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

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	

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.

<u>Information on Non-priority Pollutants</u>

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

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.

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.

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.

5.2.3 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, you can use criteria that 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 only be used as estimates 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 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

> "*Statistics should be regarded as a tool, an aid to understanding, but never a replacement for useful thought*." (Haan, 1977)

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.

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

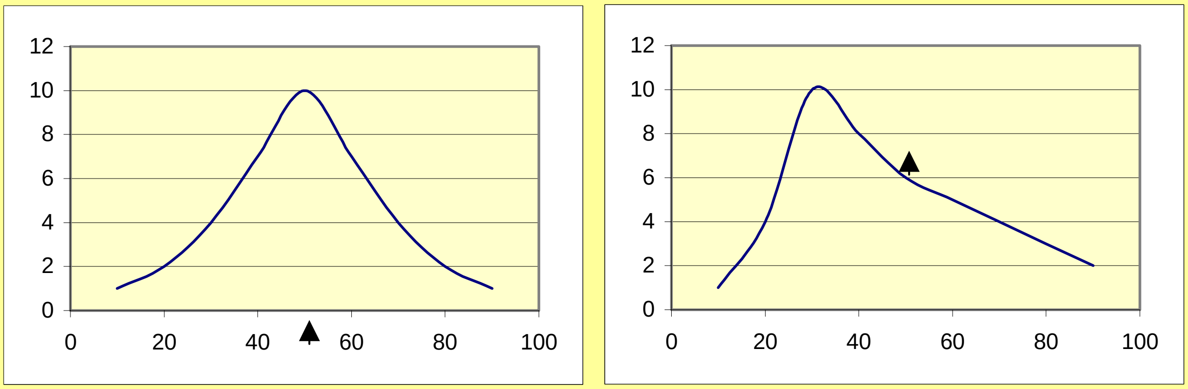

Figure 5.1 Example of a normal (left figure) and non-normal (right figure) distribution of any data. Arrows represent the mean for each set of data

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 possesses 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 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 (Figure 5.1). 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 mean 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 (Figure 5.2) 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

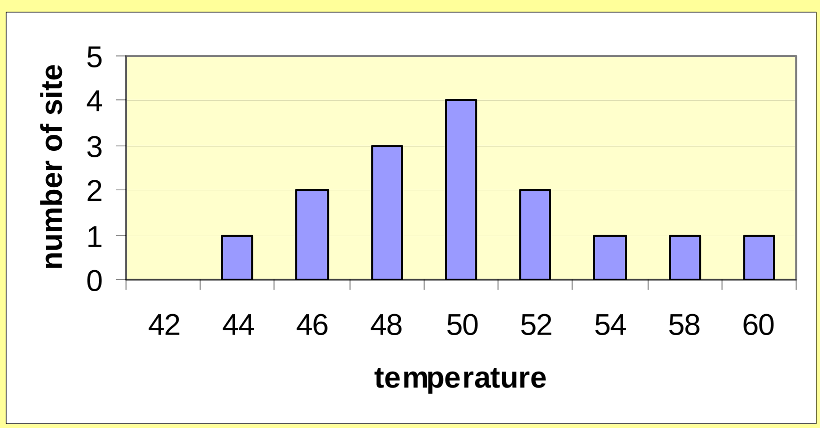

Figure 5.2 A frequency distribution plot

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, appear 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 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** (Table 5.1). In this test, you compare one 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 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

Table 5.1 Student t-test example

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	

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

Table 5.2 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 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.

Table 5.2 Spatial Scale Calculations

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

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) Based on the questions you have for your watershed assessment, decide the appropriate timeframes for the underlying

[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.

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.

Figure 5.3 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.

Figure 5.4 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

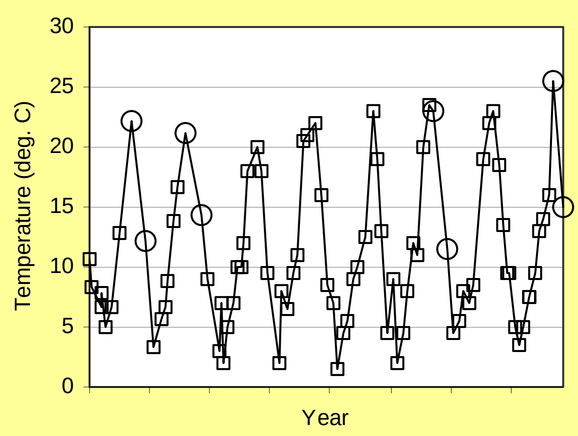

Figure 5.3 Cyclic changes in water temperature over time

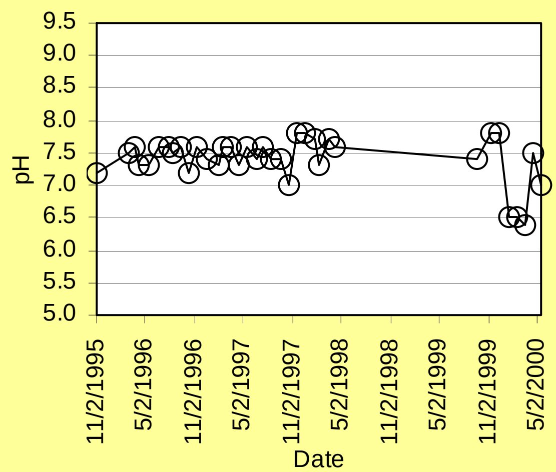

Figure 5.4 Changes in pH over time

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 Volume II 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 2005. 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 these criteria, often depending on region (coastal, inland, Sierra), stream order (1st to 5th 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 2nd 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 2nd 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.

Basic

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.

<u>Intermediate</u>

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.

<u>Advanced</u>

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.

5.7 References

Bedient, P.B. and C. W. Huber. 2002. Hydrology and floodplain analysis. Prentice Hall. 763 p.

Clement, P. and H. Piegay. 2003. Statistics and fluvial geomorphology. In: Tools in Fluvial Geomorphology, (G.M. Kondolf and H. Piegay, eds). John Wiley & Sons. pp. 596-630.

Conrad, M. and J. Dvorsky. 2003. Aptos Creek Watershed Assessment and Enhancement Plan. Coastal Watershed Council and Swanson Hydrology & Geomorphology. Santa Cruz CA. 82 p.

Dates, G. 1999. Moving from data to information. River Voices 10 (3&4):26-29. (http://www.rivernetwork.org)

Dawes, R.M. 1988. Rational Choice in an Uncertain World. Harcourt Brace Jovanovich, Inc. Orlando. 346 p.

Dunne, T. and L.B. Leopold. 1978. <u>Water in Environmental Planning</u>. W.H. Freeman, San Francisco. 818 p.

Forman, R.T.T. 2000. Estimate of the area affected ecologically by the road system in the United States. Conservation Biology. 14(1):31-35.

Georgetown Divide Resource Conservation District. 2003. South Fork American River Watershed Stewardship Project, Watershed Assessment. p. 99.

Gilbert, R.O. 1987. Statistical Methods for Environmental Pollution Monitoring. Van Nostrand Reinhold. NY. 320 p.

Gordon, N.D., T.A. McMahon, and B.L. Finlayson. 1992. Stream Hydrology: An Introduction for Ecologists. John Wiley & Sons, NY. 526 p.

Haan, C.T. 2002. Statistical methods in hydrology. Second edition. Iowa State Press, Ames. IA. 496 p.

Helsel, D.R. and L.M. Griffith. 2003. Assess and interpret data. Water Resources Impact 5(5): 25-29. (www.awra.org)

Helsel, D.R. and R.M. Hirsch. 2002. Statistical methods in water resources. U.S. Geological Survey Techniques of Water Resources Investigations, Book 4, Ch. A3. http://water.usgs.gov/pubs/twri/twri4a3/

Huff, D. 1954. How to Lie with Statistics. W.W. Norton & Co., NY. 142 p.

Journal of Time Series Analysis (JTSA). http://www.ingenta.com/journals/browse/bpl/jtsa.

Kattelmann, R. and M. Embury. 1996. Riparian areas and wetlands. In: Sierra Nevada Ecosystem Project: Final report to Congress, Vol. III, Assessments and scientific basis for management options. Centers for Water and Wildland Resources, U.C. Davis, p. 225-226.

Kerr, M. 1995. Using graphs to tell your story. Volunteer Monitor (Spring 1995).

Langendorf, R. 1995. Presentation graphics. PAS Report No. 453, American Planning Assoc., Chicago. 80 p.

Mattole Watershed Council. 1995. Dynamics of Recovery: a plan to enhance the Mattole Estuary. Petrolia, CA.

McCammon, B., J. Rector, and K. Gebhardt. 1998. A framework for analyzing the hydrologic condition of watersheds. Denver: Bureau of Land Management and USDA-Forest Service.

Michael, G.Y. 1991. Environmental Data Bases: Design, Implementation, and Maintenance. Lewis Publishers, Chelsea MI. 98 p.

National Research Council. 1986. Ecological Knowledge and Environmental Problem-Solving: Concepts and Case Studies. National Academy Press. Wash. D.C., 388 p.

National Research Council. 1999. New Strategies for America's Watersheds. Committee on Watershed Management. National Academy Press. Wash. D.C., 311 p.

North Coast Watershed Assessment Program (NCWAP). 2003. Gualala River Watershed Assessment. Gualala Assessment and Support Team, Calif. Resources Agency and CalEPA, Sacramento. 367 p. plus appendices.

Rand, G.M. and Newman, J.R. 1998. The applicabaility of habitat evaluation methodologies in ecological risk assessment. Human Ecol. Risk Assmt. 4: 905-929.

Raliegh, R.F., W.J. Miller, & P.C. Nelson, 1986. Habitat suitability index models and instream flow suitability curves: chinook salmon. USFWS Biol Report 82 (10.122) pp.64.

Schueler, T. 2000. The Importance of Impeviousness. In: The Practice of Watershed Protection (T.R. Schueler & H.K. Holland, eds.) Center for Watershed Protection, Ellicott City, MD. pp. 7-18.

Shenk, T.M. and A.B. Franklin (ed.). 2001. Modeling in Natural Resource Management: Development, Interpretation, and Application. Island Press, Washington, D.C., 223 p.

Sommarstrom, S., Kellogg, E., and J. Kellogg. 1990. Scott River basin granitic sediment study. Prepared for the Siskiyou RCD and US Fish and Wildlife Service. Etna CA. 160 p.

Tufte, E.R. 1983. The visual display of quantitative information. Graphics Press, Chelsire, CT. 197 p.

Tufte, E.R. 1990. Envisioning information. Graphics Press, Chelsire, CT. 126 p.

Tufte, E.R. 1997. Visual explanations: images and quantities, evidence and narrative. Graphics Press, Chelsire, CT. 156 p. [1-800-822-2454]

U.S. Environmental Protection Agency (EPA). Ecotox database. www.epa.gov/ecotox.

U.S. EPA. 2000. Water quality criteria for the protection of aquatic life. www.epa.gov/waterscience/criteria/aqlife.html

Walters, C. 1986. Adaptive management of renewable resources. Macmillan Publishing Co., NY. 374 p.

Washington Dept. of Natural Resources. 1997. Watershed analysis manual. Forest Practices Board. Version 4.0. Olympia WA.

Watershed Professional's Network (WPN). 1999. Oregon Watershed Assessment Manual. Prepared for the Governor's Watershed Enhancement Board. Salem, OR.

Wheater, C.P. and P.A. Cook. 2000. Using Statistics to Understand the Environment. Routledge Introductions to Environment Series, NY, 245p.

Zar, J.H. 1984. Biostatistical analysis. 2nd edition. Prentice Hall, NJ.

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