Section II. Understanding and Enhancing Watershed Ecosystems

1

Principles of Planning

Mike Cloughesy

Planning is the first step in most human activities. Watershed management is no exception. As your group starts to consider watershed enhancement projects, you'll need to plan on both the watershed level and the individual project level.

This chapter provides a general introduction to planning.

> **In this chapter you'll learn:**
> - What planning is and how it can help your watershed group
> - The steps in planning
> - What types of plans there are and when each is used

WHAT IS PLANNING AND HOW CAN IT HELP YOU?

Planning is a decision-making process focused on future actions. In order to plan, you first need to look at your objectives, the constraints you face, and the resources available to you. Then you can do the following:

- Identify alternative actions.
- Rank the alternatives based on their abilities to meet your criteria.
- Select alternatives to implement.
- Develop a timeline for implementing your selected alternatives.
- Implement the selected alternatives.
- Monitor implementation success.

Many people think that the purpose of planning is to satisfy government regulations. Although it may be true that you're required to make a plan, the important outcome of planning isn't the plan itself, but the process or journey you follow to develop and implement the plan.

There are many reasons to plan. Planning will help you achieve your objectives as completely as possible within the limits of your resources and the constraints you face. It helps you use limited resources efficiently. It helps you communicate what you want to accomplish to funding agencies, government agencies, other watershed groups, and your own members.

See Section I, Chapter 4, and Section III, Chapter 7 for information related to this chapter.

Planning also forces you to organize your thoughts and actions in a way that can be defended, and makes you document your decision-making process. Having plans on paper can make the proposed actions seem very real and concrete.

Recognize, however, that plans are only as good as the information that goes into them. Be open to revising your plans as new information becomes available.

Chapter I-4, "Decision Making," provides valuable information on decision making that may help your group set goals and develop plans.

WHAT ARE THE STEPS IN PLANNING?

Individual planning processes differ. Steps often are combined or further subdivided, but the basic process remains the same. The general steps are as follows:

1. Identify objectives.

Your watershed management goals and objectives are at the heart of planning. *Goals* are broad statements of desired outcomes. *Objectives* can be thought of as measurable accomplishments to meet specific goals. Objectives are broader than actions, but more specific than goals.

For example, a goal might be to improve salmon spawning habitat in a watershed. An objective to achieve this goal might be to improve the quality of riparian habitat along a certain stream to provide a future source of large woody debris to the stream.

Set goals and objectives based on knowledge about your specific watershed as well as on broader management directives and constraints. These directives include policy statements such as the Oregon Plan for Salmon and Watersheds and legal mandates such as the Endangered Species Act and Clean Water Act. On private lands, personal or corporate needs and values are of similar importance. The exercise at the end of this chapter is designed to help your group identify and prioritize objectives.

2. Identify constraints.

Constraints often include economic considerations, regulations, and organizational or administrative limitations. They help define what it's possible to achieve.

3. Assess or inventory resources.

A comprehensive watershed inventory provides key information for planning. Satterlund and Adams (1992) describe the categories of information that are essential to most watershed inventories. They include: watershed boundaries, property boundaries and uses, terrain, geology and soils, climate, stream hydrology, water quality, vegetation, construction features, and other resource information.

A watershed assessment should provide an excellent inventory of resources in a watershed. The *Oregon Watershed Assessment Manual* developed by the Governor's Watershed Enhancement Board (GWEB) provides an excellent way for watershed councils to conduct a watershed assessment.

4. Develop alternative actions.

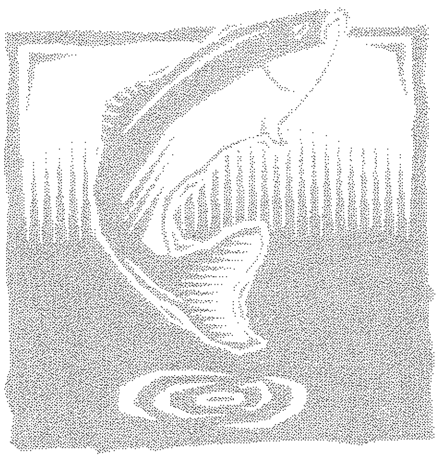
There are two levels of alternatives–strategic and tactical. *Strategic* alternatives concern long-term, basin-wide actions. They usually cover a 5–10 year time horizon and identify projects that could accomplish management goals and objectives. Watershed planning usually is strategic in nature and identifies projects to accomplish in specific subbasins or stream reaches.

Tactical alternatives concern short-term, local actions. Tactical planning is best conducted on a project-by-project basis.

For example, a strategic alternative to achieve the objective of improving riparian habitat might be to increase the number of conifer trees growing in the riparian area of a particular stream reach to a certain level over time. A tactical action or specific project to help achieve this objective might be a riparian tree planting or release project.

5. Rank and select alternatives to implement.

Few human endeavors have all of the resources they need. Thus, you usually need to prioritize alternatives and select a subset for implementation. There are lots of ways to select from a group of alternatives. Two are discussed below.



Using criteria to rank alternatives

Many approaches rely on comparing alternatives to a set of criteria and ranking them on how well they achieve each criterion. Examples of criteria include:

- *Ability to achieve objectives*: You'll want to choose alternatives that clearly contribute to achievement of your management objectives.
- *Ability to influence change*: Make sure the alternative is within your group's sphere of influence and your ability to influence change. For example, a particular large landowner may not want to cooperate with a watershed group in improving the riparian area along a particular stream reach. The group may not have the ability to influence change along this stream at present so it probably would be better off putting its efforts into other stream reaches.
- *Delay between actions and results*: Some alternatives lead to short-term changes, while others take a long time to show results. Your group needs to know what level of delay is acceptable. For example, planting conifers in a shrub-dominated riparian area will take a very long time (more than 100 years) to improve salmon rearing habitat by increasing the amount of large woody debris in the stream. Although this may be the best long-term solution, you also may need to choose other alternative ways to improve habitat in the short term.
- *Cost/benefit ratio*: Do the costs outweigh the benefits or do the benefits outweigh the costs? It can be difficult to put a monetary value on the benefits of a project, but the costs usually can be readily calculated. One way to do a cost/benefit analysis is to compare the cost of alternative ways to achieve a given benefit.
- *Educational value*: Watershed groups need landowner cooperation, which can be improved through education. Projects that have value as demonstrations can help achieve this objective.

You may want to give the most important criteria the heaviest weights. Then you can rank alternatives by how well they achieve the criteria. Next, use budget information and other constraints to decide how many of the ranked alternatives your group can achieve in a given period of time.

An alternative method for prioritizing activities

Another approach to prioritizing watershed protection and restoration activities is given in the *Handbook for Prioritizing Watershed Protection and Restoration to Aid Recovery of Native Salmon* (Bradbury et al., 1996). This approach focuses on protecting undisturbed areas and first removing the worst sources of sedimentation and other problems.

The handbook includes a general discussion of protecting and restoring salmon and aquatic ecosystems. It then discusses prioritizing geographic areas, river basins, and watersheds for protection and restoration. Finally, it describes a procedure for prioritizing watershed protection and restoration activities.

It is important that projects be prioritized by a team with adequate technical expertise to analyze the proposed projects. The team also should represent the diverse interests within your watershed.

Prioritization starts with a checklist of questions about proposed enhancement projects. These questions address:

- Predevelopment condition
- Historical changes in watershed condition
- Current conditions
- Probable trends
- Desired future conditions
- Restoration potential
- Monitoring and evaluation

Based on responses to the questions, project reviewers identify a restoration strategy or select projects using the following priorities for watershed restoration:

- Remove or stop human-caused degradation.
- Allow the watershed time to recover naturally.

Identify restoration activities that will return watershed processes to as natural a condition as possible as quickly as possible.

If there isn't enough information to identify a restoration strategy using this checklist, the handbook recommends that projects be selected based on their potential to achieve the following objectives:

- Treating and reducing upslope hazards
- Allowing the riparian ecosystem to recover by stopping negative impacts from damaging activities
- Redoubling protection efforts

6. Develop an implementation timeline or action plan.

After identifying actions, you may want to create a timeline or action plan for each one. List actions in chronological order. Include proposed start and end dates, total costs, and other pertinent information. You'll further develop this action plan through project-level planning, which provides specific project details.

7. Monitor implementation success.

Monitoring ensures that planning is more a process than a product. Monitor projects to see how well they achieve your objectives. Include this information in the planning document and use it as feedback for further planning.

TYPES OF PLANS

As indicated earlier, planning takes place on many levels. Many kinds of plans may be involved in your watershed. A few are discussed below.

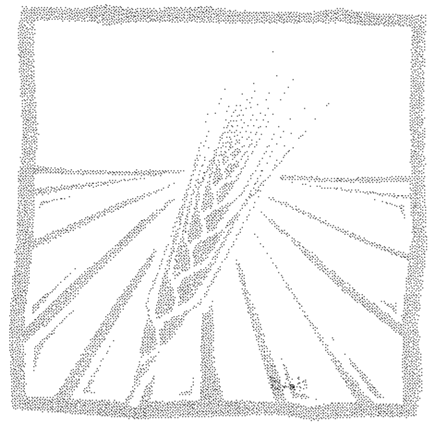
Watershed action plans

The steps above describe a generalized version of watershed action planning. This is the type of planning that most watershed groups do. The Governor's Watershed Enhancement Board (GWEB) is developing a planning process for watershed councils.

Water-quality plans

Senate Bill 1010 and the Oregon Plan for Salmon and Watersheds (Healthy Streams Partnership) direct the Oregon Department of Agriculture (ODA) and the Department of Environmental Quality (DEQ) to develop water-quality plans for 91 subbasins. These plans identify voluntary actions to be taken by landowners to help achieve nonpoint source (NPS) water pollution standards required by the federal Clean Water Act. See Chapter III-7, "Incentives and Regulations," for more information.

Individual farm plans



Landowners in subbasins identified in SB 1010 who choose to participate in basin-wide water-quality plans can get help developing individual farm plans. These plans identify voluntary actions the landowner can take to help achieve water-quality objectives.

Coordinated resource management plans

The Coordinated Resource Management Planning (CRMP) process represents a successful model for planning on a subbasin or stream reach basis. Participants may include landowners as well as federal and state agencies. The CRMP process commonly is used in eastside rangeland situations, but also works in westside situations to address watershed management concerns.

CRMPs usually fall between watershed action plans and individual farm plans. They identify specific projects to be carried out by a group of landowners to achieve a limited set of objectives within a subbasin or stream reach. CRMPs typically are coordinated by local Soil and Water Conservation Districts and the USDA Natural Resources Conservation Service.

Woodland management plans

Individual forestland owners often develop woodland management plans. Through planning, landowners document objectives and constraints, inventory resources, develop alternative actions, prioritize actions, develop implementation timelines, and establish monitoring and recordkeeping methods. Landgren and Bondi (1983) present a useful guide for woodland management planning. This model also can be used for other types of plans by individual landowners.

SUMMARY/SELF REVIEW

Planning is a decision-making process focused on future actions. It will help you achieve your objectives as completely as possible within the limits of your resources and the constraints you face. It helps you communicate what you want to accomplish to funding agencies, government agencies, other watershed groups, and your own members.

Planning also forces you to organize your thoughts and actions in a way that can be defended and makes you document your decision-making process. Having plans on paper can make the proposed actions seem very real and concrete.

Planning takes on many forms, which usually share the same basic steps. The steps include:

1. Identifying objectives
2. Identifying constraints
3. Assessing available resources
4. Developing alternative actions
5. Ranking and selecting alternatives to implement
6. Developing an implementation timeline
7. Monitoring implementation success

There are many kinds of plans involved in watershed work. Examples include watershed action plans, water-quality plans, individual farm plans, coordinated resource management plans, and woodland management plans.

Exercise

This exercise will help you identify and prioritize objectives for a watershed. It's appropriate for a Watershed Council Planning Committee or any other group that will be working together to develop a plan.

Identifying objectives (snow card exercise)

1. Give each participant three to five 3" x 5" cards. The number of cards per person depends on the number of participants. You probably don't want to have more than 100 cards in total.
2. Ask participants to write on each card a specific objective they would like to see the watershed group achieve in the next 5 years. Remember, objectives can be thought of as measurable accomplishments. They are broader than actions, but more specific than goals.
3. Have the participants put a piece of masking tape on the back of each card and tape the cards to a wall. The cards will cover the wall like snow; hence the name snow card exercise.
4. Have either the whole group or a subgroup put similar cards together in columns or categories. This step is important, so don't rush. Sometimes it's helpful to write one or two words on a larger card to name each category. Try to have no more than 10 categories. You may need a catch-all or miscellaneous category.
5. Review the categories as a large group. Try to agree on which objectives belong together.
6. Divide the large group into small groups of three or four people. Give each small group one or more categories of cards. Ask each group to write a one-sentence objective that covers the ideas on the cards in each of their categories. Then they'll write their objective or objectives on a flipchart. This list represents the group's objectives.
7. The large group then can validate or prioritize the objectives. This step can be done by preference voting or through discussion.

RESOURCES

"Handbook for prioritizing watershed protection and restoration to aid recovery of native salmon," by W. Bradbury, W. Nehlsen, T.E. Nickelsen, K.M.S. Moore, R.M. Hughes, D. Heller, J. Nicholas, D.L. Bottom, W.E. Weaver, and R.L. Beschta. In *Healing the Watershed: A Guide to the Restoration of Watersheds and Native Fish in the West* (Pacific Rivers Council, Inc., Eugene, OR, 1996).

Management Planning for Woodland Owners: An Example, EC 1126, by C. Landgren and M. Bondi (Oregon State University Extension Service, Corvallis, 1983).

Management Planning for Woodland Owners: Why and How, EC 1125, by M. Bondi and C. Landgren (Oregon State University Extension Service, Corvallis, 1983).

Putting Together a Watershed Management Plan: A Guide for Watershed Partnerships (Conservation Technology Information Center, West Lafayette, IN, 1997). Available from CTIC, 1220 Potter Drive, Rm. 170, West Lafayette, IN 47906; phone: 317-494-9555; fax: 317-494-5969; Web: http://www.ctic.purdue.edu/Catalog

Wildland Watershed Management, 2nd edition, by D.R. Satterlund and P.W. Adams (John Wiley & Sons, Inc., New York, 1992).

Moving Forward–The Next Steps

On your own, use the lines below to fill in steps, actions, thoughts, contacts, etc. you'll take to move your land management agency, watershed group, etc. ahead in improving your planning skills.

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Watershed Science

Paul W. Adams
and Derek Godwin

Watersheds are like a patchwork quilt over the landscape; they're made up of many pieces that fit together to make a whole. And because of their many connections, what happens on one patch can affect other pieces far away.

As your watershed group starts thinking about what it can do to effectively manage and restore portions of your watershed, don't bypass the important first step–understanding how watersheds work. Especially important are the watershed processes that affect how water, sediment, and other materials behave in an ever-changing landscape.

A watershed provides a very useful setting for studying and understanding these processes. But what is a watershed and how is one identified? It's an area of land that collects rain and snow and discharges much of it to a stream, river, or other water body. The specific water body of concern is what defines the watershed. If the Columbia River is this water body, the watershed is an area of about 255,000 square miles covering parts of seven states and two Canadian provinces.

Big watersheds such as the Columbia River basin are made up of lots of smaller watersheds. Some of these watersheds are near ridgetops and feed small streams that flow only part of the year. The ridgetop-to-riverbank perspective reminds us that almost any resource management practice or land use has the potential to affect water

IN THIS CHAPTER YOU'LL LEARN:

- The general pattern of water movement known as the hydrologic cycle
- Upland erosion
- Sediment transport and deposit in stream channels

resources downstream. Likewise, the unique natural features (geology, soils, etc.) and processes of each watershed can directly influence water resources, as well as how human activities affect these resources.

Looking at both natural processes and human influences from a watershed perspective is vital for dealing with concerns such as declining fish stocks. Fish such as salmon and steelhead, for example, can be affected by ocean conditions, urbanization, agriculture, and forestry during their long, complex life cycle. Many different areas, landowners, and practices need to be involved to effectively manage such key resources. An understanding of watershed processes can help focus everyone's efforts.

See Section II, Chapters 4 and 7 for information related to this chapter.

IDENTIFYING WATERSHEDS

In areas where bedrock is found within about 20 feet of the soil surface, visible terrain can be fairly reliable for identifying watershed boundaries. U.S. Geological Survey (USGS) ***topographic maps*** identify the ridges and other high points that separate one watershed from another. The map in Figure 1 shows the boundary of a large watershed as well as those of some of the smaller tributary basins that make up the larger watershed.

USGS topographic maps are available for most areas in Oregon. You can get them from a variety of sources, including outdoor and sporting goods suppliers, bookstores, and college and university libraries. For mail orders, a catalog of USGS maps and information is available from:

USGS Information Services
Box 25286, Federal Center
Denver, CO 80225
Phone: 1-800-USA-MAPS

A list of Oregon retail outlets for USGS maps also is available on the Web at http://www-nmd.usgs.gov/esic/usimage/test/or.html

THE HYDROLOGIC CYCLE

To understand how watersheds behave, both naturally and under management, it's essential to understand the general pattern of water movement called the ***hydrologic cycle.*** Figure 2 highlights the key parts of the hydrologic cycle, which also are defined briefly below. Most are discussed in greater detail later in this chapter.

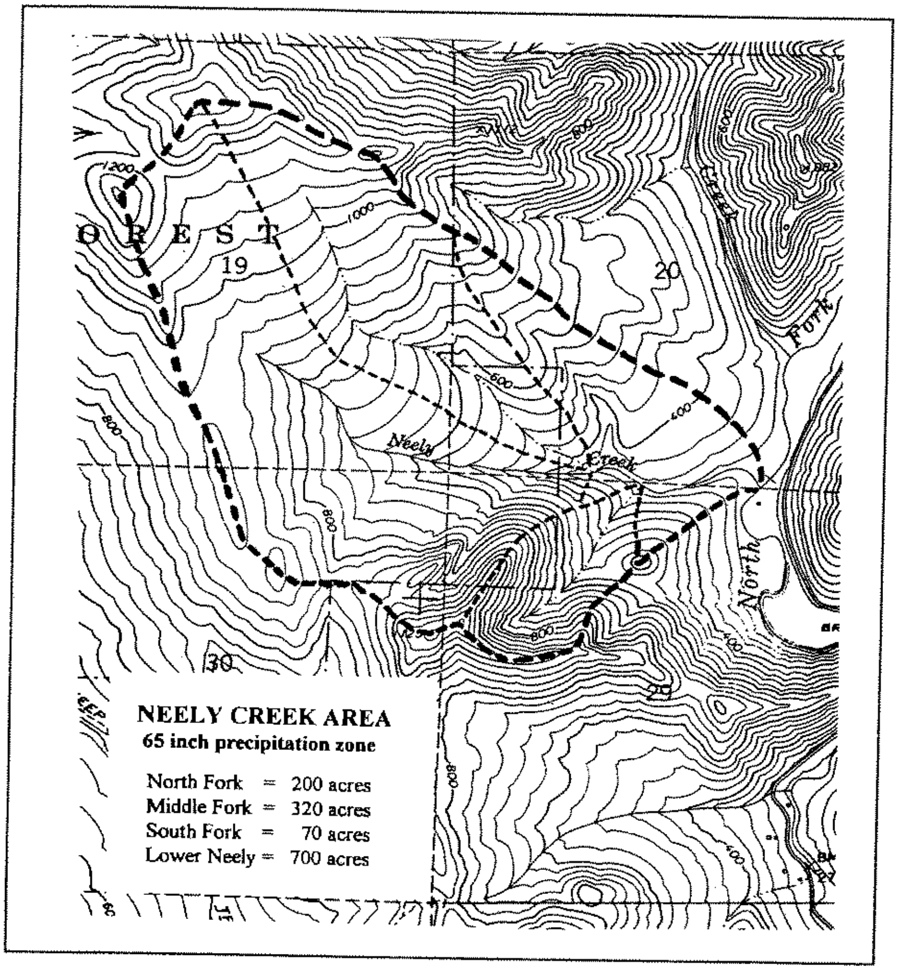

Figure 1.—*Precipitation zone map showing watershed boundaries (dashed lines).*

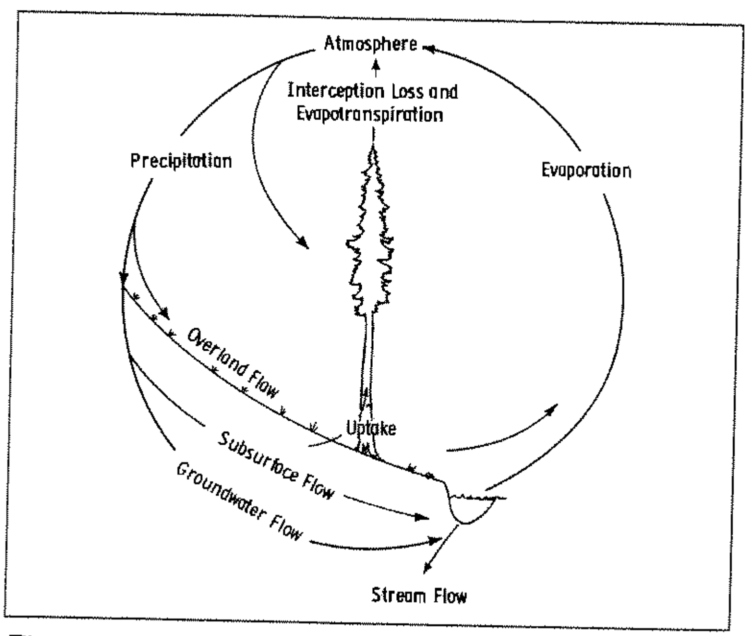

Figure 2.—*Forest hydrologic cycle. (Source: U.S. Forest Service)*

- *Precipitation*: Water from the atmosphere that reaches plants, the ground, or water bodies. Depending on local weather conditions, precipitation may be deposited in many forms, including rain, snow, sleet, hail, and condensation (dew, frost, etc.).
- *Interception*: The action of plant surfaces catching precipitation that otherwise would reach the ground. Depending on local weather conditions and the plant canopy characteristics, intercepted precipitation may evaporate quickly, leaving less water to reach the ground and contribute to stream flow.
- *Overland flow* or *surface runoff*: Water from precipitation that moves over the ground surface.
- *Subsurface* and *groundwater flow*: Water that flows through the soil and underground rock crevices.
- *Transpiration*: The uptake of soil water by plants and its evaporation to the atmosphere through leaves and other plant surfaces.
- *Evapotranspiration*: The loss of water to the atmosphere by the combined effects of interception, transpiration, and direct evaporation from ground surfaces and water bodies.

Precipitation

Precipitation is the single most important influence on the flows in forest streams. The type and amount of precipitation in Oregon varies widely by location, season, and year. In addition to rain and snow, "fog drip" from trees or other plants can contribute significant amounts of water to soils and streams in areas where heavy fog is common.

Precipitation usually is measured with a device called a *gauge* that has a funnel or other opening to collect water falling from the open sky. As precipitation accumulates in the gauge, its depth is measured in inches. Some mechanical or electronic gauges monitor precipitation continuously. Others use simple containers that a person checks manually at regular intervals, such as 24 hours or a week.

Although snow depths often are reported in inches, for hydrology it's more important to know the amount of water that will melt from the snow. The rule of thumb that 1 foot of snow contains 1 inch of water is a very rough average, and actual water amounts can be much more or less. The effort it takes to shovel snow by hand is good proof of how much snow's water content can vary!

Newspapers and television often refer to "normal" or "average" precipitation levels. These reports can give the mistaken impression that it is unusual to see much more or less precipitation than "normal." Instead, we should expect precipitation to be significantly above or below normal every few years. For example, the long-term precipitation average for Estacada, Oregon is 60 inches. Records show, however, that over a 10-year period we should expect at least 4 years with total annual precipitation at least 8 inches above or below average.

Within a given region or even an individual watershed, precipitation differences can be dramatic. One key factor is elevation. Generally, as elevation increases, so do the amounts of rain or snow.

Another major influence is the local terrain as it relates to the direction that storms typically travel. Because storms in Oregon often move from west to east, more rain or snow usually falls on west-facing slopes.

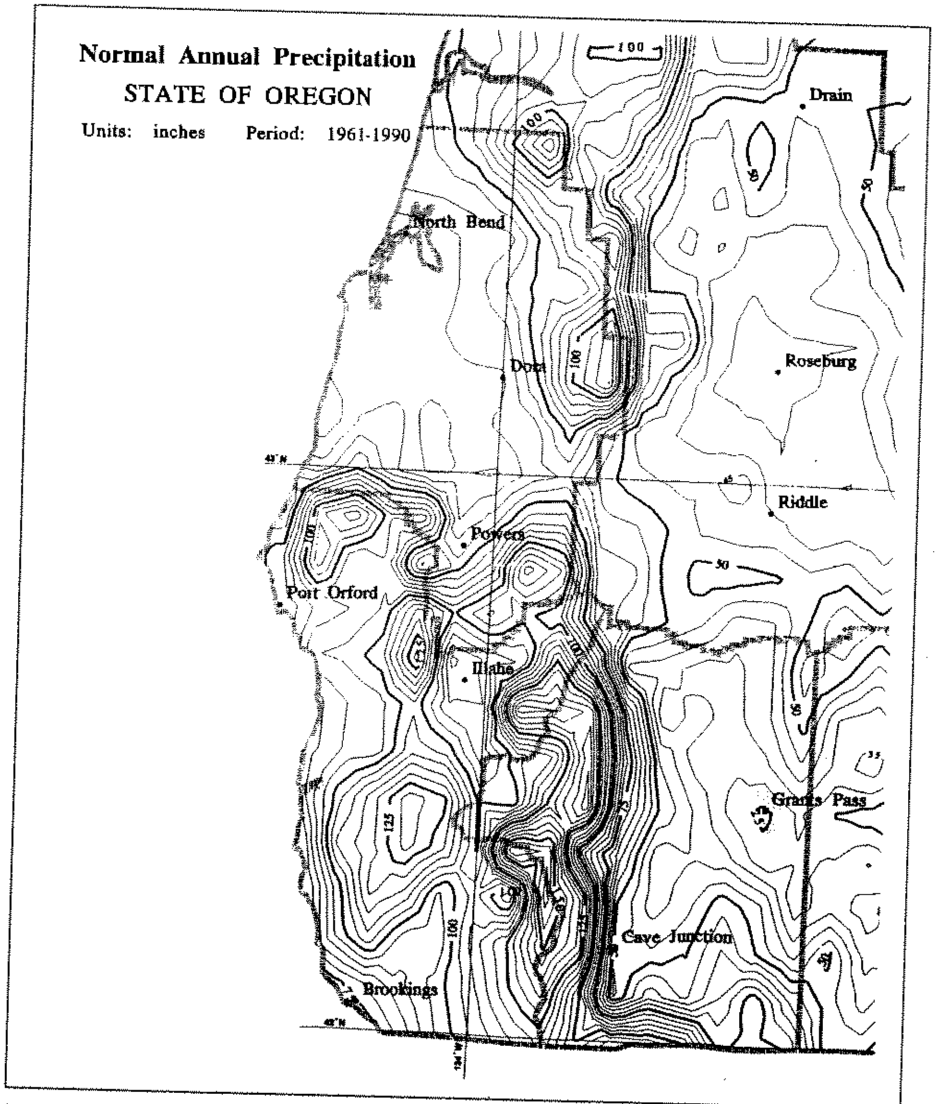

Figure 3.–Normal annual precipitation for Oregon.

An annual precipitation map for Oregon has been published by the office of the State Climatologist at Oregon State University. Part of this map is reproduced in Figure 3. Each line on the map intersects locations that are expected to have the same annual precipitation. Each adjacent line represents a 5-inch increase or decrease in precipitation. The amount of precipitation for locations falling between two lines can be estimated as something between the amounts represented by the surrounding lines.

Oregon's precipitation records and maps typically are based on gauges located at low elevations near major communities. Although useful for general purposes, these records and maps may not provide a very accurate picture of precipitation in small, rural forest watersheds. With careful installation and monitoring, it's possible to collect local precipitation data to see how well it compares with records from nearby weather stations.

Vegetation, soils, and stream flows

Vegetation can have a strong effect on the amount of water available for stream flow. First, when rain or snow falls on the canopy of trees and other plants, some of this water is *intercepted* and evaporates before reaching the soil. Evaporation is especially likely when periods of light rain alternate with dry periods, as often occurs in western Oregon.

Second, water that does reach the soil can be taken up by plant roots before it has a chance to move to the deeper soil layers that contribute to stream flow. In this process, called *transpiration*, water moves from the roots to other plant tissues and eventually to the leaves, where it evaporates from small pores. The loss of water to the atmosphere by the combined effects of canopy interception, transpiration, and direct evaporation from soil surfaces and water bodies is called *evapotranspiration*.

In western Oregon forests, evapotranspiration losses can equal about one-quarter to one-half the total annual precipitation. For example, in an upland forested area where 56 inches of precipitation falls annually, about 20 inches of that water returns to the atmosphere before it reaches deep soil layers or adds to stream flow. Large amounts of deep storage are uncommon in upland terrain in Oregon, so it's reasonable to expect most of the remaining 36 inches to contribute to stream flow.

The calculations below for a 320-acre forest watershed (1 acre = 43,560 square feet) show the total and average stream flows expected from 36 inches of water over a year.

> 3 ft (36 inches) x 13,939,200 sq ft (320 acres)
> = 41,817,600 cu ft total annual flow
>
> Average daily flow = 41,817,600 cu ft ÷ 365 days
> = 114,569 cu ft
>
> Average instant flow = 114,569 cu ft ÷ 86,400 seconds
> per day = 1.33 cu ft per sec (cfs)

Ground surface and soil characteristics also play an important role in how precipitation affects stream flow. Surface conditions determine whether water moves into or over the ground. On most forest soils, even the water from very heavy storms is absorbed. However, where soils are exposed or compacted, or in lower areas with saturated soils, precipitation water may move over the ground as surface runoff that quickly adds to stream flow.

Soil depth and ability to store water also influence stream flow. Moisture storage in soil layers near the surface can affect how much precipitation water is lost by transpiration. Where soil water storage is limited by bedrock within 5–10 feet of the surface, as in many upland forest soils in western Oregon, precipitation water can move fairly quickly to streams. As a result, stream flows respond to individual storms in a "flashy" manner (rising and falling quickly). The stream *hydrograph* (a graph of changing stream flow over time) in Figure 4 shows this type of response.

As an example, Table 1 lists the soil types on the watershed that supplies much of the municipal water for Corvallis as well as soil characteristics that can affect water in this area. Note that most of the soils in this area are well-drained and moderately deep, yet during wet weather they can generate considerable runoff. Note also that one soil (Witham) can be expected to have a shallow *water table* (a layer of saturated soil) during the winter and early spring. You can find similar information on soils in your area by checking your county soil survey, which often is available in local libraries or from the USDA Natural Resources Conservation Service.

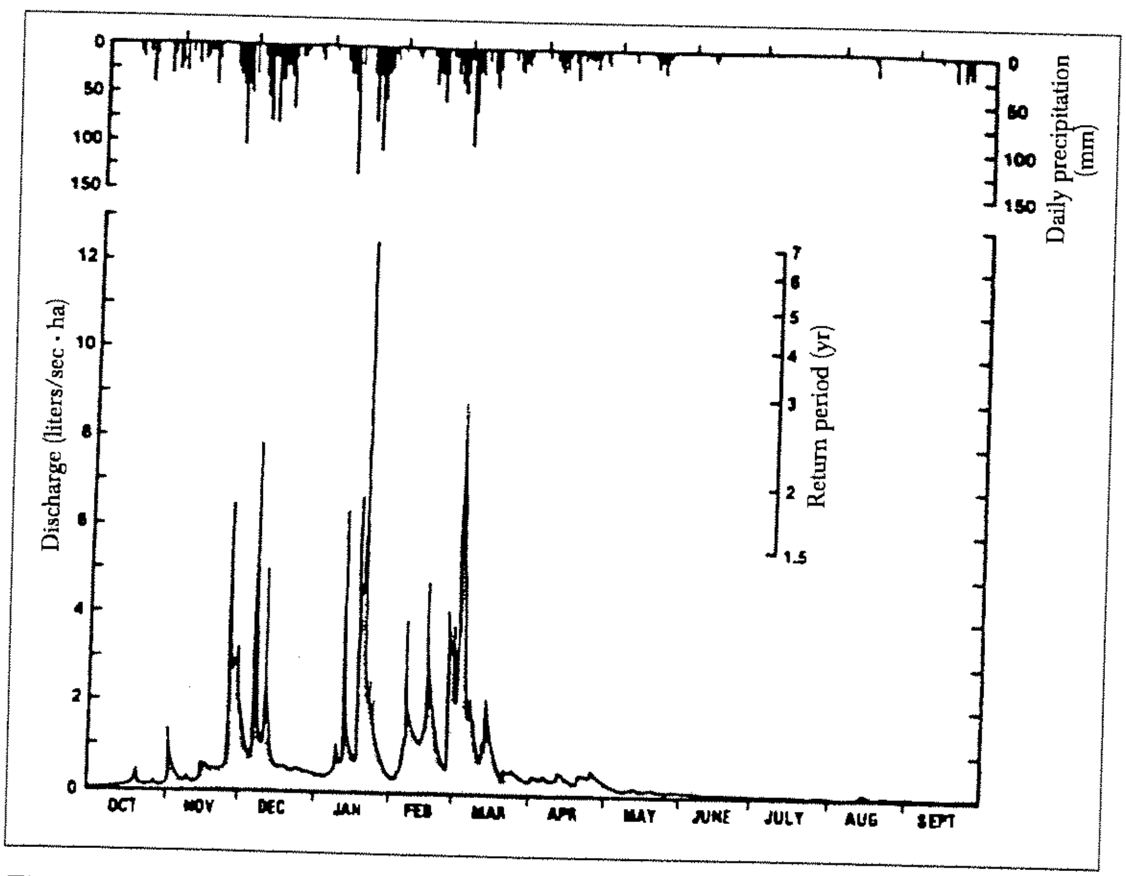

***Figure 4.**–Hydrograph showing daily precipitation and instantaneous stream flow for a forested watershed in the Oregon Cascades, 1972 water year.*

Table 1.–Corvallis municipal watershed-Marys Peak area soil hydrology information (Benton County Soil Survey).

Soil type	Surface permea-bility (in/hr)	Depth to bedrock (in)	Depth to water table (in)	Runoff potential
Abiqua	0.6–2.0	>40	>40	high
Apt	0.6–2.0	>60	>60	high
Blachly	0.6–2.0	>60	>60	high
Bohannon	2.0–6.0	20–40	>60	high
Honeygrove	0.6–2.0	>60	>60	high
Jory	0.6–2.0	>40	>60	high
Kilchis	2.0–6.0	12–20	>60	very high
Klickitat	0.6–2.0	40–50	>60	high
Marty	0.2–0.6	>60	>60	moderate
Mulkey	2.0–6.0	20–40	>60	high
Ritner-Price	0.6–2.0	30–60	>60	high
Slickrock	0.6–2.0	>40	>60	moderate
Witham	0.06	40	12–30	very high

EXTREME EVENTS

Extreme events are periods of very high or very low precipitation or stream flow that may create problems for people, soil, and water. The storms and floods of February and November 1996 were recent and very vivid examples of extreme events. If you have some idea of the size and likelihood of extreme events that can occur in a watershed, you can take more effective steps to prevent or reduce the problems they might cause. For example, you could install a larger road culvert or put large rocks along part of a stream channel to prevent a washout or bank erosion.

One way to identify what might be expected in a given watershed is to look at past precipitation or flow records. Where long-term records are available, it's possible to estimate such events as the "50-year flow" or the "2-year, 1-hour peak rainfall." The 50-year flow is the stream flow level that, on average, is likely to occur about once every 50 years. The 2-year, 1-hour peak rainfall is the maximum total rain for a 1-hour period that is likely to fall once every 2 years.

Another way to look at an extreme event is the probability or likelihood that it will happen. In the case of a 25-year flow, there is a 1 in 25 (or 4 percent) chance that it will occur in any given year. However, it's important to know that for any given 25-year period, a 25-year event may occur once, several times (like the two 1996 storms), or not at all. This is because these *return intervals* are simply averages. From year to year, large storms or droughts occur in a fairly random pattern, although some climate cycles (e.g., El Niño) are becoming better understood and more predictable.

Table 2 shows the peak flow levels expected for several different return intervals for Flynn Creek, a small stream that drains a

500-acre forested watershed in the Oregon Coast Range. The flows are estimated from long-term stream flow records for Flynn Creek.

The stream flows in Table 2 are shown in their most common measurement units, cubic feet per second or *cfs*. Note that flow levels do not increase in direct proportion to the return interval. That is, the 10-year peak flow is not twice as large as the 5-year peak flow, and the 50-year peak flow is not five times as large as the 10-year peak flow.

Table 3 shows the estimated 1-hour peak precipitation amounts for the Oregon Coast Range, based on historical records. By comparing these figures with the local *infiltration* characteristics of the soil (that is, the rate that a given volume of water can move into the soil surface), we can determine whether rain that falls during these heavy storms is likely to be absorbed by the soil or will become surface runoff. This distinction can be important because surface runoff can lead to erosion or add to peak stream flows.

Surface soil *permeability* represents how much water can be absorbed by the soil in an hour. The values in Table 1, which are as low as 0.06 inches per hour, show how it's possible for peak rainfall to be greater than the rate the mineral soil can absorb. However, these values do not include the effect of the highly absorbent *duff layer* (accumulated organic debris such as fallen leaves) that usually is found on top of the mineral soil in forests. Thus, surface runoff is rare on these lands unless significant areas of mineral soil are exposed or compacted.

Table 2.–Flynn Creek peak flows.

Return interval (years)	Stream flow (cu ft per sec)
2	73
5	111
10	153
25	234
50	321

Table 3.–Peak precipitation, Oregon Coast Range.

Return interval (years)	1-hour maximum precipitation (in)
2	0.6
5	0.8
10	0.9
25	1.1
50	1.3

Upland processes

Important links between uplands and streams can be found in every watershed. Stream hydrology and channel characteristics, for example, often reflect things that happen on the surrounding uplands. These upland processes and events may be very obvious or subtle, but they can be very important to stream characteristics, both locally and a long way downstream. Chapter II-4 discusses evaluation and enhancement of upland areas.

Erosion is one of the most important upland processes, because it helps shape landscapes, how trees and plants grow, and streams themselves. For example, erosion of topsoil in mountain terrain can limit plant growth, but deposits of these rich sediments can make floodplains and other lowland locations among our most productive sites. Similarly, heavy erosion and sedimentation can harm fish, but spawning gravels originate from erosion, and seasonal increases in fine sediment in stream water help salmon determine when and where to spawn.

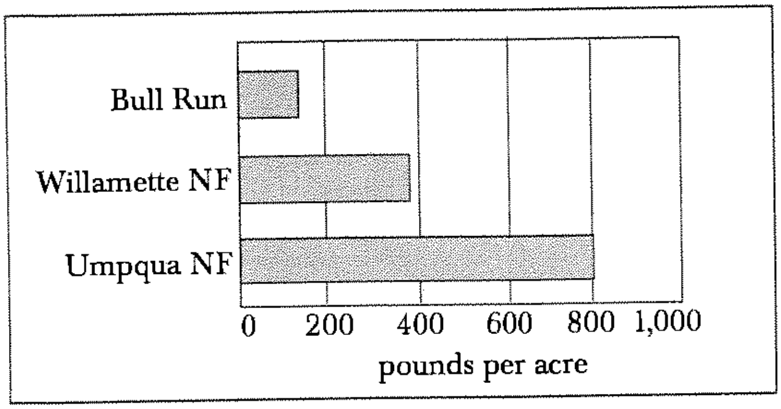

***Figure 5.**—Average annual erosion, undisturbed forests.*

Erosion is a natural, ongoing process, but erosion types and rates vary widely with local climate, soils, terrain, and vegetation (Figure 5). Erosion often increases during periods of unusually heavy rainfall or rapid snowmelt. Human activity can increase erosion to levels that cause problems for upland and aquatic systems, and controlling such erosion often is a primary objective of watershed management and restoration.

Surface erosion is the movement of individual soil particles, usually by water flowing over exposed soil surfaces. If rainfall or snowmelt exceeds the local soil infiltration rates, surface erosion may occur, especially on steep slopes where runoff water can develop more erosive energy.

Some soil types are more susceptible to surface erosion than others, usually because they have low infiltration rates and/or the individual soil particles are easily detached and moved. Most forest soils in the Pacific Northwest have fairly low surface erosion rates, especially when the duff layer is maintained and infiltration remains high.

Mass movement refers to landslides and others types of downhill movement of large masses of soil and related material (e.g., rocks and woody debris). Mass movement is a very important process in many areas of the Pacific Northwest, including the steep terrain of the Coast and Cascade Ranges. Mass movements can be rapid and dramatic, or very slow and subtle (Figure 6).

Debris avalanches or *slides* are shallow, rapid mass movements that are most common in steep, upland areas with thin soils over bedrock. If debris avalanches or slides reach a stream channel, they may become very fluid and change to a *debris flow* (sometimes also called a *debris torrent*). These flows can scour extensive lengths of stream channels, but they also may deposit a lot of sediment and other debris where they stop.

In areas of deep, fine-textured soils, large, slow mass movements such as *slumps* and *earthflows* can occur. These may move only inches per year, and clues of movement may not be very obvious (e.g., leaning trees or soil cracks). Like the other types of mass movements, they can be important sources of sediment and debris in streams.

STREAM CHANNELS

There are many different kinds of stream channels, and an understanding of their characteristics and behavior can be very useful in watershed management. For example, the kinds of stream restoration and enhancement needed can vary widely among different channel features and types. Channel processes are an especially important consideration, because many channels are active and changing. When enhancement practices and channel dynamics are not carefully matched, the result may be little or no benefit or even worsened conditions.

Stream order

Stream order is a useful way to classify streams because within a given climatic and geologic region, certain stream orders tend to share many features and processes. The most common stream order classification system is to call the initial channel where a small stream first appears a *first-order stream*, and then to increase the order with each successive downstream junction with a stream of equal or higher order. Thus, small streams have low order numbers, while large streams and rivers have high order numbers (Figure 7).

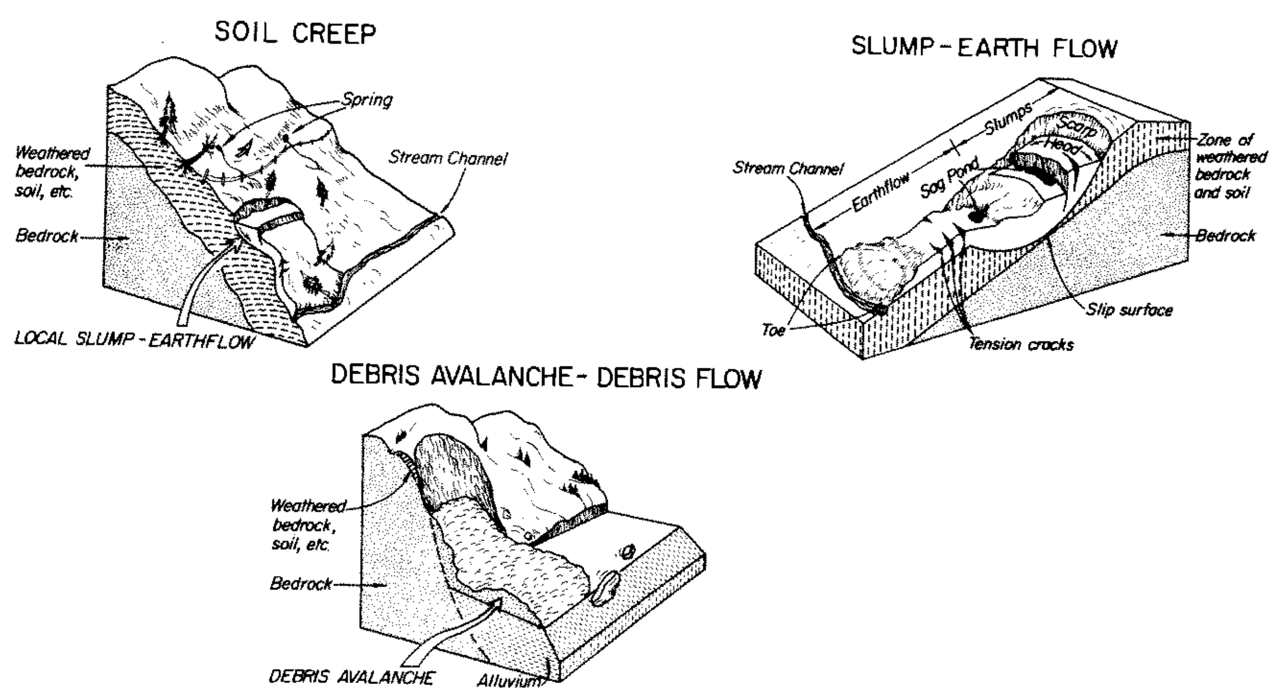

***Figure 6.**—Types of mass movement.*

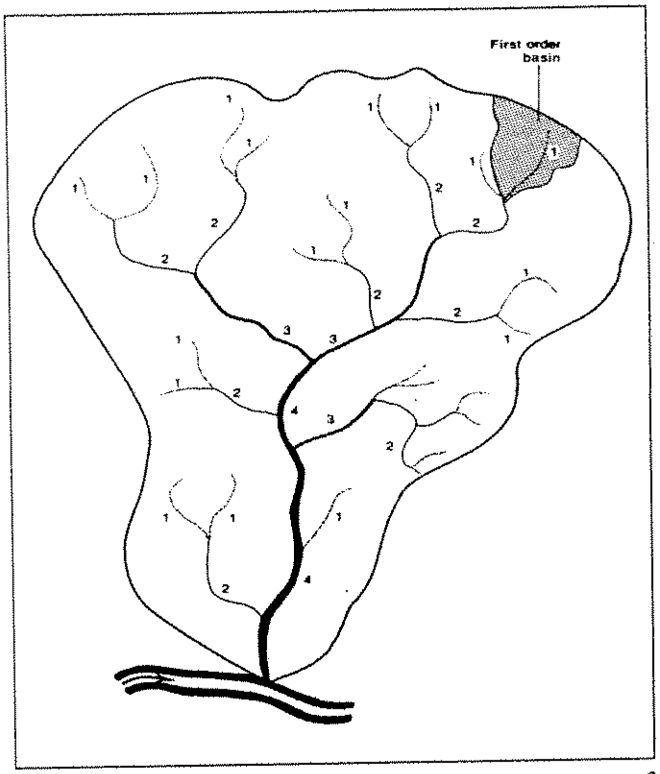

Figure 7.–Stream orders according to Horton's system of classification. (Source: Principles of Forest Hydrology, *J.D. Hewlett, 1982)*

Major channel features and types

In low areas with little slope, where valleys have formed or broadened, both large and small streams may have *floodplains, levees,* and *terraces* that can interact with the stream (Figure 8). These areas also have soil conditions, vegetation, and other important features that can be different from the nearby steeper uplands.

The shape and movement of a stream channel may be *confined* (the term constrained also is used) by resistant bedrock or large boulders. On the other hand, where streams are found in deep soils, gravels, and other easily moved material, channels may migrate or become *braided* (i.e., form secondary or smaller side channels), especially as flows change. Stream migration in unconstrained settings also often results in greater stream *sinuosity,* which is the winding or snakelike pattern of a stream. Figure 9 illustrates different channel types.

Stream channel processes

Most streams, especially those in soil and other loose material, have areas of active *channel erosion* and *sediment deposition* (Figure 10). The terms *degradation* and *aggradation* also sometimes are used to describe channel erosion and deposition processes. It's easy to see erosion on stream banks, especially during high flows. Erosion of streambed materials also may be important but less obvious. Areas of sediment deposition are common in most streams, and may be found even near eroded areas.

Channel slope *steepness* (or *gradient*) and *sediment particle size* are important factors that can control erosion and deposition in streams. Fast-moving water in steep streams can promote channel erosion, while slow-moving water in more level areas can allow eroded sediments to be deposited.

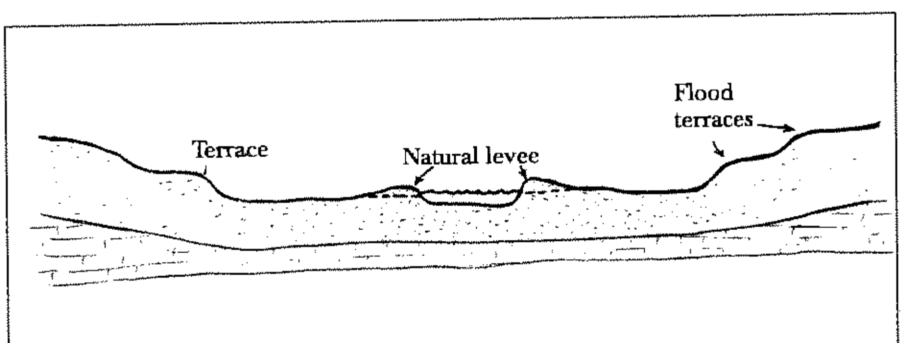

Figure 8.–Terraces and levees.

Faster water also allows coarser channel materials to erode and move some distance. When fine sediments (e.g., clays) erode, even slow-moving water can carry them long distances. Eroded sediments can be deposited in the stream channel wherever flows become slower, such as the inside of channel bends or where a stream becomes significantly wider (e.g., unconfined by surrounding terrain) or less steep. Gravel or sand bars are a common type of such deposits.

Levees, terraces, and deltas often form near larger (high-order) streams and rivers in wide, level areas where water has deposited sediment during high flows. Their location and landform often lead to unique soil and vegetation conditions that may be important to consider in watershed restoration and enhancement projects.

The dynamic and interacting processes of channel erosion and deposition can extend over long distances and can be linked to the upland processes described earlier. The success of watershed restoration and enhancement projects may depend on your understanding of these processes

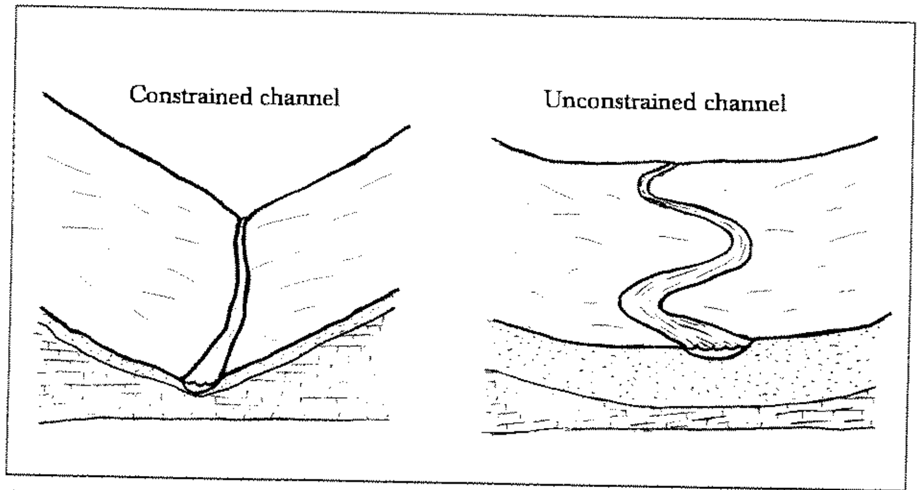

***Figure 9.**—Channel types.*

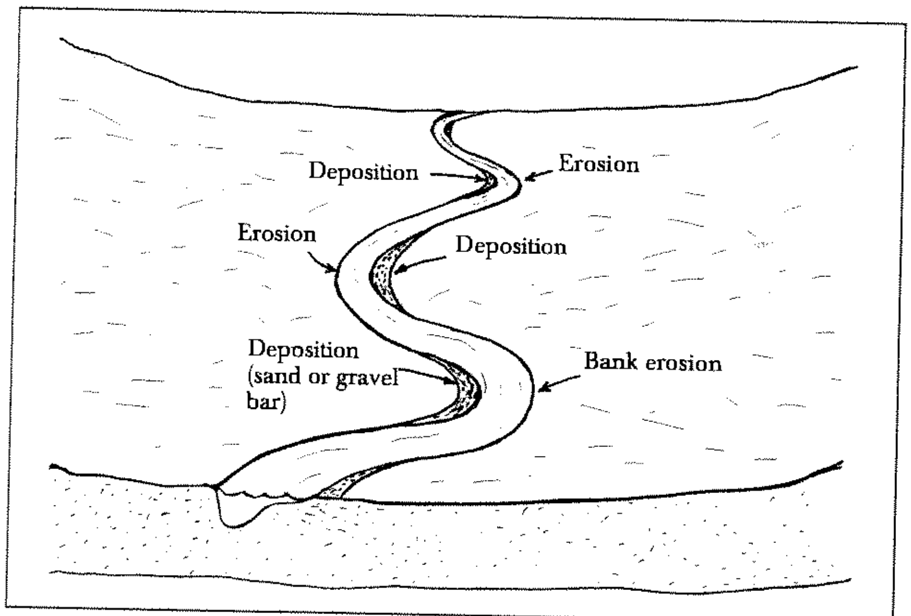

***Figure 10.**—Examples of erosion and deposition.*

Summary/Self review

Watersheds are very dynamic, and certain processes are particularly important in both the characteristics and management of watersheds. Key processes and related concepts that can help you better understand watershed features, behavior, and response to management practices include:

- Location is the most fundamental watershed characteristic, and its identification is the first step to understanding key watershed features and behavior. Topographic maps provide a simple, useful tool for locating general watershed boundaries.
- Hydrologic cycle components such as precipitation (i.e., type, amount, and distribution) have a major influence on important upland and stream characteristics. Soils and vegetation play a primary role in water storage, release, and evapotranspiration loss. Published precipitation, soil, and stream flow data are helpful resources, but you may need to collect local data to better understand your watershed.
- Most major natural and management-related watershed impacts occur during extreme events of precipitation and stream flow. Understanding and planning for such events are essential for effective watershed management and restoration.
- Upland processes of erosion are a key link between land and stream. Surface erosion and mass movements are especially important influences on sediment and debris in streams.

Stream channel features and processes vary widely within and among watersheds. Characteristics such as channel slope, confinement, and bed and bank materials can have strong effects on channel stability and responses to management.

Exercises

These exercises will help you become familiar with basic techniques and equipment for measuring key hydrologic characteristics of watersheds. In addition, by making multiple measurements, you'll begin to see and appreciate the high natural variability common in these data. This variability presents one of the major challenges in collecting and interpreting hydrologic data.

It will be helpful to do these exercises with someone familiar with the procedures who can give you additional explanation and demonstration.

Measuring precipitation

You can purchase simple rainfall precipitation gauges at garden or farm supply centers. Often, these gauges are made of clear plastic and have depth markings on the side. The water collection part may be wedge-shaped or narrower at the bottom so that small rainfall amounts are measured more accurately. You also can measure precipitation with large cans or wide-mouth jars of a uniform size, but the measurements usually are less accurate.

To generate the most useful and interesting data, sample at contrasting locations and at consistent time intervals. For example, you could use the following sampling scheme with nine rainfall gauges to see some potential effects of elevation and forest cover, and the variability among different samplers:

- 3 gauges–low elevation, open settings (suburban yard, urban office roof, etc.)
- 3 gauges–low or high elevation, under forest canopy
- 3 gauges–high elevation (>1,000 feet), open setting (clearcut, meadow, etc.)

Ideally, measure the amount of rainfall shown by the gauge once every 24-hour period for several months. This schedule would allow you to compare your data with data from local weather stations or soil surveys (e.g., soil drainage rates). For example, most weather stations are located at lower elevations near cities and towns, and precipitation often increases with greater elevations.

Fewer gauges and a less ambitious sampling schedule still could produce some interesting information, e.g., measurements from two or three gauges taken every 3–7 days for 2–3 weeks during the rainy season. Keep in mind that some water may evaporate from gauges that are checked less frequently.

Measuring stream flow and channel morphology

Choose a small stream (e.g., channel <10 feet wide) with access along at least 200 feet of stream length. Identify a channel cross-section to use for repeated flow measurements on different sampling days. Stream width and depth measurements are taken to provide estimates of cross-sectional areas of the stream.

(continued)

Measuring stream flow and channel morphology (continued)

For general flow estimates, first measure the width of the flowing stream. Then identify at least five evenly spaced points across the stream where you'll measure stream depth and velocity. A tape measure stretched across and anchored on each stream bank makes these steps easier. A yardstick or longer measuring rod can be used for depth measurements.

Now take velocity measurements at about one-half the stream depth at each sample point. Use a velocity meter if available; otherwise, you can make rough estimates with a float and stopwatch. Velocities differ across the width and depth of a stream, with the highest velocities often found at the center surface. Multiply each velocity by each stream depth measurement and the width between sample points to estimate flow rates (i.e., cubic feet per second) for the water column at each sample point. For example:

2 ft per sec velocity x 3 ft depth x 4 ft stream width represented at sample point
= 24 cu ft per sec flow at sample point

Sum the flows from each sample point to get a total flow rate for the stream.

To observe important natural variations in stream flow, repeat the flow measurement over time. For example, take weekly measurements for 1 or 2 months, or hourly or daily measurements during a major, extended storm. If possible, compare these observed flow patterns with those collected at gauging stations on nearby streams or rivers (e.g., data available on the Web at http://wwworegon.wr.usgs.gov/).

Stream channel morphology (i.e., physical form) can reflect or influence some important stream characteristics and processes, so some basic morphology measurements and observations can be helpful in understanding and managing watersheds. Because morphology can vary over even short distances, it's important to examine enough stream length to encompass some of this variation (e.g., at least 200 feet, with key measurements taken every 20–50 feet).

Channel slope is important because of its influence on stream velocity and erosion, transport, and deposition of sediment and organic debris. A clinometer is a simple tool for estimating channel slope, provided you take care to backsight to a point of equal height (a two-person crew using sighting staffs works well). A hand or engineering level provides more accurate measurements, especially for low-gradient stream sections.

Other observations can be made using a measuring tape and staff, including channel width and depth. In addition, it's often useful to note the degree of channel confinement, meander, etc. What could happen in and near the channel during very large storms or rapid snowmelt? During an extended drought?

Resources

Training

Regular public training specifically on watershed processes is not widely available outside of formal university classes, although some basics may be reviewed as part of short courses and seminars offered by various organizations. You can learn about available training opportunities by maintaining good communication with government agencies and other groups. In addition, many textbooks and other references are available (see list at the right) if you're interested in self instruction.

Information

Forestry and Water Quality, 2nd ed., by G.W. Brown (OSU Book Stores, Inc., Corvallis, OR, 1985). 142 pp. ISBN 0-88246-007-2

Hydrology and the Management of Watersheds, by K.N. Brooks et al. (Iowa State University Press, Ames, 1991). 392 pp. ISBN 0-8138-0137-0

Principles of Forest Hydrology, by J.D. Hewlett (University of Georgia Press, Athens, 1982). 183 pp. ISBN 0-8203-0608-8

Stream Dynamics: An Overview for Land Managers, USDA Forest Service General Technical Report RM-72, by B.H. Heede (Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO, 1992).

Water in Environmental Planning, by T. Dunne and L.B. Leopold (W.H. Freeman and Co., New York, 1978). 818 pp. ISBN 0-7167-0079-4

Water Resource Measurements—A Handbook for Hydrologists and Engineers, by B.P. Van Haveren (American Water Works Association, Denver, 1986). 132 pp. ISBN 0-89867-345-3

Watershed Hydrology, 2nd ed., by P.E. Black (Ann Arbor Press, Ann Arbor, MI, 1996). 425 pp. ISBN 1-57504-027-1

Wildland Watershed Management, 2nd ed., by D.R. Satterlund and P.W. Adams (John Wiley and Sons, Inc., New York, 1992). 436 pp. ISBN 0-471-81154-8

MOVING FORWARD–THE NEXT STEPS

On your own, use the lines below to fill in steps, actions, thoughts, contacts, etc. you'll take to move yourself and your watershed group ahead in understanding the key concepts of watershed science.

1. ____

2. ____

3. ____

3

Assessment and Monitoring Considerations

Paul W. Adams

"We should do some monitoring" is a common response when concerns are expressed about local watershed conditions or resources. But you need to consider many issues before acting on this idea. There's a long list of potentially useful watershed characteristics that can be assessed, and an even longer list of ways to assess them. Without some careful planning, you may waste a lot of time, energy, and money.

You can use monitoring to identify both watershed enhancement opportunities and to evaluate results of enhancement activities. Monitoring can be very challenging, however, because regardless of location within a watershed (stream, riparian area, wetland, or upland), there are many conditions that can be measured. Furthermore, these conditions vary a lot depending on time, location, and management approaches.

Simply put, you may need to take many careful measurements in order to understand a situation. Usually, there are few shortcuts to a well-designed watershed evaluation or monitoring plan.

Many formal watershed assessments and resource monitoring programs have been or soon will be conducted under a variety of public and private initiatives. Detailed guidelines and technical assistance on these activities are available from many organizations,

IN THIS CHAPTER YOU'LL LEARN:

- The need for clear objectives and terminology for evaluation and monitoring
- Why careful sampling and analysis are essential for accurate assessments
- Different approaches for comparing watershed practices and conditions

including the Governor's Watershed Enhancement Board (GWEB), Oregon Department of Fish and Wildlife (ODFW), Oregon Department of Forestry (ODF), and USDA Forest Service (USFS).

This chapter simply provides a general overview of some important considerations when undertaking nearly any type of watershed evaluation or monitoring effort. It will serve as a foundation for your work with specific projects as discussed in other chapters in this section.

See Section II, Chapters 4, 6, 8, and 9 for information related to this chapter.

PLANNING ASSESSMENT AND MONITORING PROJECTS

Perhaps the most important first step is to ask, "What's the objective of our evaluation or monitoring effort?" Often, the objective is to answer one or more basic questions about the condition of a watershed resource or the effects of a management activity or enhancement project.

The challenge is to ask a question that is broad enough to have a useful answer, yet specific enough to keep the time and expense of data collection and analysis reasonable. "Is the stream quality good?" is a question that is phrased much too simply to help direct an assessment project. The following questions, while still broad, get closer to striking the right balance between usefulness and feasibility:

- What is the current dissolved oxygen level of this stream?
- Do the temperature levels of this stream meet regulatory or other desired standards?
- Are levels of chemical contaminants in this stream declining or increasing over time?
- Does this new or different farm or forest practice reduce or prevent erosion or sedimentation?
- Has this stream restoration or enhancement practice produced better fish habitat?

Another useful step is to consider some of the major types of evaluation and monitoring projects. If you understand project types and use standard terminology to talk about them, you'll improve planning and eliminate confusion about the nature and objectives of your evaluation and monitoring projects.

The following list of monitoring categories was modified from a U.S. Environmental Protection Agency publication, *Monitoring Guidelines to Evaluate Effects of Forestry Activities on Streams in the Pacific Northwest and Alaska*. (See the Resources section.)

- *Baseline* assessments establish a reference point for measured conditions. You then can compare this baseline measurement to measurements taken at different times or locations.
- *Trend* monitoring repeats measurements over time and compares them to a baseline measurement to see whether a pattern emerges (e.g., increasing, decreasing, or a cycle).
- *Implementation* monitoring determines whether an activity such as a watershed enhancement project is being carried out as planned.
- *Effectiveness* monitoring often follows implementation monitoring to see whether an activity produces the desired results or benefits.
- *Compliance* monitoring is similar to implementation monitoring, but usually assesses whether an activity meets legal or other administrative requirements.
- *Impact* monitoring is similar to effectiveness monitoring, but typically is used to determine whether a resource use or management activity has negative impacts.
- *Validation* monitoring usually refers to measurements that are designed to see whether a mathematical model or other prediction tool provides accurate results or should be improved or used differently.

Looking at this list, you can see that, in some cases, you may need to do more than one type of evaluation and monitoring to meet a general objective or information need.

SAMPLING AND STATISTICAL CONSIDERATIONS

It's impossible to evaluate and monitor everything everywhere in a watershed, so you'll need to decide what, how, when, where, and how often to take measurements. The following discussion of some of the issues involved with assessing suspended sediment levels in a stream will give you an idea of the complexity of these decisions. Similar concerns arise when you evaluate nearly any other watershed characteristic (e.g., fish habitat, stream shading, or soil infiltration), especially when you want to determine how management activities may affect these factors.

For most evaluation or monitoring efforts, such as an assessment of suspended sediment levels, you'll need to meet the following general objectives:

- The samples or measurement points should accurately represent the larger area to be assessed (e.g., a stream). In other words, you need *good sampling design and technique.*

- There should be no changes or confusion in the samples or measurement data that may affect the results. Thus, you need *proper sample and data handling.*
- The sample and data analyses should accurately assess the characteristic of interest, so you need *good analytical procedures and statistical methods.*

With these things in mind, how can you sample a stream for sediment? One common way is to take "grab" samples, i.e., stand in the stream and collect a sample in a bottle or jar.

But how well does such a sample represent all of the sediment carried by the stream? Suspended sediment isn't carried uniformly across the width and depth of a stream. For example, coarse materials such as sand and gravel usually are carried closer to the stream bottom. Thus, samples taken only near the surface may not accurately represent total sediment levels. Specialized equipment is available for sampling coarser sediments, but such equipment adds to the cost of assessment.

Another issue is the number of samples needed. All watershed characteristics vary over space and time, some tremendously. How can you be sure you've taken enough samples to understand and account for this variability?

One approach is to take a preliminary set of samples and use a statistical analysis to see whether more samples are needed. Such a *pilot study* not only can help determine the number of samples needed, but also can identify other concerns such as equipment needs, personnel needs, or limitations of the sample design (for example, specific locations or extremely high variability that require more intensive sampling).

The following equation often is used to assess sample size in this approach:

$$n = \frac{t^2 s^2}{p^2}$$

The symbols in this equation mean the following:

- n is the number of samples needed to precisely estimate the mean value of a measurement with a desired level of confidence.
- t is the "student's t value" for the desired level of confidence (e.g., a 95-percent probability of obtaining a precise estimate). This value is available in most statistics textbooks.
- s^2 is the variance of preliminary sample set or variance expected from other sampling experience.
- p is the desired precision of the estimate (how close you want your estimate to be to the true value, for example, +/-5 percent).

To use this procedure, it helps to have some familiarity with statistical analysis and a calculator with statistical functions. Even if you don't, however, it's important to appreciate that this type of analysis can show how difficult and costly it may be to provide clear and reliable answers to questions about watershed conditions and management effects.

For example, Table 1 shows the results of an analysis to find out how many stream water samples are needed to accurately identify a 10-percent increase in sediment levels. The reason so many samples are needed is that sediment in individual samples varies so much with time and stream flows.

Table 1.–Samples needed to detect 10% increase in sediment concentration (small forest stream–Oregon Coast Range).

Stream flows (cfs)	Samples required
0.0–1.5	7,968
1.5–2.2	1,947
2.2–5.0	3,253
5.0–25	3,493
>25	51

(Adapted from "Sampling water quality to determine the impact of land use on small streams," by R.M. Rice, R. Thomas, and G. Brown (unpublished paper, presented at ASCE Watershed Management Symposium, Utah State University, 1975.)

The effect of stream flow on suspended sediment, as well as on many other stream characteristics, often is substantial and complex. As a result, it may be difficult to sample a stream at the right time or often enough to accurately characterize its condition.

Figure 1 shows how suspended sediment levels in a stream in the Oregon Coast Range change as stream flow rises and falls in response to a winter storm. Note that for the same stream flows, suspended sediment level can vary a lot, depending on whether the stream is rising or falling.

This type of complex water-quality response to flow changes is why researchers sometimes use automated samplers to take many samples during storms. Not surprisingly, it can cost a lot to purchase and maintain this equipment.

Potential *errors* or *biases* in sampling or measurement methods are another vital concern in evaluation and monitoring. Such problems result in measurements that differ from the true values. These erroneous measurements in turn can yield unclear, exaggerated, or wrong observations or conclusions.

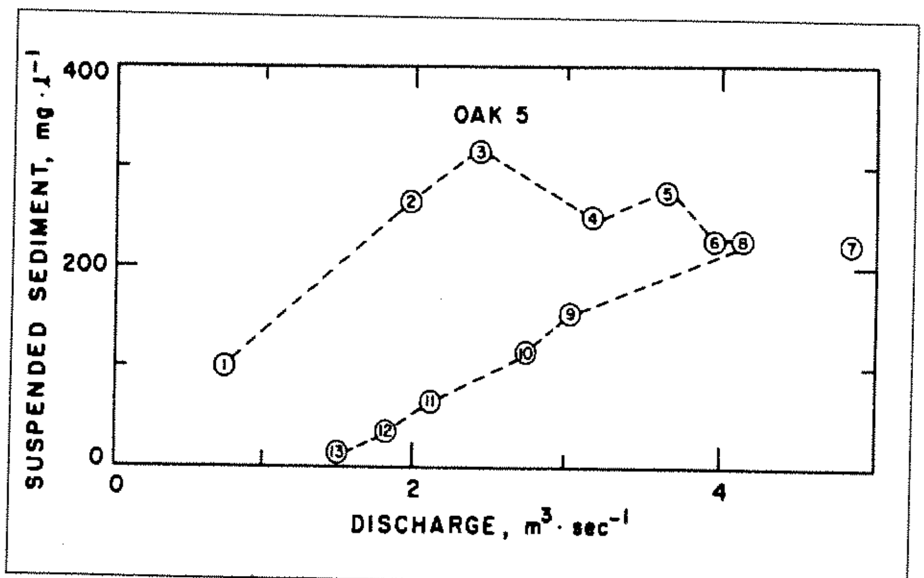

Figure 1.–Suspended sediment levels and stream flows for a small Oregon Coast Range stream.

Using grab samples to assess water quality is an example of a method that may introduce errors. For example, the types or amounts of material collected by grab samples may not accurately represent the sediment that a stream actually carries.

A common source of sampling bias in natural resource measurements is the tendency for people to work in locations that are more accessible and easier to move around in. Carefully designed sampling schemes can reduce such bias, but they don't always overcome the physical challenges of working in difficult areas such as dense, rugged riparian zones or large, complex streams.

For example, a random number table can be used to identify numbered plots for *random* sampling; a grid with consistent, fixed distances between sample points can be used for *systematic* sampling; grouping sample plots in areas with similar conditions (e.g., soil type, slope, cover, or habitat type) is an approach for *stratified* sampling. Keep in mind that if you can't achieve the fundamental assumptions on which statistical procedures are based (e.g., use of truly random or systematic samples), your results or their interpretation may be invalidated or seriously questioned.

Equipment errors also are common in watershed measurements. The most reliable and accurate equipment can be very costly to purchase and maintain; thus, older or less expensive equipment often is used. Such equipment can provide useful data and information, but you may need to verify or calibrate these measurements against those taken with better equipment to ensure that your measurements are accurate and usable. *Calibration* often involves further calculations to carefully define the relationship between similar measurements collected with different equipment.

If you send samples to a laboratory for analysis, you may run into two additional kinds of errors–sample handling and storage errors, and lab measurement errors. To identify such problems, you can take additional test and control samples and handle and analyze them in the same or different ways.

Test samples are collected normally, but specifically are used to check handling and analytical procedures. *Control* samples contain known amounts of the material or other characteristic being evaluated (e.g., a water sample that is "spiked" with a carefully measured amount of nitrate) and also are used to verify procedures.

If you use commercial laboratories, ask about quality-control procedures or professional certification. These labs also can provide information about expected measurement errors for their analytical procedures and equipment.

COMPARISON STUDIES

A common objective of evaluation or monitoring projects is to make a comparison. For example, you may want to identify effects of different management practices or see whether resource characteristics change over time.

You can use several approaches to make such comparisons. Each method has advantages and disadvantages.

For example, you might want to evaluate changes or differences in water quality or fish habitat related to a management practice such as adding a riparian buffer next to a subdivision or agricultural field. To do so, you might make *upstream vs. downstream* comparisons. That is, you could compare measurements taken from stream locations immediately upstream and downstream of a stream reach where the particular practice is used (Figure 2).

Another approach is the *paired watershed* comparison. This method compares conditions such as water quality or habitat features in two nearby watersheds (Figure 3).

For either the upstream vs. downstream or paired watershed approach to provide accurate and useful comparisons, you need to be sure that site differences (other than the management practice of interest) between the compared areas have little or no effect on the conditions being studied. If they do have an effect, you need to be able to account for this effect and clearly separate it from the management effect.

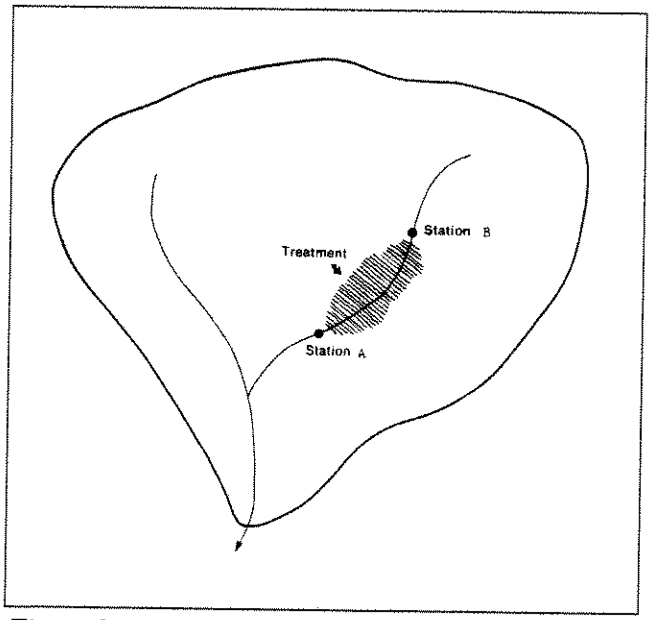

***Figure 2.**—An upstream-downstream comparison looks at measurements taken from stream locations immediately upstream and downstream of a stream reach where a particular practice is used.*

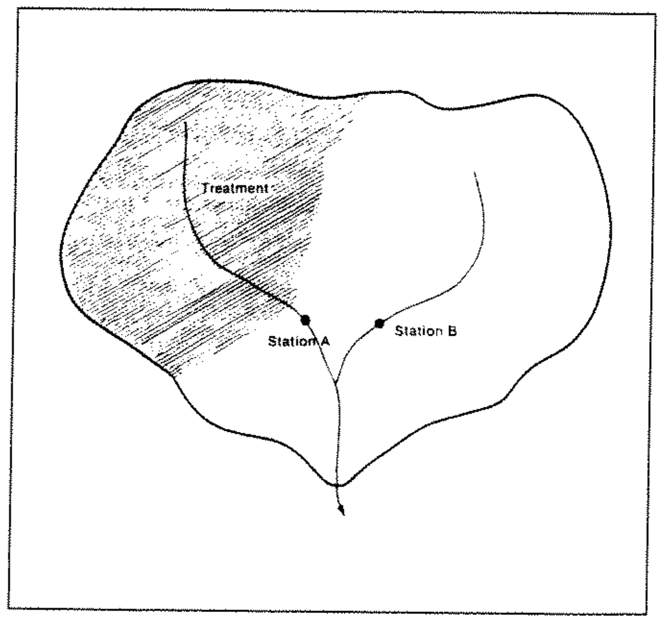

***Figure 3.**—A paired watershed comparison looks at conditions in two nearby watersheds.*

It can be very difficult to distinguish between effects of management and other factors because no two streams or stream reaches are exactly alike. There always are differences in flow, gradient, substrate, or morphology, for example. One way to deal with differences between sites is to use *replicate* comparisons, which means to compare various locations to see whether any effects due to management occur in a consistent pattern.

A third approach is the *before and after* comparison. This approach requires that site characteristics such as local climate patterns that may affect the condition being measured be very similar before and after the treatment or change of interest is implemented. Also, to use this method, you need to be sure to establish an accurate *baseline* condition to use in the comparison. As suggested by the discussion of suspended sediment measurements, it can be very challenging to identify what is "normal," given how much measurements can vary based on changing background conditions such as stream flow.

Regardless of which comparison approach you use, consistent methods and good record keeping are essential. Different sampling procedures, tools, or field crews can produce different results that may render a comparison unclear, inaccurate, or invalid. Similar weaknesses can result from poor record keeping. Both of these requirements are especially important when you make the substantial investments needed for useful long-term comparisons.

Finally, keep in mind that although well-designed comparison studies can help identify management effects or resource trends, without further study it can be difficult to determine the specific cause of an observed difference or trend. And, without some caution, it can be easy to reach a wrong conclusion.

For example, if stream sediment or temperature varies between the upper and lower points of a stream reach where a land management enhancement practice occurs, it's tempting to credit the management practice with causing the difference. Until such key factors as local channel features or cool seepage are carefully accounted for, however, the influence of the activity remains uncertain. Thus, an important question to try to answer is: "Is this a case of cause and effect, or guilt by association?"

Summary/Self review

Watershed evaluation and monitoring can be very challenging because of the time and effort often needed to provide accurate and useful information for resource management. Careful project planning begins with defining the primary evaluation and monitoring objectives and approaches. Identifying procedures for effective sample and data collection, handling, and analysis is especially important. Giving close attention to these key considerations in watershed evaluation and monitoring can help ensure that your observations and conclusions are accurate and correct. Whenever possible, avoid taking shortcuts that can lead to poor information

Exercises

Do these exercises as a group with the help of appropriate experts.

Visit a watershed study site with a researcher.

The objective of this exercise is to see, discuss, and learn more about what it takes to answer questions about watershed conditions and influences with a reasonable level of accuracy and confidence. Ask the researcher to focus specifically on demonstrating and providing insights about study design, sampling, and analytical requirements, including such factors as:

- Degree and sources of variability in samples/measurements
- Numbers and location of samples/measurements
- Timing and frequency of sampling/measurements
- Handling and lab/office analysis of samples/measurements
- Type and expense of field and lab/office equipment
- Time and expense of field and lab/office personnel
- Role of experience and expertise of personnel

Visit a USGS stream/river monitoring site and discuss agency databases.

The objective of this exercise is to see and learn how some of our streams and rivers are regularly monitored. As in the exercise above, sampling equipment and design should be discussed, including issues of variability, sampling/measurement accuracy, and equipment and personnel needs and costs.

In addition, the broad array of available USGS and other agency monitoring databases should be discussed. Ideally, do this portion of the exercise indoors so that some of the databases can be shown. If World Wide Web access is available, you'll be able to view some of these databases online (e.g., http://wwworegon.wr.usgs.gov/).

Resources

Training

Oregon State University and government organizations occasionally offer short courses on topics related to watershed evaluation and monitoring. Training programs also may be offered by various nonprofit and private organizations, including consultants. If you're interested in self instruction, consider the publications below.

Information

"How to study a stream," Chapter 2 in *Stream Hydrology–An Introduction for Ecologists*, by N.D. Gordon et al. (John Wiley & Sons, Inc., New York, 1992). ISBN 0-471-95505-1. Available by order through bookstores.

Monitoring Guidelines to Evaluate Effects of Forestry Activities on Streams in the Pacific Northwest and Alaska, EPA 910/9-91-001, by L.H. MacDonald et al. (U.S. Environmental Protection Agency, 1991). Available from the U.S. EPA, Region 10, NPS Section, WD-139, 1200 Sixth Ave., Seattle, WA 98101. Also available on the Web at http://www.epa.gov/cincl/

Oregon Watershed Assessment Manual (NonPoint Source Solutions for the Governor's Watershed Enhancement Board, Salem, 1998).

"Reliability of water analysis kits," by C.E. Boyd. In *Transactions of the American Fisheries Society*, Volume 109 (1980): 239–243. Available through university and other technical libraries.

Volunteer Water Monitoring: A Guide for State Managers, EPA 440/4-90-010 (U.S. Environmental Protection Agency, 1990). Available from U.S. EPA, Office of Water, Washington, DC. Also available on the Web at http://www.epa.gov/cincl/

Water Quality Monitoring Programs, Technical Paper WSDG-TP-00002, by S.L. Ponce, (Watershed Systems Development Group, USDA Forest Service, Fort Collins, CO, 1980). Available through university and other technical libraries.

Wildland Water Quality Sampling and Analysis, by J.D. Stednick (Academic Press, Inc., San Diego, 1991). ISBN 0-12-664100-5. Available by order through bookstores.

MOVING FORWARD–THE NEXT STEPS

On your own, use the lines below to fill in steps, actions, thoughts, contacts, etc. you'll take to move yourself and your watershed group ahead in understanding watershed assessment and monitoring.

1.____

2.____

3.____

4

Upland Evaluation and Enhancement

Paul W. Adams
and Derek Godwin

Uplands usually represent the largest areas within a watershed, so they can have important effects on streams and other water bodies. Upland management and enhancement activities focus on two things:

- Maintaining or improving conditions that promote the natural hydrologic functions discussed in Chapter II-2, "Watershed Science"
- Minimizing erosion and other problems from extreme events such as floods or droughts

Soil that lets water infiltrate quickly can reduce erosion and promote natural groundwater storage and surface flows. Likewise, well-designed road surfaces and stream crossings can reduce erosion and fish passage problems, particularly on the unpaved roads that extend throughout many rural watersheds.

A number of checklists are included in this chapter to help you evaluate some important upland features and highlight opportunities for watershed enhancement. Other broader watershed assessments can complement these focused evaluations, including identifying key watershed features and processes that can favor or hinder the success of enhancement practices.

IN THIS CHAPTER YOU'LL LEARN:

Five key topics in upland evaluation and enhancement that are particularly important in Oregon:

- Infiltration and drainage
- Road drainage
- Stream crossings
- New road construction
- Unstable terrain

Other chapters that will help you plan evaluation and enhancement projects include Chapters II-1, "Principles of Planning," and II-3, "Assessment and Monitoring."

Infiltration and Drainage of Rain and Snowmelt

See Section II, Chapters 1–3, 5, and 7, and Section III, Chapter 3 for information related to this chapter.

Chapter II-2, "Watershed Science," discussed important aspects of watershed ***hydrology*** such as precipitation, surface flows, subsurface flows, and evapotranspiration. Soil plays a primary role in nearly all of these hydrologic functions.

Infiltration and ***drainage*** of rain and snowmelt refer to the movement of this water into and through the soil. Good infiltration and drainage mean that water is less likely to run off the soil surface. As a result, groundwater recharge increases, and there is less chance that sediment and other contaminants are carried to streams.

Soil porosity and compaction

An important factor in infiltration and drainage is the ***porosity*** of the soil, both the various sizes and total volume of spaces in the soil. Highly porous soil allows water to infiltrate quickly.

Undisturbed soil often is porous and soft, so traffic by animals, people, or farm or logging vehicles easily compacts it. Compaction can reduce the number of large soil pores and can inhibit plant root growth. If these changes occur over large areas, surface runoff and erosion may increase. Areas of potential concern include slopes with many heavily compacted logging skid trails, pastures subjected to heavy livestock grazing, and fields where intensive cropping has been practiced. Contrary to popular belief, wet soils are not necessarily more prone to compaction than drier soils, but rutting and other problems are more likely with traffic on wet soils.

You can evaluate soil porosity and compaction both visually and with specialized equipment. During periods of heavy rain or snowmelt, you can recognize low soil porosity by the presence of ponded water or surface runoff. Some soils have naturally slow drainage (e.g., heavy clays in floodplains). Take care to distinguish this natural condition from slow drainage caused by human activities.

Poorly growing vegetation is another visual indicator of compaction and low porosity. When soil is compacted, it doesn't have much oxygen and it's difficult for plant roots to penetrate. Under these conditions, plants don't grow well.

Several kinds of equipment are used to evaluate and monitor soil porosity and compaction and water infiltration. Examples include ring infiltrometers, rainfall simulators, soil cores, and penetrometers.

Ring infiltrometers are open metal rings that are partially inserted into the surface soil. An observer adds a measured amount of water and notes how long it takes the water to drain. *Rainfall simulators* add a measured amount of water to the soil surface in drop form to more closely resemble real rain.

An increase in soil *bulk density* is a common measure of soil compaction. Bulk density is defined as the soil's dry weight per unit volume and can be determined by taking soil core samples.

Penetrometers measure the resistance of the soil to probing, which typically increases when soil is compacted. A spade or narrow metal rod can serve as a simple penetrometer for basic assessments. Specialized devices provide quantitative measurements. For example, probes are available that give values in pounds per square inch.

When assessing changes in soil porosity and compaction, it can be a challenge to identify relatively undisturbed soil as a baseline for comparison. This is especially true in agricultural and developed areas, but even forested areas may have old compacted trails that are difficult to see.

It's also a challenge to take enough samples to accurately assess soil conditions, especially if you want to determine whether soil changes are affecting watershed hydrology. To make such an assessment, you need an accurate estimate of the location of soil changes and how widespread they are.

Enhancing infiltration and drainage

Deep tillage of heavily compacted areas can help restore infiltration and drainage, as well as promote better growing conditions for protective vegetation. Where topsoil has been lost or removed (e.g., in heavily eroded areas or on abandoned roads), you may need to add fertilizer, organic amendments, or nitrogen-fixing plants (legumes) to further restore productivity. The publication *An Evaluation of Four Implements Used to Till Compacted Forest Soils in the Pacific Northwest* provides helpful information about soil tillage options. Tillage results from different types of equipment are shown in Figure 1.

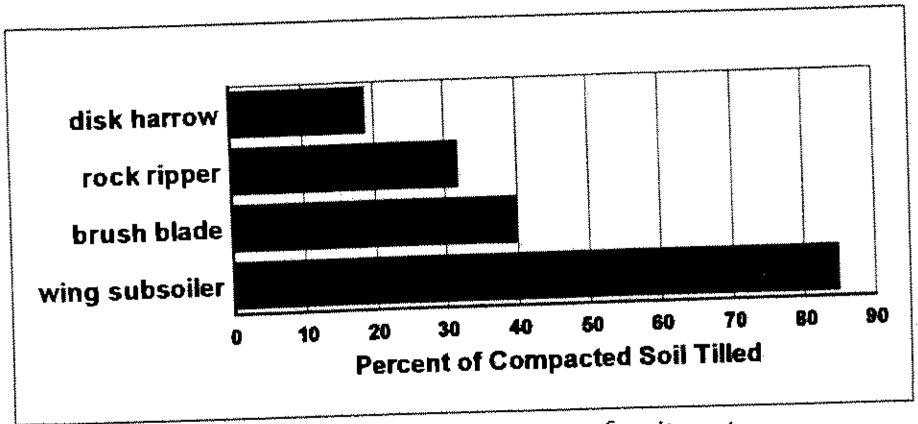

Figure 1.—*Tillage results from four different types of equipment.*

There are several ways to reduce upland soil compaction and disturbance from agriculture and forest operations:

- *Low-till* and *no-till* cropping systems minimize machine traffic.
- *Fenced pastures* and *rotation grazing* systems (moving animals among pastures) can limit the intensity of livestock use.
- Upland locations for water troughs and salt licks can help keep livestock away from wet soils, streams, and small drainages. You usually need a permit to divert water from a stream, but permit fees are kept relatively low in order to encourage such improvements.
- A system of *designated skid trails* can control logging vehicle traffic and ground disturbance. This approach includes *felling to lead* (felling trees toward skid trails) and log winching to the trails to limit disturbance by heavy logging vehicles.

See Chapter III-3, "Livestock and Forage Management," for more information about ways to minimize livestock damage to riparian areas.

Infiltration also can be enhanced by measures to slow down surface water movement so that water has time to soak into the soil. One way to do this is to leave adequate surface *duff* (plant litter), logging *slash* (tree debris), and crop residues. Another approach is to add surface mulch.

Forest managers often use *slash treatment* or *scarification* to promote reforestation success after logging. Slash treatment usually involves piling or burning, while scarification consists of mechanically disturbing the topsoil. Both techniques can enhance survival of tree seedlings. However, both expose more soil surface, which may increase the risk of surface runoff, especially on sloping terrain.

You can help reduce surface runoff problems by leaving some duff and by piling slash in windrows along slope contours. Try to manage slash to balance the needs of site preparation and watershed functions. If you do burn slash, schedule burns when weather conditions, slash, and other fuels are cool and moist enough to limit burn intensity.

Managing agricultural crop residues can follow similar principles.

Role of vegetation

Vegetation can enhance watershed processes such as water infiltration, which contributes to desirable moisture storage and release and also helps reduce excess erosion and sedimentation. Plants shield the soil from raindrops, which can break down soil clods and reduce large pores, resulting in surface runoff. In addition, plants, roots, and plant litter help slow runoff, hold soil in place, and promote soil porosity.

Watershed enhancement thus can include measures to improve vegetation cover. Such improvements are especially important in locations where plants are absent or sparse and increased runoff and erosion are evident. You might find these conditions around roadsides, ditches, construction areas, fields, or pastures.

The *Oregon Interagency Seeding Guide* and the OSU publication *Seeding to Control Erosion along Forest Roads* are two helpful references for enhancing vegetation. As mentioned earlier, you may need to improve soil growing conditions through tillage, fertilization, or organic amendments to ensure that new plants thrive and cover the area well.

Keep in mind that tree planting or natural reforestation can significantly change a forest and have unintended effects on water resources. For example, where dense, vigorous alder stands grew after historical logging of riparian forests, reduced summer flows (probably from heavy water uptake) or water-quality effects (e.g., increased color and dissolved organic matter) sometimes have been noted.

Reforestation of agricultural fields or other open lands also may reduce local stream flows because forests use more water than do crops and other plants. Figure 2 shows how stream flows in watersheds in other regions generally decreased when forest cover was increased. While streamside plantings often are desirable to provide shade, which helps maintain cooler water temperatures, carefully consider the trade-off with potential stream flow reductions.

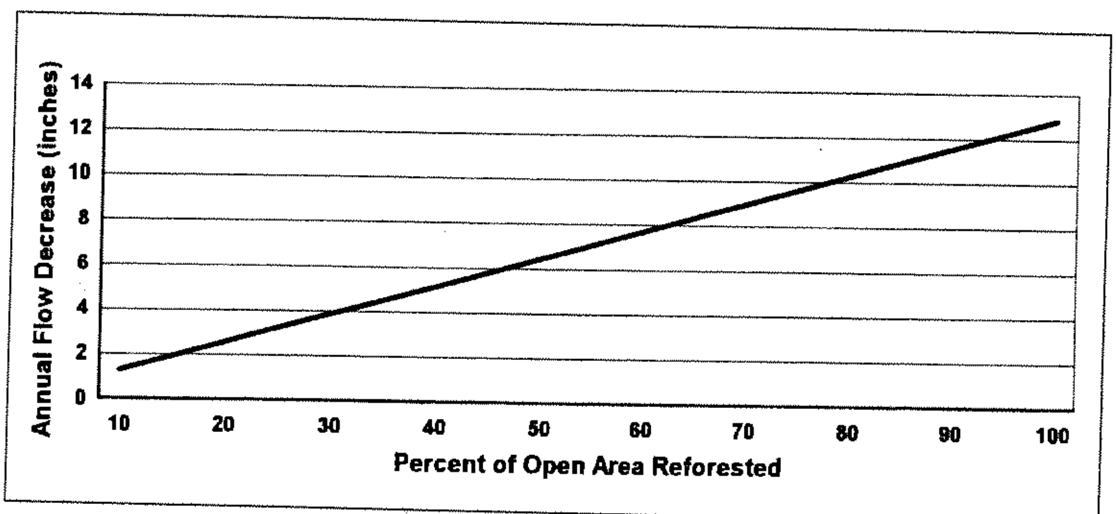

Figure 2.—Relationship of stream flow to increasing forest cover.

ROAD SURFACE DRAINAGE

Road use and maintenance

In most cases, landowners and managers rely heavily on existing roads for property access. How these roads are used and maintained should be a major part of your watershed evaluation and potential enhancement efforts.

For example, sediment losses from unpaved roads can increase if traffic is heavy or if travel occurs during wet weather. Thus, in areas where sedimentation is a major concern, it may be wise to reduce or suspend traffic on such roads during wet weather. Likewise, scheduling timber harvest and log hauling during the summer may reduce sedimentation from forest roads.

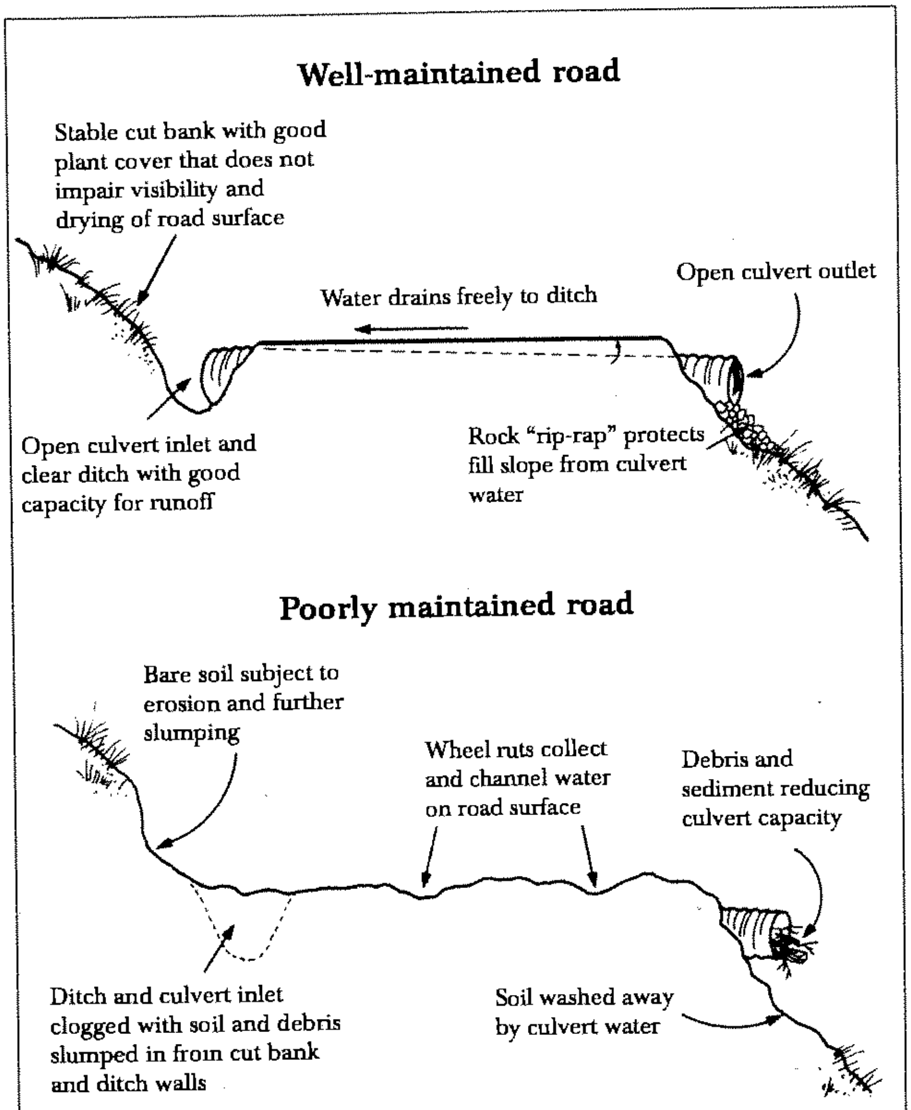

***Figure 3.**—Examples of some important differences between well-maintained and poorly maintained woodland roads.*

Both routine and emergency road maintenance can be critical to preventing or reducing erosion and sedimentation problems. Ensuring that the road drainage system functions well is a major focus of both types of maintenance. Figure 3 shows some important differences between a well-maintained and a poorly maintained forest road. It's best to do routine road maintenance before the rainy season and before roads are used heavily (for example, for log hauling or crop harvest). Key maintenance activities include:

- Road *grading* to smooth ruts and direct water off the road surface
- *Ditch and culvert cleaning* to efficiently move road drainage to stable areas
- Adding fresh *surface gravel* when earlier applications become worn by traffic

Emergency maintenance involves monitoring road conditions during large storms so that clogged ditches and culverts can be taken care of promptly to prevent serious problems such as gullies, washouts, or landslides.

To help you determine what kind of road maintenance is needed in your watershed, see the "Checklist for Storm-proofing Rural Roads: Road Maintenance," page II-4.8.

Drainage design

Road improvements to prevent or reduce watershed problems usually focus on drainage systems. Road surfaces usually are designed with a crown, inslope, or outslope to quickly move water off to a ditch or the roadside. Generally, these slopes should be 2–3 percent greater than the travel grade; otherwise, water will move down the road surface rather than off to the side.

Simple maintenance grading may be sufficient to provide surface drainage on many roads. In some cases, however, the road may need additional soil or rock to create an adequate slope.

The OSU Extension publication *Designing Woodland Roads* illustrates good road drainage design features. Another helpful tool for evaluating existing roads is the "Checklist for Storm-proofing Rural Roads: Road Drainage Design" (page II-4.9). Be aware that road design can be quite complex, and you may need to get help from a professional engineer or other specialist.

Where roads are cut into a slope, ditches and cross drains usually are needed to direct water to stable locations. If road ditches are eroding or forming gullies, they may need to be stabilized with armor rock or vegetation, or they may need additional cross drains. Even where there are lots of cross drains, however, heavy storm flows may cause erosion problems at either the inlet or outlet of the drain.

Three types of cross drains commonly are used on simple rural roads–ditch-relief culverts, rolling dips, and water bars. Tables 1 and 2 (page II-4.10) summarize key features of each of these designs.

Ditch-relief culverts are the most common type of cross drain. Where costs or maintenance requirements make them impractical, however, consider options such as rolling dips and water bars.

STREAM CROSSINGS

Stream crossings are a point of direct contact between streams and roads. Thus, erosion and other problems at these locations can quickly have a substantial impact on water quality and fish habitat. Many older crossings have a limited capacity to handle storm flows.

Checklist for Storm-proofing Rural Roads

Road Maintenance

Road surface

- ❒ Rutting or uneven surface concentrates or sends water to wrong area
- ❒ Rock surfacing has deteriorated or migrated into subgrade
- ❒ Other risky situation or comments:

____

____

Drainage ditches and roadsides

- ❒ Eroding ditch material (gullies, etc.)
- ❒ Cutbank slumping or ravel blocking ditch flow
- ❒ Roadside berms concentrate or send water to wrong area
- ❒ Cracks in road fill, indicating soil instability
- ❒ Other risky situation or comments:

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Cross drains

- ❒ Erosion at inlet or outlet
- ❒ Sediment or organic debris clogging pipe
- ❒ Denting from traffic or ditch maintenance
- ❒ Other risky situation or comments:

____

____

Other considerations

- ❒ Heavy traffic (e.g., farm vehicles or log trucks) expected
- ❒ Plans for emergency maintenance during storms
- ❒ Other:

____

____

Checklist for Storm-proofing Rural Roads
Road Drainage Design

Road location

- ❒ Intense storms locally common
- ❒ Erodible or unstable soils locally common
- ❒ Streamside location could be subject to washout
- ❒ Other risky characteristic: ______________________

Road grades

- ❒ Steep grades add to erosive power of runoff
- ❒ Low grades allow water to accumulate on surface
- ❒ Other risky feature: ______________________

Road bed and surface

- ❒ Soft road bed (e.g., weak or wet subgrade material)
- ❒ Erodible surface material (e.g., bare, fine-textured soil)
- ❒ Slope angles of road crown or sideslope inadequate for efficient flow
- ❒ Other risky feature: ______________________

Drainage ditches

- ❒ Erodible ditch material (e.g., bare, fine-textured soil)
- ❒ Cutbank seepage adds to ditch flows
- ❒ Low ditch grade accumulates water
- ❒ Other risky feature: ______________________

Cross drain size and spacing

- ❒ Small pipe could overflow or become easily clogged
- ❒ Wide spacing could cause ditch erosion or overflow at inlet
- ❒ Other risky feature: ______________________

Cross drain angle, grade, and installation

- ❒ Pipe may not efficiently move water and be self-cleaning of debris
- ❒ Fill too shallow or not well compacted (e.g., erosion or pipe bending)
- ❒ Other risky feature: ______________________

Cross drain inlets and outlets

- ❒ Inlet may not divert all ditch water into pipe
- ❒ Flow from outlet could cause erosion or instability
- ❒ Other risky feature: ______________________

Table 1.–Cross drainage on rural roads.

Ditch relief culverts–The 5 Ds	
Divert	Culvert inlet should provide direct and unhindered diversion of ditch water (i.e., water should not bypass inlet). Angle culvert at least 30 degrees downslope from the road for efficient flow into and through the pipe.
Debris	Keep inlets cleaned of debris and sediment (e.g., watch for cutbank slumps and ravel, ditch erosion, and sedimentation). Slope the culvert at least 3 percent and at least 2 percent greater than the ditch slope to help keep it self-cleaning of sediment and debris. Where debris and sediment are a chronic problem, consider control measures such as catch basins, drop inlets, and recessed cutslopes.
Discharge	Culvert installation should have sufficient capacity to handle flows from very large storms; minimum 12-inch pipe size recommended. Consider local conditions (e.g., storm intensities, slope position, cutbank seepage) that may add to flows.
Distance	Carefully space culverts to prevent ditch erosion and to avoid large discharge flows onto steep or unstable slopes. Closer spacing is needed with steeper road grades, erodible soils, locally intense storms, etc.
Dissipate	Use rip-rap, downspouts, etc. at culvert outlets to dissipate erosive energy of discharge water, especially on steep or unstable slopes.

Source: "Considerations in placement of cross drain culverts," by R.L. Beschta. Short course notes. Design and Maintenance of Forest Road Drainage (Oregon State University College of Forestry, Corvallis, 1991).

Table 2.–Other cross drainage options.

Where costs or maintenance requirements make ditch relief culverts difficult to use, consider such options as rolling dips and water bars.	
Rolling dips	Dips generally are suitable for road grades less than about 10 percent. Begin the dip cut a minimum of 50 feet upslope of the dip bottom, and extend it at least another 15 feet beyond the dip bottom. Cut the dip 1–2 feet into a firm roadbed, and angle it 45–60 degrees downslope from the road centerline. Increase the outslope cut of the dip uniformly from the upper inside start of the dip to the outlet. Use rip-rap or other outfall protection on steep or unstable slopes.
Water bars	Construct water bars at least 1 foot high, with a 30–60 degree angle from the road centerline, and a clear, stable outlet. Carefully space and locate bars, e.g., consider using ditch relief culvert spacing guidelines. Where significant traffic is expected, consider flexible water bars.

Some of them continue to add sediment to streams when high flows erode fill material around culverts or bridge abutments. Another important concern with stream crossings is that some culverts are a barrier to migrating fish.

Crossing types

The most common stream crossings are culverts and bridges. Culverts generally are less costly than bridges for crossing small streams. However, they must be designed and installed carefully to provide for storm flows and fish passage. Design suggestions are discussed later in this section. Many older culvert crossings don't meet these standards and may be good candidates for enhancement projects.

Some relatively inexpensive bridge designs are available. Examples include log and rail car bridges as well as some newer prefabricated, sectional designs.

Where traffic is very light, carefully designed fords or temporary crossings may be used. A *vented ford* crossing is a unique way to minimize the disturbance and expense of large road fills (e.g., in floodplains) while maintaining clean water and adequate fish passage during times of low flow. These crossings combine a smaller culvert (i.e., capacity for moderate storm flows) with heavily armored fill at or near the crossing to handle overflows during very heavy storms.

Flow capacity

It's critical that stream crossings have adequate flow capacity to prevent erosion or washouts during large storms. Oregon's Forest Practices Rules now require that crossings be designed to handle a 50-year storm flow. By using the following procedure to check flow capacities of existing crossings, you can identify sites that may benefit from an upgraded design.

First, you need to determine the 50-year storm flow. The easiest way to do this is to use the peak flow map developed by the Oregon Department of Forestry (ODF). Part of this map is shown in Figure 4.

The map shows some areas where the 50-year peak flow is between 100 and 150 cubic feet per second (cfs) per square mile (640 acres) of drainage area. For a stream crossing in such a location, first estimate the watershed area that drains to the crossing, and then adjust the map value accordingly.

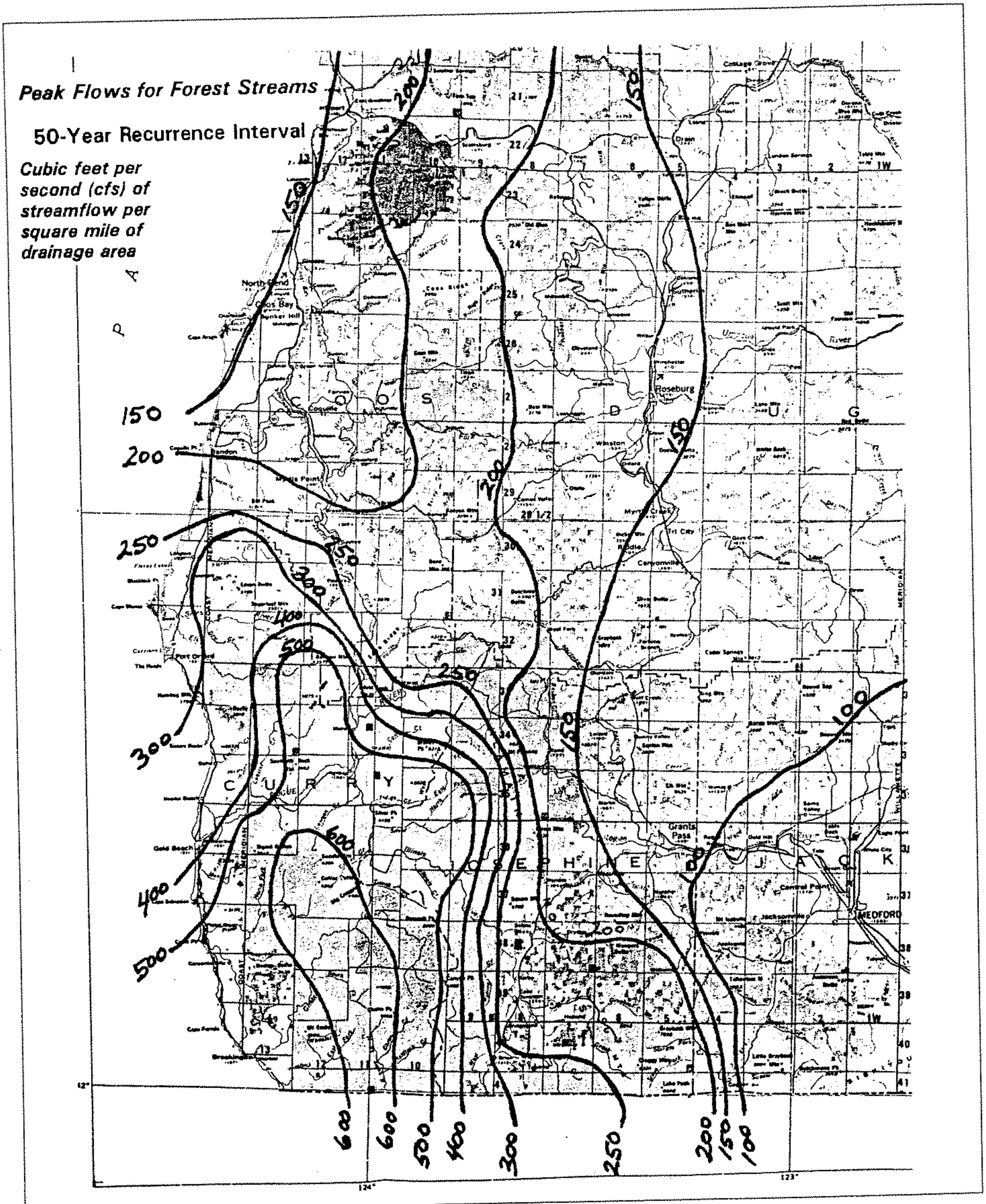

Figure 4.—Peak flow map for forest streams. (Source: Oregon Department of Forestry)

For example, if the drainage area above a local culvert crossing is 160 acres, the 50-year flow is calculated as follows:

160 acres ÷ 640 acres = 0.25 sq mile
100 cfs x 0.25 = 25 cfs
150 cfs x 0.25 = 37.5 cfs
50-year flow = 25–37.5 cfs

The next step is to measure the size of the culvert to see whether it can handle this flow. Table 3 shows the flow capacities of some common sizes of round culverts.

If the culvert crossing in our example has a pipe 36 inches or smaller, it's in danger of experiencing a washout during a heavy storm. Replacing the culvert with a larger pipe could reduce this risk.

Keep in mind that in many parts of Oregon the storms of February and November 1996 were among the largest recorded in the past century. In some locations, the resulting stream flows probably were 25- to 50-year return events, or even greater.

The condition of stream crossings after these storms provides fresh evidence of locations where improvements may be warranted. Look for signs of eroding fill material around pipes, bridge approaches, and abutments. Also look for evidence that shows whether water flowed over the road as it ponded behind the fill.

Other guidance is available for estimating storm flows and the capacities of pipes and bridges to handle these flows. One source is the OSU publication *Estimating Streamflows on Small Forested Watersheds for Culvert and Bridge Design in Oregon.* Another helpful tool is the "Checklist for Storm-proofing Rural Roads: Stream Crossings" (page II-4.14).

Because stream crossing issues are complex, you may need help from engineers and other technical specialists for successful evaluation and enhancement projects. Replacing or installing culverts larger than those shown in Table 3 is one situation where special expertise probably is needed.

Table 3.–Flow capacities of round culverts.

Culvert diameter (inches)	Flow capacity (cfs)
24	5–11
30	12–20
36	21–31
42	32–46
48	47–64
54	65–87
60	88–113

Fish passage

Fish passage at stream crossings is a major concern because barriers to passage can effectively eliminate many miles of valuable spawning or rearing habitat. Oregon's Forest Practices Rules now require that new stream crossings provide for upstream and downstream passage of both adult and juvenile fish. But older forest stream crossings and those on nonforest lands often were installed with little or no consideration for fish passage. Thus, upgrading crossings that restrict access to valuable habitat may represent an important watershed enhancement opportunity.

Checklist for Storm-proofing Rural Roads

Stream Crossings

Culvert size or bridge clearance

- ❒ Insufficient capacity to pass 50-year storm flow
- ❒ Potential for clogging by woody debris, etc.
- ❒ Water diversion with excess flow or clogging creates other risks away from crossing
- ❒ Other risky situation or comments:

____

____

Pipe or bridge condition

- ❒ Evidence of deterioration (e.g., rust or rot), settling, etc.
- ❒ Other risky situation or comments:

____

____

Inflow and outflow area condition

- ❒ Evidence or potential for erosion at high flows
- ❒ Other risky situation or comments:

____

____

Road fill height and condition

- ❒ Low fill height could be overtopped at high flows
- ❒ Evidence of poorly compacted fill (e.g., seepage, settling)
- ❒ Other risky situation or comments:

____

____

Road surface and ditches

- ❒ Road drainage contributes to flow at crossing
- ❒ Potential for direct sedimentation from road surface or ditch
- ❒ Other risky situation or comments:

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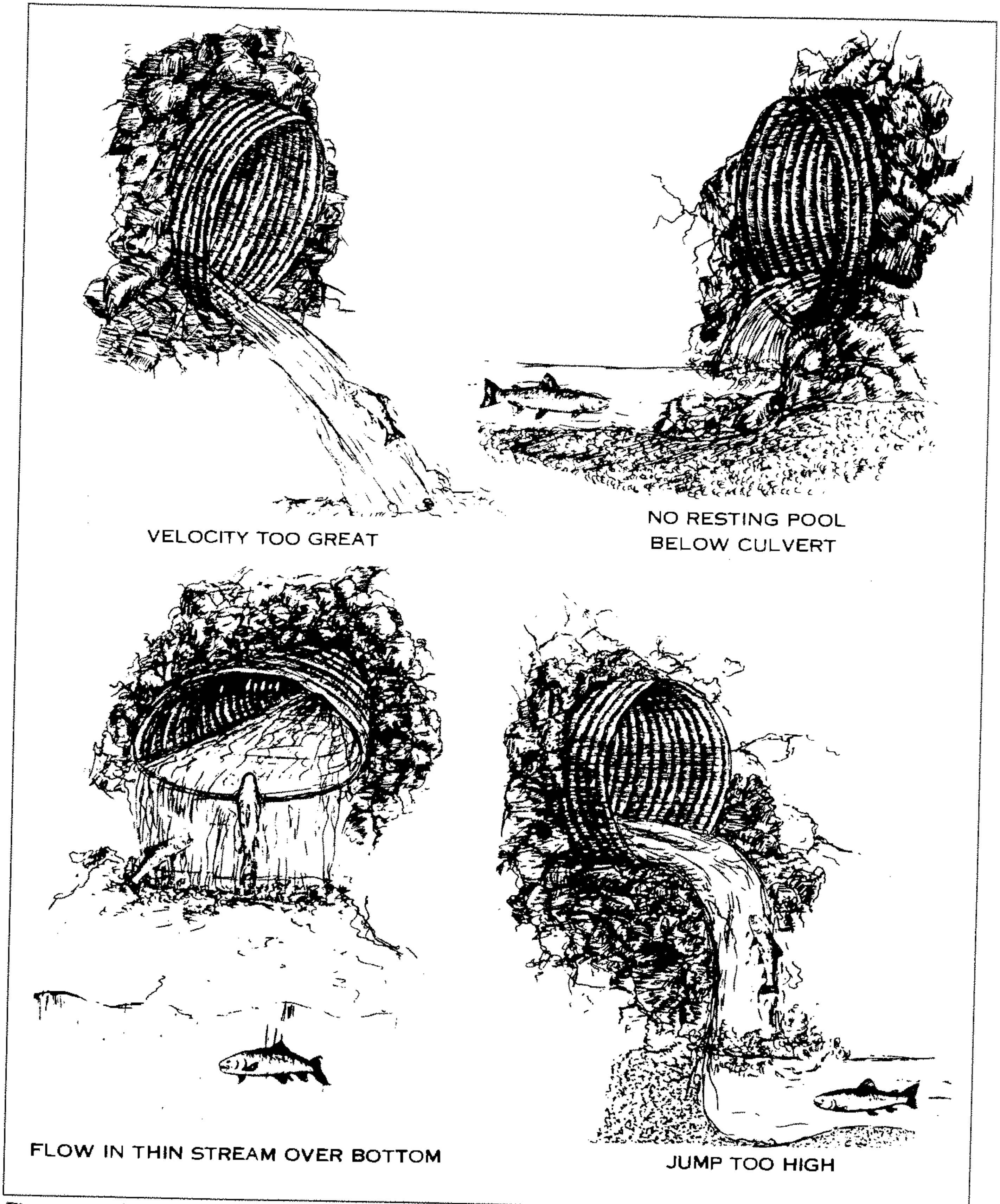


Figure 5.—Culvert installations that block fish passage.

Table 4.–Short-term burst speeds of salmonids.

Species	Maximum capability (feet per second)[1]	Acceptable flow (feet per second)[1]
Juvenile salmon, trout, and steelhead		0–3 0–4
Adult cutthroat and age 1+ steelhead		0–3 0–4
Adult sea-run cutthroat trout	6.4–13.5 11.4	0–8
Adult coho salmon	12.2–17.5 10.6–21.5	3.4–10.6 0–8
Adult chinook salmon	14.5–22.1 10.8–22.4	3.4–10.8 0–8
Adult steelhead trout	12.0–26.8 13.7–26.8	4.6–13.7 0–8

[1]*Multiple entries are observations by different authors.*

Fish passage problems occur most often with culvert crossings. Some common situations, illustrated in Figure 5, include:

- A steep slope or a small culvert results in water velocities that are too fast to allow upstream swimming.
- The culvert outlet is too high above the stream for fish to jump.
- There is no pool at the culvert outlet where fish can rest and gain velocity for upstream passage.
- Flows in or near the pipe are too shallow during low flows to allow passage.

The ability of fish to jump and swim against strong flows depends on their size and species, as well as on how long they have been migrating. Adult steelhead are known as the highest jumpers of the salmonids.

The Oregon Department of Fish and Wildlife (ODFW) recommends less than a 12-inch jump to allow passage of juvenile salmonids. If resting pools are absent or shallow, a minimum pool depth of 1½ times the jump height is advised. If flows are too fast or steep for migration, a *fish ladder* or larger pipe with baffles can provide upstream access.

Table 4 shows the short-term burst speeds for some important species and recommended velocities for constructed crossings or channels.

Some stream crossings use oversized culverts or wide concrete fords to safely handle extreme flows. While these designs may avoid washouts, they also may create very shallow flows that large fish can't swim through. In such cases, you may be able to install a secondary pipe or side channel to provide a route with deeper flow.

One particularly useful reference for evaluating and designing stream crossings for adequate fish passage is the ODF advisory memo *Interim Fish Passage Guidance at Road Crossings*. The ODFW also has developed a basic form for evaluating existing crossings, the "ODFW culvert evaluation form."

ODFW Culvert Evaluation Form

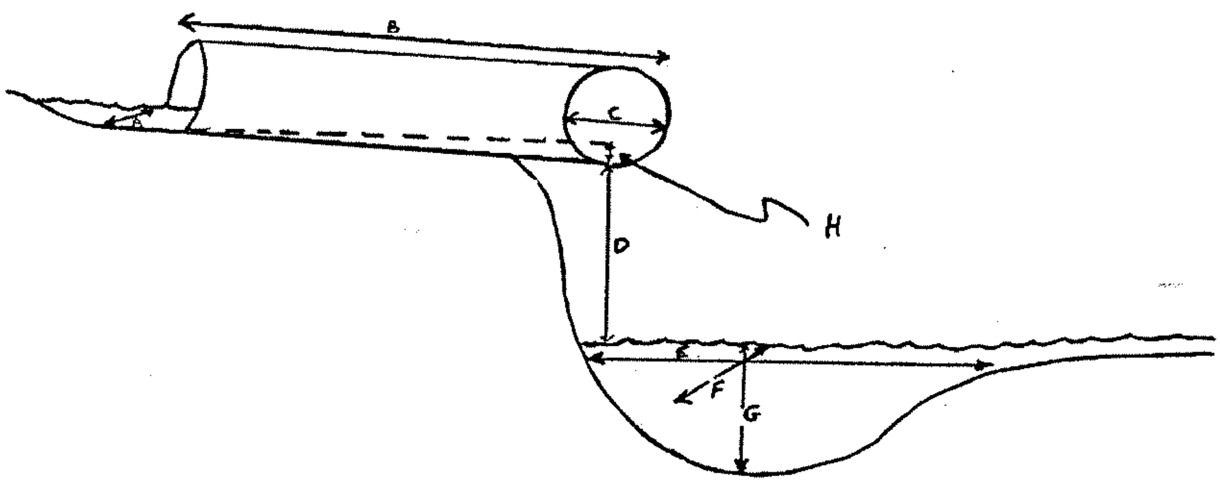
Evaluators:______________________________ Date:_________________________

Stream:____

Subbasin or fork:______________________ Basin:________________________

Legal description: T.________ R.__________ Sec.________

Road and crossing location:____



Factor	Measurement	Record
A: Width of stream above culvert		Nearest foot
A: Estimated winter width of stream		Nearest foot
B: Length of culvert		Nearest foot
C: Diameter of culvert		Feet and inches
D: Height of culvert		Feet and inches
E: Pool length below culvert		Nearest foot
F: Pool width below culvert		Nearest foot
G: Pool depth below culvert		Nearest foot
H: Drop of culvert from horizontal		Inches

Answer questions on other side of form.

ODFW Culvert Evaluation Form, page 2

Questions

What is the type of culvert?
❒ steel ❒ tarred steel ❒ aluminum ❒ concrete ❒ wood ❒ other

Who owns and maintains the culvert?

Is the culvert in good condition?

Is the culvert easily accessible from the road for fish-passage repair work?

What species and estimated size of fish are observed in the pool *below* the culvert?

What species and estimated size of fish are observed in the first pool *above* the culvert?

In your judgment, could adult fish pass upstream through the culvert in winter?
If not, why not? What would be needed to improve passage?

In your judgment, could juvenile fish pass upstream through the culvert in winter?
If not, why not? What would be needed to improve passage?

Do you have other comments about this culvert?

NEW ROAD CONSTRUCTION

Both watershed concerns and construction expense make it desirable to build as few new roads as possible. If new roads are needed primarily for logging activity, keep in mind that some logging systems require more roads than others.

Generally, ground-based logging requires the most roads. Systems that can carry logs over longer distances (e.g., multispan cable skylines or helicopters) require the fewest roads. These methods tend to be more expensive, however, and are best suited to steep or less accessible terrain.

Proper road location can prevent or reduce watershed impacts. Key principles include building roads far away from streams and other drainages, minimizing the number of crossings, and recognizing and avoiding potentially unstable areas.

In steep terrain, ridgetop roads can limit soil excavation and exposure. They also reduce the amount of water that the road's drainage system must handle because there is less area upslope to add runoff.

New road construction provides an ideal opportunity to incorporate proven design features that help reduce or prevent watershed impacts. As mentioned earlier, most of these features focus on road drainage and stream crossings.

Subgrade preparation, or preparing the road for surfacing, is another important part of road design. In steep terrain, for example, *full-bench* and *end-haul* construction can reduce landslides and other erosion problems. In this approach, the entire road width is cut into the slope, and the excavated material is hauled to a stable location. This method contrasts with *cut and fill* construction, in which some of the excavated material is used to build up a portion of the road surface. In wet or weak soils, synthetic fabrics or other subgrade enhancements can improve the bearing strength of roads and reduce rutting and drainage problems.

Gravel surfacing is another proven way to reduce erosion and sedimentation from forest roads. The OSU publication *Rocking Woodland Roads* provides further information on this topic.

Soils freshly exposed by construction can be especially prone to erosion, so time road building so soils have a chance to stabilize before the rainy season begins. The OSU publications *Planning Woodland Roads* and *Road Construction on Woodland Properties* include a suggested construction schedule and other ways to reduce problems. Another helpful resource is *Seeding to Control Erosion Along Forest Roads,* which includes guidance on both species and application method.

UNSTABLE TERRAIN

Unstable terrain where landslides occur can be an important source of stream sediment and woody debris, both natural and management-related. Identifying these areas can be very helpful in understanding current watershed conditions and in prescribing management activities.

Keep in mind that different types of slope instability can present different concerns for watershed management. Slow-moving earthflows, for example, may provide a chronic, natural source of stream sediment that may be difficult or impossible to control. On the other hand, landslide potential may be reduced locally by avoiding road construction along a slope that shows evidence of past debris avalanches.

It's not possible to identify the exact locations where landslides will occur, but broader areas of current and potential instability can be recognized. Expertise in geology, soils, hydrology, and geotechnical analysis is needed for the most reliable assessments, but preliminary surveys can be done using simple guidelines.

For example, basic clues for current or potential instability include:

- Very steep slopes (e.g., >65 percent)
- Slope depressions or other sites where water may concentrate
- Slopes with active seeps or springs (Indicators include localized water-loving plants, and black or "mottled" soil.)
- Very uneven or hummocky slopes
- Very shallow soils over bedrock
- Deep, wet soils with high clay content
- Bulging stream banks with actively sloughing soil
- "Jackstrawed" trees (trees leaning in different directions) or trees with curved trunks
- Slopes with tension cracks or "cat steps" (soil slippage that forms small steps on a slope)
- Bedrock faults or rock beds parallel to the surface slope

Be aware that most topographic maps and aerial surveys provide only a rough picture of actual ground conditions that contribute to instability. For example, a recent study by the Oregon Department of Forestry showed that standard topographic maps poorly identified the exact locations of steep slopes. Likewise, aerial photos failed to show many existing landslides, especially where there was forest cover.

It's often very difficult or costly to improve slope stability in very unstable terrain through watershed enhancements. Simply put, it's hard to hold back naturally weak soil on a very steep slope when it's soaked by an unusually large storm. However, some practices can at least help maintain existing soil strength, and a few can increase it somewhat.

Some of these practices already have been mentioned: directing road drainage away from unstable slopes, and avoiding burning or chemical treatments that remove duff and vegetation. Also, rock buttresses can be used along unstable road cutbanks, and tree planting on steep, grassy slopes may add some root strength. Experts familiar with slope stability problems and solutions can best assess such opportunities.

Tree removal to reduce landsliding is a method that has not been validated by research. Tree weight is insignificant compared to the weight of wet soil, and tree roots provide some soil strength. Most studies in very unstable terrain have shown some increase in landslides in the first decade after clearcutting, but some locations and young forests have shown fewer landslides after such cutting.

The Oregon Department of Forestry recently was given greater control of forest operations in unstable terrain, and other new efforts to deal with landslide hazards are underway. However, it's essential to recognize that in unstable terrain, a significant landslide risk will exist whether or not management activities occur.

Summary/Self review

Uplands usually represent the largest areas within a watershed, so they can have important effects on streams and other water bodies. Upland management and enhancement activities focus on two things:

- Maintaining or improving conditions that promote natural hydrologic functions
- Minimizing erosion and other problems from extreme events such as floods or droughts

Infiltration and *drainage* of rain and snowmelt refer to the movement of water into and through the soil. Good infiltration and drainage mean that water is less likely to run off the soil surface.

An important factor in infiltration and drainage is the *porosity* of the soil, both the various sizes and total volume of spaces in the soil. Highly porous soil allows water to infiltrate quickly. Compaction can reduce the number of large soil pores and can inhibit plant root growth. If these changes occur over large areas, surface runoff and erosion may increase.

Deep tillage of heavily compacted areas can help restore infiltration and drainage, as well as promote better growing conditions for protective vegetation. Infiltration also can be enhanced by measures to slow down surface water movement so that water has time to soak into the soil.

Vegetation can enhance watershed processes such as water infiltration, which contributes to desirable moisture storage and release and also helps reduce excess erosion and sedimentation. Watershed enhancement thus can include measures to improve vegetation cover.

How roads are used and maintained should be a major part of your watershed evaluation and potential enhancement efforts. Both routine and emergency road maintenance can be critical to preventing or reducing erosion and sedimentation problems. Ensuring that the road drainage system functions well is a major focus of both types of maintenance.

Stream crossings are a point of direct contact between streams and roads. Thus, erosion and other problems at these locations can quickly have a substantial impact on water quality and fish habitat. It's critical that stream crossings have adequate flow capacity to prevent erosion or washouts during large storms.

Fish passage at stream crossings is a major concern because barriers to passage can effectively eliminate many miles of valuable spawning or rearing habitat. Older forest stream crossings and those on nonforest lands often were installed with little or no consideration for fish passage. Thus, upgrading crossings that restrict access to valuable habitat may represent an important watershed enhancement opportunity.

Proper road location can prevent or reduce watershed impacts. Key principles include building roads far away from streams and other drainages, minimizing the number of crossings, and recognizing and avoiding potentially unstable areas.

Unstable terrain where landslides can occur can be an important source of stream sediment and woody debris, both natural and management-related. Identifying these areas can be very helpful in understanding current watershed conditions and in prescribing management activities.

EXERCISES

You can do these exercises on your own, but it will be helpful to work as a group so you can compare notes and discuss your findings.

Stream crossing enhancement plan

Identify a small, local stream crossing that shows evidence of a significant watershed problem such as overtopping or erosion during recent major storms, or restricted fish passage. Develop a plan to replace or improve the crossing, using the following key steps and information:

1. Estimate the 10-, 25-, and 50-year peak flows for the crossing, using local topographic maps and the ODF peak flow map. Collect and consider site-specific information (e.g., shallow soils or terrain features) and other estimation procedures (e.g., *Estimating Stream Flows for Culvert and Bridge Design*) in determining an appropriate design flow.
2. Examine and evaluate the current crossing for:
   - Sufficiency to pass a desirable design flow
   - Specific problems such as erosion, debris clogging, etc.
   - Upstream and downstream adult and juvenile fish passage
3. Using the above information, consider crossing enhancement or replacement options and develop preliminary design plans. For example, you may be able to reduce erosion problems by adding riprap or other protection to road fills or bridge abutments. Excavating a resting pool below a culvert crossing may enhance fish passage. An undersized pipe could be replaced by a larger pipe or bridge. Estimate labor, materials, construction, and maintenance requirements and costs for the different options. If possible, have a hydrologist, engineer, or road specialist review the options and plans.
4. Review the advantages and disadvantages of the different stream crossing enhancement options. If funding for an actual enhancement project is possible, contact potential contractors for project bids. Be sure to check about necessary permits or scheduling requirements by agencies such as the ODF, ODFW, etc.
5. Develop a preliminary plan for monitoring the installation and performance of the stream crossing, including needed maintenance under both normal and extreme conditions (e.g., major storms).

(continued)

Soil drainage enhancement plan

Identify a local upland farm or woodland site that shows evidence of a significant soil drainage problem such as excess runoff or surface erosion from an existing pasture, field, or logged area. Give priority to areas where the runoff or eroded soil clearly enters a stream channel. Develop a plan to improve soil infiltration and drainage, using the following key steps and information:

1. Visit areas where surface runoff and/or erosion appear to be increased by compaction from farm or forest operations. Evaluate and rank severity of observed watershed problems, particularly whether recent storm runoff and/or sediment has been delivered directly to a stream channel.
2. Examine data on storm intensities and soil infiltration rates published in local climate summaries and soil surveys. Using ring infiltrometers or other field methods, test and compare infiltration rates between a significant problem area and a relatively undisturbed adjacent area. If differences exist, evaluate the probable primary source of these differences (e.g., soil compaction, soil exposure, or lack of runoff barriers).
3. Consider infiltration enhancement options for the problem area (e.g., soil tillage, modified farm or forest practices, mulching, seeding, or planting), and develop preliminary project plans. Estimate labor, materials, construction, and maintenance requirements and costs for the different options. If possible, have a soil scientist review the options and plans.
4. Review the advantages and disadvantages of the different soil infiltration enhancement options. If funding for an actual enhancement project is possible, contact potential contractors for project bids. Be sure to check about necessary notices or other requirements by agencies such as the ODF.
5. Develop a preliminary plan for monitoring the implementation and results of the infiltration enhancement treatments, including soil behavior under both normal and extreme conditions (e.g., major storms) over time.

Resources

Training

Oregon State University (College of Forestry, Extension Service, etc.) and the *Oregon Department of Forestry* occasionally offer public seminars, field trips, and short courses on topics related to upland watershed management and enhancement. Training programs also may be offered by various nonprofit and private organizations, including consultants. If you're interested in self instruction, consider the publications and audiovisual programs listed below.

Information

General practices

Chemicals and Other Petroleum Products, ODF Forest Practice Note No. 3 (Oregon Department of Forestry, Salem).

Environmental Impacts of Brush Control, slide-tape 705.6 (Oregon State University Forestry Media Center, Corvallis).

Forest Operations: Part of the Solution, video 1071 (Oregon State University Forestry Media Center, Corvallis).

Forest Practices and Surface Erosion, slide-tape 795 (Oregon State University Forestry Media Center, Corvallis).

Healthy Watersheds (video), VTP-019 (Oregon State University Extension Service, Corvallis, 1994).

The Miracle at Bridge Creek, Watershed Improvement (video), VTP-013 (Oregon State University Extension Service, Corvallis).

Oregon Forest Practice Administrative Rules (Oregon Department of Forestry, Salem).

Oregon Interagency Seeding Guide (revised 1988). Available from local offices of the Natural Resources Conservation Service.

Oregon Watershed Assessment Manual (available from the Governor's Watershed Enhancement Board, Salem).

Oregon's Forest Practice Rules, EC 1194, by P. Adams (Oregon State University Extension Service, Corvallis, revised 1996).

Pesticides in Forestry: Behavior in the Forest Environment, video 911.2 (Oregon State University Forestry Media Center, Corvallis).

Soil and Water Conservation: Introduction For Woodland Owners, EC 1143, by P. Adams (Oregon State University Extension Service, Corvallis, reprinted 1997).

Timber Harvesting Options, EC 858, by J. Garland (Oregon State University Extension Service, Corvallis, reprinted 1997).

Timber Harvesting Options, slide-tape 767 (Oregon State University Forestry Media Center, Corvallis).

Water Quality and Our Forests: Western Oregon Research (video), VTP-014 (Oregon State University Extension Service, Corvallis, 1993).

We All Live Downstream (video), VTP-021 (Oregon State University Extension Service, Corvallis, 1995).

Soil infiltration

Designated Skid Trails, slide-tape/video 903 (Oregon State University Forestry Media Center, Corvallis).

Designated Skid Trails Minimize Soil Compaction, EC 1110, by J. Garland (Oregon State University Extension Service, Corvallis, reprinted 1997).

An Evaluation of Four Implements Used to Till Compacted Forest Soils in the Pacific Northwest, FRL Bulletin 45 (Oregon State University Forest Research Lab, Corvallis, 1983).

Recognizing and Managing Forest Soil Compaction, slide-tape/video 823 (Oregon State University Forestry Media Center, Corvallis).

Soil Compaction on Forest Lands, film/video 850 (Oregon State University Forestry Media Center, Corvallis).

Soil Compaction on Woodland Properties, EC 1109, by P. Adams (Oregon State University Extension Service, Corvallis, reprinted 1998).

Tilling Compacted Forest Soils, slide-tape/video 876 (Oregon State University Forestry Media Center, Corvallis).

Waterbars, ODF Forest Practice Note No. 1 (Oregon Department of Forestry, Salem).

Roads

Designing Woodland Roads, EC 1137, by J. Garland (Oregon State University Extension Service, Corvallis, reprinted 1993).

Estimating Streamflows on Small Forested Watersheds for Culvert and Bridge Design in Oregon, FRL Bulletin 55 (Oregon State University Forest Research Lab, Corvallis, 1986).

Interim Fish Passage Guidance at Road Crossings, ODF memo, by E.G. Robison (Oregon Department of Forestry, Salem, 1997).

Logging Road Construction, slide-tape 909 (Oregon State University Forestry Media Center, Corvallis).

Maintaining Woodland Roads, EC 1139, by P. Adams (Oregon State University Extension Service, Corvallis, reprinted 1997).

Planning Woodland Roads, EC 1118, by J. Garland (Oregon State University Extension Service, Corvallis, revised 1996).

Road Construction on Woodland Properties, EC 1135, by J. Garland (Oregon State University Extension Service, Corvallis, reprinted 1993).

Unstable terrain

Forest Practices and Mass Soil Movement, slide-tape 813 (Oregon State University Forestry Media Center, Corvallis).

Landslides in Oregon (brochure) (Oregon Department of Forestry, Salem).

Slope Stability on Forest Lands, PNW 209, by R. Sidle (Oregon State University Extension Service, Corvallis, 1980).

Ordering instructions

OSU Extension Service publications are available from county offices of the OSU Extension Service or from: Extension & Station Communications, Oregon State University, 422 Kerr Administration, Corvallis, OR 97331-2119; fax: 541-737-0817; Web: eesc.orst.edu

OSU Extension Service videos are available for purchase from: Extension & Station Communications, Oregon State University, 422 Kerr Administration, Corvallis, OR 97331-2119; fax: 541-737-0817; Web: eesc.orst.edu (These programs also may be available for viewing or loan from county offices of the OSU Extension Service.)

OSU Forest Research Lab publications are available from: OSU Forestry Publications Office, Forest Research Lab 227, Corvallis, OR 97331-7402; phone: 541-737-4271, fax: 541-737-3385; Web: www.cof.orst.edu/cof/pub/home/homepage.htm

OSU Forestry Media Center slide-tape, film, and video programs are available for purchase or rental from: OSU Forestry Media Center, 248 Peavy Hall, Corvallis, OR 97331-5702; phone: 541-737-4702; fax: 541-737-3759; e-mail: forestrm@ccmail.orst.edu; Web: www.orst.edu/Dept/fmc/

Oregon Department of Forestry publications are available from local ODF offices, or from: Oregon Department of Forestry, 2600 State Street, Salem, OR 97310; phone: 503-945-7422, fax: 503-945-7212; Web: www.odf.state.or.us/default.htm

MOVING FORWARD–THE NEXT STEPS

On your own, use the lines below to fill in steps, actions, thoughts, contacts, etc. you'll take to move yourself and your watershed group ahead in improving your understanding of upland evaluation and enhancement.

1. ____

2. ____

3. ____

5

Terrestrial Riparian Area Functions and Management

David Hibbs

Riparian area management is extremely complex because plants, animals, soils, and water all interact with each other and constantly change over time. But the task is too important for you to be put off by its complexity; in fact, the complexity is what makes it exciting!

There are many different approaches to setting riparian area goals, and many management concepts used in meeting those goals. This chapter will get you started on understanding some aspects of riparian areas so you can begin thinking about your goals. Chapter II-6 will introduce you to evaluation, enhancement, and monitoring techniques for riparian areas.

To effectively set goals or make decisions about specific management activities, however, you'll need to learn a lot about the functions and processes that make up a riparian ecosystem. We can cover only a limited amount of what you need to know here. The other chapters in this section contain important related information. To delve further into these topics, take a look at the readings in this and other chapters' Resources sections.

Please note: This chapter focuses on western Oregon riparian areas. Chapters focusing on eastern Oregon ecosystems will be developed at a later date.

IN THIS CHAPTER YOU'LL LEARN:

- Management goals are more likely to succeed if they are based on ecological functions and processes rather than on physical conditions.
- Stream structures come from many and sometimes distant places; structure changes constantly.
- A mix of forest ages and types (conifer and broadleaf) along streams provides the greatest land and in-stream diversity.
- The quality of fish habitat naturally changes with time, sometimes for the better, sometimes for the worse.
- Active management techniques can enhance all riparian functions, from new tree establishment, to fish spawning, to tree growth.

What Is a Riparian Area?

See Section II, Chapters 6 and 7, and Section III, Chapters 2, 4, 5, and 7 for information related to this chapter.

Riparian area is a term with a fuzzy meaning. At its simplest, it is a zone adjacent to water where the soil is wet. Thus, there are riparian areas around springs, ponds, and streams. In the context of streamside management today, the term includes three components:

- *The aquatic area,* which includes the stream, side channels, and depressions in the flood plain away from the stream
- The area near the stream where vegetation is strongly influenced by water. This *wet terrestrial zone* either has wet soils or often is flooded.
- The zone of influence, which refers to the many land-based factors that influence in-stream processes. The *zone of influence* includes the plants that hang over the stream as well as trees growing farther away that might shade or fall into the stream. For some functions, the zone of influence extends from ridgetop to ridgetop.

Current conditions in the riparian areas of western Oregon are highly variable. This variation comes from three primary sources:

- Climate varies greatly, with strong differences in precipitation and temperature as you go from west to east and north to south. There generally is more moisture closer to the coast than inland, and more in the north than in the south. Moisture also increases from low elevation to high. Temperature extremes (highs and lows) also increase with elevation and distance inland from the coast. These differences determine what species might be found (or could be grown) at any specific location.
- Past fires, floods, and landslides have created a variety of opportunities for plants to reseed and reestablish, resulting in a diversity of species, age classes, and physical structure of vegetation. Fires, floods, and debris flows are normal and relatively common disturbances. Each one kills some plants, gives new ones the chance to start, and often moves large amounts of soil and logs (whole trees and pieces of tree trunks).
- Management activities since 1800, such as trapping, farming, logging, mining, grazing, and fire suppression, have altered historic disturbance patterns. These new disturbance patterns, in turn, have changed and continue to change the makeup of riparian plant communities.

RIPARIAN MANAGEMENT GOALS

Today, many management goals exist for riparian areas. These goals include increasing fish populations, maintaining water quality, controlling water temperature, restoring historic habitat structures, stopping landslides, and harvesting timber, as well as many others. While all of these goals are well intended, they sometimes are contradictory and may be based on mistaken ecological assumptions.

The goals listed above focus on *conditions*, or how a riparian area looks today: the number, size, and species of plants; the location of the stream; the size and location of logs, etc. Furthermore, they tend to view these conditions as unchanging.

An alternative approach is to keep goals focused on desired ecological *functions* (Gregory et al., 1991). Functions refer to the processes that support life: establishing new plants, providing in-stream structure, shading a stream, etc. This approach is more likely to succeed because it identifies processes that must be managed and it opens the door to considering more than one way to meet a goal.

Four functions commonly are involved in riparian management goals:

- Providing structural diversity in and near streams
- Providing wildlife habitat
- Maintaining stream productivity
- Maintaining forest productivity

Each of these functions is discussed below.

Providing structural diversity in and near streams

To most people, stream structure means large conifer logs (Figure 1), although in some streams, boulders also fill this role. Current federal and state riparian management rules focus on growing this wood on the stream bank. However, recent research shows that, historically, some of the large wood in some streams entered the riparian system in landslides from steep, unstable upper slopes. These landslides also are the critical source of

Figure 1.—Large pile from old debris flow.

gravel for spawning beds. Because landslide frequency increases with precipitation and slope steepness, landslides are more common in the northern and central Coast Range than elsewhere. Chapter II-7, "Stream Ecology," talks more about these aspects of stream ecosystems.

Thus, management activities focused on providing structural diversity might consider both the near-stream area and nearby upper steep slopes. For example, an upslope option might be to identify unstable and potentially unstable slopes on which to leave trees that eventually will slide into the stream. These trees would balance harvest of riparian trees that are unlikely to fall into the floodplain.

In all of these stream and streamside discussions, it is critical to keep in mind that riparian systems are *dynamic* or ever-changing. Most people are aware of the short-term changes in riparian systems. High water one winter, for example, knocks down a few trees or shifts a short section of channel (Figure 2).

***Figure 2**—Red alder that was recently undercut by stream and fell.*

There are, in addition, normal, very long-term processes as well. For example, a large fire or a very large rainstorm may cause landslides, which carry gravel and wood into the stream (Reeves et al., 1995). Initially, this debris creates poor fish habitat because it includes lots of fine silt and clay particles, which smother eggs. After a few years, the fine sediment is washed out, leaving good gravel beds and new pools–prime fish habitat. Over the period of a century or two, the wood and gravel also are washed out of the stream, again leaving poor habitat conditions.

At the same time, conditions on the stream bank also are changing. A mix of herbs, shrubs, conifers, and hardwoods gets established after the fire or slide, and a new cycle of plant growth, or *succession*, begins. Where conifers get started, tree cover and a long-term source of wood for the stream or for harvest are assured, since Northwest conifers live for many centuries.

Where alder and other hardwoods get started, much less wood is grown and, because these trees live only 100 to 150 years, they generally die before the next disturbance comes along. In the riparian areas of the central and northern Coast Range, these hardwoods often are replaced by shrubs, which may persist until the next disturbance. In the southern Coast Range and where shade-tolerant conifers (hemlock, redcedar, Sitka spruce, and grand fir) are present (Cascades, east and west edge of the Coast Range, and some locations within the Coast Range), hardwoods tend to be replaced by conifers through succession.

Providing wildlife habitat

Many different features of riparian zones attract wildlife. For example, riparian wildlife species such as salamanders need the high moisture conditions found in riparian zones (McComb et al., 1993). These species often are found at midslope springs and seeps as well.

Other wildlife species commonly associated with riparian areas are attracted by the vegetation characteristics, such as hardwood cover, conifer cover, or rotting logs. Many of these species also are found elsewhere in the forest where these vegetation conditions occur.

Because wildlife species are so diverse in the environmental cues they respond to, no simple or single management approach meets all of their needs. Therefore, management must be planned both at the local, streamside level (the stand level) and at the larger landscape level to provide a diversity of habitat conditions.

- *Stand management.* At the stand level (the local streamside), management can focus only on the habitat needs of a small group of species. For example, both deer and common songbirds such as warblers prefer very young forests (0–15 years old) or very open hardwood forests.
- *Landscape management.* Careful planning at the landscape level is needed to meet the habitat needs of most wildlife species. This planning needs to ensure that many kinds of vegetation and stages of forest development exist. Thus, a length of streamside forest should include patches of varied ages and species.

All habitat management, at the stand or landscape scale, must recognize that all plant communities change with time. Trees get bigger and eventually die. Herbs and shrubs that initially are dense and vigorous after a fire or harvest later grow very poorly as trees grow taller and shade them.

Thus, you not only must seek to create a certain mix of conditions today, but you also must plan for changes. For example, you may want to plan disturbances to "restart" the forest in order to create open, early successional conditions. To do so, you must understand the frequency, intensity, and duration of natural disturbances that management is intended to complement.

See Chapters III-4, "Wildlife Management," and III-5, "Wildlife Evaluation and Enhancement," for more information about wildlife habitat management.

Maintaining stream productivity

The in-stream food chain is fed by sunlight, *litter* (leaves, needles, and branches) that falls into the water, and flying insects. The sunlight causes algae to grow on rocks. Insects eat the algae and the plant litter; fish eat the insects and algae; larger predators eat the fish. *Stream productivity* refers to how much food is generated at all levels of the food chain from the initial energy inputs. Chapter II-7, "Stream Ecology," discusses these processes in detail.

Since both coniferous and deciduous species play different but important roles, it seems advisable to maintain an abundance of both kinds of trees along a stream.

Different kinds of trees have different effects on stream productivity. Conifer litter falls more evenly throughout the year than hardwood litter. It also has a lower nutrient content and breaks down more slowly. A deciduous canopy (such as alder, oak, or maple) provides summer shade and lets light through for winter photosynthesis. Stream productivity sometimes is limited by low levels of nitrogen. Thus, alder, which can capture nitrogen from the air and release it into the groundwater, can be important.

Even when you understand all of these principles, it's still difficult to know how to manage riparian vegetation to aid stream productivity. Little information exists on which streams' productivity is limited by temperature, energy, or nitrogen. There has been no systematic study of how different mixtures of hardwoods and conifers affect in-stream processes; all studies have been based on a single location. Thus, since both coniferous and deciduous species play different but important roles, it seems advisable to maintain an abundance of both kinds of trees along a stream.

In the central Coast Range, an image of what some presettlement streams might have been like was provided by a study of small streams that have been minimally disturbed by humans for at least 150 years (Nierenberg, 1996). This study found that the riparian "forest" was composed of about equal patches of hardwoods and conifers, but that shrub-dominated patches were more common than either forest type.

This pattern contrasts strongly with the central Cascades, where riparian areas along small streams in old-growth forests typically are characterized by a predominance of conifers, with the hardwood component usually restricted to a narrow strip on the stream bank. In both mountain ranges, researchers believe that the dominance of hardwoods probably increases as stream size increases.

Maintaining forest productivity

Forest productivity refers to a site's ability to maintain productive plant growth, primarily trees, regardless of their use–timber, fish food, habitat, etc.

Most riparian soils grow trees very well (whether for timber or riparian structure), although historically riparian forests in some parts of the region had relatively few and irregularly spaced trees. Site conditions (drainage, soil texture, and flooding) vary greatly in riparian areas, affecting both which tree species are appropriate and how fast they grow (Minore and Smith, 1971; Minore, 1979).

Active management is required in many areas to obtain tree regeneration. Activities such as thinning may help you achieve management goals. To minimize soil disturbance and harvest costs, it's best to combine tree removal or in-stream log placement activities with nearby upslope thinning and harvest activities.

RIPARIAN SILVICULTURE

The four functions or types of management goals we've just discussed lead easily into *silvicultural* (forest management) plans. The silvicultural principles of riparian areas are no different than those used elsewhere. However, there often are overriding goals such as creating stream shade or controlling soil erosion that limit your choice of silvicultural system or physical activities.

Four riparian management activities are discussed here. See Chapter III-2, "Forest Ecology and Management," for additional information about forest management.

Buffers

Forested buffers can be left along streams to protect in-stream and streamside riparian functions. Buffers or riparian management areas are required to be left along many streams when timber is harvested. See Chapter III-7, "Incentives and Regulations," for more information.

Studies of buffers show that some can suffer blowdown, but at predictable locations (Steinblums et al., 1984). Most are surprisingly biologically stable; that is, they develop largely as if they still were part of a continuous forest (Hibbs and Giordano, 1996). Thus, buffers generally do protect riparian functions for the life of the overstory trees.

This last statement is important to emphasize. Trees do not live forever. Red alder, the most common hardwood species in riparian areas, lives only 100–150 years. In contrast, conifers can live for 500 years or more.

Regeneration

Regeneration is the process by which new trees become established. A good general reference on forest regeneration practices is Hobbs et al. (1992). Studies of tree regeneration in riparian areas (both those with buffers and those that are undisturbed) indicate that conifers and hardwoods are regenerating on their own in about the southern third of the Coast Range (Minore and Weatherly, 1994).

***Figure 3.**—Salmonberry understory filling space between overstory trees as the overstory thins. Note the lack of young trees.*

However, in the middle and northern thirds of the Range (except in the narrow coastal fog belt and the Willamette Valley margin), tree regeneration is limited by competition from understory plants (Figure 3) and by a shortage of nearby hemlock and redcedar seed sources. In these areas, there isn't enough regeneration to replace the current forest, so active management for regeneration is needed. In the Cascades, natural regeneration of conifers in riparian areas is common.

The many ongoing studies of active management for tree regeneration in riparian areas clearly show that providing enough light and controlling browsing animals (beaver, deer, and cows) are critical to success. If these things are done, survival of planted seedlings is very good, and growth is excellent (Chan et al., 1996).

Studies also show that heavy thinning of the overstory and removal of the salmonberry understory provide adequate light for shade-tolerant species (hemlock, redcedar, grand fir, and spruce). On the other hand, Douglas-fir and red alder need small gaps (diameter greater than one tree height) for good regeneration. These less shade-tolerant species survive and grow slowly with less light, such as in the conditions created by an overstory thinning, but under these conditions their exposure to browsing animals is so prolonged that ultimate survival is limited.

The process of reestablishing trees in agricultural areas relies on planting seedlings or, for willow and cottonwood, cuttings. The two primary hazards to successful regeneration are: (1) competition from grass and shrubs such as blackberry, and (2) browsing by animals, including beaver, deer, elk, sheep, and cattle. Most agricultural tree regeneration projects use fencing to reduce browsing.

Beaver populations are increasing. The long-term impact of beavers on riparian regeneration, the number of trees that survive, and the species present is not known. In a number of studies, trees that outgrew the salmonberry competition later disappeared except for a tooth-marked stump. Figure 4 shows beaver damage to mature trees. Fencing along the stream edge is an effective barrier but requires careful maintenance following each winter flood.

Figure 4.—*Beaver damage.*

Release

Understory or midsize conifers grow very well if competing alder is eliminated. This practice is known as *releasing* the conifers (Emmingham and Mass-Hebner, 1994). The alder may be cut, girdled (cut through the bark all the way around the trunk), or injected with herbicide. Girdling and injection maintain easy access to a site for follow-up understory treatments. Girdling must be done carefully and thoroughly to be successful.

For more information, see Chapter II-6, "Terrestrial Riparian Area Functions and Management."

Thinning

Thinning most often is used to maintain or increase rates of tree diameter growth. Heavy thinning beginning when trees are young can produce very large trees in a relatively short time (Newton and Cole, 1987). These trees may be important for both wildlife habitat and for in-stream structural material.

Riparian tree cover today is primarily alder and Douglas-fir. Future management activities probably will greatly increase the amount of hemlock and redcedar. Because these two species cast a dark shade, they decrease understory growth and diversity. Overstory thinning is one way to maintain this understory.

SUMMARY/SELF REVIEW

Management goals based on functions instead of physical condition create more opportunities for solutions. To effectively set goals, you need to understand the basic processes, such as energy flow and succession, that make up an ecosystem.

The following functions commonly are involved in riparian management goals:

- Providing structural diversity in and near streams
- Providing wildlife habitat
- Maintaining stream productivity
- Maintaining forest productivity

Stream structures come from many and sometimes distant places; structure changes constantly. Current federal and state riparian management rules focus on growing this wood on the stream bank. However, recent research shows that, historically, some of the large wood in some streams entered the riparian system in landslides from steep, unstable upper slopes. These landslides also are the critical source of gravel for spawning beds. Thus, management activities focused on providing structural diversity might consider both the near-stream area and nearby upper steep slopes.

Different wildlife species use different aspects of riparian areas; thus, no single management approach meets all wildlife needs. Management must be planned both at the streamside level and at the larger landscape level.

The quality of fish habitat naturally changes with time, sometimes for the better, sometimes for the worse. For example, in the long-term process, a large fire or a very large rainstorm causes landslides, which carry gravel and wood into the stream. Initially, this debris creates poor fish habitat because it includes lots of fine silt and clay particles, which smother eggs. After a few years, the fine sediment is washed out, leaving good gravel beds and new pools–prime fish habitat. Through a century or two, the wood and gravel also are washed out of the stream, leaving poor habitat conditions.

A mix of forest ages and types (conifer and broadleaf) along riparian corridors will provide the highest land and in-stream diversity. Different kinds of trees have different effects on stream productivity. Conifer litter falls more evenly throughout the year than hardwood litter. It also has a lower nutrient content and breaks down more slowly. A deciduous canopy (such as alder, oak, or maple) provides summer shade and lets light through for winter photosynthesis.

Active management techniques can enhance all riparian functions, from tree regeneration, to fish spawning, to tree growth. Some suites of management goals work together and others conflict in terms of their effects on ecosystem processes. To choose appropriate management techniques, you need to understand the regeneration requirements (light, moisture, and protection from animals) of your tree species. You also need to understand how managing the density of overstory trees can affect individual tree growth of the overstory trees as well as growth of plants in the understory.

EXERCISES

These exercises can be done on your own, but it's best to do them as a group so you can discuss your observations.

Riparian area exploration

Carefully explore a small section of riparian area to:

- Gain an understanding of how much soil, topography, drainage, and plant composition vary over short distances.
- Gain an understanding of how physical features (soil, topography, and drainage) affect plants.

Visit a local stream within a large, forested area. The stream should be one that you can wade across. Make a real (perhaps with string) or imaginary (in your mind) line that crosses the stream, covers the flatter areas near the stream, and starts to go up the adjacent hillsides.

Now make a drawing of how far the soil surface is above the stream at different points along the line. It may be easiest to think of the water level in the stream like sea level; it marks the zero height, and the ground on either side of the stream goes up from there. It is common to discover that the soil actually is higher near the stream than back toward the hill slope. Can you think of a reason why?

The shape of this drawing can vary greatly among streams or even along the same stream. There may be more than one flat surface (terrace) that steps up away from the stream. There may be shallow, dry channels or wet, swampy spots far from the stream.

Now look at the vegetation, both the trees and the understory. How do they change as the elevation of the line changes. Are some plants found most often on the stream bank, at the foot of the slope, on logs? What patterns can you detect? Look for signs of wildlife. What elements in the habitat do they seem to be using?

What signs of management or other disturbance can you detect? Is the influence local or quite extensive? How have plants responded to the disturbance? How would they respond to a management activity you would do? What will this area look like in 50 years and in 100 years if left alone?

Go up the stream 100 yards and do the exercise again (or have several teams working at different locations at the same time). Do you come to the same conclusions?

Comparing streams

After training your eye in the exercise above, enlarge your perspective on the variation that exists over a landscape and over time.

1. Visit several streams, chosen to make contrasts between:
   - Large and small streams
   - Streams in areas of high and low precipitation
   - Areas with similar precipitation–one that gets a lot of it as snow and one that gets little snow
   - Streams of similar size within forest land and within agricultural land
2. Visit the same stream at several times of the year. It certainly will have more water during the wet season than during the dry season. But look more carefully.
   - Following a rainstorm, how quickly does the stream level rise and fall? The level will vary with the size of the stream basin and the kind of bedrock.
   - At high flow, where does the water go besides in the main channel? How fast does it move on the floodplain compared to in the main channel?
   - What is happening to large logs? How does their size affect what they do?

Resources

Training

Contact your local office of the Oregon Department of Forestry, the Oregon State University Extension Service, and the Natural Resources Conservation Service.

Information

A Characterization of Unmanaged Riparian Overstories in the Central Oregon Coast Range, M.S. Thesis, by T. Nierenberg (Oregon State University, Corvallis, 1996).

Comparative Autecological Characteristics of Northwestern Tree Species: A Literature Review, General Technical Report PNW-GTR-87, by D. Minore (USDA Forest Service, Pacific Northwest Research Station, 1979).

"Designing stable buffer strips for stream protection," by I.J. Steinblums, H.A. Froelich, and J.K. Lyons. *Journal of Forestry* 82:49–52 (1984).

"A disturbance-based ecosystem approach to maintaining and restoring freshwater habitats of evolutionarily significant units of anadromous salmonids in the Pacific Northwest," by G.H. Reeves, L.E. Benda, K.M. Burnett, P.A. Bisson, and J.R. Sedell. *American Fisheries Society Symposium* 17:334–349 (1995).

"An ecosystem perspective of riparian zones," by S.V. Gregory, F.J. Swanson, and W.A. McKee. *Bioscience* 41:540–551 (1991).

Occurrence and Growth of Four Northwestern Tree Species over Shallow Water Tables, Research Note PNW-RN-160, by D. Minore and C.E. Smith (USDA Forest Service, Pacific Northwest Research Station, 1971).

Reforestation Practices in Southwestern Oregon and Northern California, by S.D Hobbs, S.D. Tesch, P.W. Owston, R.E. Stewart, J.C. Tappeiner II, and G.E. Wells (eds.) (Oregon State University Forest Research Laboratory, Corvallis, 1992).

"Riparian trees, shrubs, and forest regeneration in the coastal mountains of Oregon," by D. Minore and H.G. Weatherly. *New Forests* 8:249–263 (1994).

"Small mammal and amphibian abundance in streamside and upslope habitats of mature Douglas-fir stands, western Oregon," by W.C. McComb, K. McGarigal, and R.G. Anthony. *Northwest Science* 67:715 (1993).

Survival and growth of conifers released in alder-dominated coastal riparian zones, by W.H. Emmingham and K. Mass-Hebner. *COPE Report* 7:13–15 (1994).

"A sustained-yield scheme for old-growth Douglas-fir," by M. Newton and E. Cole. *Western J. Applied Forestry* 2(1):22–25 (1987).

Thinning hardwood and conifer stands to increase light levels: Have you thinned enough? by S. Chan, K. Mass-Hebner, and W.H. Emmingham. *COPE Report* 9:2–6 (1996).

"Vegetation characteristics of alder-dominated riparian buffer strips in the Oregon Coast Range," by D.E. Hibbs and P.A. Giordano. *Northwest Science* 70:213–222 (1996).

MOVING FORWARD–THE NEXT STEPS

On your own, use the lines below to fill in steps, actions, thoughts, contacts, etc. you'll take to move yourself, your land management agency, your watershed group, etc. ahead in improving your understanding of riparian area management.

1. ____________________

2. ____________________

3. ____________________

6

Riparian Area Evaluation and Enhancement

Derek Godwin
and Bill Rogers

Riparian area enhancement projects and/or management changes are the backbone of watershed enhancement. They often are inexpensive, nontechnical, fun to do as a group, and great projects for volunteers. Don't let the ease of implementing these projects fool you. Projects that don't consider basic riparian functions have a high failure rate. Chapter II-5, "Riparian Area Functions and Management," provides a firm foundation in riparian management and should be used with this chapter. Chapters II-1, "Principles of Planning," and II-3, "Assessment and Monitoring," contain other important information that will help you plan riparian area projects.

To maximize success, you'll need to understand five concepts about the riparian area where you'll implement projects:

- The area's present condition
- Its potential or capacity
- Its proposed future condition
- How to enhance the area to reach the proposed condition
- How to monitor the area's changes over time to judge whether it is reaching the proposed condition

IN THIS CHAPTER YOU'LL LEARN:

- Basic components of riparian assessments
- Features of three common assessment methods and how to obtain these methods
- Common goals of riparian enhancement projects
- How to choose the right riparian vegetation for the right location
- Methods for establishing and protecting vegetation
- Basic components of a riparian monitoring plan

The purpose of this chapter is to provide a basic understanding of riparian area assessments, enhancement projects, and monitoring plans. *Assessments* evaluate present conditions compared to *proposed future conditions* (what you want the riparian area to look like in the future). *Enhancement* techniques change present conditions and "speed up" ecosystem processes to reach proposed future conditions. *Monitoring* evaluates these changes over time. This chapter increases understanding of the basic principles used in existing and future statewide programs (e.g., *Oregon Watershed Assessment Manual*).

See Section I, Chapter 2; Section II, Chapters 1, 3, and 5; and Section III, Chapters 2, 3, and 7 for information related to this chapter.

Please note: This chapter focuses on western Oregon riparian evaluation and enhancement techniques. Chapters focusing on eastern Oregon ecosystems will be developed at a later date.

WHY DO WE NEED AN ASSESSMENT?

An assessment is the first step in establishing a riparian area that provides maximum potential benefits to fish, wildlife, water quality, and humans. An assessment does the following:

- Describes existing conditions.
- Compares existing conditions to reference sites or conditions.
- Recommends projects or management changes to reach a proposed future condition.

For example, an assessment describes the types of trees and grasses present, as well as how they affect fish habitat, water quality, and stream bank stability; identifies additional vegetation that could increase benefits (as compared to a reference site); and outlines projects to reach the proposed condition.

A *reference site* is a riparian area with similar climate, land forms, stream gradients, soils, and potential vegetation that is providing maximum potential benefits to fish, wildlife, water quality, and landowners. In the absence of reference sites, reference conditions are established based on historic conditions found in aerial photos, maps, books, pictures, and local knowledge.

The *proposed condition* is the desired riparian area that maximizes its potential. Proposed future conditions must be within the area's potential or capacity for vegetation quantity and types. Thus, they are based on reference sites or conditions.

BASIC COMPONENTS OF RIPARIAN ASSESSMENTS

Chapter II-5, "Riparian Functions," discussed the basic parts and functions of a riparian area. Some of these functions include:

- Supplying nutrients and woody material to the stream
- Filtering and holding sediment during floods
- Improving floodwater retention and groundwater recharge
- Providing shade to the stream
- Serving as a home for many types of plants and animals
- Keeping stream banks stable

A riparian area assessment identifies which of these parts and functions are present and evaluates how they're functioning. Table 1 summarizes some basic components of riparian area assessments.

Table 1.–Basic components of a riparian area assessment.

Vegetation	Soils	Landscape/river channel
Species present and diversity	Soil type	Size of floodplain
Age and size diversity	Percent of bare ground	Access to floodplain (e.g., is stream downcutting?)
Plant vigor	Percent organic matter or duff	Riparian area growing or shrinking
Plant survival	Erosion or deposition occurring	Beaver dams or log jams present
Root density	Bank stability (i.e., presence of excessive erosion)	
Percent canopy cover (shade)	Ease of water movement through soil (i.e., soil compaction)	
Changes occurring in the plant community		
Future sources of large woody material for the stream		

How you use this information to evaluate the riparian area and recommend changes depends on local reference conditions (sites and best information available) and proposed conditions.

CONSIDERATIONS WHEN CHOOSING AN ASSESSMENT

Many types of assessments are available. The main difference among them is the detail of the data collected. Some basic assessments can be performed by landowners with a little guidance and other resources, while others require trained workers to gather and analyze the data.

> *Because watershed conditions may have been changed by floods or human activity, historical photos and survey notes can help you determine the reference or potential future condition.*

The main question is, "How will the information be used?" If it will be used in a watershed assessment or will be combined with state agency information, it's best to follow accepted state protocols. The draft *Oregon Watershed Assessment Manual* contains riparian assessment protocols for watershed councils to follow.

To conduct an assessment, list the questions you want to answer. A sample question for a basic assessment could be, "How many conifers and hardwoods are present, and do I need to plant more conifers?" A sample question for a more detailed assessment could be, "What is the potential for future delivery of large woody material (LWM) into the stream channel given the current conditions?" *(Oregon Watershed Assessment Manual)*

Make sure the assessment provides enough data to answer your questions. Review the types of data that will be gathered before conducting the assessment. Find some examples of data gathered with the methods you propose to use.

Be sure your assessment will let you compare current conditions (indicated by collected data) to reference sites or conditions. Consult local, state, federal, and private agencies and organizations (e.g., Oregon Department of Forestry, Oregon Department of Fish and Wildlife, Natural Resources Conservation Service, OSU Extension Service) for information on reference sites and conditions.

For example, there may be reference sites that are considered to be functioning at their maximum potential, or information on reference conditions that specify vegetation types, quantity, and other characteristics. Because watershed conditions may have been changed by floods or human activity, historical photos and survey notes can help you determine the reference or potential future condition. In some cases, experts have inventoried riparian areas that are considered to be providing maximum potential benefits, and you could use their data for comparisons.

Make sure the reference information is pertinent to the local ecosystem (stream size, geology, climate, landscape, etc.). Riparian areas in the same watershed could have similar parts and function differently with the stream. For example, a riparian area along a small Coast Range stream provides large wood to create pools and shade. In contrast, riparian areas along large rivers improve stream stability and provide cover for fish during high stream flows.

Divide the riparian area to be assessed into manageable units. This will give you more flexibility in using the data for planning enhancement projects and changes in management.

Some ways to divide riparian areas include:

- Land use or management
- Riparian condition (large areas of nonriparian vegetation versus areas with appropriate riparian species)
- Type of stream (small versus large, flows year-round versus only during storms)
- Valley type (wide floodplain versus steep canyons)
- Resource values (for example, different types of fish or water use)

EXAMPLES OF COMMON ASSESSMENTS

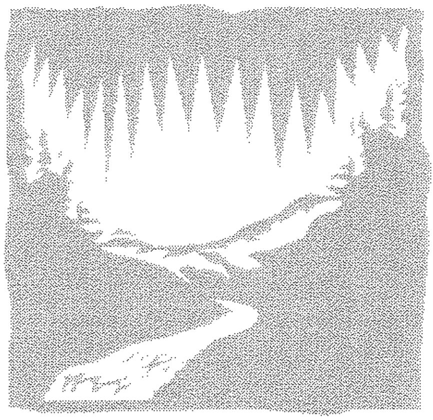
This section provides information on common riparian assessment methods. Its purpose is to familiarize you with common assessments and provide a basis for future training. This brief discussion isn't intended to be a guide for conducting assessments; all of the assessments presented require some training.

Basic assessments

Many types of basic assessments gather information for use on a local level. For example, landowners might want to evaluate their riparian condition and make management changes, or a watershed group might want to establish preliminary information and projects. The information collected usually does not follow a state-wide protocol and is used only by the people conducting the assessment.

One example is to combine photo plots with an inventory of quantity, quality, and type of trees present. The Governor's Watershed Enhancement Board (GWEB) has published a guide to establishing photo points for monitoring watershed projects (see

Resources). The information gathered could be compared to reference sites or conditions.



Another basic assessment is the Rangeland Watershed Program, which was created by the University of California Cooperative Extension. Its purpose is to help ranchers develop farm plans that address the needs of riparian areas, streams, and water quality. A rancher observes a stream and riparian area and then plans management practices based on these observations.

Appendix A shows the evaluation sheet used for the Rangeland Watershed Program assessment. It requires a series of observations about the riparian area and stream, and uses photos, data collection, and visual observations to identify whether an immediate management change is required or more information is needed. This method can be completed without extensive training in soils, hydrology, biology, or botany. For more information, contact the Rangeland Resources Department at Oregon State University (phone: 541-737-3341).

Intermediate and advanced assessments

The Bureau of Land Management (BLM) and U.S. Forest Service (USFS) have developed a riparian area assessment method for evaluating the public lands they manage. They want this assessment to be adopted as a standard method by other agencies and private landowners, and they've hosted many workshops as part of their efforts. The method is called a Process for Assessing Proper Functioning Condition, or PFC.

The process reviews characteristics similar to those in Table 1. To use this method, an assessor answers a series of questions. For example: Are beaver dams present? If so, are they active and stable? Do riparian plants exhibit high vigor? Is there excessive erosion or deposition? Appendix B shows the worksheets used for this assessment.

After completing the worksheet, the assessor rates the riparian area as either properly functioning, functional-at risk, or nonfunctional. A riparian area is considered to be *properly functioning* when adequate vegetation, landform, and/or large woody material are present to provide the basic functions appropriate for the area. A *functional-at risk* area is functioning but has a soil, water, or vegetation problem that is at risk of deteriorating. If the area is determined to be functional-at risk, the assessor determines whether this trend is deteriorating or improving. A *nonfunctional* area doesn't have the characteristics necessary to reduce erosion or improve water quality.

The PFC method should be done by a team of people with knowledge of soils, hydrology, and vegetation. The method requires observation but no data collection. It can, however, help identify data and monitoring needs and the source(s) of problems. Copies of the PFC manual (#TR 1737-9 1993) are available from the Bureau of Land Management Service Center, SC-657B, PO Box 25047, Denver, CO 80225-0047.

The draft GWEB *Oregon Watershed Assessment Manual* includes a riparian assessment. This method assesses riparian conditions and relates the information to Oregon Department of Fish and Wildlife (ODFW) stream surveys and Department of Environmental Quality (DEQ) stream temperature information. The method also utilizes aerial photos and maps created by other assessments, which are described in the manual. There are four steps to this method:

- The first step describes vegetation types and density, riparian area width, and how continuous the riparian areas are throughout the drainage network (continuous versus clearings or patchy vegetation).
- Step two compares present levels of large woody debris (LWD) in the stream with potential future LWD entering the stream from the riparian area.
- Step three measures the amount of shade on the stream and compares this with stream temperature data.
- Step four summarizes the overall riparian conditions and develops a map. Areas where increased shading levels, in-stream LWD, and improved riparian conditions may lead to improvements in stream habitat are identified.

These procedures are in draft form and probably will change. However, the basic concepts will remain, and the information will be joined with other state agency assessments. For more information on the assessment manual and training, contact GWEB, Public Services Building, 255 Capitol St. NE, 3rd floor, Salem, OR 97310-0203 (phone: 503-378-3589).

Riparian Enhancement Projects

Riparian enhancement projects aim to change the riparian area in order to restore or enhance essential ecosystem functions and maximize potential benefits. The most common goal of riparian enhancement is to restore native vegetation and width of the riparian area to historic conditions or to their highest potential.

The riparian management area includes the riparian area as well as the zone of land influencing this area and the stream. Oregon's Forest Practices Rules specify the minimum width of the riparian management area for private forest land. Federal agencies have similar rules (usually more stringent) for public land. See Chapter III-7, "Incentives and Regulations," for more information on riparian area regulations.

Agricultural land isn't covered by specific riparian zone regulations. However, regional or watershed-level water-quality management plans are required in watersheds that have been designated as water quality limited by the Department of Environmental Quality. These plans include voluntary best management practices. (See Chapter III-7, "Incentives and Regulations.") Other private land (e.g., residential) isn't covered by riparian zone regulations, except for some county ordinances.

Riparian enhancement activities shouldn't apply only to fish-bearing streams. Any area that affects stream water quality is a candidate for enhancement. In fact, many non-fish-bearing streams in the uplands play an important role in providing cool, clean water. Increasing shade reduces solar input to these streams and may reduce water temperatures.

Many headwater streams and upland *ephemeral* channels (streams that flow only during storms) are potential sites for debris flows and landslides. This process supplies large wood to the stream system downslope. Current studies indicate that large trees in these areas can be the main source of large wood in streams.

The right species for the right site

Riparian vegetation varies throughout Oregon based on local conditions such as climate, soils, geology, and topography. Choosing the proper vegetation adapted to the site is crucial for successful projects. Contact the Oregon Department of Forestry (ODF) and OSU Extension Service for information about the proper species for your area. **Please note:** This section focuses on riparian vegetation typically found in western Oregon.

Tree species vary in how well they tolerate floods or shade. Understanding these differences is critical to choosing where to plant trees in riparian areas. Plant trees that tolerate floods closer to the stream than those that don't. For example, willow trees tolerate floods and generally grow next to streams, while Douglas-fir don't tolerate floods and usually grow farther from streams.

Trees that tolerate shade generally survive better in the understory beneath other trees than do less shade-tolerant species. Douglas-fir don't tolerate shade, so they don't survive in the understory, while redwood and hemlock do. Table 2 lists some common trees found and planted in riparian areas and their associated tolerances. Additional information about characteristics of native trees is found in Chapter III-2, "Forest Ecology and Management."

Planting seedlings

Many publications explain how to buy, store, and plant seedlings with hoe dads, shovels, and augers. However, most publications are written for forest and agricultural land that has been cleared and prepared for planting and is outside of the riparian area.

Riparian areas, on the other hand, can have severe soil conditions. These zones are wet in the winter and dry in the summer, and usually aren't prepared before planting. In addition to taking standard precautions when planting trees in these areas, you're most likely to be successful if you use superior nursery stock (vigorous, large trees in good condition) and prepare the site as much as possible.

The following suggestions generally are acceptable in western Oregon. However, contact your local OSU Extension agent and ODF representative for proper tree planting and site preparation methods for your area.

Auger planting can be successful where the ground is hard and it's difficult to plant seedlings properly. Auger planting is more expensive and time consuming than planting with a hoe or shovel, but it may be necessary in some areas.

Spacing of trees in riparian zones differs from spacing in a timber stand. Since mortality can be high, a spacing of 8 feet by 8 feet isn't uncommon for nursery seedlings. When planting trees in an established riparian area (forested versus converted pasture), spacing can be wider since soil conditions usually are less severe.

All riparian plantings require some maintenance to clear grass and brush around the seedlings. Also, scalping the surrounding grasses will reduce competition for water and give trees a boost during the first spring. Some people have been very successful planting trees on agricultural lands and providing irrigation in the summer. You can find more information on planting seedlings in Chapter III-2, "Forest Ecology and Management."

Table 2.–Common tree species planted in riparian areas and their associated tolerance to flood and shade.

Tree species	Tolerance to flood	Tolerance to shade
Douglas-fir	Low	Low
Redcedar	Medium	Medium
Redwood	High	High
Spruce	Medium	Medium
Shore pine	Medium	Low
Hemlock	Low	High
White fir	Medium	Medium
Willows	High	Low
Alders	Medium	Low
Poplars	Medium	Low
Bigleaf maple	Medium	Medium
Vine maple	Medium	Medium
Dogwood	Low	High
Ash	High	Medium

Note: Not all of these species are found throughout Oregon (e.g., redwood).

Planting willows

Many agricultural riparian areas need total conversion from grass to trees. Willows often are used to stabilize stream banks and begin the conversion process. Willows, cottonwoods, and some other hardwoods sprout readily from stumps and clippings. You can use a variety of methods to plant them. These methods are called *bioengineering*, which means using vegetation and rock to restore stability to a site (usually stream banks, eroding hillsides, and eroding road cuts).

There can be many willow species throughout a watershed. Always take willow cuttings from a site near your enhancement site because these plants will be most adapted to conditions in the area. If you have to cut willows from a riparian area, limit the amount cut to maintain the existing willows.

The most common failure in planting willows is placing them in poor sites where they don't have enough water. Willows like to have their feet wet. Best success occurs when dormant willows are cut and planted in the winter, but this is the hardest time of the year to plant due to flooding. You can successfully cut and plant willows on a year-round basis if water is available (rain or irrigation). The lowest success has been reported when willows are cut while flowering.

Always plant willows within a few hours of cutting. Keep them wet and cool until planted.

Hand planting

Willow branches (less than 2 inches in diameter) can be planted with a bar or shovel. You'll probably be most successful if you use branches more than 1 inch in diameter and plant 70–80 percent of the willow into the ground (Figure 1).

Planting larger willow stakes or cuttings with a sledgehammer is a very common and highly successful method. Stakes are 3–4 inches in diameter and 3–4 feet long. Sharpen each stake to a point on one end and pound it into the ground with a large wide-head sledgehammer to minimize splitting.

Other common planting methods include building willow mattresses, planting large stakes, building fascines, building willow baffles, and planting willow bundles (Figures 2–5). The Natural Resources Conservation Service has an *Engineering Field Handbook* describing these techniques (see Resources).

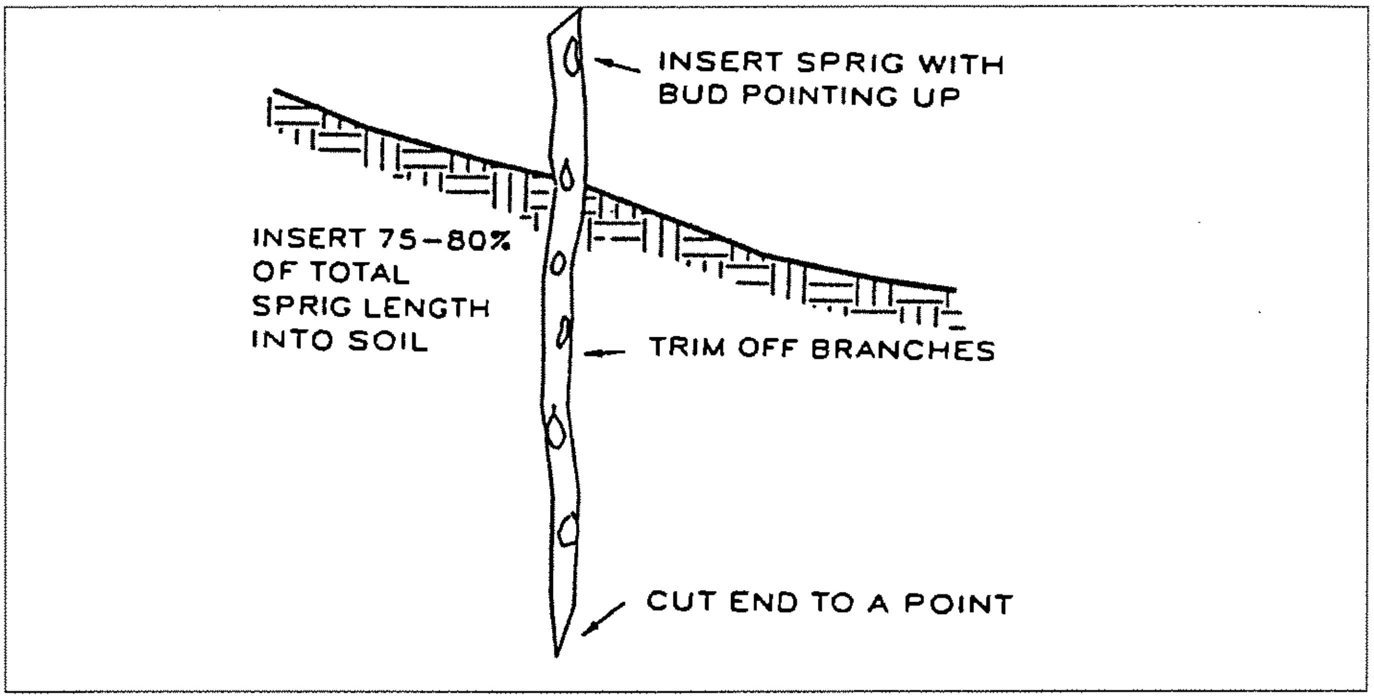


Figure 1.–Planting willow cuttings (also known as stakes, sprigs, etc.). (Source: Engineering Field Handbook)

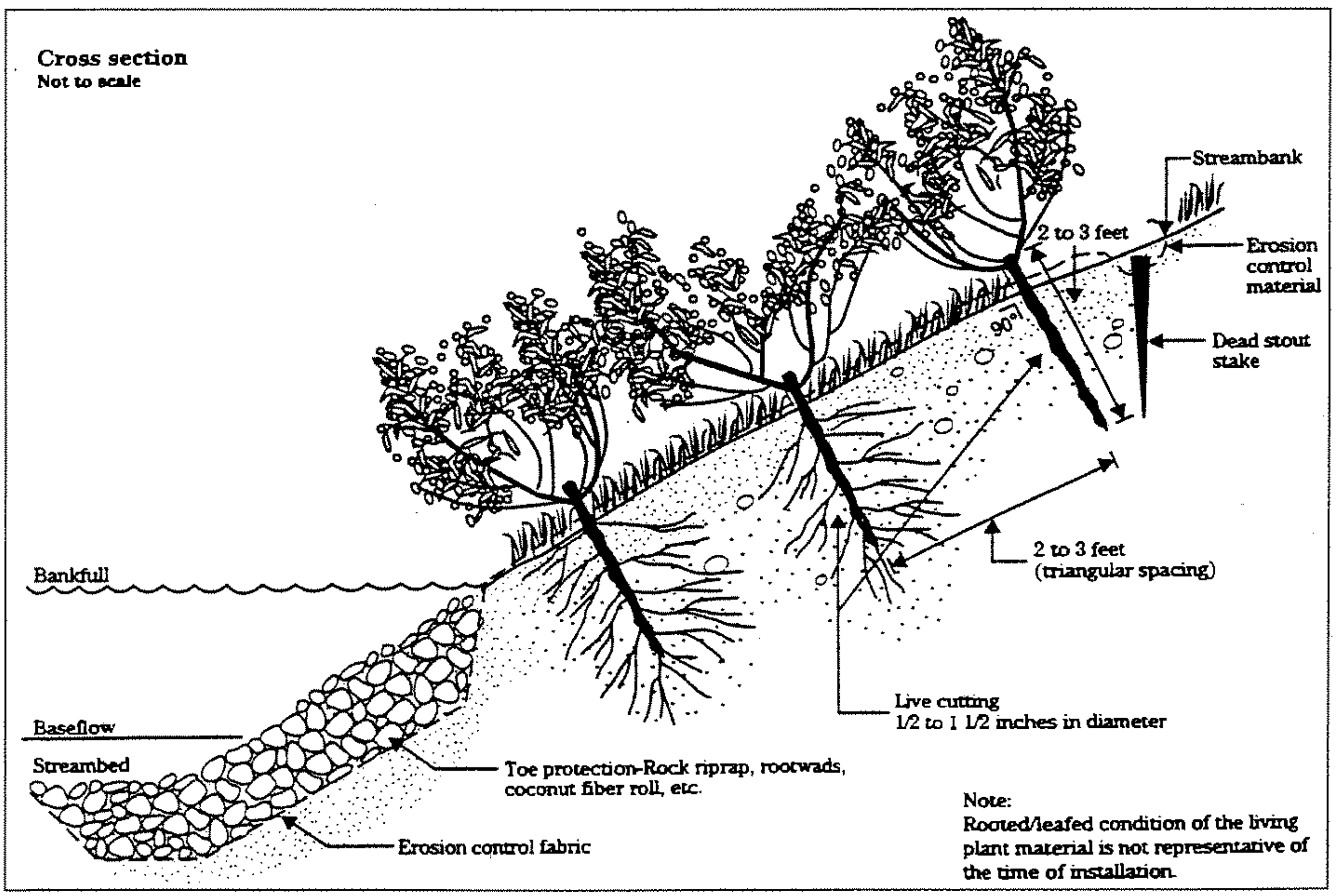


Figure 2.–Live willow stakes. (Source: Engineering Field Handbook)

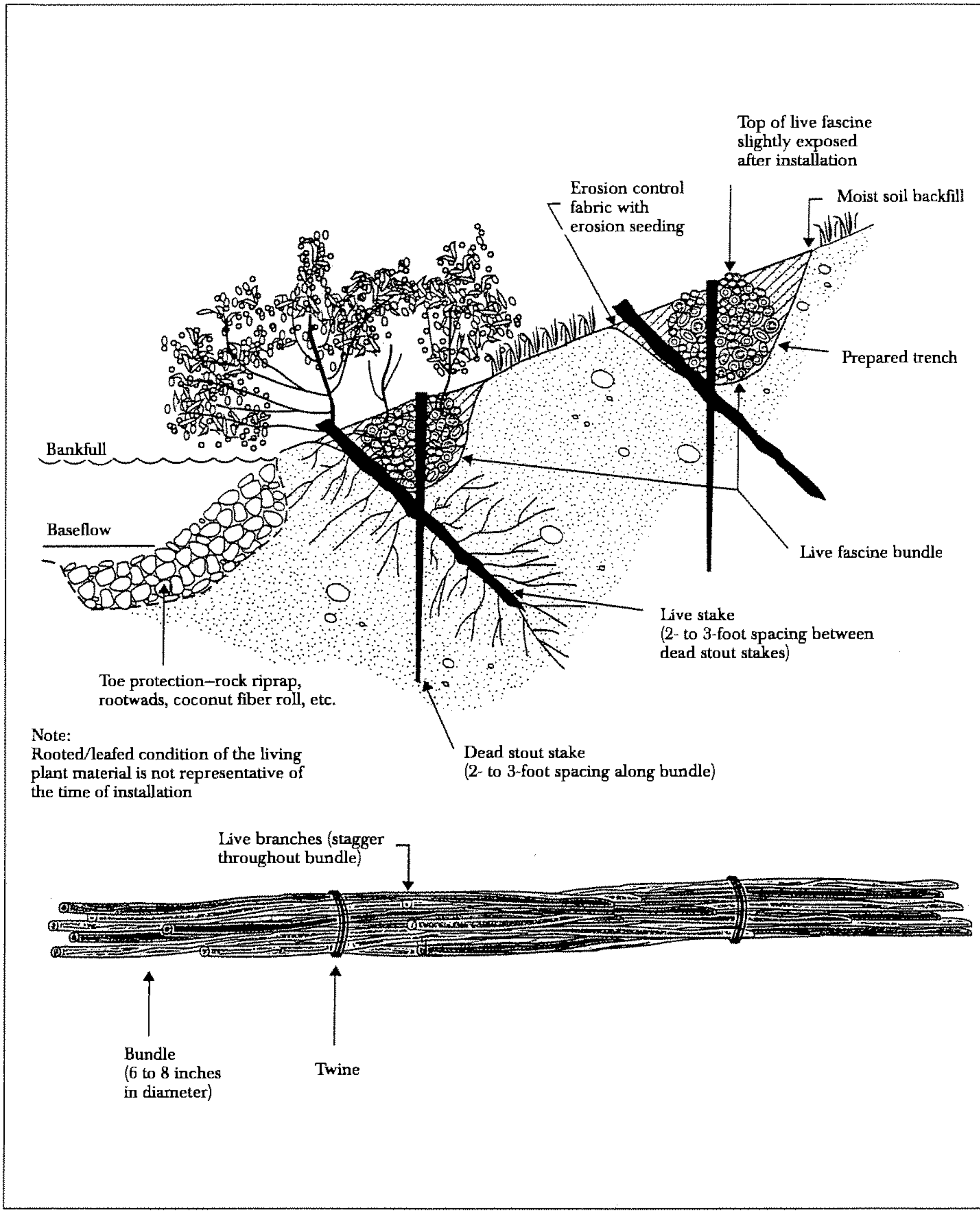


***Figure 3.**–Live fascine. (Source: Engineering Field Handbook)*

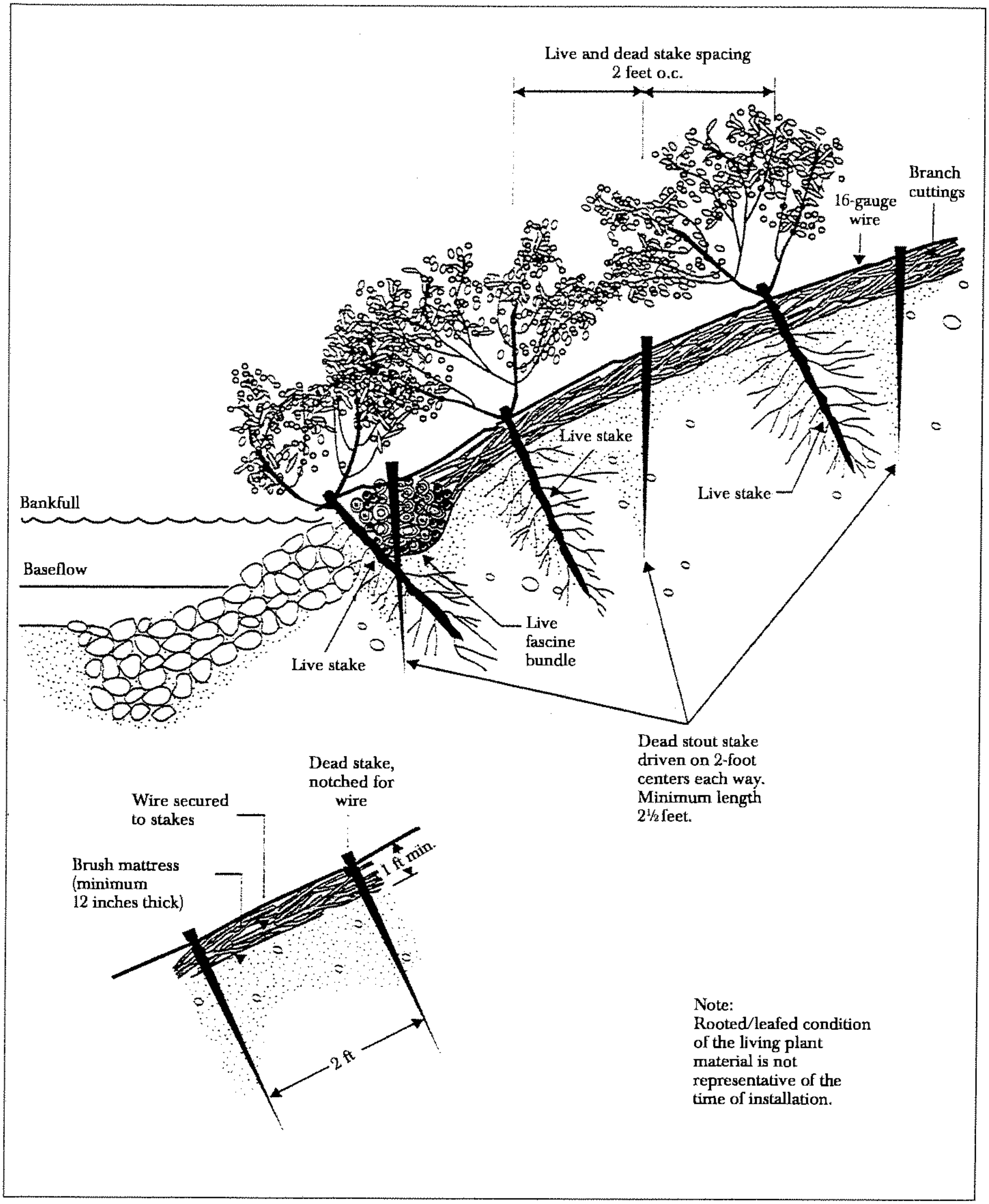


***Figure 4.**–Brush mattress. (Source: Engineering Field Handbook)*

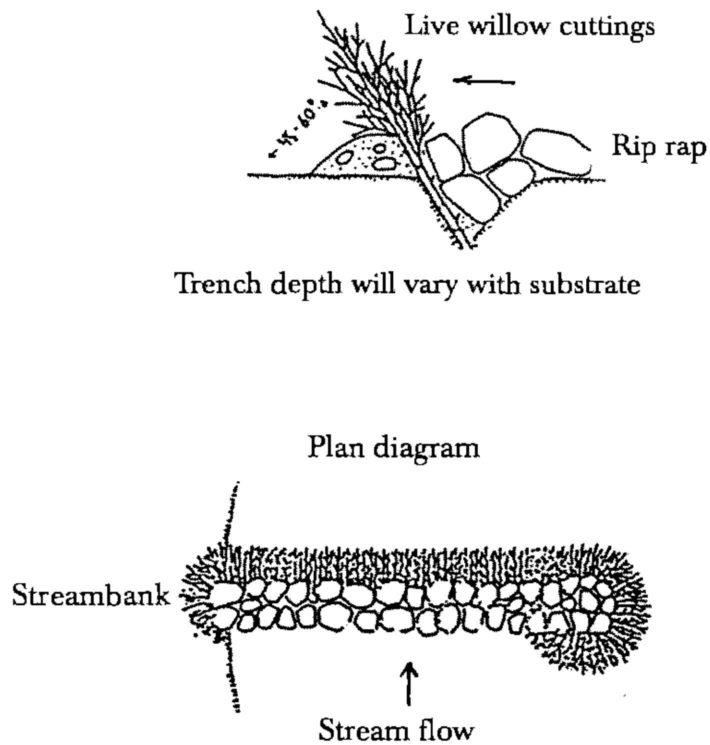


Figure 5.*–Live siltation baffle (willow baffle). (Source: Engineering Field Handbook)*

Machine planting

Machine planting willows often increases the success rate and the area that can be planted in a short amount of time. One method involves cutting large willow stakes (more than 3 feet long and more than 3 inches in diameter), cutting a point on the bottom end, and pounding them into the ground with a machine (for example, a backhoe, excavator, or front end loader). A similar method uses a machine called a stinger to create a hole first and then pound the willow into the ground. Another method is to dig out a whole willow tree with a front end loader or excavator and transplant it to another site. This method works well for establishing an extensive root system in a short time.

Releasing conifers

Some riparian areas lack diversity of species. They often have young healthy conifers in the understory of hardwood trees or brush. The conifers may not survive and grow through the overstory because of their shade intolerance. To allow them to grow, you'll need to *release* them by removing the overstory. The trees being released must have healthy crowns and be able to grow and occupy the space once the overstory is removed. Remove only the overstory trees that are affecting the desired trees. Spacing depends on the trees' tolerance to shade.

One way to release trees is to cut the overstory and remove it or leave it on the ground. Another method is to kill the overstory trees by cutting the cambium layer under the bark and letting the trees fall after they die. Chemical release also is popular. This method uses aerial herbicide spray, manual spray, or a manual "hack and squirt" to kill the overstory trees. ("Hack and squirt" involves injecting or spraying a chemical on a scraped area of the tree.) Contact your local agency representative or a private licensed applicator for assistance and information on regulations.

Protecting your investment

There are many ways to protect planted or released trees from wildlife and livestock. A common way to protect trees from livestock grazing is to fence an area and provide water away from the stream. Another approach is to allow livestock to have minimal access to the stream through gaps in the fence called *water gaps.* Seasonal grazing systems also can work in riparian areas.

Fences in riparian zones have a tendency to be flooded during storms. Smooth electric wire withstands floods the best and requires the least amount of maintenance after storms.

The most important point to remember when planning a grazing strategy is to use techniques that fit each landowner's management. See Chapter III-3, " Livestock and Forage Management," for details on riparian grazing strategies.

The most common and extensive wildlife damage to newly planted trees is from elk, deer, and beavers. Many kinds of tree protectors are available to reduce this damage. Most tree shelters reduce deer browse but don't work for elk. Large wire cages have had some success in limiting elk browse. Translucent, solid, plastic shelters have been used successfully to ward off beavers, as have chicken wire fences buried into the ground.

MONITORING PLANS

Why do we need a monitoring plan?

A monitoring plan is essential for establishing riparian areas to their maximum potential. It shows whether you are on track or have met your goals. For example, foresters establish monitoring plans known as forest inventories to evaluate the growth of a stand of trees over time. Ranchers establish monitoring plans to evaluate forage conditions in pastures throughout the year.

Monitoring can keep you from repeating mistakes and justifies the investment of resources in your projects, whether private or public. If monitoring shows the enhancement projects have not established the proposed condition, a new plan and projects need to be developed.

Basic components of a monitoring plan

Some monitoring plans are as simple as an assessment that is repeated at regular intervals over time. Other monitoring plans include a formal explanation of the assessment, proposed project, and monitoring techniques. The Environmental Protection Agency

(EPA) has published several guides for developing and implementing monitoring plans. They describe a monitoring plan as containing three main components:

- Goals and objectives of the enhancement project
- Specific monitoring techniques and factors (*parameters*) to be measured
- A process to evaluate whether goals and objectives are being met. Based on this evaluation, you'll decide whether you need to change monitoring techniques and/or measured parameters.

The goals and objectives define the proposed future condition of the riparian area and the overall aim of the enhancement project. A goal is the overall aim of the project, while objectives are a subset of the goal and are measurable. One goal can have many objectives. Goals and objectives of a sample project are shown in Table 3. See Chapters I-2, "Choosing Your Group's Structure, Mission, and Goals," and II-1, "Principles of Planning," for more information on setting goals and objectives.

Many monitoring plans establish intermediate desired conditions (benchmarks) between the present and desired future condition. For example, a newly planted riparian area will have an increasing volume of large wood over time. The intermediate benchmarks would be the desired large wood volumes at year 10, 25, 50, 75, and 100.

Table 3.–Sample goals and objectives.

Goal:	Improve water quality to support cold-water fisheries.
Objective:	Increase riparian vegetation to help lower average daily stream temperatures below 19°C (66°F) during the summer.
Goal:	Improve stream bank cover and stability to decrease bank erosion.
Objective:	Increase vegetative cover on stream banks so that 80–90 percent of the banks are rated as covered and stable.

Source: *Monitoring Protocols to Evaluate Water Quality Effects of Grazing Management on Western Rangeland Streams*

Specific monitoring techniques and parameters to be measured evaluate the riparian conditions over time to see whether the objectives (or proposed conditions) are being met. Chapter II-3, "Assessment and Monitoring Considerations," discusses the basic types of monitoring, including trend, baseline, implementation, effectiveness, project, validation, and compliance monitoring. It also describes several monitoring designs such as reference area, paired watershed, above and below, and before and after.

Most riparian monitoring techniques basically assess conditions over time. Thus, this chapter's section on assessments also applies to monitoring. The major difference between assessment and monitoring is that monitoring techniques generally focus on specific parameters related to an enhancement project. For example, you might evaluate how many planted trees have survived and how many more trees are needed to fully stabilize a stream bank. Or each year you could evaluate the percentage of healthy conifers and hardwoods in a riparian area following a release of conifers.

Considerations when creating a monitoring plan

Monitoring techniques must be appropriate for your group. Consider factors such as cost, technical requirements, available equipment, and access.

Monitoring plans should identify enhancement projects to reach the proposed condition (goals and objectives). If objectives are not being met, the monitoring plan identifies factors causing the problem and alternative projects to meet objectives.

This chapter's section on "Considerations when choosing an assessment" also relates to monitoring plans.

Example of a monitoring plan

In addition to the basic components mentioned above, most monitoring plans include information obtained from the initial assessment and describe proposed enhancement projects. Here's an example of a riparian monitoring plan.

Assessment of present conditions

Existing condition/limiting factors: Excessive fine sediment in the coastal stream has reduced salmon spawning habitat.

Probable cause: An initial assessment in the degraded spawning areas noted that bank stability is reduced significantly in some grazed areas, leading to increased erosion. Plant species composition is quite different than reference conditions and potential for the site.

Goals and objectives

Goal: Improve stream bank cover and stability to decrease bank erosion.

Objective: Increase trees, shrubs, and native grass vegetation on stream banks so that 80–90 percent of the banks are rated as covered and stable.

Enhancement practices/management changes implemented

Short-duration late spring grazing by limited numbers of cattle may allow desired vegetation to recover. As a result, banks should be strengthened and there should be less fine sediments in the stream. Grazing management was modified to include riparian pastures, temporary electric corridor fencing, hardened access points, and pasture rotation. Riparian pasture use was shifted to late spring for short duration.

Monitoring techniques and parameters measured

The area will be monitored as follows:

- Canopy cover, plant species composition, and percent eroding stream banks will be measured seasonally.
- Photos will be taken at permanently established photo points at least once a year to give a general view of stream bank recovery and vegetation changes.
- Regularly scheduled aerial photos will be taken to show major vegetation changes. If possible, copies will be made of photos borrowed from county road departments and planning departments, resource agencies, etc.
- Permanent stream cross-sections will measure the amount of stream bank eroded each year.

Follow-up evaluation

If monitoring shows that management changes are not leading to the proposed condition, new practices and a monitoring plan will be implemented. If the monitoring data do not adequately describe stream bank cover and stability, different techniques will be used.

Summary/Self review

An assessment tells you what is present, what is not present, and how the components are affecting what you value (water quality, fish habitat, etc.). It compares present conditions to desired conditions and identifies management changes or enhancement projects that will establish the proposed condition. The assessment also helps you establish a monitoring plan.

Basic components of a riparian area assessment include evaluations of how vegetation, soils, and the landscape/river channel are functioning compared to a desired condition. Make sure your assessment is designed to answer specific questions.

Several assessment methods are available. Basic methods have been developed by GWEB and by the University of California Cooperative Extension Rangeland Watershed Program. More advanced assessments have been developed by BLM and USFS (the Process for Assessing Proper Functioning Condition) and by GWEB.

Riparian enhancement projects aim to restore or enhance essential ecosystem functions. They commonly involve increasing species diversity, age diversity, and width of riparian areas. Different tree species have varying tolerances for floods and shade. Consider these factors when choosing where to plant trees in riparian areas.

It's difficult to establish seedlings and cuttings in riparian areas. These areas are wet in winter, dry in summer, and have a lot of competing vegetation. Follow all recommended tree planting procedures. Planting large nursery stock and watering in the summer may be necessary for adequate survival.

A monitoring plan basically is an assessment of conditions over time. It tells you whether your goal or desired riparian condition is being met, helps prevent repeated mistakes and justifies the investment of resources, whether private or public. Monitoring plans include three main components:

- Goals and objectives
- Specific monitoring techniques and parameters to be measured
- An evaluation process to see whether the desired condition is being met and/or monitoring techniques are adequate.

EXERCISES

You can do these exercises on your own, but it will be helpful to work as a group so you can compare notes and discuss your findings.

Assessment methods

Use one of the assessment methods discussed in this chapter to assess the condition of at least two sites. These methods will train you to look for unseen problems. Seemingly healthy sites actually may be degrading.

1. Select a site that seems to be in healthy condition and follow the steps for one of the assessment methods.
2. Select a site that seems to be in deteriorating condition and repeat the assessment using the same method.

Photopoints

Establish a permanent photo point in a nearby riparian area and take photos every 3 months. Why? It's interesting to record changes through time. Many of these changes are difficult to remember, much less prove, without photos.

Enhancement

Get involved with two different types of riparian enhancement activities–tree planting and tree release. Review the assessments used to plan the enhancement activities.

Monitoring

Establish a monitoring program (or follow an existing one) for a site where a change in management or an enhancement project has been implemented. Set up one monitoring program to evaluate project success for the first year (survival, stability, etc.), and one program to evaluate progress toward the desired condition over time.

RESOURCES

Training

Contact your local watershed council, OSU Extension Service office, Soil and Water Conservation District office, or resource agency office (Oregon Department of Forestry, Oregon Department of Fish and Wildlife, U.S. Forest Service, Bureau of Land Management, etc.) for training events or personal consultation.

Information

Assessment

Oregon Watershed Assessment Manual (Governor's Watershed Enhancement Board, Salem, OR, 1998). Available from GWEB, Public Services Building, 255 Capitol St. NE, 3rd floor, Salem, OR 97310-0203; phone: 503-378-3589.

Procedures for Ecological Site Inventory—With Special Reference to Riparian-Wetland Sites, Tech. Reference 1737-7, by Leonard et al. (Bureau of Land Management, 1992). Describes the ESI assessment method.

Riparian and Wetland Classification, Tech. Reference 1737-5, by Gebhardt et al. (Bureau of Land Management, 1990). Provides a review of the more common procedures used to classify, inventory, and describe riparian-wetland areas.

Riparian Area Management, Publication #TR 1737-9 (Bureau of Land Management, 1993). Explains the Proper Functioning Condition assessment. Available from the BLM Service Center, SC-657B, PO Box 25047, Denver, CO 80225-0047.

Rangeland Watershed Management Program Stream/Watercourse Site Evaluation, Fact Sheet #23, by J. Stechman and J. Clawson (Rangeland Watershed Program, USDA Natural Resources Conservation Service and University of California Extension Service, Davis, 1994). For more information, contact the Oregon State University Department of Rangeland Resources (phone: 541-737-3341).

Monitoring

Monitoring Guidelines to Evaluate Effects of Forestry Activities on Streams in the Pacific Northwest and Alaska, EPA/910/9-91-001 (U.S. Environmental Protection Agency, 1991).

Monitoring Primer for Rangeland Watersheds, EPA 908-R-94-001, by T. Bedell and J. Buckhouse (U.S. Environmental Protection Agency, 1994).

Monitoring Protocols to Evaluate Water Quality Effects of Grazing Management on Western Rangeland Streams, by S. Bauer and T. Burton (Idaho Water Resources Research Institute, University of Idaho, Moscow, 1997).

Monitoring Rangelands and Associated Riparian Zones with Blimp Borne Cameras, by Harris et al. (Oregon Agricultural Experiment Station, Oregon State University, Corvallis, 1995).

Photo Plots (Governor's Watershed Enhancement Board, Salem, OR, 1993).

Photo Points as a Monitoring Tool, Fact Sheet #16, by J. Stechman and J. Clawson (Rangeland Watershed Program, USDA Natural Resources Conservation Service and University of California Extension Service, Davis, 1993).

Rangeland Monitoring Handbook, Publication H-1734-2 (U.S. Forest Service, 1988).

"Shadow length estimation for woody vegetation," by L. Larson and P. Larson. In *Riparian Ecology and Management Workshop Proceedings* (Oregon State University Extension Service, Corvallis, 1997).

Monitoring (continued)

Types of Monitoring, Fact Sheet #15 (Rangeland Watershed Program, USDA Natural Resources Conservation Service and University of California Extension Service, Davis, 1992).

The Use of Aerial Photography to Inventory and Monitor Riparian Areas, Tech. Reference 1737-2, by Batson et al. (Bureau of Land Management, 1987).

Enhancement

Also see the list of resources in Chapter III-5, "Terrestrial Riparian Area Functions and Management."

California Salmonid Stream Habitat Restoration Manual (California Department of Fish and Game, 1997).

"Streambank and shoreline protection," Chapter 16 in *Engineering Field Handbook* (Natural Resources Conservation Service, 1996).

Woodland Workbook (Oregon State University Extension Service, updated frequently).

MOVING FORWARD–THE NEXT STEPS

On your own, use the lines below to fill in steps, actions, thoughts, contacts, etc. you'll take to move yourself and your group ahead in understanding riparian area evaluation and enhancement.

1.____

2.____

3.____

Appendix A—*Form for the Rangeland Watershed Management Program stream/watercourse site evaluation. (Source: University of California Cooperative Extension)*

Rangeland Watershed Program

A Water Quality Education & Technical Assistance Program for California Rangelands

FACT SHEET

U.C. Cooperative Extension and U.S.D.A. Soil Conservation Service

No. 23 November 1993

Rangeland Watershed Management Program
Stream/Watercourse Site Evaluation[1]

RANCH NAME______________________________ QUARTER SECTION____________

STREAM NAME OR DESCRIPTION______________________________

LOCATION/WITNESS POINTS______________________________

PHOTO STATION: _____ Perpendicular _____ Oblique to stream

STREAM TYPE: _____ Perennial/year around _____ Intermittent/seasonal

CURRENT PRECIPITATION YEAR: _____ Wet _____ Normal _____ Dry

CHANNEL TYPE/PATTERN:

a. _____ Deeply entrenched _____ Moderately entrenched _____ Slightly entrenched

b. _____ Well confined _____ Moderately confined _____ Poor/no confinement

c. _____ Straight/slightly sinuous _____ Meandering or braided

STREAM GRADIENT: _____ Steep (over 10%) _____ Moderate (4-10%) _____ Gentle (<4%)

STREAM WIDTH/DEPTH RATIO:

PREDOMINANT STREAMBANK CONDITIONS (% stability):

_____ Stable (<5% degradation): armored with rock/vegetation/roots/overhang/no headcuts/little impact of high flow or access traffic

_____ Some instability (5-25% degradation): occasional sloughing/erosion/exposure to bare soil/strata/ evidence of travel impacts

_____ Significant instability (>25% degradation): frequent sloughing/exposed soil/headcuts/chiselling compaction by vehicles, livestock, or people

VEGETATION:

_____ Typical riparian perennial water-loving species dominating; bottomland/alluvial or upland perennial watercourse

_____ Riparian herbaceous and woody species infrequent; upland foothill intermittent watercourse

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[1]To be used with individual streams or stream reaches.

VEGETATION: *(continued)*

_____ Principal watercourse/stream flood plain cover:

	0 -25%	25-50%	50-75%	75-100%
Trees - canopy	_____	_____	_____	_____
Shrubs - canopy	_____	_____	_____	_____
Herbaceous - canopy	_____	_____	_____	_____

Major Species ____

Watercourse residual/mulch/plant cover filter strip function: _____ High _____ Moderate _____ Low

Utilization of riparian vegetation: _____ None _____ Light _____ Moderate _____ Heavy

Grazing or browsing by: _____ Livestock or _____ Wildlife

WATER TURBIDITY/CONDITION: (period since last storm: _____ <2 days _____ >2 days)

_____ Clear or very slightly turbid/muddy: bottom objects clearly visible to depths of up to 3 feet

_____ Considerable/moderate turbidity: objects visible to only about 1½ to 3 feet depth

_____ Very turbid/muddy/sediment-loaded: objects not visible at more that ½ to 1½ feet depth

WATER TEMPERATURE: _____ Cold (<50%) _____ Cool (50 to 70%) _____ Warm (>70%)

CHANNEL BOTTOM CONDITION:

_____ No evidence of recent bed material movement/deltas/sediment bars/scouring; pools free from deposition

_____ Some or few fine gravel/sand/silt bars/deltas present and without vegetation cover

_____ Abundant evidence of erosion and/or deposition; sediment bars/deltas present and unvegetated; pools silted

_____ % bedrock _____% gravel _____% sediment

AQUATIC BIOLOGY (Riparian, perennial streams, or pools)

	Abundant/Diverse	Some/Few	None
Fish	_____	_____	_____
Amphibians	_____	_____	_____
Insects	_____	_____	_____
Emergent Plants	_____	_____	_____
Algae	_____	_____	_____

ADDITIONAL COMMENTS: ____

____

____

MANAGEMENT ACTIONS

_____ Changes in management are not justified

_____ Further examination of watershed is needed

_____ Request visitations and advice by resource specialist

_____ Consider prompt changes in kind, degree, time of land use

_____ Develop water quality management plan or element of ranch management plan

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Prepared by John Stechman, UC Cooperative Extension, USDA Morro Bay Hydrologic Unit Area Project, and Jim Clawson, Extension Range Specialist, Agronomy & Range Science, University of California, Davis.

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Appendix B—Checklist for the Proper Functioning Condition assessment.

Standard Checklist

Name of Riparian-Wetland Area: ____________________

Date: ________ Area/Segment ID: ____________ Miles: ________

ID Team Observers: ____________________

Yes	No	N/A	HYDROLOGIC
			1) Floodplain inundated in "relatively frequent" events (1-3 years)
			2) Active/stable beaver dams
			3) Sinuosity, width/depth ratio, and gradient are in balance with the landscape setting (i.e., landform, geology, and bioclimatic region)
			4) Riparian zone is widening or has achieved potential extent
			5) Upland watershed not contributing to riparian degradation

Yes	No	N/A	VEGETATIVE
			6) Diverse age-class distribution (recruitment for maintenance/recovery)
			7) Diverse composition of vegetation (for maintenance/recovery)
			8) Species present indicate maintenance of riparian soil moisture characteristics
			9) Streambank vegetation is comprised of those plants or plant communities that have root masses capable of withstanding high streamflow events
			10) Riparian plants exhibit high vigor
			11) Adequate vegetative cover present to protect banks and dissipate energy during high flows
			12) Plant communities in the riparian area are an adequate source of coarse and/or large woody debris

Yes	No	N/A	SOILS-EROSION DEPOSITION
			13) Floodplain and channel characteristics (i.e., rocks, overflow channels, coarse and/or large woody debris) adequate to dissipate energy
			14) Point bars are revegetating
			15) Lateral stream movement is associated with natural sinuosity
			16) System is vertically stable
			17) Stream is in balance with the water and sediment being supplied by the watershed (i.e., no excessive erosion or deposition)

(Revised 1995)

Remarks

____

____

____

____

____

____

____

____

____

____

____

Summary Determination

Functional Rating:

Proper Functioning Condition ____________
Functional—At Risk ____________
Nonfunctional ____________
Unknown ____________

Trend for Functional—At Risk:

Upward ____________
Downward ____________
Not Apparent ____________

Are factors contributing to unacceptable conditions outside the control of the agency?

Yes ____________
No ____________

If yes, what are those factors?

____ Flow regulations ____ Mining activities ____ Upstream channel conditions
____ Channelization ____ Road encroachment ____ Oil field water discharge
____ Augmented flows ____ Other (specify) ____________________________

7

Stream Ecology

Derek Godwin
and Jim Waldvogel

How do you increase salmon populations? How do you improve water quality? To answer these kinds of questions, you need some knowledge of biological and chemical processes of aquatic ecosystems.

To be successful in managing timber, raising livestock, growing crops, or even planting a garden, you need to understand the basic needs and processes of the resources you're working with. The same is true of watershed enhancement. For example, before planning projects to enhance fish habitat, you need a knowledge of the basic life cycle of the species.

This chapter lays a foundation for understanding biological and chemical processes of aquatic ecosystems, especially those that affect *salmonids*, the fish group that includes salmon, trout, and char.

In Chapter II-8, you'll learn about evaluating and enhancing stream ecosystems. Nearby riparian areas, wetlands, and forested uplands also have important relationships with stream ecosystems. Chapters II-4, "Upland Evaluation and Enhancement," II-5, "Riparian Functions," and II-9, "Wetland Functions," discuss those parts of a watershed and explore their connections to water quality and fish habitat.

In this chapter you'll learn:

- How organic material is turned into food for fish
- The basic life cycle of salmonids and how life cycles differ among species
- Fish habitat needs
- Properties of water quality that affect fish survival

Parts of this chapter have been excerpted and adapted from *The Stream Scene* (ODFW, 1992) and the *Ecosystem Workforce Project Curriculum* (Adams and Dewberry chapter, 1996). An updated *Stream Scene* is being developed for 1998.

AQUATIC ORGANISMS

See Section II, Chapters 2, 4, 5, 8, and 9 for information related to this chapter.

Healthy streams are highly diverse ecosystems. They contain food chains that range from microscopic organisms and algae to large fish. Two important indicators of water quality that help us study these food chains are *species diversity* (the number of species present) and *population size* (how many individuals of each species are present).

Benthic (bottom-dwelling) organisms are found on stones, in mud, or on vegetation. The streambed serves as a place for them to attach in fast-moving streams. These organisms have specialized ways to obtain food. Some remain stationary and grasp food quickly or filter small food particles from the water. Other benthic creatures gather food from the bottom. Some insects leave their positions and are carried downstream short distances before reattaching to the stream bottom. All insects moving in the water, either as drifters or during emergence, are vulnerable to being eaten by fish.

Plankton are tiny plants and animals that float or swim freely throughout a stream. They cannot live where currents are rapid without being swept downstream. Consequently, they are abundant in slower waters of large streams and rivers. Many aquatic insects use streamside vegetation during emergence and as adults. Thus, overhanging vegetation is a source of insects, which become food for fish.

Primary food sources

Freshwater plants, also called algae, are one of the major sources of food for animals in streams. Algae often appear as a thin brown film on bedrock, boulders, gravel, and logs. This is what you slip on when walking in a creek! It also may appear as long green threads floating in the water. Algae are very diverse, and a rock the size of a cantaloupe may have more algal species on it than the total number of species in the nearby forest.

In small forested streams, algae are most abundant during short periods in the spring and fall. Algal production is low during summer in streams that are completely shaded by the forest canopy. In larger streams with more open canopies, production is highest in the summer. In the Pacific Northwest, algal production is low during winter, when stream temperatures and light levels (short days) are low and storms scour the algae off rocks. However, in streams with deciduous vegetation, late winter algae blooms occur when leaves are off the trees.

Organic matter is the second major food category in streams. It includes leaves, needles, twigs, logs, etc. Leaves are the most important source of food in this category. Some riparian tree leaves such as maples break down and are quickly available to organisms. Others, such as fir needles, take longer to decay but are available year-round. In small forested streams, organic matter may represent over 90 percent of the total food resources. Microorganisms are the food source located on this organic matter that is eaten by insects.

Most leaf litter comes from riparian zones along streams. Large winter storms bring in leaves from *ephemeral* channels (streams that flow only during major storms) and *intermittent* channels (streams that flow part of the year).

Wood, ranging in size from twigs to logs, also is a food source for some organisms. Large wood generally is a poor source of food, but it does trap smaller woody material and leaves. Most wood enters the stream during fall and winter storms as a result of tree blowdowns, bank erosion, and debris flows.

Fish biologists recently have researched the historic role of salmon carcasses as a major food source in streams. Significant numbers of spawning salmon have an impact on the nutrients available to an aquatic food chain.

Food processing

Aquatic *macroinvertebrates* ("macros") are organisms lacking a backbone that are large enough to be seen with the naked eye. Stream ecologists have devised a classification scheme for macros that identifies how they obtain food. This scheme aids in understanding how invertebrate communities are interconnected and how they work.

Shredders generally exist by shredding leaves into small pieces that they can eat. *Scrapers* (or grazers) live by scraping algae off rocks. *Collectors* gather small particles of organic matter. Some collectors make nets and filter the stream current for food, while others gather it from the bottom of the stream. *Predators* eat members of all of the macro groups. (Fish are members of the predator group.) Another macro group added by some scientists is *scavengers*. Although not yet identified adequately, this group feeds on salmon carcasses and other decaying material.

Figure 1 illustrates the pathways of energy from the sun to the four main macroinvertebrate groups. Some scientists add salmon carcasses as another source of energy. Figure 2 shows common macroinvertebrates found in stream systems.

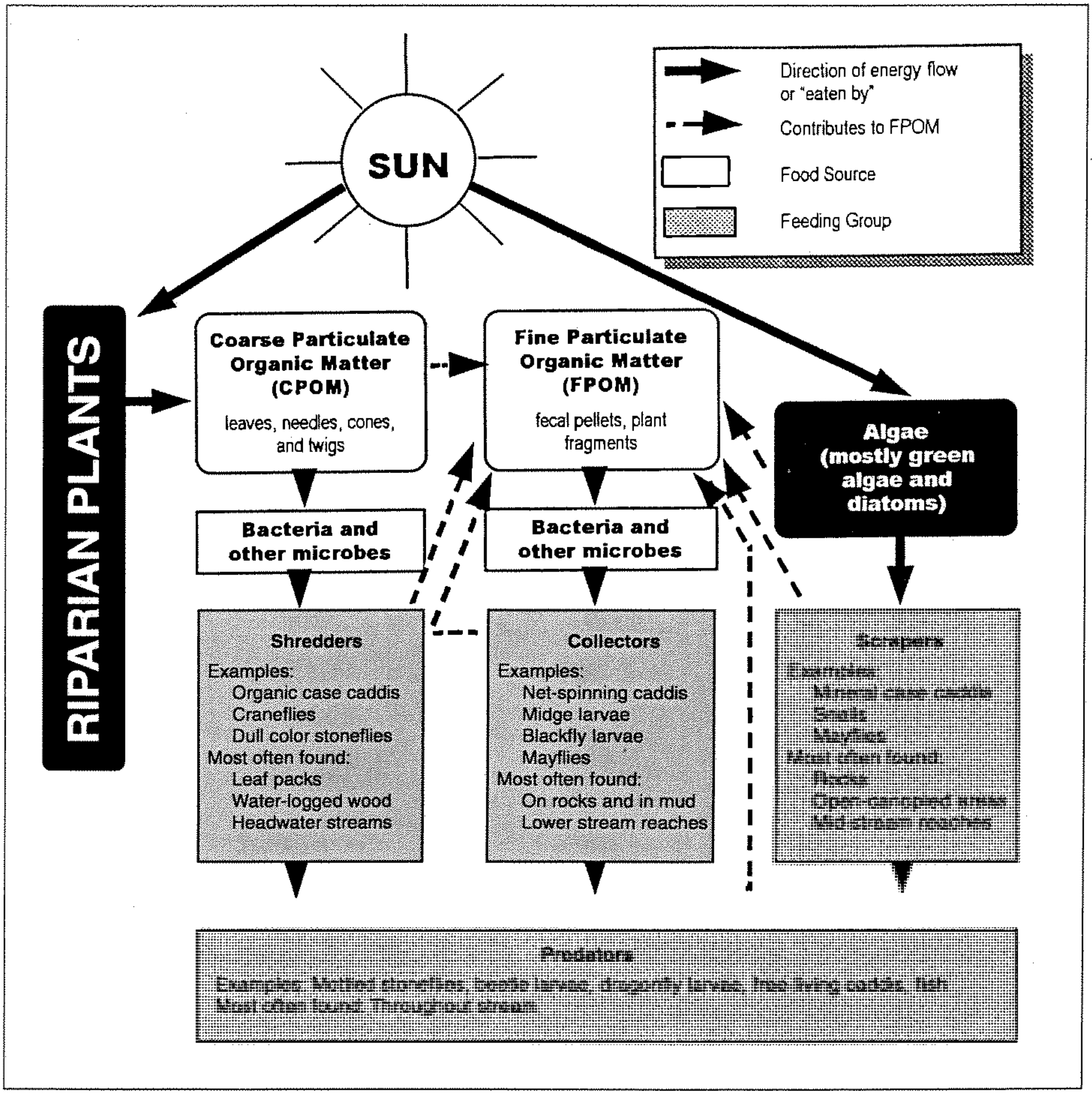


***Figure 1.**—Food processing in streams. (Adapted from "From Headwater Streams to Rivers," by Ken Cummins,* American Biology Teacher, *May 1977, p. 307)*

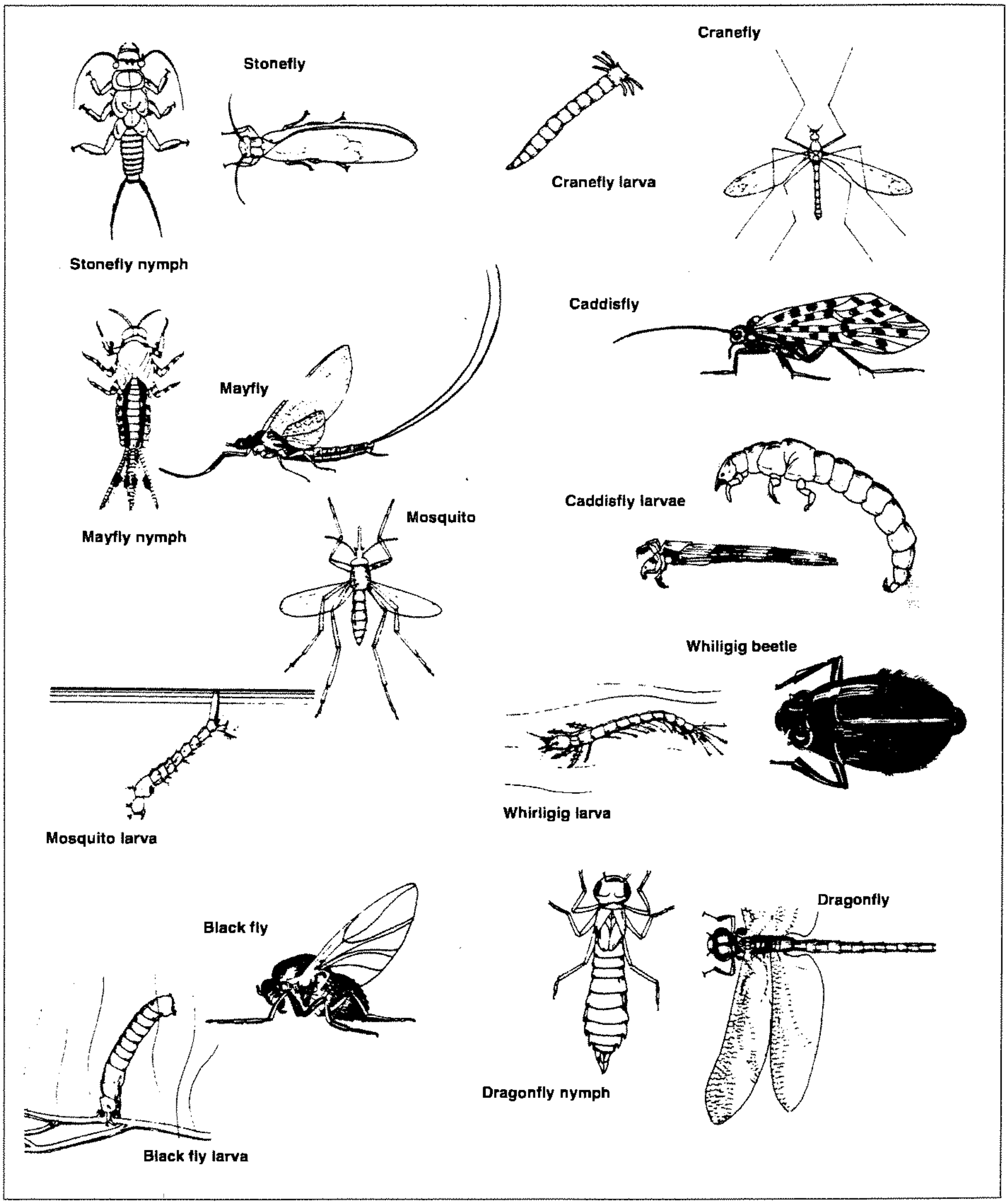


Figure 2.—Common macroinvertebrates found in stream systems. (Source: 1987 Western Regional Environmental Education Council)

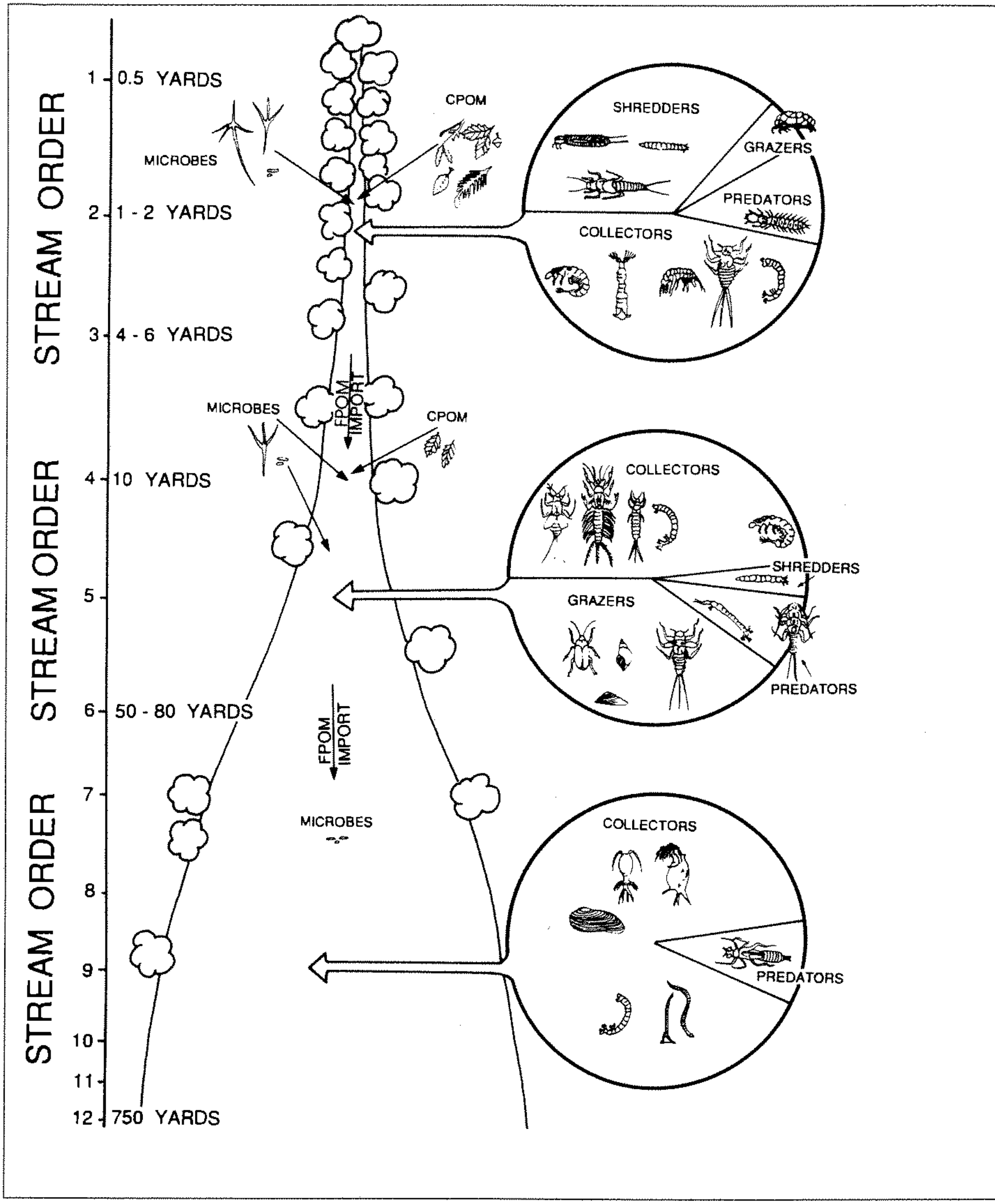


***Figure 3.**–The river continuum concept (change in food processing and macroinvertebrates from headwaters to mouth). (Source: "From Headwater Streams to Rivers," by Ken Cummins,* American Biology Teacher, *May 1977, p. 307)*

River continuum

In forested streams, the relative importance of different food sources follows a predictable pattern from the *headwaters* (source) to the mouth of a stream system. This pattern is referred to as the *river continuum* concept. It is influenced by the size and slope (gradient) of the channel, bank stability, amount of sediment in the stream, nearby vegetation, light penetration, and temperature.

Figure 3 shows the river continuum of a typical stream system. Forests located at the headwaters and along the banks have less influence as the stream gets larger. With less input from the riparian habitat, the energy base relies more on algae produced where the canopy is more open and on processed materials delivered by mid-river tributaries. As organic material changes, there are fewer shredders and more collectors and scrapers.

Annual cycle of food resources

The annual cycle of food processing begins in early fall. In October, stream flows are low, and the amount of organic matter in a stream is low but increasing. Fall brings an increase in stream flow and leaf input to the stream. Many aquatic insects, i.e., shredders, begin their life cycle at this time to utilize the increasingly abundant food.

By mid-November, stream flows have increased greatly, and leaf fall is in full swing. As leaves fall and more sunlight reaches the stream, algal production increases. Adult salmon begin to return to the rivers to spawn. This is a time of maximum food availability.

When the first major storms of the fall occur in the Pacific Northwest, food supplies decrease. Most leaf litter can be transported downstream and deposited far outside the stream channel or buried in sediments. During winter, algal abundance continues to drop as high flows scour algae off rocks and gravel.

When spring arrives, stream flows decrease, and algal production greatly increases until alders begin to leaf out. Spring is a highly productive time. Many macroinvertebrates complete their growth cycle and hatch. Spring also is a time of rapid growth for juvenile salmonids, which feed on macroinvertebrates.

Summer brings high productivity to a halt in most streams. Stream flows drop rapidly. Food resources are depleted since algal production is low. Juvenile salmonids rely heavily on insects from the riparian zone to make it through the summer.

Retention capacity

A factor in food processing is a stream system's *retention capacity* (its ability to retain food resources). If organic material enters a stream system but is not retained, then few food resources are left for fish and other organisms. Streams that are properly connected to their floodplains have high natural retention capacity. Other important retention features in a stream channel include large wood, tree tops, root wads, debris jams, boulder clusters, backwaters, and alcoves. In general, the more complex and "messy" a stream is, the higher its capacity to retain material.

SALMONID LIFE CYCLES

Salmonid is the group name for salmon, trout, and char. These fish share a common life history pattern. Many are *anadromous*, i.e., they spawn in fresh water, migrate to sea as juveniles, grow to maturity, and return to their freshwater stream to reproduce.

Adult salmonids spawn by burying their eggs in nests called *redds*. Spawning site selection depends on the species, gravel size, and flow pattern of the stream. A common spawning location is the "tail-out" of a pool–the area where a pool becomes shallow before entering a downstream riffle.

The eggs remain in the gravel for 45–70 days depending on water temperatures. Hatching *alevins* (fry with yolk sacs for nutrients) remain in the gravel until the yolk sac is absorbed. They then work their way through the gravel and emerge into the stream channel as feeding fry. This is a critical stage for all salmonid species. During this part of their life, fry need adequate food and sediment-free water that contains lots of oxygen.

Natural mortality of juveniles is high during the first month. Many fry are eaten by birds, amphibians, reptiles, and other fish. Depending on the species, juvenile anadromous salmonids grow 1–3 years before migrating to sea as *smolts*. Smolts need to adapt from freshwater to saltwater by spending transition time in the estuary. After maturing in the ocean, they return to the stream to spawn.

Generalizations often are made about where and when salmonids spawn within a river system. Life cycles vary greatly from river to river and among species (e.g., winter vs. summer steelhead, spring vs. fall chinook, sea-run vs. resident cutthroat trout). Where several salmonid species coexist in a river system, each species has its own schedule for rearing, spawning, and migration, although it is not uncommon for juveniles and adults to occupy the same stream areas throughout the year.

Adult anadromous salmonids find their way back from the ocean to the streams where they were born. This life cycle feature is called *homing* and is one of the least understood yet most wonderful aspects of salmon ecology. Every local stream is a special home for a specific run of salmon–treasure it!

Figure 4 illustrates a general salmonid life cycle. Figure 5 shows the physical characteristics used in identifying juvenile salmonids.

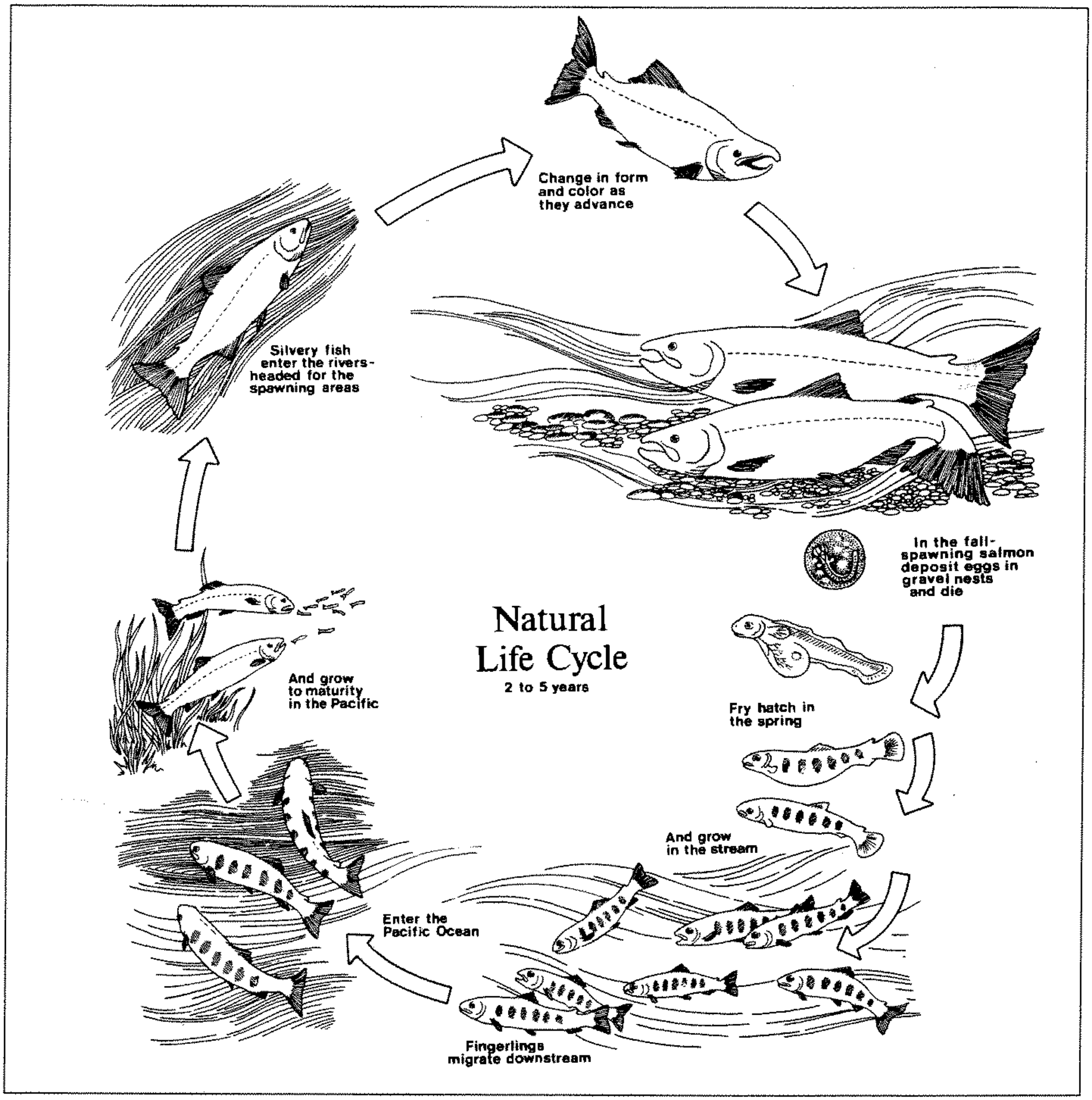


Figure 4.–Typical salmonid life cycle. (Source: The Stream Scene, by P. Bowers et al., Oregon Department of Fish and Wildlife, Portland, OR, 1992)

COMMON SALMONID SPECIES

Chinook salmon *(Oncorhynchus tshawytscha)*

Chinook (king salmon) are the largest and longest lived of the Pacific salmon. They average 20–25 pounds as adults, although individuals as large as 100 pounds have been reported. There are two basic life-history patterns of chinook in Oregon–fall and spring. Fall chinook return from the ocean in late-August through December. They spawn in main river channels and low-gradient tributaries. Since chinook are large, they can dig redds deep in the gravel, thus protecting the eggs from channel scouring during winter storms. If an unusually heavy storm does scour the eggs and a year class is lost, successive generations can replace the stock because adult chinook spawn from 3–6 years of age. All chinook spawn once and then die.

Juvenile fall chinook emerge from the gravel in February or March. They stay in the stream only about 90 days. Most move into the estuary or lower main stem river by April–June. They generally spend the next 3–4 months in the estuary and then migrate to the ocean with fall rains.

Spring chinook adults return to rivers in the spring and spend the summer in deep pools. They spawn in early fall. The life histories of these juveniles are more variable than those of fall chinook.

Coho salmon *(Oncorhynchus kisutch)*

Coho salmon (silver salmon) historically were the most abundant salmon on the Oregon Coast. Adults average 6–12 pounds and have a strict 3-year life cycle. Because coho spawn mostly at age 3 with no year class overlap, their survival is susceptible to catastrophic events. If a year class is lost, a population is likely to remain depressed for a long time. Coho can recolonize tributaries from highly populated source areas. However, this species can be eliminated from a basin quickly if these source areas deteriorate.

Coho spawn from November to March. They have two life-history patterns. "Early" coho enter streams on the first major storm of the year, usually in mid-November. If they are successful at spawning, their fry have the advantage of getting the first shot at the food resources. These fry also become the largest individuals, providing additional survival advantage.

Coho are not as large as chinook, they spawn in smaller gravel, and their redds are not as deep as those of chinook. Thus, their redds are more likely to be scoured out during winter storms. Therefore, a second stock of "late" coho has evolved to delay

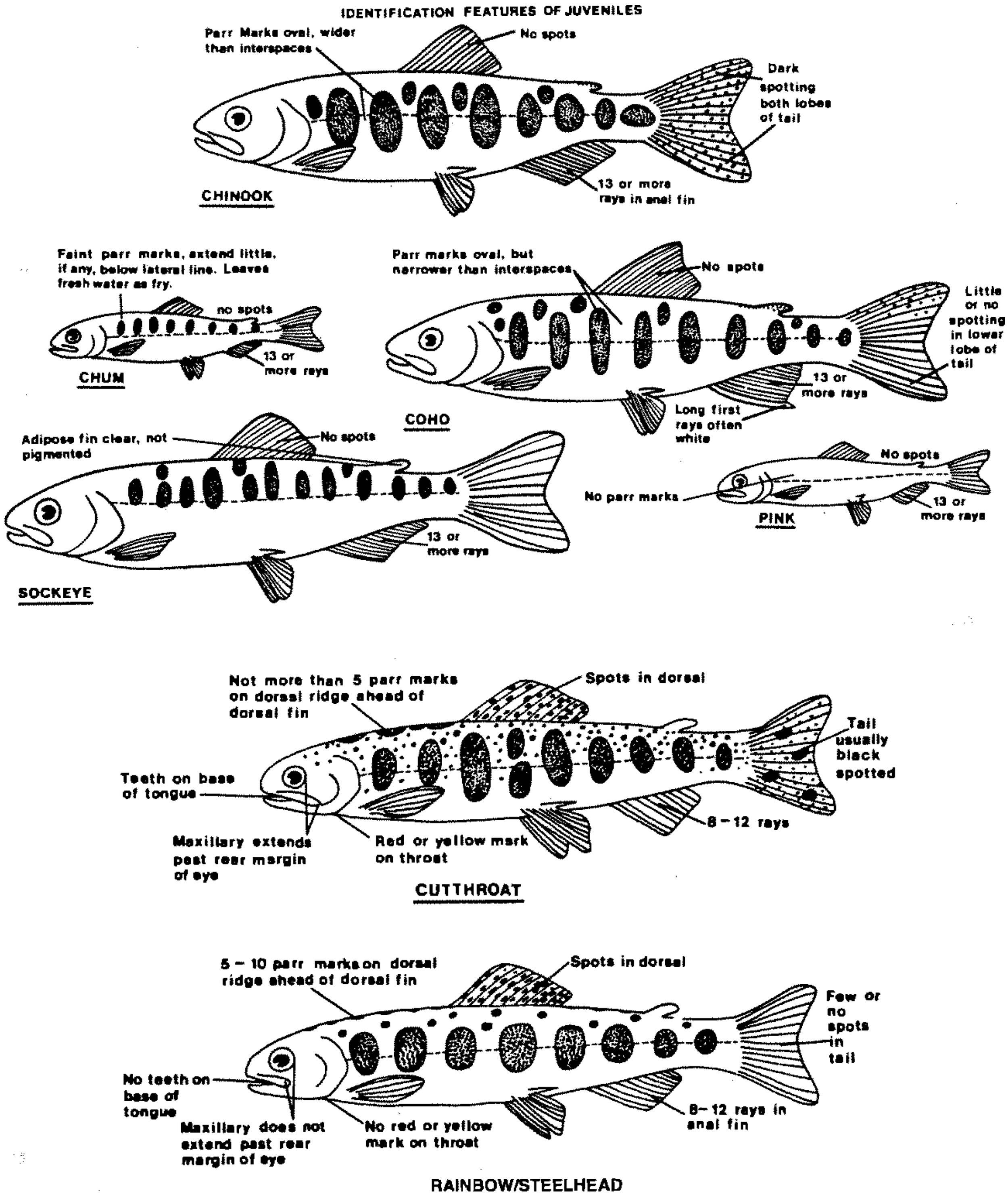


Figure 5.–Physical characteristics used in identifying juvenile salmonids. (Source: The Stream Scene, by P. Bowers et al., Oregon Department of Fish and Wildlife, Portland, OR, 1992)

spawning until most major winter storms have passed, often as late as March or April. These two groups provide important genetic variation to the species and help coho withstand natural climate variations.

Coho juveniles generally emerge from the gravel from February through April. They prefer to live in pools with slow flow or in beaver ponds. Juveniles remain in the stream for a full year and then migrate to the ocean in April or May. Some coho return as 2-year-old jacks (males), but most return as 3-year-old adults.

Chum salmon *(Oncorhynchus keta)*

Chum salmon are the third most common species of salmon in the Pacific Northwest. Unlike coho and chinook, they spend little time in fresh water. Most chum adults spawn in the fall in lower river systems just above tidewater. The fry emerge from the gravel in the spring and immediately migrate downstream and quickly enter the ocean. Chum salmon usually live 3–4 years and weigh about 7–10 pounds.

Steelhead *(Oncorhynchus mykiss)*

Steelhead are seagoing rainbow trout. Adults average 8–12 pounds, and some adults live as long as 7 years. Winter steelhead return from the ocean from December through April, allowing them to move into the headwaters of streams during winter flows. Like salmon, they deposit their eggs in gravel. However, not all steelhead die after spawning. About 30 percent survive to spawn again in the stream of their birth.

Juveniles emerge by June. During the first year they live in riffles and along the edges of stream channels. Therefore, low water conditions can severely affect steelhead. They spend 2–3 years in a stream before migrating to the ocean. This long freshwater residence time also makes them vulnerable if their habitat is degraded.

Summer steelhead adults enter river systems from April through August. Unlike winter fish, but like spring chinook, these steelhead need deep, cool pools to reside in until spawning in January–February. The juvenile life history of summer steelhead is similar to that of winter fish.

Cutthroat trout *(Oncorhynchus clarki)*

Cutthroat trout have variable life-history patterns. Some go to the ocean, while others remain in fresh water their entire lives. Some stay in certain portions of a stream, while others move throughout

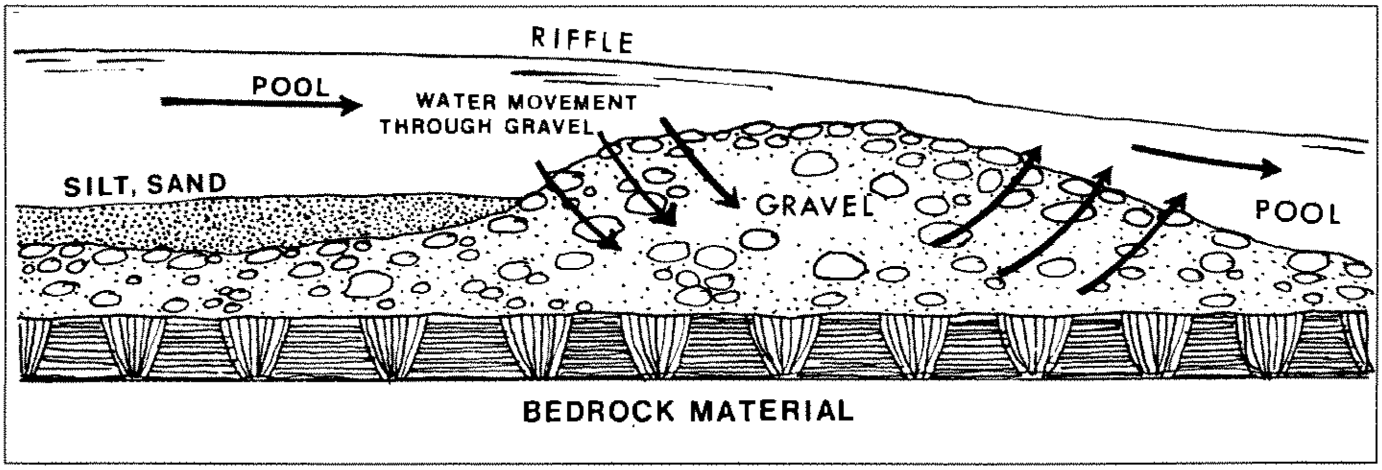


Figure 6.*—Spawning habitat. (Source: The Stream Scene, by P. Bowers et al., Oregon Department of Fish and Wildlife, Portland, OR, 1992)*

the river system. Cutthroat spawn in the fall and spring, depending on life-history patterns. Juveniles emerge by June or July. Cutthroat trout can be distributed throughout some river systems.

Bull trout *(Salvelinus confluentus)* and Dolly Varden *(Salvelinus malma)*

Bull trout and Dolly Varden are native char in the Pacific Northwest. Like other chars, they spawn in the fall, and the juveniles emerge in late winter or spring. Their life history is quite variable. Dolly Varden are the anadromous species, and bull trout is the similar resident species found in Oregon.

Most populations of bull trout are depressed. They are very dependent on cold water seeps and springs. Bull trout do not tolerate fine sediment input.

FISH HABITAT NEEDS

Salmonids use a variety of stream types. Although each species has its own specific habitat requirements, some generalizations can be made (Figure 6).

Spawning habitat

Successful spawning and development from egg to fry stages require the following:

- No barriers to upstream migration for adults
- Spawning areas (usually in a riffle or at the tail-out of a pool) with stable gravel free of fine sediment

- A combination of pools and riffles that provides both spawning areas and places to hide nearby
- A constant flow of clean, well-oxygenated water through the spawning gravel

Rearing habitat

Fry are vulnerable to predators and must endure high stream flows and food shortages. They need pools for rearing, temperature regulation, and cover. Good juvenile-rearing habitat exhibits the following characteristics:

- Low to moderate stream gradient (slope) and velocity
- A good mix of pool and riffle habitats
- Clean, oxygenated water and cool stream temperatures
- A variety of bottom types to provide habitat for juvenile fish and food organisms
- Overhanging vegetation, large woody material, and stream cut-banks, which provide protection for juvenile fish and leaf litter for aquatic insect food
- Sufficient nutrients to promote algal growth and decomposition of organic material

As young fish grow, they seek increased summer flow, moving from the edge of a stream to midstream to take advantage of insect drift. In winter, all species seek areas of lower water velocity where they can conserve energy while food and growing conditions are limited.

Habitat use

Although their basic requirements are the same, salmonid species differ in the types of habitat they use. For example, juvenile coho prefer pool areas of moderate velocity in summer, especially those with slack water current near undercut stream banks, root wads, or logs. In winter, they seek slow, deep pools or side channels, utilizing cover under rocks, logs, and debris.

Conversely, juvenile steelhead spend their first summer in relatively shallow, cobble-bottomed areas at the tail of a pool or shallow riffle. During winter, they hide under large boulders in riffle areas.

In summer, older steelhead juveniles prefer the lead water of pools and riffles where there are large boulders and woody cover. The turbulence created by boulders also serves as cover. During winter, these steelhead juveniles are found in pools, near streamside cover, and under debris, logs, or boulders.

Cutthroat trout habitat requirements are similar to those of steelhead with the exception that they spend the summer in pools.

Chinook juveniles tend to rear in large tributaries, and their habitat requirements are different than those of coho. For example, estuarine residence and growth are key elements in a chinook life-history pattern. Coho salmon require backwaters, beaver ponds, or side-channel rearing habitats to survive high winter flows and low summer flows.

Limiting factors

The quantity and quality of spawning and rearing habitat limit the success of spawning and the production of smolts. These limiting factors establish the *carrying capacity* of a stream. Carrying capacity is the number of animals a habitat can support throughout the year without harm to either the organisms or the habitat. Depending upon the limits of available habitat, salmonid populations fluctuate annually as a result of varying environmental factors (e.g., extreme high and low stream flows, high stream temperatures in the summer, or ice). A stream does not necessarily reach its carrying capacity each year because of these factors.

WATER QUALITY AND QUANTITY

Water quality for human uses as well as for fish and wildlife habitat is a primary interest in all watersheds. Even in areas undisturbed by human activity, streams do not have pure water (H_2O). All water contains some dissolved chemical elements, particulate matter, and organic matter. The amounts of these substances vary with different watershed conditions.

Water-quality standards are established by state and federal agencies. For example, to avoid health problems, nitrate-nitrogen (NO_3-N) concentrations must not exceed 10 ppm (parts per million) in water used for human consumption. Water quantity affects water-quality parameters and subsequently fish, especially during summer low flow conditions. Extracting too much water from a system is just as harmful to fish as are certain water-quality parameters.

Physical

Important physical water-quality characteristics include temperature and sediment loads. Stream temperatures regulate metabolism of cold-blooded animals such as fish. High temperatures can be stressful to fish, and extreme temperatures can be lethal. High temperatures increase metabolism, and fish cannot eat enough food to maintain body weight under these conditions. In addition, as temperatures increase, salmonids become less competitive in catching food and lose their appetite. High stream temperatures also promote disease organisms and excessive algae growth ("blooms").

Stream temperatures are affected primarily by solar radiation (sun), cool water seeps, volume of water in the stream, and the water temperature directly upstream. The relative impact of each of these factors varies within the watershed. In general, smaller streams are affected more by solar radiation and cool water seeps, while larger streams are affected more by stream volume and water temperatures directly upstream (Moore and Miner, 1997).

Sediments occur naturally as products of weathering and erosion. Nutrients necessary for life are carried as sediments in streams. There are two basic types of sediment in streams–suspended and bedload.

Suspended sediments are fine sediments such as clays, silts, and fine sands that are carried in the water. *Total suspended sediment* is a measure of how much sediment a stream is carrying. Too much fine sediment can damage gills and stress fish, reduce oxygen flow, and suffocate eggs. It also reduces light penetration, giving water a murky or cloudy appearance. *Turbidity* is the term used to describe and measure the degree to which light is blocked.

Bedload sediments are too heavy to be constantly suspended. They roll and bounce along the bottom of a stream. The location and size of the particles varies with the volume and speed of the water. Spawning gravel is transported as bedload during high winter flows. Excessive bedload movement can decrease or alter the spawning success and habitat of anadromous fish.

Chemical

Important chemical water-quality characteristics include dissolved oxygen, nutrients (e.g., nitrogen, phosphorus, and potassium), manufactured chemicals, and pH.

Most salmonids need high oxygen levels to survive. Dissolved oxygen (DO) is measured in milligrams per liter of water, or parts per million of oxygen to water.

Dissolved oxygen levels are affected by altitude, water agitation, water temperature, types and number of plants, light penetration, and the amounts of dissolved or suspended solids. Since water absorbs oxygen from the air, waterfalls and turbulent water can add significant amounts of oxygen to water. Temperature directly affects the amount of oxygen in water; the colder the water, the more oxygen it can hold. Plant photosynthesis also can increase the amount of oxygen added to the water. The chemical decomposition

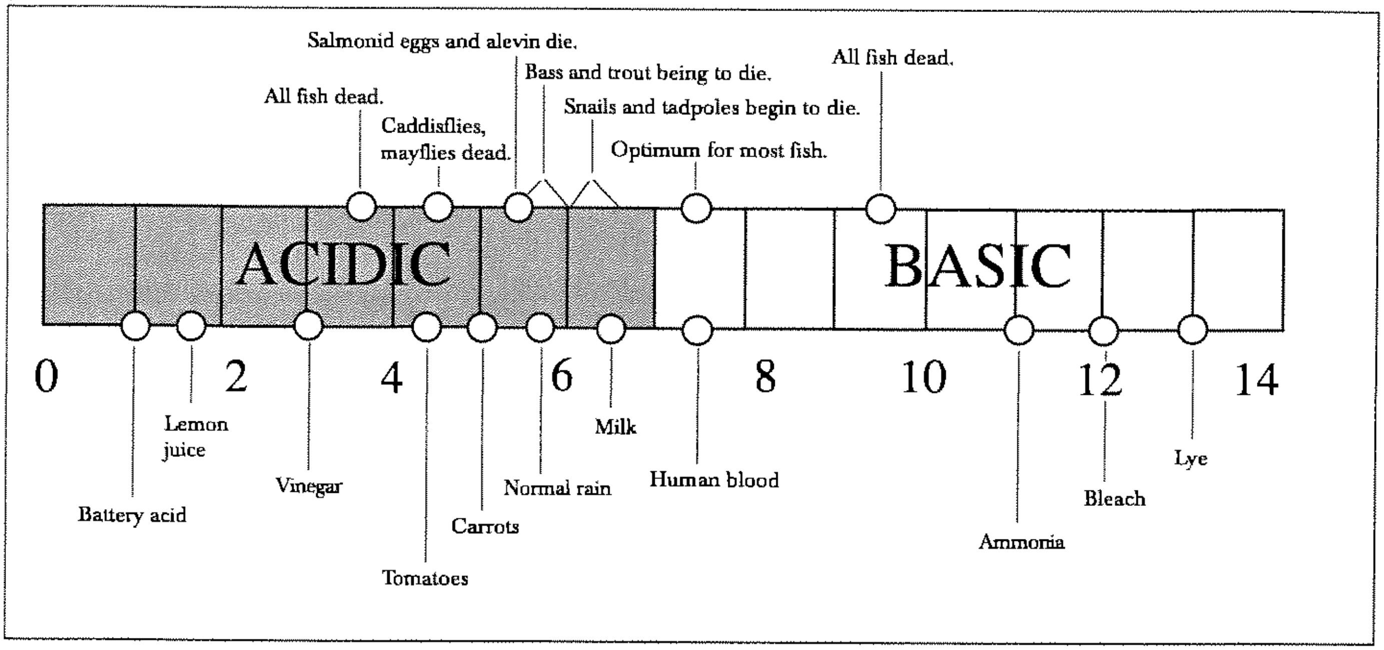


***Figure 7.**–pH scale. (Source: The Stream Scene, by P. Bowers et al., Oregon Department of Fish and Wildlife, Portland, OR, 1992)*

of organic matter, on the other hand, removes oxygen. Most dissolved oxygen problems in Oregon streams occur in summer when temperatures are at their highest and streamflows are at their lowest.

Nutrients such as nitrogen, phosphorus, and potassium are needed for growth of the plankton and algae that form the food base for fish. However, excess amounts of these nutrients can cause excessive algae "blooms." While alive, algae decrease light penetration, and when dead and decomposing they decrease dissolved oxygen. Manufactured chemicals (pesticides, herbicides, oil, etc.) also harm fish when excess amounts are present.

The concentration of hydrogen ions in a solution is called *pH* and determines whether a solution is acid or alkaline. The pH scale ranges from 1 (acid) to 14 (alkaline or basic), with 7 as neutral (Figure 7). The pH can affect nutrient, chemical, and biological reactions and characteristics of water. Most organisms have a narrow pH range in which they can live.

In eastern Oregon, many soils have a high alkaline content, and pH levels of some water bodies can rise above 10. In Oregon coastal streams, pH generally is not a problem unless large amounts of nutrients enter streams during low summer flows.

Air pollution increases concentrations of sulfur and nitrogen oxides in the air, which fall with rain as weak sulfuric and nitric acids ("acid rain"). Acid rain has caused major changes in stream pH in portions of the eastern United States, but is not a problem in Oregon or other western states.

Biological

Important biological water-quality characteristics include organic matter and living organisms. Organic matter such as leaves and similar material is very important for the aquatic food base, but excess amounts can reduce dissolved oxygen. All water has some organisms (bacteria, insects, etc.) that are normal and often beneficial. However, imbalances or harmful *pathogens* (disease-causing organisms) may cause problems for fish, wildlife, or people.

Fecal coliform bacteria are used as an indicator of pathogenic bacteria. Large numbers of fecal coliform bacteria may indicate a contamination problem. Specific standards set by the Department of Environmental Quality (DEQ) indicate when fecal coliform amounts are causing poor water quality.

Water-quality dynamics

Watershed hydrology and other characteristics (erosion, channel features, riparian areas, etc.) affect local water quality and how land use and management may alter water quality. (See Chapters II-2, "Watershed Science," II-5, "Riparian Functions," and II-9, "Wetland Functions.") In a given watershed, most water-quality characteristics vary over time. Stream flow and weather conditions are among the most important factors that can alter water quality seasonally or over shorter periods.

To accurately monitor water quality, it is necessary to take lots of samples, especially when attempting to identify changes, whether due to human activity or natural influences. The interplay over time of water-quality parameters and salmon life history needs is important. Not only the quantity and quality of water, but the timing of flows specific to life cycle needs for salmon must be considered.

SUMMARY/SELF REVIEW

A basic understanding of biological and chemical processes affecting aquatic ecosystems is essential to planning fish habitat and water-quality enhancement projects. Understanding these processes will help you identify factors affecting salmonid populations and begin to plan detailed assessments and enhancement projects.

Primary food sources for organisms in streams are freshwater algae, organic matter (such as leaves, needles, twigs, and logs), and possibly salmon carcasses. Organisms throughout the food chain rely on these sources as the basis of their existence. Food sources are most abundant in early spring before trees leaf out and in early fall when leaves fall and stream flows increase.

Fish feed on macroinvertebrates, which are the main processors of primary food sources. The primary macroinvertebrate feeding types include shredders, scrapers, collectors, predators, and scavengers. A stream system's ability to retain its organic food sources (retention capacity) is a factor in macroinvertebrate and fish productivity.

Salmonids share a common life history, but differing patterns allow several species to occupy compatible niches in the stream system. It's important to understand basic fish habitat needs and to identify the habitats that each species occupies at all life stages.

Sediment and stream temperature are important physical water-quality characteristics that may affect fish and other stream organisms. Both suspended and bedload sediments can affect egg and juvenile survival. Temperatures alter the metabolism of macroinvertebrates and cold-blooded organisms such as fish. Extreme water temperatures inhibit fish growth, decrease their ability to compete for food, reduce appetite, or cause death.

Dissolved oxygen, nutrients (e.g., nitrogen, phosphorus, and potassium), manufactured chemicals, and pH are important chemical water-quality characteristics that may affect salmonids. Fish need high dissolved oxygen levels in water. Dissolved oxygen is affected by variables including stream temperature, water agitation, plants, and light penetration. Nutrients are essential for fish survival, but excessive amounts can be lethal. Some manufactured chemicals can be tolerated only at minimal levels. Fish and other aquatic organisms can tolerate only certain pH levels. High and low ranges may be toxic.

Organic matter and micro-organisms are important water-quality characteristics that affect fish and other stream life. Excessive amounts of organic matter reduce dissolved oxygen. All waters have organisms (bacteria, insects, etc.) that are beneficial, but some have organisms that are pathogenic (disease-causing).

Water-quality characteristics vary with watershed hydrology and other characteristics (erosion, channel features, riparian areas, etc.), and each characteristic varies with time.

Exercises

The best way to understand biological and chemical processes is to measure and observe them in stream systems. Listed below are some field exercises to pursue with local state agencies to clarify these processes. Other agencies (e.g., U.S. Forest Service, Bureau of Land Management), private interest groups (e.g., Oregon Trout), and trained volunteer groups (e.g., STEP) also conduct these surveys.

- Review local watershed assessments. Find the types of fish present, their population estimates, and a list of possible limiting factors.
- Review the Oregon Department of Environmental Quality's list of water-quality-limited streams (303d list). Find some listings in a familiar watershed. Identify the water-quality parameters that caused the stream to be listed as water-quality-limited.
- Volunteer to participate with a field crew of agency personnel or trained volunteers performing an Aquatic Macroinvertebrate Survey on a stream in your area. Review data, analysis, and results.
- Volunteer to participate with an Oregon Department of Fish and Wildlife field crew in performing resource surveys (fish habitat, spawning, or population surveys).
- Volunteer to participate with an Oregon Department of Environmental Quality field crew in performing water-quality surveys (e.g., storm watch program for turbidity).

Resources

Training

Local state and federal agencies, universities, nonprofit groups, private interest groups, and trained volunteers may offer training opportunities in your area.

Information

Ecosystem Workforce Project Curriculum, by various authors (Oregon State University and LERC at University of Oregon, 1996).

Influences of Forest and Rangeland Management on Salmonid Fishes and their Habitats, by W. Meehan, ed. (1991). ISBN 0-913235-68-7

Methods in Stream Ecology, by F. Hauer and G. Lamberti (Academic Press, San Diego, CA, 1996).

"The river continuum concept," by R. Vannote, G. Minshall, K. Cummins, J. Sedell, and C. Cushing, *Can. J. Fish. Aquat. Sci.* 37(1980):130–137.

The Stream Scene, by P. Bowers et al. (Oregon Department of Fish and Wildlife, Portland, OR, 1992).

Stream Temperatures: Some Basic Considerations, EC 1489, by J. Moore and R. Miner (Oregon State University Extension Service, 1997).

"Structure and function of stream ecosystems," by K. Cummins, *BioScience* 24(1974):631-641.

"Trophic relations of aquatic insects," by K. Cummins, *Annual Review of Entomology* 18(1973):183-206.

MOVING FORWARD–THE NEXT STEPS

On your own, use the lines below to fill in steps, actions, thoughts, contacts, etc. you'll take to move yourself and your watershed group ahead in understanding stream ecology.

1. ______________________________

2. ______________________________

3. ______________________________

8

Stream Evaluation and Enhancement

Derek Godwin
and Jim Waldvogel

It's no wonder that stream enhancement projects often are popular; you really have something to show for your work when you're finished. However, these projects frequently are expensive and require technical expertise, and in many cases they aren't evaluated to see whether they're achieving their goals.

Chapter II-7, "Stream Ecology," introduced the components of stream ecosystems. The purpose of this chapter is to provide a basic understanding of stream assessments, enhancement projects, and monitoring plans.

Assessments evaluate present conditions compared to *proposed future conditions,* or what you want the stream to look like in the future. *Enhancement* techniques change present conditions and "speed up" ecosystem processes to achieve proposed future conditions. (Note: For the purposes of this chapter, the term *enhancement* is used synonymously with the term *restoration.*) *Monitoring* techniques evaluate changes over time.

This chapter will help you understand the basic principles used in existing and future statewide programs (e.g., the *Oregon Watershed Assessment Manual* from the Governor's Watershed Enhancement Board), provides field exercises, and lists resources for more information and training.

IN THIS CHAPTER YOU'LL LEARN:

- How to assess a stream's present condition and its potential or capacity
- How to determine its proposed future condition
- How to enhance the stream to reach the proposed future condition
- How to monitor changes over time to judge whether the stream is reaching the proposed condition

The first section of this chapter explains the basic components of:

- Assessments that evaluate a stream's physical characteristics, including references to the *Oregon Watershed Enhancement Manual* from the Governor's Watershed Enhancement Board (GWEB) and the Oregon Department of Fish and Wildlife (ODFW) stream habitat surveys
- Assessments that evaluate a stream's biological characteristics. These techniques include fish population and macroinvertebrate surveys.
- Water-quality assessment techniques and how environmental conditions are addressed

See Section II, Chapters 1–7; and Section III, Chapter 7 for information related to this chapter.

The second section of this chapter introduces goals and general designs for common types of enhancement projects, as well as sources of more information, assistance, and training. Although this section introduces the basics of enhancement, you will need the help of professionals (fish biologists, hydrologists, engineers, etc.) to design and implement specific projects.

The third part of this chapter discusses monitoring plans for enhancement projects. Monitoring evaluates stream conditions over time to determine whether you have succeeded in reaching proposed conditions.

You'll find additional information about planning and implementing stream assessment, enhancement, and monitoring projects in Chapters II-1, "Principles of Planning," and II-3, "Assessment and Monitoring."

Please note: This chapter focuses on western Oregon stream evaluation and enhancement techniques. Supplemental chapters focusing on eastern Oregon stream ecosystems will be developed at a later date.

WHY DO WE NEED AN ASSESSMENT?

An assessment is the first step in establishing stream conditions that provide maximum potential benefits to fish and other aquatic life, water quality, wildlife, and humans. A stream assessment:

- Describes existing conditions.
- Compares present conditions to reference sites or conditions.
- Recommends projects to reach a proposed future condition, or determines that enhancement work is not needed at this time.

For example, assessments describe the available fish habitat or water-quality conditions, estimate abundance of spawning fish or smolts, or measure a stream's length and its relation to its floodplain.

BASIC COMPONENTS OF STREAM ASSESSMENTS

A stream assessment identifies the physical (stream channel), biological, and water-quality characteristics of a stream and evaluates how they're functioning. These characteristics were described in Chapters II-2, "Watershed Science," and II-7, "Stream Ecology." Table 1 summarizes the basic components of stream assessments.

Table 1.–Basic components of a stream assessment.

Stream channel	Biological	Water quality
Number and quality of habitat units (pools, riffles, glides, etc.)	*Fish population estimates (number of juveniles, spawning adults, etc.)	*Suspended sediment and bedload movement
Width, depth, and length of habitat units	Presence of different fish species	Turbidity
Streambed materials (gravel, cobble, boulders, sand, etc.)	*Abundance of fish utilizing available habitat	Stream temperature
Stream gradient (slope)	Number and type of macroinvertebrates	Dissolved oxygen
Relation of stream to its floodplain		pH
Single or multiple channel		Bacteria
Riparian condition and stream bank erosion		Nutrients (nitrogen, phosphorus, potassium)
Cover for fish (large wood, boulders, stream banks)		

*These components are more expensive and usually are obtained only by resource agencies.

How this information is used to evaluate stream conditions and recommend changes depends on local reference conditions (sites and best information available) and proposed conditions.

CONSIDERATIONS WHEN CHOOSING AN ASSESSMENT

Streams are affected by many watershed processes, land uses, climate, geology, and other factors that make assessment techniques complex. A combination of assessments that evaluates physical, biological, *and* chemical conditions is necessary to understand a stream. Many types of assessments are available; most are time-consuming and require technical skills. Choose an assessment that will work for your group, considering your time, money, and access to technical resources and training. Chapter II-3, "Assessment and Monitoring," provides additional information about the complexity of assessment.

Using standard methods allows the information to be analyzed and used by many different audiences (e.g., state and federal agencies, private consultants, and other watershed groups).

It is recommended that you use common assessment techniques that gather information in a standard format. Using standard methods allows the information to be analyzed and used by many different audiences (e.g., state and federal agencies, private consultants, and other watershed groups). For example, ODFW has developed basic and advanced stream habitat surveys, the Department of Environmental Quality (DEQ) has developed water-quality assessments and monitoring techniques, and GWEB's *Oregon Watershed Assessment Manual* utilizes and builds on these assessments.

To conduct an assessment, list the questions you want the assessment to answer. Then choose an assessment that provides enough data to answer these questions. To assist in these steps, find some examples of data gathered using your proposed methods and the questions these assessments addressed. Chapter II-6, "Riparian Evaluation and Enhancement," discussed several considerations for designing riparian assessments. These considerations also apply to stream assessments.

Gather appropriate data to compare current conditions to reference sites or conditions. A *reference site* is a similar stream that is considered to be functioning at its maximum potential. In the absence of reference sites, *reference conditions* are established for factors such as abundance of pools and amount of large wood. Because watershed conditions may have been changed by floods or human activity, historical photos and survey notes are useful for determining the reference condition and/or potential future condition.

Consult local state, federal, and private representatives (e.g., ODFW, U.S. Forest Service (USFS), Bureau of Land Management (BLM), Natural Resources Conservation Service (NRCS), Oregon Department of Forestry (ODF), or OSU Extension Service) for information about appropriate reference sites or conditions.

Make sure the reference information is pertinent to the local ecosystem (stream size, geology, climate, landscape, etc.). The same stream naturally has different characteristics at different locations in the watershed. For example, a small, steep coastal stream may be too steep to store large wood and may naturally consist of boulders with small, cascading waterfalls. As the stream grows larger and becomes flatter, it naturally may become able to store large wood.

Divide the stream to be assessed into manageable units. This will give you more flexibility in using the data for planning enhancement projects and changes in management. Some ways to divide stream segments include:

- Land use or management
- Type of stream (e.g., small versus large, flows year round versus seasonally)
- Valley type (e.g., wide floodplain versus steep canyon)
- Resource values (e.g., different types of fish or water use)

EXAMPLES OF STREAM CHANNEL ASSESSMENTS

ODFW stream habitat surveys

Stream habitat surveys are designed to obtain basic information about stream habitat. The data collected will help you identify good habitat to be maintained, poor habitat needing enhancement, and factors contributing to present habitat conditions. The data also will help you establish monitoring programs and management plans.

The Oregon Department of Fish and Wildlife (ODFW) has developed a methodology for stream habitat surveys that is designed to be compatible with other stream habitat inventory and classification systems. It involves recording data about habitat units, amounts of large wood in the stream, and characteristics of the riparian area. These data are recorded on various forms.

This section describes the ODFW method and includes adapted excerpts from the *Ecosystem Workforce Project Curriculum* and *Methods for Stream Habitat Surveys.* Detailed survey techniques and definitions are found in *Methods for Stream Habitat Surveys.* Appendices A-1 through A-6 show the forms used for recording data. To obtain quality data with this survey, training and oversight by experienced personnel are required.

Stream habitat surveys are based on continuous walking surveys along major streams and tributaries in a watershed. Surveys move from a stream's mouth (at the ocean, lake, or estuary) or its *confluence* (where it joins another stream) all the way to its *headwaters* (where it originates). This approach relies on visual observations and regular measurements to estimate habitat area and characteristics.

Every stream is divided into sections called *reaches*. Reaches vary in length from approximately 1,500 feet to 5 miles. A reach is defined as a segment between tributaries or between two points marked by a change in valley and channel form, vegetation, land use, or ownership.

Data describing the reach are gathered and recorded on a data sheet (Appendix A-1). Data describe channel form, valley form, valley width, streamside vegetation, land form, land use, and a few other characteristics.

A habitat survey describes each reach as a sequence of habitat *units*. Each unit has relatively similar slope, depth, and flow pattern. This information is recorded on the Unit-1, Unit-2, wood, and riparian forms (Appendices A-2 through A-5). Each unit is longer than one *active channel width*, which is the distance across the channel at annual high flow. Active channel width usually is recognized by slope breaks, high water marks, and changes in vegetation.

Unit-1 and Unit-2 forms

Information on in-stream habitat units is recorded on Unit-1 and Unit-2 forms (Appendices A-2 and A-3). There are many kinds of in-stream habitat units. A few examples include:

- *Pools*–units with a water surface slope approximately zero (flat)
- *Glides*–units of generally uniform depth and flow with no surface turbulence
- *Riffles*–fast, turbulent, shallow flow over submerged or partially submerged gravel and cobble. They usually have a 0.5–2 percent slope.
- *Cascades*–fast, turbulent flow with many hydraulic jumps, strong chutes, and eddies. They usually have a 3.5–10 percent slope.

Assessors collect and record the following information for each habitat unit:

- Channel form (length, width, slope, and depth measurements)
- Streambed materials, or *substrate* (size class and percent distribution)
- *Boulder counts* (number of boulders protruding above the water surface at low flow)
- Woody material (complexity, particularly as it influences fish habitat)
- Exposure of the stream to the sun (denoted as "shade left" and "shade right" on the data form)
- Stream bank characteristics (erodibility and amount of undercut banks)

Wood and riparian forms

The wood inventory estimates the volume and distribution of large wood in the stream reaches. *Large wood material* is defined as wood greater than 6 inches diameter and longer than 10 feet. (Root wads do not have to meet the length criteria.) The wood is counted and measured, and its location and configuration are described on the wood form (Appendix A-4).

The riparian inventory is designed to provide additional information about the kinds, quantities, and sizes of riparian zone vegetation. Measurements are taken along a line known as a *transect* to measure and describe vegetation, land forms, slope, and canopy closure in the riparian zone. These data are recorded on the riparian form (Appendix A-5).

From survey to assessment

Information gathered from a stream survey will help you evaluate fish habitat and channel structure as well as compare streams. It also will help you locate potential problems, enhancement sites, and unique features.

Habitat unit descriptions indicate fish habitat potential (spawning, rearing, and cover habitat) and what components are missing. For example, stream bank classification and riparian forms indicate channel stability, sediment sources, and riparian conditions influencing in-stream habitat. Large wood forms describe how much large woody material is actively influencing habitat or might be available in the future.

GWEB's Oregon Watershed Assessment Manual

Two chapters of the GWEB *Oregon Watershed Assessment Manual* provide techniques for evaluating physical stream characteristics– "Channel Habitat Type Classification" and "Fisheries Assessment." The following descriptions include excerpts from the manual.

Channel Habitat Type classification

GWEB has developed basic channel types for Oregon streams called Channel Habitat Types (CHT). This classification system is designed to help identify which parts of a watershed have the highest potential for fish utilization and how various channel types respond to land-use impacts or restoration efforts. This information in turn will help you identify potential restoration projects that are likely to benefit fish habitat the most. The assessment utilizes and complements Oregon Department of Forestry stream classification maps and ODFW's stream habitat information.

CHTs are organized on a valley segment scale. Examples are illustrated in Figure 1. CHTs are defined by channel gradient (slope), channel pattern, degree of valley constraint, and, in some cases, stream size. Stream size is considered primarily because the role of woody debris differs in small and large streams.

Other information used to describe the CHT includes the ratio between valley width and active channel width, the position of the channel within the drainage network, and the gradient of the confining sideslopes. Finally, field measurements that further describe CHTs include the degree of entrenchment or depth of the channel, the nature and size of the material making up the channel banks, and the size of particles on the streambed.

CHTs are identified and mapped using U.S. Geological Survey Department (USGS) topographic maps and aerial photos. Field visits help verify questionable CHTs. The GWEB *Oregon Watershed Assessment Manual* provides the following information for each CHT:

- Physical description
- Fish utilization information
- Riparian management considerations
- Riparian enhancement and channel restoration options

Fisheries assessment

This assessment is designed only to provide a way to compile and evaluate available fish populations, habitat, and barriers to passage. It is used to:

- Identify fish species present in the watershed, where they occur, and what is known about their population

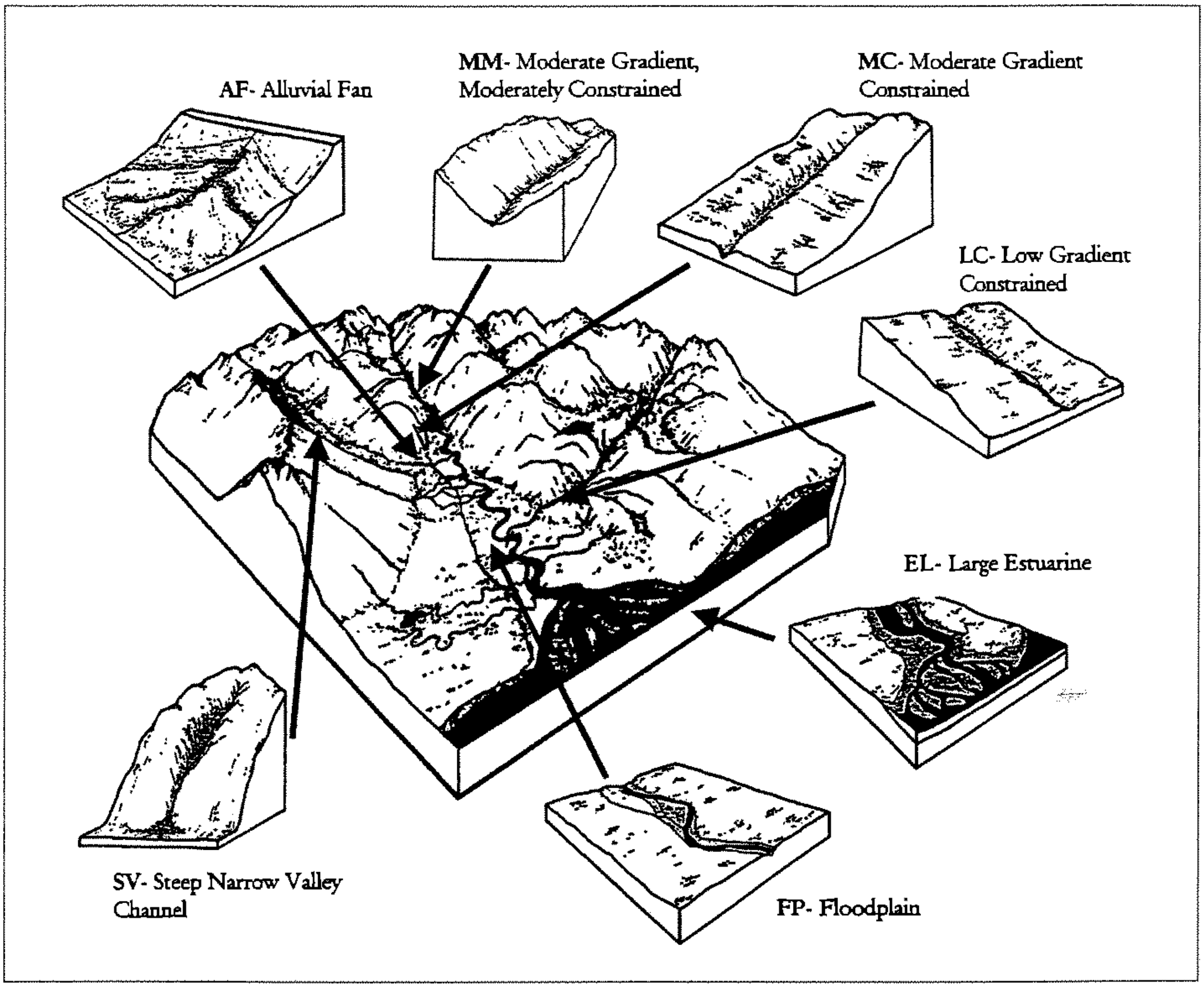


***Figure 1.**—Channel habitat type descriptions. (Source:* Oregon Watershed Assessment Manual*)*

- Identify potential interactions between species of concern
- Compile and compare existing ODFW habitat data to established ODFW/NMFS (National Marine Fisheries Service) benchmarks to evaluate in-stream habitat conditions
- Identify human-caused barriers to fish passage and prioritize them for enhancement

An example of a data sheet for compiling and evaluating habitat conditions is shown in Appendix B.

Fish passage

Fish passage surveys are discussed in Chapter II-4, "Upland Evaluation and Enhancement."

ASSESSMENTS OF STREAM BIOLOGICAL CHARACTERISTICS

Macroinvertebrate surveys

Macroinvertebrate surveys classify species based on the role they play in the food web. Stream macroinvertebrates are separated into four feeding groups–shredders, collectors, scrapers, and predators. Chapter II-7, "Stream Ecology," describes these groups and the roles they play in a stream ecosystem.

Macroinvertebrate surveys help you assess the food base of a stream ecosystem. You can use the results to analyze water quality and fish habitat. The DEQ has specific protocols for surveying macroinvertebrates and using the information to describe stream conditions (i.e., water quality and fish habitat).

The following section provides an overview of how macroinvertebrates are surveyed and how the information might be used. To use these techniques, you'll need to obtain additional training. The methodology described is based on Cummins and Wilzbach's survey procedures (see *Field Procedures for Analysis of Functional Feeding Groups of Stream Macroinvertebrates*). Many agencies (e.g., DEQ), institutions, and private entities have adapted these procedures for their own use.

General methods

The best times to conduct these surveys are midwinter through early spring, or mid- to late summer. At these times, individuals in the winter or summer populations have grown to full size and are easiest to see. Macroinvertebrates are collected from three to five of the following habitat types:

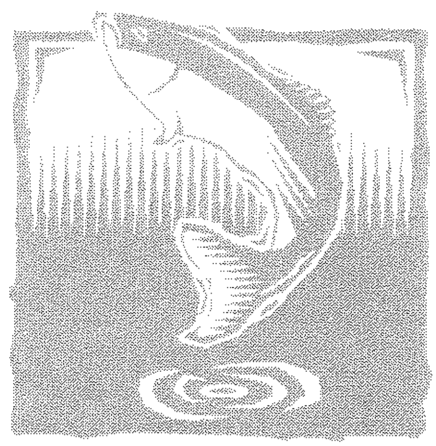
- Coarse particulate organic matter–for example, leaves, needles, bark, and twigs (>1 mm in size)
- Large wood–large branches and logs
- Fine particulate organic matter (>0.5 um, and ≤1 mm)
- Periphyton–predominantly attached algae on rock and wood surfaces
- Attached vascular plants (only if extensive plant beds or moss cover is present)

To do a macroinvertebrate survey, assessors collect a handful-size sample from each habitat type. They then identify macroinvertebrates by functional group, sort them into separate containers, and count them. Appendix C provides a key to functional groups and a sample sheet for recording data. After counting individuals, the next step is to compare total numbers in each group and calculate ratios of one group to another. For example, the shredder:collector ratio is compared to the scraper:collector ratio.

From survey to assessment

Use macroinvertebrate surveys to assess water quality and fish habitat by comparing the assessed stream to a reference stream or conditions. Combining macroinvertebrate surveys with physical habitat and water-quality analyses provides a more thorough analysis. For example, a small stream with very few trees in the riparian area will have a different shredder:collector ratio than a reference stream with many trees. A stream dominated by riffle habitat will have different ratios than a reference stream with more pool habitat. A stream with poor water quality will have fewer organisms, and these organisms may show unhealthy characteristics. Contact DEQ for specific examples and assessment protocols.

Fish population surveys



When assessing stream habitat and watershed health, don't forget to consider fish. Fish population surveys identify and estimate fish resources. Salmonids have differing life-history patterns; therefore, choose a sampling technique appropriate for the species or life stage you plan to assess. See Chapter II-7, "Stream Ecology," for more information about salmonid life cycles.

All fish sampling and data collection must be approved by and coordinated through a local ODFW biologist. The recent listings of some salmonid species under the Endangered Species Act require permits from the National Marine Fisheries Service (NMFS) and/or U.S. Fish and Wildlife Service (USFWS) to conduct surveys.

Fish population surveys document populations in a specific tributary or watershed. The following data are useful for evaluating fish populations:

- Presence or absence of species
- Spawning area distribution
- Species composition
- Relative abundance, i.e., the number of adults or juveniles
- Timing of spawning or juvenile migration
- Upper and lower limits of fish distribution

The techniques you choose depend on what information you need. Surveys may consist of simply noting whether a species is present in a particular stream, or may include a comprehensive analysis of the fish population in the entire watershed. The survey may involve researching existing information and/or collecting new data.

You can obtain much of the information you need without capturing fish, in other words by using *noncapture* techniques. Use these techniques whenever possible because capture techniques sometimes kill fish.

Noncapture techniques

Use noncapture techniques to document what fish are present, how many are present, and how they are using certain habitats during different life stages. Techniques are categorized as *stream bank* (above water) or *direct* (underwater) observations.

Examples of stream bank observation are:

- Visual spawning counts–number of live adults, carcasses, or redds (nests) in a survey area
- Visual verification of the presence or absence of juveniles or adults
- Surveys of existing sport fishery catches (*creel census*)
- Photographic or video surveys
- Sonic tracking–monitoring sonic-tagged fish

Spawning counts are used to create an *index of escapement* (the number of adult fish in a defined spawning survey area). These surveys provide good population estimates when conducted over a period of years.

Spawning data are collected by counting live fish, carcasses, redds (nests), or combinations of all three. Most spawning surveys of coho and chinook salmon use live fish and carcass counts. Redd counts commonly are used for steelhead since the adults may not die after spawning. Appendix D shows the proper procedure for conducting a valid spawning survey on small coastal streams.

Walking stream banks during summer low flow conditions is a good way to verify the presence or absence of fish. Juvenile fish can be observed in small streams using polarized glasses. However, it can be difficult to identify specific species of juvenile fish from the bank.

Direct underwater observation is a common technique to identify species, estimate numbers, or determine how different species and ages are utilizing certain habitats. Experienced divers can quickly identify and count juvenile and adult fish. Underwater observations usually are conducted in pools and runs, not in riffles. This technique requires snorkeling equipment, a wet or dry suit, and trained divers.

Where sport fisheries exist, some methods of creel census are utilized. These surveys randomly sample sport angler catches. They are useful for identifying species and aging fish, or for gathering return data for marked hatchery fish. Volunteer samplers and experienced biologists can collect data from large river sections using this method.

Photographic or video observations are used to identify species or count migratory fish. They frequently are used at fish ladders or other passage restrictors (traps, tunnels, or culverts). These techniques require technicians and expensive equipment.

Sonic tracking methods sometimes are used by fishery researchers. Sophisticated equipment is required, and technicians are needed to use these systems.

Fish sometimes die during collection or after being captured; therefore, it is important to choose the proper technique.

Capture techniques

Fishery biologists use several types of *capture* techniques to gather detailed information about fish populations (see *Methods for Stream Habitat Surveys*). These methods involve capturing, handling, marking, and releasing fish. Fish sometimes die during collection or after being captured. Therefore, it is important to choose the proper technique. Capture techniques include seining, trapping, electrofishing, and sport fishing. All of these methods require permits from ODFW.

Seining is a standard fish survey technique used in estuaries and large rivers to monitor fish growth and movement. Small mesh beach seines catch juveniles, which then are measured and identified. Seining also can be used to capture adults in the lower river for tagging and migration studies.

Traps and *weirs* capture adults or monitor juvenile movement. Fixed pipe traps and floating screw traps are used in tributaries or small rivers to monitor the outmigration of juvenile smolts. Weirs and slot traps are used together to capture upmigrating adults. The effectiveness of traps depends on flow conditions. Traps often are washed out by high flow events.

Electrofishing is used to estimate populations of juvenile salmonids. Fish are stunned by electrical current and netted before they recover. Fish are released after species and length data are collected. Only experienced fish biologists with permits can use this technique. Electrofishing is dangerous (water is a good conductor of electricity), and fish mortality can be high if not done properly.

Sport fishing techniques can be used in isolated areas where juvenile fish exist and identification from the bank is difficult (e.g., riffles, waterfalls, or deep pools). Lure and flyfishing gear catches most juvenile salmonids. However, fishing tends to catch fish of a certain size, and success depends on season and water clarity.

The following publications contain detailed explanations of proper procedures for stream fish surveys:

- *How to Do Spawning Fish Surveys* (Salmon Trout Enhancement Program (STEP), Oregon Department of Fish and Wildlife)
- *California Salmonid Stream Habitat Restoration Manual*, Chapter IV (California Department of Fish and Game, 1994)
- *Fisheries Techniques*, by L. Nielsen and D. Johnson (American Fisheries Society, 1983)
- *A Review of Capture Techniques for Adult Anadromous Salmonids*, Information Report #96-5 (Oregon Department of Fish and Wildlife)

WATER-QUALITY ASSESSMENTS AND MONITORING

Assessing water quality means documenting present conditions, while *monitoring* water quality means measuring conditions over time to track progress toward desired conditions. Most water-quality assessment techniques also are used for monitoring. This section provides a brief overview of the factors to measure and how to measure them.

Factors such as temperature, bacteria, and pH are known as *parameters* of water quality. Chapter II-7, "Stream Ecology," described the most common parameters. State and federal agencies have established water-quality standards for most parameters discussed in this section. These standards are based on the water's beneficial uses (e.g., drinking, recreation, humans, fish, or wildlife). DEQ developed a list of streams in Oregon that are designated as *water quality limited* (the 303(d) list). In other words, they do not meet applicable water-quality standards. The list specifies which measured parameters cause the stream to be limited.

It's very expensive to measure all parameters for one stream. Water-quality monitoring programs address the parameters that likely are causing problems to the user or already are identified on the state 303(d) list. A few areas of the watershed are monitored to indicate where problems are located. Then, more detailed monitoring is conducted in the problem areas.

For example, if fish populations in an area are depressed, and assessments describe poor riparian vegetation, then stream temperatures are measured in a few areas. Where excessive stream temperatures are found, more detailed analyses are conducted. Likewise, if assessments describe excessive stream bank erosion and sediment in the stream, then sediment is monitored, and upland erosion problems are surveyed.

DEQ follows the monitoring guidelines established by the U.S. Environmental Protection Agency (EPA). See *Monitoring Guidelines to Evaluate Effects of Forestry Activities* and *Monitoring Protocols to Evaluate Water Quality Effects of Grazing Management* for more information. The United States Geological Survey Department (USGS) is another source of monitoring protocols, especially for stream flows and sediment loads.

Continuous, seasonal, and storm event monitoring

There are two basic approaches to water-quality monitoring and assessment–continuous random sampling and seasonal sampling. *Random sampling* is based on the concept that water quality varies, so it's best to collect large numbers of samples from a specific point on some arbitrary schedule (for example, every Monday morning at 10:00 a.m.). This approach tries to define overall water quality.

Seasonal sampling looks at water quality in specific seasons. For example, if you're concerned about water quality during low flow in western Oregon, you would collect samples only during the summer or early fall. The extreme of seasonal monitoring is *storm event monitoring*. In this type of monitoring, samples are collected only during and immediately after a rainfall or snowmelt event.

What to measure and how

Water-quality parameters and their effects on fish, wildlife, and humans are discussed in Chapter II-7, "Stream Ecology." GWEB's *Oregon Watershed Assessment Manual* contains a water-quality assessment that compares data collected from a watershed with state standards for several water-quality parameters. First, the assessment identifies the beneficial uses of streams in the watershed. Next, it identifies water-quality criteria applicable to these uses. Third, existing water-quality information is assembled. Finally, the water-quality conditions are evaluated using available data.

The following sections identify different water-quality parameters and briefly explain how they're measured.

Stream temperature

Stream temperatures often are measured when riparian and stream assessments identify poor riparian vegetation along the stream. Chapter II-7, "Stream Ecology," discusses factors that affect stream temperature (e.g., solar radiation, groundwater seeps, air temperature, and stream flow).

Stream temperatures commonly are measured with temperature *dataloggers*–matchbox-size recorders with temperature sensors. They can be programmed to record temperatures at set time intervals. Some dataloggers are waterproof or fit into waterproof containers for in-stream placement. Others have long probes that reach into the stream from dry ground. Examples of dataloggers from Onset Instruments are hobos, stowaways, and optic shuttles.

Stream temperature usually is measured in deep riffles or runs where water is well mixed and temperatures are relatively constant.

Stream temperature usually is measured in deep riffles or runs where water is well mixed and temperatures are relatively constant. Sometimes stream temperatures are measured in pools or other types of habitat to identify cool water seeps and *refugia* (areas of cool water surrounded by warm water). Stream temperatures usually are measured from June to October if high temperatures are the focus of an assessment. Peak maximum daily temperatures occur in mid-July or August.

Sediment and turbidity

Two kinds of sediment are measured–suspended sediment and bedload. *Suspended sediment* is assessed by measuring the weight of sediment in a given volume of water (usually milligrams per liter). *Bedload* sampling measures the weight and size of sediment moving along the streambed during different-sized stream flows. To make sense of sediment measurements, you also need stream flow measurements. The sediment load in the stream at a given time can be calculated by looking at the sediment concentration and stream flow.

The difficulty with measuring suspended sediment and bedload is figuring out where and when to sample. The sediment concentration changes with the size of stream flow, time of year, and whether the stream flow is rising or falling. The most common sampling method uses the Helley-Smith sampler. The USGS and EPA are contacts for sampling procedures and equipment.

Turbidity is the degree to which light is blocked. It is a common monitoring parameter and is easy to measure. Some people measure turbidity by visual observations, while others use a *turbidimeter*. The turbidimeter measures the amount of light absorbed by a water sample compared to clean water. Turbidity varies according to the amount of organic material and type of suspended sediment. Turbidity is not a direct measure of suspended sediment, but turbidity measurements can be used together with sediment measurements to assess water quality.

Bacteria

A third water-quality parameter is bacteria. There are several different methods for measuring bacteria. Measurements typically count bacteria *indicators*. Indicators are kinds of bacteria whose high numbers indicate the presence of harmful bacteria. The most common indicators are *Escherichia coli* (*E. coli*) and fecal coliform. All methods involve filtering a water sample (100 ml) onto a medium (dish, filter paper, etc.). The sample is stained, and bacteria are allowed to grow for a period of time. Then the bacteria colonies are counted. The results are given as number of bacteria per 100 milliliters of water.

Bacteria populations fluctuate in response to stream flow, disturbance of the streambed, time of year, and time of day. Also, bacteria can survive for long periods on land and in stream sediments. Given this high variability, it's important to sample frequently. Take samples at the appropriate time of year based on how the water is used. For example, sample in summer to determine whether the water is safe for recreational swimming.

pH, dissolved oxygen

pH often is monitored because it's easy to measure. It is important to measure pH in the field as soon as the sample is taken. The procedure usually involves adding drops of solution that color the water; pH then is read on a color scale. Another method uses litmus paper, which changes color depending on pH. Measurements vary depending on the measuring kit.

pH varies by temperature, carbon dioxide concentrations, stream flow, time of year, and other conditions. Assessments of the effects of acid rain and mining operations include intensive pH monitoring.

Dissolved oxygen (DO) is easy to measure as long as precautions are taken to minimize disturbance of gas exchange. DO varies with time of day, temperature, stream flows, and time of year. Most DO monitoring studies look at activities that supply a large amount of organic material to streams, especially point source pollution (for example, pulp mill, food processing, and municipal wastes). Some nonpoint source pollution activities such as forestry, agriculture, and livestock management may affect DO, especially when stream flow is low and temperature is high.

Nutrients

Nutrients can be measured as dissolved or particulate. Most monitoring programs measure dissolved nitrogen and dissolved phosphorus because they are readily available for uptake by stream primary producers. Some programs monitor particulate phosphorus that enters the stream with sediment.

Measuring procedures vary depending on the measurement kit. Usually, chemicals are added to water samples, causing the water to change color. The color then is compared to a chart to determine the amount of phosphorus or nitrogen present.

Nutrients are measured if there is concern about algae growth or if the water is used for drinking. You might monitor nonpoint activities causing large organic or sediment inputs to streams as well as direct point sources of pollution. If you're evaluating nutrient inputs into streams, measure during storm events. Also monitor during seasons when beneficial uses (for example, algae growth or drinking water) are affected.

Herbicides and pesticides

Monitoring herbicides and pesticides is expensive and is done only if there is strong belief that these chemicals pose a threat to water quality. When monitoring herbicides and pesticides, it's critical to select the right time and place to sample. State forest practices regulations and DEQ have established procedures for sampling. Usually, one sample is taken before applying the chemical, and several samples are taken at various times after application. It's possible to evaluate how likely an application is to impair water quality, and the intensity of sampling can be adjusted to reflect this risk.

STREAM ENHANCEMENT/ RESTORATION

In this section, the terms stream enhancement and restoration are used interchangeably. The main goals of stream enhancement are:

- To restore essential physical and ecological functions (e.g., the presence of large wood or vegetated stream banks). These functions in turn maintain or restore channel stability, habitat for fish and other aquatic organisms, and water quality.
- To push stream and riparian areas toward restoring themselves and becoming self-sustaining.

Remember, stream enhancement sometimes doesn't require active projects; it may mean simply letting a stream restore itself.

An important concept in understanding channel stability is *stream geometry*. Think of stream geometry as the "shape" of the stream (dimension, pattern, and profile). It includes factors such as width, depth, gradient, and sinuosity (how winding the channel is). A stable stream channel reaches a natural equilibrium that maintains its geometry. In other words, it passes sediment without aggrading or degrading. A stable channel in equilibrium can migrate laterally quite a bit, but still keep its basic geometry.

The stream restoration techniques you use will depend on your goals, the type of stream, and the fish species present. No stream project will succeed if upland and riparian conditions influencing the stream are not addressed. To maximize project success, utilize technical guidance from hydrologists, fish biologists, engineers, geologists, etc. See Chapters II-5, "Riparian Functions," and II-4, "Upland Evaluation and Enhancement," for more information.

All projects require consultation and permits. Contact your local ODFW or Oregon Division of State Lands office for information. The NMFS and the state are developing an *Oregon Aquatic Habitat Restoration Guide* under the Oregon Plan. These guidelines must be followed to get relief from Section 9 taking prohibitions under the Endangered Species Act, where applicable.

The following sections provide basic information on a variety of stream enhancement projects. Their purpose is to help you seek guidance for selecting and implementing these projects. Information on single-site stream bank stabilization techniques also is given to help landowners make their projects more beneficial to the stream and riparian area.

Enhancing fish habitat

There are many types of fish enhancement designs. They differ according to the desired objective for each fish species. Each species has different life-cycle requirements and critical survival needs (for example, spawning versus rearing habitat). Choose a restoration technique based on the most critical need. See Chapter II-7, "Stream Ecology," for more information on salmonid habitat needs.

For example, coho juveniles rear in tributaries and require slower moving water during high flow to survive to smolt size. Coho restoration techniques tend to focus on increasing slackwater pools and woody material in the channel. Designs also depend on stream characteristics. For example, ODF suggests that logs placed in streams be 1.5 to 2 times as long as the active channel width.

Many types of designs have been used with varying degrees of success. They have evolved from "let's just try this and see" to engineered designs. Most mistakes occur when people design structures without studying the basic characteristics of the river or the specific needs of the fish. Remember, the goal of improving fish habitat with structures is to mimic what would occur naturally in a particular stream type.

Examples of stream enhancement structures

The various kinds of structure designs all serve the common purpose of imitating natural obstructions that disrupt the flow of water and sediment. By influencing *hydraulic conditions* (the movement of water), structures store and sort sediment, enhance scour, deposit streambed material, diversify velocity and depth, and fix the position of bars and pools. As water and gravel are forced under, over, around, between, or slowed by structures, the streambed is scoured or material is deposited. The result affects fish habitat and channel stability.

In 1994, the Oregon Forest Practices Rules created an incentive to place wood in streams. The emphasis is on matching the size of wood (length and diameter) to the stream size to provide for wood stability rather than relying on anchoring techniques. The goal is not to construct habitat directly, but to load the stream with wood that can reconfigure to a limited degree and work with the stream to create pools, store gravel, and provide cover.

Wood should be at least two times as long as the active stream channel width (1.5 times the width for wood with rootwad attached) and meet diameter requirements and stream size and slope requirements as outlined in the ODF and ODFW publication *A Guide to Placing Large Wood in Streams.* Figure 2 shows the effects of various placements of large woody debris.

NMFS, the *Oregon Aquatic Habitat Restoration Guide*, and the new authorization for the Division of State Lands discourage in-stream structures that are anchored to boulders, logs, and trees. Most stream enhancement projects in the past were designed using these techniques. The three general designs used for these in-stream structures are deflectors, weirs, and cover structures (Figure 3). The state and NMFS feel that these structures have not been very useful for restoring habitat in the long-term or for increasing fish productivity. But they acknowledge instances in which these projects can temporarily increase fish production or at least attract fish to treated reaches *(Oregon Aquatic Habitat Restoration Guide).*

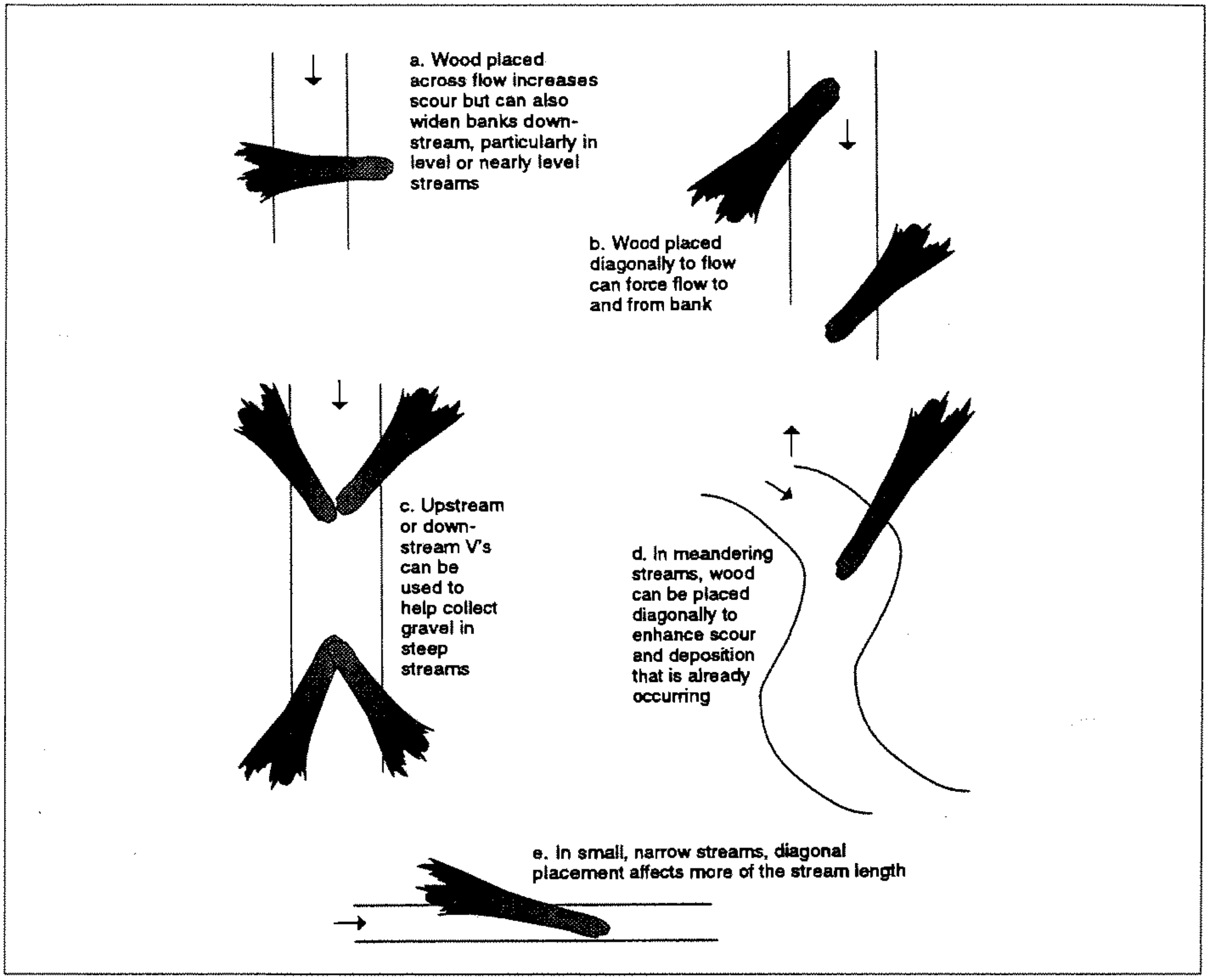


***Figure 2.**—Effects of various placements of large woody debris. (Source:* A Guide to Placing Large Wood in Streams*)*

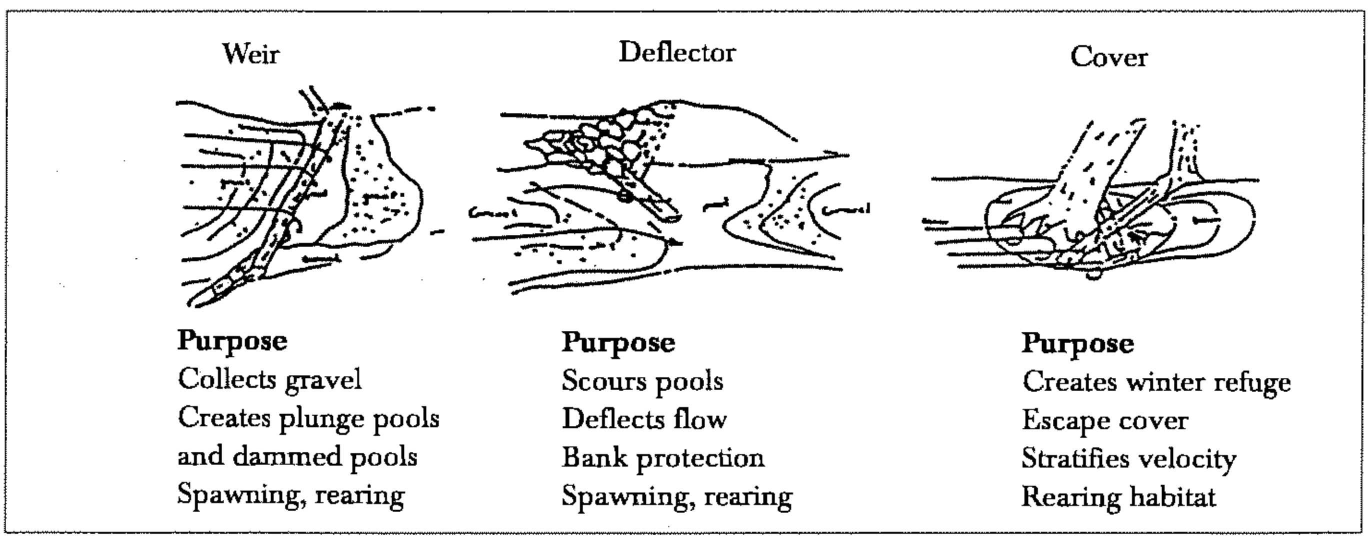


***Figure 3.**—Types of in-stream structures. (Source:* Ecosystem Workforce Project Curriculum*)*

Some key considerations when designing and using structures include (excerpted from the *Oregon Aquatic Habitat Restoration Guide*):

1. Is this a stream that normally would be expected to have large woody debris? Some meadow-based systems should not be expected to have large wood. Similarly, high-gradient reaches on large streams in most cases cannot hold wood.
2. Is the lack of wood a major contributing factor in declining fish populations in the reach? Sometimes other factors, such as a fish passage blockage, may be a leading factor in the decline of fish. In this case, adding wood makes little difference.
3. Does existing upslope and riparian management make large woody debris available for natural recruitment into the stream? Does it encourage stable banks and sediment dynamics, which in turn stabilize the channel?
4. Is large wood in the candidate stream reach currently depleted compared to expected values? (ODFW has information on Oregon's benchmark values and on some individual streams.)

Stream bank stabilization projects

The goals of single-site stream bank stabilization projects are to:

- Slow the water velocity, causing sediment to deposit and build stream bank rather than to scour
- Stabilize the stream bank with vegetation
- Begin to establish a healthy riparian area
- Provide some in-stream fish habitat where possible

One type of bank stabilization involves burying boulders or log deflectors into the bank and letting them extend into the stream channel (Figure 4). These structures deflect flow away from the bank and help stabilize the bank until vegetation is established. Deflectors also increase stream velocity at the tip of the structure and cause a scour pool on the downstream side of the deflector. The scour pool dissipates some of the stream's energy and may provide some fish habitat.

Other designs that stabilize a stream bank and revegetate the riparian area use rock, wood, and trees to decrease velocities, deposit sediment, and grow vegetation. These designs are known as *bioengineering* methods and are discussed in Chapter II-6, "Riparian Evaluation and Enhancement." Contact the Natural Resources Conservation Service and Division of State Lands for information, designs, and technical assistance.

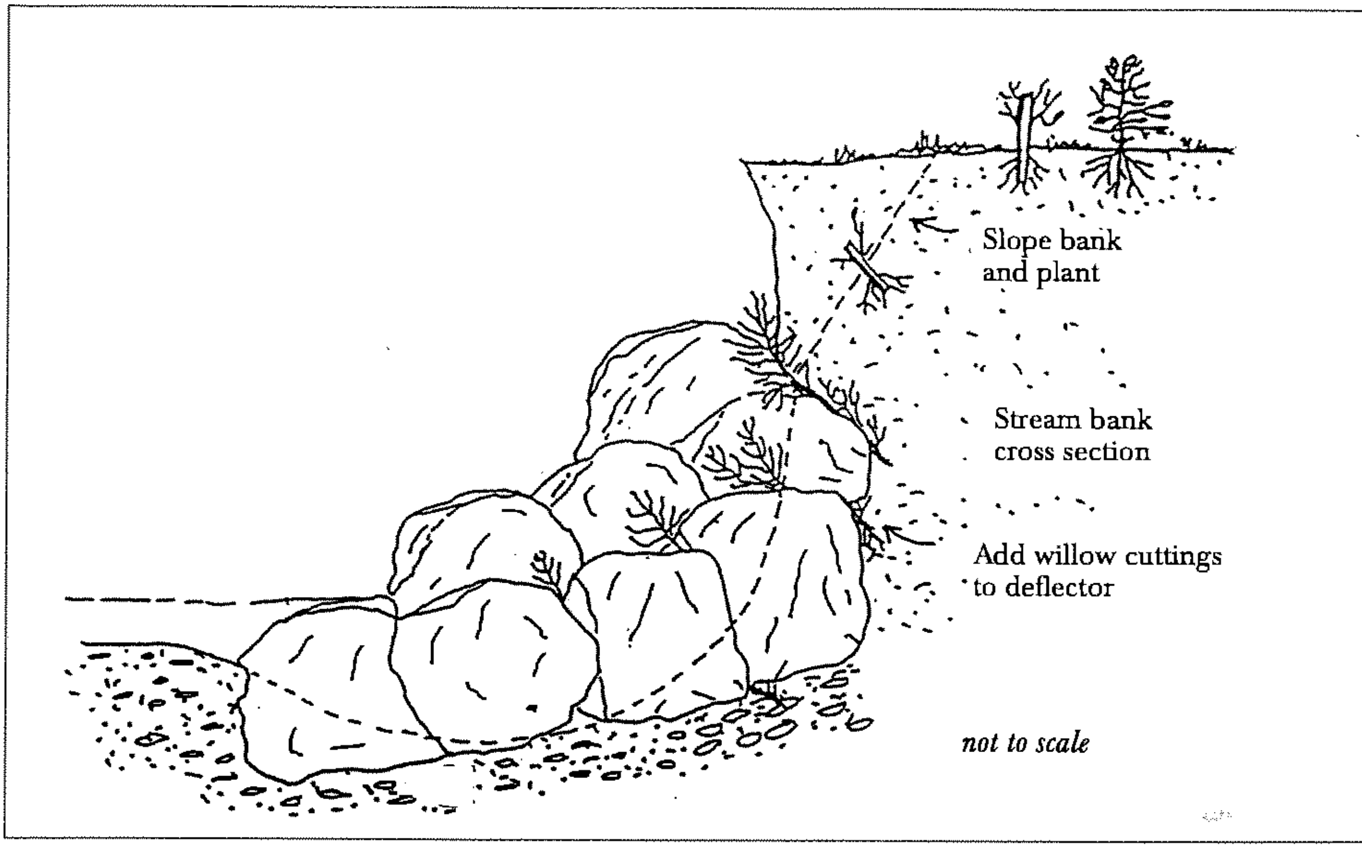


Figure 4.—Boulder deflector used for stream bank stabilization. (Source: John Schwabe, Confluence Consulting)

MONITORING PLANS

Chapters II-6, "Riparian Evaluation and Enhancement," and II-3, "Assessment and Monitoring," discussed monitoring plans in detail. Monitoring is an important part of stream enhancement projects, so this section will briefly review the key points.

Why do we need a monitoring plan?

Monitoring will measure the results of your enhancement project. It can help you avoid repeating mistakes and justifies the investment of resources (whether private or public) in your project. If monitoring shows the enhancement project has not achieved the desired stream condition, you should reevaluate the objectives of the project.

Basic components of a monitoring plan

Most stream monitoring plans use the assessment and survey techniques discussed in this chapter. These techniques help you evaluate present conditions as well as how conditions are changing over time as they move toward the desired future condition. A monitoring plan has three main parts:

- Goals and objectives of the enhancement project
- Specific monitoring techniques and parameters measured
- A process for evaluating whether goals and objectives are met and for deciding whether a change in monitoring techniques and/or measured parameters is necessary.

A monitoring plan starts with a clear statement of goals and objectives (the questions you want to answer with monitoring). Choose monitoring techniques that will provide the right kind of data to answer these questions. Make sure the techniques you choose are appropriate for your group. Take into account factors such as cost, technical requirements, training, available equipment, and access.

Your monitoring plan should indicate whether your enhancement projects are helping the stream achieve its desired condition. If a project is not meeting your objectives, the plan should help you identify factors causing the problem and ways to fix the problem.

Example of a monitoring plan

Assessment of present conditions

Existing condition/limiting factors: Assessments indicate this forested section of the coastal stream has very few pools. Alder trees reduce solar input but do not provide a future source of large woody material..As a result, salmon spawning and rearing habitat has been reduced.

Probable cause: Assessments on reference streams and evaluations of historic information indicate that past forest practices included removing woody material from the stream and did not adequately reestablish a mixed stand of conifer and hardwood trees in the riparian area.

Goals and objectives

Goal: Improve spawning and rearing habitat in the forested stream reach by increasing the number of pools. Improve future supply of large wood in the stream by increasing the number of conifer trees in the riparian zone.

Objective: Increase number of pools by placing large woody material twice the size of the active stream channel width in key locations. Convert half of the alder-dominated riparian area to conifers by manually releasing present conifers in the understory.

Enhancement projects implemented

Following ODF and ODFW guidelines, 20 large pieces of woody material (conifer) were strategically placed in the stream channel and banks to create 9 pools with cover. Following ODF Forest Practices Rules, conifer trees were manually released from the understory of alders present in the riparian zone. The project improved fish habitat and established a future supply of large wood to the stream and riparian area.

Monitoring techniques and parameters measured

- An ODFW aquatic habitat inventory was conducted prior to project implementation, 1 year following implementation, and once every 5 years thereafter. This inventory will monitor stream habitat and riparian conditions.
- All logs were surveyed and locations marked on a map. Logs will be resurveyed once a year for the first 5 years to evaluate movement of logs and stream conditions.
- Photos will be taken at permanently established photo points before and after the project is implemented and once every 5 years at the same time the habitat survey is done.
- A riparian area survey to assess tree survival will be conducted once every year for the first 2 years, then once every 5 years.
- Spawning surveys will be conducted to count spawning fish and map their locations to see whether they are using our newly created spawning areas.

Follow-up evaluation

If monitoring shows that enhancement projects have not led to the desired future condition, a new monitoring plan and enhancement projects will be implemented. If the monitoring data do not describe stream conditions adequately, different monitoring techniques will be used.

Summary/Self review

An assessment compares present conditions to reference conditions, identifies enhancement projects, and helps establish a monitoring plan. Basic components of a stream assessment include evaluations of physical, biological, and water-quality conditions compared to a reference site or reference conditions. A variety of assessment methods are available.

Physical stream assessments evaluate habitat types; width, depth, and length of units; streambed materials; stream bank stability; relation of the stream to its floodplain; stream gradient; riparian condition; large wood; and cover for fish.

Biological stream assessments evaluate fish populations (smolts, juveniles, spawning adults), fish species present, abundance of fish utilizing available habitat, and the number and type of macroinvertebrates.

Water-quality assessments evaluate suspended and bedload sediment, turbidity, stream temperature, dissolved oxygen, pH, nutrients, and bacteria.

Stream enhancement projects aim to restore essential physical, biological, and chemical characteristics in order to restore natural channel stability, habitat for fish and other aquatic organisms, and/or water quality. Enhancing fish habitat may involve strategically placing large wood in conjunction with riparian and upland management considerations.

Monitoring plans include three main components–goals and objectives, specific monitoring techniques and parameters to be measured, and an evaluation process to see whether desired conditions are being met and/or monitoring techniques are inadequate.

EXERCISES

You can do these exercises on your own, but it's helpful to work as a group so you can compare notes and discuss your observations.

Stream assessment

Volunteer to help an agency or private consultant conduct two different assessments of at least two sites (preferably a degraded site and a reference site). Review analysis of data and discuss different enhancement projects recommended to enhance present conditions to a desired condition.

Enhancement

Get involved with two different stream enhancement projects. Review the assessments used to plan the enhancement activities.

Monitoring

Establish a monitoring program for a site where an enhancement project has been implemented. Review an existing monitoring program that has evaluated an enhancement project for several years in a stream that is close to reaching the desired condition.

Resources

Training

Contact your *local watershed council, OSU Extension Service office, Soil and Water Conservation District office, or resource agency office (Oregon Department of Forestry, Oregon Department of Fish and Wildlife, U.S. Forest Service, Bureau of Land Management, etc.)* for training events or personal consultation.

Information

Applied River Morphology, by D. Rosgen (Wildland Hydrology, 1996).

California Salmonid Stream Habitat Restoration Manual, by G. Flosi and F. Reynolds (California Department of Fish and Game, 1997).

Ecosystem Workforce Project Curriculum, by various authors (Oregon State University and LERC at the University of Oregon, 1996).

"Estimating total fish abundance and total habitat area in small streams based on visual estimation methods," by D. Hankin and G. Reeves, *Can. J. Fish. Aquat. Sci.* 45(1988): 834–844.

Field Procedures for Analysis of Functional Feeding Groups of Stream Macroinvertebrates, by K. Cummins and M. Wilzbach (Appalachian Environmental Laboratory, University of Maryland, 1985).

Fisheries Techniques, by L. Nielsen and D. Johnson (American Fisheries Society, 1983).

A Guide to Field Identification of Bankfull Stage in the Western United States (video). (USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Stream Systems Tech. Center, Fort Collins, CO, 1995).

A Guide to Placing Large Wood in Streams (Oregon Department of Forestry and Oregon Department of Fish and Wildlife, May 1995). Available from the Oregon Department of Forestry, 2600 State St., Salem, OR 97310.

How to Do Spawning Fish Surveys (Salmon Trout Enhancement Program, Oregon Department of Fish and Wildlife).

Methods for Stream Habitat Surveys, Information Report 97-4, by K. Moore, K. Jones, and J. Dambacher (Oregon Department of Fish and Wildlife, Research and Development Section, Corvallis, 1997).

Monitoring Guidelines to Evaluate Effects of Forestry Activities on Streams in the Pacific Northwest and Alaska, EPA/910/9-91-001, by L. MacDonald and R. Wissmar (U.S. Environmental Protection Agency, 1991).

Monitoring Primer for Rangeland Watersheds, EPA 908-R-94-001, by T. Bedell and J. Buckhouse (U.S. Environmental Protection Agency, 1994).

Monitoring Protocols to Evaluate Water Quality Effects of Grazing Management on Western Rangeland Streams, by S. Bauer and T. Burton (Idaho Water Resources Research Institute, University of Idaho, Moscow, 1997).

Oregon Aquatic Habitat Restoration Guide: Under the Oregon Plan for Salmon and Watersheds (National Marine Fisheries Service and Oregon Department of Fish and Wildlife, 1998). Available from ODFW, PO Box 59, Portland, OR 97207.

Oregon Watershed Assessment Manual (Governor's Watershed Enhancement Board, Salem, 1998).

Photo Plots (Governor's Watershed Enhancement Board, Salem, 1993).

A Review of Capture Techniques for Adult Anadromous Salmonids, Information Report 96-5 (Oregon Department of Fish and Wildlife, undated).

"Streambank and shoreline protection," Chapter 16 in *Engineering Field Handbook* (Natural Resources Conservation Service, 1996).

Woodland Workbook (Oregon State University Extension Service, Corvallis, updated frequently).

MOVING FORWARD–THE NEXT STEPS

On your own, use the lines below to fill in steps, actions, thoughts, contacts, etc. you'll take to move yourself and your watershed group ahead in understanding stream evaluation and enhancement.

1.

2.

3.

Appendix A–Forms for a stream habitat survey.

A-1–Stream reach form

REACH

STREAM: ____________ BASIN: ____________

PAGE: ______ OF: ______

CREW: ____________

USGS 7.5' MAP NAMES: ____________

DATE	REACH #	UNIT NUMBER	CHANL FORM	VALLEY FORM	VWI	VEG CLASS DOM.	VEG CLASS SUB-DOM.	LAND USE DOM.	LAND USE SUB-DOM.	WATER TEMP	STRM FLOW	LOCATION TWN-RNG-SEC-1/4	PHOTO # /TIME	REACH NOTE
													/	

UNIT-1

PAGE:________ OF:________

STREAM:________________________ DATE:______________ ESTIMATOR:____________________

REACH #	UNIT #	UNIT TYPE	CHANL TYPE	% FLOW	UNIT LENGTH	UNIT WIDTH	SLOPE %	SHADE (0-90) LEFT	RIGHT	ACTIVE CHANNEL HT.*	WIDTH	FLOOD PRONE HT.	WIDTH	TERRACE HT.	WIDTH	VWI	NOTE

* MEASURE FROM THE STREAMBED TO THE TOP OF THE ACTIVE CHANNEL. TAKE THE MEASUREMENT AT POOL TAIL CREST ON POOL UNITS.

UNIT-2

PAGE:_______ OF:_______

STREAM:______________________________ DATE:____________________ NUMERATOR:____________________

UNIT #	UNIT TYPE	DEPTH*	DEPTH** PTC	VERIFIED LENGTH	VERIFIED WIDTH	S/O	PERCENT SUBSTRATE SND	GRVL	CBLE	BLDR	BDRCK	BLDR COUNT	% ACTIVE EROSION	% UNDER CUT	COMMENT CODES	NOTE
V																
V																
V																

* MAX DEPTH POOLS - MODAL DEPTH IN FAST WATER UNITS

** ONLY MEASURED @ POOLS (EXCEPT OFF-CHANNEL POOLS)

WOOD

PAGE:_______ OF:_______

STREAM:______________________________ DATE:______________ NAME:______________________

UNIT	UNIT	DEBRIS			DBH	LENGTH CLASS (m)												WOOD NOTE
NUMBER	TYPE	CONFIG	TYPE	LOCAT	CLASS	RW <3	3	6	9	12	15	18	21	24	28	32	36+	

RIPARIAN

PAGE:______ OF:______

STREAM:________________ DATE:________ NAME:________________

UNIT NUMBER	SIDE	ZONE	SURFACE	SLOPE	CANOPY CLOSURE	SHRUB % COVER	GRASS/FORB % COVER	TREE	COUNT (DBH in CENTIMETERS) 3-15	15-30	30-50	50-90	90+	RIPARIAN NOTE
	LEFT	1						CONIFER						
								HARDWOOD						
		2						CONIFER						
								HARDWOOD						
		3						CONIFER						
								HARDWOOD						
	RIGHT	1						CONIFER						
								HARDWOOD						
		2						CONIFER						
								HARDWOOD						
		3						CONIFER						
								HARDWOOD						
	LEFT	1						CONIFER						
								HARDWOOD						
		2						CONIFER						
								HARDWOOD						
		3						CONIFER						
								HARDWOOD						
	RIGHT	1						CONIFER						
								HARDWOOD						
		2						CONIFER						
								HARDWOOD						
		3						CONIFER						
								HARDWOOD						

PHOTO RECORD: ODFW AQUATIC INVENTORY

STREAM: ____________________ CREW: ____________________
BASIN: ____________________ ROLL #: ____________________
DISTRICT: ____________________ MAILER #: ____________________

PHOTO	UNIT	DATE	TIME	DESCRIPTION
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
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34				
35				
36				
37				

Appendix B–Habitat condition summary form (Source: *Oregon Watershed Assessment Manual)*

FORM F-2: Habitat Condition Summary: This form will be filled out for each sub-watershed where ODFW or other comparable habitat data exists measured values are recorded & compared to rating criteria.

Name: **Date:** **Page of**

Subwatershed:

Channel Habitat Type Code*	Miles of CHT in Sub watershed	Miles of CHT surveyed	Survey Date	Pool Area		Pool Frequency		Gravel Availability (% gravel in riffles)		Gravel Quality (% fines in riffles)		Overall Rating
				Measured	**Rating**	**Measured**	**Rating**	**Measured**	**Rating**	**Measured**	**Rating**	
FP1												
FP2												
FP3												
AF												
LC												
MM												
MC												
MV												
BC												
SV												
VH												
MH												
Other:												
Other:												

* see Channel Habitat Type section for a description of the codes.

These rating criteria are applied to evaluate Measured values:

Poor: Measured conditions less than 75% of the ODFW/NMFS benchmark
Fair: Measured conditions levels close to benchmark (>75% and <125%).
Good: Measured conditions exceed benchmark (>125%).

These criteria are used to develop an overall rating:

GOOD: all parameters are rated Good or Fair
INDET: one or two parameters are rated Poor
POOR: three or more parameters are rated Poor
ND: No data.

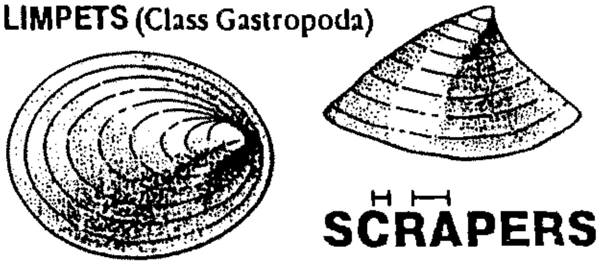
Appendix C–Key for identifying stream macroinvertebrates and sample data form. (Source: *Field Procedures for Analysis of Functional Feeding Groups of Stream Macroinvertebrates*)

KEY TO FUNCTIONAL FEEDING GROUPS

Indicates size or range of sizes

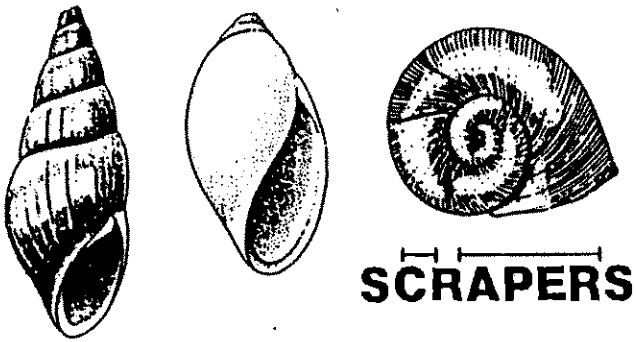
1. ANIMALS IN HARD SHELL (Phylum Mollusca)

a. LIMPETS (Class Gastropoda)



SCRAPERS

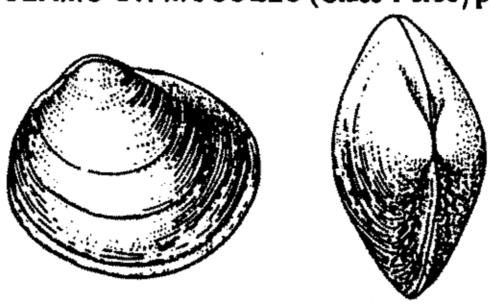
b. SNAILS (Class Gastropoda)



SCRAPERS

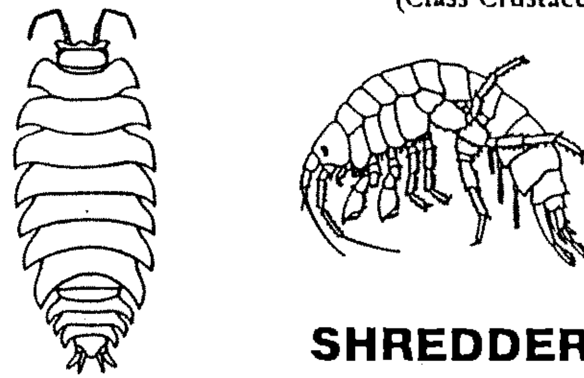
Snails are generalized (facultative) feeders and can also function as Shredders.

c. CLAMS OR MUSSELS (Class Pelecypoda)



FILTERING COLLECTORS

2. SOW BUG OR SHRIMP-LIKE ANIMALS (Class Crustacea)



SHREDDERS

Generalized, can also function as Gathering Collectors.

3. LARVAE IN PORTABLE CASE OR "HOUSE"

Go to page 6.

4. LARVAE IN FIXED RETREAT WITH CAPTURE NET

Note: Care must be taken when collecting to observe nets.

Go to page 8.

5. WITHOUT CASE OR FIXED RETREAT

a. WORM-LIKE LARVAE WITHOUT JOINTED LEGS

Go to page 10.

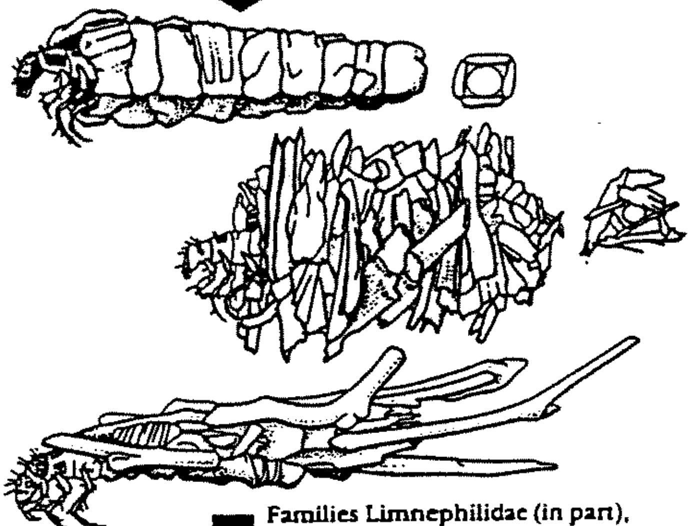
b. NYMPHS OR ADULTS WITH JOINTED LEGS

Appendix C–Key 2.

FIRST LEVEL OF RESOLUTION

LARVAE IN PORTABLE CASE
Caddisflies (Order Trichoptera)

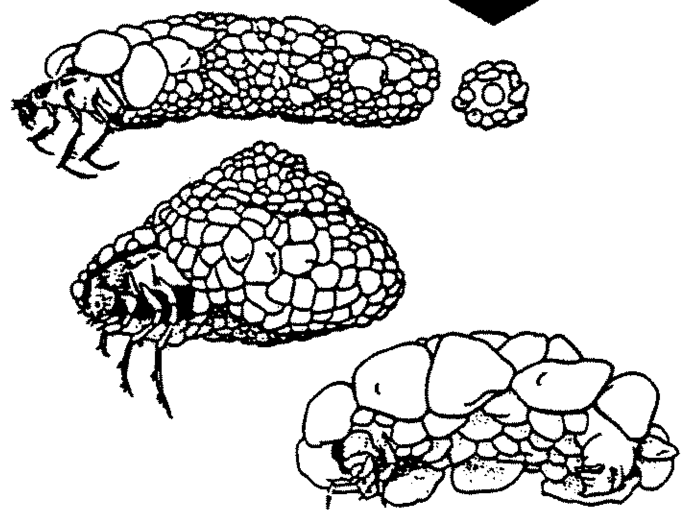
CASES ORGANIC
Leaf, stick, needle, bark



Families Limnephilidae (in part), Lepidostomatidae (in part), Phryganeidae, Leptoceridae (in part)

SHREDDERS

CASES MINERAL
Sand, fine gravel



Families Glossosomatidae, Limnephilidae (in part), Helicopsychidae

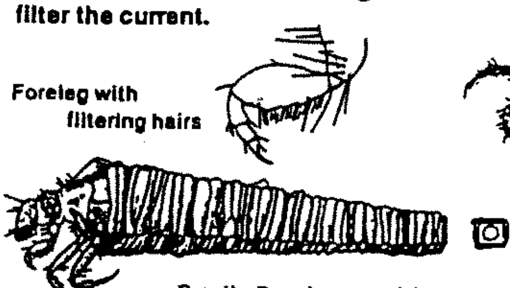
SCRAPERS

SECOND LEVEL OF RESOLUTION considers a few fairly common caddisflies that would be misclassified above on the basis of case composition alone.

CASES ORGANIC

Cases square in cross section and tapered, with no bark or flat leaf pieces included. Front attached to substrate. Larvae extend legs and filter the current.

Foreleg with filtering hairs



Family Brachycentridae

FILTERING COLLECTORS

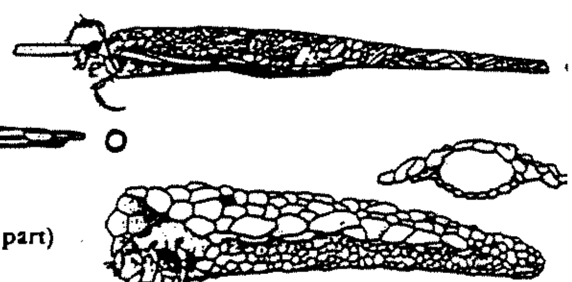
Cases long, slender, and tapered, made of plant material

Family Leptoceridae (in part)

GATHERING COLLECTORS

CASES MINERAL

Cases long, slender, and tapered (mostly fine sand) or cases ovoid and very flat in cross section



Family Leptoceridae (in part)

GATHERING COLLECTORS

FIRST LEVEL OF RESOLUTION

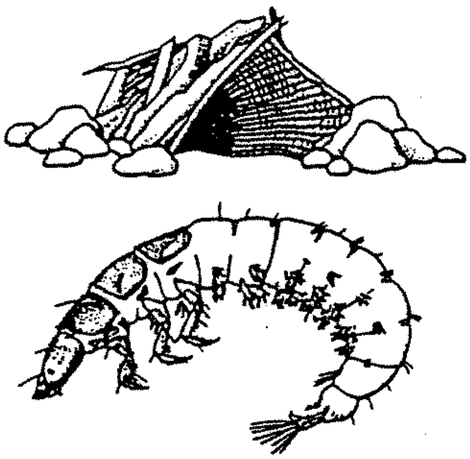
LARVAE WITH FIXED RETREAT AND CAPTURE NET

Note: Care must be taken when collecting to observe nets.

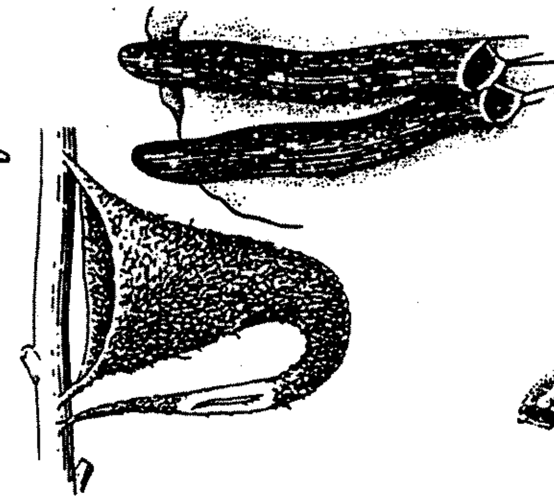
Caddisflies (Order Trichoptera)

True Flies (Order Diptera)

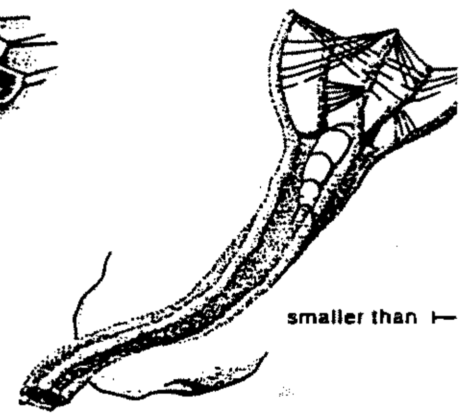
COARSE NET IN "SCAFFOLDING"



FLATTENED SOCK-LIKE OR TRUMPET-SHAPED NET OF FINE MESH



TUBE WITH SILK STRAND STRUNG BETWEEN TERMINAL PRONGS



True Midges (Family Chironomidae

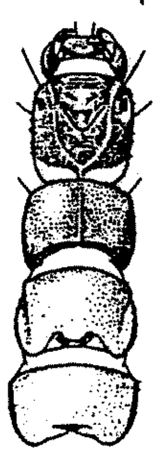
Families Hydropsychidae, Philopotamidae, Polycentropodidae

FILTERING COLLECTORS

SECOND LEVEL OF RESOLUTION separates from free living larvae those net spinning caddisflies that may have been inadvertently collected without being associated with their nets.

NET SPINNING CADDISFLIES

Frequently seperated from their nets



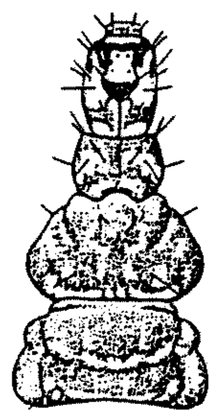
HEAD AS WIDE AS THORAX

Especially Philopotamidae (bright yellow) and Hydropsychidae (bright green or brown)

FILTERING COLLECTORS

FREE LIVING CADDISFLIES

Non net spinning



HEAD LONG, SMALL, AND NARROWER THAN THORAX

Rhyacophilidae (often bright green)

PREDATORS

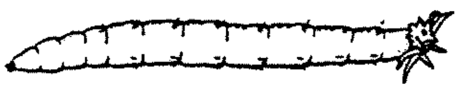
FIRST LEVEL OF RESOLUTION

WORM-LIKE LARVAE
WITHOUT JOINTED LEGS

LARGE

larger than

Head retractile and poorly developed
Caudal lobes with eye-like spiracles



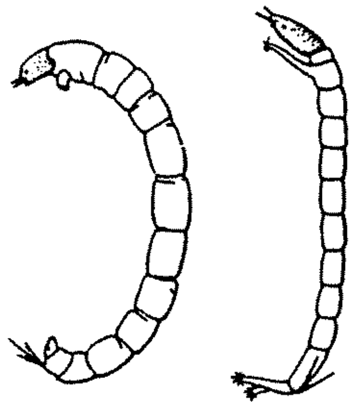
Craneflies (Family Tipulidae in part)

SHREDDERS

SMALL

smaller than

LONG AND SLENDER



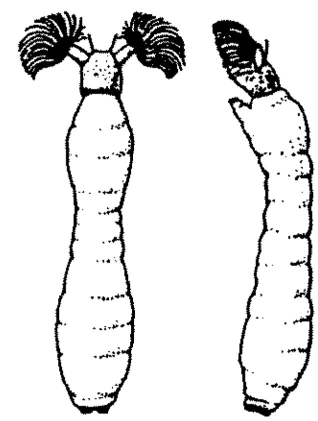
True Midges (Family Chironomidae)

Note: Subtract 10% of count for Predators.

GATHERING COLLECTORS

BOWLING PIN SHAPE

Bulbous base usually fastened tightly to substrate



Blackflies (Family Simuliidae)

FILTERING COLLECTORS

SECOND LEVEL OF RESOLUTION considers some common worm-like Predators that would be misclassified in the above key.

WORM-LIKE LARVAE
WITHOUT JOINTED LEGS

LARGE

Posterior segment swollen
Head retractile

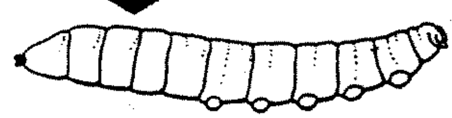
Family Tipulidae *(Eriocera* type)

SMALL

Prolegs along entire length
Head visible

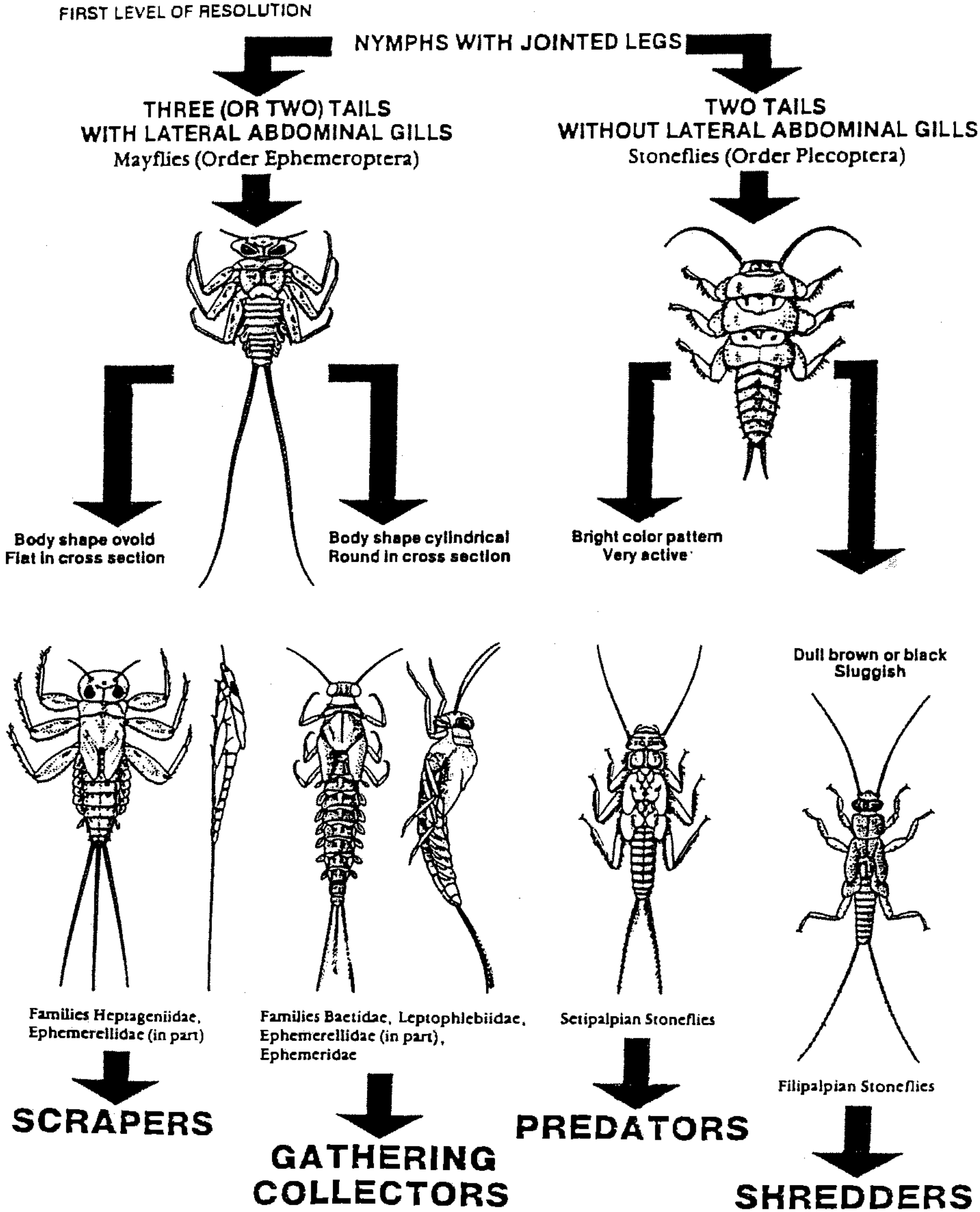
Family Athericidae *(Atherix)*

Prolegs poorly developed or absent
Jaws well developed
Very active



Family Tipulidae (*Dicranota* type)

PREDATORS

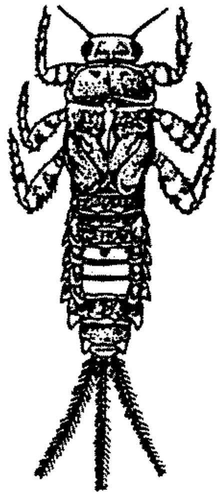

FIRST LEVEL OF RESOLUTION
NYMPHS WITH JOINTED LEGS
THREE (OR TWO) TAILS
WITH LATERAL ABDOMINAL GILLS
Mayflies (Order Ephemeroptera)
TWO TAILS
WITHOUT LATERAL ABDOMINAL GILLS
Stoneflies (Order Plecoptera)
Body shape ovoid
Flat in cross section
Body shape cylindrical
Round in cross section
Bright color pattern
Very active
Dull brown or black
Sluggish
Families Heptageniidae,
Ephemerellidae (in part)
Families Baetidae, Leptophlebiidae,
Ephemerellidae (in part),
Ephemeridae
Setipalpian Stoneflies
Filipalpian Stoneflies
SCRAPERS
GATHERING
COLLECTORS
PREDATORS
SHREDDERS

SECOND LEVEL OF RESOLUTION considers some fairly common insects that do not fit in the above key or would be misclassified on the basis of body shape alone.

LARVAE OR NYMPHS WITH JOINTED LEGS WITHOUT CASE OR FIXED RETREAT

WITH LONG TAILS
Mayflies (Order Ephemeroptera)

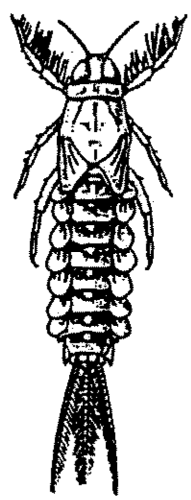
Body shape ovoid
Rear end often erected scorpion-like when disturbed



Families Ephemerellidae (in part), Caenidae, Tricorythidae

GATHERING COLLECTORS

Body shape cylindrical
Long hairs on inside of front legs
Often with stripe down back

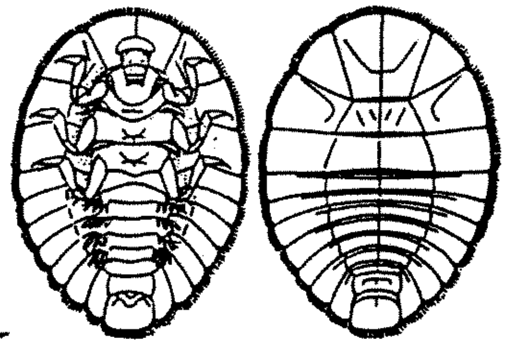


Family Siphlonuridae

FILTERING COLLECTORS

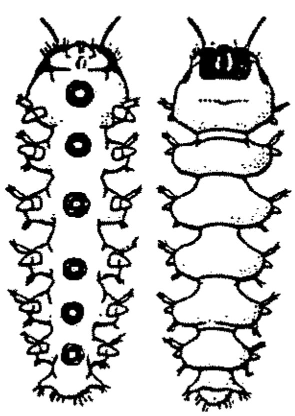
WITHOUT LONG TAILS
Beetles (Order Coleoptera)

Disc shape
Head and legs totally concealed beneath



Water Pennies (Family Psephenidae)

Lobed body
Ventral suckers

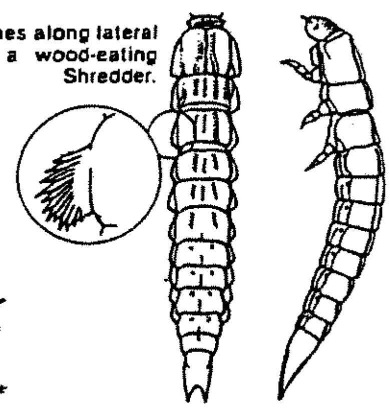


Family Blephariceridae

SCRAPERS

Slender
Triangular in cross section
Hard, yellowish brown covering

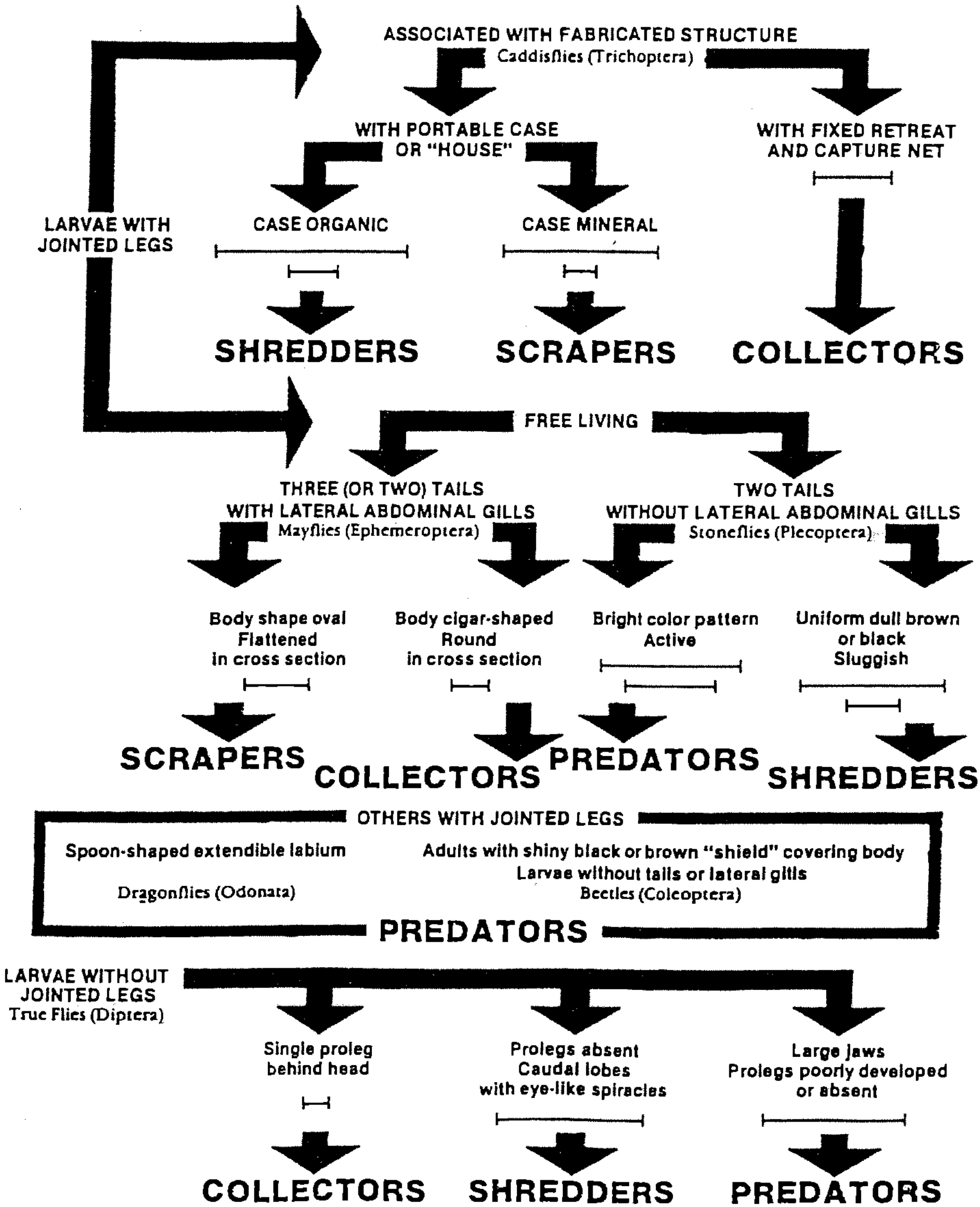
If larva has spines along lateral margins it is a wood-eating Shredder.



Riffle Beetles (Family Elmidae)

GATHERING COLLECTORS

SUMMARY OF FEEDING GROUPS



Data Sheet for Macroinvertebrate Functional Group Analysis Date ____________ Name ____________

Site ____________ Description ____________

Habitat-Organic Resource Categories

Functional Group	Leaf Pack Count F*	Rock (Periphyton) Count F*	Fine Sediments (Pools) Count F*	Wood Count F*	Vascular Plants Count F*	Σ
Shredders (SH)						
Collectors - Total (C)						
Filtering (FC)						
Gathering (GC)						
Scrapers (SC)						
Total w/o Predators (T)						
Predators (P)						
Total with Predators (PT)						

*F = Recruitment factor to indicate importance of new generations entering a given group

RATIOS (General ranges in parentheses) Riparian Habitat	Stream Orders 1-3 (Approx. 0.5-10 m wide)		Stream Orders 4-6 (Approx. 10-0 m wide)	Stream Orders > 6 (Approx. > 30 m wide)
	Shaded well developed, trees and/or shrubs	Open low shrubs and/or herbs and/or grasses	Open variable, trees and/or shrubs	Variable, flood plain or "green belt" forest
Functional Group Ratios	Calculated (Examples)	Calculated (Examples)	Calculated (Examples)	Calculated (Examples)
SH/C	(> 0.30)	(> 0.15)	(< 0.10)	(< 0.05)
SC/C	(< 0.25)	(> 0.25)	(> 0.25)	(< 0.10)
FC/GC	(< 0.50)	(~ 0.40)	(~ 0.50)	(~ 0.50)
SH/T	(> 0.25)	(> 0.10)	(< 0.05)	(< 0.01)
C/T	(> 0.50)	(> 0.40)	(> 0.50)	(> 0.75)
SC/T	(< 0.10)	(~ 0.25)	(> 0.40)	(< 0.10)
P/PT	(~ 0.10)	(~ 0.10)	(~ 0.10)	(~ 0.10)

Appendix D–*How to Do Spawning Fish Surveys* (Source: Salmon Trout Enhancement Program, Oregon Department of Fish and Wildlife)

STEP

SALMON TROUT ENHANCEMENT PROGRAM

Oregon Department of Fish and Wildlife

HOW TO DO SPAWNING FISH SURVEYS

INTRODUCTION

Spawning fish surveys are done regularly on many streams by Department of Fish and Wildlife field biologists. The information collected is vital to assessing the escapement of salmon and steelhead runs. It is an index to the status of those populations and helps predict future runs. They offer insight to whether a stream is being adequately seeded by spawners in a given year. Selected typical sections of streams are surveyed throughout the spawning season to cover the peak run. Adult salmon and steelhead are counted and fish per mile are calculated.

The department needs additional spawning escapement information on most streams. Volunteers doing spawning surveys will add valuable data that can guide Salmon and Trout Enhancement Program (STEP) efforts.

Some training, provided by ODFW personnel, is needed to prepare volunteers to do this survey. As with all STEP projects, certain procedures and guidelines must also be followed:

1. The volunteer must submit a project proposal for approval by ODFW staff. Your local STEP biologist will assist in making the application, and in selecting a stream to survey.
2. Contact landowners along the stream for permission to cross their property.
3. Training by ODFW personnel is required (about 2 hours). Classroom, hatchery and/or field trip to stress fish identification.
4. A "Volunteer Partial Liability Release Form" must be submitted and is available from STEP biologists.

GEAR AND EQUIPMENT

1. Map of stream section. Copy of USFS, BLM or USGS map in 2 inches/mile scale or larger.
2. Rain gear, hip boots or waders, warm clothes. Footgear should have non-slip material on soles, such as felt or outdoor carpet.
3. Walking stick, polarized glasses, knife, tape measure, thermometer.
4. Recording material; pencils, clipboard, stream survey form, scale envelopes (supplied by ODFW).
5. Knapsack, lunch, plastic bags for fish snouts, miscellaneous.

TIME COMMITMENT

Spawning surveys should be at least one-half mile long or longer. Under normal conditions, it takes about 1-2 hours to survey one mile of stream, plus be surveyed once every 7-10 days for duration of spawning period, which varies with species. Average 8-10 weeks. Total, about 8-10 half-days.

INSTRUCTIONS FOR SPAWNING SURVEY

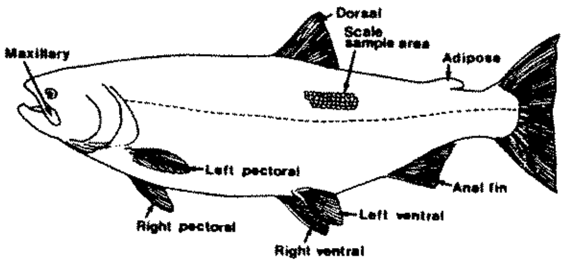
Your STEP biologist will help you select a stream section to survey. He will also help you prepare a map.

Once the section has been selected, mark the upper and lower ends so that you can return to the same spot each time you survey. Note on the map, and on the Section Description Form the STEP biologist will fill out, the beginning and end points and how it is marked.

SAMPLING FISH CARCASSES

While doing surveys, be on the lookout for carcasses of marked hatchery fish. One or more fins may be missing. If found, list under comments and include species, sex, length and fins missing. If the adipose fin (on back in front of tail) is missing, it may mean a coded-wire tag is imbedded in the fish's nose. Cut off the snout as close to the eyes as possible, note identification of stream, species, sex, date, and size in inches on slip of paper and put in plastic sandwich bag with snout and turn it in to the STEP biologist.

The biologist may ask you to collect some scales from carcasses you find. Take several scales from the side of the fish in the area below the dorsal fin and above the lateral line (see illustration). The STEP biologist will provide scale envelopes. The daily survey form slips should be turned in each week.



SUMMARY

It is highly advisable to work in pairs while doing these surveys, with extra eyes helping to observe for all spawners in the section. Since surveys are often done in rough terrain and in isolated areas, working in pairs also adds a measure of safety.

After the first time or two on the survey, you will learn where fish tend to spawn and the hiding places they use. Look under overhanging brush, under logs or cut banks and other likely places. You will soon get the hang of it and be spotting the fish with ease.

EXAMPLE: SPAWNING FISH SURVEY FORM

BASIN	Nestucca R.	WEATHER	0
SUBBASIN	Three Rivers	FLOW	M
SURVEY	Alder Cr.	VIS.	1
DATE	Nov. 15, 1984	TEMP.	43°

	LIVE		DEAD			
	A	J	M	F	J	U
CHF						
CO						

Redds	

Basin: Main river name, e.g. Nestucca River

Sub-basin: Fork creek branch, e.g. Three Rivers

Survey: Creek name, e.g. Alder Creek

Date: Date of survey

Weather: C=clear, O=overcast, F=foggy, R=rain, S=snow

Flow: Record the streamflow as L=low, M=moderate, H=high, F=flooding

Visibility: The ability to see in the water:
1=can see well on riffles and in pools
2=can see on riffles
3=cannot see on riffles or in pools

Temperature: Record water temperature in nearest whole degree Fahrenheit

Fish Observed: Mark abbreviations in column on side: CHF=fall chinook

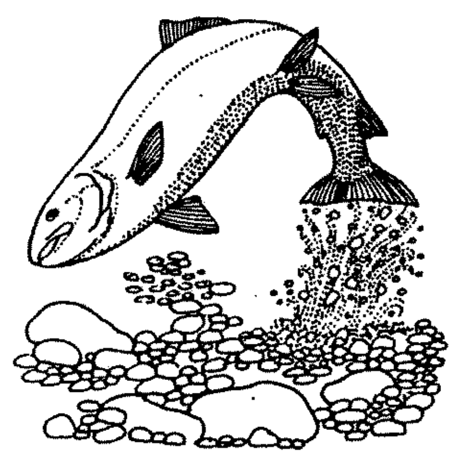
Species: CHS=spring chinook, Co=coho, CS=chum salmon, STW=winter steelhead, STS=summer steelhead

Live: Make tally marks for fish seen A=adults (over 20 inches), J=jacks (under 20 inches). At end of survey add total at bottom and circle, e.g. twenty

Dead: Record all carcasses seen with tally marks, or lengths if desired. M=male, F=female, J=jacks, U=unidentifiable. Total at bottom and circle, e.g. seventeen

Redds: Tally the number of redds observed (optional). Total and circle, e.g. eleven

Comments: Note any conditions or occurrences that are appropriate



9

Wetland Functions, Management, Evaluation, and Enhancement

Jim Good
and Mike Cloughesy

Well-functioning wetlands are vital components of healthy watersheds. They absorb flood waters, remove excess sediment and nutrients, and help maintain base flow. Where these and other functions are degraded, wetland enhancement can contribute mightily to recovery of salmon and other valued aquatic life.

Wetlands are found in many locations where the soil is saturated and other conditions are right to support their development (Figure 1). Typical locations include:

- Along rivers and streams
- In depressions on floodplains and at higher elevations
- On hill slopes where water seeps out of the ground
- Along the shores of lakes and estuaries
- On flats such as vernal pools in southern Oregon or peat bogs near the coast

Wetlands perform many valuable functions that contribute to watershed health. For example, they help to purify runoff water, reduce flood damage by temporarily storing water, supplement base flows through release of this stored water, and provide life support through habitat for aquatic species, fish, wildlife, and pollinators.

In this chapter you'll learn:

- How wetlands are defined and identified
- The principal functions and services that wetlands perform
- Actions that can improve specific wetland functions
- How different kinds of wetlands are classified
- How to obtain and use National Wetlands Inventory maps, local wetland inventories, soil surveys, and other wetland information
- The basics of several methods for classifying and assessing wetland functions

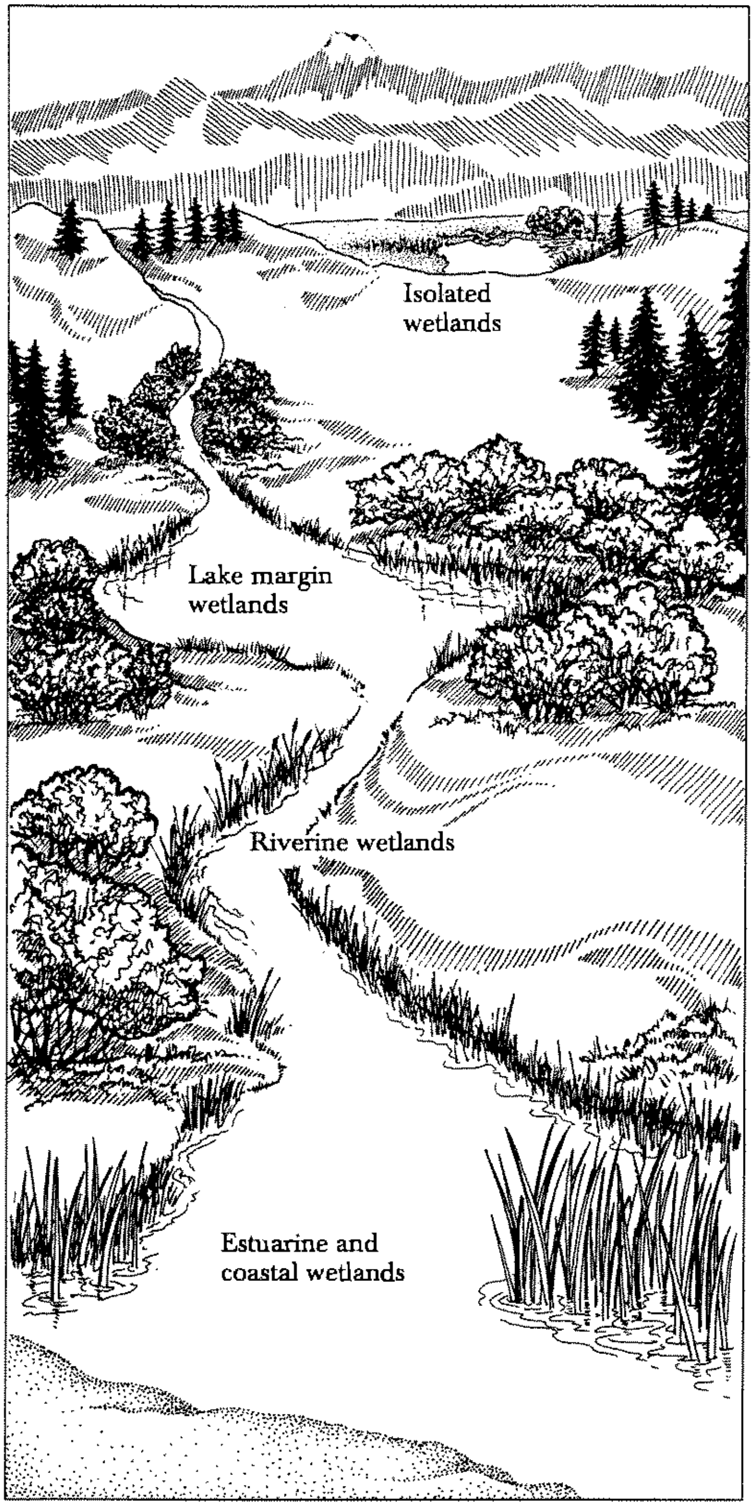


***Figure 1.**—Types of wetlands.*

If you look around, you may see many wetlands in your area that have suffered from neglect or changes in the landscape—roads that interrupt drainage patterns, dirt fill over wetlands to provide building sites, and stream diversions that cut off the water supply to wetlands. These changes greatly diminish the watershed support functions of these wetlands. With increased care and attention, however, some degraded wetlands can be rehabilitated, thereby increasing their capacity to support fish, wildlife, and human needs.

Approximately 40 percent of Oregon's original wetlands have been altered or converted to other uses since European-Americans arrived. Many of the remaining wetlands have been degraded and no longer function as they should. Some of these former and degraded wetlands could be restored or enhanced to help restore salmon runs, improve water quality, and contribute to flood control. Identifying wetland restoration and enhancement potential thus is an important part of watershed action planning.

WHAT IS A WETLAND?

Marshes, bogs, swamps, fens, sloughs, and wet meadows are some of the more common names for particular kinds of wetlands. These terms conjure up an image of ecosystems that aren't quite aquatic and aren't quite terrestrial. In other words, they are "transitional."

Many wetlands fit this image of being part of a continuum between upland and open water ecosystems. Other wetlands, however, are isolated from open-water habitats and are maintained purely by groundwater and precipitation.

So is there an accepted scientific definition of wetland that covers all types? The answer is yes. To understand these definitions, you need to know three key terms–hydric soil, wetland hydrology, and hydrophyte.

Hydric soil is soil that is saturated, flooded, or ponded long enough during the growing season to develop anaerobic conditions in the upper layer. *Anaerobic* means there is no oxygen in the soil. This condition occurs when water fills all of the pore spaces in the soil, leaving no room for oxygen. Indicators of anaerobic conditions that can be observed in the field include low chromas according to the Munsell Color Chart (<2), distinct mottles, and Soft Iron Masses (SIMs).

Wetland hydrology recognizes that the conditions that support wetlands and form hydric soils range from permanently inundated to seasonally saturated. At minimum, saturation is required within 12 inches of the surface during approximately 2 weeks of the growing season to meet the hydrology criteria as a jurisdictional wetland as defined by the U.S. Army Corps of Engineers.

A *hydrophyte* is any plant growing in water or in soil that is at least periodically deficient in oxygen as a result of excess water. Hydrophytic also can mean plants typically found in wetland habitats. The U.S. Fish and Wildlife Service (USFWS) has developed a list of plants found in and near wetlands.

A well-accepted *comprehensive definition* of wetlands was developed in 1995 by the National Research Council:

A wetland is an ecosystem characterized by sustained or recurrent shallow inundation or saturation at or near the surface of the substrate and the presence of physical, chemical, and biological features reflective of such inundation or saturation. Common diagnostic features of wetlands are hydric soils and hydrophytic vegetation. These features will be present except where specific physiochemical, biotic, or human factors have removed them or prevented their development.

In other words, a wetland typically has hydric soils and hydrophytic plants, unless it has been disturbed by humans.

Another definition that is very important if you plan to do wetland restoration projects is the *regulatory definition*. This definition is used by the U.S. Army Corps of Engineers (the Corps) and the Oregon Division of State Lands (DSL) in their regulatory programs:

Wetlands are those areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted to life in saturated soil conditions.

Three features of wetlands are common to these and most definitions:

- The presence of enough water to cause saturation of the upper 12 inches of soil for at least 2 weeks during the growing season
- Soils that are typical of saturated or ponded areas
- Plants that can tolerate such conditions

See Section II, Chapters 1, 2, 3, 5, and 7; and Section III, Chapters 2–5 and 7 for information related to this chapter.

Detailed criteria for identifying upland-wetland boundaries for regulatory purposes are described in the Corps' 1987 *Wetland Delineation Manual.* These criteria also are used by most other state and federal agencies. Most of the time, however, a formal delineation of wetland boundaries isn't required for nonregulatory wetland restoration or enhancement projects.

AN OVERVIEW OF WETLAND FUNCTIONS

Wetlands often are ecological "hot spots," playing a role disproportionate to their size in supporting endangered species and maintaining biodiversity. Wetlands play other roles too; they usually help remove excess nutrients and other contaminants from water, store flood waters, release water during low flow periods, and provide food and shelter for salmon, trout, other animals, and pollinators.

All of these roles are known as *wetland functions.* You might think of them as the services that wetlands provide to watersheds. Although there are many ways to group and describe wetland functions, we will divide them into four categories:

- *Biogeochemical* (water-quality) functions
- *Hydrologic* (water movement) functions
- *Habitat and food web* functions
- *Cultural and social* functions

There are at least 16 functions within these 4 categories. They are discussed in this chapter. We'll describe why each function is important to watershed health, how wetlands contribute to the function, and ideas for wetland restoration or enhancement.

Note that these functions may not be unique to wetlands. Streams, lakes, riparian areas, and upland habitats also contribute to many of these functions. Although we separate watersheds into parts for analysis, the parts themselves and the functions they perform are interconnected. Thus, our analyses also must be interconnected.

Many wetland functions have an especially significant impact on water quality and fish habitat in streams. Thus, Chapter II-7, "Stream Ecology," is closely related to the topics covered in this chapter. The hydrologic processes discussed in Chapter II-2, "Watershed Science," also are affected by wetland functions. Chapter II-5, "Riparian Functions," also discusses many related topics.

IMPROVING WETLAND FUNCTIONS

There are three basic kinds of wetland improvement projects—creation, enhancement, and restoration. *Wetland creation* involves the construction of a wetland at a site where no wetland has existed in the past 100–200 years (Figure 2). It may take a lot of landscape manipulation and/or maintenance to develop and maintain such a wetland.

Wetland enhancement involves the alteration, maintenance, or management of existing wetlands for long-term improvement of particular functions or services. In many cases, by choosing to enhance certain functions, you may diminish a wetland's ability to perform other functions or services.

Wetland restoration is the return of a former or degraded wetland to a close approximation of a previous higher functioning state. *Former wetlands* are areas that once were wetlands, but now are nonwetland. *Degraded wetlands* are those that have been damaged but still perform some wetland functions (Figure 3).

In restoration, both the structure and the functions of the ecosystem are recreated, and ecological damage is repaired. The goal is to recreate a natural, functioning system that is integrated into the surrounding ecological landscape (Figure 4).

Wetland enhancement generally aims to improve a specific wetland function. Based on your assessment of wetlands in your watershed and the functions you want to improve, the following discussion suggests some actions you might take to identify potential wetland enhancement projects.

Figure 2.—Wetland creation projects, even in urban settings such as this one adjacent to a Portland-area shopping center, help reestablish some of the functions of stream and wetland corridors important to fish and wildlife. (photo: Jim Good)

WETLAND FUNCTIONS AND POSSIBLE ENHANCEMENT OPPORTUNITIES

Water-quality functions

Function 1—Water temperature maintenance

Why important: High water temperatures can limit a stream's habitat value for fish and wildlife. High temperature can decrease fish survival, encourage growth of disease-causing organisms and undesirable algae, and reduce dissolved oxygen concentration.

Weather, volume of stream flow, streamside vegetation, flows to and from groundwater, and water released from industrial plants can influence stream temperature. Solar heating is the major cause of increased water temperature.

How wetlands contribute: Wetlands can help maintain desirable stream temperatures. In summer, wetlands discharge cool groundwater into streams. In winter, wetlands receiving substantial groundwater discharge may maintain ice-free conditions, which are required by wintering waterfowl. Riparian vegetation also can play an important role in shading streams from solar heating. See Chapter II-7, "Stream Ecology," and Chapter II-5, "Riparian Functions," for more information.

To improve this function, watershed groups might:

- Target restoration efforts to watersheds with known water temperature problems.
- Identify native riparian corridors that shade streams and wetlands from solar heating.
- Identify existing and potential wetlands that receive groundwater discharge and release it to a stream either through surface or subsurface flows.
- Identify existing and potential wetlands that might recharge the aquifers that discharge groundwater to a stream.
- Identify headwater wetlands that maintain base flows during summer low flows.

***Figure 3.**—These farmed fields are an example of a degraded but still functioning wetland with good restoration potential. (Photo: Jim Good)*

Function 2–Reducing bacterial concentration

***Figure 4.**–Periodic monitoring of restoration projects is necessary to judge progress toward goals and to implement needed corrective measures. (Photo: Jim Good)*

Why important: Many *pathogenic* (disease-causing) intestinal bacteria pose a substantial health risk to humans. Fecal coliform bacteria *(Escherichia coli)* are used as a general indicator of the presence of this group of bacteria. When these indicator organisms are present, it represents a strong possibility of the presence of pathogenic bacteria that threaten public health. Reduction of these bacteria in aquatic systems makes it safe for humans to use water and eat shellfish from the water.

Intestinal bacteria come from human and animal waste. For example, bacteria may enter streams from septic tank failure, poor pasture and livestock management, city sewage, pet wastes, urban runoff, and sewage from stormwater overflows.

How wetlands contribute: Wetlands can retain and destroy intestinal bacteria. Wetland size, location, water source, and volume of inflow are key factors in determining how well a wetland performs this function. For example, wetlands constructed for wastewater treatment can assist with this function. A healthy riparian area also can play an important role by filtering runoff. See Chapter II-7, "Stream Ecology," and Chapter II-5, "Riparian Functions," for more information.

To improve this function, watershed groups might:

- Target restoration efforts to watersheds with known or anticipated fecal coliform problems.
- Identify wetlands with the greatest potential to retain and process fecal coliform bacteria.
- Identify riparian areas that buffer streams from fecal coliform inputs.

Function 3–Sediment capture

Why important: Excess suspended sediments can cause many problems in streams. For example, they:

- Reduce stream channel capacity
- Transport bacteria and pollutants
- Fill gravel spaces, thus smothering eggs and juvenile fish
- Reduce algal growth

- Reduce fish feeding and growth
- Reduce dissolved oxygen concentrations
- Bury benthic (bottom-dwelling) organisms

Many human activities can increase suspended sediments, including timber harvest and related road development, construction-related earth moving, poor pasture management, and building of dikes. Loss of in-stream large woody debris, which often is caused by human activity, also reduces a stream's ability to store sediment.

How wetlands contribute: Wetlands can reduce the amount of suspended sediments in streams. Some wetlands capture and keep sediments from reaching a stream, while others capture sediments that already have entered a stream system. The flow of sediment-bearing runoff slows down when it enters a wetland, allowing suspended sediment to drop out of the water before entering a stream. See Chapter II-7, "Stream Ecology," and Chapter II-2, "Watershed Science," for more information.

To improve this function, watershed groups might:

- Target restoration efforts to watersheds with known sediment retention problems.
- Identify wetlands that capture sediments before they enter streams.
- Identify wetlands that remove suspended sediments from stream systems.
- Create wetlands to remove suspended sediments from surface sheet or stream flows.

Wetland creation for sediment removal is a challenge in areas where land-use practices create large pulses of sediments.

Function 4–Nutrient removal and transformation

Why important: Nitrogen and phosphorus are essential nutrients for all aquatic systems. Each ecosystem has its own level of nutrient inputs and outputs. When inputs and outputs change, problems can occur. For example, excess phosphorus can cause lake eutrophication or algal blooms. Too much nitrogen in the form of nitrate also can cause problems, including fish habitat degradation, excess plant and algae growth, and reduced dissolved oxygen concentrations.

Human activities can substantially increase nutrient inputs to stream systems, thus changing the ecosystem. In-stream increases in nitrogen and phosphorus can come from agricultural and residential fertilizers, detergents, cleaning products, sewage, septic tank effluent, food residues, soil erosion, and decomposing vegetation.

How wetlands contribute: Wetlands can retain nutrients and change them into less harmful forms. For example, they can convert inorganic nutrients to their organic forms, which don't move as easily in water so are less likely to end up in streams. They also can change nitrate nitrogen into gaseous nitrogen through a process known as *denitrification*. Nitrogen gas then can escape harmlessly into the air. By keeping excess nutrients out of streams, wetlands help maintain fish habitat, dissolved oxygen levels, and nitrogen balance, while reducing algae blooms. See Chapter II-7, "Stream Ecology," for more information.

To improve this function, watershed groups might:

- Target restoration efforts to watersheds with known nutrient problems.
- Identify existing and potential wetlands capable of keeping nutrients from reaching streams.
- Identify existing and potential wetlands capable of removing nutrients from stream systems.
- Identify existing and potential native riparian buffers that could keep nutrients from entering wetlands or streams.

Function 5—Improving groundwater quality

Why important: In many areas, domestic water supplies are taken from groundwater *aquifers*. Aquifers are resupplied with groundwater as water percolates downward in *groundwater recharge areas*. The greatest potential for groundwater recharge occurs within *alluvial outwash deposits* (areas where flooding has deposited sediment).

Human activities within groundwater recharge areas can diminish groundwater quality and quantity. Drinking water contaminated with nitrate at levels above 10 mg/l can cause infant sickness or, in extreme cases, death. Threats to groundwater quality come from commercial and industrial development, concentrated dairy farming, and the use of agricultural chemicals within recharge areas.

How wetlands contribute: Wetlands in groundwater recharge areas can capture and retain nitrate-nitrogen from overland flows before it percolates downward into groundwater aquifers. Wetlands can store and release nitrate seasonally or retain it for a long time. How effective a wetland is in playing this role depends on how long the water and nitrate are retained, the level of dissolved oxygen, and how much of the nitrogen is converted to gas.

To improve this function, watershed groups might:

- Identify wetlands that recharge groundwater aquifers of importance to humans.

- Identify groundwater recharge wetlands whose ability to efficiently capture, retain, or remove nutrients has been reduced.

Hydrologic or water-flow functions

Function 6–High flow storage and reducing peak flows

Why important: Flooding can result in property damage, soil erosion, increased bedload movement, loss of fish redds (nests) and stream habitat, increased sediment, invasion by non-native plants, and stream channel erosion. See Chapter II-7, "Stream Ecology," and Chapter II-2, "Watershed Science," for more information.

Runoff volume is related to human development. For example, hard surfaces such as pavement don't let water enter the soil. Soils that have been compacted by heavy equipment don't let water percolate very well. In these soils, plants also have a hard time taking up water and transferring it to the air through transpiration. Furthermore, water flowing just beneath the soil surface becomes surface runoff when road cuts send it into road ditches.

Thus, development, soil disturbance, timberland conversion, timber harvest, and slope alterations within the watershed all can increase the intensity of high flow or flood events.

How wetlands contribute: Wetlands can store waters that otherwise would intensify downstream high flows. In concert with other floodplain management activities, wetland restoration may reduce property damage, crop loss, and soil erosion by minimizing the effects of current and future development.

To improve this function, watershed groups might:

- Target wetland restoration efforts to watersheds with known flooding problems.
- Identify wetlands that capture surface flows before they reach the river system.
- Identify wetlands that capture and reduce peak surface flows within the floodplain.
- Identify wetlands that capture and reduce runoff from residential, agricultural, and disturbed lands.

Function 7–Base flow maintenance

Why important: Base flow is groundwater discharge and detained storm water that contributes to streamflow during periods of little or no direct precipitation. To function properly, a stream needs a minimum base flow. When flows drop below this rate, the stream is more susceptible to temperature increases and pollution from industrial, municipal, and agricultural wastes. Low flows also can obstruct fish passage to available habitat or can change habitat conditions.

Human activities have substantially altered both the timing and extent of surface and groundwater inputs to many streams by decreasing groundwater recharge and increasing overland flows. The result in many cases is reduced base flows.

Examples of factors that reduce base flows include:

- Draining of bottomland and depressions with seasonally high water tables
- Shallow excavations (e.g., road cuts) on well-drained soils, which intercept subsurface flows and convert them to overland flows
- Groundwater withdrawals for irrigation or domestic use
- Increased runoff resulting from forest conversion to agricultural or residential use
- The increase of hard surface areas

How wetlands contribute: Wetlands can help regulate the release of groundwater into streams and can recharge the aquifers that discharge groundwater to streams.

To improve this function, watershed groups might:

- Target wetland restoration efforts to watersheds with known or anticipated base flow problems.
- Identify wetlands that receive groundwater discharge and release it to a stream through either surface or subsurface flows.
- Identify wetlands that recharge the aquifers that discharge groundwater to a stream.
- Identify headwater wetlands that maintain base flows during summer low flows.

Function 8—Groundwater recharge

Why important: Groundwater is an important water source for domestic use.

The opportunity for surface water to recharge an underlying aquifer system depends largely on several physical conditions that don't change very much, including soil permeability, type of rock the surface soil was derived from, depth to water table, and topography. However, human activities often change these physical conditions so that less surface water recharges aquifers. Examples of factors that increase surface water runoff and reduce recharge potential include:

- Wetland drainage
- Forest clearing
- Soil compaction from agricultural activities, residential development, and other landscape-altering activities

- Road cuts that intercept groundwater and bring it to the surface
- Hard-surface barriers such as roads, parking lots, and roofs
- Incorrect riparian conversions that damage fragile streamside wetland areas

How wetlands contribute: Within groundwater recharge areas, wetlands capture and hold water that otherwise might become surface runoff, thus allowing it to move downward into groundwater aquifers.

To improve this function, watershed groups might:

- Identify potential wetland sites that could recharge groundwater.

Function 9–Shoreline stabilization

Why important: Erosion caused by waves, currents, tides, or ice can cause substantial shoreline property damage, loss of fish and wildlife habitat, and increased turbidity (cloudiness of water).

How wetlands contribute: Wetlands serve as a buffer between open water and upland areas. *Shoreline stabilization* is the binding of soil at the shoreline or water's edge by wetland plants, thus making the soil less susceptible to erosion. Wetland plants, therefore, protect beaches, stream edges, property, and ecosystems from erosion.

To improve this function, watershed groups might:

- Identify wetland restoration sites that stabilize shorelines of importance to public or private property or fish and wildlife habitat.

Habitat and food web support functions

Function 10–Anadromous and resident fish diversity and abundance

Why important: Development and land-use change have had a significant negative impact on fish habitat. While each river system is unique in the type and amount of habitat it has lost, fish habitat degradation has occurred throughout the Pacific Northwest.

Timber harvest, agricultural activities, residential development, and other activities have altered wetlands, riparian areas, and floodplains. As a result, there is less food, spawning gravel, and refuge for anadromous (migratory) and resident fish. Some of the biggest problems in Oregon include:

- Loss of channel structure
- Sedimentation in the upper watershed
- Loss of riparian trees, plants, and large organic debris

- High stream temperatures and low water quality
- Blocked access to wetland habitats
- Excessive sediment in the estuary
- Increased flooding frequency and intensity
- Loss of estuarine wetlands
- Tide gate and culvert passage problems
- Low summer flows
- Loss of winter cover
- Excessive bedload
- Degradation of near-shore habitat
- Scouring of spawning habitat
- Incorrect riparian conversion schemes that damage in-stream habitat

Damage to wetlands has contributed to these problems. The loss of wetland and riparian habitat, along with other factors, has increased flows and frequency, sediment inputs, water temperature, and barriers to fish passage. The same factors have reduced stream base flows and stream habitat diversity.

How wetlands contribute: Wetlands help maintain cool water temperatures, retain sediments, store high flows, augment stream base flows, and provide food and cover for fish.

Along with these broad watershed-level contributions to fish habitat, some wetlands may play other specific roles. For example, coho smolts survive winters of extremely high flows by using small tributary wetlands as winter habitat. In these cases, the best way to improve coho smolt production may be to restore side-channel and slough wetlands. See Chapter II-7, "Stream Ecology," for more information.

To improve this function, watershed groups might:

- Identify sites recognized by professional fish habitat biologists as having the greatest potential to provide the fish habitat that is needed most within your watershed.
- Identify additional wetland restoration sites that have some potential to provide the fish habitat that is needed most within your watershed.
- Restore degraded estuarine wetlands.
- Restore riparian habitat along stream reaches that support resident and/or anadromous fish (Figure 5).

Function 11–Migratory water bird diversity and abundance

Why important: Many migratory water birds have recreational and economic importance to humans. Extensive agricultural, industrial, and residential development within estuaries and river floodplains has destroyed or disturbed water bird wintering and migration habitat. As a result, birds are forced to seek alternative habitats. As birds are crowded into smaller areas, they must compete for limited food and space, and they're more exposed to predators, adverse weather, and disease.

In some cases, however, human activities create new habitats. Many waterfowl species, in particular, have adapted to new habitat opportunities. For example, farming practices in Oregon's Willamette Valley now provide abundant, readily available winter food that didn't exist before the area was cleared for agriculture. Some waterfowl that traditionally wintered in the central valley of California now winter in this area. On the other hand, many migratory shorebirds and wading birds haven't been able to adapt when confronted with a loss or change in their habitat.

How wetlands contribute: Wetlands provide important migration and wintering habitat for migratory water birds (Figure 6). Restoring degraded wetlands where there is a shortage of habitat can help stabilize and, in some cases, increase populations. The conversion of forested wetlands to emergent/open water wetlands also can create new wintering, migration, and production habitat for some migratory water bird species, although it may degrade habitat for others. See Chapter III-4, "Wildlife Management," and Chapter III-5, "Wildlife Evaluation and Enhancement," for more information.

***Figure 5.**–Dike and tide gate removal in a 1978 Salmon River estuary restoration project opens up tidal channels that provide important rearing habitat. (Photo: Diane Mitchell)*

To improve this function, watershed groups might:

- Identify degraded wetlands that currently provide important habitat for water birds.
- Identify wetlands that are known to support migratory water birds.
- Identify wetlands that currently provide limited habitat for water birds but have the greatest potential to provide important habitat if restored.

Function 12–Aquatic diversity and abundance

Why important: Both direct and indirect impacts such as changing patterns of water movement, land-use change, and habitat fragmentation adversely affect native plant and animal communities. As wetlands are disturbed, the *number* of species may increase or decrease, but *complexity* usually decreases as non-native species tend to invade and dominate.

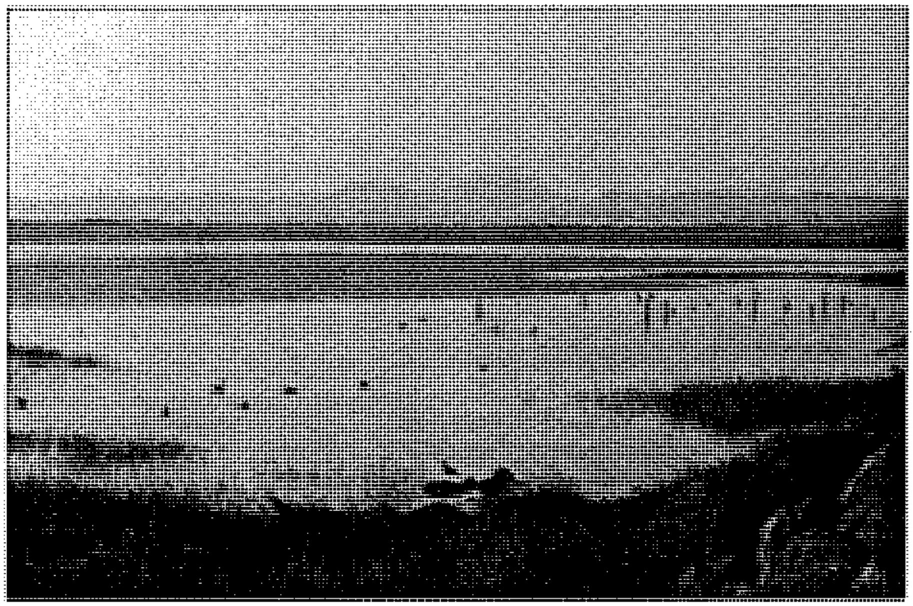


Figure 6.*–Fringing marshes and shallow waters of the Columbia River estuary attract a wide variety of wildlife. (Photo: Jim Good)*

How wetlands contribute: Healthy wetlands support a wide variety of native plant and animal communities. Thus, by reestablishing near-natural conditions, wetland restoration can restore native species richness and abundance. This process takes time though. Once the natural water cycle is reestablished, it can take years to recreate the conditions most suited for native plants and animals. See Chapter II-7, "Stream Ecology," for more information.

To improve this function, watershed groups might:

- Identify wetlands with ditches, tile, canals, levees, or similar artificial features that change the retention time of water.
- Identify wetlands that have been altered by tilling, filling, excavation, addition of inlets, or blockage of outlets.
- Identify wetlands that support or once supported rare or unique plant communities.

Function 13–Rare, threatened, and endangered species diversity and abundance

Why important: Natural systems are made up of many related parts that are in a constantly changing state of balance (*equilibrium*). The loss of species diversity and abundance alters this equilibrium and the food chain it supports, thereby affecting many other species.

As species are lost, humans lose opportunities to find solutions to medical, agricultural, and industrial problems. Species loss is important in another way; it's a good indicator of how well or poorly we take care of our environment.

The exact causes of species declines are complex and not fully understood. We do know that species declines and extinction result from both human impacts and climate change. Some of the problems caused by humans are habitat destruction, poisoning from pesticides, competition from non-native species, and indiscriminate killing and overharvest. See Chapter III-4, "Wildlife Management," and Chapter III-5, "Wildlife Evaluation and Enhancement," for more information.

How wetlands contribute: Wetlands provide habitat for many rare, threatened, or endangered plants and animals. The restoration of wetlands close to populations of these species can provide opportunities for them to relocate or expand their range.

To improve this function, watershed groups might:

- Identify wetland restoration sites having the greatest opportunity to provide habitat for rare, threatened, and endangered species.

Function 14—Food web support

Why important: Within a watershed or basin, there is a food web consisting of producers, consumers, and decomposers. Organic matter that reaches a stream system is eaten by fish and aquatic invertebrates, which in turn are eaten by predators.

How wetlands contribute: Wetlands are highly productive biological systems. *Food web support* is the production of organic material and its movement out of a wetland to areas downstream where it provides food for many fish and wildlife species. Thus, loss of wetland areas can adversely affect fish and wildlife that depend on these food sources. See Chapter II-7, "Stream Ecology," for more information.

To improve this function, watershed groups might:

- Identify wetland restoration sites with the greatest potential to support food webs by supplying organic material to streams.

Cultural and social functions

Function 15—Recreation

Why important: As our population grows and prospers, interest in outdoor activities increases. At the same time, nature-centered recreational opportunities continue to be pushed farther from city centers as development spreads into previously "undeveloped" land. As a result, outdoor recreation opportunities become less accessible. Increasing development and population also cause more pollution in areas used for recreation.

How wetlands contribute: Fishing, hunting, shellfish gathering, swimming, kayaking, boating, sightseeing, birdwatching, and nature photography are just some of the recreational opportunities that wetlands provide. The restoration of wetlands and provision for public access provide new opportunities for recreation (Figure 7).

To improve this function, watershed groups might:

- Identify wetland restoration sites having the greatest potential to provide recreation opportunities.

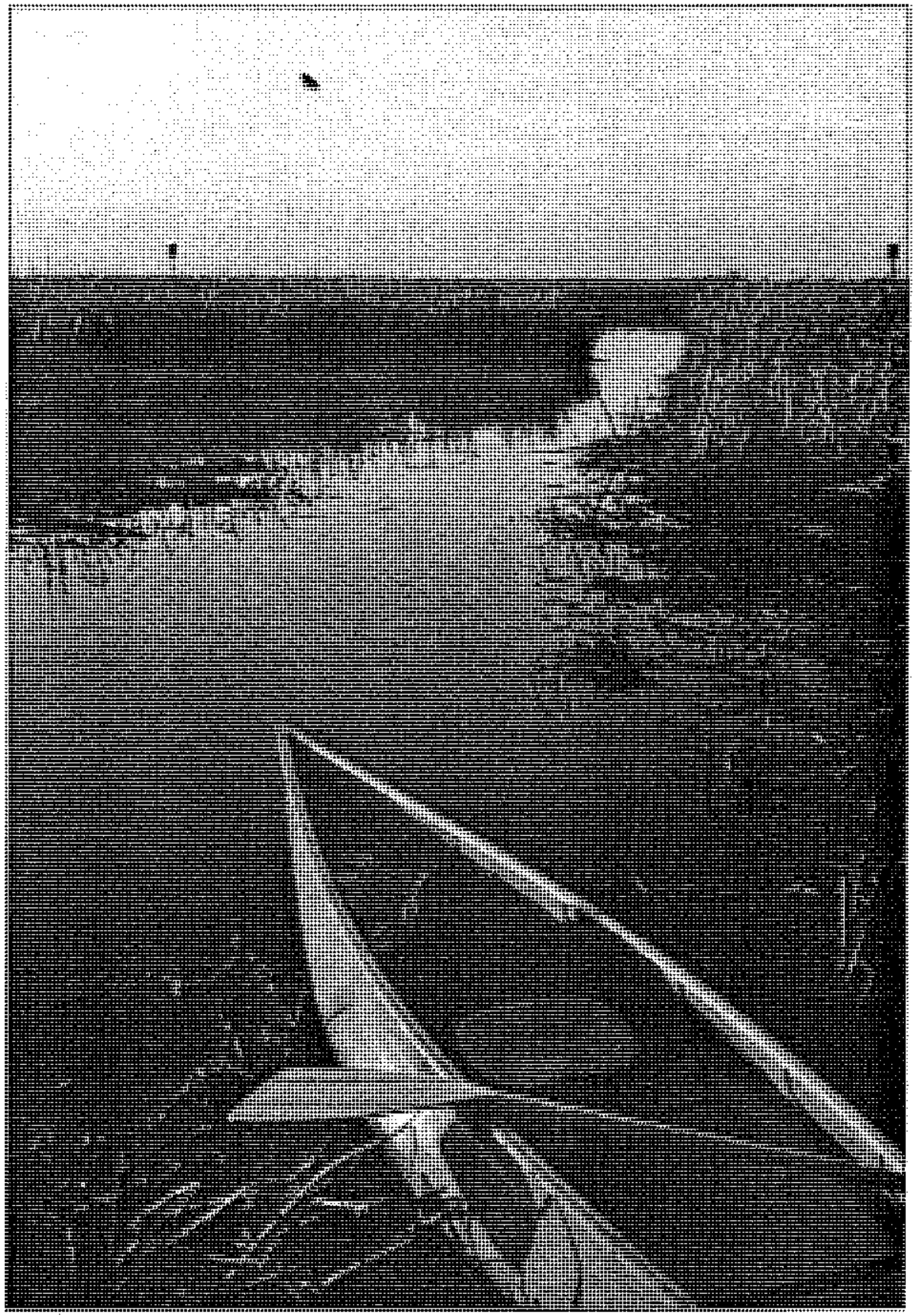


Figure 7.*—In addition to their ecological functions, wetlands also are valued as recreational resources. (Photo: USGS)*

Function 16—Outdoor education

Why important: The use of outdoor classroom settings has increased substantially as educators recognize the benefits of allowing students to explore and test what they learn in the classroom. Opportunities to use an outdoor classroom setting depend on its distance from school, ease of access, and the diversity and condition of habitats found there. Activities that degrade natural areas mean less areas are available for educational use.

How wetlands contribute: Wetlands are excellent outdoor education classrooms because of the diversity of plants and animals that live there and because of their combination of aquatic, transitional, and terrestrial environments.

To improve this function, watershed groups might:

- Identify wetland restoration sites that can provide outdoor education opportunities.

CLASSIFYING WETLANDS FOR INVENTORY AND MANAGEMENT

The National Wetlands Inventory and the Cowardin classification system

The most widely available and comprehensive wetlands information in the United States is the U.S. Fish and Wildlife Service's National Wetlands Inventory (NWI).[1] The NWI does more than locate and classify wetlands. It also maps the entire aquatic ecosystem network.

NWI maps contain information on location in the watershed, water regime, vegetation class or subclass, morphology, and sheet versus channel flow. Thus, the NWI is a useful starting point for evaluating restoration opportunities for all aquatic ecosystems, not just for wetlands. It also is useful for planning at a watershed or subwatershed level.

The NWI wasn't developed for use in regulatory programs, although it has proved useful as a basic indicator of wetlands and their boundaries. It also is used to classify wetlands at larger scales.

The NWI is based on the *Cowardin classification system*, which was published as the *Classification for Wetland and Deepwater Habitats of the United States*. This system is the most widely used wetland classification system in the United States. It has four objectives:

- To describe ecological units whose natural attributes are fairly homogenous
- To arrange these units in a system that will help people make decisions about resource management
- To provide information for inventory and mapping
- To create standard concepts and terminology for use in classifying aquatic ecosystems

An electronic version of the *Classification for Wetland and Deepwater Habitats of the United States* is available on the World Wide Web at http://www.nwi.fws.gov/classman.html

The Cowardin system includes five major *systems:* Palustrine (marshes), Lacustrine (lakes), Estuarine (estuaries), Riverine (rivers), and Marine (ocean). These systems are divided into *subsystems,* which reflect water flow regimes. Finally, the subsystems are divided into many different *classes* (Figure 8). If site data are available, users also can include information on plants, water chemistry, soil types, wetland origin, and other site-specific factors. NWI maps use codes to convey all of this information (Figure 9).

The Cowardin system classifies wetlands by structural vegetative characteristics such as forest or meadow. It's easy to identify these characteristics through aerial photos.

[1]In Oregon, the NWI has been adopted as the State Wetland Inventory (SWI) and is distributed by the Division of State Lands (DSL). Local Wetland Inventories (LWIs), based on the Cowardin classification system and mapped according to rules published by DSL, also have been developed for many cities and parts of counties where more detailed information is needed to meet advance planning goals or deal with regulatory problems in advance.

System	Subsystem	Class
M---Marine	1 Subtidal	RB Rock Bottom
		UB Unconsolidated Bottom
		AB Aquatic Bed
		RF Reef
		OW Open Water/Unknown Bottom
	2 Intertidal	AB Aquatic Bed
		RF Reef
		RS Rocky Shore
		US Unconsolidated Shore
E---Estuarine	1 Subtidal	RB Rock bottom
		UB Unconsolidated Bottom
		AB Aquatic Bed
		RF Reef
		OW Open Water/Unknown Bottom
	2 Intertidal	AB Aquatic Bed
		RF Reef
		SB Streambed
		RS Rocky Shore
		US Unconsolidated Shore
		EM Emergent Wetland
		SS Scrub/Shrub Wetland
		FO Forested Wetland
R---Riverine	1 Tidal	RB Rock bottom
		UB Unconsolidated Bottom
		AB Aquatic Bed
		SB Streambed
		RS Rocky Shore
		US Unconsolidated Shore
		EM Emergent Wetland
		OW Open Water/Unknown Bottom
	2 Lower Perennial	RB Rock bottom
		UB Unconsolidated Bottom
		AB Aquatic Bed
		RS Rocky Shore
		US Unconsolidated Shore
		EM Emergent Wetland
		OW Open Water/Unknown Bottom
	3 Upper Perennial	RB Rock bottom
		UB Unconsolidated Bottom
		AB Aquatic Bed
		RS Rocky Shore
		US Unconsolidated Shore
		OW Open Water/Unknown Bottom
	4 Intermittent	SB Streambed

Figure 8.*—Cowardin wetland classification system showing systems, subsystems, and classes.*

System	Subsystem	Class
L---Lacustrine	1 Limnetic	RB Rock bottom UB Unconsolidated Bottom AB Aquatic Bed OW Open Water/Unknown Bottom
	2 Littoral	RB Rock bottom UB Unconsolidated Bottom AB Aquatic Bed RS Rocky Shore US Unconsolidated Shore EM Emergent Wetland OW Open Water/Unknown Bottom
P--- Palustrine		RB Rock bottom UB Unconsolidated Bottom AB Aquatic Bed US Unconsolidated Shore ML Moss-Lichen Wetland EM Emergent Wetland SS Scrub/Shrub Wetland FO Forested Wetland OW Open Water/Unknown Bottom

***Figure 8.**—Cowardin wetland classification system showing systems, subsystems, and classes (continued).*

The classification of a mapped wetland is coded by a series of letters and numbers. The classification legend at the bottom of each map includes the alphanumeric code. The first letter of the code represents the system, the subsequent number represents the subsystem, and the next two letters indicate the class. If a wetland contains two different classes, they are separated by a horizontal line (see third example, below). Modifiers, when used, may be a letter or number.

CLASSIFICATION EXAMPLES

E2EM

System: Estuarine (E)
Subsystem: Intertidal (2)
Class: Emergent (EM)

Typical vegetation:

Lyngby's sedge (*Carex lyngbyei*)
seaside arrowgrass (*Triglochin maritimum*)
pickleweed (*Salicornia virginica*)
saltgrass (*Distichlis spicata*)

PSSC

System: Palustrine (P)
Subsystem: none
Class: Scrub-Shrub (SS)
Modifier: Water regime—Seasonally flooded (C)
Note: Palustrine system does not have subsystems.

Typical vegetation:

willow (*Salix spp.*)
salmonberry (*Rubus spectabilis*)
Douglas Spiraea (*Spiraea douglasii*)
red-osler dogwood (*Cornus stolonifera*)

P EM Hx
AB

System: Palustrine (P)
Subsystem: none
Class: Mixed—Emergent (EM)/Aquatic Bed (AB)
Modifiers: Water regime—Permanently flooded (H)
Special modifier—Excavated (x)

Typical emergent vegetation:

cattail (*Typha spp.*)
skunk cabbage (*Lysichitum americanum*)
reed canarygrass (*Phalaris arundinacea*)
slough sedge (*Carex obnupta*)

Typical Aquatic Bed vegetation:

common duckweed (*Lemna minor*)
white water lily (*Nymphaea odorata*)

Figure 9.—Cowardin classification codes for wetlands.

A major weakness of the Cowardin system and the NWI is that the descriptors of mapped units often don't relate consistently to ecosystem functions. Because of the system's reliance on plant types as identifying criteria, wetlands that function very differently often are grouped into the same Cowardin class simply because they have the same vegetation.

Nevertheless, because the NWI is the only universally available data, people try to identify wetland functions from NWI maps and descriptors. Often, scientists create hybrid systems that use both NWI data and other information.

Hydrogeomorphic classification

The *hydrogeomorphic* (HGM) wetland classification does address differences in wetland functions. This system is under development and will use three criteria–where a wetland is positioned in the landscape (*geomorphology*), its water source (precipitation, surface water, or groundwater), and its *hydrodynamics* (how water moves through it).

The HGM approach is being developed by the Army Corps of Engineers for use with the Section 404 regulatory program. It meets the need for a better rapid assessment tool to evaluate how wetlands are functioning and to develop requirements for actions to compensate for previous damage.

Nationally, all of the major resource agencies have agreed to develop and use HGM, but the process of "regionalizing" HGM will take some time. Oregon is just beginning to develop HGM in a way that will help people understand wetland functions at regional, watershed, and site-specific scales. Meanwhile, the national HGM prototype is being applied in Oregon because of its usefulness in describing and characterizing wetland functions.

There are seven wetland classes in the HGM system (Table 1). Identifying a wetland's class is the first step in the HGM approach to wetland functional assessment. Classes are based on three principal characteristics of wetlands, although water chemistry and soil properties also are important. These three characteristics are:

- *Geomorphic setting,* or the wetland's topographic position in the landscape
- *Water source* and *transport vector. Water sources* include precipitation, lateral flows from upstream or upslope, and groundwater. The *transport vector* is how water is transported. Precipitation is transported from the atmosphere; lateral flows are transported by surface or near-surface flows; and groundwater is transported by subsurface flow.

Table 1.–Hydrogeomorphic classes of wetlands showing associated dominant water sources, hydrodynamics, and examples of subclasses.

Hydrogeomorphic class	Dominant water source	Dominant hydrodynamics	Examples of subclasses
Riverine	Overbank flow from channel	Unidirectional, horizontal	Riparian forested
Depressional	Return flow from groundwater and interflow	Vertical	Vernal pools
Slope	Return flow from groundwater	Unidirectional, horizontal	Avalanche chutes
Mineral soil flats	Precipitation	Vertical	Large playas
Organic soil flats	Precipitation	Vertical	Peat bogs
Estuarine fringe	Overbank flow from estuary	Bidirectional, horizontal	Tidal salt marshes
Lacustrine fringe	Overbank flow from lake	Bidirectional, horizontal	Lakeside emergent marshes

- *Hydrodynamics*, or how water moves. There are three kinds of flow–vertical, unidirectional and horizontal, and bidirectional and horizontal. *Vertical* movements result from evapotranspiration and precipitation; *unidirectional* flows are downslope movement; and *bidirectional* flows are tides or wind-driven fluctuations in bays.

The strength of HGM is that variations in these hydrogeomorphic properties are directly related to the ecological functions of wetlands. Wetlands also will be evaluated in comparison to regional reference sites that are established by agencies during the process of developing the HGM for a particular state or region. However, the HGM classification system isn't intended to replace other wetland classification systems such as the NWI's Cowardin system. Both systems are useful in wetlands management.

ASSESSING WETLAND FUNCTIONS

Wetlands provide many benefits because of their functions. It therefore is important to evaluate each wetland from a functional point of view. What functions does it or could it perform, and how well is it performing them? This kind of evaluation is called a *wetland functional assessment*.

One of the frequent criticisms of wetland management and regulation is that all wetlands are treated equally, when in fact they often are very different in structure, function, and quality. Although these criticisms often are overstated, it's true that wetland managers haven't settled on a standard way to characterize and compare the functions of one wetland to another. There are many reasons for this lack of consistency:

- The ecological processes that support wetland functions often are quite complex.
- These processes aren't well understood, and there isn't enough information about them.
- Wetlands vary a lot, even within a particular type.
- Wetland functions have many parts, all of which must be considered as part of the whole.
- Assessments often have very different purposes.

Despite these very real limitations, it still is important to use the best available scientific information about wetlands to assess their functions. To accomplish this, several standardized rapid assessment methods have been developed.

Several of these methods are used in Oregon or elsewhere in the Pacific Northwest. Others are in the process of being customized for this region. No single approach is universally accepted. The most common approaches include:

- "Best professional judgment"
- The Wetland Evaluation Technique (WET)
- The Oregon Freshwater Assessment Methodology (OFWAM)
- The hydrogeomorphic approach (HGM)
- The Puget Sound Watershed Approach (PSWA)

Most of these methods require some training either in wetlands science and/or in the use of the particular method. They all rely on *indicators* of wetland function that can be observed in the field or gleaned from aerial photos, wetland or soil maps, and other resource materials.

Each of these methods is described briefly below, and sources of more information on each are listed in the Resources section of this chapter. In addition, National Wetlands Inventory (NWI) maps, local wetland inventories (LWIs), soil surveys, and other sources can help you characterize existing wetlands and identify restoration and enhancement opportunities in your watershed. See the Resources section of this chapter for more information.

Best professional judgment

Best professional judgment (BPJ) probably is the most commonly used and flexible method for evaluating wetland functions. In this approach, well-trained, experienced wetland professionals evaluate the principal functions and conditions of a wetland based on extensive field experience and information from NWI maps, soil maps and surveys, and aerial photos.

However, because BPJ is not a standardized approach, it isn't very precise, and no two individuals are likely to get the same results. Thus, it's often criticized in terms of scientific, legal, and public credibility. These shortcomings are the driving force behind the development of more precise, standardized approaches.

Wetland Evaluation Technique

The Wetland Evaluation Technique (WET) is a broad-brush, field-based approach to wetland evaluation. It's based on information about correlative predictors of 11 wetland functions and values. *Correlative predictors* are variables whose presence is highly correlated with certain watershed functions.

Data on correlative predictors can be gathered quickly in the field. Based on these correlative predictors, the WET process generates high, moderate, or low probability ratings that a particular wetland performs a given function.

A site-specific method, WET has been used mostly by regulatory agencies to assess wetlands proposed for alteration and to design and monitor restored or created wetlands. It also has been used to identify important wetlands needing protection and to set priorities for acquisition or research. WET isn't easily adaptable to landscape-level evaluation of wetland functions.

Oregon Freshwater Wetland Assessment Methodology

The Oregon Freshwater Wetland Assessment Methodology (OFWAM) assesses six wetland functions (wildlife habitat, fish habitat, water quality, hydrologic control, education, and recreation) and three wetland conditions (sensitivity to impacts, enhancement potential, and aesthetics). This method involves asking a series of questions about each of these functions or conditions. Based on the answers to these questions, assessments have three possible outcomes:

- The function is performed or is intact.
- Some of the function is performed, or it may be impacted or degraded.

- The function is not performed or has been lost.
- For each wetland assessed, results for each of the six wetland functions and three conditions are summarized in a tabular and narrative description.

OFWAM is used extensively as a planning tool because it allows functions and conditions of several wetlands to be assessed and compared. Its most common use has been as a follow-up to local wetland inventories. In this case, each wetland is assessed, and the results are used by a community to help decide which wetlands are significant and deserve special protection.

OFWAM's use for watershed-level restoration planning is limited for two reasons. First, only one of the assessed conditions addresses restoration potential. Second, OFWAM focuses solely on existing rather than on former wetlands. Nevertheless, it could be adapted for restoration purposes by asking the question, "If we restored or created a wetland here, how might each of these functions be performed?"

See the Resources section of this chapter for information on how to obtain the OFWAM.

The hydrogeomorphic approach

The hydrogeomorphic (HGM) wetlands classification system was described above as the first step in an HGM approach to assessing wetland functions. Recall that this classification is based primarily on three principal characteristics of wetlands (although water chemistry and soil properties are other important variables):

- *Geomorphic setting* (the wetland's topographic position in the landscape)
- *Water source* (e.g., precipitation or groundwater) and *transport vector* (for example, surface flows or subsurface flows)
- *Hydrodynamics* (how water moves)

Once the characteristics of the seven national HGM classes are described for a particular class or subclass of wetlands, they are used to develop a profile of the functions that subclass performs.

Oregon is developing a regional application of HGM for use at site-specific, watershed, and ecoregion scales. It will be several years before the Oregon HGM assessment method is complete. In the meantime, however, the national HGM system can be used to better understand and assess the functions of different types of wetlands. HGM also is the basis for the PSWA assessment method described below, so an understanding of HGM is important for watershed groups.

Puget Sound Watershed Approach (PSWA)

Washington State, in implementing the Puget Sound water-quality program, has developed a watershed-based wetland restoration approach known as the Puget Sound Watershed Approach (PSWA). It has been pilot-tested in the Stillaguamish basin and now is being extended to other watersheds. PSWA uses aspects of both HGM and OFWAM to evaluate the 16 functions of wetlands described earlier.

The PSWA guidebook *Restoring Wetlands at a River Basin Scale* includes a multistep process that explains how to analyze the functions a particular wetland might perform once restored. This process involves the following steps:

- Identifying a wetland's HGM class
- Establishing priorities for restoring functions based on the problems in the watershed (e.g., high water temperatures during low flows)
- Determining the potential of different wetland types to perform these functions
- Assessing the restoration potential of sites and ranking each function

One of the end products of this process is a "menu" of restoration sites and a description of how their functions could help solve locally identified watershed problems.

The PSWA method is relatively high tech, incorporating the best available science about wetland functions and using geographic information system (GIS) analysis to carry out some of the steps. At the same time, it is locally driven in terms of problems to be solved and the constraints on project implementation. And, as with watershed groups in Oregon, its restoration projects are based on the "willing landowner" principle.

You can download *Restoring Wetlands at a River Basin Scale: A Guide for Washington's Puget Sound: Operational Draft*, Publication No. 97-99, from the World Wide Web at http://www.wa.gov/ecology/sea/97-99.html. A hard copy is available from the Washington State Department of Ecology at the address given in the Resources section of this chapter.

WETLAND MANAGEMENT IN OREGON TODAY

The protection, restoration, and enhancement of wetlands in Oregon involves many players. Federal, state, and local government agencies each have certain legal responsibilities and authority, but private nonprofit land trusts and other nongovernmental organizations also play important roles. Responsibilities generally break out along functional lines and governmental levels as summarized in Table 2.

Mapping, assessment, and research

Responsibilities in this area are shared among levels of government and agencies and relate primarily to assigned management responsibilities. The U.S. Fish and Wildlife Service conducts the National Wetlands Inventory (NWI). All of Oregon has been mapped, but some maps, particularly in the Coast Range, are of poor quality. Only about 20 percent of the state's NWI maps are available in digital form.

The Division of State Lands (DSL) uses the NWI as its base State Wetlands Inventory (SWI) and also funds the development of Local Wetlands Inventories (LWIs) that provide more detail. As of 1997, 35 communities had developed LWIs.

Wetland functional assessment also is a priority at each governmental level and is used for a variety of purposes. The *Oregon Freshwater Wetland Assessment Methodology* (Roth et al., 1996), for example, is used in conjunction with LWIs and local land-use planning.

Wetland research in Oregon is conducted mainly by federal agencies–the Environmental Protection Agency (EPA), the U.S. Fish and Wildlife Service (USFWS), the Natural Resources Conservation Service (NRCS), and the U.S. Geological Survey (USGS) in particular. But state agencies, university academics, and private nonprofits such as The Nature Conservancy also conduct important research on wetland functions and characteristics, providing useful management information.

Nonregulatory wetland management

A variety of federal, state, and private programs focus on nonregulatory wetland management in Oregon. The principal activities of both public agencies and private organizations are land acquisition; management, restoration, or enhancement of wetlands; technical assistance to private landowners undertaking restoration or enhancement; and public education (Figure 10).

Table 2.–Principal wetland management functions, governmental agencies, private organizations, and authorities in Oregon.

Function	Federal government	State government	Local government	Private/ nonprofit
Mapping, assessment, and research	• *U.S. Geological Survey:* hydrology, nutrients, habitat • *U.S. Fish and Wildlife Service:* National Wetlands Inventory, habitat research, and functions assessment • *U.S. Army Corps of Engineers:* restoration and assessment research • *U.S. Environmental Protection Agency:* mitigation, risks, and cumulative impacts • *Natural Resources Conservation Service:* agricultural wetlands, functions assessment	• *Division of State Lands:* • State and Local Wetland Inventories, Oregon Freshwater Wetland Assessment Method, wetland research through EPA state grants program • *Governor's Watershed Enhancement Board:* funding for watershed assessments • *Universities and colleges:* scientific research on wetland characteristics, functions, and restoration	*Cities and counties:* Local Wetland Inventories, wetland functions assessment	• *The Nature Conservancy:* research on wetland characterization and mapping, historical ecology, functions assessment, and restoration monitoring
Nonregulatory: Land acquisition, management, restoration, enhancement, education, and technical assistance	• *U.S. Fish and Wildlife Service:* national wildlife refuges, Partners for Wildlife • *U.S. Forest Service:* natural areas management and restoration • *U.S. Bureau of Land Management:* natural areas • *Natural Resources Conservation Service:* Wetland Reserve Program, Conservation Reserve Program • *National Park Service:* national parks and monuments	• *Department of Fish and Wildlife:* wildlife management areas, funding and technical assistance, public education • *Division of State Lands:* public trust lands and waters of the state, South Slough National Estuarine Research Reserve, forest and range lands, public education • *Parks and Recreation Department:* state parks, public education • *Department of Forestry:* state forest lands • *Governor's Watershed Enhancement Board:* funding for restoration and enhancement projects, public education	• *Counties and cities:* parks, green spaces, and natural areas • *Watershed councils:* facilitation of private landowner cooperation, on-the-ground restoration	• *Oregon Wetland Joint Venture:* implementing North American Waterfowl Act-related plans for habitat restoration and enhancement, coordination and facilitation of public-private action • *The Nature Conservancy:* acquisition, restoration, and enhancement projects • *Ducks Unlimited:* acquisition, restoration, and enhancement projects • *Wetlands Conservancy:* acquisition, restoration, and enhancement projects • *Other local land trusts:* acquisition, restoration, and enhancement projects

Table 2.–Principal wetland management functions, governmental agencies, private organizations, and authorities in Oregon (continued).

Function	Federal government	State government	Local government	Private/ nonprofit
Regulation, mitigation, and permit review	• *U.S. Army Corps of Engineers*: Clean Water Act Section 404 • *U.S. Environmental Protection Agency:* Section 404 oversight • *Natural Resources Conservation Service*: "Swampbuster" agricultural wetlands • *U.S. Fish and Wildlife Service:* coordination under Fish and Wildlife Coordination Act (FWCA) • *National Marine Fisheries Service:* coordination under Fish and Wildlife Coordination Act	• *Division of State Lands:* Removal/Fill Law, Mitigation Banking Act • *Department of Fish and Wildlife:* permit review under Removal/Fill Law and federal FWCA • *Department of Environmental Quality:* CWA Section 401 wetland water quality certification • *Department of Land Conservation and Development:* state and federal consistency certification	• *Counties and cities:* local wetland and natural resource protection ordinances, federal and state permit review for consistency with local plan	No role except as occasional public commenter
Land use and watershed planning	• *U.S. Forest Service:* on national forest lands • *U.S. Bureau of Land Management:* on BLM-managed forest and range lands • *National Park Service:* on national parks and monuments	• *Department of Land Conservation and Development:* Goals 5, 16, and 17 • *Division of State Lands:* Goals 5, 17, and Wetland Conservation Plans, state-owned lands • *Department of Forestry:* watershed and land-use planning on state lands • *Governor's Watershed Enhancement Board:* funding for watershed action programs and plans	• *Counties and cities:* Goal 5, Goals 16 and 17 (coastal), and Wetland Conservation Plans • *Watershed councils:* restoration action plans, facilitation of private landowner cooperation	No significant role

The Oregon Department of Fish and Wildlife (ODFW), USFWS, the Bureau of Land Management (BLM), U.S. Forest Service (USFS), NRCS, and local Soil and Water Conservation Districts are the principal government agencies involved. Private nonprofit land trusts and similar groups involved in wetlands management include The Nature Conservancy, Ducks Unlimited, the Wetlands Conservancy, and others. Many of these private groups come under the umbrella of the Oregon Wetlands Joint Venture.

Regulation, mitigation, and permit review

At the federal level, Section 404 of the Clean Water Act (40 CFR 230) is the principal nationwide wetland regulatory program. Section 404 requires that anyone discharging dredge or fill material in the waters of the United States, including wetlands, obtain a permit from the U.S. Army Corps of Engineers (the Corps). The permit is subject to review by a number of agencies, principally the EPA (which also may veto the permit), USFWS, the National Marine Fisheries Service (NMFS), the Oregon Department of Fish and Wildlife (ODFW), and the Oregon Department of Environmental Quality (DEQ) (to certify that water-quality standards are met).

As part of the effort to implement the federal no-net-loss policy for wetlands, Section 404 applicants must follow a sequential mitigation process. First, wetland impacts must be avoided if at all possible, usually by maximizing use of nonwetland areas on or off the property. Next, onsite wetland impacts must be minimized. Finally, unavoidable wetland losses must be compensated by restoring, creating, or enhancing wetlands.

In practice, wetland compensatory mitigation (WCM) occurs on a project-by-project basis. In recent years, *mitigation banking* has become a popular alternative to the project-by-project approach. Mitigation banking involves restoration (or creation) of large

***Figure 10.**—Technical assistance teams with a range of expertise can be effective for watershed planning and for designing specific projects. (Photo: ODFW)*

wetland areas in advance of use as WCM. As needed, WCM credits are sold to permit applicants by the bank sponsor in lieu of requiring separate WCM projects.

The "swampbuster" provisions of the Food Security Act of 1985–often referred to as the "Farm Bill"–reversed a long-standing national policy of promoting drainage of wetlands for agricultural cropping. Instead, farmers who convert wetlands to agricultural uses may be penalized by removal of certain agricultural price supports and other subsidies. Wetlands that were converted to cropland prior to 1985 are exempted from the law.

The swampbuster provision of the farm bill is administered by the Natural Resources Conservation Service (NRCS) and was amended in 1990 and again in 1996. The most recent farm bill gives farmers more flexibility in meeting wetland conservation requirements, in particular expanded mitigation provisions that allow for restoration, creation, and enhancement of wetlands.

The Oregon Removal/Fill Law is the principal state regulatory tool for protecting Oregon's wetlands. Although it predated the Section 404 program, the Removal/Fill Law is very similar. The law requires permits for fill or removal of 50 cubic yards or more from wetlands or waters of the state. In some areas, such as essential salmonid habitat, a permit is required for smaller amounts of fill or removal.

An important component of the law is a three-part sequential mitigation process similar to the federal requirement. Mitigation thus is the principal link between regulatory programs and wetland restoration programs. The program is administered by the Division of State Lands and applies statewide. Federal-state streamlining is achieved through a joint permit application and review process.

Wetlands regulatory policy and programs have been a lightning rod in recent years, as farming interests, developers, and private property rights advocates generally have sought to reverse the expanding jurisdiction of federal regulatory programs, speed up the permit process for development, and as much as possible, externalize the costs associated with cropping, dredging, filling, and other wetland conversions.

These efforts have been blunted to some degree by conservationists and resource managers who are promoting even stronger wetlands protection. Although protection of remaining wetlands remains a federal and state priority, the impasse over regulatory program changes has provided at least part of the rationale for putting more emphasis on nonregulatory programs such as restoration.

You can find more information about watershed regulations in Chapter III-7, "Incentives and Regulations."

Land use and watershed planning

Oregon's statewide land-use planning program includes several provisions that provide for wetland protection and restoration. Statewide Planning Goals, especially Goal 5 (Open Spaces, . . . and Natural Resources), Goal 16 (Estuarine Resources), and Goal 17 (Coastal Shorelands) require the inventory and protection of significant wetlands.

However, there is little consideration of wetland restoration, except in Goals 16 and 17, where the emphasis is on locating sites for regulatory mitigation, not nonregulatory restoration. Recent revisions to Goal 5 have improved provisions for wetland and riparian protection, but again do not address restoration or enhancement as land-use management strategies.

The other principal planning authority dealing with wetland protection and restoration is the 1989 wetland conservation law (ORS 196.668 et seq.), also administered by DSL. This legislation enabled the development of local wetland inventories (mentioned above) and the preparation of local wetland conservation plans (WCPs). Although locating potential wetland restoration sites is a required part of the WCP process, only those necessary to mitigate future development affecting wetlands actually must be identified in inventories and plans.

Watershed planning in Oregon is carried out by federal, state, and private landowners and organizations. In recent years, the watershed approach has been institutionalized in Oregon, largely through the Governor's Watershed Enhancement Board (GWEB), which provides for establishment of local watershed councils and associations. More than 60 local watershed groups have been established in Oregon so far.

Many watershed councils have developed restoration action plans. However, few watershed plans and programs address wetland restoration as part of overall ecosystem restoration.

This brief overview of wetland management in Oregon illustrates the diversity and complexity of programs and activities addressing restoration in Oregon. In many ways, this diversity mirrors the larger society within which wetland and other aquatic ecosystem management occurs. What becomes very obvious as you examine these programs is the need and opportunity for improved public-private and interagency cooperation, better integration of wetland restoration into existing watershed and planning programs, and the enhancement and redirection of human and other resources if such goals are to be accomplished.

Summary/Self review

Wetlands are areas where water is at or near the surface at least part of the year, where soil development reflects this saturation, and where vegetation is dominated by plants adapted to a wet environment. Many wetlands are found at the transition between upland and aquatic environments, but others are isolated from open water.

Wetlands are ecological "hot spots" in watersheds, performing a variety of valuable functions that can be divided into four categories:

- Water quality-related functions
- Hydrologic functions
- Habitat and food web support functions
- Cultural and social functions

Functional interconnectedness with stream, lake, estuarine, and riparian ecosystems also is important. Thus, none of these environments can be considered in isolation from the others.

Wetlands types are classified using a number of systems. The most important are the Cowardin classification system (used for inventory and mapping) and the HGM classification system (being regionalized for Oregon to provide a better basis for functional assessment at a variety of scales).

Wetlands functions can be evaluated using a variety of methods. OFWAM is most commonly used today, and HGM is in the process of development. The PSWA method in Washington State is the only "watershed-level" method applicable to Oregon's watersheds; it incorporates aspects of both OFWAM and HGM.

EXERCISES

Identifying and describing wetland characteristics using an NWI map

This exercise will familiarize you with the wetland and watershed information that can be gleaned from NWI maps and soil surveys. This information is useful in characterizing current watershed conditions, the predisturbance extent of wetlands, and the relationship of wetlands to aquatic and upland environments. You can do this exercise on your own, but it's helpful to work as a group so you can discuss your observations.

You'll need to order NWI maps (called "quad sheets") for your area. The Division of State Lands (DSL) can help you identify which maps you need. Each map covers about 56 square miles. Because most watersheds are larger than that, you may want to order all of the maps that overlap into your area of concern, or you may want to order just those in your immediate area. Many local Natural Resources Conservation Service (NRCS) field offices own a complete set of NWI maps for their county. You also should obtain your *county soil survey, hydric soils list,* and a large-scale aerial photo of the study area (color is best). See the Resources section for ordering information.

Using an NWI map and the soil survey and hydric soils list for the same area, answer these kinds of questions. (Locate specific areas or streams, and adapt the questions as needed.)

1. Following a creek or small river tributary to its headwaters source, what wetland types (classifications) do you encounter? List them in order, using the full name. Mark them on the map where the classification changes.
2. In what township(s), range(s), and sections does the stream fall? (See Chapter III-1, "Land Survey," for more information.)
3. Moving to an area of more isolated wetlands, what are the general types of wetlands and how do they differ from the stream system you first examined?
4. Using your soil survey sheet for the two areas where you identified wetlands, draw cross-section lines through each area. Then, using the hydric soils list for the county, list the soil map units and identify which ones are hydric.
5. Using a highlighter, shade the approximate locations of the NWI wetlands you identified on your soil survey sheet. What are the differences in area between the NWI-mapped wetlands and the hydric soils? Which includes more area? Speculate why.

Conducting a wetland function assessment using OFWAM

Conducting a wetland functional assessment will familiarize you with the range of functions these ecosystems perform, how the functions vary among wetland types and within a given class of wetlands, and the "indicators" used to estimate whether or not a function is performed.

You will need a copy of the Oregon Freshwater Wetland Assessment Methodology, available from DSL (see Resources). OFWAM is designed as a step-by-step guide, and you can go through the process on your own or with your watershed group. However, it's best to arrange for some classroom and/or field training by DSL staff or other experienced users, such as wetland consultants. See Resources.

1. Select at least three wetlands for the exercise. Two should be of a single Cowardin wetland type, for example, palustrine emergent seasonally flooded (PEMC). Collect site and regional information and do the off-site analysis.
2. Then go into the field (get property owner permission first!) and go through the OFWAM field questions, tally the results, characterize, and compare wetland functions for each site. Consider these questions:
   - Do the two wetlands that are of the same type (PEMC in the above example) perform the same functions? Are the assessment results the same? Speculate why or why not.
   - How does the assessment for the third, different type of wetland compare to the first two? Are the functions performed the same? Are the assessment results the same? Speculate why or why not.
   - Which of the wetlands is the most intact functionally? Which is the least intact? What are the causes for these differences?
   - If wetland functions at any (or all) of the sites are degraded to some extent, what would you suggest doing to restore each site to improve wetland functioning?

RESOURCES

Training

Training on the following topics may be offered by the agencies listed, or these agencies can provide contacts or information for other scheduled training programs, some of which are fee-based.

The Cowardin classification system, the NWI, and local wetland inventories

Oregon Division of State Lands, Wetlands Program. Phone: 503-378-3805

U.S. Fish and Wildlife Service, Regional Wetland Coordinator. Phone: 503-231-6154

Agricultural wetlands, soil surveys, hydric soils

Natural Resources Conservation Service, regional office. Phone: 503-414-3200

Natural Resources Conservation Service, local offices

Oregon Division of State Lands, Wetlands Program. Phone: 503-378-3805

Wetland function assessment using OFWAM

Oregon Division of State Lands, Wetlands Program. Phone: 503-378-3805

Wetland identification and delineation

Oregon Division of State Lands, Wetlands Program. Phone: 503-378-3805

U.S. Army Corps of Engineers, Portland District, Wetlands Specialist. Phone: 503-808-4373

Information

National Wetlands Inventory maps

You can order NWI maps for your area or watershed from two sources. Specify the USGS quadrangle sheets you wish to order. (You can obtain a statewide map index and order form from DSL.)

State Distribution Center
Oregon Division of State Lands
Wetlands Program
775 Summer Street NE
Salem, OR 97310-1337
Phone: 503-378-3805, ext. 246

Earth Science Information Center
Western Mapping Center–ESIC
U.S. Geological Survey
Mail Stop MS 532
345 Middlefield Road
Menlo Park, CA 94025
Phone: 650-329-4309

Inventories of farmed wetlands, hydric soils, and soil surveys

The Natural Resources Conservation Service (NRCS) is compiling an inventory of farmed wetlands. It also maintains and distributes the Oregon list of hydric (wetland) soils.

Natural Resources Conservation Service
101 SW Main, Suite 1300
Portland, OR 97204
Phone: 503-414-3200

Local NRCS offices also can supply your county soil survey, which includes upland and hydric soils. Contact your local NRCS office or county Extension agent for more information.

Other materials

The U.S. Fish and Wildlife Service has a variety of information on the National Wetlands Inventory and other wetlands information. Contact the USFWS regional office (below) or explore the NWI Web site at http://www.nwi.fws.gov/

Regional Wetland Coordinator
U.S. Fish and Wildlife Service
911 NE 11th
Portland Eastside Federal Complex
Portland, OR 97232-4181
Phone: 503-231-6154

The State Distribution Center (DSL) has a number of wetland fact sheets and other information that may be ordered from the address or phone listed on the previous page. Materials include:

About Local Wetlands Inventories, Just the Facts #2 (1993). No charge

About the National Wetlands Inventory, Just the Facts #1 (1991). No charge

How to Identify Wetlands, Just the Facts #4 (1992). No charge

How Wetlands And Waterways Are Regulated, Just the Facts #3 (1992). No charge

Oregon Freshwater Wetland Assessment Methodology, 2nd edition, by E. Roth, R. Olsen, P. Snow, and R. Sumner (Oregon Division of State Lands, Salem, 1996). 184 pages. $15.50

The Oregon Wetlands Conservation Guide: Voluntary Wetlands Stewardship Options for Oregon's Private Landowners (1995). 34 pages plus appendices. No charge

Wetlands Functions and Assessment, Just the Facts #5 (1994). No charge

Wetlands Inventory User's Guide, Pub. 90-1. No charge

Wetlands Update (a periodic wetlands newsletter available by subscription; ask for available back issues as well). No charge

The U.S. Army Corps of Engineers also has information on wetlands functions assessment, wetland restoration, and other topics. For a list of available publications, contact:

U.S. Army Engineer Waterways Experiment Station
3909 Halls Ferry Road
Vicksburg, MS 39180
Phone: 601-634-2355

The Washington State Department of Ecology has many publications that may be applicable to wetlands in Oregon. Call 360-407-7470 to obtain a free order form, or write:

Washington State Department of Ecology
Publications Distribution Center
PO Box 47600
Olympia, WA 98504-7600

Restoring Wetlands at a River Basin Scale: A Guide for Washington's Puget Sound: Operational Draft, Publication No. 97-99 is available on the Web at http://www.wa.gov/ecology/sea/97-99.html. A hard copy is available from the address above.

MOVING FORWARD–THE NEXT STEPS

On your own, use the lines below to fill in steps, actions, thoughts, contacts, etc. you'll take to move yourself and your watershed group ahead in understanding wetland functions, management, evaluation, and enhancement.

1. ______________________________

2. ______________________________

3. ______________________________

10

Estuarine Science, Management, and Restoration

Jim Good

Estuaries—are they inland extensions of the sea or downstream extensions of a watershed's aquatic ecosystem? An oceanographer might find the first definition more satisfying, while a stream ecologist might prefer the latter. They are likely to agree, however, that estuaries are unique transition ecosystems—complex, dynamic, productive, and in many ways different from either the adjacent ocean or the river upstream.

Estuaries provide many goods and services to humans and other organisms. Examples include fish and shellfish production, water purification, shoreline stabilization, wildlife habitat, and recreational opportunities.

Estuaries are home to an incredible array of plants and animals, many so small and abundant that there may be billions in a single glass of bay water. Estuaries play key roles in the life cycles of important marine and anadromous aquatic species—crab, salmon, and herring, to name a few—as well as migratory waterfowl and shorebirds.

With a twice-daily ebb and flood of the tide, salt water and fresh water mixing, and rapid fluctuations in temperature and salinity, estuaries can be difficult places to live. But the plants and animals that thrive there have developed remarkable adaptations to these difficult conditions—adaptations for feeding,

IN THIS CHAPTER YOU'LL LEARN:

- What an estuary is
- Why estuaries are important
- How physical and biological processes drive these ecosystems
- How Oregon's estuaries function and how they are used and managed
- How to assess estuarine health and develop a restoration action plan
- How to design, construct, and monitor estuary restoration projects

reproducing, rearing their young, avoiding predators, and regulating their bodies' temperature and salt concentration. Estuarine ecosystems and their inhabitants thus are by nature resilient. At the same time, however, past changes and present threats make them highly vulnerable.

Human history and economic development are intimately linked to estuaries. Estuaries provide abundant, easy-to-access fish and shellfish. We build cities on their shores and ports in their sheltered harbors. We come to the sea to breathe the salt air and be renewed.

See Section II, Chapters 4, 5, 6, and 9 for information related to this chapter.

Some of the ways we use estuaries change these ecosystems, often significantly. We selectively harvest plants and animals. We consciously or inadvertently introduce nonnative organisms, including pest species. We dredge navigation channels, build jetties, fill tidelands, dike salt marshes, dump wastes, and more. Although some of these uses have economic and other benefits, they often adversely affect the natural goods and services that estuaries provide to society.

Over the past several decades, we have come to understand the value of the goods and services healthy estuaries provide. We also have learned it is not too late to protect what remains and to restore damaged areas to health. All along the Oregon coast, estuarine habitats are being protected, development is being directed to areas where adverse impacts can be avoided or minimized, and new pollution controls are being put in place.

Improving damaged and degraded estuaries is the next logical step. Local watershed councils, land trusts, other groups, and state and federal biologists are surveying and remapping Oregon's estuaries, identifying potential restoration actions, and examining pollution sources and other problems. They're using lessons learned from existing restoration projects to design and evaluate new projects.

Nevertheless, both old and new threats to Oregon's estuaries remain. An example of an emerging threat is invasion by green crab and other nonnative nuisance species. Restoration of Oregon estuaries has started, but much remains to be done.

WHAT IS AN ESTUARY?

es·tu·ar·y (es´-chew-wer´-ee), n. **1.** that part of the mouth or lower course of a river in which the river's current meets the sea's tide. **2.** an arm or inlet of the sea at the lower end of a river. *(Random House Unabridged Dictionary,* 1993)

The dictionary provides a simple, intuitive definition of an estuary. But it leaves many questions unanswered. For example, how far upriver does an estuary extend? Is a lagoon with little freshwater inflow an estuary? Why are these ecosystems so important and highly regulated? What is the role of estuaries in the life cycle of Pacific salmon and other species of commercial, recreational, or ecological importance? More technical definitions begin to answer these questions.

A classic, often-quoted scientific definition advanced by oceanographer Donald Pritchard in 1967 is that an estuary is *"a semi-enclosed coastal body of water which has a free connection with the open sea and, within which, seawater mixes and usually is measurably diluted with freshwater from land runoff."*

Oregon, in its statewide planning goal for estuaries (Goal 16–Estuarine Resources), adopted a very similar, but expanded, definition, saying that an estuary *"includes estuarine water, tidelands, tidal marshes, and submerged lands. Estuaries extend upstream to the head of tidewater, except for the Columbia River estuary, which by definition extends to the western edge of Puget Island."* We use this definition in this chapter.

WHY WE NEED HEALTHY ESTUARIES

Healthy estuaries provide important habitats for many species we value such as salmon, herring, flounder, crabs, oysters, clams, wading birds, ducks, geese, shorebirds, and harbor seals (Figure 1). Deep channels, sloughs, tidal flats, salt marshes, eelgrass beds, and other habitats provide food, shelter, resting areas, and nursery grounds. These habitats also are home to thousands of lesser known species that are vital to healthy estuarine ecosystems—burrowing ghost shrimp; strange-looking polychaete worms; and microscopic copepods, molluscs, and other planktonic species.

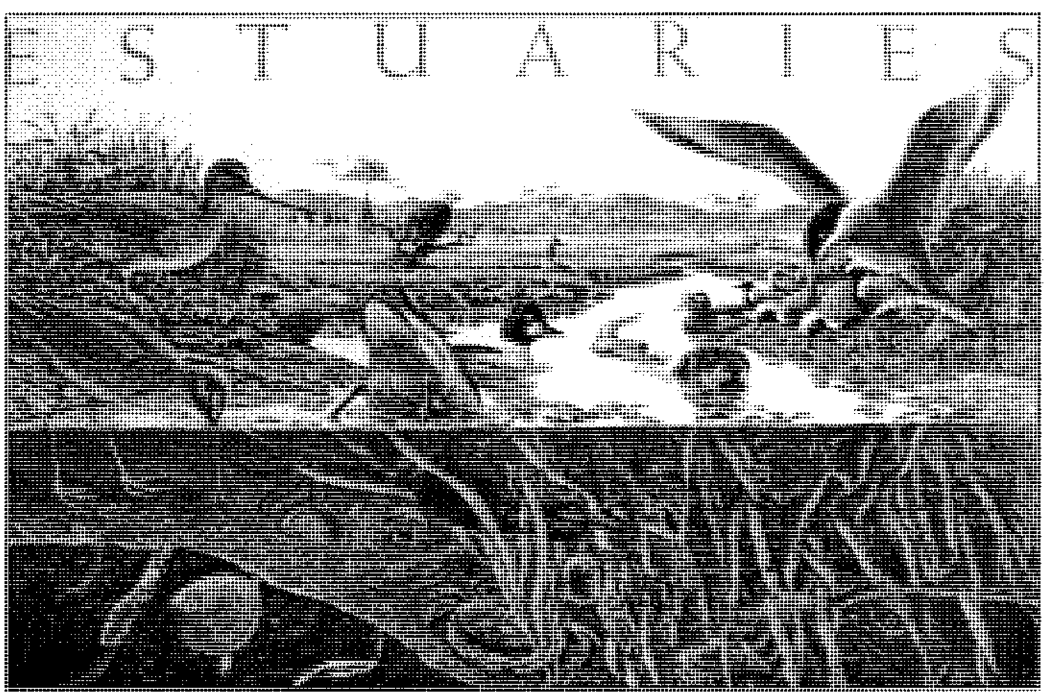


***Figure 1.**–Pacific Northwest estuaries support a great diversity of plants and animals. (Artwork by Larry Duke, courtesy of the Washington State Department of Ecology)*

One reason for the diversity and abundance of animal life in estuaries is their high *primary productivity.* In other words, they grow a prodigious amount of plant material that serves as food. Salt marsh grasses and sedges, thick beds of filamentous algae, kelp, eelgrass, and literally billions of single-celled diatoms and other microscopic plants called *phytoplankton* all are products of the estuary food factory.

Just how productive are estuaries? No one knows for sure, but scientists studying salt marshes in Nehalem Bay provide some hints. They found that just 1 square meter of Lyngby's sedge *(Carex lyngbyei),* one of the most abundant tidal marsh species, produces 1,850 grams of carbon each year–about 4 pounds. That scales up to more than 8 tons per acre per year.

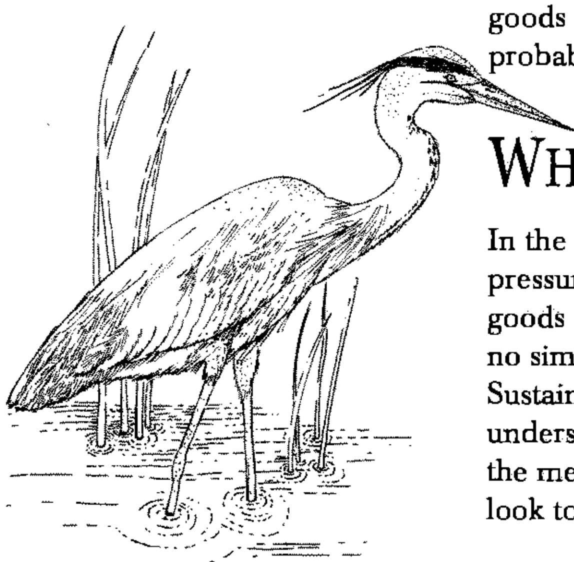
Nearly all of this material dies each fall and is recycled in the marsh or transported into estuarine waters. Microscopic bacteria break down this plant debris, contributing to the rich brew we call *detritus.* Detritus, transported by the tide throughout the estuary and into sloughs and tidal creeks, is the foundation of life in estuarine ecosystems.

Estuaries also help *keep water clean.* They use excess nutrients for plant growth and neutralize pollutants. These water-quality services would cost taxpayers millions of dollars using modern pollution-control technology, yet estuaries perform them for free if their assimilative capacity is not overwhelmed. Fringing marshes and other estuarine wetlands, like their upland counterparts, also *slow flood waters* and *stabilize the shore* to prevent erosion.

Finally, estuaries are vital for the *economic and recreational services* they provide–transportation, commerce, commercial and recreational fishing, clamming, waterfowl hunting, birding, boating, sailing, sight-seeing, and simple enjoyment of nature. Among the goods and services estuaries provide, these are the most visible and probably the most valuable in dollar terms.

WHAT CAN WE DO?

In the face of continuing population growth and development pressures, how can we sustain or even increase the flow of estuarine goods and services for ourselves and future generations? There are no simple answers, the task is not small, and no one can do it alone. Sustaining healthy estuaries over the long term requires an understanding of existing problems and challenges, clear goals and the means to achieve them, the ability to learn from the past and look to the future, and the will to make decisions.



Great blue heron

For Oregon's estuaries, we need to:

- Protect and conserve the remaining critical estuarine habitat.
- Restore former or degraded estuarine habitats where feasible.
- Link estuarine restoration actions to upland and upstream restoration and enhancement efforts for a whole-watershed approach.
- Monitor water quality, clean up existing pollution, and prevent new pollution that cannot be readily assimilated.
- Avoid the inadvertent introduction of harmful plants and animals.
- Work simultaneously from the bottom up (the community level) and the top down (through state and federal assistance) to make sure our efforts are feasible and effective both locally and regionally.
- Incorporate both local knowledge and the best available scientific information into our planning, decision making, and projects.
- Conduct necessary research to improve understanding of estuarine ecosystems and their relationships to marine and freshwater systems.

OREGON'S ESTUARIES

With 22 "major" estuaries (Figure 2) and many smaller ones, Oregon would seem to be estuary-rich. Actually, quite the opposite is true. According to a National Oceanic and Atmospheric Administration inventory, Oregon has only about 0.6 percent of the estuarine acreage in the lower 48 states (210 square miles of more than 35,000 nationally).

The Columbia River estuary constitutes more than half of this area, so the remaining Oregon estuaries are comparatively small. Except for the Umpqua and Rogue, the watersheds they drain also are small, reflecting the geology and topography of the mountainous coastal zone.

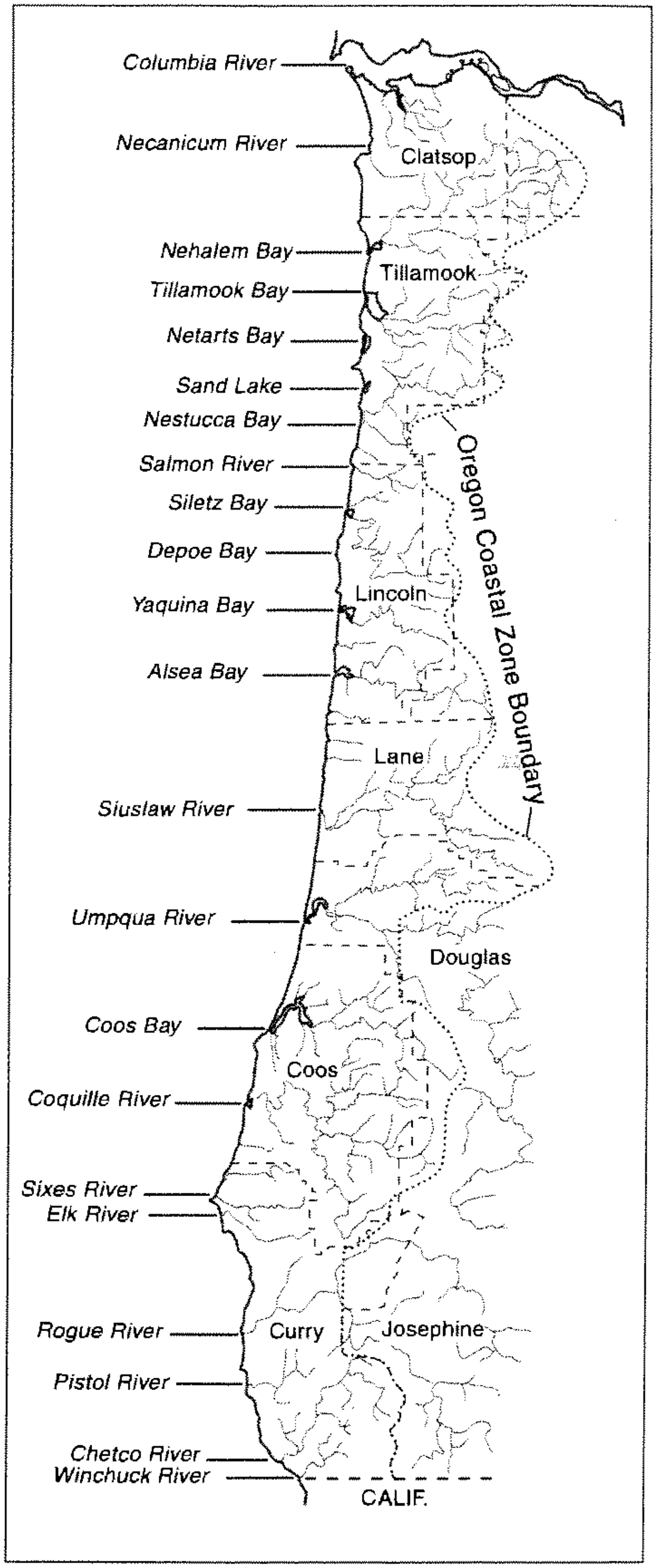


***Figure 2.**—Oregon's principal estuaries.*

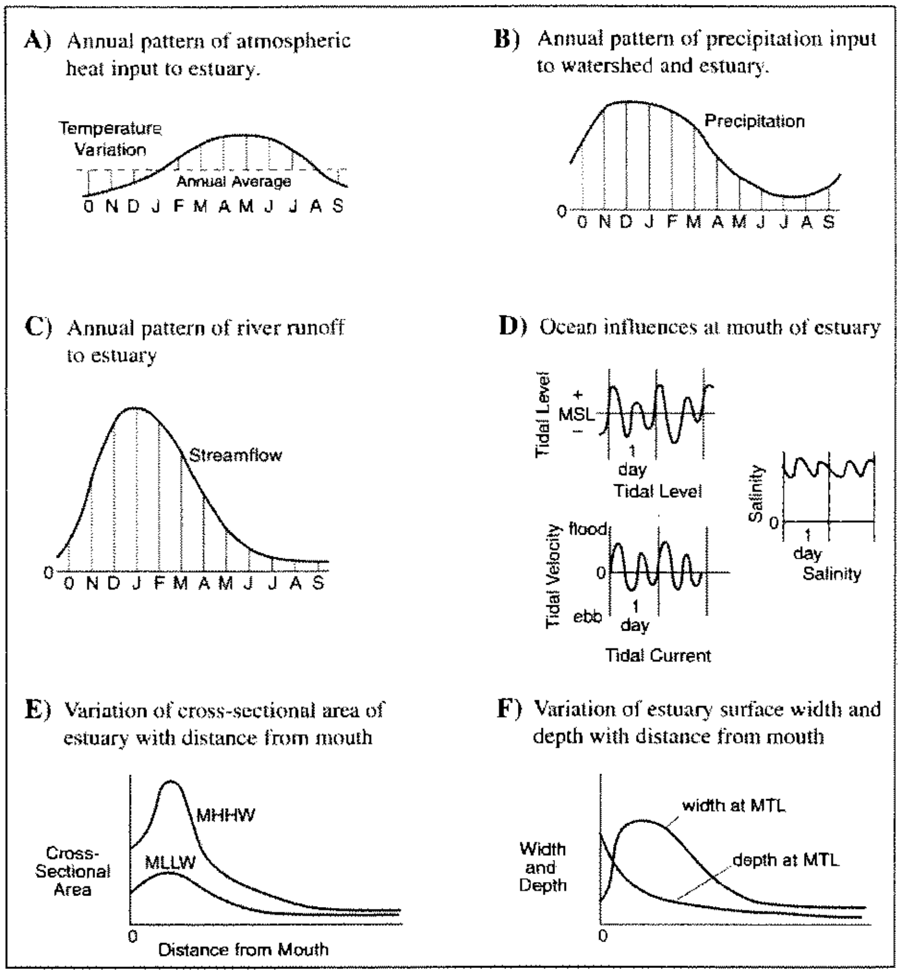


Figure 3.–Important physical factors affecting Oregon estuaries and their typical variability. (Modified from General Planning Methodology for Oregon Estuarine Natural Resources, ***Klingeman and Bella, 1973)***

Despite their small size, Oregon's estuaries play a vital role in the ecological and economic health of the coast and the entire state. For example, they are ecologically important to many fish and wildlife species, providing migration routes and habitat for reproduction, rearing, resting, and foraging.

Oregon's estuaries also serve coastal communities. Deep draft shipping, commercial fishing, port facilities, other businesses that depend on water access, and recreational uses are examples. Providing for these and other uses while protecting estuarine ecosystems and natural resources is the key challenge for public agencies, nongovernmental organizations, private businesses, and users.

Each of Oregon's estuaries is a unique ecosystem influenced by many variables–watershed size, geology, and land use; river gradient; the estuary's shape and size; and annual patterns of precipitation, river runoff, solar heat input, ocean tides, and fresh water–salt water mixing. Some of these variables can be generalized for Oregon's estuaries (Figure 3).

Typically, heat input increases during spring and summer, spurring biological productivity at the same time nutrient-rich water is upwelling along the coast. Except for the Columbia, local precipitation and streamflow are roughly *synchronous*. (As precipitation increases, so does streamflow.) Streamflow peaks on the Columbia are linked more closely to spring snowmelt in the Cascades and the Rockies.

Tides at the entrance to Oregon's estuaries are similar as well, but the ocean's influence within each estuary is unique. River flow and the shape of the estuary strongly affect mixing and circulation patterns, salinity zones, and the distribution of bottom sediments.

Oregon estuaries north to south

The *Columbia River estuary,* with more than 80,000 acres of surface area in Oregon alone, is larger than all of the other Oregon estuaries put together (Figure 2 and Table 1). Draining one of the largest river basins in North America (259,000 square miles), the Columbia's estuary is dominated by the river's freshwater inflow. Although the head of tide extends 146 miles upstream to Bonneville Dam, traces of salt water rarely are found above River Mile 30, even at low flow.

The freshwater nature of this estuary makes it very different from the smaller estuaries to the south. For example, of the more than 10,000 acres of Columbia estuary tidal marsh, only a small fraction are salt marsh. The rest are freshwater tidal wetlands.

From the Columbia River south to the Salmon River, the coastal mountains are a complex mix of sedimentary and volcanic rocks. Two estuaries–*Nehalem Bay* and *Tillamook Bay*–are relatively large by Oregon standards and have large watersheds. Other estuaries of the north coast–the *Necanicum River, Netarts Bay, Sand Lake, Nestucca Bay,* and *Salmon River*–are small and drain smaller watersheds. Netarts Bay and Sand Lake, with very small watersheds and limited freshwater input, essentially are saltwater lagoons.

South of the Salmon River are the *Siletz Bay, Depoe Bay, Yaquina Bay, Alsea Bay, Siuslaw River, Umpqua River, Coos Bay,* and *Coquille River* estuaries. The watersheds of these estuaries are moderate in size, except for tiny Depoe Bay and the much larger Umpqua system, which rises in the southern Oregon Cascades near Crater Lake and cuts through the Coast Range. These estuaries have large areas of salt marsh, eelgrass, and tidal flat habitat. The head of tide extends far upriver–41 miles on the Coquille, for example.

Along this part of the coast, the mountains are mostly older marine sediments and sands and clays eroded from ancient mountains to the south and east. These materials subsequently were folded and uplifted to form the Coast Range. Estuaries formed as sea level rose after the last ice age, drowning river valleys and stabilizing at roughly the present level about 6,000 years ago.

South of the Coquille River estuary at Bandon are six small estuaries–the *Sixes, Elk, Rogue, Pistol, Chetco,* and *Winchuck.* The estuaries of these steep-gradient rivers extend only a few miles upstream at most and have gravelly bottoms and little tideland (Table 1). These rivers drain out of the rugged Klamath Mountains and, except for the Rogue, have relatively small watersheds. During the summer, when flow becomes extremely low, the Sixes, Elk, Pistol, and Winchuck estuaries sometimes close off at the mouth as sand berms pile up and clog the entrance. The Rogue, like the Umpqua River to the north, drains a large watershed with headwaters high in the Cascades.

Table 1.–Geomorphic type, head of tide, habitat type and size, and watershed size for Oregon's estuaries.

Estuary	Geomorphic type	Head of tide (river mile)[1]	Intertidal area habitat type (acres)					Subtidal area (acres)	Estuary area (acres)	Watershed area (square miles)
			SM	FM	FSS	TF	SAV			
Columbia	RIV/DRM	146[3]	1,488	5,728	4,290	21,391	0	47,914	80,811	259,000
Necanicum	BB	~4	94	35	3	136	4	179	451	87
Nehalem	DRM	8.9	509	3	12	581	652	992	2,749	855
Tillamook	DRM	6	881	0	3	4,226	2,024	2,082	9,216	540
Netarts	BB	~5	228	0	0	1,224	957	334	2,743	14
Sand Lake	BB	~2	462	0	0	255	66	114	897	17
Nestucca	DRM	8.5	205	0	0	430	242	299	1,176	322
Salmon	BB	5	238	0	0	28	76	96	438	75
Siletz	DRM	22.6	274	0	0	425	461	301	1,461	373
Depoe[2]	DRM	<1	–	–	–	–	–	–	~25	15
Yaquina	DRM	21.8	619	2	0	807	968	1,953	4,349	253
Alsea	DRM	11.5	460	0	0	764	564	728	2,516	474
Siuslaw	DRM	22.8	746	0	0	541	338	1,435	3,060	773
Umpqua	RIV/DRM	29.2	1,054	52	95	1,196	399	3,748	6,544	4,560
Coos Bay	DRM	10.2	1,699	28	0	4,240	2,256	5,125	13,348	605
Coquille	DRM	~39	276	0	0	228	103	475	1,082	1,058
Sixes[2]	BL	~2	–	–	–	–	–	–	330	129
Elk[2]	BL	~1	–	–	–	–	–	–	290	94
Rogue	RIV/DRM	4.5	39	5	0	201	77	558	880	5,100
Pistol[2]	BL	~1	–	–	–	–	–	–	230	106
Chetco	DRM	3.4	0	4	0	9	103	55	171	359
Winchuck[2]	BL	~1	–	–	–	–	–	–	130	70
Total			**9,272**	**5,857**	**4,403**	**36,682**	**9,290**	**66,863**	**132,897**	**274,874**
% of total			7.0	4.5	3.3	27.8	7.1	50.3	100	

Source: *Oregon Estuary Plan Book,* 1987; DSL, 1989.

[1]The river mile (RM) on the major tributary stream where fluctuations in tidal elevations cease; for some estuaries, measurement begins at the mouth; for others, such as the Coos River, it begins where the river joins the estuary. (See DSL, 1989.)

[2]Specific habitat area data are not available for these smaller estuaries of the south coast.

[3]Although the head of tide on the Columbia River is RM 146, the "estuary," for habitat delineation purposes, extends only to RM 38, the upstream limit of the salt water mixing zone at the south end of Puget Island.

Key

Geomorphic type

DRM = drowned river mouth; RIV/DRM = river-dominated DRM; BB = bar-built; BL = blind/closed

Habitat type

SM = salt marsh; FM = fresh marsh; FSS = forested/scrub-shrub; TF = tidal flats; SAV = eelgrass/algae

Tides and tidal currents

What causes tides? What kind of tides do we experience along the Oregon coast? What happens when the tide enters a bay or estuary? The answers to these questions are critical to understanding how waters mix and circulate in estuaries, how and where different types of habitats develop, and how damaged or degraded estuaries might be restored.

Tides actually are very long period waves, with 12 hours and 25 minutes between successive crests (high tide) or troughs (low tide). See Figure 4. The wave length of the tide is equal to one-half the earth's circumference.

Many celestial bodies influence tides by their gravitational pull on the fluid ocean surface, but the moon and sun are by far the most important. Tides are strongest and the daily tidal range is great when the moon and sun align either on the same side of the earth (at the new moon) or on opposite sides of the earth (at the full moon). We call these *spring tides*. At the quarter moon, between new and full moons, tides are weaker, with smaller differences between the highs and lows. These we call ***neap tides***. Over the course of a

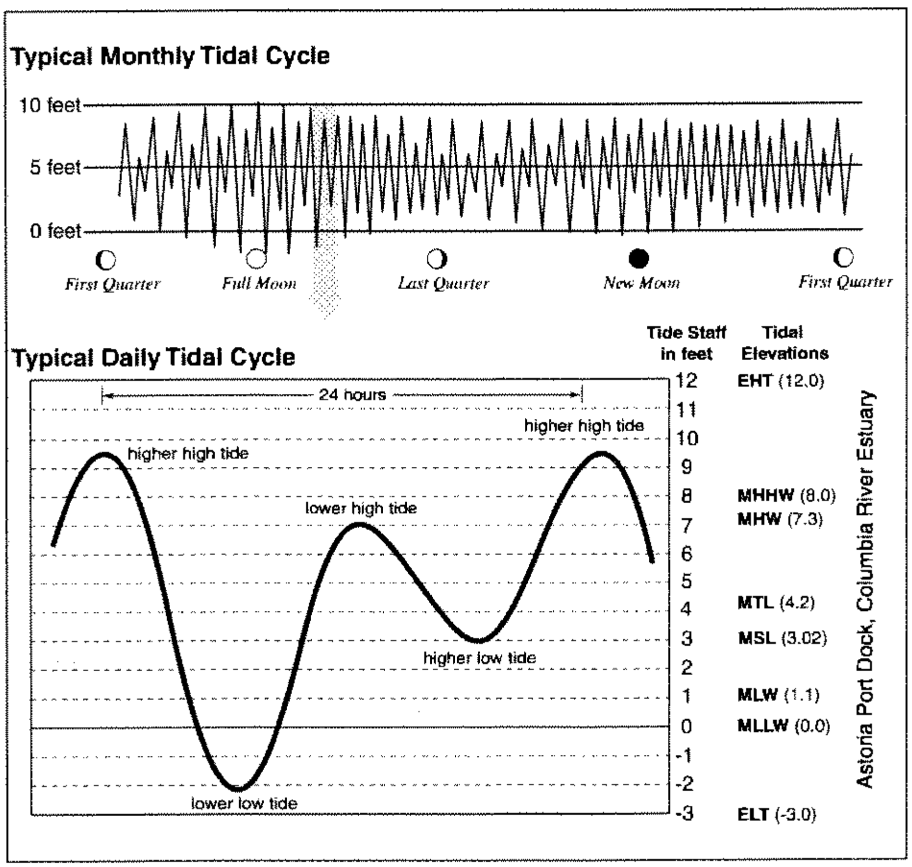


***Figure 4.**–Tidal cycles, terminology, and typical elevations along the Oregon coast.*

Tidal Terminology

Extreme High Tide (EHT)–The highest projected tide that can occur. It is the sum of the highest predicted tide and the highest recorded storm surge.

Mean Higher High Water (MHHW)–The average height of the higher of the two daily high tides observed over a specific time interval.

Mean High Water (MHW)–The average of all observed high tides. The average is of both the higher high and the lower high tides recorded each day over a specific time period.

Mean Tide Level (MTL)–The average of the MHW and MLW at a given station.

Mean Sea Level (MSL)–A datum based upon observations taken over a number of years at various tide stations along the west coast of the United States and Canada.

Mean Low Water (MLW)–The average of all observed low tides. The average is of both the lower low and the higher low tides recorded each day over a specific time period.

Mean Lower Low Water (MLLW)–The average height of the lower of the two daily low tides observed over a specific time interval.

Extreme Low Tide (ELT)–The lowest estimated tide that can occur.

lunar month, there are two periods of spring tides (new and full moon) and two of neap tides (quarter moons). See Figure 4.

Each day along the Oregon coast, there are two high tides and two low tides of unequal height and duration (Figure 4). *Mixed semidiurnal tide* is the technical term for this kind of tide. The outgoing (receding) tide is called an *ebb tide*. The incoming (rising) tide is called the *flood tide*.

The *datum* or "zero mark" for measuring tidal elevations in our region is the mean lower low water (MLLW), which is the average of the lowest of the two daily low tides over many years.

The *mean tidal range* is the difference in elevation between the average of all low tides and the average of all high tides. It is a bit more than 6 feet along the Oregon coast. Extreme low tides may be 3 feet or more below MLLW, and extreme high tides can be 12 feet or more above MLLW–a difference of 15 feet! Figure 4 shows Oregon reference elevations for a number of important tidal elevations, all referenced to the zero datum (MLLW). Several of these elevations are particularly important for estuarine management and restoration.

Mean high water (MHW), the average of all observed high tides, sets the boundary between state-owned tideland and privately owned land. Most high salt marshes (generally between MHW and the upland) thus are privately owned, although they still are part of the estuary and subject to estuarine planning and regulation. This topic is discussed further under "Human uses and management of estuaries."

Tidal currents are horizontal movements of water associated with the rise and fall of the ocean surface. For drowned river mouth estuaries such as Nehalem Bay or Yaquina Bay, these currents generally are strongest on the ebb tide as river water that was backed up by the incoming tide moves out on the ebb. In bar-built estuaries with little freshwater inflow–Netarts Bay, for example–flood currents may be equally as strong as ebb currents. See "Physical classification of estuaries" below for descriptions of these different types of estuaries. The shape of an estuary, especially its channel constrictions, also affects current velocity.

The timing of the strongest currents varies by estuary, but generally they occur about midtide, when the "tide is running." Slack water–when there is no tidal current–generally occurs soon after low tide or high tide.

How the tide affects an estuary depends on four main factors:

- The range of the tide at the ocean entrance (difference in height between high and low tide)

- The shape of the estuary basin, which determines timing and elevations of the tide at any given location as it moves in or out of the estuary
- The size of the estuary's opening at its mouth, which determines how much water can enter and exit during the tidal cycle
- The amount and variability of freshwater inflow

All but the first of these factors are different for each Oregon estuary. Despite these differences, the tide's ecological roles generally are the same in all estuaries. As they ebb and flow, tides provide huge amounts of energy to estuaries. They mix and circulate dissolved plant nutrients and they redistribute organic detritus–the tiny bits and pieces of plants, bacteria, decomposing plankton, and other debris that small animals eat. Tides and tidal currents also strongly influence the development, structure, and function of estuarine habitats through their influence on temperature, inundation time, sunlight and heat exposure, and wind and wave energy.

Physical classification of estuaries

Although each estuary is unique, a number of classification systems have been developed to help sort out similarities and differences in form and function. Some of the most useful are explained below.

Geomorphology

Geomorphology relates to the origins and development of the landscape. From a geomorphic perspective, Oregon's estuaries are classified as drowned river mouth, bar-built, or blind (closed). See Table 1.

Drowned river mouth estuaries formed as ancient river valleys were flooded by the rising sea at the end of the last ice age. Today, these estuaries have relatively large coastal watersheds. They are freshwater (river) dominated during winter, when runoff is high, but saltwater dominated in the dry summer and fall. Coos Bay is a good example. The Columbia River estuary is a special kind of drowned river mouth estuary. It is river dominated and comparatively fresh all year long. The Umpqua and Rogue also are river dominated, but not to the same extent.

Bar-built estuaries such as Netarts Bay and Sand Lake are partially enclosed and sheltered by sand spits. They have very small watersheds and little freshwater input, and are strongly influenced by tides and seawater. Some estuaries, such as the Necanicum and Salmon, might be classified as either bar-built or drowned river mouth.

Blind or *closed estuaries* are open in the winter when rainfall and streamflow are high, but are closed at the mouth by sand bars during the summer when flows are low. The Sixes River estuary near Cape Blanco and other small south coast estuaries are examples.

Mixing and circulation

Characteristic patterns of salt- and freshwater mixing and circulation also are used to classify estuaries. Mixing and circulation types include stratified, partially mixed, and well mixed.

Stratified or "salt-wedge" conditions occur when both river flow and tides are strong. Seawater intrudes into the estuary along the bottom because it is slightly heavier than the freshwater coming downstream. At the boundary between the fresh- and saltwater layers, high shear forces allow only limited mixing between the two. In cross-section, the salt water looks like an intruding wedge along the bottom.

The Columbia River estuary is strongly stratified during strong tides in May and June, when annual river flow peaks. Stratified estuarine conditions also may exist during high winter flow and flood conditions in coastal estuaries such as the Nehalem or Siletz.

Well-mixed estuarine conditions occur when river flows are low and tides are weak. This situation occurs in many Oregon estuaries during summer and early fall before winter rains begin. Well-mixed, diluted seawater can be found far upstream in coastal rivers at these times.

Partially mixed conditions occur when both river flow and tides are moderate to high or strong. These conditions are typical during winter.

At different times of the year, any given estuary may fall into any of these classifications. Generally, however, estuaries that drain large river basins (the Columbia, Umpqua, and Rogue) more frequently exhibit stratified or partially mixed conditions than do estuaries with smaller drainages. These smaller estuaries typically are well mixed.

Mixing and circulation characteristics are important because they strongly influence an estuary's ecological functioning and thus the goods and services it provides. For example, mixing and circulation help determine where the best food resources are located and thus where predator and prey interact. Mixing and circulation patterns also determine how pollution concentrates or disperses and how long it takes to flush the system of wastes. Estuaries are tuned to these and other physical factors.

Salinity zones

Differences in salinity have a major influence on the biology of estuaries. Estuaries are divided into four distinct geomorphic salinity zones. The actual boundaries of these zones shift back and forth with tidal cycles and changes in river discharge.

The *marine-estuarine interface zone* is located immediately *outside* the mouth of an estuary. This zone is characterized by a mixture of seawater and freshwater in the range of 33 to 25 psu (practical salinity units). Where the volume of river discharge is high (the Columbia, Umpqua, and Rogue, for example), this zone can extend far out into the ocean. Where river discharge volume is relatively low (Yaquina Bay, for example), the marine-estuarine interface zone is confined to the area immediately offshore the river mouth and is strongly influenced by the ebb and flood of the tides.

The *marine-dominated lower estuary zone* is located just *inside* the mouth of the estuary and is characterized by high variability in salinity (30 to 18 psu). Bottom sediments in this zone are mainly fine sands of marine origin.

The *middle estuary mixing zone* is located farther up the estuary. Salinity in this zone ranges from 18 to 5 psu, and bottom sediments are a mixture of fine sands of marine origin, riverine sediments from the watershed, silt, and organic matter.

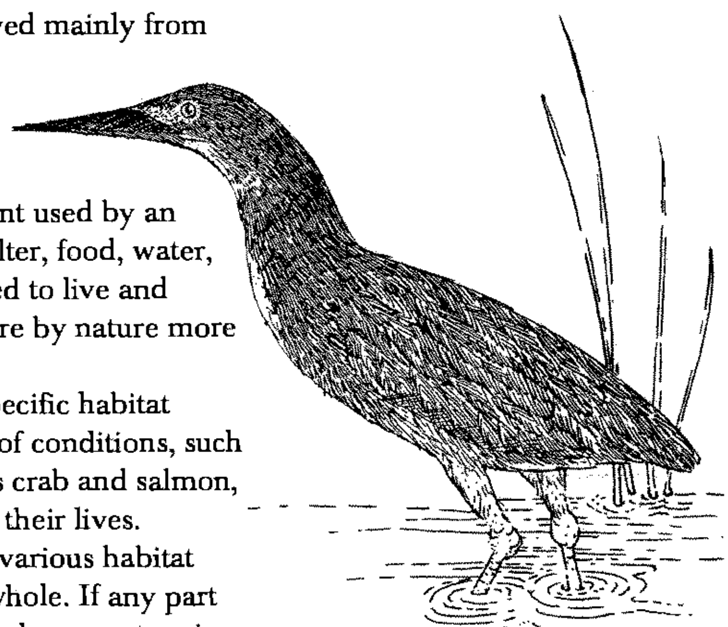
The *upper estuary riverine zone* extends from the mixing zone upriver to the head of tide. Salinity ranges from 5 to 0.5 psu—virtually fresh water at certain times of the year. Bottom sediments are fine sand, silt, clays, and other materials derived mainly from the watershed.

Estuarine habitats

Habitat is the portion of the natural environment used by an organism. It is where plants and animals find shelter, food, water, reproductive mates, and other resources they need to live and reproduce. Some habitats, such as salt marshes, are by nature more productive than others.

Some types of plants and animals have very specific habitat requirements, while others tolerate a wide range of conditions, such as those found in estuaries. Many species, such as crab and salmon, depend on different habitats at different stages of their lives.

Although we may "deconstruct" estuaries into various habitat types, they, like other ecosystems, function as a whole. If any part of an estuarine habitat is lost or degraded, the whole ecosystem is degraded.



Green heron

A number of classification systems have been developed to differentiate estuarine habitats. One example is the Cowardin classification system, which is used in the National Wetlands Inventory and is described in chapter II-9, "Wetlands." Many of these habitats and the organisms found in Pacific Northwest estuaries are illustrated in Figure 5 and described below.

Subtidal habitats

Subtidal estuarine habitats include *channel bottoms, slope bottoms,* and the *open water* above them. Plants and animals found in these habitats are influenced by the gradient of salinity, the availability of light, and the type of bottom sediments.

Bottom sediments range from coarse gravel and marine sands near an estuary's mouth to fine sands and silts of both marine and terrestrial origins farther up the estuary. Hard-bottom areas also are

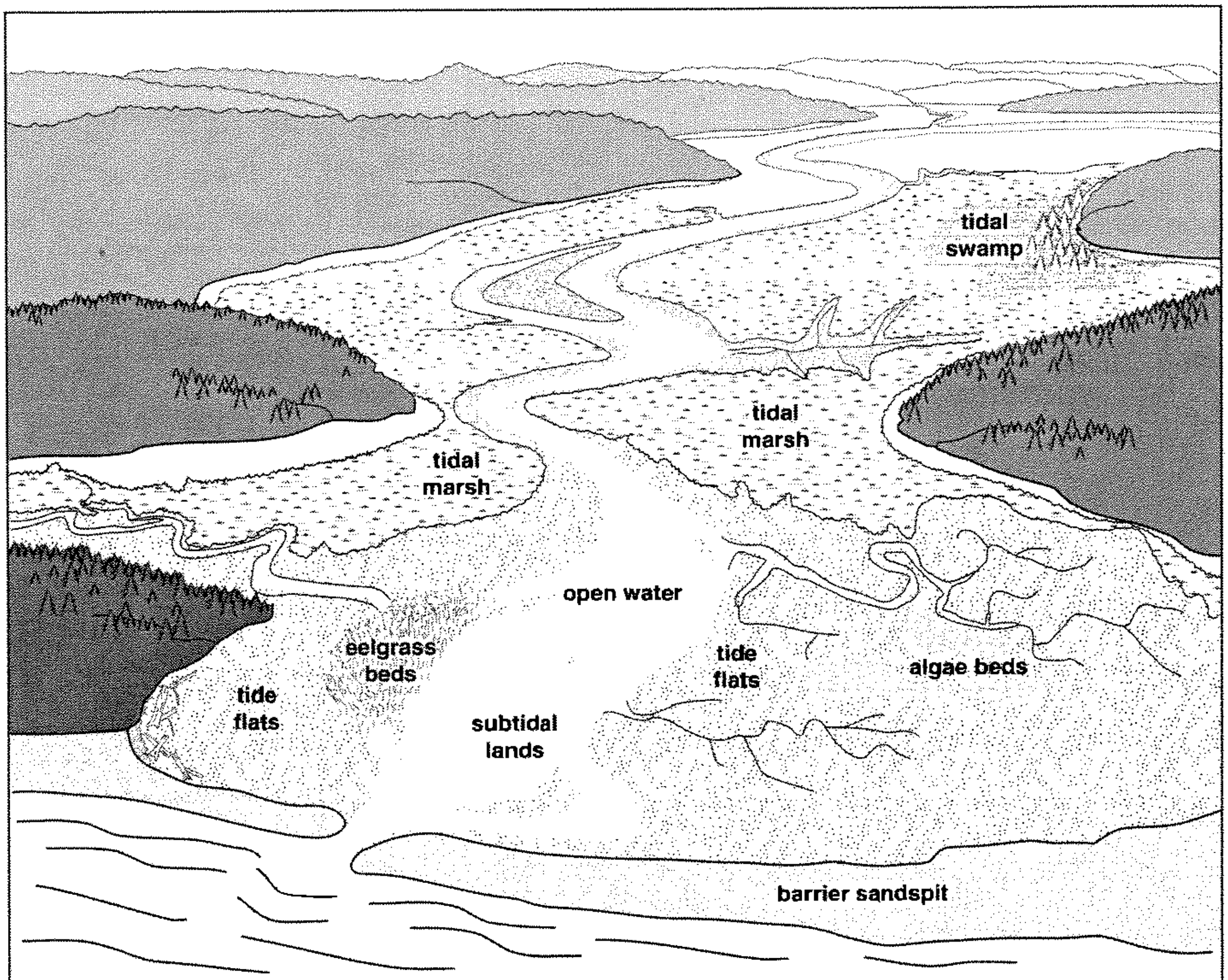


***Figure 5.**—The different habitats in Oregon's estuaries support an abundance of plant and animal life. (Drawing modified from* Oregon Estuary Plan Book, *1987)*

common, most often near the ocean entrance or within deep channels. Ebb and flood tidal currents are strongest in channels. Here they mix fine sediments and organic detritus within the water column, scour hard-bottom areas, move sandy sediments along the bottom, and process and redistribute food resources up and down the estuary.

Channels are the migratory routes for upstream-bound salmon and other fish, while juvenile salmon frequent the shallows. Large clams that make their home in the sediments of slopes and deep channels may serve as seed stock for colonizers of the shallower tidal flats.

Water column productivity reaches its maximum in the channel, where salt- and freshwater mixing is greatest. This dynamic mixing zone, which moves upstream and downstream with the tide, is called the turbidity maximum. Predator and prey alike are attracted to this region, and here the physical, chemical, and biological transformations that make estuaries unique reach a crescendo.

Eelgrass beds are another key estuarine habitat found along shallow subtidal slopes where sunlight can penetrate. Eelgrass beds are discussed below under "Tidal flat habitats."

Tidal flat habitats

Between the extreme low-water mark (about 3 feet below MLLW) and the mean tide level (about 4 to 5 feet above MLLW) are *tidal flats*. At low tide, tidal flats account for approximately one-third of Oregon's estuarine surface area, more than twice the area of tidal marshes. Tidal flats dominate backwater sloughs, shallow marginal embayments, and low-tide islands in estuaries.

Tidal flat sediments vary, ranging from coarse sand toward an estuary's mouth to fine sand, silt, and mud farther up the bay. The finer substrates often are referred to as soft-bottom habitats because they typically have a high water content and are stirred constantly by bottom-dwelling organisms.

Soft-bottom habitat can be recognized by anyone who has gone clamming in an Oregon estuary–perhaps it is where they left a boot behind. Bottom-dwelling organisms include a wide variety of clams, worms, shrimp, amphipods, and other animals that burrow below the surface. They feed on rich, detritus-laden tidal waters that they pump into their burrows, or on deposits of microscopic diatoms, bacteria, and organic detritus that form a slurry on the surface.

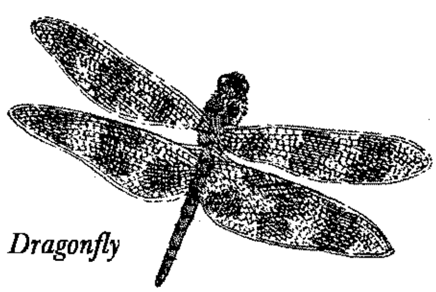
Tidal flats also are prime habitat for oysters and once supported vast numbers of the native oyster, *Ostrea lurida*. With the native oyster long ago harvested out, the imported Japanese oyster *(Crassostrea gigas)* is the predominant farmed species today.

Native *eelgrass beds (Zostera marina)* are found along the lower fringes of tidal flats and the shallow subtidal slopes they border. Like other rooted seagrass species, eelgrass' major life functions, including flowering and pollination, occur under water. Eelgrass beds serve a number of critical functions. They provide spawning substrate for herring; food for migrating black brant geese; and hiding places for young salmon, crab, and many other species. At low tide, blades of eelgrass lie across the exposed surface, protecting bottom-dwelling organisms from the hot summer sun. Eelgrass root systems also help stabilize the channels they border.

Highly productive *algae beds* also grow on tidal flats, particularly in the salty parts of an estuary. Sea lettuce *(Ulva),* filamentous algae *(Enteromorpha),* and mat-forming species *(Chaetomorpha)* are common. These species also help keep bottom-dwelling animals from drying out at low tide. Excessive algae growth, however, may be an indicator of too much nitrogen or other nutrients.

Tidal marsh and swamp habitats

At about the midtide level (4 to 5 feet above MLLW), there is a distinct transition from soft-bottom, algae, and eelgrass-dominated tidal flats to more upland-like environments dominated by rooted, flowering grasses, sedges, shrubs, and even trees. These are the estuary's tidal marsh and swamp habitats. The types of habitat and plant communities present are controlled mostly by elevation (which determines the tidal inundation period) and salinity. The tidal flooding of marshes and swamps in the upper reaches of an estuary is due in part to the "holdup" effect of the incoming tide on river flow. But even at low river flow, the tide may reach well upstream.



Dragonfly

Tidal marshes usually are highly dissected by complex networks of tidal creeks. These creeks serve as conduits for exchange of water, nutrients, and detritus, as well as low-tide refugia for small fish such as juvenile salmon. At high tide, these fish spread out across the marsh, feeding on estuarine invertebrates, aquatic insects, and even terrestrial insects wafting in from nearby riparian areas.

Tidal marshes in Oregon typically are composed of several distinct plant communities. In the lower and middle estuary, where bottom sediments are mostly fine sand, we find *low salt marsh.* Plant colonizers here include pickleweed *(Salicornia virginica)* and saltgrass *(Distichlis spicata).* Where sediments are a bit more silty, colonizers include arrowgrass *(Triglochin maritimus),* threesquare bullrush *(Scirpus americanus),* and Lyngby's sedge *(Carex lyngbyei).* The latter species forms large stands in low marshes, both salt and brackish.

At about 7 feet above MLLW (or approximately the MHW line), there often is a distinct break in elevation–sometimes 6 inches or more. This is where high salt marsh begins. This area is a highly diverse mix of grasses (e.g., tufted hairgrass, *Deschampsia caespitosa),* rushes *(Eleocharis* spp. and *Juncus* spp.), and other broadleaf species. It is flooded by tides only a few times each month, while lower marshes usually are flooded daily.

Where the high salt marsh transitions to upland, freshwater wetland species may dominate–skunk cabbage *(Lysichiton americanum),* slough sedge *(Carex obnupta),* silverweed *(Potentilla pacifica),* willow *(Salix* spp.), and others. These areas are fed by freshwater seeps from hillsides or by small streams.

As estuarine waters become brackish and then fresh farther upstream, the flora and fauna of tidal marshes, flats, slopes, and channels gradually change. Some of the plant species in tidal freshwater marshes are the same as those in salt marshes, but freshwater wetland plants begin to dominate. These marshes, like the salt marshes farther downstream, may be highly dissected by tidal creeks. They are popular habitats for juvenile salmon (chinook, coho, and chum) and sea-run cutthroat trout beginning their acclimation to the marine environment.

Brackish and freshwater tidal swamps of Sitka spruce *(Picea sitchensis)* and redcedar *(Thuja plicata)* with understories of red alder *(Alnus rubra),* willows *(Salix* spp.), and emergent marsh species once were common along the Oregon coast, but now are rare. Most of these areas were logged, cleared, and diked for agricultural use in the late 19th century–more than 24,000 acres in the Columbia estuary alone.

Some of the best preserved remnant tidal swamps are on the Oregon side of the Columbia estuary, one where Big Creek empties into the estuary, and another just upriver at Blind Slough. Both are nature reserves.

Connections to the watershed

The condition and quality of a watershed's aquatic and upland ecosystems have an enormous influence on its estuarine habitats (Figure 6). Activities such as road construction; forestry; agriculture; and urban, suburban, and rural development all have an effect. The resulting runoff pollution and changes in the quantity and timing of water inflow are particularly important. Assessment and management of upland and riparian habitats are described in detail in Chapters II-4, "Upland Evaluation and Enhancement," II-5, "Terrestrial Riparian Area Functions and Management," and II-6, "Riparian Area Evaluation and Enhancement."

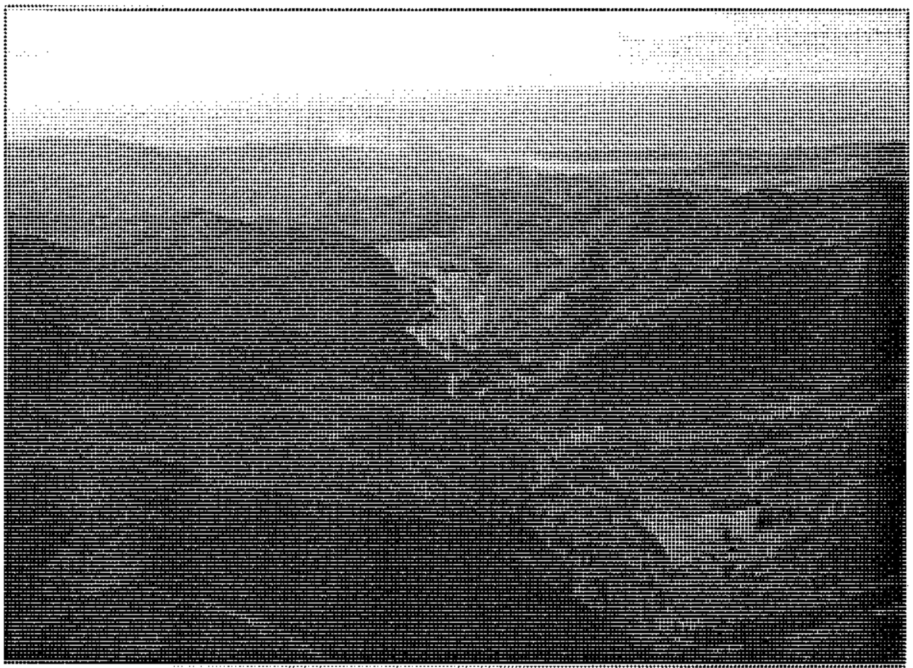


Figure 6.–What happens in the watershed affects the estuary and near-shore coastal waters. (Photo: Jim Good)

One of the most prominent links between estuaries and their watersheds relates to the life cycles of Pacific salmon and seagoing trout. The key role of estuaries in these species is discussed in the following section.

Salmon and estuaries

Recovery of salmon and steelhead stocks in the Pacific Northwest is a major environmental issue. The Oregon Plan for Salmon and Watersheds is a strategy for that recovery. Most recovery efforts have focused on improving freshwater stream and riparian habitat–primarily spawning and rearing areas.

However, by definition, any anadromous fish also must use an estuary for some part of its life. Pacific salmon and trout are no exception. Some travel quickly through the estuary to reach fresh water or salt water, while others linger longer, seeking food and shelter.

What functions do estuaries play in supporting salmonids, and how do historical and recent changes affect their capacity to fulfill these roles? Oregon's estuaries are particularly important for juvenile salmon for three reasons:

- Tidal creeks, marshes, eelgrass beds, and channels furnish young salmon with *productive feeding areas* where they forage and grow before heading out to sea (Figure 7).
- Shallow estuarine habitats *offer refuge from predators,* especially the marine mammals, birds, and fish that hunt for juvenile salmon in deep channels and near-shore areas.
- Brackish estuarine waters provide an *acclimation area for salmonid smolts* while they adapt to the marine environment.

Because estuaries are highly productive, salmon smolts often grow rapidly on the abundant food available there as they migrate to the ocean. The residence time and patterns for out-migrating juveniles differ substantially among and within species. Some move through to the ocean in just a few days, others forage in shallow embayments and backwater sloughs for months, and still others reverse their downstream migration and reenter freshwater streams for a time.

For a given species, research has shown that juvenile salmon with longer estuarine residence times have higher survival rates than those that move through quickly. Most likely this is because they grow larger and quicker before entering the sea and so are better able to avoid predators in the open ocean.

Five races of *chinook,* the largest but least abundant Pacific salmon, occur along the West Coast. Races are defined according to the season in which adults migrate from salt- to freshwater. Some populations enter coastal rivers and creeks in winter or spring, while others return in summer or fall. With the exception of a summer run in the Columbia, all chinook that use coastal Oregon streams are spring or fall migrants.

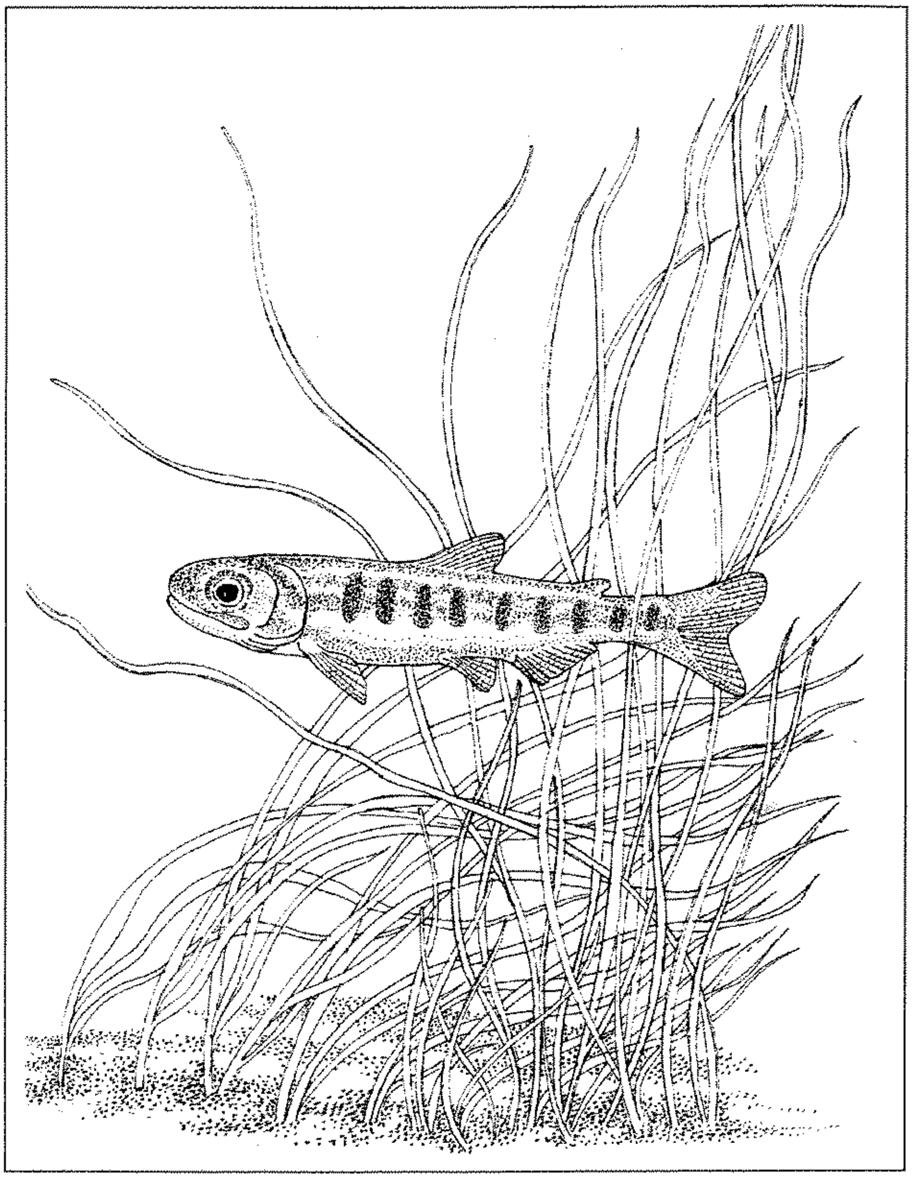


***Figure 7.**—Eelgrass beds, tidal creeks, and marshes are good hiding and feeding areas for young salmon. (Drawing by Sharon Torvik, courtesy of South Slough National Estuarine Research Reserve)*

Chinook fry and smolts often descend rapidly from their natal streams to the ocean, but some individuals spend up to 18 months in fresh water. So-called *subyearling estuarine smolts* migrate to estuaries soon after hatching, where they feed and grow for several months before entering the ocean. *Subyearling riverine smolts* spend less than a year in freshwater and move quickly through the estuary on their way to the sea. *Yearling riverine smolts* remain a year in the river, migrating seaward through the estuary the spring after they hatch.

Like adults, juvenile chinook are carnivorous. They are opportunistic feeders, meaning they will eat whatever is available. In the estuary, they frequent an assortment of habitats, from mud flats to eelgrass beds, and consume a large variety of invertebrate and fish larvae, crustaceans, insects, and fish. One of their favored foods is an amphipod with a giveaway scientific name, *Corophium salmonis*.

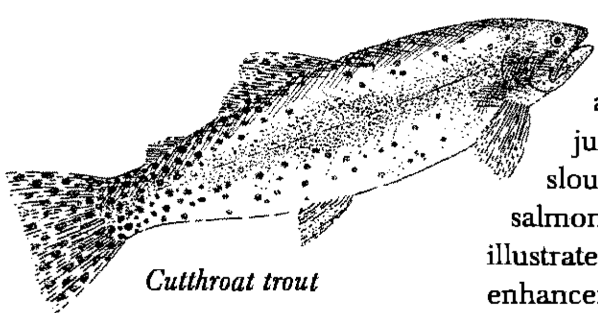
Coho salmon, which range along the Pacific coast from central California to northwestern Alaska, use all of Oregon's estuaries. Juvenile coho spend a year or more in fresh water before migrating to the ocean. Depending on location, smolts spend from a couple of days to a month or more in estuaries before heading to sea. Like chinook salmon, juvenile coho are opportunistic carnivores, feeding on large zooplankton and small crustaceans, insects, invertebrate and fish larvae, and juvenile fishes, including other salmonids.

Chum salmon occur from California to Alaska, but are most abundant in the northern part of their range. Soon after they absorb their yolk sacs, chum salmon fry head for the estuary, where they spend up to several months preparing for life at sea. Juvenile chum move throughout the estuary with tidal flows, frequenting tidal creeks, sloughs, and marshes. As opportunistic, carnivorous feeders, young chum salmon forage in shallow estuary waters for small crustaceans and terrestrial insects. Older chum move to deeper waters, where they prey on fish larvae, copepods, amphipods, and other crustaceans.

Steelhead spend little time in estuaries, usually just passing through on their way to the ocean (as smolts) or rivers (as adults). From February through May, *cutthroat* juveniles migrate from Oregon's coastal streams into estuaries, where they feed on insects, crustaceans, and fish. As they grow, young cutthroat show a marked preference for fish. Adult sea-run cutthroat often inhabit small tidal streams, sloughs, backwaters, and tidal freshwater regions of estuaries before fall rains spur their spawning migration. Some cutthroat reside permanently in estuaries.

It is not uncommon for adult salmonids occupying near-shore coastal waters to move into lower estuaries for brief periods to feed. Thus, estuaries serve as important feeding areas for both adult and juvenile salmonids. Additionally, just as some ocean-bound juvenile salmonids use the estuary to gradually acclimate to salt water, some returning adults use the estuary to reaccustom themselves to fresh water.

Historical changes to estuaries have greatly reduced the area and functions of estuarine habitats frequented by juvenile salmonids–mainly salt marshes, tidal creeks, and sloughs. Our understanding of the role that estuaries play in salmon life cycles is incomplete, but the evidence to date illustrates the high value of remaining habitat. Restoration and enhancement of estuarine habitats can increase production and



Cutthroat trout

acreage of salt marsh as well as the tidal creeks and eelgrass beds that provide food and shelter for salmonids. These actions will help restore estuaries' historical roles and provide a buffer against upstream disturbance and change.

Note: This section was adapted from *Salmon and Trout in Oregon Estuaries*, by Ken Oberrecht.

HUMAN USES AND MANAGEMENT OF ESTUARIES

People have been attracted to estuaries for millennia. In the Pacific Northwest, native peoples built their villages along the shore; harvested the abundant salmon, oysters, and other fish and shellfish; and used the estuaries as transportation and trading routes. Early Euro-American settlement of the coast centered around estuaries. Astoria, Newport, Reedsport, and Coos Bay (then Marshfield) were a few of these early cities.

Like native peoples, Euro-American settlers were attracted to estuaries by transportation convenience, vast natural resources, and flat land. Rivers were used to transport logs down to the estuary for storage, processing at local mills, or shipment to distant markets. The 20th century saw growth of existing and new settlements; improvements in ports and navigation; industrial and commercial development; and commercial and recreational exploitation of salmon, oysters, and other living resources. In recent decades, residential and recreational development has boomed along estuary shorelines, bringing demands for more public access and amenities. With all of this development has come a plethora of unwanted by-products–pollution, conversion of valuable wetlands to other uses, decline of native fisheries, invasion of estuaries by nonnative nuisance species, and crowding of highways and recreational facilities.

These historical and more recent changes are discussed later in this chapter.

Who owns Oregon's estuaries?

The State of Oregon, as trustee for its citizens, owns and manages most of the land beneath tidal and commercially navigable waters, up to mean or ordinary high water (Figure 8). When Oregon was admitted to the Union in 1859, it received title to these submerged and submersible lands from the Federal government, as other states did before and have since.

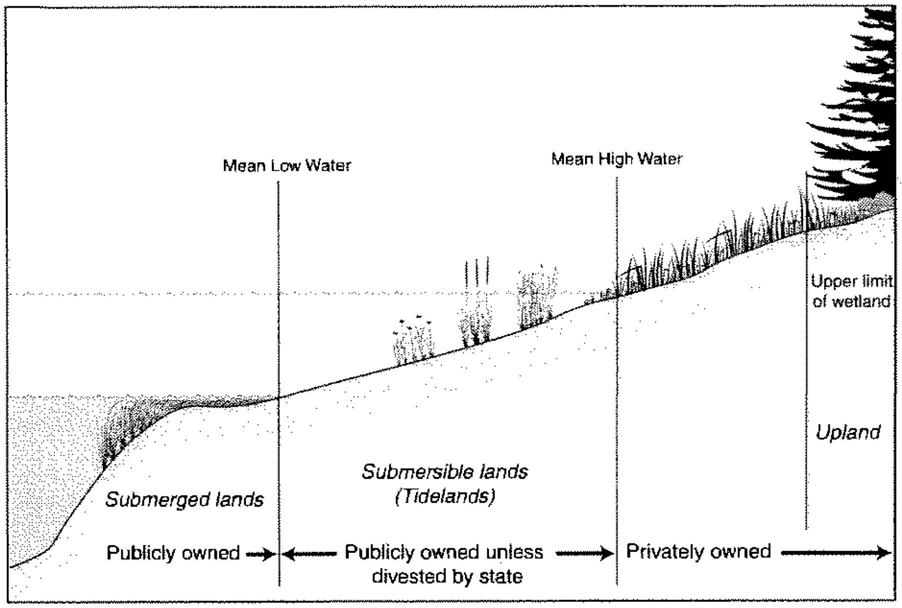


Figure 8.—Ownership boundaries for Oregon estuaries.

Through the State Land Board, Oregon has sold or leased some of these lands and still can do so. For example, tracts of tideland in larger estuaries such as Coos Bay, Tillamook Bay, Yaquina Bay, and the Umpqua estuary were sold before and just after the turn of the 20th century, often for oyster farming.

However, the state may not relinquish its responsibility to protect certain public rights to these lands. Collectively termed the "Public Trust Doctrine," these rights permit the public to navigate on and over the water; to harvest fish, shellfish, and waterfowl; and to use the water as a highway of commerce. Court decisions in the 1980s expanded public trust rights to include recreational and aesthetic values as well.

Protection of these rights is a fundamental principle used by the State of Oregon in leasing and regulating uses of state waterways and wetlands, including estuaries. Through the state removal-fill law (discussed later in this chapter and in Chapter II-9, "Wetlands"), the public trust concept has been extended to all waters of the state, both public and private, including wetlands. Even the areas of submerged land in estuaries that were sold to private parties nearly a century ago are subject to the public trust doctrine. Only permanent filling—rare today—cancels these public rights.

Although the state owns tidelands up to MHW, the extensive high tidal marshes that fringe estuaries are mostly in private ownership (Figure 8). This situation makes it necessary to involve many landowners when considering restoration and enhancement activities.

Estuary changes—prehistory, early white settlement, and development to 1970

Oregon's estuaries are affected by both natural and human disturbances. Probably the most catastrophic natural disturbances to estuaries are the large earthquakes and tsunamis that occur every 300–600 years along the Cascadia subduction zone just offshore. When one of these great earthquakes strikes (the last event occurred in 1700), coastal lands subside, soils liquefy, landslides are triggered, and tsunami waves inundate the coast and estuaries. No doubt these events have resulted in major environmental changes in estuaries. Major forest fires that predate Euro-American settlement of the region are another example of natural disturbances that likely had significant estuary impacts due to the large pulses of wood, debris, and sediment that followed. Climate variability associated with El Niños, La Niñas, and longer period oscillations likely affect estuarine ecology in more subtle ways, but these have not been studied.

Native peoples used estuaries and tidal wetlands for hunting, fishing, and shoreline settlement for several millennia, but their use likely had little adverse effect on the health and functioning of these ecosystems. Euro-American settlement of the region began in earnest in the mid-19th century. Over the next 150 years, physical alterations designed to improve navigation and provide land for growing ports, cities, and small farms changed the estuarine landscape but degraded its natural functions.

Most apparent are the direct physical changes. Examples include:

- Stabilization of river mouths with jetties–10 estuaries
- Dredging to deepen or stabilize river channels and construct turning basins and marinas–nine estuaries
- Stabilization of shorelines with rock or bulkheads–all estuaries
- Diking and draining of tidal marshes for agriculture–15 estuaries, more than 41,000 acres (Figure 9)
- Filling for industry, ports, marinas, highways, and similar development–all estuaries, nearly 8,000 acres (Figure 9)

These physical changes reduced the overall size of Oregon's estuaries by about one-quarter by 1970 (Table 2 and Figure 10). In most estuaries, the greatest change was the diking or filling of tidal swamps, marshes, and shallow

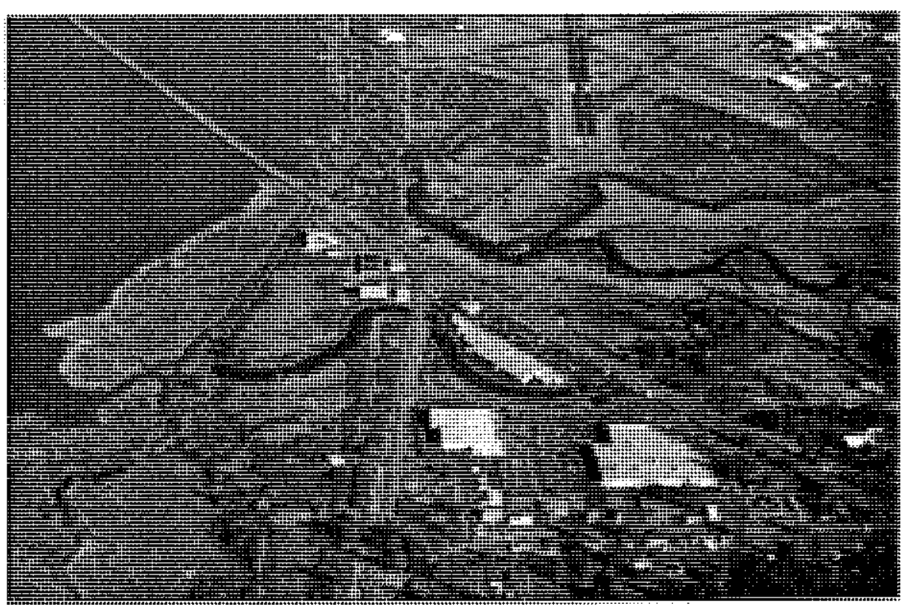


***Figure 9.**–This former tidal wetland in Warrenton, Oregon, illustrates typical physical alterations in Pacific Northwest estuaries–diking, draining, farming, logging, filling for railroad and highway construction, airport construction, and commercial and residential development. (Photo: Jim Good)*

flats. By 1970, tidal marshes and swamps along the Oregon coast had been reduced by two-thirds (Table 2 and Figure 10). Two estuaries–the Nestucca and Coquille–lost more than 90 percent of their tidal wetlands. Tillamook Bay lost 79 percent, and the Nehalem 75 percent. In absolute terms, the Columbia estuary lost the most tidal marsh and swamp habitat (Figure 11), followed by the Coquille, Tillamook, Nestucca, Coos, Nehalem, Yaquina,

Table 2.–Change in total area and area of vegetated wetlands (tidal marshes and swamps) for Oregon's 17 largest estuaries, due to filling and diking that occurred from about 1870 to 1970.

Estuary	Actual 1970 area (acres)[1]		Veg. wet. filled[2]	Veg. wet. diked[3]	Estimated 1870 area (acres)[4]		Percent change (1870–1970)	
	Veg. wet.	Total			Veg. wet.	Total	Veg. wet.	Total
Columbia	16,150	119,220	5,660	24,390	46,200	156,190	-65%	-24%
Necanicum	132	451	15	–	147	466	-10%	-3%
Nehalem	524	2,749	27	1,544	2,095	4,320	-75%	-36%
Tillamook	884	9,216	355	2,919	4,158	12,490	-79%	-26%
Netarts	228	2,743	5	11	244	2,759	-7%	-1%
Sand Lake	462	897	4	5	471	906	-2%	-1%
Nestucca	205	1,176	1	2,159	2,365	3,336	-91%	-65%
Salmon	238	438	12	301	551	751	-57%	-42%
Siletz	274	1,461	2	399	675	1,862	-59%	-22%
Yaquina	621	4,349	253	1,240	2,114	5,842	-71%	-26%
Alsea	460	2,516	25	640	1,125	3,181	-59%	-21%
Siuslaw	746	3,060	41	1,215	2,002	4,316	-63%	-29%
Umpqua	1,201	6,544	106	1,112	2,419	7,762	-50%	-16%
Coos Bay	1,727	3,348	1,260	2,100	5,087	16,708	-66%	-20%
Coquille	276	1,082	55	4,545	4,876	5,682	-94%	-81%
Rogue	44	880	27	3	74	910	-41%	-3%
Chetco	4	171	5	0	9	176	-56%	-3%
Total	24,176	170,301	7,853	42,583	74,612	227,657	-68%	-25%

[1]Data for 1970 estimates are from the *Oregon Estuary Plan Book* (Cortright and others, 1987), except for the Columbia, where estimates are based on Thomas, 1983.
[2]Data on filled lands are from filled state lands inventories (Oregon Division of State Lands, 1972). For this table, since the bulk of filled lands are adjacent to the shore, it was assumed that they were vegetated tidal wetlands. This may have resulted in a small error in totals and percent change.
[3]Data on diked lands are from Thomas, 1983 for the Columbia estuary; from S. Rumrill for Coos Bay (personal communication, 1999); and from unpublished, preliminary analyses of National Wetland Inventory maps, soil surveys, and aerial photos for the remaining estuaries (C. Cziesla, S. O'Keefe, A. Gupta, and J. Good, 1999).
[4]1870 area estimates were derived by adding the area of filled land and diked land to the 1970 area estimates.

Siuslaw, and Umpqua estuaries (Table 2).

Despite these huge changes in Oregon's estuaries, large areas of intact tidal marsh, flats, and other productive, healthy habitat remain today or are being restored in most estuaries. But none of Oregon's estuaries can be restored to the relatively pristine conditions of 150 years ago. At the very least, watershed dams, logging, agriculture, and rural settlement have changed the volume and timing of water inflow and inputs of sediment and other runoff pollution.

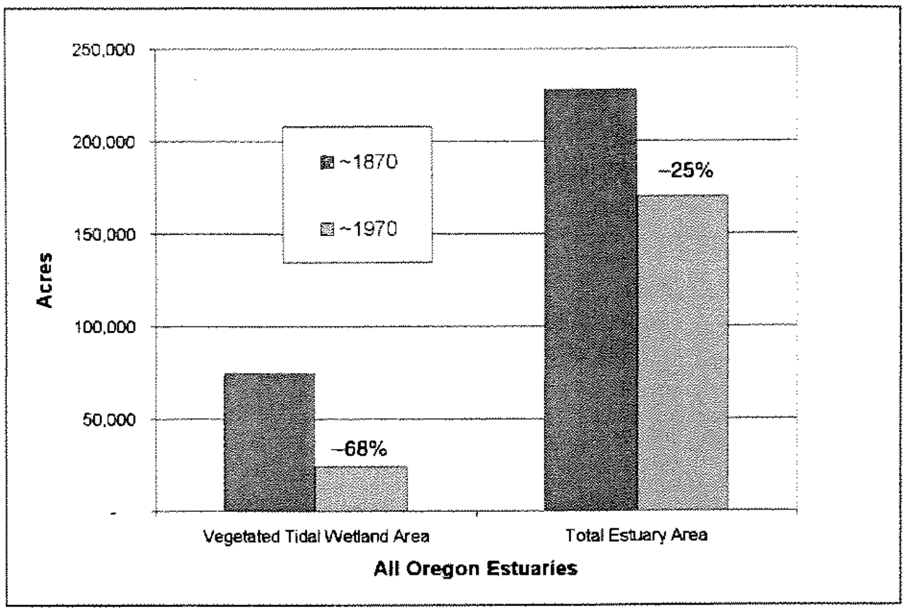


***Figure 10.**—Change in total area and area of vegetated wetlands (tidal marshes and swamps) for Oregon's 17 largest estuaries, due to filling and diking that occurred from about 1870 to 1970. (Data from Table 2)*

Other less visible changes also have occurred, including some that have greatly influenced the ecological character and functions of our estuaries. Examples include:

- Massive harvesting and decline of native salmon and oysters
- Purposeful introduction of species such as striped bass, shad, the soft-shell clam, and the Japanese oyster
- Accidental introduction of dozens of species from other parts of the world, many through the discharge of ballast water by ships from foreign ports
- Changes in the timing of freshwater inflow and sedimentation due to watershed logging, road construction, and log transport down rivers
- Changes in the quantity of available fresh water associated with the damming of rivers for power production and municipal and industrial water supply

Estuary changes and threats—1970 to present

In the late 1960s, coastal residents declared a "crisis in Oregon's estuaries." Two major reasons for concern were unregulated dredging for water access to land and filling of tidal marshes and flats to create new shoreland for development.

Governor Tom McCall responded by placing a moratorium on dredging and filling of Oregon's bays. In 1971, the state legislature

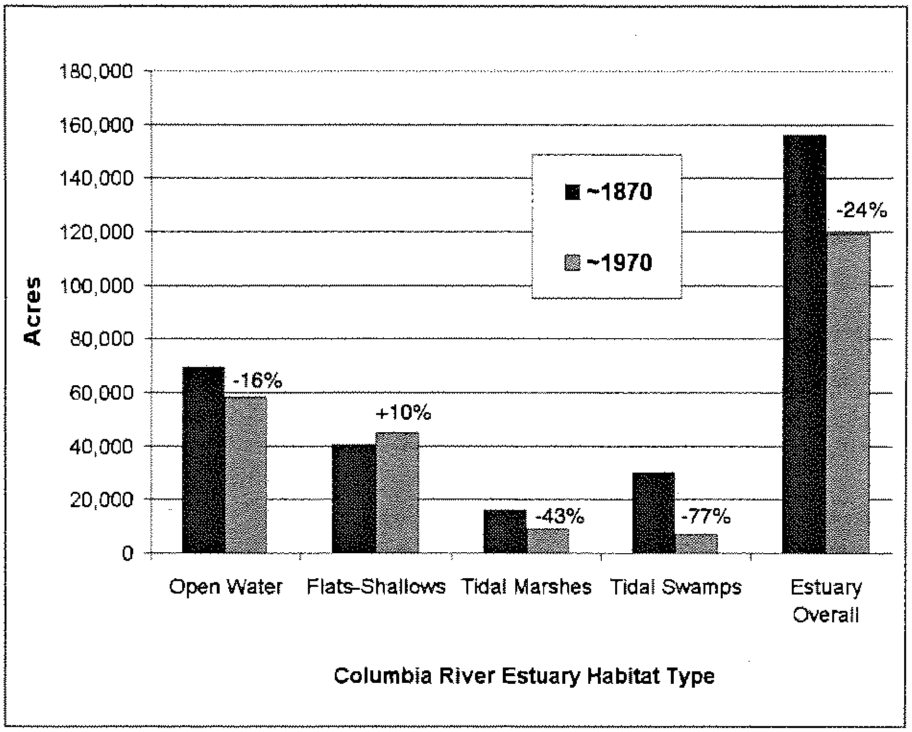


Figure 11.*—Change in Columbia River estuary habitats from about 1870 to 1970. (Data from* Changes in Columbia River Estuary Habitat Types Over the Past Century, *Thomas, 1983)*

passed a law to regulate these activities in estuaries and other waterways. These actions spurred long-range planning for protection and development of estuaries. Local governments and state agencies joined together to develop plans for Yaquina, Coos, and Tillamook bays. These plans served as prototypes for the estuary planning efforts that eventually became a central feature of Oregon's coastal management program. These early efforts at identifying protection and development priorities were among the first of their kind in the nation and contributed to Oregon's well-deserved reputation as an early leader in environmental management.

Estuary plans—balancing protection and development

All of Oregon's estuaries have comprehensive land- and water-use management plans that guide where and how development and other uses may occur. The plans are part of local comprehensive plans that were developed through intensive collaborative planning efforts in the late 1970s and early 1980s. They were guided by Statewide Planning Goals 16 (Estuarine Resources) and 17 (Coastal Shorelands), adopted in 1976 by the Land Conservation and Development Commission. They are implemented through local development ordinances and through state and federal regulation of filling, dredging, in-water construction, and other activities.

Oregon's estuary plans and the rules that guide their development and implementation are described in the *Oregon Estuary Plan Book,* published in 1987 by the Department of Land Conservation and Development's coastal management division (see "Resources"). Highlights of the plans are summarized below.

- *Overall estuary classification*–Goal 16 (Estuarine Resources) requires that each estuary be classified according to the

Table 3.–Overall classification and management unit or zoning acreage for Oregon's estuaries.

Estuary	Overall estuary classification	Subtidal zoning				Intertidal zoning				Estuary summary
		NAT	CON	DEV	Subtotal	NAT	CON	DEV	Subtotal	
Columbia	Deep draft	970	44,051	2,894	47,915	15,588	17,233	77	32,898	80,813
Necanicum	Conservation	0	179	0	179	271	252	0	523	702
Nehalem	Shallow draft	18	837	145	1,000	1,592	114	41	1,747	2,747
Tillamook	Shallow draft	103	1,942	78	2,123	4,659	2,378	55	7,092	9,215
Netarts	Conservation	160	178	0	338	2,232	174	0	2,406	2,744
Sand Lake	Natural	140	0	0	140	758	0	0	758	898
Nestucca	Conservation	50	261	0	311	771	93	0	864	1,175
Salmon	Natural	98	0	0	98	340	0	0	340	438
Siletz	Conservation	33	294	0	327	1,077	58	0	1,135	1,462
Depoe Bay [1]	Shallow draft	–	–	–	–	–	–	–	–	–
Yaquina	Deep draft	2,037	1,301	1,011	4,349	1,838	402	106	2,346	6,695
Alsea	Conservation	162	572	0	734	1,681	100	0	1,781	2,515
Siuslaw	Shallow draft	100	1,257	84	1,441	1,385	209	25	1,619	3,060
Umpqua	Shallow draft	1,947	817	984	3,748	2,393	240	161	2,794	6,542
Coos	Deep draft	1,580	2,493	2,556	6,629	6,671	679	572	7,922	14,551
Coquille	Shallow draft	4	368	103	475	529	65	12	606	1,081
Sixes[1]	Natural	–	–	–	–	–	–	–	–	–
Elk[1]	Natural	–	–	–	–	–	–	–	–	–
Pistol [1]	Natural	–	–	–	–	–	–	–	–	–
Rogue	Shallow draft	19	461	95	575	97	182	27	306	881
Chetco	Shallow draft	4	94	55	153	1	17	1	19	172
Winchuck [1]	Conservation	–	–	–	–	–	–	–	–	–
Total		**7,425**	**55,105**	**8,005**	**70,535**	**41,883**	**22,196**	**1,077**	**65,156**	**135,691**

Source: *Oregon Estuary Plan Book,* 1987.

[1]No zoning acreage data are available for these smaller estuaries.

Zoning categories

NAT = Natural management unit (high protection)

CON = Conservation management unit (moderate protection)

DEV = Development management unit (reserved for water-dependent uses)

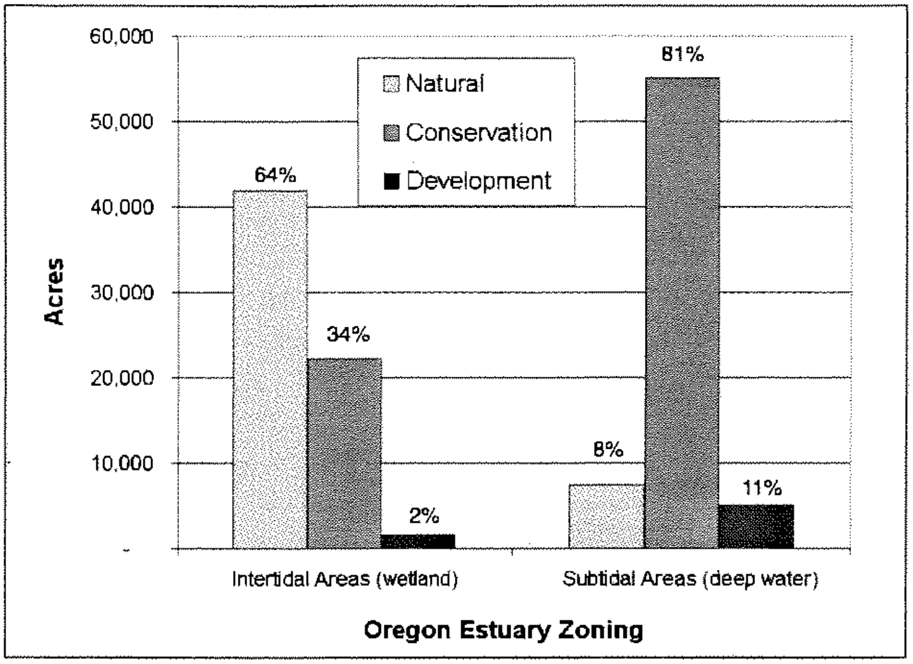


***Figure 12.**—Combined intertidal and subtidal habitat zoning acreage for 22 Oregon estuaries. (Data from the* Oregon Estuary Plan Book, *1987)*

highest level or intensity of development permitted there. There are five natural estuaries, six conservation estuaries, eight shallow draft development estuaries, and three deep draft development estuaries (Table 3, column two).

- *Individual estuary zoning*—Within each estuary, using the overall classification and specific Goal 16 criteria, estuarine habitats are designated as natural, conservation, or development "management units" or zones (Table 3). Within each type of zone, uses either are permitted outright, conditionally permitted, or not permitted, depending on the management objective for that category. Coast-wide, the tidal marshes, flats, and other estuarine wetlands that have not been altered by filling or diking are well protected from future alterations; 64 percent are in Natural management units and 34 percent in Conservation units (Table 3 and Figure 12).
- *Adjacent shoreland zoning*—Shoreland development is planned to be consistent with estuary zoning. For example, estuary Development zones generally abut water-dependent shoreland zones. Nearly 100 shoreland sites totaling more than 3,500 acres have been reserved for water-dependent development.

Regulating dredge and fill in estuaries—how effective is it?

Dredging, filling, in-water construction, and other uses are regulated in Oregon's estuarine wetlands and deep-water habitats much as they are in other wetlands and waterways through the Removal-Fill Law. (See Chapter II-9, "Wetlands.") However, the criteria for issuing permits in estuaries are stricter:

- Proposed uses must be water-dependent.
- A public need must be served.
- There must be no alternative upland site that could accomplish the same purpose.
- Unavoidable impacts must be minimized and compensated for by habitat mitigation.

Furthermore, the Division of State Lands and the U.S. Army Corps of Engineers may not issue permits in areas protected by local estuary plans.

How well have the Removal-Fill Law and estuary plans worked to limit direct physical alterations? Between 1971 and 1987, based on Division of State Lands records compiled by Fishman Environmental Services, just 19 acres of estuarine intertidal habitat were filled (0.03 percent of the 1970 base). About 5 acres of habitat were restored or created to compensate for part of that loss. Since protective zoning was established in the early 1980s, fill losses have been minimal.

Dredging between 1971 and 1987 involved about 111 acres of estuary area, mostly subtidal areas for navigation channel maintenance. As with filling, dredging has declined markedly since the early 1980s. Data have not been compiled since 1987, but estimates of additional filled and dredged areas are quite small.

Acquisition for preservation and conservation

Acquisition by purchase or easement for preservation and conservation purposes is one of the best ways to protect estuarine areas, particularly privately held high marshes and swamps above the state ownership line. (Note in Figure 8 that state tideland extends only up to MHW.) More than 10,000 acres of tidal brackish and freshwater wetlands in the Columbia River estuary are managed for wildlife by the U.S. Fish and Wildlife Service. Three additional refuges with significant salt marsh and tidal flats are located in the Nestucca, Siletz, and Coquille estuaries, and there are plans to include more land under conservation protection.

The South Slough National Estuarine Research Reserve in Coos Bay is another area managed for conservation. Research and education are its primary missions. South Slough Reserve includes 220 acres of salt marsh, 180 acres of tidal fresh marsh, 550 acres of tidal flats, 160 acres of subtidal submerged aquatic vegetation, 200 acres of open-water channels, and 3,460 acres of upland forests–4,770 acres in total.

Private conservation groups such as The Trust for Public Lands, The Nature Conservancy, and local land trusts also hold some estuarine wetlands for conservation management.

Pollution and pollution control

Located as they are at the "bottom" of watersheds, estuaries collect a variety of pollutants–introduced nutrients and organic matter, toxic metals, pesticides, herbicides, pathogenic bacteria and viruses, oil and other hydrocarbons, sediment, radioactive waste, plastic debris, and other trash.

Pipeline discharges–known as *point sources*–are responsible for some of these pollutants. Typical point sources in our region include municipal sewage treatment plants, power generation facilities, seafood processing plants, and pulp and paper mills.

Less obvious and more difficult to detect and control are pollutants from dispersed land runoff–*nonpoint sources*. Eroded soil, fertilizers, pesticides, and herbicides that run off from cropland, pastures, and forest land are major sources of pollution (Figure 13). So are septic tank wastes that drain or leach into coastal waters. Urban runoff is another example. Stormwater laden with oil, grease, fertilizer, pesticides, herbicides, and toxic metals washes into streams and rivers, and eventually into estuaries and near-shore waters.

Other pollution threats to estuaries include rare but potentially devastating oil spills, such as the 1999 *New Carissa* spill near Coos Bay.

Nonnative aquatic nuisance species, discussed later in this chapter, represent a growing and significant form of biological pollution that enters estuaries through point and nonpoint sources. Biological pollutants present a special cleanup challenge because, once released, they reproduce and spread on their own.

Estuaries and coastal waters can assimilate certain kinds and levels of pollutants, but their capacity sometimes is overwhelmed, stressing ecosystems and the organisms that live there. In an effort to limit pollution, the U.S. Congress and the Oregon legislature have passed laws to regulate point source discharges, manage runoff pollution, and help prevent and respond to spills of oil and other hazardous waste. Literally billions of dollars have been spent to upgrade municipal sewage treatment facilities throughout the U.S. in the past 3 decades, and billions of dollars more have been invested by private business to reduce and treat industrial wastes.

***Figure 13.**–Runoff from agricultural land transports animal wastes, soil, fertilizers, herbicides, and pesticides into streams, rivers, and eventually estuaries.*

What laws and agencies are designed to limit water pollution? Government uses a combination of "carrot and stick" approaches. At the federal level, the principal law for controlling point and nonpoint sources of pollution is the *Clean Water Act* (CWA, formerly the Federal Water Pollution Control Act). The U.S. Environmental Protection Agency (EPA) and the U.S. Army Corps of Engineers (Corps) have key responsibilities for implementing the CWA.

Many key provisions of the CWA, however, are delegated to state water-quality agencies–in Oregon, the Department of Environmental Quality (DEQ). DEQ administers the CWA Section 402 *National Pollutant Discharge Elimination System*–the permit program for regulating pipeline discharges. DEQ also is responsible for nonpoint source pollution control programs (e.g., CWA Section 319), as well as for certifying that Corps-issued permits for wetland or waterway alterations meet state and federal water-quality standards (CWA Section 401).

Another important coastal pollution control law is the *Ocean Dumping Act* (ODA). The Corps administers the ODA's Section 103 permit program, which regulates the transportation and dumping of wastes into coastal or offshore waters. Industrial waste dumping no longer is permitted in U.S. waters, so ODA permits today are mainly for disposal of clean sand dredged from coastal navigation projects. EPA must approve offshore dumping sites.

Another provision of the CWA set up the *National Estuary Program* in 1987. Two National Estuary Projects (NEPs) have been established in Oregon–the Tillamook Bay and Lower Columbia River estuary projects. For both estuaries, Coordinated Conservation and Management Plans (CCMPs) were completed in 1999 and are being implemented through local, state, federal, and private-sector partnerships.

Despite years of planning and voluntary programs, nonpoint source pollution problems have persisted or worsened over the past several decades. Congress responded in 1990 with Section 6217 of the Coastal Zone Act Reauthorization Amendments. The 6217 program attempts to link *enforceable* state coastal zone management policies with *voluntary* nonpoint source pollution control efforts promoted by state water-quality agencies.

In theory, this program makes good sense because poor land management is a major cause of nonpoint source pollution, and pollution reduction programs require changed land-use and management practices. For example, restoration and enhancement projects can create streamside filter strips to intercept runoff pollution that otherwise would go directly into streams and estuaries. The Section 6217 program has yet to achieve its objectives, however, in part because it is an ambitious, long-term undertaking and in part because funding has been sparse.

Oil spill prevention, contingency planning, response, and recovery are addressed under the national and state *Oil Pollution*

Acts. The most recent versions were passed in the wake of the disastrous 1989 *Exxon Valdez* oil spill in Alaska. Under these laws, the U.S. Coast Guard, the Oregon DEQ, and the ship's agent all have major responsibilities for response and recovery, with the ship's owner assuming principal financial responsibility. In Oregon, the 1999 grounding of the *New Carissa* and the subsequent oil spill, Natural Resource Damage Assessment, and cleanup operation serve as an excellent local case study of this process (Figure 14).

State and federal settlements for oil spill environmental damages have funded a number of estuarine restoration projects in the Pacific Northwest.

Nonnative species introductions

Some nonnative species introduced to Oregon estuaries generally are not considered problems. Examples include the eastern soft-shell clam *(Mya arenaria)*, striped bass *(Roccus saxatilis)*, American shad *(Alosa sapidissima)*, and Japanese oyster *(Crassostrea gigas)*. These species, in fact, are highly valued for their contributions to recreational and commercial fisheries and provide economic incentives for keeping estuarine waters clean.

Other introduced species are not so welcome in the Pacific Northwest. The European green crab *(Carcinus maenus)*, Chinese mitten crab *(Eriocheir sinensis)*, saltmarsh cordgrass *(Spartina alterniflora)*, and purple varnish clam *(Nuttallia obscurata)* are examples. They have the potential to disrupt ecosystem processes, out-compete valued species, or change habitat structure. These species are known as *aquatic nuisance species* (ANS).

Dozens, perhaps hundreds, of less prominent plant and animal species have invaded Oregon's estuaries, including microscopic and disease-causing organisms. Not all are nuisances, but they certainly have changed and will continue to change estuaries, sometimes for the worse.

Note that the difference between "nonnative" species

***Figure 14.**–The* New Carissa *oil spill was a reminder that estuaries are extremely vulnerable to unpredictable pollution events. (Photo: NOAA)*

and "nuisance" species basically is a value judgment. The two definitions are gray and shifting, depending on the interests at stake. Even some native species are considered a "nuisance" by some people. Examples are burrowing mud shrimp and ghost shrimp in oyster-growing areas such as Tillamook Bay, and harbor seals that feed on returning adult salmon at the mouths of estuaries.

The European green crab, long established on the East Coast, was first seen in San Francisco Bay in 1989 and apparently has migrated north to Humboldt Bay, Coos Bay, and other Oregon estuaries (Figure 15). Biologists and the fishing industry are concerned that this voracious, predatory, and highly adaptable species will affect native and commercial shellfish populations.

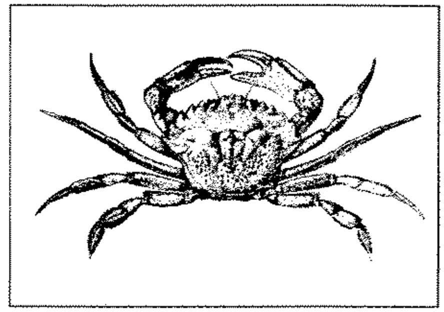


***Figure 15.**–Alien invader: the European green crab has been found in many Oregon estuaries and may compete with native species.*

The Chinese mitten crab is another threat to Northwest estuaries and upstream freshwater systems. It has become well established in San Francisco Bay, spreading as far as 200 miles up into the delta region. This species may have been introduced illegally for harvest or accidentally via shipping. The mitten crab is *catadromous*, i.e., it spends its adult life in fresh water and returns to the estuary to reproduce.

This species spreads and multiplies rapidly, burrowing into banks and dikes as it moves upstream. Damage to levees in the San Francisco Bay delta already is a concern, but the worst may lie ahead. Mitten crabs have disrupted fish passage operations in California. If repeated in Oregon, this situation could spell disaster for some of our ailing salmon stocks.

Among invasive plants, *Spartina alterniflora* is considered a pest species in Pacific Northwest estuaries. A native of East Coast tidal wetlands, it was inadvertently introduced into Willapa Bay, Washington with oysters brought from the East Coast in the early 20th century. The East Coast oysters did not do well, but *Spartina* got a foothold. Only recently has it taken off, however, increasing its range from 400 to 4,000 acres in Willapa Bay from the mid-1980s to mid-1990s.

This species is a major concern because it colonizes low tidal flats, changing the habitat of important commercial species such as oysters. A small, closely watched colony of *Spartina alterniflora* in south Tillamook County is monitored and managed by the Oregon Department of Agriculture. Might this species invade Oregon to the extent it has Washington? A hybrid relative, *Spartina anglica*, also is a significant threat, having invaded northern Puget Sound wetlands near Everett.

Another introduced estuarine species is *Zostera japonica (nana)*, a dwarf eelgrass that colonizes high intertidal mudflats. From a competitive perspective, it probably is not a serious threat to native eelgrass species, which are found much lower on flats.

Nevertheless, its ecological role is poorly understood. Like native eelgrass in the lower intertidal and shallow subtidal zones, it may be used by crabs and other species as refuge when the tide is out. If so, the longer exposure to drying and heating at higher tidal elevations may prove lethal to individuals seeking refuge there instead of in native eelgrass beds.

The pathways for ANS introductions are many. Some individuals may be attached to seaweed that serves as packing material for oysters; others hitchhike on the bottoms of ships, fishing vessels, or recreational boats from other regions. By far, however, the most significant ANS source today is ballast water discharged by ships calling at Oregon ports from locations throughout the world.

Ballast water, carried in compartments or tanks inside a ship and used to adjust a vessel's trim (its level or position with respect to the water), is a virtual witch's brew of unwanted organisms, mainly microscopic plankton and larval forms of larger species (Figure 16). Scientists sampling ballast water from more than 160 ships visiting Coos Bay found more than 400 species of living nonnative organisms that ultimately were pumped into the bay. Within the South Slough of Coos Bay, scientists have documented at least 32 introduced species, 14 of which likely were introduced in ballast water.

Once established, ANS are difficult if not impossible to eradicate. The best solution to ANS problems is to avoid introductions in the first place. One preventive measure being promoted is voluntary ballast water exchange in the deep ocean after ships leave foreign ports. Shippers argue, however, that some ships are not equipped to exchange ballast water at sea and to do so would jeopardize vessel stability and safety. Other solutions, such as ballast water treatment prior to release, are technologically feasible, but probably too expensive for Oregon's small ports.

Education and management safeguards can reduce inadvertent introductions from the many other "nonpoint" sources of ANS.

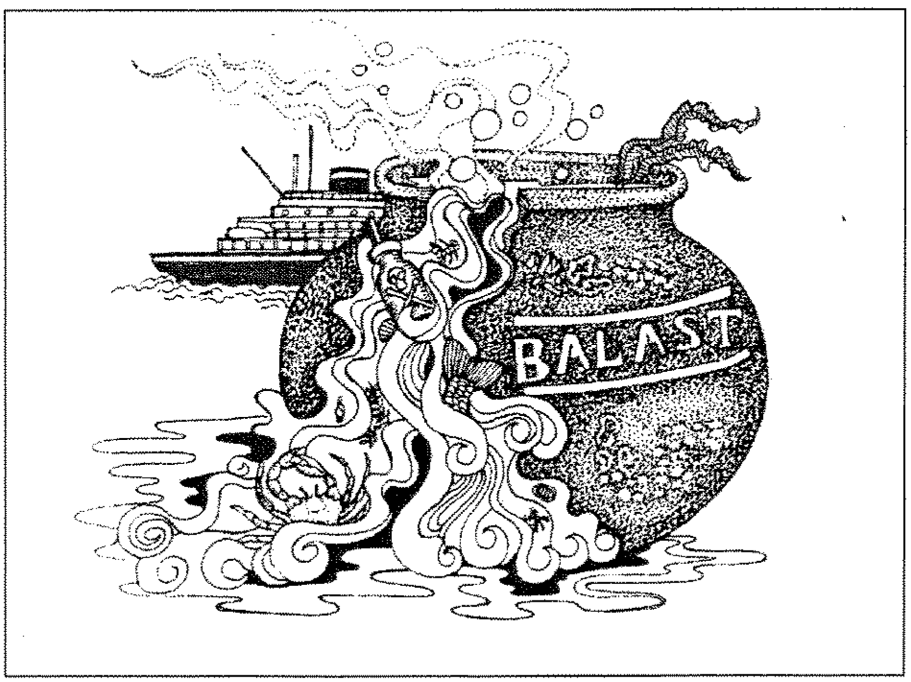


***Figure 16.**–Discharge of ballast water from ships visiting Oregon ports is the source of many new species introductions. (Drawing by Sharon Torvik, courtesy of South Slough National Estuarine Research Reserve)*

Recent restoration activities in Oregon estuaries

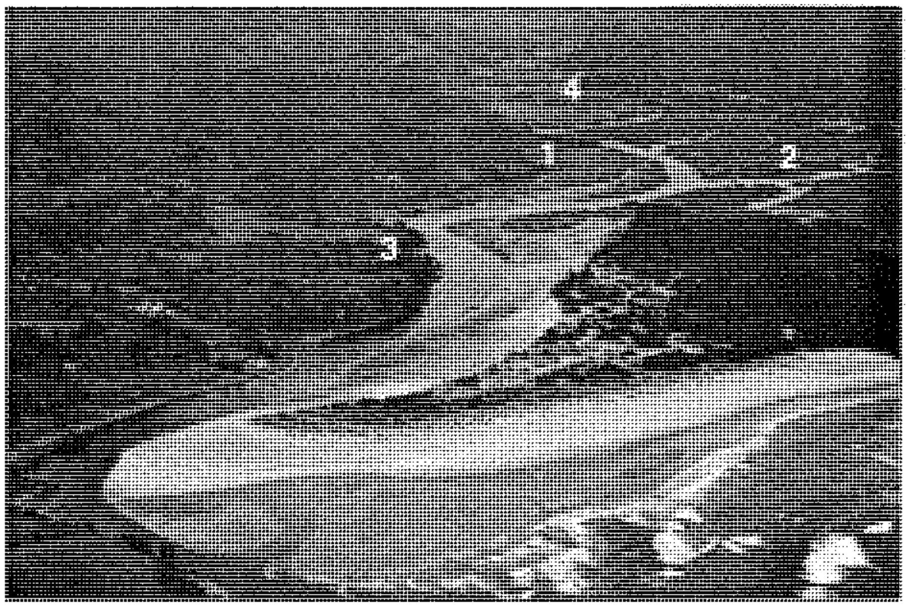


Figure 17.–Location, size, and date of dike removal for salt marsh restoration sites in the Salmon River estuary: (1) Mitchell marsh, 52 acres, 1978; (2) "Y" marsh, 200 acres, 1988; (3) Knight Creek marsh, 2 acres, 1996; (4) Salmon Creek marsh, 55 acres, 1996.

The body of knowledge and technology for estuary restoration and enhancement is growing rapidly, but there still are few carefully monitored sites. Two estuaries in Oregon where significant scientific investigation is taking place are the Salmon River estuary and the South Slough of Coos Bay.

Restoration efforts in both of these estuaries are described briefly below. References and contacts for more information are listed in the resources section. Monitoring continues at both estuaries, but results to date illustrate that significant success is possible if initial goals are realistic. Lessons learned from these and other restoration efforts are included in guidelines for restoration projects later in this chapter.

Restoring the Salmon River estuary

When Congress established the Cascade Head Scenic Research Area in 1974, one goal was the restoration of the Salmon River estuary just south of the massive headland. The tidal marshes along the estuary had been used for years for hay production and grazing. About 75 percent were diked and drained during the 1950s and 1960s to improve agricultural productivity and create pasture. Another marsh was dredged for a marina that never materialized. The rerouting and shortening of U.S. Highway 101 with a filled causeway and bridge across the estuary in 1961 caused additional major hydrologic changes to the estuary and its tributary creek system.

Salt marsh restoration projects began in 1978 with removal of a tide gate and the breaching of 17-year old dikes on the 52-acre "Mitchell" marsh parcel on the north shore (Figure 17). Scientists from Oregon State University surveyed the site prior to breaching and set up a long-term monitoring program to evaluate the restoration process, especially vegetation reestablishment.

In 1988, the entire dike was removed at the Mitchell site to allow more natural tidal flow and drainage across the site. At the same time, the 200-acre "Y" marsh on the south side of the estuary was restored by breaching and removing dikes and a tide gate at Rowdy Creek. Other restoration projects followed, including the 2-acre Knight Park marsh and the 55-acre Salmon Creek marsh in 1996. The location of each of these projects is illustrated in Figure 17.

Generally, restored marshes took several years to pass through a succession of species and develop full wetland plant cover. After 5 to 10 years, Lyngby's sedge—a common low salt and brackish marsh species—dominates much of the restored area. Restored tidal marsh vegetation seems to reach a relatively stable community about 10 to 20 years after dike removal, although vegetation does continue to change after that time.

Tidal creeks, made shallow and wide from years of grazing and the absence of tidal exchange, have deepened and narrowed. In the more mature project areas, these restored tidal creeks now resemble those in control marshes that never were altered.

In 1997, monitoring expanded to include fish utilization of restored areas, particularly by juvenile salmon. This work still is in progress, but should yield data on juvenile salmon residence times, habitat and food preferences, and growth rates in both restored marshes and unaltered reference sites. This information is vital to understanding the role of estuarine restoration in the recovery of salmon populations along the Oregon coast.

Restoring South Slough: The Winchester Tidelands Project

In the South Slough National Estuarine Research Reserve (SSNERR)—the south arm of Coos Bay—a unique experiment in integrated upland–floodplain–estuary restoration is underway. Scientists from the SSNERR, with advice from an interdisciplinary team of specialists, are restoring fresh- and saltwater marshes, eelgrass beds, tidal creeks, and channels; reconnecting historical floodplains to creeks; passively restoring long-abandoned roads and decommissioning others; and planting a mixture of native trees—fir, hemlock, cedar, alder, and maple—along slopes that have been logged as many as three times since early settlement.

The Winchester Tidelands Restoration Project (WTRP) is the coastal wetland component of the project (Figure 18). It includes a variety of passive and active tidal wetland restoration projects along Winchester Creek.

At Kunz marsh, which subsided several feet after diking at the turn of the century, an experiment is underway to determine whether manipulation of site elevation can accelerate recovery of different types of wetlands. Five experimental cells were established, and soil from the dike was redistributed within the cells to establish different base elevations. After 3 years of sampling, this project illustrates that site manipulation does result in the development of different vegetative cover and drainage. Several more years of monitoring will be necessary to more fully document site development and evolution and to draw definitive conclusions.

Active or passive restoration of other wetlands along the tidal creek is proceeding. One site–Cox Canyon marsh–is getting significant help from beavers that have recolonized the area (Figure 19).

Lessons learned at South Slough, like those at the Salmon River estuary, are proving extremely valuable to watershed groups and others seeking to restore other estuarine habitats. These lessons are incorporated into the project planning guidelines presented later in this chapter.

Figure 18.–Winchester Creek marsh restoration sites: (1) Kunz marsh, with different research cells (a–e); (2) Dalton Creek marsh; (3) Fredrickson marsh; (4) Cox Canyon marsh; (5) Tracy marsh; (6) Toms Creek. (Photo courtesy of Craig Cornu, South Slough National Estuarine Research Reserve)

Prognosis for Oregon estuaries–decline or restoration?

What is the outlook for estuarine ecosystem health in Oregon? Many factors need to be considered. Population growth, demand for fresh water, coastal economic trends, efforts to control pollution and aquatic nuisance species, the integrity of plans designed to provide habitat protection, and restoration and enhancement efforts all play a role.

Oregon's 1999 permanent coastal population was about 350,000, with numbers doubling or tripling during peak tourist season. Statewide, Oregon's population is expected to swell from 3.2 million in 2000 to 4.6 million in 2020, with 80 percent of the growth in the Willamette Valley. Many new Oregonians living in the Willamette Valley will be part-time coastal residents or at least regular visitors. The permanent coastal population also will grow as baby boomers retire on the coast.

Given this projected growth, what changes might we expect for Oregon's estuaries over the next 20 to 50 years? While predictions can be risky, they are useful if taken with a grain of salt (pun intended). Recent trends suggest the following:

- Estuaries will continue to support a diversity of uses and activities, among them deep-water shipping (Coos Bay, Yaquina Bay, and the Columbia River estuary), home ports for fishing fleets, recreational fishing and marinas, charter fishing, sailing, aquaculture (oysters, clams, and

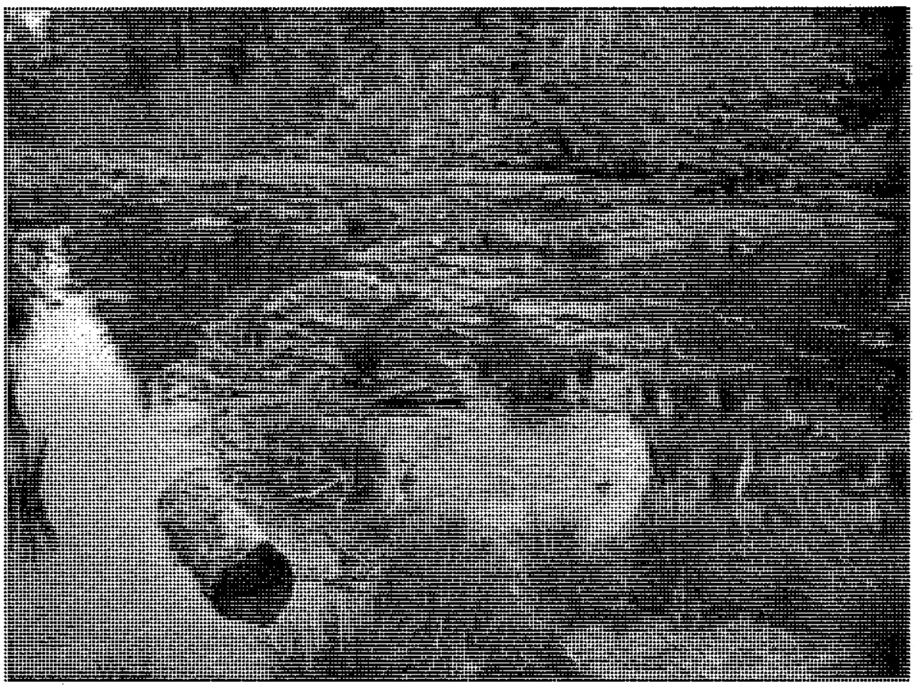


Figure 19.–Beaver have served as restoration project assistants at the Cox Canyon marsh (see Figure 18) portion of the Winchester tidelands restoration. (Photo: Jim Good)

salmon), waterfowl hunting, birding, and other nature activities.

- Strict estuary zoning plans probably will prevent significant new dredging or filling for development.
- Increased withdrawals of fresh water by urban and rural users will change freshwater inflow to estuaries, which, in turn, will change mixing and circulation patterns, estuarine habitats, and biology.
- Fish and shellfish resources may decline due to increased harvest pressure, particularly from recreational users.
- Our understanding of the impacts of runoff pollution will increase, as will our ability to pinpoint sources and provide control technologies. Political considerations and costs will determine whether problems persist, increase, or are reduced.
- The adverse impacts of introduced species will become better known as scientists continue to study their distribution, spread, and ecological interactions.
- Estuaries probably will continue to expand, as former marsh areas are restored or revert to salt marsh after dikes or tidegates fail. This trend may lead to improved ecosystem health and increase the supply of fish and wildlife habitat, offsetting other losses.
- Estuary-related tourism and recreation will continue to increase as more people call the coast home for at least part of the year.
- Competition for limited shoreline and estuarine surface area likely will increase, with residential developers, marinas, tourist businesses, and recreational users challenging traditional users such as ports, fish processors, oyster farmers, and commercial clammers.
- Natural resource industries that use the estuary, despite decline in recent decades, still will be important economically and culturally.
- Public access to estuaries, particularly in urban areas where waterfront revitalization plans are being developed and

implemented, will continue to improve, further enhancing recreational and tourism uses.

- Urban shoreline changes will have ramifications for ecosystem protection and restoration by increasing both the awareness of the need and opportunities for ecosystem restoration and pressure to expand urban growth boundaries along the shoreline.

Assessing Estuary Health and Planning for Rehabilitation

Assessing estuary health and developing an estuary-wide rehabilitation plan are part of the overall watershed process. These steps can, however, be done independently, as long as the important upstream and watershed connections are made. A model process for evaluating estuarine health and developing an estuary-wide restoration and enhancement plan includes five steps. They are listed briefly in the sidebar and described in more detail below.

The process in the sidebar sounds relatively simple…or does it? Successfully accomplishing this process, even for a relatively small estuary, is a significant undertaking. It requires detective work to track down useful information, an understanding of how estuaries work (tides, circulation, mixing, and habitat structure), sensitivity to existing land uses and private property rights, inclusion of people who could be affected,

Estuary-wide planning for rehabilitation

Step 1. Assess the condition and health of your estuary.

- What were presettlement historical conditions?
- What are current estuary conditions and health?
- What are today's principal ecological problems and foreseeable threats and risks?

Step 2. Set restoration and enhancement goals.

- Considering current and historical conditions, ecological problems, and threats, what are the goals for restoration and enhancement, protection, management, research, monitoring, and public and decision maker education?

Step 3. Identify potential restoration, enhancement, management, and education projects and priorities.

- Based on results from Steps 1 and 2, what specific projects will do the most to accomplish each restoration goal?

Step 4. Screen potential projects for constraints and feasibility.

- Considering possible constraints, such as land-use conflicts, property ownership, willingness to participate, and public and private cost, what projects are realistic and cost-effective?

Step 5. Synthesize planning results, write an action plan, and begin work.

- What is the overall vision for estuary restoration, enhancement, and management?
- Commit the plan to writing, maps, and drawings; begin its implementation project by project; monitor progress; and periodically reevaluate priorities, recognizing that goals and constraints may change over time.

and incorporation of local knowledge and values. A bottom-up, team approach is needed to pull together and analyze information, to go neighbor to neighbor with proposals, and to arrive at an acceptable restoration vision. Top-down help is needed as well to help locate and interpret information and to help access financial resources.

This process may take a year or more. However, some projects will be feasible from the start and address problems that everyone agrees on. Start working on these projects as soon as possible. *Early success in implementing restoration projects is critical to building and maintaining community support and interest.*

A well-reasoned plan is important and will help you get financial support, but we all know about plans "gathering dust on the shelf." Your plan should include ways to monitor progress and publicize success stories and milestones. It also should include provisions for revising goals to address new problems, opportunities, or constraints.

Each step in this process is discussed below, with emphasis on the first–estuary assessment.

1. Assess the condition and health of your estuary.

- What were pre-white-settlement conditions?
- What are current estuary conditions and health?
- What are today's principal ecological problems and foreseeable threats and risks?

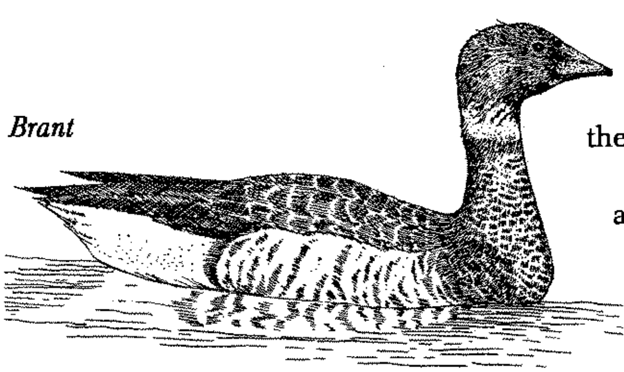
A good information base is the first step in any planning process. To evaluate your estuary's health, you need a reference point. Its *ecological history* from presettlement to present provides this context.

Current conditions would seem to be the easiest part of the assessment. We have maps of existing habitats, for example, plus detailed aerial photos and at least some water-quality data.

However, you quickly will find that little published information is available that explains how your particular estuary works at the scale you seek to understand. Thus it is useful to tap into the knowledge of local biologists, other professionals, and those who spend lots of time on the estuary.

Even more challenging is trying to predict future risks and threats. Present trends offer some clues, however. For many estuaries, threats such as runoff pollution and aquatic nuisance species need to be documented.

Brant



Each of the three questions in Step 1 is discussed in more detail below. By answering these questions, you can generate an initial list of potential restoration and enhancement projects.

What were pre-white-settlement conditions?

The purpose of researching the estuary's ecological history is to provide insight into how the estuary functioned in a relatively pristine, unaltered condition. Its purpose is *not* to try to turn back the clock to recreate these pristine conditions. Even if it were physically possible to recreate presettlement ecosystem conditions (which it is not), it would not necessarily be ecologically desirable, nor would it be realistic from a community or economic perspective. Instead, estuary restoration (and watershed restoration generally) needs to be set in the context of present conditions and the problems to be solved. (See Step 2.)

The historical conditions assessment should begin at presettlement times and continue to the present. Common physical alterations include jetty construction, stabilization and dredging of channels, filling of flats or marshes, logging of forested swamps, diking and draining of marshes, and installation of tidegates.

It will be apparent that some physical changes that have damaged or degraded estuarine ecosystems are reversible. Your task is to identify and describe opportunities to rehabilitate the estuary in ways that are consistent with present and projected economic uses and your goals for improving estuary health and functioning. For example, replacing an undersized road culvert that prevents tidal exchange into a slough with a larger culvert or small bridge would benefit the estuary without interrupting traffic flow. Restoring diked wetlands no longer used for agriculture is another example.

Other changes to the estuary clearly are not reversible. It is unlikely, for example, that jetties will be removed or dredged channels filled in.

Watershed groups can use a variety of resources to assess historical conditions and compare them to present conditions. The most recent, consistent habitat data and maps are compiled in the *Oregon Estuary Plan Book* (Table 1). The Division of State Lands can provide permit data and records on alterations since the mid-1970s (the baseline for the plan book data). You may have to search individual permit records, but the DSL resource coordinator for your region can help.

Looking farther back in time, however, is more important, since most changes in estuaries occurred in the late 19th and early to mid-20th centuries. There are many resources available to help in this task:

- *Aerial photos* dating back to 1939
- *National Wetlands Inventory* (NWI) maps, which superimpose estuarine habitats (and most diked areas) on USGS quadrangle maps
- *County soil surveys* and maps, which show tideland and other hydric soil areas
- *U.S. Coast Survey charts* dating as far back as the mid-1800s, which show channels, bottom sediment types, marsh vegetation, forested swamps, and changes such as jetties, fills, and other development (Figure 20 is an example for Coos Bay.)

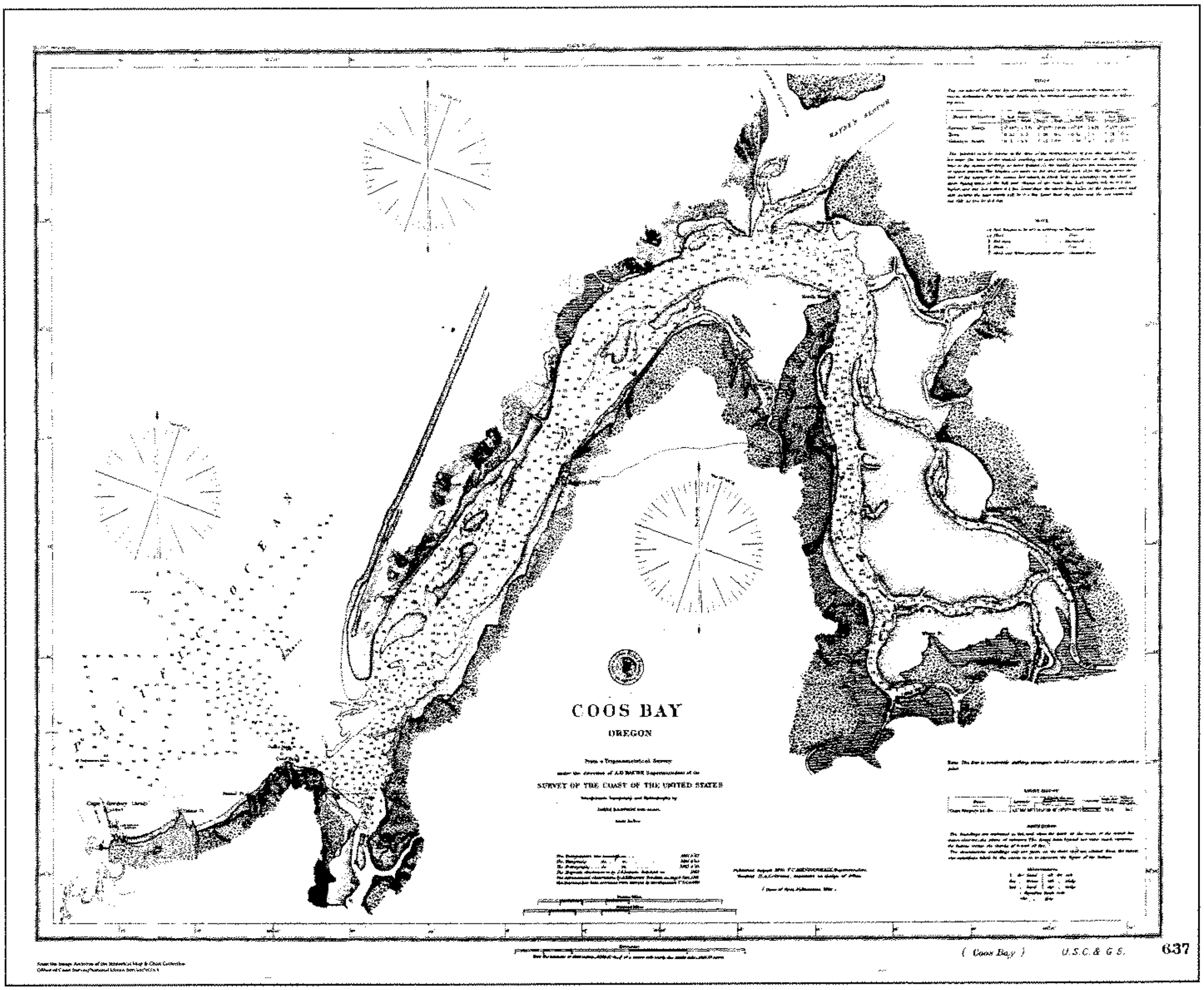


***Figure 20.**—Early Coast Survey navigation chart of Coos Bay (1901), showing areas of channels, tidal flats, tidal marshes, and estuary–upland boundaries. (Source: NOAA)*

- *Original Public Lands Survey Records* from the mid-1800s, which include maps and descriptions of forested and grassy areas, tidal creeks and streams, and other landscape features
- *U.S. Army Corps of Engineers navigation and snag removal records*
- *Hydrologic and water-quality records* from state and federal agencies
- *Fisheries statistics and records* that document fish runs and harvests
- *Historical ground photos and written accounts*
- *Local diking and drainage district records*

These data sources and how to acquire them are described in more detail in Appendix A.

What are current estuary conditions and health?

A comparison between historical habitat conditions and current conditions is one indicator of estuary health. For example, changes in estuarine salt marshes and tidal creeks can be used to estimate changes in the estuary's capacity to support salmon. This information then may serve as a basis for restoration goal setting.

The extent to which remaining habitats are protected from future alterations is another important, if speculative, consideration. Generally, key Oregon estuarine habitats are well protected. Estuary plans; zoning; wildlife areas; and strict regulation of filling, dredging, pollution, and other alterations provide significant direct protection for critical habitats.

Habitat information. Two sources of relatively recent habitat information are readily available for Oregon's estuaries:

- NWI maps (described above, in Appendix A, and in Chapter II-9, "Wetlands")
- Estuary habitat maps, data tables, and digital data from the *Oregon Estuary Plan Book*, which is based on a modified version of the NWI

Recent physical alterations. One source of information is the study of 1971–1987 physical alterations of estuaries by Fishman Environmental Services. (See "Regulating dredge and fill" earlier in this chapter.) It documents recent dredge and fill projects for each estuary. To assess how well your estuary currently is protected from physical alterations, obtain copies of local estuary plan implementation ordinances and set up mechanisms for monitoring local and state permit actions on development, dredging, and filling, as well as possible violations.

Aquatic nuisance species (ANS). As noted earlier, some introduced species are welcome in Oregon estuaries. Others are not. The European green crab *(Carcinus maenus)* and saltmarsh cordgrass *(Spartina alterniflora),* for example, were discussed earlier. Many less prominent plant and animal species that have invaded Oregon's estuaries eventually may be recognized as aquatic nuisances.

As part of your estuary assessment, collect information on what is known about ANS in your estuary—the severity of infestations, potential sources of introductions, and possible control strategies. Early detection of new ANS populations sometimes allows successful control or eradication. Watershed groups can play an important role in a statewide ANS detection network.

Nonpoint source or "runoff" pollution. Because excessive pollution can derail otherwise successful restoration and enhancement efforts, it is important to identify potential pollution sources. Gathering and making sense of pollution data can be complicated. Local or headquarters DEQ staff can provide technical assistance.

Pipeline-introduced pollution is strictly regulated by the Department of Environmental Quality (DEQ) as part of the National Pollutant Discharge Elimination System (NPDES) permit program. Information on these discharges can be obtained from DEQ.

Information on broadly distributed runoff pollution from farms, forests, and rural and urban areas is much more difficult to obtain. How these pollutants affect estuarine health also is poorly understood. DEQ does have limited water-quality measurements for some estuaries. The Oregon Department of Agriculture monitors coliform counts in estuaries where shellfish are produced commercially.

Where dairy and other livestock operations are common, check with local farm organizations and OSU Extension Service agents about problems and how the watershed council can get involved in finding solutions.

Find out whether and how communities along estuary shorelines capture, treat, and discharge stormwater, and how they regulate and enforce sediment runoff controls at construction sites. Link up with local citizen monitoring efforts such as CoastNet, a program operated through high schools and middle schools along the Oregon coast, or start a citizen monitoring program.

Controlling runoff pollution is a long-term proposition requiring training, monitoring, evaluation, and problem solving. See Chapters II-5, "Riparian Functions," II-8, "Stream Evaluation and Enhancement," and II-9, "Wetland Functions and Management," for more information on water quality, runoff pollution, and actions that may reduce pollution.

What are today's principal ecological problems and foreseeable threats and risks?

As you examine historical and current estuary conditions, ecological problems will be revealed—invasive pest species, pollution sources and hot spots, restricted tidal circulation, habitat degradation, and other conditions that diminish estuarine health, functions, goods, and services. Restoration and enhancement activities and projects may help resolve these problems or at least make them less severe.

It is very important to make problem identification and goal setting a community-based process. You can use a combination of techniques to collect local viewpoints and, at the same time, present the estuary assessment information being compiled. Examples include newspaper or mail surveys, programs at meetings of local organizations, coffee klatches, and door-to-door, neighbor-to-neighbor discussions (Figure 21).

2. Set restoration and enhancement goals.

- Considering current and historical conditions, ecological problems, and threats, what are the goals for restoration, enhancement, protection, management, research, monitoring, and public and decision maker education?

As problems are identified in the community-based process discussed above, consider goals for restoring and enhancing estuary health. In meetings with local organizations and the public, present findings of the health assessment (Step 1) and facilitate discussion to identify estuary problems, restoration opportunities, and goals for improving the estuary.

Setting goals is relatively simple once there is a consensus about key problems. Simply turn problem statements from negative to positive to create a goal. Before finalizing goals, present them to the community and ask for feedback. This process takes time, but it is worthwhile in terms of building community and property owner support and understanding.

3. Identify potential restoration, enhancement, management, and education projects and priorities.

Based on results from Steps 1 and 2, what specific projects will do the most to accomplish each restoration goal?

The next step in developing a realistic estuary action plan is to screen restoration and enhancement opportunities identified in Step 1 for their potential to help solve problems and achieve the goals identified in Step 2. This process requires a careful, even tedious, examination of each project as it relates to each goal.

***Figure 21.**—Local workshops are one way to survey available information and set goals for restoration. (Photo: Jim Good)*

It may be useful to create a large matrix of opportunities (project sites) versus goals. Give each site a rating of 1 to 5 (high to low) for its ability to meet each goal. Then add up all of the ratings for each site to establish site priorities. Some goals may need to be weighted more heavily than others, depending on their relative importance. This sort of process can be helpful, but needs to be supplemented by good judgment and common sense.

4. Screen potential projects for constraints and feasibility.

- Considering possible constraints, such as land-use conflicts, property ownership, willingness to participate, and public and private cost, which projects are realistic and cost-effective?

The result of Step 3 is a set of site priorities based on the match between restoration/enhancement opportunities and goals. However, other constraints need to be factored into a final set of priorities. For each on-the-ground project or proposed action, ask the following questions:

- Are there potential land-use conflicts?
- Who owns the property?
- Is the property owner willing to sell or donate the property?
- How do neighbors feel about the project?
- How much will the project cost?
- Where will the money and labor come from to actually implement and monitor the project?

Answers to some of these questions may drop some sites or projects off the list immediately. Project feasibility may change over time; what is not feasible today may be feasible 5 years from now, for example, if land ownership changes or funding becomes available.

Some projects may involve working to get land-use or water-quality rules changed so that otherwise feasible on-the-ground projects can go forward. In Coos Bay, for example, reservation of a diked wetland for use as future development mitigation made it ineligible for nonregulatory restoration, even though it was owned by the South Slough National Estuarine Research Reserve. The county changed the rule to allow habitat restoration for research purposes, but similar constraints exist in other estuaries.

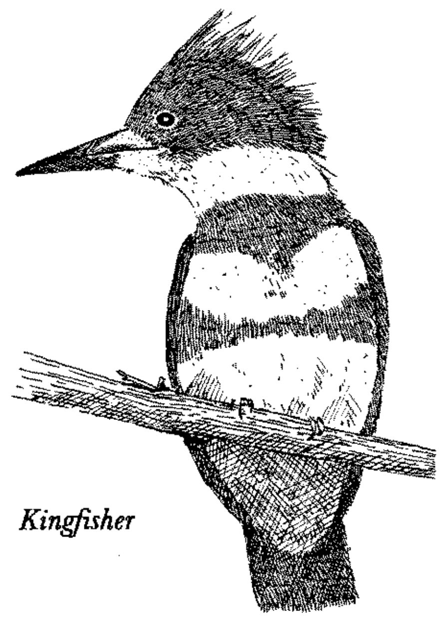
5. Synthesize results, write an action plan, and begin work.

- What is the overall vision for estuary restoration, enhancement, and management?
- Commit the plan to writing, maps, and drawings; begin its implementation project by project; monitor progress toward its accomplishment; periodically reevaluate priorities, recognizing that goals and constraints may change over time.

The action plan developed to this point is a vision for improving an estuary's health and condition. Document your planning process and decisions with maps and text.

RESTORING THE ESTUARY–PROJECT BY PROJECT

An estuary-wide action plan developed using the process described above will yield specific, high-priority projects to achieve estuary and watershed goals and will have community and property owner support. The next step–actually constructing and monitoring projects–is the rewarding part. But it is not so simple as breaching dikes or installing new culverts. Project by project, you must survey sites, set realistic goals, make drawings of present and projected conditions, secure funding and equipment, undertake construction, and begin monitoring. The needs associated with any given project will vary, but all require the same general steps.



Kingfisher

There is a growing body of knowledge about how to best restore or enhance estuarine habitats and functions. Particularly valuable for Oregon are lessons learned from more than 20 years of salt marsh restoration in the Salmon River estuary and the restoration of a variety of habitats in the South Slough of Coos Bay.

From these experiences and other restoration and enhancement projects in the Columbia River estuary, Washington, and California, it's possible to derive a general process and set of principles for carrying out estuary restoration or enhancement projects. This process is outlined below as four steps:

1. *Project planning and design*
2. *Project construction*
3. *Monitoring*
4. If needed, *project modification* to correct problems or revise goals to be more consistent with actual site potential.

This kind of approach often is called *adaptive management,* meaning that we recognize our limited ability to predict outcomes and thus treat every project as an experiment.

1. Project planning and design

Planning and design considerations for estuarine restoration or enhancement projects vary by project type. However, some general aspects of project planning and design are similar for all projects. First, a thorough assessment of historical and current site conditions is needed. Next, clear goals and objectives–consistent with site potential and expected restoration trajectory–must be set. Finally, a monitoring plan is needed for estimating progress toward goals and suggesting corrective actions as needed.

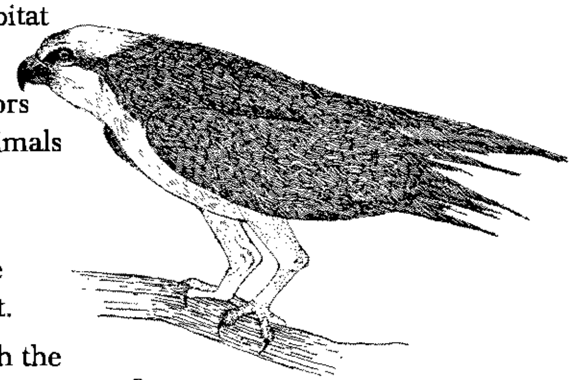
Beyond these general considerations, each type of restoration project and each individual project will have unique design considerations. Establishment of salt marsh vegetation on a dredged material island, for example, will have different design specifications than an eelgrass planting, clam bed restoration, or culvert replacement.

The project used here to illustrate design considerations is a *tidal marsh restoration*–a common opportunity in Oregon's estuaries, given the extensive wetland diking and draining that took place early in the 20th century. Many factors listed here are purely physical considerations, reflecting the perspective that if you restore appropriate hydrology and landscape conditions, the biology will follow. But biological considerations also are important in planning.

Based on previous tidal marsh restoration experience in the region, the following design principles and planning considerations are recommended. They can serve as a checklist for groups undertaking similar projects.

- ☐ *Watershed disturbances*–Consider existing or potential upland and upstream disturbances when designing estuarine restoration or enhancement projects.
- ☐ *Links to other projects*–Consider opportunities to simultaneously plan and construct estuarine, upstream, riparian, and upland enhancement projects to increase effectiveness and efficiency at the watershed level.
- ☐ *Buffers*–Minimize boundaries shared with developed areas that will disturb wetland wildlife or interfere with desired functions or values. Where such boundaries are unavoidable, plan for adequate buffers between the wetland and adjacent development.

- ☐ *Size*–Large estuarine restoration projects are, in general, preferred over small projects because of their potential habitat and functional diversity.
- ☐ *Corridors*–Consider the need for water and wetland corridors between separated habitat areas so wildlife and aquatic animals can move from one area to another.
- ☐ *Energy regime*–Carefully consider the site's energy regime. Exposure to excessive tidal currents and wave action is the most frequent reason for failure of vegetation development.



Osprey

- ☐ *Manipulation*–Minimize manipulation of the site. Work with the site to take advantage of its natural configuration, drainage, and other characteristics. Extensive manipulation is expensive and prone to failure.
- ☐ *Sustainability*–Plan for self-sustaining habitats, thus minimizing maintenance costs.
- ☐ *Subsidence*–Because diked and drained tidal marshes subside a foot or more and may continue to utilize unnatural drainage patterns after dike removal, complete restoration to former, pristine conditions is not a realistic goal. However, restoration to a well-functioning part of the estuarine ecosystem is realistic.
- ☐ *History*–Historical conditions at and surrounding the site may or may not be a good predictor of site restoration potential, given past alterations. However, understanding the history of the site and its likely prediking elevations and habitats will provide clues that are useful in setting goals, designing the project, and understanding limitations.
- ☐ *Prerestoration survey*–A careful prerestoration survey of historical channels and creeks, present drainage patterns, adjacent tidal and salinity regimes, water quality, soil characteristics, and land elevations is important for setting realistic restoration goals and developing a monitoring program. Also survey nearby intact reference sites to serve as control sites.
- ☐ *Hydrology*–Restoring prior hydrologic connections is critical to successful restoration. If possible, completely remove dikes. Open tidal creeks at their former locations and dredge them to ensure adequate tidal exchange.
- ☐ *Vegetation*–Vegetation reestablishment can be passive if there are nearby "seed bank" tidal marshes of the type expected to develop at the restoration site. Planting is expensive and usually unnecessary for tidal wetlands. If vegetation does need to be planted, use local plants or seed stock, and pay careful attention to site elevations, slopes, energy regime, tidal influence, salinity regime, and freshwater input.

- ☐ Permits–You will need a permit from the Division of State Lands and the Corps (and possibly the city or county) to construct your project. (See "Resources.") Involve them early. Specialists from these and other agencies, such as the Oregon Department of Fish and Wildlife, and from nongovernmental agencies and universities also can be helpful.

2. Project construction

After you complete the site assessment, planning, and design and secure funding, construction can begin. The following considerations and principles are important:

- ☐ Follow construction plans–Construction should follow the site plan exactly. Next to poor planning, construction that did not meet specifications is the most common cause of failed restoration and enhancement projects. Wetland specialists and engineers should be onsite during construction to ensure plans are followed.
- ☐ Salvage materials–Construction should be phased to allow salvaging of vegetation and substrates of ecological value.
- ☐ Timing–Time construction to accommodate the tide cycle and seasonal cycles of vegetation growth and fish and wildlife activities.

3. Monitoring

The importance of monitoring a site after it has been manipulated for restoration or enhancement cannot be overemphasized. Every estuarine restoration or enhancement project should be monitored at some basic level (Figure 22). Monitoring lets you know whether you are moving along the projected restoration trajectory and suggests ways of correcting problems that inevitably arise. Monitoring also can be used to set more realistic goals and improve the design of future projects.

Monitoring has both short- and long-term considerations. In the short term, monitor drainage pattern development, sedimentation and erosion, fish and wildlife use, and vegetation establishment. In the long term, the concern is whether the estuarine habitat has become a well-functioning, integral part of the estuarine ecosystem.

Plans for post-restoration monitoring vary depending on the size, scope, and goals of the project; the purpose of monitoring; and the training, skills, and time available. *Basic monitoring,* which can be carried out by trained volunteers and/or watershed council members with engineering, map-making, and other skills, may include:

- ☐ *General photo documentation*–Take photos from established locations before, during, and immediately after construction.
- ☐ *Construction assessment*–Create plan views, cross-section maps, and drawings to ensure that construction follows plans.
- ☐ *Physical site development*–Use periodic photo documentation and mapping to follow the evolution of drainage patterns, tidal connections, tidal creeks, undesirable ponding, and, if possible, sedimentation and changes in elevation (monthly at first, quarterly later).
- ☐ *Vegetation*–Continue photo documentation, mapping, and description of vegetation development and succession, including percent cover, species composition, and distribution. If relevant, compare success of planted areas with natural recruitment (quarterly).
- ☐ *Water quality*–Monitoring estuarine salinity and water quality requires specialized equipment and training, but your group can work with local schools who are part of the CoastNet water-quality monitoring program. (See "Resources.")
- ☐ *Aquatic life use*–Describe initial colonization, succession, and use of tidal flats, tidal creeks, channels, and marsh surface by bottom-dwelling plants (e.g., eelgrass and algae) and animals (amphipods, worms, clams, and fish such as juvenile salmon, trout, and skulpin), land and aquatic mammals (seasonal for at least a full tidal cycle and dawn and dusk period), and birds (seasonal for at least a full tidal cycle). Sediment cores and sieves, fish nets, traps, and visual inspection are useful techniques. While resulting data may not be statistically accurate, these methods can give a good overall view of changing site use by estuarine organisms.
- ☐ *Recreation use*–Evaluate the site for recreational use, including levels of disturbance and effectiveness of established buffers.

The above monitoring guidelines are the ideal but are unrealistic for many projects because people, funds, or equipment may not be available. The extent of monitoring should be related to the level of investment in the project, its importance, the risk of failure, and so on.

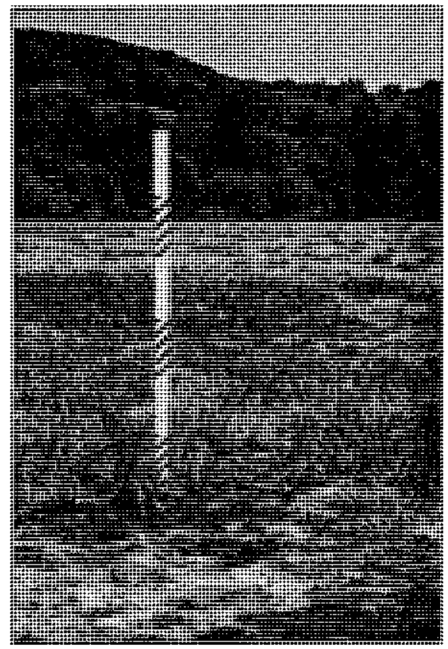


***Figure 22.**–Setting up a monitoring grid is the first step in tracking changes at a restoration site. (Photo: Robert Frenkel)*

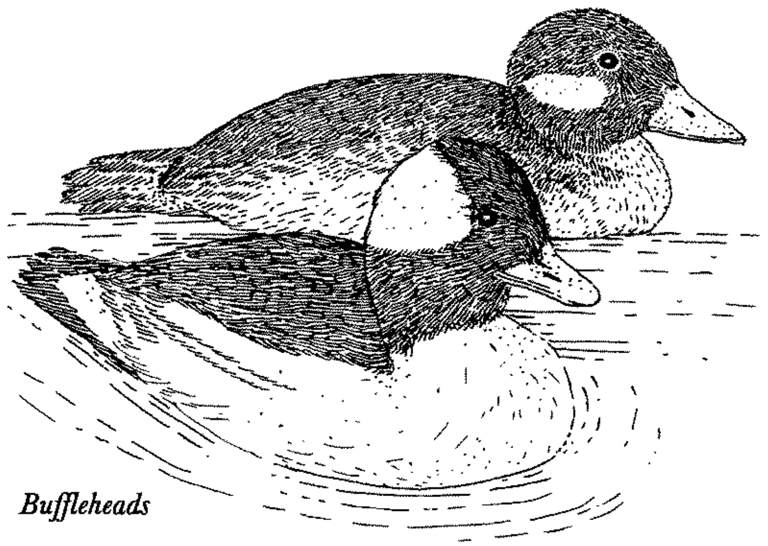
In some cases, even more in-depth monitoring may be desirable. In this case, professionals and scientists probably already are involved. In-depth technical monitoring, such as calculating sedimentation rates, analyzing sediment salinity, measuring plant biomass, quantifying use of the site by endangered species, and evaluating food and habitat preferences, generally is carried out by professionals and scientists.

How long should monitoring continue? Research on estuarine restoration and enhancement the past 20 years suggests that determining "success" requires at least 10 years of postrestoration monitoring, both because sites take time to develop and because needed corrective actions may not be apparent over shorter time periods. Few watershed council projects are monitored formally for this long. However, productive partnerships with schools, hunting or fishing organizations, and other groups may allow longer term tracking of project success.

Whatever the proposed level of monitoring, it is advisable to secure technical assistance before initiating monitoring. Resource specialists and scientists from agencies and universities can help outline a program and train local volunteers.

4. Practicing adaptive management

If monitoring shows the project is not proceeding as planned, physical or other modifications may be needed. Alternatively, you may need to modify project goals to be more realistic and consistent with the site's actual potential to perform desired functions.



Buffleheads

Summary/Self review

Estuaries are transition ecosystems characterized by sheltered wetlands, tidal flats, strong tidal mixing of salt water and fresh water, and an assemblage of plants and animals adapted to highly variable conditions.

Estuaries provide a variety of valued goods and services–fish and wildlife habitat; food production that supports the estuarine food chain; water-quality maintenance; moderation of floodwater flows; shoreline stabilization; and a variety of economic, recreational, and educational benefits.

To maintain and increase the benefits estuaries provide to people and the environment, we need to:

- Protect the critical remaining estuarine habitat.
- Restore former or degraded estuarine habitats where feasible.
- Link estuarine restoration actions to upland and upstream restoration and enhancement efforts for a whole-watershed approach.
- Monitor water quality, clean up existing pollution problems, and prevent new pollution that cannot be readily assimilated.
- Avoid inadvertent or intentional introduction of harmful, nonnative plants and animals.
- Incorporate both local knowledge and the best available scientific information into our planning, decision making, and projects.
- Support research to improve understanding of estuarine ecosystems and their relationships to marine and freshwater systems.

Estuary-wide planning for restoration involves five key steps:

1. Assessment of historical conditions, current conditions, and threats
2. Setting restoration and enhancement goals
3. Identifying potential restoration, enhancement, management, or education projects and setting priorities
4. Screening potential projects for constraints and feasibility
5. Synthesizing planning results, writing an action plan, and beginning work

The purpose of studying an estuary's ecological history is to understand how the estuary functioned in the past, how it has been changed, and how it might be rehabilitated to better serve economic and ecological functions.

Experience with estuary restoration and enhancement projects in the region suggests that careful planning and design, clear goals, construction that follows plans exactly, and follow-up monitoring are keys to success.

EXERCISE

You can do this exercise on your own, but it is helpful to work in a small group so you can pool your observations.

Constructing a map of former estuarine habitats

This exercise will familiarize you with the habitat information that can be gleaned from a variety of recent and historical data sources. (See Appendix A.) You will find that not all sources are available for all parts of all estuaries. The end product will be two maps showing distribution of salt- and freshwater tidal marshes, tidal forested swamp, tidal flats, deeper channels, and other habitats. One map will show present conditions, the other historical conditions (Figure 23).

Select a relatively small area of an estuary that has been obviously altered by diking, filling, or other human actions. Obtain as many of the following information sources as possible, using the "Resources" section and Appendix A to locate them:

- The National Wetlands Inventory (NWI) "quad sheet" for the area (See Chapter II-9, "Wetlands," for ordering instructions.)
- Recent, and if available, historical aerial photos at no smaller than 1:24,000 scale (same as NWI maps)
- The county soil survey and instructions for locating hydric (wet) and tideland (former estuary) soils
- If available, old U.S. Coast Survey charts for the estuary (and information on how to interpret map symbols)
- Original Public Lands Survey records for the area (optional, but may be especially important if they are the only good early historical source)
- U.S. Army Corps of Engineers navigation records, if available
- Historical ground photos, written accounts, and local diking and drainage district records (Local and state historical societies are good sources.)

Using these sources, two blank sheets of transparent, gridded mylar (registered to the NWI map with tic marks in the corners), and a set of transparent colored pens, develop both present and historical habitat maps, using the following steps to guide the process:

1. Affix one of the mylar overlays to the NWI map with masking tape. Using appropriate colors, identify estuarine and tidal freshwater wetlands and deep-water habitats such as salt marshes (light green), tidal freshwater marshes (medium green), tidal forested wetlands (dark green), eelgrass beds (very light green), tidal flats (beige to brown), and deep-water channels and tidal creeks at low tide (light blue). See Chapter II-9, "Wetlands," for detailed information on the NWI.
2. Using the most recent aerial photos for the area (ideally 1:24,000 scale, so you may need to make reduced or enlarged copies), examine the first overlay with NWI data superimposed. Are any errors in the NWI apparent? Do the wetland boundaries seem accurate? Make changes as needed.
3. At low tide, conduct a rapid field check, looking for changes since the aerial photos used to develop the NWI, or your more recent photos, were taken. Again, correct your map as needed. The resulting *current estuary habitat* map is your first product.
4. Obtain the soil survey sheet (normally 1:20,000 scale) for the area, make an overhead transparency copy of it (reduce to 80 percent to get 1:24,000 scale), and overlay it on the NWI map. How do the

boundaries for hydric and tideland soil types compare to present estuarine wetland boundaries? Does the NWI map contain clues such as notations that a freshwater, nontidal marsh adjacent to the estuary is diked? Are tidegate locations apparent, and are dikes across former tidal creeks clearly visible? Based on soils and NWI maps and codes, estimate the former extent of tidally influenced areas and the types of habitat that may have been present. Pencil in your results on the second mylar sheet.

5. Three other sources of data may provide further clues to historical habitat types and distribution–old Coast Survey charts (Figure 20), original Public Lands Survey records, and old ground photos. The old charts show vegetation types along the shore and in wetlands, helping to differentiate forested upland from forested swamp and tidal swamp from tidal marsh.

6. From an analysis of these data sources, draw a map of historical habitat conditions for your site on the second mylar sheet, with appropriate notes and qualifiers. Calculate the area of former estuarine habitat types (e.g., tidal swamp, marsh, flats, and subtidal areas) by counting grid cells on the mylar overlay and converting to acres of habitat.

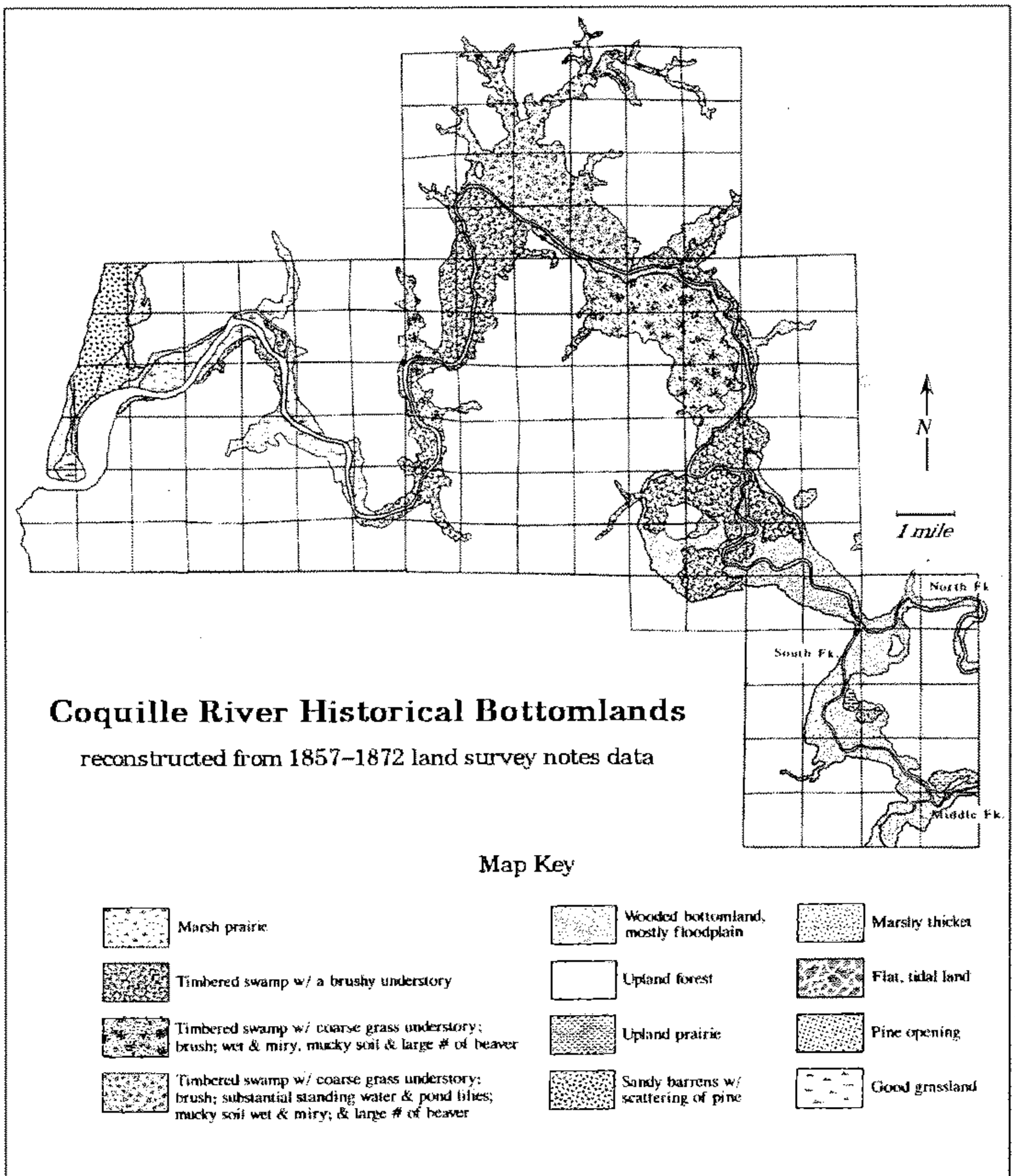


***Figure 23.**–Reconstruction of historic vegetation patterns from old maps and public lands survey records was a valuable source of data for identifying potential estuarine restoration projects in the Coquille estuary. (Map courtesy of Patricia Benner)*

RESOURCES

Technical agencies and information sources

South Slough National Estuarine Research Reserve (SSNERR)
P.O. Box 5417
Charleston, OR 97420
Phone: 541-888-2581, Ext 301 or 302
Contact: Craig Cornu or Steve Rumrill
E-mail: ccornu@oimb.uoregon.edu or srumrill@oimb.uoregon.edu
Web: http://www.southsloughestuary.com/

Oregon Coastal Management Program
Department of Land Conservation and Development
635 Capitol Street NE, Suite 150
Salem, OR 97301
Phone: 503-373-0050
Contact: Don Oswalt
E-mail: don.oswalt@state.or.us
Web: http://www.lcd.state.or.us/coast/index.htm

Oregon Department of Fish and Wildlife, Marine Division
Hatfield Marine Science Center
Newport, OR 97365
Phone: 541-867-4487

Oregon Division of State Lands
775 Summer Street, NE
Salem, OR 97310
Phone: 503-378-3805
Contact: Larry Devroy
E-mail: larry.devroy@dsl.state.or.us
Web: http://statelands.dsl.state.or.us/wetlandsintro.htm

U.S. Environmental Protection Agency, Coastal Ecology Laboratory
Hatfield Marine Science Center
Newport, OR 97365
Phone: 541-867-4040

U.S. Fish and Wildlife Service
Oregon Coastal Refuges
2127 SE OSU Dr.
Newport, OR 97365-5258
Phone: 541-867-4550
Contact: Roy Lowe, Manager
E-mail: roy_lowe@fws.gov

Education programs and facilities

South Slough National Estuarine Research Reserve (SSNERR)
P.O. Box 5417
Charleston, OR 97420
Phone: 541-888-5558
Contact: Tom Gaskill
E-mail: tgaskill@harborside.com
Web: http://www.southsloughestuary.com/

Sea Grant Extension Oceanography
College of Oceanic and Atmospheric Sciences
104 Ocean Admin Building
Oregon State University
Corvallis, OR 97331-5503
Phone: 541-737-1339
Contact: Jim Good
E-mail: good@oce.orst.edu
Web: http://seagrant.orst.edu/

Hatfield Marine Science Center
2030 S. Marine Science Drive
Newport, OR 97365
Contact: Janet Webster, librarian
Phone: 541-867-0108
E-mail: janet.webster@hmsc.orst.edu
Web: http://www.hmsc.orst.edu

Videos

Estuaries: Oregon's Coastal Treasures (available from Oregon Department of Fish and Wildlife)

Tide of the Heron (available from South Slough National Estuarine Research Reserve)

Publications

Field Trip Guide to South Slough National Estuarine Research Reserve (available from South Slough National Estuarine Research Reserve)

Oregon Estuary Plan Book, 1987 (available from the Oregon Department of Land Conservation and Development)

Planning and Evaluating Restoration of Aquatic Habitat from an Ecological Perspective, IWR Report 96-EL-4 (1996, available from the U.S. Army Corps of Engineers, Institute for Water Resources, Alexandria, VA 22135-3868)

South Slough National Estuarine Research Reserve publication series, written by K. Oberrecht and illustrated by S. Torvik:

- *Salmon and Trout in Oregon Estuaries*
- *Native Shellfish and Introduced Species in Oregon Estuaries*
- *Oregon Salt Marshes*
- *Flooding on the Oregon Coast*

Web sites

USGS digital orthophotos and other products
http://www-nmd.usgs.gov/esic/esic.html

CoastNet, local schools water-quality monitoring program, some data for some estuaries
http://secchi.hmsc.orst.edu/coastnet

The Nature Conservancy's heritage sites
http://www.heritage.tnc.org/nhp/us/or/

South Slough National Estuarine Research Reserve site, with information on the Winchester Tidelands Restoration Project
http://www.southsloughestuary.com/

North Oregon Joint Ventures Wetlands Plan. Focus is on restoration.
http://wetlands.dfw.state.or.us/plan.htm#

U.S. Fish and Wildlife Service Refuges; includes Oregon coast
http://www.nationalgeographic.com/refuges

References

Changes in Columbia River Estuary Habitat Types over the Past Century, by D.W. Thomas (Columbia River Estuary Study Taskforce, Astoria, 1983).

Coastal Wetlands of the United States: An Accounting of a Valuable National Resource, NOAA (91-3) (National Oceanic and Atmospheric Administration and U.S. Fish and Wildlife Service (NOAA-USFWS, Strategic Environmental Assessment Branch, Ocean Assessments Division, 1991).

A Comparative Study of Salt Marshes in the Coos Bay Estuary, National Science Foundation Student Originated Study, by J. Hofnagle, R. Ashley, B. Cherrick, M. Gant, R. Hall, C. Magwire, M. Martin, J. Schrag, L. Stuntz, K. Vanderzanden, and B. Van Ness (University of Oregon, Eugene, 1976).

Habitat Classification and Inventory Methods for the Management of Oregon Estuaries, by D. Bottom, B. Kreag, F. Ratti, C. Roye, and R. Starr (Oregon Department of Fish and Wildlife, Portland, OR, 1979).

"History of Estuarine Wetland Development and Alteration: What Have We Wrought?" by M.E. Boule and K.F. Bierly. *Northwest Environmental Journal* (1987) 3(1):43–62.

National Estuarine Inventory: Data Atlas, volume 1: Physical and Hydrologic Characteristics, NOAA (87-1) (National Oceanic and Atmospheric Administration, Strategic Environmental Assessment Branch (NOAA-SEA), Rockville, MD, 1985).

National Estuarine Inventory: Supplement 1: Physical and Hydrologic Characteristics: The Oregon Estuaries (National Oceanic and Atmospheric Administration, Strategic Environmental Assessment Branch (NOAA-SEA), Rockville, MD, 1988).

"Oregon CZM Profile: Protection of Estuaries and Coastal Wetlands," unpublished report prepared as part of the National CZM Effectiveness Study, by J.W. Good (1997). Available for $3.00 from OSU; e-mail jburck@oce.orst.edu

Oregon Estuaries (Division of State Lands, Salem, OR, 1973).

"Oregon Estuarine Conservation and Restoration Priority Evaluation: Opportunities for Salmonid Habitat Enhancement in Oregon's Estuaries," by A. Lebovitz, unpublished manuscript, prepared for Oregon Trout and the U.S. Fish and Wildlife Service (Portland, OR, 1992). 92 pp.

Oregon Estuarine Invertebrates: An Illustrated Guide to the Common and Important Invertebrate Animals, FWS/OBS-83-16, by P. Rudy, and L.H. Rudy (U.S. Fish and Wildlife Service, Department of Interior, 1983).

Oregon Estuary Plan Book, by R. Cortright, J. Weber, and R. Bailey (Oregon Department of Land Conservation and Development, Salem, 1987). Also accessible on the Web at http://www.interrain.org/

Restoration of the Salmon River Salt Marshes: Retrospect and Prospect, Final Report to the USEPA, by R.E. Frenkel and J.C. Morlan (Oregon State University, Corvallis, 1990).

Restoration Potential of Diked Estuarine Wetlands in Washington and Oregon, Phase 1: Inventory of Candidate Sites, EPA 910/9-88-242 (U.S. Environmental Protection Agency, Wetlands Section, Water Division, USEPA Region 10, 1988).

Salmon and Trout in Oregon Estuaries, by K. Oberrecht (South Slough National Estuarine Research Reserve, Charleston, OR, 1998).

MOVING FORWARD–THE NEXT STEPS

On your own, use the lines below to fill in steps, actions, thoughts, contacts, etc. you'll take to move yourself ahead in understanding the key concepts of estuarine science, management, and restoration.

1.____

2.____

3.____

Appendix A–Sources of historical information about Oregon estuaries

Aerial photos

The earliest aerial photos of the Oregon coast date from 1939, but they cover only the immediate coast and do not extend upriver. More recent aerial photos are available, and some can be downloaded from the Internet. For example, USGS digital orthophotos and other products are available at http://www-nmd.usgs.gov/esic/esic.html. 1986 color aerial photos of all major estuaries are available from the Department of Land Conservation and Development's Ocean and Coastal Management Program. Although somewhat dated, these photos are very useful because of their clarity and upstream coverage to the head of tide. Other estuary photos are available from other government and private sources.

National Wetlands Inventory (NWI)

NWI maps and data, described in Chapter II-9, are available from the Oregon Division of State Lands. These maps are based on expert interpretation of aerial photos dating from the 1970s. They provide a wealth of information, showing existing estuarine wetlands, for example, as well as diked wetlands, some of which are potential restoration sites. NWI maps are a valuable complement to the *Oregon Estuary Plan Book* maps referred to earlier because they include the entire aquatic ecosystem.

County soil surveys

Soil survey maps and soil descriptions help delineate the extent of former tidelands, thus indicating what areas might be subject to tidal inundation if dikes were removed or culverts installed or enlarged. These surveys are available from the local Soil and Water Conservation district office or the OSU Extension Service.

U.S. Coast Survey charts

Topographic surveys (T-sheets), hydrographic (bathymetry) surveys, and composite charts from the late 19th and early 20th century are available for some estuaries. (Figure 20 is a sample for Coos Bay.) These maps, along with interpretation aids in government publications, provide surprisingly accurate geographic data showing pre-alteration conditions of tidal marshes, forested swamps, and flats, as well as changes in channels and estuary volume due to sedimentation.

Original Public Lands Survey records

In the middle of the 19th century, the Government Land Office conducted a mile-by-mile Public Lands Survey of much of Oregon, including coastal lowlands surrounding estuaries and upstream areas. These surveys used the familiar township-range system found on present USGS topographic maps. The old survey records are available from the Bureau of Land Management on microfiche. These records can be used to reconstruct habitats in and around estuaries and other areas. Figure 23 is an example for the Coquille estuary.

Except for the Tillamook Bay area, there are no comprehensive reconstructions of Oregon estuarine conditions using the PLS system records. However, for restoration site planning, site-specific maps and survey notes can be quite useful in evaluating historical drainage patterns and vegetation.

U.S. Army Corps of Engineers navigation records

The Corps of Engineers has long been responsible for keeping estuaries and rivers navigable. They have dredged, built water-control structures, and cleared snags from river and estuary channels since the mid-1800s. The Corps keeps excellent records, which have been used to help reconstruct former estuarine and river conditions. These records for Oregon are available from the Portland District of the Corps.

Hydrologic and water-quality records

A change in the amount or timing of freshwater inflow to estuaries changes the makeup of the estuarine ecosystem, altering the turbidity maximum as well as plant and animal communities. The Oregon Water Resources Department and USGS are good sources of hydrologic information, and the Oregon Department of Environmental Quality maintains water-quality records. Only recent records are available, but they are important complements to historical habitat information from other sources.

Fisheries data and records

Compilations of fish catches and processing records are another useful source of data. Some data are available from the National Marine Fisheries Service (formerly the Bureau of Commercial Fisheries) and some from the Oregon Department of Fish and Wildlife. Still others are available in university libraries, for example, at OSU's Valley Library and the OSU Hatfield Marine Science Center Branch Library in Newport. Librarians there can assist you.

Historical ground photos, written accounts, local diking and drainage district records

Local records available from state and county historical societies are another good source of information. Local diking districts, map collections at university libraries, and local "old-timers" are other useful sources.