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 could 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 research tools. 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

Table 6.1 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?

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 Table 6.1 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.

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.

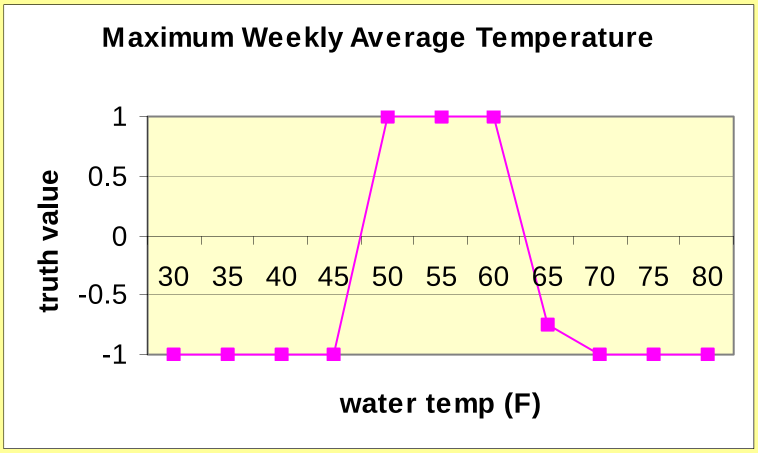

Figure 6.1 Probable temperature impact on salmon

In Figure 6.1, 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

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.

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 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

A list 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

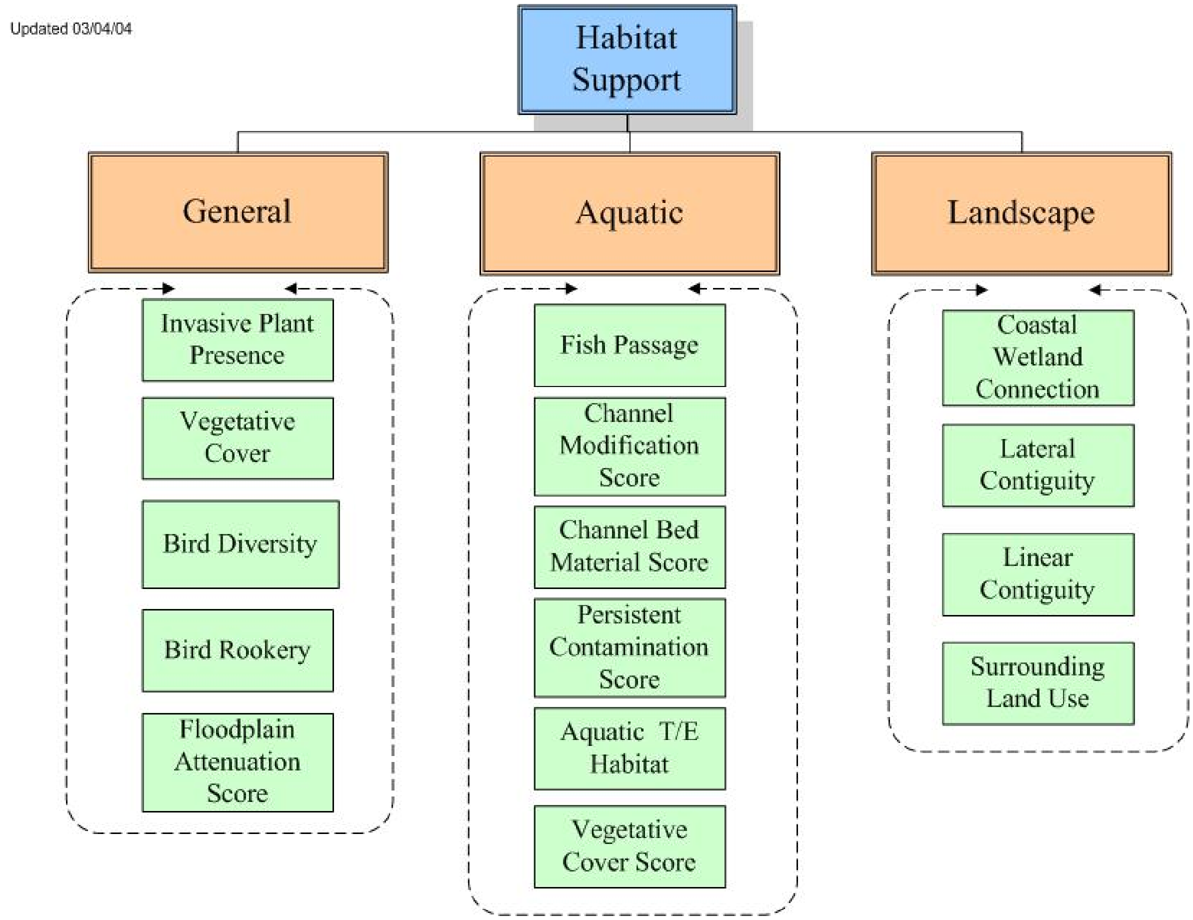

Figure 6.2 The 15 factors associated within the "habitat support" module of the SCREAM model

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.

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 be varied at a time. In some ways, this is similar to sensitivity analysis (see above).

6.6 References

Berg, N.H. K.B. Roby and B.J. McGurk. 1996. Cumulative watershed effects: Applicability of available methodologies to the Sierra Nevada. Sierra Nevada Ecosystem Project: Final Report to Congress, Vol. III, Assessments, Commissioned Reports, and Background Information. pp. 39-78. Davis: University of California, Centers for Water and Wildland Resources.

Bunte, K. and L.H. MacDonald. 1996. Scale considerations and the detectability of sedimentary cumulative watershed effects. Report to the U.S. Forest Service and National Council for Air and Stream

Improvement of the Paper Industry. Fort Collins: Colorado State University.

Coats, R.N. and T.O. Miller. 1981. Cumulative silvicultural impacts on watersheds: A hydrologic and regulatory dilemma. Environmental Management 5(2): 147-160.

Dunne, T., J. Agee, S. Beissinger, W. Dietrich, D. Gray, M. Power, V. Resh, and K. Rodrigues. 2001. A scientific basis for the prediction of cumulative watershed effects. Report 46. Berkeley: University of California, Wildland Resources Center.

Gilbert, G.K. 1917. Hydraulic mining debris in the Sierra Nevada. Professional Paper 105. Washington, DC: U.S. Geological Survey.

Girvetz, E.H. and F.M. Shilling. 2003 Decision support for road system analysis and modification on the Tahoe National Forest. Environmental Management. 32(2): 218-233.

Harr, R.D. 1989. Cumulative effects of timber harvest on streamflows. Unpublished paper presented at the technical session on cumulative effects of forest practices at the National Convention of the Society of American Foresters in Spokane, WA.

Harwell, M.A. and J.H. Gentile. 2000. Environmental Decision-making for Multiple Stressors: Framework, Tools, Case Studies, and Prospects. In: Multiple Stressors in Ecological Risk and Impact Assessment: Approaches to Risk Estimation. S.A. Ference & J.A. Foran, eds., SETAC Press, Pensacola, FL, pp. 169 - 236.

Landis, W.G. and M-H. Yu. 2003. Ecological Risk Assessment. In: Introduction to Environmental Toxicology, Lewis Publ., Boca Raton, pp. 359-400.

MacDonald, L.H. 2000. Evaluating and managing cumulative effects: Process and constraints. Environmental Management 26(3): 299-315.

Menning, K. M., D.C. Erman, K.N. Johnson, and J. Sessions. 1996.Modeling aquatic and riparian systems, assessing cumulative watershed effects, and limiting watershed disturbance. Sierra Nevada Ecosystem Project: Final Report to Congress, Addendum. Pp. 33-51. Davis: University of California, Centers for Water and Wildland Resources.

McGurk, B.J. and D.R. Fong. 1995. Equivalent roaded area as a measure of cumulative effect of logging. Environmental Management 19(4): 609-621.

Michael, G.Y. 1991. Environmental data bases: design, implementation, and maintenance. Lewis Publishers, Chelsea MI. 98 pp.

NCWAP methods manual (http://www.ncwatershed.ca.gov/pdf/Draft_NCWAP_Manual.pdf)

Reid, L.M. 1993. Research and cumulative watershed effects. General Technical Report PSW-141. U.S. Forest Service, Berkeley, CA.

Reynolds, K., Cunningham, P., Bednar, L. (and others). 1996. A design framework for a knowledge-based information management system for watershed analysis in the Pacific Northwest U.S. AI Applications. 10: 9-22.

Reynolds, K. 1999. Netweaver for EMDS user guide (version 1.1); a knowledge base development system. Gen. tech. Rep. PNW-GTR-471. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Shenk, T.M. and A.B. Franklin. 2001. Modeling in natural resource management: development, interpretation, and application. Island Press, Wash. D.C. 223 p.

US EPA, 1998, Guidelines for Ecological Risk Assessment, EPA/630/R0-95/002F, Washington, DC

Wiegers, J.K., H.M. Feder, L.S. Mortense, D.G. Shaw, V.J. Wilson, & W.J. Landis. 1998. A regional multiple-stressor rank-based ecological risk assessment for the fjord of Port Valdez, Alaska. Human Ecological Risk Assessment 4: 1125-1173.

Information Integration Checklist

- ❑ Select a method for data synthesis and integration
  - o Team mental integration
  - o EMDS
  - o RRM
  - o SCREAM
  - o Other appropriate model
- ❑ If appropriate, use sensitivity analysis to evaluate the model