# Table of Contents

**Chapter One**  Introduction with Key Findings ............................................................. 1

- Science and the Watershed Assessment ........................................................................ 2
- Key Findings .................................................................................................................. 7
  - Environmental History .............................................................................................. 7
  - Air Quality .................................................................................................................... 8
  - Upland Water Quality and Lake Clarity .................................................................... 9
  - Biological Integrity .................................................................................................... 14
  - Social, Economic, and Institutional Conditions ....................................................... 17

**Chapter Two**  A Contextual Overview of Human Land Use and Environmental Conditions ........ 23

- Introduction .................................................................................................................. 23
- Paleoclimate and Environmental History ..................................................................... 24
  - Environmental Change in the Tahoe Sierra .............................................................. 24
  - Prehistoric Era (Prior to 1850s) ................................................................................ 34
  - Comstock Era (1850s to 1900) ............................................................................... 47
  - Post-Comstock Era (1900 to 1950s) ........................................................................ 73
  - Urbanization (1950s to Present) .............................................................................. 84
- Time Line of Paleoclimate and Environmental History in the Lake Tahoe Basin .............. 92
- Time Line of Transportation and Community Development ....................................... 95
  - Time Line of Human Land Use and Environmental Conditions in Lake Tahoe Basin ...... 99
  - Time Line of Human Land Use and Environmental Conditions, Upper Truckee River/Trout/Saxon/Heavenly Valley Creeks Watersheds (Lake Valley) T12N/R18E .......... 106
  - Time Line of Human Use and Environmental Conditions, Emerald Bay/Cascade and Fallen Leaf Lakes/Taylor Creeks Watersheds ......................................................... 111
  - Time Line of Human Land Use and Environmental Conditions, Meeks Creek Watershed/Meeks and Rubicon Bays ............................................................... 112
  - Time Line of Human Land Use and Environmental Conditions McKinney Creek Watershed (Homewood/Chambers/Sugar Pine PT) .................................................. 112
  - Time Line of Human Land Use and Environmental Conditions, Blackwood Creek Watershed ................................................................. 113
  - Time Line of Human Land Use and Environmental Conditions, Ward Creek Watershed ............................................................. 114
  - Time Line of Human Land Use and Environmental Conditions Truckee River (Tahoe City) .............................................................. 114
  - Time Line of Human Land Use and Environmental Conditions, Burton Creek Watershed (Lake Forest) ................................................................. 115
  - Time Line of Human Land Use and Environmental Conditions Watson Creek Watershed (Carnelian Bay) ............................................................... 115
  - Time Line of Human Land Use and Environmental Conditions, Griff Creek Watershed (Lake Vista/Kings Beach/Brockway) ........................................................ 116
  - Time Line of Human Land Use and Environmental Conditions, First/Second/Third/Incline/Mill Creeks Watersheds T16N/R18E ................................................................. 117
  - Time Line of Human Land Use and Environmental Conditions, Marlette and Spooner Lakes/Glenbrook, Logan House, and Lincoln Creeks Watersheds ...................... 118
  - Time Line of Human Land Use and Environmental Conditions, McFaul/Burke/Edgewood Creeks Watersheds (Kingsbury) .......................................................... 121
- References .................................................................................................................... 122
CHAPTER THREE  AIR QUALITY ....................................................................................................................131

Introduction ..............................................................................................................................................131
Historical Conditions...............................................................................................................................132
Current Status of and Trends in Air Quality at Lake Tahoe .................................................................133
Effects of Air Pollutants at Lake Tahoe .................................................................................................135
Link Between Science and Policy for the Benefit of Lake and Watershed Management .................137
Watershed Assessment Focus .............................................................................................................138

Issue 1: The Need to Collect Discontinuous Air Quality Data at Lake Tahoe into a Consistent Form through the Development of a Heuristic Model ..........................................................139
What is the model that was developed specifically for the Lake Tahoe basin, and what are the sources and reliability of data used for its development? ..........................................................139
What are the scenarios that were developed for demonstration of the watershed models for the assessment, and what output is given by the LTAM? .................................................................178

Issue 2: The Need to Determine Spatial Location and Natural versus Anthropogenic Origin of Pollution that Degrades Air Quality in the Lake Tahoe Basin ............................................184
What are the relative contributions of in-basin versus out-of-basin air pollution sources, especially sources in the Sacramento Valley and western slopes of the Sierra Nevada, that affect the Lake Tahoe basin? .................................................................184
What are the relative impacts of natural versus anthropogenic sources, especially the relative contribution of smoke from wildfires versus prescribed fires? ............................................186
How has air quality changed from prehistoric to present times? .........................................................191
How does air quality degradation generated within the basin affect downwind recipient areas, such as the Carson Valley? .................................................................................................................192

Issue 3: The Need to Determine the Adequacy of Existing Air Quality Standards to Protect the Tahoe Watershed’s Terrestrial and Aquatic Resources through Existing Air Quality Control Programs ..........................................................................................................................194
What is the present structure of air quality management in the Lake Tahoe basin, and what are the applicable air quality standards? .................................................................................................................194
How is air quality regulated in the Lake Tahoe watershed? ................................................................196
Will air quality improve, degrade, or remain unchanged under the present regulatory structure? ...........................................................................................................................................197
How would the regulatory system respond to emission increases in the Tahoe basin? ... 198
Are the present standards and programs adequate to prevent adverse effects on the scenic, terrestrial, and aquatic resources in the basin? .................................................................................................................200

Issue 4: The Need to Assess the Relative Impact of Air Quality Sources to Other Sources in Lake Tahoe Basin Welfare .....................................................................................................................202
What are the relative impacts of transported versus local nitrogenous air pollutants on lake clarity? .........................................................................................................................................................202
What are the relative impacts of transported versus local phosphate containing air pollutants on lake clarity? ...............................................................................................................................................203
How well known are the deposition rates of atmospheric pollutants to Lake Tahoe? ...... 204
What are the relative impacts of prescribed fire (low temperature) smoke and wildfire (high temperature) smoke to lake clarity? .........................................................................................................................205
What is the nature of smoke from different types of wildfire (ground, passive crown, active crown) and prescribed fire? .........................................................................................................................206
<table>
<thead>
<tr>
<th>Issue 5: The Need to Establish the Means by which Emissions Can Be Reduced to Levels Necessary to Avoid Deleterious Effects</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lake Clarity ........................................................................</td>
<td>206</td>
</tr>
<tr>
<td>Air Clarity .........................................................................</td>
<td>206</td>
</tr>
<tr>
<td>Forest Health ......................................................................</td>
<td>207</td>
</tr>
<tr>
<td>Human Health ......................................................................</td>
<td>207</td>
</tr>
<tr>
<td>Potential Mitigation Strategies for Reducing Airborne Inputs to Lake Tahoe</td>
<td>208</td>
</tr>
<tr>
<td>References ..........................................................................</td>
<td>209</td>
</tr>
</tbody>
</table>

**CHAPTER FOUR AQUATIC RESOURCES, WATER QUALITY, AND LIMNOLOGY OF LAKE TAHOE AND ITS UPLAND WATERSHED** ................................................................. 215

<table>
<thead>
<tr>
<th>Issue 1: Upland Water Quality In The Tahoe Basin, With Emphasis On Sediment And Nutrient Discharge</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>What are the current sources and sinks of nutrients to Lake Tahoe? How do these compare to previous periods of disturbance and restoration since the mid-1850s?</td>
<td>220</td>
</tr>
<tr>
<td>What is the evidence linking tributary sediment and nutrient loading to land use and watershed geomorphologic characteristics?</td>
<td>252</td>
</tr>
<tr>
<td>What is the effect of nutrient cycling in the watershed on transportable carbon, nitrogen, and phosphorous? How does system hydrology interact with nutrient cycling to influence nutrient loading?</td>
<td>261</td>
</tr>
<tr>
<td>What are the major characteristics of sediment transport in tributary flow to Lake Tahoe? What is known regarding the important sources of this material?</td>
<td>274</td>
</tr>
<tr>
<td>What is the water budget for Lake Tahoe and how might future regional warming scenarios affect precipitation and runoff in the Tahoe basin?</td>
<td>282</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Issue 2: Reduction of Sediment and Nutrient Loading to Lake Tahoe using Best Management Practices, Restoration, and Other Management Techniques</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>What management/restoration approaches are currently being used in the Tahoe basin?</td>
<td>284</td>
</tr>
<tr>
<td>What types of runoff treatment and erosion control techniques have been used in the Tahoe basin?</td>
<td>286</td>
</tr>
<tr>
<td>What is the effect of large hydrologic events on BMP and restoration effectiveness?</td>
<td>295</td>
</tr>
<tr>
<td>Can the expected reduction in sediment and nutrient loading to Lake Tahoe assuming varying restoration and implementation scenarios be quantified?</td>
<td>296</td>
</tr>
<tr>
<td>How will prescribed burning affect sediment and nutrient reservoirs in the watershed and the system hydrology and ultimately the loading of these materials to Lake Tahoe?</td>
<td>298</td>
</tr>
<tr>
<td>Are the available data from demonstration projects and other monitoring activities in the basin adequate for management decisions at the watershed scale? What are the concerns associated with managing restoration at both the project and watershed scales?</td>
<td>300</td>
</tr>
<tr>
<td>What are the primary characteristics of a potential project that should be used to rank its priority (e.g., distance from the lake, proximity to roadway, land slope, soil erodibility, and hydrologic connectedness to other disturbed areas)?</td>
<td>301</td>
</tr>
<tr>
<td>What are the implications for future monitoring?</td>
<td>303</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Issue 3: Ecology, Biology and Biogeochemistry of Lake Tahoe, with Emphasis on Water Clarity</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>What has been the long-term trend for algal growth in Lake Tahoe? What are the major factors regulating the phytoplankton primary productivity?</td>
<td>303</td>
</tr>
<tr>
<td>What is the long-term trend for water clarity in Lake Tahoe and how is clarity affected by phytoplankton and suspended mineral sediment?</td>
<td>310</td>
</tr>
<tr>
<td>What has been the pattern of algal response to nutrient additions? Should management focus on reduction of a single nutrient?</td>
<td>320</td>
</tr>
<tr>
<td>Do the existing long-term data for other biological chemical or physical characteristics of Lake Tahoe show significant trends for other parameters besides algal growth, clarity, and nutrients?</td>
<td>326</td>
</tr>
<tr>
<td>What is known regarding phosphorus and nitrogen in Lake Tahoe and regarding the long-term behavior of these nutrients?</td>
<td>342</td>
</tr>
<tr>
<td>What is the magnitude of nutrient loss from Lake Tahoe and what is the importance of loss processes on mass balance and nutrient accumulation?</td>
<td>348</td>
</tr>
<tr>
<td>What has been the lake response during historical periods of disturbance and recovery?</td>
<td>351</td>
</tr>
<tr>
<td>How does predictive modeling of lake response allow better strategies for restoration and management efforts at Lake Tahoe? What is the scientific basis behind the proposed TRG Clarity Model to be selected?</td>
<td>352</td>
</tr>
<tr>
<td>What is the current status of macroflora (submerged aquatic plants) and macrofauna (benthic invertebrates, crayfish, zooplankton, and fish) in Lake Tahoe?</td>
<td>362</td>
</tr>
</tbody>
</table>

References: 377

**CHAPTER FIVE BIOLOGICAL INTEGRITY**

Introduction: 403

Factors Influencing Biological Integrity in the Basin: 404

A Historical Context for Biological Integrity: 405

Our Assessment of Biological Integrity in the Basin: 407

Issue 1: Define Desired Future Conditions for Old-Growth Forests in the Lake Tahoe Basin: 408

What are the traits of modern relictual stands of old-growth forest in the basin that make them unique from the surrounding matrix of more disturbed (seral) forest vegetation? 409

How does the present condition of old-growth forest differ from precontact time and what are the reasons for that difference? 423

How does the disease incidence of modern old-growth Tahoe forests compare with seral Tahoe forests and those in SPM? 428

What is the present condition of seral (non-old-growth) forests in the basin? 430

What is the distributional pattern of relictual old-growth forest now and what should it be in the near future? What sustainable mix of seral and old-growth forests is possible? 431

Issue 2: The Current Likelihood of Fire; the Relative Importance of Weather, Fuels, and Ignitions in Contributing to the Likelihood of Fire; and Effects of a High Severity Fire on Urban Areas, Air Quality, Lake Clarity, and Biotic Health: 433

What is the likelihood of large fires in the Lake Tahoe basin under different weather conditions? 435

What are the likely weather conditions associated with a high severity fire or a large fire? 441

What is the relative importance of fuels, weather, and ignitions in contributing to the likelihood of large or high severity fires? 444

What are the likely effects of a high severity or large unplanned fire on soil erosion, air quality, lake clarity, biotic health, old growth, and urban areas? 449

How will susceptibility to fire change in the future when snags fall to the ground? 458

Where are the key areas to restore or manage to reduce the likelihood of unplanned, large, or severe fires? 458
TABLE OF CONTENTS (continued)

<table>
<thead>
<tr>
<th>Issue 3: The Need to Determine the Extent to which Prescribed Burning Reduces Fire Risk, Affects Wildlife Habitat, and Mimics the Process of Historic Fire</th>
<th>465</th>
</tr>
</thead>
<tbody>
<tr>
<td>What were the historic fire regimes in the Lake Tahoe basin?</td>
<td>465</td>
</tr>
<tr>
<td>What is the state of knowledge of fire in the ecosystem in the Lake Tahoe basin?</td>
<td>472</td>
</tr>
<tr>
<td>What is the effectiveness of current prescribed burning and other treatments in reducing fire hazard and risk, and mimicking the process of historic fire?</td>
<td>472</td>
</tr>
</tbody>
</table>

Issue 4: The Need to Develop a Conceptual Model of Forest Vegetation and Function as a Basis for Identifying Attributes of Integrity

<table>
<thead>
<tr>
<th>What are the key ecosystem processes and stressors?</th>
<th>473</th>
</tr>
</thead>
<tbody>
<tr>
<td>What are the potential attributes of integrity that are useful for monitoring?</td>
<td>474</td>
</tr>
</tbody>
</table>

Issue 5: The Condition of Aquatic Ecosystems in the Basin

<table>
<thead>
<tr>
<th>What aquatic ecosystems currently occur in the basin?</th>
<th>477</th>
</tr>
</thead>
<tbody>
<tr>
<td>How have aquatic ecosystems changed from historic times to the present?</td>
<td>479</td>
</tr>
<tr>
<td>Which aquatic ecosystems are potentially imperiled or vulnerable to future imperilment in the basin, and what is the state of knowledge about these ecosystems?</td>
<td>483</td>
</tr>
<tr>
<td>What data gaps were revealed in the process of assessing aquatic ecosystems?</td>
<td>490</td>
</tr>
<tr>
<td>What conservation, monitoring, and research activities are most appropriate for the focal aquatic ecosystems identified?</td>
<td>492</td>
</tr>
</tbody>
</table>

Issue 6: The Need to Understand the Identity and Condition of Ecologically Significant Areas in the Basin

<table>
<thead>
<tr>
<th>What are some of the most ecologically unique and biologically intact environments and areas in the basin, and what is the state of knowledge about these areas?</th>
<th>496</th>
</tr>
</thead>
<tbody>
<tr>
<td>What data gaps were revealed in the process of assessing ecologically significant areas?</td>
<td>522</td>
</tr>
<tr>
<td>What monitoring, conservation, and research activities are most appropriate for the ecologically significant areas identified?</td>
<td>522</td>
</tr>
</tbody>
</table>

Issue 7: The Need to Understand the Condition of Species and Populations in the Basin

<table>
<thead>
<tr>
<th>What species currently occur in the basin?</th>
<th>526</th>
</tr>
</thead>
<tbody>
<tr>
<td>How has species composition changed from historic times to the present?</td>
<td>529</td>
</tr>
<tr>
<td>Which species should be of special focus within in the basin based on ecological and cultural criteria?</td>
<td>538</td>
</tr>
<tr>
<td>What is the status of our knowledge about select focal species of greatest interest to local agencies and organizations ?</td>
<td>566</td>
</tr>
<tr>
<td>What data gaps were revealed in the process of assessing species and populations?</td>
<td>570</td>
</tr>
<tr>
<td>What monitoring, conservation, and research activities are most appropriate for the focal species identified?</td>
<td>574</td>
</tr>
</tbody>
</table>

Concluding Remarks

References

<table>
<thead>
<tr>
<th>Employment and Income</th>
<th>602</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population and Demography</td>
<td>607</td>
</tr>
<tr>
<td>Housing</td>
<td>610</td>
</tr>
<tr>
<td>Socioeconomic Well-being and Community Capacity</td>
<td>611</td>
</tr>
</tbody>
</table>

Issue 1: Determining Appropriate Indicators and Geographic Scales for Measuring Social Well-being and Economic Health as They Relate to Environmental Quality

Issue 2: Understanding Patterns of Recreation and Tourism as They Affect Environmental Quality, Social Well-being, and Economic Health

<table>
<thead>
<tr>
<th></th>
<th>614</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>635</td>
</tr>
</tbody>
</table>

Lake Tahoe Watershed Assessment
# TABLE OF CONTENTS (continued)

## Issue 3: Understanding How Land Use Trends Affect the Basin’s Environment and Socioeconomic Dynamics .......................................................... 645

## Issue 4: Determining Appropriate Institutional and Organizational Aspects of Adaptive Management in the Lake Tahoe Basin Context ......................................................... 661

## References ................................................................................................................. 679

## Chapter Seven  Elements of an Adaptive Management Strategy for the Lake Tahoe Basin .......................................................... 691

### Introduction ................................................................................................................. 691

### The Role of Science and Research in Adaptive Management ............................................ 693

- Development of New Information ........................................................................ 694
- Integrated Research ......................................................................................... 695
- Packaging Scientific Information .................................................................. 695

### The Role of Monitoring in Adaptive Management ....................................................... 696

- Monitoring Goals, Objectives, and Questions .................................................. 696
- The Use of Conceptual Models for Indicator Selection ...................................... 697
- Selecting and Interpreting Indicators for Monitoring ......................................... 698
- Considerations in Data Collection .................................................................. 699
- Interpreting the Ecological and Management Significance of Indicator Values .......... 700

### The Role of Modeling in Adaptive Management ......................................................... 701

- Types of Models and Their Applications .......................................................... 702
- Taking a Systems Approach .......................................................................... 703
- Criteria for Evaluating Model Utility .............................................................. 703
- Integration through Modeling .......................................................................... 704
- Decision Support Tools .................................................................................. 704

### Information Acquisition and Assessment in the Lake Tahoe Basin ................................ 706

- Research Needs ................................................................................................. 709
- The Status of Monitoring ................................................................................ 714
- The Status of Modeling .................................................................................. 714
- Quantitative Models of Key Resource Conditions and Interactions .................. 720

### Toward the Future ...................................................................................................... 727

- Collaborative Structures for Adaptive Management ........................................... 727
- Next Steps for the Adaptive Management Cycle ............................................... 730

## References ................................................................................................................. 732
# List of Appendices (Volume II)

<table>
<thead>
<tr>
<th>Appendix</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Wildland Fire Susceptibility Analysis</td>
</tr>
<tr>
<td>B</td>
<td>Aquatic Ecosystem Ratings for the Sierra Nevada and the Lake Tahoe Basin, based on the System of Moyle (1996)</td>
</tr>
<tr>
<td>C</td>
<td>Accounts of Focal Aquatic Ecosystems and Ecologically Significant Areas</td>
</tr>
<tr>
<td>D</td>
<td>Details of Models of Riparian Biodiversity and Community Diversity</td>
</tr>
<tr>
<td>E</td>
<td>Vascular Plants of the Lake Tahoe Basin</td>
</tr>
<tr>
<td>F</td>
<td>Nonvascular Plants of the Lake Tahoe Basin</td>
</tr>
<tr>
<td>G</td>
<td>Vertebrate Species of the Lake Tahoe Basin</td>
</tr>
<tr>
<td>H</td>
<td>Invertebrates of the Lake Tahoe Basin</td>
</tr>
<tr>
<td>I</td>
<td>Fungi of the Lake Tahoe Basin</td>
</tr>
<tr>
<td>J</td>
<td>Historical Changes in Vertebrate Species Composition</td>
</tr>
<tr>
<td>K</td>
<td>Focal Vascular Plant Species of the Lake Tahoe Basin</td>
</tr>
<tr>
<td>L</td>
<td>Designation of Focal Vertebrate Species for the Lake Tahoe Basin</td>
</tr>
<tr>
<td>M</td>
<td>Imperilment and Vulnerability of Lake Tahoe Basin Terrestrial Vertebrates</td>
</tr>
<tr>
<td>N</td>
<td>Focal Vertebrates of the Lake Tahoe Basin</td>
</tr>
<tr>
<td>O</td>
<td>Species Accounts for Select Focal Species</td>
</tr>
<tr>
<td>P</td>
<td>Biologists Queried in Determining Select Focal Species</td>
</tr>
<tr>
<td>Q</td>
<td>Recommended Conservation for Focal Species</td>
</tr>
<tr>
<td>R</td>
<td>Recommended Monitoring for Focal Species</td>
</tr>
<tr>
<td>S</td>
<td>Draft List of Key Indicators Identified by the Socioeconomic and Institutional Working Group</td>
</tr>
</tbody>
</table>