Toward a Resilient Watershed

Addressing Climate Change Planning in Watershed Assessments

The Resource Innovation Group
January 2012

Acknowledgements

We are grateful to the Oregon Watershed Enhancement Board for providing funding for our *Climate Change and Watershed* project, which was the foundation for this guidebook. www.oregon.gov/OWEB

Our thanks to Ethan Rosenthal of David Evans and Associates, Inc., for his insightful feedback and review, www.deainc.com

Thanks to our watershed intern Ben Reder for his work on this project and the indicators.

We greatly appreciate members of the watershed councils of Oregon and southern Washington for their engagement, including identification of needs and case studies. http://oregonwatersheds.org

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About TRIG

The Resource Innovation Group (TRIG) is a nonprofit organization based in Eugene, Oregon. TRIG provides innovative solutions to the challenges of sustainability, climate change and other social, economic, and ecological concerns. TRIG is engaged in partnerships with a number of academic institutions, non-profits, private companies and government agencies across the United States.

Founded in 1996 at the Portland State University Hatfield School of Government, TRIG worked through the Institute for a Sustainable Environment at the University of Oregon from 2001 through 2010. Today, TRIG is affiliated with Willamette University's Center for Sustainable Communities and is a member of the NOAA sponsored RISA (Regional Integrated Science Assessment Program) for the Pacific Northwest.

TRIG's Climate Adaptation & Preparedness Program provides a range of services including support of model adaptation planning projects, best practice research and evaluation, policy advisory services, technical assistance, and training. A key component of our work involves developing watershed basin-level climate projection analysis and recommendations for building resilience across natural, human, economic, built and cultural systems. Visit us at: www.theresourceinnovationgroup.org.

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Introduction

In the most basic sense, a **watershed assessment** is a process for understanding a watershed's current conditions and the likely causes of those conditions.[1] An assessment can include steps to identify issues, examine the history of the watershed, describe its features, and evaluate various resources within the watershed. More specifically, watershed assessments can help to identify features and processes essential for fish habitat and water quality; determine how natural processes are influencing aquatic species and systems; assess human impacts on fish habitat and water quality; and evaluate cumulative effects of land management practices over time.

Many watersheds in the eastern part of the Willamette Valley, Oregon, are snowpack dependent.

Climate change planning involves developing strategies to address mitigation (reducing greenhouse gas emissions) and adaptation (preparing for impacts by building system resilience). Planning may happen across the management strategy by integrating climate change considerations throughout programs and projects, or on a project-by-project basis.

By incorporating the suggestions put forth in this document into your watershed assessment, you will be on the road to initiate a climate planning process. This guidebook will help you to understand how future potential climate scenarios could impact your watershed and identify proactive measures that can be taken to improve the resilience of stream habitat and water quality in the face of a changing climate.

Overarching Goals of Climate Planning

1. Highlight the most critical areas of concern regarding climate change effects on the watershed.
2. Highlight the critical areas of uncertainty to inform future monitoring, data gathering, and study efforts.

1 Oregon Watershed Enhancement Board. 1999. "Oregon Watershed Assessment Manual." Developed for the Governor's Watershed Enhancement Board with Support from the Watershed Professionals Network. See: www.oregon.gov/OWEB

Good watershed management is essential for our communities, as it will sustain human life and the ecological systems upon which we depend. Water resource management has traditionally focused on preserving and enhancing aquatic ecosystem functions and structures. Growing populations, development, habitat fragmentation, degraded water quality, and increased demand are just some of the challenges that resource managers face while working to ensure that water supply remains healthy and abundant. As flood, droughts, changes in precipitation and temperature, and other impacts of climate change affect water quality and quantity, watershed management responsibilities will increase.

These impacts will exacerbate existing conditions and create new challenges for watershed councils and resource managers to overcome. Building resilience to these changes is one way that watershed managers can proactively begin to cope with the impacts of climate change and ensure that watersheds continue to provide the services upon which human and natural communities rely. Both the environment and our social systems can play a role in building resilience to climate impacts and reducing vulnerability of our communities and economies.

Drought and overgrazing can impact upper tributary watersheds.

This guidebook is intended to complement, or supplement, the watershed assessment process. However, it can also serve as a stand-alone document to understand potential future conditions for watersheds as well as to identify management priorities and opportunities. While this document loosely follows the structure outlined in the Oregon Watershed Assessment Manual, it can be applied to watershed assessment processes used by other states and the Environmental Protection Agency.

The guidebook includes the following components:

- Section I covers key watershed fundamentals and provides an overview of potential climate risks to watersheds;
- Section II describes a process for developing future climate scenarios and identifying consequences to your watershed;
- Section III provides questions to address and sample activities for key components of the watershed assessment process (following the Oregon Watershed Assessment Manual technical chapters); and
- Section IV provides an overview on the benefits of monitoring and sample indicators for evaluating your watershed's level of resilience.

As you work through this guidebook, keep in mind that your watershed council or organization does not have to conduct this work alone. Collaboration with other community organizations, university programs, governmental agencies and other watershed councils may be essential for building an effective watershed program and overcoming barriers to build resilience. These types of collaborations may also support you in securing new and unique funding sources to further your resilience efforts.

The following terms are used throughout this document:

Adaptation, used interchangeably with preparation, describes adjustments in natural or human systems in response to actual or expected climatic stimuli or their effects, which either moderates harm or exploits beneficial opportunities.

Preparedness, used interchangeably with adaptation, means to proactively reduce the vulnerability of natural, built, human, cultural and economic systems to the negative impacts of climate change.

Mitigation is a human intervention to reduce the sources or enhance the sinks of greenhouse gases.

Resilience strategies are aimed at building the capacity of systems to withstand and recover from climate change impacts. While resilient ecosystems may change over time, they do so while retaining essentially the same function, structure, identity, and feedbacks.

Section I. Watershed Fundamentals, Climate Impacts, and Watershed-Climate Assessment Integration

To understand how climate change will impact your watershed, it's important to have a strong appreciation of the different processes and functions of your watershed. Therefore, completing the activities outlined in this guidebook as you move through the assessment process is helpful. At the very least, you should refer to the most recent assessment report that has been completed for your watershed to ensure you are not missing any key components for the climate impacts assessment. Before diving into the assessment, we'll first look at some of the key factors that shape your watershed, assessment processes used to evaluate conditions, and how climate change might put the health of your watershed at risk.

Watershed Fundamentals

Key watershed fundamentals that you should be aware of before moving through this guidebook include the following patterns and processes as described by EPA[2] and analyzed in Components III through IX of the Oregon Watershed Assessment Manual:

- **Landscape Conditions:** Such as types and extent of upland and riparian vegetation; wood recruitment; shade cover; wetlands, such as flood alleviation potential; fish and wildlife habitat; land management, such as types and potential effects.
- **Biotic Conditions:** Such as type of fish and economic potential; species presence, number, and conditions of individuals and populations.
- **Chemical/Physical Parameters (water, air, soil, sediment):** Such as nutrient loads, bacteria, toxics, changes in chemistry, levels of dissolved oxygen, and temperature.
- **Natural Disturbance Regimes:** Such as soil erosion and stream sediment, sources of erosion, raveling,[3] landslides, and soil creep.
- **Hydrology/Geomorphology:** Such as geology; the hydrologic cycle, collection, storage, and use of water; stream networks, including channel habitation types (CHTs).
- **Ecological Processes:**[4] Such as production, composition and decomposition of organic matter; energy flow; nitrogen cycling.

A clear understanding of the historical and current state of these key components of a watershed system will better inform you about potential impacts from climate change. Your approach to a watershed assessment may vary depending on your region, stakeholders, and the agency you represent. The Environmental Protection Agency, for example, looks at key components of the watershed to describe the ecological and economic significance and characteristics, evaluate resources, and help to abate and manage for risks. In Oregon, the watershed assessment process helps watershed organizations, local citizens, private landowners, and public resource managers work together to understand historical

2 As defined by using Environmental Protection Agency watershed assessment categories. See http://water.epa.gov/polwaste/nps/watershed/index.cfm
3 Similar impacts as erosion and sediment loading. See OWEB Manual (Watershed Fundamentals) for more information.
4 Very difficult to monitor, except very site specific studies. Not covered in the EPA Healthy Watersheds Assessment Guidebook because tested indicators are not available. See page 12 of the EPA Guidebook for more information. http://water.epa.gov/polwaste/nps/watershed/index.cfm

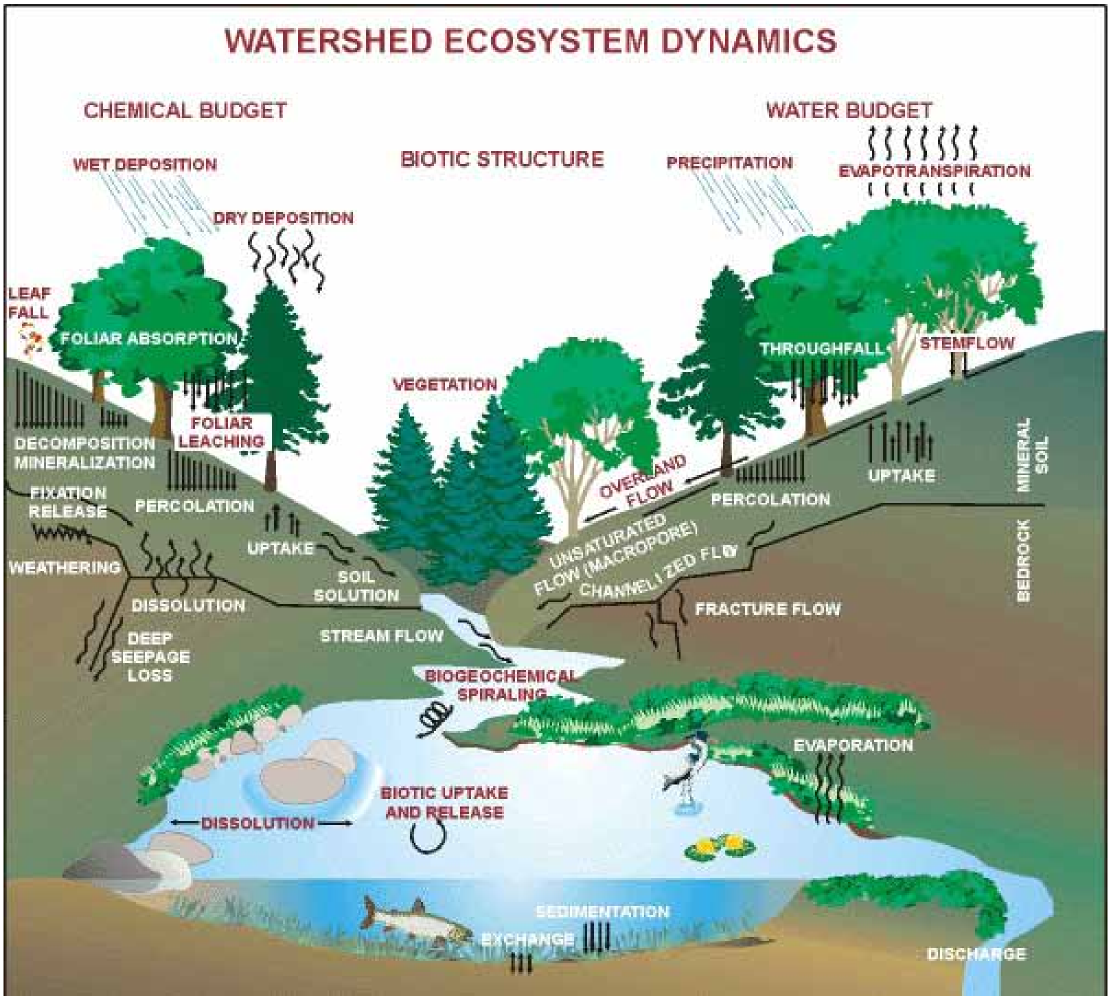


Figure 1. A watershed is made up of a number of dynamics that have complex interactions. (From Johnson and Van Hook, 1989. Analysis of biogeochemical cycling processes in Walker Branch Watershed.)

and current conditions as a means for supporting management decisions to benefit the health of the watershed. In Washington State, watershed assessments are focused on development of a cooperative method to determine the current situation of the watershed and allow for local citizen input, with a critical focus on how much water is available, how much is being used, and how much is needed. The California Watershed Assessment guide considers watershed basics such as water, land climate, biology and people, while collecting and organization data by physical, chemical, biological, and geographical conditions.

While each of these assessment processes follow their own specific approach, there are a number of commonalties — many of which you should be familiar with if you've conducted your own watershed assessment.

1. Define the scope within which you will conduct the assessment (i.e., the watershed boundary)
2. Identify the processes and components that will be the focus of the assessment. These should be factors that determine the health of the watershed, help to address the goals and objectives

for management of the system, and are relevant to stakeholder interests. You may want to consider feasibility and access to data.

3. Engage stakeholders and conduct community outreach.
4. Determine the type of data to collect and identify reliable sources of information.
5. Collect data, identify gaps, and conduct analysis as appropriate.
6. Prepare a report for use in decision-making.

Before diving into the climate assessment, let's first look at some of the potential climate impacts that could affect the components and processes you will consider in your assessment.

Potential Climate Impacts

A warming and changing climate is likely to exacerbate existing watershed stresses while also creating new stresses. While impacts vary depending on where your watershed is located, some potential risks you may face include*:

- Warmer ambient temperatures
- Reduced snowpack
- Changes in streamflow (higher in early spring, lower in summer)
- Changes in precipitation (more intense and concentrated)
- Increase in intensity and frequency of extreme weather events
- Increase in extent, intensity and frequency of wildfires

This in turn could result in the following consequences to your watershed*:

- **Landscape Conditions:** drying of wetland areas; shifts in vegetation conditions; changes in the biomass, production, and composition of terrestrial communities, thereby affecting supply of organic matter, shading, light, and characteristics of runoff.
- **Biotic Conditions:** shifts in species timing, migration, and abundance; conditions favoring invasive species and generalist species.
- **Chemical/Physical Parameters:** warmer water temperatures and loss of cold water habitat for aquatic species; loss of organic matter that supplies nutrients; higher concentrations of pollutants; increased algal blooms and associated water quality effects.
- **Natural Disturbance Regimes:** greater frequency and intensity of flood and fire events; increase in landslides during extreme events.
- **Hydrology/Geomorphology:** shifts in streamflow, with higher rates in the winter and lower rates in the summer, potentially impacting channelization; impacts to sediment transport during both high and low flows.
- **Ecological Processes:** shifting temperatures and flow patterns will likely have consequences for nitrogen and other key cycles; shifts in energy flow and interruptions to photosynthesis.

* *Risks and consequences listed above are examples typical to the northwestern United States, which currently experiences a climate characterized by cool wet winters and warm to hot dry summers.*

In addition, there are likely to be socio-economic consequences such as lack of water for irrigators, hydroelectricity generation, recreational use, and municipal demand.

If these types of changes are not anticipated and steps are not taken to build resilience, watershed managers and the communities and businesses that depend on them may be forced to act suddenly to cope with a harmful event and mounting costs.

Some of the benefits of proactively planning for climate change include:

- Increased effectiveness and reduced long term costs;
- Identification of immediate local benefits such as opportunities for business and job development, cost savings such as "greener" infrastructure that reduces energy costs, improved water use efficiency, increased access to funding, and potential opportunities for recognition;
- Increase in local economic and community security by reducing the risks of damage from major floods or droughts;
- Enhanced efforts to reduce greenhouse gas emissions through carbon sequestration and other approaches; and
- Identification of — and potential to take advantage of — new economic, social, and ecological opportunities that may arise with changing climate conditions.

Integration of Watershed Assessments and Climate Change Assessments

While a watershed assessment typically considers historical and current conditions, as well as the factors leading to those conditions, **a climate change assessment attempts to anticipate what future conditions may exist and the resulting beneficial or negative consequences of those conditions.** By integrating the two, we are essentially asking watershed managers and stakeholders to look across the systems and sectors within your watershed, and based on future projections, make decisions now that

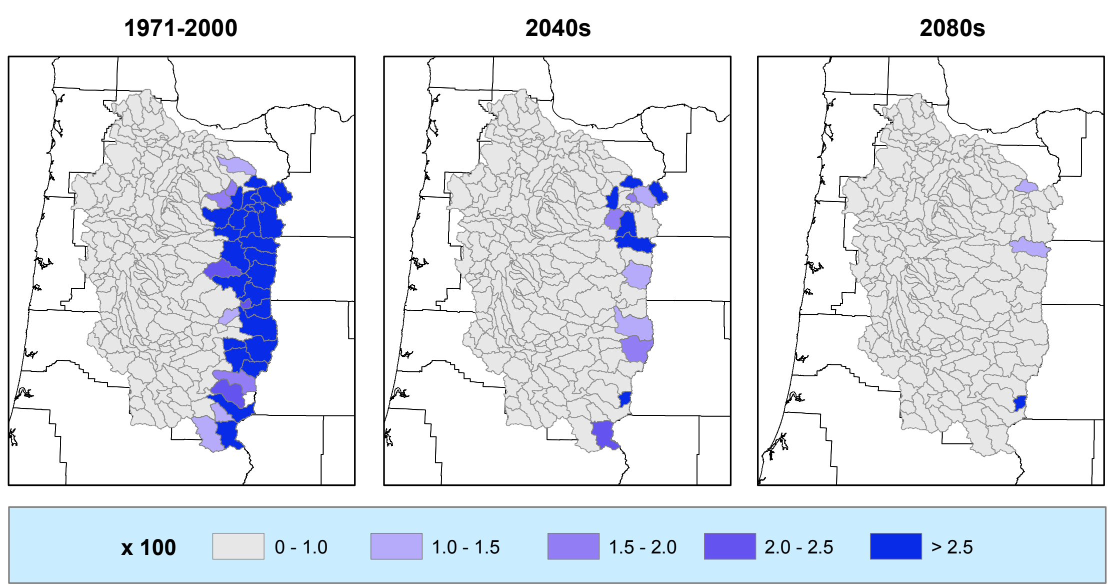


Figure 2. April 1 Snow-Water Equivalent for the Willamette River Basin of Western Oregon under the A1b IPCC Emissions Scenario. Produced by Portland State University.

will enhance the benefits and reduce the risks. This can happen two ways: you can either conduct the climate assessment and planning process (as outlined in this guidebook) after completion of a watershed assessment, or integrate the recommendations and activities throughout the watershed assessment process (whether OWEB, EPA or for your own state) – essentially applying a climate "lens" to each of your activities. By working through Section II first, you can get an overall understanding of potential climate impacts that your watershed system as a whole may face in the future. Section III will focus in on certain components or functions of your watershed, providing questions for consideration and activities to integrate within your assessment process. Section IV will help set up your monitoring component, either as a supplementary monitoring program to your existing efforts, or by integrating considerations into your current process.

Effective watershed management requires long term monitoring programs.

Getting Started

As with any watershed assessment, prior to embarking on this process, you should:

1. Assemble a diverse assessment team to support you through the process. You may want to consider climate scientists, aquatic and terrestrial ecologists, hydrologists, landowners and other stakeholders from your watershed.

2. Identify the purpose of your assessment- what do you hope to get out of it and how will it inform future management and decision-making? Who is the target audience?

3. Develop a strategy for engaging the public, and particularly watershed stakeholders such as landowners.

Section II. Identification of Watershed Issues: Future Conditions Assessments

During the watershed assessment process, you should have conducted an historic conditions assessment. For understanding potential climate impacts, we'll assess future climate projections for your watershed. One of the key issues to keep in mind about climate change is that historical trends and resulting management implications will shift. We can no longer rely on past data to decide how we will manage for the future. However, referring back to your historical assessment will support you in identifying which components of your watershed have been resilient in the past (e.g. during a major drought or flood event) and therefore may help you identify areas that will be resilient to changing climate conditions.

Because producing modeling projection data at the watershed or river basin level is expensive, this section assumes that you will take advantage of existing resources, and not be conducting the modeling yourself. The Resource Innovation Group (in collaboration with research universities and government agencies) has developed climate projections at the watershed scale for the following regions in Oregon: Rogue, Klamath, Willamette (upper and lower), and Umatilla. In each of these regions, TRIG has also worked with watershed stakeholders to identify impacts to natural and community systems, and strategies for building resilience (see www.theresourceinnovationgroup.org for reports). Similar processes have taken place in other parts of the country and can provide a starting point for watershed councils to assess future conditions for their region. More information on different modeling resources is described below and available in Appendix A.

Key questions to consider when conducting a future conditions assessment include:

1. How will future conditions (e.g. temperature, precipitation, stream flow, etc.) be different from the past (e.g. consider trends, not absolutes)?
2. What are the most vulnerable areas of the watershed, including species and habitats? Vulnerability may result from direct changes in climate conditions or indirectly from increased competition for resources resulting from climate change (e.g. increased competition between irrigators and instream water needs during summer low flow periods).
3. Given the uncertainty associated with climate modeling, what management strategies can you implement that will build resilience of the system no matter what the future looks like?

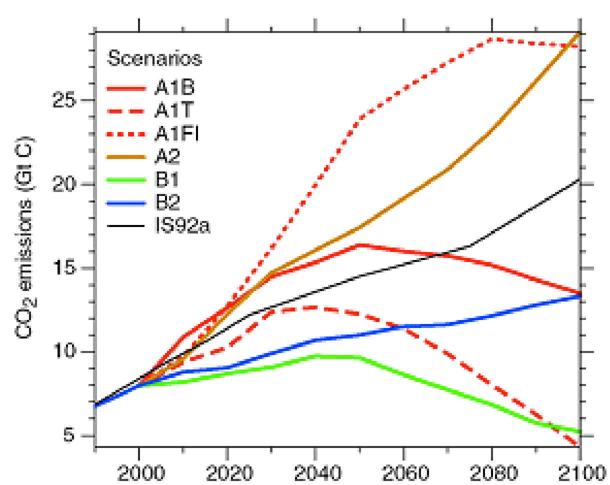


Figure 3. IPCC Global Emissions Scenarios.

Greenhouse Gas Emissions Scenarios and Climate Modeling

The Intergovernmental Panel on Climate Change (IPCC) developed a Special Report on Emission Scenarios (SRES). The scenarios were developed following a story line, describing what the future might look like and the resulting global concentration of global greenhouse gas emissions. The story lines include A1, A2, B1, and B2. There are various scenarios within each of the story lines, such as the A1b ("Business as Usual").

The upcoming IPCC fifth assessment report, which will be released in 2013-2014, has shifted from using the SRES emissions scenarios to Representative Concentration Pathways (RCPs). The RCPs provide a more descriptive future of greenhouse gas emissions, and fill in gaps in pathways left by the SRES. The emissions scenarios, whether SRES or RCP, are a key component in the modeling process and understanding potential future impacts (see Figure 3).

Institutions that provide climate projections typically use a number of different emissions scenarios and types of models. Different models interpret the physical interactions of chemicals in the atmosphere differently, as scientists are still unsure about how some of these interactions play out. Therefore, using a number of models will provide a better range of possible future conditions.

The SRES scenarios present a range of future storylines on how global policies affect greenhouse gas emissions, population and fertility, trade, economic development, and social and political interactions. Because the scenarios are different portrayals of the future, we must consider them when modeling future climate to understand a greater range of projections.

As you assess the potential impacts of climate change in your watershed, consider different timescales. Most climate modelers can produce results as far out as mid and end of century, but you might find data for 2020 or shorter time periods more useful in your planning efforts.

For more information, see:

http://www.grida.no/publications/other/ipcc_sr/?src=/climate/ipcc/emission

http://www.ipcc-data.org/guidelines/ddc_ar5_new_scenarios.html

Assumptions and considerations to keep in mind:

- Climate models represent projections- these are not hard and fast predictions for what the future may look like, but instead represent a range of possibilities or trends.
- Models have their own assumptions, so make sure you select a range of models from different sources if possible.
- The finer the spatial resolution of the projections, the more meaningful they may be, but the greater the uncertainty.

Materials Needed

- Watershed maps
- Climate modeling data including maps and time series graphs
- Pens
- Spreadsheet

Essential Skills

- Map and graphic analysis and interpretation
- Computer spreadsheet manipulation
- Products
- Written report describing possible vulnerabilities and impacts based on different model assumptions
- Written report describing possible strategies for building resistance to impacts
- Written report identifying further research and monitoring requirements

Coastal watersheds face additional challenges with sea level rise and storm surges.

Methods

1. Gather Scenarios and Models to Understand Possible Future Conditions

Climate model projection data is widely available at the 150km^2 resolution. However, it is not often detailed enough data for the purposes of watershed planners nor does it take into account complexities in local geography, topography, and microclimates. To the extent possible, you should gather local or regional climate projections at the 25 to 8km^2 grid scale. Availability of this data will depend on your region. If it is not available, you may be able to contract with university or agency researchers to conduct the modeling.

One source of data may be through universities funded under NOAA's Regional Integrated Sciences and Assessments (RISA) program. Many of these universities, along with state and federal agencies and institutions, have begun generating finer resolution climate data. For instance, the Pacific Northwest RISA, the Climate Impacts Research Consortium, is a collaboration of multiple universities and their extension services. They provide basin level climate modeling for much of the region, with expectations to produce finer scale results in the coming years.

A Note On Using Downscaled Climate Scenarios

All climate modeling comes with some uncertainty. The uncertainty stems, in part, from the modeling process itself, as a computer model is a simplified representation of complex processes. Other levels of uncertainty stem from the variable nature of the Earth's climate system: because the climate system is chaotic and sensitive to amplifying feedbacks, small changes in one variable can lead to large effects elsewhere in the system. Uncertainty is also generated when trying to 'downscale' global climate models to specific geographic locations.

Therefore, modeled future climate scenarios must always be considered to be possible changes, not predictions: focus on the overall trends (e.g. temperatures increasing, snowpack decreasing, seasonal shifts) instead of the specific numbers or rates of change.

2. Assess the Potential Vulnerability of Your Watershed

Once you have an idea of future conditions for your watershed, examine the potential vulnerability of specific ecological functions and processes, organisms, and locations in your watershed. For example, use temperature thresholds of various organisms in your watershed to identify those at risk given the climate scenario temperature projections. Complete a thorough examination of how changes in precipitation patterns, snowpack, runoff, stream flows, wildfire and other core processes might change under different climate scenarios and what the consequences of those changes might be for ecological structure, functions and species in your watershed. Track this data in notes to incorporate into your assessment, but also use the maps of your watershed to draw circles around areas that might be particularly vulnerable to changing conditions, or naturally buffered against certain impacts. You will use the list of potential impacts and vulnerabilities later in this section to conduct a risk analysis.

3. Consider Impacts on Other Parts of the Watershed

Watersheds are composed of multiple smaller subsystems that interact among themselves and are nested within larger systems. Processes occurring at one scale can influence processes occurring at other scales. The resilience of a watershed to climate change will be determined in large part by the interaction of the systems across multiple scales. Therefore, it is important to consider how a stress triggered by climate change at one scale might interact with other systems.

For instance, forest fires occur when a certain set of conditions are present such as sufficient fuel loads and fuel connectivity, dry conditions conducive to combustion, and an ignition source such as a lightning strike or human-set fires. This convergence of conditions can be described as a cross-scale interaction. Fire ignition occurs on a short-time scale, plant growth occurs over many years, and fuel loads and drought cycles occur at still longer time scales, often decades long. When analyzing the vulnerability of your watershed to climate change try to determine how a change at one scale, e.g. plant growth, might interact with conditions changing at different scales, e.g. fuel loads. Another example is ground water and surface water interactions and sensitivities at different time scales.

4. Identify Potential Opportunities

Don't limit your examination to negative effects that climate change might induce. You should also consider potential benefits or opportunities that might be experienced from the climate change scenarios. Will some systems or species be better off, at least for a few years, compared to existing conditions? By identifying opportunities, you can take action to capture these benefits.

5. Assess the Risks

Once you identify the likely consequences of climate change on your watershed, you should next determine the level of risk that exists for each of the potential impacts. One way to do this is to use a standard risk assessment matrix. This involves assessing: (i) the probability, or likelihood, of the impact occurring; and (ii) the magnitude, or consequence, of the impact should it occur. The product of these factors represents risk:

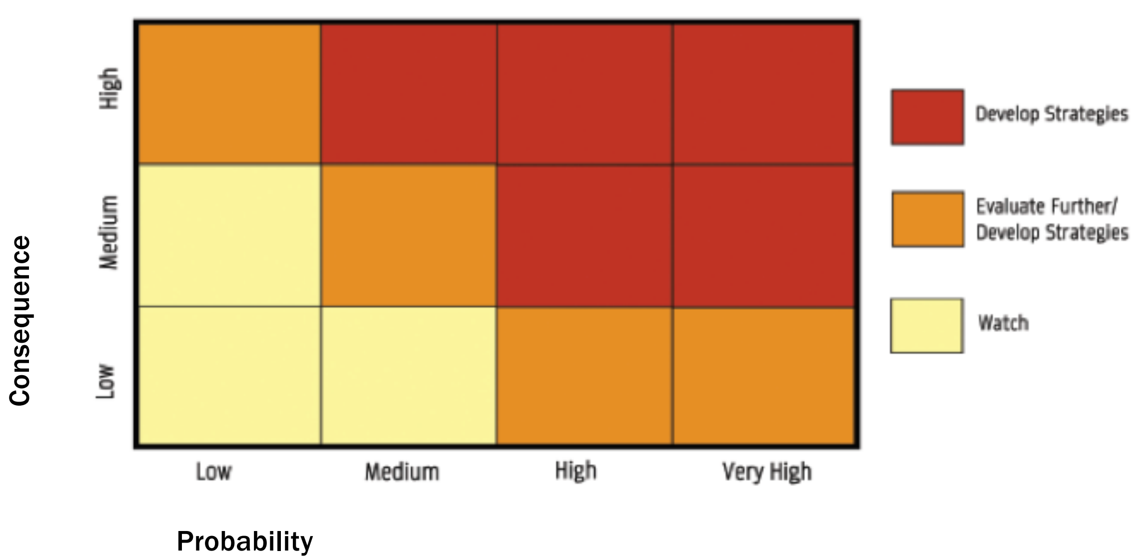
Risk = the probability of occurrence x the consequence of occurrence (R=PxC)

There are several approaches to risk assessment. Your council or agency may have its own in-house risk assessment methods. If you are new to risk assessment, you can complete the following process to help you conduct a very simple and qualitative assessment of climate risks. Please note that if you are making an important investment decision or designing a major project you will need to do a formal risk assessment using a risk framework and costing methodology.

In completing this exercise, consider the timescales over which these risks will occur and how these relate to your situation (e.g. some climate risks might diminish with time, while others might increase). Assess the likelihood (probability) and consequence of each potential climate impact listed above using the sample matrix. Plotting these risks into a chart that has likelihood of impact and magnitude of consequence as its axes can make it easier to visualize your key risks.

The risk and consequences may vary across your watershed depending on shade availability and gravel.

- For each impact, assign a value of 0-5, or low, medium and high for (a) the likelihood of an impact occurring and (b) the magnitude of its consequence should it occur, and enter the value into your matrix. In assigning these values, consider the climate risk based on the changes in climate over the lifetime of the decision that you are making.
- Determine the risk by multiplying the probability of impact by the magnitude of consequence for each impact.
- If possible, you may want to consult with stakeholders to estimate the costs of particular impacts. This information could be important in considering your risks and aiding your assessment of adaptation options.



For example, let's take a watershed that is prone to frequent flooding and consider a 100-year flood event. The likelihood that this event will occur more frequently under a climate change future is very likely (5), but because the ecosystem and community deals with flooding frequently, they are well pre-pared and the consequences will be minor and short lived. This scenario will fall in the lightest blue category (Medium). Next, consider a snow-dominant basin. Some modeling runs for the basin project an 80% decline in snowpack by end of century. The consequences for this would be extreme – water temperatures would increase from lack of cold-water fed springs, flashier flooding events would be likely, and the community would lose its source of drinking and irrigation water. Because only some modeling projections show such a severe decline in snowpack, the watershed managers might rank this scenario as unlikely (3) or possible (4), but the consequences are catastrophic (5), earning this scenario a Very High (dark blue) risk ranking.

Risks falling in the "Very High" ranking (high probability, high consequence) will typically be those for which you want to develop a strategy. Those falling under "High" will need to be evaluated further and possibly develop a strategy for depending on costs and other priorities. Those in the "Medium" or "Low" ranking should be closely monitored to see if your assessment of probability and consequence are accurate.

6. Determine the Importance of Climate Risks in Your Watershed

Some decisions are directly driven by the need to manage climate risks. However, for many decisions, climate risks are just one of a number of risk factors that must be considered. Consider how decisions will perform under climate and non-climate risks so that the measures taken are reasonable and proportional to the risks posed.

Note that the relative importance of the suite of risks will change over time. For example, an outbreak of a livestock disease may change a farmer's priorities, but once that outbreak is over, other risks such as extreme heat or droughts produced by climate change may assume greater importance. The relative importance of all the risks faced should be regularly reevaluated.

In addition to potential climate impacts, you may also want to draw up a list, or table, of the non-climate risks affecting your activities (land use decisions, development, etc). Compile a rank ordered list of non-climate risks against which you can compare the climate risks affecting your decision. Consider the uncertainties associated with your findings, as well as the confidence you can place in your findings, even if a more quantitative assessment of your risk may not yet be possible.

7. Determine Priority Risks That Require a Response

Having completed the climate risk assessment and non-climate risk analysis, you should now be in a position to identify your priority climate risks. To do this, you may want to consider:

- High risks already faced
- Risks that will increase most rapidly due to climate change
- Risks where it will take some time to plan and implement an adaptation response
- Contingency planning
- Early-mover advantage on a climate change business opportunity
- Complementary non-climate driver (i.e. co-benefits) for taking action, such as health and safety, damage mitigation or achieving a better work/life balance

Similar to the exercise before, draw up a rank order listing of the most significant threats and opportunities, or draw a line across your matrix separating your high priority risks from lower priority risks.

High quality spawning areas may be at risk due to extreme precipitation events, and increased water temperature and turbidity.

Those that fall into the top right region of your chart will be of greater priority than those in the lower left region. In identifying your priority risks, consider your tolerance for risk, the resources available to deal with this risk, and the time over which the risks are being considered.

8. Write It Up!

Once you have completed all the activities outlined in Section II (or as many as are feasible and appropriate for your watershed) you may want to develop a summary report to share with your board and stakeholders for feedback. Engaging a diverse array of reviewers may lead you to reconsider some of the potential impacts, the consequence of certain impacts, of costs to reduce risks. In addition, as more refined climate data becomes available, you may want to review and update your analysis.

9. Incorporate Climate Action Strategies Into Your Overall Watershed Action Plan

Once you've identified the key climate risks and priorities to address in your watershed, you'll begin to identify specific actions to reduce impacts and build resilience. The following section of the guidebook will take you through some sample activities. You may also want to work with your board and stakeholders to develop an overall strategy for addressing climate change that can be integrated throughout your planning documents and help direct future fundraising efforts and projects. While activities will be specific to the particular watershed's current conditions and projected impacts, the following criteria may help you to evaluate your preferred adaptation options:

- **No-regrets** options will deliver benefits that exceed their costs, whatever the extent of climate change. These should be the priority for implementation whenever possible. For instance, if you are already experiencing weather-related problems, then cost-effective actions to deal with them should be no regret options. No-regret options are particularly suitable for the near term as they can deliver obvious and immediate benefits, and can provide experience on which to build further climate risk assessments

- **Low-regrets** options yield large benefits for relatively low costs and seek to maximize the return on investment when certainty of the associated risks is low.

- **Win-win** options enhance your adaptive capacity (i.e. they reduce climate risks and exploit positive opportunities) while also contributing to the achievement of other social, environmental or economic outcomes.

- **Flexible or adaptive management** options are important means of handling uncertainties. Flexible management involves putting in place incremental options, rather than undertaking large-scale preparation in one step, making the best decision at each decision point and reviewing the performance of previous decisions. A decision to delay the implementation of an adaptation measure can also be a legitimate risk management strategy. This approach can buy time for further information gathering and can help reduce the risk of under- or over-preparing as better information on climate risk may become available.

- **Conscious decision to do nothing** is the most basic response, and may be legitimate and appropriate in the case of low priority impacts or in situations where climate risks are outweighed by non-climate factors. It may also be appropriate for more significant impacts where no obvious preparedness response can be clearly identified, or where there are prospects that other factors may change future circumstances. However, a decision to do nothing should not be the default position, and should only be reached after careful consideration of your climate risks and adaptation options. Such a decision must also be continually monitored and reviewed to ensure nothing has changed that requires you to shift your position.

Section III. Key Questions and Methods of Analysis to Consider Throughout the Watershed Assessment Process

This section addresses specific questions and related exercises that can be applied to each of the components of the watershed assessment. We have identified a few specific areas to look at under each of the major assessment categories defined by EPA and as described in the Oregon Watershed Assessment Manual. Depending on where you are in the process of conducting your assessment, you can integrate these questions and exercises as you move through each step, or revisit them as an appendix to your existing assessment if it was recently completed.

Hydrology/Geomorphology: Channel Habitat Type Classification

Stream classification enables you to better understand how land use impacts can alter the channel form, and identify how different types of channels respond to restoration efforts. Both channel modifications and restoration will ultimately affect fish habitat. Through your watershed assessment, you should have conducted a thorough Channel Habitat Type (CHT) classification process. The questions and steps proposed below can be used to supplement this process in order to consider the consequences of climate change on different CHTs.

Questions to Consider:

1. Based on climate projections identified in Section II, along with the CHT classification conducted during your watershed assessment, how might impacts vary among CHTs throughout the watershed? Which channel types are likely to be more or less resilient to climate change in your watershed?
2. Which areas providing critical habitat might be the most sensitive to projected changes?
3. Which areas might be most buffered against projected impacts?

Areas of watersheds with strong connectivity between wetlands and the main channel may face less risk.

Sample Exercise:

Collect a 1:24,000 scale state Department of Forestry or USGS basin map, aerial photograph, Mylar for overlay, pencils, pens and permanent markers. (This exercise can also be conducted electronically using GIS.) Preferably, use the same map that was used for the CHT classification exercise during your assessment. Overlay a new Mylar sheet. Based on the future land and climate projections, identify areas that might be most sensitive to change. With different color pens, circle areas of greatest concern, those likely to be most resilient to projected changes, and areas that you are not sure about. For areas that you are unsure about, consider field visits to better understand the characteristics of the area and how it might change under future climate conditions.

Loss of glaciers can affect water temperature and quantity.

Hydrology/Geomorphology: Hydrology and Water Use

The hydrology of your watershed is greatly impacted by land and water use, as well as climatic factors. It is important to understand the natural hydrologic cycle, including peak and low flows, and how it is impacted by different land uses and climate conditions. Anticipating these impacts can help you identify projects that best support building the resilience of the hydrologic system.

Questions to Consider:

1. What impact would more frequent and severe floods and droughts have on the system?
2. How will anticipated patterns of land use and population growth affect, and be affected by, shifts in peak and low flows?
3. How is water use expected to change with future conditions (e.g. more water needed for irrigation due to increased evapotranspiration)? How will ground water supply, surface water supply, and storage conditions change?
4. Will your watershed experience changes in the amount of water that is imported or transferred out (e.g. are there other areas of your state that are likely be more severely impacted by climate change)?

Sample Exercise:

If available, obtain projected changes to monthly stream flow under future climate conditions from a state or federal agency or a local university. Identify the current percent of land use under each category (e.g. forestry, agriculture, rural development, etc). Identify projected changes in land use. For each type of land use, identify key months or seasons when water requirements are high and low (e.g. high in summer for agriculture and urban developments with lawns – see Appendix A for assessment processes that provide more information on impacts of land use on hydrology).

Compare existing patterns of land use with future projections and determine the water deficit (or surplus) for each consuming sector (agriculture, municipal water supply and wastewater treatment, hydroelectricity generation, industrial uses) that may be anticipated as a result of future climate change projections.

Identify projects that may enhance supply when and where there is a deficit as well as those that can provide storage opportunities when and where there is a surplus. For example, enhanced groundwater storage in floodplains where projections show higher precipitation in the winter, but high evapotranspiration and lower summer stream flows in the summer may enhance summer stream flows for deficit sectors like agriculture and residential consumption. Seek solutions that provide a sustainable balance between human system needs and natural systems needs.

Landscape Conditions: Riparian & Wetland Assessment

Riparian and wetland components of a watershed are key habitat for many species, provide critical functions for maintaining the health of the system, and play a strong role in keeping the system cool by recruiting large woody debris and providing shade. Understanding how climate change may impact these areas can help you identify priority restoration and/or conservation areas.

Questions to Consider:

Volunteers and students can help you gather data on wetland functions.

1. How are future climate conditions likely to impact riparian and wetland areas in your watershed? What types of shifts might you see from current conditions? (e.g. drying of wetlands during summer months, introduction of new vegetation types, etc).
2. Are there key riparian areas that provide cooling or habitat for critical species that should be prioritized for restoration or protection (e.g. vegetation cover restored, woody debris introduced, or additional shady areas provided)?
3. What strategies can be taken to protect existing or create new wetlands under future climate conditions?
4. For wetland and riparian areas likely to shift towards upland systems, what are appropriate management strategies?

Sample Exercise:

To identify how resilient wetlands are in your watershed, you can conduct an assessment of current conditions of landscapes within your watershed (see samples in Appendix A). For wetlands where the following questions are answered in the affirmative, they are more likely to be able to manage changing precipitation, air temperature, and hydrologic conditions. For wetlands not meeting these criteria, you may want to consider opportunities to enhance them, or focus on restoring and protecting those that are already in good condition.

a. The wetland has well-defined inlet and outlet with water flowing through the area.

b. The wetland is within a 100-year floodplain of a river or stream (consider that floodplains are likely to be expanded under future conditions)

c. Precipitation is not the only water source for the wetland.

d. Surrounding lands (sheetflow) are not the only water source for the wetland.

e. Groundwater (often indicated by springs or hillside seeps) is a source for the wetland.

f. The wetland contains no or very little artificial drainage.

g. (For coastal communities) The wetland is subject to tidal flows.

Next, you can assess six wetland functions — wildlife habitat, fish habitat, water quality, hydrologic control, education and research — and the sensitivity and enhancement potential for the water. For each function there are likely to be different impacts based on future projections for temperature and precipitation. For example, salmon species intolerant to high ambient stream temperatures may be exposed to lethal conditions without access to cold-water hyporheic flows or shading from stream side vegetation. Strategies that protect cold-water refuges or that restore vegetative cover may be essential for salmonid survival. Expanding wetlands in floodplains and improving vegetative cover is another example that has potential benefits across multiple functions for reducing downstream flood damage during periods of intense precipitation.

Areas that have been overgrazed will require restored vegetative cover.

Natural Disturbance Regimes and Hydrology/Geomorphology: Sediment Sources Assessment

Erosion from nearby streams or slopes is a natural part of any watershed, and aquatic organisms and vegetation have adapted to a steady sediment source. Heavy precipitation events and flooding often have a greater impact on the system, but are rare enough that the watershed can recover. Human induced erosion, through development, roads, etc., can be much more impactful on the system because it is highly variable and diverts the system from levels of sediment to which it is naturally adapted. With changes in precipitation patterns and types (i.e. more rain than snow), erosion is likely to be more severe.

Questions to Consider:

1. How are future sediment sources likely to deviate from current? (Refer back to your watershed assessment of current and historical conditions.)
2. How are future climate conditions likely to impact sources of sediment?
3. Are there key areas (logging roads, sloped hillsides, stormwater infrastructure) where proactive restoration can prevent sediment load into the system?

Areas that have been logged or that are on sloped hillsides will require preventative measures to reduce sediment load.

Sample Exercise:

Refer back to your sediment source worksheet of your watershed assessment, where you identified current sources of sediment from roads instability and runoff, slopes, urban runoff, surface erosion from crop and rangeland as well as burned land, and other areas of erosion. If you identified priority areas of concerns, review why they were prioritized. Then, with an understanding of likely changes to precipitation patterns, extreme events, fire and other conditions, reevaluate the priorities. Identify if these priorities might shift today, in 5 years, 10 years, and longer term.

For example, an inventory of the size and condition of existing culverts and a survey of culverts that have failed during specific storm events may be compared to future precipitation projections. A program for replacement with culverts that are sized to accommodate higher levels of runoff may prevent future sediment flows that damage fish habitat or obstruct channel passage.

Natural Disturbance Regimes and Hydrology/Geomorphology: Channel Modification Assessment

Depending on the type and magnitude, channel modification could have devastating impacts on the species and habitats of the system. Channels are important components of dynamic systems that modify themselves in responses to changes. Channel modification may become more frequent given that extreme events, drought and flooding are likely to become more common and severe. Understanding what changes could occur may help in protecting the various stakeholders in your watershed.

Questions to Consider:

1. How is climate change likely to affect future channel modification (natural and human modifications)?
2. Are there likely to be shifts in the types of impacts based on climate projections?

Sample Activity:

Review your historical assessment of channel modifications. Reclassify as low, moderate, or high probability of impact occurring and identify risks to different aquatic and terrestrial species and human populations in the specific channel segment. You can use these definitions of impact as a rough guide:

- *Low*: Impacts not apparent or effect less than 1% of area
- *Moderate*: Impacts are localized, but apparent; changes to channel characteristics are detectable, but not obvious
- *High*: Impacts are obvious and a significant length or portion of the channel has been affected

For an example of a high modification, if a stream channel has been simplified and meanders have been eliminated for more efficient cultivation of farm land, stream velocities downstream will likely increase during flood events resulting in soil erosion and damage to infrastructure. Riparian habitat for fish and wildlife will also be compromised.

Blow-outs of logging roads due to culvert failure during heavy rains or rapid snow melt may cause large boulders and logs to at least temporarily obstruct stream channels, inhibit migratory fish passage, or impair recreational boating.

Adequately sized culverts are essential to preventing road wash-out and allowing for fish passage.

Chemical/Physical Parameters: Water Quality Assessment

A watershed's water quality should be maintained at a level that can sustain aquatic life and provide water resources for human needs. Having a basic understanding of how climate conditions may affect future water quality can support your efforts. Key water quality issues to consider under climate conditions include: water temperature, dissolved oxygen, pH, nutrient, bacteria, chemical contaminants, and turbidity.

Questions to Consider:

1. How will short term impacts (e.g. extreme weather event, single flood event) impact water quality compared with long term change (e.g. warming water temperatures, reduced dissolved oxygen, increase in algal blooms)?

2. How will existing practices and projected changes in land-use related to climate change affect water quality (e.g. reduction in flows due to increased consumptive withdrawals leading to higher concentration of contaminants)?

Sample Activity:

Review your assessment of existing water quality for pollutants, dissolved oxygen levels, and temperature and compare with anticipated changes in hydrology and the capacity of the stream to dilute these contaminants and buffer against lower stream flows. Focus on stream segments that have been identified as critical habitat for fish or important recreational areas for camping, boating and swimming. Identify strategies that reduce pollutants at their source (e.g. runoff from residential or agriculture development), enhance filtration (e.g. expanding wetlands), or reduce stream temperature (e.g. planting shade trees).

Warm temperatures and low stream flows can cause harmful algae blooms.

Biotic Conditions: Fish and Fish Habitat Assessment

Understanding which fish are present in your watershed system, and key areas that provide quality habitat can provide you with an overall estimation on the health of your watershed. In your watershed assessment, you should have identified species presence, abundance, location, interaction with other native or non-native species, quality of key habitat, and any barrier to migration. In this component, you'll look at how climate change may impact the most sensitive species (often salmonid) and identify critical areas to support species survival.

Questions to Consider:

1. How will certain fish species and fish habitat be affected by projected changes in temperature, water quality, water quantity, and habitat?
2. What existing species and critical habitat and refuges will no longer be suited or suitable under projected conditions?
3. What proactive steps can be taken to provide access to more suitable habitat or buffer against climate impacts?
4. What human system adaptations to climate change may have the potential to conflict with fish and aquatic system needs (e.g. increased pesticide use for vector control, increased levee construction for flood protection, etc.).

Sample Activity:

Identify temperature tolerances for existing species and opportunities for reducing temperatures under projected conditions- these can be either natural or engineered strategies such as improving access to cold-water refuges, hyporheic flows, and restoring vegetative cover for shading. For example, fish passage may be improved for salmonids that currently encounter barriers such as dams or debris flows into higher elevation streams. Existing dams may be modified to release cold water from deeper waters in reservoirs or ground water storage may be enhanced with wetlands and beaver restoration in upland tributary sectors to support streamflows during the dry season.

Consider climate impacts to key species in your watershed.

Section IV. Monitoring and Evaluating Your Strategies

The purpose of this section is to describe an approach for monitoring and evaluating climate adaptation strategies or planning approaches that are developed through the earlier components. Your monitoring program can be used to:

a. evaluate existing conditions;

b. identify cause-and-effect relationships; and

c. determine trends and responses to actions.

Because your watershed assessment will evaluate existing conditions, this section focuses on identifying cause-and-effect relationships and determining trends and responses to actions. A monitoring program is intended to be ongoing, but it can be used for short-term evaluation, e.g. the results of a five-year project. The indicators presented here will need to be adapted to your particular watershed conditions and needs, and should be used only as a starting point for building a more robust monitoring plan. The indicators can be used to identify any shifts from historical and current conditions in your watershed as a means for informing management and planning.

What Should You Monitor: Identifying Relationships and Determining Trends and Responses

At the watershed scale, early recognition and assessment of potential climate change impacts will allow communities to be proactive in identifying solutions that will reduce the disruptive effects of climate change impacts. Continued monitoring over time will allow for identification of changes that need to be made in management and intervention. Currently, many watershed managers are tracking various environmental components through watershed assessments. These assessments are used to establish the current health of streams by monitoring chemical, physical and biological properties of the watershed. This type of information is useful in determining management strategies that ultimately seek to improve the health of a watershed. However, to build resilience watershed managers will need to expand their focus and begin to assess and monitor indicators of climate change impacts.

Here we provide a sample framework that watershed managers can use to confront this issue. These indicators can help focus on the critical details that will increase the resiliency of watershed to climate change impacts. A summary of the indicators is presented below. Please see Appendix B for additional details on measurement and data sources.

1. Type of Basin (Rain, Transient or Snow Dominant)
2. Major Water Source (Surface or Groundwater Dominant)
3. Shifts in Flow Volume and Timing of Peak Flow
4. Change in Average Air Temperature
5. Change in Ambient Air Quality
6. Change in Average Seasonal Precipitation
7. Change in Percent Impervious Surface Coverage
8. Change in Land Ownership

9. Change in Major Water Uses and Availability
10. Shifts in Water Storage Systems
11. Shifts in Surface and Ground Water Quality
12. Shifts in Estuarine Health
13. Shifts in Human Population
14. Presence of Climate Change Planning

Other consideration to include when developing indicators and monitoring strategies:

- **Identification of cumulative effects** through time or spatially are essential to assessing the range of climate impacts that may be anticipated. For example, a warming climate may attract invasive species that are more opportunistic and flexible than existing species, and predators that may threaten the viability of current populations. Through time, as populations of threatened natives are stressed, native predators may also disappear or leave the area. Migratory refugees from regions severely impacted by drought or flooding may populate an area, including human refugees, and development impacts may stress native populations as intensively as climate impacts. While no single impact may deal a decisive blow to the viability of a species, the incremental additions of each stressor may finally push the native species into extinction. Other examples of cumulative impacts: engineered projects built to resist climate impacts such as seawalls and jetties for coastal storm protection and sea level rise that in themselves create impacts on adjacent property and habitat; reservoirs to impound water in drought-stricken areas that reduce stream flows; vegetation removal to reduce wildfire intensity that also disturb or reduce habitat.

- **Action opportunities** to monitor climate trends and assess the efficacy of strategies and projects are numerous. Networking with other agencies and organizations to avoid duplicative efforts is often useful, as is access to centralized data and information systems. Volunteer networks and incidental monitoring for reasons not directly related to climate change may also be useful, such as the impacts of habitat disturbance from development and harvest on fish species.

Continued monitoring of your projects after completion is essential for assessing success.

Developing a Monitoring Strategy for Your Watershed

Climate adaptation planning is an ongoing process: you must frequently evaluate your strategies to ensure they are still relevant and update and adapt them when they are not. Your framework and strategies should be flexible so that they can easily and often be adapted to current situations and updated modeling projections. Here we will help you think about how to assess whether your strategy is still relevant and understand when it needs to be modified.

The real test of a preparedness strategy is whether it enables you to cope with climate change. However, you may not be able to test effectiveness until climate projections come to bear over the next 10 to 100 years. Asking the following questions of your strategy may help in understanding whether or not it is likely to succeed:

- Does it fit your purpose?
- Will it help you to reduce vulnerabilities and capture opportunities?
- Does it address the risks present within your planning horizon?
- Does it address the objectives you set out to achieve?
- Does it make sound economic sense? That is, do the benefits outweigh the costs?
- Does it help you to fulfill other social, environmental and economic goals?
- Can it be readily – or reasonably – implemented?
- Is it flexible and what implications does it have for the future?
- Has new information come to light that could cause a shift in strategy?
- Can it be readily understood and accessed by all relevant stakeholders?
- Does it consider co-benefits or conflicts with other sectors?

Sample Exercise: Critically review and monitor your adaptation strategy on a routine basis, asking the questions of it that are posed above.

You should improve your strategy if it does not deliver the benefits you were expecting it to, and if the options you chose have not performed as you expected them to.

You should also keep a constant eye out for new information on climate risks. Our knowledge of climate change is improving all the time, and our understanding of potential impacts of climate change is continually developing. Keep on top of the key information for your activity to ensure you have a strategy that is valid, relevant and responsive to changing conditions. Ideally, build the review of your adaptation planning into part of a regular, organization-wide review of all strategies to ensure they are performing as required.

Section V. Conclusions

Watersheds are an ideal geographic unit for organizing climate resilience strategies and establishing meaningful human and ecological relationships in the context of climate change impacts. One of the primary impacts of a changing climate over time will be its effects on stream flows and conditions resulting from intense precipitation events, persistent drought, and elevated temperatures. Species, ecosystems, and human activity are all interconnected by rivers and their tributaries, floodplains, riparian areas, and uplands as defined and bounded by a given watershed.

Watersheds also provide a mechanism for connecting disparate political and institutional entities with common interests and interdependencies both upstream and downstream. While some entities such as watershed councils, management compacts, and formal and informal governance agreements may already be in place, more commonly activities are often uncoordinated at best or competitive at worst.

A resilient watershed provides multiple uses.

Building climate resilience into a watershed has enormous benefits for ecosystems and human systems. A resilient watershed continues to provide suitable habitat for ecosystems and species in the face of the intense disturbances anticipated under projections of a changing climate, and may continue to provide clean and sufficient water for human consumptive uses like drinking water, clean and sufficient water for recreation like boating and fishing, Functioning flood plains provide water storage during periods of drought, and buffering against floods during intense precipitation events and rapid snowmelt. Intact and healthy forests in upland portions of a resilient watershed reduce the intensity of wildfire in the summer months, and sediment deposition endangering fish spawning habitat and drinking water quality during winter storm events.

In order to implement strategies for building resilience and scoping out the impacts of climate change at each level, the most challenging barrier may be the human element. Effective person-to-person and agency-to-agency collaboration and communication for funding and strategic cooperation will be essential, as will an ongoing long-term monitoring program.

The purpose of this guidebook has been to provide watershed managers and their stakeholders with strategies for integrating a climate analysis component into the watershed assessment process. Ultimately, we hope that this will help watershed councils and managers to build and maintain watershed resilience in the face of multiple stressors including human development activities and climate change.

Appendix A. Resources

Oregon Watershed Assessment Manual:

Oregon Watershed Enhancement Board. 1999. "Oregon Watershed Assessment Manual." Developed for the Governor's Watershed Enhancement Board with Support from the Watershed Professionals Network. Available at: www.oregon.gov/OWEB/docs/pubs/OR_wsassess_manuals.shtml

National Resources for Climate Projections and Modeling:

- National Climatic Data Center: http://lwf.ncdc.noaa.gov/oa/ncdc.html
- National Climate Prediction Center: www.cpc.noaa.gov
- UW Climate Impacts Group: http://cses.washington.edu/cig/fpt/fpt.shtml
- Climate Wizard from The Nature Conservancy: www.climatewizard.org
- Earth System Research Laboratory, part of the National Oceanic and Atmospheric Administration: www.cdc.noaa.gov
- National Center for Atmospheric Research GIS datasets (requires login): www.gisclimatechange.org
- The U. S. Global Change Research Information Office offers a wealth of publications and reports to download or order hard copies: www.gcrio.org, www.globalchange.gov/publications/reports
- IPCC Data Distribution Centre (International data): www.ipcc-data.org/index.html
- Socioeonomic Data and Applications Center: http://sedac.ciesin.columbia.edu/maps/client
- Climate Adaptation Knowledge Exchange (CAKE): www.cakex.org
- American Association of State Climatologists – a clickable map with links to state climatologist offices, where available: www.stateclimate.org
- The Pew Center on Global Climate Change – a clickable map of the United States with listings of climate actions: www.pewclimate.org/states-regions

Pacific Northwest Resources:

- Western Climate Initiative is a consortium of 7 western states and 4 Canadian provinces – collection of resources and documents: www.westernclimateinitiative.org/documents
- Local Governments for Sustainability – Northwest region: www.icleiusa.org/about-iclei/iclei-by_region/pacific-northwest-regional-capacity-center
- USFS Pacific Northwest Research Station: www.fs.fed.us/pnw
- Climate Change in Oregon Portal: www.keeporegoncool.org
- The Resource Innovation Group: www.theresourceinnovationgroup.org
- Oregon Climate Change Research Institute: www.occri.net
- Office of the Washington State Climatologist: www.climate.washington.edu
- Climate Change in Washington State: www.ecy.wa.gov/climatechange/index.htm
- King County -- Available to download are the Annual Climate Report and How to Prepare for Climate Change: A Guidebook as well as information geared towards various sectors: www.kingcounty.gov/exec/globalwarming.aspx

Sector Specific Resources:

- Climate Change Impacts By Sector on the US Global Change Research Program Website – divided as Water Resources, Energy Supply and Use, Transportation, Agriculture, Ecosystems, Human Health, and Society: http://globalchange.gov/publications/reports/scientific-assessments/us-impacts/climate-change-impacts-by-sector
- Climate Change and Public Health, The Center for Disease Control: www.cdc.gov/ClimateChange
- Three business-as-usual emission scenario economic impact reports currently available on Oregon, Washington, and New Mexico: www.theresourceinnovationgroup.org
- The Economics of Climate Change: A Primer, April 2003 – from the Congressional Budget Office: www.cbo.gov/doc.cfm?index=4171&type=0

Appendix B. Sample Watershed Resilience Indicators

Contact admin@trig-cli.org for more information on these sample indicators.

1. Type of Basin

Sub-Indicator: Rain, Transient, or Snow Dominant Basin

Data Source: Hydrograph assessment (average flow/month), look for peak flow trends to define basin type; temperature data; stream gauges; Oregon Climate Service

2. Major Water Source

Sub-Indicator: Surface or Groundwater dominant

Data Source: Department of Water Resources, Bureau of Reclamation

3. Annual Surface Water Flow

Sub-Indicator$_1$: Trends in flow volume

Measurement Type: Percent change in seasonal (spring average, summer average, winter average, fall average) flow volume (cf/s). Percent change over ten year periods (to smooth out local perturbations associated with the ENSO cycle).

Data Source: Historic trends, Oregon DEQ, Dept Water Resources, stream gauge

Sub-Indicator$_2$: Shifts in timing of peak flows

Measurement Type: Average date of peak flow for last ten years (or as available)

Data Source: Historic peak trends from Oregon DEQ, stream gauge, Dept of Water Resources

Sub-Indicator$_3$: Contribution of tributaries to mainstem base flow

Measurement Type: Percentage (%) of base flow contribution for each tributary.

Data Source: Historic trends, Oregon DEQ, Dept Water Resources, stream gauge

4. Average Air Temperature

Sub-Indicator: Average air temperature for the overall basin, low, middle, and upper basin elevations.

Measurement Type: Average seasonal temp for overall/low/middle/upper basin and change over last 10 years (or as long as data is available)

Data Source: Oregon Climate Service, NOAA National Weather Service

5. Ambient Air Quality

Sub-Indicator: Trends in ambient air quality for certain air pollutants

Measurement Type: Number of days that exceed the National Ambient Air Quality_Standards (NAAQS) over a ten-year period; need measurement for other toxics data.

Data Source: DEQ – Oregon Air Quality Data Summaries

6. Average Seasonal Precipitation

Sub-Indicator: Average precipitation for the overall basin, low, mid, and high basin elevations.

Measurement Type: Average inches per season and percent change over last 10 years (or as long as data is available)

Data Source: Oregon Climate Service

7. Impervious Surface Coverage

Sub-Indicator: Identify percent impervious surface cover in watershed.

Measurement Type: Percent of total watershed area with impervious surface coverage.

Data Source: Planning departments, Comprehensive plans

8. Major Land Ownership

Sub-Indicator: Identify the percentage of land owned by private, federal, tribal, and state interests.

Major Land Owner	Positive	Negative
Private	Private land owners may be able to respond more quickly to a changing environment	May be reluctant to initiate action, for adaptation related projects, if they do not see the benefits directly affecting them or if they do not believe in climate change in a general sense. A large percentage of private land holdings, held by a large number of individual property owners may make it more difficult to implement coordinated adaptation strategies.
Public	Implementing adaptation strategies may be easier and more effective, in areas where there is a larger percentage of Publicly owned land. There will be fewer parties to work with and implementation can occur (more or less) uniformly over larger areas.	Multiple public landowners can also be a challenge. Implementation may be difficult due to different agency mandates, especially when working with agencies in different levels of government (federal, state, and local)
		The issues and actions of adapting to climate impacts may get mixed into larger political debates on climate mitigation (i.e. emissions reductions), making it difficult to move forward on adaptation strategies.

Measurement Type: % of watershed owned by private landowners, state, federal, tribal

Data Source: DLCD, county

9. Major Water Uses

Sub-Indicator$_1$: Identify the predominant consumptive water uses in the watershed by type and percentage of total water use.

Measurement Type: Percentage of total water budget allocated for individual uses.

Data Source: Oregon Dept of Water Resources

Sub-Indicator$_2$: Percentage of human use of the total available water budget for the watershed.

10. Water Storage Systems

Sub-Indicator: Identifies and quantifies major surface water and groundwater storage systems in the watershed.

Measurement Type:

- Presence of Dams/Aquifers & Recovery (ASR) sites,
- Acre-feet of storage
- Ratio of storage to annual flow
- Capacity of Storage Site

Data Source: Oregon Dept of Water Resources

11. Water Quality

Sub-Indicator: Known surface and groundwater quality problems within the watershed. Surface water [temperature, dissolved oxygen, pH, fecal coliform, tss/turbidity, metals, phosphorus, nitrogen]. Groundwater [chlorides, salt water intrusion, nitrates, phosphorus, iron, manganese, fecal coliform].

Measurement Type: Look at the extent to which the watershed meets water quality standards for each parameter.

Data Source: DEQ, Oregon Dept of Water Resources

12. Estuarine Health

Sub-Indicator_1: Presence of a coastal or estuary zone

Sub-Indicator_2: Water Quality Index (Dissolved Inorganic Nitrogen, Dissolved Inorganic Phosphorus, Chlorophyll a, water clarity, dissolved oxygen)

Sub-Indicator_3: Sediment Quality Index (contamination of sediments with toxic metals)

Sub-Indicator_4: Benthic Indicator (Benthos [worms, clams, crustaceans, other invertebrates] used as an indicator of disturbance/ecosystem health)

Sub-Indicator_5: Change in Sea Level

Sub-Indicator_6: Change in pH Level

13. Population

Sub-Indicator: Human population trends within a watershed (current, projected change, average percent increase).

Measurement Type: % increase in population over last ten years, current population, projected population increase over next ten years, average annual increase in population.

Data Source: US Census, State of Oregon

14. Planning for Climate Change

Sub-Indicator_1: Presence of major planning challenges sensitive to climate impacts (e.g. water supply limitation, instream flow requirements, water rights limitations, and water quality).

Data Source: watershed assessment, city or county climate action plans