey to be a National Water-Quality Assessment site and they initiated studies on water quality and biota. The Willamette Liveability Forum was recently created by the governor and a part of its mandate is to evaluate how future development scenarios affect environmental conditions in the valley, such as the health of the Willamette River. Another entity concerned about the ecological future of the Willamette River is the Gravel Group, an affiliation of gravel extraction companies, state agencies, federal agencies, and university researchers interested in funding and spearheading improvements in Willamette River fish and wildlife habitat, particularly where gravel extraction operations have occurred. Our research will address topics not covered by others and be useful for integrating this growing pool of scientific understanding of the river and increasing interest in its future condition.
Figure 4. Factors that can influence habitat quality for native fishes using alcoves and side channels of the Willamette River
Previous studies of off-channel habitat

Previous studies of off-channel fish habitat in the Willamette River are limited to gill net sampling done by the Oregon Department of Fish and Wildlife during the 1960's and 1970's. Gill nets were set in off-channel features located upstream of the Yamhill River confluence and provided some information about the community structure of the larger fish (mostly > 10 cm). Gill nets were usually set near the entrances of side channels or alcoves and then checked the next day. Over one-third of fish caught in the off-channel features were introduced species and most of these were white crappie (Table 1).

Table 1. Fish Length and Percent of Total Fish for 59 Gill Net Sets in Willamette River Off-Channel Areas from 1967 to 1979 (between the Yamhill River confluence and Eugene).

<table>
<thead>
<tr>
<th></th>
<th>Mean Length** (cm)</th>
<th>Maximum Length (cm)</th>
<th>Percentage of Total Catch**</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Native Fish</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Largerscale sucker</td>
<td>33</td>
<td>52</td>
<td>33.9 %</td>
</tr>
<tr>
<td>Chiselmouth</td>
<td>23</td>
<td>31</td>
<td>13.8</td>
</tr>
<tr>
<td>Northern squawfish*</td>
<td>28</td>
<td>51</td>
<td>12.7</td>
</tr>
<tr>
<td>Peamouth</td>
<td>24</td>
<td>33</td>
<td>3.4</td>
</tr>
<tr>
<td>Cutthroat trout*</td>
<td>35</td>
<td>43</td>
<td>0.4</td>
</tr>
<tr>
<td>Redside shiner</td>
<td>13</td>
<td>15</td>
<td>0.3</td>
</tr>
<tr>
<td>Sculpin</td>
<td>13</td>
<td>15</td>
<td>0.3</td>
</tr>
<tr>
<td>Other</td>
<td>-</td>
<td>-</td>
<td>0.2</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td>65.0</td>
</tr>
<tr>
<td><strong>Introduced Fish</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>White crappie*</td>
<td>17</td>
<td>29</td>
<td>24.5 %</td>
</tr>
<tr>
<td>Bluegill*</td>
<td>13</td>
<td>19</td>
<td>3.7</td>
</tr>
<tr>
<td>Brown bullhead</td>
<td>23</td>
<td>31</td>
<td>1.6</td>
</tr>
<tr>
<td>Yellow bullhead</td>
<td>23</td>
<td>42</td>
<td>1.4</td>
</tr>
<tr>
<td>Common carp</td>
<td>40</td>
<td>60</td>
<td>1.2</td>
</tr>
<tr>
<td>Black crappie*</td>
<td>17</td>
<td>27</td>
<td>1.0</td>
</tr>
<tr>
<td>Warmouth*</td>
<td>13</td>
<td>18</td>
<td>1.0</td>
</tr>
<tr>
<td>Largemouth bass*</td>
<td>19</td>
<td>30</td>
<td>0.6</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td>35.0</td>
</tr>
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</table>

* Indicates species is partially or totally piscivorous.
** Calculated as the average of each of the 59 gill net sets.

Of the eight introduced species caught in the nets a majority of the fish were partly or totally piscivorous (fish that feed on other fish). The only native piscivores in the samples where northern squawfish and a few large cutthroat trout. Of all fish caught, 44 % were piscivores (Figure 5), suggesting that off-channel features are used for feeding by these fish. Electrofishing sampling of
Figure 5. Percentage of fish caught with a gill net left overnight within an alcove or side channel of the Willamette River. Introduced piscivores include white crappie, bluegill, black crappie, largemouth bass, and warmouth. Native piscivores include squawfish and cutthroat trout. Data from the Oregon Department Fish and Wildlife (1967 to 1979).
the main channel in 1983 for the same reach of the Willamette River resulted in no capture of introduced piscivores. The only native piscivores captured in the main channel were northern squawfish and they made up 35% of the total catch (Hughes and Gammon 1987).

We are not aware of any other studies that have been conducted in the Pacific Northwest in which the off-channel features of large rivers have been examined at multiple temporal and spatial scales. However, several studies conducted in the Pacific Northwest and elsewhere have evaluated the importance of selected off-channel areas for certain life stages of fish. A one-time sampling of 20 km of the Hoh River in Washington during the fall showed that nearly all rearing of salmonid fish occurred in off-channel areas and tributaries. Salmonid density in off-channel areas was 0.364 fish per square meter but only 0.004 in the main channel (Sedell et al. 1980). Similarly, a study of juvenile coho salmon within the nearby Clearwater River revealed that these fish made heavy use of riverine ponds during the winter (Peterson 1982).

Studies conducted in Europe on large rivers provide a glimpse of juvenile fish community dynamics within off-channel (or flood plain) habitats. Results of a study of the Great Ouse catchment in England revealed the importance of restoring those natural fluvial processes that form new side channels and backwaters and of alleviating pollution loads in order to sustain rich assemblages of reproducing native fish (Copp 1992). The diversity of off-channel features in the upper Rhone River, both newly formed and those in senescence, was seen as key to providing a "stable" environment for fish reproduction (Copp 1989). The resilience of flood plain systems in the middle Danube River was shown to depend on the presence of a diversity of macro and microhabitats. High habitat diversity ensured that fish reproductive success occurred somewhere in the system, even if drought or pollution incidents created major perturbations to the system (Copp et al. 1994). A comparison of off-channel features (dike fields) and the main channel in the lower Rhone River indicated that the dike fields served as a critical nursery for fish. Every juvenile fish species studied was more abundant in the dike fields than the main channel. At the microhabitat scale, water depth and cover were found to be the major drivers of fish abundance (Poizat and Pont 1996).

**Interests of the EPA**

This research on off-channel habitats features in the Willamette River follows from EPA's Pacific Northwest five-year research strategy (Baker et al. 1995). The strategy document was prepared by EPA in response to the 1993 Timber Summit convened by President Clinton. The Interagency Ecosystem Management Task Force formed at this time defined ecosystem management (their major charge), as follows:

"Ecosystem management is a goal-driven approach to restoring and sustaining healthy ecosystems and their functions using the best science available. It entails working collaboratively with state, tribal and local governments, community groups, private landowners and other interested parties to develop a vision of desired future ecosystem conditions. This vision integrates ecological, economic, and social factors affecting the management unit defined by ecological, not political boundaries."

True to this context, the proposed off-channel habitat research focuses on using the scientific approach to develop an understanding of the ecological functions of these features in large river ecosystems. We propose to develop a quantitative understanding of how habitat complexity has changed over the last 100 years with the objective of being able to establish possible future condition
for riparian habitat.

We have established a working relationship with state and federal agencies and private landowners involved with aggregate mining near the Willamette River. Our work, conducted at multiple scales of time and space, will provide information directly to potential end-users of the information. At present, each large regulated aggregate mining operation operating on the Willamette River must provide a rehabilitation plan describing how detrimental disturbance will be mediated after extracting gravel from an area. A connection between our proposed research and the aggregate industry involves establishing realistic, science based goals for rehabilitated sites, reaches, or the entire main stem of the river.

Our work will also link with the alternative futures being developed by the EPA-funded Pacific Northwest Ecosystem Research Consortium. This is a coordinated research effort comprised of aquatic and terrestrial scientists, landscape planners, and economists from Oregon State University, the University of Oregon, and the University of Washington (Gregory et al. 1996). One aspect of the Consortium’s work is to provide landscape to watershed scale “visions” of the future based on sound science conducted to aid decision makers in defining the potential future results of environmental management decisions. These “alternative futures” will offer decision makers choices and probable outcomes that are meaningful from an environmental and economic perspective. Our proposed work will fit readily within this interdisciplinary context and will focus on off-channel riparian habitats and the effects management decisions could have on their overall number and functional attributes.

EPA is also interested in this research because of the potential for transferring information gained on the Willamette River case study area to other large river systems in the United States. Little is known about off-channel habitats and other major rivers have experienced the same or greater levels of historic anthropogenic disturbance. While the specific results are likely to not be directly transferable, the approach and advances in the Willamette River research will contribute to the overall understanding of their functions in large rivers.

**Overall goals of the proposed research**

The overall goals of this project are to evaluate the functions of alcoves and side channels in a large river ecosystem, determine factors that currently affect their ecological functions, and identify future management options to improve these functions.

We intend to relate the processes occurring within alcoves and side channels to processes occurring in the main channel, in adjacent groundwater, in the aquatic and terrestrial vegetation, and the fish community. Ecological processes will be investigated at a variety of spatial and temporal scales.

**Strategy of the proposed research**

The strategy of the proposed research is to examine the physical, chemical, and biological processes associated with off-channel features of the Willamette River at temporal scales that vary from one day to decades and at spatial scales that vary from a single off-channel feature to the entire river system for a 207-km-long study area (Figure 2) that extends from the Yamhill River confluence to the city of Eugene. By including a wide range of temporal and spatial scales we will not only evaluate discrete processes but also provide a context in which to link these processes to the river
system in time and space.

The proposed research will take place during a 3-year period. Building upon insights gained during our 1996 pilot study, we will use the first year to evaluate ecological processes and fish communities in alcoves and the main channel upstream of Albany (the halfway point in the study area) and the main channel throughout the study area. In the second year we will broaden our investigations to include side channels. During the third year we will center our efforts on understanding landscape level processes for off-channel features and the main channel throughout the study area. A key element of this work will be to integrate our investigation of off-channel habitats into the analysis of alternative futures being developed with the Pacific Northwest Ecosystem Management Research Consortium (Gregory et al. 1996).

The first two years will focus solely on summer conditions, while the third year will also include evaluations of the seasonal differences in fish use within off-channel features and the main channel. We have put an emphasis on summer fish community structure because we feel that this is the time of year that stresses to many fish are highest. During these low flow periods small fish have the least access to areas outside the main channel to avoid predation and find refuge from fast water. Also, it is the time of year when water temperature and dissolved oxygen limitations are likely to occur. In addition, habitat volume is smallest during the summer.

The project is an inter-disciplinary effort that will meld the fields of hydrology, limnology, fisheries, water chemistry, and landscape ecology. The various components of the project, as outlined in this proposal are:

1. Fish use of alcoves and side channels
2. Physical and chemical properties of water
3. Subsurface water interactions
4. Terrestrial vegetation
5. Aquatic macrophytes
6. Geomorphology of off-channel features
7. Integration and modeling

Each of these components address a number of key processes that we feel are important for understanding the overall functions of off-channel features and of the river ecosystem. These processes include:

- Nutrient cycling among subsurface water, surface water, sediment, aquatic plants, terrestrial vegetation, and animals.

- Carbon cycling among subsurface water, surface water, sediment, aquatic plants, terrestrial vegetation and animals.

- Oxygen production in water due to photosynthesis and oxygen consumption in water due to respiration and chemical reduction processes.

- Sediment scouring and deposition during high flows and the sorting of substrate by size.

- Subsurface flux of water, whether it be groundwater originating from adjacent land or hyporheic river flow.
- Biomass production, including algae, macrophytes, terrestrial vegetation, fish, and other animals.

- Shelter creation or maintenance for a variety of organisms.

The matrix below (Table 2) shows the suspected strength of the relationships between research components of the project and the major ecological processes occurring in and near off-channel features. This list is not exhaustive but illustrative of how project components link with these processes and with each other.

Table 2. Relationships Between Research Components and Ecological Processes that Occur in Off-Channel Features.

<table>
<thead>
<tr>
<th></th>
<th>Nutrient cycling</th>
<th>Carbon supply &amp; processing</th>
<th>Oxygen flux</th>
<th>Sediment flux</th>
<th>Groundwater flux</th>
<th>Biomass production</th>
<th>Shelter</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Fish</td>
<td>○</td>
<td>○</td>
<td>●</td>
<td>○</td>
<td>○</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>2. Water quality</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>3. Subsurface interactions</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>4. Terrestrial vegetation</td>
<td>●</td>
<td>○</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>5. Aquatic macrophytes</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>○</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>6. Geomorphology</td>
<td>○</td>
<td>○</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>○</td>
</tr>
<tr>
<td>7. Modeling</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
</tbody>
</table>

- Major relationship
○ Minor relationship
Pilot Study

Previous studies on the Willamette River and other large rivers provided us little insight about water quality, fish habitat, and ecological processes within off-channel features. Therefore, we conducted a pilot study in 1996 to give us a basic understanding of the physical and chemical processes that occur within alcoves and the main channel of the Willamette River. Knowledge of these characteristics helped us to infer ecological processes and identify topics for further study. The pilot study also provided an opportunity to identify physical or chemical characteristics that are good indicators of various ecological processes.

During this pilot study we focused on spatial and diurnal variation in water chemistry and physical characteristics within alcoves and the main channel during the summer. We wanted to gain insight into the characteristics and sources of water within alcoves, how nutrients were cycled, and how these processes influenced fish habitat. We sampled alcoves along a 53-hm-long reach of the upper Willamette River and evaluated differences among alcoves as well as differences between alcoves and main channel. For several alcoves we conducted detailed investigations of spatial variation in temperature and dissolved oxygen. We also examined maximum water temperature in the main channel. Finally, we conducted limited investigations of fish use within alcoves.

Pilot study design

We selected 15 alcoves from a population of over 30 alcoves located between Corvallis and Eugene (80 km) and measured water quality and physical features within each alcove and in the adjacent main channel. Alcove selection was based on an initial survey of all potential sites. We then excluded alcoves that were less than 1 m deep, greater than 600 m long, greater than 40 m wide, or those that had obstacles at their confluence with the main channel which would prevent anchoring of the research boat. From the remaining alcoves we selected 15 that seemed to represent the range of conditions with respect to morphology, size, riparian vegetation, water clarity, and longitudinal position within study area.

Sampling was done both early in the morning when photosynthesis of aquatic plants was low and in the afternoon of the same day when photosynthesis was high. Sampling occurred during warm sunny days in late August and early September. Dissolved oxygen and water temperature were measured at three depths for upstream, midway, and downstream locations within alcoves. In addition, conductivity was measured at mid-depth for each of the three locations. Water samples were collected at mid-depth for each of the three locations and analyzed in the laboratory for pH, dissolved organic carbon, total organic carbon, total phosphorus, soluble reactive phosphorus, ammonium, nitrate, and TKN. All of the water quality parameters mentioned above were also measured for the main channel in well-mixed sections next to the alcoves.

For four alcoves we measured detailed longitudinal profiles of water temperature and dissolved oxygen at mid-depth and made comparisons with the main channel. Seeps at the upstream ends of alcoves were also included.

We also set out 18 recording thermistors in the main river channel from the Yamhill River to Eugene (207 km) in order to determine temperature fluctuations during a summer hot spell.
Finally, we electrofished and snorkeled several alcoves and made qualitative observations of fish in alcoves throughout the summer.

**Pilot study results**

**Physical and chemical characteristics of water**

The alcoves we sampled varied from 90 to 500 m long. The water depth within an alcove often varied along its length. All alcoves had sections that were at least 1 m deep and the maximum depth never exceeded 3 m. Some alcoves were deepest at the downstream end while for others water was deepest in the middle.

Dissolved oxygen levels in the main channel were uniformly high throughout the study area. Morning levels were lower than afternoon levels but did not fall below 90 percent saturation at any time. Afternoon levels were as high as 130 percent saturation, probably a reflection of ample aeration within riffles and oxygen production by periphyton attached to the river substrate (Rickert et al. 1977).

Dissolved oxygen within alcoves was usually less than the main channel and often dramatically less at the upstream ends of alcoves. Differences in dissolved oxygen between alcoves and the main channel were most pronounced in the morning. Morning dissolved oxygen levels in the upper ends of alcoves (measured 30 cm from the bottom) varied from 12 to 86 percent saturation. Variability among alcoves was not correlated to physical features such as alcove length, width, depth, or distance from the main channel. Dissolved oxygen levels at downstream ends of alcoves were often similar to levels in the main channel (Figure 6).

The abundance of aquatic plants in alcoves did not seem to have a consistent effect on dissolved oxygen. During afternoon field sampling we came across situations where movement of the dissolved oxygen probe nearer to a concentration of aquatic plants resulted in a large increase in dissolved oxygen. Yet, variation in dissolved oxygen was not significantly different among aquatic plant density classes assigned to alcoves (Figure 7). The measure of plant density was simply a visual estimate and may not have consistently reflected actual plant density. Alternatively, the influence of aquatic plants may have been muted by other processes.

Water temperatures within alcoves varied widely, with some alcoves being warmer than the main channel and others being cooler (Figure 8). Differences that existed in the morning were usually similar in the afternoon. Water temperature always increased between morning and afternoon. Afternoon water temperature levels in the upper ends of alcoves (measured 30 cm from the bottom) varied from 13 to 19°C. Variability in temperature among alcoves could not be explained by any of the alcove physical features we measured.

The data indicated an important relationship between dissolved oxygen, water temperature, and pH within alcoves. Dissolved oxygen, expressed as percent saturation, decreased with decreasing water temperature (Figure 9). Alcoves with low temperature and low dissolved oxygen also tended to have low pH. Disturbance frequency seemed to influence dissolved oxygen and water temperature within alcoves, especially at the upper ends. Alcoves were considered to have a frequent disturbance history if land between the alcove and main channel was mostly void of permanent vegetation. Infrequently disturbed alcoves were those that supported permanent vegetation. Frequently disturbed alcoves
Figure 6. Dissolved oxygen in the main channel and three locations within alcoves for afternoon and early morning sampling periods.
Figure 7. Afternoon dissolved oxygen at the upstream end of alcoves for three classes of aquatic plant density. Aquatic plant density is a visible estimate of the volume of the water column within a 10-meter radius of the sampling point that is occupied by aquatic plants.
Figure 8. Water temperature in the main channel and three locations within alcoves for afternoon and early morning sampling periods.
Figure 9. Relationships between dissolved oxygen, water temperature, pH, nitrate, and conductivity for water at upstream end of alcoves in the morning. Values for the main channel adjacent to each alcove are also shown. We defined cool alcoves are those that had a morning water temperature of 16 deg C or less.
tended to have lower combinations of dissolved oxygen and water temperature than most alcoves bordered by older vegetation (Figure 10).

Alcoves that had cool water (< 16 deg C), lower dissolved oxygen, and lower pH also tended to have high nitrate levels and some had unusually high conductivity readings (Figure 9). We suspect that these alcoves are influenced more by terrestrial groundwater from adjacent farm land than are other alcoves. Alcoves probably also intercept some hyporheic river flow which may be warmer and higher in dissolved oxygen, and higher pH than terrestrial groundwater. The chemistry and nutrient characteristics of an alcove are probably influenced by the proportion of terrestrial groundwater to hyporheic river flow as well as overall subsurface water flux.

Nitrate concentrations were usually higher in alcoves than the main channel. In contrast, soluble reactive phosphorus concentrations were usually lower in alcoves than the main channel. We speculate that this may indicate that primary productivity is limited by the amount of phosphorus in alcoves and by the amount of nitrogen in the main channel.

Our 80-km study area encompassed only one point waste discharge, which was the shared outfall for two pulp mills at river mile 147. We sampled the main channel at six locations (in the early morning on September 10) immediately upstream and downstream of the outfall and found no significant decrease in dissolved oxygen downstream of the outfall. Neither did pH nor nutrient concentrations change appreciably. Furthermore, dissolved organic carbon concentrations were similar upstream and downstream of the outfall (Figure 11). The only significant change in water characteristics downstream of the outfall we measured was an increase in conductivity. The volume of effluent discharge is about 15 million gallons per day, which was about 0.3 % of the river’s flow at the time of sampling.

Dissolved organic carbon concentrations were relatively low in both alcoves and the main channel. Values averaged about 1 mg/l and rarely exceeded 2.5 mg/l (Figure 12). Differences between the main channel and alcoves showed no pattern and were seemingly unrelated to any of the physical, biological, or chemical parameters we measured in this study.

**Detailed temperature and dissolved oxygen measurements**

The detailed investigations of water temperature and dissolved oxygen within several alcoves revealed some interesting information on subsurface flow processes and lead us to develop a conceptual model of subsurface flow. In the example illustrated in Figure 13, water flowing through coarse gravels near the upstream end was not cool but did exhibit a decrease in dissolved oxygen. Throughout the length of the alcove the dissolved oxygen remained 3 to 4 mg/l less than the main channel, suggesting an influx of hyporheic water into the alcove along the gravel bar or of terrestrial groundwater. The alcove had very little algae or macrophytes and did not show appreciable increases in dissolved oxygen during the afternoon, so biological oxygen demand was probably not the cause of the depressed morning dissolved oxygen values.

**Maximum water temperature in the main channel**

Maximum water temperature in the main channel increased only slightly in the downstream direction for the first 45 km downstream of Eugene (Figure 14). The temperature increased rapidly and then
Figure 10. Morning dissolved oxygen and water temperature measurements for frequently disturbed and infrequently disturbed alcoves. Frequently disturbed alcoves are alcoves not bordered by permanent vegetation.
Figure 11. Concentrations of dissolved oxygen, dissolved organic carbon, and nutrients upstream and downstream of outfall for pulp mills.
Figure 12. Dissolved organic carbon in the main channel and three locations within alcoves for afternoon and early morning sampling periods.
Figure 13. Detailed dissolved oxygen and water temperature measurements within an alcove without permanent vegetation. Right bank of alcove has been riprapped.
Figure 14. Maximum and minimum water temperature for the main channel during a hot spell in August.
plateaued over the next 70 km. This was followed by a general rise in temperature for the remainder of the study area. During the early summer, fishermen angle for cutthroat trout mainly upstream of Peoria. They catch few cutthroat trout downstream of Peoria. Interestingly, this corresponds to where the main channel experiences a rapid increase in temperature. The disease, *Ceratomyxa shasta*, in tandem with higher water temperature, may limit the distribution of trout during the summer. Other native fish such as chinook salmon and whitefish may also find thermal and disease barriers in the main channel.

**Fish use**

We electrofished or snorkelled only a few alcoves in 1997 but we had a good opportunity to observe fish during water quality sampling. This provided us with qualitative information on fish communities in alcoves. Fish were absent or sparse in alcoves or portions of alcoves with low dissolved oxygen (about 5 mg/l or less) or where no cover features existed. Cover features that attracted large numbers of fish included accumulations of woody debris, dense beds of aquatic plants, and riprapped banks within alcoves. Fish observed within alcoves were generally young native fish. Large fish seen in alcoves were often the introduced largemouth bass and carp or the native squawfish and largescale sucker.

The rootwads of toppled cottonwoods seemed to attract some of the largest concentrations of fish, particularly where those logs were stranded at the downstream end of alcoves and near the eddy line separating the alcove and main channel. Presumably, fish are attracted to this eddy line by the proximity of low-velocity water in the alcove and food moving downstream in the main channel. The crevasses found within rootwads may provide the young fish critical refuge from predators.

**Pilot study conclusions and key questions**

The pilot study provided us a fundamental understanding of key indicators should be useful for interpreting ecological processes within alcoves. Furthermore, it provided information on the variability of these processes at several spacial scales.

Results of this pilot study reveal that alcoves can have distinct physical and chemical water characteristics. If water in the upstream end of an alcove is unusually cool then it also usually has low dissolved oxygen, low pH, and often high nitrate concentration (and occasionally high conductivity). These indicators suggest that influential amounts of terrestrial groundwater may be entering the alcove. The water quality within some alcoves and sluggish side channels may be indicative of the chemistry of terrestrial groundwater entering a river throughout much of its length and provide a useful tool for understanding longitudinal changes in main channel water chemistry that relate to land use practices, particularly agricultural. Only one point discharge occurs between Eugene and Corvallis and it did not result in significant increases in main channel nitrate and phosphorus. Neither did it cause a decline in morning dissolved oxygen concentrations.

Pilot study results also suggest that alcoves which are frequently disturbed are different than alcoves that are infrequently disturbed. Frequently-disturbed alcoves may be bounded by substrates that are more permeable than infrequently-disturbed alcoves, thereby allowing a higher rate of groundwater or hyporheic flow into the alcove.
Through subjective observations made during the summer we noticed that fish seem to avoid alcoves or portions of alcoves with low dissolved oxygen (i.e. < 4 mg/l), in spite of the thermal refuge they could provide. During the day, some alcoves are used by young fish but mostly around cover features. Predation by larger native and exotic fish, blue herons, and osprey probably make cover an important habitat element for fish in the summer.

Key questions that arose from the pilot study include:

- What are the sources and relative contributions of subsurface water entering alcoves of various types?

- How does terrestrial groundwater from surrounding farm fields differ from hyporheic river flow?

- How does geomorphic setting influence water quality characteristics in alcoves and the main channel?

- How do physical and chemical characteristics of water and structural features in alcoves relate to fish utilization?

- To what degree do cover features influence the abundance and community structure of fish in alcoves?

- Is there a preferential use of off-channel features by exotic fish and does this represent a significant threat to small native fish that use alcoves?

- What is the origin of large woody debris and the processes that account for large woody debris in alcoves?

- What is the role of adjacent streamside vegetation for supplying both large woody debris and other allochthonous carbon that can be used by aquatic organisms?
Proposed Research

In this proposal we outline research to evaluate ecological processes associated with off-channel features and the interactions of these processes with the main channel of the Willamette river. This research is intended to demonstrate how development of such scientific understanding can lead to sound management of off-channel habitat and the river ecosystem. The proposed research plan is organized into seven integrated components, as described below:

1.) Fish use of alcoves and side channels. In this component we present a strategy for evaluating the structure of fish communities. While fish are not the only aquatic animals that use alcoves and side channels they are sensitive to changes in water quality and physical structure. In addition, fish are highly mobile and therefore respond rapidly to changes in habitat condition. Furthermore, society assigns a relatively high value to fish. For these reasons, we selected the composition of fish communities as a key indicator of habitat condition.

2.) Physical and chemical properties of surface water. In this component we propose to evaluate water quality in off-channel features for the purpose of determining potential effects on fish, the interactions between groundwater sources and surface water, and comparison with main channel water quality.

3.) Subsurface water interactions. In this component we outline research to examine subsurface water movement into and out of alcoves as geomorphic settings vary. Included, are investigations into the subsurface transport and processing of nutrients by both terrestrial groundwater and hyporheic river flow.

4.) Terrestrial vegetation. In this component we propose research to develop techniques for efficient gathering of information on riparian vegetation growing near off-channel features and demonstrate how this information can be used evaluate the influence of riparian vegetation on ecological processes within alcoves.

5.) Aquatic macrophytes. In this component we propose to quantify the type and extent of macrophytes growing within alcoves and side channel and evaluate the influence of aquatic vegetation on water quality and habitat quality. We will also evaluate physical and chemical attributes of alcoves to determine what alcove features (depth, nutrients, light, etc.) are correlated with various macrophyte characteristics and abundance.

6.) Geomorphology of off-channel features. We propose to evaluate how and why off-channel features change over time, particularly after unusually high seasonal flows. We also outline a method for combining this information with historic records to better understand how the geometry of the river has been altered over the last century. The historic abundance and characteristics of off-channel features can provide a context for understanding how overall river fish habitat and water quality were once influenced by off-channel features.

7.) Finally, in the seventh component, integration and modeling, we propose a strategy for combining and linking information developed within the other six components and generate an integrated understanding of physical, chemical, and biological processes associated with off-channel features and the main channel. Additionally, we outline a method for developing a model of off-
channel feature processes so we can evaluate and illustrate the probable outcomes of various alternative future management scenarios.

**Integration of project components**

We view the integration of the seven project elements as an essential component of this project and a key measure of overall research success. Project integration will be by achieved, in part, by:

- *Location overlap.* Project components will be conducted at the same sites or reaches as much as possible with significant overlap in the time or season of sampling.

- *Product hand-offs.* Data or information from one project component will be received and used by other components. Sequencing of these transfers of information will be timed to promote project success.

- *Joint synthesis and publication.* Research papers will often be authored by multiple scientists representing different disciplines, providing an interdisciplinary viewpoint of ecological processes.

- *Synthesis.* Products of each component were designed to create a broad, interdisciplinary understanding of issues across temporal and spatial dimensions. Overall conceptual and functional models will be constructed to formalize the relationships established by the research.

While we have identified seven discrete components within the Off-Channel Habitat Research Project, there is considerable overlap between them and clear linkages. Moreover, there are linkages among the components with respect to the discrete ecological processes we will be studying. The relationships among the components and the processes to which they relate are represented in the conceptual model illustrated in Figure 15.

**Study area**

The study area is a 207-km-long reach of the Willamette River between the Yamhill River and Eugene (Figure 2). The upper half of the study area has a higher gradient (0.07%) than the lower half (0.03%) and the channel is less constrained by topographic and man-made features. As a result, off-channel features are more common in this upstream half. Discharges from sewer treatment plants and industrial sources are more common in the downstream half.

Cutthroat trout, a favored sport fish in the Willamette River, commonly does not occur in the downstream half of the study area during the summer. The disease, *Ceratomyxa shasta*, has been implicated as the reason trout are not able to occupy these areas during warmer months. The water is warmer and freshwater mussels (a suspected alternate host for the disease) are more numerous in the downstream half, thereby making the disease more of a problem for trout (ODFW, personal communication). The introduced largemouth bass occurs throughout the study area but is believed to be more numerous in downstream areas due to the warmer water.

Much of the Willamette River in the study area is bordered by agricultural fields. Commonly, a narrow band of cottonwood trees or other riparian vegetation separates the fields from the river. In
Figure 15. Conceptual view of cycles and fluxes associated with the ecological processes occurring in an alcove. Arrows show the flux.
some places the river channel has meandered towards adjacent fields, eroding away the strip of riparian vegetation, thereby positioning farm fields at the very edge of the river. Patches of riparian forest occur in flood-prone areas, on steep banks, or on land owned by the State. Gravel extraction operations are common in the riparian zones of the study area but, today, most gravel is mined from pits set back from the main channel. Only two commercial bar scalping operations occur within the study area.

The banks of the Willamette River are lined by many miles of revetment and levies (Figure 16). The channelization of the Willamette River began over a hundred years ago, starting with the creation of a channel deep enough to allow steamboat traffic. More channelization occurred in the following decades as banks were armored to prevent the river from meandering across farm fields and urban areas. The siting of homes along the river has increased recently, especially near Salem. The river banks at many of these sites have been riprapped to prevent the river from undermining the homes.

**Temporal and spatial scales**

Objectives will be pursued at a variety of temporal and spatial scales within each project component. For example, in the first year water quality will be studied in detail at 3 alcoves. These alcoves are a subset of 16 alcoves that occur throughout the upper half of the study area which will be evaluated using methods that are less detailed. The combination of detailed measurements at a few sites and coarser measurements at many sites can provide an economical way of understanding processes within alcoves and variability across the landscape. Sampling frequency and location for summer 1997 field work is shown in Table 5.

The temporal scales associated with the proposed research varies from a point in time to changes spanning decades. Initial stages of the study will focus on changes throughout the summer while later stages will incorporate changes from season to season. The temporal and spatial scales incorporated into the research project are illustrated in Figure 17. For specific temporal and spatial scales associated with tasks proposed in each component refer to Tables 6 to 12 near the end of this document.
Figure 16. Map of revetments along the Willamette River from Albany to Eugene. Revetments are usually rock riprap along the bank on the outside of curves. Map produced by Patricia Benner, Corvallis, Oregon.
Figure 17. The continuum of temporal and spatial scales addressed in the proposed research project. See Tables 5 to 11 for specific scales associated with each research component.
Table 3. 1997 Sampling Design for the Various Project Components

<table>
<thead>
<tr>
<th>Component</th>
<th>Sampling Frequency for Summer 1997</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Intensive Investigation of Two Natural Alcoves and One Constructed Alcove</td>
</tr>
<tr>
<td>1. Fish Communities</td>
<td>monthly (3 times)</td>
</tr>
<tr>
<td>2. Water Quality</td>
<td>monthly (3 times)*</td>
</tr>
<tr>
<td>3. Groundwater</td>
<td>bi-weekly/monthly (6 times/3 times)</td>
</tr>
<tr>
<td>4. Terrestrial Vegetation</td>
<td>monthly</td>
</tr>
<tr>
<td>5. Aquatic Vegetation</td>
<td>once</td>
</tr>
<tr>
<td>6. Geomorphology</td>
<td>once</td>
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</tbody>
</table>

* Water sampling of intensively studied alcoves will coincide with sampling of the main channel

**Research Components**

1. **Fish use of alcoves and side channels**

**Objective:** To understand the importance of alcoves and side channels in supporting fish communities that inhabit large rivers such as the Willamette, evaluate key ecological processes that influence fish habitat, and determine whether or not manipulations of the river to increase the abundance or improve the condition of these off-channel features would benefit native fish.

The Willamette River within the study area is known to support over 30 species of fish, two-thirds of which are native (Hughes and Gammon 1987). This assemblage of fish is unusually diverse compared to other rivers in the Pacific Northwest. The relatively large number of species in the Willamette River provides a unique opportunity to evaluate subtle variations in habitat conditions. Habitat preference by a given species of fish can be a complex integration of water temperature, dissolved oxygen, depth, velocity, water clarity, food supply, disease, and predation pressure. Fish may respond to combinations of these variables in unique ways at different life stages. Therefore,
the structure of the fish community can potentially reveal much about physical and ecological conditions in a certain area (Karr 1981, Fausch et al. 1990).

We learned from the pilot study that alcoves are used by fish of a variety of ages, but particularly by young fish. We hypothesize that alcoves are important areas for young fish to feed and escape fast water. We also surmise that young fish in alcoves are subject to predation by large fish from the main channel, particularly where little cover exists. Predation pressure may vary between day and night. Nighttime sampling by the Oregon Department of Fish and Wildlife suggests that large predator fish can be more numerous during the night than the day in alcoves and side channels (personal communication). The introduction of largemouth bass and other exotic fish to the Willamette River has probably intensified predation pressures within off-channel features.

Because many species of fish and a variety of age classes can occupy an alcove or side channel it is important to have fish sampling techniques that minimize differential selection due to size or species. Our experience during the pilot study suggested that standard electrofishing techniques from a boat may not be adequate to deal with selectivity issues. As would be expected, larger fish were more affected by the electrical field than small fish. Species such as largescale suckers were more susceptible to electrofishing than species such as sculpins. Furthermore, some species such as largemouth bass and carp were easily spooked by the boat and were seldom within reach of the electrical field. Therefore, an essential element of this research component is to develop methods for fish sampling that reduce such bias, or alternatively, quantify the bias. In the first year we will experiment with manipulations of block nets to evaluate catch efficiencies across species and size classes within alcoves, both during the day and night. In the following year we will refine our techniques so that we can also evaluate fish communities within slow side channels. In the third year we will modify our fish detection methods again so that we can quantify seasonal use of alcoves and side channels by fish.

We observed dense schools of young-of-the-year fish in alcoves during early summer, 1996. We suspect that many were spawned in the alcoves, although our observations were not detailed enough to detect eggs attached to physical features or deposited on or within alcove substrate. We have decided to not sample early summer young-of-the-year fish in this project but to focus on fish that comprise the late summer community. We reasoned that very young fish populations reflect mostly spawning success and are not particularly sensitive indicators of rearing conditions. The community structure of older fish better reflects food supply, predation pressure, and physical habitat availability. Our fish sampling methods will be designed to capture fish that are about 80 mm and larger. This means that minimum ages for late-summer catches will include young-of-the-year for some species and one-year-old and older fish for nearly all species.

Observations from 1996 indicated that cover features such as woody debris, aquatic plants, and low overhanging vegetation greatly influence the number and diversity of fish within alcoves. Also, we noted that the position of these cover features within an alcove influenced the fish community. Cover features seemed to be used more by fish at the downstream end of alcoves and where dissolved oxygen levels were not depressed. In 1997 and 1998 we will explore the hypothesis that fish communities within alcoves are influenced mostly by the amount and type of cover, position within the alcove, and water quality.

In Year 2 we will evaluate both side channels and alcoves and sample during the night as well as the
day. Results from Year 1 will guide us in how we should account for cover features, position, and water quality. Movement of large predatory fish will be indirectly assessed during Year 2 by tagging large predatory fish caught during the first sampling (either nighttime or daytime) and recording the number of tagged and untagged fish caught during a second sampling of that site, occurring 36 hours later.

In Year 3 we will take on the much more difficult task of evaluating fish communities in alcoves and side channels throughout the year. We hypothesize that fish community structure changes dramatically with the seasons and as river levels rise and fall. Because of problems electrofishing in deep water, our sampling techniques may be supplemented by radio tracking of individual fish. Since radio tracking large numbers of fish is not feasible we may choose to focus our investigations on only selected species and size classes of fish.

Certain gravel extraction companies who operate along the upper Willamette River have expressed interest in working with us to evaluate alcoves and side channels that have been constructed or manipulated to improve fish habitat. In Year 1 they will construct an alcove at the downstream end of a gravel bar located immediately upstream of Corvallis. We intend to approach this as an experimental manipulation. Over the course of the summer we will evaluate daytime fish use after it is constructed, after woody debris has been added to the alcove, and again after the woody debris has been removed. In Years 2 and 3 we will continue to evaluate fish use in this alcove as well as several other manipulated alcoves or side channels to evaluate annual variability. Two other alcoves that will be intensively monitored for groundwater movement and water quality will also be sampled for fish at monthly intervals throughout the summer.

We have not included plans to sample fish communities in the main channel, mostly because we could not come up with non-destructive methods that we felt were not differentially selective for the size and species of fish. Block nets are impractical in the swift waters of the main channel and we have already learned that boat electroshocking while drifting with the current selects for larger fish and for vulnerable fish such as largescale suckers. Furthermore, catch efficiency is highly dependent on water depth. Quantifying this bias in large rivers can be very difficult. Annual seining of selected pools in the main channel by the Oregon Department of Fish and Wildlife will provide us some information for comparison. Other information may be available from the National Council on Air and Stream Improvement, who is planning to establish long-term fish community monitoring in the main channel of the Willamette River starting in 1997.

Objectives

1. Develop methods for sampling fish communities in alcoves (summer, during the day and night) that are effective even where cover features such as woody debris, aquatic plants, and low overhanging vegetation are present. Year 1

2. Evaluate daytime and nighttime fish communities within alcoves during the summer. Determine to what degree water quality and cover features such as woody debris, aquatic plants, and low overhanging vegetation influence fish community composition. Year 1

3. Evaluate fish community variation throughout the summer for a constructed alcove (with and without woody debris) and for two other intensively monitored alcoves. Year 1
4. Develop methods for sampling fish communities in slower moving side channels during the summer. *Year 2*

5. Evaluate both daytime and nighttime fish communities within alcoves and side channels during the summer and relate to water quality and physical features. Investigate predator and prey interactions between large fish that migrate back and forth between the main channel and off-channel features and smaller fish that normally occupy only off-channel features. *Year 2*

6. Evaluate diurnal fish use within a few constructed or enhanced alcoves and side channels during the summer and relate to water quality and physical features. Investigate predator and prey interactions between main channel fish and off-channel fish. *Year 2.*

7. Develop daytime and nighttime methods for sampling fish communities in alcoves and side channels that allow comparisons among seasons. *Year 3*

8. Evaluate fish communities within alcoves and side channels for various seasons and relate to water quality and physical features. Determine how fish disperse among main channel, alcoves, side channels, and flood plains during high flows. *Year 3*

9. Evaluate diurnal fish use within a few constructed or enhanced alcoves and side channels for various seasons and relate to water quality and physical features. *Year 3*

**Design**

1. Early in the summer, electrofishing and block net techniques will be developed to minimize and quantify catch bias among size classes and species of fish inhabiting discrete cover features within alcoves. Maximum depths that limit the use of electrofishing gear will be determined and techniques developed to extract fish from cover features such as log jams, aquatic plants, and low overhanging vegetation. We intend to evaluate electrofishing efficiency rates by selecting six alcove reaches, each 91 m in length, and sample during four sessions. The six alcoves will be chosen at random among a population of about 60 alcoves. Sessions for a single alcove will be at weekly intervals and include the following:

   1. Daytime electrofishing with no interior nets around cover features
   2. Nighttime electrofishing with no interior nets around cover features
   3. Daytime electrofishing with interior nets around cover features
   4. Nighttime electrofishing with interior nets around cover features

   A session will consist of sampling the reaches 3 times (passes) within a 7-hour period. This includes the time to install and remove nets and waiting periods between passes. Fish caught during a pass will receive a unique tag or clip that will be noted if caught on subsequent passes. *Year 1.*

2. Starting in July, a constructed alcove immediately upstream of Corvallis will be electrofished several weeks after it is excavated. Large woody debris will be added to the alcove and sampled again after several weeks. Finally, the large woody debris will be removed from the alcove and it will be sampled after another several weeks. Weekly qualitative observations (snorkeling or from a kayak) will help us determine when fish communities have stabilized following the latest disturbance.
Periodic sampling of fish communities (about monthly) will also occur within two natural alcoves that also will be intensively monitored for water quality and groundwater movement.  *Year 1*

3. Early in the summer, various electrofishing and block net techniques will be developed to evaluate catch efficiencies for various size classes and species of fish inhabiting discrete habitat features within side channels.  *Year 2*

4. During August, 30 slow moving side channels located between Albany and Eugene will be electrofished once during the day and once during the night.  Sites will be distributed according to information gained during sampling in the first year.  The second sampling will occur at the same location as where first sampling took place and will be separated by 36 hours to allow fish time to recover from the disturbance.  The order of sampling, daytime or nighttime, for each site will be randomly chosen.  Predator and prey interactions will be investigated for fish that move between the alcove area and elsewhere by tagging predator fish caught during the first sample period and comparing with the tagged and untagged predator fish caught during the second sample period.  *Year 2*

5. Diurnal fish use within several constructed or enhanced alcoves and side channels will be evaluated during the summer.  Electrofishing will occur during the day and during the night, both before and after the construction or enhancement activity.  Several weeks will separate sampling periods to allow for equilibration of the fish community following the manipulation.  The order of sampling, daytime or nighttime, for each site will be randomly chosen.  Predator and prey interactions will be investigated for fish that move between the alcove area and elsewhere by tagging predator fish caught during the first sample period and comparing with the tagged and untagged predator fish caught during the second sample period.  *Year 2*

6. Daytime fish sampling methods will be developed that allow comparisons among seasons, including periods of higher water.  *Year 3*

7. Fish communities within alcoves and side channels will be evaluated during the day for various seasons.  Fish dispersion among main channel, alcoves, side channels, and flood plains will be evaluated during high flows using a combination of electrofishing techniques and radio tracking of individual fish.  *Year 3*

**Metrics (Year 1)**

The fork length of each captured fish will be measured and species identified.  Clipped fins or punch marks indicating capture during a previous pass will also be noted.  Deformities such as scars, thick mucous, and missing body parts will be described when they occur.

For each of the four sampling sessions that will occur at an alcove over the course of a month, the following metrics will be determined.  When interior nets are present, metrics will be determined individually for within interior nets and outside interior nets.

- Total number and biomass of fish per unit area by size class (small = greater than 2.4 inches (60 mm) but less than 11.8 inches (300 mm); large = 11.8 inches (300 mm) or greater).

- Number and biomass of introduced fish (by size class) per unit area.
• Number of biomass of native fish (by size class) per unit area.

• Number and biomass of large 11.8 inches (>300 mm) predator fish per unit area (includes squawfish, largemouth bass, and cutthroat trout).

• Number of native species represented.

• Number of introduced species represented.

• Percent abnormalities by size class for native fish and for introduced fish.

Electrofishing capture efficiencies will be calculated from the 3 passes that occurs during each sampling session. Capture efficiencies will be determined for the following four fish classes: 1) large native fish, 2) small native fish, 3) large introduced fish, and 4) small introduced fish. For each fish class an alcove will have 12 calculated capture efficiencies, as shown below:

<table>
<thead>
<tr>
<th>Sampling session</th>
<th>Interior Nets in Place</th>
<th>No Interior Nets</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Inside Interior Nets</td>
<td>Outside Interior Nets</td>
</tr>
<tr>
<td>Daytime sampling, no interior nets</td>
<td>E1</td>
<td>E2</td>
</tr>
<tr>
<td>Nighttime sampling, no interior nets</td>
<td>E4</td>
<td>E5</td>
</tr>
<tr>
<td>Daytime sampling, with interior nets</td>
<td>E7</td>
<td>E8</td>
</tr>
<tr>
<td>Nighttime sampling, with interior nets</td>
<td>E10</td>
<td>E11</td>
</tr>
</tbody>
</table>

Analysis (Year 1)

The metrics described above will be used to evaluate whether or not sampling with interior nets set up around individual cover features in a 91 m reach of alcove influences capture efficiency and whether this differs between day and night.

An analysis of variance of capture efficiencies will include the following covariates and effects, with the alcove reaches serving as blocks:

Covariates
  • Water temperature
  • Dissolved oxygen
  • Turbidity

Effects
Daytime / Nighttime
With interior nets / Without interior nets
Interaction between time and nets

We will determine whether or not the use of interior nets within alcove reaches results in a better characterization of the fish community by using the following criteria:

- Did the use of interior nets increase the number of species caught?
- Was the variability in efficiency rates among alcoves less when interior nets were used?
- Did the use of interior nets reduce the number of situations where calculated capture efficiencies were volatile due to small numbers of fish during recapture passes?

Upon applying capture efficiency rates to the catch data, we will conduct some preliminary analysis on how cover features influence fish communities within alcoves and whether or not fish communities vary between day and night. Using the following dependent variables derived for the 2 sampling sessions for which interior nets were used we will evaluate through analysis of variance the effects of cover features. Alcove reaches will serve as blocks in the analysis of variance.

Dependent variables in the analysis will be:

- Total number and biomass of fish per unit area by size class (small = greater than 2.4 inches (60 mm) but less than 11.8 inches (300 mm); large = 11.8 inches (300 mm) or greater).
- Number and biomass of introduced fish (by size class) per unit area.
- Number of biomass of native fish (by size class) per unit area.
- Number and biomass of large 11.8 inches (>300 mm) predator fish per unit area (includes squawfish, largemouth bass, and cutthroat trout).
- Number of native species represented.
- Number of introduced species represented.
- Percent abnormalities by size class for native fish and for introduced fish.
2. Physical and chemical properties of water

Objective: To understand key physical, chemical, and biological processes that influence water quality within alcoves and side channels of large rivers such as the Willamette and to relate these processes to those that occur within the main channel. In addition we seek to determine how various river management options would potentially affect water quality within off-channel features and the main channel.

Results from the 1996 pilot study indicated that the physical and chemical properties of water in alcoves often vary from that of water in the main channel. Combined values of low temperature, low dissolved oxygen, and low pH in some alcoves suggest the influence of terrestrial groundwater (White et al. 1990). High nitrate concentrations found in many alcoves provides additional evidence that alcoves intercept terrestrial groundwater. Intercepted hyporheic flow also seems to influence the physical and chemical properties of water of some alcoves but probably not in the same way as terrestrial groundwater. Finally, macrophyte communities seem to influence water quality in at least portions of alcoves.

Initially, we had hypothesized that fish would use the cool water found in some alcoves as thermal refuge during hot summer days, similar to what others have observed in some Pacific Northwest rivers (Matthews and Berg 1997; Nielsen et al. 1994). However, some of these cool pockets of water had very low dissolved oxygen levels and we seldom observed fish in the cool pools. The lack of fish use may also be related to the distance of this cool water from feeding areas (where it occurred, cool water was usually at the upstream end of an alcove) or the presence of warm water in downstream ends of alcoves that acted as a thermal barrier.

In Year 1 of this project we intend to further investigate the source of water entering alcoves of various types and determine how characteristics of this water influence ecological processes within alcoves. In addition to the suite of water quality parameters measured during the pilot study we will include dissolved inorganic carbon to better evaluate groundwater influences. Chlorophyll and turbidity will be added to provide information on primary productivity in alcoves.

Measurements on 16 alcoves out of a population of about 60 will occur each summer of the project. This will provide us with some information on year-to-year variability. During the pilot project we found that diurnal (early morning and late afternoon) sampling was probably not necessary to evaluate water quality in alcoves. We found the early morning sampling was less confounded by the effects of photosynthesis than was afternoon sampling and, hence, provided more information about water quality differences among alcoves. So, the 16 alcoves will be sampled only during the early morning.

Also in Year 1, we will evaluate in detail temporal and spatial variation in water quality at 3 of the 16 alcoves. These 3 alcoves are the sites where detailed groundwater investigations will take place, as described later. Detailed temporal and spatial measures of water quality will also take place as a constructed alcove immediately upstream of Corvallis.

In order to better understand longitudinal and temporal variability in main channel water quality, each year we will conduct three, two-day synoptic surveys of the entire 207-km study area. Sampling will be in the early morning and occur early summer, mid summer, and late summer. Information on main channel water quality variability will provide us a way to later evaluate the interactions between
off-channel features and the main channel. We learned during the pilot project that summer water quality in the main channel can vary significantly over a period of weeks, which might be related to changes in upstream reservoir releases, changes in weather, and algal senescence. This drives our need to complete a sampling of the entire study area within a 2-day period.

Objectives

1. During the summer, evaluate water quality and determine the source of groundwater flowing into 16 alcoves having a range of water quality and physical characteristics. *Years 1, 2, 3*

2. Investigate summer temporal and spatial variation in water quality within 3 alcoves for which detailed subsurface water studies are conducted. *Year 1, 2, 3*

3. Evaluate main channel water quality from the Yamhill River confluence to Eugene in early and late summer with particular emphasis on water quality changes downstream of point sources of pollution, major tributary junctions, and zones of river down welling. *Year 1, 2, 3*

4. Evaluate temporal and spatial variation in water quality for a constructed alcove with and without woody debris. *Year 1*

5. Evaluate summer water quality within the 16 alcoves and a yet undetermined number of side channels. *Year 2*

6. Evaluate detailed temporal and spatial variation in water quality for one or more constructed (or enhanced) alcoves and side channels. *Year 2*

7. Evaluate water quality within 16 alcoves and a set of side channels and where fish sampling will occur during various seasons in the third year. *Year 3*

8. Evaluate detailed temporal and spatial variation in water quality for one or more constructed (or enhanced) alcoves and side channels during various seasons. *Year 3*

Design

1. Early morning water quality will be measured in 16 alcoves representing a range of watery quality and physical characteristics. Sampling will occur mid-depth in the upstream end, midpoint, and downstream end of alcoves and in the adjacent main channel. *Years 1, 2, & 3*

2. Detailed measurements of water quality will be made within the 3 alcoves for which detailed subsurface water studies are being conducted. Measurements will be taken at regular intervals within the alcove both laterally and longitudinally, and at three depths. Measurements will be taken during both early morning and late afternoon at intervals of at least every two weeks from early July to late August. In addition, dye transport studies will be conducted to estimate the flow of water out of the alcove. *Years 1, 2, & 3*

3. A synoptic survey will be conducted of water quality in the main channel for a two-day period in late June, taking samples at about 40 locations between the Yamhill River confluence and Eugene.
Sampling will occur upstream and downstream of point sources of pollution, upstream and downstream of major tributaries, upstream and downstream of suspected zones of significant down welling, and at regular intervals elsewhere. Sampling will be in the early morning from 6:00 to 9:00 AM. This survey will be repeated for the same locations in late July and early September. All three of the sampling periods will occur following warm and sunny days. Sampling will progress in the downstream direction so that we can more or less be measuring the same mass of water as it moves downstream Years 1, 2, & 3.

4. Water quality will be measured in a constructed alcove immediately upstream of Corvallis upon completion and two weeks after excavation. Large woody debris will be added to the alcove and after two weeks water quality will be measured again. Finally, the large woody debris will be removed and water quality measured after another two weeks. Sampling will occur at the upstream end, midpoint, downstream end, and in the adjacent main channel. Year 1

5. Water quality will be measured in detail at one or more constructed (or enhanced) alcoves and side channels. Measurements will be taken several times during the summer and be timed to coincide with fish sampling. Year 2

6. Afternoon water quality will be measured seasonally where Year 3 fish sampling will occur. Year 3

8. Water quality will be measured in detail at one or more constructed (or enhanced) alcoves and side channels. Measurements will be taken several times each season and be timed to coincide with fish sampling. Year 3

Metrics

Alcove physical metrics will include water depth, width, length, and aquatic plant abundance. Water quality metrics will include water temperature, dissolved oxygen, conductivity, turbidity, pH, total suspended solids, nitrate, ammonium, total nitrogen, soluble reactive phosphorus, total dissolved phosphorus, dissolved organic carbon, dissolved inorganic carbon, and chlorophyll.

Analytical approach

Graphical methods, simple regressions, and ANOVA will be used test for significant relationships within and among the 16 alcoves. Water temperature and possibly alcove geomorphic parameters will be covariates and position (upstream, midway, and downstream) will be an effect. Values of dissolved oxygen, water temperature, and pH in terrestrial groundwater sampled from shallow wells and in river hyporheic flow will be used to calculate the relative contribution of each water source to alcoves. Graphical methods and shallow groundwater modeling will be used to evaluate detailed water quality measurements within 3 alcoves. Graphical techniques and trend analysis will be used to detect longitudinal changes in water quality parameters within the main channel. Residuals from trend analysis will be evaluated to test the significance of point discharges, major tributaries, and down welling zones on main channel water quality. Since early summer sampling and late summer sampling will occur at the same points, the significance of early/late summer effects will be tested by simply using a paired T-test.
3. Subsurface water interactions

Objective: To evaluate subsurface movement of water into and out of alcoves and understand how nutrient cycling, carbon cycling, oxygen status, water temperature, and productivity of various organisms within alcoves are influenced by this subsurface water.

The Willamette River lies within an alluvial valley that forms an extensive aquifer; water flows between the river and aquifer through a continuum of geohydrologic units in which water volume and residence time are primary features. The magnitude and direction of subsurface flow between the river and adjacent aquifer depend upon water level gradients and substrate depositional patterns that can vary from a local to a regional scale. Subsurface flow occurs in the direction of and at a rate proportional to hydraulic gradient and substrate hydraulic conductivity.

During the 1996 pilot study we discovered that water temperature, dissolved oxygen, pH, nitrate, and conductivity varied widely among alcoves, particularly at their upstream ends. We hypothesized that these differences were related, in part, to the magnitude and source of subsurface water entering an alcove. We surmised that most alcoves probably intercept some terrestrial groundwater and some hyporheic river flow, and that the magnitude of flow from each source varied among alcoves. Records from shallow wells near the river indicated that shallow aquifers have high nitrate and relatively low pH, so we suspect that the nature of terrestrial groundwater entering alcoves is different than that of hyporheic river flow.

Results of the pilot study indicated a loss of dissolved oxygen after river water went subsurface (see Figure 13 for an example). Other studies have shown that hyporheic river flow is also often cooler than the surface water and nutrient levels can differ. Hyporheic flow into a central Oregon stream caused reductions in stream temperature and provided thermal refugia for fish (Lowry, 1993). Groundwater diluted organic carbon in streams in New Hampshire (Fisher and Likens, 1973), however riparian groundwater was thought to have higher levels of organic matter and associated organic carbon than adjacent streams in Ontario (Hynes, 1983).

To quantify groundwater flow and solute transport processes adjacent to alcoves, we will conduct a detailed groundwater investigation at three alcoves. The three alcoves will be selected from the 16 for which water quality measurements will be taken and, as much as possible, chosen to cover a range of hydraulic conductivities. Obtaining landowner permission to be on the land surrounding an alcove is likely to be the primary deciding factor in the final selection of these three alcoves. Detailed measurements on the three alcoves will continue for three years. Measurements will be most intensive during the summers but we will also attempt to take measurements during other seasons, if possible.

Groundwater data along with data from the water chemistry component of this research will be used to help interpret the influence of groundwater on physical, chemical, and biological characteristics within alcoves. We will identify and assess the value of various geochemical indicators that relate to groundwater flow into alcoves; indicators will be selected from the suite of parameters measured in the water chemistry portion of this project. Relationships between indicators and key processes at a local scale will provide the potential for inferring groundwater exchange processes and associated effects at a larger scale.
Objectives

1. Evaluate the type, distribution, and permeability of substrate materials within aquifers adjacent to alcoves.

2. Evaluate the distribution of hydraulic heads within alcoves, adjacent aquifers, and in the nearby main channel.

3. Determine how variation in substrate permeability and water level gradient affect flow patterns within aquifers adjacent to alcoves.

4. Identify groundwater source areas and investigate their effects on water quality within alcoves.

5. Distinguish geo-chemical indicators that relate to groundwater flow into alcoves; indicators will be selected from the suite of parameters measured in the water chemistry component of this research.

Design

1. In spring we will conduct a survey of topographic features around each of the three alcoves. *Year 1*

2. In early summer we will install an array of about 20 piezometer nests at each of the three alcoves. Each nest will consist of three closely-spaced wells with consecutively lower depths. The nests will be arranged in a series of transects extending through the land peninsula between the river and the alcove, and through the riparian zone along the side and upstream of each alcove. Each transect will have between four and five piezometer nests. In addition we will install stage gauges at the upstream and downstream end of each alcove, and in the main channel lateral to the head of the alcove. We will map the position and elevation of the piezometers and stage gauges. *Year 1*

3. We will conduct hydraulic conductivity tests within each well in order to determine the type and permeability of the substrate (Dawson and Istock, 1991). These hydraulic conductivity tests will be repeated in early summer for each year. *Years 1, 2, & 3*

4. We will measure the water levels within each piezometer and stage gage in order to determine hydraulic head distributions throughout each study area. Water level measurements will be taken by hand once per week. In addition, piezometers within two of the transects at each site will be instrumented with data logger/pressure transducer units for continuous water level measurement. Measurements will be taken during summer, and during spring and fall if sites are accessible. *Years 1, 2, & 3*

5. Every two weeks during the summer, we will determine physical and chemical characteristics of water sampled from each well. Sampling will coincide with water quality measurements taken within the adjacent alcove and main channel. If the groundwater chemistry is not highly variable through time the sampling frequency may be reduced in later years. Water quality sampling will also be done for visible seeps in the alcoves. *Years 1, 2, & 3*

6. In order to identify water sources, transport pathways, and travel times, we will inject chloride and bromide, both inert tracers, into piezometers at selected locations within each transect. Water in the
piezometers and alcove will be tested for chloride and bromide at various time intervals following the
injections. *Years 1, 2, & 3*

**Metrics**

Site metrics include ground surface elevations, piezometer and stage gauge positions and elevations,
piezometer depths, groundwater levels within each piezometer, and surface water levels for each
stage gauge. Groundwater quality metrics include water temperature, conductivity, pH, nitrate,
ammonium, dissolved inorganic carbon, dissolved organic carbon, and dissolved oxygen.
Concentrations of chloride and bromide will be measured during the tracer studies.

**Analytical approach**

Groundwater flow through aquifers adjacent to each of the three alcoves will be analyzed using a
transient, three-dimensional finite-difference groundwater model (McDonald and Harbough 1988).
Quantitative relationships will be established between substrate hydraulic conductivity, water level
gradient, and flow magnitude and direction. Tracer study data will be evaluated using transient mass
flow analysis and end member mixing models (Mulholland 1993). Geostatistical analysis and
graphing techniques will be used to interpret this information and to develop three-dimensional
representations of substrate hydraulic conductivity values, hydrologic flow paths and water quality
characteristics adjacent to the alcove.

**4. Terrestrial vegetation**

*Objective:* To examine the role of riparian vegetation in the dynamics and functioning of off-channel
habitats at multiple temporal and spatial scales.

The River Continuum Concept (Vannote et al. 1980; Allan 1995) suggests that the influence of
riparian vegetation on aquatic organisms and physical processes is relatively minor for large rivers
such as the Willamette River. The greater width, depth, and flow of large rivers diminishes the
potential influence of surrounding vegetation on ecological processes such as shading, channel
formation, and carbon inputs (Table 4). However, the off-channel features of large rivers are often
relatively narrow and shallow and the water moves slowly, if at all. Under these circumstances
well-developed riparian vegetation may have considerable influence on water quality and aquatic
energetics.

The level of riparian vegetation influence on water quality and aquatic habitat of off-channel features
is hypothesized to be controlled by three factors: riparian vegetation extent and stature, off-channel
surface water area/volume, and subsurface flow rate. Potential influence increases with increasing
extent and stature of vegetation, e.g., more shade, more wood/litter deposition, more rooting, more
retention, system more heterotrophic. In contrast, increasing alcove size and subsurface flow limit
influence, e.g., relatively-less water surface shaded, less concentration of wood/litter, less water
temperature control, system more autotrophic. These localized relationships are influenced by larger,
temporal- and spatial-scale processes, e.g., historic flooding, damming and channelization, and
landscape pattern, that influence how and where off-channel features form and the pattern and rate at
which vegetation develops (Gregory et al. 1987).

Efficient and complimentary, multiple-scale metrics and data collection approaches are needed to examine the relationship of riparian and aquatic conditions within and between off-channel features distributed over a large area (Table 5). Traditional aerial photography (usually 1:24000) is useful for estimating certain parameters, but is limited by the inability to discern fine details; meanwhile, on-the-ground plot data is often limited by the great amount of time required to survey a large area. Large-scale aerial photos may provide information about riparian vegetation that bridges the gap between small-scale aerial photos and ground plots (Ham 1995). In addition, permission to access private land may limit ground-based measurements, requiring development of remote data collection techniques that provide more detailed information.

Table 4. Ecological Processes Influenced by Riparian Vegetation

<table>
<thead>
<tr>
<th>Hydrologic</th>
<th>Erosion</th>
<th>Deposition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Reduces entrainment of soil and gravels when roots and organic matter armor banks and bar surfaces.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Traps sediment and organic debris (tree boles, stems, and branches)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Nutrient Cycling</th>
<th>Sink</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Extracts nutrients from water and incorporate into biomass.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Contributes carbon and other nutrients by sloughing off leaves, stems, and woody debris.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Physical</th>
<th>Aquatic</th>
<th>Terrestrial</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Produces root masses and large woody debris that can create undercut banks and control sediment deposition and scouring.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Creates a canopy cover that can control the quality and quantity of light hitting the water, thereby influencing primary productivity, water temperature and dissolved oxygen concentration.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Creates habitat features for fish and other aquatic organisms, particularly that associated with wood debris, undercut banks, scoured pools, and shade.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Creates habitat elements for terrestrial vertebrates and invertebrates such as cover, food, microclimate, breeding sites, and perching sites.</td>
<td></td>
</tr>
</tbody>
</table>

Objectives

1. Develop an integrated approach to quantify and map riparian vegetation and other physical features associated with alcoves and side channels using data acquisition methods that vary from coarse grain to fine grain. This objective has two main components:

   a) develop and field test methods for obtaining and analyzing large-scale aerial photos (1:200 to 2,500), and

   b) compare metrics derived from different aerial and ground methods and scales and recommend a complimentary set based on their relative information content, logistic feasibility, data quality,
and usefulness in analysis of ecological function. Year 1 & 2.

2. Evaluate the relationship of current riparian vegetation with off-channel water quality and aquatic habitat, especially water temperature, wood/litter loading, and macrophyte abundance. Year 1 & 2.

3. Quantify the pattern of riparian vegetation development in and around off-channel habitats within the 207-km study area and estimate the rate of vegetation development after flood and land use disturbances and how this affects off-channel stability and longevity. Year 2.

4. Develop a riparian vegetation restoration rating scheme for off-channel features using a combination of local factors that affect vegetation-aquatic relationships and landscape factors that effect the dynamics of off-channel formation and riparian vegetation development. Year 3

Design

1. To address these objectives, vegetation and habitat metrics will be acquired as follows:

   a) Using small-scale photos (1:24,000) from 1993 and 1997 for all alcoves in a 207-km reach.

   b) Using a combination of small- and large-scale photos for 16 alcoves used in fish and surface water quality studies.

   c) Using a combination of small- and large-scale photos and ground-based surveys for 3 alcoves used in subsurface water quality studies [these are a subset of b].

   d) Using a combination of small- and large-scale photos and ground-based surveys for a constructed alcove.

2. Data from b), c), and d) will be used to address objective 1 (methods development and comparability). The logistics and comparability of metrics measured at multiple scales will be evaluated. Large-scale photo of off-channels will be acquired using either a boat-operated blimp rigged with small-format cameras on a gimbal, an ultralight aircraft (contracted), highly magnified small-scale aerial photos, or some combination of these. Under b) metrics of riparian vegetation and habitat features will be quantified from small- and large-scale photos (one time); however, ground-based measurements will probably not be possible except for the subset of the 3 alcoves measured under c). However radiation, angular canopy density measurements, and fish-eye photos will be taken at these alcoves from a watercraft. Under c) and d), metrics are the same as under b), except large-scale photos will be made 2 or 3 times and be supplemented with corresponding ground-based measurements on plots and points. Additional state-owned sites may be needed to reliably examine relationships between aerial and ground measurements. Years 1&2

3. Data from b), c), and d) will also be used to address objective 2 (vegetation-aquatic relationship). This effort will be closely coordinated with the fish, and surface/subsurface water components. Intra-and inter-annual variation in water temperature, wood/litter and substrate loading and stability, and macrophytes abundance and distribution will be examined in relation to riparian vegetation development and shading, off-channel surface water area/volume, and subsurface flow rate. Metrics
measured at multiple scales will be compared for their relative relationship with aquatic processes. Under b) we anticipate that the distribution of the 16 alcoves among seral stage classes and subsurface water classes will as follows:

<table>
<thead>
<tr>
<th>Seral stage of riparian vegetation</th>
<th>Highly influenced by entry of subsurface water into alcove</th>
<th>Not highly influenced by entry of subsurface water into alcove</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Mid to Late</td>
<td>4</td>
<td>8</td>
</tr>
</tbody>
</table>

Additional state-owned sites will be evaluated to complete the above experimental design, including a range of alcove sizes. *Years 1&2*

4. Data from a) will be used to address objective 3 (riparian vegetation dynamics). This effort will be closely coordinated with the geomorphology component. Vegetation and other landscape features will be characterized for all alcoves within a 207-km length of the river. Image analysis software will be used with 1:24,000 aerial photos taken in early summer 1993 and late spring 1997 during higher flow conditions to evaluate changes in riparian vegetation and certain physical features. Several unusually high winter flow events occurred between 1993 and 1997, thereby allowing an evaluation of changes following disturbance. These measurements will also assist with evaluating the role of riparian vegetation at sites where fish are sampled that do not overlap with water quality study sites. *Year 2*

5. Data from a-d) will be used to address objective 4 (vegetation and site restoration classification). This will be a team effort and involve the use of results from detailed alcove studies and large scale surveys and geomorphic/landscape analyses. Metrics measured at multiple scales will be used to classify sites without detailed data. Collectively this information would serve as a template for identify sites needing restoration of vegetation functions and selecting or creating sites in relation to factors controlling longer term stability.

**Metrics**

The proposed metrics for vegetation and physical features at each scale of measure are presented in Table 5.

**Analytical approach**

Data from b), c), and d) will be analyzed to address objective 1 (methods development and comparability). The relative accuracy of metrics measured at multiple scales will be evaluated using regression analysis, with data of the highest resolution serving as target values. In addition, the mean difference of paired measurement (same location within same site) will be calculated and a paired t-test used to test for significant differences from 0.

Data from b), c), and d) will also be analyzed to address objective 2 (vegetation-aquatic relationship), specifically the relationships and patterns of riparian shading, large wood abundance and
distribution, and bar/bank stability with aquatic processes and conditions. For example fish abundance and distribution is expected to vary with vegetation development and its influence on shading, food chain support, and retention of sediment and organic matter. Vegetation shading of the water surface is expected to relate to the pattern of water temperature in some off-channel sites. Likewise, shading would control light input, and thus influence aquatic primary production and the distribution of macrophytes. ANOVA will be used to test the statistical significance of selected factors thought to influence ecological functions within alcoves, i.e., level of vegetation development, alcove size, carbon status, nutrient fluxes, and groundwater influx. These types of analyses will be extended to the three intensively-studied alcoves and the constructed alcove. For these alcoves changes in vegetation throughout the summer will also be included in the evaluation.

Data from a) with be analyzed to address objective 3 (riparian vegetation dynamics). Changes in riparian vegetation composition, stature, and extent with local factors, e.g. geomorphic setting or substrate, and landscape factors, e.g. amount and proximity of agriculture land, basin position, will be examined for changes from 1993 to 1997 to determine the effects and pattern of flood disturbance and vegetation recovery.

Data from a-d) will be analyzed to address objective 4 (vegetation and site restoration classification). Results from objectives 2 and 3 will indicate riparian and aquatic conditions under local versus landscape control. A cluster analysis will be conducted using a combination of local and landscape factors to group sites by their relative need for vegetation restoration and their relative feasibility or potential for successful restoration.
Table 5. Metrics for Vegetation and Other Physical Features within Alcoves at Various Scales

<table>
<thead>
<tr>
<th>Metric</th>
<th>Scale</th>
<th>Fixed area plots on ground</th>
<th>Point samples on ground¹</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1:24000 aerial photos</td>
<td>1:200 to 1:2500 aerial photos</td>
<td></td>
</tr>
<tr>
<td>Vegetative type area (conifer, hardwood, grass, etc.)</td>
<td>x²</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Vegetative pattern (area, shape, patch connectivity, etc.)</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Canopy cover area over water</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Land cover/use area (farm field, pasture, urban, etc.)</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Area of off-channel features (surface water, banks and bars with/wo vegetation)</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Riprap area and location</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Vegetative sub-type area</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Area for classes of vegetation density and height</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Canopy cover from above (density, roughness, etc.)</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Ecotone area and location</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Overstory vertical strata (number)</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Large woody debris (number and size)</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Emergent aquatic plant surface area</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Overstory tree measures (crown diameter/area &amp; length, height)</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Overstory stand measures (stem density, mean height, crown volume)</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Canopy cover from below (densiometer, angular canopy density &amp; fisheye photos)</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Incoming solar radiation</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Understory cover, strata, and horizontal patchiness.</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Plant species by functional group</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Plant species richness or density</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Exotic plant species and cover</td>
<td></td>
<td></td>
<td>x</td>
</tr>
</tbody>
</table>

¹ Point samples and / or quadrants

² An x indicates that the scale is apt to be adequate for obtaining reliable information on that parameter.
5. Aquatic vegetation

Objective: To evaluate the relative abundance and growth habits of aquatic macrophytes in alcoves and to understand how macrophytes influence key ecological processes that occur in alcoves and to determine alcove factors that favor macrophyte abundance.

The presence of aquatic macrophytes can directly affect the physical and chemical aspects of water as well as provide structural habitat for aquatic biota. During the 1996 pilot study we often observed dramatic differences in daytime dissolved oxygen between open water and dense patches of macrophytes. In addition, we noticed that aquatic macrophytes in many alcoves seemed to be used by large numbers of young fish and sometimes frogs. In addition, we noticed that alcoves with macrophytes seemed to be clearer while alcoves that were turbid (in summer primarily due to suspended algae) contained fewer macrophytes. Several clear alcove contained few macrophytes as well. Studies have shown that aquatic plants can influence a number of other aquatic processes such as nutrient cycling, dissolved oxygen production, shelter, sediment retention, and carbon cycling. These effects can range from diurnal to seasonal.

Design

We will explore the influence of aquatic macrophytes within alcoves by determining the relative abundance of aquatic macrophytes in the same 16 alcoves selected for intensive water quality study.

1. Each of the 16 alcoves will be carefully mapped in June to obtain information with which to develop GIS (geographic information system) base maps of length, depth, width, substrate type, general classification of terrestrial land use and extent of revetments, if any. The data for base maps will be collected in the field using a combination of surveying tools and techniques including: line transects, optical rangefinders, sounding poles, aerial photographs, free diving, ponar grabs and GPS.

2. The spatial distribution and relative abundance of aquatic macrophytes will be determined for the 16 alcoves over a four-week period in late July/early August, which is about when macrophyte communities become fully developed. Methods used to quantify macrophytes will be non-destructive and as unobtrusive as possible so as not to interfere with subsequent project measurements. During the pilot study we noticed that macrophyte growth was quite patchy and varied considerably with longitudinal position within an alcove. Therefore, a relatively intense sampling design is proposed to characterize the patchiness of the macrophyte growth. We expect that in most alcoves that macrophytes will comprise less than ~20% of the surface area of the entire alcove. As a result, sampling should proceed relatively quickly. We will use the following line transect method:

The riverside shore of the alcove will be taken as the base line. Transects will be established perpendicular to the riverside bank starting at the upper end of the alcove using a random start distance of from 1 to 6 m. The interval between transects will vary depending on the length of the alcove. For alcoves with an overall length less than 300 m, the transect interval will be 5 m; for alcoves with an overall length equal to or greater than 300 m, the interval will be 10 m. The sampling interval along the transect will be 3 m and will be viewed as continuous between consecutive perpendicular transects. If we assume that an average alcove width is 10 meters then the maximum number of sample points will be: 600 m / 10 = 60 transects; 60 transects x 10 m average width = 600 m of transect; 600 m of transect / 3 m point interval = 200 sample points. Similarly, a 200 meter alcove would have a transect...
interval of 5 m which would result in 133 sample points.

At each sampling point the presence or absence of macrophytes will be determined visually from a boat or by snorkeling. Where macrophytes occur they will be assigned a dominant form class (submerged, floating leaved and emergent) and relative density (sparse, moderate, dense). For macrophyte communities that include more than one form, a form class and relative density will be noted for each form that is represented. The dominant genera in each class will be noted and vouchered by taking a sample and pressing and preserving it, and the substrate (silt, sand, gravel, cobble, bedrock) at sampling points by using a plastic or metal pole that will transfer the sound and feel of the substrate to allow classification into five classes. This method will be calibrated with samples obtained with a ponar dredge. The transect information will be compiled into maps (that are hand drawn maps on the initial alcove base map) showing the spatial extent of substrate and macrophyte classes, relative density, and dominant species.

The above procedures will be repeated for three years to evaluate interannual variability of macrophytes. Variability will be analyzed with respect to annual variability in the extent and duration of high flow events.

Metrics

Measurements will include the area occupied by macrophytes for each growth form, dominant species in growth form, and substrate type. Methods will be standardized among alcoves and sampling of all alcoves will occur within a four-week period.

Analytical approach

The measurements described above will be compared to a broad suite of metrics from the surface water, groundwater and fish components of this project for the purpose of determining the effect macrophytes have on various indicators of ecological processes within alcoves. We will analyze differences in chemical conditions and fish usage among alcoves having different proportions of aquatic macrophytes. We will also explore ways to incorporate information obtained from large scale aerial photographs that are described in the terrestrial vegetation component of this project.

6. Geomorphology of off-channel features

Objective: To understand the natural and human-induced processes that control the distribution and type of off-channel features that occur in large rivers such as the Willamette. In addition, we seek to determine how changes in these processes affects the ecological functions that occur within off-channel features.

During the pilot study we noticed that the type and distribution of off-channel features varies widely throughout the 207-km study reach. The upstream 15 km of the river has few alcoves but many side channels. Downstream of this reach, alcoves become numerous and side channels scarce. Then, downstream of Corvallis both become scarce until the most downstream 20 km where both become
numerous again. Side channels and alcoves that exist along the river today seem to be more permanent in the downstream direction, as indicated by the age and type of adjacent vegetation. Furthermore, our visual observations in 1996 indicated surface substrate within and adjacent to off-channel features seems to become finer in the downstream direction. These casual observations lead us to speculate that the short-term and long-term processes that create, alter, and obliterate off-channel features may differ throughout the study area.

The character and setting of an alcove or side channel may influence the quality of water and the type of fish habitat found within it. For example, we suspect an alcove that is bordered by loose deposits of coarse gravels will have higher inflow of hyporheic water than an alcove bordered by fine sediments. We hypothesize that an alcove with a bottom of fine sediments that is seldom scoured by high flows will likely be more favorable for aquatic plant establishment than one with a gravel bottom that is scoured each year. It may also provide a more available carbon source for the base of the food web within an alcove.

The main channel also exhibits longitudinal variability that may influence off-channel features. Detailed flow measurements made by the USGS show pronounced zones of downwelling and upwelling (unpublished data). Presumably, downwelling occurs where the river is underlain by deep deposits of coarse gravels and local channel gradient changes and lateral constriction result in a downward force on the water. The volume of hyporheic water available for interception by alcoves and side channels as well as the chemical and physical characteristics of that subsurface water may be unique in these downwelling and upwelling zones.

Without reservoirs to dampen flood flows and without revetments to channelize water the river was undoubtedly far different than what we see today (Kellerhals and Church 1989). In order to consider how might a river be managed to promote some aspects of the historical ecological functions of off-channel features a comparative investigation into what existed prior to human disturbance and an understanding of current conditions is needed. For example, if we find that water chemistry, nutrient cycling, and subsurface water movement varies considerably among types of off-channel features, knowledge of historic and current frequencies of these different feature types may allow us to understand cumulative changes for the entire river.

In Year 1 we plan to use aerial photography to quantify changes in alcoves and side channels from 1993 to 1997, a four-year period during which several unusually high flow disturbances occurred. We will also use these photos to understand whether downwelling and upwelling zones identified by the USGS are coincident with landscape level features. In an attempt to understand short-term morphological changes within alcoves we will take detailed measures of depth and width for 16 alcoves and then repeat the measurements in later years.

In Year 2 we will combine the detailed maps that we made of current off-channel features with historical maps showing the river's configuration and attempt to understand the geomorphic processes that once shaped the Willamette River.

**Design**

1: Using 1:24000 aerial photography, we will map changes in alcoves, side channels, and the main channel features over a period when several unusually high flow events occurred (1993 to 1997) and quantify the differences observed. Photo interpretation will be combined with rectification to a base
map, allowing comparisons among photography of different years and for data from other sources. The base map and photo interpreted data will be compiled into a Geographic Information System so that various layers of data can be displayed and manipulated. *Year 1*

2. We will use detailed flow data gathered by the USGS several years ago to identify landscape features from aerial photographs that might explain the occurrence of upwelling and downwelling zones in the river. These features may be associated with segments of the river that are unconstrained by revetments and where channel braiding is common. *Year 1*

3. We will take detailed width and depth measurements along the 16 alcoves that are being evaluated for water quality and fish use in other components of this study. Determine year-to-year changes in width and depth due to scouring and filling during high flows. *Years 1, 2, & 3*

4. Using historical maps of the Willamette River compiled by Stan Gregory at Oregon State University, we will compare past and current occurrences of alcoves and side channels. We will attempt to rectify historic maps of the channel with current aerial photography and use GIS software to quantify changes. During this exercise we will also attempt to understand the geomorphic processes that lead to the creation, modification, and obliteration of alcoves and side channels by noting larger landscape features that are associated with current off-channel features. For example, most current alcoves are located on the downstream lobe of pronounced point bars. Examination of the historical information to see if associations such as these are similar or different will provide us a way to understand shifts in geomorphic processes over the last decades. *Year 2*

**Metrics**

Metrics will include, changes in the area of bare and vegetation surfaces associated with each off-channel feature, changes in the feature's connection with the main channel, and location of man-made features that might have influenced feature geometry. For the 16 alcoves that will be measured each year, the metrics include, width, depth and substrate type.

**Analytical approach**

Photogrammetric and mapping techniques will be used to interpret photos and rectify the information to base maps. A GIS will be used to organize and display information and to quantify changes in area for various land forms.
7. Integration and modeling

Objective: To develop empirical relationships between indicator variables and the various ecological processes occurring within off-channel features (and the main channel) and to illustrate through modeling techniques how ecological conditions change for various river management alternatives.

The six research components described above are designed to yield information that will allow us to understand combinations of ecological processes within off-channel features. Out of this we intend to identify indicators that are the major drivers of ecological processes and then be able show how these indicators can be used to evaluate proposed alternative ways for managing the river.

For example; suppose the ability of an alcove to support a robust community of young native fish during the summer turns out to be primarily a function of the extent and form of aquatic plants growing in the alcove. And suppose that the extent and form of these aquatic plants hinges mainly on alcove water depth and whether or not exotic macrophytes are present. And further suppose it is the unusually high winter peak flows that scour out alcoves and keep them from filling with sediment and keep exotic macrophytes from becoming established. One might then be able to simply examine peak flow magnitude and frequency (the indicator in this case) to understand how alternative ways of managing reservoir releases during the winter influences communities of young native fish in alcoves during the summer.

Much of our understanding of the various ecological processes will eventually take the form of empirical relationships derived from field data. For example, summer maximum water temperatures in alcoves may turn out to be highly correlated to subsurface water flux and shading from surrounding vegetation. In this case, an empirical model such as this may be more useful (and economical) than a process-based water temperature model that would require careful calibration and validation of multiple climatic and physical parameters.

For other issues we will explore the use of process or quasi-process models to quantify ecological processes within alcoves. This approach is likely to be most useful when evaluating main channel and off-channel water quality (and their interactions) for long reaches of the river or when evaluating the overall condition of fish habitat within off-channel features. For example, nitrate inputs and cycling throughout a long reach of the river may be best understood by calibrating an existing process-level model that has been designed to account for the various pathways that nitrate enters and is cycled within a river.

One quasi-process model that we may choose to adapt for purposes of evaluating fish physical habitat availability in off-channel features is the incremental method (IFIM). This popular program, recommended by the U.S. Fish and Wildlife Service, has been severely criticized for its simplistic assumptions on limiting factors to fish productivity and for not being responsive to processes that create wide temporal variability in fish numbers (Mathur et al. 1985; Orth and Maughan 1982; Gan and McMahon 1990). Nevertheless, once modified to reflect limiting factors for fish in off-channel features, it may provide a useful template for evaluating the importance of depth and living space on fish in off-channel features.

Some of our attempts to integrate various ecological processes may turn out to be purely exploratory. For example, currently we have no explanation for what we observed in the pilot study about the lack
of fish in the cool upstream portions of some alcoves. Dissolved oxygen was often low in these pools but rarely did it fall to levels that would preclude fish. Unlike what has been observed in mountain streams on hot summer days, these cool pools of water did not seem to be used by fish as thermal refuge areas. The reason may involve multiple effects that are not easily detected by traditional correlation methods or conform to existing models of fish habitat suitability.

Examples of some river management issues that we may be able to address in this integration and modeling component are:

- The amount of water released from reservoirs during the summer. This could affect the depth of water in off-channel features; the type and extent of aquatic macrophytes; the depth and volume of water and amount of cover for fish; the flux of hyporheic flow into alcoves relative to terrestrial groundwater, and the type of vegetation growing along the margins of off-channel features.

- Regulation of the magnitude and frequency of peak flows from flood control reservoirs. This could affect the creation, characteristics, or the obliteration of off-channel features; the type and extent of aquatic macrophytes; the abundance of woody debris used as cover by fish; and the type of surrounding vegetation.

- New construction, maintenance, or dismantling of revetments along the river. This could affect the abundance and geometry of off-channel features; the movement and deposition of coarse substrate; the abundance of new woody debris added to the river each year; and the characteristics of vegetation along the river.

- Increases or decreases in biological oxygen demand, nutrients, and suspended solids within effluent from sewer treatment plants and industrial sources. This could affect dissolved oxygen levels in the main channel and off-channel areas; primary productivity due to nutrient loads and light attenuation; and the food web for fish communities.

- Fertilizer application rates and techniques for agricultural fields near the river. This also could affect dissolved oxygen levels in the main channel and off-channel areas; primary productivity due to nutrient loads and light attenuation; and the food web for fish communities.

- Construction of new off-channel features or enhancement of existing features. This could affect fish habitat abundance and quality. If done extensively, this could affect how nutrients are cycled within the river system.

Objectives

1. Quantify relationships between the components of this study: fish, water quality, subsurface flow, terrestrial vegetation, aquatic vegetation, and geomorphology.

2. Develop and adapt models to illustrate the interactions among the various components, to link complex ecological processes, and to quantify the outcomes of various alternative river management scenarios.
Design

1. Using data from each of the other research components we will search for relationships that are major drivers of ecological processes within off-channel features and the main channel and identify indicators that can be used to efficiently evaluate these relationships. For example, if the data indicate that the source and amount of subsurface flow into an alcove is a major influence on nutrient dynamics, then simple water quality measures (such as morning dissolved oxygen and conductivity) may be found to provide a powerful tool for quickly assessing this ecological process.

2. We will build upon previous work done by the Oregon Department of Environmental Quality to adapt the water quality process model QUAL2E to our study area (Tetra Tech 1995b). QUAL2E is a model supported by the EPA (Watershed Modeling Section, Athens Georgia) and is being promoted widely as a tool for developing total maximum daily loads for water quality limited streams and rivers (EPA 1995). This computer program simulates stream flow, water temperature, transformation and uptake of nutrients, algal oxygen production, benthic and carbonaceous oxygen demand, atmospheric reaeration and concentrations of multiple conservative and nonconservative constituents.

Previous efforts to calibrate QUAL2E for the Willamette River have been frustrated by a lack of data to verify calibration and by limitations of earlier versions of the model for handling diurnal variation in dissolved oxygen, algal growth, and attached phytoplankton. The first two limitations have since been resolved but the current version still does not incorporate processes associated with attached algae and macrophytes, which are an important factor within our study area. We will try to modify the program further and possibly remedy this.

We will explore the possibility of adapting QUAL2E for simulating processes within single alcoves or side channels. If successful, output from each alcove model could be treated as "tributary" influences for a main channel model. Previous research by the USGS to apply a variation of this model (CE-QUAL-W2) to the brackish Tualatin River may include information on applying this type of model to slow moving water and be useful to us for modeling off-channel features of the Willamette River. Before trying to adapt QUAL2E to single alcoves or side channels we will first determine if other models exist that would be more appropriate for these relatively shallow and stagnant features. Results from the subsurface flow component of our research project will provide needed information on the flux of water and nutrients into and out of off-channel features.

Recent work complete by the USGS on developing streamflow routing models for the Willamette basin, including the reservoir system, will be invaluable in evaluating river management alternatives that concern summer river levels and winter peak flows (Laenen and Risley, in press). In addition, recent evaluations by the USGS on stream velocity on selected stream and river reaches in the Willamette River basin will also enhance the accuracy of any modeling efforts (Lee 1995).
Data Management

The seven components of this research project will yield large quantities of data each year and this will require a concerted effort to transfer field measurements from data sheets or electronic data loggers to computer files, verify the accuracy of the entered data, document the structure and content of each file, and produce a data file structure that makes the information accessible to a variety of users.

A combination of Quattro Pro spreadsheets and Paradox databases will be used to enter and verify data. The two software packages shuttle files seamlessly back and forth between each other, allowing the user to choose which format is most appropriate for the specific task. For example, the spreadsheet format is often more useful for downloading information from electronic data loggers and conducting exploratory evaluations of the information while the Paradox software is more useful for setting up templates for typing in diverse information from field data sheets and for final archiving of data. Paradox has features allowing explanations of variables, units of measure, and any coding to be attached to the file. A final archived version of all data files will be transferred to CD-ROM and be made available to others once the project is over.

In order to ensure accuracy when entering data by keyboard the following procedures will be used:

1. Value checks will be set up for each variable so that if numbers are entered outside a specified range a flag is raised, allowing the person to check and see if the number entered is indeed correct.

2. After all values have been entered into a file, each entry will be 100% checked by visual comparison with field sheet values.

Quality Assurance

A quality assurance and quality control plan for chemical, physical, and biological sampling techniques mentioned in this project proposal will be provided in a separate document.

Summaries of Component Tasks and Scales

The following tables provide a summary of proposed tasks for each of the components in the project. Included is a time line for each task and the associated temporal scale and spatial scale.
Table 6. Summary of Component 1. Fish Use of Alcoves and Side Channels

<table>
<thead>
<tr>
<th>Component</th>
<th>Task</th>
<th>Temporal Scale</th>
<th>Spatial Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fish Use of Alcoves and Side Channels</td>
<td>1. Quantify catch efficiencies associated with electrofishing in alcoves and where cover features are present. Evaluate daytime and nighttime fish communities within 6 alcoves and determine the influence of interior block nets, cover features, water quality, and position within alcove. [summer]</td>
<td>repeated 4 times, once a week</td>
<td>among 6 alcoves</td>
</tr>
<tr>
<td></td>
<td>3. Evaluate daytime fish use for two natural alcoves an a constructed alcove with and without woody debris. [summer]</td>
<td>single afternoon repeated weekly to monthly</td>
<td>within alcove</td>
</tr>
<tr>
<td>Year 1</td>
<td>4. Develop methods for sampling fish communities in slow moving side channels. [summer].</td>
<td>methods development</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5. Evaluate both daytime and nighttime fish communities within alcoves and side channels. Investigate predator and prey interactions between main channel fish and off-channel fish. [summer]</td>
<td>single afternoon/night</td>
<td>within alcoves/side channels</td>
</tr>
<tr>
<td></td>
<td>6. Evaluate daytime and nighttime fish use for two natural alcoves and constructed or enhanced alcoves and side channels during the summer. Investigate predator and prey interactions between large fish and small fish in these features. [summer]</td>
<td>single afternoon/night repeated weekly to monthly</td>
<td>within alcoves and side channels</td>
</tr>
<tr>
<td>Year 2</td>
<td>7. Develop daytime and nighttime methods for sampling fish communities in alcoves and side channels that allow comparisons among seasons.</td>
<td>methods development</td>
<td></td>
</tr>
<tr>
<td></td>
<td>8. Evaluate both daytime and nighttime fish communities within alcoves and side channels for various seasons. Determine how fish disperse among main channel, alcoves, side channels, and flood plains during higher flows.</td>
<td>continuous several weeks each season combined with single afternoon/night several days each season</td>
<td>within alcoves/ side channels and among many alcoves/side channels</td>
</tr>
<tr>
<td></td>
<td>9. Evaluate diurnal fish use within two natural alcoves and a few constructed or enhanced alcoves and side channels throughout seasons.</td>
<td>continuous several weeks each season combined with single afternoon/night several days each season</td>
<td>within alcoves and side channels</td>
</tr>
<tr>
<td>Component</td>
<td>Task</td>
<td>Temporal Scale</td>
<td>Spatial Scale</td>
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<td>----------------------------------------</td>
</tr>
<tr>
<td>Physical &amp; Chemical Properties of Water</td>
<td>1. Evaluate morning water quality within 16 alcoves. Repeated in Years 2 and 3. [summer]</td>
<td>one morning</td>
<td>within alcoves and among many alcoves</td>
</tr>
<tr>
<td>Year 1</td>
<td>2. Investigate detailed temporal and spatial variation in water quality for instrumented alcoves; 2 natural and 1 constructed [summer, fall]</td>
<td>varies from continuous to weekly</td>
<td>within alcoves</td>
</tr>
<tr>
<td>Year 2</td>
<td>3. Evaluate main channel water quality during the morning for a longitudinal transect from the Yamhill River to Eugene, once in early summer, once in mid summer, and once in late summer. Repeated in Years 2 and 3.</td>
<td>single mornings, three times during summer</td>
<td>within main channel</td>
</tr>
<tr>
<td>Year 3</td>
<td>4. Evaluate detailed temporal and spatial variation in water quality for two natural alcoves and one or more constructed (or enhanced) alcoves and side channels. [summer]</td>
<td>varies from weekly to continuous</td>
<td>within alcoves and side channels</td>
</tr>
<tr>
<td>6. Evaluate morning water quality within the alcoves and side channels for which fish sampling will occur during various seasons.</td>
<td>one morning, several times each season</td>
<td>within alcoves/side channels and among many alcoves/side channels</td>
<td></td>
</tr>
<tr>
<td>7. Evaluate detailed temporal and spatial variation in water quality for two natural alcoves and one or more constructed (or enhanced) alcoves and side channels during various seasons.</td>
<td>varies from weekly to continuous, each season</td>
<td>within alcoves and side channels</td>
<td></td>
</tr>
</tbody>
</table>
Table 8. Summary of Component 3. Subsurface Water Interactions

<table>
<thead>
<tr>
<th>Component</th>
<th>Task</th>
<th>Temporal Scale</th>
<th>Spatial Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subsurface</td>
<td>Year 1, 2, &amp; 3. Install an array of about 20 piezometer nests at each of three alcoves, conduct hydraulic conductivity tests, and measure water levels throughout the summer and fall. Repeated in Year 2 and 3.</td>
<td>varies from continuous, daily, and within months; each of 3 years</td>
<td>within alcoves</td>
</tr>
<tr>
<td>Water</td>
<td>Year 1, 2, &amp; 3. Determine physical and chemical characteristics of water sampled from each well. Repeated in Year 2 and 3.</td>
<td>several times each month, each of 3 years</td>
<td>within alcoves</td>
</tr>
<tr>
<td>Interactions</td>
<td>Year 1, 2, &amp; 3. Inject chloride and bromide, both inert tracers, into piezometers at selected locations within each transect of each alcove in order to determine flow paths and rates for subsurface water. Repeated in Year 2 and 3.</td>
<td>one time, each of 3 years</td>
<td>within alcoves</td>
</tr>
</tbody>
</table>
Table 9. Summary of Component 4. Terrestrial Vegetation

<table>
<thead>
<tr>
<th>Component</th>
<th>Task</th>
<th>Temporal Scale</th>
<th>Spatial Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terrestrial</td>
<td>Year 1 &amp; 2 1. Develop an integrated approach to quantify and map riparian vegetation and other physical features associated with alcoves and side channels using data acquisition methods that vary from coarse grain to fine grain. This objective has two main components:</td>
<td>several times during summer for two years</td>
<td>among many alcoves</td>
</tr>
<tr>
<td>Vegetation</td>
<td>a) develop and field test methods for obtaining and analyzing large-scale aerial photos (1:200 to 2,500), and</td>
<td>once to several times during summer</td>
<td>among many alcoves</td>
</tr>
<tr>
<td></td>
<td>b) compare metrics derived from different aerial and ground methods and scales and recommend a complimentary set based on their relative information content, logistic feasibility, data quality, and usefulness in analysis of ecological function.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2. Evaluate the relationship of current riparian vegetation with off-channel water quality and aquatic habitat, especially water temperature, wood/litter loading, and macrophyte abundance.</td>
<td>a) several times during summer</td>
<td>a) among a few alcoves</td>
</tr>
<tr>
<td></td>
<td></td>
<td>b) once during summer</td>
<td>b) among many alcoves</td>
</tr>
<tr>
<td>Year 2</td>
<td>3. Quantify the pattern of riparian vegetation development in and around off-channel habitats within the 207-km study area and estimate the rate of vegetation development after flood and land use disturbances and how this affects off-channel stability and longevity.</td>
<td>once for different years (1993 and 1997)</td>
<td>among all alcoves, including surrounding landscape</td>
</tr>
<tr>
<td>Year 3</td>
<td>4. Develop a riparian vegetation restoration rating scheme for off-channel features using a combination of local factors that effect vegetation-aquatic relationships and landscape factors that effect the dynamics of off-channel formation and riparian vegetation development.</td>
<td>multiple scales</td>
<td>multiple scales</td>
</tr>
</tbody>
</table>
Table 10. Summary of Component 5. Aquatic Vegetation

<table>
<thead>
<tr>
<th>Component</th>
<th>Task</th>
<th>Temporal Scale</th>
<th>Spatial Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aquatic Vegetation</td>
<td>1. For each of 16 alcoves create maps showing general features such as beds of aquatic plants, substrate type, water depth, and dimensions of alcove. [Summer]. Repeated in Year 2 and 3.</td>
<td>between years</td>
<td>within alcoves and among many alcoves</td>
</tr>
<tr>
<td></td>
<td>2. For each of 16 alcoves systematically sample aquatic plant communities for growth form, substrate type, relative density, and dominant species. Repeated in Year 2 and 3.</td>
<td>between years</td>
<td>within alcoves and among many alcoves</td>
</tr>
</tbody>
</table>

Table 11. Summary of Component 6. Geomorphology of Off-channel Features

<table>
<thead>
<tr>
<th>Component</th>
<th>Task</th>
<th>Temporal Scale</th>
<th>Spatial Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geomorphology of off-channel</td>
<td>Year 1. Using 1:24000 aerial photography, map changes in alcoves, side channels, and the main channel over a period when several unusually high flow events occurred (1993 to 1997).</td>
<td>among multiple years</td>
<td>all alcoves and side channels and the entire main channel within study area</td>
</tr>
<tr>
<td>features</td>
<td>2. Use USGS data to identify zones of river upwelling and downwelling. Identify landscape features from aerial photographs that might explain why these zones occur where they do.</td>
<td>single summer</td>
<td>entire river within study area</td>
</tr>
<tr>
<td></td>
<td>3. Take detailed measures of depth and width along a longitudinal transect for each of the 16 alcoves included in the Year 1 water quality sampling. Repeat measurements in Years 2 and 3.</td>
<td>once in summer</td>
<td>within alcoves and among many alcoves</td>
</tr>
<tr>
<td>Year 2</td>
<td>4. Use historical maps of the Willamette River compiled by Stan Gregory to compare past extent of alcoves and side channels with current extent.</td>
<td>decades</td>
<td>entire river within study area</td>
</tr>
<tr>
<td></td>
<td>5. Using historic and current maps and aerial photos investigate the geomorphic processes that lead to the creation, modification, and obliteration of alcoves and side channels.</td>
<td>decades</td>
<td>entire river within study area</td>
</tr>
</tbody>
</table>
Table 12. Summary of Component 7. Integration and Modeling

<table>
<thead>
<tr>
<th>Component</th>
<th>Task</th>
<th>Temporal Scale</th>
<th>Spatial Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integration and</td>
<td>1. Quantify relationships among the components of this study: fish, water quality, subsurface flow, terrestrial vegetation, aquatic</td>
<td>variable, ranging from single day to many decades</td>
<td>variable, ranging from within an off-channel feature to among all off-channel features</td>
</tr>
<tr>
<td>Modeling</td>
<td>aquatic vegetation, and geomorphology.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2. Develop or adapt simulation models to organize the interactions of the various components and to quantify the outcomes of various future river management scenarios.</td>
<td>variable, ranging from single day to many decades</td>
<td>variable, ranging from within an off-channel feature to among all off-channel features</td>
</tr>
</tbody>
</table>

### Table 13. Off-Channel Habitat Research Products *

<table>
<thead>
<tr>
<th>Research Component</th>
<th>Year</th>
<th>Contributing Components</th>
<th>Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Fish use of alcoves and side channels</td>
<td>1st</td>
<td>2, 3</td>
<td>Journal article: The influence of cover and water characteristics on catch efficiencies when electrofishing within alcoves of a large river.</td>
</tr>
<tr>
<td></td>
<td>2nd</td>
<td>2, 3</td>
<td>Journal article: Diurnal variation in fish communities within alcoves and side channels of a large river.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2, 3, 4</td>
<td>Journal article: The influence of cover and water characteristics on summer fish use of constructed alcoves in comparison to natural alcoves.</td>
</tr>
<tr>
<td></td>
<td>3rd</td>
<td>2, 3</td>
<td>Journal article: Seasonal variation in the use of alcoves and side channels by fish in a large river.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2, 3, 4</td>
<td>Journal article: Effectiveness of constructing or enhancing off-channel features to benefit native fish communities in a large river.</td>
</tr>
<tr>
<td>2. Physical and chemical properties of water in off-channel features</td>
<td>1st</td>
<td>3</td>
<td>Journal article: Diurnal and intra-annual variation in physical and chemical properties of water within alcoves of a large river in comparison to the main channel.</td>
</tr>
<tr>
<td></td>
<td>2nd</td>
<td>3, 4, 5, 6</td>
<td>Journal article: The influence of vegetation, subsurface flow, and geomorphology on the physical and chemical characteristics of water within alcoves of a large river.</td>
</tr>
<tr>
<td>3. Subsurface water interactions</td>
<td>1st</td>
<td>1, 2</td>
<td>Journal article: The source, flux, and properties of subsurface water entering alcoves of a large river.</td>
</tr>
<tr>
<td></td>
<td>2nd</td>
<td>1, 4</td>
<td>Journal article: Effects of subsurface flow on dissolved oxygen and water temperature within alcoves of a large river.</td>
</tr>
<tr>
<td></td>
<td>3rd</td>
<td>1, 6</td>
<td>Journal article: Using surface water indicators and groundwater modeling to evaluate the influence of subsurface water on aquatic habitat within alcoves of a large river.</td>
</tr>
<tr>
<td>4. Terrestrial vegetation</td>
<td>1st</td>
<td>5</td>
<td>Journal article: The use of large scale aerial imagery for inventorying riparian vegetation according to its potential for influencing off-channel features of a large river.</td>
</tr>
<tr>
<td></td>
<td>2nd</td>
<td>1, 2, 3</td>
<td>Journal article: The influence of riparian vegetation on water characteristics and on physical characteristics of fish habitat within alcoves of a large river.</td>
</tr>
<tr>
<td></td>
<td>3rd</td>
<td></td>
<td>Journal article: The use of coarse and fine scale measurements to evaluate functions of riparian vegetation associated with off-channel features of a large river.</td>
</tr>
<tr>
<td>Research Component</td>
<td>Year</td>
<td>Contributing Components</td>
<td>Product</td>
</tr>
<tr>
<td>--------------------</td>
<td>------</td>
<td>-------------------------</td>
<td>---------</td>
</tr>
<tr>
<td>5. Aquatic vegetation</td>
<td>1st</td>
<td>2</td>
<td>Journal article: The influence of aquatic macrophytes on water quality within alcoves of a large river.</td>
</tr>
<tr>
<td></td>
<td>2nd</td>
<td>1</td>
<td>Journal article: The influence of aquatic macrophyte abundance and structure on fish habitat within alcoves of a large river.</td>
</tr>
<tr>
<td></td>
<td>3rd</td>
<td>6</td>
<td>Journal article: Interannual variability of macrophytes within alcoves of a large river and relationships to substrate and high flow events.</td>
</tr>
<tr>
<td>6. Geomorphology of off-channel features</td>
<td>1st - 3rd</td>
<td>5</td>
<td>GIS maps: Annual maps of morphometry, substrate, macrophytes, and other physical features for 16 alcoves.</td>
</tr>
<tr>
<td></td>
<td>2nd</td>
<td></td>
<td>Journal article: A comparison of the abundance and type of off-channel features along the Willamette River: 1890, 1930, and 1997.</td>
</tr>
<tr>
<td></td>
<td>3rd</td>
<td></td>
<td>Journal article: Interannual variation in the geomorphology of off-channel features along the Willamette River (1993 to 1999) and relationships to high flow events.</td>
</tr>
<tr>
<td>7. Integration and modeling</td>
<td>2nd</td>
<td>1, 2, 3, 4, 5, 6</td>
<td>Journal article: A landscape perspective of factors influencing water quality and fish habitat within off-channel features of the Willamette River.</td>
</tr>
<tr>
<td></td>
<td>3rd</td>
<td>1, 2, 3, 4, 5, 6</td>
<td>Journal article: Projecting the outcome of watershed management decisions on water quality and fish habitat within off-channel features and the main channel of the Willamette River.</td>
</tr>
</tbody>
</table>

* The primary products of this project will be journal articles with the focus ranging from single issues to synthesis of multiple project elements. Articles are organized in the table according to the component which will be most dominant in the article. Research personnel in charge of a component will be taking the lead on preparing manuscripts organized under that component. Major contributions to an article by research personnel in charge of other components are indicated in the third column. The second column indicates the year in which the manuscript will be submitted for laboratory review and clearance.
References


Ecological Functions of Off-Channel Habitats


Resumes of key personnel

Dixon Landers (EPA)
Chip Andrus (Dynamac)
Diana Sharps (Dynamac)
Marilyn Erway (Dynamac)
Steve Cline (EPA)
DIXON HAMILTON LANDERS

EDUCATION

Indiana University, Ph.D., Zoology (Limnology), 1979; Indiana University, M.A.T., Biology, 1974; Kansas State University, B.S., Zoology, 1969;

PRESENT POSITION

Senior Research Environmental Scientist (GS-15) responsible for leading the Watershed/Ecoregion research project in the Pacific Northwest Research Program. Research efforts are directed toward designing and implementing interdisciplinary projects which involve strong multiscalar (temporal and spatial) objectives. The overall goal of this research is to develop tools that can be used in managing ecological systems for various societal objectives.

AWARDS & HONORS

1993 Appointed as a member of the National Research Council Review Panel for the Young Investigator Program on Ecological Concerns in the Development of the Arctic and Far Northern Regions (with Russia).

1992 Invited to serve as a member of the Dahlem Conference Steering Committee for the Conference on Acidification in Freshwater Ecosystems. Selected as Rapporteur for working group.


1987 EPA Bronze Medal for Commendable Service and outstanding contributions to the National Surface Water Survey.

1986 Chancellor's Award from State University of New York for Outstanding Performance as scientific leader for the design and implementation of the Eastern Lake Survey.

SELECTED PUBLICATIONS.


CHARLES (CHIP) W. ANDRUS

EDUCATION

M.S., Forest Hydrology, Oregon State University, 1982; B.S., Forest Engineering, Oregon State University, 1978.

EXPERIENCE

- 6 years of experience developing modeling techniques for evaluating the effects of various land use practices on water quality and aquatic habitat.
- 12 years of experience conducting research on the consequences of timber harvest and other activities on water quality and fish habitat.
- 3 years of experience involving in policy development and consensus-building among various interest groups affected by a regulatory program.
- 3 years of experience administrating a regulatory program on private forest lands.
- 4 years of experience supervising technicians or field crews.

EMPLOYMENT

Dynamac Corporation
Research Scientist, EPA Research Lab, Corvallis, Oregon, 1994 to present

Designed methods for evaluating the effects of various timber harvest and other land use practices on salmon productivity and other environmental concerns in watersheds of southwest Washington. Developed modeling techniques for evaluating the consequences of proposed management actions on water quality and biota in large watersheds such as the Willamette River.

Oregon Department of Forestry

Provided the technical support for a major revision to the stream protection rules that apply to non-federal forest lands in Oregon. Developed a stream classification system to replace the existing classification system. Designed and conducted water temperature monitoring programs in forest drainages. Developed various predictive tools for field use, such as determining where fish use occurs within forest watersheds and estimating peak flows for purposes of culvert design. Developed a model for evaluating the amount of woody debris that accumulates in stream channels over time for various types of stands. Developed mitigation plans for streams and wetlands damaged as a result of landowners violating the stream protection rules.

Oregon Water Resources Department.
Hydrologist, Salem, Oregon, 1990 to 1991

Developed and conducted a program for evaluating the effectiveness of stream improvement projects conducted by agencies and private entities in Oregon. Supervised a two-person field crew that collected detailed field information on individual stream improvement projects. Evaluated water quality parameters and streamflow for certain basins in Oregon to determine recommended minimum flows within state scenic waterways.
Planned, conducted, and documented research projects on timber harvesting and its effect on fish habitat and water quality. Studies included understanding the effects of streamside stand management on channel structure and the evaluation of timber harvesting on landslide rates in steep terrain.

Environment and Policy Institute, East-West Center.
Researcher, Honolulu, Hawaii, 1984-1986

Compiled research on soil erosion and water yield for tropical watersheds of the Asia-Pacific region. Evaluated how grazing, farming, and timber harvesting affected water resources and recommended ways to reduce damage that were appropriate for developing countries.

SELECTED PUBLICATIONS


DIANA E. SHARPS

EDUCATION


EXPERIENCE

• Four years of experience conducting research on stream and riparian groundwater interactions.

• Five years of experience performing water quality monitoring and analysis.

• Ten years of experience providing technical support for watershed research and management projects.

EMPLOYMENT

Dynamac Corporation
Hydrologist, EPA Research Lab, Corvallis, Oregon, 1996 to present
Conduct hydrologic monitoring and analysis to characterize surface and groundwater flow at riparian research sites in the Willamette Valley.

Environmental Science and Engineering
Field Site Operator, Corvallis, Oregon, 1994 to present
Collect and analyze of precipitation samples from two monitoring stations in the National Atmospheric Deposition Program.

The Nature Conservancy
Vegetation History Intern, Corvallis, Oregon, 1995 to 1996
Transcribed and interpreted 1850's U.S. General Land Office survey notes in a collaborative effort to map the vegetation of the Willamette Valley prior to continuous Euroamerican contact.

Self Employed
Research Hydrologist, Corvallis, Oregon, 1991 to 1995
Designed and conducted research on relationships between streamflow, groundwater levels and related riparian zone characteristics. Developed finite-difference model to simulate groundwater dynamics in western and central Oregon stream systems.

Soil and Water Testing Laboratory
Research Associate, Colorado State University, Fort Collins, Colorado, 1987 to 1989
Supervised the water quality division of an analytical laboratory. Determined major and minor inorganic constituents in stream and groundwater samples. Managed and compiled data.

San Juan National Forest
Hydrologic Technician, Durango, Colorado, 1985
Joined interdisciplinary teams that reviewed forest practice activities. Evaluated timber harvest applications for potential impacts to runoff response, sediment delivery and fisheries habitat.
MARILYN MORRISON ERWAY

EDUCATION

M.S., Resource Utilization, Plant and Soil Sciences Dept. University of Maine, Orono, 1979
B.S., Botany, University of Maryland, College Park, Maryland, 1974

EXPERIENCE

Fifteen years of experience in collecting and analyzing surface water and sediment samples, with
the major area of research being studies investigating the effects of acidic deposition on aquatic
resources. Ten years of experience in designing and coordinating the quality assurance (QA)
programs for aquatic monitoring and watershed research projects, including assessing QA needs,
developing QA plans, and conducting on-site technical systems reviews of both field and
laboratory projects. Extensive experience with interlaboratory comparability studies used for
evaluating laboratory performance over time.

EMPLOYMENT

Dynacom Corporation
Staff Scientist, Environmental Research Laboratory, Corvallis, OR, 1996 to present

Provide logistics coordination and technical support for research activities relating to water and
sediment sampling, including the preparation of field implementation plans, health and safety
plans, and quality assurance plans. Provide quality assurance support for long-term aquatic
monitoring projects.

ManTech Environmental Technology, Inc.
Senior Scientist, Environmental Research Laboratory, Corvallis, OR, 1987-1996

Designed and coordinated the quality assurance programs for two aquatic monitoring projects
within the Environmental Monitoring and Assessment Program's Surface Water Resource Group
(EMAP-SW): the Long-Term Monitoring (LTM) Project and the Sierra Episodes Project.
Assisted in the coordination of these projects. Evaluated the quality assurance requirements for
a third project, the Temporally Integrated Monitoring of Ecosystems (TIME) Project. Conducted
on-site technical systems reviews of LTM projects to ensure that sample collection, preparation,
and chemical analyses performed as part of the LTM Project follow the methods, protocols, and
quality assurance procedures as described in the LTM QA Project Plan. Evaluated laboratory
performance for long-term monitoring projects. Initiated and has continued to coordinate for the
last 5 years the participation of EMAP-SW laboratories in an international interlaboratory
comparability program. Responsible for establishing a field laboratory for the Sierra Episodes
Project, including development of sample handling and quality assurance procedures,
procurement of supplies, and analyses of samples for pH, acid neutralizing capacity, and
conductivity. Responsible for the weekly collection of precipitation samples for two sites in the
National Atmospheric Deposition Program.
Northrop Services, Inc., Environmental Sciences Division

Quality Assurance Specialist, Environmental Research Laboratory, Corvallis, OR, 1986-1987
Provided support for quality assurance (QA) program at EPA Environmental Research Laboratory (ERL-C): reviewed QA project plans and publications to assure compliance with ERL-C requirements; conducted technical system audits of intramural and extramural projects to assess compliance with project plans; and assisted investigators in developing QA plans.

University of Maine
Research Associate, Department of Geological Sciences, Orono, Maine, 1980-1986
Research Laboratory Director. Supervised geochemical laboratory, with up to 5 full-time employees and 3 to 6 undergraduate and graduate students, supporting the research of Dr. Stephen A. Norton and performing analytical contract work. Research assessed chronology and impact of atmospheric deposition on terrestrial and aquatic ecosystems. Started as Research Assistant and was promoted to Research Associate in 1983. Developed sample collection and laboratory protocols, and analytical methods using atomic absorption spectrophotometry (flame and graphite furnace). Conducted quality control program, coordinated and led field sampling trips, and maintained and repaired lab facilities including field and analytical equipment. Managed and compiled data, including preparation of computer graphics on IBM mainframe. Major aspects of research were chemical stratigraphic analysis of lake sediments and chemical analysis of lake and stream water samples.

PUBLICATIONS


STEVEN P. CLINE

EDUCATION

B.S., Forestry (Minor, Zoology), University of Illinois, 1973 ; M.S., Forest Science (Minor, Wildlife Science), Oregon State University, Corvallis, 1977.

AREAS OF SPECIALIZATION

• Applied forest ecology

• Design and management of multi-resource inventory and monitoring programs

• Use of quality assurance principals in program management

PROFESSIONAL EXPERIENCE

1994 to present

Biologist/Qaulity Assurance. US EPA, National Health and Environmental Research Lab, Western Ecology Division, Corvallis, OR.

PUBLICATIONS (last 5 years)


