# The California Watershed Assessment Manual

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Irrigated fields east-side Sierra Nevada
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Downtown Los Angeles

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# Contributing Groups/Organizations

(In addition to the agencies/organizations represented in our Steering Committee, representatives from these groups, agencies, organizations, and businesses provided feedback in the initial stages of the Manual's development)

- California Departments of Parks & Recreation, Water Resources
- East Bay Watershed Center (Merritt College)
- Friends of Five Creeks
- Los Angeles San Gabriel Rivers Watershed Council
- Mattole Restoration Council
- MUSCI-Natural Resource Assessment
- Orange County (Michael Wellborn)
- Pacific Lumber Company
- Pit River Watershed Alliance
- Regional Water Quality Control Board (Central Valley, North Coast)
- Roseburg Forest Products
- San Francisco Public Utilities Commission
- Santa Clara Basin Watershed Management Initiative
- Santa Cruz Blue Circle
- Sonoma Ecology Center
- Southern California Wetlands Recovery Project
- US Army Corps of Engineers (Los Angeles office)
- US Forest Service (Redwood Sciences Laboratory)
- Western Shasta Resource Conservation District

# Executive Summary

Watersheds by their nature are fluid and complex, making it difficult to fully understand their processes and conditions. Understanding watersheds in California is all the more challenging, due to the state's exceptionally diverse array of geographic and hydrologic conditions, which is overlain by an equally diverse set of social and economic conditions. The amount of data available about these conditions also varies greatly from watershed to watershed which adds to difficulty in understanding watershed condition. All of these factors contribute to watershed assessment in the state being a challenging undertaking.

"Watershed assessment" is one method used to understand a watershed. It is a process for evaluating how well a watershed is functioning. Watershed assessment may include identifying important issues, examining historic conditions, evaluating present conditions and processes, and determining the effects of human activities. It can mean describing the parts and processes of the whole watershed and analyzing their functioning in general, or relative to some standard (such as a water quality standard or historic condition). It also can mean focusing on particular concerns about human activities, conditions, or processes in the watershed.

The California Watershed Assessment Manual provides a series of approaches that will assist watershed assessors, and those guiding assessments, in planning and carrying out watershed assessments. These approaches are appropriate for a variety of watershed stakeholders, including members of watershed groups, agency representatives, landowners, scientists, members of the academic community, business representatives, and consultants. While the Manual is not prescriptive, it is thorough. It presents a comprehensive view of the watershed assessment process, with specific guidance on starting the process, putting together an integrated assessment team, determining the assessment's purpose, planning and conducting the assessment work, and completing the assessment report. The Manual also describes the basics of watershed functioning, thus laying a foundation for understanding the rest of the Manual and watersheds generally. It lays out methods for defining the assessment's boundaries, for determining how complex the analysis should be, and for identifying gaps in data, knowledge, or analysis. It provides methods for gathering, managing, analyzing, and presenting data, and it suggests approaches for integrating information in order to better understand watershed conditions. The Manual describes ways to present the assessment and use it to support decision-making and adaptive management.

This is the first version of the Manual. It is intended to provide guidance for planning and conducting watershed assessments for wildland and rural areas of northern and central California. However, many aspects of it will be useful for other areas in the state and country. Future editions of the Manual will focus on the remainder of California and issues relating to particularly agricultural and urban areas, pending additional funding. We welcome your feedback and contributions, which will make future versions of the Manual even more responsive to the needs of California's watershed assessors.

Manual Structure

The Manual currently contains 8 chapters. These flow from the introductory chapter (1), through chapters describing the details of assessment planning (2), fundamentals of watershed functioning (3), data collection (4), data analysis (5), and data integration (6). Chapter 7 gives details on how to structure an assessment report; and chapter 8 describes connecting the assessment with decision-making. An additional chapter (9) will talk about using the assessment to support a continuing assessment (or monitoring) program. The Appendix will be a compendium of tools for use in specific circumstances and with specific natural or human processes or conditions. The chapters are described in slightly more detail below.

*Chapter 1*

We describe the Manual's purpose, intended audience, regional focus, identified need, development process, format, and next steps in evolution.

*Chapter 2*

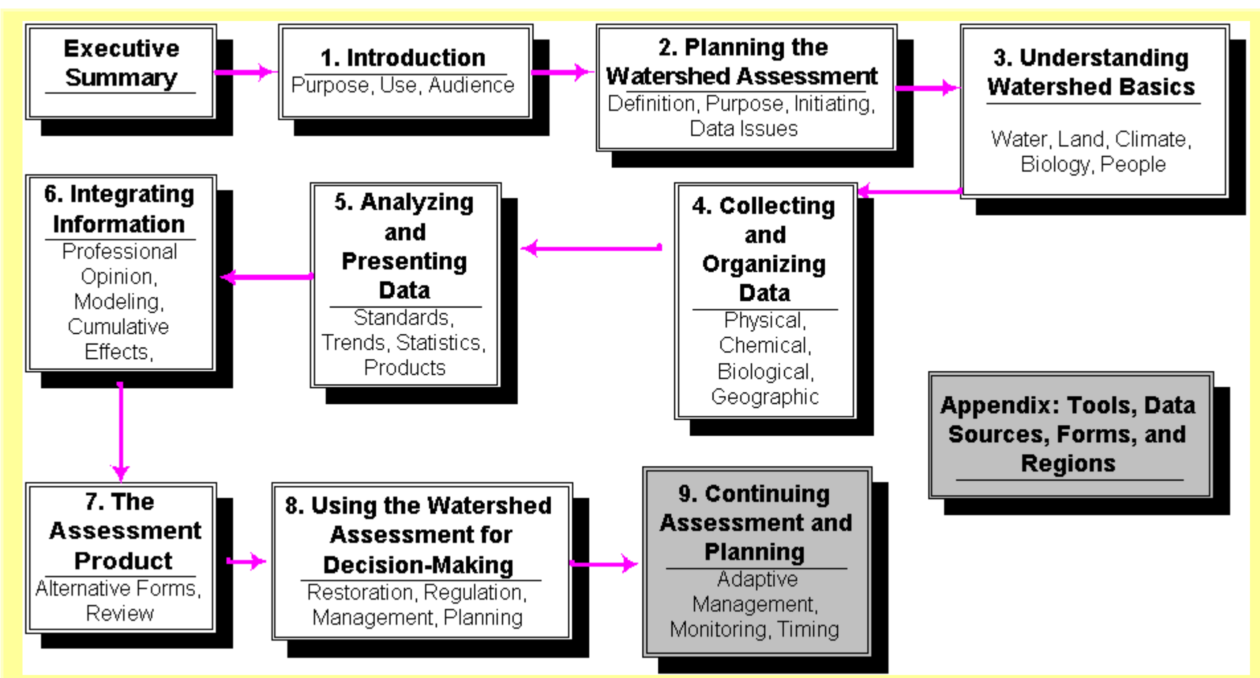
We describe some of the decisions that need to be made before beginning the assessment, after first defining what a watershed assessment is and is not. Planning topics include deciding the purpose, focusing on questions about watershed condition, developing the assessment team, working with the watershed communities, and deciding the boundaries of the analyses and the assessment area. We talk about steps that should be taken to prepare for the assessment and give a rough sketch of the assessment itself. We also take on the topics of scale, uncertainty, and data and knowledge gaps.

*Chapter 3*

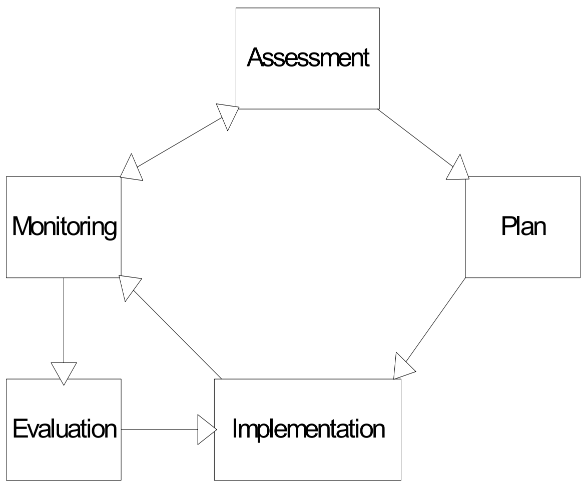
To provide a baseline for understanding the watershed processes that are usually the subject of watershed assessments, we devote this chapter to describing many of these processes within the general categories of geography, hydrology, climate, geology, sediment, water quality, aquatic and terrestrial ecosystems, land and water use and management, and socio-economics. Readers with substantial background in particular topics can skip around to areas where they want more information.

*Chapter 4*

This chapter marks the beginning of the data-intensive part of the assessment – the collection and organization of information about the watershed. We suggest sources of information about watershed conditions in California. We also talk about the how to organize collected data appropriately



"Ideal" Adaptive Watershed Management Sequence




relative to the questions developed earlier in the planning process.

*Chapter 5*

Data analysis is at the heart of figuring out the conditions in the watershed in response to questions about these conditions. This chapter provides tools for preparing the data analysis, resources for conducting data analysis and applying statistics, information on space and time considerations, and ways to evaluate and present data.

*Chapter 6*

Information integration is the focus of this chapter. We define information integration as the process of synthesizing data on social, physical, chemical, and biological conditions in the watershed, and the watershed processes that mediate them, into a single analysis. The integration product is intended to be used for decision-support. Data integration is not easily done and is not commonly done in today's watershed assessment. We discuss ways that watershed assessors can take information collection and knowledge development, described in earlier chapters, and draw conclusions about potential relationships between activities in the watershed and impacts and condition. We also "demystify" modeling, talk about the role of change over time, and provide guidance for conducting scenario development.

*Chapter 7*

This chapter describes the basic components of a watershed assessment report, including the minimum information to include, how to present different kinds of data, and tailoring the assessment report to match the decision-making process.

*Chapter 8*

This chapter focuses on the different decision-making processes that a watershed assessment can support, since the product is not an endpoint. These processes range from designing a monitoring program, responding to regulatory requirements for land use or nonpoint source pollution discharge, and local land use planning to developing a watershed restoration or protection plan.

*Chapter 9 (to be constructed)*

Once a watershed assessment is done, it becomes a point in the continuum of knowledge about a watershed. We will discuss how to make a watershed assessment a continuing process through periodic assessment and monitoring programs.

*Appendix (to be constructed)*

The Appendix will offer a variety of tools for analyzing natural and human processes and conditions, organized by topic. For example, we will describe how channel processes are measured, how surface erosion process can be described and quantified, how benthic macroinvertebrate data can be collected and used in watershed assessment, and how spatial modeling is conducted.

# Glossary of Terms

**acid mine drainage (AMD)**--water draining out of operating or abandoned mines that has very low pH and may contain high concentrations of various metals and/or sulfur.

**adaptive management**--monitoring or assessing the progress toward meeting management objectives and incorporating what is learned into future conceptual models, management plans and actions, and monitoring.

**anadromous**--a type of life cycle where fish return from the ocean to freshwater to spawn

**aqueduct**--a pipe, conduit, or channel designed to transport water from a remote source, usually by gravity.

**aquifer**--a geologic formation(s) that is water bearing. A geological formation or structure that stores and/or transmits water, such as to wells and springs. Use of the term is usually restricted to those water-bearing formations capable of yielding water in sufficient quantity to constitute a usable supply for people's uses.

**aquifer (confined)**--soil or rock below the land surface that is saturated with water. There are layers of impermeable material both above and below it and it is under pressure so that when the aquifer is penetrated by a well, the water will rise above the top of the aquifer.

**aquifer (unconfined)**--an aquifer whose upper water surface (water table) is at atmospheric pressure, and thus is able to rise and fall.

**artificial recharge**--an process where water is put back into ground-water storage from surface-water supplies such as irrigation, or induced infiltration from streams or wells.

**base flow**--streamflow coming from ground-water seepage into a stream.

**benthic**--referring to the bottom of a waterway

**benthic macroinvertebrates**--invertebrates (e.g., snails, worms, aquatic larvae of insects) living in or on the benthos (bottom) of waterways.

**bioengineering**--usually plant-based structural approaches to controlling geomorphological responses to land-uses and disturbance.

**biota**--living things, such as plants, animals, and microorganisms.

**capillary action**--the means by which liquid moves through the porous spaces in a solid, such as soil, plant roots, and the capillary blood vessels in our bodies due to the forces of adhesion, cohesion, and surface tension. Capillary action is essential in carrying substances and nutrients from one place to another in plants and animals.

**Central Valley Project (CVP)** - Federally operated water management and conveyance system that provides water to agricultural, urban, and industrial users in California

**Central Valley Project Improvement Act (CVPIA)** - This federal legislation, signed into law on October 30, 1992, mandates major changes in the management of the federal Central Valley Project. The CVPIA puts fish and wildlife on an equal footing with agricultural, municipal, industrial, and hydropower users

**commercial water use**--water used for motels, hotels, restaurants, office buildings, other commercial facilities, and institutions. Water for commercial uses comes both from public-supplied sources, such as a county water department, and self-supplied sources, such as local wells.

**conceptual model**--a descriptive picture or diagram of the relationships among key factors within the watershed. Explicit statements of the hypothesized functional relationships underlying management decisions regarding environmental resources."

**conjunctive use** - Integrated management of surface water and groundwater supplies to meet overall water supply and resource management objectives

**consumptive use**--that part of water withdrawn that is evaporated, transpired by plants, incorporated into products or crops, consumed by humans or livestock, or otherwise removed from the immediate water environment. Also referred to as water consumed.

**conveyance loss**--water that is lost in transit from a pipe, canal, or ditch by leakage or evaporation. Generally, the water is not available for further use; however, leakage from an irrigation ditch, for example, may percolate to a ground-water source and be available for further use.

**cubic feet per second (cfs)**--a rate of the flow, in streams and rivers, for example. It is equal to a volume of water one foot high and one foot wide flowing a distance of one foot in one second. One "cfs" is equal to 7.48 gallons of water flowing each second. As an example, if your car's gas tank is 2 feet by 1 foot by 1 foot (2 cubic feet), then gas flowing at a rate of 1 cubic foot/second would fill the tank in two seconds.

**cumulative watershed effects** (CWE)—the combined impact on watershed processes from multiple sources of natural and human disturbance in a watershed.

**decompose**--to rot or decay

**discharge**--the volume of water that passes a given location within a given period of time. Usually expressed in cubic feet per second.

**disturbance**--a change or cause of change in an ecosystem originating from natural or human sources. A natural disturbance could be fire or flood, a human-caused disturbance could be land development or logging.

**diversion** - The action of taking water out of a river system or changing the flow of water in a system for use in another location

**domestic water use**--water used for household purposes, such as drinking, food preparation, bathing, washing clothes, dishes, and dogs, flushing toilets, and watering lawns and gardens. About 85% of domestic water is delivered to homes by a public-supply facility, such as a county water department. About 15% of the Nation's population supply their own water, mainly from wells.

**drainage basin**--land area where precipitation runs off into streams, rivers, lakes, and reservoirs. Large drainage basins, like the area that drains into the Mississippi River contain thousands of smaller drainage basins. Usually considered larger than a "watershed."

**drawdown**--a lowering of the ground-water surface caused by pumping.

**ecological processes**—processes that act directly, indirectly, or in combination, to shape and form the ecosystem. These include streamflow, watershed (closely linked to streamflow; includes fire and erosion), stream channel (includes stream meander, gravel recruitment and transport, water temperature, and hydraulic conditions), and floodplain processes (include overbank flooding and sediment retention and deposition). [

**ecosystem**--a biological community together with the physical and chemical environment with which it interacts

**ecosystem function**--1) any performance attribute or rate function at some level of biological organization (e.g., energy flow, detritus processing, nutrient spiraling; 2) Ecosystem productivity and functions of hydrology, feeding, and transport

**ecosystem management**-- management that integrates ecological relationships with sociopolitical values toward the general goal of protecting or returning ecosystem integrity over the long term

**effluent**--material flowing from a source, such as wastewater from a treatment plant

**enhancement**-- in the context of restoration ecology, any improvement of a structural or functional attribute.

**EPT index**--the relative abundance of three pollution-sensitive orders of benthic macroinvertebrates to the abundance of a tolerant species of benthic macroinvertebrate. (the sum of the number of *Ephemeroptera*, *Plecoptera*, and *Trichoptera* divided by the total number of midges, *Diptera*: *Chironomid*)

**erosion**--the process in which a material is worn away by a stream of liquid (water) or air, often due to the presence of abrasive particles in the stream.

**eutrophication**—the gradual increase in nutrient concentrations of nutrients in a water-body from cycles of plant growth and decomposition, where the plant growth exceeds the consumption by grazing animals. This can result in low oxygen concentrations in the water due to microbial activity in the decomposing plant material.

**evaporation**--the process of liquid water becoming water vapor, including vaporization from water surfaces, land surfaces, and snow fields, but not from leaf surfaces.

**evapotranspiration**--the sum of evaporation and transpiration.

**flood**-- flow that exceeds the capacity of the channel. Floods have two essential characteristics: The inundation of land is temporary; and the land is adjacent to and inundated by overflow from a river, stream, lake, or ocean.

**flood, 100-year**--A 100-year flood does not refer to a flood that occurs once every 100 years, but to a flood level with a 1 percent chance of being equaled or exceeded in any given year.

**flood plain**--a strip of relatively flat and normally dry land alongside a stream, river, or lake that is covered by water during a flood.

**fluvial**--to do with streams and rivers

**gaging station**--a site on a stream, lake, reservoir or other body of water where observations and hydrologic data are obtained.

**geographic information system (GIS)**--a tool used to collect, store, combine, analyze and present geographic data (e.g., computer software such as ArcView, ESRI Inc.).

**geomorphology**--the study of earth surface processes and landforms, including landslides on hillslopes or erosion and sedimentation in rivers.

**ground water**--(1) water that flows or seeps downward and saturates soil or rock, supplying springs and wells. The upper surface of the saturate zone is called the water table. (2) Water stored underground in rock crevices and in the pores of geologic materials that make up the Earth's crust.

**habitats**--areas that provide specific conditions necessary to support plant, fish, and wildlife communities.

**headwater streams**--the small streams in the upper parts of the watershed that feed into larger streams below

**hydrologic cycle**--the cyclic transfer of water vapor from the Earth's surface via evapotranspiration into the atmosphere, from the atmosphere via precipitation back to earth, and through runoff into streams, rivers, and lakes, and ultimately into the oceans.

**impermeable layer**--a layer of solid material, such as rock or clay, which does not allow water to pass through.

**impervious surface**--usually a human-manufactured surface that water cannot penetrate (e.g., asphalt-covered street).

**indicators**--features or attributes of the system that are expected to change over time in response to implementation of management actions. Indicators are selected to provide measurable evaluations of important ecological processes, habitats, and species whose status individually and cumulatively provide an assessment of ecological health. Indicators of ecosystem health are the gauges we will use to measure progress toward the goal.

**infiltration**--flow of water from the land surface into the subsurface.

**integrated resource management**-- resource management that seeks to restore the structure and function of whole ecosystems by striving to understand and respond holistically to cumulative ecological impacts.

**integrated water management**--a way to maximize water quality and quantity to meet water needs for consumptive use and aquatic ecosystems by integrating water and land-use decision-making by local and regional agencies.

**irrigation**--the controlled application of water for agricultural purposes through manmade systems to supply water requirements not satisfied by rainfall.

**monitoring**--the periodic collection of information about a process (e.g., change in vegetation in response to disturbance) or attribute (e.g., water temperature) that may be an indicator of condition or management actions.

**municipal water system**--a water system that has at least five service connections or which regularly serves 25 individuals for 60 days; also called a public water system

**non-point source (NPS) pollution**--pollution discharged over a wide land area, not from one specific location. These are forms of diffuse pollution caused by sediment, nutrients, organic and toxic substances originating from land-use activities, which are carried to lakes and streams by surface runoff. Non-point source pollution is contamination that occurs when rainwater, snowmelt, or irrigation washes off plowed fields, city streets, or suburban backyards. As this runoff moves across the land surface, it picks up soil particles and pollutants, such as nutrients and pesticides.

**nutrient** an element or compound required by a living organism for growth.

**pH**--a measure of the relative acidity or alkalinity of water. Water with a pH of 7 is neutral; lower pH levels indicate increasing acidity (high concentration of hydrogen ions), while pH levels higher than 7 indicate increasingly basic solutions (low concentration of hydrogen ions).

**parameter**--measured or observed property

**pathogen**--a disease-producing agent; usually applied to a living organism. Generally, any viruses, bacteria, or fungi that cause disease.

**peak flow**--the maximum instantaneous discharge of a stream or river at a given location.

**percolation**--the movement of water through the openings in rock or soil.

**permeability**--the ability of a material to allow the passage of a liquid, such as water through rocks. Permeable materials, such as gravel and sand, allow water to move quickly through them, whereas impermeable materials, such as clay, don't allow water to flow freely.

**point-source pollution**--water pollution coming from a single point, such as a sewage-outflow pipe.

**porosity**--a measure of the water-bearing capacity of subsurface rock. With respect to water movement, it is not just the total magnitude of porosity that is important, but the size of the voids and the extent to which they are interconnected, as the pores in a formation may be open, or interconnected, or closed and isolated. For example, clay may have a very high porosity with respect to potential water content, but it constitutes a poor medium as an aquifer because the pores are usually so small.

**potable water**--water of a quality suitable for drinking.

**precipitation**--rain, snow, hail, sleet, dew, and frost.

**public supply**--water withdrawn by public governments and agencies, such as a county water department, and by private companies that is then delivered to users. Public suppliers provide water for domestic, commercial, thermoelectric power, industrial, and public water users.

**public water use**--water supplied from a public-water supply and used for such purposes as firefighting, street washing, and municipal parks and swimming pools.

**rating curve**--A drawn curve showing the relation between gage height and discharge of a stream at a given gaging station.

**recharge**--water added to an aquifer. For instance, rainfall that seeps into the ground.

**regime**--a natural pattern in at least two time scales: for example, the daily-to-seasonal variation in water and sediment loads, and the annual-to-decadal patterns of floods and droughts.

**rehabilitation**-- used primarily to indicate improvements of a visual nature to a natural resource; putting back into good condition or working order

**remediation**--a process by which something is fixed or repaired

**remote sensing**--the detection of conditions (e.g., types of plants) on the landscape through the use of satellite and aerial photography/imagery.

**reservoir**--a pond, lake, or basin, either natural or artificial, for the storage, regulation, and control of water.

**restoration**--1) return of an ecosystem, or ecosystem process to a close approximation of its condition prior to human disturbance; 2) the renewal of a natural process (e.g., natural fire regimes) or feature (e.g., native fish species) through human actions

**restoration, ecological**-- involves replacing lost or damaged biological elements (populations, species) and reestablishing ecological processes (dispersal, succession) at historical rates.

**restoration, stream**-- various techniques used to replicate the hydrological, morphological, and ecological features that have been lost in a stream due to urbanization, farming, or other disturbance.

**return flow**--(1) that part of a diverted flow that is not consumptively used and returned to its original source or another body of water. (2) (Irrigation) Drainage water from irrigated farmlands that re-enters the water system to be used further downstream.

**riffle**--the part of a stream with shallow, fast-moving water flowing over cobbles or rocks.

**riparian—**the region of the landscape immediately adjacent to and influenced by a waterway with moving water.

**risk assessment**--analysis, characterization, and possible quantification of the risks to health or the environment from disturbing agents or stressors

**river**--a natural stream of water of considerable volume, larger than a brook or creek.

**runoff** --that part of the precipitation, snow melt, or irrigation water that appears in uncontrolled surface streams, rivers, drains or sewers. Runoff may be classified according to speed of appearance after rainfall or melting snow as direct runoff or base runoff, and according to source as surface runoff, storm interflow, or ground-water runoff.

**sediment**--usually applied to material in suspension in water or recently deposited from suspension. In the plural the word is applied to all kinds of deposits from the waters of streams, lakes, or seas.

**sediment budget**--a mass balance of sediment supply, storage, and yield over time

**seepage**--(1) The slow movement of water through small cracks, pores, Interstices, etc., of a material into or out of a body of surface or subsurface water. (2) The loss of water by infiltration into the soil from a canal, ditches, laterals, watercourse, reservoir, storage facilities, or other body of water, or from a field.

**solute**--a substance that is dissolved in another substance, thus forming a solution.

**species diversity**--the relative density of an individual or group of species compared to the density of all species

**stakeholder**--someone who will be impacted socially, culturally, financially, physically, or in some other manner by a decision or decision process

**State Water Project (SWP)**--a state-operated water management and conveyance system that provides water to agricultural, urban, and industrial users in California.

**storm sewer**--a sewer that carries only surface runoff, street wash, and snow melt from the land. In a separate sewer system, storm sewers are completely separate from those that carry domestic and commercial wastewater (sanitary sewers).

**stream**--a general term for a body of flowing water; natural water course containing water at least part of the year. In hydrology, it is generally applied to the water flowing in a natural channel as distinct from a canal.

**streamflow**--the water discharge that occurs in a natural channel. A more general term than runoff, streamflow may be applied to discharge whether or not it is affected by diversion or regulation.

**stream order**--the relative size of a stream compared to other streams in the watershed; first-order streams are the smallest and twelfth order the largest.

**stressor--**natural or unnatural sources of stress to a system or component of a system (usually called the "receptor" for the stressor).

**substrate**--the sediment material that makes up the benthos of a waterway

**surface water--**water that is on the Earth's surface, such as in a stream, river, lake, or reservoir.

**suspended sediment**--very fine soil particles that remain in suspension in water for a considerable period of time without contact with the bottom. Such material remains in suspension due to the upward components of turbulence and currents and/or by suspension.

**thermal pollution**--a reduction in water quality caused by increasing its temperature, often due to disposal of waste heat from industrial or power generation processes. Thermally polluted water can harm the environment because plants and animals can have a hard time adapting to it.

**Total Maximum Daily Loads (TMDLs)**—the maximum amounts of individual pollutants contributing to impairment of the "beneficial uses" of the waterbody allowed to enter a waterbody from watershed sources

**transpiration**--process by which water that is absorbed by plants, usually through the roots, is evaporated into the atmosphere from the plant surface, such as leaf pores.

**tributary**--a smaller river or stream that flows into a larger river or stream. Usually, a number of smaller tributaries merge to form a river.

**turbidity--**the amount of solid particles that are suspended in water and that cause light rays shining through the water to scatter. Thus, turbidity makes the water cloudy or even opaque in extreme cases.

**unsaturated zone--**the zone immediately below the land surface where the pores contain both water and air, but are not totally saturated with water. These zones differ from an aquifer, where the pores are saturated with water.

**water cycle** -- the circuit of water movement from the oceans to the atmosphere and to the Earth and return to the atmosphere through various stages or processes such as precipitation, interception, runoff, infiltration, percolation, storage, evaporation, and transportation.

**water quality**--a term used to describe the chemical, physical, and biological characteristics of water, usually in respect to its suitability for a particular purpose.

**water table**--the top of the water surface in the saturated part of an aquifer.

**water use**--water that is used for a specific purpose, such as for domestic use, irrigation, or industrial processing. Water use pertains to human's interaction with and influence on the hydrologic cycle, and includes elements, such as water withdrawal from surface- and ground-water sources, water delivery to homes and businesses, consumptive use of water, water released from wastewater-treatment plants, water returned to the environment, and instream uses, such as using water to produce hydroelectric power.

**watershed**--the region draining into a river, river system, or other body of water above a particular point.

**watershed assessment**--a process for analyzing a watershed's current condition and the likely causes of these conditions, usually resulting in a report documenting findings of the process.

**watershed health**-- 1) an index or estimate of the degree to which the generation and transport of water and its constituents within a watershed function in a relatively natural manner; 2) an index or estimate of the natural functioning of the watershed relative to a reference or historic condition.

**watershed management**--1) a multiple-step, iterative process consisting of watershed monitoring, assessment, planning, implementation, and evaluation; 2) a process for making decisions about activities that will affect the health of a watershed.

**watershed plan**--the product of a planning process a the watershed scale considering natural and human processes relevant at the scale (e.g., natural and artificial flows). Sometimes used synonymously with "watershed management plan". A watershed plan consists of an overall vision or set of goals for the watershed, a series of steps needed to achieve those goals, and detailed consideration of how to implement those steps.

**watershed restoration**-- reestablishing the structure and function of an ecosystem, including its natural diversity; a comprehensive, long-term program to return watershed health, riparian ecosystems, and fish habitats to a close approximation of their condition prior to human disturbance.

**well (water)**--an artificial excavation put down by any method for the purposes of withdrawing water from the underground aquifers. A bored, drilled, or driven shaft, or a dug hole whose purpose is to reach underground water supplies or oil, or to store or bury fluids below ground.

**wetland**--an area of the landscape that is periodically or frequently inundated and containing vegetation and animals adapted to that condition.

**withdrawal**--water removed from a ground- or surface-water source for use.

***Compiled from online and other sources***

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1997

***Additional Online Watershed Glossaries***

Hubbard Brook Ecosystem Study (USDA Forest Service);
http://www.hubbardbrook.org/education/Glossary/Glossary.htm

Know Your Watershed (Conservation Technology Information Center – National Association of Conservation Districts) http://www.ctic.purdue.edu/KYW/glossary/glossary.html

Science in Your Watershed (USGS online glossary); http://water.usgs.gov/wsc/glossary.html

Terms of the Environment (USEPA); http://www.epa.gov/OCEPAterms/

Water on the Web (University of Minnesota Duluth and Lake Superior College);
http://waterontheweb.org/resources/glossary.html

Watershed Education for Communities and Local Officials (North Carolina Cooperative Extension Service); http://www.ces.ncsu.edu/depts/agecon/WECO/pdfs/Watershed%20Glossary.pdf

# 1 Introduction

Californians are responsible for protecting and managing their natural environment. Watersheds, also known as catchment or drainage basins, provide a useful, natural unit for better understanding and achieving this responsibility (California Resources Agency & State Water Resources Control Board 2002). Assessing a watershed to understand its current condition, and how it got there, is usually the first step taken in developing a strategy toward improving and protecting the watershed's condition.

Chapter Outline



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## 1.1 Audience and Purpose of the Manual

The California Watershed Assessment Manual (CWAM or Manual) provides guidance for conducting a watershed assessment in California. It is intended to support the planning and technical needs primarily of watershed groups but also local and state agencies, academic scientists, consultants, and individuals involved in developing and conducting a watershed assessment. In doing so, the Manual includes the recognition that not all assessments have the same level of complexity of questions or analysis. It is intended to reduce the reinventing of planning, data collection, and analysis approaches each time an assessment is done. This will result in less time spent by the assessor getting up to speed and provide a range of ways to approach a problem.

The Manual includes guidance on planning and operational principles and steps that are useful for assessment processes anywhere in the state. The topics addressed in the Manual cover the primary natural and human processes in rural watersheds of northern and central California. Many of the approaches for assessing urban and agricultural areas are still being developed for inclusion in a future update of the Manual. The optimal organizational and geographic scale for use of the Manual is for watershed groups conducting assessments in 10,000-acre to 1 million-acre watersheds.

The key reasons for developing this Manual are:

*1. Citizen organizations and agencies requested a manual*

The "12 Steps to Watershed Recovery in California," an action plan developed in May 2000 at the California Watershed Management Forums (Watershed Management Council 2000), included a recommendation for developing a state manual to help provide consistency and clear expectations to watershed groups, managers, and restoration specialists about recommended methods for: watershed assessments, water quality and habitat monitoring, data reporting, and watershed plans. Further, Assembly Bill 2117 Report to the Legislature (CRA & SWRCB 2002) identified the following need: "*Develop manuals that define the minimum level of science needed for acceptable watershed assessments, watershed plans, and monitoring activities. These manuals should provide technical assistance to newly formed watershed partnerships and to those choosing to upgrade their existing assessments and plans. The manuals* *should build on existing manuals and provide a menu-driven approach that can be tailored to the unique conditions of each watershed in California*."

CWAM is a response to these requests.

*2. State watershed grant programs want assessments*

CWAM seeks to provide useful information to fulfill the requirement of many grant programs for watershed assessments (see text box below). Although the Manual includes assessment approaches and methods that are compatible with these state-agency funding programs, anyone conducting a state-funded watershed assessment should clarify proposed methodology with the appropriate state funding agencies.

**State Watershed Grant Programs**

| **State Agency** | **Watershed Grant Program** |
|---|---|
| California Bay-Delta Authority (CALFED) | Watershed Program |
| Coastal Conservancy | Watershed Restoration Program, Resource Enhancement Program, Southern California Wetland Recovery Program |
| California Department of Conservation | Resource Conservation District Grants / Watershed Coordinator Grants |
| California Department of Fish & Game | Fisheries Restoration Grants Program (CCSRP, Prop. 40) |
| California Department of Water Resources | Urban Streams Restoration Program Grants |
| State Water Resources Control Board | Nonpoint Source Program (NPS), Prop. 13, Prop. 204, CWA 205(j), CWA 319(h), Prop. 40, Prop. 50 |

*3. Other manuals do not necessarily meet California's needs*

This Manual is intended to complement and extend the information in other manuals. Whereas other states, such as Oregon and Washington, have prepared very useful manuals, no single existing manual meets the unique and current needs of local watershed practitioners in California, mainly because of the State's incredible hydrological, geological, and biological diversity. Further, most do not discuss methods for synthesizing data that links human activities to alterations in watershed processes. The Oregon Watershed Assessment Manual (WPN 1999) probably is the closest to meeting the needs of California practitioners. Its target audience is quite similar, the format is user-friendly, and the content is scientifically sound. However, it focuses only on salmon-producing watersheds, the local examples are all from Oregon, and the state technical and information sources are not applicable to California. Its low-tech, low-cost approach offers some advantages, but because of this approach, the manual does not include computer-modeling methods. In addition, it does not address a variety of important assessment issues related to scale, data analysis, complexity of analysis, and information integration.

Watershed conditions related to forest practices are the emphasis of several other state manuals: the Washington manual (Washington Department of Natural Resources, 1997), California's North Coast Watershed Assessment Program Manual (North Coast Watershed Assessment Program, 2002), and the watershed analysis manual for Jackson Demonstration State

**Attributes of Successful and Failed Watershed Analysis: Live or Dead?**
**(from: Furniss 2001)**

| Live Watershed Analysis - As It Should Be - | Dead Watershed Analysis - As It Sometimes Is - |
|---|---|
| Science-based | Truth by assertion |
| Multiple scales, scale integrative | Single scale, not scale integrative |
| Interdisciplinary | Mono-disciplinary |
| Needed and effective inquiry | Doing what I like to do |
| Place-based | Actions-, proposals-, recommendations-based |
| Genuine learning | Shoring up one's position |
| Syn-ecological | Aut-ecological |
| Rates | States |
| Open, readily updated and revised | Onto the shelf. "Done" |
| Clean communication | Jargon-encrusted |
| Finds the holes, the critical uncertainties | Data bulking, nothing but knowns and givens |
| Seeking truth | Same old advocacy, spin, and worn-out, unexamined conclusions |
| Embracing complexity | Oversimplified |
| Active doubt | Dogma |
| Distilled meaning | Gobs of data |
| Multiple hypotheses | Single hypothesis, tightly held |
| Parallel, iterative | Strictly linear |
| Questions oriented | Methods oriented |
| Seeking results | Process obsessed |
| Teaching each other | Strutting our stuff |
| Adaptive, seeks to learn from failures | Static, ignores failures |
| Discerns patterns | Obsessed with details |
| Discovers that it's an elephant | "This is a fire hose, a brief case, a hat, a…" |
| Integrative | Reductionist |
| GIS is a tool | Obsessed with GIS |
| Welcomes and encourages critique | Critique is unwelcome and polarizes |
| Findings based on logic and backed by data | Data bulking with no logic trail between data and conclusions |

Forest in Mendocino County (Stillwater Sciences 1999). The assessment methods described in these three manuals require professional knowledge and extensive experience with physical and biological analyses. Other limitations pertain to the federal land managers' equivalents of watershed assessment manuals, such as the guides for "Ecosystem Analysis at the Watershed Scale" (U.S. Department of Agriculture 1995), "Hydrologic Condition Assessment" (U.S. Department of Interior & U.S. Department of Agriculture, 1998), or "Reconnaissance Level Assessment" (USDA Forest Service, 2000). In addition, the issues that these forest and wildland guides address are not always applicable to the rest of California, their focus on public lands means they may differ appreciably in purpose (e.g., urban and agricultural issues are not addressed at all), users, scale, data collection, management options etc. For these reasons, to name a few, there is a need for a California-specific manual. However, the manuals from other states and agencies can provide very useful information. Links to many other manuals are posted on the CWAM website (http://cwam.ucdavis.edu).

*4. A manual will improve assessment quality and lower costs*

Common shortcomings seen in many assessments include data cataloging with little attempt at analysis, little integration of different parts of the assessment, weak application of science, and few links to decision-making processes.

By clearly identifying a variety of accepted assessment methods, and presenting various data integration and analysis techniques, this Manual can be used as a tool to help improve the quality of watershed assessments being performed and increase the effectiveness of state-supported watershed projects. Assessment preparation costs can also be reduced. Groups often spend time and money (through consultants or staff time) to identify available assessment options, a process that can be redundant and inefficient. The Manual helps individuals and organizations narrow options at the outset. As a result, it saves time and money by reducing the spinning of wheels so common at the start of the process, and it gets the assessment process underway more quickly.

## 1.2 What are Watersheds and Watershed Assessments?

A common saying holds that "we all live in a watershed," yet watersheds and their needs for assessment can be quite diverse. A watershed assessment for San Jose's watershed (Santa Clara Basin), for example, will be different from one for Honeydew's (Mattole River watershed) or for Porterville's (Tule River watershed). There are still common features, however, for defining "watershed" and "watershed assessment" for the purposes of this Manual. Despite their diversity, watershed practitioners agree to common definitions. It is useful to know these definitions when conducting an assessment.

**A "watershed" is defined as "the region draining into a river, river system, or other body of water above a particular point."** Geologists commonly refer to watersheds as drainage basins. In Australia, New Zealand, and Great Britain, watersheds may also be called catchments. It is not uncommon for people to use the term 'watershed' to refer to a stream or riparian corridor. In fact, a stream is just one part of the watershed. Common zones within a watershed, often used for management purposes, are: 1) the upland area, the land above the zone inundated by floods or the transition between riparian and terrestrial vegetation, 2) the riparian zone, the vegetated area between the waterbody edge and the upland area, and 3) the waterbody itself, any stream, river, abandoned channel, pond, lake, wetlands, estuary, or ocean (U.S. Environmental Protection Agency, 2002). Ecologists also distinguish between headwaters, where water, sediment, and nutrients originate and hillslope is important (Meyer et al. 2003), and lowlands, where channel and floodplain interactions are important (Vannote et al., 1980).

Most of California's river systems eventually drain into the ocean. On the east side of the Sierra and in arid regions like the Mojave Desert, water may drain into a water body that has no outlet to the ocean. A watershed's physical features may include valleys, floodplains, ridges, plateaus, foothills, mountains, stream and river channels, riparian environments, estuaries, and wetlands.

The size of watersheds in California varies from very small such as the one-square-mile Codornices Creek watershed in Berkeley to very large such as the 26,000-square-mile Sacramento River Basin.

The term "**watershed assessment**" has been described in a variety of ways:

1. The analysis of watershed information to draw conclusions concerning the

conditions in the watershed. (Nehalem River Watershed Assessment, Washington)
2. A process for evaluating how well a watershed is working. (Oregon Watershed Assessment Manual, Watershed Professionals Network, 1999)
3. A process that characterizes current watershed conditions at a coarse scale using an interdisciplinary approach to collect and analyze information. (North Coast Watershed Assessment Program 2001)
4. The translation of scientific data into policy-relevant information that is suitable for supporting decision making and action at the watershed level. (Watershed Academy, U.S. Environmental Protection Agency).

Despite their differences, what is common to each definition is a process composed of actions—analysis, process, translation—that leads to the interpretation of information about the watershed's current condition. What is most critical is that the watershed assessment effort lead to a better understanding of watershed condition and why the watershed is in a certain condition. In this way, the assessment becomes a useful tool to help direct further actions.

**A watershed assessment is usually composed of:**

- A question or set of questions about watershed condition that sets boundaries on the assessment;
- A collection of relevant information about human and natural processes at the watershed scale;
- The identification of gaps in knowledge;
- The combination of information about various natural processes to reflect the integrated nature of watersheds;
- Analysis and synthesis of the information regarding the watershed's condition drawn from data collections, often at various geographic scales;
- A description of how the analysis can assist with decision making in the watershed;
- A design for the collection of future monitoring data; and
- A strategy to evaluate future data and communicate that information via a status and trends analysis.

An assessment moves beyond a simple description of what a watershed looks like, or what historical activities took place in the watershed. While these are some of the building blocks, an assessment should try to connect past and current human activities with current conditions and processes. To the degree that hypotheses can be developed about these relationships or actual cause and effect relationships can be identified, the watershed practitioners can propose solutions to problems and identify ways to achieve common goals. Without this understanding, proposed solutions may address only the symptoms. Frequently, watershed assessments stop short of making critical connections, yet are considered complete. A successful watershed assessment leads to the implementation of actions that benefit watershed processes and conditions—the ultimate "performance measure".

A watershed assessment is ideally part of an overall watershed management package consisting of:

- Problem or needs identification
- Assessment and analysis
- Planning
- Implementation
- Monitoring and evaluation
- Adaptive management

**<u>What an Assessment Is</u>**

- An objective problem-solving tool that identifies the potential causes of problems
- The scientific interpretation of watershed information and data, leading to conclusions about watershed condition

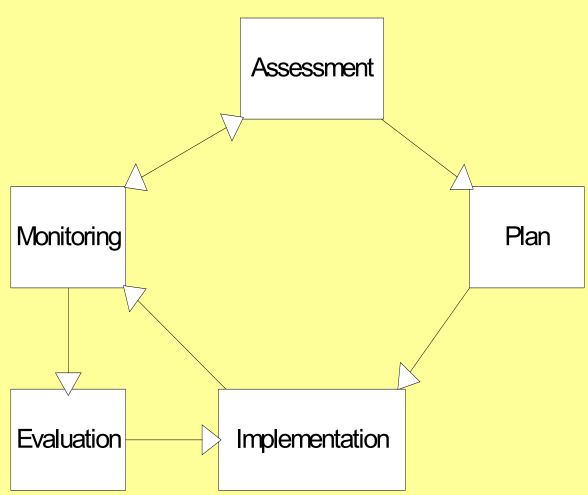
- A tool to help identify data and information gaps
- Analysis and findings that can be used to develop appropriate actions
- A component of a watershed management package that leads to planning, implementation, evaluation, and additional monitoring
- A product that is useful for its audience

**<u>What an Assessment Is Not</u>**

- Monitoring and data collection only
- A list of data only
- A consolidation or summary of existing information only
- Historical conditions or "baseline" only
- An identification of symptoms of problems only
- A plan
- An endpoint

The sequence in the diagram below describes an ideal process, involving a cycle of data collection, analysis, strategy, decisions, actions, evaluation, and more data collection. Feedback loops that assess whether the watershed's problems are improving – at the project or action level and at the watershed level – are important for gauging success.

"Ideal" Adaptive Watershed Management Sequence




Decision making, however, is part of the planning process that follows an assessment. The assessment report itself is not the place to make management or policy recommendations. The appropriate decision-makers should deal with the assessment's findings under the necessarily subjective next step, which begins the planning process. What to do—such as identifying and recommending specific projects, policies, and priorities—is not necessarily obvious or easy. Political and economic choices come into play during the planning stage, which includes deciding the what, where, when, and how to be accomplished in the implementation phase (see Chapter 8). As a result, it is best to clearly separate the "apolitical" assessment product from those decisions, which may have political, economic, or social implications.

In practice, watershed assessments and plans are sometimes combined into one document in order to fulfill a grant requirement or to show the transition from assessment to plan. In these cases, the assessment product should be distinct from the planning product so the reader can first understand the findings and then see what choices were made.

A federal watershed analysis usually suggests "management recommendations responsive to watershed processes identified in the analysis," but these suggestions are only for federal lands, which represent a different situation than a mixed-ownership watershed with various management expectations (Regional Interagency Executive Committee 1995).

### 1.3 Approach Taken in This Manual

The Manual provides a toolbox of appropriate approaches and methods designed to help those developing and conducting watershed assessments. These approaches and methods address:

**A watershed assessment is: "a process for analyzing a watershed's current condition and the likely causes of these conditions".**

**A watershed assessment report is: "a report documenting the findings of the watershed assessment process."**

- Developing questions and strategies for conducting a watershed assessment;
- Determining the necessary complexity of an assessment (e.g., from reconnaissance to thorough)
- Collecting appropriate data;
- Analyzing data while taking appropriate account of time and space scale issues and uncertainty about data and results;
- Integrating the data to assess watershed condition; and
- Ensuring that the assessment can be integrated with future watershed monitoring, planning, implementation, and evaluation.

The approaches and methods described in the Manual are guidance for watershed assessment and are not the State's prescription of how watershed assessments must be done. While the Manual presents various existing tools and techniques, other valid tools and techniques are also possible. In keeping with comments received during the Manual's development, it is neither a "one-size-fits-all" guide nor a "cookbook". Given California's diverse landscapes and watersheds, there is a need for creative and flexible approaches to performing watershed assessments. At the same time, however, watershed assessments and other components of watershed management should be founded in credible, science-based approaches like those described in this Manual.

### 1.4 How Complex Should Your Assessment Be?

Watershed assessments can be conducted at a wide range of levels of detail and complexity – from simple reconnaissance-level overviews to very thorough studies involving an array of mathematical models. The team contributing to this Manual discussed various approaches to levels of analysis over several months. Eventually, the team decided that there wasn't much value to dividing the continuum of detail into several discrete groups. The spectrum of progressive detail and analysis does not naturally break into clean categories. Different parts of an assessment will inevitably receive different degrees of attention and analysis depending on the personal interests of the people developing the assessment, the expertise and availability of those people, the principal issues and driving questions of the watershed assessment, data availability, financial resources, and time constraints. In most cases, the level of effort will simply depend on how thorough an assessment you desire balanced against your constraints of time, money, and data. Another way to evaluate the appropriate level of detail for a particular part of your watershed assessment is to consider the following question: How much confidence in your conclusions can you afford? Alternatively, how much uncertainty can you live with?

In practice, most watershed assessments that lie in between a simple reconnaissance and a multi-decade, thoroughly interdisciplinary watershed research project vary in their level of detail in different aspects of the assessment. Some rely only on existing data, but use that data in some complex mathematical models to arrive at some carefully considered conclusions. Others compile a mass of existing data and just tabulate it without any real analysis. Still other assessments acquire a lot of new data that present a thorough snapshot of current conditions, but largely ignore historical information and are thus unable to say anything about how the current condition developed. Some assessments are strong on hydrology and geomorphology, but pay little attention to biology. Conversely, some assessments are all about biology and give scant attention to the physical environment. Very few assessments adequately consider the social aspects of the watershed or of the assessment process itself. Because most assessments are a mix of complexity in various parts, ranking one as "more advanced" than another usually requires focusing on just a single aspect of the assessments.

Some of the factors that contribute to the complexity of an assessment are:

- Data Quantity
- Data Quality
- Data Analysis
- Data Synthesis & Integration
- Professional Understanding and Acceptance
- Social Understanding and Acceptance

Estimating where along the continuum of LOW ←——→ HIGH various aspects of the assessment fall provides an indication of the complexity of the analysis. For example, one assessment might reflect very high data quality but low data analysis. Watershed assessments that have most marks near the higher end of the scale will be more complex and have a lower degree of uncertainty associated with the conclusions than those that fall toward the lower end of the scale. Valuable assessments can and have been performed at all points along the continuum. Perhaps the important thing to remember is that you can approach your assessment in many different ways at many different levels of detail and still end up with a useful product IF your approach fits your issues and problems. The only real way to know whether your approach has potential is to leap in and do a reconnaissance-level assessment, get a lot of feedback from a broad audience, refine your approach, and focus on the important lessons learned from the first iteration. The availability of time, expertise, interest, and money will limit what you can do at any stage. At almost every possible level of detail, there is something to be learned from an assessment—something that will contribute to dealing with the issues and questions you have identified.

In an effort to give you a better understanding of the diversity of types of watershed assessments and the various levels of complexity associated with them, the following assessments and URLs are provided for your review.

1. Basic watershed assessments

- Aliso Creek (USACE/OC) http://www.ocwatersheds.com/watersheds/Aliso_reports_studies.asp.
- Tomales Bay Watershed Stewardship Plan www.tomalesbaywatershed.org/stewardship.html
- Cottonwood Creek Watershed Assessment/Analysis http://wim.shastacollege.edu/watersheds.aspx?ws=5

2. Intermediate level of complexity

- Arroyo Seco Watershed Restoration Feasibility Study www.arroyoseco.org/WatershedSlides.htm
- Upper Clear Creek Watershed Analysis www.shastalink.k12.ca.us/clearcreek/WA%20Final.htm
- Aptos and Gazos Creeks www.coastal-watershed.org

3. More complex watershed assessments

- Lake Tahoe Watershed Assessment www.fs.fed.us/sw/publications/documents/gtr-175/.
- North Coast Watershed Assessment Program (Gualala and Mattole Rivers) www.ncwatershed.ca.gov/all_watersheds.html.
- Newport Bay/San Diego Creek Baseline Condition Report (USACE/OC)

www.ocwatersheds.com/watersheds/pdfs/NewportBay_Baseline_Conditions_Report(F3).pdf.

- Napa River Basin Limiting Factors Analysis http://www.coastalconservancy.ca.gov/Programs/EXECUTIVE%20SUMMARY.pdf

4. Research watersheds (sites where long-term, continuous, in-depth studies of watershed processes and experimental alterations are occurring)

In California

- Caspar Creek Experimental Watershed www.fs.fed.us/psw/rsl/projects/water/caspar.html.
- Castle Lake http://outreach.ucdavis.edu/programs/castel2.htm.
- Kings River and Teakettle Creek Experimental Watersheds http://zimmer.csufresno.edu/~sblumens?KREW_INFO/KREW%20USFS1c.pdf.

Outside California:

- H.J. Andrews Experimental Forest (OR) www.fsl.orst.edu/lter.
- Fraser Experimental Forest (CO) www.fs.fed.us/rm/fraser.
- Walnut Gulch Experimental Watershed (AZ) www.tucson.ars.ag.gov/unit/Watersheds/WGEW.htm.

Finally, some useful insight can be gained from the experiences of British Columbia and Washington. Earlier watershed assessment approaches (e.g., British Columbia Ministry of Environment 1995 http://www.for.gov.bc.ca/tasb/legsregs/fpc/fpcguide/iwap/iwap-toc.htm and Ministry of Forests, 1999 http://www.for.gov.bc.ca/tasb/legsregs/fpc/FPCGUIDE/wap/WAPGdbk-Web.pdf; Washington State Department of Natural Resources, 1997) recognized the need to conduct watershed assessments at different levels of detail. Each increasing level represents progressively greater data amounts and precision, intensity of analysis, time, and (usually) cost. Each tier is designed to increase understanding and reduce uncertainty. However, the less complex levels of analysis can still produce very valuable information and should contribute to the more complex levels, and the more detailed approaches should build on the fundamentals of the broad overviews. To get an idea of how people in other states and provinces have approached the issue of complexity in watershed assessments, information from British Columbia and the State of Washington is provided below.

British Columbia's Coastal / Interior Watershed Assessment Procedure Guidebooks (1995 & 1999) for forested watersheds divides its assessment protocols into three levels:

- BC Level 1: A reconnaissance-level analysis intended as a coarse filter to identify watersheds that may have impacts from the cumulative effects of past logging or planned future logging.
- BC Level 2: An overview stream channel assessment performed by someone with basic experience in hydrology and/or geomorphology
- BC Level 3: A very detailed analysis performed by a watershed specialist, involving mostly field work. The work is guided by the results of the level 1 and level 2 analyses.

The State of Washington distinguishes detail into two levels:

- WA Level 1: A reconnaissance assessment, relying predominantly on maps and remotely sensed information with some field checking. The assessment is designed to take one to two weeks of effort by the team, but could take longer depending on the time needed for data acquisition.

- WA Level 2: This level may be similar to Level 1, but results in a more detailed assessment of the overall watershed, or it may be focused on specific resource issues identified in Level 1. More experience and education are required for Level 2 specialists, and more time may be needed.

### 1.5 Manual Development

The concept for this Manual came from the California Watershed Management Forum (see section 1.5.1). The California Department of Forestry and Fire Protection (CDF) and CALFED provided funding to the University of California, Davis, to develop the Manual, with the project coordinator selected from within the Department of Environmental Science and Policy. The Manual was developed by an interdisciplinary team of watershed scientists affiliated with U.C. Davis and the Office of Environmental Health Hazard Assessment (California EPA) with assistance from staff at CDF. A technical steering committee was established to advise the team in development of the Manual. The committee was composed of practitioners, agency representatives, and researchers involved in watershed assessment in California.
A critical part of the process involved collecting ideas and advice from diverse interests and experts from the larger watershed community. Various announcements about the project were distributed and team members made presentations at regional and statewide conferences and to local, regional, and state groups, (e.g., the Bay-Delta Public Advisory Committee Watershed Workgroup). The team solicited comments about the types of problems encountered in conducting watershed assessments and suggested tools for conducting assessments.
The team assembled various watershed assessment approaches from a wide range of sources. The team determined which tools best address the variety of watersheds and watershed factors that need to be assessed and the social and environmental issues facing California watershed groups and analysts. This document represents the first version of the Manual. A revised Manual will be released in December, 2004 with edits based on public comment on the first draft.

The Manual is available in two formats: CD-ROM and online http://cwam.ucdavis.edu. The Web-site also provides relevant technical and spatial information.

In the Manual, there is an emphasis on narrative explanations for why particular approaches are important, short explanations for how to do various tasks, and references and links to outside resources for specific protocols. Look for the text boxes inserted throughout the text and the action steps following certain sections.

### 1.6 Next Steps in Manual's Evolution

The Manual focuses on watersheds of northern and central California. It also focuses primarily on the processes of planning and conducting assessments and secondarily on the specific tools associated with investigating particular watershed processes. Future Manual sections will include protocols for assessing specific watershed conditions (e.g., land-use analysis) and functions (e.g., ground-water supply). The process may eventually include testing in real-world situations and further revision of the Manual. A training program may be developed to assist Manual users.

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# 2 Planning Your Watershed Assessment

This chapter address the typical process for beginning your watershed assessment: a) pulling together the assessment team and b) developing a statement of purpose and a plan for the assessment. Assessing watersheds involves "art" as well as "science". The first part of this chapter reviews the art of working with people and their decisions. The remainder of the chapter reviews the process for developing a statement of purpose and the factors you should consider when laying out the plan for your watershed assessment.

Chapter Outline



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**Introduction**

This chapter addresses the question of how to plan a watershed assessment. To summarize the process: the first step involves organizing the assessment team. Once the group is assembled, you need to define the issues of concern and develop a plan for the assessment. Some of the key parts of this plan include defining the purpose and the audience, defining the watershed processes or parts of the system which will be the focus of the assessment, identifying the scope of the assessment, developing a conceptual model of the watershed, and developing a plan for the actual analysis of the issues. The plan should contain information on what data will be collected, how it will be analyzed, and finally, how information will be synthesized into a single analysis to inform decision-making.

## 2.1 Organize the Assessment Team: Assessment Planning as a Group and With the Community

If a group functions well and builds successful community relations, it is more likely to produce a successful watershed assessment. Conversely, a dysfunctional group with inadequate public participation has a poor likelihood of producing an assessment with broad acceptance, as shown by evaluations of watershed groups and collaborative processes (Wondolleck et al., 2000, Huntington & Sommarstrom 2000). This section of Chapter 2 will provide some suggestions on how to successfully organize your assessment team.

It is beyond the scope of this Manual to describe ways to structure and manage your group's organizational abilities. There is no single method that will work in every watershed. Useful books, manuals, and other tools to help your group include: Kaner 1996; Moote 1997; Sierra Nevada Alliance 1999; For Sake of the Salmon Web site (http://www.4sos.org); River Network Web site (http://www.rivernetwork.org); and Know Your Watershed (KYW) Web site (http://ctic.purdue.edu/KYW/KYW.html).

One increasingly popular approach to improving community and agency relations is the use of collaborative, multi-stakeholder watershed groups, also referred to as watershed partnerships.

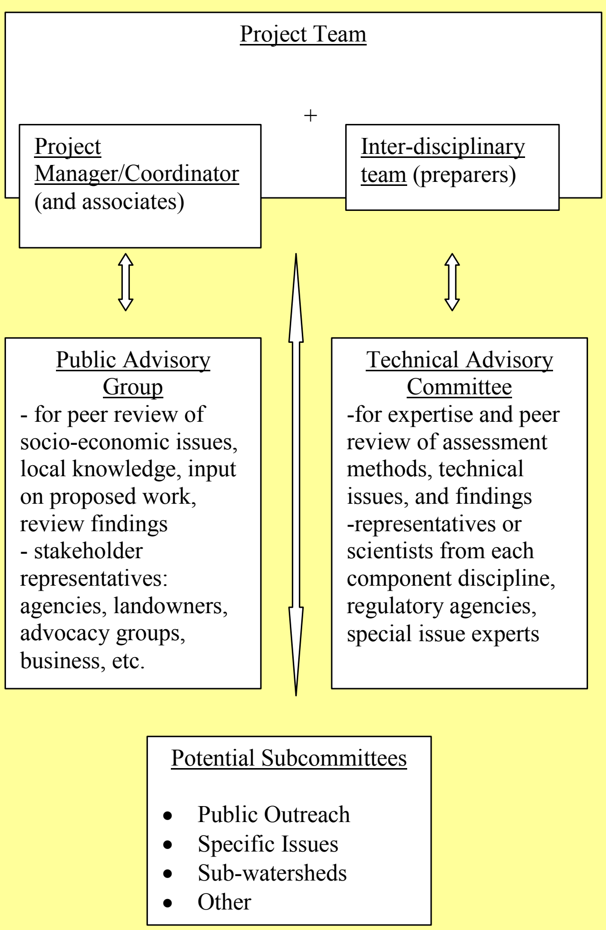
According to Know Your Watershed, common characteristics of a watershed partnership include:

- Broad range of stakeholders who make decisions
- Neutral coordinator respected by all with a stake
- Actions are voluntary; benefits are personal
- Strategies are specific to a watershed

This Manual does not assume that your watershed assessment group is such a partnership, but this approach may make your community involvement and ultimate acceptance of your product easier than alternative approaches (such as agency advisory committees, or a single stakeholder group) (Moote 1997; Huntington & Sommarstrom 2000; Wondolleck et al., 2000).

**Sample Assessment Team and Committee Structure**

(adapted from: California Coastal Conservancy 2001; Coastal Watershed Council 2003)




### 2.1.1 Assemble the Team and Committees

No one has all the expertise required to do an assessment, not consultants, agencies, academics, or watershed groups. As a result, your assessment effort will need to draw on an assessment team.

Mixing Disciplines: Taking an interdisciplinary approach is a hallmark of the watershed assessment process. Accordingly, a good watershed assessment team should include members with a variety of disciplines or specialties. Because of the many physical, biological, and social connections that exist at a watershed scale, discussions, analyses, and interpretations across different specialties are often required to understand the cause and effect of a watershed problem. A specialist in fluvial geomorphology (the geologic study of the stream channel shape and evolution), for instance, may be able to perform a sediment budget, but collaboration with a fisheries biologist may be required in order to interpret the sediment's effect on fish habitat, with a civil engineer to interpret the effect on flooding, and with an long-time local resident to describe historical land uses that may have triggered increased sediment production.

Group Size: Keeping the assessment team and committees relatively small allows the group to make decisions in a timely fashion. Small for a group means from three to 12 members. The team can bring on additional support people for short-term efforts on an as-needed basis. In rural areas, finding sufficient qualified and interested people (agency, academic, or public) who are available to travel potentially long distances and attend many meetings will likely limit the number involved. In urban areas, the opposite may be true. In this case, having multiple, small committees may allow for increased participation by the higher number of interested and available people. The Santa Clara Basin Watershed Management Initiative (http://www.scbwmi.org) used this approach, for example.

Project Manager/Coordinator: This person provides administrative leadership and coordination for the process. Responsibilities may include:

- Assigning tasks;
- Contacting stakeholders;
- Coordinating the assessment components and team;
- Compiling and sharing existing data and information;
- Integrating results from individuals with different expertise;
- Setting the schedule and managing the team against it;
- Ensuring that the project stays within budget; and
- Achieving a satisfactory, completed product.

At a minimum, the Project Manager/Coordinator should possess good organizational and communication skills, project management experience, and training and experience in facilitation. A background in a natural resources-related field is very desirable. The Project Manager/Coordinator could be a staff person from the agency or organization conducting the assessment, or a consultant. In either case, before selecting the Project Manager/Coordinator, you should contact references provided by the potential hire/contractor, review the candidate's past work, and make expectations for the assessment job clear. If the Project Manager/Coordinator is an outside consultant, you must address several critical issues before developing a contract with that person (see 2.1.3).

Assessment Team: The Assessment Team includes the Project Manager/Coordinator, plus the people who will actually be developing the product. These may include your group's staff, private consultants, agency staff, community volunteers, scientists, college students, or a combination of such people. Each person's responsibilities may include one or more of the following:

- Helping focus the assessment on the important questions and issues;
- Deciding upon appropriate assessment methods;
- Compiling and evaluating existing data and information;
- Collecting and analyzing new data; using appropriate statistical design;
- Developing new maps, graphs, and other visual aids;
- Preparing a written draft section or sub-section of the assessment;
- Attending team meetings, working sessions, and public meetings;
- Reviewing and commenting on sections or sub-sections prepared by others; and
- Revising draft sections and completing the final product.

Assessment Team members should possess skills relevant to the technical requirements of their roles.

Technical Committee: Members of the Technical Committee may prepare and/or review the assessment, depending on how the committee is used. If committee members serve as peer reviewers of technical material prepared by the Assessment Team, then it may be appropriate to include experts from each relevant discipline, as well as representatives of regulatory or other agencies, funding sources, and special issue experts. Responsibilities for peer reviewers of technical issues may include:

- Attending committee meetings;
- Advising Assessment Team members,
- Advising on appropriate assessment approaches;
- Recommending and evaluating statistical methods; and
- Reviewing and commenting on specialty areas of the draft assessment.

Technical Team members should possess identifiable and respected expertise in the topics to be covered in the assessment.

Public Advisory Committee: One structural model has the Public Advisory Committee performing peer review of socio-economic issues only, while other models have it providing input on all matters (California Coastal Conservancy 2001; Coastal Watershed Council 2003). Members may be volunteer representatives of key local stakeholder groups (e.g., business, landowners, agencies, environmental groups, etc.) and/or at-large members of the public.

Responsibilities for Public Advisory Committee members may include:

- Sharing their knowledge of the watershed;
- Attending committee meetings;
- Learning about assessment methodologies;
- Reviewing and commenting on the assessment's draft findings;
- Helping with public outreach on the assessment; and
- Assisting with the next phase after the assessment is done.

Public Advisory Committee members should have local watershed knowledge and good communication abilities at the minimum. Being willing to serve as an unpaid volunteer and having the requisite time and patience for the process may be the most critical abilities to possess.

**"Lessons Learned—Pilot Watershed Assessment Process" by the Santa Clara Basin Watershed Management Initiative**

This very large, urban group in the San Jose area prepared a "Lessons Learned" report in February 2003 based on its experience with pilot watershed assessments, which began in September 2001. Comments came from its Watershed Assessment Subgroup (WAS), a stakeholder group composed of representatives from agencies, municipalities, and nonprofit groups, and from Watershed Captains, who are members of the WAS and who have specific expertise and knowledge of the pilot watersheds being assessed. WAS worked initially with its Watershed Assessment Consultant on data gathering and evaluation, then on reviewing the draft assessment.

Some of the procedural lessons may be unique to this group's experience, but the following lessons learned might also apply to other watershed assessment planning processes.

- Establish preliminary review points for working drafts of the assessment's chapters. Allow sufficient time to make changes in direction before it's too late.
- Once assessment steps begin, ensure that the same support staff and scientific experts are available for each meeting.
- Ensure that sufficient copies of all relevant materials are readily available to participants in all meetings.
- Make sure the experts, people with local knowledge, and the appropriate stakeholders are more involved in the review processes and meetings.
- Establish clear communication channels for inter-subgroup or team relations and coordination of work products.
- Have consultant offer feedback on issues brought up by commenters during the review process to make this phase move more efficiently and smoothly.
- Give more time for review and comment on completed draft documents.

For more information: http://www.scbwmi.org

Special Subcommittees: In addition to the above committees, subcommittees may also be formed for special technical and public purposes. Subcommittees may address:

- Public outreach;
- Sub-watershed advisory;
- Specific issue or topic areas (e.g., water quality, fish habitat, flooding, groundwater, etc.);
- Monitoring and statistical analysis; and
- Report preparation.

Membership and skill level are linked to the subcommittee type, with skills ranging from the ability to translate technical reports to the public to the ability to generate these reports.

Interim Task Force: A short-term task force, either technical or public advisory in nature, may also be needed during the assessment process. It may contribute to a portion of the assessment and then disband before the assessment is completed. Members may come from existing committees or subcommittees, or they may be recruited only for this purpose. Examples of possible functions might be:

- Developing the assessment process (before the coordinator, teams, and committees begin);
- Collecting field data on selected parameters or certain locations;
- Working through a contentious topic;
- Developing new protocols, models, or methods as needed.
- Membership and skill level would be as appropriate for the task force's defined function.

### 2.1.2 Making Decisions

The above options for who coordinates, prepares, advises, and reviews the assessment lead to the inevitable question: Who makes the decisions? Is it all of the above, the Project Coordinator, the technical committee, the funder(s), an agency, or the entire watershed group? Make this determination very clearly at the beginning of the watershed assessment process. A group's by-laws or other rules may already state who has decision-making authority for its efforts, including an assessment. If the assessment is being done by an *ad hoc* or temporary group, the decision-making authority might not be as obvious. Sometimes public or stakeholder advisory committees have the impression (rightly or wrongly) that their recommendations are decisions rather than advice that can be taken or ignored. Without clarifying who makes what decisions and when during the assessment process, your watershed assessment may drag on unnecessarily, hit a dead-end, or not be accepted by important participants in the watershed community. How decisions can be made is discussed in section 2.4.2 below, which also addresses the various roles of possible decision-makers.

### 2.1.3 Contracting Analysis and Coordination Work

It is possible that your assessment team will consist of people in your watershed group. However, for many assessments, a consultant will be hired through a contracting process to do part of the work. This person could fill a management and coordination role, or be a technical analyst, or bring the information you have collected together in an integrated assessment. Whatever the consultant does, there are some things to consider when developing the relationship.

The assessment decision-makers (e.g., technical advisory group or contract managers) should decide as many of the main topics and questions for the assessment as possible before contracted work starts. Other parts of this Manual describe formulation of questions, identification of problems, and other types of conceptual work that the assessment decision-makers and stakeholder committees can do before contracting with consultants. One Bay Area watershed group spent more than $200,000 on consultant time before it had formulated its primary assessment questions. After the fact, the group decided that this expenditure had been a waste and that group members could have done the work without the consultant.

The role of analyst is an important one on the assessment team. Funding is limited for most assessments, so often you must decide which analyst positions are most critical.

The types of analysis required and the amount of money needed to fund analysis are tightly tied to the primary questions of your assessment. For example, in two cases in Southern California, assessment developers decided that the largest expenditure (one-third of total funds) was to be on various kinds of hydrological modeling because their projects revolved around local groundwater storage and improved water quality and conservation.

In a sprawling urban area, for example, the impact of stormwater runoff on local stream water quality, channel integrity, and endangered aquatic wildlife might dominate the assessment. In this case, you would want an understanding of the hydrology or hydraulics of the system (hydrologist), an assessment of riparian and aquatic habitat condition (ecologist or geomorphologist), surveys of plant and wildlife communities (botanist and/or wildlife biologist), someone knowledgeable about contaminants in stormwater (toxicologist), and someone or a group process to integrate the information to inform decision-making.

Once you have identified the scientific expertise of the analysts needed for the assessment, you will face the most challenging aspect of team creation: deciding who is qualified to carry out the work. Nonprofit organizations, water districts, and local agencies have described their selection of consultant analysts as an *ad hoc* process based exclusively on reputation. This approach tends to favor larger, more well-known public and private organizations, without necessarily reflecting the abilities of these organizations to deliver the products expected or desired.

To evaluate possible analysts, check with references provided by the contractor or agency for similar projects. References can give you a sense of whether the information provided by the analyst was relevant to the project or decision-making process, whether the consultant can meet desired timeframes and communicate the work to diverse audiences, and whether cost matches the work expected.

Evaluate past analyses and reports in which the analyst did an identifiable part of the work. This will help you decide if a past project is similar to the needs of your assessment. Look at research or other articles written by the analyst. If the technical or scientific communities are peer-reviewing the analyst's work and approving it for publication, then other experts have already done part of the reference checking for you.

After choosing possibilities for the Project Manager/Coordinator and analyst part of the team, you must establish a contract, which can range from a contract with an individual to agreements with academic institutions or agencies. One of the first questions in the contracting process is usually about cost. Individual or company consultants usually charge higher hourly rates than universities or agencies, but these consultants also cover costs that may be part of the overhead costs of the latter organizations. Universities also charge an overhead rate, usually called "indirect costs", but total rates are still usually lower than those of private consultants. Universities and agencies often have access to resources not available to individual consultants (e.g., software licenses and interns). Ask for the actual hourly rate for agencies and academics so you can accurately compare these rates with those of private consultants.

The actual work expected should be detailed and agreed to in a Scope of Work (SOW) document. The more explicit the SOW, the more likely the finished product will reflect the needs of the assessment. Once contracts are underway, the SOW can be amended if needed to reflect changes in expectations or new information. The SOW should lay out a series of tasks with an explanation of the work to be performed as part of each task, the deliverables for each task, the timeframe for the deliverables, the time the task will take, and the budget devoted to each task. The SOW should reflect expectations of both the consultant and the funder, the role the funder will play in reviewing and approving deliverables, and what happens when something important changes (e.g., a delay in funder review of deliverables). The SOW informs the development of a budget, which might include additional costs for administration, supplies, equipment, and travel.

The SOW, the budget, and the contract language together form the usual contracting package. You should not expect work to commence before the contract between the funder and the consultant is signed. Similarly, work after the contract has expired will only occur if the consultant agrees to continue working. If changes to deliverables are desired after the contract has expired, an extension or amendment to the contract should be generated. The extension or amendment may or may not provide for additional funding, depending on the consultant. Keep in mind that most consultants will move on from your assessment fairly quickly—any changes in work or deliverables should be made as soon as possible within the contract period.

### 2.1.4 Keep Costs Under Control

The cost of doing a watershed assessment can vary greatly, depending on the scope, scale, time, and use of paid consultants. A few groups have kept their costs low by using experts (agency staff and academics) who have contributed their time for free, as well as by receiving volunteer time from their members and the community. The Mattole Restoration Council in Humboldt County is a good example of this approach. Geologists from Redwood National Park trained council staff to evaluate erosion problems and sediment sources so that staff members could do their own assessments and also train others. In Oregon, the State's manual anticipated that most watershed assessments would be done at a fairly low cost by watershed council members themselves, including staff, community members, and technical members from local, state, tribal, and federal agencies. As more funding became available, consultants became more involved.

Minimizing scale, scope, time, and consultant use can reduce costs. However, each assessment effort has certain minimum built-in costs no matter what the scale: project management, public participation, data and information collection, analysis, report writing, and draft and final report publication. While perhaps tempting, using a per-acre cost of estimating an assessment budget is probably not realistic.

Costs of completed watershed assessments vary considerably. The California Bay-Delta Authority's (CALFED) Watershed Program has awarded grants in recent years (2001 & 2002) ranging from $96,700 to $771,000 for projects described as watershed assessments. State grants are often for a watershed assessment combined with a watershed management plan and some monitoring, so the separate assessment costs are difficult to determine. In the central coast, combined watershed assessment and watershed enhancement plans that include field work performed by consultants generally average about $200,000-250,000 for a 40 square-mile (26,000-acre) watershed. (Kate Goodnight, Coastal Conservancy, pers. comm.) Some grant programs have set a ceiling on the maximum the agency will spend on its share of an assessment and/or plan.

In Oregon, assessments based on the state manual have ranged from about $600 to almost $400,000 for fifth-field watershed-level assessments (at 60,000-acre scale), with 90% costing less than $100,000 and consultant-prepared assessments at the higher end (Ken

Bierly, Oregon Watershed Enhancement Board, pers. comm.).

### 2.1.5 Develop a Schedule

It's important to be realistic about how much time it takes to perform a watershed assessment, but estimating time required can be challenging. Experience has shown that simpler assessments performed in-house with sufficient expertise and information may take four to eight months, while more complicated assessments or assessments where the process was not under tight scheduling controls can take as long as 36 months.

Whether you are doing the assessment yourselves or having a consultant do it, you should establish a schedule of the different steps or milestones from beginning to end. Assign a due date to each step.

<u>Sample Milestones (adapted from California Coastal Conservancy 2001)</u>

- Start-up
- Initial project team meeting (define approach)
- Public meeting #1 (review issues, concerns)
- Technical Advisory Committee (TAC) meeting #1 (review strategy)
- Begin assessment
- TAC meeting #2 (mid-progress review)
- Draft assessment complete
- Review results—TAC and Public Advisory Committee
- Release revised draft to public
- Revise and deliver final assessment

The Santa Clara Basin Watershed Management Initiative had a slightly different experience than the example above. They began outlining a detailed assessment process in 1998, when the assessment was only in its "gestational phase"; looking back five years later, the group concluded that it was "much smarter" about the detailed steps necessary to complete an assessment by the time it began one in 2001. Instead of spending so much time at the beginning detailing the assessment process, the group felt it should have spent that time producing a simple assessment workplan with work-product-specific trigger dates. When those dates were reached, the group could have developed an expanded action plan for the specific work product, adding more details as the group learned more about what it wants and needs in the assessment.

A key scheduling lesson from this group's experience (and others) is to allow more time for review and comment on completed draft documents. Without sufficient time for this phase, unnecessary frustration in the process

**<u>Common Causes of Failure in Watershed Restoration Efforts</u>**

(from: Williams, Wood & Dombeck (1997). Watershed Restoration: Principles and Practices, pp. 10-11.)
This list of common causes of watershed restoration failures also highlights the reasons for doing a good watershed assessment, and the critical elements that need to be included in your approach.

1. Failure to understand the ecological history of area,
2. Failure to look at proper scale (i.e., watershed scale),
3. Failure to treat root causes of degradation, instead of symptoms,
4. Failure to work with local communities and to solicit their support for project goals,
5. Failure to integrate ecological principles,
6. Failure to develop proper goals,
7. Failure to institutionalize commitments within local communities and agencies, and
8. Failure to monitor and adapt management accordingly.

and lack of trust in the product could result due to unresolved issues.

### 2.1.6 Involve the Community

Those who will be making decisions using information in the assessment should be included, consulted, or at least considered when designing an assessment. From start to finish, the assessment should make clear how and why various steps were taken. This approach has the benefit of getting all-important buy-in—stakeholders and decision-makers are more likely to trust the assessment's conclusions if they understand the reasons various approaches were taken or they were involved in gathering data and information for each step.

Some watershed groups, such as collaborative, community-based partnerships and most Coordinated Resource Management Planning (CRMP) groups, have community participation built into their membership and their processes. Others may not. The committee-subcommittee structures discussed can formally incorporate members of the community into your assessment process. Data gathering is another means of public involvement—citizen volunteer monitoring efforts are a popular example of a hands-on contribution to an assessment. However, such volunteer work demands quality training, supervision, and scheduling for it to make a meaningful contribution to the assessment.

Two-way communication—listening and informing—is a goal of community involvement in the assessment. Informal outreach—telling the public about the assessment—can occur in a variety of relatively traditional ways: newsletters, Web sites, press releases, flyers, photographs for newspaper articles, videotape for television spots, speaker presentations, etc. Getting input from members of the public not already involved in the process can require somewhat different approaches. The traditional method is formal public meetings publicly noticed in the newspapers; getting a human-interest story in the newspaper is a better method. Designing public participation processes is an art as well as a science, and guides are available to help you (e.g., Beierle & Crayford 2002; River Network's Web site: http://www.rivernetwork.org).

Public workshops, where watershed assessors explain the assessment process and progress and informally solicit comments, can serve functions of both outreach and input. Targeting public awareness campaigns to groups representing people with a stake in the watershed's condition—farming, ranching, fishing, recreation, conservation, industry, business, governing entities—through all the means mentioned above may help increase awareness and feedback. Public involvement can and will be different at different watershed scales. It's easier to contact a high percentage of a small or rural watershed's residents and users than of large basins or population centers. On the other hand, media can broadcast well throughout metropolitan watersheds like the Sacramento River basin, San Francisco Bay watersheds, and the Los Angeles-San Gabriel Rivers basin.

Using the media to explain what a watershed assessment is, why people should be interested, and how they can best be involved may require you to tap the expertise of public relations specialists.

### 2.1.7 Record the Assessment Process

Effectively tracking the progress of the assessment process for your group, for your funders, and for the public is very important. The larger the scope and scale of your effort, the more critical this tracking becomes. Key questions to address for your recording efforts are:

- Who should be responsible for tracking?
- How should progress be recorded?
- When or how often should recording be done?
- Where should the records be maintained and accessed?
- What form should the records take?

**Actions 2.1**
- *Assemble assessment team and committees*
- *If necessary, develop contracts*
- *Keep an eye on cost and schedule*
- *Involve the community*
- *Record the process*

Funding entities may have their own requirements for recording the progress of the assessment. The Coastal Conservancy recommends that groups require their consultants to prepare quarterly reports. According to the Conservancy, "These reports come in handy to keep funding agencies informed of progress and are also useful to provide to all interested parties, including your committees and the community."

Web sites have become a common form of accessible communication. Regular postings can be put online under your home page's Watershed Assessment heading. Postings could include:
- Assessment's purpose/focus/issues
- Assessment's framework or outline; map of assessment area
- Scope of work for the consultant and the assessment's budget
- Organization chart and members of assessment's team, committees, subcommittees, task forces; application for membership
- Identification of decision-makers and decision-making process
- Agendas and minutes of meetings; schedule of future meetings
- Quarterly progress reports
- Data and information sources being used for assessment
- Explanation of how and why various steps were taken
- Public outreach efforts: past and proposed
- Draft chapters as completed, or the full draft document
- Final assessment

## 2.2 Define the Purpose and Scope of the Assessment and Develop a Plan for Conducting the Assessment

The next step in planning a watershed assessment is to agree on why one should be done. This effort spawns many questions: What purpose will it serve? What is going to happen with the assessment when it is done? Who wants the assessment to be done and why?

### 2.2.1 Identify the Questions and Issues of Concern

Watershed assessments may be motivated by one or more influences:
- to evaluate watershed conditions from a neutral perspective, i.e., with no prior assumptions;
- to address identified watershed issues or problems;
- to meet a particular purpose, e.g., identify conditions that need to be improved in order to increase drinking water quality;
- to meet a particular goal, such as educating the public about natural and human features of the entire ecosystem and assist in planning and decision-making.

For many assessments, one or more issue-

"*Watershed councils have completed watershed assessments in most basins of the state, helping to assure that restoration dollars are invested wisely ... Watershed assessments completed by local citizens have significantly helped to identify key limiting factors present in individual watersheds and guide local restoration activities.*"

"The Oregon Plan for Salmon and Watersheds: 2001-2003 Biennial Report", Oregon Watershed Enhancement Board, 2003, p. 42 & 54.

**Examples of five individual purpose statements for five different watershed assessments**

"The purpose of the watershed assessment is to…"

A. Analyze conditions in the sub-watersheds of the basin and determine whether the waters of the basin are supportive of beneficial uses and community interests.
B. Integrate historical information with new assessment data to create a comprehensive steelhead restoration plan.
C. Educate the public about the human and natural features of the entire ecosystem, and assist planning and decision making.
D. Inform stakeholders about the human and natural features of the entire ecosystem and assist in identifying areas in which additional data are needed.
E. Gather and synthesize existing information on the historical and current environmental and land use conditions within the watershed.

As an exercise, decide how well each example answers the questions in 2.2.2. What could be changed to develop a "model" purpose statement?

based questions usually drive the process. A set of questions may be as generic and general as, "What is the condition of our watershed, and why is it that way?" More specific questions might be along the lines of, "Why did the salmon stop spawning in our stream? Why did the big flood come from such a small storm? Why can't we drink the stream water any more? Why does the stream now dry up in May when it used to flow until August?"

Questions based on observations and community concerns will direct the watershed assessment, which will in turn provide the basis for solving known problems. The term "problem" here means a potential or actual impact to the natural functioning of the watershed. If there are no fundamental questions guiding a watershed assessment, you may wish to reconsider the perceived need for the assessment. The questions should be stated clearly enough to capture the prevailing concerns that led to wanting or needing a watershed assessment. They should also open the door to the next step of defining watershed assessment approaches appropriate to the questions and specific protocols that can be used to assess particular conditions.

Watershed assessments are typically conducted when an opportunity for restoration or enhancement is recognized or in response to some commonly acknowledged problem relating to the local waterway or aquatic habitat. Such problems often relate to whether anything is perceived to be wrong or whether dramatic (and detrimental) changes have been measured with respect to streamflow, water quality, fish, or other aquatic organisms.

Often, the cause of a recognized problem is readily apparent: a new subdivision has resulted in loss of wetlands and change in local hydrology; a catastrophic wildfire removed 80% of the vegetation in the watershed and the stream's sediment load increased dramatically, a new reservoir was completed and most of the annual streamflow is diverted out of the watershed; etc. However, the causes of many other problems are not so obvious and may result from the cumulative effects of many localized disturbances. In cases where there is a dramatic water-related problem without an obvious cause, a watershed assessment may be useful in identifying the causative agents and may lead to possible solutions.
The problem(s) should drive the assessment. Again, any watershed assessment must have a reason for being conducted. This reason could be anything from meeting a narrow legal requirement (e.g., water quality

standards in an agricultural area) to a very general "watershed condition" assessment.

### 2.2.2 Develop a Statement of Purpose

Watershed assessors should develop a clear purpose statement. A "fuzzy," implied, or absent purpose statement that never gets clarified can lead to bigger and bigger problems (such as getting off target, or creating misunderstandings about different expectations of the product) as the assessment process continues. For this Manual, the term "purpose" is basically synonymous with "goal". Questions (or parameters) to help focus your purpose statement are:

- What will occur during the assessment process? What will be assessed?
- What will the assessment product be used for?
- How does it lead toward managing (e.g., protecting, improving) the watershed? Will it make our effort in the watershed any better? If so, how?

People sometimes want to use a watershed assessment to measure "*watershed health*". Watershed health is a subjective concept, however, and defining it precisely can be challenging. Most references talk about it without defining it. Here are two possible definitions that might help your effort:

- "An index or estimate of the degree to which the generation and transport of water and its constituents within a watershed function in a relatively natural manner [so as not to impair beneficial uses]"
- "An index or estimate of the natural functioning of the watershed relative to a reference or historic condition"

#### 2.2.2.1 Who Is the Intended Audience for the Assessment Product?

Identifying the target audience for the assessment is important both for refining the assessment's purpose and for developing and writing the assessment. Watershed assessors should agree to and clearly state the assessment's intended audience at the beginning of the process. In stating the audience, it may become apparent that the audience needs to be more diverse than originally envisioned. Initially, the audience might be perceived as only the advisory and decision-making bodies of a sponsoring agency or group. Then the general public might be added. However, those people who will be translating the assessment into action may need to also be a specific target audience. Otherwise, the product might not be very useful for implementation when completed. For example, state in the introduction that local restoration groups and landowners are intended audiences (and potential users) of a watershed assessment that is focused on identifying restoration opportunities. Then be sure that the assessment process involves your target and expanded audience and the product is useful to them.

#### 2.2.2.2 How Might the Assessment Be Used?

Another factor to consider when developing a statement of purpose is to identify the potential uses for the assessment. Assessments generally serve to inform certain functions:

- General watershed planning with multiple purposes
- Regulatory concerns
- Restoration or enhancement planning
- Monitoring program development
- Management of risk areas and practices

You may want your assessment to serve all these functions, or just one or two of them. The more functions an assessment serves, the more complex it can become. The need to address many functions may reflect the complexity of the watershed, its problems, and possible solutions. As the assessor, you must show how the assessment can serve the functions you identify as important.

**Balancing the needs of the community and governmental agencies**

It is important to clearly identify who really wants the watershed assessment, and why they want it. Otherwise, misunderstandings can occur. For example, the impetus may come from the local level—from a cooperative group (e.g., a watershed council), a local agency (e.g., a resource conservation or water district), or other private or public stakeholders—for a variety of reasons. On the other hand, the driving force often comes from the state or federal level as a requirement of a grant program or a regulation. For example, funding agencies may require that a watershed assessment be done as a condition of funding a watershed plan or restoration projects. Often, the agencies' intent is to help target limited public funds to what is most likely to succeed in meeting agency goals and get the most bang for the buck. Members of a watershed group, however, might feel that their intimate knowledge of the watershed has allowed them to develop a good restoration project without any formal assessment work. They are concerned that an assessment will take years to complete, and they don't want to wait that long, nor seek that much funding. Thus one of the challenges of whether and how to do an assessment then becomes how to balance the needs and perceptions of the agencies with those of the community. Fortunately, this balance can be met, but it will require successful meshing of various desires for the content and use of the assessment. The local group may do some research and find that watershed assessment doesn't have to take a long time or be expensive. The more defined and widely supported the purpose of an assessment, the less time and money it will take to conduct. Successive assessments can be done, each focusing on another issue as other problems are identified, or as f se days due to political and financial realities, and it can also be scientifically defensible. Funding

Assessments have been prepared for a variety of uses in California. For example, the North Coast Watershed Assessment Program (http://www.ncwap.ca.gov) provided a baseline assessment of conditions in certain watershed for use in restoration planning and implementation of existing regulations. This assessment was not intended to be used at the site or reach-specific scale, to result in new regulations, or to describe risk management.

An example of a focused landowner watershed assessment is that for the Upper Mokelumne River (Foster-Wheeler Environmental Corporation, 2002). In this case, the consultant analyzed certain existing conditions (e.g., road interactions with erodible soils) and ignored others (e.g., the relationship between riparian vegetation and temperature) to come up with a ranking for susceptibility of sub-watersheds to disturbance. This ranking was used to develop management recommendations for the development of timber harvest plans under the California Forest Practices Rules.

The Coastal Watershed Council (2003) developed the Aptos Creek Enhancement Plan, which contained a watershed assessment and was focused on salmonid restoration in the creek based on voluntary landowner participation (www.coastal-watershed.org).

- **Using the Assessment to Develop a Watershed Management Plan**

Many local agencies and watershed groups choose to develop a watershed management plan (WMP) to guide a variety of different activities in a given watershed. WMPs are usually based on a previous watershed assessment, or one that is included in the watershed management plan itself. There are only general legal guidelines for the development and use of these plans, several of which are given below.

WMPs are different from watershed assessments. They represent the action corresponding to the evaluations in the watershed assessment. California Water Code Section 79078 provides one definition of a "local" watershed management plan:
"(c) '**Local watershed management plan**' means a document prepared by a local watershed group that sets forth a strategy to achieve an ecologically stable watershed, and that does all of the following:
(1) Defines the geographical boundaries of the watershed.
(2) Describes the natural resource conditions within the watershed.
(3) Describes measurable characteristics for water quality improvements.
(4) Describes methods for achieving and sustaining water quality improvements.
(5) Identifies any person, organization, or public agency that is responsible for implementing the methods described in paragraph (4).
(6) Provides milestones for implementing the methods described in paragraph (4).
(7) Describes a monitoring program designed to measure the effectiveness of the methods described in paragraph (4)."

The San Diego Regional Water Quality Control Board defines watershed management plan similarly:

"*Watershed management plan*—A planning document that presents solutions for addressing the water quality problems identified in the state of the watershed report for a single watershed management area or portion thereof. This document includes assessment results, specific management strategies and corresponding stakeholder roles for implementation to attain water quality goals."

The California Agency Watershed Management Strategic Plan (CalEPA and Resources Agency 2003) also defines "watershed management":

"Watershed Management"
- Effective watershed management results in successful projects that yield positive outcomes for the State's watersheds.
- Watershed management is a process for making decisions about activities that will affect the health of a watershed.
- The process is characterized by considerations of how actions in one location in a watershed will affect conditions in other parts of the watershed or other watersheds. This process uses open and transparent decision-making involving collaborations among interested parties by:
- Reliance on scientific description of conditions in the watershed and the application of scientific methods to develop decision support information and tools;
- And by a process of planning, implementation, assessment, and adaptive decision-making.
- The issues under consideration include ecological health (e.g., habitat, hydrologic function, and aquatic life), land use (e.g., commercial, industrial, agricultural, and residential uses), and resources use (e.g., recreation, water supply, water quality and flood control)."

Connecting Watershed Assessment With Watershed Management

Orange County has developed several watershed assessments embedded within watershed management planning processes. The plans focus on stormwater runoff, water quality, and restoration of channel and riparian function. The Aliso Creek Watershed Management Plan (http://www.ocwatersheds.com/watersheds/alisocreek_watershed_management_toc.asp) summarizes watershed conditions and lists specific actions that could be taken in certain reaches to improve functioning. The assessment findings and management actions are not always linked, but the plan's structure and layout make it easy for the reader to make the connections.

To encourage implementation of effective management actions, a watershed assessment that will inform watershed management planning should include the following components:

- Obvious connections between individual assessment findings and potential WMP elements. Example: Analysis of erosion potential in connection with road construction and maintenance practices.
- Specific findings for geographic sub-areas within the assessment area for individual impacts or cumulative effects of disturbances. Example: "The impervious surface area for Urban Creek is very high relative to standards for stormwater runoff management."
- Assessment of processes at scales appropriate for the scales at which decisions are made. Example: Waterway effects of licensed water management occur on hourly to centuries-long timeframes, so multiple timeframes during hydroelectric project analysis are important for licenses with fixed time periods.

- **Using the Assessment to Support Regulatory Requirements**

Some regulatory processes require watershed assessments. Under the federal Clean Water Act, for example, states must identify impaired water bodies and begin describing "total maximum daily loads" (TMDLs) (http://www.epa.gov/region09/water/tmdl/) for pollutants causing the impairment. Establishing TMDLs requires that Regional Boards in California analyze pollutant loads entering waterbodies on a watershed scale. The state must declare the maximum load allowed, and apportion the allowable load to polluters and dischargers within the watershed. A good TMDL will be based on a watershed-scale assessment of pollution sources and resemble a watershed assessment.

The State of Washington developed its watershed assessment manual (Washington Department of Natural Resources, 1997) explicitly to deal with the impacts of logging activities on anadromous fish. The manual describes how to assess watershed conditions in forested areas and how those conditions might influence salmon spawning and rearing habitat. The State of California has not yet adopted this approach. California's Forest Practice Rules (FPRs) require watershed assessment for long-term, large-scale management plans for logging operations on private lands. These assessments are usually focused on habitat concerns for endangered salmonids in waterways affected by the operations. Typically, the analyses are restricted to those parts of watershed functioning where impacts are known to limit salmon spawning and rearing habitat (e.g., riparian retention and erosion risk). Examples of these types of assessments include the Pacific Lumber Company's watershed assessments for creeks on its property in the redwood forest of coastal Northern California, the upper Mokelumne River assessment for Sierra Pacific Industries lands (Foster-Wheeler Environmental corporation, 2000), and the Albion River watershed assessment for the Mendocino Redwood Company's holding in this basin (Mendocino Redwood Company 1999).

Sustained yield plans (SYPs) are a mechanism used by the state to regulate logging activities on private lands. The Forest Practice Rules state that SYPs are "a means for addressing long-term issues of sustained timber production, and cumulative effects analysis, which includes issues of fish and wildlife and watershed impacts on a large landscape basis" (Article 6.75, FPR; http://www.fire.ca.gov/ResourceManagement/doc/FPR200301.doc).

**Examples of Potentially-Regulated Impacts of Land and Water Uses**

| General Land/Water Use | Regulatory Issue or Stressor |
|---|---|
| *Agriculture* | |
| Row-crop | Ground and surface water quality impacts, ground and surface water diversion and use |
| Orchard/vineyard | Ground and surface water quality impacts, ground and surface water diversion and use, woodland habitat loss |
| Grazing | Surface water quality, riparian vegetation loss, woodland regeneration |
| | |
| *Housing development* | Ground and surface water diversion and use |
| Road system | Habitat fragmentation, stream channel alteration, erosion, stormwater runoff |
| Ownership | Fragmentation of responsibility/accountability and stewardship |
| Wastewater | Surface and ground water quality impacts |
| | |
| *Logging* | |
| Road system | Habitat fragmentation, stream channel alteration, erosion, stormwater runoff |
| Vegetation removal | Erosion, stormwater runoff, nutrient cycling impacts, habitat loss and fragmentation, stream channel alteration, herbicide applications |
| | |
| *Mining* | |
| Hard-rock | Changes to local sub-surface hydrology, mine pollutant drainage |
| Hydraulic | Excessive sediment contribution to streams, pollutant drainage (e.g., mercury), Changes to local surface and sub-surface hydrology |
| Gravel | Depletion of gravel from stream beds and floodplains, disturbance of benthic and riparian/floodplain habitat |
| | |
| *Water Diversion & Storage* | |
| Dams | Block migration of aquatic organisms, interrupt natural flow regimes |
| Reservoirs | Change water chemistry, trap sediment heading toward lower reaches, harbor lake-dwelling fish predatory on young of river fish |
| Pumps | Mortality for un-screened fish |
| Canals | Removal of riparian vegetation, flow regimes intended for irrigation needs not aquatic life |

The SYP must define a “watershed assessment area” and the “assessment shall include an analysis of potentially significant adverse impacts, including cumulative impacts, of the planned operations and other projects, on water quality, fisheries, and aquatic wildlife.” The Board of Forestry has included some detail on how the assessment under the SYP must be conducted. For example, one required data type is a “map of existing roads and approximate location and miles of proposed new, reconstructed, and abandoned roads." However, there are no prescribed analysis methods.

- **Using the Assessment for Restoration and Enhancement Planning**

While not all watershed assessments are intended to inform restoration planning, it is a common goal of most watershed partnerships. Restoration is defined here as the renewal of a natural process (e.g., natural fire regimes) or feature (e.g., native fish species) through human actions. These actions could include changing permitted land or water uses (e.g., developing on steep slopes or diverting a majority of flow), restoring natural features (e.g., willow or gravel), or removing structures that are suspected or known to cause damage (e.g., roads or diversion dams).

The term "restoration" has been used to define numerous management strategies, from removing constraints, such as dams, and breaching levees to planting native riparian trees, but most river managers and scientists agree that fully restoring watersheds to their pre-disturbance conditions will be extremely difficult, if not impossible. For this reason, it is essential to define what is meant by restoration. Restoration science currently uses a definition such as "a return to sustainable processes," while terms such as "enhancement" are used for beneficial actions, such as replacing exotic vegetation with native species, planting vegetation to stabilize an eroding area, or placing spawning gravel in a river where gravel supply is limited by upstream dams. "Bioengineering" or "eco-engineering" describes actions that include erosion control or channel bank stabilization using hard structures that incorporate vegetation. Other terms often used to describe sustainable beneficial actions in watersheds include rehabilitation, naturalization, or recovery.

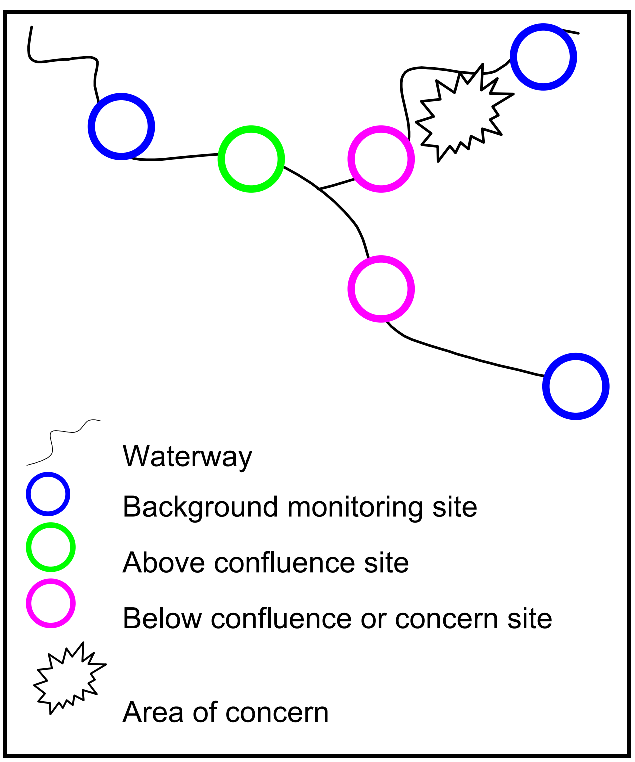
The ideal situation is for restoration planning to take place in the context of watershed assessment for the upslope and in-stream area surrounding the proposed restoration site. Taking a watershed approach to restoration planning is essential in order to determine how upstream or downstream processes and land uses may affect the restoration area. If the restoration is focused on an area of a hill-slope or a reach of a river, the essential unit for assessment and planning is the watershed. For this reason, watershed assessment can support subsequent decision making about where, when, and how to restore natural processes at specific sites or in larger areas (e.g., sub-watersheds) to benefit native wildlife. It can also inform decisions about how to monitor the effectiveness of the restoration action and how to maintain the action over time.

Some watershed assessments make explicit connections between the analysis of existing (or historical) conditions and specific actions that could be taken to restore natural functioning. Conducting the watershed assessment as if you are planning future restoration projects will help connect components of the watershed assessment and the restoration plan. For example, if your assessments suggests that road construction is resulting in multiple risks to natural functioning (e.g., weed invasion and increased erosion), then restoration actions could consist of modifying existing roads to accommodate natural processes, or changing how and where new roads are constructed. The Mattole Restoration Council, for example, identified excessive sediment from roads on private lands as a critical limiting factor for salmon reproduction. It established the "Good Roads, Clear Creeks" program, where sub-watershed and parcel-specific assessments are used to prioritize road fixing or removal projects (http://www.mattole.org/program_services/grcc.html). The council does this in collaboration with landowners and reports a high level of success with owners of small to medium parcels (Chris Larson, personal communication).

- **Using the Assessment to Support Monitoring Programs**

Watershed assessments are closely tied to past and current monitoring in watersheds. The assessor relies on data and conclusions drawn from monitoring programs to analyze watershed processes and conditions. In turn, the assessment can form the basis for developing or updating monitoring programs. This iterative process is part of an adaptive management and assessment approach that incorporates new information as it becomes available in order to make decisions. One important caveat is that monitoring information can lead in rare cases to regulatory action, which the assessor/monitoring team should explain to the stakeholders involved.

From the watershed assessment point of view, it's important to find areas in the watershed that might impact waterway condition (e.g., water quality). These areas will include both human-created and natural features that have the potential or are known to be releasing material into a waterway or otherwise influencing in-stream processes. At one end of the impact spectrum might be ridgeline roads that connect to streams through impacts to hillslope geomorphology or pollutant runoff. At the other end of the spectrum might be riparian developments (e.g., in urban settings) that have direct connections to channels and dominate the relationships between watershed hillslopes and waterways.




Watershed assessments or other inventories of disturbance could reveal that certain human activities are particularly concentrated in an assessment area's sub-watersheds. This could help focus monitoring efforts in these areas. Human activities that may impact water quality include housing developments, abandoned or current mining, agricultural operations, roads, and logging. Pollutant monitoring could take place downstream of the potentially impacted area within the sub-watershed (see boxed figure above), and, for comparison, in nearby un-impacted sub-watersheds and upstream of the area of concern. In addition, monitoring sites could be placed on the mainstem river above and below the confluence with the waterway originating from the area of concern (see figure) to measure the actual impact of the disturbance on the river. The data resulting from this combination of monitoring sites will provide information about the types and extent of impacts the site is causing on nearby waterways.

Ultimately, the watershed assessment should serve in part to inform monitoring programs by revealing potential and actual impacts of human and natural processes in the watershed. Water quality monitoring is a form of continuing assessment of one watershed condition, and is one way to measure the effectiveness of protective actions taken on the landscape.

Other aspects of watershed monitoring may also tie into the assessment. These monitoring efforts include measuring and evaluating variables that can change over time, such as streamflow, aquatic organisms, channel conditions, riparian vegetation, water use, and upland vegetation. It is important to identify the type of monitoring (past, current, and proposed) because each type has a different purpose (baseline, trend, effectiveness, implementation, project, and compliance) (MacDonald 1991).

- **Using the Assessment as a Risk Management Tool**

Risk assessment is a relatively new analytical field intended to support decision making in the absence of a complete understanding of a system. It usually employs analytical approaches in combination with "deliberative" approaches, which are linked to value judgments (National Research Council, 1996). The U.S. EPA has developed a framework under which large-scale "cumulative risk assessments" are done for multiple "stressors" (sources of stress to a system). Under this framework, cumulative risk assessment is defined as "an analysis, characterization, and possible quantification of the combined risks to health or the environment from multiple agents or stressors." (U.S. Environmental Protection Agency, 2003). This approach is similar in concept to watershed assessments, and the two approaches could act in concert (see later in this chapter and chapter 6 for more detail). The difference lies partly in the terminology, as many aspects of risk assessment can be found in watershed assessment. There is also a difference in substance – watershed assessment is often about actual impacts to condition, whereas risk assessment often stops at potential impacts. To the degree a watershed assessment estimates the potential for or actual harm caused by various human activities and the resultant stressors, it is quite similar to risk assessment.

A sub-category of cumulative risk assessment is ecological risk assessment, which is defined as a process that involves consideration of the aggregate ecological risk to a target entity (such as aquatic biota) caused by the accumulation of risk from multiple stressors (U.S. Environmental Protection Agency, 1998). One outcome of risk assessment is exposing uncertainty and data gaps that were found in the analysis phase and presenting recommendations for dealing with them. The final step in the risk assessment process is risk characterization, where "the information from all the steps is integrated and an overall conclusion about risk is developed that is complete, informative, and useful for decision-makers" (U.S. EPA 2003; CWAM chapter 6). An excellent tutorial on watershed risk assessment is available online at http://www.epa.gov/watertrain.

The connection between risk assessment and watershed assessment is that doing watershed assessment may involve analyzing risk to individual processes or features in the watershed as a result of human actions, or analyzing the cumulative risk of various actions on various watershed features or processes. A watershed assessment that includes risk analysis, and especially cumulative risk assessment, can then inform management activities intended to manage risk from human actions. It is not essential that risk assessment and management be part of watershed assessment. However, these concepts are often part of people's picture of watershed assessment because managing risk influences many areas of applied environmental science.

## 2.3 Basic Watershed Assessment Process

The following sections address the question of: "How do I design the assessment?". To summarize the process, the first step is to get a basic picture of the watershed, what we call an *initial scoping*. This includes clarifying the assessment's purposes, identifying the focus of the assessment, and developing a conceptual model or diagram that reflects the relationships of key factors and processes in the watershed. Next comes the task of collecting and *analyzing existing and new information* and data. The final step is the *information integration* phase in which all the information is assembled in some systematic fashion to see what it means.

### 2.3.1 Phase 1: Initial Scoping - Defining the Biological, Spatial, and Temporal Scope of the Watershed Assessment

We suggest that you begin with an initial assessment or scoping of your watershed. Defining the scope of the assessment involves identifying the breadth of your efforts. What temporal and spatial scale will you select? This involves identifying the boundaries of your watershed and determining time period over which data will be collected; both existing data and future collection efforts. Like most parts of the assessment, you will likely revise your initial estimate based on the availability of data and other factors. Nonetheless, it is valuable to identify the scope of the assessment before beginning so you have some sense how much time and effort might be involved. This initial assessment will help organize your team and your approach, show what might be gained from a more detailed assessment, and provide some clues about which parts of a more thorough assessment will be relatively easy to perform and which parts will be more difficult. Taking an iterative approach to assessing a watershed is usually an efficient use of personnel, consultants, and finances.

In most cases, it is not obvious at the outset how deeply your assessment must delve into a particular problem. You must first learn some basics about the problem before deciding how and how hard to tackle that problem. For some problems, a well-

**Guidelines for Choosing a Starting Place**

Getting started with a watershed assessment assumes there is something already going on in the watershed. Sometimes an appropriate sponsoring group for the assessment does not already exist or may not be apparent. An example from the Bay Area offers a way to look at the spectrum from “good” to “best” in opportunities for choosing the appropriate group as a “starting place” for a watershed assessment.

**The starting place should help reduce the cost of getting started.** The following conditions suggest the suitability of a starting place. The upper two sets of conditions, dealing with local, non-governmental interest groups and volunteers, are probably the most important for reducing costs.

| ***Good*** | ***Better*** | ***Better*** | ***Best*** |
|---|---|---|---|
| *There is a local interest group* | | | |
| | *that includes all pertinent local agencies* | | |
| | | *and non-governmental organizations* | |
| | | | *and wants science support.* |
| *There is a local volunteer monitoring organization* | | | |
| | *that focuses on watershed health care* | | |
| | | *and has strong links to public education* | |
| | | | *and pertinent local agencies.* |
| *There is a local legacy of environmental studies* | | | |
| | *that includes a written natural history* | | |
| | | *and the history of fire and flooding* | |
| | | | *and the history of land use.* |

“Bay Area Watersheds Science Approach*”, San Francisco Estuary Institute (1998)* considered experimental design, a prolonged period of data collection, and rigorous hypothesis testing may be necessary. In other cases, existing data and earlier analyses may offer a perfectly adequate answer for your purposes. The appropriate level of detail for different parts of your assessment will depend on the tradeoffs between the level of confidence you want and the effort required to obtain that level.

An initial scoping serves as the foundation on which all further work is built. In some cases, especially for watersheds where little information is available, the watershed assessment might consist only of this phase. This initial assessment or problem definition phase involves identifying your purpose, developing a basic picture of the watershed, identifying the valued watershed resources and processes about which you are most concerned, and building a conceptual diagram or “a descriptive picture” of the relationships between key factors within the watershed.

**2.3.1.1 Defining the Boundaries of the Watershed**

Establishing the boundaries of your watershed assessment area is a critical early step. The only watersheds defined by nature are those with a low point at the ocean or a closed-basin lake. All others (including those contained within a “naturally-defined” watershed) are defined by a human choice of the lowest point (e.g., the map of the Yuba River basin on the next page, from the confluence with the Feather River). Not all watershed boundaries are obvious, and decisions about boundaries and other related issues will have to be made early in your assessment process. Choosing the size or “scale” of the watershed will determine where to pick the lowest point that defines the entire watershed and vice-versa. Some watershed studies start at a point in the middle of the river, such as at a dam or a stream-gaging station, and evaluate the watershed above this site. Agreeing on the assessment area at the outset so that everyone knows exactly what piece of ground is under discussion can head off many problems and arguments.

In determining your assessment area, consider only watershed boundaries—the perimeter of the area in which water drains to some arbitrarily defined point. Do not confuse your watershed boundary with county lines, property boundaries, rivers, highways, fences, vegetation-type edges, federal reserves, or any other non-watershed boundary.

The availability of information used in an assessment may vary across property-ownership or political lines, but you should still think about all parts of your topographically defined watershed. Although information may be hard to obtain (or simply doesn’t exist) for some areas of your watershed, these areas may still play important roles in influencing the downstream water bodies.

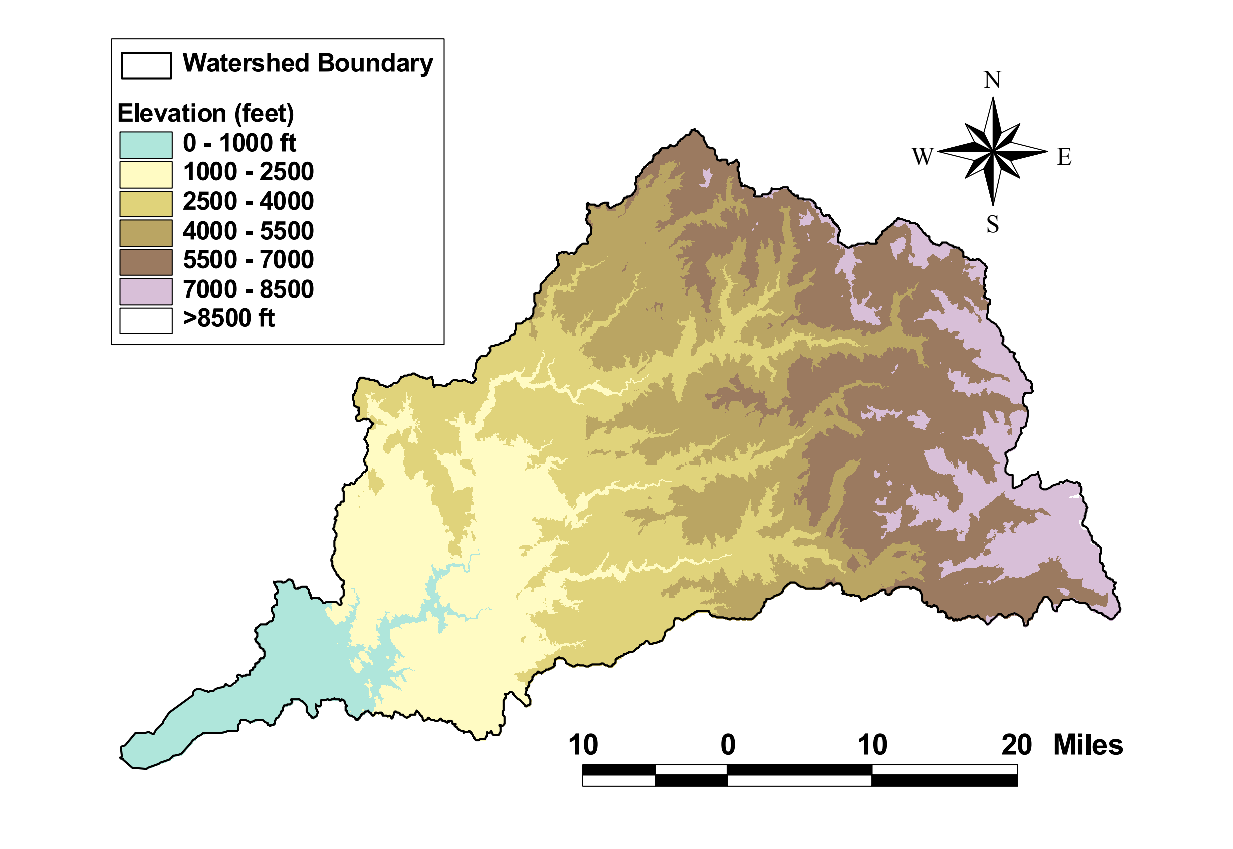
**2.3.1.2 What Is the Watershed Boundary?**

Choosing a point along a stream or river that then defines the lowest point or downstream end of your watershed is the sole decision that defines a watershed. Once you choose that point, everything upstream of it becomes your watershed. Your watershed includes all land that drains downhill (or could contribute water via gravity) to the point of your choosing. Imagine there is a line extending uphill away from your point along the stream on either side of which water flowing downslope will reach the stream above or below your point. This line may be hard to visualize or accurately map (and the exact location isn’t important for your assessment because errors of a few feet are insignificant with respect to your entire watershed), but there is a physical micro-topographic divide (or underground geologic structure, sometimes termed the phreatic divide) that separates water to one direction or the other with respect to your point on the stream. This line will eventually reach a ridgetop, where it becomes obvious that water will flow either into or away from your watershed—imagine the Continental Divide where water on the west side flows toward the Pacific Ocean and water on the east side flows toward the Atlantic Ocean. The same concept of a divide scales down to the smallest watershed you care to define with your chosen point.

For mapping purposes, locate your point on a topographic map and draw a line away from your point separating the area inside your watershed from that outside. Following along the obvious ridgetop is generally easy, while connecting the ridgetop to your point along the stream may not be so easy if the topography has little relief. See *Water: A Primer* (Leopold 1974) or *Watershed Hydrology* (Black 1996) for more details on drawing watershed boundaries. Alternatively, almost all common GIS packages have a simple function for drawing watershed boundaries given the defining point on the stream.

Obviously, delineating watershed boundaries is much easier in steep terrain with lots of relief than in low-lying, nearly level areas. Prominent ridges make the process very obvious and straightforward. Conversely, defining a watershed boundary in flat areas with all the topographic relief of the Sacramento-San Joaquin River Delta is nearly impossible. In flat areas such as the Delta, having an uncertain boundary is probably adequate for most purposes (imagine using a very broad crayon to mark the divide on your map).

Another complication is the presence of engineered water imports and exports. Aqueducts, canals, penstocks, storm drains, and pipelines can interfere with the otherwise-clean delineation of a watershed. In such cases, start with the natural, topographically defined boundaries. Then consider the effects of the water diversions and append those considerations to the natural watershed. For example, if 100% of a neighboring watershed's flow is captured and diverted into your watershed, then you may wish to add the entire area of that other watershed to yours. If only a small fraction of the flow is imported



into your watershed, then you probably don't want to adjust watershed area, but will instead deal with the imported water just as quantity of water (and its constituents) added from outside. In the case of water exports out of your watershed, you should usually maintain the natural watershed area and consider the impacts of the diversion on aquatic resources.

So, how do you choose this all-important point to define the watershed boundary? That depends largely on the objectives of your assessment and the general area in which you are interested. Common points to pick are the mouth of a stream at an ocean or lake, the confluence of a stream of interest with another stream or a much larger river, a point immediately upstream of a major water diversion, a stream-gaging station where flows have been measured for several years or decades, or a location where water quality samples have been consistently obtained. Sometimes, another entity (e.g., a funding agency) will pick the point for you. Also consider using the state's CalWater system of delineated watersheds if your watershed approximates one of the CalWater watersheds. Be aware that topographic and hydrologic errors exist in some of the watersheds in CalWater 2.2 and that there may be seemingly odd distinctions between "upper" and "lower" watersheds. Another source of information for defining watershed boundaries is the US Geological Survey. Each hydrologic unit in the U.S. is identified by a unique hydrological unit code (HUC) consisting of two to eight digits based on the four levels of classification in the hydrologic unit system. You can get additional information about this system at http://water.usgs.gov/GIS/huc.html.

Selecting the watershed boundaries is also influenced by the objectives of the assessment.  You may wish to define watershed boundaries broadly or narrowly. For example, if you wish to study the effect of local land-use changes, you may wish to assess several small watersheds where these changes will have a more noticeable impact on the local stream (simply because they occupy a greater proportion of the watershed area). If you are primarily interested in broad regional issues, you may wish to assess a single large watershed or river basin where impacts from small disturbances tend to be diluted.

Your watershed will be part of one or more ecoregions—a term defined as "major ecosystems largely determined by climatic conditions that affect the distribution of plant and animal species" (Bailey 1995). Ecoregion classification systems, such as those of Bailey (1995) and Omernik (1995), distinguish areas based on terrain, climate, and major vegetation cover. Although ecoregions rarely correspond to watersheds, the finer-scale ecoregion characterizations provide much information about vegetation and other influential factors, as well as attributes of aquatic habitats that should be useful in your watershed assessment (Omernik & Bailey 1997). Keep watershed boundaries in mind as you seek ecological information from larger-scale ecoregions.

Table 2.1

| **Watershed Assessment Purposes** | **Ecosystem Endpoints** |
|---|---|
| Determine sustainability of native fish population in the stream | Reproducing steelhead population |
| Determine ecological requirements of riparian vegetation to aid in long-term management. | Viable population and condition of cottonwood trees |
| Determine availability of recreational lands | Amount of and accessibility to urban parks |
| Determine impacts to creek in the face of rapid urbanization | Species composition, diversity, and organization of fish and benthic macroinvertebrate communities |

#### 2.3.1.3 Identify the Watershed Processes and Valued Ecological Components to Focus on

Once you have defined the purpose(s) of the assessment and geographically defined the area of assessment, you can apply this information to identify the processes and components of the watershed that reflect the purpose and goals of the assessment. This involves identifying the watershed processes or components are most important to the stakeholders. Watershed processes refers to the natural physical, chemical, or biological processes that interact to form an aquatic ecosystem, such as the water cycle. Valued ecosystem components refers to the things within the watershed that stakeholders value, such as fish, trees, or open space. Some watershed scientists have used the term '*ecological endpoints'* to refer to any ecological components or processes that are the focus of the assessment. We will use that generic term or the related term "ecosystem endpoint" in this Manual.

There are numerous valued components and processes in a watershed. You could spend forever studying them. By identifying a few that are especially important, you can focus your efforts and simplify the assessment. A few criteria are useful for selecting the ecosystem processes that will be the focus of the assessment.
These should be:

- Important to the health and sustainability of the watershed;
- Related to the assessment's purposes;
- Have societal value; in other words, are important to the community

These ecosystem endpoints might include, for example, benthic macroinvertebrate communities, drinkable water, a species of fish or a plant that is important to the stakeholders, or, more generally, the overall riparian corridor or upland habitats. Table 2.1 presents some possible purposes for conducting a watershed assessment and related ecosystem endpoints.

Often it is difficult to measure these endpoints directly. For example, quantifying steelhead reproduction is a challenging task. So a series of measurements or monitoring data can be substituted that reflect the condition or status of the endpoints that are the focus of the assessment.

In one of the examples in Table 2.1, stakeholders believed the population of native fish was declining, which prompted their watershed assessment. Because steelhead were among the most visible native fishes in the stream and are a listed species, they were selected as the ecological endpoint. However, due to the difficulty of accurately measuring steelhead population itself, the stakeholders selected a number of other measurements that were relatively easy to collect that would serve as indicators or surrogate measurements of the steelhead population (Table 2.2). Without the appropriate habitat and water quality conditions, it is unlikely a viable population of fish could persist. Measurements of stream morphology or water quality, for example, serve as useful indicators because they reflect the conditions in the stream that are needed to support a viable population of steelhead AND are relatively easy to measure.

#### 2.3.1.4 Develop a Conceptual Model

One of the last preliminary yet very important steps in the scoping process is the development of a conceptual model. A conceptual model is a graphical representation of important relationships within the watershed. Once you have identified the ecological endpoints you are most interested in, you will need to think about how they are impacted by changes in watershed processes and the stress that may result from human activities. The relationship between human activities, watershed processes, sources of stress ("stressors"), and the ecological endpoints are depicted in the conceptual model. The term stressor refers to anything, natural or human-induced, that could cause harm to components and processes within the watershed. Watershed

Table 2.2

| Purpose | Ecosystem Endpoint(s) | Measurement or Data to be Collected |
|---|---|---|
| Determine sustainability of native fish population in the stream | Reproducing steelhead population | Water temperature Habitat suitability Contaminant concentration, etc. |
| Determine impacts to warm-water habitat in creek in the face of rapid urbanization | Species composition, diversity, and organization of fish and benthic macroinvertebrate communities | -Index of Biotic Integrity (composed of 12 attributes) - Invertebrate community index (based on 10 measurements) |

assessments typically focus on those stressors that are human-induced, since they are the ones we have some ability to control. The specific interactions will be unique to your watershed, though experts and technical and scientific literature can provide you with many of the clues you need to understand the interactions. At this point, you should not draw conclusions as to what the relationships are; you should think about what they could be.

The conceptual model can be a valuable learning tool. When initially drawing the model, represent the relationship you think exist based on the initial scoping you have done. It is not necessary to wait until you collect additional data and information. At this point, it is simply useful to hypothesize the relationship between the human activities/land uses, altered conditions or processes, and the potential effects of these alterations on the ecological endpoints..

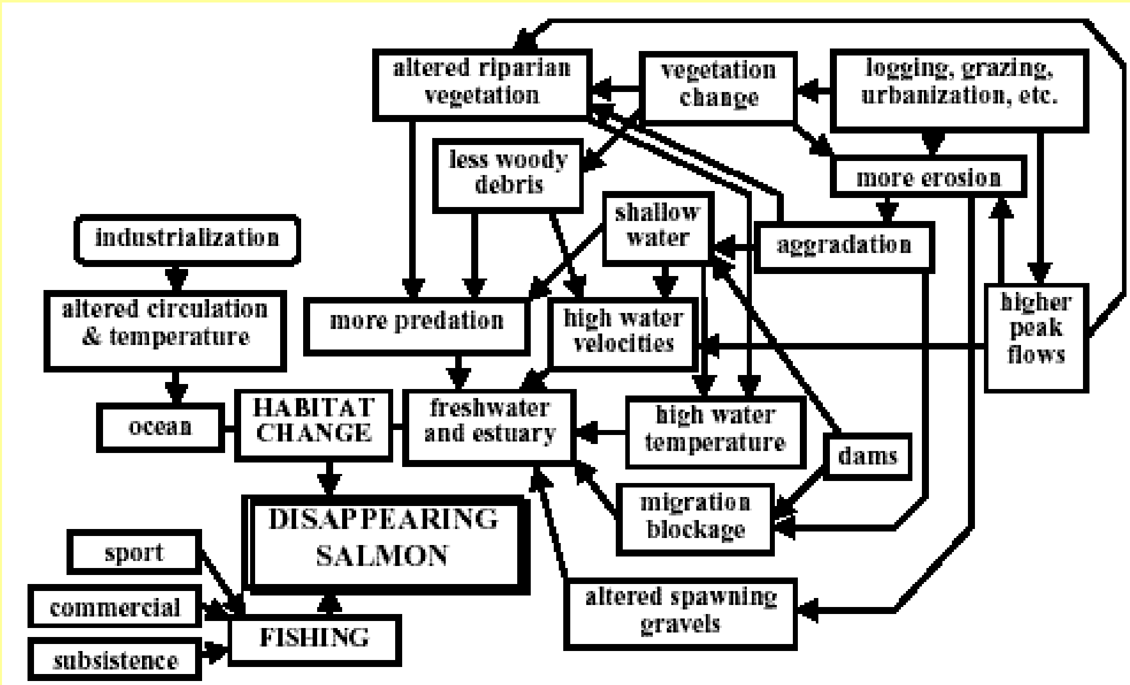
Over time, as the team gains additional information, you can modify the conceptual model to better reflect the reality in the watershed. But in the beginning, it primarily serves as a aid to your understanding and a guide to the type of data and information you might want to collect for the assessment.

Conceptual models can be developed in a variety of ways. You should develop one as part of the scoping process. In the first example, the model below was developed to represent hypothesized relationships in a small watershed where salmon populations were declining. The diagram shows the possible influences of landscape and in-stream processes on salmon populations (Ziemer, 2004). In this case, municipal water use, oceanic processes, roads, and logging are the primary influences on success of salmonid reproduction and population health.

It quickly becomes clear that in order to prepare these diagrams, you will need to understand the watershed processes or mechanisms that link human activity to changed conditions. For example, increases in impervious surfaces (e.g., urban areas and roads) can cause alterations in stream morphology as a consequence of changes in peak flow rate and total surface.

Using another example from the same conceptual diagram, the relationship identified between increased fine sediment from excessive erosion and mortality of salmon eggs and yolk-sac fry is based on an understanding that conditions of depleted oxygen occur as fine sediment are deposited in spawning gravels. The knowledge required to draw accurate conceptual models can be significant. That is why having a team of people with varied backgrounds is very helpful.

Another example of a conceptual model diagram is shown on the next page. It focuses on the influences on domestic water quality in the Mad River watershed (Reid & Zeimer, unpublished).




*where ree ocean*

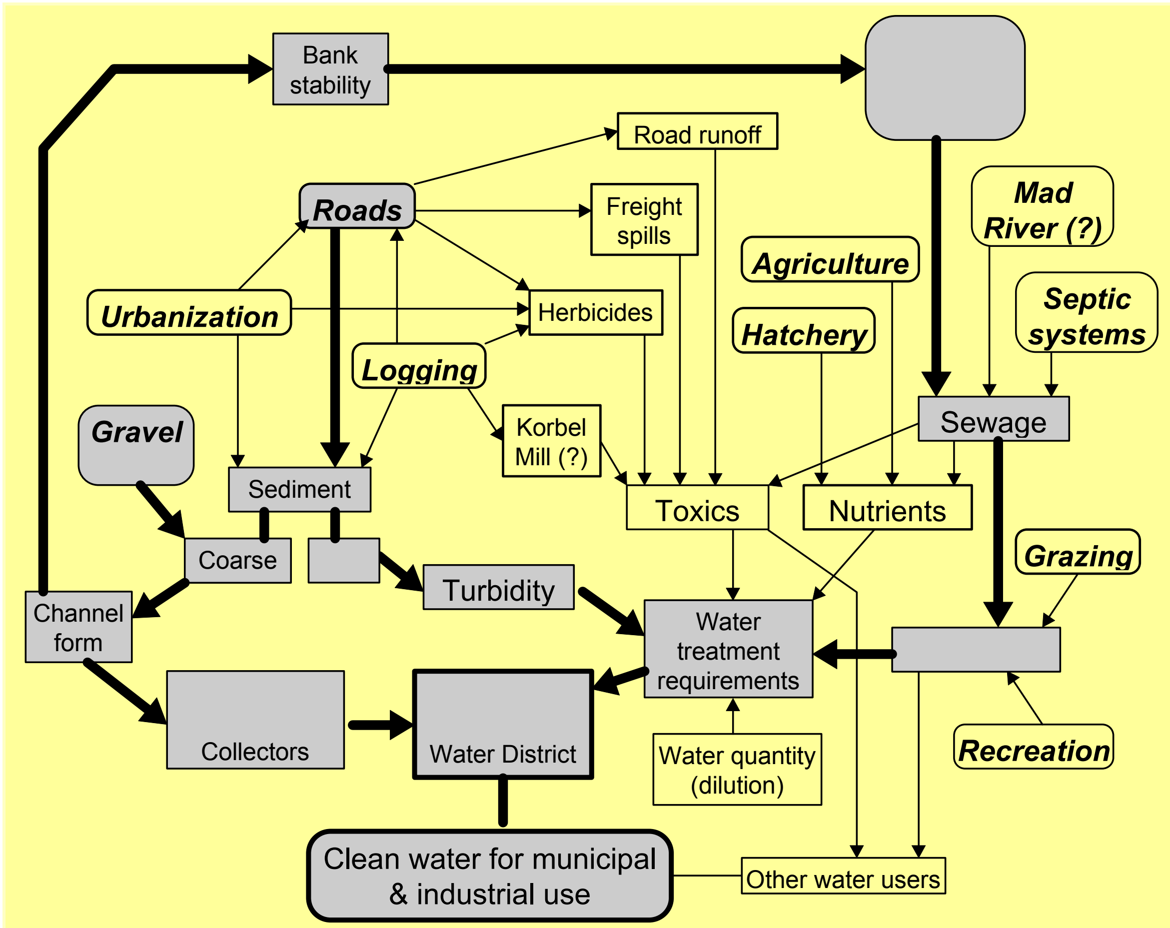
Shaded boxes and thickened arrows indicate the impact mechanisms that are expected to be most important. Lines without arrowheads indicate subsets within a category (e.g., coarse and fine sediment). In this case, channel dynamics, sediment composition, and the presence of pathogens have the most impact on the quality of the municipal water supply.

*The key point is that the diagrams should identify hypothesized relationships between human activity, changed conditions in the watershed, and the potential effects of these changed conditions on the selected ecological endpoints.*

When preparing a conceptual model, a few points should be kept in mind. First, the development of the conceptual model is not data dependent. You are trying to reflect relationships that you think exist, even if there is little available data to support it. Based on the model, you can identify key areas for which you need data. If such data exists, you can assemble it. If it is not available, you might decide to collect it on your own. Second, the conceptual model is a 'work in progress'; it will change as your understanding of the watershed expands. Most conceptual models undergo numerous revisions as the work proceeds and new relationships are revealed.

### 2.3.2 Phase 2: Plan Data Collection and Analysis

The previous section described conducting an initial assessment. From this point on we will be discussing ways you can approach the main part of your assessment.




The next step in planning your watershed assessment is actually writing a plan for analysis. Having laid the foundation for the assessment by focusing the assessment on key issues of concern, defining the scope, and developing your conceptual model, the final step before actually commencing the assessment is to lay out a plan to do the work. This section reviews the factors you should consider in developing your analysis plan. Each of the topics are discussed in detail in subsequent chapters, which are identified in the appropriate section. One point to keep in mind, as with everything in a watershed assessment, is that this is an iterative process. To the best of your ability and based on your present knowledge, lay out a plan for analysis. But keep in mind that it is likely you will need to revise it as you go along and learn about factors you had not considered in the beginning.

The data collection and analysis effort constitutes the heart of the watershed assessment. The conceptual model or diagram constructed as part of the initial scoping can serve as a guide. Accordingly, as you plan for the analysis phase of your assessment, you should identify the data and information that must be gathered and outline the process for organizing and analyzing this material (discussed in more detail in chapters 4 and 5). There are two primary forms of data and information you will collect based on your conceptual model or similar plan. One is existing data and the other is new data. Existing data already exist for the watershed, though they may not have been collected to support an assessment. New data are collected to fill gaps in information and knowledge about how the watershed functions.

The watershed assessment focuses in part on the potential harmful effects of human activities on watershed properties and function. These effects occur when human activities cause changes in the physical, chemical, or biological characteristics of the watershed.

Physical changes include water temperature and flow rate, sediment characteristics, stream channel shape and connectivity with the floodplain, erosion and incision of the streambank, and any other physical characteristic that makes up the habitat on which the watershed processes being evaluated depend.

Chemical changes include the introduction of pesticides, excess nutrients, oil/grease, effluent from industry, or other contaminant to the targeted habitat. Biological alterations that might be associated with harm could include invasive species, pathogens, habitat fragmentation, and changes in ecological processes. *A key function of the analysis plan is to focus attention on the relevant changes in processes and conditions and outline how these changes might affect the ecological endpoints, the valued ecosystem components and processes that you identified as the focus of your work.*

#### 2.3.2.1 Identify the Data to Collect

In determining what data you want to collect, one criteria you might want to consider is its relevance to the focus of the assessment, the ecological endpoints. The table on the

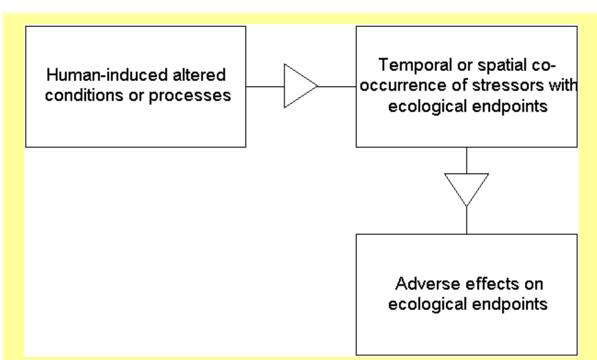
| **Issue** | **Some Relevant Questions to Ask** |
|---|---|
| Topography | What are the elevation profiles and slope angles? |
| Hydrology and water use | How much water is in the watershed and where does it go? What is the seasonal pattern of stream flow? Are there dams, diversions, and/or culverts that might affect flow and act as barriers to fish passage? What about floods and the floodplain? |
| Sediment Sources and Transport | Has turbidity in the stream changed over time? Have the characteristics of the streambed changed? Is there evidence of erosion upland or in the stream banks? Have fine sediments filled what were once pools or gravel beds? |
| Riparian Vegetation | What proportion of the watershed is covered by native vs. non-native species? What is the extent of the riparian corridor? |
| Instream habitat, including water quality | Does it appear that the stream channel has been altered? Does the water appear clear and of good quality? Is there a history of fish kills? Are there human activities close by that might degrade the water quality? |
| Fish and wildlife | Has there been a decrease in the diversity or abundance of fish in the stream? Have the number and kinds of birds and mammals in the watershed changed? Have the number of frogs and toads decreased? What changes have occurred in streamside vegetation? Are there invasive animals present? |
| Historical and present land uses | What was the land in the watershed used for historically? What is the legacy of these land uses? What are the present land uses? Could any pose a risk to aquatic life either directly or indirectly (i.e., releasing contaminants or increase sedimentation)? |

previous page contains a list of key issues and examples of questions related to the issues. It might serve as a useful exercise to ask yourself – To what degree are these issues and their related questions relevant to the focus of my watershed assessment? This table is not inclusive; there might be other issues of importance in your watershed.
The above list is not comprehensive. In any particular situation, there might be additional major categories of importance. However, the list highlights key topics that are likely to be important in most watersheds.

**2.3.2.2 Decide How You Will Evaluate and Analyze the Data**

The following section describes one approach to collection and analysis of data. It has been proposed in the U.S. EPA's watershed risk assessment guidelines (posted at: www.epa.gov/watertrain). It is limited to human effects on water quality and the impacts of water quality on waterway biology ("ecological endpoints"). This simplified diagram illustrates EPA's recommendations.

The diagram below reflects the relationship between altered conditions and processes associated with human activity, the potential for exposure, either temporally or spatially, of the ecological endpoints to these stressors, and the potential adverse effects that might result from this exposure.




The following questions might serve as a useful guide to determine the degree to which each of these issues is important in your particular situation.

*1. Is there temporal and spatial co-occurrence of the stressors or altered conditions and the ecological endpoints?*

You should assess the pattern of stressors occurring in space and time and the pathway by which this pattern might lead to harmful effects on watershed processes. To do this, ask yourself two questions.

- Is it likely that the ecological endpoints are present at the same time as the altered conditions/stressors and/or processes?

An example can best be used to explain what we're getting at with this question. Assume changes in the riparian canopy have occurred as a result of changes in the hydrological patterns in the watershed. The hydrological changes have caused streambank erosion and loss of some riparian cover. Consequently, the summer temperature of the water has increased. If one of the ecological endpoints is anadromous fish, then it is necessary to determine if this species was present in the stream in the summer, during the period that the temperature was high. Although the water temperature might exceed tolerance limits for this fish, if the fish isn't present, there is no *temporal coincidence*, and there is no opportunity for harm to occur.

- Is there spatial overlap between the geographical distribution of the ecological endpoints and the altered conditions/stressors or processes?

For example, warm-water fish, such as bass, often prey on young salmon. Typically, the bass live at lower elevations, where the water is warmer than that inhabited by juvenile salmon, which need cooler waters. Although non-native bass and salmon share the same stream, if there is no/little spatial overlap, it is unlikely that invasive bass will act as a biological stressor on the salmon, except for the relatively brief period when the young salmon migrate downstream and pass through the bass habitat.

You might also want to consider the effect of secondary stressors or alterations in evaluating possible harm. For example, acid mine drainage in Northern California has been a significant problem in certain areas. During the rainy season, sulfuric acid spills into the rivers and creeks, depressing the water's pH and causing significant toxicity to aquatic life. Not only does the acid spill cause direct toxicity, but it also increases the solubility of copper, zinc, and other potentially harmful metals. These metals are secondary stressors and can independently cause toxicity to fish and invertebrates.

*2. Is it likely or is there evidence to suggest that the altered conditions might have an adverse effect on the ecological endpoints?*

To make this analysis, you need to determine whether conditions in the watershed have been altered enough to reduce the viability of the watershed processes that are the focus of the assessment. You will want to understand the conditions in your watershed relative to those known to be protective of aquatic resources. One way to do this is to characterize the stressor-response profile.

In summary, when planning your data collection effort, consider the value and appropriateness of collecting data on the human activities (i.e., land uses) within the watershed that might alter watershed processes or conditions, thereby causing stress on the ecological endpoints of interest. Second, consider the temporal and spatial co-occurrence of these stressors on the ecological endpoints. If there is no temporal or spatial overlap, it is unlikely the stressor will/does present a problem for the ecological processes that are the focus of your assessment. If there is co-occurrence, then it is important to evaluate if theses stressors have an adverse effect on the ecological endpoints. These are important issues to review when planning data collection and analysis.

#### 2.3.2.3 Scale: An Important Issue in Planning Your Analysis

One important consideration in developing an analysis plan is the question of scale. The term scale has a variety of uses depending on the context and need of the user. In ecology, the scale of measurement refers to the classes or types of values that describe a feature or process. For example, soil classes are an example of a "nominal" (naming) scale of measurement, whereas temperature is an example of an "interval" scale because values range across a numeric scale (Jongman et al. 1995). There is also "spatial scale", which refers here to the scale at which a place is measured or viewed. Temporal scale is the timeframe over which analyses or measurements are taken for a process. This

**Examples of typical types of data collected in a watershed assessment and the optimal scale for these data**

| Type of Data | Temporal/Spatial Scales |
|---|---|
| Contaminants in water | Throughout the year and immediately after rain events; above and below sites of concern (storm drains, road effluent, wastewater treatment plants). Ideally, regular monitoring over many years. |
| Sedimentation | In streambed, on hillslopes, below roads, primarily following storm events, in smaller streams and periodically in smaller and larger waterways |
| Dissolved oxygen, temperature | Weekly or monthly in all sub-watersheds of the stream |
| Road maps | 1:24,000, updated every five years |

Manual deals primarily with the latter two uses of the term and qualifies the word where needed.

The spatial and temporal scales used in a watershed assessment must be appropriate for the type of information being collected and the questions or problems being addressed.

Different analytical approaches depend on different scales of input data. Varying results and conclusions are possible depending on how fine or coarse the resolution of data collection is. The scale at which data and knowledge (what we know from the data) have been developed determine the kinds of management, regulatory, or restoration decisions that can be supported by a watershed assessment For example, if it is likely to take six months before logging activity potentially causes environmental changes, then data should be collected before logging begins, again six months later, and at least one more time per season (for wildlife) or week and storm event (for water quality) within several years of the activity. By collecting data over this period of time, there is a good chance that changes that might have resulted from the logging will be detected.

- *The link between the assessment questions and scale*

This Manual is designed for watershed assessments that support questions, decisions, and implementing actions. The types of questions you ask in your assessment, the decisions you expect to make, and the actions that might result will determine the scale of data you need. If you are assessing the condition of a 10,000-acre watershed in order to prioritize sites for restoration, you may need to go beyond most readily available spatial data sets and use custom digital spatial data or field data to differentiate among areas within the watershed. For large watersheds (e.g., 1 million acres), the condition assessment may allow you to differentiate among sub-watersheds for potential action and likely condition, but there probably won't be data for the whole watershed with fine enough resolution to answer site-specific questions. These types of issue highlight the relationship between the assessment questions and the spatial scale of your data.

- *Data scales*

You may be relying on existing data for your assessment. In this case, you will not have an opportunity to make a decision about scale. This situation exists for topics like plant and animal distribution across the landscape, as well as for topics like changes in water quality over time. Academic definitions of studies, including watershed assessments, often differentiate between those where the investigator can control some aspects of the system (an experiment) and those studies where the investigator has no control of the system and relies on already-collected data (a "survey"; Jongman et al. 1995). This difference is important because cause and effect are harder to determine in surveys than experiments.

Watershed assessments will generally involve only survey data that has already been collected. Data collected at scales that you cannot control constrains the use of that data in new analyses. However, much of the information that an assessment relies upon as "data" may actually be products of computer models (e.g., for wildlife habitat, fire hazard, and landslide risk), which potentially increases the range of uses of data, but not necessarily the reliability.

### 2.3.3 Phase 3: Data Synthesis and Integration

Another part of the plan you develop should contain your best estimate of the methods you plan to use to integrate the data and identify relationships among watershed processes and problems. Integrating data refers to the process of incorporating the analysis of the physical, biological, and chemical conditions in the watershed into a single useful estimate of the potential for adverse effects on the watershed processes and features of interest. This topic is discussed in more detail in Chapter 6.

The integrated assessment evaluates the likelihood that a potentially harmful event has occurred or will occur. Comparing data of disparate types can be challenging. The difficulty of data integration is that the data exist in a variety of forms that do not lend themselves to comparison. Data on water quality might be reflected in units of parts per billion. Data on riparian vegetation could be expressed in terms of percent canopy cover or area covered by invasive species. Data related to stream morphology might be expressed as particle sizes (mm), percent fines, or percent change in pool volume. Information on land use might be expressed as acres of land use “x”. All of these watershed characteristics are important to the overall assessment, yet the basis for quantitatively comparing them is difficult because you are, in effect, comparing apples and oranges. An unfortunate consequence is that many watershed assessments do not include an information integration step.

The data synthesis phase of the watershed assessment allows you to evaluate the nature of the relationships you hypothesized in the conceptual model. For example, you might have speculated that high turbidity was responsible for a decline in the population of a valued aquatic organism. However, in synthesizing all the data, you might learn that in fact, depleted food supply associated with changes in riparian cover is a more important factor. Your initial speculation might have been inaccurate. But you have identified those factor(s) that appear to be most important for protecting or restoring the valued processes and resources in your watershed. This prioritization is the real power of the data synthesis/integration step - it can serve as a guide for action.

At present, there is not one single method of information integration that is widely used or accepted. A variety of methods have been used; each has its strengths and weakness. Different methods are appropriate for different situations. Chapter 6 focuses on these methods. The following list summarizes a few of the methods used for information integration and analysis

**2.3.3.1 Models for Data Integration**

- Team Mental Integration: Weighing the Evidence

Team Mental Integration is really nothing more than using best professional judgment to analyzing and synthesizing the data. Pulling from the knowledge and experience of the assessment team and appropriate experts, a systematic weighing of the data and information collected can help link the impacts on the watershed to potential causes.

- The Relative Risk Model

The Relative Risk Model (RRM) methodology assigns numbers or ranks to stressors identified in the conceptual model so that the potential effects of a variety of chemical, physical, and biological factors can be compared to each other. This method can be applied to assessments with only limited amounts of data, as well as those with significant amounts of data.

- Knowledge-Base Models

The Ecosystem Management Decision Support model (EMDS) is one knowledge-based model that can be used to integrate and analyze data. The model evaluates the “truth” of an assertion about a place, such as “changed land uses impact aquatic ecosystems.” A knowledge base provided by the user guides the evaluation. The knowledge base shows relationships among the parts of the system under study. A variety of environmental conditions can be evaluated with this model; all are integrated into a single analysis. Maps are then generated that reflect ranking of areas by watershed or process conditions.

- The SCREAM Model (Southern California Wetlands Recovery Project)

The Southern California Riparian Ecosystem Assessment Method (SCREAM) is a GIS-based tool to assess the ecological condition and stressors affecting riparian habitat at a landscape scale. In the SCREAM model, existing or new GIS data layers are compiled and organized, and the information contained in those layers are used to calculate hydrologic, biogeochemical, and habitat condition scores. The developers of the model, the Southern California Coastal Water Research Project or SCCWRP, envision that the SCREAM tool will be used as part of a comprehensive assessment program to evaluate the condition of and stressors affecting wetlands and riparian ecosystems in southern California.

Although you can probably say for sure which approach you will eventually use, it is wise in the planning stage to review the various options and tentatively identify which one is most suitable to your level of expertise and the amount of data you plan to collect.

In conclusion, the analysis or assessment plan should outline the key steps in the assessment and how they will be carried out. As you proceed with the assessment, you will likely modify the plan as you gain new knowledge about the watershed or recognize things you might have initially overlooked. An analysis plan is similar to a business plan or a work plan for a project in that it facilitates carrying out the assessment in a more systematic fashion.

**Actions 2.3**
- *Conduct initial scoping for focus of assessment*
- *Develop a conceptual model*
- *Plan collection and analysis of data*
- *Describe the spatial and temporal scales of the data*
- *Plan synthesis and integration of data to describe watershed condition*

## 2.4 Important Issues in Conducting a Watershed Assessment

This section tells you about issues such as uncertainty and data gaps that are important to cover in your assessment. Just as important as what is known about a watershed is what is not known.

### 2.4.1 Uncertainty

The term “uncertainty” has a variety of uses in everyday language, in social and natural sciences, and in statistics. The dictionary defines “uncertainty” as literally a lack of certainty about something. There is also a statistical meaning to the term that refers to the probability of an outcome occurring, for which the variation in possible values might be known and specific statistical tools can be used to measure the uncertainty. One statistics text considers “uncertainty to be synonymous with diversity” (Zar 1984). This example presents one way to think about uncertainty: Let’s say that there is a high probability of occurrence of salmon spawning in gravels between one and three inches in diameter that are deeper than 6 inches below the water’s surface and a low occurrence of spawning anywhere else. The diversity of places that salmon spawned would be low and the uncertainty about where salmon spawn would also be low.

There is often a great deal of uncertainty associated with the measurement and analysis of natural conditions. Some of this uncertainty is associated with the measurement and analytical approaches themselves, because we don’t know how to perfectly sample or represent complex systems. Some uncertainty comes from incomplete measurements of the systems due to inadequate resource investment, for example, or inaccessibility of a place. Generally, most science and knowledge development aims to reduce uncertainty (Dawes, 1988) and increase our ability to predict things around us, for which there is a known or unknown probability.

### 2.4.2 Data Gaps

A critical part of any assessment is recording gaps in data or knowledge that become obvious when gathering and analyzing watershed information. These gaps may be large enough to make the assessment insufficient for certain kinds of decision making. They may also form the foundation of future monitoring and data collection activities that will allow for more comprehensive condition assessments. One approach to this issue, suggested by Bingham (1998), is to inventory and collect existing data and, based on these data and on watershed management goals, develop critical questions before continuing the planning process (as described in Section 2.2 on "Formulating Questions"). These questions will determine the amount and type of data that is needed to continue.

#### 2.4.2.1 Data vs. Knowledge

Data refers to "facts or pieces of information" (Spellman & Drinan 2001), while knowledge is the use of that information to form a mental picture of a process or phenomenon. Usually monitoring programs collect data, which then must be analyzed and assembled in some way to provide knowledge about a place or process.

#### 2.4.2.2 What is a Complete Data Set?

A "complete data set" may be defined as "sufficient data to answer the assessment questions". However, most investigators may not have sufficient data to adequately address assessment questions. They may also not have investigated the question of sufficiency (how much data is needed) appropriately to actually answer the assessment questions. This is particularly true for water quality data. Although quality assurance is required for data collected by state-funded projects, there is no requirement to calculate the sampling intensity (number of samples and frequency of sampling) needed to determine 1) the actual value of a measured constituent, 2) differences between or among mean values, and 3) trends in values over time. The approaches to calculating how much data is needed for an analysis are available in statistical texts (e.g., Zar 1984) and summarized in this Manual and should be understandable to most assessors with professional scientific degrees.

> "*Where is the wisdom*
> *We have lost in knowledge?*
> *Where is the knowledge*
> *We have lost in information?*"
> ~T.S. Eliot
>
> "*Where is the information*
> *We have lost in data??*"
> ~Anonymous

For parts of the watershed assessment not dependent on comparison of measures of watershed condition, there are few standards for determining data completeness. The approach to determining adequacy of the available data should consist of first identifying the questions, then determining the data that are needed to answer the questions, and finally comparing the available data to the list of data needed. Deciding whether or not there is a complete data set then becomes a job for professional judgment.

#### 2.4.2.3 When do You Know Enough?

Watershed assessment is a continuous process, reflecting the changing nature of the subject. The minimum information needed to answer the assessment questions may turn out to be a fuzzy concept, based on the people involved and the complexity of the questions. For example, resolving a question about the immediate and cumulative impacts of new urban development in a sub-watershed might revolve around the timeframe for the question, the particular natural processes affected, and the likelihood that general plan and specific plan amendments that could modify the actual extent and layout of the development will occur in the timeframe of the question. An example of a data gap in this case could be the actual developed area that will result and a knowledge gap could be the linkage between the modification of the sub-watershed and the response of a particular natural process (e.g., seasonal drying-out of the streambed). Whether or not you know enough may be a research question. Detailing the steps between developing critical assessment questions, collecting relevant data, and making linkages between the questions and the data is the job of the assessment planning team.

#### 2.4.2.4 Prepare a List of Data and Knowledge Gaps

A primary product in your assessment that should result from this section of the Manual is a list of data and knowledge gaps. This list should include the nature of the gap, how and why it was identified as a gap, what would be required to fill the gap, and who should fill it. This product tells you and future assessment users how complete the data set and knowledge base were for the analyses performed and judgments made. It also lays out what is needed in order for future assessment to be more thorough. If this task is carried out thoroughly, it should lead directly to funding proposals and program development for monitoring and research into watershed condition and processes.

*Examples of data gaps:*
a) Flow data available for 50% of major tributaries
b) Water quality data available for1970 to 1990; no recent data is available
c) Plant community map does not show actual condition or land use
d) Cross-section survey data utilized in hydraulic model collected in 1940 instead of in 2004

*Examples of how a data gap is identified:*
a) To run a hydrologic or hydraulic model, flow data are needed for all major tributaries for water years representing a range of flows for a minimum of 10 years.
b) Watershed development has occurred primarily since 1990. Long-time watershed observers and experts consider the current condition relatively deteriorated.
c) Vegetation maps show the plant community type, but not the growth stage, canopy closure, human extraction activities, or fragmentation.
e) Hydraulic models rely on a definition of channel shape characterized by cross-section or topographic data, and the channel may have changed significantly in the past 60 years since the survey data were collected.

*Examples of how a data gap should be filled:*
a) Establish flow gauging stations at the mouth of the major tributaries in cooperation with regional expert (university, USGS, DWR, water district).
b) Develop and implement a water-quality monitoring program using a combination of professional and volunteer monitors.
c) Take the vegetation map and add attributes for land condition and use based on local knowledge, recent aerial photos, and recorded extraction activity (e.g., timber harvest plan) relying on GIS consultant or staff.
d) Conduct field-work to resurvey channel cross-section or topographic data.

#### 2.4.2.5 Using Data Gap Information to Inform Future Monitoring

An explicit link should be made between the watershed assessment process and the development or maintenance of a monitoring program. This can be done by describing data and knowledge gaps and proposing resolution for the gaps. Thus new data collection fills data gaps and develops knowledge about processes. For example, a monitoring program may intensify its existing sampling and increase the number of sample sites in order to meet data needs identified in the knowledge gaps part of the assessment. Or additional processes may be investigated to aid in developing an understanding of how activities in a watershed affect natural processes and other beneficial uses.

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**SUMMARY**

DEVELOP your watershed assessment to:

- Answer fundamental questions—let the problem drive the assessment
- Address the cause and not the just the symptoms of your watershed's problems
- Understand **why** the current watershed condition seems to be the way it is
- Interpret the physical, biological, and social interconnections within the watershed
- Be useful for later decisions and actions

CLARIFY the:

- Purpose of the assessment—Who wants it and why? Who will use it?
- Structure of who will be involved and what their roles will be
- Decision making—Who are the decision-makers? How are decisions made?
- Recording of the process—Who, how, when, where?
- Best options that will meet your needs
- Reasonable expectations of the assessment product
- Scope of the assessment

FOCUS on:

- Your most critical or key issues, so the product is useful and not too general
- Effects and processes occurring within your watershed boundaries
- Using consensus effectively in your partnership group
- Keeping costs under control and meeting timelines
- Working with the public through two-way communications
- Satisfying and helping the ultimate users of the assessment

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**Assessment Planning Check List**

| | |
|---|---|
| **Organize the Assessment Team and Community Input** | |
| 1) Assemble assessment team and committees | |
| 2) Develop contracts, if necessary, with outside consultants | |
| 3) Track itemized costs and schedule | |
| 4) Involve the community | |
| 5) Record the planning and implementation process | |
| | |
| **Define Purpose and Scope and Plan the assessment** | |
| 6) Formulate questions about your watershed | |
| 7) Describe the purpose of the assessment | |
| 8) Identify the audience and users of the assessment | |
| 9) Describe the uses of the assessment | |
| | |
| **Basic Watershed Assessment Process** | |
| 10) Conduct initial scoping for focus of assessment | |
| 11) Develop a conceptual model | |
| 12) Plan collection and analysis of data | |
| 13) Describe the spatial and temporal scales of the data | |
| 14) Plan synthesis and integration of data to describe watershed condition | |
| | |
| **Important Issues in Conducting a Watershed Assessment** | |
| 15) Identify sources of uncertainty | |
| 16) Provide estimate of uncertainty and ways to reduce uncertainty | |
| 17) Develop list of data and knowledge gaps | |
| | |

# 3 Watershed Basics

This chapter provides an overview of the main natural and social science disciplines and the main types of issues that come up during a watershed assessment. It discusses the watershed as a whole, as well as its component parts. Just as watersheds are naturally integrated, watershed assessments are interdisciplinary in nature. This means that components analyzed separately need to come together through integration and synthesis, as described in a later chapter.

Chapter Outline



## 3.1 Geography

Geography—the distribution of plant, animal, and human communities across a watershed—is integral to landscape and watershed assessment. Geography also encompasses the relationships among a landscape's processes (e.g., fire and human development) and features (e.g., vegetation types and dams). Underlying processes involving geological formations, hydrologic flows, and ecological transformation result in the presence of particular features, such as soil and plant types. Changes in the processes result in changes in the distributions of these features.

Geographic investigations show that people tend to aggregate around certain features of their environment. For example, many towns have grown up around the intersections of roads, year-round waterways, coastal bays, and fertile agricultural areas. At these locations, people engage in various types of social and economic interactions that may be dependent on or independent of their surroundings. These interactions are the subject of human geography.

A common tool in geography is a geographic information system (GIS), which can be available as software that plots the distribution of human and natural features and processes across a place. GIS maps show how different features (e.g., vegetation types, road alignments, general plan zones) are arrayed within a watershed. GIS can also reveal important clues as to why a particular effect is occurring—such as why one sub-watershed has more erosion than others. In the case of erosion, slope steepness, precipitation, soil types and other watershed features could indicate areas where erosion is naturally high, or high due to human activity. These clues, combined with improved management of human activities in the watershed and monitoring, can lead to improved findings by future watershed assessors.

### 3.1.1 Cumulative Watershed Effects

Many watersheds experience multiple impacts from current and historical natural and human processes. All of these processes combined are called "cumulative watershed effects" (CWE). When planning land-use activities, private parties and some agencies are required to assess the cumulative effects of their proposed actions and the actions of others in the past, present, and anticipated future on the natural functioning of watersheds.

A watershed assessment must consider the cumulative watershed effects on the watershed processes of interest. Although each individual impact may be insignificant with respect to the entire watershed, their cumulative effects may be dire. For example, changing runoff processes in a small fraction of the watershed (perhaps by converting a stand of trees to an agricultural field) or even adding a small quantity of a pollutant to a stream will not result in any detectable change at some point well downstream. However, changing many runoff processes or adding a small quantity of the pollutant at many places along the stream will produce a detectable change downstream.

## 3.2 Hydrology

Understanding the general interactions between water and the landscape is fundamental to your watershed assessment. Hydrology is the study of the occurrence and movement of water over and under the land surface. In watershed assessments, the basic hydrologic concerns are flow (volume of water per unit of time), timing (when this flow occurs), storage (volume of water in groundwater, reservoirs, lakes, or snowpack at a particular time), and quality (what's in the water besides just water). The hydrologic cycle and the water balance (an abbreviated accounting of the hydrologic cycle) are useful frameworks for thinking about how water moves through your watershed. The hydrologic cycle is a conceptual description of the ways in which water moves around the world. Water is generally moving in the hydrologic cycle, although some of it may be in temporary storage for a wide range of time periods.

*The Hydrologic Cycle*

Starting with water in the atmosphere, some of the water precipitates as snow or rain. Once on the ground or other surface, such as a leaf, precipitation in the form of snow will be stored until enough energy is available to melt the snow. The meltwater will then behave similarly to rain. Most precipitation will land on vegetation or other elevated surfaces before reaching the soil surface. Most of this "intercepted" water will drip or flow to the soil, but a small portion will be evaporated back into the atmosphere.

Water that reaches the ground surface will be absorbed, stored in small depressions, or flow downslope over the surface. The absorbed water that has "infiltrated" into the soil becomes "soil moisture". This soil moisture may remain in place, flow downslope toward a stream, or "percolate" vertically to become "groundwater". Some of the water temporarily stored in the soil may evaporate from the soil surface or be taken up by plant roots and "transpire" from the plant's leaves.

Water can reach streams and lakes via "overland flow" across the surface (minutes to hours), downslope flow through the upper layers of the soil (hours to weeks), and release from groundwater (weeks to centuries). Some water in streams may percolate into groundwater storage elsewhere along the stream channel and perhaps emerge again into the channel farther downstream. Groundwater and surface water (water in streams and lakes) are often regarded as completely distinct, but in most watersheds, a lot of water moves back and forth across the ground surface and streambeds. Some surface water will evaporate, but most of the water that has made it to a stream channel will eventually flow to an ocean (or a lake without an outlet, such as Mono Lake), where it will be available for evaporation, replenishing the atmospheric water where the cycle began.

The global hydrologic cycle can be fitted to your watershed as general concepts that describe the processes that affect the movement and storage of water through your particular watershed. When applied to a watershed, the hydrologic cycle is not a closed system, but has quantifiable inputs and outputs. These inputs and outputs, along with temporary storages, can be estimated in the simple accounting scheme of a water balance (section 3.2.1). Estimating the water balance of your watershed is a useful means of exploring its hydrology. Some of the basic components of the water balance (and hydrologic cycle) are discussed in sections 3.2.1 to 3.2.3.

In addition to describing natural hydrologic processes, your watershed assessment should consider how these processes have been altered by human activities and how the water, both in streams and underground, has been intentionally managed. Most land use alterations affect water's infiltration into the soil and evapotranspiration (evaporation from vegetation) in a small proportion of the watershed and thereby alter these components of the water balance a relatively small amount over the entire watershed. However, changing the land use of many small fractions of the watershed will eventually add up, and the cumulative effect of all those incremental effects can result in significant changes to the water balance. Engineering works, such as dams, canals, and networks of pumped wells, that allow deliberate management of water resources often change the water balance to a much greater extent than the indirect effects of land use change.

### 3.2.1 Overall Water Balance

Determining your watershed's overall water balance is useful for understanding its basic hydrology because the water balance describes the quantities of water affected by various processes in your watershed. Although a written water balance is instructive to a reader, the primary value of a water balance is to the analysts who carefully think about the hydrologic pathways and processes. There is no other thought process that yields an equivalent understanding of a watershed's hydrology. The conceptual description of the water balance is far more important than the estimated values you develop. You should expect the numerical values to be difficult to estimate and highly uncertain. Water balances are sometimes called "water budgets", although that term has the unintended implication of future prediction. A water balance or budget can be considered analogous to balancing one's checkbook—with deposits, withdrawals, and cash on hand being analogues to the key components of a water balance.

A general water balance equation starts as WATER IN = WATER OUT +/- CHANGE IN STORAGE. The basic challenge of the water balance is to fill in the details of what constitutes WATER IN, WATER OUT, and CHANGE IN STORAGE for your situation.

WATER IN is almost always just precipitation, but it could also include artificial imports of water from another watershed through canals or pipelines.

WATER OUT includes evaporative losses, streamflow, groundwater flow out of the basin, and artificial exports of water through canals or pipelines.

CHANGE IN STORAGE includes soil moisture, deeper groundwater, lakes, reservoirs, and water temporarily flowing in stream channels. The CHANGE IN STORAGE term is usually important over shorter time periods (days to months), but can often be considered negligible over a year or longer. However, you must consider whether storage is a quantitatively important term for the watershed and time period in which you are working.

An annual timeframe is perhaps most useful and easiest to work with. In most cases, change in storage over a year will be negligible, especially if you use the conventional "water year" of October 1 through September 30. In early autumn, before the rainy season has begun in California, streams tend to be at their lowest flow and soil moisture is at a minimum. So this October 1 start date begins the water year at a time of minimal hydrologic activity.

#### 3.2.1.1 Estimating a Water Balance

Water balances and many other hydrologic quantities are commonly expressed in terms of a depth of water. This is in order to control for watershed area. Hydrologic volumes (amount of water moved through waterway over a time period) are converted to depth by dividing volume by the surface area of the watershed. Flow rates vary over time, which also needs to be accounted for (see box below).

In most parts of California, the largest output of the water balance is evaporation. The term evapotranspiration (ET) is often used to describe the role of evaporation from vegetation. Good estimates of ET are difficult to develop, so in simple, conceptual water balances, ET is often the leftover quantity of water after accounting for changes in storage. For a typical, quick-and-dirty water balance calculation, estimate average precipitation over the watershed, assume changes in storage are negligible, subtract depth of streamflow out of the watershed, and the result will be ET.

Precipitation = Streamflow + ET +/- change in storage (assumed zero).
Using the streamflow number from the example in the box (rounded to 9 inches), a precipitation value of 30 inches, an assumed change in storage of 0, annual evapotranspiration would be 21 inches.

The value of the water balance exercise, even with all its inherent uncertainties, is that it provides a general idea of how much water comes into a watershed and where it goes, and it can indicate how precipitation input is transformed within the watershed. Obviously, with a more detailed water balance, these factors (e.g., fate of the water) can be estimated more precisely.

Good general reference books on hydrology for the non-hydrologist include Leopold (1974, 1993, 1997), Mount (1995), and Gordon, McMahon, and Finlayson (1992).

### 3.2.2 Surface Water

Many watershed assessments are conducted because of some perceived

**An example of converting average annual streamflow to depth**

1 cubic feet per second for 1 year =
1 $ft^3$ / s x 3600 s / hour x 24 hours / day x 365 days / year =
31,536,000 cubic feet per year.

A useful (and very common) unit for water volume is the acre-foot, which is the volume of water that would cover an acre of surface area one foot deep. An acre is 43,560 square feet, so an acre-foot is 43,560 cubic feet (1 cubic foot = 7.48 gallons).

To convert the volume of streamflow above to acre-feet, divide by 43,560:
31,536,000 cubic feet per year / 43,560 cubic feet per acre-foot =
724 acre-feet per year

Finally, to convert the volume of streamflow to depth of water over your watershed, divide by the area of the watershed:

If your watershed is 1,000 acres in area:
724 acre-feet per year / 1,000 acres =
0.72 feet per year or 8.7 inches per year

problem with surface water (streams and lakes)—there's not enough of it, there's too much at the wrong time, its availability has shifted seasonally, or it is polluted, for example. Surface water also supports aquatic life—a primary issue driving many watershed assessments. Availability of surface water for supplying municipal and industrial uses, irrigation, and hydroelectric facilities is a major social and economic concern throughout most of California. Human demands for surface water resources resulted in the investment of hundreds of billions of dollars in infrastructure to store, divert, transport, and treat water from the state's streams.

The aspects of surface water typically addressed in watershed assessments are volume, timing, and quality. In most cases, water volume is not reported as sheer volume only, but rather as volume over some period of time. In streams, water is flowing—we can picture some volume of water moving past a fixed point in some amount of time. However, even where water isn't obviously flowing, as in lakes and reservoirs, the water level (and corresponding volume) go up and down, so time must be considered. Similarly, water stored as snowpacks or in the soil changes with time. But time is most obviously involved in streamflow, both at a particular moment and in changes throughout a storm or a year. Concerns about watershed condition are often raised when someone notices that the timing of streamflow appears to have shifted compared to some baseline in the past—streams seem to rise more quickly after a particular amount of rainfall, or spring snowmelt runoff seems to occur a couple of weeks earlier than it did a decade ago.

**3.2.2.1 Streamflow Generation**

A basic understanding of how rainfall or snowmelt is transformed into streamflow is important in evaluating how human activities may alter the processes that generate streamflow. There are many possible pathways by which a raindrop can reach a stream or be returned to the atmosphere without contributing to streamflow. The most direct route into the stream is for the raindrop to fall directly into the stream channel. However, stream channels occupy a small proportion (usually less than 1%) of the overall area of most watersheds, so most of the total rainfall volume falls on land. Vegetation or other surfaces cover much of the land area, so some of the rainfall is "intercepted" on leaves or other material above the soil surface and may evaporate. When rainfall exceeds the capacity of intercepting surfaces to store water, the excess drips or flows to the soil surface. Rain that arrives at the soil surface may "infiltrate" (pass through the surface into the soil), be stored on top of the soil surface in small depressions, or begin to flow downhill over the soil surface—these alternatives also interact over time and space. For example, water stored in small depressions may later infiltrate, or water flowing over the surface may infiltrate into more porous soil somewhere downslope. Some of the water flowing over the surface will collect in small channels that in turn join larger channels and eventually feed the main streams. Some of the water in the soil will move downslope below the surface and later enter a surface channel.

Human activities can alter the physical processes that generate streamflow in a variety of ways—removing or adding intercepting surfaces, such as vegetation and leaf litter, changing the "infiltration capacity" of the soil (ability of soil to absorb water), changing the storage capacity of the soil, changing the transmission capacity of the soil (ability of the soil to allow water to move through it), changing the ability of vegetation to remove water from the soil and release it to the atmosphere, changing the density of small channels that collect surface flow, for example. Compacting soil is a common result of foot and vehicle traffic that reduces the ability of the soil to absorb, store, and transmit water. As less water enters the soil, more water runs off into channels, thereby increasing streamflow over shorter time intervals than would occur in the absence of compaction. Sealing soil with concrete, asphalt, or buildings can prevent any water from entering the soil and causes almost all the rain to flow quickly to a stream. The amount or proportion of impervious (watertight) surfaces in a watershed is a common indicator of the degree to which runoff-generating processes have been altered. A watershed assessment should consider both how intense (for example, reducing infiltration capacity by 50%) and how extensive (for example, changing 30% of the surface area of the watershed) a particular alteration might be. A single parking lot may direct 90% of the rainfall that falls on its surface into a small stream, but if the lot occupies only 0.1% of the watershed area, the net impact on streamflow at the gaging station is negligible.

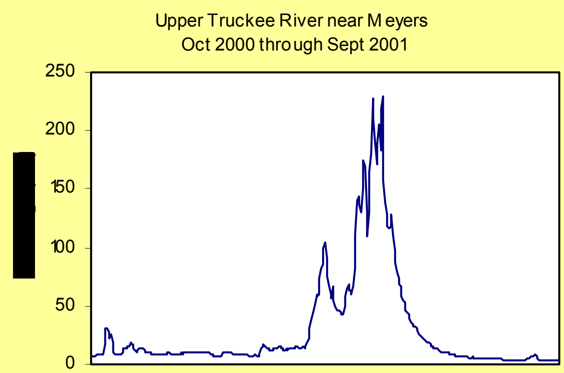
### 3.2.2.2 Streamflow Measurement

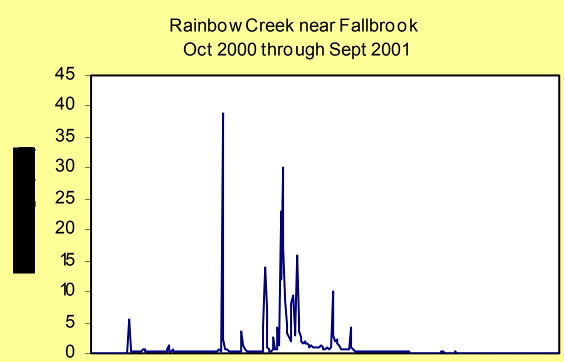
Streamflow is generally expressed as volume per unit of time, typically cubic feet per second. You may also see streamflow reported as cubic feet per day or acre-feet per year. Streamflow reporting must also include a particular time and geographical location. Streamflow changes from day to day (sometimes minute to minute), as well as up and down a stream channel. Knowing when and where streamflow is measured is critical to thinking about surface water.

Local water districts, hydroelectric utilities, the U.S. Geological Survey, and a few other entities measure streamflow at gaging stations, locations where the depth of water in a stream is measured and recorded at regular intervals (15 minutes is common) and where occasional manual measurements of water velocity and the area of the cross-section of the channel through which water is flowing have been made that allow a relationship to be developed between the depth and the flow. This relationship, known as a rating curve, allows calculation of the streamflow from the records of depth. A gaging station may cost tens of thousands of dollars to install and thousands of dollars per year to operate. These high costs explain the paucity of long-term streamflow records. USGS maintains the most accessible streamflow records (e.g., http://water.usgs.gov). Other streamflow records are available from the California Department of Water Resources (http://cdec.water.ca.gov/stainfo.html).

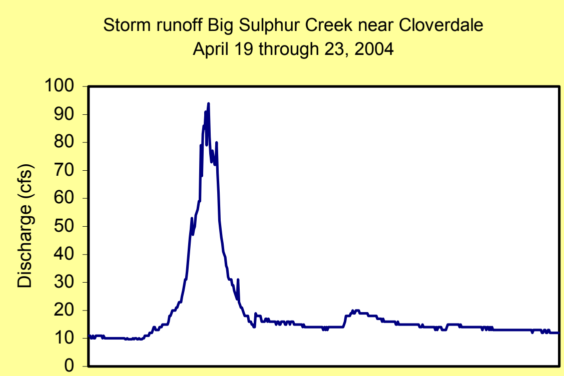
In assessing streamflow data, important

*Annual hydrographs*




*Storm hydrograph*



characteristics to consider include long-term averages, extremes of high and low flows, seasonal patterns, trends over time, and sudden changes (e.g., construction and operation of a diversion). A useful means of examining streamflow data to discern some of the above characteristics is plotting a stream hydrograph. Hydrographs plot streamflow over time. The most common type is an annual hydrograph (figures above) that depicts changes in flow over the course of a year. A storm hydrograph (figure above) that shows the rise and fall of a stream over a few days may be useful in assessing how your watershed responds to a rainfall input.

### 3.2.3 Subsurface Water

Water below the surface of the ground exists within the pore space (holes or voids) between or within the solid materials of the soil or rock. Subsurface water is commonly separated into one of two categories: soil moisture or groundwater. Soil moisture is found relatively close to the surface (generally within 10 feet, although there can be wide variation depending on soil characteristics and geology) and is usually in an unsaturated condition (the pores contain both air and water). In contrast, groundwater is found at greater depth and under saturated conditions (the pores contain only water or an insignificant amount of air). You may also see the terms unsaturated zone or vadose zone vs. saturated zone or phreatic zone.

#### 3.2.3.1 Soil Moisture

Soil moisture, the water in the pore space or openings between and within the solid parts of the soil, is a relatively active part of the hydrologic cycle. The water content can vary several-fold over a few hours to a few days. Precipitation that enters the soil can rapidly fill the available pore space. Irrigation adds additional water in agricultural fields. Soil moisture is withdrawn by plant roots and subsequently transpired. Water moves through the soil vertically and downslope (roughly parallel to the soil surface) and changes the localized water content en route.

Infiltration (the passage of water through the soil surface) is an important factor determining how watersheds transform rainfall into streamflow and is readily altered by human activities. The maximum rate at which water can enter the soil, known as the infiltration capacity, depends on both the physical properties of the soil and how much water is already in the soil. If the rate of rainfall is less than the infiltration capacity, then all the rainfall will be absorbed. If the rate of rainfall is greater than the infiltration capacity, then infiltration occurs at the capacity rate. The additional rainfall ponds on the soil surface and begins to flow downslope toward a stream channel. In general, the water flowing over the soil surface enters streams much faster than water flowing through the soil. Through the process of infiltration, soils greatly affect the volume of streamflow resulting from a storm, the timing of this streamflow, and the maximum rate of streamflow. In other words, soils can strongly influence the size and shape of the storm hydrograph. Infiltration can be easily changed (almost always decreased) by human activities, including compaction of soils by vehicles or livestock, removal of vegetation and leaf litter, plowing, burning, and covering the soil with an impervious surface such as concrete.

Water movement through the soil depends on the structure of the openings within the soil and the moisture content. The open space within the soil, which often accounts for 40% to 50% of the total soil volume, consists of small spaces between individual particles of soil; larger voids between clumps or aggregates of soil; tubes carved by worms, insects, and rodents; and holes left after roots have decayed. The size, shape, and degree to which these pores of various types are connected are primary influences on water movement within the soil. The rate of water flow generally decreases as the size of the pores decreases. Air within the pores restricts the flow of water, so as air is displaced by incoming water, the rate of water flow generally increases. Some soils with high moisture contents and large, well-connected pores or channels can transmit water downslope to a stream within a few hours after infiltration in a process called subsurface storm flow. Most water movement through soils occurs at a slower pace and contributes to the underlying groundwater or to a stream over a period of days to months.

#### 3.2.3.2 Groundwater and Aquifers

The term groundwater usually refers to water within the saturated zone of the subsurface where water fills all the pore space. A less formal use of the word sometimes refers to all water below the soil surface. This Manual uses the standard hydrological definition of groundwater, which is water in the saturated zone. Groundwater accounts for about 30% of California's water supply in an average year and about 40% in dry years (Department of Water Resources 2003). Even though groundwater is a slow-moving and slowly changing part of the hydrologic cycle, the role of groundwater in your watershed's hydrology and water resources management should be evaluated in your watershed assessment. Recommended introductions to groundwater hydrology include Heath (1983) and Department of Water Resources (2003).

Groundwater exists in geologic formations called aquifers that contain and transmit "significant" quantities of water. Use of the word "significant" is vague, but implies that aquifers can be used for water supply. An aquifer can be composed of hard rock or of unconsolidated materials, such as sand and gravel. Aquifers vary widely in the total amount of pore space filled with water and the degree of connectivity that allows water to flow between pores. Aquifers can be unconfined, where the water level is free to rise and fall with changes in water volume in the pore space. The top of water in the saturated zone is called a water table, and unconfined aquifers are also known as water-table aquifers. Other aquifers are confined by a relatively impervious layer that overlays the more permeable aquifer. Water in confined aquifers tends to be under pressure as a result of the confining layer acting as a cap, and the water will rise in a well that penetrates the confining layer.

Groundwater in unconfined aquifers flows from areas of higher elevation to areas of lower elevations or in the downslope direction of a sloping water table. In confined aquifers, the pressure is combined with the elevation to determine the direction and driving force of groundwater movement. Groundwater flow rates are also controlled by the aquifer's cross-sectional area permeability (capability to transmit water).

A water balance for a groundwater basin or an aquifer can aid in understanding the inflows and outflows of groundwater and the resulting changes in storage in a manner similar to a water balance for a watershed (section 3.2.1).

Groundwater storage remains fairly constant from decade to decade in relatively undisturbed watersheds that have little or no groundwater pumping. In smaller watersheds, groundwater storage may vary between seasons and between wet years and dry years. The subsurface water balance is readily affected by human activities—both indirectly and through active use and management of groundwater resources. Recharge of groundwater can be increased by excessive irrigation, filling of reservoirs, and artificial recharge with infiltration basins and injection wells. Groundwater recharge can be reduced by limiting infiltration, covering the soil with impervious surfaces, draining wetlands and lakes, reducing leaks from canals and pipes, and channelizing streams. The big variable under the control of people is groundwater extraction through wells. The number or density of wells, the depth of the wells, and the pumping rate of the individual wells all combine to control the volume of water extracted over a certain period of time. The condition of declining storage called "groundwater overdraft" occurs when more water is withdrawn by pumping than is recharged over a period of years. Groundwater overdraft has become common throughout most parts of California (Department of Water Resources 2003). As overdraft persists, pumping costs increase, wells need to be deepened or replaced, the land surface may subside and the aquifer's storage capacity may permanently decline, remaining groundwater may become more brackish, and, in coastal areas, seawater may flow inland.

Surface water and subsurface water are thoroughly interconnected and exchange water back and forth across the ground surface in different parts of the watershed. Much of the interaction occurs within and adjacent to stream channels. At different locations along a channel and during portions of the year, water infiltrates through the streambed to recharge groundwater. At other locations and during other times of the year, groundwater may flow into the stream. Interchange of water between a stream and its bed can influence the temperature, dissolved oxygen content, and chemical composition of the stream. Interactions of groundwater and surface water can be difficult to observe and measure; the effects of these interactions on water supply and water quality need to be understood (U.S. Geological Survey 1998).

## 3.3 Climate

Regional climate exerts a controlling influence on a watershed's hydrology by determining water and energy inputs. Precipitation provides the raw material that becomes streamflow or deep groundwater, or that is returned to the atmosphere through evapotranspiration. Energy (ultimately from sunlight) is needed to evaporate water and melt snow. Climate is usually considered the "average" weather of a region, including the variations between seasons and years and the known extremes. In conducting a watershed assessment, the most important aspects of climate to consider are precipitation, solar radiation, air temperature, relative humidity, and wind.

### 3.3.1 Precipitation

Precipitation is the water entering your watershed from the atmosphere as rain, snow, hail, and fog drip (cloud droplets captured by trees in sufficient quantity to form drops that reach the ground—it can be significant under coastal forests). Precipitation characteristics of greatest interest in assessing a watershed include annual average precipitation, variability from year to year, seasonal distribution, type (rain vs. snow), frequency of rainfall of different intensities, storm totals, and storm durations. Estimates of these characteristics can reveal, for example, how much water is available to the watershed in an average year and how that amount can vary, or whether multi-day, low-intensity storms are more typical than short-duration, high-intensity cloudbursts.

Precipitation over a watershed can be surprisingly variable, especially if the watershed covers an elevation range of more than a few hundred feet and is larger than a few square miles. Precipitation amounts from a single storm per unit area (e.g., acre) can range by two to ten-fold across a watershed. Variability of precipitation from a single storm (ignoring topographic influences) can be expected to be least in northwestern California, where most storms are widespread and can last several hours or days, and greatest in the southeastern part of the state, where highly localized thunderstorms may pass through in a few minutes. Several rain gages spread around a watershed would be desirable to assess the variability and obtain a reasonable estimate of watershed-wide precipitation. However, precipitation is routinely measured at only a few hundred locations throughout the entire state, so precipitation information for your watershed is likely to be sparse and may need to be inferred from neighboring areas.

### 3.3.2 Energy Exchange

Energy from sunlight is the driving force of the hydrologic cycle. Energy is absorbed, moved, released, and changed into different forms as water moves through the hydrologic cycle. “Energy exchange” is the common term for the various physical mechanisms involved in hydrologic processes such as evaporation and snowmelt. Most of these processes occur on water surfaces in contact with the atmosphere. Therefore, energy exchange is intimately linked to atmospheric processes and properties such as radiation, air temperature, humidity, wind, and precipitation. The physics of energy exchange are well beyond the scope of this brief introduction to hydrology, but the basics of energy on the earth’s surface can be found in any text on physical geography or hydrology. Two examples of the importance of energy exchange in the hydrologic cycle will be mentioned—evaporation and snowmelt.

Evaporation from open water or a wet surface or from within leaves of a plant (evapotranspiration) doesn’t just happen. Sufficient energy must be available and the air immediately above the surface must not be saturated (filled to capacity) with water vapor. Water loss to the atmosphere from both wet surfaces and plants (often lumped together in the term evapotranspiration) is greatest when solar radiation, air temperature, and wind speed are all high, and relative humidity is low. The amount of water loss (often termed actual evapotranspiration) is controlled by both the energy and atmospheric conditions (which can be used to calculate the potential evapotranspiration) and the amount of water available at the surface and in the soil that can be taken up by plant roots and moved to the leaves.

Snowmelt is another major result of energy exchange in the hydrologic cycle. Snow melts primarily in response to inputs of solar radiation. Properties of the snow surface, such as the size and shape of the snow grains and the presence of impurities (e.g., dust, pine needles), and the angle of the sun determine how much solar radiation is absorbed and how much is reflected. Snow melts slowly (if at all) in the winter when the surface is composed of new snow grains and the sun angle is low. Snow melts relatively rapidly in the spring when the surface is composed of large grains and debris and the sun angle is high. Another complicating factor is the conversion of sunlight (which has a relatively short wavelength) into longwave radiation. If sunlight is absorbed by a rock or tree, that object warms up and emits longwave radiation, which is completely absorbed by snow. An example of why this conversion can be important in a watershed assessment is the effect of forest harvesting. Trees shade the snowpack from sunlight. If half the trees are removed, more sunlight reaches both the snowpack surface and the trunks of the uncut trees, which in turn emit longwave radiation to the snow. The combined effect of these changes in energy exchange is a marked increase in the rate of snowmelt. Relatively little snowmelt occurs directly in response to air temperature. The principal exception is when the air is saturated with water vapor and wind speeds are high—typically during warm storms when rain is falling on the snowpack

### 3.3.3 Climate Cycles

People have long been interested in forecasting the weather and have looked for repeating patterns or cycles in weather behavior that might offer clues about future weather. In early childhood, we recognize seasonal cycles of day-length, temperature, and precipitation. Other cycles of climate are not so easy to discern. In the late nineteenth century, geologists in Europe began to find signs of ice ages that indicated great swings of climate causing the growth and decline of continental-scale ice sheets. A few decades later, Milutin Milankovitch of Serbia calculated cyclic variations in the amount of solar radiation reaching the earth based on regular variations in earth-sun geometry. With rough intervals of 20,000, 40,000, and 100,000 years, these so-called Milankovitch cycles were later correlated with dozens of glacial advances. Over the past few decades, scientists around the world have searched for evidence of past climates in a variety of sources: sediment deposits in lakes and oceans, pollen, fossilized plankton shells, coral reefs, dust layers, tree rings, and, most successfully, in deep cores from ice sheets in Greenland and Antarctica. These various indicators of global climate, primarily air and ocean temperatures, have supported the regularity of the Milankovitch cycles, but have also suggested a complex array of feedback mechanisms involving carbon dioxide, reflection of sunlight by ice cover, sea level, biological processes, and other factors. The current consensus among climatologists seems to be that the slight changes in sunlight received at the earth's surface are strongly amplified by the other factors to trigger the cyclic ebb and flow of the ice sheets.

Besides the vast time scales of the ice ages, other apparently cyclical variations of climate have been observed within the average human life span. As the historical climate record incrementally increases, climatologists have greater opportunity to seek patterns within the record. One of the large-scale climate patterns that is widely discussed is the El Niño/Southern Oscillation (ENSO) phenomenon. Every few years, the ocean temperatures off the coast of Peru and sometimes thousands of miles to the west become unusually warm, generally beginning in December and persisting until June. This change in ocean temperature is associated with a calming of the trade winds near Indonesia and abnormally high air pressure over the western tropical Pacific Ocean and abnormally low air pressure over the eastern tropical Pacific (the Southern Oscillation part of the name). These changes in the ocean and atmospheric conditions alter the weather in regions far removed from the tropical Pacific, including reducing the number of hurricanes over the Atlantic and usually increasing precipitation in Southern California. During most El Niño winters, the jet stream and storms track across the southwestern part of the United States instead of across their more typical northern location. Because there are so many interacting factors that contribute to weather, El Niño conditions are not a sure thing for increased rainfall in California. Some El Niño years, such as 1965 and 1991, have been droughts. Conditions lumped under the name La Niña represent the opposite extreme of atmospheric and ocean circulation within the ENSO cycle.

Another large-scale ocean-atmosphere pattern recognized in the past few years is the Pacific Decadal Oscillation (PDO) that affects the northern part of the Pacific Ocean (Mantua et al. 1997). This cycle consists of two phases, apparently persisting for 20 to 30 years each. During a "positive" phase, the ocean along the west coast of North America is warm, and sea surface temperatures in the central north Pacific are cool. The relative temperature differences are opposite in the "negative" phase. The north Pacific is currently in a negative phase. The preceding positive phase lasted from 1977 to 1997. Precipitation tends to be above-average during the negative phase in Washington and Oregon, with a less-distinct signal in Northern California. An analysis of a broad range of Pacific Northwest climate records extending over more than a century identified the ENSO and PDO cycles at five- to seven- and 20- to 25-year periods, as well as other apparent oscillations at two to three years and 50 to 75 years (Ware

1995). Still other weather patterns have been associated with 11-year sunspot cycles and 18-year lunar cycles.

### 3.3.4 Climate Change

Climate was widely regarded throughout most of the twentieth century as stable, with only minor variations around an average condition. Many climatologists held a philosophical belief that climate was self-regulating and, if perturbed (for example, by a huge cloud of volcanic ash), would "naturally" return to its average state. However, as weather records lengthened and indicators of past climates emerged from sediment and ice cores, coral reefs, and other sources, climatologists found signs of distinct trends, as well as signs of abrupt changes, suggesting that climate is not nearly as stable as was broadly accepted not long ago. In addition to the gradual swings between ice ages and interglacial warm periods over tens of thousands of years described above in section 3.3.3, recent theories suggest that average air temperatures have changed by several degrees over periods of a few decades following sudden shifts in ocean circulation (Committee on Abrupt Climate Change 2002).

Suggestions that human activities could alter the climate have been made for at least a century, but were largely ignored until the past two decades. In the late 1800s, Svante Arrhenius of Sweden calculated that the burning of coal could eventually increase carbon dioxide in the atmosphere and that doubling the concentration of carbon dioxide could raise global temperatures by 5-6$^{o}$C. In 1961, Mikhail Budyko, the famed Russian climatologist, published a warning that humans were warming the atmosphere through burning fossil fuels and other energy use. In 1971, Budyko provoked his colleagues by proclaiming that human-induced global warming was unavoidable. Two decades passed before these warnings were generally accepted in the climatology community. During the 1990s, physical evidence and modeling results rapidly accumulated for a strong case that human activities were changing the climate (Intergovernmental Panel on Climate Change 2001).

A variety of human activities that are extensive in nature, such as conversion of tropical forests, conversion of lands to desert, and production of dust and soot, are believed to affect atmospheric processes and feedback mechanisms. However, the generation of carbon dioxide from the burning of fossil fuels is the greatest and most immediate human influence on the atmosphere. Atmospheric measurements and calculations of carbon dioxide release from the quantity of oil, coal, and natural gas burned over the past century show a dramatic increase in carbon dioxide concentrations in the atmosphere over the past few decades.

Carbon dioxide, water vapor, methane, and a few other gases affect temperature in upper layers of the atmosphere by absorbing some of the longwave (infrared) radiation emitted by the earth (all objects emit radiation in these "long" wavelengths in proportion to their temperature). The gas molecules warm and re-emit longwave radiation in all directions, including back toward the earth's surface. The role of these gases in reducing the loss of longwave radiation, especially at night, was recognized 140 years ago by John Tyndall. Although these gases do not function in the same manner as the glass of a greenhouse (which traps hot air rather than radiation), the term "greenhouse gases" and "greenhouse effect" are now commonplace, even in scientific literature. Increasingly complex mathematical models of atmospheric processes have calculated temperature increases associated with increasing concentrations of greenhouse gases. Most current estimates of global average temperature rise associated with a doubling of carbon dioxide concentration relative to pre-industrial levels (280 parts per million) are in the range of 1.4° to 5.8°C (Intergovernmental Panel on Climate Change 2001). A recent modeling study using a fine-scale regional climate model suggests a temperature rise of 1.4° to 3.8°C in California for a doubling of carbon dioxide (Snyder et al. 2002).

Water supply agencies in California have been concerned about the potential effects of climate change on the state's water resources for almost two decades. Most agency and researcher attention has focused on changes to the snow hydrology of California's mountains. A recent synthesis of research results noted, "Higher temperatures will have several major effects: increase the ratio of rain to snow, delay the onset of the snow season, accelerate the rate of spring snowmelt, and shorten the overall snowfall season, leading to a more rapid and earlier seasonal runoff" (Kiparsky and Gleick 2003:9). Other expected consequences of climate change in California include increases in average annual precipitation, greater variability in precipitation, increased storm intensity, increased evapotranspiration, and changes in vegetation cover (Kiparsky and Gleick 2003). Evaluations of these and other possible hydrologic effects of climate change and how water agencies, communities, farmers, businesses, and natural systems will accommodate or respond to those effects should be included in a watershed assessment.

## 3.4 Flooding and Stormwater Runoff

Flooding is a natural attribute of rivers. Flooding is defined as flow that exceeds the capacity of the channel, i.e., when flow inundates the floodplain. A flood is a streamflow event where there is more water flowing in the stream than the channel can handle. Under these flood conditions, water spills over the streambanks onto the adjacent floodplain, which can be considered as part of the natural channel that is periodically used by the stream and that has been constructed by the stream over millennia. Floods represent the upper extreme of runoff generation and produce most of the sediment erosion, transport, and deposition within a watershed.

Stormwater runoff is the "excess" rainfall that exceeds the infiltration capacity and flows over the ground surface. It is the portion of runoff that causes the initial rise in a storm hydrograph and usually causes the peak flow in the receiving stream. In the urban context, stormwater runoff often contributes to flooding because the streets, parking lots, and storm drains generate far more (often 10 to 1,000 times more) surface runoff than would have occurred prior to development and paving. The collection and conveyance of stormwater runoff in efficient storm drains also delivers water to streams much faster than a natural channel would. Therefore, the lag between rainfall and runoff is greatly reduced, and the peak flow is usually increased. The creation of large impervious surfaces and storm drains in urban areas may generate flooding (overbank flows onto the floodplain) from much smaller storms than would have occurred in the absence of development.

### 3.4.1 Flooding Frequency

In a very broad sense, streamflow exceeds the capacity of a stream's channel and rises above its banks about every 1.5 to 2 years, on average. However, this frequency must not be considered as a consistent interval. It is better to think that streamflow will rise to the "bankfull stage" and inundate the floodplain whenever there is sufficient river flow. Overbank flow occurs every year on some rivers, and infrequently on other rivers. On average, flow rises to bankfull about 50-65 times in 100 years, or in any given year, there is a 50% to 65% chance that flow will equal or exceed bankfull capacity.

As floods get bigger, they occur less frequently. Accordingly, a magnitude-frequency relationship can be estimated on streams with long-term flow records, or more crudely estimated given flood data elsewhere in the general region. A flood of a particular magnitude is often described as a 10-year, 25-year, or 100-year event. The concept behind this type of description is that a flood of the given magnitude occurs once in the particular time period, on the average. However, the "on the average" part is often ignored, so we recommend thinking that a big flood (for example, a 100-year event) occurs 10 times in 1,000 years, or that there is a 1% chance that such an event could occur in any given year. But these ways to describe floods are merely statistical constructs. There is no physics (or physical hydrology) involved. The combination of conditions that generates large floods just doesn't happen very often. However, there is no physical reason why two floods of some very large and rare magnitude couldn't happen in the same year or three years apart or 200 years apart. All these statistical descriptions of flood magnitude and frequency involve an assumption of "stationarity"—that climate, landscape, channel, and measuring conditions won't change. However, that assumption is obviously flawed, particularly as time periods of analysis lengthen.

### 3.4.2 What Causes Flooding?

Beyond the usual magnitude-frequency characterization of floods, watershed assessments must also consider the physical mechanisms of flood generation—the hydrologic processes involved in producing an overbank flow event. In general, an unusually large amount of rainfall or unusually intense rainfall is required to produce a flood. But other factors can contribute to or influence flood magnitude and timing. For example, a previous storm may have left the soil saturated or a wildfire may have reduced the infiltration capacity. Human activities may also influence factors that cause or augment flooding. For example, deforesting an area minimizes transpiration, resulting in greater soil moisture. In turn, there is less available storage capacity in the soil to absorb rainfall, and more of the precipitation quickly enters a stream channel. Construction of forest roads compacts soil and drastically reduces infiltration, which, in turn, leads to greater and faster surface runoff.

In urban areas, much of the landscape is converted to impervious surfaces (e.g., streets, parking lots, and rooftops). Most of the resulting stormwater runoff is directed into storm sewers that empty into stream channels and deliver much greater quantities of water at much faster rates than occurred under natural conditions. Urban stream channels may also be confined by levees, bridges, construction, and debris in the channel. Reduction of the channel capacity forces water to rise and spill over the banks at lower flows, which the natural channel could have handled. Very often, the floodplain is occupied by houses and various structures that reduce flow capacity and further augment flood damage.

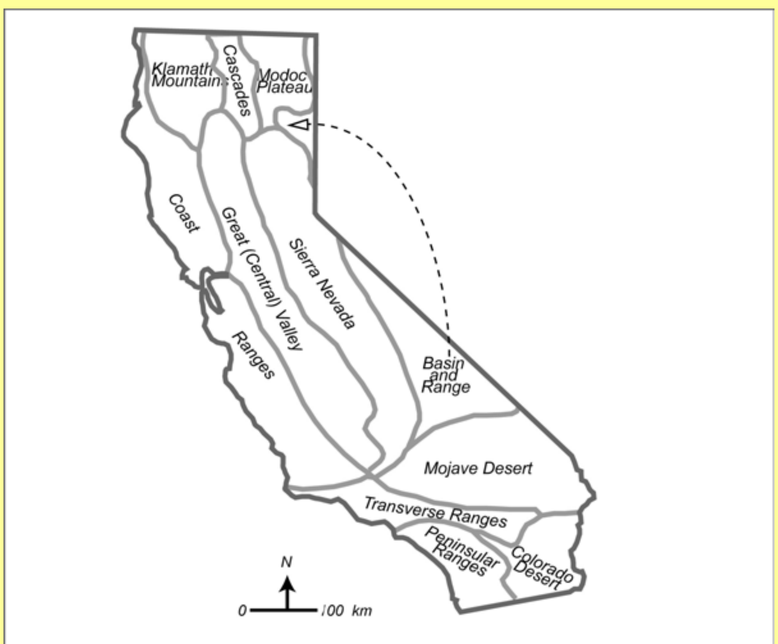
## 3.5 Geology, Soils and Sediment in Watersheds

California's watersheds span 11 geomorphic provinces—each with distinct geology, tectonic setting, topography, climate, soils, hydrology, vegetation, and land use history. These factors combine in complex ways, causing each watershed and each sub-watershed to be unique. This Manual describes approaches toward understanding physical processes and changes over time that alter sediment dynamics and linkages in California's diverse watershed systems. Every watershed has a natural disturbance regime—or a combination of factors that influence how and why geomorphic processes, such as sediment erosion and deposition, change. In many cases, humans accelerate or alter these natural processes, in turn altering ecosystem dynamics that depend on these processes.

### 3.5.1 Geology

The physical character of watersheds is dependent on processes acting on the underlying material over time. The lithology (rock type) underlying a watershed influences hillslope stability, erosion processes and rates, and the background-level sediment supply to rivers. Watersheds underlain by resistant bedrock supply less sediment to rivers than do watersheds underlain by erosive material. The highly erosive Franciscan Formation, a geologic unit representative of California's tectonic history, underlies watersheds with extremely high erosion rates. The high erosion rates translate to high rates of sediment supply to rivers—the Eel River, for example, has the highest suspended sediment yield in California.

California is influenced by active tectonics (forces that deform the earth's crust) that create a diversity of watershed morphologies (shapes) such as the high relief and rugged topography in mountain ranges like the Sierra, Klamath, Transverse and Peninsular, and Coast. These tectonic forces also create lowland areas, such as the Central Valley and the San Francisco Bay-Delta Estuary. The different topography in California's geomorphic provinces, coupled with climatic and vegetative variation, lead to differences in the dominant processes of erosion and sediment transport. For example, in the Southern California Transverse Ranges, chaparral-vegetated watersheds have a semi-arid Mediterranean climate, and dry ravel (dry sliding of sediment under the force of gravity) or fluvial (channel and floodplain) processes commonly transport sediment following wildfire, while infrequent high-intensity rainfall produces debris flows (Florsheim et al., 1991). In contrast, in coastal streams in the relatively humid northern Coast Ranges, episodic erosion in forested watersheds produces sediment through processes such as debris flows, earth flows, and debris slides. Understanding the influence of watershed geology on the dominant erosion and sedimentation mechanisms throughout California is critical in distinguishing natural processes and the natural disturbance regime from anthropogenic (human-caused) disturbances and land use-caused changes.

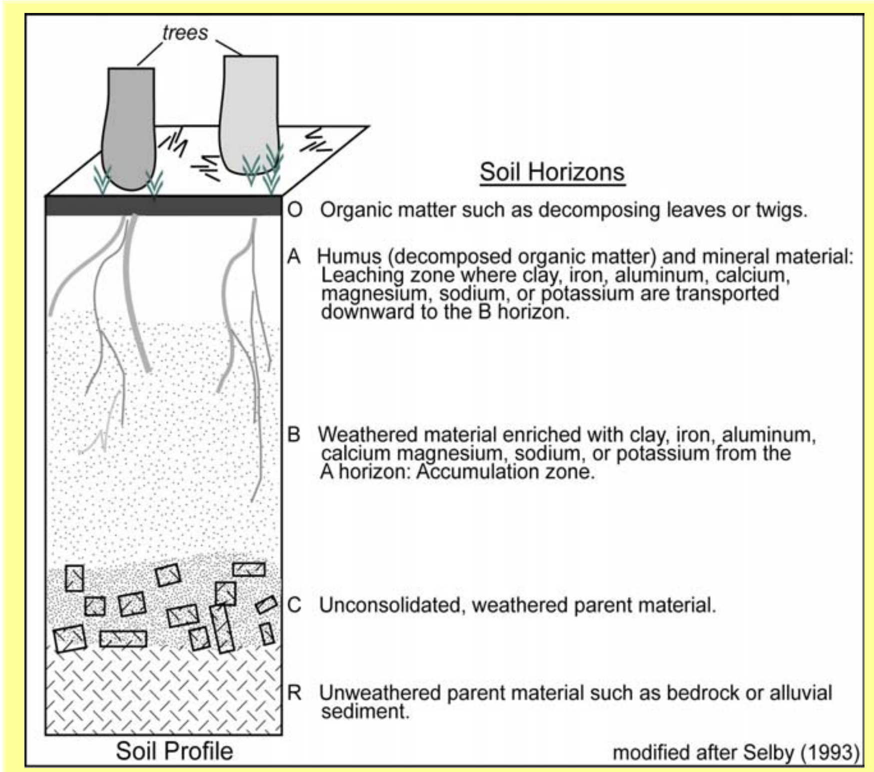


Geomorphic Provinces of California (after Norris and Webb, 1990; Harden 1998)

### 3.5.2 Soils

Soils form through interactions of physical, chemical, and biological processes. They are important as a resource for California agriculture and as the growth medium for vegetation throughout the state.

A soil profile includes layers, called "horizons", of mineral and/or organic constituents of variable thickness that differ from the parent material in morphology; physical, chemical, and mineralogical properties; and biologic character (see box below).




Soil development is dependent on geologic properties, such as bedrock lithology and topography, climate, vegetation and other organisms, and time. Soils exist in various degrees of development. For example, thin, poorly developed soils may not contain a B horizon (see box), and in other locations, soils may not have formed at all.

Land use activities may accelerate surface erosion of soil where vegetation and its binding root structure are removed. In such cases, this additional contribution of fine sediment to rivers raises the suspended sediment load and turbidity, and aquatic habitat may become degraded. Other land use activities compact soils or pave them over, reducing the water's ability to infiltrate between soil particles during storms. In this case, a reduction in infiltration leads to increased surface runoff and erosion in downslope areas.

### 3.5.3 Hillslope and Fluvial (Channel and Floodplain) Processes and Morphology

Geomorphologists are scientists who study earth surface processes and landforms, including landslides on hillslopes or erosion and sedimentation in rivers. Geomorphologists take a "watershed approach" to assessment and planning that recognizes that within a watershed, everything is connected. The connectivity and linkages between hillslope and channel and floodplain systems are important in controlling the input of water, sediment, woody material, and other constituents that determine the character of river and floodplain morphology (see explanation in section 3.5.2.3) and ecology. Connectivity between hillslopes and floodplains and between hillslopes and channels provides a direct route for sediment to the fluvial system. Connectivity from tributaries to downstream channels is sometimes interrupted by dams that trap sediment, whereas increased upstream erosion from various land uses sometimes supplies too much sediment that fills in downstream pools and estuaries.

On a watershed scale, geomorphic processes are affected by upstream controls, such as climate, geology, topography, land uses, and vegetation, and downstream controls, such as changes in sea level (baselevel). Throughout the watershed, areas of erosion and sediment storage are continually in flux in response to storms that create hillslope runoff, river flow, and floods. Sediment transport, or "routing," through a watershed does not occur at a constant rate. In California, the episodic nature of hydrologic processes dictates rates of sediment erosion, transport, and deposition. So while average rates of geomorphic change are sometimes useful, predicting the possible range in magnitude of change is essential for planning purposes. For example, estimating an average magnitude and rate of channel bed erosion may describe long-term river channel changes. But actual changes occur episodically during individual events. Thus, during some storms, there may be substantially more geomorphic change than the average amount, while at other times, there may be less. This variation in rates and magnitudes of processes is a normal part of California's rivers and should be recognized and accommodated in order to minimize hazards and maintenance and to maximize habitat and safety.

#### 3.5.3.1 Sediment Erosion and Transport on Hillslopes

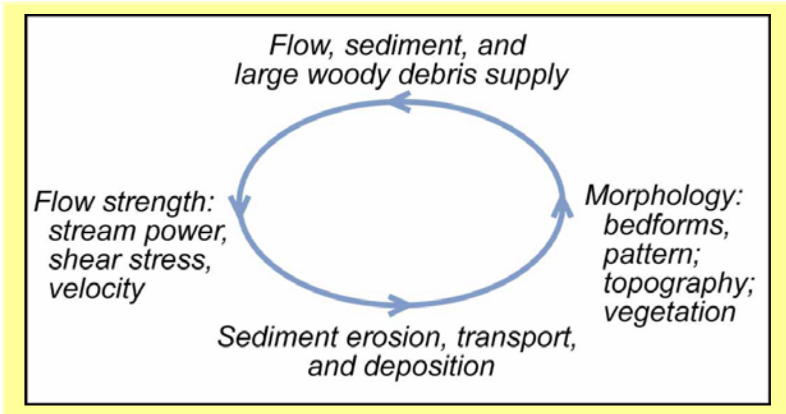
Erosion is a natural process that loosens and removes sediment from hillslopes or the channel bed and banks. Erosion and transport occur by physical and chemical weathering, abrasion, or entrainment of particles by running water. Hillslope erosion processes include rain splash, overland flow, incision of rills and gullies, and a broad category of processes called mass wasting, which includes landslides and debris flows. Features created by mass wasting are classified depending on whether they occur in bedrock or soil, whether they occur in unconsolidated or consolidated materials, and by their water content and rate of movement (Varnes 1958). A complete description of types of mass movement process types is contained in Selby (1993). Additional detailed descriptions of mass wasting processes are included in Ritter et al. (1995) and in other watershed assessment guides such as Appendix A of the Washington Forest Practices Board Manual (Washington State Department of Natural Resources, 1997) and in the Sediment Sources Assessment Chapter of the Oregon Watershed Enhancement Board Watershed Assessment Manual (Watershed Professionals Network, 1999).

Mass movement on a hillslope occurs when the forces resisting movement are overcome by the driving forces. This threshold may be crossed due to intrinsic processes, such as weathering over time, or by extrinsic factors, such as high-intensity rainfall. While the hillslope erosion processes that shape the landscape over time are natural, human activities may lower the erosion threshold and reduce the time it takes for sediment generated on hillslopes to reach channels. Moreover, human activities may reduce hillslope resistance to erosion, concentrate runoff, or increases slope moisture. These responses may result from activities such as removal of vegetation and root networks, or hillslope grading for road construction. Understanding how human activities affect hillslope stability and the connectivity between hillslopes and channels is critical in watershed assessment.

#### 3.5.3.2 Erosion, Transport, and Deposition Processes in Rivers: Interactions with Morphology

As water flows in river systems, it interacts with the bed, banks, and floodplain. This interaction is affected by the size of the particles on the channel's bed, the shapes of the channel and floodplain, vegetation, and structures, such as bridges or bedrock, protruding into the channel.

During floods, flow strength increases to the point where a river gains the ability to move sediment particles on its bed, banks, or floodplain. Flow strength is an important measure of the ability of a certain magnitude of flow to move sediment. Geomorphologists measure flow strength along the interface, or boundary, between the flow and the channel or floodplain. The point where flow strength is large enough to lift particles off the channel bed and transport them downstream is called the" threshold of entrainment." Above the threshold, the bed material begins to move in the direction of flow. In rivers, sediment transport from upstream to downstream




maintains the shape and pattern of channels, or "channel morphology," and is one of the most important processes in creating the form of the watershed landscape.

Channel bed lowering, or "incision," occurs when individual grains are mobilized from one portion of the river, but not replaced by sediment transported from upstream, or when a river's ability to transport sediment is greater than the sediment supply. Deposition occurs when the flow strength during a flood decreases below the threshold of entrainment, or when the supply of sediment is greater than the river's ability to transport it downstream.

The figure in the text box above depicts the interactions between flow, sediment, and vegetation as a dynamic cycle because each element interacts with the others, mutually adjusting to changes in the system. Stream power, shear stress, and velocity are measures of flow strength and represent the force needed to entrain and transport sediment. In turn, sediment erosion, transport, and deposition are the dynamic processes that create and maintain channel morphology. The channel's morphology and the floodplain's topography form the physical structure of habitat. Every flood has the potential to modify channel morphology and riparian vegetation, providing a supply of sediment and large woody material to downstream areas. The cycle continues as flows with the strength to entrain and transport sediment further downstream act on these elements.

The streambed itself is biologically active, providing shelter for many aquatic organisms. For example, freshwater crayfish and dragonfly larvae occupy the spaces between and beneath gravel and larger-sized sediment. A mix of gravel with small amounts of cobbles and fines (sand, silt, and clay) provide optimum spawning substrate for trout and salmon. The substrate size these organisms depend upon may differ, but those native to streams with good water quality are harmed by excessive fine-sized sediment. Streambeds covered with silt or clay-sized sediment cannot maintain the exchange of water and air from the surface to the pore spaces between the gravels. This subsurface flow is essential because it replenishes oxygen and nutrients and removes wastes. Sensitive organisms, like mayfly larvae and trout eggs, can suffocate or get trapped under finer sediment layers. Over time, the fish and aquatic insect species occupying a sediment-impacted stream may shift toward less sensitive species, like midge-fly larvae (Gordon et al. 1992)

Depending on the size of sediment particles relative to flow strength, sediment moves in channels and on floodplains along the bed (bed material load), in suspension within the flow (suspended load), and as solutes (dissolved load). Mobilization of bed material during floods maintains the quality of substrate (the base upon which organisms live) habitat for aquatic invertebrates and fish that spawn in river gravel by flushing out finer clay and silt. A critical issue in maintaining aquatic habitat is preserving the balance of coarse to fine particles. An oversupply of fine sediment, from soil erosion, for example, may cause a fining trend that overwhelms the natural processes that bring the system back to balance. Watershed assessment helps determine the natural range of variability in substrate size and can help identify the watershed conditions responsible for substrate changes over time. The disturbances caused by erosion, sediment transport, and deposition during floods are a requirement for ecological sustainability in dynamic rivers; thus, watershed assessment should consider the benefits of these natural processes and changes.

Bank erosion is a natural process that occurs due to the force of water against the bank. The rate of bank erosion depends on such factors as the resistance of bank material and the presence of vegetation. Riparian plants' root systems promote bank stability. Dynamic rivers maintain their morphology through erosion and sedimentation, and the disturbance caused by removing vegetation from one area and creating new bare patches promotes riparian succession. If these natural processes, called "disturbances" by ecologists, knock the system out of balance, other natural processes acting as feedback often restore the system to a new balanced state. These natural disturbances are essential for sustaining ecosystems. In contrast, chronic or pervasive disturbances caused by human activity may continue to cause instability over time, or may knock the system off balance to the extent that it cannot achieve a new balance.

Bank erosion is a type of disturbance that is an essential part of a functioning ecosystem, but it becomes a hazard when human activity encroaches on the width the river requires to accommodate natural processes. Human activity that removes riparian vegetation and its binding root network will accelerate bank erosion to the extent that the system may attain its former balance. Contributing to this cycle, many human interventions that are intended to stop bank erosion actually promote erosion in other areas by deflecting the force of flow or by generating turbulence around hard edges of the structure.

#### 3.5.3.3 Flooding and Sediment

Flooding (often called the "flood pulse" by ecologists) is a natural attribute of rivers. Most sediment erosion, transport, and deposition occur during floods. Flooding, defined as flow that exceeds the capacity of the channel, occurs when flow inundates the floodplain. Infrequent large floods reconfigure channel morphology and maintain or create side channels and floodplain topography. Moderate floods maintain channel bedforms and spur the evolution of river channel pattern. Frequent small floods sustain ecosystem function. The relation between floods and sediment in watersheds depends on the connectivity in the longitudinal, lateral, and vertical

***"Dominant" Discharge***: the range of flow magnitudes that determines channel cross section width and depth (Wolman and Leopold, 1957).

***"Bankfull" Discharge***: the flow magnitude that is contained within a channel without overtopping its bank (Leopold et al., 1964).

***"Effective" Discharge***: the range of flow magnitudes that transports the majority of a river's annual sediment load over the long-term (Wolman and Miller, 1964). In a gravel bed stream, this is the discharge that transports the greatest quantity of bedload.

In some alluvial rivers, the dominant, bankfull, and effective discharge are equivalent, and generally correspond to frequently occurring flow magnitudes. However, this assumption is not valid in all rivers, for example in disturbed channels or rivers in semi-arid or arid environments.

dimensions. Human activities alter connectivity in numerous ways. For example, in the longitudinal dimension, dams trap sediment and reduce supply to downstream reaches; in the lateral dimension, levees concentrate flow into one main channel and limit connectivity between rivers and their floodplains; in the vertical dimension, an influx of fine sediment in a gravel bed river infiltrates into the spaces between larger sediment particles and reduces the oxygen supply to anadromous fish eggs.

The shape of natural alluvial channels is adjusted to accommodate a range of frequently occurring floods. This range of flood magnitudes is often is simplified to a single discharge called the "dominant discharge." The dominant discharge is defined as the flow responsible for creating the characteristic width and depth of the channel and is sometimes equivalent to the flow that transports the majority of sediment over time. This important definition stems from a comparison of the magnitude and frequency of a range of sediment transporting floods conducted by Wolman and Miller (1960). The magnitude-frequency concept suggests that in many rivers, moderate sediment transporting floods that occur frequently are most effective in transporting sediment over time, in contrast to larger floods that transport large volumes of sediment, but that only occurs infrequently. Thus, a large flood that erodes and deposits sediment may alter channel morphology in the short term, whereas frequent small floods approximately equal to the flow that governs channel shape and size over the long-term. Leopold et al. (1964) found that the shape and size of many natural alluvial channels is adjusted to a flow that fills the channel from bank top on one side of the channel to the other side. They found that the "bankfull" flow has an average recurrence interval of about 1.5 years, often ranging from about 1 to 3 or more years.

The importance of these concepts to watershed assessment is the recognition that in addition to the large floods that typically receive attention, small to moderate floods are capable of channel change. In fact, floods contained within a natural channel are significant in creating and maintaining channel morphology and associated riparian and aquatic habitat as are larger overbank floods to other aspects of channel morphology and to floodplains. Altering the prevailing relationships between sediment supply, transport, and discharge magnitude, frequency, and duration will alter the shape of a channel through erosion and sedimentation processes. Care should be taken when applying these concepts to disturbed channels or to rivers in semi-arid or arid environments. For example, in an incised river, the bankfull discharge may be significantly larger than the effective discharge. In semi-arid environments where vegetation is sparse, the characteristic channel morphology may be formed during large infrequent floods rather than smaller floods that occur frequently.

### 3.5.4 Morphology

The dynamic interaction between water, sediment, vegetation, and woody material creates the shape of the channel and floodplain referred to as "morphology." Because of the continual changes in water and sediment supply and transport, morphology is not a static feature in fluvial systems. Rather, morphology is dynamic and changes in response to erosion and sedimentation during the range of flow magnitudes. Conserving and accommodating or allowing dynamic morphology is a key to preserving riparian ecosystem diversity.

Whereas the morphology (shape) of river channels along the profile from the headwaters to estuaries forms a continuum that incorporates considerable variability, classifications of these morphologies help identify the dominant processes responsible for their formation and help in the characterization of fluvial systems needed in watershed assessments. A number of books that contain descriptions of morphology and the processes that create and sustain fluvial landforms are included with the references at the end of this chapter.

*Channels*

Channels begin in the headwaters of watersheds because of springs, seepage erosion, or overland flow in gullies. Some channels begin in association with hillslope processes near ridge tops in swales called “colluvial hollows” (Dietrich et al. 1986). Headwater channels are usually steep and narrow and contain bedrock or boulders. They are directly influenced by hillslope processes. Headwater streams are extremely important ecological zones (Meyer et al., 2003) as they provide water, sediment, nutrients, and energy into the system. In forested northwest California, morphology in headwater streams is greatly influenced by large woody debris (Keller & Swanson, 1979; Montgomery et al.,1996).

The morphology along the longitudinal profile of a riverbed contains a continuum of morphology called “bedforms,” (see box to right) which adjust to the flow and sediment supply. This bedform continuum changes longitudinally with the capacity of the river to transport sediment and as slope, particle size, and roughness decrease, and channel width and depth increase. The bedform continuum is often simplified by geomorphologists in a hierarchical classification that includes cascades, step-pools, plane-beds, riffle-pools, and dune-ripples (Montgomery & Buffington 1997) that describes the physical characteristics of the channel bed. Fish biologists use other classifications that describe the way fish utilize bedforms, e.g. riffle-pool, glide, and run.

The type of bedform present is a reflection of the location within the watershed and the physical processes active in the fluvial system. Most importantly, aquatic organisms utilize specific micro-habitats formed by bedforms, such as riffle-pool sequences, and other aspects of physical habitat, such as overhanging banks, for various portions of their life cycle. Understanding the type of bedform that is characteristic of a certain portion of a river is required before assessing the effects of human activities and before predicting the type of bedforms that may be stable during restoration of disturbed systems. Land use activities may affect the bedform continuum through alteration of channel slope, channel width and depth, particle size distributions, pool depth and frequency, and water and sediment discharge. For example, channelization often obliterates bedforms that created heterogeneity of aquatic habitat needed in functioning riparian ecosystems.

Whereas understanding the processes and physical conditions necessary to sustain characteristic river bedforms is a necessary component of watershed assessment, by itself, bedform classification does not give a complete picture of aquatic habitat in many watersheds. Bedforms describe the longitudinal changes in morphology of a channel. However, to understand the interactions of a river with its banks and with its floodplain (when present), geomorphologists also investigate river channel pattern, the shape of the river when viewed from above.

Bedforms are associated with the type of bed material (bedrock, boulders, gravel, or sand) and the slope of the channel, among other factors.

*Cascade* – bedrock or boulder bed, slope greater than 0.08;
*Step-pool* – boulder bed, slope greater than 0.02 (<0.08);
*Riffle-pool* – gravel bed, slope greater than 0.01 (<0.02);
*Dune-ripple* – sand bed, slope less than 0.01.

Modified after Montgomery and Buffington (1997)

*River Pattern*

Classifications of river pattern usually define four endpoints in order to simplify the continuum of river morphology. Straight, meandering, and braided patterns refer to the channel, while the anabranching pattern that contains multiple channels must be considered in the context of a floodplain, described further below.

“Straight” patterns occur in channels without bends and are sometimes associated with geologic or structure control. Channelized rivers are often straightened in order to increase flow velocity for flood control, whereas, natural channels are not usually straight over long distances.

“Meandering” patterns occur in channels that contain bends that evolve through a combination of bank erosion on the outside of bends and sediment deposition on the inside of bends. These processes lead to meander migration, the movement of a channel across its floodplain through erosion and deposition. Understanding natural processes of meander migration is important in order to anticipate the effects of human interventions. For example, using hard structures, even the rock and large woody debris that are often promoted as a natural way to prevent bank erosion, inhibits meander migration and may lead to erosion in a different area as the river adjusts to its imposed pattern.

“Braided” patterns occur when flow splits around in-channel bars. Braided patterns are common in streams with high sediment loads and high slope, and they tend to be very unstable.

“Anabranching” rivers have multiple channels separated by islands (composed of the same material as the floodplain, in contrast to braided rivers, where flow splits around in-channel bars). In anabranching rivers, the dominant geomorphic process is “avulsion,” or the dynamic switching of channel location through a breach in a naturally formed or engineered levee. The anabranching pattern is typically found in low-gradient rivers with floodplains. It was common in many lowland California rivers prior to the construction of levees that concentrated river systems into single channels.

Documenting and understanding the effect of human activity on channel pattern are critical in predicting potential future river-system processes, especially in restoration activities.

*Floodplains and Estuaries*

Floodplains are integrally linked to their channel systems, and separating floodplain morphology from channel morphology is an artificial distinction. Floodplain classification is based on stream power and sediment particle size in the adjacent channels (Nanson & Croke 1992).

Floodplains contain a diverse assemblage of sediment deposited by a variety of processes that occur during floods. One process, vertical accretion, occurs as overbank flow brings fine material suspended in the water onto the floodplain. This fine material is deposited in zones of low flow strength that may occur where vegetation slows flow. Other vertical accretion processes include deposition in “crevasse splays,” or sand splays, fan-shaped deposits of sand that occur as a river breaches a natural or artificial levee, scours an area immediately adjacent to the breach, and deposits its sediment load over older floodplain sediment. Another process, lateral migration, occurs as sediment is eroded on the outside of bends and is deposited on the inside of downstream channel bends. Over time, the channel migrates in the direction of the eroding channel bank, leaving behind a bar on the inside bend, called a point bar, that continues to build in height until only overbank floods are deep enough to inundate and deposit sediment in that location. Floodplains contain a stratigraphic record documenting variability in these processes over time. Prior to their development for agriculture or other land uses, floodplain surfaces contained topographic relief that created high and low areas supporting diverse ecosystems

Many rivers in California form estuaries, a biologically rich ecotone (transition zone) where freshwater and saltwater mix in the portion of a watershed farthest downstream from the headwaters. The San Francisco Bay-Delta Estuary in California is the downstream portion of the large Sacramento-San Joaquin River watershed. Smaller California watersheds also contain important estuaries, such as the Klamath River Estuary to the north and the Tijuana River Estuary to the south, and the Navarro, Garcia, Russian, and numerous other small estuaries in between. Estuaries are affected by sediment deposition, dredging, subsidence, shoreline stabilization or alteration, and changes in upstream watershed flow and sediment regimes. For example, an increase in a river's sediment load may fill in an estuary, while a decrease in river flow may increase salinity.

### 3.5.5 Sediment Budget Framework

A sediment budget is a mass balance of sediment supply, storage, and yield over time (Reid & Dunne, 1996). Specific components of a sediment budget may be used to address the effects of natural processes or human-cause disturbances (Reid & Dunne, 1996).

The sediment budget is useful to account for watershed sediment through the relation:

$I - O = \Delta S$

Where I is the volume of sediment input, O is the volume of sediment output or yield, and $\Delta S$ is the change in sediment storage over a particular time period.

Sediment input, or supply, is a measure of the material produced by hillslope mass movement and upstream channel bed and bank erosion. Sediment storage is the sediment in channel bedforms and bars, the floodplain, and terraces. The output, or "yield," from a basin is a measure of the sediment leaving the watershed. The time period over which the sediment budget is relevant must be defined based on the timeframe of the input data. Because sediment erosion, transport, and deposition are dependent on the magnitude, frequency, duration, and intensity of storms, the components of the sediment budget must be placed in the context of California's episodic flood regime.

A sediment budget generally provides an order of magnitude estimate of sediment volumes produced, stored, and transported through a watershed. Although exact quantification is usually not possible, the sediment budget is a useful framework for identifying important processes and the linkages between processes that affect sediment in a watershed. The sedimentation rate and residence time of sediment in storage is critically important and can be addressed through watershed assessment to evaluate the effects of land use changes. Moreover, a sediment budget may be used to document changes in connectivity, such as loss of sediment supply following construction of a dam.

## 3.6 Water Quality

Water quality encompasses the physical and chemical characteristics of water in waterways or in water entering a waterway. Aspects of soil and atmospheric water quality are not included here, although the geochemical cycles occurring in the atmosphere and the soil and geology of a watershed are critical controlling forces in determining the quality of water in streams. Measuring water quality is important in assessing watershed condition because "changes in water quality indicate a change in some aspect of the terrestrial, riparian, or in-channel ecosystem." (Naiman et al., 1992). Water quality is one of the primary measurable, non-biological indicators of watershed condition.

This section covers legal and regulatory issues, but first provides information on key scientific concepts related to water quality. These include:

- Classes of contaminants
- Major effects of the contaminants on aquatic life
- Information on evaluation of chemical contaminants in water

Protecting or improving water quality often includes protecting and restoring natural functioning to watersheds. Activities related to understanding impacts to water quality often involve figuring out where in the watershed impacts are occurring. According to the U.S. EPA, nonpoint source pollution is "pollution from numerous widespread locations or sources that have no well-defined points of origin. The pollution may originate from land use activities and/or from the atmosphere. Examples include leaching of excess fertilizer from fields and acid rain." In contrast, point source pollution comes from a specific, identifiable source or site. In many places, nonpoint source pollution is the primary source of water quality problems.

The concept of water quality is embedded in federal (Clean Water Act, CWA, 1973) and state (Porter-Cologne Act) law, which require that state agencies and permittees meet certain standards for managing chemical inputs and other forms of pollution that might impact "beneficial uses." Beneficial uses generally refer to the "fishability," "swimmability," and "drinkability" of water, but also include protection of aquatic life and habitat.

If water quality is impaired or threatened with impairment from point or nonpoint sources, then the state must act to protect or improve water quality. In California, the State Water Resources Control Board is responsible for managing water quality in the state's waterways, including listing waterways under section 303(d) of the CWA (http://www.swrcb.ca.gov/quality.html). Listing waterbodies means that the state has determined that there is sufficient scientific basis for calling individual waterbodies impacted to invoke their legal protection.

U.S. EPA has adopted the ambient water quality criteria, which are water quality standards for the protection of aquatic life (http://www.epa.gov/waterscience/pc/revcom.pdf). These standards can be used to evaluate water quality in the context of an overall watershed assessment. Where standards don't exist, indicators can be drawn from technical and scientific literature to inform the analysis.

The characteristics of water vary across watersheds and according to time of day, season of the year, and human activities that might affect water quality. To account for this variability, it is usually necessary to collect many samples at many times in many places in order to characterize water quality.

Sometimes waterways in a region (e.g., the Central Coast) are chosen as reference sites because they have many or all of the expected natural processes (e.g., frequent fire) and features (e.g., anadromous fish populations). Data collected from a reference monitoring site can be compared to data collected from sites of concern to establish how much the sites of concern have deviated from the natural state.

### 3.6.1 Nutrients

Naturally occurring chemicals that contribute to instream plant and bacterial growth include nitrogen-containing compounds (e.g., nitrates) and phosphorous-containing compounds (e.g., phosphates). The cycling of these chemicals, or nutrients, through terrestrial and aquatic ecosystems is a natural process that can be influenced by modifications of vegetation, soils, and rock formations; changes in the flow rate and other physical characteristics of waterways; changes in the biological conditions in waterways; and the introduction of nutrients from outside sources. Human activities usually increase nutrient concentrations, resulting in increased potential for the growth of algae and other plants in waterways. Excessive growth of algae, bacteria, or vascular plants can result in secondary impacts to dissolved oxygen concentrations and downstream organic carbon concentrations, due in part to the breakdown of plant material. When dissolved oxygen levels become too low, the normal physiological functions of aquatic animals are impaired, resulting in mortality in some cases. The U.S. EPA's ambient water quality criteria include nitrates and phosphates.

### 3.6.2 Temperature

Water temperatures must remain within a certain range in order for native aquatic organisms to maintain healthy populations and distributions. This temperature range varies from species to species, and sometimes from population to population within a species. Temperatures within a given body of water vary naturally due to seasonal and diurnal influences. The temperature of inflowing water, flow rate, wind speed, air temperature, and riparian shade influence water temperature. When natural or human processes affect these factors, temperatures may rise or fall. Relationships between landscape condition and water temperature exist, but have not been well characterized for all habitat types of California.

Temperature changes and temperatures above a certain point have particular direct and indirect effects on the health of instream aquatic communities. Temperatures above a certain point will have sub-lethal impacts (e.g., reduced growth rate, impairment of physiological function) or lethal impacts on embryonic and adult insects, amphibians, fish, and other aquatic animals. This point varies with geography and species. Rapid temperature changes can also have adverse effects. The temperature of a waterbody will affect the concentration of dissolved oxygen (colder water has more oxygen) and the instream portion of nutrient cycles

By changing the vegetative cover, hydrologic cycle, and rate and timing of instream water flow, human activities can influence the water temperatures of streams and rivers. Removal of upslope or riparian vegetation (e.g., by logging or development), for example, results in increased sunlight on the water surface, which heats the water, and increased wind speed across the water surface, which decreases the benefits of riparian shading if the air is warm (Holtby 1988). Water diversion and storage reduce instream flow, which can have serious impacts if these reductions are in the summer when the air is warm anyway. Reduced natural storage of water as snow or in shaded soils can also result in lower flows in the summer.

Water temperature can fluctuate over 24-hour periods, weather events, seasons, and climate cycles. It can also fluctuate over short lengths of a stream. These fluctuations can complicate measurements and analysis of water temperature in still and moving waters.

The mean weekly average temperature (MWAT) and the summer pool temperatures (where pools are providing cool-water refuges) are two common methods for tracking water temperature. The standards for these indices vary depending on where the waterway is in California and the species of concern. For example, in the North Coast region in 2001, the RWQCB had the following standard for temperature: "At no time or place shall the temperature of any COLD water be increased by more than $5^oF$ above natural receiving water temperature. At no time or place shall the temperature of WARM intrastate waters be increased more than 5°F above natural receiving water temperature." (North Coast Regional Water Quality Control Board, 2001). In other regions, there may be different standards, and the basis for the standard may vary.

### 3.6.3 Suspended Material

Both organic (e.g., leaves) and inorganic (e.g., silt) material enters streams and can affect the clarity of the streams, as well as the sediment budget for a waterway or watershed. "Total suspended solids" refers to all the material suspended in the water, and "total suspended sediment" refers to just the inorganic portion. Suspended sediment is sometimes defined as including both organic and inorganic particles (Spellman & Drinan, 2001), so the use of either term must be accompanied by a definition.

Suspended sediment is a natural part of an aquatic ecosystem; as with most aspects of water quality, it is the concentration and duration that matters. Natural concentrations of suspended sediment will vary with geological and soil formations, precipitation, upstream slope steepness, and land cover. Human activities, including road construction and maintenance, logging operations, agricultural operations, housing construction, mining, grazing, and changes in flow (reservoir releases or water diversion) can result in changes in suspended sediment in -stream.

It is natural for landscapes to erode and for vegetation and other organic material to enter streams, and for these materials to become suspended or settle in response to flows. However, modifications of these processes through land and flow disturbances can cause negative impacts to aquatic communities and human uses of water. The negative impacts of excessive suspended sediment include: 1) the smothering of embryonic and larval stages of insect, amphibian, and fish species in the benthic sediment, 2) the blocking of light needed for photosynthesis by algae and vascular plants, 3) the spreading of pathogenic microbes and toxic metals bound to the surface of particles, 4) increased costs for water purification, and 5) the filling of downstream reservoirs.

Two approaches for investigating the potential for suspended sediment problems in watersheds are to: 1) monitor in-stream concentrations periodically and during and immediately following storm events and 2) develop a risk assessment or similar map-based modeling approach using information about slope steepness, precipitation, soil and geology, land cover (vegetation), and land use. Data from both approaches can be collected in the same watershed and, in combination, can reveal potential or actual impacts of suspended sediment on aquatic communities.

Just as with temperature, suspended sediment concentrations can fluctuate widely over short time periods and distances. This can complicate understanding natural and human-induced erosion processes and transport of sediment through stream and river systems.

### 3.6.4 Dissolved Oxygen

Aquatic ecosystems must contain oxygen in order to sustain the lives of all animals and

Humbug Creek, Yuba River watershed
Photo by David Fallside

plants (but not all bacteria). The concentration of oxygen dissolved in water depends primarily on the temperature of the water and the waterway's elevation (which affects atmospheric pressure). Oxygen is naturally introduced into aquatic ecosystems from the atmosphere and from photosynthesis by algae and vascular plants growing in the water. Oxygen is naturally limited in the water of benthic (bottom of the waterbody) sediments because it must diffuse in from the water above, and it is simultaneously used up by respiring animals and microorganisms, as well as by chemical reactions.

There are two primary units for measuring the concentration of oxygen in water: 1) milligrams per liter, "mg/L", which refers to the amount of oxygen dissolved in one liter of water, and 2) % saturation, which refers to the proportion of the theoretical maximum concentration of oxygen that is present.

Human activities can contribute to the depletion of dissolved oxygen (DO) from waterways. For example, dams and reservoirs contribute to depletion of oxygen through microbial action in the deep water and bottom sediments. Water released from deep in a reservoir to a stream or river can be very low in oxygen. In addition, reduced flows during the summer can result in increased water temperatures, which will result in lower concentrations of oxygen and possibly excessive algal growth, which will eventually rot and further deplete the oxygen. Excessive nutrients can also contribute to bacterial, algal, and vascular plant growth, which can deplete nighttime oxygen in the benthos (bottom of the waterbody). When the excessive growth dies off, the rotting material will result in oxygen depletion in or near the benthos. Settling of fine sediments between larger gravel in benthic sediments reduces the flow of water through the gravels and hinders the replenishment of oxygen depleted by benthic organisms.

Standards for dissolved oxygen concentrations are usually based on the needs of aquatic organisms present in a particular watershed. For example, trout populations and their prey depend on oxygen concentrations >6.5 mg/L (milligrams per liter) in order to survive. Populations of warm-water fish, such as largemouth bass, will not grow at dissolved oxygen concentrations <6.5 mg/L, but can tolerate lower concentrations than cold-water fish.

California's Regional Water Quality Control Boards use two different kinds of standards for dissolved oxygen. One is a saturation standard. For example, waters must average >85% saturation in the Central Valley region. The other standard requires that concentrations be above a certain standard. For example, in the Central Valley region, dissolved oxygen be >5 mg/L for the Sacramento River at the Delta to >7 mg/L for the upper Sacramento River.

Besides causing the loss of fish and other aquatic biota, oxygen depletion can promote unwanted chemical reactions. For example, anoxic (no oxygen) or hypoxic (low oxygen) sediments are more likely to host the methylation of mercury (a chemical modification of mercury atoms) by bacteria, which allows mercury to enter the food chain through bacteria and algal food sources for aquatic animals (D'Itri, 1990).

### 3.6.5 Inorganic and Organic Pollutants

<u>I. Classes of Contaminants</u>

Contaminants are any chemical that can have an adverse effect on aquatic life if present in sufficient concentration. "Sufficient concentration" is the key phrase. In small enough quantities, most chemicals are harmless. In larger quantities, chemicals that might be essential for life can be very toxic. This well-documented pattern is the basis for the slogan "the poison is in the dose (or concentration)". One classic example of this is the metal copper; it is an essential mineral for all living organisms, but above a certain concentration, it becomes increasingly toxic, especially to aquatic animals. Most contaminants of concern are toxic at low concentrations, typically in the parts per billion (ppb) range.

Contaminants can be divided into two major groups of chemicals: organic and inorganic. Organic chemicals contain carbon and include most pesticides, dioxins, PCBs (polychlorinated hydrocarbons), PAHs (polycyclic aromatic hydrocarbons), oil and grease, and surfactants and plasticizers. The metals that are of greatest concern with respect to aquatic life are typically heavy metals, such as zinc, copper, mercury, and lead, as well as other groups of metals that include arsenic.

Aquatic contaminants can be acute and/or chronic toxicants. Acute toxicity causes mortality, while chronic exposure to lower levels of the contaminant can cause harm to the reproductive, nervous, or other physiological system.

The U.S. EPA has developed benchmark values, those considered safe for most aquatic life, for both short-term (acute) and long-term (chronic) exposures.

II. Organic Contaminants

Organic compounds that are contaminants play no normal role in the functions of aquatic organisms.They are often designed to kill insects or other animals. Alternatively, many serve as ingredients in various manufacturing processes or are constituents of commercial products. Over time, organic contaminants will be broken down to less harmful substances.

However, some can persist for decades. Those that persist for long periods of time can accumulate in the tissue of animals and be passed up the food chain. The tables above contain an abbreviated list of common organic contaminants found in waterbodies, their sources, the type of effects they have on aquatic life, and reference information to collect additional details.

| **Organic Chemical** | **Environmental Source** | **Effects** | **Special information** |
|---|---|---|---|
| Organophosphate pesticides (diazinon, malathion, chlorpyrifos) | Lawns, golf courses | Neurotoxin, acutely toxic | Very water soluble, persists in water for weeks-months |
| Pyrethroid pesticides (esfenvalerate, permethrin) | Lawns, golf courses | Neurotoxin, acutely toxic, some cause chronic toxicity (reproductive harm) | Not easily dissolved in water, found in sediment, persists in sediment up to a year |
| Organochlorine pesticides | Pesticides, many such as DDT, are currently illegal to use | Neurotoxin, but also many other chronic adverse effects | Very insoluble in water, commonly found in sediment, persists for long periods (75 years) |

| Organic Chemical | Environmental Source | Effects | Special information |
|---|---|---|---|
| Polycyclic aromatic hydrocarbons (PAHs such as benzo[a]pyrene) | Combustion by-product (gasoline, wood, burning of just about any organic material) | Carcinogen, can cause tumors in fish | Insoluble in water, found in sediment, persists for decades under certain conditions |
| Dioxins | Combustion by-product involving reaction with chlorine; by-product of synthesis of some herbicides, found in bleached pulp mill effluent, incinerator emissions | Carcinogen, disrupts normal hormone function (endocrine disruptor) | Insoluble in water, persists for long periods of time in sediment if shielded from light |
| PCBs (polychlorinated biphenyls) | Hydraulic fluid, coolant, insulator, historically used in transformers, current source is manufacturing waste, currently illegal to use | Carcinogen, numerous other harmful effects | Very insoluble in water, very persistent in the sediment |
| Surfactants (detergents) | Numerous commercial/residential uses; enter water via wastewater treatment plants | Can interfere with reproduction in aquatic animals | Water soluble, are not persistent |
| Plasticizers (phthalates) | Commercial uses, makes plastics more pliable; wetting agent; found in wastewater effluent | Reproductive toxicant in fish and invertebrates | Low solubility in water, associated with sediment, persists for less than 1 month in most cases |

III. Metals

Metals are natural substances, many of which are essential nutrients. However, if present in aquatic ecosystems in sufficient quantities, they are harmful. Unlike organic compounds, metals are not biodegradable. Unlike organic compounds, metals persist indefinitely. They also tend to bioaccumulate, or collect, in fish tissues.

The toxicity of metals in water and sediment is complicated because normal constituents of water affect the solubility and availability of metals to be absorbed by invertebrates and fishes. Water hardness is a key factor that affects the solubility of metals. Hardness refers to the concentration of positively charged atoms (calcium, magnesium, etc.) dissolved in water. If the concentration of a metal is hardness-dependent, then special considerations must be made in assessing harmful levels in a specific water body. Another important consideration when looking at metals is that they are often found in greater

| **Metal** | **Environmental source** | **Hardness-dependent** | **Toxic effects** |
|---|---|---|---|
| Arsenic | Naturally occurring; used in some pesticides and herbicides, wood preservatives | No | Acute toxicity, reproductive toxicant |
| Lead | Mining, incineration of batteries, pigments | Yes | Acute toxicity, neurotixcant, impairs reproduction |
| Mercury | Fungicide; many manufacturing processes; mining | No | Methyl mercury form of greatest concern; endocrine disruptor, not acutely toxic |
| Cadmium | Used in a variety of industrial processes; most common in urban watersheds | Yes | Acute toxicity, a variety of physiological effects with long term exposure, including deformities of young |
| Copper | Mining, dormant sprays; fungicide used on boats | Yes | High toxicity with acute exposure; interferes with function of gills |
| Zinc | Mining, electroplating, roads (from worn tires), manufacturing of brass, steel, and iron alloys; dormant sprays | Yes | Acutely toxic; teratogenic with chronic exposures |
| Chromium | Numerous manufacturing processes, including tanning leather, manufacturing steel, aircraft industry | hexavalent form not affected by hardness; trivalent form less water soluble, toxicity hardness dependent | Acutely toxic, possible carcinogen |

concentrations in the sediment, bound up with other particles, than in a free (or soluble) form in the water. Over time, the bound metals in the sediment leach out into the water. Many invertebrates and various life stages of fishes live in the sediment. Consequently, it is important to examine the potential toxicity of metals in both the sediment and water column.

The table above lists key metals of concern, their environmental sources, whether the metal's concentration in water is dependent on water hardness, and toxic effects of metals.

## IV. Evaluating Contaminants in Water as Part of a Watershed Assessment

If there are land uses or activities within the watershed that might be associated with the release of contaminants, or if there is evidence within the waterway that contaminants might be a problem, there are a number of steps that can be taken to determine if contaminants are a problem.

1. Check with the Regional Water Quality Control Board, local Water Districts, Municipalities, Sanitary Districts, Regional Urban Runoff Programs, and Local Publicly Owned Treatment Works (POTWs), to determine if they have conducted monitoring within the watershed. If data already exists, independent monitoring may not be necessary.

2. Collect water to perform a toxicity test. These tests utilize invertebrates and/or fish to determine whether something in the water or sediment causes acute toxicity. Although the test is not specific for any particular contaminant, it does reflect the overall quality of the water. When possible, it is best to perform the tests with both water and sediment samples from the waterbody.

3. If the toxicity tests are positive, further analysis can be done to identify the cause of the toxicity. Toxicity identification evaluations (TIEs) can be performed to initially identify the class of contaminant responsible. For example, TIEs will differentiate between metals, certain types of pesticides, or other harmful chemicals. Once the class of contaminants is determined, a variety of analytical techniques can be used to determine the specific “bad actor(s).”

### 3.6.6 Pathogenic Bacteria

The primary bacteria types of concern in waterways are fecal coliform and enterococcal. They usually originate from deteriorating septic systems, incomplete wastewater treatment, the presence of livestock, or stormwater flooding of wastewater treatment facilities. They may also be associated with natural sources in a watershed, such as dense congregations of birds or other wildlife. Certain strains of one bacterial species, *Escherichea coli*, may cause intense gastrointestinal problems if ingested.

U.S. EPA has established standards for water quality in waterways used for recreation and as sources of drinking water. These standards are based on generalities about the consumption of water containing bacteria and the sensitivity of people potentially exposed. If waterways exceed these standards, then the state has a legal responsibility to protect residents from potential harm by notifying the public of the problem through signs and other advertising and by then identifying sources of the problem and implementing cleanup through regulatory or restoration activities. More information on this topic is posted at: http://www.swrcb.ca.gov/beach/index.html.

### 3.6.7 pH

pH is a measure of the relative acidity or alkalinity of freshwater. pH is literally the concentration of hydrogen ions in water. Hydrogen ions have a positive electrical charge, allowing them to associate with negatively charged ions, such as nitrate and chloride ions. The pH depends in part on the relative concentrations of electrically charged compounds present in the water and can therefore be affected by natural and human processes that influence the concentrations of these compounds.

In California, pH naturally ranges around neutral pH (pH = 7.0) by about 1 pH unit. Most Basin Plans for the various State Water Resources Control Board regions record a pH range of 6.5 to 8.5 as ideal for maintaining the health of aquatic communities. Violation of drinking water standards is not an appropriate indicator for pH problems because changes in pH can affect aquatic organisms before reaching a level that humans can’t tolerate.

Acid mine drainage, microbial processes at the bottoms of lakes and reservoirs, and effluent from wastewater treatment plants and industry are possible sources of pH change in a watershed. Erosion of certain geological features, such as serpentine outcroppings, can also change the pH of receiving waters. Changes in pH outside the range of 6.5 to 8.5 are usually associated with identifiable sources that can be readily investigated.

### 3.6.8 State Programs and Regulations That Affect Water Quality

[THIS SECTION IS UNDER CONSTRUCTION]

## 3.7 Aquatic Ecosystems

Although waterways constitute a small proportion of a watershed's total size, they integrate many of the human and natural processes in the watershed, and they are often the political and social focus of watershed efforts. Aquatic ecosystems include physical (e.g., temperature), chemical (e.g., nutrient concentrations), and biological (e.g., fish populations) components. The physical and chemical constituency of an ecosystem in large part determines the various plants, microbes, vertebrates, and invertebrates that live there. In turn, interactions among the various organisms determine the aquatic community structure.

### 3.7.1 Physical

Many factors in an aquatic ecosystem can be described as "physical," such as temperature, suspended and benthic sediment, and flow. Some of these are described in more detail in the water quality section (chapter 3.6).

Benthic sediment is an important component of aquatic ecosystems. While difficult to characterize, benthic sediment is critical to the health and well-being of native organisms. The structure and composition of benthic sediments determine the size of spaces among sediment particles and, in part, the rate of particle movement. Small particles result in small pore sizes, which lead to low flow rates among the particles and limit dissolved oxygen concentrations. Small particles are more easily mobilized in low flow rates, resuspending and resettling in the turbulent stream and river flows. Large particles have large pore sizes among them. They usually don't limit flows and the availability of dissolved oxygen to benthic organisms.

Measuring the proportion of benthic sediments of different sizes and the rate of downstream sediment transport are important ways to characterize stream condition. These physical measures of habitat condition often accompany studies of benthic macroinvertebrates, one biological measure of the aquatic ecosystem's condition.

Flow, the physical movement of water, impacts many other aquatic ecosystem characteristics. Low flows can result in warming of water, reduced sediment transport, and physical barriers to the movement of migratory fish. High flows can increase the rate of sediment transport, replenish depleted dissolved oxygen, and provide deeper water for fish movement.

### 3.7.2 Chemical

Most of the important chemical characteristics of aquatic ecosystems are presented in the water quality section (chapter 3.6).

Changes in stream chemistry can determine the well-being of the aquatic ecosystem. Individual organisms may not tolerate either changes in water quality (e.g., pH, dissolved oxygen, and nutrients) or the absolute values for these water quality parameters. Other organisms may be quite tolerant of wide variations in water chemistry. Changes may originate from human activities (e.g., nutrient runoff from an agricultural area), natural processes (e.g., growth and decomposition of aquatic plants), or a combination of both (e.g., excessive growth of algae due to excessive nutrient inputs. A critical part of watershed assessment is understanding the nature of water chemistry in the watershed and the causes of high or low values or changes in values for specific parameters. Many water quality standards are based on human health considerations and not on ecological effects of changes in waterbody chemistry. Therefore, standards relevant to aquatic organisms must be used when analyzing pH values in the watershed.

### 3.7.3 Biological

The biological components of aquatic ecosystems are the microbes, plants, invertebrates, and vertebrates that inhabit the water column (the water above the bottom) and the benthos (the bottom of the waterway). These grow and change relative to each other depending on the physical and chemical conditions in the waterway and can therefore indicate conditions or changes in the watershed. Understanding the natural biological condition of waterways is often challenging, as there are few "reference" waterways, that is, streams and rivers in a relatively natural state. However, many scientists use the biological composition of aquatic ecosystems to determine whether or not a watershed or waterway is deviating radically from a natural state (Karr 1981; Moyle & Randall 1996) and may be in need of restoration (Adaniya et al. 1997; Murray et al. 2001).

Plants and Microbes

Plants in aquatic ecosystems occur in several main forms. Phytoplankton, single-celled algae suspended in the water column, grow in slow-moving waterways and lakes. Periphyton, single-celled and multi-celled algae, occurs attached in films or filaments to rocks in still or moving water. Vascular plants (plants with true stems) can grow from lake, river, and stream bottoms. All these plants use nutrients and gases dissolved in the water and light from the sun in order to photosynthesize (make food using light as an energy source) and grow. Changes in flows, temperature, and nutrient availability can affect the growth of these aquatic plants. Low flows and excessive inputs of nutrients from various land uses and point sources may result in high temperatures, reduced mechanical stress (from flow), and excessive growth. Excessive growth can cause changes in pH, reduced dissolved oxygen concentrations in the bottom sediments, and production of particulate and dissolved organic carbon as the plants grow, die, and decompose.

Although fungi and bacteria may occur in the water column (millions of individual cells per liter), most of the important microbial activity occurs on the surface of or within the bottom sediments (Horne & Goldman 1994). Decomposition of plant material from terrestrial vegetation and from aquatic plants is an important process in the slower-moving major rivers and lakes, however, it may also occur in waterways, such as mountain rivers, if the water is warm enough and there is sufficient material. Microbes on the surface of decaying vegetation are an important food source for invertebrates grazing or filtering food from the water and sediment (Horne & Goldman 1994). High levels of microbial activity can alter the chemistry of water within the bottom sediment and of water near the bottom. This activity is one of the main reasons that water deep in lakes and reservoirs is oxygen-depleted.

Viruses are not usually thought of in the world of watershed assessment, but they are present in freshwater and can pose risks to wildlife and humans alike. Hepatitis and animal influenza viruses are just two of many pathogenic viruses that can be transmitted through freshwater, usually as a result of inputs of animal and human waste (Horne & Goldman 1994).

Benthic Macroinvertebrates

Benthic macroinvertebrates are the larger invertebrates (animals without backbones) dwelling at the bottom of waterways. Several major animal groups fall into this group, including insects and crustacea (arthropods), mollusks, and worms. However, most people using this term are referring primarily to the aquatic larval forms of various insects (e.g., stone flies, caddis flies, and dragonflies). Aquatic invertebrates are a major food source for many aquatic and terrestrial organisms. Their well-being can determine how well these other animals do. They are also interesting from a watershed assessment perspective because they can function as indicators of watershed condition. Certain benthic macroinvertebrates are sensitive to change, i.e., watershed degradation, and can be monitored for their presence and relative abundance to give a measure of watershed health integrated across generations of the organisms.

Vertebrates

Aquatic vertebrates include fish, amphibians and reptiles, mammals, and birds. The presence of individual species depends on geography, hydrology, management conditions, presence of other species, and other factors. All species, with the exception of anadromous fish, eventually rely on plant productivity within the waterway itself or on plants adjacent to the waterway that fall or are washed in. They also rely on certain aspects of the waterway's physical or chemical makeup. There are many connections between watershed landscape condition and waterway habitat condition, so impacts to aquatic vertebrates are often measured using other condition indices (e.g., physical structure of the channel, riparian vegetation, or water quality). Simplification (loss of natural complexity) of watershed and waterway conditions through habitat loss and modification (i.e., from land and water management) has led to the absence of many species from significant parts of their historic range in California.

Many watershed assessments focus on freshwater fish, usually because the fish are useful indicators of aquatic health, are listed under the federal Endangered Species Act (1973), or are of concern locally (http://www.dfg.ca.gov/whdab/html/lists.html). Most watersheds include fish, which may be viewed by the watershed assessor as another resident of the watershed, as a commercial or social resource, or as a legal problem. Anadromous ("up-running") fish migrate between different environments (i.e., the ocean and inland freshwater) to carry out particular parts of their lifecycle. Salmon (chinook and coho) and steelhead are anadromous species, spending their larval and juvenile phases in freshwater and their adult years (1-4 years) in the ocean. Their primary needs in California watersheds are unimpeded travel routes from the ocean, good quality spawning habitat (i.e., gravel bars for laying eggs), sufficient quality and quantity of rearing habitat (cool sheltered pools and riffles), and downstream transport to coastal estuaries and the ocean. Land and water management activities can impact these various life cycle needs depending on their location, type, extent, and timing of activities. Assessments of watersheds supporting these species should therefore incorporate evaluation of conditions in the waterways and on the landscape that might impact and could limit anadromous fish reproduction.

Many native fish in California lakes, rivers, and streams also deserve the attention that anadromous fish receive (Moyle et al. 1995). Their habitat requirements may be just as narrow as those of salmon. These habitat requirements are often generalized in Basin Plans as "cold-water fisheries", "warm-water fisheries," migration of aquatic organisms", "spawning, reproduction, and/or early development". For some of these requirements there are broad ranges (e.g., 35°F to 70°F for "cold-water fisheries"). Each species has its own ecological "niche," composed of its preferred habitat, the prey it eats, and how it reproduces. Individual fish species range in their needs, so assessing habitat conditions and the potential impacts to these conditions for many species is more complicated than for one species alone. Some common impacts to fish species are loss of historical habitat (e.g., from dam construction), fragmentation of existing habitat (e.g., from culverted road crossings), loss of prey, degradation of existing habitat (e.g., from reduced flows and excessive sediment input), competition from non-native species and diseases, and over-fishing. Measuring all of these impacts for individual fish species may seem daunting, but it is important for understanding a watershed's condition.

Amphibians and reptiles often inhabit the margins of waterways. Some species are listed as endangered or threatened, or Species of Special Concern, while others have no special designation or protection (Jennings & Hayes 1994; http://atlas.dfg.ca.gov/). Examples of native aquatic amphibians and reptiles include the Arroyo toad, Cascade frog, California tiger salamander, western pond turtle, and two-striped garter snake. Their habitat has been reduced or degraded in many places by land and water uses that affect riparian vegetation, sedimentation processes, prey availability, and habitat connectivity (usable connections among habitat areas). In some instances, they have fallen prey to invasive and/or exotic vertebrates and pathogens. Just as with fish, they rely on a particular set of physical (e.g., temperature) and biological (e.g., insect prey) conditions to survive. For individual species, these conditions could be a wide window or a very narrow one. If these conditions are altered significantly, abundance and presence will change. The job of the watershed assessor is to find out what changes are significant.

Aquatic mammals and birds often play significant roles in an ecosystem, either by physically manipulating the waterway (e.g., beavers) or by functioning as a top predator (e.g., river otters, herons). Many mammals were killed off by trappers in the last century. Their return has been hampered by land and water uses and by public perceptions of their role in modern waterways. Beavers may be a delightful sight to a grade-schooler, but not necessarily to the person who has to maintain an agricultural slough or diversion. Mammals' habitat needs and population dynamics (how populations of a species change over time) may be poorly understood, leading an assessor to guess at relationships between these species' habitat needs and watershed conditions and use. Aquatic birds (e.g., ducks, geese, mergansers, cormorants, dippers, herons) are in a similar boat, with few species having complete descriptions of their preferred habitats. For both birds and mammals, many general statements can be made about their habitat requirements and roles in a watershed. For example, where beavers are particularly active, they can affect how riparian areas function by cutting down riparian trees and contributing to local changes in channel structure and flow. In turn, beavers are affected by the composition of the riparian forest in terms of size and species of trees. Otters do not do very well in places where there are few smaller fish and aquatic invertebrates, which are the food for the larger fish the otters prey on.

Invasive and Introduced Organisms
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#### 3.7.4 Anadromous Fish – Salmon & Steelhead
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## 3.8 Wetlands and Riparian Habitats
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## 3.9 Terrestrial Landscapes and Habitats

The majority of watershed area is composed of the terrestrial landscape—the uplands, hillslopes, and ridgelines. Although almost all watershed assessments discuss conditions of the landscape outside of riparian and wetland areas, very few tackle terrestrial plant communities and habitat condition, except when discussing erosion. There are many processes in the terrestrial landscape that interact directly with waterways and the riparian zone. These include erosion, nutrient cycling, input of organic material, evaporative water loss, and movement of wildlife back and forth. The condition of the upslope vegetation and soil can critically affect the capability of the watershed to retain moisture and meter surface and subsurface runoff into streams. In fact, the role of vegetation management to water supply and control is one of the original research topics of the emerging field of watershed management in the early 20th century (Colman 1953).

**Characterizing Terrestrial Plant Communities**

For botanical diversity in California, the Jepson Manual (Hickman 1993) describes 24 climatic zones and 50 geographic units contained within three floristic provinces (California, Great Basin, and Desert). Individual plant species are often grouped into communities—they often form "associations" among each other (i.e., they live together) because of similar habitat requirements or because they have a biological interaction. These communities are represented in fairly general vegetation maps (e.g., "CalVeg 2000") that show the location of plant community types. Some agencies have created more spatially refined maps for plant community types (e.g., vernal pools, wetlands, and oak woodlands), usually because human activities threaten the habitat type. Specific plans for urban area development may have even more precise maps for locations of plant community types because of legal obligations to have the information. These maps are created by on-the-ground surveying, or by using remote sensing (e.g., satellite photographs).

Most plant community location maps don't tell anything about the age of trees, the percentage of vegetation cover (how much ground is covered), and actual plant species present. One notable exception is the California Department of Forestry and Fire Protection's "hardwoods" map, which includes these types of data. Assessments in large watersheds may not have the resources to support surveys or mapping of actual plant species presence and demographics. These plant surveys might be carried out in monitoring stations or associated with specific restoration projects. Assessments of smaller watersheds, especially where there are plant communities of concern (e.g., redwood forests and vernal pools), may allow the generation of high-resolution maps. More detailed and diverse information obviously allows post-assessment decisions to have more detail and greater resolution.

**Changing Conditions**

The terrestrial landscape is undergoing constant change—there is no equilibrium or stasis in these landscapes. Both human activities and natural processes can cause changes in the terrestrial landscape. Even where the natural state has been largely converted (e.g., in urban areas), over long enough time periods, natural features have changed and will continue to change due to fluctuating climate, changing human values, and invasions by new species.

Plant communities may be replaced by another or undergo "succession" following extreme disturbance. This means that one species may take the place of another, such as the growth of chaparral following a fire that removes a conifer forest. Plant communities also age, which leads to changes in the plant and animal species that can thrive there.

A watershed assessment should measure this change as thoroughly as it represents the "snapshot" of watershed condition. While it is often difficult to predict or even to measure change, there are various indicators that are useful in assessing this dynamic state. For example, varying tree ring widths show changes in growth rates in a forest region—changes that could be related to climate, frequency of disturbance (e.g., fire), or competition with other trees. Understanding how forest complexity might have changed over a period of time will give a recent history of the physical structure of that forest and provide clues as to vegetative cover, wildlife presence, nutrient cycling, erosion, and other ecological processes.

**Wildlife**

Six hundred and forty three vertebrates occur in the state (California Wildlife Habitat Relations, California Department of Fish and Game, 1994). Assessing habitat conditions for terrestrial wildlife (here defined as all animals) or including information about individual species' presence and abundance is usually not a watershed assessment priority. However, because a watershed's area is mostly land and not water, it makes sense to complete the description of the landscape by describing the animals that live there. Many of them are indicators of the condition of the vegetation and natural processes in the watershed. A few of them will have observable influences on the ecology of the landscape (e.g., deer). After identifying those wildlife species found in your watershed, their status can be found on lists of threatened, endangered, or species of special concern (http://www.dfg.ca.gov/whdab/html/lists.html).

One of the main data and knowledge gaps encountered in landscape assessments is a lack of easily obtainable data about the actual distribution, abundance, and population dynamics of individual wildlife species. Even such models as the California Wildlife Habitat Relations model (CWHR), which maps potential wildlife occurrences based on the presence of plant communities, rely on incomplete knowledge of habitat requirements and behavior, and they may not reflect actual species presence, let alone abundance. The California Natural Diversity Database (NDDB, http://www.dfg.ca.gov/whdab/html/cnddb.html)—the main statewide database for wildlife occurrence—relies on the voluntary submission of observations by qualified wildlife biologists. However, this database includes only species of management concern, is not based on a surveying protocol, and is biased toward areas where the number of observers is high (e.g., urban areas). Within the CNDDB, records of rare plant and animal species within your watershed boundaries (location, dates observed, ecological descriptions, legal status, population information, land ownership, data sources) can be searched for using CDFG's RareFind3 software. (http://www.dfg.ca.gov/whdab/html/rarefind.html)

The best response for a watershed assessment that lacks readily available wildlife data because of the problems listed above is to go and collect these data. This might involve collecting databases maintained by agencies that manage land (e.g., the USDA Forest Service), that build and maintain infrastructure (e.g., the California Department of Transportation), or that plan and regulate development (e.g., jurisdictions and their consultants). Developing a complete landscape assessment database might also involve hiring a wildlife biologist to conduct surveys, which is feasible for smaller watersheds (i.e., less than 10,000 acres).

Without these data, a watershed assessment will be incomplete, and analyses and decisions that affect plant community structure and wildlife habitat will be open to question.

**Natural Disturbance**

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**Human Disturbance**

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## 3.10 Human Land Uses

Human land uses can potentially affect many aspects of the hydrologic cycle. Precipitation is the least subject to human intervention. Large-scale earth-moving operations for commercial and residential development and open-pit and mountaintop mining can change topography and geology. More commonly, watershed assessors are concerned with changes in vegetation that affect evapotranspiration, changes in surface conditions that affect infiltration, and changes in channel conditions that affect water conveyance. It is important to distinguish between temporary disturbances, from which hydrologic recovery is possible, and land use conversions, where the hydrology remains altered unless the conversion is reversed.

As with other land use changes, the proportion of the watershed altered and the proximity to stream channels determine the impacts on water quantity, timing, and quality.

### 3.10.1 Residential, Commercial, and Industrial Development

Building houses is a fundamental component of the interaction between humans and their environment. From the scale of the individual parcel to that of a town or city, the impacts to the environment and benefits to quality of life are relevant to assessing conditions in California watersheds. Residential development can occur on remote parcels hundreds of acres in size, in suburbs on the periphery of growing towns, and deep in inner cities. The development process is locally governed, is guided by state planning rules, and usually responds to a housing, political, or financial need of local communities and landowners (Fulton 1999). This use of land is sometimes called land "conversion" because of the extreme nature of the impacts (e.g., grading and covering an area with asphalt), and in sub-watersheds may be the predominant influence on natural watershed processes.

Residential development often occurs alongside commercial and business/industrial development. From a watershed perspective, these developments may have similar impacts to natural systems. From a socio-economic perspective, how these different components develop may be important. The proportion of residential to commercial/industrial development can influence traffic patterns, infrastructure development, and local economic wellbeing. For the most part, when people don't live near work/school/community, they tend to travel by road to get to those places. In addition, as the focus of communities changes from commodity production (e.g., farming) to other economic activities (e.g., technology development), the perceived costs and benefits of certain activities on the landscape may change.

Development can have significant impacts on watersheds. Impervious cover, such as roads, driveways, rooftops, and walkways, can greatly reduce the land's ability to absorb rainwater, resulting in increased volume and rate of stormwater runoff. Stormwater that would otherwise percolate into the soil now ends up in waterbodies, carrying a wide variety of contaminants. The amount of water entering stream and creeks often increases significantly, causing numerous changes to the shape and characteristics of the physical environment in and around the stream or creek. In general, the more that land is developed—converted from its natural state—the more likely it is that natural watershed functioning will be negatively impacted.

#### 3.10.1.1 General Plans

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### 3.10.2 Agriculture

Agriculture usually converts land use in the long term, if not permanently, for the production of food and fiber. Certain alterations to watershed conditions result from this conversion. Native vegetation is replaced with actively cultivated crops of commercial value. Changes in transpiration vary with the particular crop and seasonal nature of production. Because more water is available where irrigation occurs, actual evapotranspiration generally increases. Infiltration capacity generally declines because of compaction from farm machinery. However, in some cases, active tilling may break up a naturally occurring soil layer that restricts infiltration. Depending on the nature of cultivation practices, fine sediment can also be washed off agricultural lands and into waterways. Where excess irrigation takes place, subsurface water delivery to streams may increase. This irrigation return flow (irrigation water returning to a waterway) may contain high levels of pesticides and fertilizers.

Many of the most harmful chemicals, the majority of which require permits, are used in agricultural settings. Pesticides, which persist in the environment for long periods of time, and sprays containing metals are frequently used in orchards and on row crops. If not properly controlled, these chemicals end up in water that seeps out of agricultural soils and/or stormwater and eventually drains into natural waterways.

In some areas, wetlands have been artificially drained to allow for the cultivation of agricultural crops. Subsurface drains that maintain a lower water table may alter water delivery to streams by providing a faster, more efficient route for water than natural groundwater flow. As with other land uses in this section, the area affected by agricultural conversion and its proximity to streams may be more important than the intensity of hydrologic changes at the fields.

Some people argue that it is better to have land in agricultural production than have it developed for urban/suburban uses. Agricultural land use provides socially valuable open space and, if proper management practices are followed, can have limited impacts to water quality, water supply, and certain fish and wildlife habitat. To validate this perspective, it may be useful to analyze the impacts of urbanized or urbanizing areas relative to agricultural areas and both relative to less-impacted areas.

Other effects of agriculture often include leveling of floodplain topography and filling of secondary channels and sloughs. Thus, in agricultural areas today, single channel rivers are often separated from their floodplains by levees, and they lack the topographic diversity that once sustained ecosystem diversity.

### 3.10.3 Timber Management

Commercial timber management, or logging, is a land use that causes a recurrent disturbance rather than a complete conversion of land use. A forestry operation may completely change vegetation type, species mix, and age structure of the forest. However, forest management generally aims to optimize the growth and yield of selected tree species and periodically cut them—a situation not radically different in a hydrologic sense from a natural forest. Logging has dramatic impacts on the water balance of the immediate site. But as analyses increase in spatial scale, consequences to the watershed are not as obvious. Most current forestry operations do not affect a significant proportion of a watershed in a single year or decade. As with other land use changes, the proportion of the watershed logged compared to the entire watershed and the proximity of the logging to stream channels determine the impacts on water quantity, timing, and quality. While cutting trees in isolation may not have dramatic hydrologic consequences, the associated activities of road construction, stream crossings, yarding (collecting logs for transport), slash treatment, and mechanical site preparation may have much more serious impacts.

Forest practices on private land are regulated by the state Board of Forestry and Fire Protection and the California Department of Forestry and Fire Protection under the Forest Practices Act, the Regional Water Boards under the Federal Clean Water Act and Porter-Cologne Act, the California Department of Fish and Game, the U.S. Fish and Wildlife Service (for listed species), and NOAA-Fisheries (for listed salmon and steelhead). The state recently completely an assessment of the status, trends, and challenges to California's forest resources that also addresses timber harvesting (California Department of Forestry and Fire Protection, 2003; http://www.frap.cdf.ca.gov/assessment2003/ ).

Impacts to the watershed that have been documented to result from timber harvest include effects on sediment, water temperature, in-channel volumes of organic debris, chemical contamination, increased nutrient concentrations, the amount and physical nature of aquatic habitat, and increases in peak discharge during storm runoff. While certain of these impacts can be minimized or mitigated through the use of good management practices, the major concern today with logging in California is the potential for adverse cumulative effects at the watershed scale (Dunne et al., 2001). As a result, watershed assessment (also called "watershed analysis") is being increasingly used as a predictive tool in the state by those responsible for management and protection of the State's terrestrial ecosystems (North Coast Watershed Assessment Program, 2001).

The type of cutting also affects the degree of hydrologic impacts. Hydrologic impacts of selection harvests (where scattered individual trees are selected for cutting) are generally considered to be less of a problem that those of clear-cuts because the residual trees remaining after the selection logging use soil moisture and provide some protection to the soil surface (Anderson, et al. 1976).

Hydrologic processes altered by logging begin a slow recovery as young trees grow on the disturbed site. After vegetation becomes re-established on logged sites, it restores a forest cover's hydrologic benefits, such as absorbing soil moisture for evapotranspiration, providing protection of soil from raindrop impact, adding organic matter to the soil, and supporting soil masses on slopes with their roots.

Logging can increase annual water yield to streams by reducing losses to the atmosphere. Tree removal eliminates the possibility of any interception losses (evaporation of rainfall captured on leaves) in the area previously covered by tree canopies. Cutting trees reduces transpiration in rough proportion to the areal extent of harvesting and the ability of the remaining plants to consume water. Forest soil depth and moisture storage capacity largely control the change in evapotranspiration that results from harvesting (Zinke 1987). Removing trees in shallow soils that have little moisture storage capacity impacts hydrology much less than removing trees that had access to lots of water in deep soil. The harvest area's position on a hillslope is also important. Harvesting trees at the base of a slope near a stream will allow much of the soil water formerly used by the trees to enter the stream. However, harvesting trees near the top of a slope will probably only provide more water to the trees lower on the slope rather than to the relatively distant stream.

In addition to changes in annual water yield, timber harvesting can affect peak flows. Soil moisture is greater where trees have been removed. Accordingly, less rainfall is required to satisfy soil moisture storage before runoff may begin. This effect is most likely to have a measurable impact during small and moderate storm events and in small watersheds (Hewlett 1982). During big, intense storms, differences in soil moisture storage between cut and uncut areas are almost incidental compared to the massive amounts of rainfall that tend to overwhelm any effect of land-use change (Ziemer 1981). At the scale of larger river basins, flood peaks depend mostly on the synchronization of contributions from tributaries, which can be affected by dramatic changes in land use but are not predictable without a detailed model of the channel system. In watersheds with shallow snowpacks, timber harvesting can augment peak flows by altering the distribution of snow and the energy available for melt. More snow accumulates in open areas than in areas under forest canopy; hence, more water storage. During warm storms, greater wind speeds in forest openings compared with dense forests generate more snowmelt in the openings than under trees (Harr 1981).

Logging can increase sediment production from both surface erosion and mass movements. Tree canopy loss can allow greater raindrop impact on the soil with consequent soil displacement, but there is usually a thick layer of organic debris left on the soil after logging that absorbs the energy of falling drops. Landslides occur after harvest because soil moisture is greater in the absence of transpiration and because roots no longer help stabilize the soil after they decay. This structural support seems to be at a minimum about nine years after timber harvest, on the average, when decay of roots of harvested trees has not been compensated by growth of new roots (Ziemer 1981).

Sediment from clearcuts, logging roads, skid trails, stream crossings, and ditches may be transported to streams, rivers, and lakes by water (Swift 1988; Waters 1995) or wind (Steedman & France 2000). Nutrients may also increase in streams flowing from commercially logged watersheds (Swank et al. 2001).

Logging on public lands in most California watersheds is now almost exclusively "thinning" and "salvage" operations. Fire risk is the primary reason given for removing as many as half of the trees in any given stand. Although short-term negative impacts to wildlife (e.g., small carnivores) and natural processes (e.g., soil nutrients and water retention) have been shown to occur with these practices (e.g., Kaye et al. 1999), the longer-term effects are harder to measure, and less well-understood.

Removal of forest cover by logging results in decreased evapotranspiration (use of water by plants) and increased streamflow (Bosch & Hewlett 1982; Callahan 1990; Stednick 1996; Swank et al. 2001; Troendle et al. 2001). In one watershed study, removal of 24% of forest in small clearcuts (3-7 acres) and haul roads resulted in a 17% increase in streamflow (water volume) from the watershed (Troendle et al. 2001). This was partly due to increased peak flows during storms, but mostly due to increased duration and frequency of water release. These changes mean a net dehydration of the watershed and increased chance of "scouring" flows in the affected creeks, which may negatively impact terrestrial, riparian, and aquatic plant and wildlife communities.

### 3.10.4 Mining

Mining operations can be split into surface and underground mining. Surface mining techniques, such as dredging, quarrying, strip mining, open-pit mining, and heap leaching, are used when the mineral ores are located within a few tens of feet (sometimes hundreds of feet in giant open-pit mines) of the surface. In all cases, the removal of vegetation and topsoil accelerates erosion. If runoff is not contained, sediment yield from surface mining can be enormous.

Underground mining involves excavation of vertical or inclined shafts and/or horizontal tunnels and mechanical extraction of ore to the surface. In another type of underground mining, a solvent is injected underground to dissolve the mineral of interest, and the resulting solution is pumped out for processing. Excavation exposes tunnel walls and the extracted tailings to oxygen and water, allowing chemical reactions to occur at far higher rates than with intact rock. Mining activity also allows the products of these reactions to be leached into groundwater and streams. The surrounding rock's mineral content and chemistry determine the potential for toxic metals (e.g., arsenic, chromium, lead, copper, etc.) and acids to be released from the site. Few areas in California have the acid mine drainage potential that is common in the Rockies.

The principal mining activity in California is sand and gravel extraction, the value of which far surpasses the combined value of all metallic minerals mined in the state (McWilliams & Goldman 1994). Because sand and gravel are critical to most types of modern construction, they are used in almost every road and building project. Utilizing aggregate sand and gravel sources near construction sites greatly reduces transportation costs, so this mining activity is dispersed throughout California.

Sand and gravel are often extracted from stream channels because deposits located within stream channels tend to have fewer impurities and are more durable than hillslope deposits. Aggregate mining in stream channels and floodplains has a variety of direct and indirect geomorphic consequences (Collins & Dunne 1990; Kondolf & Matthews 1993; Florsheim et al. 1998; NOAA Fisheries 2003). Excavating gravel or sand from a streambed changes the channel's hydraulic properties and interferes with the natural transport of sediment through the stream. For example, sediment in transport from upstream fills in the excavated area, reducing sediment supply to downstream reaches. Moreover, at the upstream edge of the excavated reach, channel slope and flow velocity are increased, and incision of the channel bed occurs, extending in the upstream direction (a process called headcutting). Thus instream aggregate extraction commonly causes channel bed erosion in both the upstream and downstream reaches. Secondary effects of the incision include loss of spawning gravels and an increase in bank height and bank erosion. Channel incision may initiate a lowering of the water table and associated losses of riparian vegetation. Gravel pits that are outside of an active channel can contribute significant amounts of sediment to a stream during mining activities, and sometimes present a flood hazard, through "pit capture." Floodplain aggregate extraction results in a loss of floodplain wetland habitat.

Suction dredging for gold in streambeds continues as an activity, more recreational than commercial, in the Klamath and Trinity river systems and in many streams on the west slope of the Sierra Nevada. While less intensive than commercial instream aggregate mining, the continuing disturbance of the streambed can potentially harm aquatic habitat, such as spawning and rearing sites for salmonids.

Watershed assessments should inventory and study both the current effects of active mines and the persistent effects of past mining. In areas once subjected to hydraulic mining, for example, some slopes may still be eroding at rates much greater than untouched hillsides, while downstream, large sediment deposits may still form unstable terraces high above a stream channel. Mercury may persist in stream channels where placer mining occurred and below ore-processing sites. Transformation of this elemental mercury to methyl mercury, a form more easily taken up by biota, introduces the toxin into the food chain and is the subject of current research. Heavy metals and other toxic leachates may be found in streams and groundwater below some mines and processing sites. Tailings piles and deposits should be checked for potential water pollutants. A good general reference on watershed impacts of mining is Nelson et al. (1991).

### 3.10.5 Grazing

Livestock grazing on California's rangelands can cause watershed impacts through changes in vegetative cover and soil conditions. When the number of animals and their access to streams and riparian are limited, the watershed impacts are modest and usually not noticeable. When the grazing pressure is great enough to restrict vegetative regrowth and compact the soil or cause direct impacts to streams and riparian areas, then the term overgrazing is descriptive. Overgrazing can remove most of the vegetative cover of an area, leaving the soil exposed to raindrop impacts, reducing infiltration, and accelerating erosion. The hooves of hundreds or thousands of livestock can also compact the soil, especially when the soil is wet. The combination of soil exposure and compaction can decrease infiltration and increase surface runoff. If infiltration capacity is severely limited on a large fraction of a watershed, the extra runoff can quickly reach streams and generate higher peak flows (e.g., Davis 1977).

Most of the concern about grazing impacts is associated with the riparian zone. Livestock gather in riparian areas for the water itself, as well as for abundant food and shade. Excessive streamside grazing that causes loss of trees, shrubs, and grasses along a stream affects the stream's shading and temperature and the stability of its banks. Without the protection of aboveground vegetation during high flows and the structural support of roots, stream banks erode back and develop shallower angles. This bank erosion eventually leads to channel shapes that are much wider and shallower than those of intact streams with vigorous riparian vegetation. Alternatively, some overgrazed streams begin an erosion cycle that results in a deep gully. When riparian areas are fenced off from other pastures and allowed to rest for a few years, the vegetation and subsequently the channels tend to recover remarkably well. A dramatic exception is where gullying has progressed to the point where the water table has been lowered, and the streamside meadows or riparian strips are literally high and dry.

The loss of vegetation cover and soil compaction also accelerates surface erosion. Many studies in the western United States have documented dramatic increases in sheet erosion and gully development in overgrazed sites compared to ungrazed sites (Fleischner 1994). The erosional effects of overgrazing add large amounts of sediment directly into the stream. The fine sediments tend to clog stream gravels and diminish spawning habitat for certain fish.

Concentrations of livestock in and around streams provide a direct pathway for nutrients and pathogens to enter the water (Springer & Gifford 1980). Animal wastes tend to be high in nitrates, a nutrient that is a water pollutant of concern. High nitrate loads promote the growth of aquatic algae, which can clog streams at low flow, as well as ponds and lakes. High levels of coliform and other bacteria have been found in streams with large numbers of livestock in adjacent areas. Good range and livestock management practices can help prevent or reduce impacts of grazing on the watershed. California recently completed a decade-long assessment of the status, trends, and challenges to California's rangelands (California Department of Forestry 2003).

### 3.10.6 Recreation

Impacts from recreational activities fall into two general categories: 1) localized effects, such as vegetation damage, soil compaction, and stream alteration that result from individuals visiting an area, and 2) large-scale effects, such as vegetation removal or conversion, creation of impervious surfaces, and engineered modification of stream channels that result from developing facilities to support recreational activities.

The individual recreational activities tend to have the greatest potential for watershed effects when they occur in and adjacent to a stream channel. Water is often a focal point for recreational activities, and streamside areas receive a disproportionate amount of recreational use within a watershed. Campgrounds, picnic areas, hiking and equestrian trails, and other facilities located near a stream provide easy access to water and contribute to degradation of riparian vegetation. As more people congregate along streams, the banks are trampled and the vegetation dies back, with impacts similar to riparian overgrazing (erosion accelerates and the channel changes form).

Off-highway vehicle use has both more intensive and more extensive effects on vegetation and soils than does non-motorized traffic, resulting in more loss of vegetation, more soil compaction, and more erosion. Operation of vehicles in stream channels kills aquatic and riparian vegetation, mobilizes sediments, and decreases channel stability.
Large-scale commercial recreational developments cause watershed impacts similar to those of other land use changes and conversions. Trees are cut down, roads and parking lots are built, topography is reshaped, drainage channels are constructed, and people congregate near water. These effects lead to changes in streamflow, accelerated erosion, and degraded water quality. Some developments require a substantial water supply, which may deplete local streamflow or groundwater. Two examples of large-scale recreational developments are golf courses and ski areas. Golf courses can transform the vegetation cover from deep-rooted species to shallow-rooted grasses requiring artificial irrigation and fertilizers. Developing a ski area involves permanent timber removal, major earthwork, extensive parking lots, and alteration of streamflow timing through snowmaking. Each of these changes leads to changes in streamflow volume, timing, and quality.

## 3.11 Water Management and Uses

Management of surface water resources occurs in the waterway and differs fundamentally from management of the landscape and resources other than water. Although land use changes and other resource management activities alter vegetation and soil properties that subsequently affect streamflow, water management avoids the intermediate steps and intentionally and directly changes the hydrologic regime. In many watersheds, this direct manipulation of the surface water alters flow, timing, and quality to such a great extent that the indirect consequences of land use change are incidental. In most cases, the measurable changes in streamflow or sediment delivery from a timber harvest or subdivision or other changes on the landscape are small compared to the hydrologic effects of dams that can store a large fraction of the annual runoff or diversions that can dry up a stream.

Management of groundwater resources is conceptually straightforward—deliberate control of input (recharge through ponds, canals, and injection wells) and output (pumping of wells). In practice, there is little true “management” of groundwater. In most areas, wells are just pumped to satisfy demand within any cost constraints, and there is no coordination or control of pumping. Groundwater management is rarely part of a watershed assessment but in many places should be. You should consider whether the topic warrants study in your watershed.

### 3.11.1 How Surface Water Is Managed

Water management includes all activities intended to change natural streamflow volume, timing, and location for the purpose of supplying water for human demands.

Water is rarely available directly from nature at a desired quantity, time, and place. Human individuals and societies have gone to extraordinary efforts to change the natural availability of water to be more suitable for their needs. Great engineering works have been constructed to hold back floods, store water for the growing season, and deliver water hundreds of miles away from its source.

Dams and diversions (any structure that facilitates removing water from a stream for the purpose of transporting the water to another location) alter streamflow in a variety of ways. A stream's hydrograph (a graph of how flow changes over time) is very different above and below a dam or major diversion.

Dams are constructed to alter streamflow timing. Water generated during the rainy or snowmelt season is captured behind the dam in a reservoir and released later to meet downstream needs (irrigation, municipal supply, hydroelectric generation, or instream flow, for example).

Depending on a dam's size and flood reservation (management guidelines that keep part of the reservoir unfilled at different times of the year as related to the flood risk), peak flows may be entirely captured behind the dam and slowly released later in the year at a controlled rate. Smaller dams lack the capacity to have much effect on the hydrograph of large floods, whereas downstream of a big dam, there may be no indication of the floodwaters pouring in upstream. During the portions of the year when flows would be low under natural conditions, water releases from a reservoir may increase streamflow several fold above its natural level.

While dams primarily affect streamflow timing, diversions send water elsewhere, reducing natural instream flow. Individual water user's diversions not associated with large dams may have little effect on hydrograph timing except during low flow periods. However, larger water storage structures usually involve both storage and diversion.

Reservoirs dramatically change a stream's sediment transport properties. When a river enters the placid water of a reservoir, it deposits almost all the sediment it was carrying.

Streams below dams contain much less sediment than they would in the absence of the dam. Accordingly, they have an enhanced capacity to erode and transport particles from the bed and banks of the downstream channel. Progressive lowering of the riverbed often occurs below new dams. Further consequences that can result include reduction of groundwater levels and consequent loss of riparian vegetation, reduction in overbank flooding, deposition of sediments and nutrients, bank erosion, and loss of adjacent land (Galay 1983). Severity of channel lowering depends on the size of particles in the bed, channel characteristics, reservoir operation, and the sequence of flood events following construction. The alteration of sediment supply and transport changes the streambed conditions that many fish require for successful spawning. The unnatural channel and bank conditions created by the sediment alterations can also negatively impact the establishment, growth, and survival of riparian vegetation. In some cases where dams prevent high flows from scouring the channel, the stream can become choked with vegetation.

### 3.11.2 Aquatic Habitat

The aquatic system in any stream has evolved in response to the natural hydrologic regime—long-term average flows and timing, as well as extremes. Water management is designed to alter those attributes of streamflow. Impounding water behind a dam converts riverine habitat into an artificial lake. The continuity of aquatic and riparian habitat is abruptly cut by the dam and its reservoir. Organisms that migrate in the channel or along its banks may no longer move freely up or downstream. The dam greatly alters the flow of water and sediment downstream. The temperature and chemical content of water released below the dam may also be very different from the natural conditions. Such changes fundamentally alter the conditions for aquatic and riparian organisms. Inevitably, water management impacts aquatic communities with dramatic changes in community structure, species mix, and populations.

### 3.11.3 Irrigation

Providing water for irrigation is the main reason for impounding water in California, particularly in the reservoirs of the Central Valley Project. The vast majority of dams in the state were originally intended to store water from the winter wet season and release it for irrigation during the summer dry season. Irrigation requires massive volumes of water—about 33 million acre-feet each year in California (Department of Water Resources 1998). Much of this amount is diverted dozens to hundreds of miles from its source. Where farms are located adjacent to streams and rivers, the irrigation water will be diverted locally, and your watershed will include both the source and area of use. Typical water application rates range from 3 to 5 feet of water over the irrigated area. These application rates vary widely by crop and location around the state (see box). The county farm advisor and district offices of the California Department of Water Resources should have good crop water demand estimates for local conditions. If you are estimating irrigation water use within your watershed, most of that amount can be assumed to evaporate.

**Typical application rates of irrigation water for various crops in California**. (Source: Department of Water Resources 1998)

| Crop | Range of Applied Water (feet) |
|---|---|
| Corn | 1.5 to 4 |
| Cotton | 2.5 to 6 |
| Rice | 4.5 to 7 |
| Tomatoes | 2 to 5.5 |
| Grapes | 1 to 5.5 |
| Orchard Crops | 1 to 6.5 |
| Alfalfa | 2 to 10 |
| Pasture | 1 to 9 |

### 3.11.4 Hydroelectric Generation

Generating electricity from water and gravity requires a different management regime than storing water for irrigation. Although large, multipurpose water projects generate electricity in concert with releases for irrigation, projects intended primarily for hydropower release water to maximize revenue. Such projects aim to generate electricity at times when electric demand and rates are highest, such as on summer afternoons. Unlike most other sources of electricity, hydropower-generating facilities can be turned on and off relatively quickly. Below some hydroelectric powerhouses, discharges related to power demands can fluctuate drastically over a few hours. In such cases, there is usually an afterbay immediately downstream that regulates releases back into the river.

The process for the federal relicensing of hydroelectric projects under the Federal Energy Regulatory Commission (FERC) provides an opportunity to re-evaluate flow release schedules from these types of dams.

### 3.11.5 Municipal

Water storage and diversion for municipal supply influence streamflow in many watersheds. Timing of this demand differs from irrigation in that there is a base level of demand year-round, but water use for landscaping increases significantly during the summer growing season. This may stress aquatic environments during the summer, when temperatures may become too high due to reduced flows. Runoff from urban areas (e.g., for landscape irrigation) may turn seasonally dry streams into perennial waterways.

Municipal water supply utilities may be a potential partner in watershed management and restoration activities because of their need for high-quality water.

### 3.11.6 Recreation

Managing water for recreational purposes is generally interpreted as maintaining high water levels in large, multipurpose reservoirs during the summer boating season. Inevitably, there are management tradeoffs that attempt to balance irrigation, hydropower, flood management, and flat-water boating in such reservoirs. Flood control agencies prefer empty reservoirs. Irrigators, power companies, and boaters all want reservoirs filled to capacity, but the boaters prefer that level to be constant and the power producers and irrigators want to drop that level in response to their respective demands. Water releases from a dam are closely associated with the reservoir levels. The interests of different groups of recreationists conflict over reservoir management. Lake boaters and lake fishers prefer that reservoir levels remain high, but whitewater boaters and stream fishers prefer that reservoir levels drop to provide greater streamflow.

Downstream of some recently re-licensed hydroelectric projects, water releases are designed to benefit white-water boating. A significant example is the July 2000 settlement agreement on the Mokelumne River. As conditions for obtaining a new license to operate a series of powerhouses, dams, and diversions, the operator (Pacific Gas & Electric Company) will modify the operation of its system specifically to enhance recreational opportunities on the river. The agreement establishes an annual schedule of water releases at levels requested by whitewater boating enthusiasts and businesses. The agreement also includes an adaptive management program that adjusts streamflow volumes and frequency of releases based on actual use. Streamflow in the Mokelumne River is now regulated on certain days at flows desired by recreationists—yet another variation on natural streamflow. Increasing summer flows to support whitewater boating are unlikely to mimic the low-flow conditions that were naturally present before the reservoir was built.

### 3.11.7 Import and Export

Trans-basin diversions can import water into a watershed or export water out of it. Imports and exports can have major effects on the water balance. Water entering or leaving the watershed through engineered channels can also alter the timing of flows in natural channels, assuming there is some storage facility involved in the water diversions.

## 3.12 Social and Economic Setting

Watershed assessments rarely focus on human communities, or, if they do, it is usually to list the resource activities communities are involved in. There are many facets to characterizing watershed communities. Some of these are economic descriptions, how people in a watershed make money, how many people don't make very much, and the net exports or imports of commodities. Some are demographic pictures, showing more about who the people are, their ethnicity, their population centers, their age, education, and income distributions. The hardest to quantify is the part of the community picture that shows how involved people are in watershed protection activities and therefore how likely it is that particular restoration, monitoring, or management approaches will succeed if community participation is required.

### 3.12.1 Watershed Communities

Because watersheds literally cover the earth's landscape, everybody lives in one.

The watersheds usually bear the name of the primary waterway, but human towns and cities only occasionally do. People may not identify with their watershed by name, but if there is any topography around, they are often aware that they are near a creek or river with a name. Certain economic, political, and social relationships depend on waterways and watersheds, for example, water diversion, county boundaries, and locations of towns and agricultural areas. The influence of the location of water on human geography is probably obvious. In the past, many towns sprang up where there was a water supply and fertile areas to grow or catch food (e.g., old floodplains and coastal areas). Now that water can be moved around in canals and pipes, and food can be imported, this is less of an issue.

Describing the interactions between human communities and watersheds is important because human activities and humans' perceptions of their environment are critical drivers in many ecosystems. Understanding how people are interacting with your watershed will provide information about potential impacts, likely future scenarios, possibilities for reduced impacts or restoring past impacts, and benefits to human communities of a naturally functioning watershed.

### 3.12.2 Economic Activity and Measures

[THIS SECTION IS UNDER CONSTRUCTION]

### 3.12.3 Characterizing Communities

If you characterize who lives in the watershed, you will have information to inform your decision making about restoration planning, the feasibility of monitoring, the need for education and outreach, and whether or not there is a constituency for watershed protection. The U.S. Environmental Protection Agency's "Community Culture and the Environment: A Guide to Understanding a Sense of Place" (U.S. EPA 2002) offers methods for this process. The guide's principles include: "holistic, place-based environmental protection efforts will lead to more effective long-term protection," "approaches [that] integrate ecological issues with local economic and social concern" help resolve or prevent environmental problems, and "tailoring environmental protection efforts to local realities and partnering with the community members leads to greater public support and involvement and, ultimately, to better environmental protection (U.S. EPA 2002). The handbook describes ways to characterize communities in terms of community capacity, demography, economics, and governing structures and provides various quantitative and qualitative assessment tools to develop a "community cultural assessment."

Another index of a community's character is the nature of its political activity. For example, Proposition 50 authorized the sale of bonds to protect watersheds and water supply. If 74% of the residents of a watershed voted against this proposition, then a watershed group planning Prop 50-funded projects might want to spend some time doing outreach and education to communities within the watershed to let them know what is happening. Information about community voting records at a watershed scale can be readily obtained with a GIS containing both the watershed boundaries and records from voting precincts. Because particular propositions can't really be called partisan in nature, they provide a politically neutral way to measure voter sentiments. There are other more direct and expensive ways to get this type of information. For example, surveying watershed residents about their preferences for watershed protection and restoration could provide important clues. If the watershed contains public lands, then the surveying should also include people outside the watershed who would then have a direct interest in management options for the watershed.

Although it may seem that information like this would only be interesting to a sociologist, the information might tell the watershed assessor a lot about likely attitudes and priorities for people in the watershed. Some of these will be obvious to a stakeholder group that represents the range of interests in a watershed, while some will be surprising. The worst-case scenario (which isn't really so bad) is that the watershed group discovers things they already knew, but now have numbers and other data to reinforce their intuitive knowledge.

### 3.13 Historic Context and Analysis

The condition of your watershed today needs to be interpreted in the context of historic changes since at least the time that European exploration and settlement began. Native American occupation appears to extend back 10,000 to 12,000 years, and their former use of the watershed is also important to understand, where possible. For some areas of California, European settlement began in the 1700s with the Spanish and Mexican occupation while in other areas, it was primarily the discovery of gold in 1849 that triggered the huge "American" influx. However, in the early 1800s, the Hudson Bay trappers came down from Oregon and extensively trapped the native beaver out of most of the state's streams where beaver could be found. Removing (or decimating) much of the population of this one aquatic mammal, which has a tendency to form woody debris dams in streams, may have had a profound effect on stream channel conditions, water storage, and hydrologic processes decades before the arrival of the gold miners and other early settlers.

Identifying the condition and use of a watershed's resources at the time of settlement can be a type of "baseline" for your assessment, though it will necessarily be a fuzzy one. Accounts of local tribal customs may indicate the role of fire as a tool for hunting or acorn production, or the role of fish and popular fishing sites. Initial observations from the first wave of European visitors (as noted in personal diaries, army reports, etc.) can offer valuable insights into the condition of vegetation, streamflow (with extremes of drought and floods most commonly noted), and wildlife, for instance. Sometimes crude maps were drawn to identify trails or boundaries, and some useful landscape impressions or landmarks were perhaps noted (e.g., "hills covered with timber"; "creek dry"). Of course, geographic place names on old or current maps are another source of which natural resources in that area seemed to initially impress the pioneers: "Deer Creek", "Salmon River", "Dry Gulch", or "Beaver Valley", for examples.

The next step is to identify the location, timing, and the extent of changes in land and natural resource uses that could have affected the watershed's condition between settlement and the present. Such human uses include: roads, mining, logging, farming, grazing, urbanization, water development and use, hydropower, fishing, hunting, etc. Patterns of landscape disturbances also need to be described, such as the dates and size of wildfires, floods, and droughts. A chronology of events by year or decade can summarize the major changes. Old maps and landscape photographs can depict the changes even better.

Without knowing the context of land, water, and other environmental changes over time, our interpretation of the watershed's condition today could be missing the real reasons or causes. A devastating fire back in the 1920s might have altered the soil and therefore the vegetation types in one area; gravel mining to help surface a new highway in the 1960s might have rerouted the channel; a small dam built in 1900 but removed in 1970 might still be causing sediment and channel impacts. These are just a few examples of the richness in interpretation that can be gained in your watershed assessment through a good historical evaluation of natural resource uses and changes. With this understanding, then the "ah-hah!" light bulb may go on and we can become more realistic in the next phase after the assessment – what to do next.

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# 4 Collecting and Organizing Existing Data

Collecting and organizing data is a key part of a watershed assessment. It makes sense to begin by collecting existing data. If you identify data gaps and if you have the resources, you might decide to collect new data as well. This chapter addresses the issues of how to collect and manage all types of data. Specific approaches for collecting new data in association with a watershed assessment will be discussed in detail in the Appendix to the Manual.

**Chapter Outline**



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### 4.1 Overview and Key Considerations

Data are "known facts or things used as a basis for inference or reckoning." Data pertinent to watershed assessment may include quantitative measurements, qualitative information (e.g., observations of a species' presence), maps, anecdotal information, photographs, and other "facts" relevant to the watershed assessment.

Collecting data can be both time consuming and labor intensive. Therefore, you should focus your efforts on the specific questions you've identified for your watershed. The extent of your data collection will hinge on how complex and detailed your assessment will be. There should be a direct path from the questions you are asking about the watershed to the types and amounts of data you collect within the project timeframe.

Gaps in knowledge—questions that cannot be answered within the project timeframe and currently available budget—should be identified to indicate the nature of any remaining uncertainty and to prioritize data needed for future assessment.

#### 4.1.1 Types of Data

Data types can be broadly classified as numeric and spatial. Numeric data can be highly quantitative, semi-quantitative, or qualitative. Examples of quantitative data include most water quality and flow data. Semi-quantitative data might include data that involves scoring habitat characteristics based on standards that might be interpreted differently by different people. For example, characterizing stream bank stability might involve an estimate of the percentage of the bank covered with vegetation. Frequently, this is estimated visually, not by actual measurements. Biological surveys often fall into this category. Qualitative data is descriptive. For example, anecdotal data describes conditions based on observation of a single or a few individuals. The observation that the pools in the stream have filled up with sediment over the past 20 years is one example. This is very useful information, even though it is not quantitative. Spatial data is data that has a geographic reference point. It can be quantitative, semi-quantitative, or descriptive data that is located at a point or area on a map.

As data are collected, they should be organized in a manner that suits the questions being asked and the users' needs. Because watershed assessment usually involves the collection of several different types of data, consider developing file organizational systems for each type of data that conform to a single standard for categories (e.g., wildlife habitat, water quality, land use). One way to keep track of information collected is to make a database of the category types. If you will be collecting data for aquatic and terrestrial systems and of various different types (i.e., from text to digital spatial data), then keeping track of the types of data and the areas they cover will help in both organizing the data and describing how much of the watershed they cover.

### 4.1.2. Evaluation of data

Once you find a few reports or data sets for your watershed, look them over with a critical eye. When examining past reports, ask yourself if the conclusions make sense and whether the supporting evidence justifies them. Check to see whether there was any sort of external or peer review. It is important that collection of data include a critical analysis of the methods used to obtain the information. Sample design, frequency of sampling, exact type of measurement made, and analytical technique, can all affect the usefulness of data you find and want to use. Not infrequently, streamflow gauges are not serviced regularly and therefore, produced unreliable data on flow rate. Verify their accuracy with knowledgeable people. Compare findings from different reports to see if they corroborate each other. There may be a legitimate reason why two reports may seem to be in conflict, based on different methods, objectives, assumptions, dates, biases, etc.

Consider establishing a record/database of information attributes that describe its usefulness (e.g., date of collection, source, purpose, scale, peer-reviewed, etc.). An example of this is in the North Coast Watershed Assessment Program Mattole watershed assessment report (http://www.ncwatershed.ca.gov, select Mattole watershed and the table is in the Appendix) and an excerpt is shown in the box below.

When citing information for your assessment, check the original document for its methods and conclusions. Avoid contributing to the all-too-common rumor chain of many environmental documents that sequentially misrepresent an original reference by citing a secondary source that misinterpreted the original. Do not ignore or disregard data just because they don't seem to "fit" or because they run counter to preconceived expectations of what the data should say. During the Data Analysis process, the various data sources can be evaluated for quality and deficient sources can be discarded.

**Mattole River Watershed, NCWAP DATA CATALOG**

| Name | Source | Description | Data Quality | Metadata | Analytical Use in NCWAP |
|---|---|---|---|---|---|
| surveys | | major Mattole River tributaries conducted during 1938 and 1985. | unknown | | stream habitat surveys. |
| Stream fish inventories | DFG | Stream fish inventory data for Mattole river, north fork Mattole river, squaw, mill, Thompson, baker, and bridge creeks. | Not digital. Quality unknown | No | Comparison with current in-stream habitat surveys. |
| Stream flow data | DFG | Stream flow data for the Mattole river, 1976. | Not digital. Quality unknown | No | Comparison with current in-stream habitat surveys. |
| Historic photos | Froland | Historic photographs of the Honeydew slide. 1983 | Not digital. Quality unknown | No | Historic geological information |
| Erosion data | MSG | Aerial photo interpretation of erosion in the Mattole river basin | Not digital. Quality unknown | No | Historic geological information |
| In-stream habitat data | DFG | In-stream habitat data for yew, barnum and dream stream creeks. | Not digital. Quality unknown | No | Comparison with current in-stream habitat conditions |
| Fisheries data | DWR | Unspecified fisheries data, north coast basins. 1962. | Not digital. Quality unknown | No | Comparison with other fish population data. |
| Erosion and sedimentation data | MRC | Sediment source and erosion data for the Mattole watershed. 1989. | n/a | n/a | Historic geological information |

Data obtained over the internet, a common source of information, has particular limitations. Until the mid-1990s, most agencies and organizations did not put their data and reports online. Only a small number of older reports have been scanned in, such as for special digital libraries (e.g., Shasta College's WIM project, http://wim.shastacollege.edu/default.aspx; U.C. Berkeley's Digital Library Project http://elib.cs.berkeley.edu/). The University of California's MELVYL online catalog does not go back earlier than 1971 for the documents it lists, although its vast

**Sources for Watershed Assessment Information**

*Previous watershed assessments*

*Local Government*

County or city
- General plan
- Master environmental assessments
- Specific plans and environmental impact reports for projects
- Local enhancement or restoration plans
- Departmental documents and data (planning, public works, agriculture, environmental health)
- Flood control plans, documents, and data

Water supply, irrigation, and other special districts—reports and data

*Local Organizations*

Resource Conservation Districts (RCDs) —annual reports and documents
Watershed groups—documents
Conservation groups (e.g., Friends of the XXX Creek/River) —reports

*State of California Agencies*

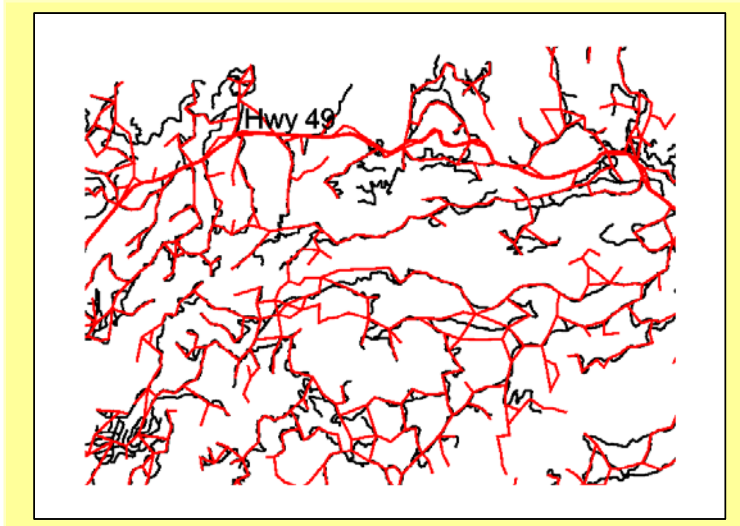
Regional Water Quality Control Boards
- Basin plans
- Monitoring studies
- Total maximum daily load (TMDL) studies and determinations

State Water Resources Control Board
- Water quality reports and data
- Water rights reports and data

California Department of Forestry and Fire Protection—timber harvest plans (THPs), maps, data, and documents
State Park Management Plans
California Department of Transportation
- Highway environmental impact reports
- Monitoring data on road runoff

California Department of Fish and Game—documents and data, land management plans
California Geological Survey (Division of Mines & Geology) —documents and data
California Department of Water Resources—documents and data
California Coastal Commission and Coastal Conservancy—documents and data
California State Lands Department—documents and data

collection of historic documents and maps for California goes back to Spanish land grant days. You should consider seeking out data by visiting and looking through traditional libraries and agency filing cabinets. They frequently contain historical data and information that can be invaluable.




### 4.1.3 General Sources of Data

One good place to start collecting data is to use an Internet search engine like Google to search for the names of rivers and their tributaries in your watershed, as well as other relevant place names and topics. Your search results may return thousands of links so it is important to selectively narrow your search terms until you find items of interest. You may find that reports you really want are only available in libraries and at local agency offices. The U.S. Geological Survey has an online database of publication abstracts that can be searched by theme or location (http://usgspubs.georef.org/usgsns.htm). Many state agencies and federal agencies post reports online—use the search engines for their sites to search for the name of your watershed or waterway.

### 4.1.4 Spatial and Temporal Scale of Data

Data collected at scales that you cannot control constrains the use of that data in new analyses. Your task as the assessor is to know the scales at which data were collected and determine the kinds of analyses you can conduct and the decisions you can make based on these data. The scale of data will be associated with any well-developed set of data or obvious from the data distribution (e.g., monthly water quality samples from the same 10 sites in the watershed over 3 years). Be aware that, some of the information that an assessment relies upon as "data" may actually be products of computer models (e.g., for wildlife habitat, fire hazard, and landslide risk), which potentially increases the range of uses of data, but not necessarily the reliability.

Frequently, you will encounter a mix of data scales. Some spatial data will be low resolution and tell you only generally what kinds of plant community, land ownership/use, hydrology, and geology are present. Some temporal data, say for water quality, may be high resolution if they were collected continuously or at frequent regular intervals over a long time. Your knowledge of flow in your watershed will probably be based on very few regularly maintained streamflow gaging stations, due to the gradual loss of this critical data resource in California. On the other hand, water quality monitoring may have taken place in your watershed, with regular collection of periodic and storm event measurements. Most information about non-point source pollution, natural condition, and decisions about combined land and water management comes from the combined measurement of flow and water quality constituents. Sometimes water quality data alone are the basis for management decisions.

In general, when you combine scales, the resolution of your analysis product is the same as the lowest resolution input data.

Provided below are some guidelines for your actions related to watershed assessment based on the more established principles in the scientific disciplines where scale is important.

- *Spatial Scales*

The term spatial scale refers to two characteristics. In everyday usage, the term refers to the extent of the area covered by a dataset, which is useful when talking about the "scale" of a project or analysis. However, more technically, spatial scale refers to the fineness of the resolution of the data. For example, the Natural Resource Conservation Service (NRCS) is gradually mapping soil formations across the country at a resolution of 1:24,000, which translates to a six-acre minimum unit size for a soil area (http://soils.usda.gov/technical/manual/). The spatial scale at which this data should be used is a minimum of six acres. In ecology, this characteristics is referred to as the "grain" of the spatial data. You could use the data at finer scales (e.g., one acre), but uncertainty would increase because the data was designed only to provide a coarse overview of soil types. To use this relatively coarse data to describe soils in smaller units could lead to misrepresentation and errors. Therefore, it is important to consider the grain of the data when you collect spatial data so you can use it appropriately when you get ready to analyze your findings.

The NRCS data would provide good resolution for a large watershed assessment where the goal was decision-support at the creek sub-watershed, agricultural parcel, or U.S. Forest Service road-segment scale. However, at finer spatial resolution, say for hillslope stabilization, small timber harvest planning area, and protection of rare plant communities in developing areas, you might want a new field survey of soils that has a finer spatial scale.

In some cases, the accuracy of commonly-used spatial data can be a concern. For example, the quality of road data is generally poor in California, in terms of actual road position, road type and condition, and road length. At the scale of a creek watershed, it might be critical to know the points of interactions between the roads and the creek, riparian areas, and slopes. The map example above shows the data available from the TIGER database (1:100,000 TIGER data from the Teale Data Center, in red or light color) and those developed by the Tahoe National Forest (TNF) (in black, from a combination of GPS and aerial photos). Within the TNF, road system and watershed analysis can take advantage of higher resolution data, potentially leading to higher resolution decision making. Outside the TNF boundary within the same watersheds, only TIGER data is available, so the data scale coarsens

**Examples of typical types of data collected in a watershed assessment and the optimal scale for these data**

| Type of Data | Temporal/Spatial Scales |
|---|---|
| Contaminants in water | Throughout the year and immediately after rain events; above and below sites of concern (storm drains, road effluent, wastewater treatment plants). Ideally, regular monitoring over many years. |
| Sedimentation | In streambed, on hillslopes, below roads, primarily following storm events, in smaller streams and periodically in smaller and larger waterways |
| Dissolved oxygen, temperature | Weekly or monthly in all sub-watersheds of the stream |
| Road maps | 1:24,000, updated every five years |

and the analysis suffers resolution, leading to lower resolution decision making.

If you are fortunate enough to be able to collect new data using a monitoring or assessment program, you can set the scale of data collection to match your analysis and decision needs. Selecting the correct scale for monitoring isn't easy. Some of the material referenced in this manual might be of use, but you should seriously consider consulting with an expert so you can get the most from your investment of time and money.

- *Temporal Scales*

Most data that you will use will have a time element. It will either be a single point in time for an observation or measurement, multiple points in time (e.g., daily or weekly) over a certain period, or continuously measured. A water quality measurement or grab sample is a snapshot of conditions, which may be accurate for that hour or day, but loses accuracy as you generalize across time (e.g., to a month). Measurements of aquatic insect communities may be accurate for estimating conditions over the population and individual life spans (months to years), but only in extreme lethal conditions will it tell you much about shorter timeframes (e.g., days). A satellite image that is used to model likely plant communities captures conditions today and will be relatively stable (potentially over years) unless there is an abrupt removal or replacement of the vegetation due to plant community restoration, logging, fire, agriculture, or urban development. The time scale over which new data are collected is another consideration. A one-time grab sample may be all you are able to collect, and it is better than nothing. However, it will provide a limited picture of reality. For example, in some eastern Sierra Nevada streams, episodic events of low pH are associated with snowmelts that are of short duration, but may be lethal to trout. In this case, collecting samples that reflect the extreme conditions, not the average pH, is crucial. Sampling over a short timeframe could totally miss these events. Data should be collected over the period of time in which you would expect to see changes and/or when there is the greatest likelihood of detecting infrequent, but important, events.

The sample list in the text box below is an easy way to keep track of key considerations when evaluating the scale of your data. It will be particularly helpful later in the assessment when you begin data analyses and integration. WQ refers to water quality evaluation; LFA refers to limiting factor analysis, which is a way of discovering environmental conditions that are limiting survival of a species (e.g., salmon). These kinds of metadata

**Scale Reference List**

| **Data type** | **Use** | **Spatial scale**<br>**Spatial units** | **Temporal scale**<br>**Time units** |
|---|---|---|---|
| Dissolved Oxygen | WQ, LFA | Station | Monthly, hourly, event |
| Temperature | WQ, LFA | Station | Continuous |
| Road map | GIS, erosion | 1:24,000 | 5-year update |
| Employment Sectors | GIS, community characterization | census blocks | 10-year update |

(information about your data) are important when deciding on appropriate uses of the assessment and additional data collection.

## 4.2 Sources of Numerical Data and Information

The availability of hydrologic and water-quality data on the Internet has thoroughly transformed the hunt for watershed data in recent years. Rather than conducting long searches and even longer copying and transcription sessions in libraries of distant universities and archives of local agencies, an amazing amount of material is now accessible from any computer connected to the Internet. Online resources do not eliminate the need to seek specialized and unpublished information from a variety of sources, but your office computer is now a convenient place to start your search for data.

The U.S. EPA's "Surf Your Watershed" Web site (http://cfpub.epa.gov/surf/state.cfm?statepostal=CA) is a good place to begin. An interactive map will direct to your region. This site provides links to a variety of other Web sites and resources that may be useful in your search for watershed data. The number of links on EPA's site varies tremendously, depending on the watersheds. Also, smaller watersheds tend to be combined together with other ones to form larger units. Data records may be incomplete.

The U.S. Geological Survey (USGS) is a repository for the nation's water data. Your search for USGS data can begin at http://ca.water.usgs.gov or http://waterdata.usgs.gov/ca.nwis/nwis. The USGS Web site contains primarily flow information, although for some sites there is water quality data as well.

### 4.2.1 Water and Sediment Quality Data

Water quality data include information on both the water column and sediment. Categories of data include: suspended sediment, temperature, dissolved oxygen, nutrients (e.g., phosphates), organic and inorganic chemicals such as pesticides and pharmaceuticals, dissolved organic carbon, pH, etc. Changes in these water quality parameters can occur in response to natural processes, human activities, and the interaction between human activities and natural processes. The data can be collected through grab sampling (i.e., scooping up a volume of water) and continuous sampling/measuring.

The importance of data on the water column is clear—fish and most other aquatic organisms live in and breathe the water. Water quality problems can affect these organisms' respiratory (gills), excretory (kidney), reproductive, nervous, and cardiovascular systems. Often, the effects of poor water quality on the organism(s) of interest are not obvious. If poor conditions persist, however, or if the concentration of the harmful constituents is high enough, mortality will result. Many toxic chemicals found in surface and ground water are carcinogenic, can cause tumors in fish, and/or attack the nervous or endocrine systems.

Sediment contaminants have the potential to affect all aquatic organisms as well. Frequently, invertebrates living in sediment will accumulate contaminants. These animals are subsequently eaten by fish, which concentrate the contaminants, so the fishes' exposure is actually greater than the chemical's presence in the environment. In this way, fish (or things that eat the fish) that normally wouldn't be exposed to a contaminant can be harmed.

Many non-water soluble contaminants are primarily found in sediment. Pesticides, such as DDT (now illegal), persist in sediment for very long periods of time. Sediment contaminants can diffuse into pore-water, the water between streambed particles. Depending on the contaminants' solubility, diffusion occurs at different rates.

Compounds found primarily in sediment include PCBs, DDT, dioxins, and many polycyclic aromatic hydrocarbons, byproducts of fossil fuel combustion. Pyrethroid insecticides, such as esfenvalerate, and metals are also primarily found in the sediment. Measurements of these chemicals in the water column do not give a true picture of their presence in the waterway because their highest concentration is in sediment or pore-water, the water found between the streambed material.

Water and sediment quality data will generally be used to evaluate conditions by comparing data from your watershed to standards. These standards, promulgated by the U.S. EPA, USGS, and/or the State Water Resources Control Board, contain benchmark values for acute and chronic exposure to dissolved oxygen, nutrients and other conventional water quality parameters as well as contaminants such as organics, pesticides, and metals. These benchmarks reflect the highest concentration of a contaminant to which an aquatic organism can be exposed without risking adverse effects and will allow you to estimate whether water and sediment conditions pose a risk to the important ecological resources included in the watershed assessment.

#### 4.2.1.1 Sources of Information on Water and Sediment Quality

*1. STORET*

The primary source for water quality data is the U.S. EPA's STORET system (http://www.epa.gov/storet/dbtop.html). STORET has recently been split into two separate entities: the Legacy Data Center (LDC), a static archive containing historical data collected through 1998, and STORET, the modern system.

STORET contains data collected since January 1, 1999, and older data that have received current levels of documentation.

The current STORET program is available to users who wish to organize their water quality data under the STORET protocols on their own computers. Users can upload these local files to the central STORET system and make the data available through the STORET Web site. As of July 2004, the "Modernized STORET Data" site did not contain many California data, in contrast, the "Legacy STORET Data" site did.

Both the LDC and STORET contain a wide range of chemical, biological, and physical data under the broad heading of water quality. A diverse assortment of people, agencies, and organizations collected these data for a myriad of purposes with the common goals of making the data available to the public. Each water quality value is associated with information on where the sample was taken (geographic coordinates, state, county, USGS Hydrologic Unit Code, and a brief site identification), when the sample was collected, the medium sampled (e.g., water, sediment, fish tissue), and the name of the organization that collected the sample. In addition, STORET contains information on why the data were obtained; sampling and analytical techniques used; the laboratory that analyzed the samples; the quality control checks used when sampling, handling the samples, and analyzing the data; and the people responsible for the data. EPA's general description of the STORET database (http://www.epa.gov/storet/descript.html) provides additional details. The Pennsylvania Department of Environmental Protection's Web site offers detailed instructions for navigating through both the LDC and STORET (http://www.dep.state.pa.us/dep/deputate/watermgt/Wqp/WQStandards/STORET-Access.htm).

Depending on your data requirements and computing options, there may be some advantages to obtaining the EPA STORET (both legacy and modern systems) on CD instead of via the EPA website. Two companies publish CDs of the EPA water quality data (http://www.earthinfo.com and http://www.hydrosphere.com).

*2. USGS*

Water quality data from discrete samples are accessible from the USGS's Web site http://waterdata.usgs.gov/ca/nwis/qw. Under the "Tutorial" button are instructions for accessing water quality data in watersheds. You can get to your watershed of interest quickly if you already know the USGS hydrologic unit code. Otherwise, navigate to your watershed by starting with your county. Depending on what, if any, data are available for sites in your watershed, you can specify a variety of output formats to meet your needs. The USGS has a good summary of its procedures for sample collection and onsite measurements at http://ca.water.usgs.gov/archive/waterdata/text/onsite.html. More detailed information can be found in the USGS reports, Techniques of Water-Resource Investigations, at http://water.usgs.gov/pubs/twri/.

USGS has 35 sites in California equipped with continuous monitoring sensors and telemetry gear that allow reporting of near-real-time measurements and the record of the past 31 days (http://waterdata.usgs.gov/ca/nwis/current/?type=quality). Under the menu for "Available data from site", select "Recent daily" to obtain daily values of the onsite measurements for up to two years. Most of these sites only report water temperature, but some also measure conductance, dissolved oxygen, pH, and turbidity.

*3. State Water Resources Control Board (SWRCB) and Regional Boards*

Water quality data from the Central Coast Regional Water Quality Control Board's Central Coast Ambient Monitoring Program is available at http://www.ccamp.org. Here you can navigate to a sampling location or water body and then view a summary table of attributes and values. Alternatively, you can first choose "Monitoring Data" for dozens of water quality parameters organized under categories of conventional water quality, freshwater invertebrates, hydrocarbons, metals, and organic chemicals. This path allows you to compare summary values among sampling locations.

The SWRCB is developing the Surface Water Ambient Monitoring Program (SWAMP) (http://www.swrcb.ca.gov/swamp), a Web-based source of water quality data that aims to coordinate and compile data programs of several agencies within California into a common database. SWAMP and a broader Water Information Network are anticipated to be active in the near future.

Water quality standards for each stream in California, based on Regional Board basin plans, can be found on a GIS-based inventory developed by Caltrans' Environmental Program (http://endeavor.des.ucdavis.edu/wqsid/). Queries can be by waterbody name, beneficial uses, regional board, county, or keyword search.

Finally, the Regional Boards perform toxicity tests in accordance with U.S. EPA guidelines on rivers and streams throughout the state. Although not presently published anywhere, this data is public information.

*4. Additional Sources of Water Quality Information*

- Water Data Library Web site (http://wdl.water.ca.gov/)—California Dept. of Water Resources (DWR). Water quality data, access to hydrologic data (searchable by station and county) collected by the Division of Planning and Local Assistance and other groups within the department, and information on a wide variety of chemical contaminants, such as pesticides and metals, as well as conventional parameters, such as conductivity and hardness.

- The California Digital Conservation Atlas (http://www.legacy.ca.gov) —the Legacy Project at the California Resources Agency. An Internet map-making site with a wide variety of water quality data (under the Environmental Stressors tab) for certain waterbodies in California; data from the Musselwatch Program, Toxic Substances Monitoring Program, and others can be identified on stream and waterbody maps of streams and waterbodies throughout the state; information on contaminants in water and data on toxicity tests, which involve exposing model organisms, such as a water flea or amphipod, to water or sediment samples and measuring mortality or other biological endpoint. These tests do not identify the reason for the toxicity, but they are an excellent way to determine if anything in the water/sediment might pose a risk to aquatic life. You will need to determine the cause of the toxicity independently.

- Surface Water Monitoring Program database (http://www.cdpr.ca.gov/docs/sw/surfdata.html) —The Department of Pesticide Regulations. Data on pesticide concentrations in waterways throughout California, not just agricultural regions.

- Drinking Water Program (http://www.dhs.ca.gov/ps/ddwem/technical/dwp/dwpindex.htm) and Drinking Water Source Assessment and Protection Program (http://www.dhs.ca.gov/ps/ddwem/dwsap/DWSAPindex.htm)—the California Department of Health Services. Information and data on the quality of water used for drinking water supplies. The Web site of the Drinking Water Program also has a fairly thorough directory of other potential sources of data (http://www.dhs.ca.gov/ps/ddwem/dwsap/DWSAP_directory.htm). Contact your county health department and local water-supply utilities for water quality data for local water supplies (surface water and groundwater).

- United States Forest Service (local offices)—water quality studies and monitoring on local water bodies for watersheds that include any national forest lands.

- Data from aquatic bioassessment work (http://www.dfg.ca.gov/cabw/cabwhome.html)—California Department of Fish & Game. As of 2003, a centralized results database did not exist, but SWRCB has recognized the need for such a database (Tetra Tech, 2003).

#### 4.2.1.2 Hydrological and Climate Data

Information and data about your watershed's hydrology are critical components of any watershed analysis, although data have not been collected for many, if not most, watersheds. Streamflow is particularly important for addressing concerns about flooding, aquatic communities, and water quality in your watershed assessment. The availability of hydrologic data largely depends on whether some agency thought the water in your stream had some utility, either locally or for export. If there are major or formerly proposed water engineering projects in or near your watershed, then there is a high likelihood of current or historic stream gauging stations. If your stream is an un-dammed tributary that doesn't supply water to municipalities, hydroelectric facilities, or irrigation districts, the stream is unlikely to have a gauging station. The main exception is if flooding concerns exist. Many small streams and creeks near urban areas contain gauging station for flood control purposes. In general, where there is concern about the waterway, there are more gauges and measurements.

*Flow Data*

Streamflow data come from three basic types of measurements: 1) continuous records of stage (water level) and discharge at a calibrated cross-section, 2) spot measurements, and 3) crest-stage gauges (where only the highest water level is recorded). From a watershed assessment perspective, the most useful data comes from a long-term continuously recorded stream gauge (#1 above) that has measured daily or monthly streamflow for the past few decades. Gauging stations typically record stream stage at 15-minute intervals. Corresponding discharge is then calculated from a rating curve based on manual measurements of instantaneous discharge across the channel cross-section and stage at time of the measurement. Some stream gauges may not have a recording device, but instead rely on manual observation of a staff gauge (basically a well-anchored ruler from which an observer can read the water level) approximately once a day. Such gauges are common in irrigation ditches and sites with full-time staff. Chapter 3 presents fundamentals of stream gauging. For more detailed information, see Dunne and Leopold 1978:594-598;Hornberger, et al. 1998:100-103) or the USGS Web sites: http://ca.water.usgs.gov/archive/waterdata/text/explain.html and http://water.usgs.gov/pubs/twri/. If the gauging station is in close proximity to a dam or diversion, both the actual flow at the location and a calculated value that includes diverted water or changes in reservoir storage may be reported.

Spot measurement data is generated from occasional measurements with a current meter (device that measures the local speed of the flowing water) or other technique (e.g., Herschey 1985). Unless there is little streamflow variability, such measurements do not reveal much information about the long-term characteristics of streamflow. If such data are all you have, interpret them with caution because a lot can happen in between the measurements. Spot measurements can be valuable longitudinally along a stream when streamflow is measured at several places up and down a channel on the same day. In this case, you can learn how much streamflow changes in the downstream direction as the contributing area increases. These longitudinal studies are also useful for measuring the effects of diversions, irrigation return flow, and subsurface hydrogeology (where the stream is naturally gaining or losing water to the alluvial aquifer).

Maximum water levels (high water marks) from crest-stage gauges generate data useful in flood studies where installation and maintenance of many recording stream gages is not feasible. Crest-stage gauges can be as simple as a vertical pipe containing a ruler and a marker with a few holes in it to allow water to flow in and out. This marker can be something that floats, such as cork particles, and adheres to the ruler at the highest water level or something that dissolves in water and has been applied to the ruler. After an increase in streamflow, a hydrographer (one who measures water) removes the ruler and records how high the water rose in the pipe (and therefore the stream). Estimating the corresponding discharge is difficult and involves considerable uncertainty (often +/-50% or more). Nevertheless, such data are often the only estimates of peak flows.

Although not strictly streamflow, another common type of hydrologic data is estimates of volume in lakes and reservoirs. Similar to stream gauging stations, the lake's or reservoir's water level is observed (either visually on a staff gage or with a water-level sensor and recorder), and the volume is calculated from an equation or table relating water level and volume.

The USGS is primarily responsible for the nation's water data, including streamflow. Navigating USGS streamflow data is easiest when you have the USGS gauge numbers, which have a structure similar to USGS hydrologic unit codes for watersheds. From USGS entry portals http://ca.water.usgs.gov or http://waterdata.usgs.gov/ca.nwis/nwis, you can easily get to a site selection page and enter your county or a pair of latitudes and longitudes to begin your search for stream gages in your watershed. USGS publishes a series of schematic diagrams of the major river basins in California that are very helpful for understanding the geographic arrangement of tributaries, stream gages, and major dams and diversions.

Keeping a copy of the relevant schematic(s) for reference while navigating USGS data archives will aid your search. These schematics can be found within four regional volumes (Vol. 1 – Southern California, Vol. 2 – Central and North Coast; Vol. 3 – Southern Central Valley and Great Basin from Walker to Truckee; Vol. 4 – Northern Central Valley and Northern Great Basin) for California. Volumes for 1999 through 2002 can be downloaded as .pdf files from http://ca.water.usgs.gov/archive/waterdata/. Older volumes can be found at most university libraries and in some offices of public agencies.

Another important piece of information within these volumes is the list of discontinued gauges (online at http://ca.water.usgs.gov/archive/waterdata/99/disc_sw.html). Information about stream gages, or what the USGS calls a "station manuscript" (precise location, drainage area, period of record, summary of extremes, etc.), that were in service between 1994 and 2001 can also be found at http://ca.water.usgs.gov/archive/waterdata/ The search function here works best if you have the gauge number or if the name is unique. Common names like "Clear Creek" will yield thousands of results.

Although the USGS portal (http://ca.water.usgs.gov/archive/waterdata/) provides annual tables (flat files) of daily discharge values for gauges operated between 1996 and 2001, you may wish to obtain more data in a format that can be manipulated on your computer. For access to more thorough data after you know what sites and periods of record are available, go to: http://waterdata.usgs.gov/ca.nwis/sw or http://nwis.waterdata.usgs.gov/ca/nwis/discharge.
Graphical output is also an option. A tutorial on accessing historical streamflow data is available at http://nwis.waterdata.usgs.gov/tutorial/historical_streamflow.html.

In addition to daily streamflow values, USGS also publishes data of the highest annual flows over the period of record for selected sites. Access the peak streamflow database at http://waterdata.usgs.gov/ca/nwis/peak. Again, your progress will be fastest if you already have the station ID number.
You can specify the output format and file information.

Depending on your data requirements and computing options, there may be some advantages to obtaining USGS streamflow on CD instead of via the USGS Web site. Two companies publish CDs of USGS daily streamflow and peak flow data (http://www.earthinfo.com and http://www.hydrosphere.com).

Other sources of streamflow data include water districts, municipal utility districts, irrigation districts, hydroelectric generating companies, the U.S. Forest Service, and any other local entity that needs to measure streamflow. Data from such sources may not be available online and may require a personal inquiry to the agency or company. Some records are not considered public information and may not be available. In cases where the data are not public records, be prepared to make a good case for your need, demonstrate that release of the data will not be harmful to the supplier, and be prepared to pay for staff time to copy or otherwise prepare the data for you.

Local or regional flood control agencies may also have streamflow and stage data. This data is often available on the city/county websites and serves as a warning system for local residents. Because some stations may not be maintained carefully due to local budget constraints, ask local public utilities department engineers about the data's accuracy.

The California Department of Water Resources' Division of Flood Management maintains the California Data Exchange Center (CDEC) at http://cdec.water.ca.gov, which provides very recent and real-time data in response to flooding (i.e., real-time river stages) and for water project operations. If you need current daily and monthly streamflow and reservoir data, see this site.

*Climate Data*

Climate data are also available from CDEC at http://cdec.water.ca.gov. Select "Precipitation/Snow" from the menu "CDEC Resource Directory" for a list of precipitation stations where you can select an individual station and obtain the latest data. At the bottom of a page for a particular station, select "Historical Data" to get to the "Bulk Data Selector". Using the three-letter station code from the previous page, specify the data, period of record, and output format. A pair of interactive maps for locating stations with available data can be found at http://cdec.water.ca.gov/cgi-progs/mapper.

The Western Regional Climate Center in Reno, Nevada, is the other major source for precipitation, temperature, and other climate data. Begin your search at http://www.wrcc.dri.edu/CLIMATEDATA.html. Interactive maps with locations of climate stations are available for Northern California (http://www.wrcc.dri.edu/summary/climsmnca.html) and Southern California (http://www.wrcc.dri.edu/summary/climsmsca.html). After selecting a particular site, you will obtain a monthly summary over the period of record and a menu for accessing more detailed information for the site.

### 4.2.2 Riparian Vegetation and Wetlands Data

The riparian zone is where the aquatic and terrestrial landscapes come together and where species from both environments benefit. As a result, riparian data collection generally reflects both aquatic and terrestrial ecosystems. Description of riparian habitat generally involves interpretation of aerial photography for large watersheds (>100,000 acres) and field surveys for small watersheds (10,000 acres) or parts of large ones.

Commonly collected characteristics of riparian data include:

- Plant species (native and introduced),
- Plant community (e.g., cottonwood riparian, mixed conifer riparian),
- Tree canopy cover (average as a percentage),
- Tree canopy closure over stream (or other index of stream shading)
- Tree size,
- Large woody debris (including potential for more wood to enter the stream channel),
- Stream bank erosion,
- Average width of riparian zone,
- Disturbances (type, extent, and intensity),
- Fragmentation of riparian habitat,
- Water impoundments,
- Stream bank structure and stability

Data about riparian vegetation and other characteristics of riparian areas are likely to be scarce for your watershed. In the past, there has been little demand for systematic surveys of riparian areas (National Research Council 2002). The California Riparian Habitat Conservation Program was created within the Wildlife Conservation Board (WCB) at the Department of Fish and Game in 1991 (http://www.dfg.ca.gov/wcb/california_riparian_habitat_conservation_program.htm.) with the objective of assessing the current amount and status of riparian habitat throughout the state. However, this extensive mapping effort has not yet occurred. This program is partnering with the state-federal-private Riparian Habitat Joint Venture, which is riparian bird habitat protection effort. The Joint Venture also aims to identify riparian areas in the state, but it has not yet compiled a database (http://www.prbo.org/calpif/htmldocs/rhjv). Challenges include the difficulty of mapping land cover statewide with sufficient resolution to characterize the narrow riparian zone and the cost of doing this high resolution work.

Riparian areas have been mapped for parts of the state through several projects conducted by CDF's Fire and Resource Assessment Program (FRAP) (http://frap.cdf.ca.gov). It has developed a California Hardwood Rangeland Riparian Vegetation Database, where riparian is one of the seven database fields mapped in 1990 using satellite imagery. http://frap.cdf.ca.gov/foofoo2/veg_data/riparian_metadata.html. It also mapped and assessed several north coast watersheds for riparian vegetation conditions through the North Coast Watershed Assessment Program (http://www.ncwatershed.ca.gov). Using existing U.S. Forest Service and CDF vegetation maps, FRAP updated species, canopy cover, and tree size using DFG stream habitat survey data (see above), aerial photograph interpretation, and new field data where needed. FRAP's Forest and Range Assessment 2002 developed a single GIS data layer for vegetation that includes riparian categories by merging multiple sources of data.

The most complete information and data about riparian vegetation are usually found for areas downstream of hydroelectric projects that have been through or are currently in the relicensing process. As part of the relicensing effort's environmental review, the Federal Energy Regulatory Commission (FERC) and U.S. Forest Service (if the project is on national forest land) generally require a thorough assessment of riparian resources that have been affected by the hydroelectric operation to date or that could be impacted if the project continues. The basic information is usually found in an appendix to the Environmental Impact Statement. If this description is not detailed enough, you may be able to obtain raw survey data from the personnel or consultants who worked on the riparian assessment.

Environmental documents for proposed new projects are another source of information,

**The San Joaquin River Riparian Habitat Restoration Program**

(http://www.usbr.gov/mp/cvpia/sjr/) serves as a case study for using riparian data sources. The program evaluated historical riparian habitat conditions and changes through the use of soil surveys, historical maps, and historical aerial photographs going back to 1937 (Jones & Stokes 1998a). Geographically corrected maps at a scale of 1:24,000 were compiled for riparian soils, habitat, and land use for several dates during that period of time. Data were entered into a GIS database, which allowed the changes in areas and types to be quantified for those years. A second riparian study analyzed how physical processes, such as flow conditions and sediment regimes, shaped the San Joaquin River and affected the riparian habitat patterns along 150 miles of the river below Friant Dam to the confluence with the Merced River (Jones & Stokes 1998b). Low-altitude aerial reconnaissance flights were made to record current vegetation patterns, as well as geomorphic and hydrologic features. Ground-level surveys recorded riparian vegetation structure, condition, dominant species, and relation of species to channel geometry, in addition to physical channel measurements.

though in very limited areas. Environmental Impact Reports (EIR) for new project require surveys of existing conditions and potential impacts of the project. All EIRs are to be filed in the State Clearinghouse maintained by the state Office of Planning and Research (http://www.opr.ca.gov). These EIRs could be a source of useful information on riparian and other habitat. The local county planning department often keeps an archive of such reports as well. You can also search for documents prepared under the California Environmental Quality Act at http://www.ceqanet.ca.gov.

If your watershed includes some federal land, there may evaluation or monitoring data for selected riparian areas at your local Forest Service or Bureau of Land Management (BLM) office. Most national forests have conducted stream surveys for parts of their forest, both in a systematic process as well as for specific projects. Prior to the mid-1990s, little of this data was collected or archived in a consistent format. In the past few years however, a procedure known as Stream Condition Inventory have been used to characterize riparian conditions. Contact hydrologists, botanists, and fisheries biologists in the local district or supervisor's office to check on the availability of stream and riparian survey data for your watershed. The BLM also has a continuing program for assessing riparian conditions on the lands it administers. The BLM approach is known as "proper functioning condition" (PFC), which can be evaluated on the adequacy of vegetation, landform, or large woody debris to serve certain functions (U.S. Department of the Interior BLM 1995). This assessment method tends to be used on public lands and some private rangelands.

There is a chance that some sort of riparian research may have been conducted in your watershed. Many of the riparian studies in California during the 1970s and 1980s were reported on or referred to in a series of conference proceedings (Sands 1977, Warner & Hendrix 1984, Abell 1989). An online bibliographic search may yield leads to other scientific papers, such as the user-friendly riparian research Web site by the University of Washington with over 8,000 citations (http://riparian.cfr.washington.edu/).

Aerial photography is a potential source of raw data about riparian vegetation (primarily vegetative cover and human disturbances), although it requires a lot of effort to interpret the images (e.g., Nelson & Nelson 1984, Grant 1988). Sources of archived aerial photography include offices of the USFS, the BLM, the CDF, county planning departments, the Earth Science and Map Library at U.C. Berkeley, and the Map and Imagery Library at U.C. Santa Barbara. Videotapes of a few California river corridors under study for Wild and Scenic River status filmed from helicopters by the National Park Service are available at the Water Resources Center Archives at U.C. Berkeley. There are also "digital ortho quarter quads" (DOQQs) and "digital raster graphs" (DRGs) available for the state, which are types of satellite or aerial photographs that you can use in GIS. These can be downloaded from the state GIS repository (California Spatial Information Library, http://gis.ca.gov/data.epl) in various forms. This site also has a variety of other statewide data.

The National Wetlands Inventory (NWI) of the U.S. Fish and Wildlife Service provides information about wetlands throughout the United States. About 90% of the wetlands of the continental U.S. have been mapped, with much of the information available in digital form online (http://www.nwi.fws.gov). With the exception of southern desert areas, most of California has been mapped as of November 2003, with digital information available for about half the state. Other potential sources of wetlands information and data include county planning departments, the Natural Resources Conservation Service, and the U.S. Army Corps of Engineers.

**4.2.3 Physical, Channel, and Habitat Conditions**

Geologic and topographic information are essential components of watershed assessment. California maps are readily available from a variety of agency and private sources—and are always useful in an overview-scale assessment. Data that provide a physical overview of watershed characteristics are available from USGS topographic maps (http://ask.usgs.gov/maps.html) and geologic maps from various agencies. The USGS site also provides numerous thematic maps, such as geology, groundwater resources, seismic, and vegetation maps that may or may not be available for your watershed. The California Geological Survey has specialized geology maps at various scales (http://www.consrv.ca.gov/CGS/information/geologic_mapping/index.htm). Other important geologic maps that are available statewide but are not online include the California Resources Agency Geologic Map Sheets (scale of 1:250,000).

Historic and current aerial photographs are another valuable source of watershed-scale data that helps characterize a watershed's physical character (as well as vegetation and land use character). Topographic data and photographs are available online from http://terraserver-usa.com/ sponsored by USGS and other groups. County planning departments, museums, Caltrans, NRCS, and a variety of agencies and private firms can sometimes provide historic and current aerial photographs that may be used to evaluate trends and changes in physical watershed characteristics over time.

Collecting data on physical channel and habitat conditions at the scale of individual river reaches or habitat units involves primary reconnaissance and field work, as these features cannot easily be discerned from aerial photographs or maps and very little online or existing information is typically available. Field surveying for these data is very involved and can be comprehensive only for small watersheds. For large watersheds, field work could be used to calibrate a more generalized (e.g., GIS-based) description of classes of sub-watersheds.

Stream channels and associated habitat vary tremendously throughout California as a result of the variability in climate and tectonics that differentiate the landscape, and specific sediment erosion, deposition, and morphologic conditions cannot be generalized without very specific regional and local knowledge. Moreover, stream channel conditions vary longitudinally from the headwaters to the lowlands and laterally from the low flow-high flow channels to the floodplain, and data collection in one area of the watershed system may not represent conditions in another area. For example, measurements of suspended sediment or bed material load at one gauging station will not represent downstream conditions if a dam traps sediment or a tributary is a source of sediment between the two areas. But because of the wide range of natural spatial and temporal differences, extrapolating information from short-term data sets needs qualification. An overview of the USGS sediment collection program is summarized at http://ca.water.usgs.gov/projects02/ca004.html. Geomorphic and sediment-related data can be stored in spreadsheets where it can be easily accessed to report as a table or in a graph.

**4.3. Archiving and Managing Numerical Data**

Use of a database or spreadsheet is very helpful in managing the data you have collected. Spreadsheets are easy to use, but lack the ability to conduct a focused search or queries that are the hallmark of a database. For example, you may wish to examine particular attributes, locations, sampling dates, or numeric values within or above a certain range. Databases are made to support these types of analyses. A

**Table 4.1. Example of tabular streamflow and suspended sediment data**

| Location | Year | Day | Discharge (cfs) | Suspended sediment concentration (mg/L) |
|---|---|---|---|---|
| Clear Creek | 2001 | 1 | 10 | 4.0 |
| Clear Creek | 2001 | 2 | 11 | 2.2 |
| Clear Creek | 2001 | 3 | 19 | 12.1 |
| Clear Creek | 2001 | 4 | 12 | 22.5 |

useful introductory reference on environmental data management is Michael (1991). Environmental databases: design, implementation, and maintenance. Lewis Publishers. Boca Raton FL. A more comprehensive reference on this topic is Michener, et al. (1994).

If you are able to take advantage of a reliable online source of data (e.g., USGS daily streamflow records) or a CD archive of data, it is often best not to copy the data on to your computer. A great advantage of these vast databases is their easy and long-term accessibility. In most cases, a link to the data is as good as having it on your hard drive. There are a lot of exceptions to this general recommendation, the main one being that if you want to integrate or overlap data among "disciplines" (e.g., land-use and water quality), then it makes sense to have it all in one place.

Existing environmental data will be stored in some sort of file structure or database, with the particular details dependent on the type of data, the agency archiving the data, the needs of data users, and the dynamic nature of the variable being assessed. The simplest data structure is usually a single column of values, such as daily average streamflow for a year at a single gage station. In such a file, there would be 365 records (lines or rows) with a single number in each line or row. Metadata (information about data) would be associated with this file to allow you to interpret the data. In this example, to make sense of the single column of numbers, you must know the location of the stream gauge, the year, the starting date (so you could assign a date to each successive entry), and the units of the values.

A more common file structure is a table with multiple rows and columns (or records and fields in database terminology). Simple data tables are often called "flat files". In the streamflow example above, some or all of the metadata could be entered in columns (table 5.1). The day of the year would be unique for each record, but the location, year, and units would be common for all records. The metadata would still need to include the start date of the year (calendar year on January 1, water year on October 1, rainfall year on July 1) and the headings for the columns (which are usually not part of the table).

A wide variety of database management systems have been developed, primarily for business needs. Environmental data archiving and retrieval needs can usually be accommodated by these systems, although there may not be an ideal match. Most common database management systems (Microsoft Access, FileMaker Pro, Oracle etc.) can result in relational databases and use Standard Query Language (SQL). The relational structure allows use of many data tables that are linked together by one or more common fields. These linked data tables reduce the need to enter redundant data, such as location, in every record. Questions or queries can be asked of the database through SQL (usually via some simple-to-use interface) without writing a program to perform the search. In addition, the database management software facilitates data entry, updating, deletion, simultaneous processing of commands from multiple users, import and export of large amounts of data, and recovery from system crashes.

### 4.4 Anecdotal Information

Anecdotal information may provide knowledge about watershed processes and conditions that might otherwise be lacking. Common types of anecdotal data include:

1) The change in the extent of salmon runs in river before and after building of a dam or bridge,
2) Change in turbidity of streams and rivers over time,
3) Changes in land use,
4) Changes in riparian vegetation,
5) Changes in the frequency or size of floods

Anecdotal information has been useful in many assessment efforts. For example, fisheries scientists in the Central Valley have re-constructed the history of salmon runs in the Valley over the past 170 years from archaeological site findings (i.e, fish bones) and written accounts in newspapers, diaries, technical reports, and letters to government agencies (Yoshiyama et al. 1996 & 2001). The South Yuba River Citizens League has provided a more detailed account for the Yuba River basin based on a similar approach (http://www.syrcl.org/majorissues/SalmonReport.htm). In both cases, the results of visual observations by anglers and others were combined with more contemporary fish surveying methods to assess the condition of the salmon populations in the Central Valley watersheds relative to historical distributions.

If you plan to include historical or contemporary anecdotal information, your main tasks will be finding, organizing, and interpreting the data. Public libraries (including holdings at universities and agencies) have extensive archives of newspapers and other written records. People who have lived in the area for a long time and enjoy the rivers or streams are walking resources for certain kinds of information. Neither resource may give you quantitative information. But in the absence of or in combination with other information, it is useful to at least know the presence or absence of watershed processes and the potential range of natural processes (e.g., flooding). This information is best recorded with some associated index or coding for the type of information and where in the watershed it is relevant. The data can be organized using the index or codes, allowing for more efficient retrieval later on. Data interpretation will depend heavily on the source of information, the type of information it is, and the questions you are addressing. You will probably use these data for "yes/no" questions about the watersheds more often than "how much" kinds of questions. The interpretation is probably best done by someone who has familiarity with both the data source and the watershed feature being discussed. It is important for credibility with all stakeholders to qualify your findings and statements when you use of anecdotal data in your analysis, reports, and presentations.

### 4.5 Types and Sources of Landscape Data

The majority of the area in any California watershed is the terrestrial landscape. Terrestrial landscape data are often collected for entire watersheds. It may also have been collected initially at individual survey sites (e.g., soil or vegetation) and then subsequently generalized to areas. Currently, most contemporary data about a watershed landscape are collected with a geographic reference point. In contrast, historic data may be very valuable, but lack easily usable or identifiable reference points.

Historic maps inform analyses of change and historic condition. Unless these maps have been transferred to an electronic format, they are on paper and may be challenging to use to compare with present day conditions.

Local and regional governments maintain data on land uses. They reflect past or current zoning ordinances and present a reasonable estimate of activities occurring within the watershed. Land use categories include industrial, open space/parks, low density residential, and commercial. Land use maps are usually maintained as GIS files. They can be very helpful in a watershed assessment because they suggest possible practices that could impact the waterways. The State's online GIS center is a good source of land-use maps (http://gis.ca.gov). The Department of Conservation and county agriculture commissioners have maps for rural and agricultural regions of the state.

### 4.5.1 Data Types

Spatial data comes in a variety of types, including paper maps, digital spatial data ("GIS data"), tables of attributes of areas (such as vegetation types), the results of summarizing or condensing data (e.g., by computer models), and anecdotal data (e.g, un-mapped descriptions of place). Each data type requires different storage and organizational strategies (described in more detail below). Typically, each data type is associated with different levels or complexity of analysis. For example, in a simple and rapid assessment, you might rely on paper maps and anecdotal information, while for a comprehensive assessment involving computer models and multiple questions, you might rely on digital spatial and water quality data.

#### 4.5.1.1 Non-Digital Spatial Data

Historically, spatial data was non-digital. These maps still have useful functions and often can be converted into a digital format. Many local, state, and federal agencies have archives of paper maps. You can collect copies of these maps and make digital versions of them. Alternatively, the information can be summarized and interpreted for later analysis. Paper maps are probably most useful when they show high-resolution information about local occurrences. For most watershed assessments, collecting all paper maps available isn't feasible. You may want to collect maps for select areas where, for example, you are interested in the historical condition or for features where digital information is not available.

Older data can be digitized to create digital maps, which allows historical data to be incorporated into a contemporary database. According to the Information Center for the Environment (ICE, U.C. Davis, http://ice.ucdavis.edu), digitizing costs about $0.50 per acre. Another way to store data from paper maps is to code the data and store that information. Coding refers to attaching a value or code to a particular map feature. For example, if a feature's position has not changed (e.g., a public roadway), but its type, use, or condition has (e.g., paving the public roadway), then the feature can be identified and recorded in a table, and the corresponding coding can be recorded with it. For landscape features that may not have precise position information, you can use nearby positional information (e.g., property name, township name, road number, etc.) to code the data. If data is available on clear acetate sheets, then it is possible to overlay various kinds of data for analysis. As always, you should record the process you use to extract or summarize the information from the paper map source to inform future users of your extracted information.

#### 4.5.1.2 Digital Spatial Data

Digital spatial data are electronic versions of a paper map and shows the relative position of mapped features (e.g., roads, rivers) in a geographical location (e.g., a watershed). These data are often used in watershed mapping for watershed assessments and plans. However, they are useful for much more than just cartography (mapping). They can be used in modeling and understanding the distributions of features across the landscape and how things interact with each other.

#### 4.5.1.3 Non-Spatial Data

Some of your watershed data may have been collected for a project where the exact position of surveying was not critical and where sub-sampling of an area was used. For example, a botanist may have surveyed native and exotic plant communities across a ranch or sub-watershed and provided lists of species present and estimates of percent cover for each of them. This is valuable information for this place, but the data cannot be attributed to particular places except the area being assessed. You can collect data like these and record them by survey area. In cases like this, collecting data and placing it in tables might be the best way to organize it.

There may be other kinds of data that are more suitable to list over a timeframe. For example, if you are interested in flooding occurrence but not in the area that is inundated, then just recording the approximate location of the flooding, the date, and perhaps a ranking for severity may be enough. Certain data will be best collected only on a time "map", for example, number of returning salmon per year, flood frequency, number of landslides per year, number of storm events per month summed over the last four decades, etc.

#### 4.5.1.4 Condensed or Summarized Data

Many agencies and academic institutions have conducted analyses and models of natural and human processes. Condensed or summarized data is new information generated from analysis or modeling. For example, maps of vegetation types, precipitation, fuels moisture, and temperature permit estimates to be made of fire risk, which can result in a new map of fire risk. The values in the fire risk map are derived from the values in the other maps and are a form of data. When recording these data, it is important to record the origin of the values so they are not treated as measurements or the results of surveys, which may have been the case for the base information used in the modeling. Again, describing the data can be as important as the data values themselves. This "metadata" (description of the data) is its own form of information that can inform decision making about data quality, quantity, and sufficiency. The condensed or derived data that results from modeling or analysis may be summarized for specific geographic locations spread throughout the watershed (e.g., erosion risk for all sub-watersheds), or may be summarized only for certain features of the watershed (e.g., stormwater runoff from developed areas).

### 4.5.2 Sources of Landscape Data

There are a wide variety of sources for data about landscapes. However, these sources are not always easy to find. Large agencies or institutions may hold data, which may be available online. Local agencies or private organizations are other data sources. However, these organizations and agencies may require a more direct approach to explore their databases and retrieve information (i.e., negotiating in person). A list of potential data sources is below, but this list is not exhaustive—there are hundreds of different possible sources of data in California. In all cases, when you access and organize data, maintain a log of where you got the data, make sure you get the metadata, and set up a filing system that is easy to use and intuitive. A list of data source websites is posted at: http://cwam.ucdavis.edu.

#### 4.5.2.1 Federal Sources

Common federal sources of land cover/land use data are land-management agencies, such as the US Forest Service, Bureau of Land Management (BLM), National Park Service (NPS), Bureau Indian Affairs (BIA), and US Fish and Wildlife Service (USFWS), regulatory agencies, such as NOAA-Fisheries, and the Army Corps of Engineers, and research and technical agencies, such as US Geological Survey, Natural Resource Conservation Service (NRCS), and National Oceanographic and Atmospheric Administration (NOAA).

The local offices of these federal agencies are a good place to begin assembling data about the watershed landscape. These data may be in map (spatial) or non-map format. There are usually several natural science professionals (e.g., a soil scientist or a wildlife biologist) who can answer questions about the data and direct you to the appropriate staff for retrieving data. However, in larger offices, there may not be a central directory of all available data, and you may have to dig around a bit before you find everything you want. Some data may be called ‘draft’ or described as unavailable to the public. In some cases, you may be able to gain access to these data anyway for analysis purposes, especially if the agency has pledged cooperation to your watershed group.

#### 4.5.2.2 State Sources

State land management and regulatory agencies also have a variety of types of data available online or upon request. Examples are the California Department of Forestry and Fire Protection (CDF) Fire and Resource Assessment Program, which has data for vegetation and fire risk, the Department of Conservation (DOC), which has information about landscape conditions and disturbance (e.g., mined areas, agricultural preserve lands), and the Department of Fish and Game (DFG), which has data about wildlife and plant communities. As with the federal agencies, technical staff are familiar with the data the agency has, but you may need to talk with several people to discover everything available. Local offices are generally the best places to begin.

#### 4.5.2.3 University Resources

Academic institutions can have rich mines of information, but it is not always easy to find the right people because they are often spread out among departments. If the university has a directory of faculty research interests on their website, this is a good place to identify experts. If such a directory does not exist, an alternative approach is to go to the webpage for the relevant department website, The departments may be divided among different colleges or schools (e.g., “Agriculture and Environmental Science” at U.C. Davis). Departmental websites usually contain web pages for each faculty member or research program. Reviewing these can help you find people who may have conducted research in your watershed or nearby. Call or email them—they will usually be happy to provide you with information or forward you to someone who can help. If you are lucky, they may have already conducted analyses in your watershed, the products of which may be useful to your assessment. Student theses and dissertations are another source of detailed information about a specific topic and may be found in campus libraries.

#### 4.5.2.4 Local and Regional Agencies

Local agencies are sometimes the richest sources of local data, though not always in the format you want. Only recently has GIS become common among county, municipal, and district agencies. The data are not always free (e.g., if the local agency has bought it from a data provider) and may have less predictable barriers for access than you might encounter with state or federal agencies. However, these data can sometimes be of finer resolution and more current than larger-scale efforts by state or federal agencies. In this case, it is important to check the standards used to generate and update data so that even if these standards don’t meet state or federal standards, you know what they are.

#### 4.5.2.5 Private Sources

Private companies, utilities, or nonprofit organizations in your watershed may collect and maintain their own databases about their holdings, the region, the county, or the watershed. These data may be easy to access (e.g., from a nonprofit organization) or nearly impossible (e.g., from a large landowning company), depending on the data owner's level of trust as to how the data will be used and what the owner may lose from certain uses. The watershed assessor should work with the stakeholder watershed group (if one is present) to access certain privately held data that are deemed critical or important to answering questions about watershed processes or disturbance. Data sharing may improve if the data are not associated directly with landowner names. Even if you think getting the data is a long-shot, it can't hurt to ask.

## 4.6 Geographic Information Systems and Spatial Data

The term "GIS" (geographic information system) gets used a lot in the watershed world. To some it means a single digital map; to others it refers to a series of maps on a computer and includes analysis of spatial data. The spatial data often originates from remote sensing of the earth, from digitization of features from paper maps, or from using global positioning system (GPS) units to geo-reference points or lines on the ground. The history of GIS includes people taking pictures of battlefields from balloons (remote sensing), putting pins in maps for the locations of features (geo-referencing), and the development of rapid automated calculations with computers. Computer-operated GIS was created when these capacities were refined and paper maps could no longer capture processes on earth. If you are responsible for conducting a watershed assessment that involves GIS, you should become familiar with the terms and system descriptions below in order to understand the opportunities and limitations of this approach.

### 4.6.1 Definitions

**GIS** One older definition of GIS is "*a system of hardware, software, data, people, organizations, and institutional arrangements for collecting, storing, analyzing, and disseminating information about areas of the earth*". (Dueker & Kjerne 1989, from Lillesand & Kiefer, 1999). Another is "*a GIS combines layers of information about a place to give you a better understanding of that place*" (http://www.GIS.com, a project of Environmental Systems Research Institute). These two definitions capture the uses of the term GIS in this Manual. One important point is that a GIS is not simply a repository of maps or a software package for making and printing maps, which might be better termed "digital cartography." It is an analytical environment, populated by data that you provide, data that are spatially referenced to a place on the earth (ESRI, Inc. 1995). A GIS for your watershed is something you can use to find out things that are otherwise difficult or laborious to do manually (e.g., which roads lie on steep slopes).

**Digital map** An electronic version of a paper map and shows visually the relative positioning of mapped features (e.g., roads) in a place (e.g., watershed).

**Spatial data** Data about a space, such as distribution and kinds of vegetation growing in a watershed, that can be displayed in a digital map.

**Remote sensing** The "science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation" (Lillesand & Kiefer, 1999). Satellite imagery is an obvious example of remote sensing information. Remote sensing relies on the detection of electromagnetic radiation (e.g., visible light and radar) that is either originating or reflecting from surfaces (e.g., leaves on trees in the Amazon). Properties and changes in the properties of the electromagnetic radiation can be used as surrogates for measuring properties of the thing under investigation (e.g., plant type).

**Digitizing** The process of making a paper map usable in an electronic GIS by manually drawing and transferring map features into an electronic form using mapping software. This process attributes real-world coordinates to the points or lines on a map, which are stored as an electronic data table, which, in turn, can then be visualized as a digital map. Digitizing could take place on the computer screen, where a drawing is created on top of a base map of some kind, such as an aerial photograph of a place, or it could be done by tracing the points and lines on a map using a desktop digitizing tablet.

**GPS** A global positioning system is a satellite-based system that allows someone holding a GPS receiver unit to determine latitude and longitude of their location on the earth's surface. The unit receives distance information from at least four satellites, which allows it to determine its position on the globe. Positional data from the unit allows the user to "GPS" the location of features of interest on the ground (e.g., landslide) for later entry into a GIS.

**Geo-reference** Information referenced to the earth, or "geo-referenced" by relating points, such as the corners of a map, to a coordinate system for the earth's surface, such as latitude and longitude. Points are thus associated with "coordinate pairs" or a value for each of the north-south and east-west axes (e.g., longitude and latitude). Once information about a place is geo-referenced, it can be overlaid by other maps, enabling analysis to be done that relates to a specific location or area.

### 4.6.2. Using Spatial Data

Non-digital spatial data

Many maps available to an assessment team will not be in digital form. Some of the most useful maps of historical activities or conditions may only be in paper form. These can be valuable resources even if they are never digitized and used in a GIS. Useful maps will relate to common location schemes, such as the quadrangle, township, range, and section maps of the USGS, or latitude and longitude coordinates. In order to analyze data contained on these maps, you may need to transfer some of it to digital form (e.g., a table of logging activity by sub-watershed), or to acetate overlays, a cheap and non-digital way to create a GIS. What such a system loses in precision (lost during copying) and accuracy (actual representation of ground features) may be made up for in speed and cost of acquisition. However, just as with the most expensive GIS, the quality of the analysis will be determined by the quality of the data and process of assessment. It is important to record actions and results so that others may easily tell how something was done and why a certain result was obtained.

Digital spatial data

Once information is entered into a computer database with spatial descriptors, it becomes digital spatial data and can be used in a computer GIS. This provides many opportunities both to simplify your assessment and to make it more complicated. Analyzing sets of data in various combinations from visual overlays to calculated or modeled relationships becomes somewhat easier. Because different types of information about a place are being used in such a way that the location is the commonality, you may discover relationships and qualities about a place that otherwise weren't obvious. For example, if you had a database of street addresses for parcels within your watershed and a map of the streams, and you wanted to find all of the riparian owners, you could use your GIS to combine these two sets of digital data that have a common spatial referencing scheme (e.g., latitude and longitude) and find the landowner addresses within a certain distance from a stream.

Development of new spatial data should be done in accordance with Federal Geographic Data Committee (FGDC; http://www.fgdc.gov) guidelines. This committee is responsible for coming up with common standards for data development, storage, and description. If the guidelines are not used, then data sharing becomes limited, and the utility of the data declines.

Types of digital data

There are two main types of digital information: 1) "spatial," which tell you where something is, and 2) "descriptive," which tell you about the something. There are also two primary types of data used in GIS: 1) raster data, which refers to information that is distributed into "cells" arranged in a grid pattern across the earth's surface, and 2) vector data, which is information occurring in a series of coordinate points termed "point" (single coordinate pair), "line" (two coordinate pairs), and "polygon" (one coordinate pair per angle/corner) features.

Each data type allows for different types of data distribution and calculations. It is possible to convert between raster and vector forms, though some information may be reduced in value or resolution depending on the scales of the original data type and new data type.

### 4.6.3 Data Scale and Resolution

Not all spatial data have been collected at the same spatial resolution. In this case, "spatial resolution" refers to the ability of a sensor (e.g., a camera) to separate detail on the ground (Lillesand & Kiefer, 1999). If data for a map were collected by digitizing features from aerial or satellite photographs, then the spatial resolution of the recording device is important, since this determines the limits of the data's use. The resolution of particular films and digital recording devices, the height of the camera, and variables, such as atmospheric conditions, determine the actual resolution of the resulting photographs and derived maps. In addition, remotely collected data may be aggregated into blocks of multiple pixels of a similar land-cover type or that are dominated by one land-cover type. This process decreases the data's resolution and affects the data's subsequent use.

**The Federal Geographic Data Committee**

"The FGDC develops geospatial data standards for the National Spatial Data Infrastructure only when there are no externally developed standards appropriate for Federal use. FGDC standards are developed in consultation and cooperation with State, local, and tribal governments, the private sector and academic community, and, to the extent feasible, the international community. FGDC standards are intended to be national in scope and go beyond individual agencies and the Federal government enterprise. Federal agencies are required to use FGDC standards.

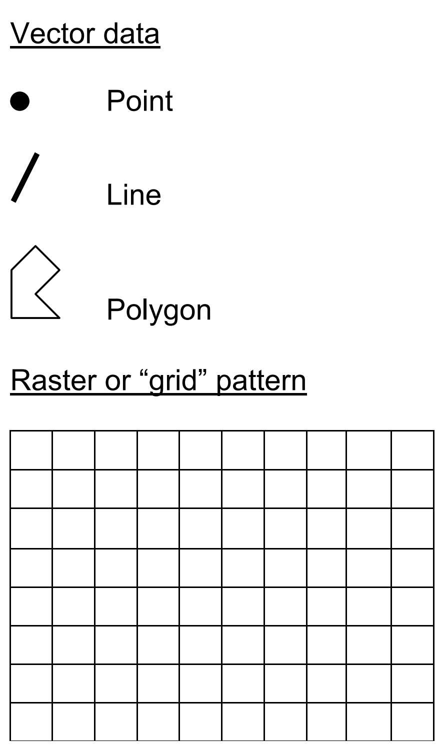
State and local agencies are not required to use FGDC standards, but are encouraged to do so to promote data sharing between different levels of government."

The standards are online at: http://www.fgdc.gov/publications/documents/standards/endorsed.html

(FGDC Web site, 2003)

Scale refers to the relationship between distance on a map or photograph compared to the actual distance on the ground. An example of scale is “1:24,000”, which means that one inch on a map is equivalent to 24,000 inches, or 2,000 feet, on the ground. If map data are derived from photographs, then the resolution of the photographs will determine the map resolution or scale. In general, the smaller the scale ratio, the higher the resolution, assuming similarities in the resolution of the recording devices. A map derived from a 1:5,000 aerial photograph may have higher resolution than one derived from a 1:500,000 satellite photograph. However, if the resolution of the satellite camera is 100 times that of the aerial camera, then the resulting data will have similar spatial resolution. In other words, the analyst can discriminate between objects just as well in the satellite photograph as in the aerial photograph.

As you collect data into a database and GIS, it is likely that they will vary in their scales and resolutions. You may have high-resolution aerial photographs (1:2,000) of your county and low-resolution maps of soil series or geological formations (1:250,000) that you want to combine in analyses (e.g., percent of housing development on erosive areas). If data sets have been collected at different scales, use caution in any analyses involving two or more with different scales. In an extreme case, 1:500,000 scale data should not be referenced to a 1:24,000 data set because this represents an artificial increase in accuracy. However, it is possible to surrender data accuracy and use high-resolution data (e.g., 1:24,000) at a reduced scale of 1:500,000 if that is the only way to perform an analysis.




### 4.6.4 Metadata

Metadata refers to the information describing the data. Various information about scale, how the data were created, how they are stored, purpose of the data, source of the data, originating agency/organization/individual, and updates should be included in the metadata. The FGDC has developed standards for documenting spatial data. Most state and federal agencies follow these or similar standards and formats when describing data. It is critical to standardize these metadata so that the data can be used beyond a single person and that limitations and opportunities for uses are understood. An example of this would be the Calwater 2.2 system.

### 4.6.5 Developing your Watershed GIS

When developing a new GIS, a good starting point is to ask yourself two questions: “What questions do I intend to answer with this GIS?” and “How much do I have to spend?” Answers to the first question will tell you the scope of your GIS project and help inform the second question. Costs for a GIS can vary widely and this is where there may be the least amount of information for the watershed group to make fiscal decisions. For example, you may decide you want to

**Questions for Your Watershed GIS**

1) Location information (e.g., zip code, watershed, county)

2) Location of important features you plan to characterize (e.g., road-less areas, fragile soils, roads crossing streams)

3) Trends in a place over time

4) Spatial patterns and distributions (e.g., fish populations and water storage)

5) What would happen if you changed things on the landscape (e.g., added a road or other disturbance)

(ESRI, 1997)

collect digital spatial data and do simple analyses (e.g., where roads cross streams) with an emphasis on visual presentation of map information. In that case, your cheapest route is to use free GIS software on a donated computer, taking advantage of spatial data online and printing on a color inkjet printer. Being able to do this requires a basic education in GIS, which you can get cheaply or for free online. At the other end of the spectrum, you may want to spend $10,000 to $100,000 hiring staff or a consultant to do all of this for you on a purchased computer, using licensed software, and presenting your maps in large printed format and online using a map server. A likely outcome of hiring a consultant is that a GIS professional will do a good job more quickly than someone local having to learn GIS. At the same time, if GIS is likely to be part of your planning, monitoring, and management work for several years, it may make more sense to train a volunteer or staff person to carry out the GIS in order to increase local capacity.

### 4.6.6 Data Organization

Most people who have used GIS for a while are familiar with the problems of storing, sorting, and updating the files associated with a GIS. It is possible to accumulate thousands of files and take up gigabytes of disk space. The key to managing this is organization of your files in a structure. Once you have created a logical architecture for your GIS, organizing it should be relatively straightforward.

Filing systems

Just as with the filing system in your local library, the best GIS filing system is one that has an intuitively obvious structure and can be understood by users. There is no one perfect way to create such a system, but there are sets of rules that can be used to guide the construction.

Develop categories that match your expectations for the types of data you will

**Free GIS Software**

*"a complete index of Open Source / Free GIS-related software projects"*
http://www.opensourcegis.org

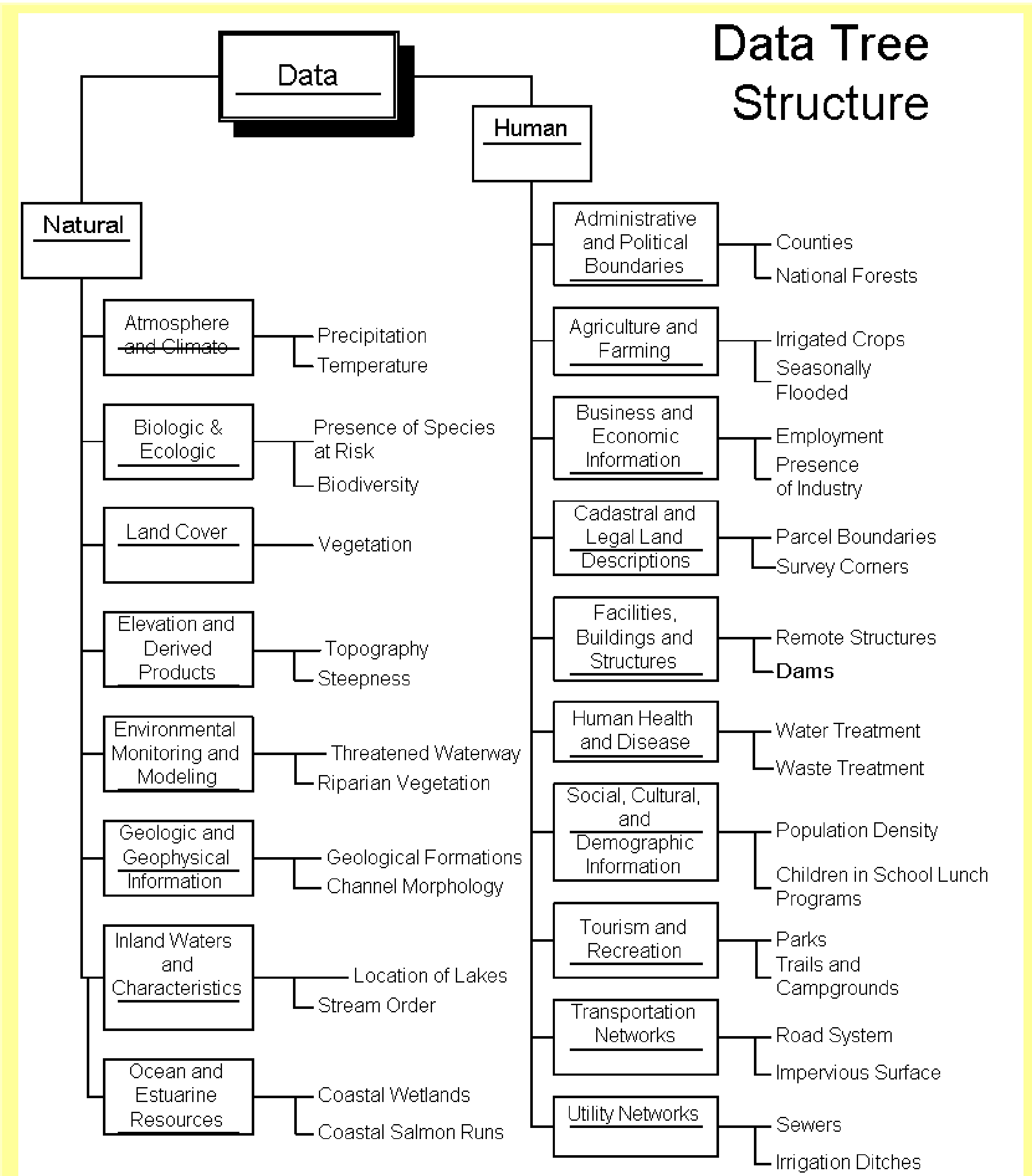
*"GRASS GIS (Geographic Resources Analysis Support System) is an open source, Free Software Geographical Information System"*
http://grass.itc.it

*"MapServer is an OpenSource development environment for building spatially enabled Internet applications."*
http://mapserver.gis.umn.edu/index.html

*"open-source GIS-based applications you can download written for a variety of platforms and in various languages"*
http://gislounge.com/ll/opensource.shtml

*"IDRISI, developed by Clark Labs, is an innovative and functional geographic modeling technology that enables and supports environmental decision making for the real world"*
http://www.clarklabs.org/

be collecting, analyzing, and storing. The FGDC (http://fgdclearhs.er.usgs.gov/) uses the following categories: administrative and political boundaries; agriculture and farming, atmospheric and climatic data; base and scanned maps and charts; biologic and ecologic information; business and economic information; cadastral and legal land descriptions; earth surface characteristics and land cover; elevation and derived products; environmental monitoring and modeling; facilities, buildings and structures; geodetic networks and control points; geologic and geophysical information; human health and disease; imagery and aerial photographs; inland water resources and characteristics; ocean and estuarine resources and characteristics;



society, cultural, and demographic information; tourism and recreation; transportation networks and models; and utility distribution networks (see box above).

If you don't have limitations on electronic storage space, there are several ways to deal with using and modifying digital maps after their initial acquisition or creation. One is to maintain the original versions of maps in separate backup directories so that you can always go back to the original. Later, or "final", versions of maps that are the most recent can be retained in a unique directory. This will make updating maps easier as modified versions can replace the most recent version. Any modification should of course be accompanied by an update of the metadata describing the changes and giving the date.

Develop a structure rationale that fits people's expectations for the system. The usual structure is a hierarchical, or tree structure. The diagram below shows an example of this type of structure, using FGDC categories and samples of data types you might have.

In conclusion, the nature of your watershed assessment should guide your collection and organization of the various kinds of data. The questions you ask in your assessment determine the kinds of data you need (e.g., water quality, mapped sources of pollution, projected human activities). The level of complexity and nature of the analyses determine the data types (e.g., digital vs. paper maps), which, in turn, determine your strategy for data organization.

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**Collecting and Organizing Data Check List**

| | |
|---|---|
| *Collect Data* | |
| ❑ Identify sources and gather numeric data on water quality, hydrology, riparian and wetland areas as well as physical/habitat conditions | |
| ❑ Identify sources and gather anecdotal information on any topic relevant to the assessment | |
| ❑ Identify sources and gather landscape data, in both digital and non-digital forms | |
| ❑ Evaluate the quality of data | |
| *Archive Data* | |
| ❑ Store numeric data in a database management system | |
| ❑ Store, organize and categorize spatial data in a file structure | |
| ❑ Store metadata | |

# 7 The Assessment Report

Reporting the assessment questions, approaches taken, findings, and conclusions is one of the most critical parts of watershed assessment. Other than people involved in the assessment process, nobody else will understand what you did unless you clearly report it.

Chapter Outline



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## 7.1 Alternatives Forms of Report

Many different types of studies have been called watershed assessments. Because of the broad scope of the definition of the term, many of them contain elements that are legitimately assessments of watershed condition. Because of the various goals an assessment could have, funding source(s), and types of issues or problems in a watershed, there are a variety of ways of presenting the results. The following section briefly reviews various types of reports.

### 7.1.1 Watershed Assessment

In this Manual, we have defined watershed assessment to be a process for analyzing a watershed's current condition and the likely causes of these conditions. We have defined the watershed assessment report as documenting the findings of the watershed assessment process The box to the right gives some basic components of a watershed assessment report. They are not intended to show the exact order, so much as important things to include.

**Basic Watershed Assessment Report Components**

*Problem statement*

*Watershed and watershed assessment definition*
- A question or series of questions about watershed condition
- Reasons for conducting the assessment, such as supporting planning
- The likely or intended audience for the assessment
- Planning and management process used for assessment

*Descriptions of Watershed Attributes*

*Methods Used in the Assessment*
- Data and Information Collection
  - Sources of existing data
  - Collection of new data
  - Catalog of pertinent data
- Monitoring methods
- Methods used for data analysis
  - Statistics/trend analysis
  - GIS
  - Modeling

*Watershed Conditions – Historical and Present*
- Geography
- Cultural and economic conditions
- Management and policy context
- Land use
- Climate
- Hydrology
- Geomorphology
- Water quality
- Aquatic habitat
- Riparian habitat
- Upland habitat and wildlife
- Sources of uncertainty
- Critical information gaps

*Results of the Assessment – Key Findings*
- Comparison of conditions/processes to benchmarks or historical or reference conditions
- Result of information integration
- Overall watershed condition or sub-watershed condition

*Conclusions, recommendations, and next steps*

The basic report structure is the description of the problem or question, the methods used to collect and analyze information about watershed attributes, description of conditions for watershed attributes, key findings and results of integrating condition information, conclusions, and recommendations.

Examples of watershed assessment reports scan be found at: http://cwam.ucdavis.edu. One report that has similar organization to that proposed in this Manual is the Millerton Area Watershed Assessment report (http://www.sierrafoothill.org/watershed/draft_assessment.htm).

### 7.1.2 Disturbance Inventory

A disturbance inventory, as its name suggests, is a listing and description of the types of natural and anthropogenic disturbances in a watershed. The inventory could be used to determine the goals of a future assessment, based on the kinds of disturbances identified. In limited circumstances, it could also function as an assessment if it describes where and how the disturbances are occurring. A disturbance inventory could precede a watershed assessment by detailing the basic characteristics of the watershed and the natural and human disturbances occurring there.

- If a disturbance inventory is intended to support a later watershed assessment, explicit connections should be made between elements of the inventory and components of the assessment.
- If the disturbance inventory is to stand alone, then it can list the disturbances in the watershed without necessarily going to the lengths described in this Manual of linking conditions to potential sources of problems or stress.

### 7.1.3 Existing Conditions Report

This type of report often leads to a subsequent assessment containing analyses of future scenarios and/or a management plan. It is a form of watershed assessment in that it can be a description of the conditions within a watershed, which could be used for certain types of watershed management decisions. As with the disturbance inventory, there are a couple of things to keep in mind.

- If an existing conditions report is intended to support a later watershed assessment or watershed management plan, explicit connections should be made between elements of the conditions report and components of the assessment or plan.
- An important element of the report could be recommendations for watershed analysis and development of models addressing future scenarios.

### 7.1.4 Watershed Management Plan

Assessments often form the basis for a watershed management plan (WMP). The WMP will typically describe actions that can be taken by decision-makers to address impacts to watershed condition, restore various parts of watershed function, or to describe negative actions and accompanying mitigations. The assessment may be embedded within the WMP as one component of the overall planning process.

Here are some things to consider when developing a watershed assessment as part of a WMP:

- Steps should be taken to make clear distinctions between the findings contained within the assessment phase and the recommended actions in the WMP. You will also need to make connections between the assessment findings and the recommended actions in the WMP.
- There will be WMP recommended actions that are linked to different kinds

**U.S. EPA's Description of Required (9) Elements of a Watershed-Based Plan:**

To ensure that Section 319 projects make progress towards restoring waters impaired by nonpoint source pollution, watershed-based plans that are implemented with Section 319 funds to address 303(d)-listed waters must include at least the elements listed below. The watershed planning process should be dynamic and iterative to assure that projects whose plans address each of these nine elements may proceed even though some of the information in the plan is imperfect and may need to be modified over time as information improves. Existing plans may be used as building blocks for plans that meet these nine elements. U.S. EPA believes that these nine elements are critical to assure that public funds to address nonpoint source water pollution are used effectively.

**a.** An identification of the causes and sources or groups of similar sources that will need to be controlled to achieve the load reductions estimated in this watershed-based plan.
**b.** An estimate of the load reductions expected for the management measures described under paragraph (c) below.
**c.** A description of the NPS management measures that will need to be implemented to achieve the load reductions estimated under paragraph (b) above and an identification (using a map or a description) of the critical areas in which those measures will be needed to implement this plan.
**d.** An estimate of the amounts of technical and financial assistance needed, associated costs, and/or the sources and authorities that will be relied upon, to implement this plan.
**e.** An information/education component that will be used to enhance public understanding of the project and encourage their early and continued participation in selecting, designing, and implementing the NPS management measures that will be implemented.
**f.** A schedule for implementing the NPS management measures identified in this plan that is reasonably expeditious.
**g.** A description of interim, measurable milestones for determining whether NPS management measures or other control actions are being implemented.
**h.** A set of criteria that can be used to determine whether loading reductions are being achieved over time and substantial progress is being made toward attaining water quality standards and, if not, the criteria for determining whether this watershed-based plan needs to be revised or, if a NPS TMDL has been established, whether the NPS TMDL needs to be revised.
**i.** A monitoring component to evaluate the effectiveness of the implementation efforts over time, measured against the criteria established under item (h) immediately above.

You may also refer to the full text of the Section 319 guidelines that is available on EPA's NPS website at: http://www.epa.gov/owow/nps/Section319/319guide03.html

of assessment findings. For example, impacts may be observed for which specific remedial actions are recommended. There may also be recommendations for local ordinances, monitoring programs, and site-specific restoration projects.

- Part of the WMP should be devoted to describing how assessment will continue as management actions are carried out.

**Action 7.1**
- *Name your assessment based on its actual content*

## 7.2 Presentation of Information

How you present your data will determine a large part of how much people will accept your findings and use the assessment to inform their decisions. Identifying presentation formats that are understandable to a broad audience is the goal.

### 7.2.1 Audience

Different audiences and purposes require different approaches for presenting the results of your watershed assessment. Be prepared to deliver the results of your watershed assessment to a wide variety of audiences, from schoolchildren to renowned researchers. For example, you may present to watershed committees, groups, and councils, which are usually composed of people with some level of watershed knowledge and experience. However, you may also need to present your assessment to people who did not have time to be involved in the process of developing it. They will not be as familiar with the issues, data, and results, or their significance so they may require more in-depth presentation (e.g., in a workshop). Local officials, on the other hand, may only have time for a five-minute presentation. Be prepared and careful when presenting your story to the press. Stories in the local media can do wonders for political support of your watershed work. However, many journalists are looking for a catchy headline that may not accurately represent your findings.

### 7.2.2 Text

One way to start writing your report is to develop an outline of the components that you expect to include (see box on first page of this chapter). You can fill in this general outline to make it more detailed and assign authors to various sections as you collect the assessment material. Early in the process, consider how you will use maps, graphs, charts, etc., and plan your text accordingly. In this process, balance brevity with the need to present lots of technical material. Consider an Executive Summary for overview and appendices for very detailed and technical information.

Throughout your report, balance is needed between quickly reaching your audience and presenting lots of technical material. This Manual intentionally goes into detail on some topics to provide adequate resources for those seeking detailed information, but it is not a good model for your watershed assessment. Too much emphasis either way may weaken the effectiveness of your assessment product.

Formatting and presentation can be as important as content, even though most of your effort up to the report writing phase has been on content. Too often, budgets for technical reports like assessments underestimate the time and cost that are needed to do a good job in presenting the findings. The writing and presentation effort can be a full one-third of the assessment's costs, especially if multiple drafts are required. Keeping a style manual handy for guidance on proper sentence structure, tense use, and other grammar issues is a good idea. Many are available, but two good ones are Strunk and White (2000) and the Chicago Style Manual (2003).

Hiring a technical editor is usually worthwhile. This person can help the assessment authors at each stage of the preparation. If multiple authors are involved, this assistance is even more critical. Ask the technical editor to provide you with Editorial Guidelines before you begin writing your assessment. Such guidelines can clearly address: target audience, tone and style,

**"A Vivid Description of Watershed Processes: Hot Salsa in the Mattole"**

The Mattole Watershed Council's watershed assessment and plan for the estuary, Elements of Recovery (1995), represents a well-written document, with minimal jargon, that attests to the importance of language in helping the reader visualize a key concept.

"*…the Mattole estuary / lagoon feels the effects of events upslope. Sometimes these effects persist long after the upstream impacts have ceased, as the forces unleashed continue to work their way through the system like the chili peppers of hot Mexican salsa revisiting the diner the next day. Lasting recovery will require that the impacts oozing down from the hillsides and roads diminish throughout the watershed."*

writing tips, formatting conventions, style guidelines, and standard terms, spellings, and acronyms. An effective writing style can really improve the readability of your report. Try to avoid a dry, jargon-filled style for your general audience.

Having the topic "Limitations of the Assessment" as your last chapter is highly recommended. Each watershed assessment is limited by duration, scope, detail, scale, and analysis level due to constraints in budget, time, access, and overall resources. Acknowledge how your particular assessment process and product were limited, and how these limitations also provide opportunities for improvement for future assessment efforts. The Gualala River Watershed Assessment's last chapter provides a helpful example of how to address this issue (North Coast Watershed Assessment Program, 2003).

### 7.2.1 Tables & Graphs

Tables can quickly summarize important quantitative or qualitative data in a logical order and reduce the need for text. For example, the table below provides a readily readable indicator of which streams and stream reaches contain what limiting factors (based on previously-collected data). This same amount of information presented on one map would likely be difficult to decipher.

Lengthy tables, (those longer than one page), should probably be placed in an appendix.

A graphical presentation of data and findings can be a very effective communication tool (Kerr 1995; text box below). Simple plots that require a minimum of explanatory text in the caption usually are most effective. One criterion for judging simplicity is whether you could understand the graph's message if all the text and labels were in a different language.

<u>Graphs can be great!</u>

- Graphical displays are valuable for revealing patterns that might be missed.
- Clearly illustrated and labeled graphs can say a thousand words in a relatively small space.
- Three-dimensional and color plots can be particularly effective in some cases.

When creating a graph, be sure to:

- Make the graph easy to follow like a good story.
- Make a point.
- Avoid excess complexity, such as fancy options with computer graphing.

Example of a Qualitative Table: Limiting Factors for Steelhead and Coho Salmon, Aptos Creek stream system, Santa Cruz County (excerpt from: Conrad & Dvorsky (2003) Aptos Creek Watershed Enhancement Plan)

| Location | Sediment-Spawning | Sediment-Rearing | Adult Passage Barriers | Spring & Summer Streamflow | Summer Water Temperature | Large Woody Material |
|---|---|---|---|---|---|---|
| Lagoon | No | Yes | No | Yes | Yes | Yes |
| Mainstem to Moores Gulch | Yes | Yes | Yes-drought only | Yes | Yes | Yes |
| East Branch to Hinckley Creek | Yes | Yes | No | Yes | No (Yes for coho) | Yes |
| Hinckley Cr. | Yes | Yes | Yes | Yes | No | Yes |

The best uses of different graph types (adapted from Kerr, 1995).

| Type of Graph | Best Uses |
|---|---|
| Line graph | To emphasize the relationships between data points and illuminate trends in data. (Also called a “scatter plot” in software such as Excel.) |
| Bar graph | To put more emphasis on the individual points. Useful for comparing quantity at one site over time, or multiple sites at one time, and for displaying summarized data. |
| Stacked bar graph | To show data as proportions of a whole. Especially useful to show comparisons between several similar stacked bars. |
| 3-D bar graph | Preferable for slide show or poster, but not useful for trying to read the actual numbers. Three-axis graph helpful in visualizing the data set as a whole, though takes longer to digest. |
| Pie charts | Easy for general public to understand, but can only be used for data that can be expressed in terms of proportions, or percentages, of a whole. Types of data that work well are land uses, population by species at a site, and pollutant loadings. |

- Avoid a misleading graph, such as one that exaggerates small differences.
- Find graphing software programs that are capable of producing the kind of product you want.
- Use the appropriate scale for your data; don’t combine more than one parameter on a graph if the scales are very different.
- If you are comparing between time points or you are looking at trends, be sure to include the results of statistical tests of significance of your findings.

**7.2.2 Maps**

Many watershed attributes can be best expressed in map form, especially since this is the way many people picture their watershed. Most landscape data (e.g., vegetation types) are best viewed as maps. Waterway data (e.g., for water quality) can be attributed to the waterway on a map as a way of visualizing some property of the waterway. For example, if the average water temperatures for particular creeks are considerably warmer than for some other creeks, then the temperature values can be incorporated into the information about the streams in your GIS. These values can then be represented by map colors that show the range of temperatures.

> “For information displays, design reasoning must correspond to scientific reasoning. Clear and precise seeing becomes as one with clear and precise thinking…It also helps to have an endless commitment to finding, telling, and showing the truth.”
>
> ~ Edward Tufte (1997) Visual Explanations, p. 53

Certain types of maps may be very useful for funders, legislators, supervisors, or other people who need succinct information in order to support recommended projects. Examples of this would be the locations of fish passage impediments and some indication of the relative habitat value that would be gained upstream if the impediment is removed, or locations and graphic indicators of sediment sources and their relative contribution of sediment (such as larger circles for higher volume sources). These can help “make the case” graphically for high priority projects and are useful to include in grant proposals.

#### 7.2.2.1 Common Map Features

The point of your maps is to convey a story to the viewer. Your assessment maps will live on past your immediate use of them and may be used in ways you did not anticipate. Make sure that they unambiguously show what you want them to show. Make sure map features are obvious. Make sure the map can speak for itself and does not need you to interpret it.

A good way to convey information in a very direct way is to use a wide range of colors and textures (e.g., hatching) for different features. You could have a random variety of colors for things that are not on a gradient (e.g., vegetation types), or a range of intensities of a single color for things on a single gradient (e.g., average income). However, don't overdo the number of colors or the intensities of a single color. Your readers can only deal with about five color intensities or perhaps a dozen different colors per map before they will be overloaded.

A readable legend is critical to a good map. If the map is used alone, the legend may contain the only description of the map's contents that a reader will see. The legend should have a title, a scale bar, a compass rose, a description of each type of feature on the map (e.g., lines, roads, and streams), units, publication date, and the name of the analyst/mapper.

Most people relate to certain watershed features, so these things should also be included on your maps as basic components. Important components of a watershed map include the following: a) watershed and sub-watershed boundaries, b) waterbodies, c) highways and major roads, d) topography, and e) urban centers. You can represent (a) through (d) with different colored lines, (d) with shading, and (e) with dark polygons.

#### 7.2.2.2 Designing the Informative Map

Once you have the basic information down for the watershed map, you will overlay or underlay particular information about the watershed, sub-watersheds, or areas within the watershed. Although the human eye can detect differences between a wide array of colors, there is only so much information the brain can handle at once. It is best not to overdo the amount of information in a single map. It is possible to include two or three concepts about the watershed (e.g., where human populations are high and water quality is poor); this can be done by using colored or hatched polygons (areas) for certain concepts, and lines for others. Although you may want to include more than three concepts on a map, you should instead create several related maps.

Certain map components and concepts are easier to display together, while others will be more challenging. Combining several data sources with the same symbol type (e.g., line or point) will be more difficult than using several different symbol types in combination. It may be necessary to have several kinds of points and lines on the same map to make a particular point. In this case, try to develop classes or groups of symbols to match the classes of features you are representing. For example, you can use shades of grey and black to represent roads and towns, shades of blue to represent different kinds of water-related features, and shades of green and red to represent natural features and potential risks to these features respectively.

#### 7.2.2.3 Publishing the Maps

There are several ways to publish your map, online within an internet map server, online as an image file, in your report, and as a poster.

1) Internet map servers are increasingly common ways to present multiple layers of mapped information. They can be very complex if they include all the information

for a watershed. One way to deal with the complexity is to split the map server project into several pieces which may contain common elements. For example, a) hydrology – including locations of waterways, waterway-associated vegetation, locations of potentially impacting land uses, locations of roads, ownership; b) land use – including vegetation, hydrology, developed areas, county general plan land allocation, parcel boundaries. Consider maps as portals to other information (e.g., tables and text narratives).

**Action 7.2**

- *Develop an outline*
- *Write text suited to the audience that accurately and concisely describes your approach and findings*
- *Develop tables and graphs summarizing data analysis and findings*
- *Map watershed information and publish online or in your report*

## 7.3 Assessment Product Evaluation

A watershed assessment report should contain the why, how, and who of the analysis and data collection effort. All aspects of the assessment should be reviewed with different standards and potentially different reviewers. For example, an assessment intended to support watershed management planning by a watershed group may need different performance standards than one intended for decision-support about pollution discharge. Because assessments should include a very wide array of types of information, reviewers from a range of disciplines should be employed. After review, an edited version of the report should be developed and provided to the reviewers to ensure that their comments were adequately addressed. You should expect the review and revision process itself to take a fair amount of time and to involve your assessor(s) as (s)he or they respond to comments. In this case, time may equal money and so the review process should be included in the overall budget.

### 7.3.1 Performance Indicators

An assessment report must meet certain expectations for its support of future decisions. This is the “performance” of the assessment. There are indicators for this performance, some of which are:
1) An easy to follow structure to the assessment and report so that the users can follow the logic used by the assessor(s).
2) The connections between questions/issues, data collection, data analysis, conclusions, and any recommendations should be clear.
3) The presentation of data, analytical techniques chosen, and analysis products should be very clear.
4) If conclusions are developed from quantitative information, then statistical tests should be included as the basis for the conclusions.

### 7.3.2 Draft and Partial Products

There will probably be many parties involved directly or indirectly in the analysis and decision-making phases of your assessment. They should be apprised of the progress and direction your assessment is taking during the process. Intermediate and draft products should be reviewed by stakeholders and assessment team members. If you choose to have this review take place then make sure you also reserve time to respond to their queries and comments.

Possible checkpoints for external review could be the following:

- An assessment plan and outline. Detail the questions, data collection, analysis and presentation approaches. Describe potential audiences and management or policy connections.

- An internal draft assessment. Show the data collected, the sources for the data, the data analysis completed, and the preliminary findings.

- A public draft assessment. Finalize data collection and analysis, integrate the data if desired, show data and knowledge gaps, describe findings relative to original questions and otherwise, detail recommendations.

Once these documents have been presented to the technical team, stakeholders/watershed group, and/or the public, a process for accepting comments should be described and a clear statement made about whether or not these comments can result in changes to the assessment. If the assessment will lead to management activities, many stakeholders may want this chance before feeling comfortable with your moving on.

Assessing watershed condition should be a continuous process. However, once you have summarized your findings in a report, released the final draft, and accepted and responded to comments, it is okay to state that monitoring or management actions may occur before the next assessment is completed several years later.

### 7.3.3 Peer-Review

Peer-review of publications is a common occurrence in scientific and technical fields and watershed assessment should be no different. There will obviously also be a significant amount of internal review before a report is released for external review.

The selection of reviewers is a critical task in this process. Expert reviewers willing to spend their precious time reading your assessment report may be hard to come by. There are various ways to capture their attention, from recognition to paying them a stipend for the review. The reviewers should come from a range of backgrounds related to the issues in the watershed examined in the assessment. They should also be both familiar with the management and policy aspects of the assessment and not invested in the outcome of the assessment. For example, a forester might make a good reviewer for an assessment of a heavily-logged watershed, but only if (s)he was not connected in any way to those doing the logging.

Here are some guidelines to consider when choosing reviewers for your report:
1) The number of reviewers should correspond roughly to the number of issues raised in the assessment and the complexity of the assessment.
2) The range of reviewer experience should include people with extensive field experience in the watershed to people doing academic research in relevant scientific disciplines.
3) The reviewers should commit in writing at the beginning of the process to providing a written review of part or all of the report by a certain deadline and be willing to check the responses to their review.
4) The reviewers will preferably have done similar reviews before and be familiar with working with watershed groups and/or the watershed scale.
5) The reviewers should show some enthusiasm about the review process and working with the assessor(s).
6) Reviewers should be chosen with the knowledge or agreement of the committee of interested parties (e.g., a watershed group).

There are several basic steps to carrying out a report review process. A) Adopt a protocol for the review and revision. B) Carry out recruitment and selection of reviewers. C) Communicate with the reviewers to remind them to actually do the review and send their critique. D) Provide a summary and complete list of comments to the assessor(s) and the steering committee. E) Decide which comments will be addressed and by whom. F) Follow-up with those doing the revision to make sure it is happening. G) Incorporate revisions into a final draft version of the assessment report and review internally. H) Send the final revised draft to the reviewers to ensure that their comments were addressed. I) Incorporate any new changes and publish the final report.

**Action 7.3**
- *Use performance indicators and a peer-review process to evaluate interim and final products*

## 7.4 Report Release and Publication

You have several primary options for publishing and releasing your assessment report. These include CD-ROM, online, and as a hard-copy report. You may choose one or several options depending on your needs and budget.

1) CD-ROMs are an efficient way to widely distribute your assessment report, including large volumes of text, pictures, maps, and appendices. You can you use hyperlinks embedded in your report to connect your reader with background and reference material important for understanding your assessment. Other than developing the report, copying CDs is your main cost, which includes the CD-writer. One disadvantage of this approach for some of your readers will be that (s)he will be reading the report on a screen rather than a paper page.

2) Online publication is one way to reach a wide assortment of people who you may or may not know, who may be forwarded the URL for the report or who may find it using an online search. Examples of online watershed assessment reports are given on the CWAM website under the "watershed assessments" button: http://cwam.ucdavis.edu. This approach allows for the same large volumes of material and hyperlinking as CDs. Two disadvantages of this approach are that the reader will be reading your report on a screen and that you will have to invest effort into developing an assessment Web site.

3) Hard-copy reports are the traditional way to report on assessment work. They are what people are used to reading and can be distributed widely (assuming you have a good printing and mailing budget). Hyperlinks and large volumes of material are more difficult to manage with this format. In addition, because there is an expectation that reports will be published online, a search of watershed assessments will not find yours.

The best publication scenario may be to combine 2 or 3 of the above possibilities. This will both increase the breadth of your audience stretch your publication budget. If you already have an organizational website or have access to part of another organization's or agency, then contemporary software can be easily used to publish the report online. For example, if you are reading this text online, it was written in MS Word, converted to PDF format (Adobe), and both file formats saved to a server containing the CWAM website. The time to do that was less than it would take to print and bind the report or burn and label a CD. In most cases, it is probably not worth converting your report to an HTML format as your Word document could look and perform (e.g., links to other material) the same way. In whatever form you think is best, post your report on your organization's Web site.

**Action 7.4**
- *Choose a publication type to match your budget and intended audience*

## 7.5 References

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**THE ASSESSMENT REPORT CHECKLIST**

- ❑ Select a report format
- ❑ Write the Report
    - Outline the content, including texts, figures, etc.
    - Develop a draft
- ❑ Obtain internal and external review of the draft
- ❑ Develop a final report based on feedback
- ❑ Publish the report online, on CD, or as a hard-copy

# 6 Information Integration

Once you have collected all the data needed or available to answer your watershed assessment questions, you face the challenging step of integrating the information in a way that informs decision-making. Information could be numerical data, or some other form of data. Data analysis comes before integration (see Chapter 5).

"Information integration" here means combining or linking information about various watershed processes and attributes in a way that leads to conclusions about overall watershed condition and why the watershed is that way. You could integrate information for particular processes, like the movement of sediment from hillslopes through waterways until it is deposited and the impacts of that transport and fate, for example. You could also combine multiple processes and potential impacts in a system using indicators for potential impacts (e.g., land use), system stressors (e.g., water temperature), and impacts (e.g., aquatic biota). Without integrating individual processes (or separate disciplines or specialties) into the watershed assessment, it may fail to identify potential causes of the watershed's condition and important linkages among watershed processes.

Integrating information about your watershed's condition aids in decision making that transcends management or restoration actions associated with a single process or problem. For example, moderate levels of resource extraction, agriculture, urban development, water management, and permitted waste discharge may individually result in measurable impacts, but may not result in legal concerns about any one of these processes. However, their cumulative impacts on a waterway may be sufficient to make the water unusable by wildlife and humans. In some cases, there will not be enough knowledge about the relationships among processes and their effect on the conditions to be able to integrate this information. But bringing together information on the conditions is very valuable in and of itself. It is easier to work with a combined information set because reference values are available for many conditions thus facilitating analysis and integration of information.

Chapter Outline



## 6.1 Choosing the Integration Approach

While assessments typically involve information integration of some kind, there are few formalized approaches to integration. In this section, methods are presented that might fit your needs and available resources. we present several examples of approaches that scientists and watershed partnerships have used in California. None of them is necessarily "right" or always usable; they are listed here to inform you of the range of available choices.

The relative condition of watersheds and waterways can be expressed in a variety of ways, but it is commonly measured using such indicators as drinking water standards, aquatic community composition, terrestrial and riparian vegetation condition, and constraints on the free flow of water. A majority of watershed or waterway monitoring and restoration projects are based upon definitions of "health" that are either explicit (e.g., water quality standards) or implicit (often expressed as deviation from "historical condition"). Any risk or condition assessment scheme should make these watershed health definitions explicit so that stakeholders understand and support the relevance of the findings or products of the assessment activities. Making these overall watershed assessments will require the development of a scheme for integrating the information.

There are many possible ways to integrate information, from qualitative to highly quantitative, from informal to formal. Many watershed partnerships contain a group of experts from different disciplines who can evaluate information and form professional opinions about watershed condition(s) and the potential causes of those conditions. Other watershed assessments rely on computer modeling for most of the processing of information and then base conclusions on the products of these models. Some assessment programs develop models that return evaluations of watershed condition as the final product.

*When Not to Integrate*

Some watershed experts interviewed during the development of this Manual argued against the integration of watershed data. Their position was based on the generally poor understanding of how many natural systems work in California and the inadequate data and knowledge available to most assessors doing the integrating. They also believed that by doing a good job of investigating individual processes in a watershed, the typical assessor and group or agency will find out enough to make good decisions about management and restoration. By pursuing an integrative component, there is the risk that the assessor could invest large amounts of time and end up producing a questionable or useless product. The argument against integrating has merit and deserves acknowledgment here. Here are several suggestions for dealing with deciding whether or not to integrate if you choose to pursue integration for describing watershed condition:

1) Take on information integration only if you (or your technical advisors) have prior experience in doing so or in doing something similar.
2) Integrate only if you have adequate information about the component systems and knowledge about how they interact with each other.
3) Be sure that integrating information answers a scientific or management question about something that relates to more than one watershed process.
4) Test whether or not you have enough knowledge about the system to proceed by developing a conceptual model and diagram for the watershed. See how many of the boxes and arrows have mathematical relationships associated with them, as opposed to guesses.

## 6.2 Understanding the Modeling Process

Many methods of data integration involve the use of models. A model is a scaled representation of a system, just as a model boat is a scaled model of a real boat. The term "model" covers a lot of conceptual and computational territory. You could model using only mental processes, or you could rely on a physical model intended to represent a system, such as a watershed. When you developed the picture, or conceptual diagram (chapter 2) of your watershed's processes and influences, you were modeling, even if the picture was only in your head.

There are many types of models. The four main categories of models are: a) conceptual, b) verbal, c) mathematical, and d) physical or mechanical (Shenk & Franklin 2001).

- Conceptual models are mental pictures of how a particular system works, which often get put into a diagram (see Ch. 2 for more details).

- Verbal models are narrative explanations of systems.
- Mathematical models are equations or series of equations that describe rate processes (amount of something over unit time) or relationships among processes.
- Physical models are based on measured rules driving a system as well as data from the system and are intended to represent the system. Physical models must be calibrated using data that accurately describe existing conditions.

Following calibration, and periodically throughout their useful life, models must be verified by demonstrating that they accurately predict existing conditions (Michael 1991).

One part of understanding modeling is having an appreciation for its limitations. Probably one of the best rules for any kind of modeling is “garbage in, garbage out.” This means that a model is only as good as the modeler’s knowledge of the system used to construct the model and the data supplied to run the model. A system where there is very little overall understanding of function and not much data available is not a good candidate for computer modeling. However, if it is similar in some ways to nearby systems, then you may be able to develop a conceptual model sketch for it. Models sometimes are perceived as “black boxes” because the assumptions, uncertainties, and methods are not clearly identified. Without clearly identifying what factors contribute to the development of the model, there won’t be much public trust and confidence in the results.

A model is:
- A representation of a system
- Based on understanding the types and magnitudes of relationships
- Created mentally, visually, or with computers
- An aid for evaluation and decision-making
- Dependent on the quality of inputs

A model is not:
- A replacement for understanding a system
- Independent of experts
- A substitute for good science and field work
- The answer

## 6.3 Cumulative Watershed Effects

Considering how the effects of human activities may combine to have greater consequences than the individual effects is central to the watershed approach. Thinking about processes and impacts in the watershed context usually involves combining individual, seemingly isolated events.

Irrigators and water diverters have been aware of cumulative watershed effects for thousands of years. As individual farmers successively diverted water out of a stream to irrigate their fields, they quickly noticed that less water was available downstream. None of the individual diversions had much of an effect, but the combination of dozens to hundreds of diversions could dry up a stream.

The first known scientific evaluation of cumulative watershed effects was a study of the downstream consequences of hydraulic mining in the Sierra Nevada foothills during the 1860s. Geologist G.K. Gilbert (1917) described how sediment from hundreds of hydraulic mines raised the beds of rivers in the Sacramento Valley and, in combination with the unintended side-effects of levee construction, caused widespread flooding of towns and farms. Gilbert (1917) also recognized that the combination of mining debris and reclamation of tidal marshes around San Francisco Bay significantly reduced the cleansing actions of tides in the Bay—a combination that continues to have water quality implications a century later (Reid 1993).

**Policy Context**

The National Environmental Policy Act of 1969 mentions that cumulative impacts must be addressed in assessing a project's environmental consequences. A couple of years later, the Council on Environmental Quality defined "cumulative impact" used in the Act as "the impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency (Federal or non-Federal) or person undertakes such other actions. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time "(CEQ Guidelines, 40 CFR 1508.7, issued April 23, 1971).

The U.S. Forest Service Soil and Water Conservation Handbook (FSH 2509.22) defines "cumulative watershed impact" as "all effects that occur away from the locations of actual land use which are transmitted through the fluvial system. Effects can be either beneficial or adverse and result from the synergistic or additive effects of multiple management activities within a watershed." This language has been simplified by a Forest Service hydrologist by asking, "How much disturbance can occur in a watershed before bad things happen?" A variety of other definitions and interpretations are compiled in Reid (1993) and Berg, et al. (1996).

A recent University of California panel of scientists defined cumulative watershed effects as "significant, adverse influences on water quality and biological resources that arise from the way watersheds function, and particularly from the ways that disturbance within a watershed can be transmitted and magnified within channels and riparian habitats downstream of disturbed areas (Dunne et al. 2001).

**Adding Up the Impacts**

The comprehensive nature of cumulative effects analysis is both the benefit of carrying out the analysis as well as the difficulty. We are accustomed to thinking of watershed processes and impacts in a piecemeal manner rather than holistically. For example, when we think about agricultural impacts, we might traditionally focus on irrigation water withdrawals or pesticide residues. When considering cumulative effects in an agricultural watershed, we need to think about all the water uses, pesticide and herbicide applications and chemical transformations, fertilizers, tillage practices, soil compaction, management of agricultural waste, fuel spills, buffer strips, associated roads and buildings—all the other land uses and impacts in the watershed, and the distribution of everything in space and time.

At a conceptual level in a watershed assessment, the primary task is to recognize that the impact of a particular human activity does not occur in isolation and must be considered in the context of all other impacts and natural events. A watershed assessment should examine the immediate, local impact of the activity, potential or risk of off-site (i.e., downstream) impacts, similar impacts elsewhere in the watershed or on the same site in the past or future, persistence of the impact(s), and whether there is potential for recovery from the impact over some time period. For example, will the activity accelerate erosion on site? Will the eroded soil leave the site and end up in the stream? Are other sites in the watershed producing sediment at unnatural rates? Will the erosion continue for years and will the sediment remain in the channels? Will the site recover and produce less sediment over time?

You should also consider how natural events can affect the impacts. Wildfire, insect and disease outbreaks, and climatic extremes can add to or even overwhelm the human impacts. With most water balance and sediment effects, the impacts' size and duration are affected by the magnitude and timing of storm events (Coats & Miller, 1981). A site might be stripped of vegetation and compacted, but the severity of erosion will still depend on rainfall. If there are no big, intense storms over the several years when vegetation is re-growing on a disturbed site, that site might not contribute any sediment to the local stream. On the other hand, an intense storm during grading of a subdivision could generate vast amounts of sediment from that single site. If many sites are in a disturbed state during that intense storm, the local stream could become severely clogged with sediment. Sediment storage is another complicating factor. For example, sediment from accelerated erosion may accumulate for years in ephemeral and small channels before being flushed out into the larger channels by a major storm. A thorough description of sediment-related cumulative effects may be found in Bunte and MacDonald (1996).

Most work to date on cumulative watershed effects has focused on increases in peak flows and sediment delivery. However, cumulative effects may just as well involve decline in dry-season streamflow, water temperature, nutrient loading, availability of dissolved oxygen, toxic organic and heavy metal pollutants, introduced species, large woody debris and channel stability, fishing pressure, riparian vegetation, and a host of other aquatic ecosystem attributes. For example, many amphibian species are believed to be in widespread decline throughout the Sierra Nevada. These potential extirpations and extinctions appear to be a cumulative effect of such factors as fragmentation of habitat by dams and roads, widespread and persistent fish stocking, exotic diseases, and airborne pesticide drift.

Cumulative watershed effects need not always be considered in a negative light. In some areas, there could be a sufficient number of successful restoration projects to have a positive cumulative effect on sediment, biodiversity, or another watershed component (Dunne, et al. 2001).

Assessing cumulative watershed effects can take the form of prospective or retrospective analysis. Prospective analysis involves the characterization of present conditions as a tool for estimating potential cumulative impacts of human activities in the future. Retrospective analysis, in contrast, involves analyzing the existing conditions that are associated with physical, chemical, and biological stressors.

Unfortunately, there is no straightforward procedure for assessing how various impacts may combine in a watershed. All papers and reports on the topic readily acknowledge the great difficulty of evaluating cumulative effects. A variety of methods for addressing cumulative watershed effects have evolved over the past two decades (reviewed by Reid 1993, Berg et al. 1996, and MacDonald 2000), largely in response to particular agency directives or regulations governing logging. None of these methods are comprehensive, and most are tailored to specific situations. Although one of the earliest papers on cumulative effects (Coats & Miller 1981) recommends that assessment methodologies factor in grazing, agriculture, mining, construction of roads and buildings, and water diversions, almost all procedures to date focus on logging.

*Equivalent Roaded Areas*

One of the most common approaches to evaluating cumulative watershed effects with respect to logging activity is the Equivalent Roaded Area (ERA) procedure. The ERA method was developed for and has been widely applied to national forests in California. The original ERA concept focused on channel destabilization in relation to increased peak flows caused by soil compaction. Accordingly, it used area covered by roads (thoroughly compacted surfaces) as an index of watershed disturbance. Other types of impacts were expressed as road-equivalents. For example, one acre of fresh clear cut might be equivalent to 0.3 acres of road; one acre of five-year-old clear cut might be equivalent to 0.1 acres of road; and one acre of one-year-old 50% selection harvest might be equivalent to 0.1 acres of road. These coefficients are highly subjective and site dependent. The coefficients are multiplied by the areas of the corresponding disturbance types (e.g., clear cut), and those products are added together. The resulting sum is the Equivalent Roaded Area. This area is usually divided by the watershed area to obtain a percentage of the watershed disturbed to the equivalent of a road (%ERA). In many applications, this percentage is compared to another percentage called the Threshold of Concern, an index of watershed sensitivity to disturbance. The threshold is compared to the %ERA to help assess whether the watershed can handle further disturbance or is in need of rest and restoration. Despite the subjectivity and uncertainty in the values, the ERA method has proven to be a useful accounting procedure for watershed disturbance (Menning et al. 1996). Based on results of a study linking ERA calculations within 300 feet of a stream to measures of aquatic biodiversity (McGurk & Fong 1995), the Forest Service has been modifying the ERA method to examine near-channel effects separately from upland effects (Menning et al. 1996). The ERA methodology is not intended to act as a predictive indicator of watershed condition and would probably have little role in watershed assessment beyond comparing disturbance indices between sub-watersheds.

*Integrating the Effects*

To conduct watershed assessments, operational watershed management, and logging regulation, the ability to estimate cumulative impacts of past activities, alternative management scenarios, and proposals for future land use changes are necessary (Dunne et al. 2001). At a conceptual level, the watershed assessor need only think through the possible linkages among multiple impacts by type, location, and timing to progress well beyond the typical, piecemeal approaches of the past. At a minimum, you should know the watershed's disturbance history; where the most sensitive lands are located and the history of disturbance on those lands; the extent, timing, and location of proposed land use changes; and the observation record of hydrologic and geomorphic events. Simple comparison of the disturbance history to the hydrologic record may suggest some associations worth considering as possible causal mechanisms. Such associations do not imply cause and effect, but merely provide pointers for where to look for potential causes. For example, you might find a steady increase in impervious surface and a corresponding increase in peak flows, and there are physical reasons for hypothesizing a relationship between these two processes. Other trends might be completely coincidental and should be regarded as such unless you have a solid physical explanation. Even then, cause-and-effect relationships should be presented as possibilities rather than certainties.

Most of the methods described in this Manual support a retrospective analysis of the cumulative effects of human activities on waterways. The cumulative effects include a variety of types of stressors and their effects on various characteristics of the watershed. For example, in an urban area, one way of understanding cumulative effects is to consider the contribution of numerous small residential or commercial developments to the condition in a waterway. Each new project makes a small contribution to what, when taken together, could cause a significant impact on the watershed. Integrating data on these types of cumulative effects involves considering the source of the stressors (i.e., human activities, land use changes), the type of alterations in conditions that result, and their impacts on the valued ecological endpoints. Trying to assign a percent contribution of various sources of stress is difficult; models are being developed in an effort to address this problem. At present, it is possible to gain a sense of the relative contribution of various human activities to the existing conditions by using a number of different available models discussed in this chapter.

### 6.3.3 Using Models for Cumulative Watershed Effects

While holistic thinking about watershed conditions or processes is difficult in its own right, the next step—attempting to quantify the combined effects of multiple disturbances—is highly complex as well as uncertain. Nevertheless, steady progress in the capacity to model biophysical processes is beginning to offer some possibilities for rigorously calculating cumulative effects. The key to such estimates is to calculate various stream or watershed attributes (e.g., annual stream-flow, peak flows, sediment yield, water temperature, nutrient concentration, aquatic biodiversity indices, etc.) under natural conditions and under various levels and types of disturbance. Most of these calculations necessarily involve assumptions about climate during the period of disturbance. A variety of storm scenarios can be coupled with the alterative disturbance types, intensities, extents, locations, and timing. Another way to examine cumulative effects is to explicitly consider whether a particular disturbance increases the risk of adverse impacts (higher peak flows, more and larger landslides, higher water temperatures, etc.) under alternative climate scenarios (Dunne et al. 2001).

Harr (1989) suggested the use of mathematical models to gain insight into cumulative watershed effects at a time when hydrologic models were primarily a research tool. In the past 15 years, the state of the art of hydrologic, geomorphologic, and ecologic modeling has advanced significantly. In watersheds with adequate data, application of new models offers great potential in estimating some types of cumulative watershed effects (Dunne et al. 2001).

## 6.4 Methods for Data Integration and Synthesis

There are several possible reasons for integrating information about processes and conditions in your watershed. One is to find areas within the watershed that are likely to be in worse overall condition than other areas because of a combination of different activities located there. Another is to give a relative ranking for a watershed compared to other watershed evaluated in the same way to aid in regional prioritization. A third is to investigate possible causes of measured impacts in the watershed.

This last can be quite difficult. Frequently, historical, hidden, or multiple factors contributed to observed conditions. It is appropriate to make assumptions about cause and effect; this is necessary when developing your conceptual model. For example, attributing streambank erosion as one cause of sediment input to a creek is a logical first guess. However, your data might show instead that roads caused most of the sediment input. The assessment needs to clarify the linkage between what it is about the roads that has caused, or is causing, sediment yield to the stream. Is it erosion from the fill slope, cutslope, dirt road surface, inboard ditches, stream crossings, blown-out culverts and road fill, slope above the road, landslides, streambank erosion undercutting the road, poor road maintenance practices, or what? Does all of the road erosion end up in the stream (as "sediment yield"), or does it get deposited in other areas with less connection to the drainage system? A good road erosion inventory can help identify, at both a coarse and a fine scale, these more detailed causes within this category of "roads." This greater detail about road causes will provide more useful information for your watershed assessment and any subsequent plan.

Sometimes, the initial hypothesis used to develop the conceptual model is not supported by the data. The responsibility of the assessment team is to make these important evaluations – the question is: how is this best accomplished? Testing a hypothesis using a statistical procedure usually offers the most certainty or confidence in evaluating a suspected cause and. Looking for significant relationships between various factors (e.g. road density and sediment inputs) with available data in your watershed could be performed. There are many useful references to help you in this process (e.g., Leopold 1994; Gordon et al. 1992; Center for Watershed Protection 1998). However, a sound statistical approach can be difficult to apply in a non-research setting due to lack of controls and inadequate data, funding, or resources. As an alternative indicator of cause and effect, you can cite relevant research that has been able to make statistically significant inferences about cause and effect. If others have studied the issue relevant to your watershed under more controlled conditions, you can utilize this knowledge in your analysis.

This section of the Manual presents various methods for integrating information about watershed conditions. One of the most common methods is to assemble a team of experts in particular disciplines, collect and analyze information about watershed processes and conditions, collectively draw conclusions about potential reasons for the present circumstance, and suggest actions that could be taken to improve or protect the situation. Recently, more quantitative methods and models have been developed. Several of these approaches will be reviewed in this section. Which of these methods might be useful depends on the amount of data that has been collected, the level of expertise of the assessment team or its consultant, and available financial resources.

### 6.4.1 Team Mental Integration

Just about every watershed assessment will involve some sort of team mental integration. The Team Mental Integration method is really nothing more than the assessment team and appropriate experts systematically reviewing the data and, using best professional judgment, assessing the relative condition of different parts of the watershed and impacts of various alterations in the watershed on natural processes. In many watersheds, a collection of experts may provide more detailed and accurate knowledge about influential processes than the best computer model. This may be partly due to the absence of adequate data and the lack of a model that truly represents real world conditions, and because expert knowledge is still superior to mathematical models in many cases.

One of the strengths of the 'team mental integration' method is that, in most cases, it can be performed by members of local watershed groups without engaging in expensive consultation or more sophisticated methods of statistical analysis.

On the other hand, this approach has certain limitations. There is not a single, widely-accepted approach for evaluating the weight of the evidence for an assessment. Also, it may be difficult to ascertain whether the team members have sufficient knowledge to thoughtfully interpret the data. If your team does not have the right qualifications, the insight gained from integration of their knowledge and information will be limited. Competency is best measured in the amount of formal training in one or more scientific disciplines, field experience, the amount of time spent understanding the watershed or watersheds like it, and the ability to see watershed functioning from more than one perspective.

The suggestions in the following list address some of the potential benefits and pitfalls of the expert team approach:

- Record whatever approach you use in a way that will allow a reader of your assessment, or a future assessor, to understand exactly what you did. This means describing both the details of the data considered and the analyses chosen and rejected, as well as a summary of the approach taken by your team.
- The composition of your team determines the quality of your assessment. Include team members' qualifications, experience, and training as part of the assessment so readers can assess for themselves how much confidence to put in the conclusions drawn.
- Comparing professional judgment with numeric modeling approaches can be done in various ways, where the most common (and possibly easiest) method involve turning each set of information into rank values and comparing these values using readily available statistical tests.
- Because you will rarely get a group of experts together again to discuss your watershed, take advantage of this opportunity and make sure they stretch their brains. Encourage them to think about novel ways that data and knowledge about individual processes can be brought together. Record the full spectrum of their suggestions, from speculation with little data to sturdy conclusions based on a lot of data, analysis, and expertise.
- Find ways to express professional judgment graphically so people can visualize their ideas. This will help make the knowledge of experts about the watershed more broadly understandable.
- Promote diversity in your team by including members from a wide range of disciplines, ages, and organizational origins. This is bound to lead to raising critical questions, involving a range of approaches, and creating interesting discussions.

An early step in the team integration process should be to review and revise the conceptual model, assuming one was developed for the watershed. The conceptual model clearly identifies what you believe to be possible relationships between altered conditions or processes in your watershed and adverse effects on watershed processes or value attributes. There are no hard and fast rules for how to do this. However, having a conceptual model as a starting point in such a team approach will facilitate communication among disciplines. It will also possibly lead to accurate evaluations of relative risk or harm to particular sub-watersheds and potential causes of observed or measured impacts. One way to investigate "cause and effect" relationships in the context of this team approach is through the "weight of evidence" approach.

*Weighing the Evidence*

There is no one widely accepted way to go through the process of weighing evidence. However, the US EPA has developed some guidelines that recommend one approach. The EPA has developed methods for identifying cause and effect relationships (US EPA Stressor Identification Guidelines, 2000; posted at: http://www.epa.gov/ost/biocriteria/stressors/stressorid/pdf). The Stressor Identification approach involves reviewing a series of questions about data on each of the conditions evaluated. Depending on your answer to these questions, you can identify factors or stressors that appear to be related to the observed conditions. The US EPA is also developing a new website that supports this approach, the Casual Analysis Diagnosis/Decision Information System (CADDIS). As of August, 2004, CADDIS was still in the development stage, but will be available to the public in the near future. The approach recommended by the US EPA is based on the weight-of-evidence, i.e., the greater the number of factors that support a relationship, the more confidence you have in that relationship.

If your team chooses a cause-and-effect approach to evaluating watershed condition, then the following table may be useful. It contains a list of criteria, which if met, provide evidence of a cause and effect relationship.

The US EPA recommends assigning a rank based on your answer to each of the above questions, ranging from very unlikely to maybe to very likely (--, -, 0, +, ++ for example). You can then assess if the evidence is sufficient to identify a cause and effect relationship. This process can also help identify data gaps – what types of new data you might need to gather – to be able to draw conclusions regarding cause and effect. The strength of the relationships between various human activities, alterations in different watershed processes and conditions, and adverse effects on ecological endpoints can be sorted out using this process. By reviewing the data and evaluating the weight of the evidence, you will develop a group of hypotheses about the most likely causes of the impairments.

| **CRITERIA FOR EVALUATION OF CAUSE AND EFFECT RELATIONSHIPS** | |
|---|---|
| **Factor to Consider** | **Question to Ask** |
| Spatial Co-occurrence | Did the stressor or altered process and the harmful effect occur at the same place or in reasonable proximity? |
| Temporal co-occurrence | Did the stressor or altered process occur prior to the observation of effects? |
| Consistency of association | Is the effect associated with the alteration or stressor at more than one place in the same location? |
| Biological gradient | When you get farther away from the source of the stressor (e.g., particular land use), is the observed effects reduced or not as severe? |
| Route of exposure | Is there a logical way for the ecological endpoint to be exposed to the stressor or for the altered watershed process to affect the ecological endpoint? |
| Experimental evidence | Is there independent experimental evidence to support the association between potential causes and effects? |

In some cases, this is as far as your assessment will go, and in many cases this is all that is necessary to get a basic picture of the key stressors or alterations in watershed processes and the likely causes of these changes.

Remember that at some point, your team must produce an integrated assessment. Your watershed assessment will not be complete if it consists of a series of chapters that have no obvious connection to each other and no actual integration step for the information gathered and the knowledge gained. It might help to have a group of authors who can write effectively together, or a single author who can pull all of the parts together and have the product checked by the rest of the team.

### 6.4.2 Ecosystem Management Decision Support: A Knowledge-Base Model

One process for evaluating watershed condition involves using a new modeling approach designed both to reflect inexact knowledge about natural processes and to be based upon expert knowledge of a system. The approach is embodied in the software tool “Ecosystem Management

Decision-Support" (EMDS)[1] (Reynolds et al., 1996 & 1999). EMDS has been used in the North Coast Watershed Assessment Program (NCWAP) to evaluate the condition of and restoration potential for salmon habitat in several North Coast watersheds (http://www.ncwap.ca.gov/default.html) and by UC Davis to evaluate watershed condition and risk to that condition in the Yuba watershed, (http://snepmaps.des.ucdavis.edu/snner/yuba/StateYubaLands.pdf). It has also been used to prioritize restoration sites for mercury remediation in the Sacramento River basin (http://www.sacriver.org/subcommittees/dtmc/documents/DTMC_MSP_App5.pdf).

**Knowledge Base**

A knowledge base is a collection of the best available information about a system or process. It explicitly lays out the connections between categories of things in the system and describes the relationships thought to be present between them. There is often a hierarchical structure to a knowledge base, starting at the top with the broadest concept. This could be "watershed condition". Branching off from this concept is supporting knowledge about factors that contribute to determining watershed conditions. For example, watershed condition could be based on a combination of 1) valued ecological components and processes and 2) human and natural disturbances. Each of these sub-categories is in turn based on component information. For example, (2) could include a) human activities and structures that affect habitat, b) water and aquatic habitat quality, and c) natural processes that affect habitat. Eventually, to assess watershed condition, sub-categories would have to attach to data that described conditions in the watershed.

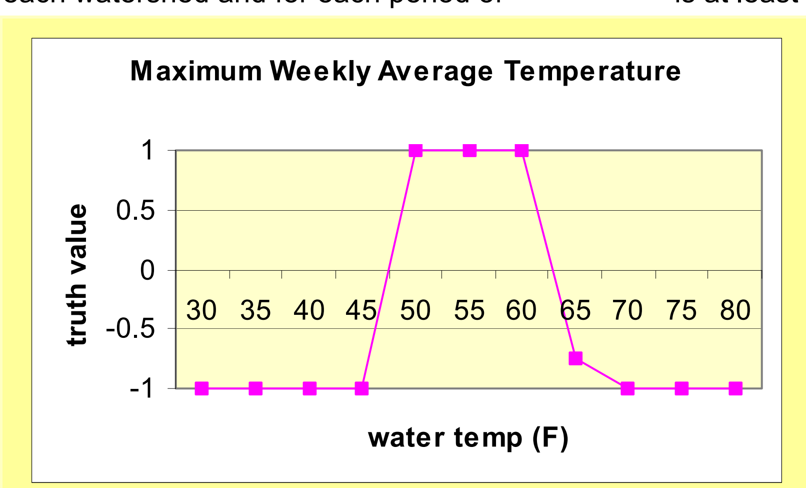
EMDS is based on a "knowledge base" of interactions among components and processes in a system based around a single question or assertion about the system. EMDS develops and make explicit a set of assertions used to evaluate a concept, such as water quality. An example of such an assertion could be: "where are potential sediment sources in the watershed?" The main idea behind the knowledge-base is to pull together a set of raw data about the system, such as water quality and biological data, into a single number that measures the broad concept of watershed condition.

The main assertion in the knowledge base is split up into sub-assertions that further define the main assertion. Example of a sub-assertion might be: "where are sites of mass-wasting?" and "where have human structures been built on fragile sediments?" The explicitly defined relationships among sub-assertions are based on a combination of published literature and expert opinion. The criteria for evaluating the assertion are defined in the structure of the knowledge-base. These criteria are generally based on a specific set of state or federal water quality standards, identified risks from land uses, and other threats to ecosystem processes identified in the scientific and technical literature. The final product of an EMDS analysis is an assessment of the primary assertion's "truth-value", which is a number ranging between –1.0 (completely false), 0 (undetermined), and +1.0 (completely true). The truth-value can be thought of as an index for measuring risk to ecological function or watershed condition.

[1] A group of Powerpoint presentations explaining the EMDS model and the most recent release (version 3.0) are posted at: http://www.fsl.orst.edu/emds/. There are two usable versions of the EMDS software: versions 2.0 and 3.0. Both versions are free. Version 2.0 is an extension of the GIS software ArcView 3.2 and uses grid data. Version 3.0 interacts with ArcGIS and can be used with either polygon or grid data. Version 2.0 is no longer being offered on the website, although it can be obtained from the authors.

In the figure below, a reference curve for temperature impacts to salmon is illustrated. The truth-value is plotted on the y axis and represents the suitability of certain temperatures for salmon. This example is from a North Coast Watershed Assessment study that used EMDS, posted at: http://ftp.dfg.ca.gov/outgoing/whdab/ncwap/public/watersheds/EMDS_Appendix_1.16.pdf. In this example, when water temperature remains between 50-60 F, it is suitable for salmon and is “true” for suitable water temperature (truth value = 1). When it falls below 50 or goes above 60, temperature starts acting as a stressor and has a correspondingly reduced truth-value. When the temperature reaches less than 45 or greater than 68, it is very unsuitable for salmon, causing a variety of adverse physiological effects, and is false for suitability (-1). The condition within any single waterway can be evaluated on this curve to determine the truth-value for suitable temperatures. A series of such values can be accumulated, reflecting a variety of conditions in a stream or conditions in several streams in a watershed.

The advantage of this approach is that all components of a watershed’s condition (e.g., water temperature and habitat fragmentation) are scaled to a –1 to 1 range, which allows for the combination of the component values into a single index for each watershed and for each period of analysis, permitting ready comparisons between and among watersheds. Component values may also be grouped according to a common feature (e.g., physical vs. chemical) and the relationship among components (e.g., nitrates, phosphates, sulfates) within a group (e.g., nutrients). This analysis produces a range of values from a single index value for the combined water quality components to individual values for each component.




*Decision-Support*

EMDS was designed with management decisions in mind. It is sufficiently flexible to be used for many types of decision support and evaluations. The main product of the analysis are maps containing “answers”, in the form of different values for pixels or grid cells on the map, for the assertion and sub-assertions. How much confidence you put in these values depends on your confidence in the quality of the base data and your knowledge of the system, both of which were used to develop the knowledge base. Like all models, and especially ones that integrate a lot of information, its products should be used with caution

With large complex models and places, you may not be able to arrive at an assessment product simply by analyzing everything in your head. With well-understood processes and high-quality data, the modeling product is at least good enough to base next-step decisions on, like where to do a field evaluation. If the input data and your knowledge are of similar quality across the watershed, then the product can also allow you to compare areas within the place. If you have moderate or less confidence in your knowledge of the processes and similar confidence in data quality, then the product may still be valuable as a tool to understand what you don’t know about the watershed. One group using this approach found that identifying the knowledge and data gaps was a very useful part of the whole modeling exercise (Girvetz & Shilling, 2003).

### 6.4.3 Relative Risk Model

**Background**

The Relative Risk Model (RRM) was originally developed as a tool for watershed risk assessment (WRA). WRA is a process for estimating risk associated with chemical, physical, and biological stressors affecting ecological systems (Harwell & Gentile, 2000). Stressors are physical, chemical, or biological factors that may cause adverse effects on natural systems (e.g., fish habitat) and components of these systems (e.g., individual fish populations). WRA lays out a process for using science to inform environmental decision-making concerning watershed features (components of a system, like plants or waterways). WRA is intended to answer the questions:

- What is the current state of the watershed?
- What are the possible causes of the current conditions or processes?

Watershed risk assessment follows a basic 3 step process very similar to the more general watershed assessments described in this Manual: problem definition, analysis, and risk characterization. Risk characterization is essentially the same as data synthesis and integration. A variety of methods are used by risk assessors to estimate risk associated with various stressors. The US EPA has developed an online training manual on watershed issues, which includes one module on watershed risk assessment. It is posted at: http://www.epa.gov/watertrain.

The RRM model was developed to evaluate risk factors at different locations in the watershed, ranking the importance of these locations, and combining this information to predict the relative risk among the different areas and from the different stressors (Wiegers et al., 1998; Landis & Wu, 2003). The RRM is based on numerical ranks so that data on different types of risk (eg., chemical, invasive species, etc.) can be compared without regard to the metric or units of the original measurement (Landis & Wu, 2003).

The RRM was designed to serve as an initial screen or assessment of stressors within a watershed. It is especially useful when there is limited in-stream data. It is very useful for estimating which stressors are likely to be most important, for identifying which land uses and human activities are most likely associated with adverse effects, and for prioritizing which stressors should be the focus of future investigation. One of the products of this analysis is a group of hypotheses that can be used as a guide for future monitoring and analysis. The basic steps in using this model are the same as those suggested in this Manual: defining the purpose of the analysis, selecting ecological endpoints, developing a conceptual model, and gather existing or new data. The conceptual model is particularly important because it forms the basis for identifying stressors as well as different land uses and human activities that are assigned a risk scores in the model.

*Using the Relative Risk Model for Watershed Assessment*

The discussion of the RRM in this chapter will focus on the principles and basic outline so you can determine if it would be useful for your situation. Details of how to perform the analysis, including all calculations, are included in the Appendix. The following review of key steps to use the RRM is drawn from Landis & Wu (2003).

Step 1: Make a map of the watershed and break it into regions based on a combination of hydrology and human activities.
If you are using a GIS, identify sub-watershed fairly easily using a hydrological modeling tool. If you are using a topographical map, you will need to rely on

the contours of the map to approximate sub-watersheds. These divisions create risk regions for which risks will be calculated. In some cases, you might identify so many risk regions that it is impractical to work with them. In these cases, group small regions together based on common land uses or sources of stressors.

Step 2: Adopt a method for evaluating types of land uses, stressors, and habitats.
The relative risk model is based on relative ranks which are assigned to land uses, stressors, and habitats. The areal extent, or total acreage for each land use and habitat types, within each sub-watershed is calculated using either a GIS or making estimates by hand. To evaluate each stressor, initially the values for the in-stream or riparian conditions in the watershed are compared to benchmarks, those levels above which it is probable that an adverse effect will occur. This follows the same process described in Ch 5.2 of the Manual.

Step 3: Calculate the risk.
The risk calculation involves a comparison of various land uses (sources of stress) with each other, as well as comparisons of various stressors and habitats with each other. For example, ranks of 0, 2, or 4 could be assigned to various land uses/human activities. A rank of zero would be assigned if a particular human activity did not occur within the risk region. Alternatively, a rank of zero would be assigned if the average water temperature fell between the lower and upper temperature thresholds for the aquatic species of interest. A rank of 4 might be assigned if the land use associated with a stressor (such as golf courses which are often heavy users of pesticides) covered large areas of the sub-watershed. The key take-home message here is that these ranks are assigned based on the magnitude of the factor being evaluated. Ranks are used because diverse factors as concentrations of chemical contaminants, characteristics of the benthic substrate, and amounts of large woody debris cannot be directly compared to each other, but ALL can potentially cause stress to aquatic organisms.

Step 4: Evaluate uncertainty and sensitivity of the relative rankings.
It is important to at least qualitatively identify uncertainty in your analysis. Refer to Chapter 4 of the Manual for more details.

Step 5: Identify next steps.
One important 'next step' is to identify hypotheses that form the basis for future study and effort. For example, if in the risk analysis, certain stressors or land uses were identified as high risk, then future study should be directed to evaluate the risks of these human activities and/or stressors. For example, in one watershed assessment using the RRM, contaminants in the sediment and the amount of fine sediment in the streambed were found to be high-risk stressors. Since there was limited data, statistical analysis could not be performed and the degree of uncertainty was high. But the assessment was nonetheless useful because it pointed to those areas which needed further study; it generated a series of hypotheses which laid the basis for future data collection efforts.

*Possible RRM scenarios*

The relative risk model can be used in those situations in which little or a lot of data are available. An example of two different conditions illustrates how these analyses would differ:

Scenario 1: No or very little in-stream data available

If your group has very little in-stream data, you can use the RRM to assess the land uses within the watershed and make a first estimate of what human activities have the potential to be associated with observed issues of concern. The RRM will help to focus attention on those habitats and sub-watersheds that are at greatest risk. The principle behind this approach is that the greater the areal extent or acreage of land

**An example of ranking a biological stressor**

In this example, invasive species have been found in a salmon spawning stream. Predatory bass are present and you wonder to what degree they might contribute to the observed decline in the salmon population. Do the bass prey on the juvenile salmon? Assume you have data on water temperature and have done a bit of seining so you know the approximate distribution, size, and abundance of the two species within the 3 major reaches of the waterway. A ranking system was developed that reflected a various combination of factors such as temperature, abundance and size of bass, and the distribution of salmon in the stream. Using this scheme, ranks were assigned to each of the 3 reaches, to evaluate if and where the bass posed a risk. In this case, statistical analyses would not be valid, but a basic estimate of potential harm produced from this analysis can serve to guide future monitoring efforts.

uses that might be the source of stressors will probably pose a greater risk than those with a smaller areal extent. Likewise, the larger the extent of various habitats, the greater the amount of a natural system that is at risk of harm. Land uses with the greatest coverage are assigned higher ranks than those with fewer acres.

<u>Scenario 2: Existing or new data has been collected</u>

In this circumstance, you will be able to compare data from your watershed on key stressors/conditions to benchmarks or thresholds that are thought to protect aquatic life or whatever valued ecological components you have identified as important for your assessment. The methods for doing this are discussed in detail in the Appendix. Briefly, a rank is assigned to each stressor based the relationship between the in-stream/riparian conditions and the benchmark. Conditions that appear to exceed values known to protect aquatic organisms, for example, will be assigned a moderate or high rank (2, 4, or 6 on a scale of 0 - 6) compared to values that are at or below the benchmark (0 on a scale of 0 - 6). Using some simple calculations, you can group those stressors into high, moderate, or low risk categories.

In conclusion, the Relative Risk Model is one method that can be used to begin to gain an understanding of the effects of human activities on valued ecological systems that are the focus of your assessment. This method is especially useful when relatively small amounts of data are available or when you have a limited budget for hiring consultants. It provides a method for making a first-cut estimate of risk to valued resources and can serve as a tool for developing plans and strategies for future work.

### 6.4.4 Southern California Riparian Ecosystem Assessment Method (SCREAM)

Goals of the Southern California Wetlands Recovery Project (WRP) include the identification and recovery of riparian wetlands in coastal watersheds. The SCWRP team is developing a model (Southern California Riparian Ecosystem Assessment Method-SCREAM) for information integration about watershed condition to help prioritize places and actions for wetlands restoration. This model may not be suitable for all watersheds in California, but its design should help with the design of similar integration of information in other places. SCREAM is a GIS-based tool to assess the ecological condition and stressors affecting riparian habitat at a landscape scale. The method was developed collaboratively by the WRP, Southern California Coastal Water Research Project (SCCWRP), and the NOAA Coastal Services Center.

WRP has identified critical ecological indicators and used them to develop rules for the decision-support process. These indicators are linked to the recovery objectives. There are five recommended quantifiable recovery objectives:

1) Maintain existing and increase new wetlands and riparian acreage
2) Recover habitat diversity to reflect historic distribution
3) Recover biological structure and function
4) Restore physical processes
5) Recover landscape elements of ecosystem structure and function.

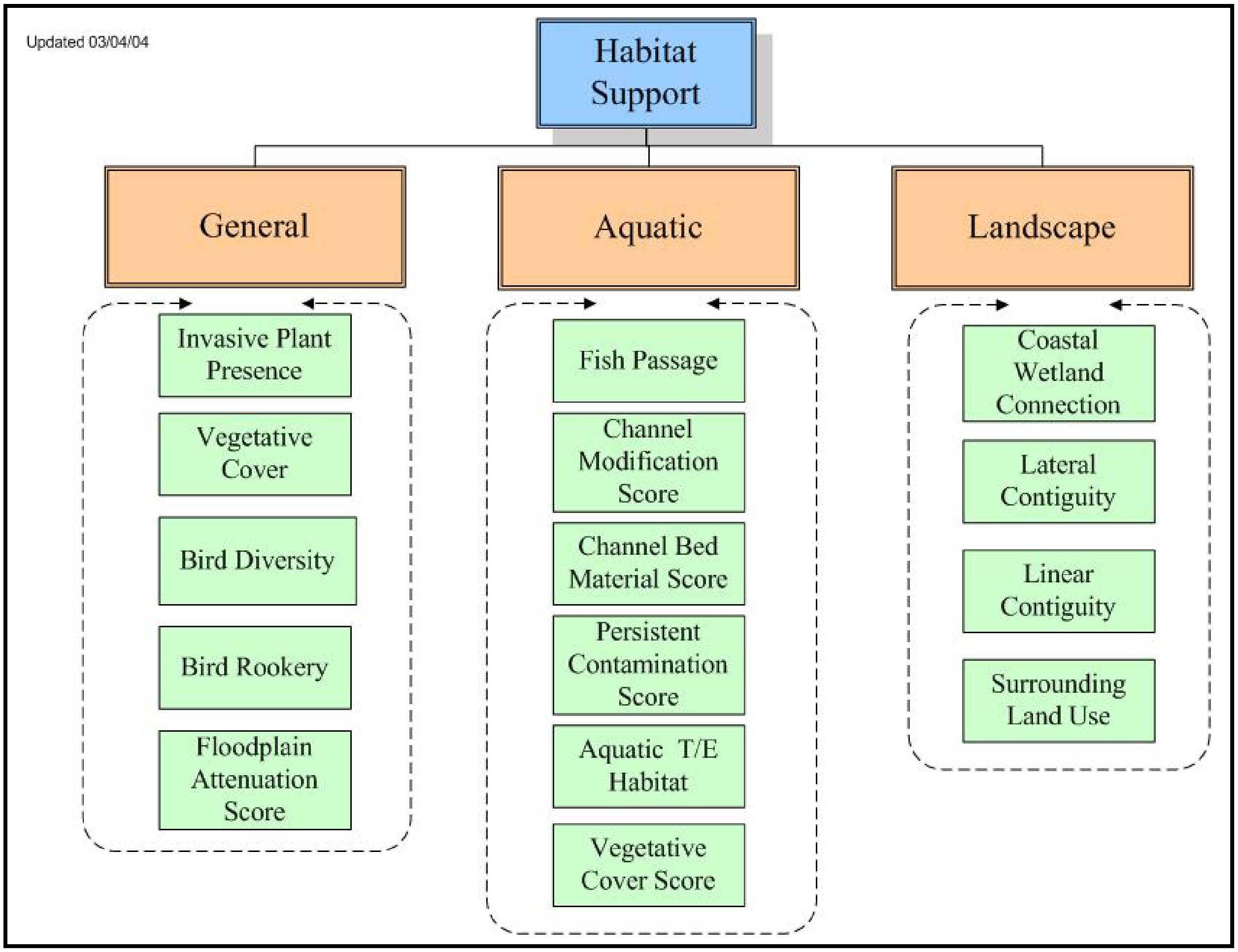
The evaluation of wetland and riparian areas will include consideration of both the attributes and condition of the areas themselves and of surrounding and upland areas. The categories of attributes and metrics include:

1) "General" habitat quality: presence of invasive species, domestic predators, habitat diversity, threatened and endangered species habitat, and riparian vegetative cover
2) Aquatic habitat quality: water quality, presence of persistent sources of contamination, known contaminated sediments, streambed condition, presence of adjacent floodplain, opportunity for hydrologic connection
3) Fish habitat: fish passage, known spawning ground
4) Bird habitat: bird diversity, known rookery
5) Landscape: connectivity to coastal wetlands, riparian connectivity and extent, surrounding land use, connectivity between open spaces, adjacency to preserved areas, and component of a corridor network
6) Channel-floodplain interaction: adjacent floodplain, opportunity for hydrologic connection, stream profile, streambed hardness
7) Hydrologic continuity: stream system complexity, degree of impoundment, flow restrictions
8) Runoff/infiltration: infiltration capacity, groundwater recharge, and width of natural area
9) Flow augmentation: dry season artificial discharges and NPDES-permitted daily discharges
10) Regional planning: position in landscape and drinking water conservation areas
11) Sediment processes: intact sources of sediment, stream slope, sinuousity, adjacent floodplain, and impoundments
12) Sources of contamination: persistent sources of nutrients, pesticides, heavy metals, and organics; contaminated sediments; and water quality impairment
13) Factors affecting biogeochemical cycling: upstream engineered system, streamed hardening, impoundments, perennialized flow, adjacent floodplain, opportunity for hydrologic connection, sinuousity, riparian vegetative cover, wetland edge-to-area ratio);
14) Regional planning: position on landscape and soil composition

Lists like this may be useful for your watershed assessment as you consider what information to integrate and how to categorize it. The conditions for these parameters within a watershed are used to assess altered conditions. Although the specifics will vary from one watershed to another, the general categories being evaluated are applicable to most all areas of the state.

In the SCREAM model, existing or new GIS data layers are compiled and organized, and the information contained in those layers is used to calculate hydrologic, biogeochemical, and "habitat support" scores. In SCREAM, all streams in a watershed are divided into "units of analysis" (UAs) and condition scores are calculated for each UA

The foundation of SCREAM is a geospatial database (ArcGIS geodatabase) that is




created using GIS data layers on the physical, biological, hydrologic, and chemical properties of a watershed. Input data layers include land use/land cover, channel properties (i.e. channelization), infrastructure (e.g. bridges), locations of known pollutant point-source discharges, soil characteristics, topography, and documented occurrences of sensitive and invasive species.

Once compiled, the model queries the geospatial database and assigns scores to series of metrics using a defined set of formulas. Metric scores are then integrated into component scores, and finally into overall scores for hydrology, biogeochemistry, and habitat, using a series of rule based models. Condition scores are based on an integration of features within a specific UA as well as in surrounding or adjacent areas that may affect the overall condition of the UA. Specific scoring algorithms and weightings can be user-modified based on availability and confidence of specific data layers. The output of the model is a GIS coverage in which each UA is attributed with overall condition scores, as well as scores for the underlying metrics.

The WRP envisions that the SCREAM tool will be used as part of a comprehensive assessment program to evaluate the condition of and stressors affecting wetlands and riparian ecosystems in southern California. SCREAM also has potential to aid in the prioritization of recovery activities by identifying riparian areas with a high functional contribution to the watershed. The results of SCREAM could be used in combination with other considerations such as feasibility of restoration and cost to inform decisions about restoration priorities. SCREAM is intended to be flexible and accessible to a variety of user levels. SCREAM could easily be adapted to other areas of the state by adjusting the parameters of the model to reflect the appropriate landscape and physiographic conditions of the region.

The diagram above illustrates the 15 factors identified above that are included in the "Habitat Support" part of the SCREAM model.

#### 6.4.6 Common Aspects of the Methods for Data Integration

There are a number of common characteristics that all the methods for data integration share:

- They utilize a pre-established set of criteria for evaluation of data, thereby minimizing subjectivity from the analysis as much as possible.
- They employ a system of ranking of the geographical areas, stressors, or conditions based on an evaluation of the altered watershed conditions or processes.
- The results of the evaluation can be used for decision support and the development of a watershed management plan.

### 6.5 Sensitivity Analyses and Developing Future Scenarios

#### Sensitivity Analysis

Sensitivity analysis is a technique to test how sensitive the model "output" or results are to changes in the "input" data. Sensitivity analysis involves changing the input parameters of a model over a reasonable range and examining how this change affects the model outputs. By clarifying how the model outputs respond to changes in the inputs, the appropriate level of confidence in the model becomes clearer. Information derived from sensitivity analysis helps clarify which parameters in the model have the greatest influence on the model outputs. For example, if you are uncertain about the magnitude or sign of the coefficient for a model parameter, and the model is relatively sensitive to that parameter, it may be worth taking steps to reduce that uncertainty, e.g., through additional research. The more sensitive a model is for a given parameter, the more concerned you should be with the quality (accuracy and variability) of the data since small difference could result in a large difference in the model output. If the model is highly sensitive for a parameter, and the quality of the input data for the associated independent variable is poor, it might be worth investing more money or effort into improving the quality of the input data.

Sensitivity analysis can be applied to conceptual models as well as to computer-intensive quantitative models. If your watershed assessment does not involve computer modeling, you can still conduct the same exercise of iteratively leaving out certain types of information (e.g., intensive land use) from your conceptual model and seeing how that impacts your condition assessment. You may find that certain processes have greater potential impact on your findings than others. You can then determine whether data quality is high for the processes that have the greatest impact on your condition assessment.

#### Statistics for Sensitivity Analysis

When doing sensitivity analysis with numeric values, including ranks, be sure to statistically analyze the differences among different treatments. Each treatment is an independent model slightly different from the others. The point of sensitivity analysis is to assess the magnitude of change in the model's product after modifying an input variable. The greatest sensitivity corresponds to the greatest difference between values in your indicator variable. The greater the difference there is in your indicator variable, the more the system is sensitive to that variable. If the model's product is spatial data or a time series, then how you compare the original model product with the alternatives is important. Useful statistical principles and tools are described in the Appendix and on the CWAM website (http://cwam.ucdavis.edu).

**Developing Future Scenarios**

Many models are intended to describe how a system works and can therefore be valuable for anticipating change and predicting the impacts of change in the future. Many watershed groups and decision-makers are interested in the potential consequences of future actions. These actions could be ones they have control over or not. By using different models and changing assumptions both within the models and within the data sources, it is possible to project actions and potential impacts in the future. For example, a county anticipates that under its revised general plan 2,500 acres of rural landscape will be developed in five-acre parcels. Although the exact distribution of these parcels is unknown, the county anticipates that development will take place in three watersheds. Planners could model potential impacts of increased impervious surface development on runoff, potential increases in sediment production from disturbed areas, and fragmentation of wildlife habitat by new roads and parcels. In addition, if what attracts people to develop is known and can be mapped (e.g., proximity to public lands, proximity to services), then it will also be possible to estimate where development will occur and thus assess the kinds of impacts to be expected.

Although this Manual doesn't describe many of the ways to develop future scenarios, here are ways of deciding how and whether to do this type of modeling.

1) Consider whether your assessment question or purpose logically leads to projecting conditions into the future. For example, if you are concerned about impacts of specific land uses, you might want to model potential impacts of these uses under climate scenarios that did not occur during your data collection.
2) Accurately projecting forward from historical data requires that you be confident in your knowledge of cycles and trends. Without knowing how watershed parameters change and respond to each other, you won't be able to construct a model correctly.
3) Future scenarios are usually developed to inform policy (e.g., land use, regulation, restoration). Therefore, the description of scenario development and the products should be written and presented is such a way as to be understandable to the intended audience.
4) Because there are likely many unknowns, several scenarios should be developed that reflect variations in the amounts, distributions, or rates of an influential process (e.g., logging). To keep things simple, one major influence should

**Information Integration Checklist**

- ❑ Select a method for data synthesis and integration
  - Team mental integration
  - EMDS
  - RRM
  - SCREAM
  - Other appropriate model
- ❑ If appropriate, use sensitivity analysis to evaluate the model

be varied at a time. In some ways, this is similar to sensitivity analysis (see above).

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# 5 Analyzing Data

This chapter helps you move from raw data, as described in Chapter 4, to interpretation. You might be data rich, but information poor and find yourself staring at a bunch of numbers that do not yet tell a story (Dates 1999). The material presented here and in Chapter 6 on information integration will assist you in making the assessment more complete and accurate. In moving from raw data to interpretation, you may encounter a few stumbling blocks along the way. Suggestions to overcome these problems can be found in this chapter. A discussion of options for presenting your findings in an easy-to-understand format is reviewed in Chapter 7.

This chapter is not intended to turn you into an expert in statistics. It should provide you with a basic understanding of the terms and concepts related to the statistical analysis of data. This background should help you to understand existing statistical analyses of data from your watershed and to work effectively with consultants or collaborators who will be conducting new analyses of watershed data.

Chapter Outline



## 5.1 Analysis Overview

The analysis portion of your watershed assessment is critical to your effort. The careful and thorough analyses of existing and new data you generate will support the integration and synthesis of all information (results of data analyses) into a useful story about how your watershed evolved into its current condition and what that condition is (see Chapter 6). Your analyses will also help establish the events and processes that contributed to different aspects of your watershed's condition.

As you pursue different analytical procedures, stay focused on your objectives. With so many possible analyses that might be conducted, try to choose only those that will help you answer the fundamental questions posed at the outset of your assessment.

The following sections describe a variety of approaches to exploring and analyzing typical watershed data sets. When your analysis is finished, consider the outcome: Do the results make sense? Will other people believe and accept the results? If the analysis was inconclusive or the uncertainty was too great, reevaluate your procedures and your available data. Quite often, sample sizes are just too small to provide definitive answers. In such cases, if there is no clear alternative means of analysis, it is perfectly acceptable to state that you are unsure or that there is a lot of uncertainty in the analysis. It is quite common to have an indefinite outcome from analysis of environmental data sets where tight experimental control is not feasible or cost-effective. Honestly state the limitations of the analysis and resulting conclusions.

### 5.1.1 Revisit Your Original Questions and Conceptual Model

When choosing which analyses to perform, think strategically about what you want to get out of the process. Go back to your original watershed assessment questions and issues and determine what kinds of answers would be useful. Because you can easily go astray in this phase by pursuing intriguing, though not necessarily useful, analyses, you should be very deliberate in choosing which analytical paths to follow. Review the conceptual model. Have the data you've collected supported the relationships you initially hypothesized? Or, have the data suggested that certain relationships you thought existed actually do not? If so, you might need to revise the conceptual model. This new version can, in turn, be used to help focus your data analysis. You may find that reviewing the initial questions and conceptual model is beneficial at several stages of your data compilation and analysis..

### 5.1.2 General Considerations in Data Analysis

The following principles are common to data analysis (Dunne & Leopold 1978; Gordon et al. 1992; Washington Department of Natural Resources, 1997).

<u>Common Principles</u>

1. All the data, information, maps, photos should be in hand before the analysis begins.
2. Leave your preconceived conclusions behind. Bias is not acceptable. Let the data and information lead to the conclusions. Test hypotheses with data.
3. Since many data analysis methods are available, the methods chosen depend upon the nature of the available data and the purpose of the investigation. The method(s) for drawing conclusions from results should be outlined.
4. Conclusions in a controlled study can only be as good as the study design, the accuracy of measurements, and the appropriateness of statistical analysis.
5. There are no "cookbook methods" for data analysis.

With these principles in mind, and with the data collection steps in previous chapters behind you, it's time to assess how prepared you are for data analysis. The checklist below can help with this assessment.

- Do the data and data collection techniques meet quality standards?
- Are the gathered data and information useful for your needs?
- Are the data at appropriate scales of resolution for your questions?
- Do the data contribute toward answering your questions?
- Do you require new or more data? What good will it do you?
- When will you be satisfied? How much is enough?
- Do all the potential users and detractors of the watershed assessment accept the raw data?
- Do all the stakeholders support the choice of analysis types?
- Are you thinking in ranges rather than single values for the data?
- Are you making comparisons to natural variability, which requires determining or estimating baseline and reference conditions?

There are two major aspects of data analysis: 1) comparison of data on your watershed to some reference values or standards and 2) the statistical treatment of the data. This chapter will focus on these key issues.

## 5.2 Indices and Standards for Evaluation

The purpose of analyzing data is to put the information you have about watershed conditions into a framework or context that will help you answer the questions or address the issues that brought the assessment team together in the first place. One way to create this context is to compare the conditions in your watershed to standards that are recognized as supporting 'normal' hydrological function, 'healthy' riparian and instream habitat, or water quality that is 'adequate' to support aquatic life. Much debate exists on what is meant by 'normal', 'healthy', or 'adequate'. One definition of such terms is 'pre-development' conditions. For example, hydrological processes within the watershed are usually altered by urbanization or commercial activities. Pre-development conditions are a standard to which you can compare the present hydrological conditions. Another definition is the concentration of certain constituents in water that are known to allow survival of aquatic life. The water quality measurements collected in your local stream can be compared to the reference values known to protect either warm-water or cold-water aquatic species. Reference values are the benchmarks, standards, thresholds against which measurements and conditions are assessed (http://www.fs.fed.us/institute/monitoring/rv_factsheet.htm). In some cases, the benchmark values are specific to certain types of stream or regions of the state. Except for drinking water standards, no one standard can be used for all waterways. In other cases, such values are not available. Sometimes, comparisons can be made to a similar waterway that has been subjected to fewer human impacts, and is therefore in a more pristine' condition. Streams such as this are referred to as 'reference' streams. Regardless of the specifics, indices or standards can be used to analyze the meaning of the data you have collected.

### 5.2.1 Indices and Standards for Water Quality Analysis

Background

The U.S. Environmental Protection Agency (U.S. EPA) has developed a set of water quality criteria that can be used for comparative purposes. These criteria identify the concentrations of constituents and contaminants in water that are thought to protect aquatic life. The U.S. EPA's Water Quality Criteria were developed pursuant to Section 304a of the Clean Water Act, which required U.S. EPA to develop and publish criteria for water quality that accurately reflect the latest scientific knowledge for a variety of aquatic species. These criteria are based solely on data and scientific judgment of the relationship between pollutant concentrations and environmental effects. They do not reflect consideration of economic impact or technological feasibility (U.S. EPA, 2002). The U.S. EPA categorizes pollutants into three major categories: priority pollutants, non-priority pollutants, and pollutants with "organoleptic" effects (those that affect water's taste or odor). Priority pollutants include pesticides, PCBs, and a variety of anthropogenic chemicals. Non-priority pollutants include conventional water quality parameters, such as pH, dissolved oxygen, turbidity, and temperature. Pollutants with organoleptic effects are primarily applicable to drinking water.

The criteria that the U.S. EPA uses for aquatic life protection are the same as those contained in the California Regional Water Quality Control Boards' Water Quality Goals. Each of the nine Regional Boards prepares a Basin Plan, which designates the beneficial uses of that region's waters, as well as water quality objectives for a wide variety of constituents that will support the identified beneficial uses. The Water Quality Goals contain numeric criteria that, for aquatic life protection, are the same as U.S. EPA criteria.

Each Regional Board's Basin Plan identifies beneficial uses of the water, water quality objectives, and a plan for implementation of these objectives. Each Basin Plan's Chapter 3 contains the water quality objectives, including criteria values for conventional and priority pollutants. Some Regional Boards attach relevant documents, including recommended numerical limits for pollutants, to their Basin Plans. The Central Valley Regional Board has prepared "A Compilation of Water Quality Goals," a staff report that "contains numerical water quality limits from the literature for over 800 chemical constituents and water quality parameters" (http://www.swrcb.ca.gov/rwqcb5/available_documents/wq_goals/index.html). The companion document Recommended Numeric Limits, available at the same URL, is an Excel spreadsheet containing a list of water quality criteria for a wide variety of conventional and priority pollutants. It is an excellent reference document and the criteria can be used for comparison with the data collected in your local waterway.

A number of other water quality standards in California reflect protection of various other beneficial uses of water. For example, the Maximum Contaminant Level (MCL) is a drinking water standard based on human health, economic, and technological considerations. Frequently, these standard concentrations are higher than those used for aquatic life protection. Public Health Goals (PHGs) for drinking water are another set of standards based solely on the protection of human health.

For the purposes of a watershed assessment, you should compare the data obtained on the stream(s) in your watershed with numerical criteria that are protective of aquatic life. You may also be interested in identifying the designated beneficial uses set forth by the local Regional Board and in determining which, if any, pollutants are impairing those uses. You might find that other water quality constituents might not meet the standards required for a beneficial use. When some watershed groups have identified problems like this some have recommended to the Regional Board that a total maximum daily load (TMDL) standard for that contaminant be established.

Information on Priority Pollutants

The U.S. EPA Water Quality Criteria provides the best source for reference values to compare with those data you have collected in your watershed. Criteria values have been established for both freshwater and saltwater. The values are regularly updated, with the most recent update occurring in 2002. See http://www.epa.gov/waterscience/criteria/aqlife.html. Criteria exist for a large number of metals, volatile organic compounds, pesticides, hydrocarbons, and "conventional" water quality values such as alkalinity, ammonia, hardness, nitrates, oil and grease, and pH. The National Oceanographic and Atmospheric Administration (NOAA) publishes an easy-to-use list of these criteria known as Screening Quick Reference Tables or SQuiRTS (http://response.restoration.noaa.gov/cpr/sediment/squirt/squirt.html). SQuiRTS contain benchmarks for both water and sediment quality.

Two values are identified for each constituent on the list. The "criteria maximum concentration," or CMC, is the maximum value that is safe for an acute exposure, defined as a one-hour exposure. The "criteria continuous concentration," or CCC reflects the maximum concentration for exposure for a 96 hours or longer. CCC reflects chronic exposure. Both values reflect safe levels of exposure for most aquatic life and were derived from a review of scientific studies on many different species of aquatic organisms. A more detailed explanation is contained in the SQuiRTs.

While most values can be read directly from the tables published by either NOAA or the U.S. EPA, many values for metals are dependent on the hardness of the water. Some metals will form complexes in water that is hard or that has a high mineral content. Therefore, the actual concentration that aquatic animals will be exposed to is different than the dissolved concentration typically measured. Most often, aquatic organisms will tolerate a greater concentration of these metals in hard water and a lower concentration in soft water. The NOAA and EPA tables contain formulas that permit the user to adjust the criteria value depending on water hardness (see text box on next page).

Additionally, SQuiRTS contains the most easily accessible information on sediment quality criteria. These types of criteria are slightly different from the CMC and CCC values for water. For example, instead of the acute or chronic criteria values, sediment standards are reported as Effects Range-Low, Median, or Probable Effects Levels. Effects Range-Low is the lowest 10th percentile contaminant concentration among samples shown to be toxic to aquatic organisms. SQuiRTS contains a detailed explanation of these terms. This document also includes graphs that allow you to easily determine the criteria value for metals corrected for hardness. Using these tables allows you to avoid performing any calculations to correct for metals solubility in water of varying hardness.

Information on Non-priority Pollutants

Although non-priority pollutants, such as altered temperature or dissolved oxygen are included in the U.S. EPA Water Quality Criteria, EPA frequently refers the reader to other reference material because these values are highly species-dependent. For example, a warm-water fish in warm water might be able to tolerate a dissolved oxygen concentration of 5 ppm, but a cold-water fish in cold water could not. Consequently, to obtain criteria or benchmark values for the species of interest in your watershed, you will need to gather information from other sources.

A good place to obtain this information is the Regional Boards' Basin Plans. For example, the Central Valley Board's Recommended Numeric Limits document contains recommended criteria for pH, sulfate, total dissolved solids, ammonia, and other conventional water quality parameters. This information is posted at: http://www.swrcb.ca.gov/rwqcb5/available_documents/wq_goals/index.html. If the information you are seeking is not available in these documents, you may wish to carry out a literature search for the constituent of concern and the species of interest. The best place to perform such a search is through the Aquatic Sciences and Fisheries Abstracts (AFSA). This database of scientific literature is available at most university libraries, but is usually not available online. Using the ASFA database, you can find scientific articles that have been published on that topic and then check out or copy the pertinent articles.

In many waterways that support salmonids, excessive suspended and benthic fine sediment are a serious issue. Yet, criteria values for these endpoints are not readily available. The British Columbia Ministry of Water, Land, and Air Protection has prepared a review that contains ambient water quality guidelines for excessive sediment that may be useful in certain circumstances. They are posted at: http://wlapwww.gov.bc.ca/wat/wq/BCguidelines/turbidity.html#tab1. The US EPA is in the process of preparing similar guidelines for US waterways,

*The Hazard Quotient*

The ratio of the actual concentration of a contaminant in your waterway to the protective concentration listed in the criteria tables is known as the hazard quotient. This is a widely used value in environmental toxicology. A hazard quotient greater than 1 suggests that there is a risk for harm from that constituent or contaminant. If it is much greater than 1, the possibility exists that harm to aquatic life could be significant. If the hazard quotient is less than 1, it is unlikely the contaminant could cause harm.

The hazard quotient is a useful, but rough, estimate of whether a contaminant is likely to be of concern.

To summarize the key points regarding the use of standards to evaluate water quality:

- Obtain water quality criteria for contaminant of interest
- Collect data on the concentration of chemicals in your waterway
- Compare contaminant concentrations to standards and criteria.

How to Use the Water Quality Criteria: An Example

Water quality criteria reflect concentrations of constituents that are generally considered protective of aquatic life. These criteria can be used to compare data from any individual waterbody to determine whether there is a risk for adverse effects from contaminants. For example, copper is a common contaminant in many California creeks and streams. The chronic value (or "chronic continuous concentration", CCC) is 9.0 parts per billion (ppb) or µg/L at a hardness of 100. Assume a creek in your watershed has a hardness of 50 and the concentration of copper was measured at 8 ppb. At face value, the 8 ppb in the water is below the 9.0 ppb criteria value, so you would guess there isn't cause for concern. However, because the hardness of the water is different than 100, the original chronic value requires an adjustment. Using the formula provided by both U.S. EPA and NOAA in the publications cited, the hardness-corrected safe concentration of copper is actually 5.15 ppb. Therefore, the copper concentration in your local creek could pose a risk to aquatic life since 8 ppb is greater than the adjusted criteria value of 5.15 ppb.

One issue to keep in mind when using water quality criteria data is the length of time the aquatic organisms were or might be exposed to the contaminants. This question is often difficult to answer because the answer requires collecting a considerable amount of data, an impractical task in many cases.
Use best professional judgment to estimate the duration of exposure to the contaminant. If the exposure is for a brief period of time (minutes or hours) and the concentration is not great, perhaps little harm will result. If exposure is continuous, or at regular intervals, then it is more likely that adverse effects could result. It might be useful to consult with a local aquatic biologist (at a university or state department with responsibilities for health of aquatic organisms such as the Dept. of Fish & Game) to get a professional opinion on this or other related issues.

### 5.2.2 Benchmarks for Water Quantity and Flow

[under construction]

### 5.2.3 Benchmark Values for Land Cover

When trying to evaluate the impacts that changes in land cover might have on your watershed, there are few standards to which you can compare your watershed values. Two of these are area of impervious surfaces (impacts to hydrology) and the fragmentation of habitat by human infrastructure and activities.

Impervious surface (IS) refers to areas such as roads, driveways, houses, patios, and any other surface that is no longer permeable to water. As IS increases in a watershed, there are changes in runoff quantity and timing, erosional processes, water quality, and channel condition. These effects are reviewed in Chapter 3 of CWAM. Watershed performance can be linked to the percentage of the landscape that is covered by roads and other developed areas (i.e. impervious surfaces). Total imperviousness can be calculated for the watershed and/or sub-watersheds. Information on how to estimate impervious area is available online at http://www.nemo.uconn.edu/publications/index.htm#technical. Technical Bulletin #3 posted on the NEMO website contains information on calculating imperviousness using a few different methods. Having estimated IS in your watershed, you can compare your values to those shown to be associated with degradation of stream and waterways. The benchmarks identified by the Center for Watershed Protection are:

- <10 % impervious cover associated with minimal impacts in most cases
- >10% -- <25% associated with moderate impacts
- >25% associated with serious-severe impacts

(Schueler, 2000). If your watershed is located in an urban or urbanizing area, these values can be used to make rough estimates of the degree of potential impacts you might encounter. This could be very useful for future planning efforts as well.

In rural developed areas, road density is sometimes simpler to estimate than impervious cover and can act as a surrogate. It is also useful in estimating impacts in forested areas where logging roads pose a risk to rivers and streams. In forested areas, road position on slope, proximity to streams, and disturbance of steep erodible soils all contribute to road impacts to aquatic ecosystems. As road density increases, the likelihood of road impacts increases

Fragmentation of plant communities is an important ecological impact of human activities, as well as a naturally occurring process. There are various indicators for this phenomenon, including the extent and type of roads in an area, the density of developed parcels, human population density, and actual forest cover remaining after logging. You may have data for only two of these indicators for your watershed. Sometimes one or two fragmentation indicators can stand in for the rest (depending what they are), giving you a sense for where fragmentation may be high. The best-case scenario is where you have digital spatial data derived from recent geo-referenced aerial photographs combined with remote sensing of vegetation types. This combination will allow you to determine the actual edges of patches of particular plant communities and thus measure fragmentation directly.

Human-caused fragmentation of aquatic communities is primarily caused by such structures as dams, reservoirs, diversions, and roads. A rough indication of where these barriers might be is at the intersection of the waterway with the structure as a point (dam) or line (road). For some regions of California, major barriers to salmonid migration have been mapped. For some local areas, finer-scale analysis of barriers has been accomplished, including locations, types, and characteristics of culverts (water-carrying pipes running under roads). Culverts can pose a significant barrier to migrating fish, effectively fragmenting aquatic habitat. To determine if culverts in your waterway are acting as a barrier, criteria have been established by the Dept. Fish and Game. The Culvert Criteria for Fish Passage document can be downloaded at: http://www.dfg.ca.gov/nafwb/pubs/2002/culvert_criteria.pdf.

The location of potential physical barriers is not the only indicator of fragmentation. For example, below a dam and between diversions, there may be miles of a stream or river where flows are insufficient or excessive for supporting certain aquatic species. In this case, the ecosystem would be effectively fragmented by water management, independently of being near, downstream, or upstream of a physical structure that acts as a barrier.

### 5.2.4 Reference Values for Habitat Characteristics

Identifying reference values for habitat characteristics is not as straightforward as for water quality. For any group of plants or animals, different habitat characteristics are important. No one set of benchmarks is useful for more than a handful of species. Probably the greatest number of benchmark values for habitat characteristics are available for salmonid species. The Oregon Watershed Assessment Manual contains benchmarks for salmon spawning streams for percent pools, characteristics of riffles, percent canopy cover, amount of large woody debris, and number of riparian conifers for coastal waterways. Some of these values might be useful for other locations as well. This data can be found in Appendix IX-A of the Fish and Fish Habitat chapter and is posted at: http://www.oweb.state.or.us/publications/wa_manual99.shtml. This information provides a rough idea of the conditions that are favorable for salmon, but are not "hard and fast" numbers.

The California Department of Fish and Game has published the California Salmonid Stream Habitat Restoration Manual. It contains desired conditions for stream habitat that could be used to develop estimates of benchmarks. The manual is posted at: http://www.dfg.ca.gov/nafwb/manual.html. Keep in mind when you use these benchmarks that many of them are based on best professional judgment and have not undergone a peer-review process. Consequently, these values should be used as estimates only in your analysis.

The North Coast Watershed Assessment Program (NCWAP) has developed a series of reference curves for salmon spawning streams along the north coast. Reference curves show the relationship between a stressor and the response of an organism, in this case salmon. The values they have identified are probably useful for many northern California streams, but likely not for southern California where some salmonids are more tolerant of warmer temperatures. The reference curves developed by NCWAP, based on the best available information, can be used to identify conditions that are 'fully unsuitable' to 'fully suitable' for salmon species. The benchmark values are contained in the Appendix on Ecological Management Decision Support (EMDS) Model, posted at: http://ftp.dfg.ca.gov/outgoing/whdab/ncwap/public/watersheds/mattole_river/pdf/Final_Mattole_Synthesis_Rpt_032403_Subbasin_Profiles.pdf. By locating the value for habitat conditions in your waterway on the reference curve, you can estimate how suitable that habitat characteristic is for salmon. Unfortunately, similar curves are not available for other species at this time.

One additional source of information on benchmark values for habitat for aquatic species is the USFWS. In the 1980s, they developed a series of Habitat Suitability Indices (HSI) for numerous terrestrial and aquatic species. These models "provide an objective quantifiable method of assessing the existing habitat conditions" for many aquatic species (Raleigh et al., 1986). Conditions in your stream can be compared using the curves developed by the USFWS. In effect, these curves are a variant of a stressor-response curve; they relate a single variable like temperature or % pools to a suitability value between 0 and 1. The higher the number, the closer the condition in your waterway is to optimal or highly suitable condition required by a particular species for that particular habitat characteristic. The suitability models and indices are posted at http://www.wes.army.mil/el/emrrp/emris/emrishelp3/list_of_habitat_suitability_index_hsi_models_pac.htm. There are various strengths and weaknesses to using HSIs. A review of how these models work, their uses and limitations, is available and worth reading (Rand & Newman, 1998).

### 5.2.5 Use of a Reference Site

In some cases, you can identify a relatively undisturbed watershed in the same general region as your watershed. The habitat, water quality, hydrological conditions, etc. can in effect serve as reference values. The conditions within the reference watershed can be used to compare to the conditions in your watershed. The differences between the two can be used to evaluate the degree to which human activities have altered conditions and processes in your watershed. The main difficulty in using this approach for comparisons is that there are few watersheds in the state that have not been disturbed to one degree or another. In addition, it takes some work to determine

"*Statistics should be regarded as a tool, an aid to understanding, but never a replacement for useful thought*." (Haan, 1977)

and ensure similarity between the reference and assessment watershed. Further, data isn't necessarily available for the reference watershed. However, if such data is available, it can be very useful as part of the analysis of conditions in your local waterway.

### 5.3 Applying Statistics

At this point, you have reviewed your data and have obtained the appropriate standards against which to compare data for your watershed. You will now want to find out if there are significant differences between your environmental measurements and the standards. Alternatively, you may want to know how one reach of the stream within the watershed compares to another. As a third alternative, or in addition, you may want to measure trends or changes over time in conditions in all or part of the watershed. Statistics are used to make unbiased comparisons like these.

"Statistics" is a set of mathematical tools that may help guide the design of data collection efforts and assist in summarizing and interpreting the data. Statistics are particularly valuable in describing data variability that reflects the inherent variability in natural watershed processes and phenomena. Statistical methods may be used to calculate data significance and the differences among measurements across time and space. They provide a way to assess how reliable your conclusions are when drawn from a particular data set (Zar 1984).

This section explains the basic concepts that are important to understand in order to use statistics properly and describes some of the most common statistical tools used in watershed assessment. The information presented here is very basic relative to the many texts that natural scientists have used for decades to analyze environmental data. Even if you do not plan to use statistics yourself, it is important that you understand how these tools work so you can participate in discussions about data analysis.

- *How and when should statistics be applied within a watershed assessment?*

Any time a watershed assessment includes a quantification of condition (e.g., water flow), it is appropriate to consider statistics.

- *When are statistics NOT necessary?*

There are times when statistics may be less informative. For example, many metrics of geomorphology, surveys of plants and soils, and descriptions of a community's socio-economic status may be expressed without consideration of statistical analyses.

- *How much statistical rigor is necessary for the purposes of the assessment?*

The use of statistics provides much of an assessment's rigor. You must decide how much confidence you want to have in the quantification of conditions used to inform your decision-making.

- *What level of "significance" is necessary?*

The term "significance" in statistics refers to how likely the conclusion you draw from data reflects a real condition, which is analogous to the confidence you can have in the conclusion being correct. A common standard in natural sciences is "95% confidence", which refers to how confident you are that a conclusion drawn from numeric data is correct.

**Examples of Using Statistics in Watershed Assessment**
[Under Construction ]

### 5.3.1 Terms and Definitions

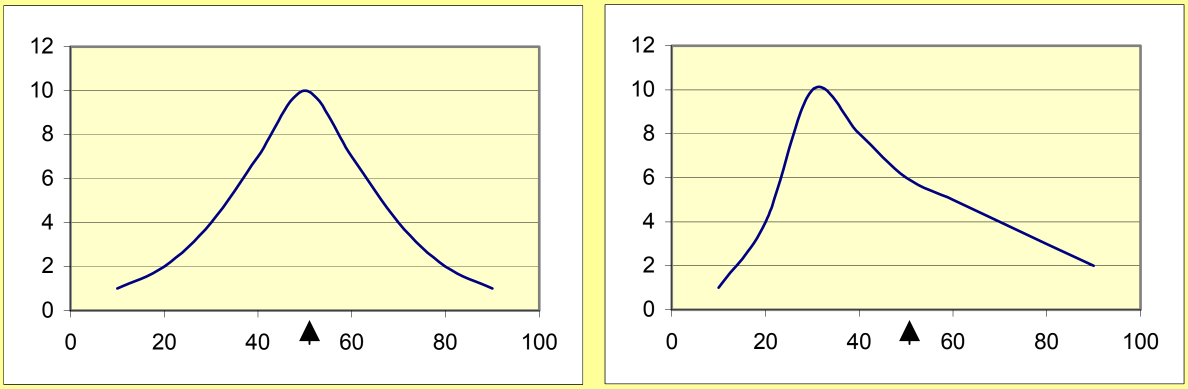
*Types of data*—You will find several main types of data in your assessment work. Discriminating among data types is critical for choosing the appropriate data analysis tools. “Nominal data” refers to classes, such as soil types, that have names rather than numeric values. “Ordinal data” are data that have been ranked or ordered in some way according to attributes of the data. For example, stream orders are on an ordinal scale. The stream order numbers themselves don’t mean anything in a quantitative sense, but they do rank the streams according to their relative contribution to higher order waterways. “Interval data” refers to data on a scale that does not have a true zero. Temperature is a good example of this type of data. There are constant intervals between degrees of temperature, but there is only an arbitrary point assigned the value of zero and many intervals below zero. “Ratio data” are similar to data on an interval scale, but with an absolute zero. For example, tree heights are measured on a scale with a constant interval (e.g., meters) and a true zero point.

*Population*— The term refers to the entire collection of items that are the focus of concern, such as a particular water quality characteristic. The population of temperature values for a given stream reach consists of all of the temperatures that occur. It is usually impossible to collect all of these values, but it is usually possible to collect some small fraction of them.

*Samples and sampling*— A sample is a set of items drawn from the population. “Sampling” means collecting a subset of the population of values. Each sample is intended to be a representative of the whole population. An individual surveyed by the Census Bureau on income and employment information would be a sample, whose data can be grouped with those of other samples and generalized to the larger population. Sampling can be either random or directed. Usually random sampling, or its cousin “stratified random sampling”, involves selecting at random a subset for the total population of the target of analysis. For example, if you have 100 sub-watersheds in your watershed and you want to study sediment production in the overall watershed, you could create a random sample by choosing 10 of the sub-watersheds at random, by literally placing the sub-watershed names in a hat and picking 10. Stratified random sampling involves first creating groups of likes (e.g., sub-watersheds that are geologically-similar) and then selecting randomly from within each group. This approach ensures a representative sample from each major group in the population.

*Replicates*—If you collect two or more samples from a population of something at the same time and place and in the same way, then you have collected replicate samples. Collecting two samples (X1 and X2) means that you can calculate the average value ([X1 + X2]/2) but you won’t have a measure for how representative the average value is of the population. If you collect three or more replicates, then you can use the values in statistical comparisons comparing average values for each group of samples .

*Variance and variability*— Nature possess natural variation. When you try to describe some factor by taking samples, you are taking a partial snapshot of the true quality of the thing you are measuring. The sample values will be different from each other, and the magnitude of the differences will depend on what you are measuring and how you measure it. A measure of these differences is the “variance”. For example, if you take multiple water temperature measurements in the same spot on a stream one after the other using the same thermometer, you will get values that are very similar to each other, and the variance will be low. If you




Example of a normal (left figure) and non-normal (right figure) distribution of any data. Arrows represent means for both sets of data.

took three samples of benthic macroinvertebrates from a single riffle, you would probably find a wide variation of types and numbers of these animals among samples, and the variance would be high. Measures of variance are critical for making comparisons among places in the watershed, over time, and between reference and measured parameters.

*Distribution*—For ratio and interval types of data, your measurement values will usually be spread across a range of possible values and will be grouped around an average value. Measured values for some population of possible values are distributed in one of two ways: normally or non-normally (see box above). Normal distribution means that most values tend to be near the mean and evenly distributed above and below the mean value. Non-normal distribution refers to there being more values either above or below the mean and clumped differently on either side of the mean. A frequency distribution represents graphically the way the data varies around the mean.

The concept of normal distribution is important because subsequent calculations involving variation will depend on whether your distribution of values is normal or not.

*Statistical significance*—Comparing your values against some standard (e.g., for water quality) or with each other requires a measure of statistical significance. This term means how much confidence you can put in the conclusion reached from the calculation (e.g., how water quality has changed over time). For example, let's say that you want to know whether measured contaminant values in your waterway are "significantly" lower than a water quality standard. You would use a statistical test such as a "t-test" to determine whether or not there was a true difference between your measured values and the standard. How much difference there was between your values and the standard would determine how confident you were in the significance of the difference.

### 5.3.2 Summarize and Explore the Data

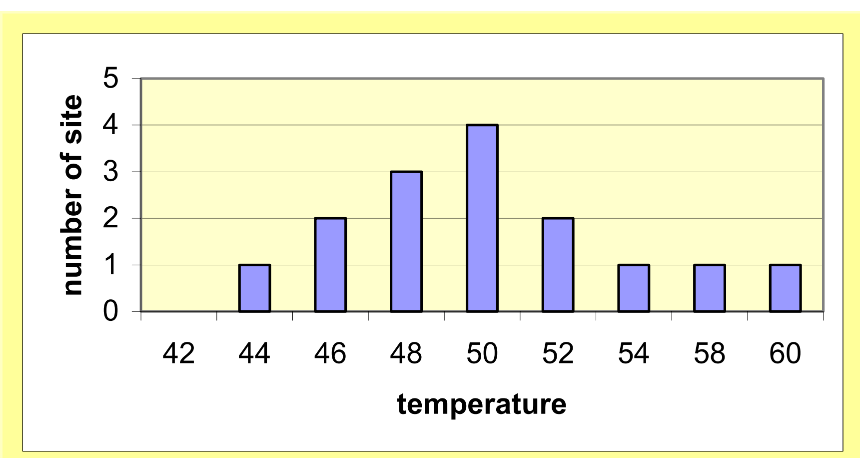
Before beginning any formal statistical analysis, you should explore the data informally. This can be done with descriptive statistics. Descriptive statistics can be calculated using an Excel spreadsheet and includes calculating the mean value, the standard deviation (or range of variation), and as well as a frequency distribution if you have sufficient data points.

The **mean** of several replicate measurements theoretically represents the population or process that is being measured. For example, if three samples are taken for suspended sediment at a certain depth near the same time on a given day, the mean concentration value is the "true" value for suspended sediment at that depth at that time on that day. Means should only be calculated for three or more samples so that the variation can be calculated. If you have only two values, then you can calculate an average, but you won't know how well the average represents the "true" value. Variation is a measure for how well the mean represents the population of values. The higher the variation relative to the mean, the less likely it is that the mean value represents that population or process. The **standard deviation** is a common form of representing variability around the mean. Both mean and standard deviation are easily calculated in a spreadsheet program such as MS Excel.

You can calculate means by adding up all values and dividing that sum by the number of data points used. For example: 2 + 3 + 4 = 9; 9/3 = 3. In this example, the means is 3.

For example, if you've collected water temperature data once a month for 3 years, you might decide to summarize the data for each month, based on the value you collected over the 3 years, by calculating the mean and standard deviation. You can then construct a graph or table that reflects the average temperature each month.

A frequency distribution plot (shown below) is another way to look at variability of the data. If you collected data on temperature from 15 sites in the watershed in the month of September, you might plot the data to see how similar or different the sites are. Plotting the data in a frequency distribution gives you a visual picture of the variability in temperature throughout the stream. It helps to give more meaning to the average.




It is also important to know when not to calculate a mean and standard deviation. For example, if you are investigating a process that changes over the timeframe you examined, such as suspended sediment concentration during a storm event. Calculating the mean suspended sediment concentration and standard deviation for that timeframe will be less meaningful than other ways of analyzing the data, such as calculating the total suspended sediment load during the whole storm event. Deciding whether to calculate a mean value for a watershed feature depends on the questions you have.

Overall, descriptive statistics allow you to get a better feel for the data. These simple statistics are sometimes all that is possible for the watershed assessment, especially if you have a small dataset.

### 5.3.3 Perform Statistical Analyses, if Warranted

Once you have summarized your data, you will need to determine if it would be useful to perform a statistical analysis in order to identify significant changes over time, between different places within the watershed, or between your watershed data and reference or benchmark values.

Here are some questions to review to determine how to proceed:

- What statistical tests do you plan to use?
- Is the data of sufficient quality to use?

- Would it be worthwhile to consult with an 'expert' on statistics?

If your team decides it is appropriate to move forward with a more formal statistical analysis of the data, one of the most common analysis methods is a **comparison of means.** Frequently data collected from different sites, for example, appears to be different; but when you do a formal statistical comparison, the differences aren't significant. You may want to compare two or more collections of values (e.g., for a water quality parameter) across space (e.g., upstream vs. downstream) or time (e.g., last year vs. this year). You may also want to compare your mean for a range of values to a standard. To do any of this, you must calculate the variation around each mean and use these calculations to compare the means, or a mean to a standard. The significance of the difference or similarity between the sets of values is what you will be determining with these comparative tests.

Just as with the calculation of the mean, it is also important to know when comparing means is appropriate. In a situation involving time (last year vs. this year), there are many factors that change over long time periods that affect comparisons of watershed values between years. So, although you may find a year-to-year difference for a particular watershed parameter value, the difference diminishes in importance as larger forces change the watershed over the timeframe of several years.

To compare means, there are several comparative statistical tests to choose from. A common one is the **Student t-test** (see box below). In this test, you compare one

### Student t-test

The following table displays data for two months, October and April, and the output from performing the T-test. In this case, the calculation in Excel provides critical values, so you don't need to look them up in a book. The critical value is like a benchmark value: if the T-statistic is greater than the critical value, then the difference between means is significant. In this example, the critical t-value is 2.13 while the t-statistic for the actual data is -4.27. Since the absolute value of the t-statistic is greater than the critical value, the difference is significant. The p, or level of significance value, is 0.006. This number implies that there is a 0.6% chance that the mean temperature in October and April are <u>not</u> significantly different from each other.

**Temperature Readings by Month**

| October | April |
|---|---|
| 13 | 21 |
| 12 | 18 |
| 15 | 25 |
| 20 | 24 |

t-Test: Two-Sample Assuming Equal Variances

| | *Oct.* | *April* |
|---|---|---|
| Mean | 15.67 | 22.33 |
| Variance | 16.33 | 14.33 |
| Observations | 4 | 4 |
| Pooled Variance | 15.33 | |
| **Hypothesized Mean Difference** | **7** | |
| df | 3 | |
| **t Stat** | **-4.27** | |
| **P(T<=t) one-tail** | **0 .006** | |
| **t Critical one-tail** | **2.13** | |
| P(T<=t) two-tail | 0.013 | |
| t Critical two-tail | 2.78 | |

set of data with another by comparing their means. Your data should be normally distributed in order to use this test. You will get a t value from this test, which you can compare to standard values from a t-table. If your t value is greater than the standard, then your difference is likely to be significant. These calculations can be performed in MS Excel.

There are numerous additional statistical tests that can be used to compare means, some of which are listed in the box below. Others are described in the Appendix. For additional information, it would be best to consult with someone knowledgeable about selecting the best statistical tests for the type of data you have.

### 5.4 Spatial and Temporal Analysis

Watershed assessment requires the consideration of human and natural processes occurring over space (the watershed) and time (history). Analyses of these processes are often performed on either spatial or temporal scales, and occasionally, on both.

- An example of an analysis over a spatial scale is the measurement of extent of development (e.g., human population or parcel density) in watershed areas that erode more rapidly than other areas.
- An example of analysis over a temporal scale is determining the frequency and regularity of pesticide applications in an agricultural watershed over a several-year period.

The analysis methods used for things that change over space are different from those used for things changing over time. There is extensive technical literature on how to measure each of these types of changes, depending on what needs to be measured (e.g., analysis of trends over time). This type of analysis is fairly sophisticated so it would be wise to consult with a knowledgeable person to determine if these methods are appropriate for your data and to obtain assistance actually performing the analysis. One cautionary note is that most analyses involve assumptions about the

**Overview**
**Additional Statistical Methods**

- **ANOVA -** Another common and powerful test for comparing among means is the Analysis of Variance (ANOVA). This test gives an F-statistic to compare against standard F-values. Just as with the t-test, if your F-statistic is greater than the standard, then the differences among means are significant. You might want to analyze your data using more complex, multivariate methods. These methods permit you to estimate which factors contribute the most to minimizing variability in the results. In most cases, those factors that reduce variability in the data are usually the most important re: meaningful relationship.
- **Principals components analysis** - One method to determine, for example, which watershed condition out of many might contribute the most toward the change in habitat that you have observed.
- **Regression analysis** – A method for finding the relationship between two factors (e.g., road density and human population density). Regression tests the strength of the relationship or how much one variable depends on another. For example, the relationship between road density and wildlife occurrence could be analyzed with regression analysis. This analysis could be for linear or non-linear relationships.
- **Correlation –** A method for measuring the strength of an association between two factors. Correlation does not imply causation. A strong correlation warrants further investigation to determine causation.

nature of the process being analyzed. In other words, that it is possible to represent a process with spatial data. In addition, in the past, analysts have employed inappropriate analysis tools, so copying an approach used elsewhere should be done with caution. An example of this would be the use of an erosion model developed for agricultural areas in rugged mountainous areas without modifying the model.

### 5.4.1 Spatial Analysis

Geographic information systems (GIS) were created to allow calculations for specific places on the earth. If you have a GIS software program, you can carry out these calculations. Examples of common straightforward analyses are densities of objects located within a certain area of the landscape (e.g., abandoned mine density in a sub-watershed), intersection of lines of different types (e.g., roads crossing streams), and summarizing data for an area (e.g., the number of people in a watershed). Not all spatial analysis needs to involve a computer-based GIS, but that is the focus in this Manual.

*Types of spatial scale calculations*

The table below summarizes a sampling of the types of spatial scale calculations that you or your analyst might consider carry out. Other, more intensive, analyses can be found in the Appendix or online at http://cwam.ucdavis.edu. The first column describes the type of analysis; the second column, the type of data used or needed for the analysis; the third column, a possible product; and the fourth column, the relative difficulty. "Easy" calculations could be performed by someone (including a volunteer) with basic skills in ArcGIS or similar GIS software. "Moderate" analyses could be performed by someone (a GIS technician or scientist with GIS proficiency) with skills in ArcGIS. "Hard" analyses should be performed by a professional GIS technician with guidance from a natural scientist.

There are several important principles to keep in mind when carrying out this type of analysis

1) Not all spatial data are created equal. Spatial data will vary in scale, accuracy, and quality, depending on how and when they were collected. Use care when carrying out calculations using two or more data sets that were created at different scales from each other and vary in their accuracy (i.e., how well the data represent the actual landscape).

2) Principles of statistics hold for spatial data too, but the methods are not as clear as for other kinds of data. Spatial data are similar to water quality and other data in many respects, except that they are geo-referenced—they are for a specific place. If

| Analysis | Data source or type | Product | Difficulty |
|---|---|---|---|
| Line density | Line data, (e.g., roads and streams) | Line density per unit area (e.g., square mile or sub-watershed) | Easy |
| Point density | Point data (e.g., mines, low-income schools) | Point density per unit area | Easy |
| Attribute density (e.g., population density) | Numbers of attribute type per grid cell | Attribute density per unit area | Moderate |
| Summarize attribute data by area (e.g., sub-watershed) | Sum, mean and other statistics for attribute | Summarized data for a particular area (e.g., number of miles of roads on steep slopes) | Moderate |
| Contribution of areas to downstream problems | Distribution of problem sources, driving natural processes, and impacted values | Relative ranking of areas or mass calculation of pollutants from contributing areas | Hard |

you have a range of measurements for a place, it is possible to calculate the mean and variance, as well as compare with another place.

3) Avoid over-interpreting the data. Because GIS programs usually allow you to create pretty maps, there can be a strong temptation to enhance or reduce apparent differences using colors or color intensity in order to create a certain impression.

4) Relative differences among areas within a watershed can be shown using a broad palette of colors (e.g., low = green, high = orange, very high=red). However, if some kind of reference is available for an area near your watershed (e.g., road-stream crossing density), you should use it to provide a color or other standard in your mapping. This will inform your audience of the importance of your finding relative to the standard.

### 5.4.2 Trends Analysis

A large proportion of your data is likely to be related to time. However, analyzing data over time and interpreting it is not a trivial task. Analyzing trends in some parameter over time is essential to understanding how things are changing in your watershed[1]. You may wish to analyze trends over decades in order to get a general idea of how conditions are generally changing. You may also want to figure out how things are changing over much shorter timeframes, for example, pesticide runoff during storm events. While short-term data collection is extremely valuable, interpretation of these data must be consistent with temporal and spatial scales for which the data are collected.

For example, data on short-term changes in channel morphology are sometimes erroneously used as the basis for decisions regarding river behavior. An example of this occurs when conclusions are drawn from surveyed channel cross-sections showing channel aggradation after one storm, a series of storms, or even after several years. These short-term changes only reflect the river's response to watershed conditions over the period of measurement, and may simply represent "blips" in the longer-term trends and alterations in channel morphology. Thus, when changes in the river process being evaluated occur over a longer timeframe than the period of measurement, certain data analyses may be misleading, because they represent only a small part of the big picture.

#### 5.4.2.1 Choosing a Timeframe for Analysis

Choosing the "right" timeframe for analysis is just as critical as choosing the method to use for analyzing trends. The question you ask determines the timeframe. For example, you may want to figure out if certain land uses are having a negative impact on water quality. From other studies, you might know that the effects are best detected over several years, rather than over several months. You might also know that to detect change, you need both frequent periodic sampling (e.g., weekly) and measurements during storm events. In order to draw any conclusion about the impacts of land-use on water quality, you would have to design your sampling and analysis with this timeframe in mind.

There are no strict rules for choosing the right timeframes. However, there are some guidelines you can use.

[1] The Journal of Time Series Analysis (JTSA), the abstracted articles of which can be viewed at http://www.ingenta.com/journals/browse/bpl/jtsa, covers the very technical aspects of trends analysis. In 2003 alone, outside of the JTSA, there were over 300 scientific articles on time series analysis in the medical, sociology, biology, climate, and manufacturing journals. Many of these articles discussed how to use statistical analyses and models to explain or discover apparent trends. Conducting these analyses and approaching these models requires training in statistical analysis. However, for many analyses of watershed processes, using sturdy statistical tools to analyze how things change over time is essential.

1) Based on the questions you have for your watershed assessment, decide the appropriate timeframes for the underlying processes. These timeframes will inevitably be closely linked to the sampling regimes for monitoring data that you are relying on.

2) Decide whether you are interested in how your watershed is changing over years or decades, or whether you are looking for rapid impacts in specific areas from specific sources.

3) Initially, separate the “where” (in the watershed) part of your questions from the “how long” (in time units) and “how much” (relative to zero or some standard) parts of your questions.

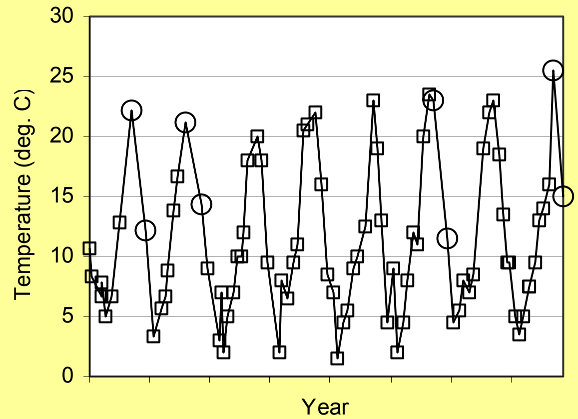
4) Decide whether you can analyze each of these parts separately, or whether you need two or more of these parts together (e.g., how much for how long).

5) Once you have laid out the concepts for your analyses, decide on a statistical or data analysis method that is appropriate for the question. There will not be much point in performing an analysis that is not appropriate for the questions you have. It would be better to leave the analysis undone and identify the topic as unresolved and in need of more study.

**5.4.2.2 Cycles**

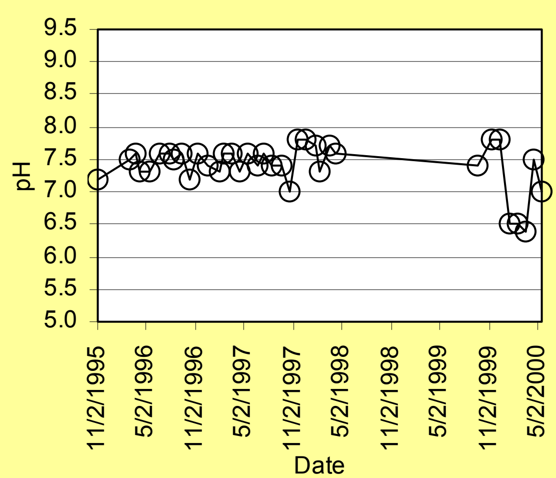
Many natural processes occur in cycles of intensity. The continuous occurrence and maintenance of these cycles is part of how things naturally work and can indicate a healthy, dynamic system. This cycling makes trend analysis very challenging. For example, if water temperature, precipitation intensity, erosion rates, or wildlife abundance changes in a positive or negative direction, the change may be occurring against a background of cycles of intensity, frequency, or numbers of the natural parameters of interest.

The chart below shows an example of cyclic changes in water temperature in a managed river in the Sierra Nevada. Temperatures were measured nine times a year at roughly even intervals over eight years. The seasonal cycle in temperature is obvious in this chart. Changes (e.g., in peak water temperature) over the eight years shown are less obvious, even though there seems




to be an upward trend. It is also not apparent that the highest temperature has been captured with a particular sampling event in a given year. This can be seen by looking at the gap between the data points marked by circles. It is possible that higher water temperatures occurred in between measurements.

The graph below shows pH changes over



time in the same river, where 10 measurements a year were taken. Although there may be sufficient data between 11/95 and 11/97 to suggest no long-term change in pH outside of seasonal variation, beyond that point the values vary more widely, and there is a significant data gap for a year and a half. With this data set, only a crude analysis of trends in pH will be possible for the period 1995 to 2000.

These observations point to several considerations to keep in mind when analyzing trends: 1) depending on sampling frequency, certain cycles or trends may be obvious, but others may not be detectable; 2) cycles with wide swings at one time scale, such as seasonal water temperature, may mask other trends with smaller annual changes, such as gradual warming or cooling over many years; 3) data collection should correspond to the questions being asked; and 4) scope of data analysis will be limited by the frequency of data collection.

#### 5.4.2.3 Analytical Tools

Analyzing change in watershed condition over time requires specialized approaches. The simplest and most familiar approach is to take a measured attribute of the watershed (e.g., peak daily average water temperature or nutrient load) and see how it changes over years, assuming data is available. More complicated approaches include analyzing the change in watershed process over time, while taking into account the influence of seasons, climate cycles (e.g., El Niño cycles), and gradual climate change.

Benchmarks exist for evaluating over time some watershed processes (e.g., infiltration capacity as related to impervious surface) or attributes (e.g., water quality). Although you may be able to isolate certain watershed properties to look at change over time, in reality, these properties are linked to other processes in the watershed. The truth is that there is no simple way to analyze the changes in most processes of interest.

The data analysis and statistical tools available usually require experienced technical staff and a high level of understanding of how natural processes work and interact with each other. Summary descriptions for data analysis tools are available online at http://cwam.ucdavis.edu and in the Appendix of the Manual. For example, the "R Statistical Package" provides a wide variety of statistical (linear and nonlinear modeling, classical statistical tests, time-series analysis, classification, clustering, etc.) and graphical techniques. It has tools for handling and storing data, a large collection of intermediate tools for data analysis, and graphical facilities for data analysis and display either on-screen or on hardcopy. The data analysis and statistical tools available usually require fairly expert technical staff to operate and a high level of understanding of how natural processes work and interact with each other.

Even with these tools, there are many questions about change at the watershed scale that are beyond the current scope of relevant scientific fields and where sufficient high-quality data are not available. When faced with these obstacles, it is best to think ahead to likely future assessment needs and try to figure out how much and what kinds of data a future assessor will need. This means that your consideration of trends analysis may end up usefully informing monitoring and research in your watershed

### 5.5 Factors Complicating Interpretation of Statistical Analysis

A number of different factors affect the interpretation of data and statistical analyses. Three that are of particular importance are uncertainty, disagreement among experts, and confounding variables. Uncertainty is associated with the difficulty of knowing and accurately describing complex conditions and processes in nature. This can be due to a variety of factors. Confounding variables are factors that could influence the results of the analysis that haven't been taken into account when conducting the analysis. Disagreements among experts are often associated with trying to interpret data in the face of uncertainty. In the following section, these three commonly-encountered problems will be reviewed and suggestions offered for dealing with the challenges they present.

### 5.5.1 Uncertainty

The term "uncertainty" refers to the probability of an outcome occurring, for which the variation in possible values might be known and specific statistical tools can be used to measure the uncertainty. One statistics text considers "uncertainty to be synonymous with diversity" (Zar 1984). This example presents one way to think about uncertainty: Say there is a high probability of occurrence of salmon spawning in gravels between one and three inches in diameter that are deeper than 6 inches below the water's surface. Also say there is a low occurrence of spawning anywhere else. The diversity of places that salmon spawned would be low and the uncertainty about where salmon spawn would also be low.

There is often a great deal of uncertainty associated with the measurement and analysis of natural conditions. Some of this uncertainty is associated with the measurement and analytical approaches themselves, because we don't know how to perfectly sample or represent complex systems. Other uncertainty comes from incomplete measurements of the systems due to inadequate resource investment, for example, or inaccessibility of a location. Generally, most science and knowledge development aims to reduce uncertainty and increase our ability to predict events and parameters around us, for which there is a known or unknown probability.

Watershed assessment is based on making the most scientifically sound decisions in the face of uncertainty. The watershed assessment is an excellent place for analyzing uncertainty because the assessment contains the information and tools needed to do so. An evaluation of uncertainty helps a future decision-maker gain a better understanding of the information on which they based their decisions.

#### 5.5.1.1 Sources of Uncertainty

In most cases, uncertainty cannot be eliminated, but being aware of the various ways uncertainty shows up in a watershed assessment will help you realistically analyze how much weight to place on any one aspect of your assessment. Examples of sources of uncertainty include (Warren-Hicks & Moore, 1998):

- The degree of exposure of ecological processes to a chemical or a habitat alteration
- The accuracy and completeness of the conceptual model, a reflection of our understanding of watershed processes
- The severity of adverse effects
- Lack of information or data gaps
- The appropriateness of the temporal or spatial scale of the assessment
- Extrapolation of information from one species to another or from the laboratory to the field. For example, using data on toxicity tests from a surrogate test plant or animal for another species that resides in the watershed
- The ability to differentiate between natural variability and human-induced changes
- Accuracy or appropriateness of an analytical or statistical test
- Human error

If the uncertainty is associated with identifying the range of possible choices, then more information should be collected prior to decision-making. However, if uncertainty is primarily associated with the presence of a number of known choices, then the decision-making process is clearer to the decision maker. For example, if restoration scientists want to install gravel beds in a salmon-bearing stream to enhance spawning, but the variation in flows in the river were unknown, then they don't know where to place the gravel bars and how long the bars would exist before the gravel was transported downstream by river flow conditions. In this case, the uncertainty is associated with the range of possibilities, which the assessment could make clear when discussing flow conditions Additional examples of uncertainty in watershed assessment can be found in McCammon et al (1998) Framework for Analyzing Hydrologic conditions of Watersheds.

#### 5.5.1.2 Measuring Uncertainty

Statistical analysis is one way to measure data uncertainty. This is done by placing confidence limits (a measure of how confident you are in the value representing a population of values) around the mean of the data that represent a specified probability or confidence. The limits that contain a parameter with a probability of 95% are called the 95% confidence limits for the parameter. The wider the upper and lower limits (or interval) of confidence are around the mean, the less certainty that the mean represents the population; the narrower the interval, the higher the certainty.

For example, the mean diameter of the streambed substrate at Site A is 13.81 mm, with a 95% confidence interval of 12.74 to 14.87. This interval is quite narrow (< 8% from the mean), indicating that there were probably sufficient samples collected (or the substrate was quite uniform) to have a 95% probability that the actual mean is within that narrow range and that the measured mean reflects the population mean.

#### 5.5.1.3 Reducing Uncertainty

The main way to reduce uncertainty in your watershed analysis is to increase the richness of the information you have at your disposal for analysis. Ideally, this won't just be more information, but will also be more data that represent the "true" condition of a watershed process or feature. Uncertainty can be reduced to some degree by performing more analyses and employing more sophisticated methods to analyze information. However, no matter how much time and money are spent, it is not possible to remove all uncertainty.

Most watershed assessors must decide how to reduce uncertainty within the limitations of their available resources. Here are some suggestions for accomplishing this:

- Involve people with diverse backgrounds in the assessment process—the variety of stakeholder experience and expertise makes it less likely that the assessment will overlook some important watershed factors, thereby reducing uncertainty in the conceptual model
- Carefully select analytical tests, being sure to follow quality control/quality assurance protocols. This will help reduce uncertainty associated with data quality.
- Consider the processes you are investigating, being sure to select appropriate temporal and spatial scales. This will reduce uncertainty associated the question of whether findings reflect the actual watershed conditions.
- Learn as much about the history of the watershed as possible to reduce the chance of attributing changes to human activities when they might just be part of natural variation.
- Avoid over-interpreting information or data. If you have only one years' worth of water quality data, don't under- or over-interpret its significance. Be sure to identify in your report the uncertainty associated with the information.
- Consider collecting more data if uncertainty could undermine the work you are trying to do.

### 5.5.2 Disagreements among 'Experts'

Another issue that frequently arises in the course of analyzing data is that experts can interpret the same data differently. Interpreting the results of your assessment's findings could be confounded by contradictions in what experts or the literature says the findings might mean. Sometimes the apparent disagreement may be due to differing experiences based on regional variations (e.g., coastal vs. inland, Pacific Northwest vs. Southern California), as well as differing methods of analysis, professional specialization, agency missions, and other causes. Professional opinions and findings can also change over time, so an article on optimal fish habitat from the 1970s might not have the same interpretation as one from 2003. Disagreements can also be associated with uncertainty in the data (see 5.5.1).

If differing conclusions are noted in your assessment, be sure to clarify why they might be different. For example, a fish habitat survey of 'Mill Creek' may have found that the average density of large woody debris (LWD) is 20 pieces (> 12 in. diameter) per 100 meters of stream. Does this amount of LWD provide adequate habitat for salmonids or not? The literature on LWD varies on this criteria, often depending on region (coastal, inland, Sierra), stream order (1$^{st}$ to 5$^{th}$ order), and assumptions (e.g., historic condition, logging history). Only a few studies have measured LWD in streams of the Sierra Nevada, for instance (Kattelmann & Embury, 1996). Those limited results revealed a range from one to 16 pieces per 100 m (> 6 in. diameter) in small streams. In contrast, interim LWD objectives for the U.S. Forest Service in California's North Coast streams are > 80 pieces per mile (> 24 in. diameter) (USFS & BLM 1994). In other words, this no one single benchmark or reference value to which you can refer to. Professionals in your area might want to adopt the coastal objectives to your watershed—and then they would be in conflict with the Sierra research. You need to check the units and the assumptions when citing sources for interpretation of your data. When there is little research upon which to base a conclusion, be sure to qualify any interpretation of your findings. Here are some suggestions for what to do when the perceived experts disagree on the interpretation of your data:

1. Acknowledge the disagreement. ("Ideal LWD density is not clearly known for 2$^{nd}$ order streams in our watershed, since the experts seem to disagree.")
2. Clarify the possible source of the disagreement. ("Different assumptions and regions were used for previous studies." or "Different units and scales were used—feet versus miles—and different diameters were used to define LWD.")
3. Suggest options for resolving the conflicting interpretation, if possible. ("Search for existing LWD surveys in 2$^{nd}$ order watersheds in our region that could be compared to our watershed.")
4. Offer a range of interpretation ("Our average of 20 pieces of LWD per 100 meters is lower than one benchmark of >30, but higher than one suggesting >15."), or a qualitative conclusion ("Large wood was extremely scarce in Mill Creek compared to similar streams recently surveyed in the region.")
5. Make a recommendation that this issue needs to be revisited after more surveys or research have been done in the region.

Another type of "expert disagreement" is the difference among the various schools of professional and practitioner opinion. Operating in the watershed field are professionals from many disciplines—hydraulic engineers, geologists, geomorphologists, fishery biologists, and botanists, along with stream restorationists, who might represent a combination of disciplines and/or unique field experiences. Each of these disciplines offers distinct analysis tools, and each tool has its own strengths and weaknesses. There may be not right vs. wrong tools—the approach really depends upon which perspective is being applied to the watershed. Looking at all these perspectives and using as many tools of analysis as appropriate will contribute to putting together a more complete picture of the watershed.

### 5.5.3 Confounding Factors

Sometimes your assessment data and information just do not seem to add up correctly. There is a blip in your temperature graph that is not readily explainable. Fish are not being found in obviously good habitat. A mile of stream lacks riparian vegetation for no apparent reason. Whatever the mystery, you cannot easily find an answer.

Detective work might be in order to determine if confounding variables might be contributing to the observations. This challenge can actually be fun and, if successful, very rewarding. Look at the data more closely. Ask others, including specialists and local residents. Historical information might help—what used to be in that area? An old dam or millsite? Check the museum, ask longtime residents, review old aerial photos. For example, in one sediment study, increased fine sediment was measured in a reach that was not the lowest gradient and was not below a tributary. After asking a longtime resident of the area, it was discovered that that a 30-year-old small diversion dam had been removed recently from the site. Apparently, the sediment previously stored behind the dam was moving downstream in a sediment plug (Sommarstrom et al. 1990).

It is not always possible to find an accurate explanation. Too many variables may be interacting, and you may have insufficient data to separate them. The farther downstream you examine and the larger the watershed, the more likely “confounding effects” will be found. Is bank erosion in the lower channel being caused by increased flows due to a greater number of impervious surfaces, or lack of riparian vegetation, or upstream channelization, or channel widening due to increased sediment load, and/or all of the above? Without a carefully controlled study design, determining the precise contribution of these factors will probably not be possible in your assessment.

Chapter 6 presents various methods for integrating information that may help you to better understand confounding influences in your watershed.

## 5.6 Statistical Resources

The following books cover a variety of statistical material and approaches ranging from the very basic to the advanced. Their listing does not constitute an endorsement, rather these books represent a selection you might find useful.

<u>Basic</u>

Statistics a self-teaching guide. 1997. D.J. Koosis. 4th edition. John Wiley and Sons Inc. NY. 278 p.
Includes descriptions of samples, populations, means, variance, and comparison among means.

Statistics with Microsoft Excel. 2001. B.J. Dretzke. 2nd edition. Prentice Hall Inc. NJ. 257 p.
Provides guidance for the use of this spreadsheet program in conducting many basic statistical procedures.

The cartoon guide to statistics. 1993. L. Gonick and W. Smith. HarperCollins Publisher Inc. NY. 230 p.
Very basic introduction to statistics in a graphical form.

Statistics for dummies. 2003. D. Rumsey. Wiley Publishing Inc. 355 p.
Another very basic introduction with thorough introductions to the basis of statistical analysis.

Intermediate

Statistics and fluvial geomorphology. Clement, P. and Piegay, H. 2003. In: Tools in Fluvial Geomorphology, G.M. Kondolf and H. Piegay, editors. Pp 596-630.

Using statistics to understand the environment. Wheater, C.P. and Cook, P.A. 2000. Routledge Introductions to Environment Series, NY, 245p.

Statistical methods in water resources. Helsel, D.R. and R.M. Hirsch. 2002. U.S. Geological Survey Techniques of Water Resources Investigations, Book 4, Ch. A3. http://water.usgs.gov/pubs/twri/twri4a3/

Statistical methods in hydrology. 2002. C. T. Haan. Ames, IA: Iowa State Press. 496 p. Standard reference for statistics applied to hydrology; good section on time series analysis

Statistics for environmental science and management. 2001. B.F.J. Manly. Chapman & Hall. 326 p. Basic statistics, discussion of sampling and monitoring, time series analysis, and spatial analysis.

An introduction to multivariate statistical analysis. 2003. T.W. Anderson. John Wiley & Sons Inc. NJ. 721 p. Basics of multivariate analysis, correspondence analysis, principal components analysis, and variate distribution.

Advanced

An introduction to applied geostatistics. 1989. E.H. Isaaks & R.M. Srivastava. Oxford University Press Inc. NY. 561 p. Theory based discussion of the basic statistics to use when analyzing spatial data.

Introduction to time series analysis and forecasting. 2002. P.J. Brockwell & R.A. Davis. 2nd edition. Springer-Verlag Inc. NY. 434 p. Theory based discussion of the analysis of trends in various environmental, economic, and other data.

Nonlinear time series nonparametric and parametric methods. 2003. J. Fan and Q. Yao. Springer-Verlag Inc. NY. 551 p.

**Analyzing Data Checklist**

- ❑ Choose benchmarks and reference values for comparison to data collected
- ❑ Assess quality, quantity, and scale of data
- ❑ Agree on approach(es) for analysis of data
- ❑ Summarize data using descriptive statistics
- ❑ Apply more sophisticated statistical analysis as appropriate, including spatial and temporal analysis methods
- ❑ Assess uncertainty and confounding factors that might influence the interpretation of the data
- ❑ Consider differences of opinions among experts

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# 8 Using the Watershed Assessment for Decision-Making

One of the most important uses of a watershed assessment is to support watershed-scale decisions that protect or restore watershed function. This is probably one of the most difficult as well. Watershed assessments and watershed planning are the cornerstone for effective human action at the watershed-scale, but only if the findings and proposed actions are implemented and the response of the watershed monitored (Naiman, 1992; Reimold, 1998). This chapter expands on chapter 2 and describes different ways that a completed watershed assessment can be used to support watershed-scale decisions. Restoration planning, water quality regulation, land-use planning, water management, watershed planning, floodplain management, and monitoring are all activities where watershed assessment can be useful.

Chapter Outline



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## 8.1 Watershed Planning

Watershed plans are the logical follow-up to watershed assessments. Plans take the information developed during the assessment and design a program of solutions to address the fundamental needs and problems identified in the assessment. A watershed plan consists of a series of proposed actions that seek to improve any conditions regarded as detrimental or degraded in the assessment. Information from the assessment contributes directly to the plan by providing the knowledge on which to base the proposed actions. In a recent study of watershed groups, the use of watershed plans was one of the few factors that had a high correlation with potential positive environmental outcomes (Huntington & Sommarstrom 2000).

In general, a watershed plan consists of an overall vision or set of goals for the watershed, a series of steps needed to achieve those goals, and detailed consideration of how to implement those steps. The plan should also include prioritization of the goals and actions, optimization of the sequence of actions for greatest efficiency and effectiveness, and means of monitoring the implementation and results of the actions. However, “effective plans can range in size and content from simple documents of only a few pages to multi-volume comprehensive reports” (Born & Genskow 2001).

Actions typically found in watershed plans include:

- public awareness and education programs
- agency coordination mechanisms
- proposals for changes in land use via incentives, regulations, zoning, and conservation easements
- aquatic and riparian habitat restoration
- proposals for changes in water, vegetation, and waste management
- best management practices to minimize soil loss and water-borne transport of waste materials and pollutants
- structural changes in drainage systems, storm water conveyances, bridges, dams, and diversions.

Information contained in your watershed assessment should be helpful for designing each action. Each proposed action should relate to at least one objective or goal of the watershed assessment, and contain information about:

- basis in assessment findings,
- alternatives,
- responsible parties, partners and assistants,
- public education and involvement,
- time schedules,
- costs,
- opportunities for funding,
- resources needed,
- potential impediments,
- potential jurisdictional conflicts and cooperation,
- steps for implementation, and
- measures of success.

'Good' planning processes lead to better recommendations for action (Born & Genskow 2001), so be careful about jumping into developing a "Wish List" of proposed projects and actions. It is tempting, and sometimes watershed groups need to have some relatively easy projects under their belts first in order to garner public interest to sustain a longer planning process (see "Action" type of planning in the table of concepts of schools of planning).

Your list of actions will likely exceed more than you can possibly accomplish in a 2-5 year period, or your ability to find the immediate funding to help implement. To help set priorities for the proposed actions, considering the following (Conservation Technology Information Center, 1994 and others):

- watershed assessment findings of critical causes of problems
- funds available
- opportunities for partnerships
- return on funds to be invested - "most bang for the buck"
- time and other non-financial resources
- ability to get the action done
- early successes motivate more action
- some actions rely on other actions for success
- preventative actions versus remedial ones
- ability to measure progress or success with performance indicators

### 8.1.1 Develop a Successful Plan

A useful assessment provides an evaluation of how well a watershed is working and how it got that way. It does not necessarily give a direction, which requires decisions. Here we are now, but where do we want to go with these helpful new findings about our watershed? Planning is a process that enables you to determine where you want to go, how and when you're going to get there, and who is going to do what.
First, however, you need to clearly define why a plan is needed. People will not participate in the planning process or accept the final plan unless they understand the need for the plan and the decisions to be made (Saul & Faast 1993). An assessment can usually make this explanation easier by identifying what needs to be improved in the watershed. The assumption (explicit or implicit) is that people will want to follow through with working on the findings of the assessment through a plan and its implementation. Do not always assume, though, that a good assessment will automatically lead to a publicly-supported plan.

> *"A key question underlying all watershed planning is: What is an effective process to relate science, policy, and public participation? Watershed planning demands integrative thinking and a coordinated approach. Perhaps the greatest contemporary concern is to provide meaningful public involvement in the process, because experience has shown that top-down planning can create a variety of implementation barriers grounded in the lack of public involvement at key points in the planning process."*
>
> ~ National Research Council (1999)

As emphasized in Chapter 2, the process your group uses with your watershed community will be critical in developing the understanding and support for your plan as well as your assessment. Who makes the decisions about what goes into the plan is another key factor toward developing a sound strategy. The assessment process entails some decision-making, but the planning process involves much more. Decisions have to be made on the best strategy, and priorities have to be set. Opinions and values become more involved, and trade-offs have to be made. The primarily objective assessment process becomes transformed into an essentially subjective planning process. Science informs those decisions through the assessment, but choices still are made. Not everyone can necessarily be satisfied, though consensus should still be sought. Planning must "be seen as part of a process that strives to create a watershed community" (National Research Council, 1999).

With a credible assessment and plan having strong stakeholder support, successful implementation should be able to follow – pending funding, permitting, and other needs, of course. If monitoring and other evaluations later indicate that the plan needs to be changed, then the planning process should readily provide for adapting the plan's content and approach as needed.

A successful plan must be able. It must be:

- Understandable
- Supportable
- Implement-able
- Adaptable

### 8.1.2 Choose a Type of Planning

How to approach planning for watersheds will necessarily involve the different concepts or "schools of planning" that have evolved in the U.S. Each concept carries its own set of expectations as well as strengths and weaknesses. There is no ideal form of planning for all cases. Today watershed plans could be one or all of these types, depending on your needs and preferred choice.

Planning expertise can often be lacking in community-based watershed planning efforts, as it is not usually a discipline associated with watershed efforts. One suggestion is to work with your local county and city planners to help improve your own watershed planning process and product (Huntington & Sommarstrom 2000).

Remember that the key is the process - *"the process by which people of different vantage points come together, learn each others' languages, and begin to forge a common language to describe what they want to achieve with their rivers, streams, and surrounding lands*" (Environment Now & Southern California Wetlands Recovery Project, 2002).

**What Helps Create Good Planning Decisions?**

Your planning process will entail many decisions. Researchers have found that five key factors seem to distinguish successful decision-making processes (i.e., decisions that will be implemented) from the rest:

1. Builds trust
2. Builds understanding
3. Incorporates value differences
4. Provides opportunities for joint fact-finding
5. Provides incentives for collaboration and cooperation

Source: Wondolleck (1988) in: Saul & Faast (1993)

**Concepts or 'Schools' of Planning**

| Type of Planning | Description | Planning Strengths | Planning Weaknesses |
|---|---|---|---|
| Comprehensive | Sytematic, step-by-step setting of goals and objectives for a number of related mgt. needs, evaluation of alternatives, adoption of implementation measures; also called "rational planning" | Can recognize the interrelationships of many issues and disciplines; emphasis on science and data collection; logical process is appealing; used by many federal agencies; needs strong laws to implement. | High costs; too broad and not site-specific enough; low implementation rates; often entails a top-down process, so little public support; may create illusion of scientific objectivity; planning is not a rational science but an art; |
| Incremental | Developed and implemented gradually over time through a bargaining process; Focus is on specific problems or issues & short-term results, which over time address the larger problems. | Results oriented with focus on what can be done; the public guides and makes the plan; small-scale solutions reduce risks; adopted now as "adaptive management"; little steps help map future steps | Actions may not address some of larger, more difficult issues; plans may proceed without adequate science & knowledge; implementation may or may not be coordinated; continual interaction required with clients for implementation |
| Consensus | Involves as many stakeholders in an area as possible; all players treated as equals; implementation based on negotiated political agreement. | Implementation rates high due to political buy-in; can be successful in resolving difficult issues; helps communities build and learn; good strategy for attracting diversified funding sources | Process can be lengthy and perceived as too "time-consuming"; plan may be a package of diverse benefits to satisfy partners but not focused and integrated; very difficult individuals can derail the process. |
| Advocacy | Citizens organize to advocate a position or action; plan used to strategically show alternative approach to a more traditional one. | Can be politically empowering if coalition or consensus is developed; can help with community building across formerly disparate groups; can break political impasse | Technical content of plan may be professional but may not be representative of broader community; may lack integration with other disciplines; polarization may result if consensus not reached from advocacy. |
| Action | Initiated by citizen groups, districts, and agencies to make something visible and positive happen on the ground in order to build public support and interest; a form of incremental planning. | Builds public awareness for the difficult Big Picture needs and watershed-wide approaches; confers credibility on planning process; can develop credibility for government programs or expertise; helps develop new community leadership | Small action projects may or may not correctly apply science or restoration methodologies; plans may not develop enough integration, coordination, or expertise; monitoring may be lacking. |

(based on Riley 1998)

### 8.1.3 Set Direction: Goals & Objectives

Your plan should be based on the direction set by a hierarchy of consistent goals and objectives. Following your group's setting of broad goals and specific objectives comes the details of your proposed strategy, which includes tasks, activities, or actions. The latter can get more and more detailed within the outline of your hierarchy. Too often, these plan terms are used sloppily or interchangeably and unclear expectations can result. Purported "plans" with no stated goals or objectives and only a list of recommendations do not give any measure for evaluating success in the direction you desire for your watershed.

Some helpful hints for reviewing and revising watershed plans are:

- Have a yearly informal "here's where we are" session to update folks on plan implementation.
- Ask people to evaluate your planning process so you can do better next time.
- Issue periodic "report cards" to the public on plan implementation and monitoring results to keep them informed and to "give dignity to the plan".
- Ask yourselves, "Do we still need to do this action?"; "Has our vision changed?"; "What else can we do?"; "What has been successful, and why?"; "What has not worked, and why?"
- Celebrate your successes! You've accomplished several tasks, you've achieved an objective, or you've made significant progress towards your goal. Feel good about your progress!

*Sources: Saul and Faast (1993);* Conservation Technology Information Center *(1994)*

The table in the box below provides practical definitions for the terms most commonly applied to a plan's structure.

While your Goal statements can be long-term and somewhat lofty, your Objective statements should be more achievable (Conservation Technology Information Center, 1994). Examples of such Objectives include: "Reduce sediment to improve habitat for trout" or "Incorporate watershed protection into county and city General Plans and Specific Area Plans". Each goal will likely have more than one objective, and each objective may have more than one strategy, which may have more than one task/action. One way to check if your draft statements for each of these terms make sense is to read them from the bottom up (tasks-strategy-objective-goal).

### 8.1.4 Revising & Updating Plans

Plans should be viewed as "living documents" that are assumed to change as needed, and not remain fixed to gather dust. Dog-eared pages of plans are a good sign that they are being used frequently. But even well-used plans still need regular review, updates, and revisions. This cyclical evaluation and opportunity for adjustment is a form of adaptive management, which is encouraged by the scientific community but not widely practiced (Born & Genskow 2001).

As the Washington Guide to Watershed Planning and Management states, "*A watershed plan does not need to offer all the answers. Instead, it can lay out a long-term process towards finding answers and improving solutions…"* Plan to be adaptable!

Through experience, monitoring results, and other continuing assessments, your group will evolve a greater understanding of what implementation actions work and do not work in your watershed. Restoration and ecosystem management are still in the experimental stages, and feedback is necessary for their progress. New

**Defining the Hierarchy of Plan Terms**

| Term | Definition |
|---|---|
| Goal | Broad statement of intent, direction, and purpose. |
| Objective | Specific, clear statement that describes desired condition for a specific area, activity, or species. May be qualitative or quantitative. |
| Strategy | Explicit description of what will be done to achieve objectives. |
| Task / Action | Specific step, practice, or procedure to get the job done, usually organized sequentially with timelines and assignments. |

(Saul & Faast 1993)

challenges, such as rapidly increasing development in a rural sub-watershed or a recently discovered pollutant or invasive species, may stimulate your group to go back to the drawing boards and develop new strategies. Watersheds - and their social and political community - are dynamic systems with changing needs. Economic cycles may affect the availability of partners and funding sources to share costs of your plan's implementation. With stakeholders and other key decision-makers changing over time, plans will also need to reflect continually evolving priorities and practicalities.

### 8.1.5 Examples of Watershed Plans

#### 8.1.5.1 Subbasin Plans

In the huge Columbia River Basin, the Northwest Power and Conservation Council (NPCC) called in 2000 for the development of approximately 60 subbasin plans that are to guide implementation of its Columbia Basin Fish and Wildlife Program. The management plans were to help the Council prioritize projects for a limited amount of funding, through identification of past and ongoing work (the inventory) and an assessment of habitat conditions and factors that limit fish and wildlife production,. A "Technical Guide for Subbasin Planners" was prepared to assist those developing a subbasin plan (http://www.nwcouncil.org/).

The NPCC's Independent Scientific Review Panel (ISRP) reviews each draft plan to determine if it meets the Council's expectations for completeness and scientific soundness (e.g., the Program's Scientific Principles). In particular, the Panel is concerned that subbasin plans address:

- the need to adequately use available information,
- the need to clearly link the Assessment, the Inventory, and the analysis of information in these two documents to the resulting Management Plan, and
- the need to carry the planning process to scientifically justified, integrated, and prioritized conclusions in the form of realistic priorities for achievable "next steps" for managing the subbasin's fish and wildlife populations. (http://www.nwcouncil.org/library/isrp/isrp2004-4.htm)

#### 8.1.5.2 Water Quality Emphasis Plans

Watershed-based plans are encouraged by both the EPA and SWRCB for various water quality-related programs, such as the Nonpoint Source (NPS), storm water management, and TMDL programs. Expectations for federally-funded or required watershed management plans are described under EPA's Section 205(j) and Section 319 grant programs. Polluted runoff is also being addressed through the State and Regional Boards' Watershed Management Initiative (WMI), which promotes "integrated planning" with local stakeholder groups.

A well-developed example is the Santa Clara Basin Watershed Management Initiative (WMI) (http://www.scbwmi.org). This collaborative effort has prepared a three-volume Watershed Management Plan, composed of a Watershed Characteristics Report, a Watershed Assessment Report, and a Watershed Action Plan. Water quality is the primary focus, but other watershed values and uses are also incorporated.

Urban runoff management triggered by municipal storm water permitting helped initiate much of the San Diego watershed planning efforts (http://www.projectcleanwater.org/html/ws_efforts.html). Some of these urban runoff plans appear to have meshed or integrated with other watershed issues, some have not. As a means of complying with a regulatory program, these watershed plans and their implementation need to maintain their focus on water quality compliance.

#### 8.1.5.3 Coastal Watershed Plans

The State Coastal Conservancy encourages the development of watershed plans through financial and technical assistance to local groups and has prepared a short *Watershed Planning Guide* outlining a step-by-step sequence of actions during the process to achieve a watershed plan. While acknowledging that every watershed will have a unique planning process, the Guide seeks to highlight the steps that are common to most planning efforts as well as the stumbling blocks: "It should be modified as much as necessary to fit the particular circumstances of your watershed." Since the Conservancy funds many projects, it sees the plans as a means of identifying and prioritizing coastal restoration projects. A variety of watershed efforts have used the assistance of the Conservancy to prepare their plans (http://www.coastalconservancy.ca.gov). These plans include, but are not limited to, the watersheds of: Tomales Bay, Pescadero Marsh, Aptos Creek, Morro Bay, Calleguas Creek / Mugu Lagoon, Arroyo Seco, and San Luis Rey River.

In coastal Southern California, there are "many different patterns to get watershed planning underway", rather than a single rational sequence of events (Environment Now & Southern California Wetlands Recovery Project, 2002). A snapshot at the end of 2002 revealed that watershed management planning was "still in its infancy" in the five-county region, but many new efforts were underway. Of 20 completed plans, most were for partial watersheds and a number focused on the same region (e.g., Santa Monica Bay and Los Angeles River). Los Angeles County was the most productive for completed or in-progress watershed plans. The Santa Monica Bay, part of the National Estuary Program, region had 4 completed watershed plans, supported by over 80 studies. Water pollution and recreation concerns initially jump-started these collaborative restoration planning efforts, such as in the Malibu and Topanga Creek watersheds.

## 8.2 Restoration Planning and Projects

Restoration efforts are frequently an important part of a watershed plan or they can be undertaken independently of a plan as an application of a watershed assessment. California is the home to multiple state- and federally-funded restoration programs that have evolved from diverse legislative mandates, ballot initiatives, and citizen-sponsored programs. The term "restoration" offers a sense of purpose, of restoring something that has been lost, and has developed a popular following throughout the state. We seek to "restore" many natural features within the watershed: fisheries, wetlands, streams, water quality, ecosystems, and habitat, among others.

Restoration plans and projects need a solid scientific underpinning to be successful. A recent study by the State found, "Absence of useful watershed assessments and plans can result in restoration projects that don't address priority problems and their causes" (California Resources Agency & State Water Resources Control Board, 2002). Agencies are concerned that projects may be scattered, unfocused on achieving watershed management objectives and, therefore, inefficiently using state grant funding.

"*Watershed-scale restoration should begin with an understanding of watershed structure and function and of how human activities affect and shape watershed health*." (Williams, Wood & Dombeck 1997)

"*To achieve long-term success, aquatic ecosystem restoration should address the causes and not just the symptoms of ecological disturbance*." (NRC 1992, p. 55)

**An Example of a Fluvial Restoration Strategy**

The Goal of fluvial restoration in _____ Watershed is to restore the river or stream to dynamic equilibrium. [The assumption is that dynamic equilibrium of the physical system establishes a dynamic equilibrium in the biological components.]

The Objectives under this broad goal are to:

1. *Restore the natural sediment and water regime*. ['Regime' refers to at least two time scales: the daily-to-seasonal variation in water and sediment loads, and the annual-to-decadal patterns of floods and droughts.]
2. *Restore the natural channel geometry, if restoration of the water and sediment regime alone does not*.
3. *Restore the natural riparian plant community, which becomes a functioning part of the channel geometry and floodplain/ riparian hydrology*. [This step is necessary only if the plant community does not restore itself upon achievement of objectives 1 and 2.
4. *Restore native aquatic plants and animals, if they do not recolonize on their own*.

Source*:* National Research Council (1992) pp. 206-207.

The analysis contained in a watershed assessment lays the very foundation for successful restoration projects. The analysis made as part of the assessment serves to explain, based on the best available information, the likely causes of the alterations within the watershed that led to the need for the restoration activities. More specifically, the analysis in the assessment can help to:

- Provide baseline and reference data, with which to compare restoration progress or success.
- Help understand the patterns of water and sediment transport that create and maintain the natural morphology of the channel and its associated floodplain.
- Provide information for aquatic restoration, including descriptions of upslope connections to the riparian and waterway
- Help identify the causes and not just the symptoms of problems needing correction.
- Reveal restoration opportunities, including getting beyond preconceived perceptions about problems and solutions.
- Coordinate with other stakeholders in developing a common understanding of how the watershed behaves
- Provide basis for a Restoration Plan, including goals and objectives.
- Help identify types of restoration methods needed to address the problem causes.
- Locate the priority sub-watersheds, stream reaches, or other areas within the watershed for restoration projects, based on the above.
- Identify priority restoration projects, based on the above

The California Department of Fish and Game's *California Salmonid Stream Habitat Restoration Manual* recommends that a 'preliminary watershed assessment' be done to get the "big picture" about present and potential fish production in a stream system before beginning field surveys and designing projects. However, the expectation is more of a watershed "overview" rather than a full assessment as described in this Manual. The concept still advocated is that restoration efforts need to address how the watershed works and what key processes and conditions have been altered, before prescribing the remedies.

It is the physical and biological processes operating in the watershed are the mechanisms that govern the watershed's condition. Working with the natural processes in your restoration strategy will improve your chances of success. Some players tend to be more interested in the project phase than the assessment or planning phase, and they might not have been aware or interested in your assessment process. Their enthusiasm might also get ahead of them. Do a reality check with everyone on previous restoration assumptions and project ideas now that the assessment is completed.

Moving from watershed condition evaluation - your assessment - into identifying the appropriate restoration measures often involves another set of skills and approaches. Applied science and technologies tend to become more important, such as engineering, surveying, contracting, heavy equipment, and resource management skills. Experience with what works and doesn't work with certain restoration techniques, especially in your area, becomes of critical importance. Some agencies, consultants, landowners, and citizen organizations may have a wealth of experience with certain methods – be sure to ask around. Use the same collaborative process applied to your assessment, but now bring in those people with the applied restoration skills. This difference in needed expertise is one of the reasons that project recommendations within the watershed assessment product can appear naïve or impractical when evaluated later by restoration practitioners (Riley 1998).

## 8.3 Land Use Planning

Watershed assessments are intimately tied to land use planning. The relationship between land use and watershed conditions and processes has been described in detail in this Manual. However, this relationship is not always appreciated by local planning department staff, planning commissioners, or city council members who make decisions about land uses. Usually, people in these positions are civic-minded individuals with no special knowledge of watersheds and how land uses influences the hydrological cycle as well as other potential impacts on waterways. The information generated by a watershed assessment and plan could be invaluable to local decision-makers.

California planning law requires that landowners and local planning agencies engage in the formulation of zoning and parcel-specific land use plans to guide the development of residential, commercial, and industrial areas. The most common way of doing this is through the general plan process, where a municipality or county planning agency decides which areas in the jurisdiction should fall under which zone type and what proportions of land uses would be appropriate.

There are very few instances where watershed assessments have been used explicitly to aid decision-making in land-use planning, although information contained in an assessment could be very useful for planning purposes. Orange County has conducted many watershed assessments through cooperative arrangements with the Army Corps of Engineers (ACE). These assessments are associated with restoration goals and programs and are not explicitly intended to support land-use decision-making. However, they contain information relevant for land-use decisions and could be used in that fashion.

Some of the information frequently contained in a watershed assessment that could be used to support land use planning include:

> *Land use planning is the process by which public agencies, mostly local governments, determine the intensity and geographical arrangements of various land uses in a community*
>
> Fulton, 1999

- Data on surface and ground hydrology under natural and modified conditions
- Stream bank stability and channel characteristics which are influenced by the area of impervious surfaces and other land use modifications

**Watershed-related References in the State's General Plan Guidelines [Office of Planning & Research; http://www.opr.ca.gov]**

**Watershed Based flood protection** , p. 12 **Safety Element**
Cities and counties should identify risks from natural hazards which extend across jurisdictional boundaries, then use any available data from watershed-based floodplain management, mapped earthquake faults, or high fire hazard areas as planning tools to address any significant issues. Each local planning agency carries a responsibility to coordinate its general plan with regional planning efforts as much as possible.

**Relationships Among Elements and Issues**, p. 37
General plan elements and issues interrelate functionally. For example, consideration given to the vegetation which supports an endangered wildlife species in the conservation element also involves analyzing topography, weather, fire hazards, availability of water, and density of development in several other elements. Thus, the preparation of a general plan must be approached on multiple levels and from an interdisciplinary point of view.

**Ideas for Data and Analysis, Open-Space***,* p. 38
The following consists of topics which should be considered during the preparation of the general plan and, if relevant, included in a **land use element**. These subjects are based upon a close reading of the statutes and case law. When the information collected for the land use element overlaps that needed for other elements, the related element has been noted in parenthesis.

- Delineate the boundaries of watersheds, aquifer re-charge areas, floodplains, and the depth of groundwater basins (diagrams) (CO, OS, S)
- Delineate the boundaries and description of unique water resources (e.g., saltwater and freshwater marshes, wetlands, riparian corridors, wild rivers and streams, lakes). (CO)

**Conservation Element**
The conservation element may also cover the following optional issues:

- Protection of watersheds;

*Water, p. 56-7*

- Inventory water resources, including rivers, lakes, streams, bays, estuaries, reservoirs, ground water basins (aquifers), and watersheds (Map) (LU, OS)
- Identify the boundaries of watersheds, aquifer recharge areas, and groundwater basins (including depths) (Map) LU, OS)
  - Assess local and regional water supply and the related plans of special districts and other agencies
  - Analyze the existing land use and zoning within said boundaries and the approximate intensity of water consumption
- Map the boundaries and describe unique water resources (e.g., salt water and fresh water marshes and wild rivers) (LU, OS)
- Assess the current and future quality of various bodies of water, water courses, and groundwater (LU, OS)
- Inventory existing and future water supply sources for domestic, commercial, industrial, and agricultural uses (LU, OS)
- Assess existing and projected demands upon water supply sources, in conjunction with water suppliers (LU, OS)
  - Including: agricultural, commercial, residential, industrial, and public use
- Assess the adequacy of existing and future water supply sources, in conjunction with water suppliers. (LU, OS)

**Watershed-related Citations in the General Plan Guidelines [Office of Planning & Research] cont'd.**

- Map riparian vegetation (LU, OS)
- Assess the use of water bodies for recreation purposes (LU, OS)

*Forests,* p. 62

- Inventory forest resources including a comprehensive analysis of conservation needs for forests, woodlands and the interrelationship they have with watersheds (Map) (LU, OS)
  - Describe the type, location, amount, and ownership of forests with a value for commercial timber production, wildlife protection, recreation, watershed protection, aesthetics, and other purposes

*Fisheries*, p. 62

- Identify water bodies and watersheds that must be protected or rehabilitated to promote continued recreational and commercial fishing – including key fish spawning areas
- Evaluate water quality, temperature, and sources of contaminates
- Identify physical barriers (man-caused or natural) to fish populations within the watershed, then propose alternatives and set priorities

**Open-Space Element, Background**, p. 68
The following topics are to be addressed, to the extent that they are locally relevant:
*Open-space for the preservation of natural resources* including, but not limited to:

- Areas required for ecologic and other scientific study; rivers, streams, bays and estuaries; and, coastal beaches, lake shores, banks of rivers and streams, and watersheds;

*Open-space for public health and safety* including, but not limited to:

- Areas that require special management or regulation because of hazardous or special conditions such as earthquake fault zones, unstable soil areas, flood-plains, watersheds, areas presenting high fire risks, areas required for the protection of water quality and water reservoirs and areas required for the protection and enhancement of air quality.
- Identify watersheds and key areas for the protection of water quality and reservoirs (map) (CO)

**Safety Element**, p. 77
*Flood Hazard* - A comprehensive approach should include mapping floodplains…, and floodplain management policies (which may include both structural and non-structural approaches to flood control using a **multi-objective watershed approach**). Flooding is often a regional problem that crosses multiple jurisdictional boundaries.

**Slope instability and the associated risk of mudslides and landslides**

• Identify areas that are landslide-prone by using, among other sources, Division of Mines and Geology's seismic hazard zone maps, landslide hazard identification maps, watershed maps, and geology for planning maps, and landslide features maps produced by the U.S. Geological Survey (map) (OS)

- [General Plan Elements: LU=Land Use; OS=Open Space; CO=Conservation; S=Safety ]

- Existing and potential future surface and ground water quality under different land use and development scenarios.
- Biological diversity and status of aquatic and riparian species of plants and animals

### 8.3.1 General Plans

Municipal and county general plans govern the development of land annexed by a city for residential, commercial, or industrial development and general or specific uses of lands within a county outside developed areas[1] General plan "elements" (e.g., land

[1]. These plans are required by Govt. Code 65300 *et seq.* and are implemented through policy narratives, zoning ordinances and maps (Gov't. Code 65850 *et seq.*), and subdivision maps and regulations (Gov't. Code 66410 *et seq.*; Fulton, 1999).

use, circulation, open space; see chapter 3.10) are used to detail the planned growth and consequences of the growth. Because a general plan must be analyzed for its potential impacts to the environment (California Environmental Quality Act), there is a nexus between the plan and watershed assessment. CEQA requires that the 'best available information' be used to evaluate potential impacts of a general plan or a specific project. Many times, the best available information can be found in watershed assessments. For example, the land use element must show the location, distribution, and intensity of development and particular elements (e.g., wastewater treatment facilities) allowed under the plan. This is usually done using a map, which along with zoning and parcel maps can make the general plan process a very tangible part of watershed assessment and vice-versa. Frequently, consultants hired to perform CEQA assessments rely on incomplete databases or field assessments of limited scope. The information in a watershed assessment could be an invaluable source of data and analysis of conditions.

There are three locations in the state where state law requires the consideration of natural resource protection at a "pseudo-watershed scale" when developing general plans. These are the Lake Tahoe basin, the California coastline, and the Sacramento and San Joaquin Rivers Delta. In all other parts of the state, there is nothing approximating a requirement to consider watershed processes when developing plans.

Three classes of regulations require that the effects of harmful actions be mitigated, though rarely is this requirement accompanied by performance measures for the evaluation of effectiveness. A watershed assessment approach could be used in conjunction with wildlife and habitat assessments to expose the environmental costs and benefits of actions proposed in a general plan, or that were not considered feasible (e.g., restoring natural processes or features). The three classes of regulations are:

- Both the federal and California Endangered Species Acts require that populations and habitats of listed species be protected from take (destruction of habitat or individuals), or if take is planned, that it be mitigated. For aquatic, wetlands, vernal pool, and riparian species this would seem to require a watershed perspective for general planning as developed areas will have direct and indirect impacts on aquatic natural processes, wildlife, and plants. *Watershed assessments can inform these decisions by showing the linkages between existing and proposed land-use decisions in the general plan and downstream habitat and populations of listed species.*

- The federal Clean Water Act and the state Porter-Cologne Act require that state regulators analyze and consider for permitting any activity that may cause harm (e.g., pollution) to California waterways and wetlands.
  *Watershed assessments can inform these decisions by showing the linkages between existing and proposed land-use decisions in the general plan and downstream habitat, water quality, channel conditions, and natural processes (e.g., flooding).*
  (see "Improving our Bay-Delta Estuary Through Local Plans and Programs: A Guidebook for City and County Governments (Association of Bay Area Governments, Oakland, CA), 1995, 21 pp.)

- The federal National Environmental Policy Act and the California Environmental Quality Act require that plans such as general plans be analyzed for potential impacts to human and natural environments. Alternative plans must be put forward by the lead planning agency, based in part on public input, that show different ways to achieve the plan's objectives and the potential impacts from each alternative. The lead agency must, theoretically, choose the least environmentally damaging and feasible alternative. *Watershed assessment can list the various natural and human features (e.g., streams and roads) and processes (e.g., agriculture and fire) that are important in watersheds and sub-watersheds within the general planning area. It can describe the overall and localized condition, make linkages between human activities and condition, and serve as a major type of environmental assessment against which to judge proposed actions.*

In all of the above cases, data contained in a watershed assessment can aide local municipalities in meeting these requirements. Frequently, the analysis performed by local government is incomplete and omits important information related to protecting waterways. The data and analyses contained in an assessment can play an important role in informing local decisions-makers of this important information. In cases where general plans are being adopted, community watershed groups should bring their analysis to the attention of local planning commissions and city councils to ensure that all requirements can be evaluated with the best available and most complete set of information

When considering informing general planning with snapshot or continuing watershed assessment work, scale is an important quality to keep in mind. A fine-grained assessment is needed to judge the impacts of parcel and subdivision scales of development activities. A coarse-grained watershed-wide assessment is not an adequate substitute for this. Similarly, the right time frame for analyzing and modeling potential impacts is needed. Changes in watershed functions and outputs may be immediate, substantial, and long-lasting at the sub-watershed scale and not measurable until full general plan build-out at the river basin scale. Matching scales of assessment or monitoring activity is critical in the use of this approach in informing general planning.

### 8.3.2 Ordinances

Municipal or county ordinances govern certain uses of public and private property and their environmental impacts. These are binding and enforceable at that scale and tied to local problems and governance styles. For example, a rural county with a natural fire ecology may be very proactive in enforcing vegetation control immediately around structures, whereas an urban county or municipality may be very active about dumping into storm drains. Information contained in watershed assessments can also be useful to local decisions makers in crafting local ordinances that might impact the health and conditions of waterways. In particular, data on the conditions of local waterways and the links to local land uses, could be used to highlight the impacts of local policies on watershed health. The development of ordinances dealing with flooding and floodplains, stormwater run-off, subdivision landscaping and design, roads and grading, and stream buffers or setbacks all could benefit from knowledge and analyses typically contained in a watershed assessment.

Examples of these ordinances are:

- Subdivision & zoning ordinances
  Data from your watershed assessment combined with information on watershed-friendly ordinances could be a powerful tool in the hands of local land use planners. Information on model ordinances, design guidelines, and other relevant guidance for local officials is available online from the Center for Watershed Protection (http:www.cwp.org), the Low Impact Development Center (http://ww.lowimpactdevelopment.org)

and the NEMO Project (http://www.nemo.uconn.edu).

- Flooding and floodplain development ordinances are a useful way for local governments to reduce damage from flooding. Guidance from the State on the development of general plans to minimize flooding can be combined with data your assessment has produced to identify the need for sound development planning.  The state's guidance is posted at: http://www.fpm.water.ca.gov/generalplan.html.

- Stormwater runoff and dumping into storm drains are a commonly-recognized problems in urban settings,. Because developed areas have highly impervious surfaces (e.g., roads and parking lots), water will not percolate naturally into the ground over large areas. Stormwater not only frequently contains contaminants that is harmful to aquatic life, but the increased volume associated with reduced percolation is damaging to streams. Chemicals tend to collect on impervious surfaces and attached to dust and dirt particles. When it rains, especially with the first rain of the rainy season, these chemicals can be washed into local streams. Similarly, illegal dumping of chemicals into industrial, commercial, and stormwater drains can be an occasional but major input to streams. Municipal and county ordinances can regulate the flow of water and chemicals from urbanized areas. If excessive storm flows and diffuse or localized chemical inputs are disrupting your waterways, then storm water and dumping ordinances could help. Water quality analysis, impacts to aquatic biota, diversion of surface water from natural percolation areas, and timing and volumes of flow of storm water described in your watershed assessment can help determine if this type of ordinance might be helpful.

- Landscaping and water conservation ordinances can regulate the rate of pesticide application and irrigation in order to reduce the input of chemicals and excessive water into streams. Pesticides can cause direct mortality of aquatic biota, excessive nutrients can cause potentially harmful algae blooms, and summer irrigation in arid areas can upset the ecology of seasonally dry streams in the arid West. The state of Vermont and the cities of Sebastopol (CA), Buffalo (NY), and Burlington (VT) limit the application of pesticides to residential and forestry landscapes to reduce impacts to human and ecosystem health. If pesticides and excessive nutrients from fertilizer applications are a problem in your waterways, then municipal ordinances restricting these chemicals could be appropriate. Water quality analysis and the condition of aquatic communities described in your watershed assessment could inform local government officials about the development of landscaping ordinances.

- Riparian ordinance

[under construction]

## 8.4 Public Lands Management

On federally-managed lands, watershed assessments are usually termed watershed analyses. Some people believe the term "analysis" implies more detail at a finer spatial scale than typical "assessments", but "analysis" is the usual term used by the Forest Service and Bureau of Land Management for their process.

These watershed analyses on federal lands became institutionalized during the development of the Northwest Forest Plan (FEMAT 1993, USDA-Forest Service 1994). Among the recommendations of the Northwest Forest Plan was an aquatic conservation strategy intended to improve stream conditions for anadromous fish. A major part of this strategy was an assessment process that became known as watershed analysis. Although it was initially designed to focus on riparian issues, federal watershed analysis was soon recognized to be useful for evaluating a broad range of issues throughout a watershed (Grant 1994). During the 1990s, watershed analysis evolved as a tool for describing watershed attributes, issues, and capabilities that would form the basis of future land management on National Forests and Bureau of Land Management properties (Reid, et al. 1994).

Individual National Forests and some BLM offices have been conducting watershed analyses for the past decade using the protocol outlined by USDA-Forest Service (1995). In the federal context, watershed analysis is a tool for description and assessment of watershed processes and ecological conditions. It is based on processes, ecosystem components, and locations, but not on projects or proposals as is typical of other Forest Service planning processes. Watershed analysis on federal lands is not designed to produce a decision document and is not subject to the National Environmental Policy Act. Instead, the information generated from a watershed analysis can be used to inform and guide the projects that eventually implement a forest plan.

The basic parts of watershed analysis as described in the Federal Guide to Watershed Analysis (USDA-Forest Service 1995) include the following: The usual scale of analysis is for watersheds of 20 to 200 $mi^2$. A particular watershed is selected for analysis on the basis of regional interests, controversies, and opportunities for management. Public input is sought to identify critical issues, locate contributing information, and provide reality checks. The federal approach includes the following steps:

1) Characterization of the watershed
2) Identification of issues and key questions
3) Description of current conditions
4) Description of reference conditions
5) Synthesis and interpretation of information
6) Recommendations (usually including desired future conditions and potential strategies for moving the landscape toward those conditions)

The resulting report of a federal watershed analysis usually includes:

1) Description of the watershed including its natural and cultural features
2) Description of the beneficial uses and values associated with the watershed and, when supporting data allow, statements about compliance with water quality standards
3) Description of the distribution, type, and relative importance of environmental processes
4) Description of the watershed's present condition relative to its associated values and uses
5) Maps of interim and potential riparian reserves
6) Description of the mechanisms by which environmental changes have occurred and description of specific land-use activities in generating change
7) Description of likely future environmental conditions in the watershed, including discussion of trends and potential effects of past activities
8) Interpretations and management recommendations

Much of the federal guide covers various analysis methods for describing key processes and conditions and their possible causes. These topics include fire history, existing and potential vegetation, roads, mass movements, surface erosion, channel erosion, sediment yield, streamflow characteristics, runoff generation, stream temperature, channel conditions, aquatic and terrestrial habitat, and water supply. Descriptions of these methods include generic goals, data needs, assumptions, products, and procedures at both a cursory level and a more quantitative level depending on the needs of a study (USDA-Forest Service 1995). Another related set of procedures that focus on watershed hydrology is found in the publication, *A Framework for Analyzing the Hydrologic Condition of Watersheds* (McCammon, et al. 1998).

If your watershed includes some National Forest land, looking at the approaches and techniques of the federal guide is certainly worthwhile. The “analytic modules” will provide some guidance for a variety of measurements and analyses that may be appropriate for your situation. Just decide on your objectives first and see if any of the federal procedures would help meet those objectives, rather than charging into a measurement program just because the Forest Service finds it useful.

Within the National Forests of California, a variety of watershed analyses have been conducted. In general, the forests in the northern part of the state that were part of the Northwest Forest Plan have had a more active (and better funded) watershed analysis program. This program has been driven by northern spotted owl and salmon issues. The Shasta-Trinity National Forest has produced more than a dozen watershed analyses. Other forests are still working on their first analysis. The quality and level of detail of the initial round of watershed analyses is quite inconsistent, depending on the issues and local support for a particular analysis. Many of the watershed analyses have had their scope expanded somewhat by also incorporating guidance from the Region 5 (California) guide to ecosystem management (Manley et al. 1995). Reduction of the risk of catastrophic wildfires through management of fuels is the primary focus of many of the recent watershed analyses. At least one analysis has incorporated hydroelectric project re-licensing as the principal issue. The ultimate utility of the wide range of watershed analyses is yet to be determined. The Sierra Nevada Framework for revising the Forest Plans of the National Forests of the Sierra Nevada includes a major component of watershed analyses, but few had been completed to date within the Sierra Nevada. Web sites for most of the National Forests include the completed reports as well as progress of ongoing efforts.

Perhaps the most comprehensive watershed analysis completed to date on federal land in California and Nevada was for the Lake Tahoe Basin (USDA-Forest Service 2000). The national significance and public visibility of the Lake Tahoe Basin allowed an investment of about $2 million in this assessment. The document is a good source of ideas and approaches to watershed assessment, even if your budget is on a somewhat smaller scale.

You can take advantage of watershed analyses done by the National Forest in your region for a variety of background material relevant to your own watershed assessment. Check the web site of your local National Forest for completed watershed analyses. They may be found under resource management, watersheds, or publication or by using the web site’s search engine. Alternatively, call the nearest ranger district or supervisor’s office and ask about watershed analyses that have been completed or are in progress. The basic descriptions of climate, hydrology, vegetation, management, and disturbance history may be directly applicable to your watershed if the analysis area is close enough or may provide some good leads for pursuing information about your watershed. We recommend that you use Forest Service watershed analyses as information sources and not as templates or models for your assessment. Your fundamental goals and driving issues are likely to be quite different than the motivations behind the federal analyses.

## 8.5 Water Management

A consideration of watershed conditions is part of an integrated water management plan. In previous eras, water management was viewed primarily from an engineering perspective – how to deliver and dispose of water. More recently, however, the structure and function of the overall watershed is considered as another important factor in water management. Integrated water management has the potential to go beyond watershed management which focuses on conditions in the waterway and the processes that influence them. Science-based integrated water management considers the best way to develop/retrofit infrastructure in coordination with land use planning and protection of the aquatic ecosystem. The term "best way" reflects the development of a plan that includes the wise use of water, the environmental sound disposal of stormwater and wastewater, land use plans, and ecosystem protection and restoration. To address all these issues successfully involvement of critical stakeholders is essential. **Watershed assessments can provide an important source of information and analysis that is required for the development of an integrated water management plan.**

In 1998, the Washington State legislature passed the Watershed Planning Act to set a framework for addressing the State's water resource issues… When lawmakers passed the Act, they stated that the primary purpose of the statute was "…**to develop a more thorough and cooperative method of determining the current water situation in each water resource inventory area of the state and to provide local citizens with the maximum possible input concerning their goals and objectives**…". This statement identifies the purpose and issues associated with water management. To manage water, issues of surface and groundwater water supply and quality need to be evaluated**.**

In 2002, several acts were passed in California that were aimed at achieving similar goals as Washington state. The statutes added to the Water Code are:

- **Integrated Regional Water Management Planning Act of 2002** (Water Code sections 10530-10537) was created by SB 1672 (Costa). This act's implementation is to lead to the development of integrated regional water management plans, as a means of "maximizing the quality and quantity of water available to meet the state's water needs by providing a framework for local agencies to integrate programs and projects that protect and enhance regional water supplies." A "regional water management group" is defined as "three or more local public agencies, at least two of which have statutory authority over water supply." Groundwater management and grant-funded projects are also to be tied into such plans (section 10753.7)

- **The Integrated Water Management Program** (IWMP) (sections 79560-63) was created by Proposition 50 as a grant program operated by two state agencies: the Department of Water Resources (DWR) and the State Water Resources Control Board (SWRCB). It requires that eligible projects are consistent with an adopted integrated regional water management plan, or such a plan is in progress. Such a plan under the DWR grant program is to address, at a minimum: water-related objectives and conflicts in the watersheds of the region, including: 1) water supply, 2) groundwater management, 3) ecosystem restoration, and 4) water quality.

The details and coordination of these new programs are being worked out by the departments and the California Watershed Council, a state-supported collaborative partnership effort (http://cwp.resources.ca.gov/cwc_about.html). Under the SWRCB program, the integrated plan must be designed "to improve regional water supply reliability, water recycling, water conservation, water quality improvement, storm water capture and management, flood management, recreation and access, wetlands enhancement and creation, and environmental and habitat protection and improvement."

In addition to contributing to sounder land use planning, a watershed plan and the assessment on which it is based, can also inform the integrated water management effort. The analysis of the effects of human activities on watershed components and processes needs to be integrated into a water management plan. The impacts of water conveyance and discharge must be evaluated in this plan as well. This analysis usually part of watershed assessments and therefore, has direct relevance and use in water management plans.

Integrated water management might include some or all of the following:

- Balancing water use with water supply
- Connecting water supply protection with watershed management.
- Utilizing low impact development methods[2] to improved groundwater recharge, reduced stormwater volume, and protection and enhancement of instream habitat
- Integrating land use planning with water management and ecosystem protection
- Coordinating water supply infrastructure and planning among water agencies within a region
- Affecting inter-basin water transfer and delivery decisions, and/or
- Linking regional water availability with future land use development
- Balancing viewpoints of diverse societal interests into decisions about water resource allocation.

A well-developed watershed assessment has a number of important uses for water management (Washington Department of Energy, 1998):

- Identifying the water supply and demands within the watershed,
- Analyzing the relationship between surface water and ground water,
- Analyzing the connection between water quality and water quantity,
- Integrating short-term and long-range water planning,
- Addressing and integrating water quantity, quality, and habitat needs,
- Providing part of the information that is crucial to making water-right decisions.
- Providing information the facilitates decisions that protect and enhance the aquatic ecosystem.

The following section reviews some of the key components of an integrated water management plan and identifies how information generated in a watershed assessment is useful for decision-making around each of these issues.

### 8.5.1. Water Supply

A key part of a water management plan is identifying and planning for water supply. Interestingly, the first watershed assessments in California were conducted to evaluate potential for water resources development. Thorough field studies were conducted early in the 20th century to evaluate whether different watersheds had the capability to serve as a reliable water source for San Francisco (Freeman, 1912) and Sacramento (Hyde, et al., 1916). These studies included detailed descriptions of watershed conditions.

However, in the 21st century, a primary use for information from watershed assessments related to water supply projects will be in identifying alternatives for operation of existing or proposed projects. Such information can be used to identify

[2] Low impact development methods utilize swales, rain gardens, pervious pavement, landscaped bioretention structures, and other integrated management practices to reduce imperviousness and the production of stormwater.

opportunities for alternative management of facilities to serve new uses not recognized during initial project design and construction. A recent example is the July 2000 settlement agreement on the operation of Pacific Gas and Electric Company's hydropower facilities on the Mokelumne River. Detailed evaluations of natural hydrology and system operation contributed to the settlement agreement and relicensing of the project (McGurk and Paulson, 2000). About 30 hydroelectric projects in California will go through the relicensing process during this decade. Proposals for "re-operation" of these and other water projects will require much of the basic hydrologic and operational hydraulic information that might be contained in a watershed assessment. However, the data and analysis needs related to these projects and proposals for different management will usually be far more detailed than in a typical watershed assessment.

Watershed assessment data useful for water supply management

- Surface and ground water - present and available in the watershed
- Surface and ground water - use, by type (agriculture, municipal, etc.)
- Water rights summary, by source (ground, surface)
- Water storage, by source (natural, artificial)
- Streamflow (max /min / mean acre-feet per year)
- Land use summary, by Type & % cover
- Vegetation cover, by Type & % cover
- Impervious surface area, % cover

Water information developed in a watershed assessment can also help local land use agencies in their decision-making. Connecting water supply availability to land use planning was required in recent state legislation (e.g., SB 610 and SB 221 in 2001). While focused on large development approvals, the new laws demand an assessment of the water supply situation. In Washington State, the legislature wanted water rights decisions to be influenced by a good watershed assessment and plan.

#### 8.5.1.1 Drinking Water Source Assessment and Protection Program (DWSAP)

Watershed assessment can provide useful information for drinking water source protection efforts. Protecting sources of drinking water is the purpose of the federal and state Drinking Water Source Assessment and Protection Program (DWSAP). The initial part of this effort is the Source Water Assessment Program (SWAP), which is where watershed assessments become directly relevant. Each of California's 15,000 active public water systems must delineate the boundaries of the area around their drinking water source(s) through which contaminants might move and reach that drinking water supply. They next must inventory "possible contaminating activities" (PCAs) that might lead to the release of microbiological or chemical contaminants within that delineated area. This inventory allows for a determination of the water source's vulnerability to contamination. After the assessment and vulnerability analysis are completed, the water source protection approaches, including protection zones, are identified. Local protection programs are enacted voluntarily, while the assessments are mandatory.

For surface water sources, the watershed boundaries above the point of diversion for drinking water use delineate the logical assessment area. Previously, a "watershed sanitary survey" of the drinking water source(s) was required at least every five years, but the vulnerability ranking was not a component. For ground water sources, the source areas and protection zones are delineated based on "readily available hydrogeologic information on ground water flow, recharge and discharge, and other information deemed appropriate by the State" (California Department of Health

Services, 1999). This ground water portion of the DWSAP also serves as the State's wellhead protection program.

#### 8.5.1.2 Groundwater Management Planning

Your watershed assessment may also be able to contribute to a groundwater management plan that is independent or part of an integrated water management plan, by improving an existing one or helping to create a new one. A California groundwater law, Assembly Bill 3030 (Water Code section 10750-10756), provides a systematic procedure for an existing local agency to develop a groundwater management plan. This section of the code provides such an agency with the powers of a water replenishment district to raise revenue to pay for facilities to manage the basin (extraction, recharge, conveyance, quality). About 150 water agencies have developed groundwater management plans in accordance with AB 3030, which then allows them to qualify for certain state grants and loans for groundwater management (posted at: http://www.groundwater.water.ca.gov). Public water systems that have performed evaluations under AB 3030 requirements may satisfy all or part of the DWSAP (see 8.4.1.3).

In developing groundwater management plans, one important consideration is the effects of these plans on the conditions in the waterway. For example, depletion of the groundwater could cause perennial streams to become ephemeral. Springs that historically have fed a river might no longer do so if groundwater supplies are over-utilized. Information from your watershed assessment might lend insight into the potential impacts of groundwater management plans on the aquatic ecosystem.

#### 8.5.1.3 Water Quality Considerations

Watershed assessments can be very useful in management of water quality by providing basic information about the various factors that affect the constituents of water. A comprehensive watershed assessment should include information about:

- the climate and hydrology of the watershed that will determine the water availability during different seasons and at different places in the watershed and the consequent capacity for dilution of introduced materials;
- the geochemistry of parent material and soils that will determine natural contributions of dissolved constituents;
- soil properties, terrain features, vegetative cover, land use, and climatic factors that control potential for sediment production;
- hydraulic and geomorphic properties of channels that influence sediment transport;
- riparian vegetation properties that influence energy input to streams and consequent water temperature;
- known and suspected sources of pollution (both point and non-point); past measurements of water quality parameters; and
- changes in watershed conditions over time.

These types of information will provide the general context of water quality and allow identification of problems that should be addressed. While some polluters will voluntarily reduce their sources of contamination once these problems are brought to their attention through the information of the watershed assessment, some form of regulation is often necessary. A detailed watershed assessment may incorporate modeling results from models such as the EPA's Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) and Stormwater Management Model (SWMM). Such models can aid in identifying sources and factors subject to control and estimate the effectiveness of various controls and practices on downstream water quality.

Considerations of water quality issues is an essential part of any integrated water management plan. Data and analysis from a watershed assessment can make significant contributions to the understanding of water quality conditions and the stressors in the watershed that pose a risk to maintaining high water quality and meeting the beneficial uses of the waterways.

## 8.6 Floodplain Management

Another aspect of integrated water management is floodplain management. Planners need to consider how the management of water produced by large rain events fits into the overall water management plans. City and County general plans must evaluate flood hazards and develop strategies for floodplain management, as noted in the **OPR General Plan Guidelines**:

> "Cities and counties should identify risks from natural hazards which extend across jurisdictional boundaries, then use any available data from **watershed-based** floodplain management…as planning tools to address any significant issues. Each local planning agency carries a responsibility to coordinate its general plan with regional planning efforts as much as possible. " (p. 77)

The safety element must also identify flood hazard areas and establish policies which will avoid unreasonable flood risks. A comprehensive approach should include mapping floodplains, establishing general policies to keep intensive new development out of floodplains or to mitigate and protect against flood impacts if development is to be located in such areas, minimizing impacts on existing development where possible, establishing policies regarding capital improvements or acquisitions necessary to ensure flood protection, and floodplain management policies (which may include both structural and non-structural approaches to flood control using a **multi-objective watershed approach**). Flooding is often a regional problem that crosses multiple jurisdictional boundaries. Policies should be developed cooperatively with local, state, and federal agencies, including special districts, to create feasible solutions, Guidelines for the preparation of an optional floodplain management element are provided in Appendix C. http://www.fpm.water.ca.gov/generalplan.html. The Department of Water Resources' Division of Flood Management can provide floodplain management and flood control information, including floodplain maps, where available.

In addition, the state Cobey-Alquist Floodplain Management Act encourages local governments to plan, adopt, and enforce floodplain management regulations through an ordinance or other means(Water Code §8400, et seq.). Where a federal flood control project report has been issued which designates floodway boundaries, the Department of Water Resources or the State Reclamation Board will not appropriate money in support of the project unless the applicable agency has enacted floodplain regulations. Those regulations must provide that: (1) Construction of structures in the floodway which may endanger life or significantly reduce its carrying capacity shall be prohibited; (2) Development will be allowed within the "restrictive zone" between the floodway and the limits of the floodplain as long as human life and the carrying capacity of the floodplain are protected.

As a result of the above, local government and special districts can be both a contributor to and user of your watershed assessment where it addresses flooding and floodplains.

### 8.6.1 Floodplain Processes and Ecology

In our channel-centric view of rivers, the floodplain is often a neglected component of the fluvial system. This view has been prevalent historically in developed areas of California, where attempts to convey flood flows within existing channels are common. There are several problems with this approach:

1) Prior to development, natural alluvial channels evolved to accommodate the dominant discharge, or bank full flow (flows with a range of recurrence intervals of about 1 to 5 years) while higher magnitude floods inundated the adjacent floodplain riparian zone on average every few years. The current assumption that the channel itself, without its floodplain, can convey a full range of flood flows is unrealistic, and has led to considerable flood hazards. Moreover, the hazard worsens incrementally with increases in watershed development that reduce infiltration and increase runoff and peak discharges

2) Floodplain development has led to a situation where there is often no riparian buffer between the top of the channel bank and the adjacent development. In this case, attempts are made to prevent the natural processes of bank erosion and channel migration, processes integral to the storage and transfer of sediment within a fluvial system, as well as to vegetation succession. Levees and bank protection are employed to prevent geomorphic processes acting between channels and their floodplains, thus creating static river morphology. Such attempts to arrest erosion, and in some cases sediment deposition, has led to extensive channelization efforts throughout California

3) Relatively short hydrologic records are used in statistical methods to predict future flood magnitudes and recurrence intervals. However, high magnitude floods change the flood statistics, and lower the recurrence interval associated with specific magnitude floods—otherwise stated, the occurrence of a high magnitude flood may increase the discharge of the design flood, such as the 100-year event commonly used for floodplain management.

Floodplain riparian ecosystems are sustained by the very disturbances that our past floodplain management efforts often try to eliminate: flooding and erosion. In California, as in most of the developed world, over 90% of riparian ecosystems have been lost. Agricultural and urban development often extends all the way to the top of the channel bank, leaving only a single line of trees. In creeks where cattle or other livestock graze, vegetation may be completely absent. In order to minimize flood and erosion hazards, and to sustain or restore floodplain ecosystems, floodplain management should:

- Accommodate physical processes, or the “natural disturbances” that create and maintain processes and functions of floodplain ecosystems (flooding, channel migration, avulsion, overbank flow, sediment erosion and deposition);
- Expect and accommodate change in the relation between the river channel and floodplain boundary (e.g. erosion, deposition, and migration);
- Preserve longitudinal and lateral connectivity between the channel and floodplain (e.g. dam releases to maintain geomorphic processes, vegetation succession, overbank flow, and fish use of floodplain areas);
- Preserve flood storage function of floodplain;
- Preserve floodplain riparian zone as a buffer between developed areas and the fluvial system.

### 8.6.2 A watershed approach to floodplain management

A watershed approach to reduce flood hazards must consider cumulative effects of past and proposed floodplain changes. The most successful approach to minimize flood hazards it to minimize floodplain development, and to instead preserve the natural flood storage capacity of the floodplain. Flood hazard reduction and floodplain management is encouraged by many, including the California Department of Water Resources (DWR; http://www.fpm.water.ca.gov) and the professional, non-profit educational organization, the Floodplain Management Association (FMA; http://www.floodplain.org). Flooding often crosses multiple jurisdictional boundaries for ownerships and responsibilities: county, city, special district (water, flood control, community services, etc.), state, federal, and tribal.

A watershed assessment that evaluates upslope-downstream hydrologic effects and causes of alterations can provide a very useful tool for floodplain management. Downstream communities will likely have more interest in a watershed assessment addressing flooding and floodplain issues than upstream ones, often driven by recent or continuous experience with damaging floods. Urbanizing areas tend to discover that previous "flood control" channels and reservoirs, as well as road culverts, are not sized to withstand the flood peaks ("peak discharge") estimated when the watershed was more rural, with less paved and covered (impervious) surfaces.

Some examples of downstream California communities (and their watershed) actively working with partnerships on watershed assessments and plans with floodplain management and flood protection as a major focus include:

- City of Newport Beach – San Diego Creek watershed
- City of Santa Cruz – San Lorenzo Creek watershed
- City of Napa – Napa River watershed
- Marine Corps Base Camp Pendleton – Santa Margarita River watershed
- City of San Jose / Santa Clara County – Guadalupe River watershed [http://www.scbwmi.org]
- City of East Palo Alto – San Francisquito Creek watershed

## 8.7 Regulation

Regulations influence water quality, land uses, resources extraction (e.g., timber) and integrated planning. Federal, state and local regulations define the environment in which all of the issues are considered. There are many state and local regulatory processes where watershed assessment and management are either required or are useful tools to achieve regulatory goals.

### 8.7.1. Water Quality Regulation

The federal Clean Water Act and the state Porter-Cologne Act are the two primarily water quality statutes (see box below). These acts prescribe that permits be issued to regulate the release of contaminants into waterways and that reports are prepared to evaluate the conditions and status of waterways, among other requirements. Before discussing how information from your watershed assessment might be useful in this regulatory context, the following section reviews basic background information

#### 8.7.1.1. Major categories of water pollution

Water pollution is grouped into two major categories – point source and nonpoint source (NPS). Point source pollution is defined as anything that is regulated by the National Pollution Discharge Elimination System (NPDES) and generally comes out of the end of a pipe. This includes most urban stormwater run-off, which, now in large part is regulated through NPDES Storm Water programs. Although urban runoff is collected from a large geographical area, it is regulated by NPDES, and is generally released into a waterway via a pipe so is considered a point source. NPS

**State statutes that affect water quality**
There are two key laws that regulate water quality in California

| Name of Law | Key provisions |
|---|---|
| Clean Water Act (federal, 1972) | • Regulations to meet the goal of zero discharge of pollutants.<br>• Includes sections on water standards (303) and TMDLs (303d); assessment of water quality (305b); nonpoint source management (319); NPDES permits (402), and wetlands (404). |
| Porter-Cologne (state, 1990) | • Established the State Water Resources Control Board and 9 Regional Boards to control water rights and water quality in California.<br>• Empowers the regional boards to prepare water quality control plans (Basin Plans) to ensure that beneficial uses of water are being met and actions are taken to control point and nonpoint source pollution.<br>• Authorizes the Boards. to issue NPDES permits under the federal CWA |

pollution includes all other sources of pollution, including run off from agriculture, rural areas, most abandoned mines, and forested areas. In particular, data and analysis from a watershed assessment could provide useful information in the development of non point source pollution regulations.

In reality, almost all NPS pollution is really point source pollution because contaminants and other disruptors of watershed function originate from points on the landscape. Typically, however, the term point source pollution is applied only to focused human activities that discharge contaminants or modify physical or chemical qualities of a waterway (e.g., an industrial operation).
As a watershed assessor, you will find that there is a gray area between permit-regulated and unregulated pollution that can be associated with a type of land-use. For example, agricultural operations in the Central Valley have been given a conditional waiver by the state for the pollutants originating from agricultural lands in the Valley. In exchange, the growers monitor water quality at the sub-basin level and employ “best management practices” to reduce pollutant runoff to waterways. A watershed assessment can still be very useful in this setting as one aspect of the conditional waiver is to understand watershed conditions for a given planning area.

#### 8.7.1.2 Point Source Pollution Regulation

Point sources may have a wide-range of potential impacts, from minor to being drivers of waterway function. Stormwater permits are given to local municipalities for point source discharges under the National Pollutant Discharge Elimination System (NPDES) and are called NPDES permits. These permits contain a list of criteria that cities and counties must comply with regarding stormwater effluent. Large cities fall under the Phase I permits and are required to monitor waterways. Monitoring data collected in the course of preparing a watershed assessment could be very valuable for those involved in overseeing compliance with the permits (e.g., Regional Water Quality Control Boards). Within the Public Works or Utilities departments of each Phase I city, a “Stormwater Quality” division oversees monitoring of selected waterways for a variety of conventional and toxic water quality constituents to comply with their permit. Data from a watershed assessment could aid the effort to prioritize pollutant monitoring. This prioritization process involves identifying key locations for monitoring and key constituents that are most toxic and most prevalent. Data generated as part of an assessment could identify stream reaches where particular pollutants were problematic. Additionally, the assessment will contain an analysis of the impacts of contaminants, sediment, and total water volume on habitat conditions. These impacts need to be evaluated during the permitting process and would be useful to the staff at the Regional Boards.

Watershed assessments should at least include the location of point sources and estimated discharge of pollutants, or other effects on watershed function. These points sources may have a wide range of potential impacts, from minor to being drivers of waterway function. Assessment of watershed function can also inform future permitting of point source discharge. If waterways within a watershed are already impacted by point or non-point sources of pollution, the future permitted discharges would be inadvisable.

There are various ways that you can deal with point source information:

1) Point source dischargers and the state regulatory agency must monitor the pollution originating from the permitted facility and also the potential impacts of the pollution. This information is an important local source of information for the water quality part of your assessment.

2) Information about single point sources, or a combination of point and non-point sources of pollution can be combined to give an assessment of existing impacts. This combined impact should be assessed for ecosystem and other impacts and the information presented and summarized in a way that is useful for future permits.

3) Types of pollution that are covered by permits include those listed in Chapter 3.6 (e.g., organic compounds, metals, high temperature). Contaminants may have their effects in isolation from each other, but often they have their negative impacts in concert. This is where watershed assessment, which is by definition integrative, can have a valuable role in decision-making. For example, future land-use decisions could impact the volume and composition of municipal waste discharge, the timing and volume of managed storm-water runoff, and suppress natural processes. When existing conditions and impacts are compounded with future possible scenarios, then the combined impacts can be assessed.

4) Ultimately, the regulatory agency, the State Water Resources Control Board, must accept the finding of a negative impact to deny a pollution discharge permit, or accept a finding of no net impact to allow a permit. There is not always a clear role for watershed groups in this process, though local agencies may be able to bring forward watershed assessment information to the decision-making process.

#### 8.7.1.3 Non-Point Source Pollution Regulation

The problem of non-point source pollution has contributed to the widespread application of watershed assessment and management. Widely distributed and occasional appearance of water pollution across a watershed is a product of the combination of the natural environment and human actions. It is possible in some cases to attribute responsibility for NPS pollution to individual actions, land uses, or parcels.

Non-point source pollution enters waterways at non-specific places as a consequence of the movement of water across the landscape. When the beneficial uses of the waterbodies are impaired as a consequence of this pollution, total maximum daily loads (TMDLs) can be established to reduce the contaminant(s). TMDLs have been established in waterways for pesticides, nutrients, sediment, and other types of contaminants.

The TMDL process is a framework of assessing a watershed, but with a water quality emphasis. Each TMDL has five general objectives, quite similar to the watershed assessment process described in this Manual:

1. To assess the condition of a waterbody, and determine/confirm cause(s) / source(s) of pollutant;
2. To quantify the sources of the pollutant;
3. To determine how much of a particular pollutant a waterbody can handle and still meet desired conditions;
4. To identify whether and how much the different sources need to be reduced in order to support desired conditions;
5. To develop a plan which, when implemented, will restore waterbody health.

TMDLs are determined by state agencies for pollutants impacting specific waterways. For example, in the Newport Bay watershed (Southern California), San Diego Creek has a TMDL established by the US-EPA for organic and inorganic pollutants originating from residential, commercial, industrial, and agricultural lands (see box below). The Garcia River has a TMDL for sediment (posted at: http://www.krisweb.com/biblio/garcia_usepa_regix_1998_finaltmdl.pdf).

TMDLs can consider and allocate loads (amounts) for contaminants originating from both non-point and point sources. Natural loads are calculated and are often considered the background for a particular substance (e.g., sediment or nutrients). TMDL reports describe the data analysis and modeling used to determine likely or actual sources of pollutants and eventually "waste load allocations", or the amount of pollution each polluter or area may contribute to the waterway.

There are no fixed protocols for the determination and allocations of pollutant loads under individual TMDLs. Like watershed assessments, they are tailored to the watershed and the sources of pollution. The San Diego Creek TMDL used the proportion of sub-watersheds in different land use categories and measurements or estimates of loads originating from land-use types to determine loads for each pollutant in each sub-watershed.

Watershed assessment approaches are more general than TMDL calculations and might provide more detail about natural processes and human activities in the same sub-watersheds. This additional detail would help the TMDL process and potentially inform the implementation of the waste load allocation and reduction.

1) TMDLs being carried out in watersheds with assessments or similar analyses should explicitly take into account the watershed characteristics and processes described in the assessment.

*A TMDL identifies the maximum amount of a pollutant that may be discharged to a water body without causing exceedences of water quality standards and impairment of the uses made of these waters. The federal Clean Water Act requires development of TMDLs for polluted waters to assist in identifying pollutant control needs and opportunities.*
(Total Maximum Daily Loads For Toxic Pollutants San Diego Creek and Newport Bay, California; US-EPA, Region 9, 2002)
http://www.epa.gov/region09/water/tmdl/nbay/summary0602.pdf

2) Watershed assessments should describe historic, present, and likely future conditions, which is all useful information for determining a TMDL.

3) Watershed management plans based on watershed assessments in TMDL watersheds should take into account the source calculations and waste load allocations in the TMDL when describing management recommendations.

### 8.7.2 Timber Harvest Plans

Developing and implementation of timber harvest plans (THPs) are required by the Board of Forestry under the California Forest Practices Act. It is the intention of the state that these THPs not result in non-point source pollution to the state's waterways. Watershed assessment can provide several types of information for THP development:

1) The physical and biological setting for THP activities should be described at several watershed scales. For example, the impacts of logging and grading under a THP will be most apparent at the smallest sub-watershed scale. It is most valuable to collect data at this fine scale on many watershed processes in order to provide an appropriate description of the natural environment. However, some impacts of the project may work their way downstream into the stream and river system meaning that processes should be measured there as well.

2) Different geographic scales will be appropriate for different potential impacts (Ziemer, 2000). For example, road crossings may change stream channel properties for only a few hundred meters up and down stream of the crossing. In contrast, skid trails and road cuts may contribute excess sediment, nutrients, and surface water to downstream channels for many miles.

3) Cumulative effects of past, proposed, and future activities are also best measured at several scales, from the sub-watershed to watershed. Smaller watersheds may respond more quickly and to fewer actions than larger watersheds as well as in different ways.

4) Effects of the proposed actions and cumulative effects should be analyzed over appropriate time scales for the processes in question. For example, if the logging will impact shade on upland slopes, what will the change in subsurface water temperature be and how will that change affect the immediate stream reach? At another scale: how will the combined actions change natural disturbance processes and population dynamics on the landscape and in the waterways of the larger watershed over decades?

### 8.7.3 Federal and State Endangered Species Acts

Both the Federal and California Endangered Species Acts (FESA and CESA, respectively) require that federal and/or state agencies consider and regulate the impacts of land and water use actions on imperiled plant and wildlife species and their habitats. For certain species, e.g., salmon, these impacts are often considered at the watershed scale in order to include landscape impacts on waterways. Many watershed assessments have been done because of the presence in the watershed of endangered or threatened species.

Watershed assessments can be used to inform decisions for managing impacts to endangered species in the following ways:

1) Identify potential and actual impacts to endangered species that may originate from single or multiple sources that are best measured at the watershed scale.
2) Identify the spatial and temporal scales at which potential and actual impacts should be measured within the watershed.

3) Use the conceptual model approach from the assessment planning stage (see chapters 2 and 6) to identify human and other actions and processes that influence the well-being of endangered species.
4) Give relative weights to the human and natural influences on endangered species habitats and populations. Use these relative weights to prioritize the influences for remedial action.
5) Describe protection or restoration strategies that could be implemented at the watershed scale for the benefit of endangered species or their habitats.
6) Identify data and knowledge gaps specific to the species and their habitats that are needed prior to making decisions that are based on knowledge of ecosystem and population dynamics.

### 8.8 Voluntary Private Lands Management

In general, most landowners have intimate knowledge of their property, so it is unlikely that a watershed assessment will tell them much that they don't already know about general condition. Scientific aspects of the assessment may be more revealing to them. Perhaps the principal benefit of a watershed assessment to a private landowner is setting the context of their property within the entire watershed. For some people, this perspective will be of interest and benefit and may lead to alterations in management practices. For others, a watershed perspective and associated information will not affect their established way of doing business. A watershed assessment may contain substantial resources such as aerial photographs, satellite imagery, and GIS layers of their land and adjoining properties that an individual may not have ready access to. These types of information may be of value to some owners in their planning and decision making.

Some landowners have partnered with neighbors to restore a waterway. One example is Murphy's Creek in San Joaquin County, where landowners obtained a CALFED grant to remove a non-functioning earthen dam which had prevented migration of anadramous fish. Landowners such as this group could benefit from the data and analysis contained in a watershed assessment.

Regional information on geology, climate, soil productivity, erosion risk, land capability, and vegetation may be useful for operations of some farmers and ranchers or for planning construction and other development. These general types of information would be necessary for environmental analysis of development proposals. Watershed information could also be useful in complying with regulations and as background in applications for grants from state and federal agencies for soil conservation and habitat restoration projects.

Watershed assessments should be helpful to owners of forest-land in scheduling of logging, road construction, and road maintenance to minimize impacts on streams. Information from watershed assessments should also assist in complying with California's Forest Practice Rules and preparing Timber Harvest Plans, Sustained Yield Plans, or Non-industrial Timber Management Plans. Watershed assessments probably have the greatest direct applicability to evaluating cumulative watershed effects as required for Timber Harvest Plans. If the Board of Forestry adopts the recommendations of the University of California Committee on Cumulative Watershed Effects (Dunne, et al. 2001), then watershed assessments could become an integral part of planning for forest operations.

### 8.9 Monitoring Programs

Monitoring is an important part of adaptive management and the implementation of watershed plans, restoration programs, regulation, and land and water use decisions. Monitoring is closely tied to watershed assessment. The results of monitoring should be useful to assessment and assessment in turn should be used to design and implement monitoring programs.

Two important ways that watershed assessment can inform monitoring program design and implementation are: 1) by exposing gaps in knowledge and data about watershed conditions and 2) by showing geographically areas that are at risk or have actual impacts from human activities.

**Knowledge and Data Gaps**

Part of your watershed assessment should involve identifying gaps in information about systems in your watershed and deficiencies in knowledge about how the systems work (see chapter 2.5.2). These gaps should be separated into these two major categories, data and knowledge, and a monitoring and research program recommended to address deficiencies. Obviously implementation of the program will depend on factors beyond the control of the assessment project. In addition, not all data and knowledge gaps can be readily filled, even by the most advanced watershed groups. However, it will help your own, or someone else's, future understanding of the watershed if you go through this exercise.

*Data gaps*

Monitoring is conducted to find out how a system works or is changing over time. The term is typically applied to water quality monitoring programs, but you could just as easily use it to refer to wildlife or ground water monitoring. There are a wide variety of things you could conceivably monitor in response to findings in your watershed assessment. Here are some things to keep in mind:

1) The spatial scale and resolution of your monitoring program (e.g., location and distribution of monitoring sites) should be determined by the nature of your monitoring/assessment question or the information gap. For example, if there are particular land-uses of concern distributed throughout your watershed (e.g., roads), then you should monitor enough of them closely to statistically determine whether or not an impact is occurring, as well as the extent of the impact throughout sub-watersheds.

2) The temporal scale and resolution of your program is as important as the spatial resolution. If your data gaps are related to storm event impacts (e.g., large movements of sediment or contaminants), then monitoring should occur intensively during and after storms and for several storms. Between storms, you would want to determine non-storm related impacts in order to provide a "baseline" against which to compare storm impacts. Frequency of sampling is a critical issue here as it both determines whether or not you can tell something about individual events, changes during a water-year, and/or trends over decades.

*Knowledge gaps*

Data gaps are different from knowledge gaps. Knowledge gaps refer to things you don't know about a system or thing you are interested in. To address gaps in your knowledge about how your watershed is working, changing over time, or responding to stress from human activities, you may need to implement monitoring that is basically research. An example of a knowledge gap is the contribution of nutrients to waterways from different land use and cover types. Addressing this knowledge gap would demand collecting data about nutrients upstream, adjacent to, downstream, and in sub-surface water for each land use or cover type of interest. The data would need to be collected over a reasonable time and space resolution and for long enough to establish any trends. Along the way you might fill data gaps (e.g., nutrient concentration in a certain waterway), but the knowledge gap filling occurs when you find statistically-significant relationships between land-uses and nutrient conditions under a range of climate and other conditions. This obviously requires specialized analytical skills that you may or may not find in your current assessment team or watershed group.

Here are some things to keep in mind when designing programs to address knowledge gaps:

1) Differentiate between data gaps and knowledge gaps. Data gaps require the collection of information about a system about which you already have some knowledge. Knowledge gaps occur where you may or may not have data, you just aren't sure how processes and things are interacting with each other, or occurring over space and time.

2) Approach knowledge gaps in the same way you went after conceptual modeling (Chapter 2). Think of how a system might work based on your knowledge of how similar systems work. Draw or describe a conceptual model of the system including where the gaps occur. Pencil in possible ways that things might work and use this exercise to come up with targeted questions for future monitoring or research.

**Using the Assessment in Decision-Making Checklist**

*Consider the following potential uses for your assessment:*

- ❑ Watershed planning
- ❑ Restoration Projects
- ❑ Integrated Water Management Projects
  - Water Supply Projects
  - Drinking Water Protection Efforts
  - Groundwater Management Planning
  - Water Quality Protection
  - Floodplain Management
- ❑ Regulations relating to:
  - Water quality
  - Timber harvesting
  - Federal and state endangered species
  - Local land-use planning
- ❑ Voluntary Private Lands Management

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