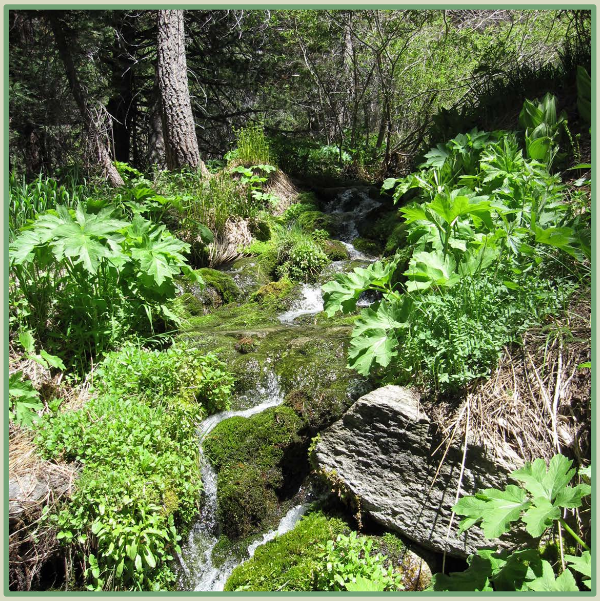
CALIFORNIA INTEGRATED ASSESSMENT OF WATERSHED HEALTH



A Report on the Status and Vulnerability of Watershed Health in California

EPA

November 2013

CALIFORNIA INTEGRATED ASSESSMENT OF WATERSHED HEALTH

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Disclaimer

The information presented in this document is intended to support screening level assessments of watershed protection priorities and is based on modeled and aggregated data that may have been collected or generated for other purposes. Results should be considered in that context and do not supplant site-specific evidence of watershed health or vulnerability.

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Cover photos courtesy of Dr. Raphael Mazor (a small rivulet in the South Fork of the Santa Ana River, left; and Pine Valley Creek in the Tijuana Watershed, lower right) and Greg Smith (Yosemite Falls, upper right).

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

Healthy waters are a vital part of California's identity and economy. The state's high-quality streams, lakes, and wetlands provide a wealth of recreational opportunities, clean drinking water, and other ecosystem services to residents and visitors alike. Their continued function and status as *healthy* aquatic ecosystems depends in large part on the implementation of protection measures to prevent direct impacts and to maintain key watershed features and processes. A more concerted effort to protect high-quality waters by state agencies and other organizations can support the effectiveness of current efforts to restore impaired waters and circumvent the need for costly restoration in the future.

The purpose of the California Integrated Assessment of Watershed Health (the Assessment) is to identify healthy watersheds and characterize relative watershed health across the state to guide future protection initiatives. A healthy watershed has the structure and function in place to support healthy aquatic ecosystems. It is characterized as having either in its entirety, or as key components: intact and functioning headwaters, wetlands, floodplains, riparian corridors, biotic refugia, instream and lake habitat, and biotic communities; natural vegetation in the landscape; natural hydrology (e.g., range of instream flows and lake levels); sediment transport and fluvial geomorphology; and natural disturbance regimes expected for its location.

The goals of the Assessment were to:

1. Integrate multi-disciplinary data to both identify healthy watersheds and characterize the relative health of watersheds across the state;
2. Make watershed health data and information readily available to a variety of state, federal, and local programs for watershed protection planning; and
3. Encourage inter-agency partnerships and collaboration to build upon previous efforts to assess watershed health and protect healthy watersheds.

This report presents the methods and results of the planning and analysis phases of the Assessment, and outlines proposed next steps and applications. The Assessment applies a *systems approach* that views watersheds and their aquatic ecosystems as dynamic and interconnected systems in the landscape connected by surface and ground water and natural vegetative corridors. Watershed health is quantified across the state at the catchment (or subwatershed) scale from existing statewide geospatial datasets and from predictive models derived from field monitoring data collected as part of existing statewide assessment programs. This information is synthesized into several indices that describe watershed condition, stream health, and vulnerability to future degradation.

An important facet of the Assessment is that it leverages existing efforts that have been undertaken to analyze the characteristics of watersheds and the aquatic ecosystems within them. Recent years have seen several agencies and organizations assess various aspects of watershed health at statewide and national scales and/or generate data or tools that facilitate watershed health assessment. This project has forged partnerships among these groups to gather and standardize disparate datasets and provide a more complete picture of watershed health across California.

One outcome of the Assessment is a watershed health database that is available through the California Healthy Streams Partnership (HSP) to groups involved in watershed protection and restoration planning. The database is intended to help identify healthy watersheds that are priorities for local-scale assessment of protection opportunities. Several immediate uses of the database have been identified by HSP partners. For example, watershed health data will support the “Watershed Report Cards” currently being developed by two Regional Water Boards to assess and display monitoring data from a Regional perspective. State and Regional Water Boards are also exploring ways to incorporate Assessment results into the biennial Integrated Report (Clean Water Act Section 303(d) List and 305(b) Report) by identifying watersheds where beneficial uses are presently supported and integrating them into statewide watershed protection and restoration plans and policies.

A second, more enduring, outcome is the integrated assessment framework developed by project partners. This framework reflects our understanding of the interconnected nature of the physical, chemical, and biological condition of aquatic ecosystems; the significance of landscape and watershed scale processes on aquatic ecosystem health; and the need to view water bodies as connected parts within a larger system rather than as isolated units. At present, the framework serves as a starting point for agencies and organizations tasked with protecting healthy waters to collaborate and apply a unified approach rather than undertake disjointed efforts. Over the long term, the HSP envisions that the existing framework will be updated as data gaps are filled and improved methodologies are identified.

1 INTRODUCTION

1.1 *Purpose and Intended Use*

Over the past several decades, considerable effort has been made to restore the impaired streams, rivers, and lakes of California. While some success has been achieved, many miles of streams and acres of lakes remain degraded and new impairments continue to be identified at a rapid pace. Degradation of California's aquatic ecosystems has important economic and societal consequences. In addition to the large capital expenses associated with restoration, impaired waters often lose their ability to provide valuable ecosystem services to the public, such as recreation and supplies of clean water. Together, these issues call for the expanded use of watershed protection as a tool to preserve ecosystem services and preclude the need for costly restoration.

This report presents the methods, results, next steps, and applications of the California Integrated Assessment of Watershed Health (the Assessment). The overarching goal of the Assessment is to characterize the relative health of watersheds across the state for the purpose of guiding future watershed protection initiatives. The Assessment synthesizes disparate data sources and types to depict current watershed condition and stream condition throughout California. It is framed around the recognition that the biological, chemical, and physical health of a stream are fundamentally connected to one another and to the maintenance of natural watershed processes. The Assessment further recognizes that California's watersheds are dynamic, ever-changing systems and characterizes the vulnerability of watershed health to future degradation. By integrating information on multiple ecological attributes at several spatial and temporal scales, a systems perspective on watershed health is provided.

Readers are asked to consider the following points regarding the scope of the Assessment as they review methods and interpret results:

- The term *watershed health* can have several connotations. Its use here refers to the holistic condition of *freshwater* ecosystems within a watershed. The condition of terrestrial, estuarine, coastal, and marine ecosystems are not explicitly analyzed and results should not be used to infer the condition of these ecosystem types.
- The Assessment characterizes *relative* watershed health throughout the state using a collection of indicators that focus on the natural attributes of a watershed and its freshwater streams. No statement on the *absolute* condition of any watershed or water body is made and results do not reflect the influence of factors not considered for analysis.
- Watershed health data generated by the Assessment are intended to support a screening-level assessment of protection priorities across broad geographic areas (e.g., statewide or within the jurisdiction of a Regional Water Control Board). The data should not supplant in-depth, site-specific evidence of protection priorities. Conclusions drawn for smaller-sized areas should be validated with site-specific information.

1.2 The Healthy Watersheds Initiative

The US Environmental Protection Agency (EPA) launched the Healthy Watersheds Initiative to motivate and support active protection of our nation's remaining healthy watersheds (US EPA, 2012). A cornerstone of the Initiative is the promotion of a strategic, systems approach (Beechie, Sear, & Olden, 2010) to watershed protection planning and implementation. The US EPA has proposed the use of *integrated assessments* of watershed health to assist states and others with identifying healthy watersheds and prioritizing candidate watersheds for protection and restoration. Integrated assessments synthesize information on landscape condition, hydrology, fluvial geomorphology, habitat, water chemistry, and biotic communities. By combining multidisciplinary data from multiple spatial scales, integrated assessments reflect our understanding of 1) the interconnected nature of the physical, chemical, and biological condition of aquatic ecosystems; 2) the significance of landscape and watershed scale processes; and 3) the need to view water bodies as connected parts within a larger system rather than as isolated units.

1.3 The Healthy Streams Partnership

The Healthy Streams Partnership (HSP) is an interagency workgroup of the California Water Quality Monitoring Council. The mission of the HSP is to promote the protection of California's healthy streams and the restoration of threatened and impaired streams by providing timely and accurate information directly useful for resource management decisions and actions. Acknowledging that an important information gap existed on healthy streams in California, the HSP requested support from EPA's Healthy Watersheds Initiative for a statewide healthy watersheds integrated assessment.

Learn More Online

Visit the US EPA Healthy Watersheds Initiative and California Healthy Streams Partnership websites to review background material and information on related projects:

Healthy Watersheds Initiative: http://www.epa.gov/healthywatersheds
Healthy Streams Partnership: http://www.mywaterquality.ca.gov/monitoring_council/healthy_streams

1.4 Overview of California's Aquatic Ecosystems

Covering more than 150,000 square miles of mountains, valleys, deserts, and coasts, California is home to a remarkably diverse collection of aquatic ecosystems and biota. This diversity stems from the breadth of topographic, climatic, and geologic variability throughout the state. From north to south, California connects rainforests of the Pacific Northwest to the arid Sonoran desert. From east to west are the rugged mountains of the Sierra Nevada, broad plains of the Central Valley, and coastal mountain ranges flanking the Pacific Ocean.

California's water quality management agencies have defined eight biogeographic regions to frame the efforts of the Perennial Streams Assessment (PSA) program (Figure 1). Each PSA region contains a unique blend of headwater streams, medium and large river systems, riparian forests, floodplain wetlands, and other aquatic ecosystem types. Below is a brief description of PSA regions with information adapted from Ode et al. (2011) and the *California Wildlife Action Plan* (2007):

- **North Coast** – Covers the northwest corner of the state and is typified by rugged forested mountains. Climate is generally moist and cool though semi-arid conditions exist inland due to rain shadow effects.

Major rivers in the north are part of the Klamath River system (e.g., the Klamath, Shasta, and Salmon Rivers). Upper reaches of these rivers flow through alluvial valleys that once supported freshwater wetlands but have largely been lost due to agriculture. Along the coast are several streams and rivers draining coastal mountain ranges. Floodplains broaden near the coast and once supported expansive floodplain forests but are now predominantly under agricultural use.

- **Central Valley** – The Central Valley lies between the Sierra Nevada mountains to the east and coastal mountain ranges to the west. Flat topography dominates and climate is Mediterranean (hot, dry summers and mild, rainy winters). Land cover is predominantly agricultural and most small streams have been dammed or diverted for water supplies. From the north, the Sacramento River flows through the valley to San Francisco Bay. The river historically experienced overbank flows that fed riparian forests and floodplain wetlands but is now mostly constrained by levees and is subject to diversions. The San Joaquin River flows through the southern portion of the valley to San Francisco Bay and habitats in/around the river have also experienced significant alteration due to damming, diversions, and levee construction. In the far south are several rivers that flow into the closed Tulare Basin. Once the site of vast wetlands and natural lakes, the Tulare Basin is now mostly dry due to water diversions for agriculture.
- **Coastal and Interior Chaparral –** Includes a diverse group of ecosystems along the central coast and the foothills of the Sierra Nevada mountains. Climate is generally Mediterranean, with conditions progressively drier inland and further south. Perennial streams are typical near the coast while many interior streams are intermittent. Natural cover types vary with elevation and longitudinally and include forest, woodland, shrub/scrub, and grassland. Forested riparian areas can be found along coastal mountain streams and valley-bottoms. Agriculture has reduced the extent of floodplain and riparian forest along the Salinas River valley and other larger rivers. The region also includes streams and wetlands stressed by the large human population in the San Francisco Bay area.
- **South Coast** – Covers the varied landscapes of the southwest corner of the state. Climate is Mediterranean and natural vegetation types range from shrub/scrub to woodlands and forest. Coastal and inland mountain ranges feed high elevation headwaters that join and flow west through the urban centers of Los Angeles and San Diego. Flood control structures and water use have cut off major rivers from riparian zones and floodplains and reduced the extent of natural riparian forests and wetlands.
- **West Sierra and Central Lahontan** – Comprised of the rugged mountains of the Sierra Nevada range. At lower elevations, climate is characterized by mild, dry summers and rainy winters. Upper elevations experience cold, snowy winters and cool, dry summers. The western slope of the Sierras contains a dense network of snowmelt fed streams that are critical headwaters of the Sacramento and San Joaquin Rivers. Land cover is mostly forest with grasslands and meadows found at lower elevations. Population growth in the Sierra foothills, forest management, grazing, and wildfires have impacted the health of mountain streams and together with climate change represent potential sources of future degradation.
- **Desert - Modoc** – Covers the northeast and southeast corners of the state. The Modoc region in the north and the Mojave Desert in the south are high desert landscapes, with hot, dry summers and cool to cold, moist winters. In the far south is the lower elevation Colorado Desert, with mild to hot temperatures year-round and precipitation arriving as both winter rains and summer monsoons. Land cover is mostly shrub/scrub and woodland, with some forests found at higher elevations. Ephemeral washes predominate and playas, alkali marshes, springs, and seeps are scattered across the landscape. Human population is low but threats to ecosystem health exist in the form of off-road vehicle use, cattle and sheep grazing, and groundwater depletions, and growth is expected in some areas such as the Coachella Valley. Some agriculture is supported in the south through extensive irrigation. The southeastern border of the region is the Colorado River. Riparian forests that once flanked the river have declined as a result of river management practices and invasive species.

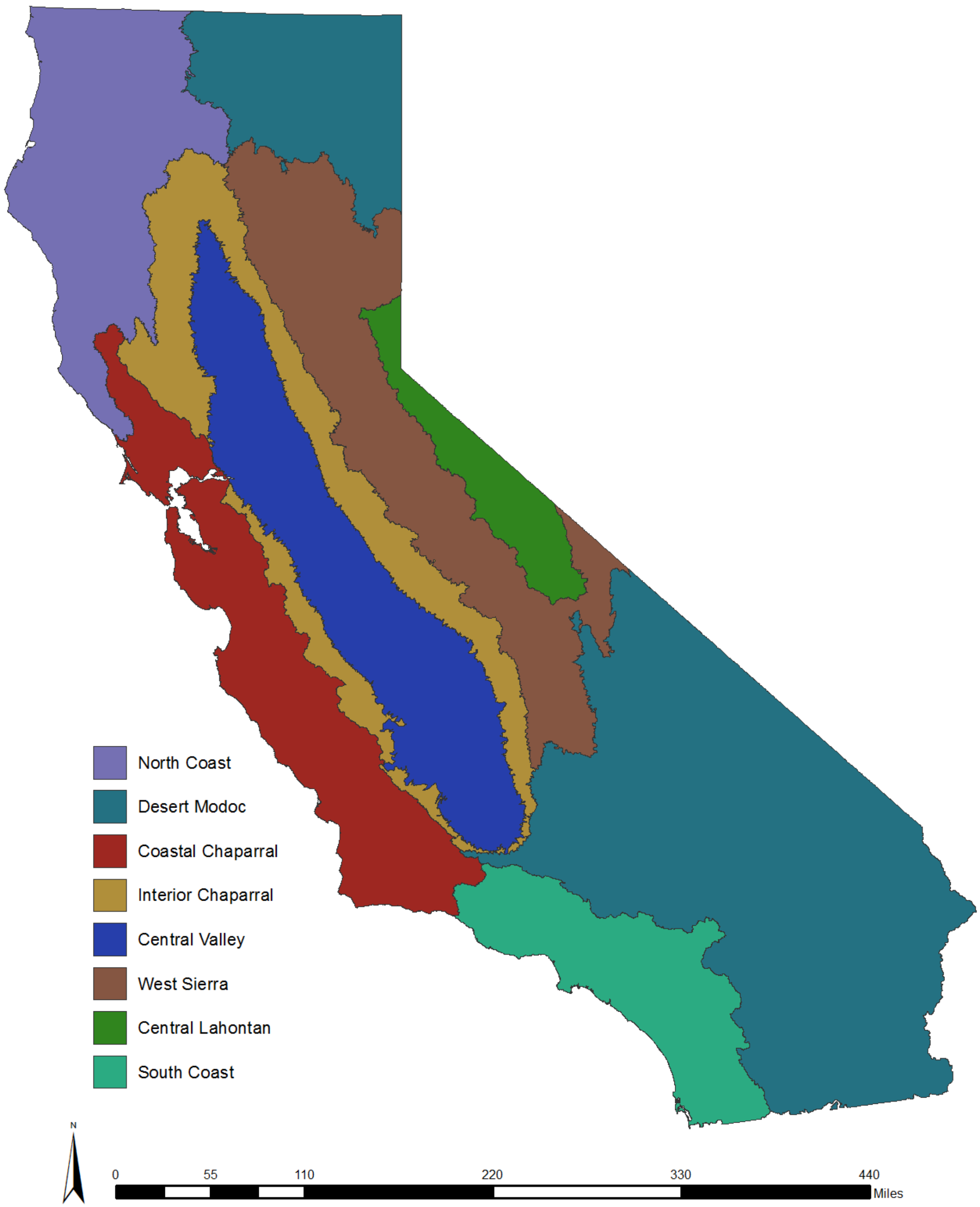

FIGURE 1. BIOGEOGRAPHIC REGIONS OF CALIFORNIA DELINEATED BY THE PERENNIAL STREAMS ASSESSMENT PROGRAM.

2 METHODS OVERVIEW

2.1 *Healthy Watersheds Assessment Process*

This report is the result of a collaborative effort between the US EPA and HSP to assess watershed health throughout California. The Assessment was initiated with the formation of an Assessment Team with representation from US EPA and multiple California state agencies and organizations to develop the assessment methodology, review and communicate results, and implement next steps. The Assessment Team is comprised of members from:

- Participating State Agencies
  - State Water Resources Control Board
  - Central Coast Regional Water Quality Control Board
  - Lahontan Regional Water Quality Control Board
  - Los Angeles Regional Water Quality Control Board
  - North Coast Regional Water Quality Control Board
  - San Diego Regional Water Quality Control Board
  - San Francisco Bay Regional Water Quality Control Board
  - California Department of Fish and Wildlife
  - California Department of Water Resources
- Participating Federal Agencies
  - US EPA Office of Water
  - US EPA Region 9
- Other Participating Organizations
  - California Department of Fish and Wildlife, Aquatic Bioassessment Laboratory
  - Moss Landing Marine Labs
  - San Francisco Estuary Institute
  - San Francisco Estuary Institute/Aquatic Science Center
  - Southern California Coastal Water Research Project
  - State and Federal Contractors Water Agency
  - University of California, Davis
  - Watershed Stewardship Consultation

The first task undertaken by the Assessment Team was to prepare an inventory of available field monitoring data and geospatial data for assessing current landscape, habitat, hydrological, geomorphological, water quality, and biological condition throughout the state and projected vulnerability to future degradation. From this inventory, a list of candidate indicators of watershed health and vulnerability was generated.

The Assessment Team then refined the technical approach to the Assessment, examined and completed the data inventory, and discussed the candidate indicators of watershed health and vulnerability. Also discussed were options for communicating results and potential uses of Assessment output. From this step, an Assessment Roadmap (Figure 2) was produced to serve as an outline for assessment planning, analysis, reporting, and implementation.

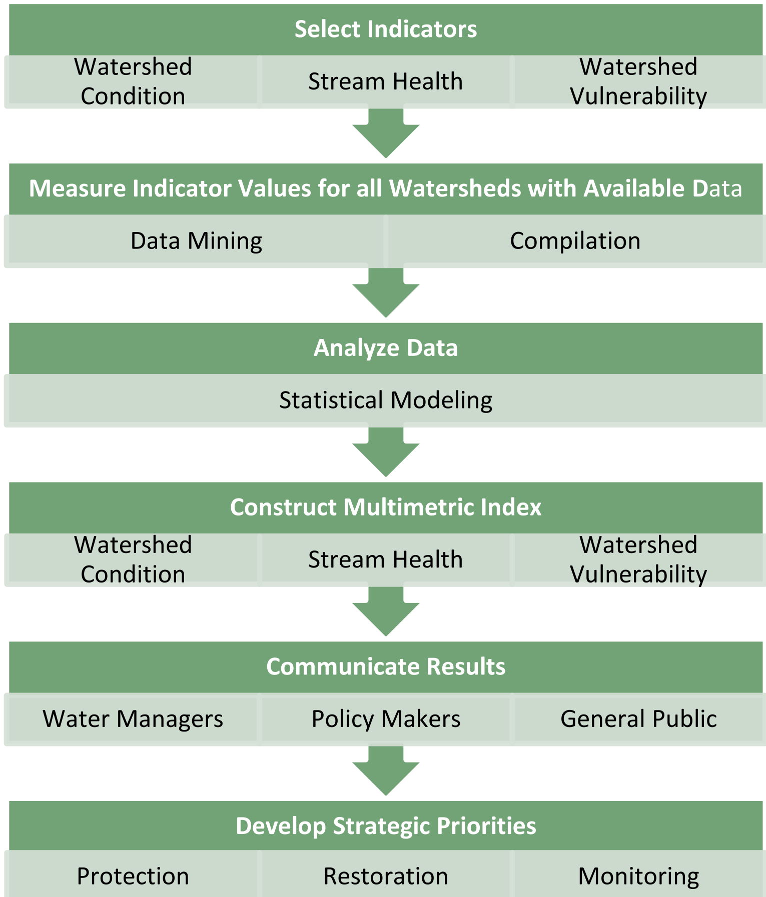

FIGURE 2. ROADMAP FOR THE CALIFORNIA INTEGRATED ASSESSMENT OF WATERSHED HEALTH.

2.2 Conceptual Framework

The US EPA defines a healthy watershed as one in which "natural land cover supports dynamic hydrologic and geomorphic processes within their natural range of variation; habitat of sufficient size and connectivity supports native aquatic and riparian species; and water quality supports healthy biological communities" (US EPA, 2012). This definition encompasses six distinct but interrelated attributes of watersheds and the aquatic ecosystems within them: landscape condition; habitat; hydrology; geomorphology; water quality; and biological condition (Figure 3).

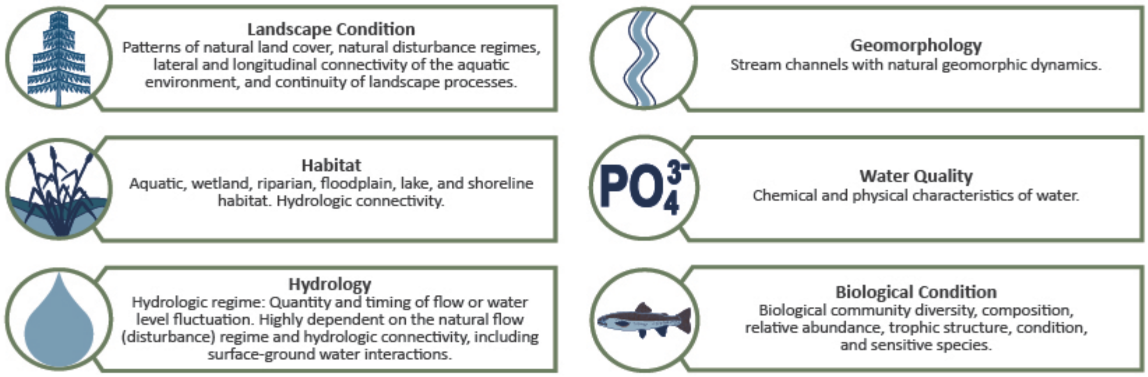

FIGURE 3. SIX ATTRIBUTES OF WATERSHED HEALTH DESCRIBED IN *IDENTIFYING AND PROTECTING HEALTHY WATERSHEDS CONCEPTS, ASSESSMENTS, AND MANAGEMENT APPROACHES* (US EPA, 2012).

An *integrated assessment* of watershed health sets out to evaluate each of these six attribute using a collection of w*atershed health indicators*. Watershed health indicators are specific metrics of the six attributes that are quantified throughout the entire assessment area from existing data. For the California Integrated Assessment, indicators are broadly grouped as:

a) *Watershed Condition Indicators* – These indicators describe the physical setting of the watershed as it relates to aquatic ecosystem conditions. They depict the "naturalness" of structural watershed characteristics and characterize the landscape condition attribute of watershed health; or

b) *Stream Health Indicators* – These indicators focus on in-stream conditions and characterize the hydrologic, aquatic habitat, geomorphic, water quality, and biological attributes of watershed health.

Data used to quantify indicators of watershed condition and stream health are selected to depict present conditions. Because watershed health is a dynamic property that can vary with future changes in climate and human activity, the Assessment also evaluates the vulnerability of watershed health to future degradation. Vulnerability is quantified from a collection of *Watershed Vulnerability Indicators* that characterize potential exposure to future climate, land use, and water use change and wildfire risk. Further discussion of indicators and data sources is provided in Sections 2.4, 2.5, and 2.6.

Two approaches are used to calculate indicator values for every watershed in California. Indicators of watershed condition and watershed vulnerability are quantified from existing geospatial datasets. These datasets are derived from remote sensing activities or other methods that provide continuous and complete coverage across the state. Stream health indicators are quantified from a group of statistical models that relate instream conditions to landscape characteristics. These models are built from existing field monitoring datasets and therefore incorporate information from stream sampling efforts that is otherwise not applicable for an assessment of every watershed in the state. See Section 2.4, Section 2.5, and Appendix C for details of indicator calculation methods.

A total of 23 indicators are used to characterize the relative health and vulnerability of California's watersheds. To integrate this information for reporting and application, indicators are aggregated into 12 indices of watershed condition, stream health, and watershed vulnerability. Each index combines related indicators into an overall score that ranges from 0 to 1, with 1 representing the best condition in the state. Methods for developing index scores are further discussed in Section 2.8.

2.3 Spatial Framework

One objective of the Assessment is to characterize watershed health and vulnerability within a spatial framework that accommodates watershed protection planning across varied spatial scales and planning unit delineations. Toward this end, the geographic units selected for analysis are reach-scale watershed segments of the National Hydrography Dataset Plus Version 1 (NHDPlus) geospatial dataset (US EPA and USGS, 2005)[1]. These watershed segments, termed *catchments* in NHDPlus documentation, comprise the direct drainage area of individual NHDPlus stream reaches. The NHDPlus stream network is a medium resolution 1:100,000 scale representation of all streams in the state.

NHDPlus catchments in California are illustrated in Figure 4. A total of 135,255 catchments fall completely within the state or on the border and are included in the Assessment. Average catchment size is approximately 1.2 square miles.

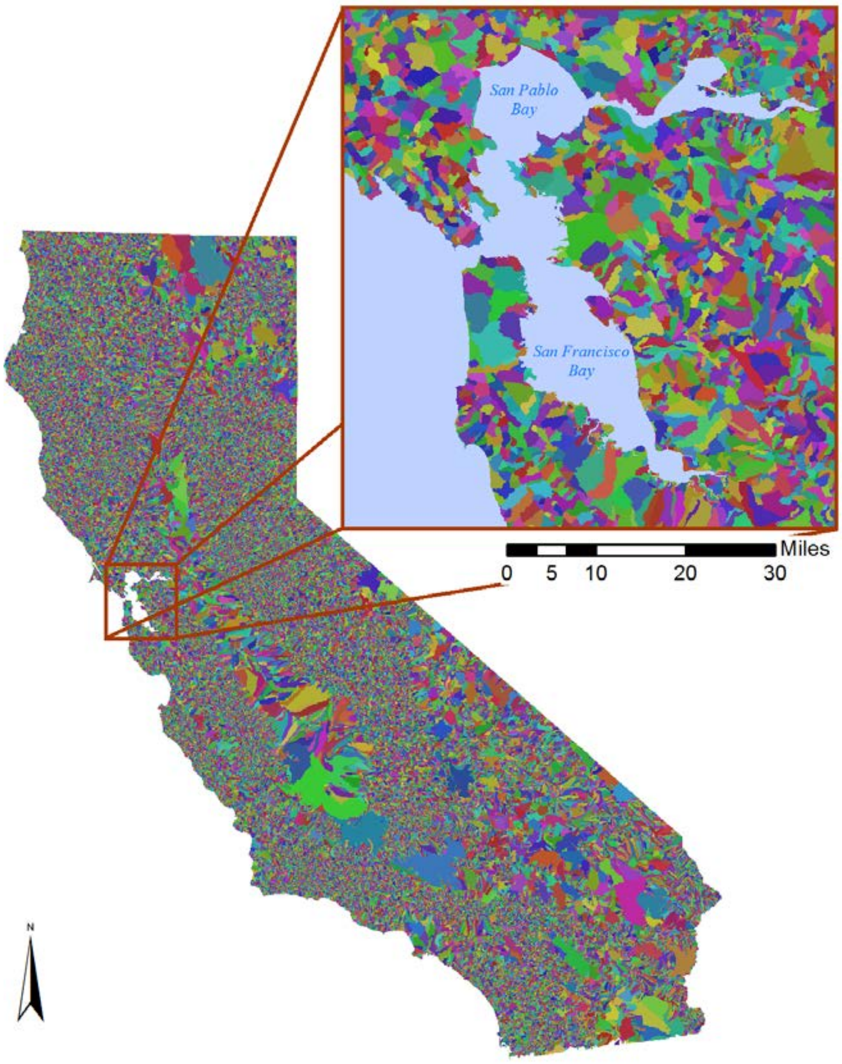

FIGURE 4. NHDPLUS CATCHMENTS OF CALIFORNIA AND THE SAN FRANCISCO BAY AREA (INSERT).

[1] NHDPlus *Version 2* was released in the course of the Assessment but was not available until after planning and initial analysis steps had been completed with NHDPlus Version 1.

Indicators of watershed condition, stream health, and watershed vulnerability are quantified for each NHDPlus catchment throughout California. Calculation of all indicators involved summarizing existing geospatial datasets to catchment-specific values. For stream health indicators, several landscape variables quantified from geospatial data served as input to predictive statistical models of stream condition. Landscape variables describe channel, riparian, and watershed characteristics (e.g., percent riparian forest) at both the incremental (within catchment) and cumulative (within all upstream catchments) scales (Figure 5). Cumulative values were included due to the potential for upstream conditions (above catchment boundaries) to influence the health of a given stream reach. The NHDPlus dataset supports aggregation of incremental-to-cumulative data by storing a unique numeric identifier for each catchment as well as upstream/downstream catchment IDs.

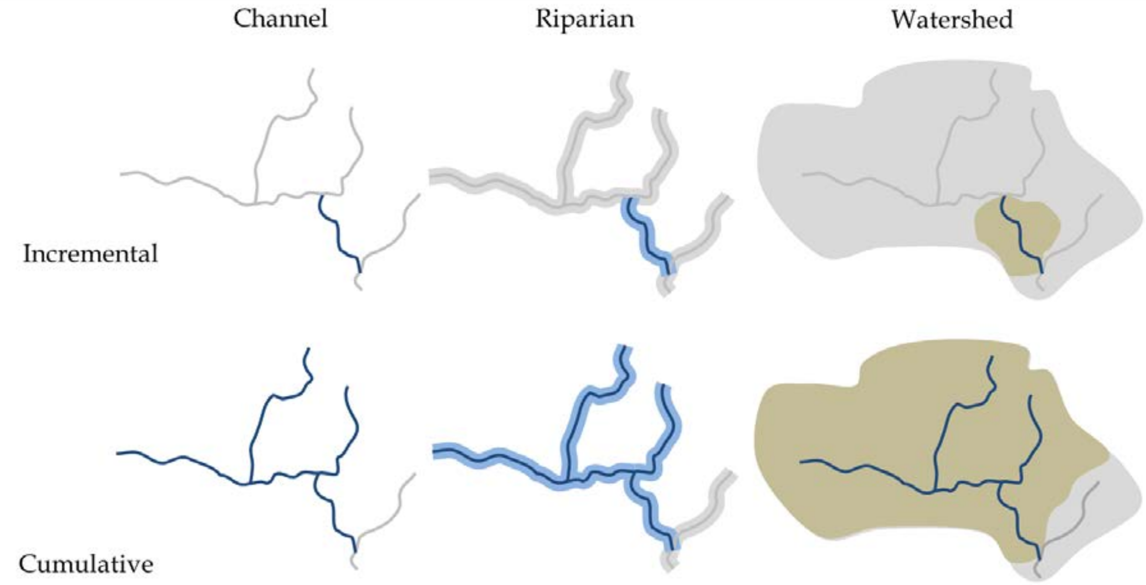

FIGURE 5. DIFFERENCE BETWEEN INCREMENTAL AND CUMULATIVE SCALES FOR QUANTIFYING LANDSCAPE VARIABLES. VARIABLES QUANTIFIED AT THE INCREMENTAL SCALE SUMMARIZE CONDITIONS WITHIN CATCHMENT BOUNDARIES ONLY. VARIABLES QUANTIFIED AT THE CUMULATIVE SCALE ALSO SUMMARIZE CONDITIONS THROUGHOUT ALL UPSTREAM CATCHMENTS.

A final note on the spatial framework of the Assessment relates to differences between the scale of analysis and the intended scale of interpretation. Although NHDPlus catchments serve as analysis units, results are not intended to be used to assess the condition of a single catchment. Rather, results should be viewed over broad geographic areas to identify patterns and prioritize watersheds for in-depth, site-specific assessments of protection needs.

2.4 Watershed Condition Indicators and Data Sources

Watershed condition describes the degree to which certain structural characteristics of a watershed (those most relevant to aquatic ecosystems) are in their natural or pre-settlement state. Watershed condition, as described here, is analogous to the landscape condition attribute of watershed health depicted in Figure 3 and discussed in EPA's *Identifying and Protecting Healthy Watersheds Concepts, Assessments, and Management Approaches* (US EPA, 2012).

The HSP selected indicators of watershed condition (Figure 6) after considering potential watershed characteristics that are relevant to aquatic ecosystem health in California, the availability and quality of data for quantifying indicators, and the objectives of the Assessment. Indicators reflect natural watershed characteristics that provide a foundation for healthy aquatic ecosystems and anthropogenic features whose presence is tied to degraded ecosystem conditions.

The remainder of this section describes watershed condition indicators, the reasoning for their selection, and data sources used to calculate indicator values.

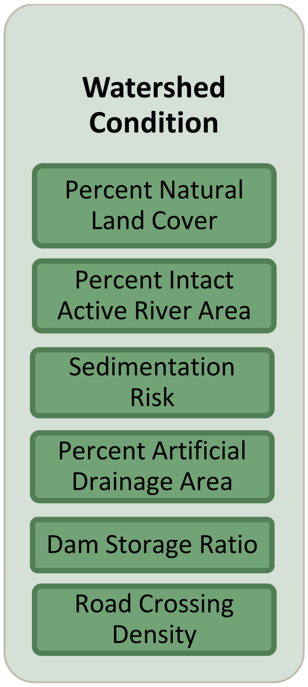

FIGURE 6. INDICATORS OF WATERSHED CONDITION.

Percent Natural Land Cover

Rivers interact with the riparian, floodplain, and upland portions of the landscape through surface and subsurface drainage. Natural land cover throughout a watershed maintains important natural hydrologic processes such as infiltration, evapotranspiration, and groundwater recharge, and protects aquatic ecosystems from nonpoint sources of pollution, including urban and agricultural runoff. Further, natural land cover in and around the riparian zone, floodplains, and wetlands serves as habitat for aquatic species and supports connectivity between habitat patches. Many aquatic organisms depend on the connections provided by natural corridors to migrate to and among suitable habitats as conditions vary over the short-term and seasonally.

The significance of natural land cover on watershed health is captured in the Assessment with the *Percent Natural Land Cover* indicator. Percent natural land cover is calculated from the 2006 National Land Cover Dataset (NLCD) (Fry, et al., 2011) as the area of natural NLCD cover types in a catchment divided by catchment area, multiplied by 100. A list of natural and non-natural NLCD cover types is provided in Table 1.

TABLE 1. CLASSIFICATION OF NATURAL AND NON-NATURAL NLCD COVER TYPES.

Class	NLCD Cover Type & Code[a]
Natural	Open Water (11); Perennial Ice/Snow (12); Barren (31)[b]; Deciduous Forest (41); Evergreen Forest (42); Mixed Forest (43); Shrub/Scrub (52); Grassland/Herbaceous (71); Woody Wetlands (90); Emergent Herbaceous Wetlands (95)
Non-Natural	Developed, Open Space (21); Developed, Low Intensity (22); Developed, Medium Intensity (23); Developed, High Intensity (24); Pasture/Hay (81); Cultivated Crops (82)

[a] NLCD classification codes are shown in parentheses.

[b] *Barren* is considered a natural cover type because desert areas are classified as Barren in the NLCD dataset.

Percent Intact Active River Area

The Active River Area (ARA) has been proposed as a spatially explicit, holistic framework for stream conservation that focuses on portions of a watershed that are most influential to stream conditions (The Nature Conservancy, 2008). Geographically, the ARA includes:

- Material Contribution Areas – Areas that provide the majority of organic and inorganic material input to a stream;
- Meander Belt – The area within which a stream channel migrates over time;
- Floodplains – Expansive, low-slope areas adjacent to a channel;
- Terraces – Former floodplains created during large landscape forming events such as glacial retreat; and
- Riparian Wetlands – Low gradient areas with hydric soils that support wetland dependent species.

The presence of natural land cover in the ARA supports natural flow, sediment, and water temperature regimes, and maintains natural levels of nutrient and organic matter input to streams. *Percent Intact ARA* is included as an indicator of watershed condition and was quantified for each NHDPlus catchment by delineating California's ARA[2], calculating the area of natural NLCD land cover types in a catchment's ARA, dividing by a catchment's total ARA, and multiplying by 100. See Table 1 for list of natural and non-natural NLCD cover types.

Sedimentation Risk

Stream channel morphology exists in a state of dynamic equilibrium with no net aggradation or degradation under balanced inputs of material and energy (Rosgen, 1996). A key variable in this balance is the volume of sediment supplied to streams by near-channel and upland areas. Natural levels of erosion within a watershed

[2] See Appendix E for details of Active River Area delineation.

supply sediment in an amount and rate that support healthy aquatic ecosystems by maintaining natural channel morphology and bed substrates.

Sedimentation Risk is included as an indicator of watershed condition to represent the benefits of the natural sediment regime on watershed health and the detriments of excess erosion and deposition. Sedimentation risk is quantified as the average annual soil loss from a catchment predicted from a modified Universal Soil Loss Equation (USLE) (Wischmeier & Smith, 1978). In the modified USLE, annual soil loss (*A*) is a function of rainfall erosivity (*R*), soil erodibility (*K*), a land cover factor (*C*), and a slope length and gradient factor (*LS*):

$$A = R * K * C * LS$$

Rainfall erosivity (*R*) and soil erodibility (*K*) values used in soil loss calculations are those reported by the USGS for every NHDPlus catchment in the nation (USGS, 2010). Land cover factor (*C*) values were calculated from the area of NLCD cover types in each catchment and *C* factor conversions listed in Table 2 (Montana DEQ, 2012). Slope length and gradient factor (LS) values were calculated from mean catchment slope (θ) and the equation:

$$LS = 1^m * (65.41 \sin^2 \theta + 4.56 \sin \theta + 0.065)$$

Where

m = 0.2 for $\theta < 1\%$ *m = 0.3 for* $1\% \leq \theta < 3.5\%$

m = 0.4 for $3.5 \leq \theta < 5\%$ *m = 0.5 for* $\theta \geq 5\%$

Values of catchment slope used in the above equation are those reported by the USGS for every NHDPlus catchment in the nation (USGS, 2010).

Table 2. Land cover (*C*) factor values for NLCD cover types used in Sedimentation Risk calculations.

NLCD Cover Type & Code	C Factor
Developed, Open Space (21)	0.003
Developed, Low Intensity (22)	0.001
Developed, Medium Intensity (23)	0.001
Developed, High Intensity (24)	0.001
Barren Land (31)	0.001
Deciduous Forest (41)	0.003
Evergreen Forest (42)	0.003
Mixed Forest (43)	0.003
Shrub/Scrub (52)	0.02
Grasslands/Herbaceous (71)	0.02
Pasture/Hay (81)	0.02
Cultivated Crops (82)	0.2
Woody Wetlands (90)	0.013
Emergent Herbaceous Wetlands (95)	0.003

Percent Artificial Drainage Area

A stream's flow regime refers to its characteristic pattern of flow magnitude, timing, frequency, duration, and rate of change (Poff, et al., 1997). The flow regime plays a central role in shaping aquatic ecosystems and the health of biological communities. Aquatic organisms have adapted to the range of physical and chemical conditions brought about by natural flow patterns. Alteration of natural flows (e.g., more frequent floods) can reduce the quantity and quality of aquatic habitat, degrade aquatic life, and result in the loss of ecosystem services.

The natural flow regime is influenced by several structural watershed characteristics. Among these is channel density, which influences peak flow magnitude, timing, and recession. Also important is the nature of the connection between surface water and groundwater, which influences baseflow dynamics. These characteristics are represented in the Assessment by the *Percent Artificial Drainage Area* indicator. This indicator is a measure of the relative extent of a catchment that is drained by man-made surface ditches or subsurface tile drains. Estimates of artificially drained areas used in the Assessment are those reported by the USGS for all NHDPlus catchments in the nation (USGS, 2010).

Dam Storage Ratio

Dams can be a natural feature of the landscape formed by landslides, ice, glacial deposits, or beaver activity, resulting in pooling of water above the dam and limited flow below. While natural dams are often temporary phenomena, man-made dams have lasting impacts on a stream's flow regime and aquatic biota. Several studies have linked changes in natural flow patterns below dams and loss of lotic habitat above dams to declines in populations of California's native aquatic species (UC Davis Wildlife Health Center, 2007). *Dam Storage Ratio* is therefore included as an indicator of watershed condition.

The dam storage ratio of each NHDPlus catchment is quantified as the volume of water impounded by dams in the catchment divided by annual flow volume at the catchment outlet. Dam locations and impounded water volumes were provided by the California Department of Water Resources (2010). Estimates of annual flow volume at NHDPlus catchment outlets are reported in the NHDPlus dataset (US EPA and USGS, 2005).

Road Crossing Density

Longitudinal connectivity refers to the upstream/downstream connectivity of stream habitats. In natural systems, aquatic species can migrate freely throughout a stream network in search of optimal habitat, with connectivity disrupted by natural dams, waterfalls, or segments with intermittent flow.

Stream networks can become highly fragmented with the construction of road-stream crossings. While culverts generally maintain the flow of water, they are typically not designed to maintain connectivity for aquatic species. Culverts also alter the velocity and depth of water above and below a crossing, resulting in alteration of natural channel geomorphology.

To characterize longitudinal connectivity and the potential for geomorphic alteration within catchments, *Road Crossing Density* is included as an indicator of watershed condition. Road crossing density is quantified for each NHDPlus catchment as the number of road-stream crossings in the catchment divided by catchment area. Road crossing counts used for indicator calculations are those reported by the USGS for all NHDPlus catchments in the nation (USGS, 2010).

2.5 *Stream Health Indicators and Data Sources*

Stream health is characterized by the physical, chemical, and biological makeup of a stream. The HSP selected indicators of stream health (Figure 7) based on the availability and quality of data for quantifying indicators, and the objectives of the Assessment. Stream health indicators characterize the aquatic habitat condition, geomorphic condition, hydrologic condition, water quality, and biological condition attributes of watershed health depicted in Figure 3 and described in EPA's *Identifying and Protecting Healthy Watersheds Concepts, Assessments, and Management Approaches* (US EPA, 2012). For the Assessment, they are categorized as indicators of Physical and Biological Habitat Condition, indicators of Water Quality, and indicators of Instream Biological Condition.

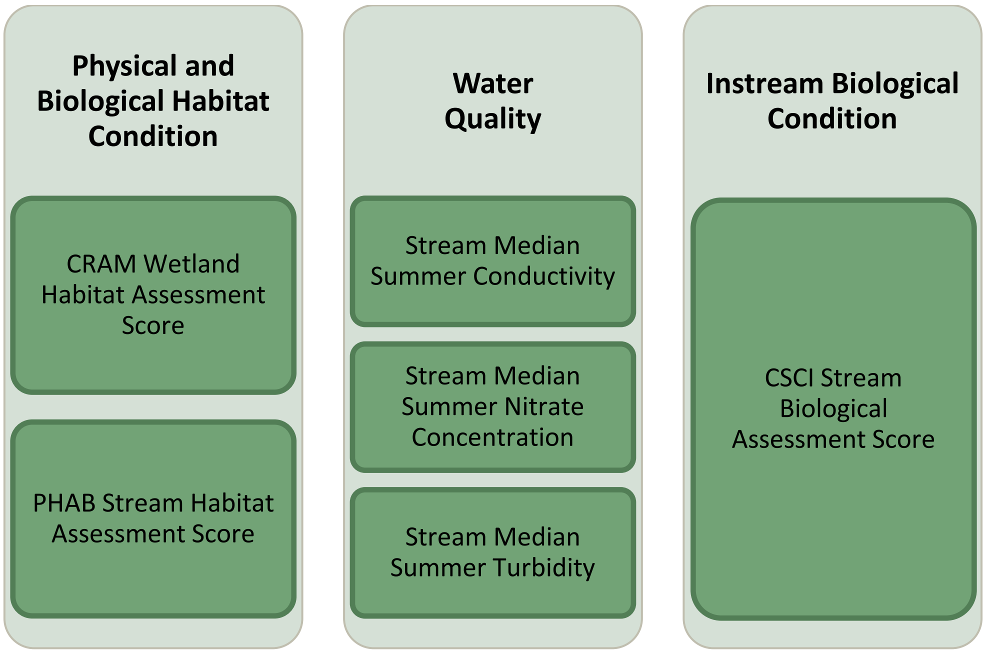

FIGURE 7. INDICATORS OF STREAM HEALTH.

Note that indicators of Physical and Biological Habitat Condition are relevant to both the habitat condition and geomorphic condition attributes of watershed health in EPA's Healthy Watersheds framework, and that a separate group of geomorphic condition indicators is not included in the Assessment. Further, separate indicators for the hydrologic condition attribute of watershed health are not included due to data limitations. However, scores for certain stream health indicators are influenced, in part, by the presence/absence of natural hydrology. Watershed hydrology is also reflected in several indicators of watershed condition (e.g., percent natural land cover, percent intact ARA, etc.).

The underlying source of data for all stream health indicators are field samples collected across the state through various stream monitoring programs. A limitation of stream monitoring data for this assessment is that samples are not available to characterize present conditions for all 135,255 NHDPlus catchments in California. Values of stream health indicators for NHDPlus catchments are, therefore, not calculated directly from monitoring data. Rather, monitoring data were used to develop and validate predictive statistical models that quantify relationships between stream health indicators and landscape variables.

The statistical models developed for the Assessment are regression models that predict a representative value of a stream health indicator for any catchment using landscape variables as predictors. Landscape variables describe land cover, soils, climate, elevation, topography, and geology, as well as anthropogenic features such as dams and roads, at both the incremental and cumulative scales (see Figure 5). Landscape variables used for statistical modeling are listed in Table 3.

TABLE 3. LANDSCAPE VARIABLES USED IN STATISTICAL PREDICTIVE MODELS OF STREAM HEALTH.

Landscape Variables
Stream Channel Characteristics *Stream Length; Sinuosity; Stream Density; Stream Slope; Stream Maximum Elevation; Stream Minimum Elevation; Stream Order*
Basin Topography Characteristics *Mean Elevation; Mean Slope*
Hydrologic Characteristics *Mean Baseflow Index; Mean Recharge; Mean Infiltration-Excess Overland Flow; Mean Saturation-Excess Overland Flow; Mean Curve Number; Mean Rainfall-Runoff Erosivity*
Climatological Characteristics *Mean Annual Temperature; Mean Annual Precipitation*
Soil Characteristics *Mean Percent Sand, Mean Percent Silt, Mean Percent Clay, Mean Percent Organic Matter; Mean Percent Calcium Carbonate; Mean Saturated Hydraulic Conductivity; Mean Soil Erodibility; Mean Electrical Conductivity; Mean Depth to Water Table; Mean Cation Exchange Capacity; Mean Available Water Capacity; Dominant Hydrologic Soil Group; Dominant Surface Texture*
Geologic Characteristics *Dominant Surface Geology*
Watershed Land Cover *Percent of each NLCD Cover Type; Percent Natural Cover; Percent Urban Cover; Percent Agricultural Cover*
Active River Area Land Cover *Percent of each NLCD Cover Type; Percent Natural Cover; Percent Urban Cover; Percent Agricultural Cover*
Anthropogenic Characteristics *Population Density; Road Density; Road Crossing Density; Fish Barrier Density; Dam Density; Mine Density; Toxic Release Inventory Density; Point Source Density; Superfund Site Density; Dam Storage Ratio; Percent Irrigated Area; Percent Artificial Drainage Area*

Stream health indicators are predicted for NHDPlus catchments using *Boosted Regression Tree* (BRT) models. BRTs are a relatively recent approach to modeling ecological relationships that combine two methods: 1) regression tree modeling; and 2) boosting (Elith, Leathwick, & Hastie, 2008). BRT models are well-suited for modeling complex ecological relationships. Example applications of BRT models for guiding management decisions include the prediction of water chemistry and stream condition scores in West Virginia watersheds (Merovich, Petty, Strager, & Fulton, 2013) and prediction of fish community condition scores and species presence throughout the Midwestern US (Clingerman, et al., 2012).

BRTs were selected for use in the Assessment because they have several advantages over other statistical methods (e.g., multiple linear regression or generalized linear modeling):

- BRTs can be used to predict several data types (e.g., numeric, categorical, or binary) and can include any combination of data types as potential predictors.

- BRTs are insensitive to outliers in response and predictor datasets. A pre-processing step to evaluate data distributions and remove outliers is therefore not required.
- BRTs capture interactions between individual predictors in the regression tree structure and do not require the use of "interaction terms" as possible predictor variables (e.g., the product of two predictors that together have an interaction effect).
- There is no assumption of a linear relationship between predictor and response variables and nonlinear relationships are accounted for.
- Techniques have been developed to address overfitting that preclude subjective determinations of "significant" predictors.

Refer to Appendix C for details of stream health indicator modeling methods and results. The remainder of this section describes the selected indicators of stream health, the reasoning for their selection, and methods used to quantify indicator values.

Physical and Biological Habitat Indicators

The term habitat encompasses a host of physical, chemical, and biological characteristics of aquatic ecosystems and the optimal set of conditions for aquatic life will vary from one species to another. Here, assessment of habitat condition focuses on stream habitat characteristics that are monitored as part of the state's Perennial Streams Assessment (PSA) program and wetland habitat characteristics that are monitored as part of the state's California Rapid Assessment Method (CRAM) monitoring program.

The PSA program monitors several physical habitat variables for perennial, wadeable streams throughout California (Ode, Kincaid, Fleming, & Rehn, 2011) and calculates an overall physical habitat (PHAB) score. CRAM assessments monitor physical and biological habitat variables for riverine, depressional, vernal pool, and estuarine wetland types, with data collected by multiple agencies and organizations. These variables are combined into an overall CRAM score. A detailed description of the CRAM field assessment methodology can be found in Collins et al. (2008).

Indicators of habitat condition are the overall *PHAB Score* and the overall *CRAM Score*. PHAB and CRAM scores integrate multiple habitat variables into a single overall value. PHAB and CRAM variables used for habitat scoring are listed in Table 4.

PHAB scores compiled for the Assessment are draft scores acquired from the Southern California Coastal Water Research Project (Eric Stein, personal communication). PHAB scores were available for 632 stream monitoring sites throughout California. CRAM scores were acquired from the San Francisco Estuary Institute (Cristina Grosso, personal communication) and were available for 1,078 wetland monitoring sites.

TABLE 4. HABITAT VARIABLES MONITORED BY PHAB AND CRAM ASSESSMENTS.

PHAB Variables	CRAM Variables
% Macroalgae Cover	Landscape Connectivity
Mean Bankfull height	Percent of Assessment Area with Buffer
% Stable Banks	Average Buffer Width
% Fast Water Habitat	Buffer Condition
Mean % Natural Fish Cover	Water Source
% Canopy Cover	Hydroperiod or Channel Stability
Mean % Cover of Riparian Vegetation	Hydrologic Connectivity
% Coarse Particulate Organic Matter	Structural Patch Richness
Median Particulate Substrate Diameter	Topographic Complexity
% Sands and Fines	Horizontal Interspersion and Zonation
Proximity-Weighted Human Influence Metric	Vertical Biotic Structure
	Number of Plant Layers Present
	Number of Co-dominant Species
	Percent Invasion

PHAB and CRAM scores were summarized by NHDPlus catchment as the median of all scores reported for sites within catchment boundaries. In total, observed PHAB scores were available for 482 NHDPlus catchments and observed CRAM scores were available for 837 NHDPlus catchments.

Observed PHAB scores were used to develop a BRT regression model to predict a representative PHAB score for any NHDPlus catchment outside of the Desert-Modoc PSA Region. The Desert-Modoc region was excluded from model development and prediction because PHAB scores are relevant to perennial streams and not the intermittent/ephemeral streams that dominate the Desert-Modoc Region. Observed PHAB scores for 36 catchments within the Desert-Modoc Region were not used for model development.

Observed CRAM scores were used to develop a BRT regression model to predict a representative CRAM score for any NHDPlus catchment outside the Desert-Modoc PSA Region for reasons noted above. Observed CRAM scores for 37 catchments within the Desert-Modoc Region were not used for model development.

Landscape variables listed in Table 3 were included as potential predictors in models of PHAB and CRAM scores. Refer to Appendix C for details of monitoring data, modeling methods, and model results.

Water Quality Indicators

Under natural conditions, stream water chemistry varies within a characteristic range. For example, average conductivity is 336 µS/cm or less in nearly all of California's good condition streams (Ode, Kincaid, Fleming, & Rehn, 2011). Aquatic biota have adapted to such conditions and the presence of water quality parameters in their natural range is a key feature of healthy streams.

Stream water quality is monitored by several agencies and organizations in California, with dozens of parameters sampled. For this Assessment, the focus is on water quality parameters that most reflect natural ecosystem conditions. Initially, a stream water quality database was compiled using data acquired from the California Environmental Data Exchange Network (CEDEN) database and the USGS National Water Information System (NWIS) for the period January 1, 2000 through December 31, 2011. The following parameters were included in this database:

- Water Temperature
- pH
- Conductivity
- Turbidity
- Nitrate Concentration

Representative values of each water quality parameter were generated for monitored NHDPlus catchments and were calculated as median summer values (i.e., the median of all samples reported for sites within catchment boundaries collected between April and September). Table 5 lists the number of catchments with observed summer medians for each parameter.

TABLE 5. NUMBER OF NHDPLUS CATCHMENTS WITH WATER QUALITY MONITORING DATA.

Water Quality Parameter	Number of Catchments
Median Summer Water Temperature	1,598
Median Summer pH	1,416
Median Summer Conductivity	1,531
Median Summer Turbidity	996
Median Summer Nitrate Concentration	1,197

BRT models were developed from observed water quality data to predict the summer median of each parameter for any NHDPlus catchment outside of the Desert-Modoc PSA Region. The Desert-Modoc region was excluded from model development and prediction because the intermittent/ephemeral streams that dominate the region are not well-represented in water quality monitoring datasets. Observed water quality data for approximately 150 catchments within the Desert-Modoc Region were not used for model development.

Landscape variables listed in Table 3 were included as potential predictors of water quality. Based on model performance and discussions among HSP team members, a subset of the six modeled parameters were ultimately selected as indicators of water quality: *Median Summer Conductivity*, *Median Summer Turbidity*, and *Median Summer Nitrate Concentration*. Refer to Appendix C for details of monitoring data, modeling methods, and model results.

Instream Biological Condition Indicators

A stream's biological condition can be described by the abundance, diversity, and functional organization of fish, invertebrates, and other aquatic fauna. A healthy biotic community demonstrates a natural balance of native species that are integrated across trophic and functional levels and are able to adapt to short- and long-term variation in ecosystem conditions. Healthy watersheds support biotic communities with these characteristics due to hydrologic, geomorphic, and water quality regimes that provide habitat of sufficient size, variety, and connectivity.

The biological characteristics considered in this assessment are macroinvertebrate community variables monitored in perennial streams as part of the state's Surface Water Ambient Monitoring Program (SWAMP). SWAMP monitors the number and proportion of several taxonomic and functional macroinvertebrate groups. Macroinvertebrate variables are combined into an overall *California Stream Condition Index (CSCI) Score* that is used as the indicator of instream biological condition for the Assessment. CSCI scores consider taxonomic completeness (measured by observed versus expected macroinvertebrate species counts) and community structure (measured by a multimetric index that integrates several macroinvertebrate community variables). Additional information on CSCI scoring can be found in Mazor et al. (2012).

CSCI scores for 1,971 stream monitoring sites throughout California were acquired from the California Department of Fish and Wildlife (Pete Ode, personal communication). Scores were summarized by NHDPlus catchment as the median of all scores reported for sites within catchment boundaries. In total, observed CSCI scores were available for 1,687 NHDPlus catchments.

Observed CSCI scores were used to develop a BRT regression model to predict a representative CSCI score for any NHDPlus catchment outside of the Desert-Modoc PSA Region. The Desert-Modoc region was excluded from model development and prediction because the intermittent/ephemeral streams that dominate the region were not well-represented in biological monitoring datasets. Observed CSCI scores for 71 catchments within the Desert-Modoc Region were not used for model development.

Landscape variables listed in Table 3 were included as potential predictors of CSCI scores. Refer to Appendix C for details of monitoring data, modeling methods, and modeling results.

2.6 Watershed Vulnerability Indicators and Data Sources

Watershed vulnerability is defined as the potential for future degradation of watershed processes and aquatic ecosystems. Vulnerability can be driven by a variety of factors. Here, four vulnerability attributes are considered:

- Climate Change Vulnerability;
- Land Cover Vulnerability;
- Water Use Vulnerability; and
- Fire Vulnerability.

The HSP selected indicators of watershed vulnerability (Figure 8) based on the availability and quality of data for quantifying indicators, and the objectives of the Assessment. This section describes watershed vulnerability indicators, the reasoning for their selection, and data sources used to calculate indicator values.

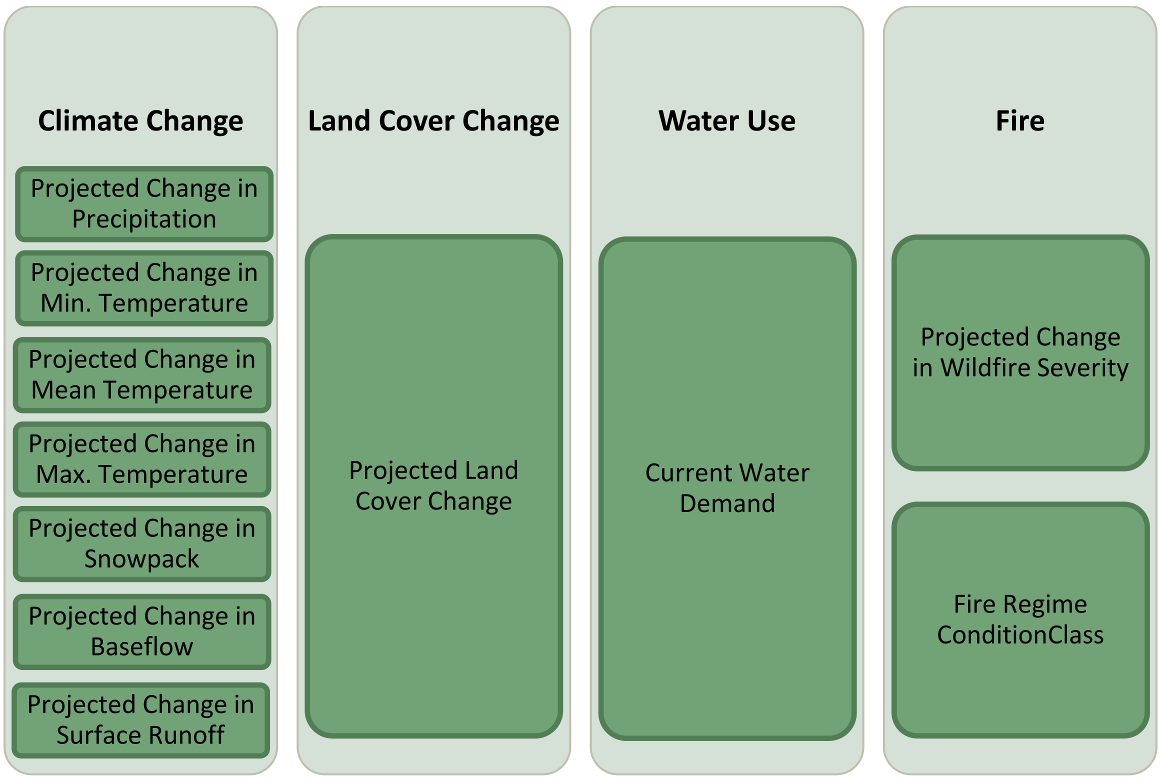

FIGURE 8. INDICATORS OF WATERSHED VULNERABILITY.

Climate Change Vulnerability Indicators

Changes in climate translate to a shift in material and energy inputs to aquatic ecosystems. The impact of climate-driven changes to aquatic ecosystem health can be significant and in line with those posed by large-scale landscape disturbance by humans.

With the availability of downscaled global climate model data, projected changes in temperature and precipitation can be evaluated for watersheds across a large region or state. These projections, however, do not explicitly portray impacts to watershed processes or aquatic ecosystem health. With this goal in mind, several organizations have recently collaborated to model the hydrologic response to projected climate change in California (California Energy Commission, 2013).

This assessment incorporates projections of future climate and hydrology to characterize the vulnerability of California's watersheds to climate change. Seven indicators of climate change vulnerability are used:

- *Projected Change in Precipitation (2010 – 2050)*
- *Projected Change in Mean Temperature (2010 – 2050)*
- *Projected Change in Minimum Temperature (2010 – 2050)*
- *Projected Change in Maximum Temperature (2010 – 2050)*
- *Projected Change in Snowpack (2010 – 2050)*
- *Projected Change in Baseflow (2010 – 2050)*
- *Projected Change in Surface Runoff (2010 – 2050)*

Climate change indicators are quantified from projections acquired from Cal-Adapt (California Energy Commission, 2013). Gridded projections were obtained for the years 2010 and 2050 for annual precipitation, mean temperature, minimum temperature, maximum temperature, mean snow water equivalent, mean baseflow, and mean surface runoff. Grids were averaged by NHDPlus catchment and indicators were calculated as the absolute percent difference between 2050 and 2010 values.

Land Cover Vulnerability Indicators

As described in Section 2.4, natural land cover maintains hydrologic processes within a watershed, protects aquatic ecosystems from nonpoint sources of pollution, provides habitat for aquatic biota, and supports connectivity between habitat patches. Future changes in land cover will occur with the expansion of urban and agricultural lands. *Projected Land Cover Change* is therefore included as an indicator of watershed vulnerability.

Future impervious cover projections from EPA's Integrated Climate and Land Use Scenarios project (US EPA, 2010) served as the source of data for the projected land cover change indicator. Gridded impervious cover projections for the years 2010 and 2050 were acquired and summarized by NHDPlus catchment as the percentage of total catchment area with impervious cover. Indicator values were calculated as the percent difference between 2050 and 2010 impervious cover percentages. Note that projections of agricultural land cover change are not included in the Assessment due to a lack of data.

Water Use Vulnerability Indicators

Surface and groundwater withdrawals can severely alter the natural flow regime, and thus, the health of aquatic ecosystems. Future water demand will increase beyond current levels with population growth and expansion of agriculture, industry, and mining. Projections of future water use are not presently available at a scale that is compatible with the Assessment. For this reason, *Current Water Demand* is used as an indicator of water use vulnerability under the assumption that future patterns of water use will follow present day patterns.

Estimates of current annual water demand for NHDPlus catchments were derived from county water use estimates reported in Kenny et al. (2009). County totals for seven water use categories (Table 6) were distributed among catchments in each county using ancillary data on land use (Fry, et al., 2011), livestock feedlot locations (US Forest Service - Region 5, 2006), mine locations (Esselman et al., 2011), thermoelectric facility locations (US EPA, 2013), and irrigated lands (USGS, 2010). This method for allocating data from one large geographic unit to many smaller geographic units is termed dasymetric mapping and is frequently applied to estimate population sizes in small areas[3]. Note that it does not identify actual locations of water withdrawals.

TABLE 6. SUMMARY OF METHODS FOR DISTRIBUTING COUNTY WATER USE TOTALS TO NHDPLUS CATCHMENTS.

Water Use Category	USGS Water Use Code(s)	Method for Allocating County Total to NHDPlus Catchments	Ancillary Data Source
Domestic	DO-WFrTo; PS-Wtotl	Weighted by area of developed land cover in each catchment (includes low, medium, and high intensity cover types)	Fry et al. (2011)
Industrial	IN-WFrTo	Weighted by area of developed land cover in each catchment (high intensity only)	Fry et al. (2011)
Irrigation	IR-WFrTo	Weighted by area of irrigated lands in each catchment	USGS (2010)
Livestock	LS-WFrTo	Weighted by number of feedlots in each catchment	USFS (2006)
Aquaculture	LA-WFrTo	Weighted by area of each catchment	NA
Mining	MI-WFrTo	Weighted by number of mines in each catchment	Esselman et al. (2011)
Thermoelectric	PT-WFrTo	Weighted by number of thermoelectric facilities in each catchment	US EPA (2013)

Fire Vulnerability Indicators

Wildfires can alter the water balance of a watershed, resulting in reduced evapotranspiration, increased surface runoff, and an altered flow regime. Burned lands are also subject to increased erosion due to a lack of canopy cover and instream responses to wildfires can include increased sedimentation and increased water temperatures.

To account for the effects of wildfires on stream health, two indicators of fire vulnerability are used in the Assessment. The *Fire Regime Condition Class* indicator depicts the existing potential for severe wildfire due to excessive fuel loads. It is quantified from gridded fire regime condition class data acquired from the California Fire and Resource Assessment Program (2010). Values were calculated as the mean condition class of each NHDPlus catchment.

The risk for severe wildfire can be aggravated with increased temperatures, reduced precipitation, and/or other changes in climate. The influence of future climate on wildfire risk is captured with the *Projected Change in Wildfire Severity* indicator. Projected change in wildfire severity is quantified using fire risk projections acquired from Cal-Adapt (California Energy Commission, 2013). Values were calculated from gridded fire risk projections for the period 2020-2085 as the mean fire risk in each NHDPlus catchment.

[3] See geography.wr.usgs.gov/science/dasymetric/ for more information on dasymetric mapping.

2.7 Indicator Rank-Normalization

All indicators of watershed condition, stream health, and watershed vulnerability are *rank-normalized* for reporting and for index calculations (discussed in Section 2.8). Normalization provides a dataset that is both unit-less and on a shared scale, typically 0 to 1 or 0 to 100. Normalizing by rank (rank-normalization) provides a dataset with uniform scale *and* uniform distribution (Figure 9). The benefits of standardizing indicator distributions are discussed further in Section 2.8.

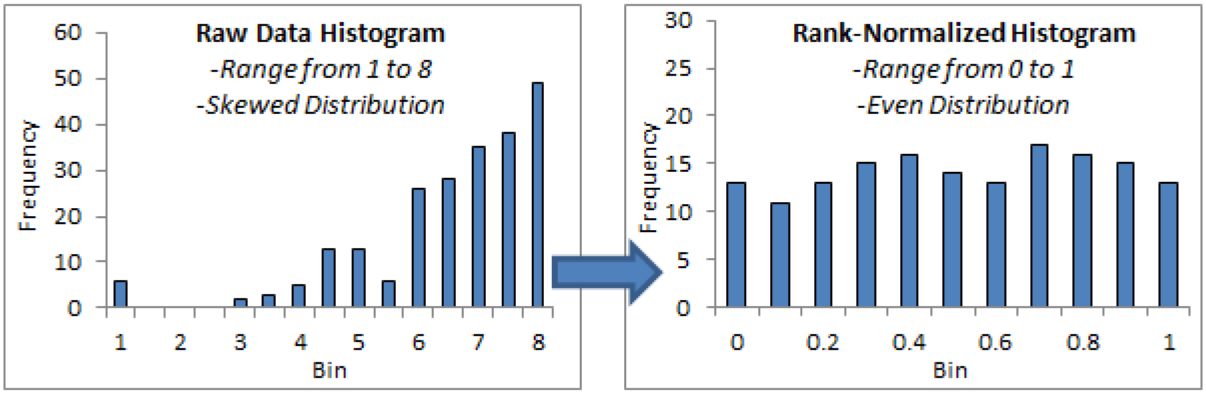

FIGURE 9. EXAMPLE HISTOGRAMS FOR RAW (LEFT) AND RANK-NORMALIZED (RIGHT) DATA. NOTE THAT RANK-NORMALIZATION STANDARDIZES BOTH THE SCALE AND DISTRIBUTION OF COMPONENT METRIC DATA.

Here, rank normalization is performed by:

1. Ranking catchments on the basis of raw indicator values.
    a. Indicators are ranked in ascending order if higher values correspond to higher watershed condition, stream health, or watershed vulnerability.
    b. Indicators are ranked in descending order if higher values correspond to lower watershed condition, stream health, or watershed vulnerability.
2. Applying the following formula to calculate a catchment's rank normalized score:

$$Rank\ Normalized\ Score = \frac{Catchment\ Rank - 1}{Maximum\ Rank - 1}$$

The above steps provide indicator scores ranging from 0 to 1 with consistent *directionality*. Directionality refers to the relationship between indicator scores and watershed health or vulnerability (i.e., whether high scores correspond to higher or lower watershed health). Table 7 lists the original directionality of watershed condition, stream health, and watershed vulnerability indicators. For all indicators, rank-normalized scores are directionally aligned so that higher scores correspond to higher watershed condition, stream health, or watershed vulnerability.

Table 7. Original directionality of watershed condition, stream health, and watershed vulnerability indicators. Rank-normalized scores of all indicators are directionally aligned so that higher scores correspond to higher watershed condition, stream health, or watershed vulnerability.

Indicator Category	Indicator Name	Original Directionality
Watershed Condition	Percent Natural Land Cover Percent Intact ARA	Higher Value = Higher Watershed Condition
	Sedimentation Risk Percent Artificial Drainage Area Dam Storage Ratio Road Crossing Density	Higher Value = Lower Watershed Condition
Stream Health	CRAM Habitat Assessment Score PHAB Habitat Assessment Score CSCI Biological Assessment Score	Higher Value = Higher Stream Health
	Stream Conductivity Stream Turbidity Stream Nitrate Concentration	Higher Value = Lower Stream Health
Watershed Vulnerability	Projected Change in Precipitation Projected Change in Mean Temperature Projected Change in Minimum Temperature Projected Change in Maximum Temperature Projected Change in Baseflow Projected Change in Snowpack Projected Change in Surface Runoff Projected Land Cover Change Current Water Demand Projected Change in Wildfire Severity Fire Regime Condition Class	Higher Value = Higher Watershed Vulnerability

2.8 *Index Development*

Twenty-three indicators are used to characterize the relative health and vulnerability of California's watersheds. To integrate this information for reporting and application, indicators are aggregated into three indices describing overall watershed condition, stream health, and watershed vulnerability:

- Relative Watershed Condition Index
- Relative Stream Health Index
- Relative Watershed Vulnerability Index

An additional nine indices describing individual watershed condition, stream health, and watershed vulnerability attributes are also reported:

- Watershed Condition Attributes
  - Natural Watershed Condition Index
  - Anthropogenic Watershed Condition Index
- Stream Health Attributes
  - Physical and Biological Habitat Index
  - Water Quality Index
  - Instream Biological Condition Index
- Watershed Vulnerability Attributes
  - Climate Change Vulnerability Index

- Land Cover Vulnerability Index
- Water Use Vulnerability Index
- Fire Vulnerability Index

Each index combines related *component metrics* into a single value that ranges from 0 to 1. Component metrics are indicators or other indices of watershed condition, stream health, and watershed vulnerability. See Table 8 for a list of component metrics for each index.

TABLE 8. LIST OF COMPONENT METRICS FOR EACH INDEX OF WATERSHED CONDITION, STREAM HEALTH, AND WATERSHED VULNERABILITY.

Index Category	Index Name	Component Metrics
Watershed Condition	Relative Watershed Condition Index	Percent Natural Land Cover; Percent Intact ARA Sedimentation Risk Percent Artificial Drainage Area Dam Storage Ratio Road Crossing Density
	Natural Watershed Condition Index	Percent Natural Land Cover Percent Intact ARA Sedimentation Risk
	Anthropogenic Watershed Condition Index	Percent Artificial Drainage Area Dam Storage Ratio Road Crossing Density
Stream Health	Relative Stream Health Index	Physical and Biological Habitat Index Water Quality Index Instream Biological Condition Index
	Physical and Biological Habitat Index	CRAM Habitat Assessment Score PHAB Habitat Assessment Score
	Water Quality Index	Stream Conductivity Stream Nitrate Concentration Stream Turbidity
	Instream Biological Condition Index	CSCI Biological Assessment Score
Watershed Vulnerability	Relative Watershed Vulnerability Index	Climate Change Vulnerability Index Land Cover Vulnerability Index Water Use Vulnerability Index Fire Vulnerability Index
	Climate Change Vulnerability Index	Projected Change in Precipitation Projected Change in Mean Temperature Projected Change in Minimum Temperature Projected Change in Maximum Temperature Projected Change in Baseflow Projected Change in Snowpack Projected Change in Surface Runoff
	Land Cover Vulnerability Index	Projected Land Cover Change
	Water Use Vulnerability Index	Current Water Demand
	Fire Vulnerability Index	Projected Change in Wildfire Severity Fire Regime Condition Class

Index scores are calculated as the average of rank-normalized component metrics. Normalization is a standard step in multimetric index development that standardizes the scale and distribution of component metrics (as discussed in Section 2.7). This eliminates the potential for one single component metric to dominate index scores due to varied scales and distributions. Note that the rank-normalization methodology described in Section 2.7 provides scores that are directionally aligned (i.e., higher rank-normalized scores correspond to higher watershed condition, stream health, or watershed vulnerability). Index scores follow the same directionality:

- High watershed condition index scores correspond to high watershed condition;
- High stream health index scores correspond to high stream health;
- High watershed vulnerability scores correspond to high watershed vulnerability.

Raw index scores calculated from rank-normalized component metrics are also rank-normalized for reporting. This ensures that scores for each index range from 0 to 1. Further, rank-normalization eases interpretation by providing index scores that correspond to percentiles. For example:

- A Watershed Condition Index score of 0 corresponds to the lowest condition in the state;
- A Watershed Condition Index score of 0.25 corresponds to the 25th percentile condition;
- A Watershed Condition Index score of 0.5 corresponds to the 50th percentile condition;
- A Watershed Condition Index score of 0.75 corresponds to the 75th percentile condition;
- A Watershed Condition Index score of 1 corresponds to the highest condition in the state.

3 RESULTS & DISCUSSION

This section presents maps illustrating scores for the 12 indices of watershed condition, stream health, and watershed vulnerability listed in Table 8 and a discussion of assessment results (full page maps of all indices and indicators are provided in Appendix A). When reviewing index maps, recall that scores depict relative conditions across the state for the purpose of screening priority areas for detailed assessment of protection and restoration needs and other potential uses outlined in Section 4.

3.1 Watershed Condition

Relative Watershed Condition index scores for California catchments are displayed in Figure 10. Regional patterns in Relative Watershed Condition include:

- Highest scores are concentrated in the Sierra Nevada, Modoc, Mojave Desert, and Colorado Desert regions. Not surprisingly, this includes some of California's least inhabited areas. Headwater watersheds of the Sierra Nevada are critical sources of water for the Sacramento and San Juan Rivers. Protecting these watersheds from landscape degradation will maintain their function and increase the resilience of downstream ecosystems to pressures from climate change and anthropogenic stress.
- Large patches of moderate to high condition areas are apparent in the North Coast, Central Coast, and South Coast regions. Many of these patches are surrounded by low scoring areas and may harbor high-quality aquatic ecosystems that have not yet been impacted by surrounding landscape disturbance. Protecting watershed condition in such areas is important for preserving remaining high-quality waters and facilitating restoration of nearby degraded waters.
- Low scoring areas occur throughout the Central Valley and in the vicinity of the Los Angeles, San Diego, and San Francisco metro areas. Low scores are also concentrated in Salinas Valley, Imperial and Coachella Valleys, and the Upper Klamath watershed. These areas are dominated by urban and/or agricultural cover.

Although Relative Watershed Condition scores are in line with patterns of human activity across the state, the index provides information tailored to watershed protection planning that is not offered by a simple map of land cover or human population. By incorporating indicators of land cover configuration and resource connectivity, the index presents a view of locations where ecological infrastructure is intact and able to support healthy aquatic ecosystems.

Figure 10 also illustrates scores for the Natural Watershed Condition and Anthropogenic Watershed Condition indices. As its name implies, the Natural Watershed Condition index focuses on indicators of natural watershed features (i.e., vegetation and characteristics influencing erosion potential), with high scores corresponding to the presence of natural features and processes that contribute to watershed health. The Anthropogenic Watershed Condition index focuses on man-made structures (ditches, tile drains, dams, and roads), with high scores corresponding to a lack of anthropogenic features that can negatively impact watershed health.

Differences in *what* is measured by the Natural Watershed Condition index versus the Anthropogenic Watershed Condition index can be important for interpretation and application. Protection efforts focusing on land protection, for example, may provide the most ecological value if directed toward areas with high Natural Watershed Condition scores. Anthropogenic Watershed Condition scores, on the other hand, may be more relevant to protection efforts centered on minimizing impacts of new water management structures or roads by locating them away from areas with few manmade features.

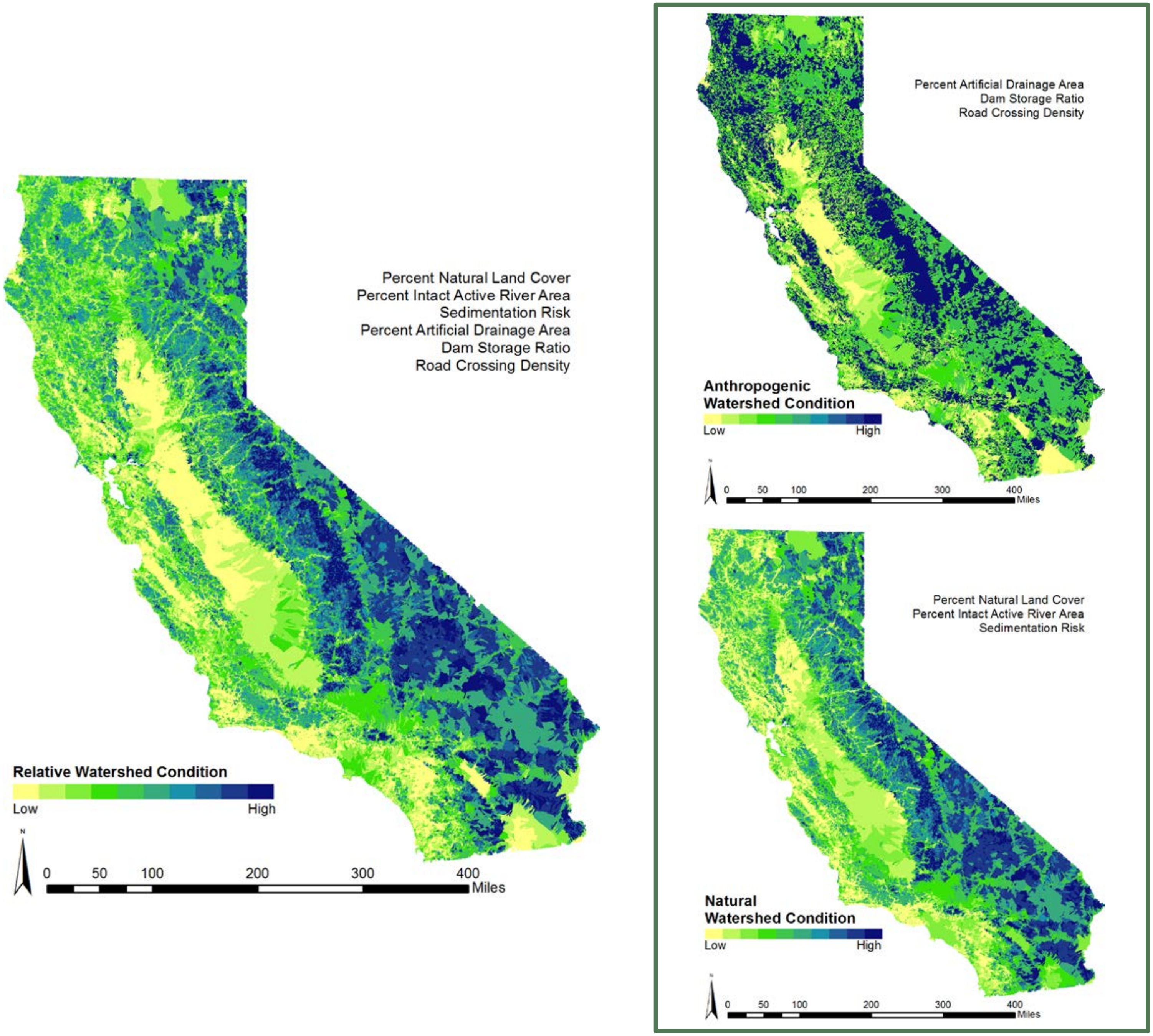

Figure 10. Watershed Condition Index maps.

3.2 Stream Health

Relative Stream Health index scores for California catchments are displayed in Figure 11[4]. Regional patterns in Relative Stream Health scores include:

- High scores are concentrated in the Sierra Nevada and North Coast regions, though stream health varies throughout each region. In the North Coast, low scores are apparent in the Upper Klamath River watershed, in/around the City of Eureka, and in the greater San Francisco Bay area. In the Sierras, low to moderate scores occur along the western foothills and east slope.
- Large patches of mid to high stream health are located in the Central Coast and South Coast regions. In the Central Coast, these patches occur near the City of Santa Cruz and south of the City of Carmel and fall in/around Los Padres National Forest. High scoring portions of the South Coast are generally mountainous areas in the north and east.
- Stream Health scores are consistently low throughout the Central Valley. Large patches of low stream health are also evident in the Salinas River Valley in the Central Coast, and the Los Angeles/San Diego metro areas of the South Coast region.

Relative Stream Health scores are derived from statistical models that relate stream health indicators to several landscape variables. Landscape variables with the largest influence on stream health indicators vary by model and characterize both natural and non-natural watershed features (refer to Appendix C for details of influential predictors). Relative Stream Health scores therefore reflect: 1) ecological gradients shaped by natural variation in soils, topography, geology, hydrology, etc.; and 2) anthropogenic stressors determined to be relevant to stream health through regression modeling. High scoring areas possess natural watershed characteristics that are shared by healthy streams and lack anthropogenic characteristics associated with degraded stream health.

Figure 11 also presents scores for the Physical and Biological Habitat, Water Quality, and Instream Biological Condition indices. These indices are comprised of indicators that are specific to each stream health attribute. Scores for the three attribute indices are generally consistent with one another and with the overall Stream Health Index. However, differences in attribute scores are apparent in some areas. For example, Water Quality index scores along the North Coast and Central Coast are slightly lower than Physical and Biological Habitat index scores and Instream Biological Condition index scores. The opposite is true for the Sierra Nevada and Central Valley regions, where Water Quality index scores are slightly higher than Physical and Biological Habitat index scores and Instream Biological Condition index scores. Such differences underscore the importance of integrating physical, chemical, and biological indicators to assess stream health rather than focusing on a single indicator type.

[4] Stream health indicators and indices were not calculated for catchments in the Desert-Modoc PSA Region. Sufficient data were not available to characterize the health of the ephemeral and intermittent streams that dominate this region.

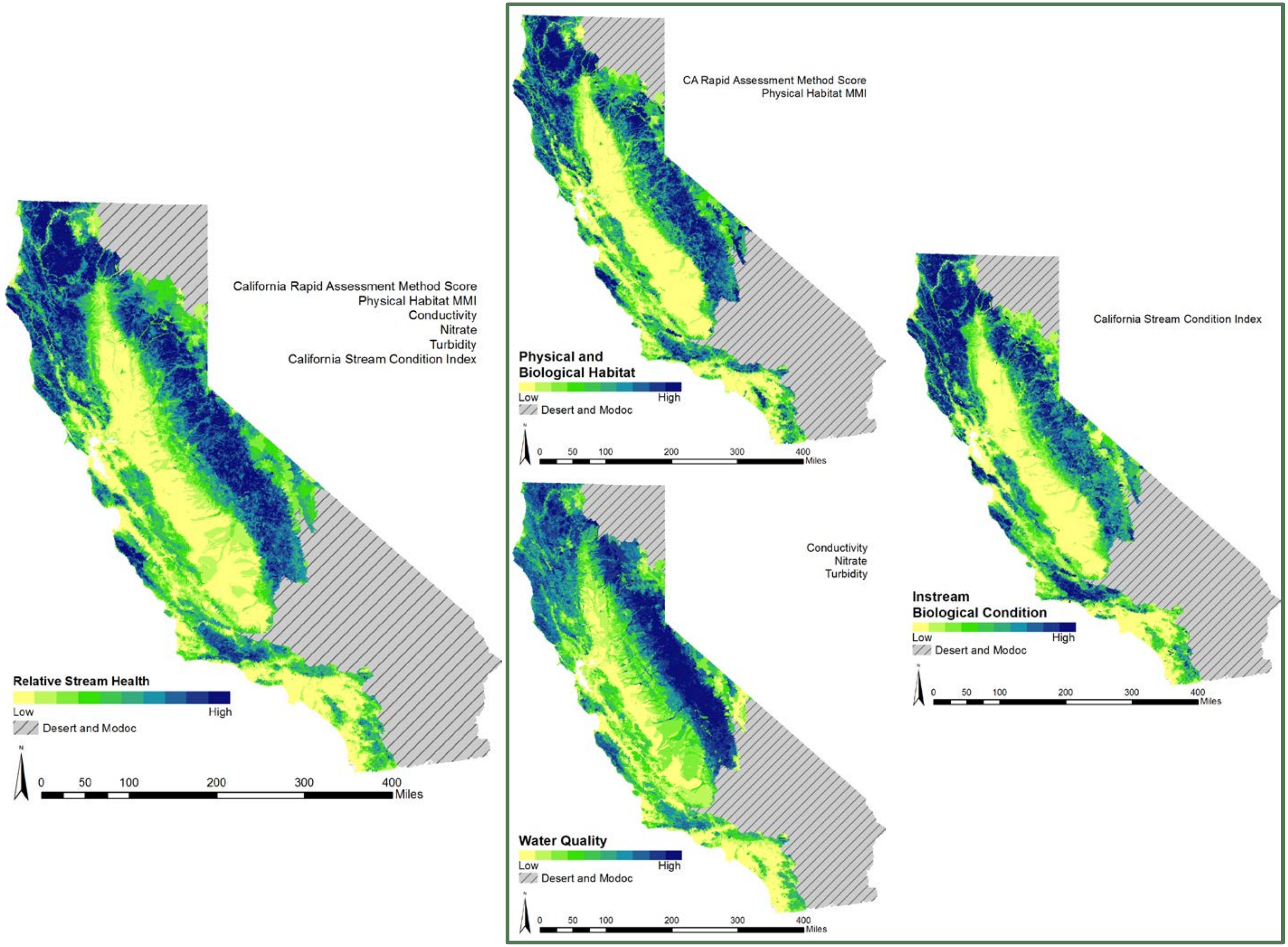

Figure 11. Stream Health Index maps.

3.3 Comparison of Watershed Condition and Stream Health

This assessment uses two indices to characterize watershed health: 1) the Relative Watershed Condition Index, which focuses on structural watershed characteristics; and 2) the Relative Stream Health Index, which focuses on instream conditions. To facilitate a review of similarities and differences between the indices, Relative Watershed Condition Index scores were re-calculated for just the catchments outside of the Desert-Modoc region (i.e., the domain of the Relative Stream Health Index) and compared to Stream Health Index scores.

Figure 12 displays Relative Watershed Condition and Relative Stream Health scores side-by-side. Scores of both indices generally follow patterns of human activity, with mid to high scores throughout the Sierra Nevada and low scores prevalent in the Central Valley and in the urban areas of Los Angeles, San Diego, San Francisco, etc. However, considerable differences are apparent in some portions of the state, such as the North Coast region, where Stream Health scores consistently exceed Watershed Condition scores.

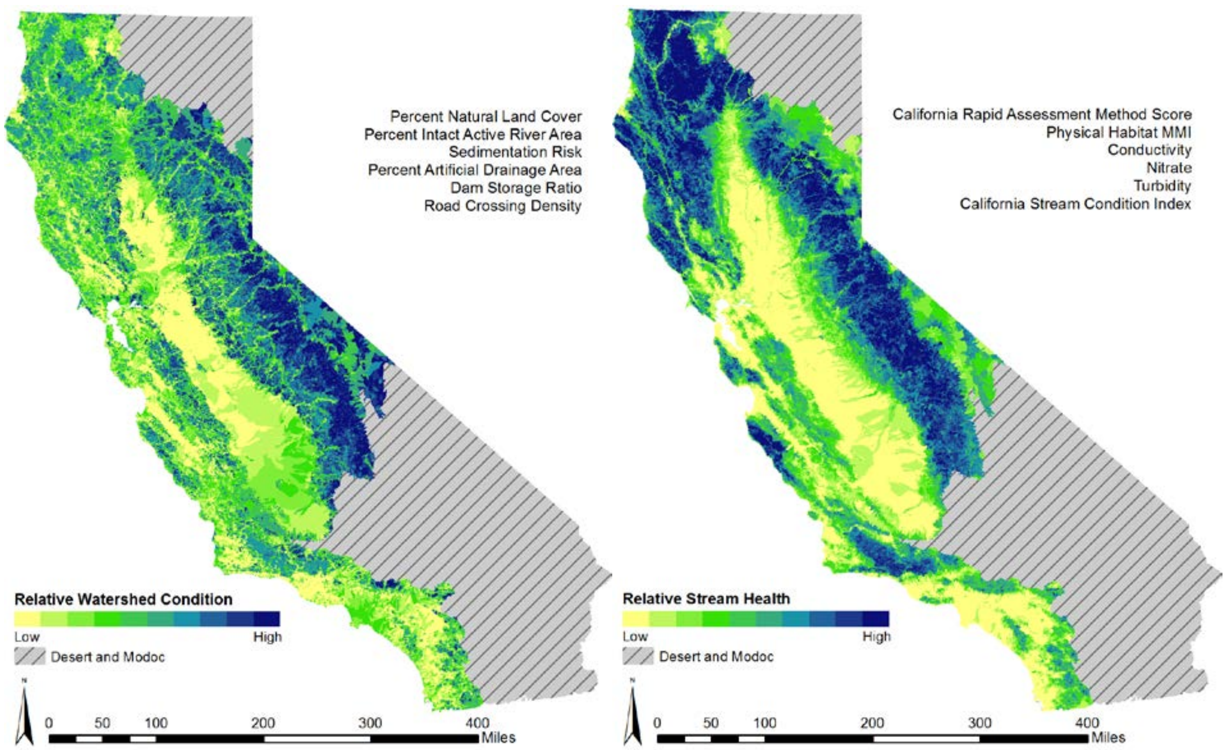

FIGURE 12. RELATIVE WATERSHED CONDITION AND STREAM HEALTH INDEX SCORES.

Figure 13 illustrates deviation in Relative Stream Health Index scores from Relative Watershed Condition Index scores (calculated as Stream Health minus Watershed Condition). Deviation is zero or near-zero throughout much of the state (yellow-colored areas). In the North Coast, Stream Health scores are consistently higher than Watershed Condition scores (positive deviation; blue-colored areas). Stream Health scores are lower than Watershed Condition scores (negative deviation; red-colored areas) surrounding the Central Valley, on the Sierra Nevada east slope, and in the San Francisco and Los Angeles areas.

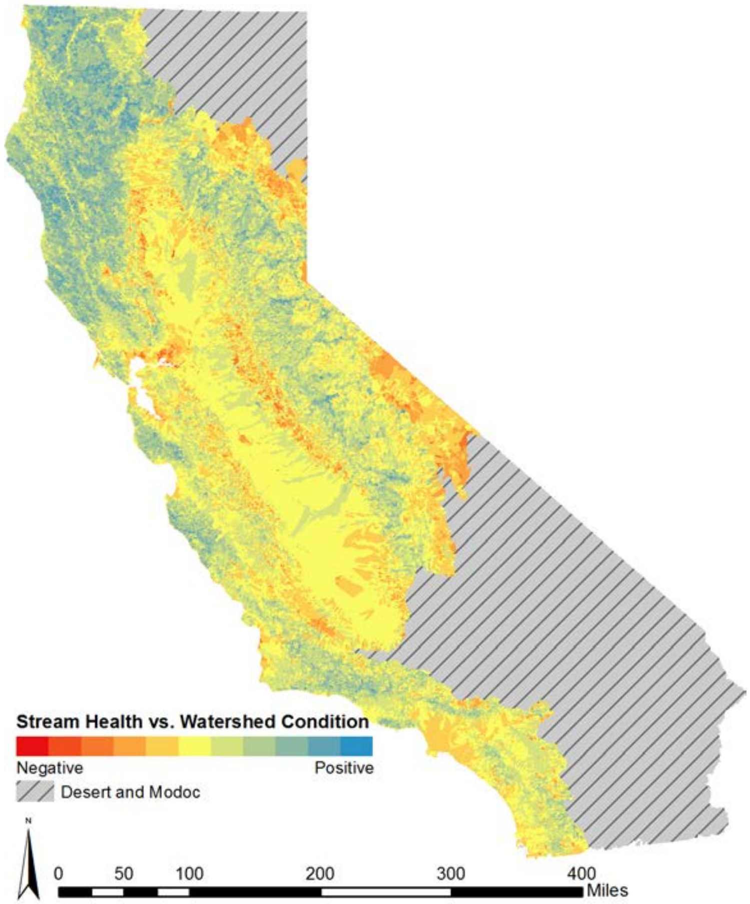

Figure 13. Deviation of Relative Stream Health Index scores from Relative Watershed Condition Index scores (calculated as Stream Health minus Watershed Condition).

There are several possible explanations for observed differences between Relative Stream Health Index scores and Relative Watershed Condition Index scores. These generally fall into three categories:

- Scale – The Relative Watershed Condition Index is derived from indicators that are quantified at the *incremental* scale only (i.e., within catchment boundaries). The Relative Stream Health index is derived from indicators that are predicted from *incremental and cumulative* scale landscape variables. The Relative Stream Health Index therefore accounts for conditions upstream of catchment boundaries that are not depicted in Relative Watershed Condition scores.
- Representation – Indicators of watershed condition are limited in scope relative to landscape variables used for stream health prediction. The Relative Stream Health Index therefore accounts for watershed characteristics that are not captured in Watershed Condition Index scores.
- Influence – Most watershed condition indicators are included as predictors in regression models of stream health (exceptions are Dam Storage Ratio and Road Crossing Density, see Appendix C). However, the influence of watershed condition indicators on stream health scores is relatively low because of the large number of total predictors (65) and because of the structure of each model (see Appendix C for the most influential predictors in each model).

3.4 Watershed Vulnerability

Relative Watershed Vulnerability index scores for California catchments are displayed in Figure 14. Regional patterns in Relative Watershed Vulnerability index scores include:

- High vulnerability scores are concentrated in the Modoc and northern Central Valley regions.
- Large patches of mid to high vulnerability scores occur throughout the remainder of the state. Examples include portions of the Sierra Nevada mountains, the San Francisco Bay area, Salinas Valley, Imperial and Coachella Valleys, and areas north of Los Angeles and north of San Diego.
- Low vulnerability scores are concentrated in the Mojave and Colorado Deserts. Patches of low scores also occur throughout the Sierra Nevada foothills, to the east of San Diego, and across much of the Central Coast.

Scores for individual watershed vulnerability attribute indices (Climate Change, Land Cover, Water Use, and Fire Vulnerability) are also shown in Figure 14. Regional patterns vary considerably among indices due to thematic differences:

- High Climate Change Vulnerability scores are limited to the northern third of the state, where temperatures are expected to increase and climate change is projected to alter snowpacks, surface runoff, and baseflow.
- Land Cover Vulnerability scores are highest in the vicinity of existing towns and cities, and reflect expected expansion of populations into nearby undeveloped areas.
- High Water Use Vulnerability scores are also concentrated in existing urban/agricultural hubs.
- Fire Vulnerability scores are highest in the forested regions of the northwest and Sierra Nevadas, with developed areas receiving low fire vulnerability scores due to the absence of natural vegetation.

Relative Watershed Vulnerability scores represent a best approximation of the potential for future degradation of aquatic ecosystem health. They depict projected changes in natural and anthropogenic watershed characteristics that are related to aquatic ecosystem health rather than explicit changes in physical, chemical, and biological stream conditions. The index is most valuable when used in conjunction with information on current levels of watershed health, such as Relative Watershed Condition Index scores and/or Relative Stream Health Index scores. For example, high vulnerability scores are evident west of Lake Tahoe, and high Relative Stream Health Index scores are also concentrated in this region. Such areas where high stream health coincides with high vulnerability to future degradation can be viewed as priorities for detailed assessment of protection opportunities.

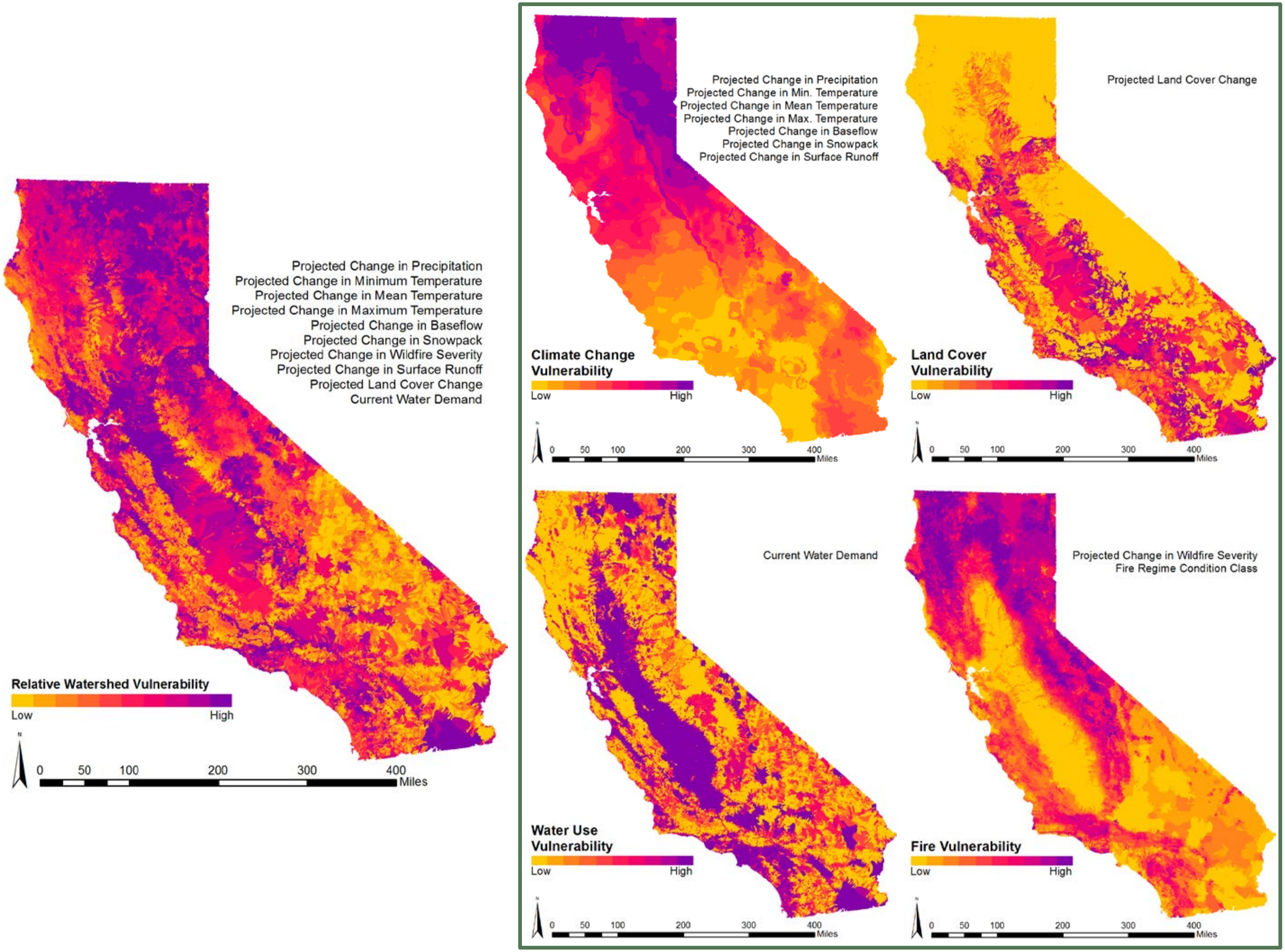

FIGURE 14. WATERSHED VULNERABILITY INDEX MAPS.

3.5 Assumptions & Limitations

Assumptions were made throughout the assessment process that may impose limitations on the use of results for certain watershed protection planning efforts. These assumptions should be recognized by users of Assessment output and are described below:

- **Spatial Framework**
  - The accuracy of the NHDPlus stream network and catchment delineations were determined to be sufficient for statewide and regional screening of watershed protection priorities. Refer to the *NHDPlus Version 1 User Guide* (US EPA and USGS, 2005) for more information on NHDPlus accuracy. Note that the updated and improved NHDPlus Version 2 was released in the course of the Assessment but was not used because planning and analysis had been initiated with NHDPlus Version 1.
  - Indicator and index scores describe overall or average conditions within a given NHDPlus catchment. Assessment results do not supply information at a resolution finer than the catchment scale.
  - If summarizing indicator and index scores over larger planning units, users should investigate inconsistencies between catchment and planning unit boundaries. For example, summarizing by HUC12 (12-digit hydrologic units of the Watershed Boundary Dataset) will result in the aggregation of scores for some catchments outside of a given HUC12 due to differences in HUC12 and catchment delineations.
- **Watershed Condition Indicators and Indices**
  - Watershed condition indicators were selected on the basis of data availability, data quality, and expert judgment of relevance to watershed health. Index scores do not account for aspects of watershed condition beyond those represented by selected indicators.
  - Watershed condition index scores may not reflect the condition of aquatic ecosystems within a given watershed due to upstream influences and factors not represented by watershed condition indicators.
  - Sedimentation risk is a measure of *potential* erosion and sedimentation based on average values of Universal Soil Loss Equation (USLE) parameters. Scores do not account for factors affecting erosion beyond those captured by USLE parameters and do not account for factors affecting sediment transport/delivery.
  - The accuracy and completeness of data used to quantify Dam Storage Ratio and Road Crossing Density were assumed to be sufficient for statewide and regional screening of watershed protection priorities. These datasets may not account for all dams and road crossings in the state and likely contain some positional error.
  - Artificial drainage area estimates used for indicator calculations were derived by the USGS from county totals for the year 1992. These estimates are assumed to reflect present day patterns in artificial drainage practices.
  - Correlation among indicators was not factored into the indicator selection process. Correlation can suggest that one indicator supplies “redundant” information that is already provided by another indicator, thus resulting in biased index scores.

- **Stream Health Indicators and Indices**
  - Stream health indicators were selected on the basis of data availability, data quality, and expert judgment of relevance to watershed health. Index scores do not account for aspects of stream health beyond those represented by selected indicators.
  - Water quality indicators are limited in scope due to data availability. For example, stream temperature was not included as a water quality indicator because available samples did not adequately capture the large temporal variability at any given site and spatial variability throughout the state. Therefore, although selected water quality indicators provide insight into important aspects of water quality, they do not provide a comprehensive picture of water quality in California streams.
  - Flow regime indicators were intended to be used as indicators of stream hydrologic condition but were omitted due to data quality concerns (see Appendix C).
  - Selected indicators of stream health are most relevant to perennial streams. For this reason, stream health is not characterized for the Desert-Modoc region of California, where ephemeral/intermittent streams dominate.
  - Stream health indicators are quantified from statistical models that relate stream health to several landscape variables. Error and uncertainty in model predictions can result from error/uncertainty in both model structure and predictor data. Model predictive error was reviewed through two validation methods (k-fold cross-validation and independent validation; see Appendix C). However, detailed error and uncertainty analysis was not undertaken as part of this effort (e.g., calculation of prediction intervals or quantification of uncertainty) but are assumed to exist at levels appropriate for statewide and regional screening of watershed protection priorities.
  - Correlation among indicators was not factored into the indicator selection process. Correlation can suggest that one indicator supplies “redundant” information that is already provided by another indicator, thus resulting in biased index scores.
- **Watershed Vulnerability Indicators and Indices**
  - Watershed vulnerability indicators were selected on the basis of data availability, data quality, and expert judgment of relevance to watershed vulnerability. Index scores do not account for aspects of watershed vulnerability beyond those represented by selected indicators.
  - Correlation among indicators was not factored into the indicator selection process. Correlation can suggest that one indicator supplies “redundant” information that is already provided by another indicator, thus resulting in biased index scores.

4 NEXT STEPS & APPLICATIONS

The primary goal of the Assessment is to identify healthy watersheds by bringing together multiple datasets for use by management and technical staff to support programmatic goals to protect healthy watersheds. The HSP is committed to building on and refining the framework developed for the Assessment to better inform watershed protection and stream restoration efforts throughout California. To this end, the HSP has identified the following recommended actions:

- The Assessment results and data layers should be displayed on the MyWaterQuality website portals (http://www.mywaterquality.ca.gov/) and EcoAtlas (http://www.ecoatlas.org/). This will foster greater coordination among monitoring efforts by the member agencies as they strive to address their management questions. The websites also serve as an outreach tool for the general public as well as local government planning agencies. For example, the Assessment results can be displayed on the Healthy Streams Portal, and can also be incorporated as an additional data layer for landscape profiles in the EcoAtlas.
- The HSP should incorporate California Environmental Data Exchange Network (CEDEN) data for additional metrics and parameters into the Healthy Streams Portal and use such information to validate and/or adjust Assessment scores, as needed. This will ensure that the California Assessment process continues to be useful and relevant through periodic improvements.
- Assessment data layers should be incorporated into GIS tools to assist agency staff with watershed level assessments.
    - The State Water Board can integrate the Assessment information with existing efforts to map beneficial uses, water quality objectives, and TMDLs. This will help turn the Assessment into a resource that will provide planners, permit writers, NPS staff and TMDL writers with a tool that combines regulatory information with biological and physical context for work within watersheds.
    - The Assessment vulnerability maps can be made accessible to staff to ensure that climate change issues are incorporated into every day decisions.
- The State Water Board should consider using the Assessment results for existing regulatory programs and policy development efforts.
    - The Assessment data layers can be integrated into the 305(b)/303(d) integrated report to provide a better representation of the health of California waters. The Assessment information can be used with probability based data and other models to identify areas where beneficial uses are being supported.
    - Stormwater program staff can utilize the Assessment to assist permitees as they develop watershed plans required by some municipal stormwater permits.
    - The Assessment data layers can provide additional information for State Water Board efforts such as the wetlands policy, biological objectives and the Nonpoint Source Implementation Plan to identify and protect streams that are in good condition.
- The California Department of Water Resources should further investigate the utility of incorporating information generated in the Assessment into the State Water Plan updates through the Sustainability Indicators project.
- The HSP should investigate opportunities to partner with other similar efforts to aggregate multiple datasets into indices of environmental health. The Central Coast and San Diego Regional Water Boards are developing multi-metric report cards for their waters and should be able to incorporate

Assessment information. Potential partnerships include the California Department of Fish and Wildlife's State Wildlife Action Plan and Areas of Conservation Emphasis or The Nature Conservancy's efforts to identify areas of freshwater biodiversity.

- The HSP should work with partner agencies to identify resources to conduct research and monitoring designed to improve watershed health predictions in areas with limited data.
- The HSP should identify opportunities for increased stewardship through citizen monitoring groups and other local organizations to help maintain the condition of healthy watersheds and to identify problems and potential solutions for those watersheds identified as vulnerable.

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APPENDIX A MAP ATLAS

This Appendix contains full page maps for all indicators and indices of watershed condition, stream health, and watershed vulnerability.

The following guidelines were used for map development:

- Maps display rank-normalized indicator or index scores and therefore depict relative conditions;
- Maps were created using 10 equal-interval color classes. Because scores are rank-normalized, these classes generally correspond to deciles;
- To ease interpretation, maps display indicators in their original directionality (see Table 7) rather than directionally aligned scores used for index calculations. For example, areas with "high" Sedimentation Risk scores in Figure 17 correspond to areas with high erosion potential. The inverse of these scores (1-x) were used to calculate the Relative Watershed Condition Index so that higher erosion potential corresponded to a lower index score.

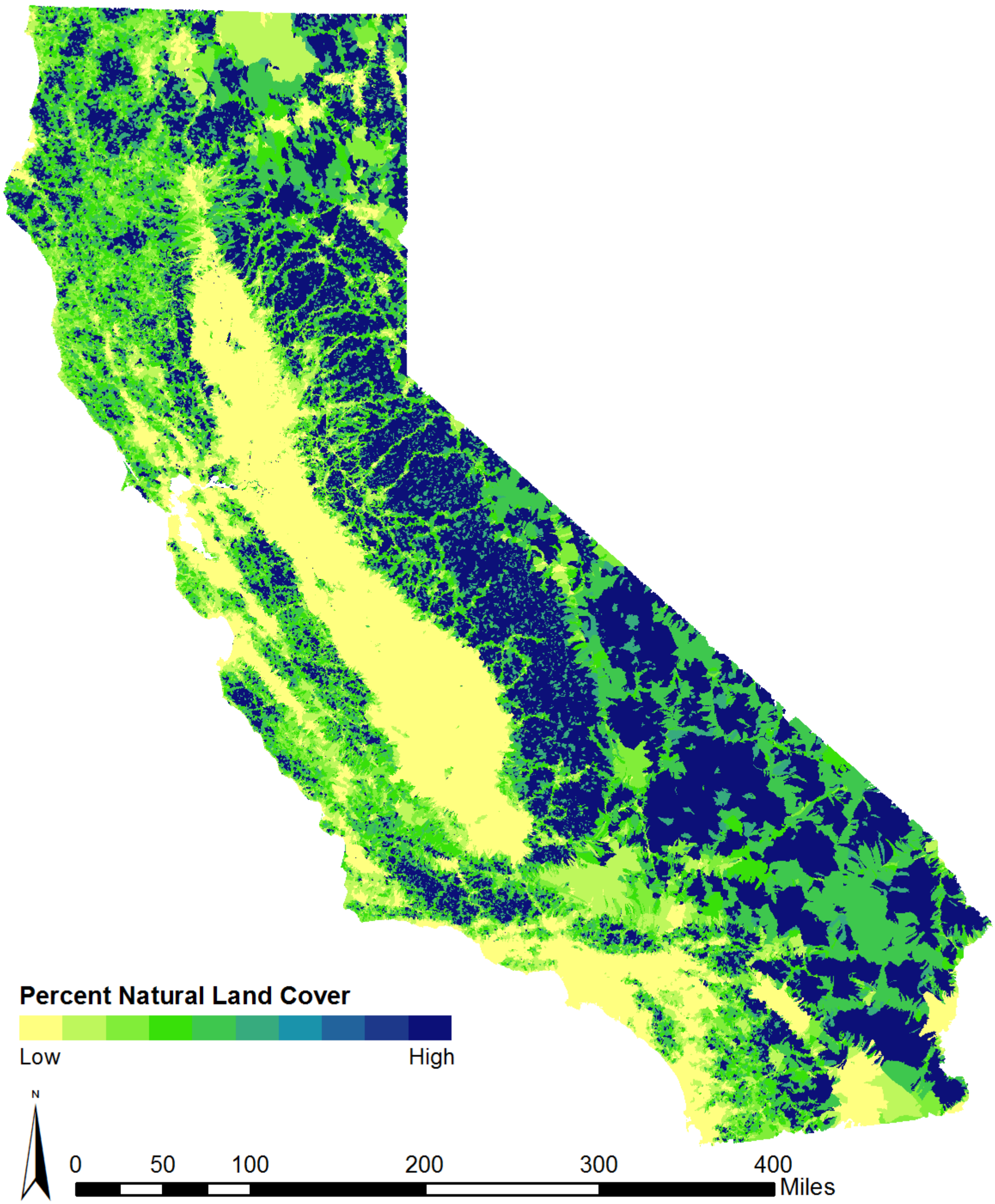

FIGURE 15. PERCENT NATURAL LAND COVER SCORES.

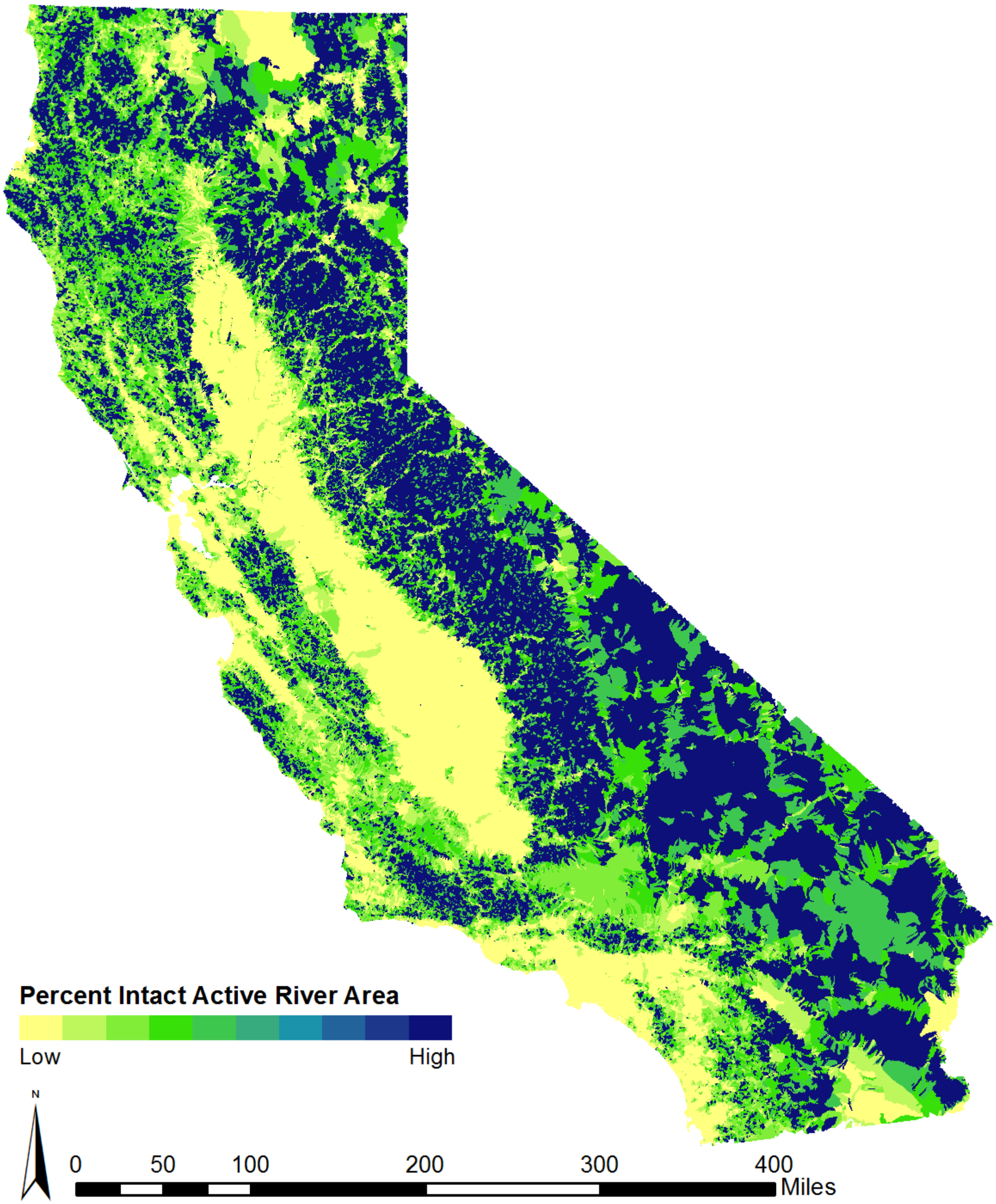

FIGURE 16. PERCENT INTACT ACTIVE RIVER AREA SCORES.

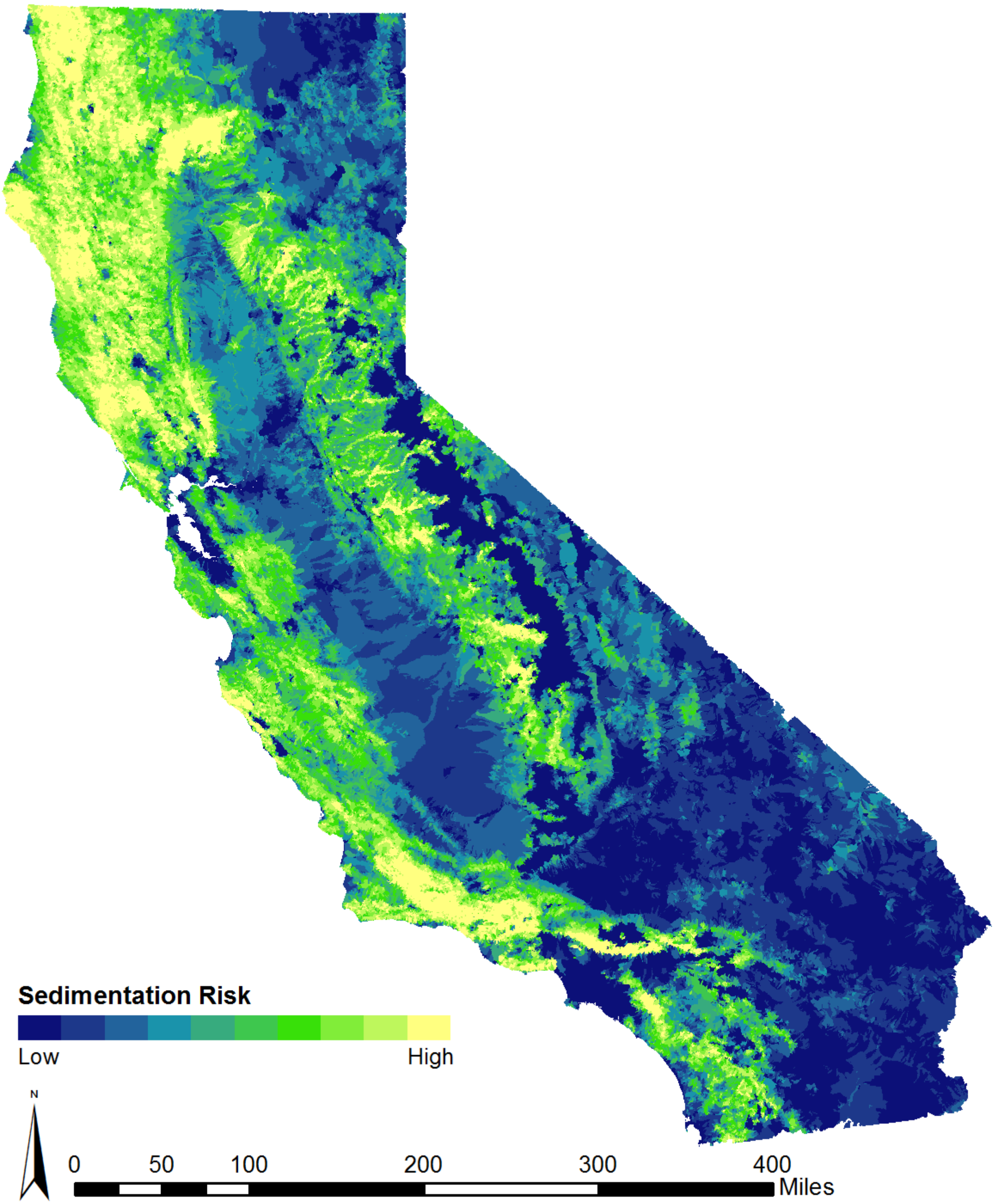

FIGURE 17. SEDIMENTATION RISK SCORES.

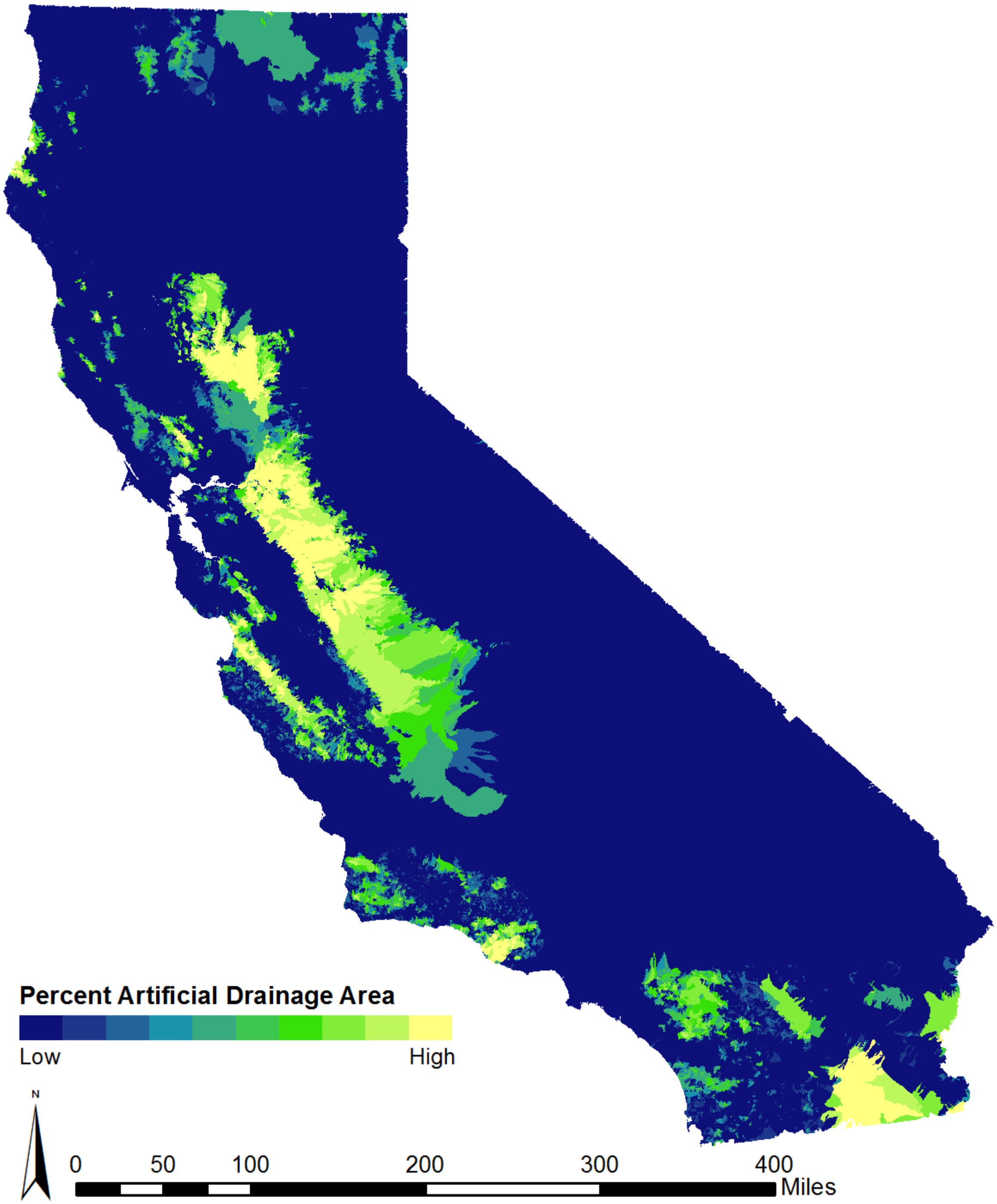

FIGURE 18. PERCENT ARTIFICIAL DRAINAGE AREA SCORES.

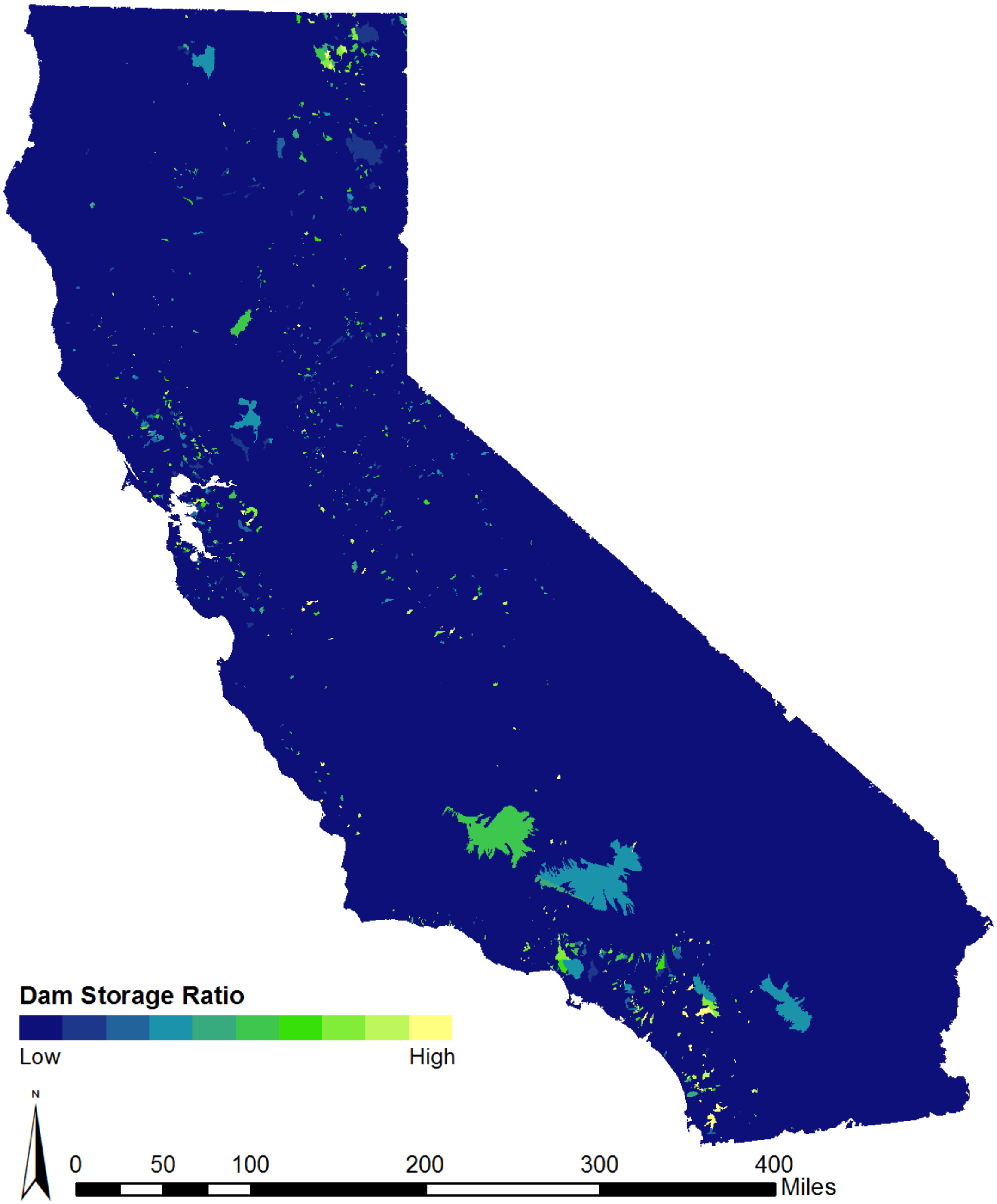

FIGURE 19. DAM STORAGE RATIO SCORES.

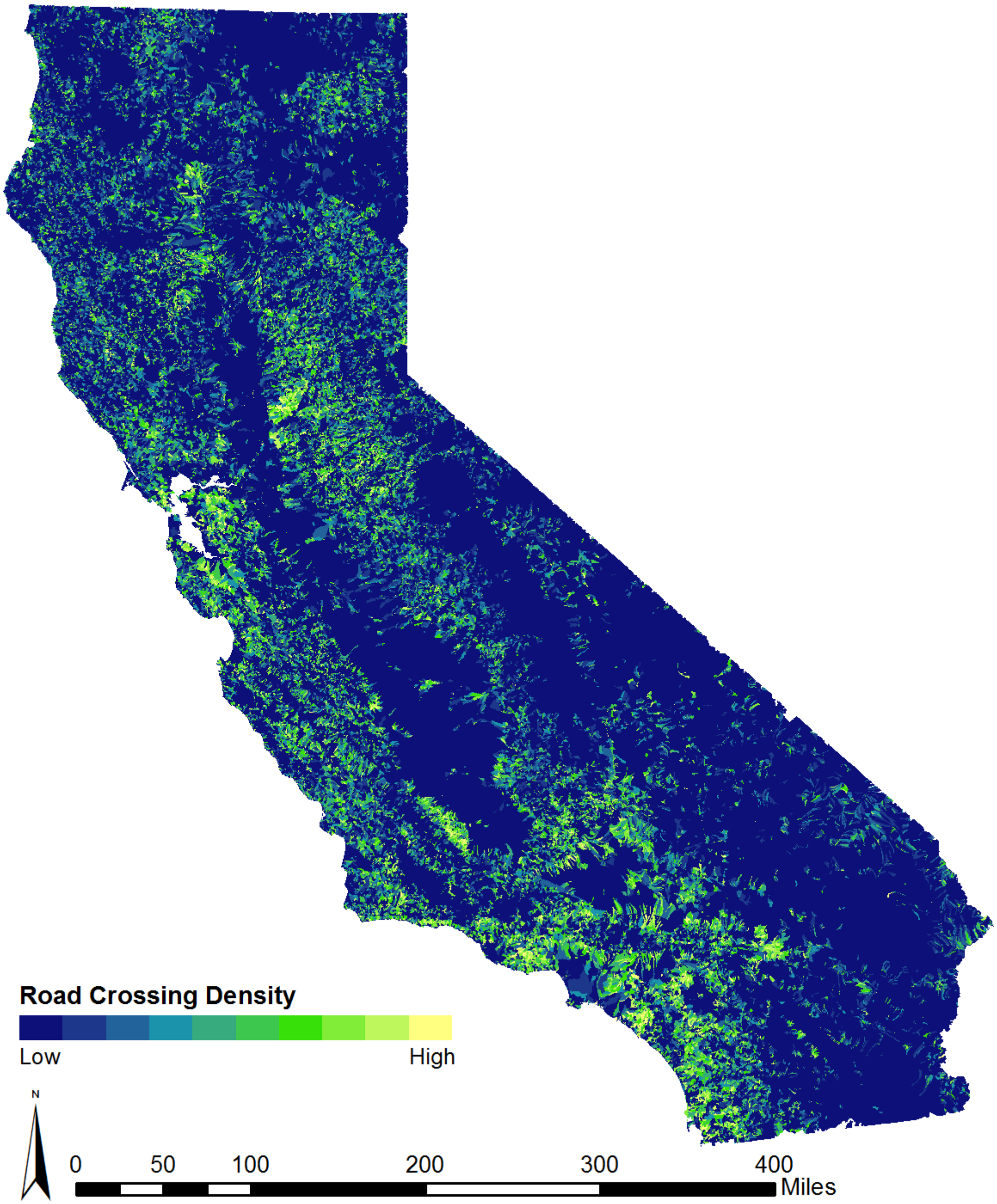

FIGURE 20. ROAD CROSSING DENSITY SCORES.

A2 Watershed Condition Indices

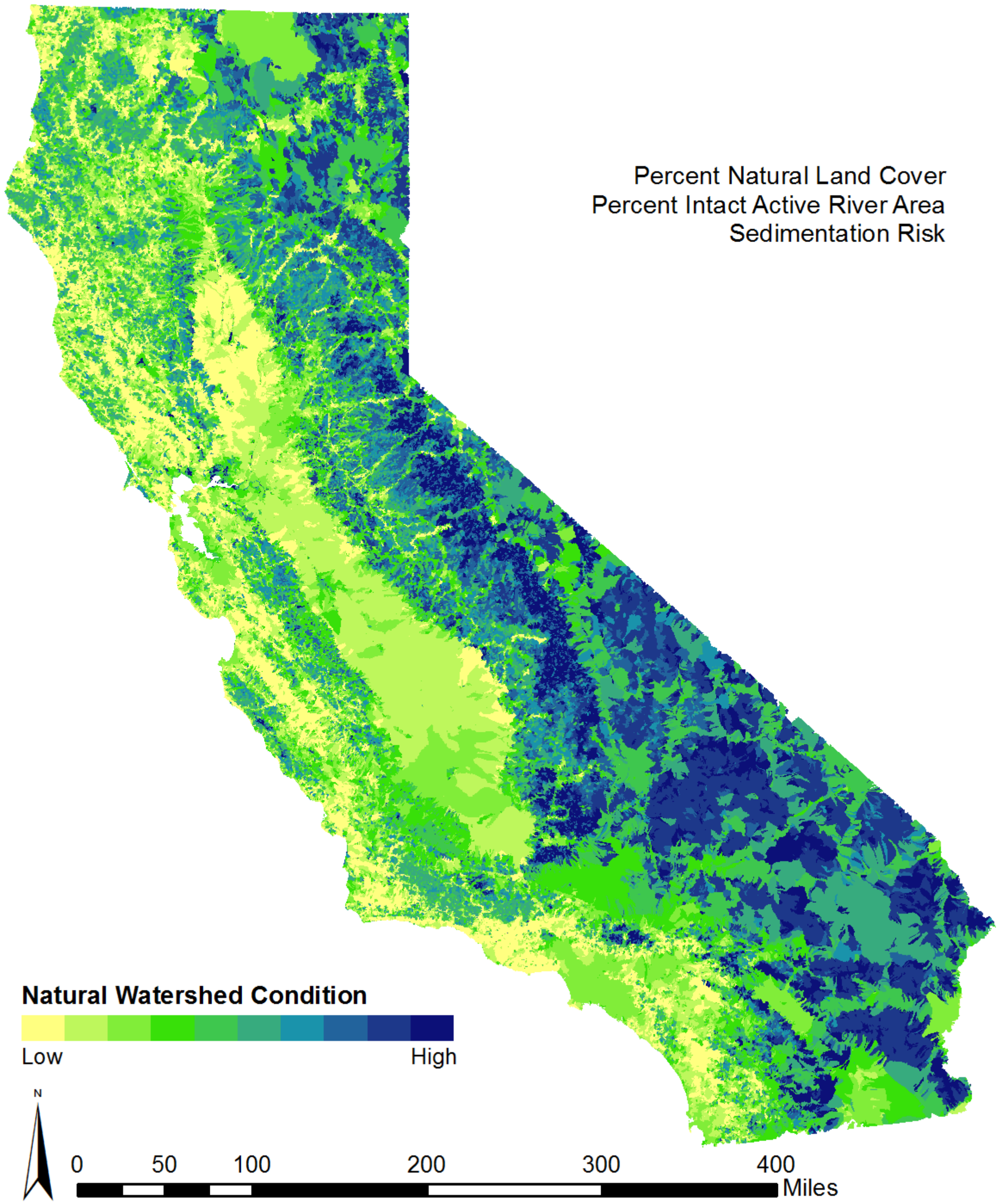

FIGURE 21. NATURAL WATERSHED CONDITION INDEX SCORES.

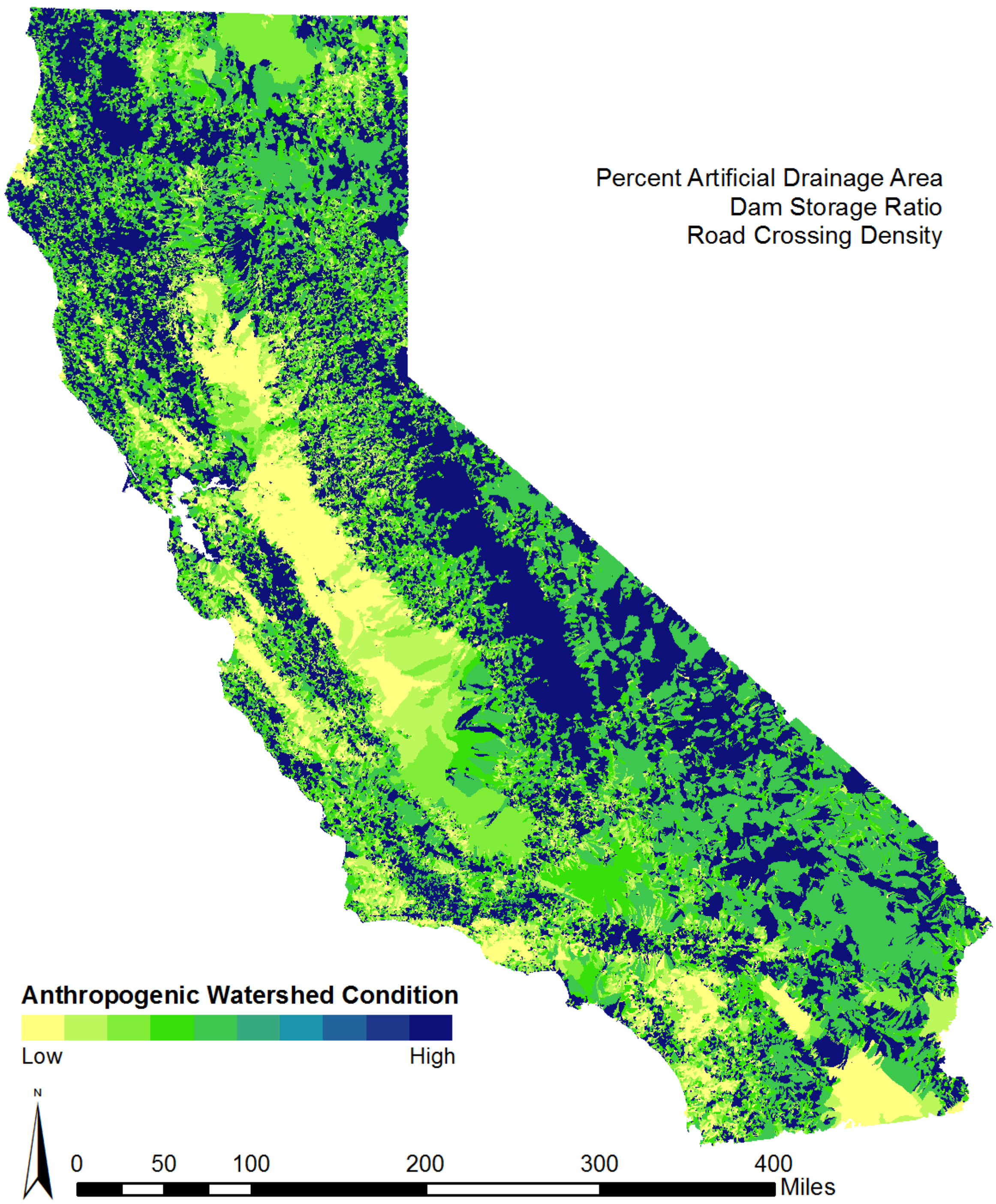

FIGURE 22. ANTHROPOGENIC WATERSHED CONDITION INDEX SCORES.

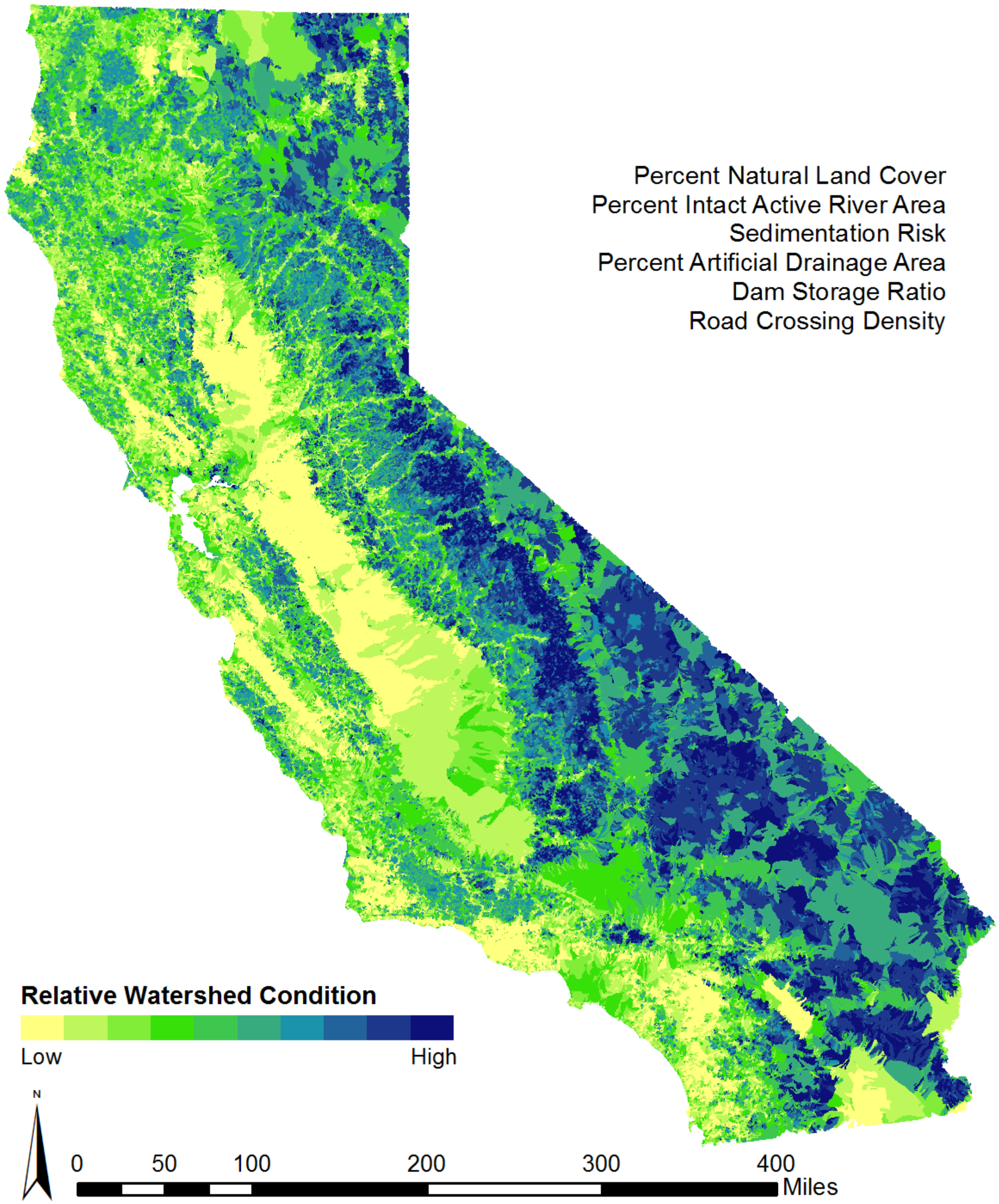

FIGURE 23. RELATIVE WATERSHED CONDITION INDEX SCORES.

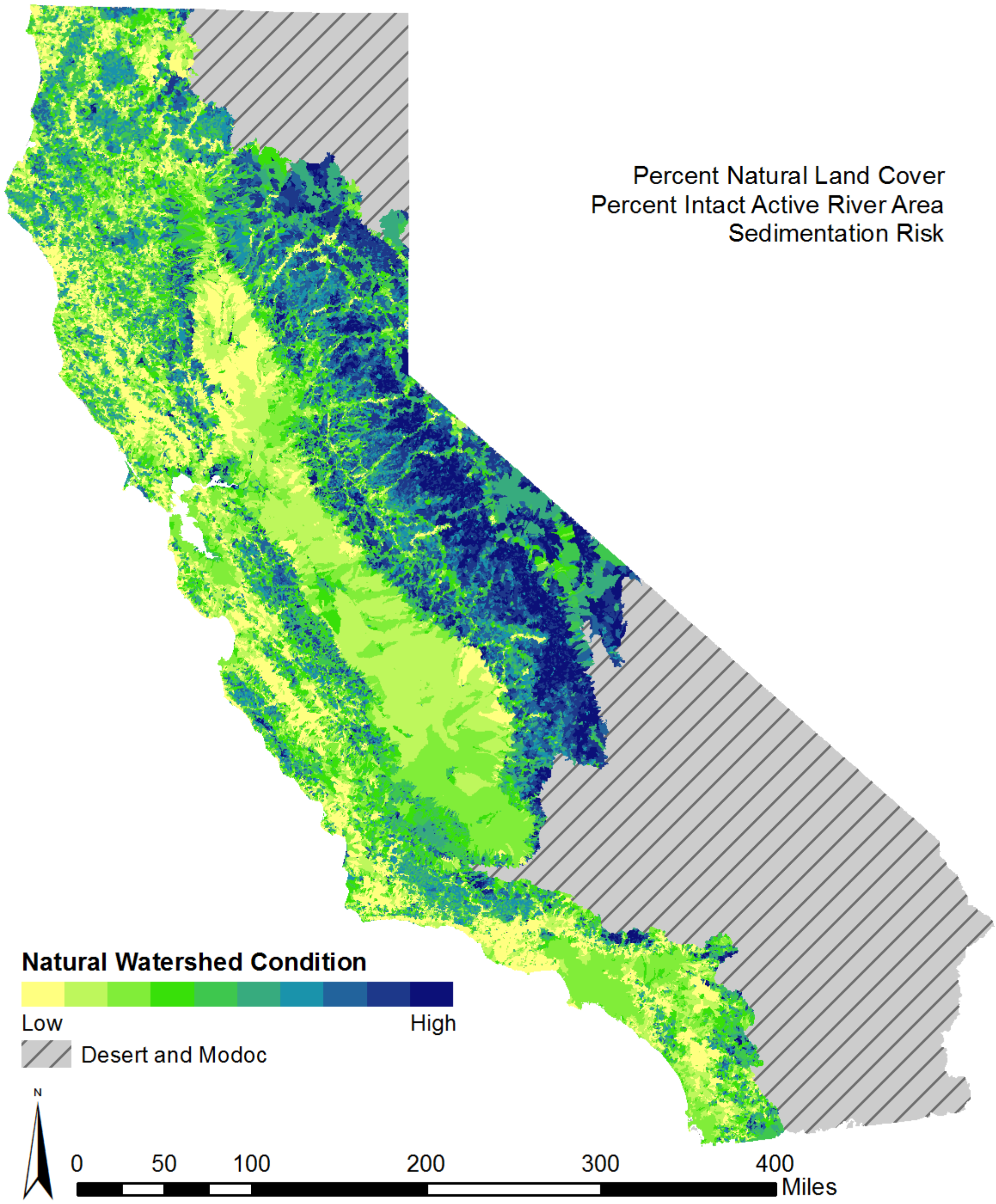

FIGURE 24. NATURAL WATERSHED CONDITION INDEX SCORES (EXCLUDES DESERT-MODOC REGION).

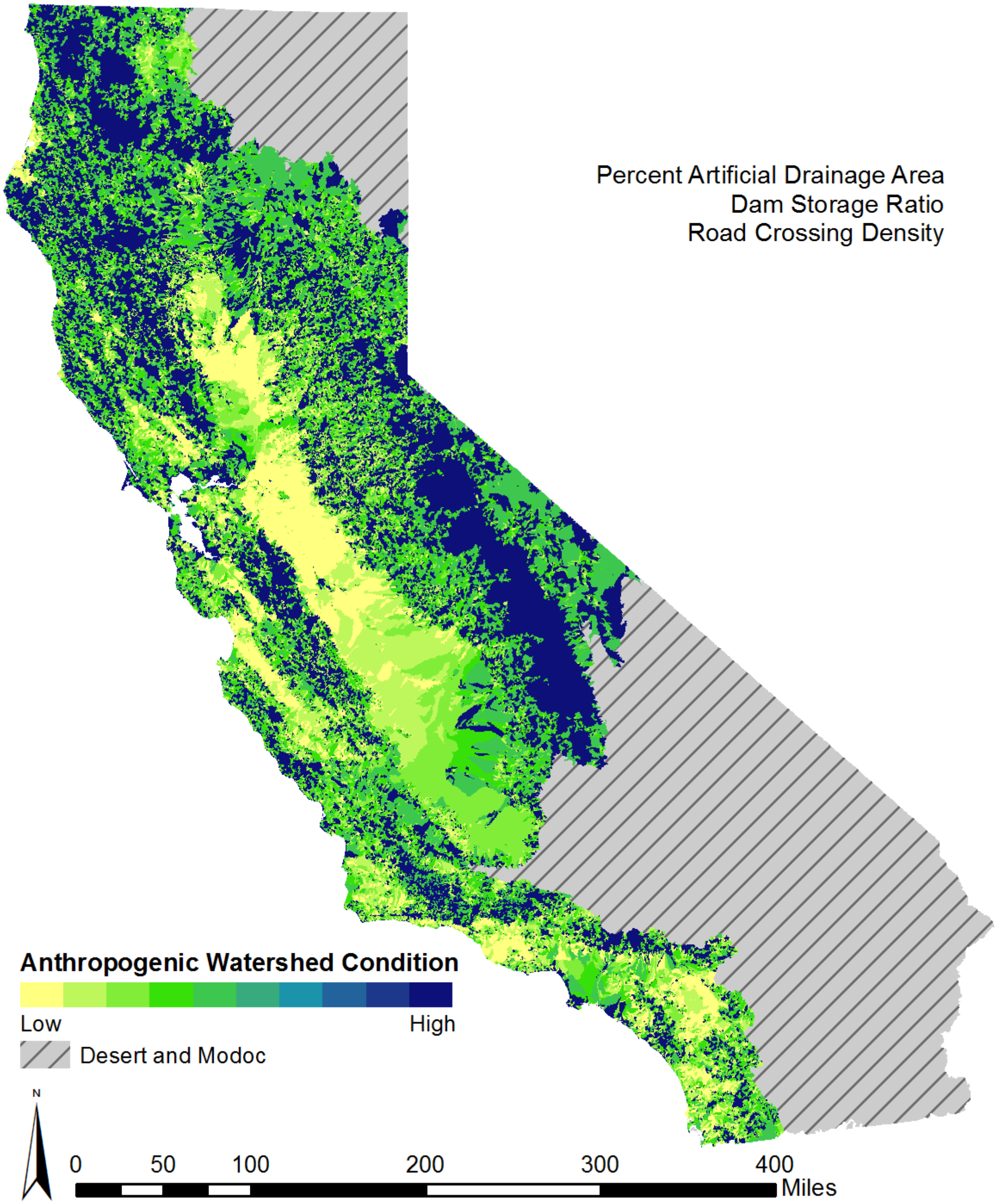

FIGURE 25. ANTHROPOGENIC WATERSHED CONDITION INDEX SCORES (EXCLUDES DESERT-MODOC REGION).

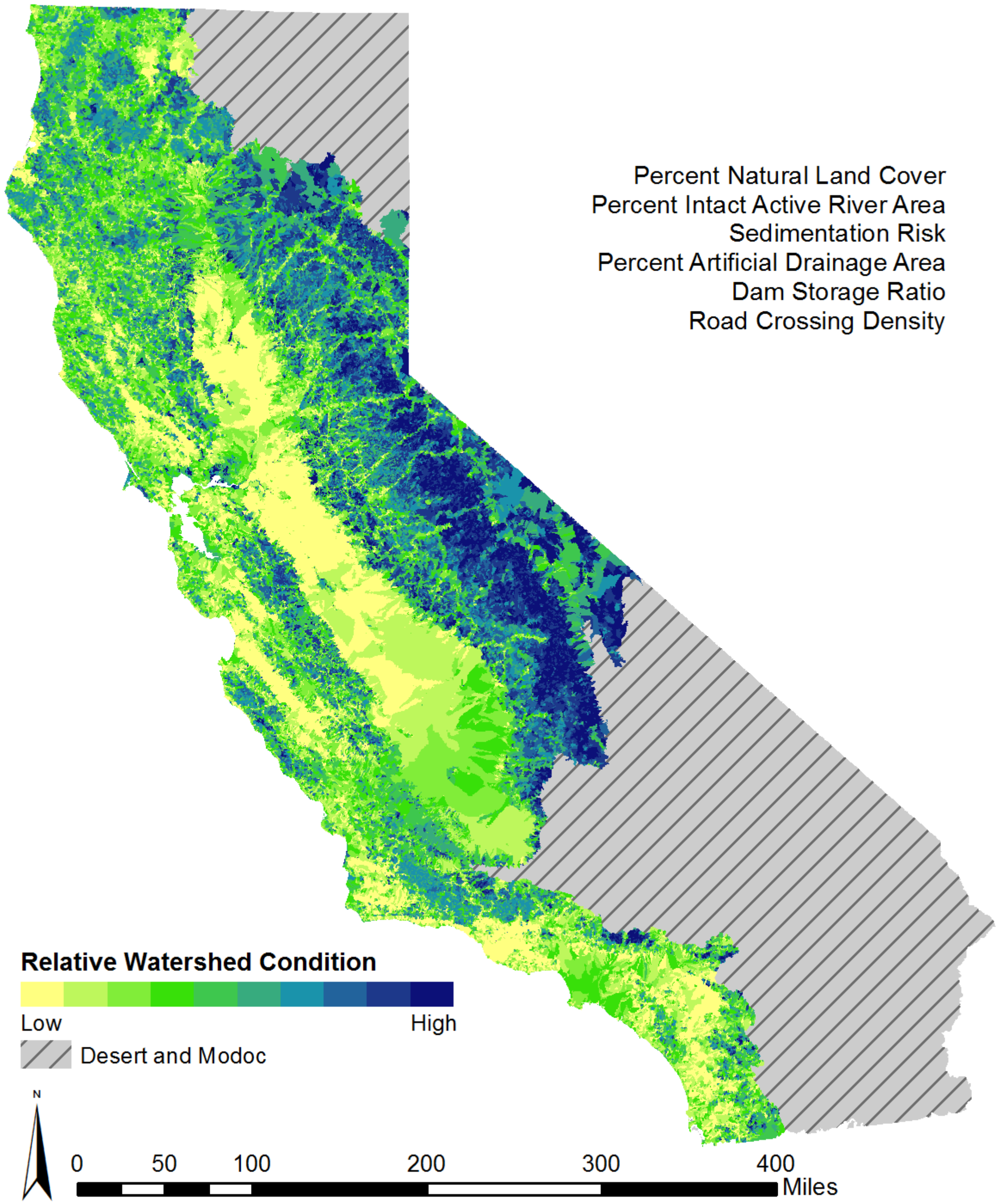

Figure 26. Relative Watershed Condition Index scores (excludes Desert-Modoc region).

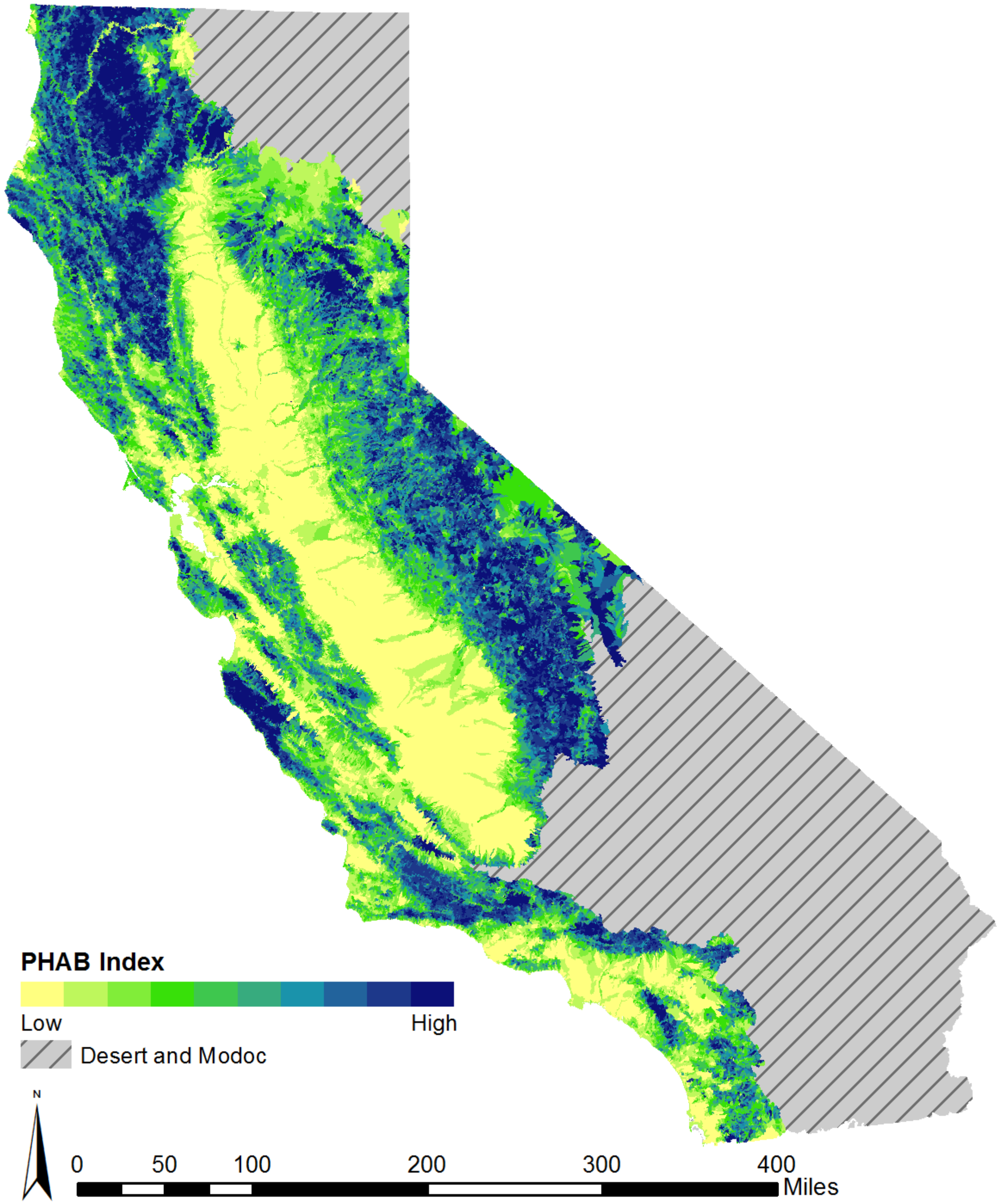

FIGURE 27. PHYSICAL HABITAT (PHAB) STREAM HABITAT ASSESSMENT SCORES.

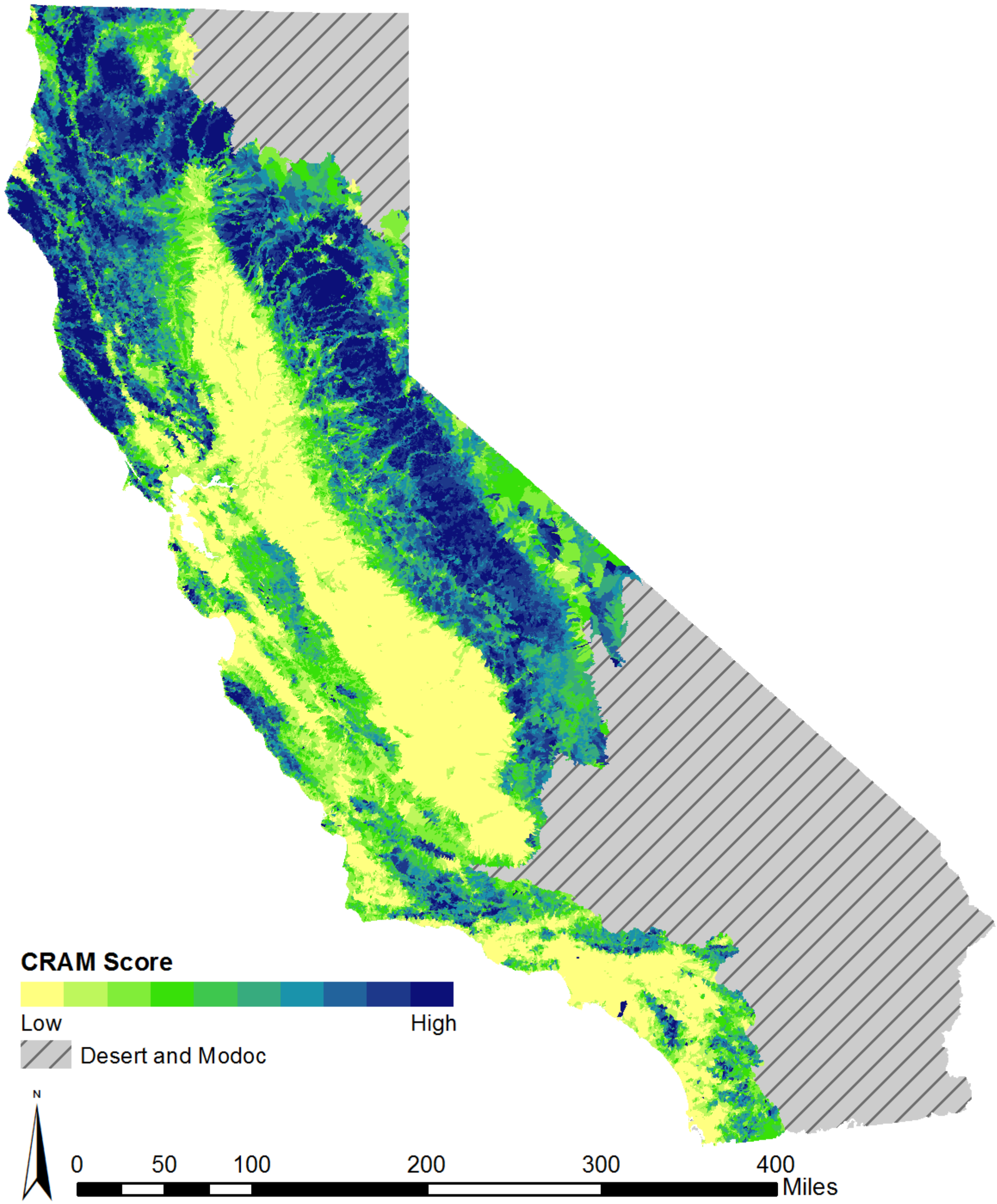

Figure 28. California Rapid Assessment Methodology (CRAM) wetland habitat assessment scores.

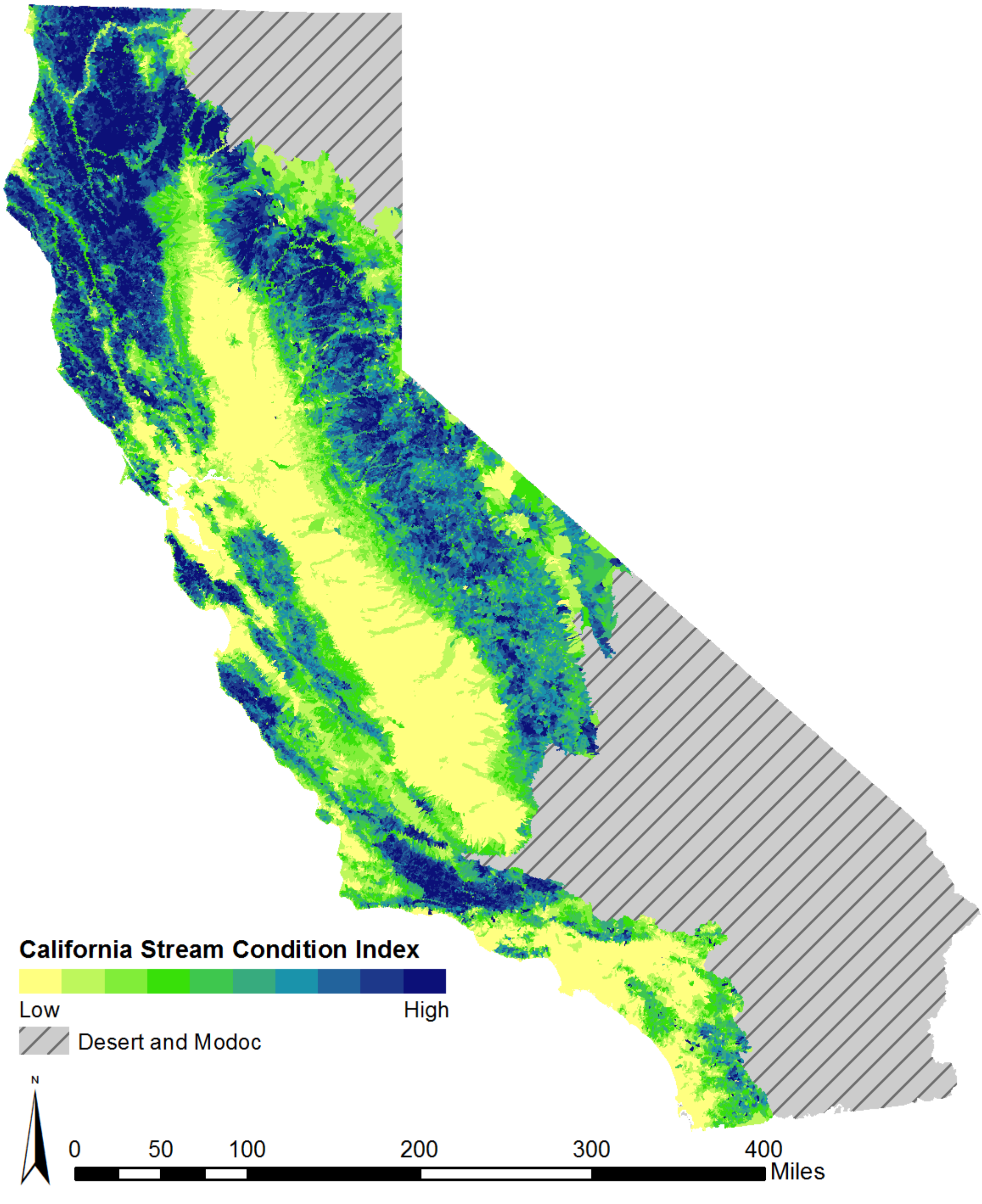

FIGURE 29. CALIFORNIA STREAM CONDITION INDEX (CSCI) STREAM BIOLOGY ASSESSMENT SCORES.

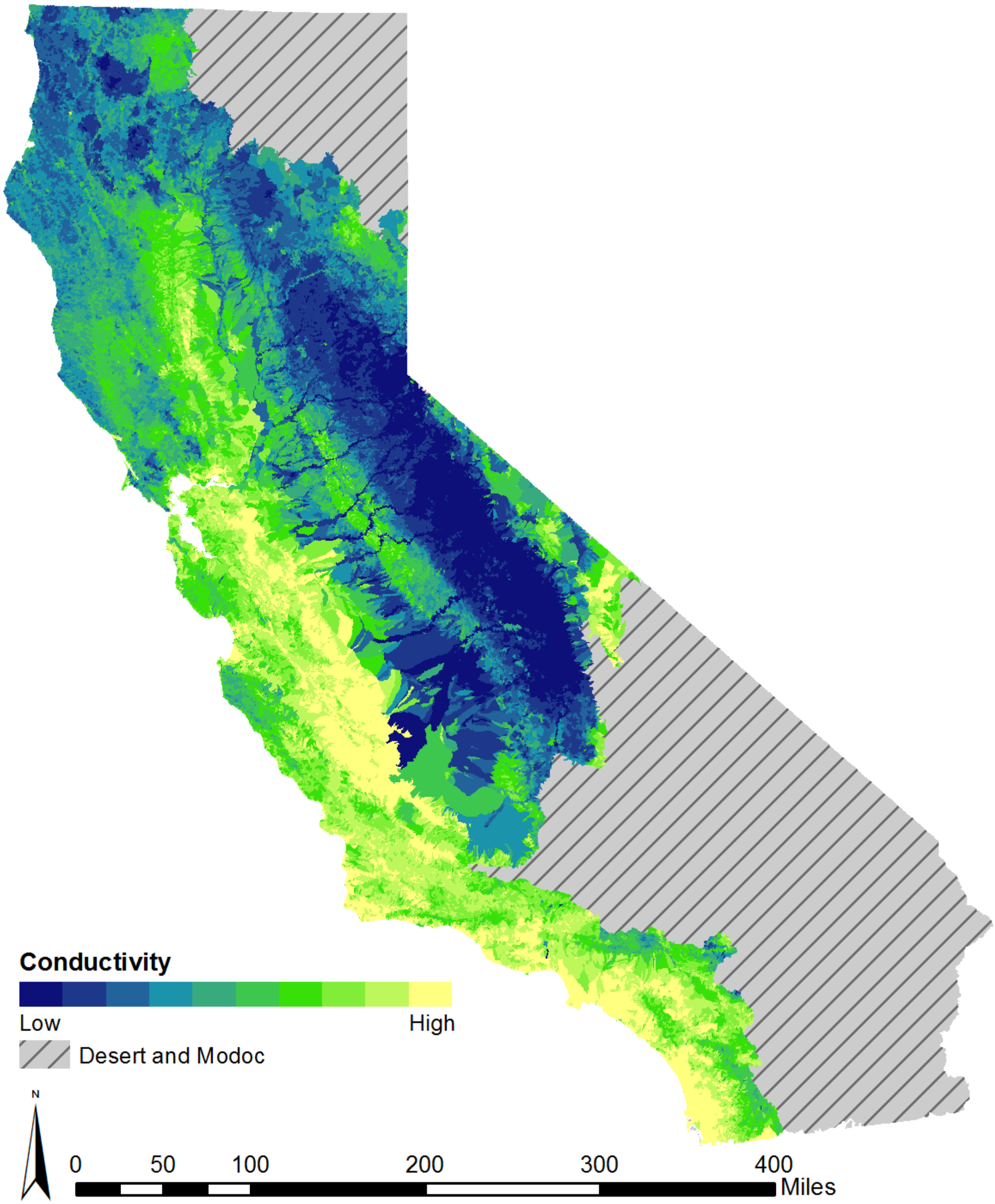

Figure 30. Stream median summer conductivity scores.

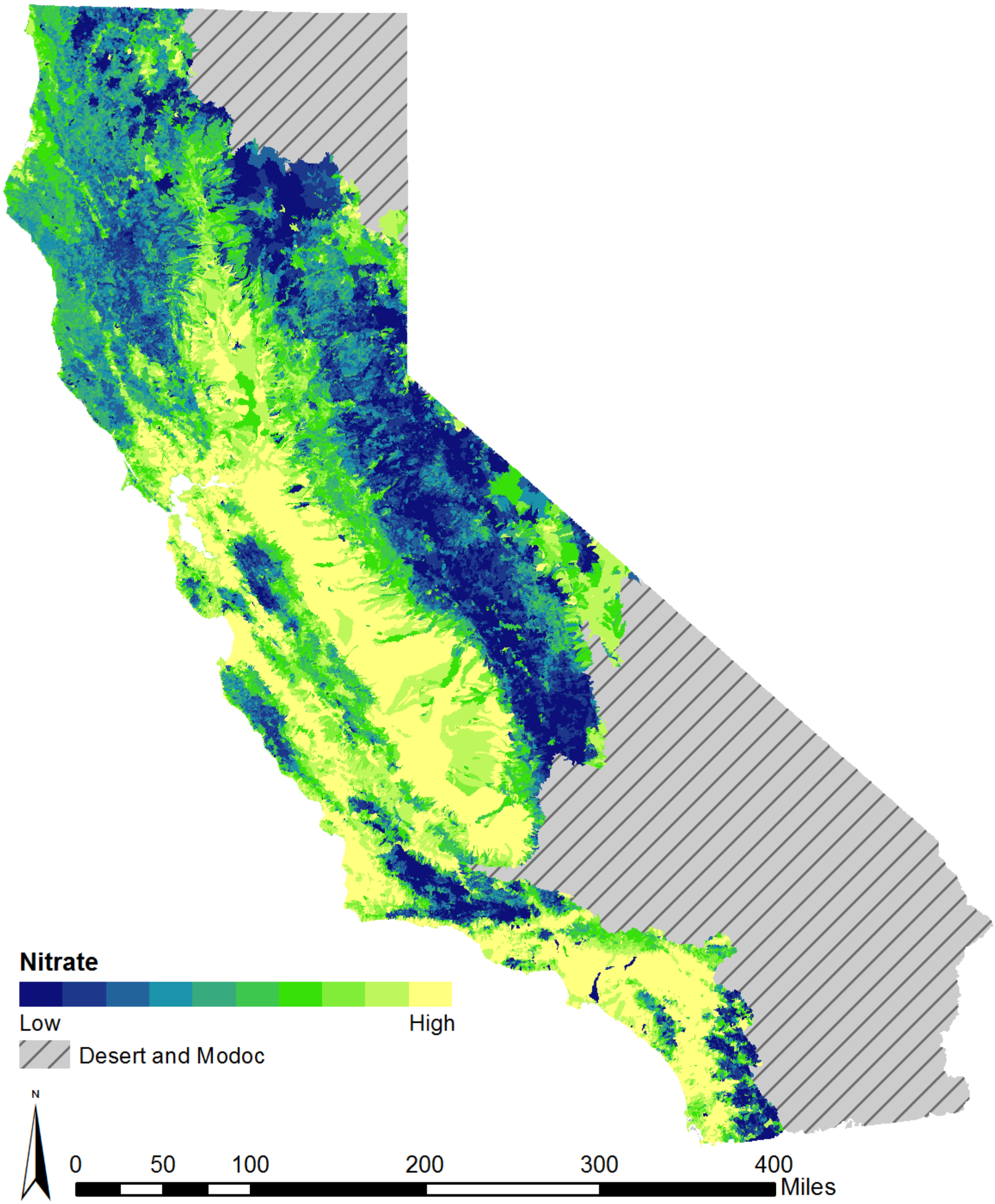

FIGURE 31. STREAM MEDIAN SUMMER NITRATE CONCENTRATION SCORES.

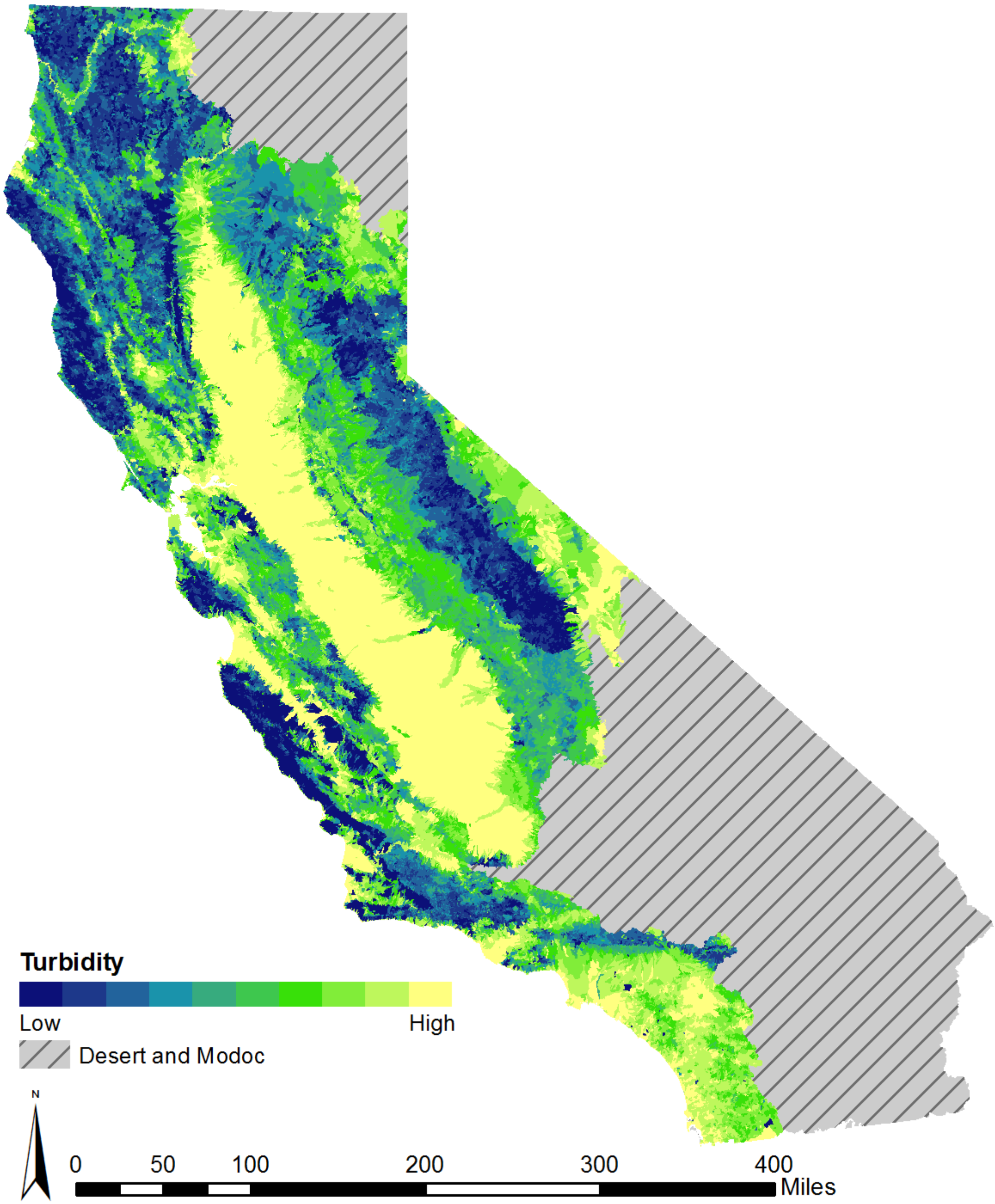

Figure 32. Stream median summer turbidity scores.

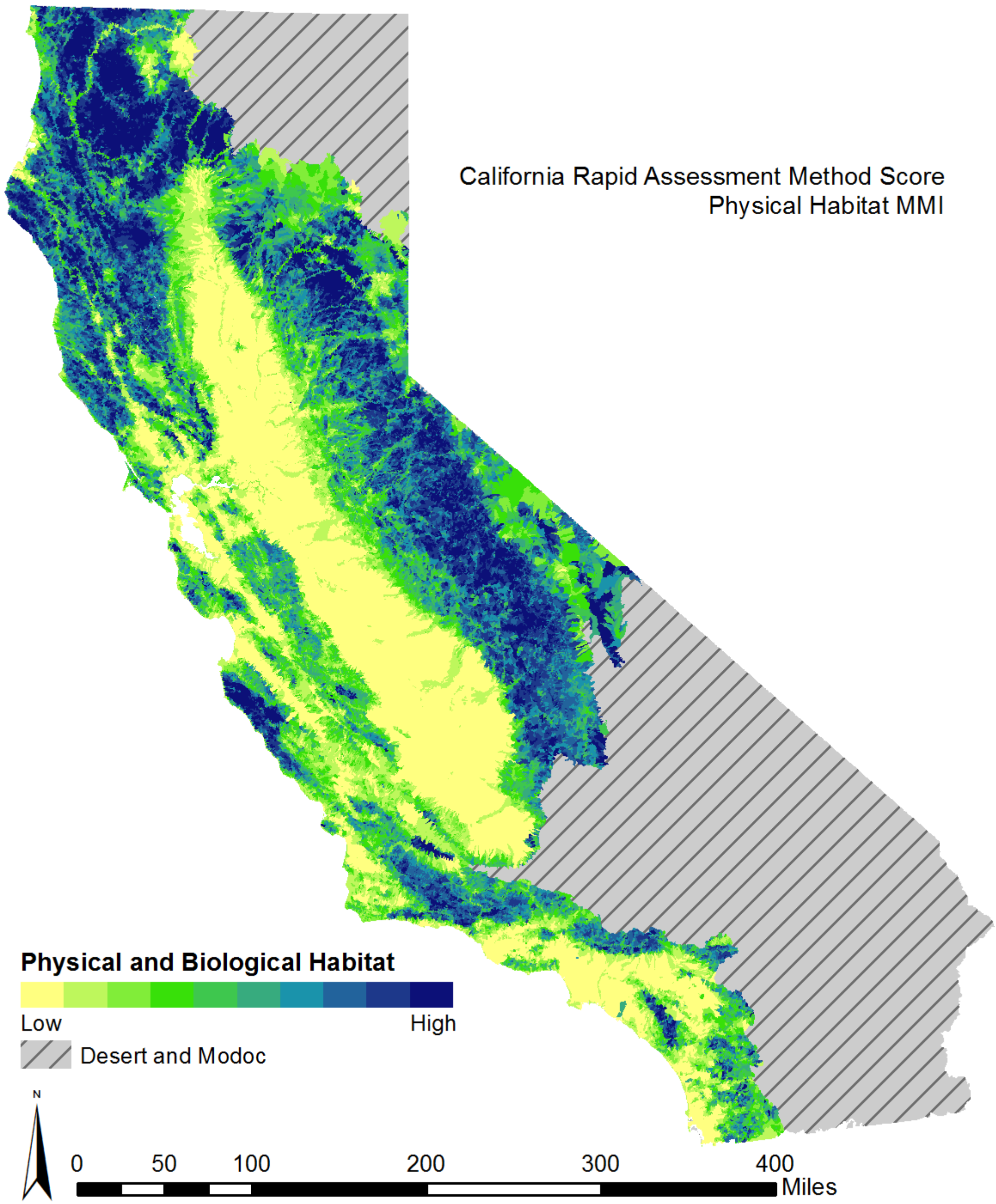

FIGURE 33. PHYSICAL AND BIOLOGICAL HABITAT INDEX SCORES.

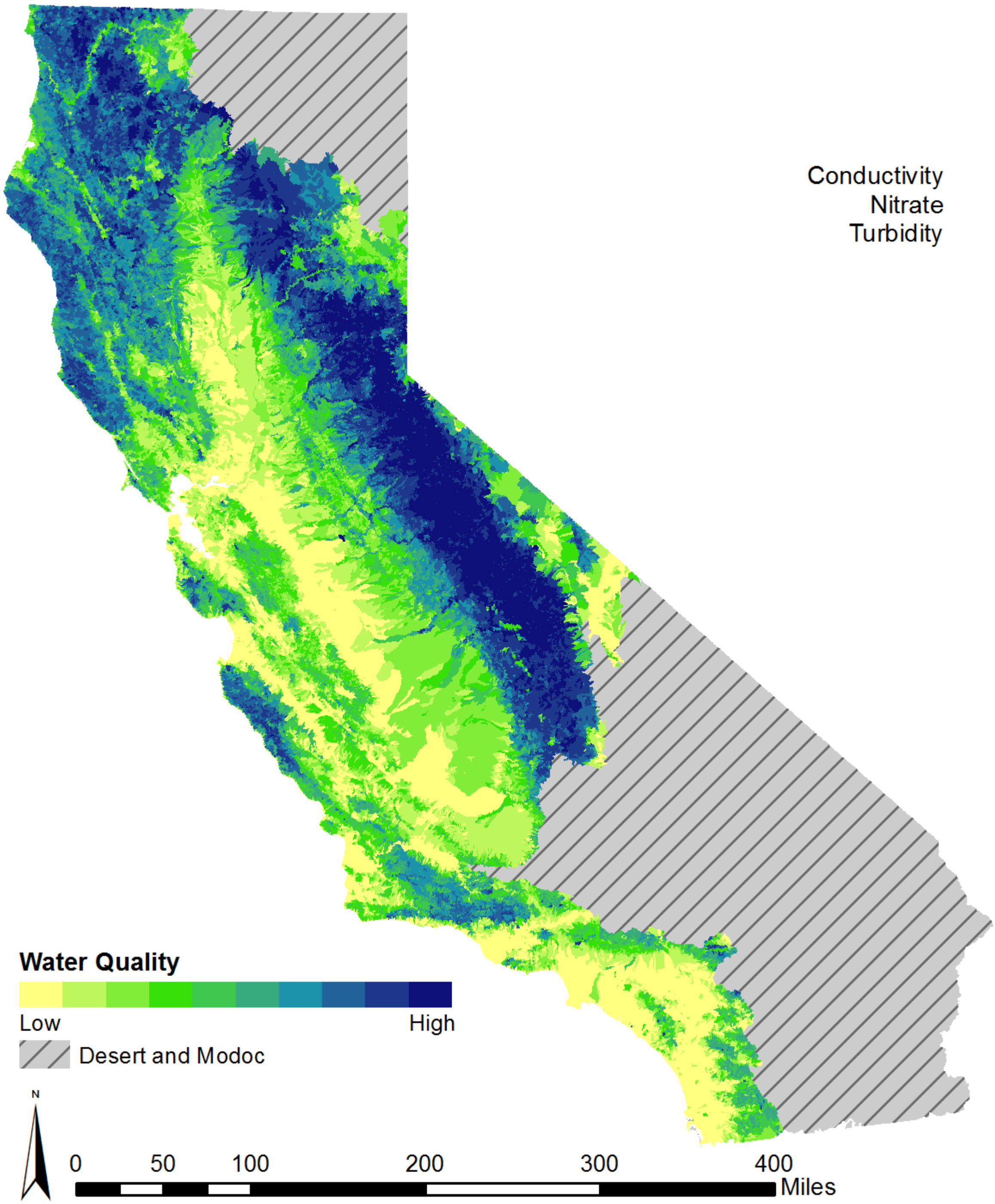

FIGURE 34. WATER QUALITY INDEX SCORES.

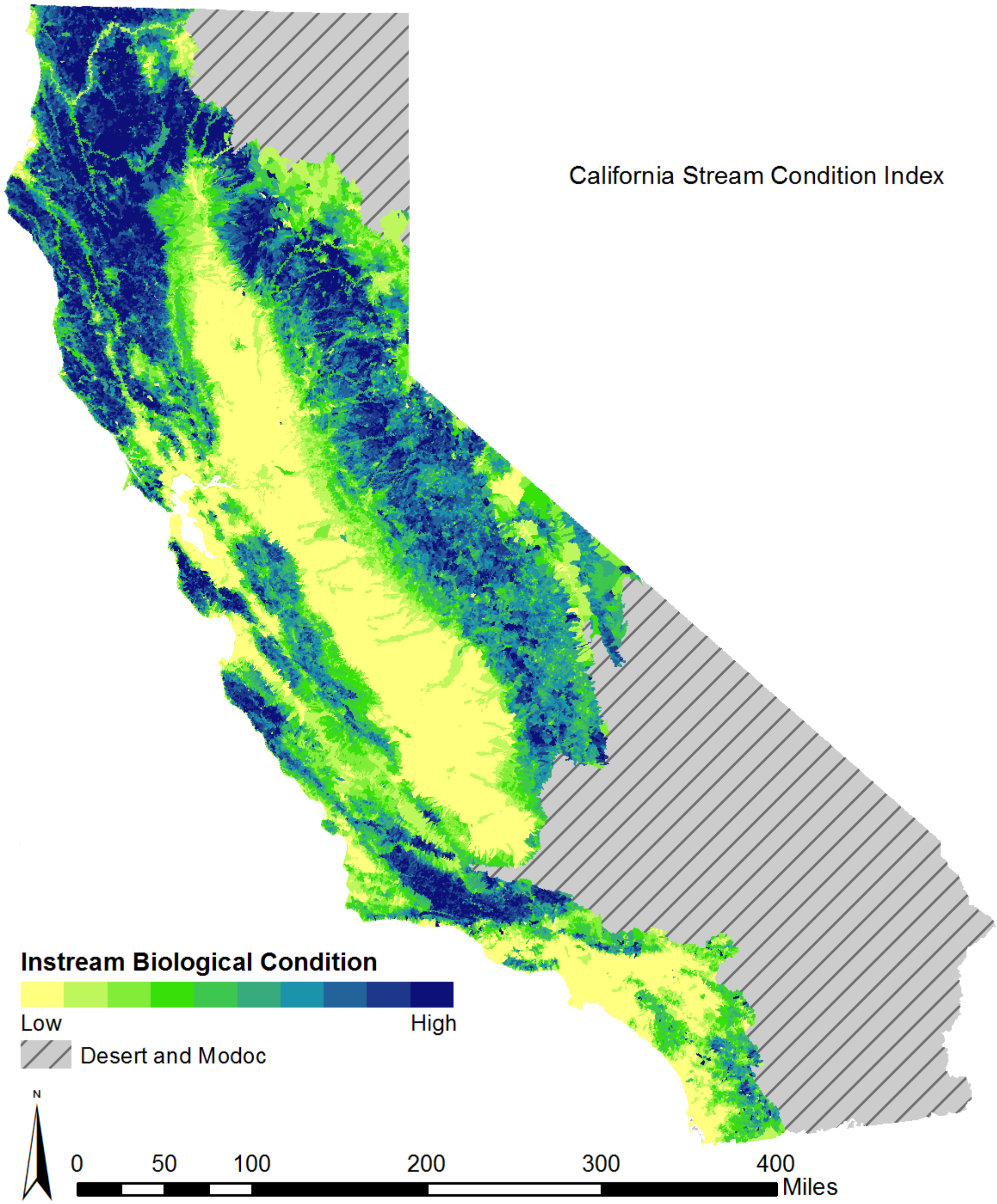

FIGURE 35. INSTREAM BIOLOGICAL CONDITION INDEX SCORES.

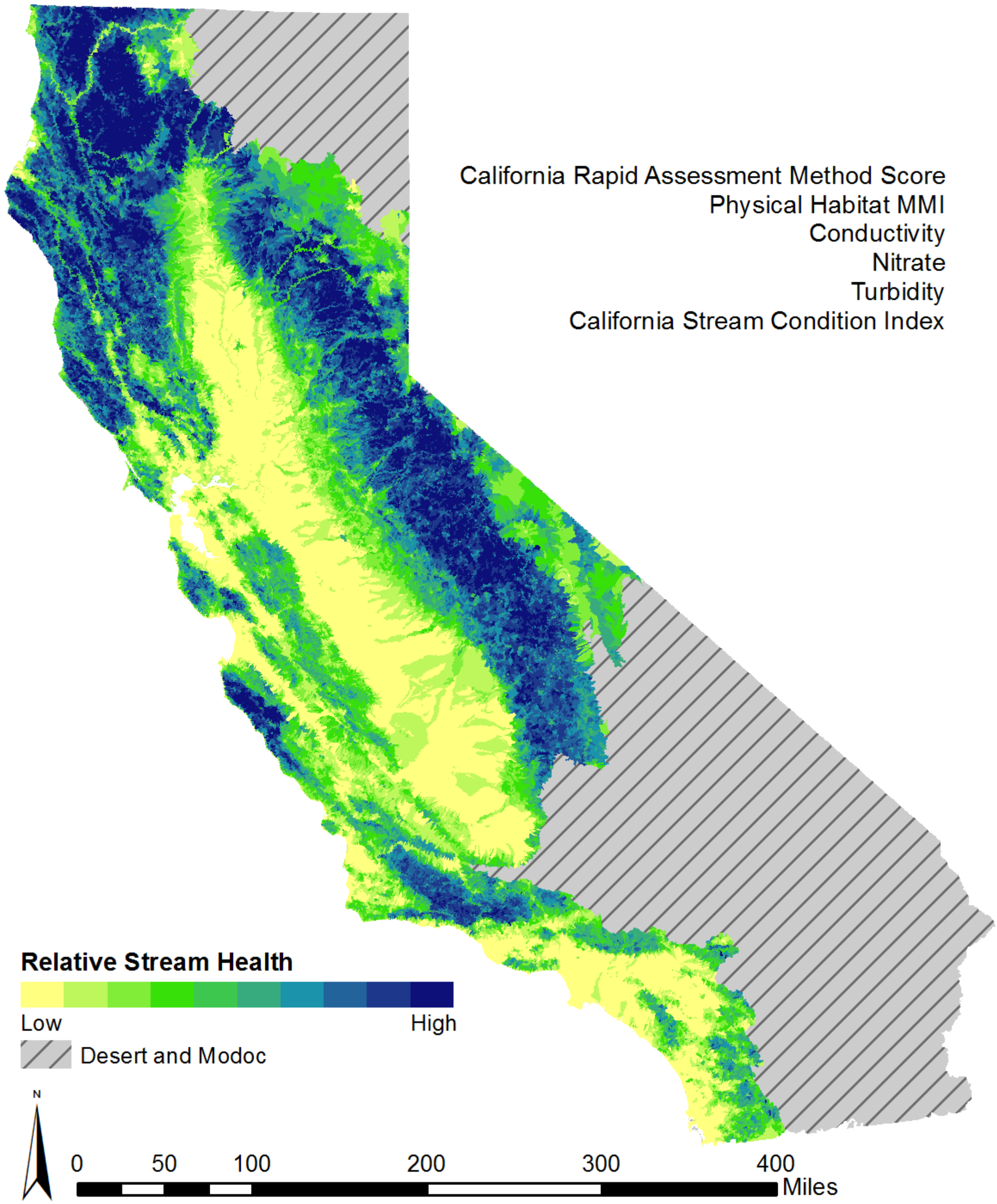

FIGURE 36. RELATIVE STREAM HEALTH SCORES.

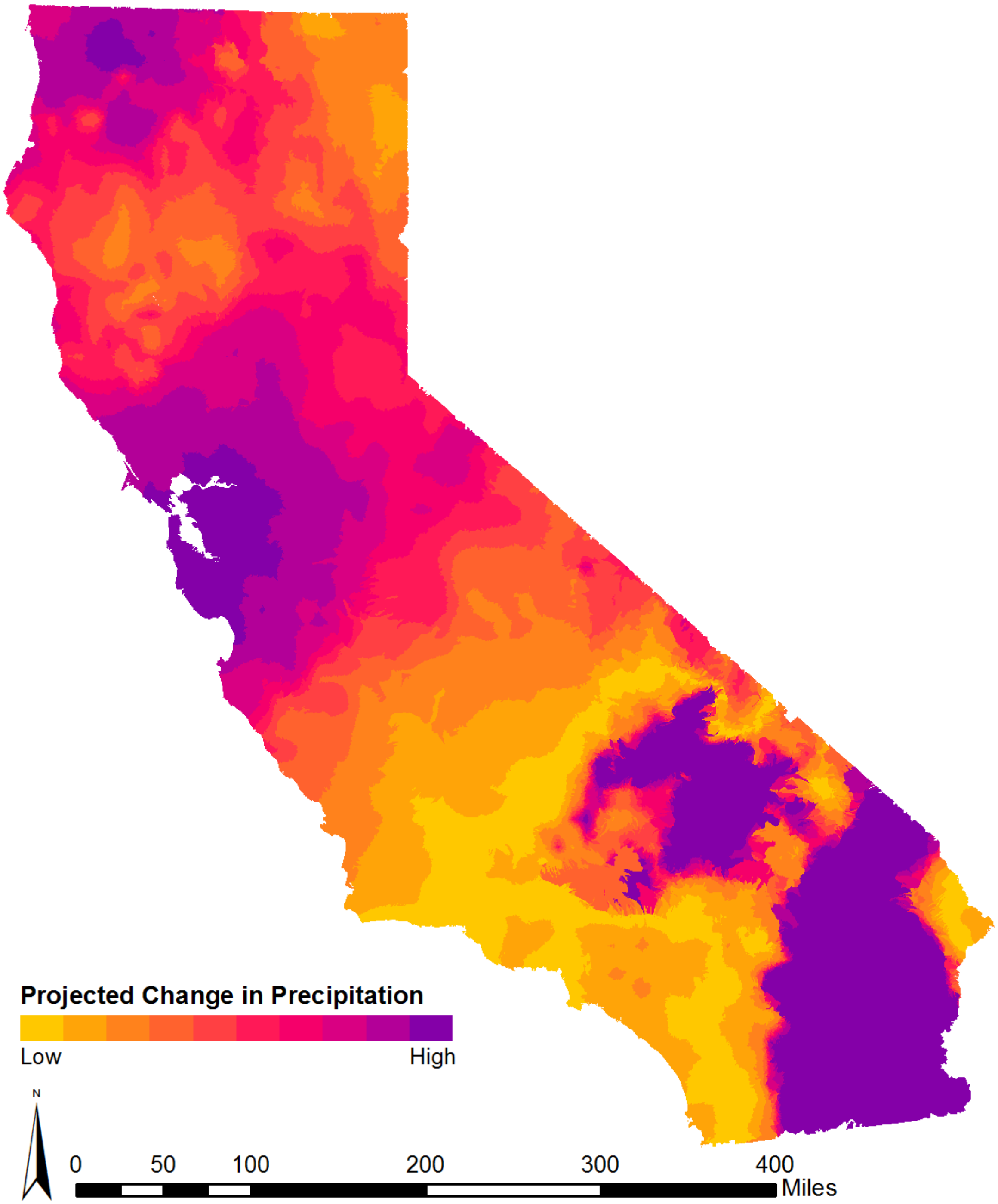

FIGURE 37. PROJECTED CHANGE IN PRECIPITATION SCORES.

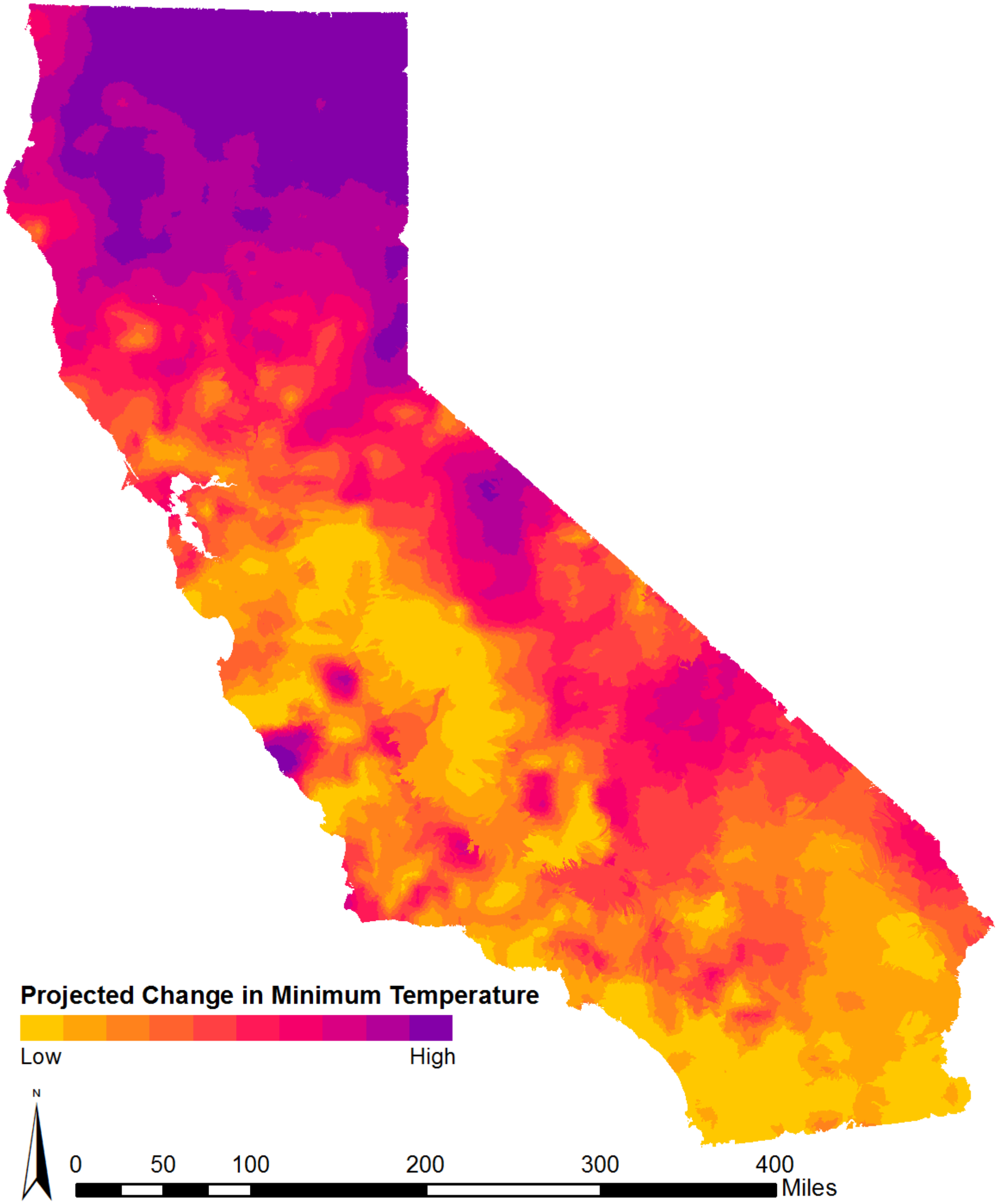

FIGURE 38. PROJECTED CHANGE IN MINIMUM TEMPERATURE SCORES.

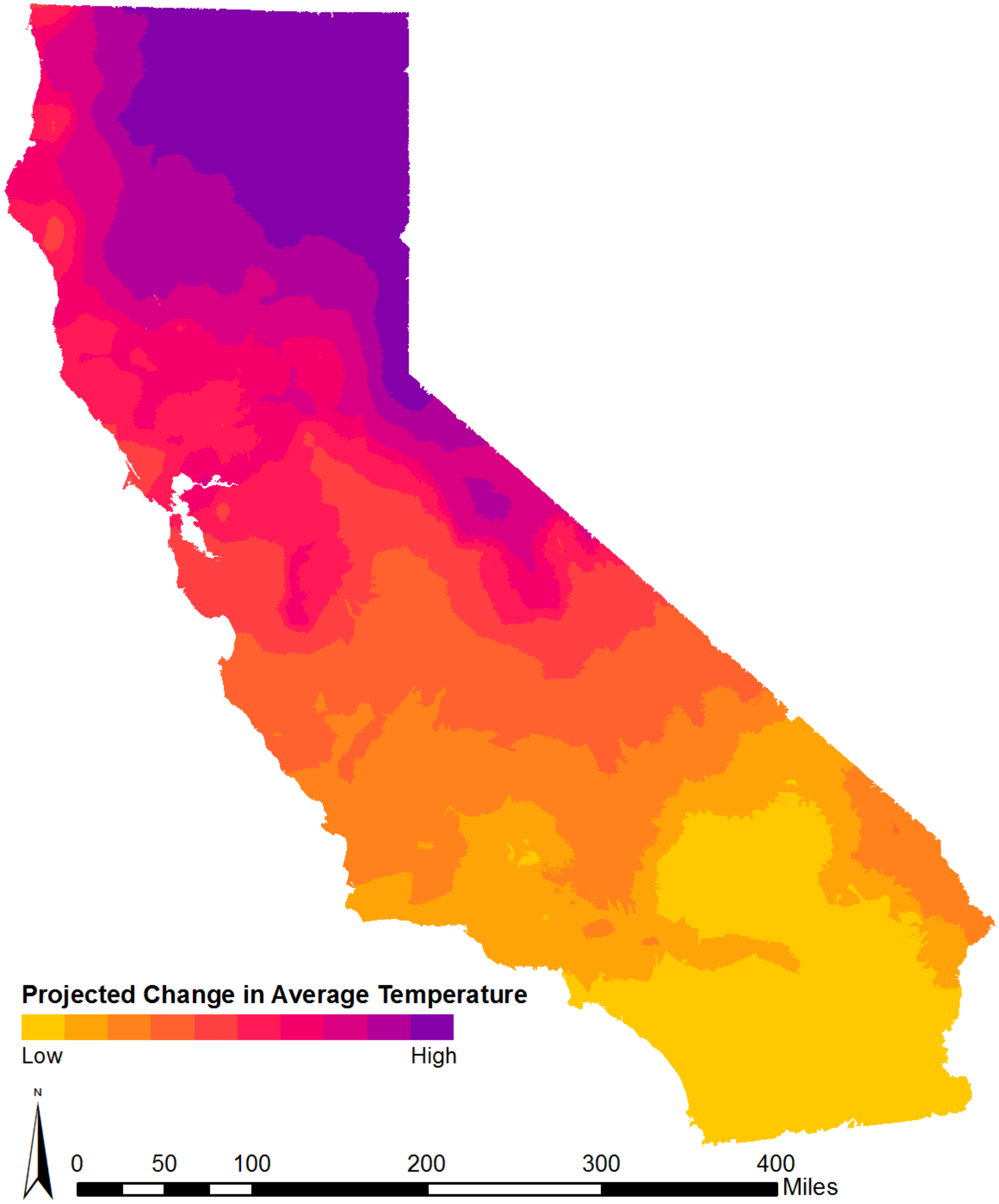

FIGURE 39. PROJECTED CHANGE IN MEAN TEMPERATURE SCORES.

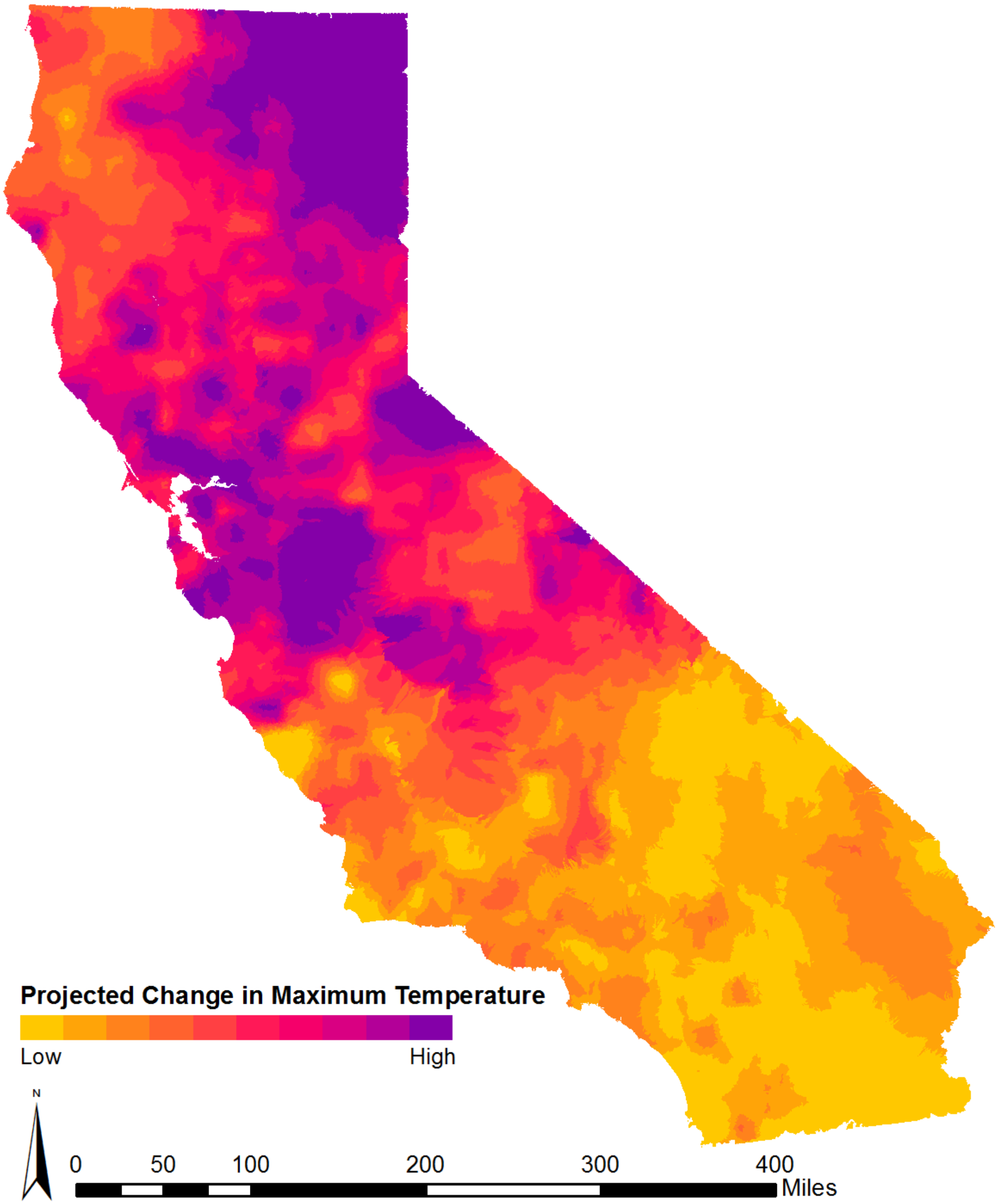

FIGURE 40. PROJECTED CHANGE IN MAXIMUM TEMPERATURE SCORES.

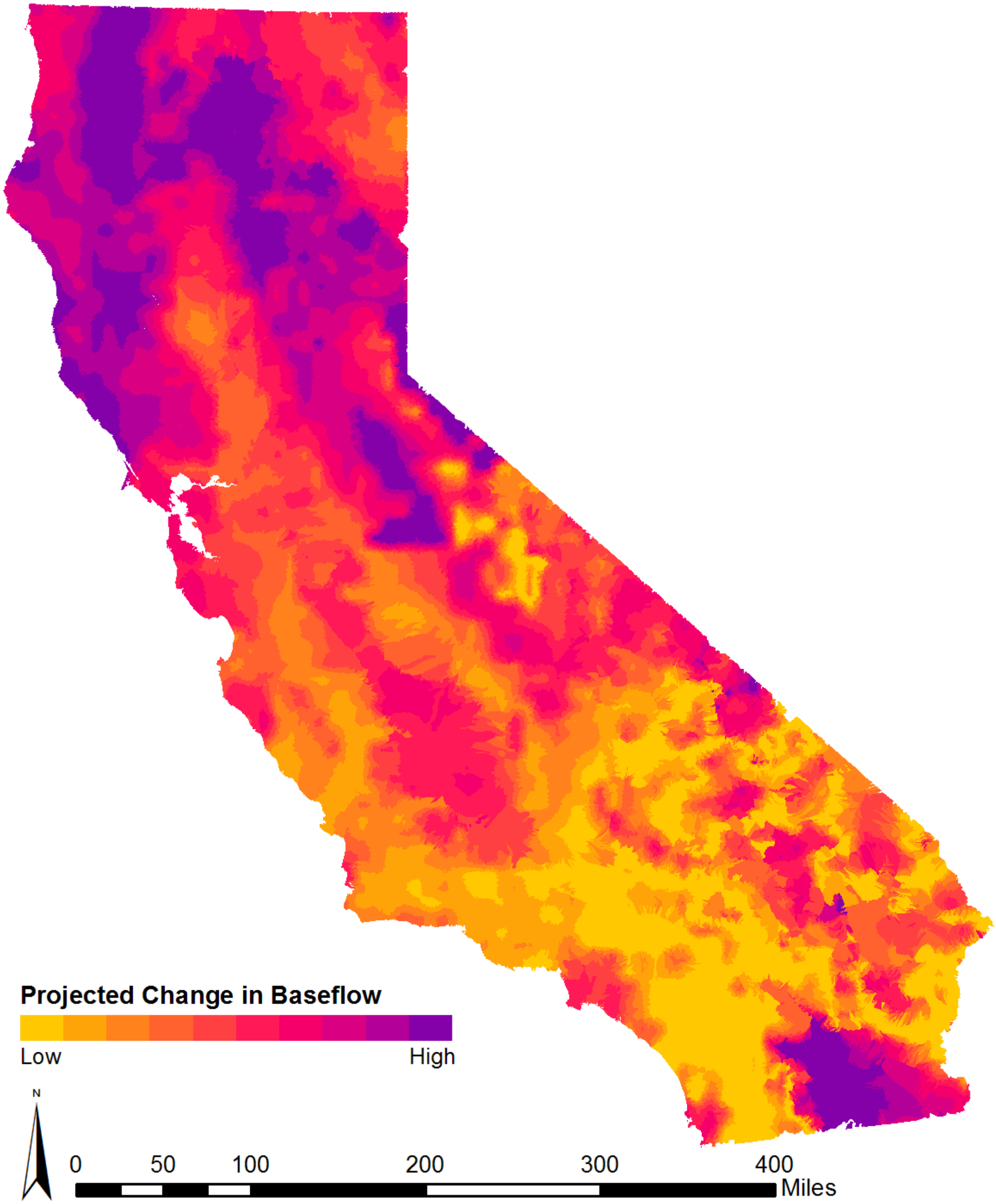

FIGURE 41. PROJECTED CHANGE IN BASEFLOW SCORES.

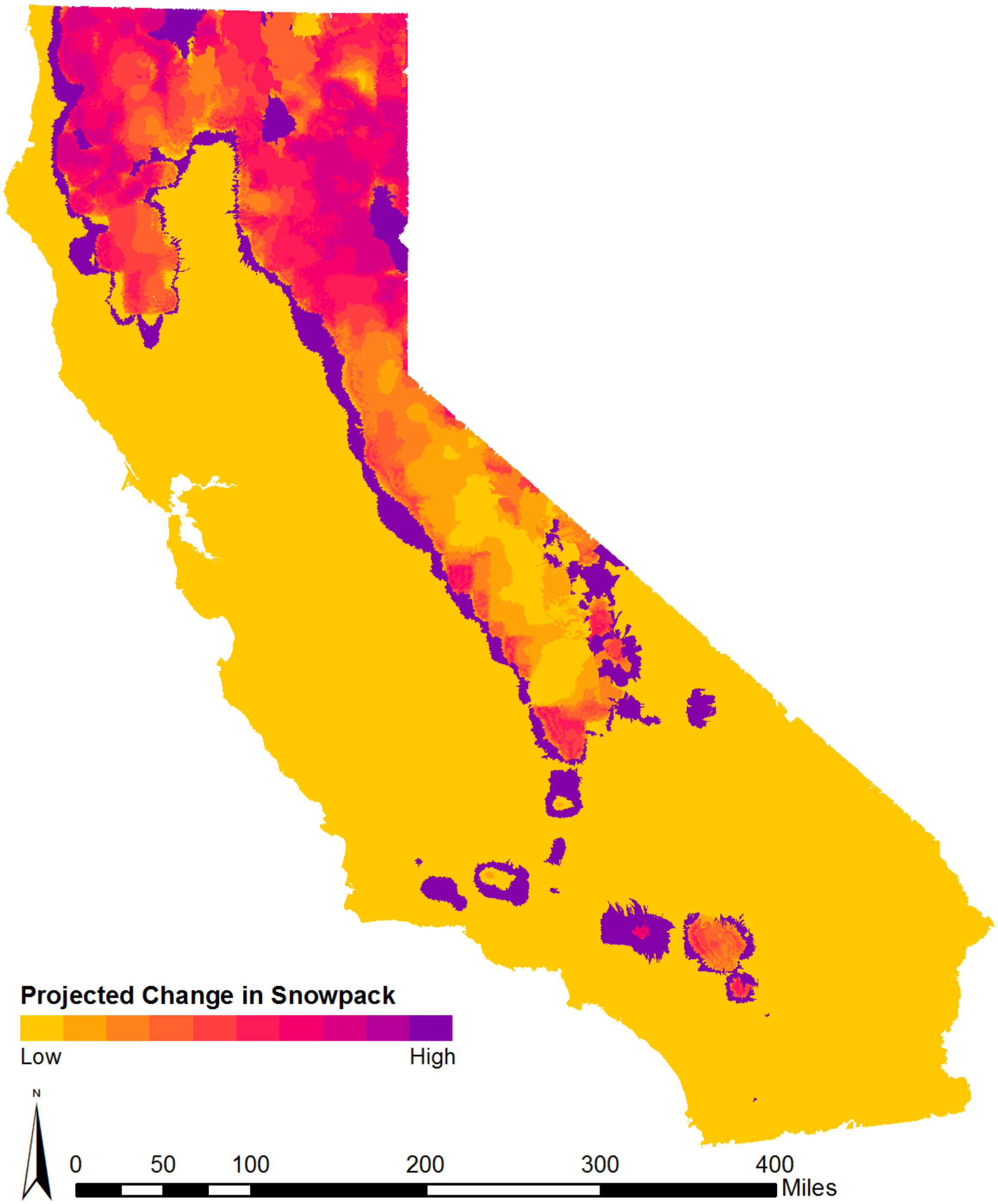

FIGURE 42. PROJECTED CHANGE IN SNOWPACK SCORES.

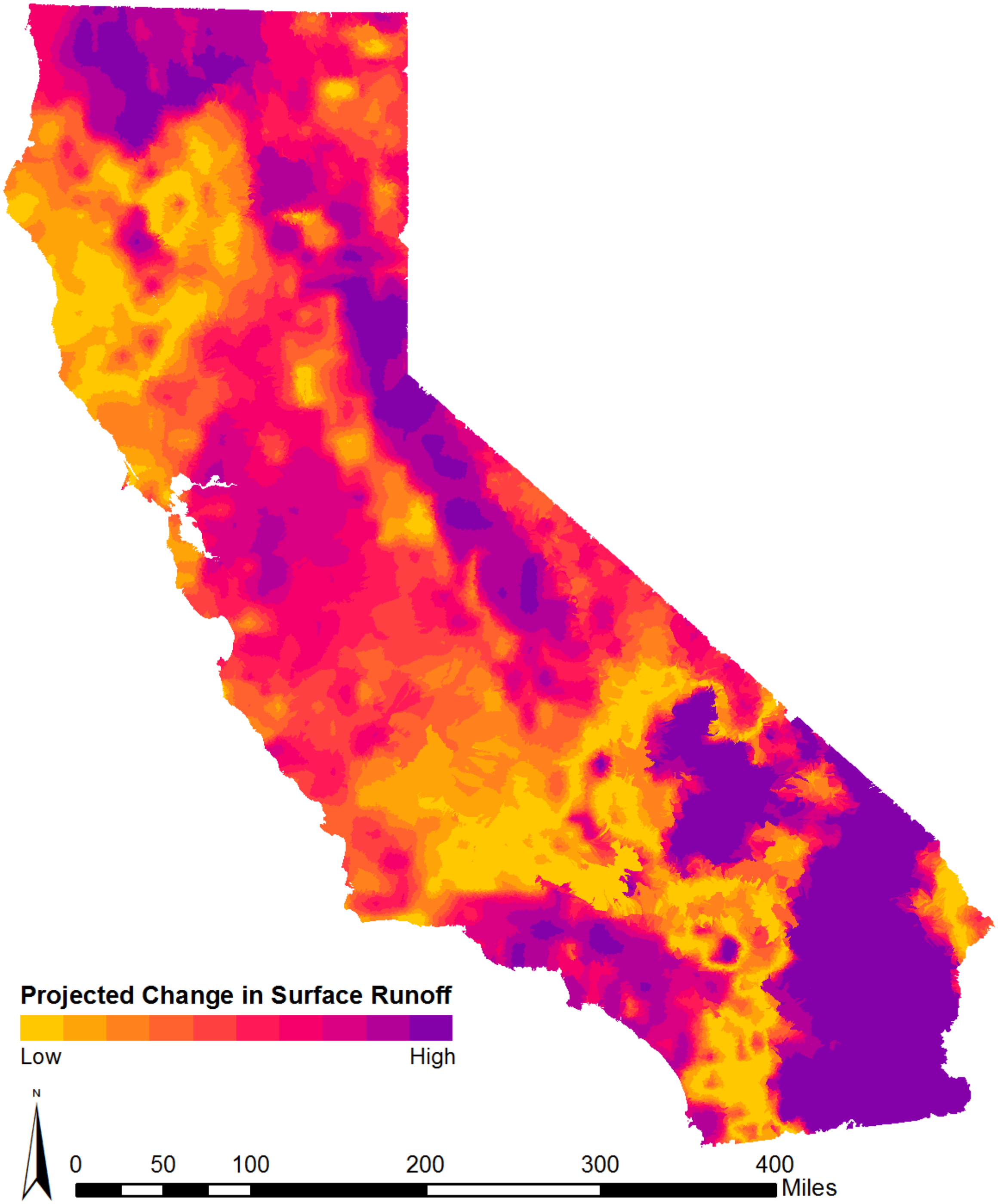

FIGURE 43. PROJECTED CHANGE IN SURFACE RUNOFF SCORES.

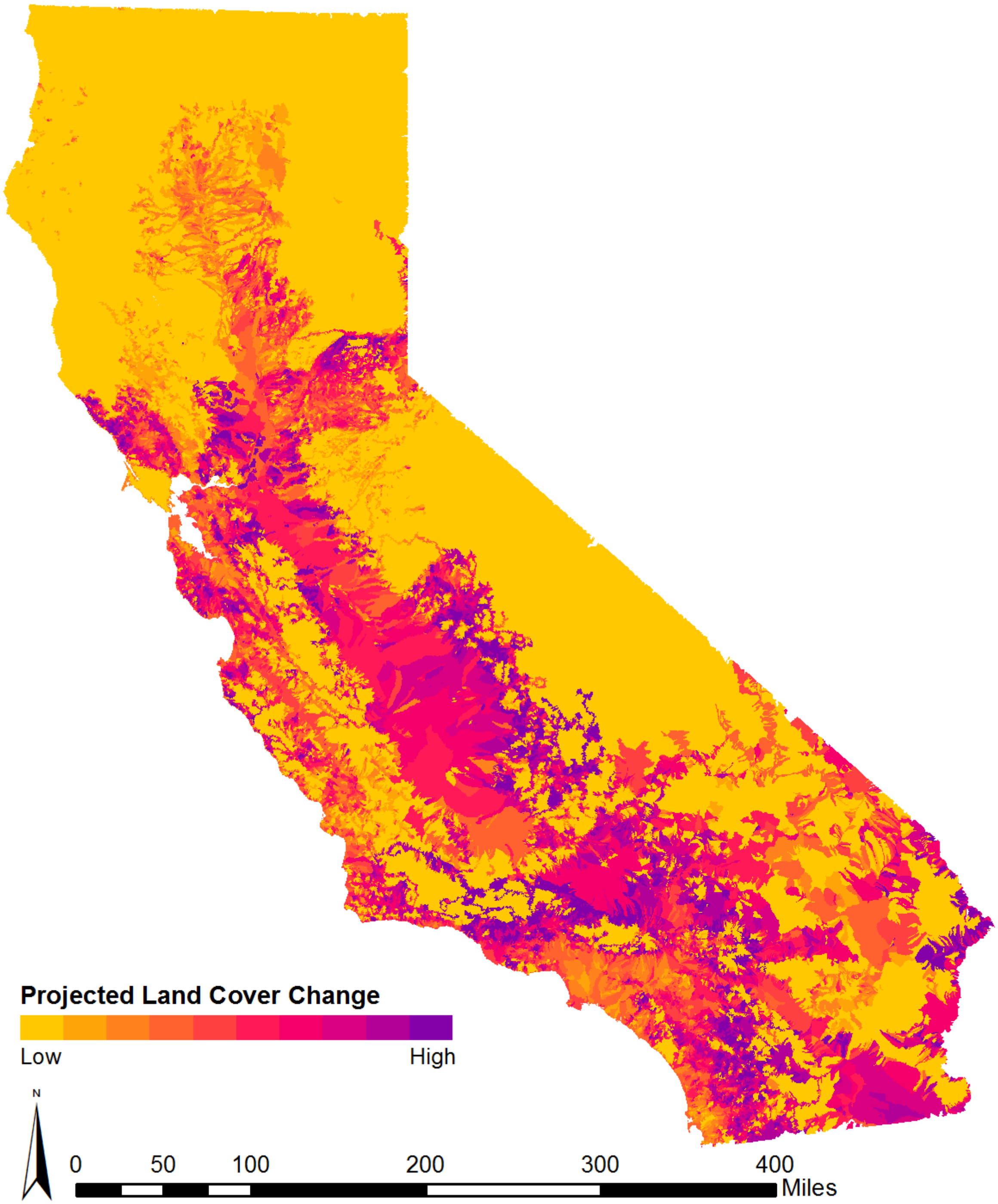

FIGURE 44. PROJECTED LAND COVER CHANGE SCORES.

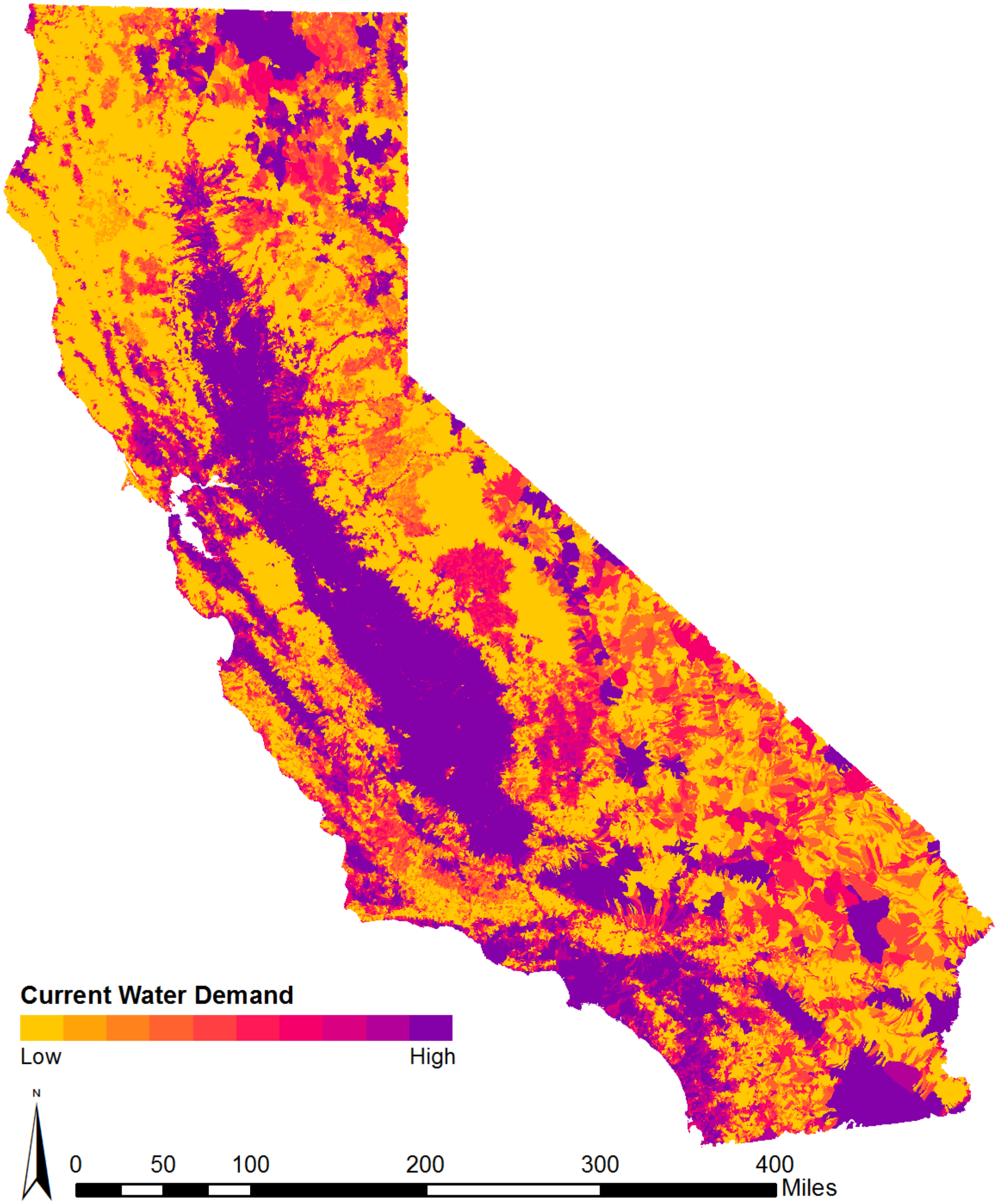

FIGURE 45. CURRENT WATER DEMAND SCORES.

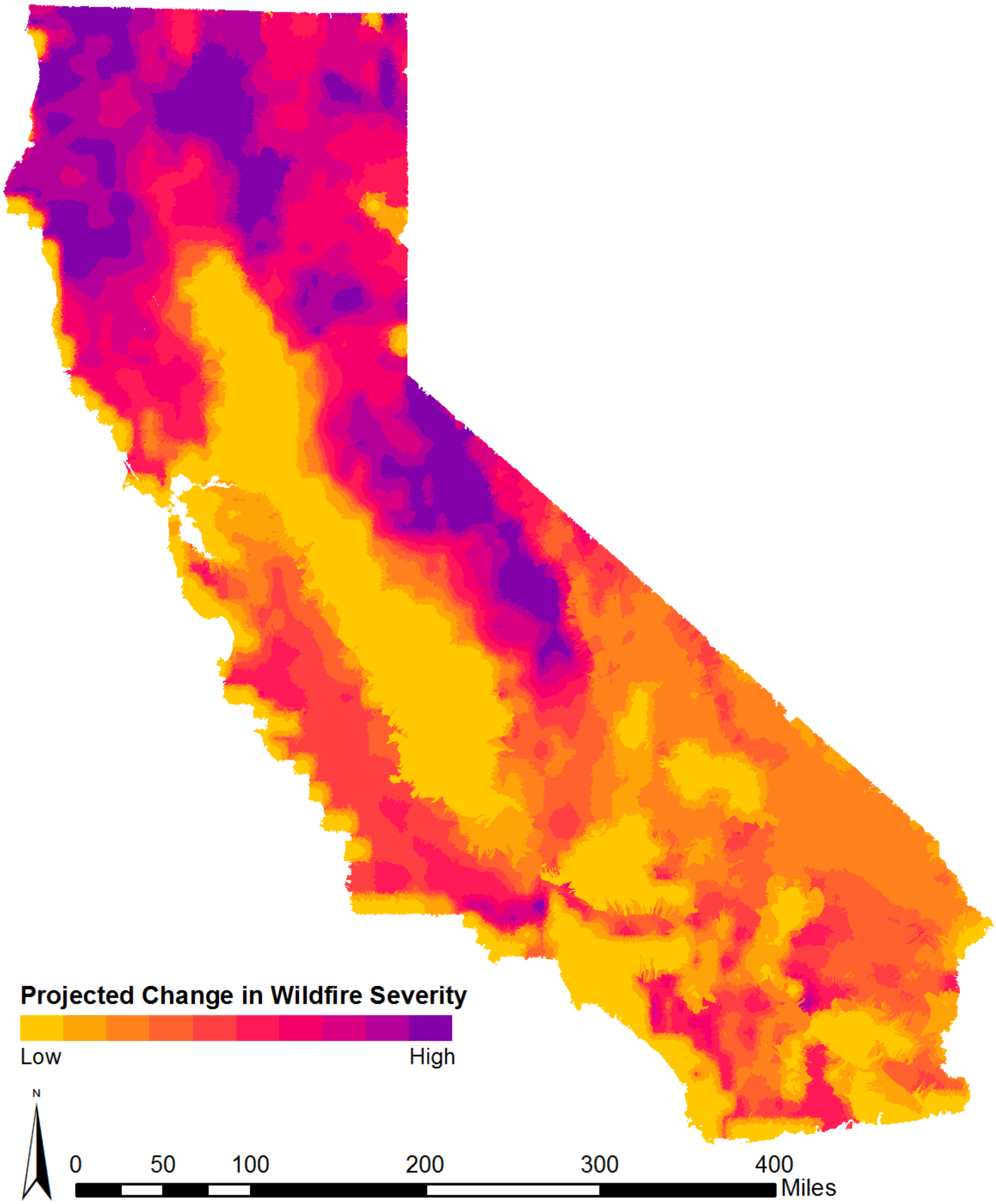

FIGURE 46. PROJECTED CHANGE IN WILDFIRE SEVERITY SCORES.

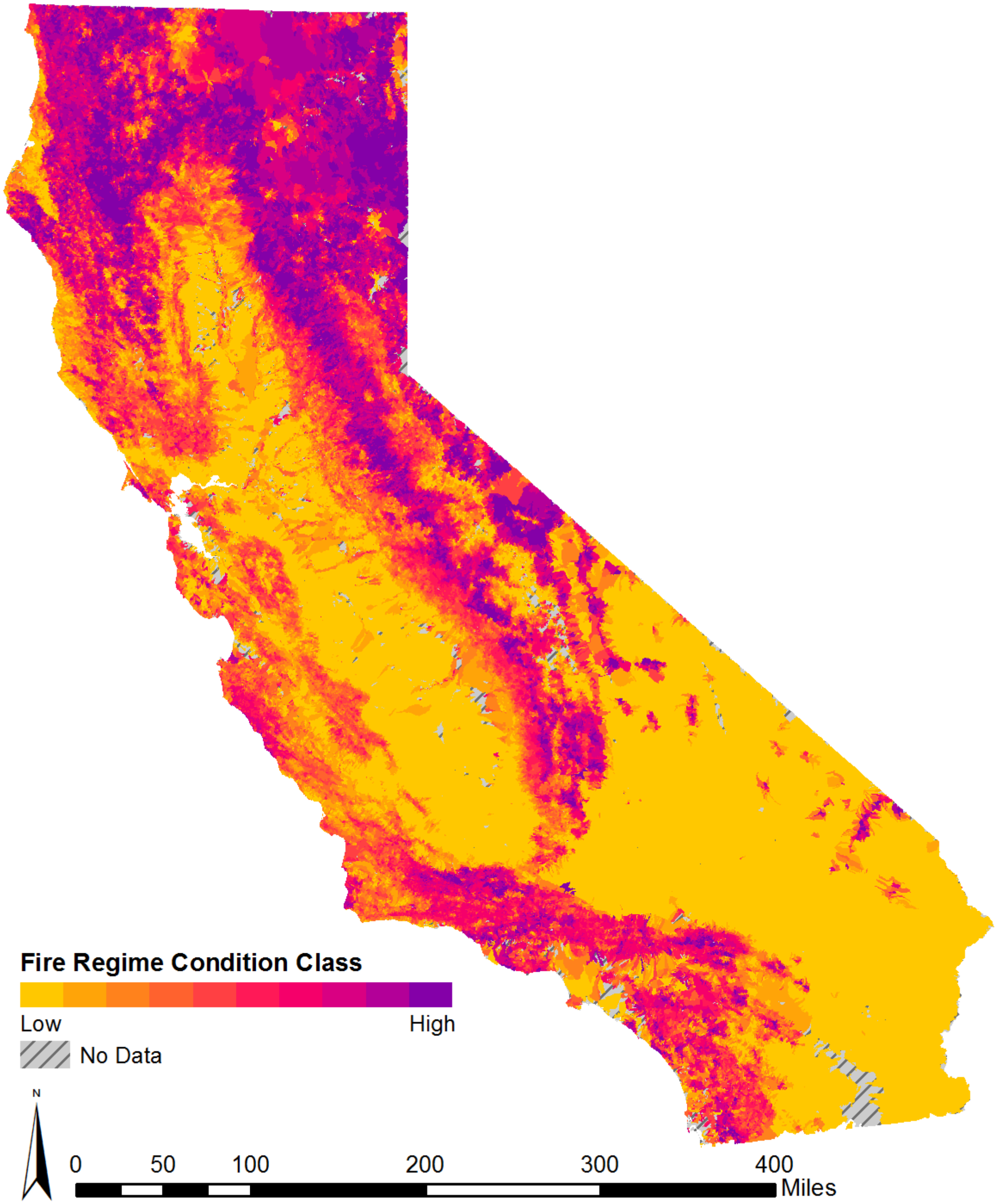

FIGURE 47. CURRENT FIRE REGIME CONDITION CLASS SCORES.

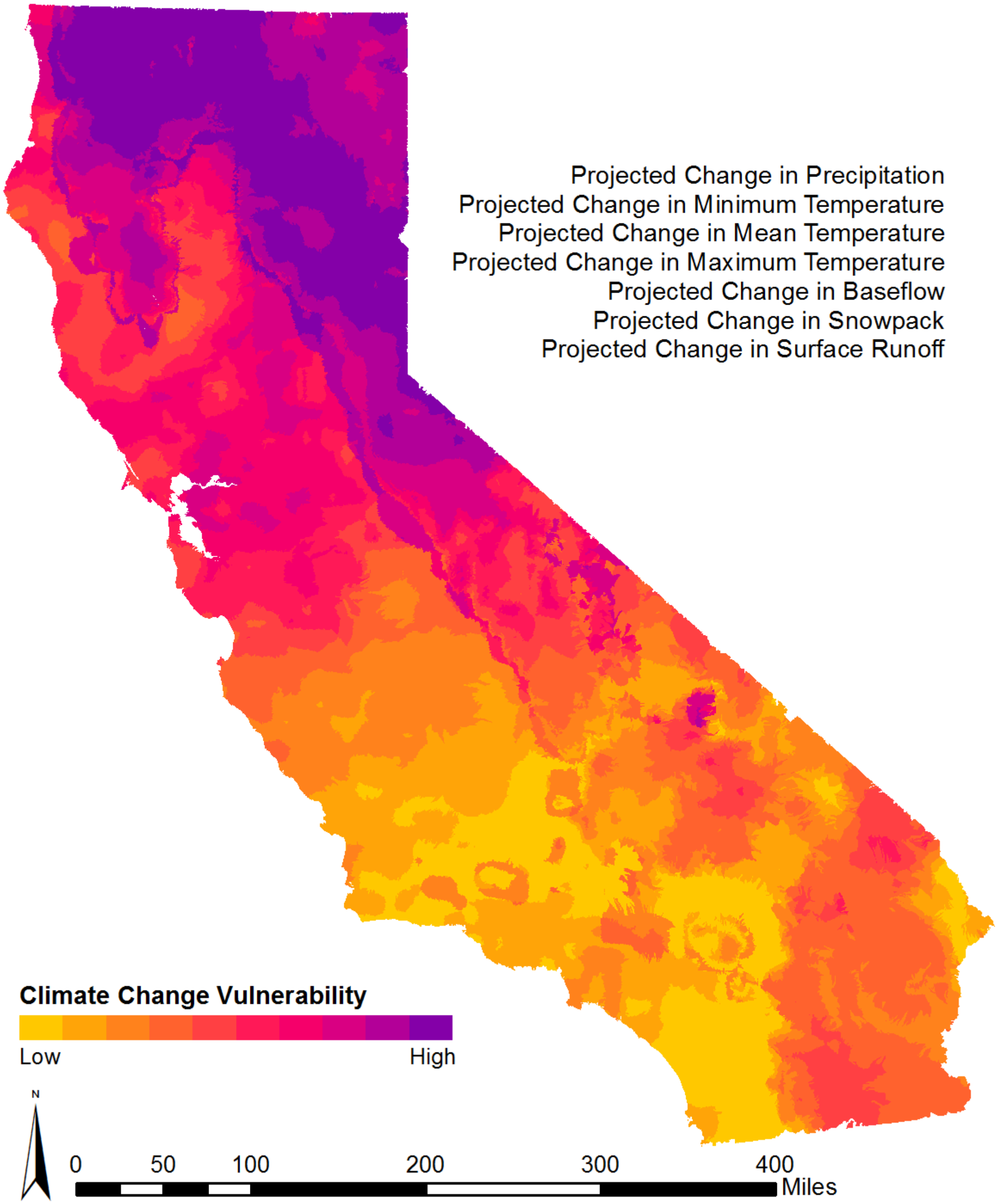

FIGURE 48. CLIMATE CHANGE VULNERABILITY INDEX SCORES.

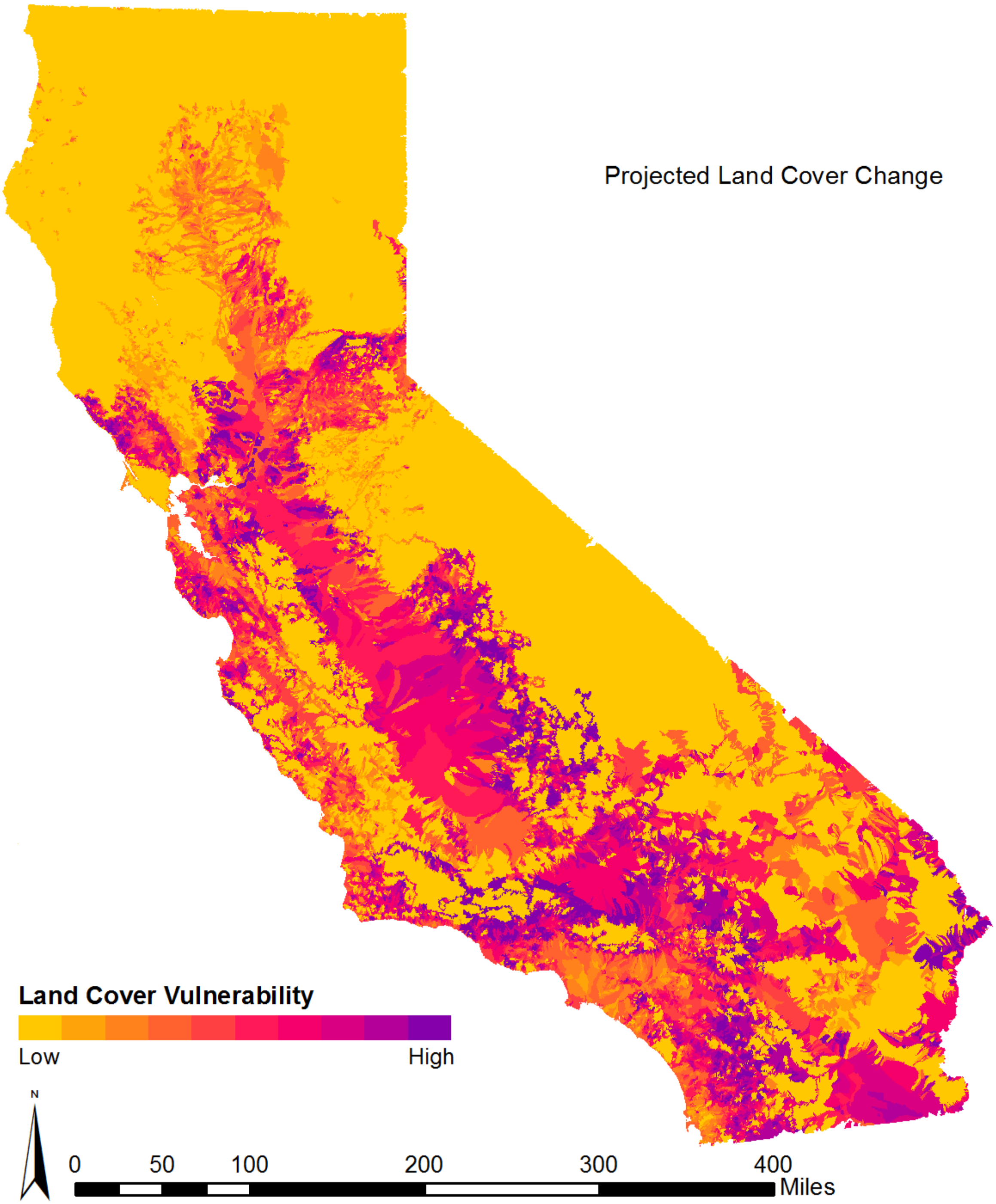

FIGURE 49. LAND COVER VULNERABILITY INDEX SCORES.

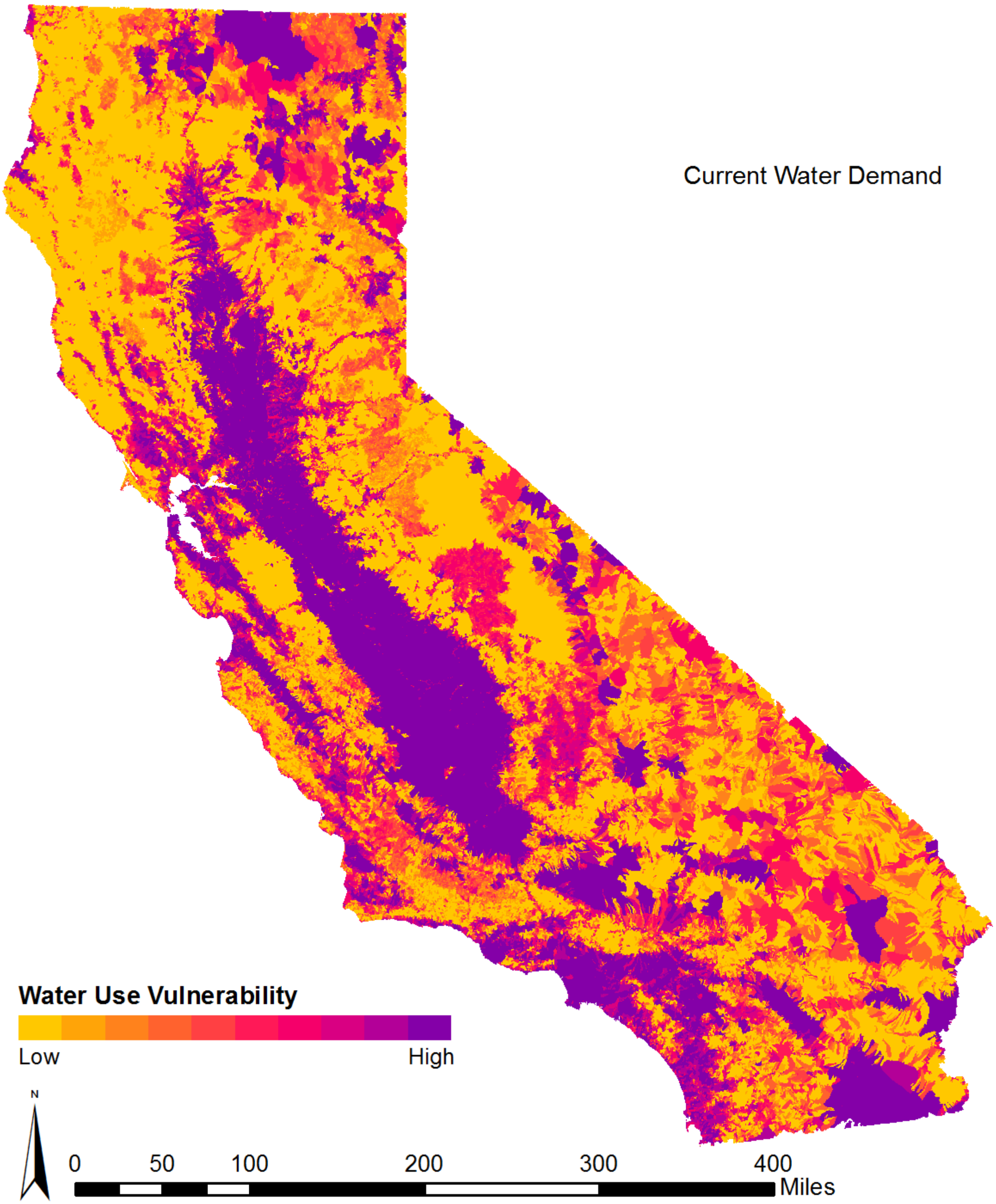

Figure 50. Water Use Vulnerability Index scores.

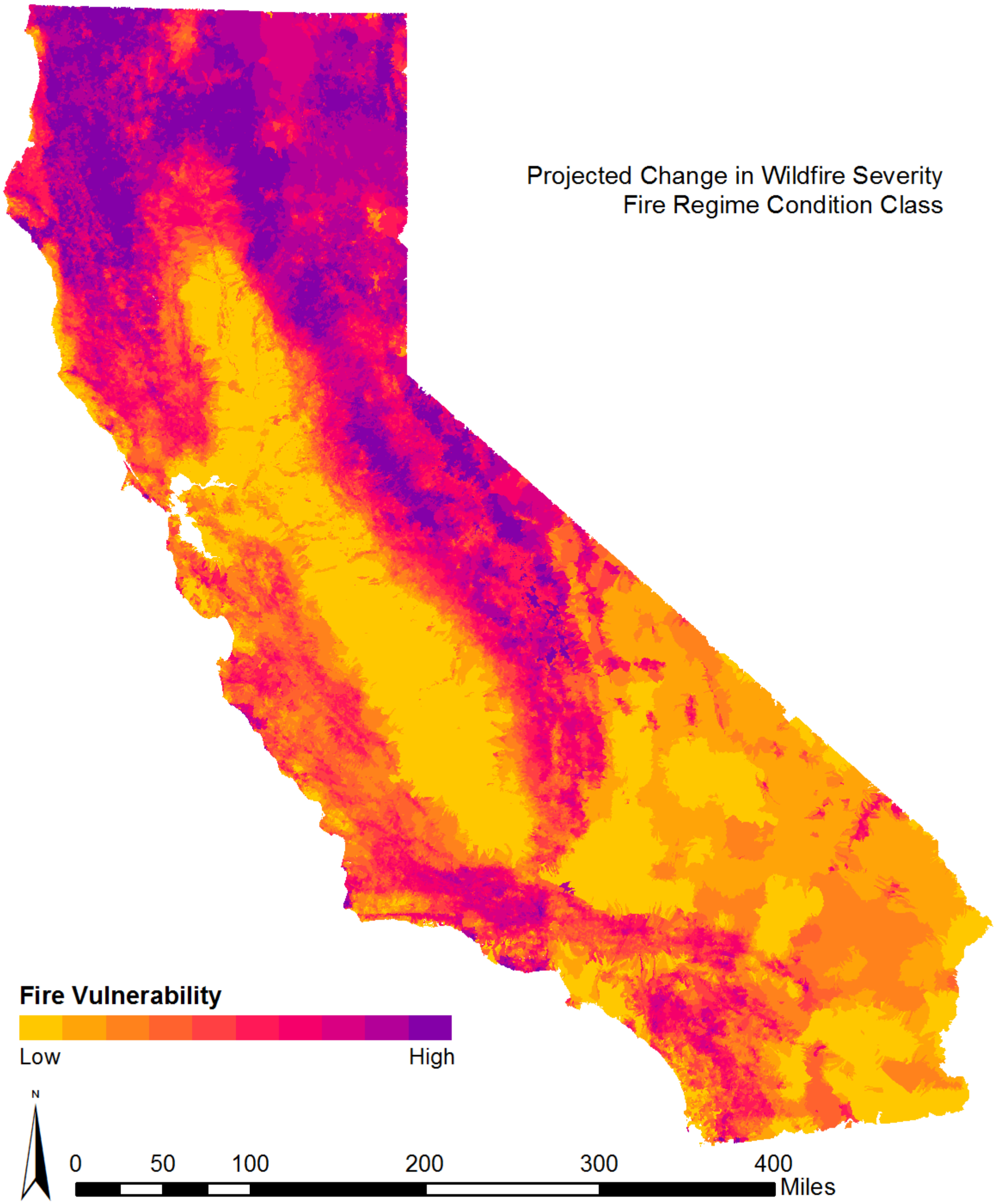

FIGURE 51. WILDFIRE VULNERABILITY INDEX SCORES.

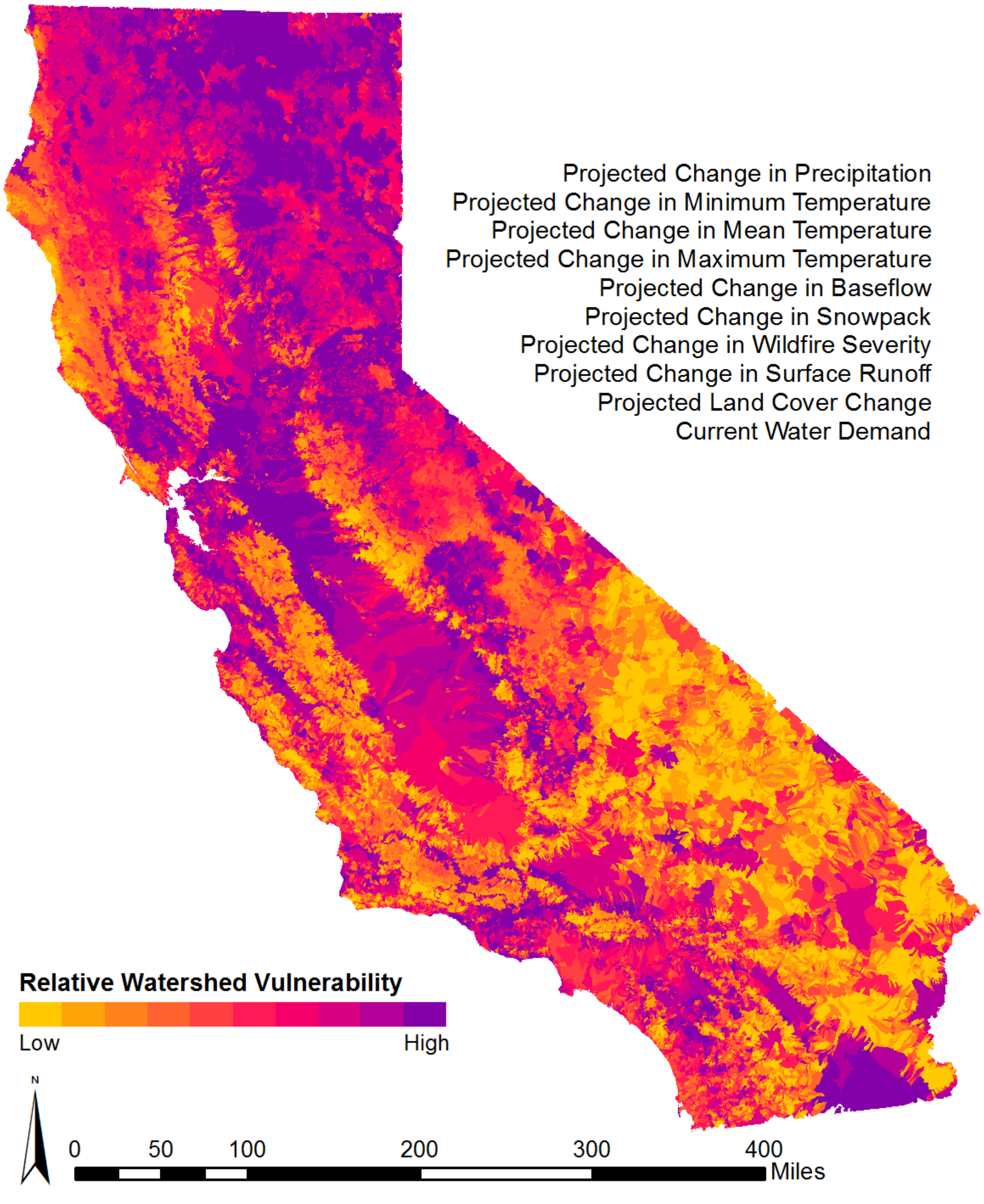

FIGURE 52. RELATIVE WATERSHED VULNERABILITY INDEX SCORES.

APPENDIX B INDEX BOXPLOTS

This Appendix contains boxplots that display summary statistics for watershed condition, stream health, and watershed vulnerability indices by Perennial Stream Assessment (PSA) region and by Water Quality Control Board (WQCB) region.

B1 Watershed Condition Indices

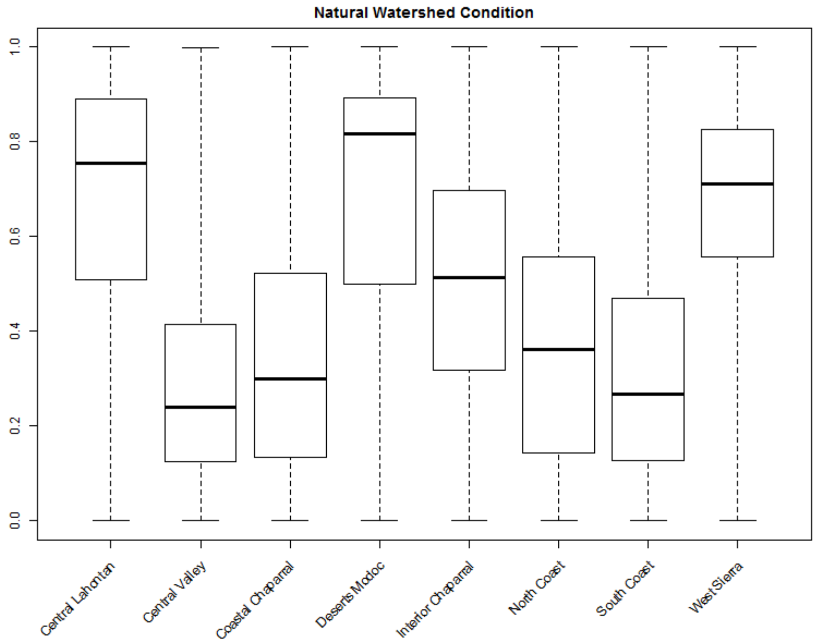

FIGURE 53. NATURAL WATERSHED CONDITION INDEX SCORES BY PSA REGION.

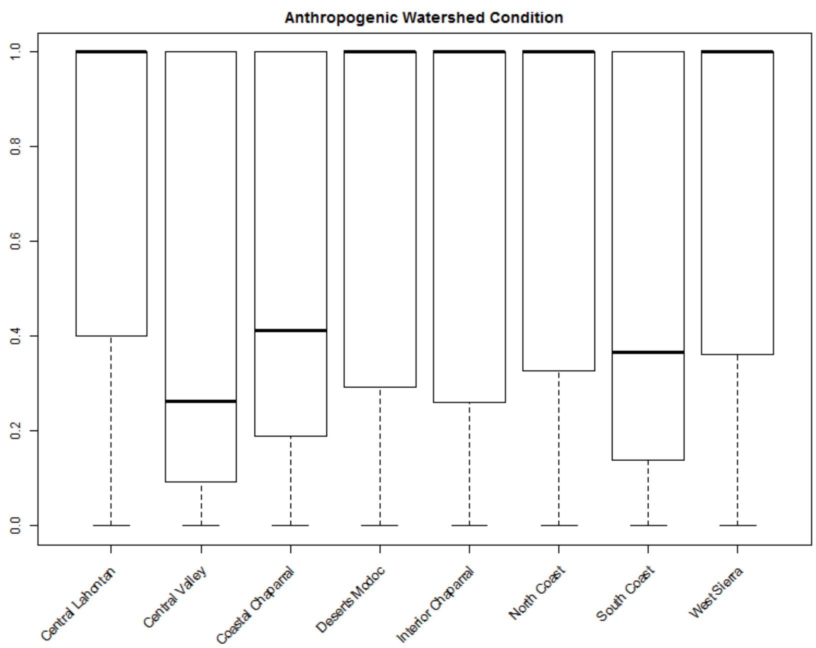

FIGURE 54. ANTHROPOGENIC WATERSHED CONDITION INDEX SCORES BY PSA REGION.

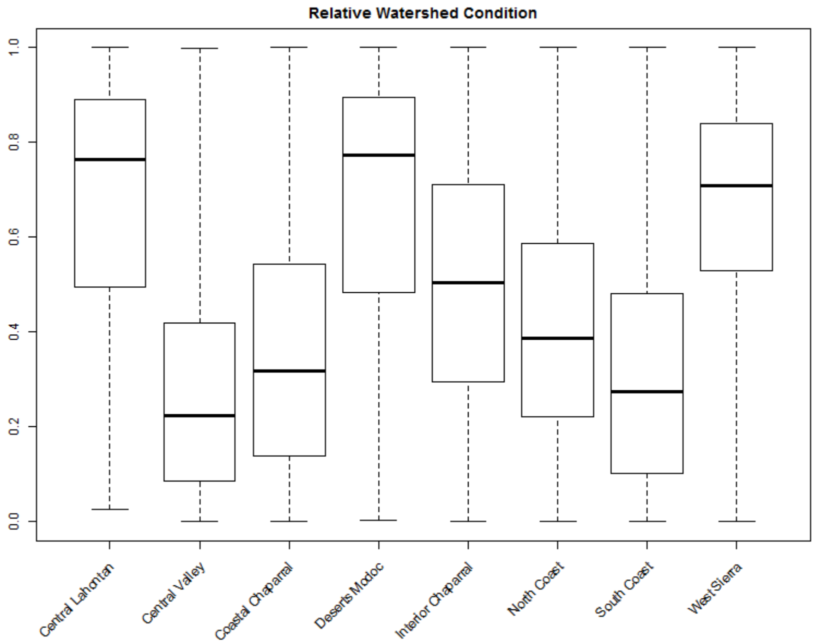

Figure 55. Relative Watershed Condition Index scores by PSA Region.

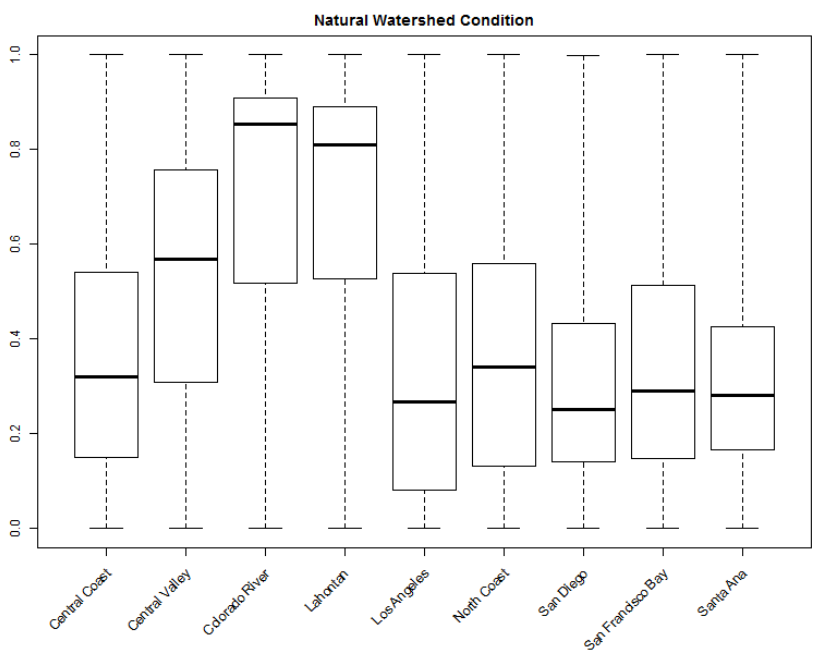

Figure 56. Natural Watershed Condition Index scores by WQCB Region.

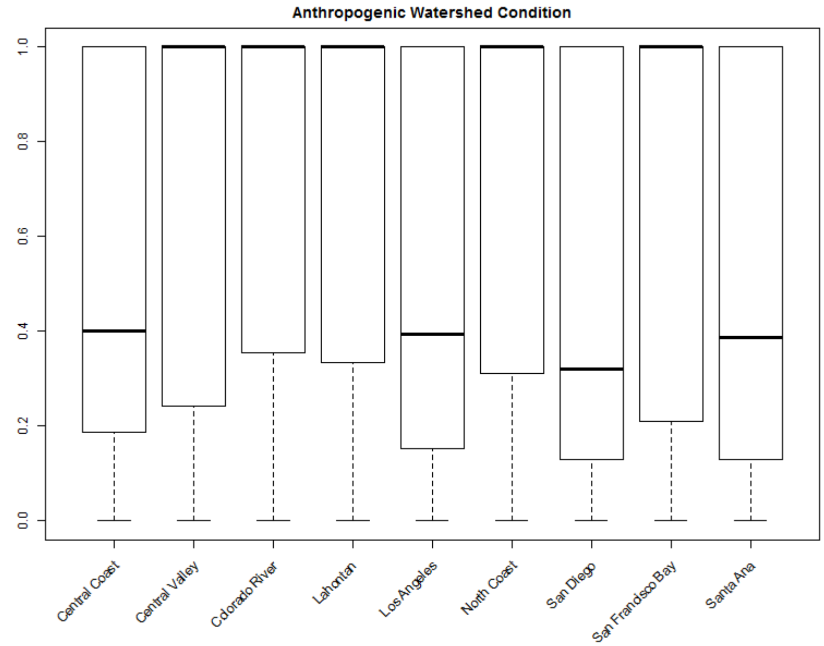

FIGURE 57. ANTHROPOGENIC WATERSHED CONDITION INDEX SCORES BY WQCB REGION.

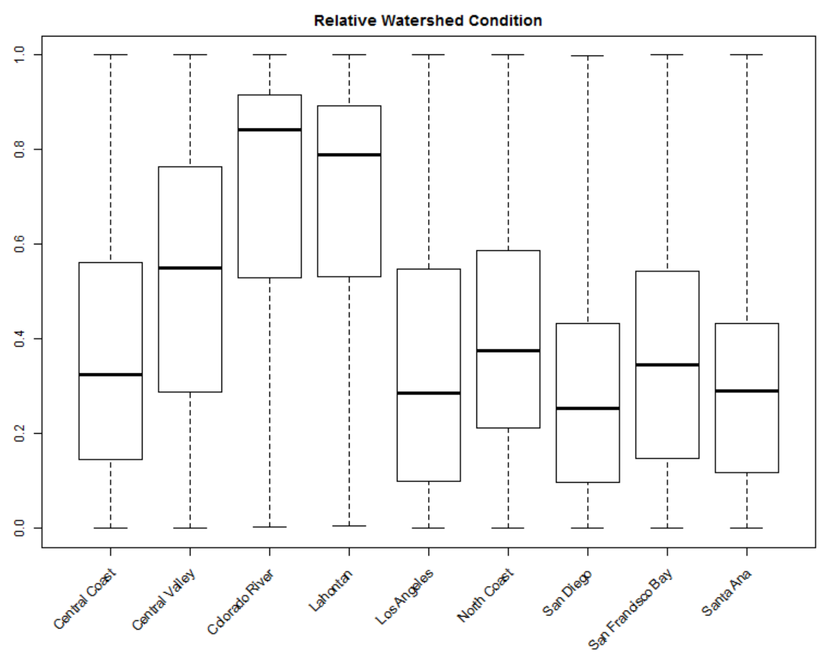

FIGURE 58. RELATIVE WATERSHED CONDITION INDEX SCORES BY WQCB REGION.

B2 Stream Health Indices

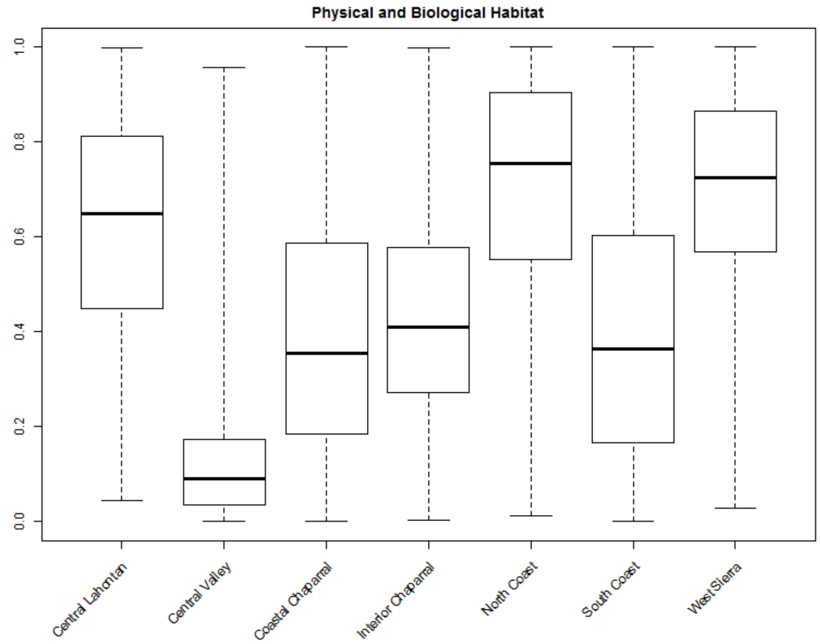

FIGURE 59. PHYSICAL AND BIOLOGICAL HABITAT INDEX SCORES BY PSA REGION.

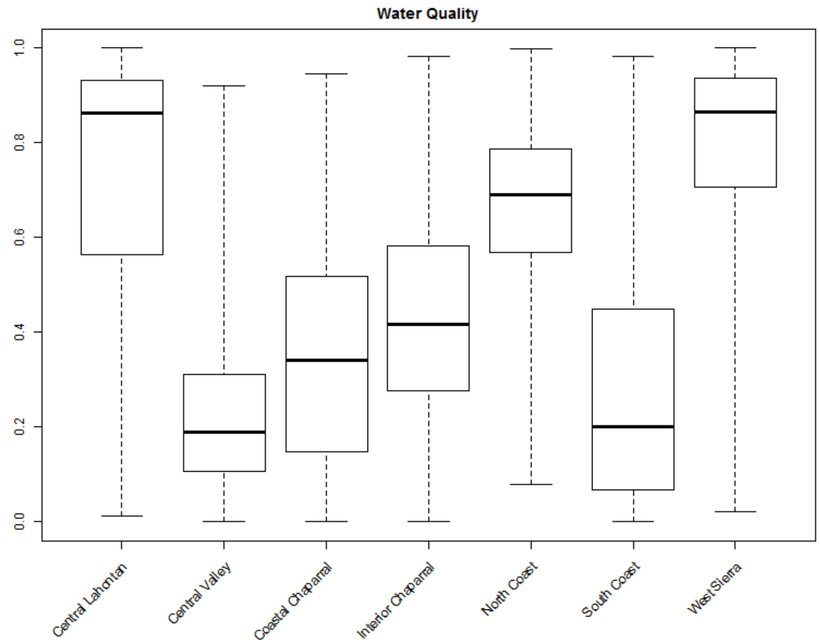

FIGURE 60. WATER QUALITY INDEX SCORES BY PSA REGION.

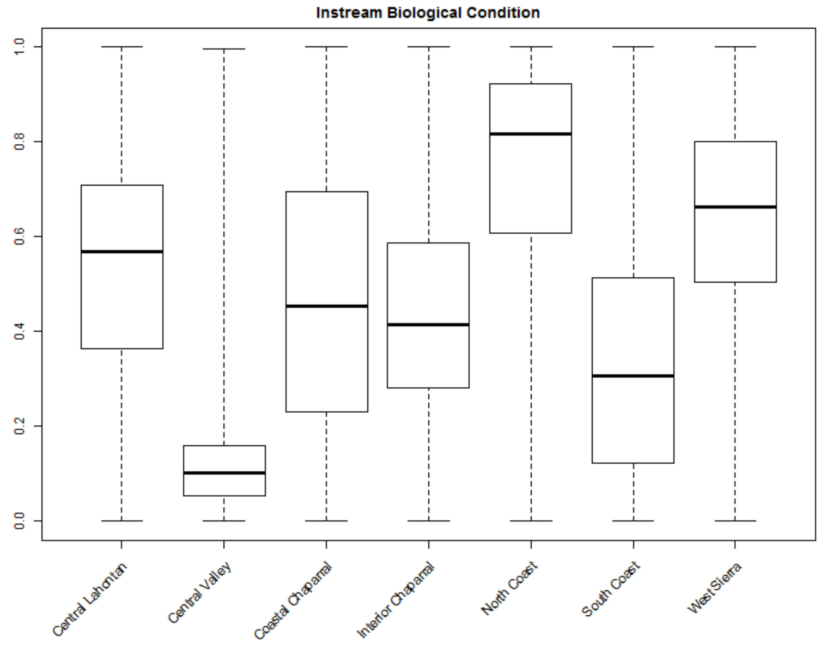

FIGURE 61. INSTREAM BIOLOGICAL CONDITION INDEX SCORES BY PSA REGION.

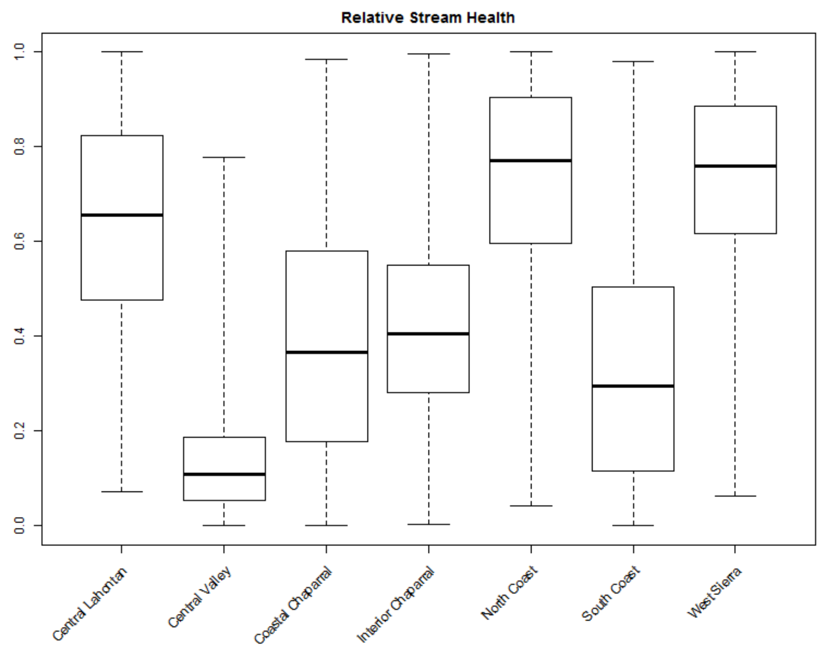

FIGURE 62. RELATIVE STREAM HEALTH INDEX SCORES BY PSA REGION.

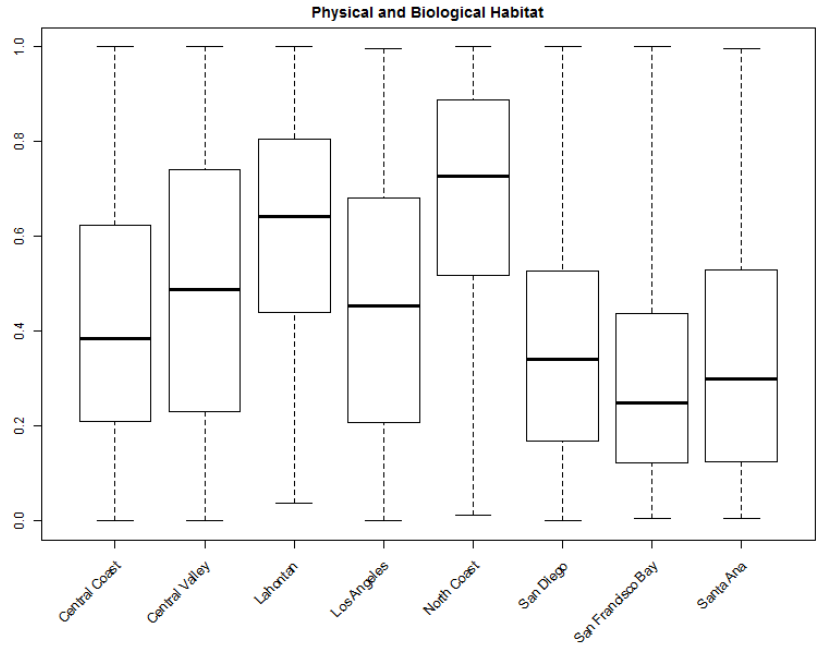

FIGURE 63. PHYSICAL AND BIOLOGICAL HABITAT INDEX SCORES BY WQCB REGION.

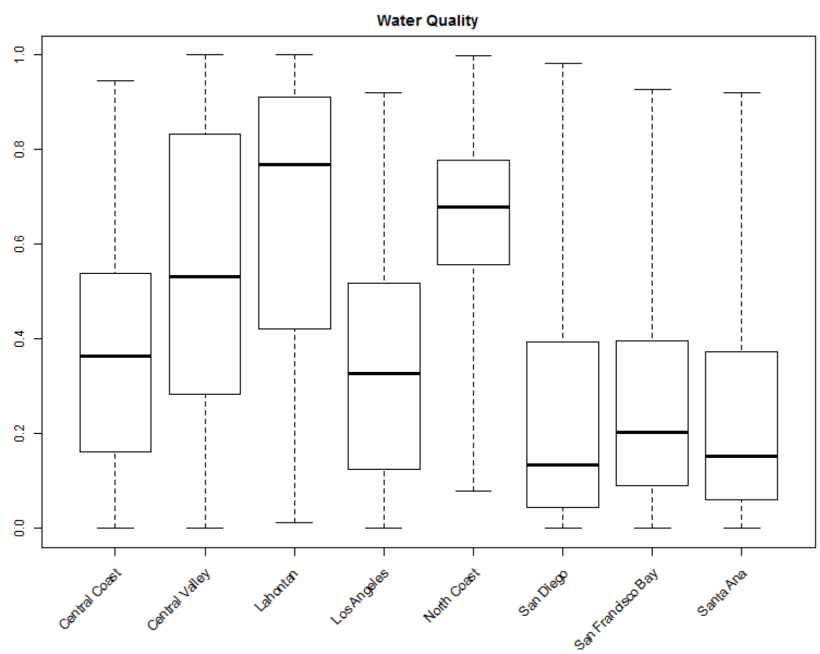

FIGURE 64. WATER QUALITY INDEX SCORES BY WQCB REGION.

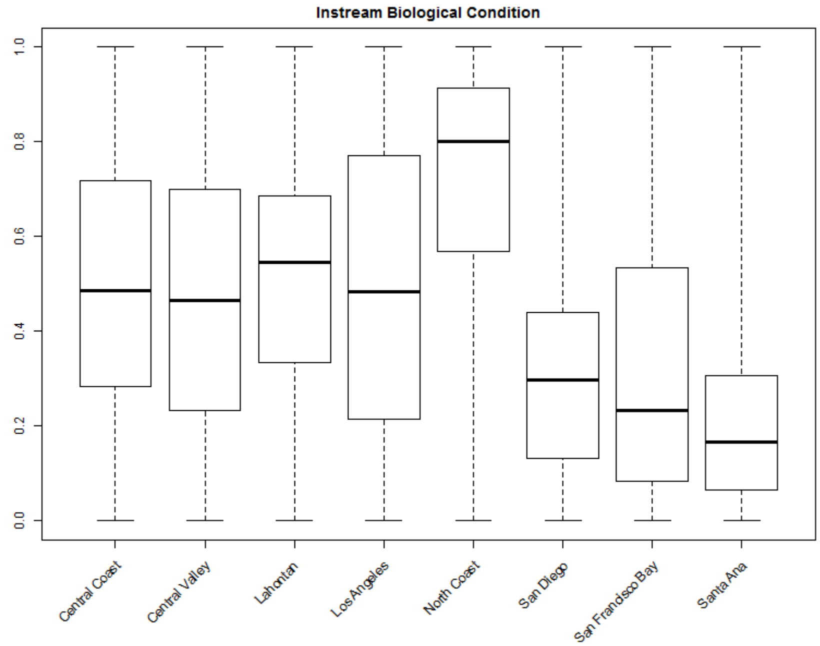

FIGURE 65. INSTREAM BIOLOGICAL CONDITION INDEX SCORES BY WQCB REGION.

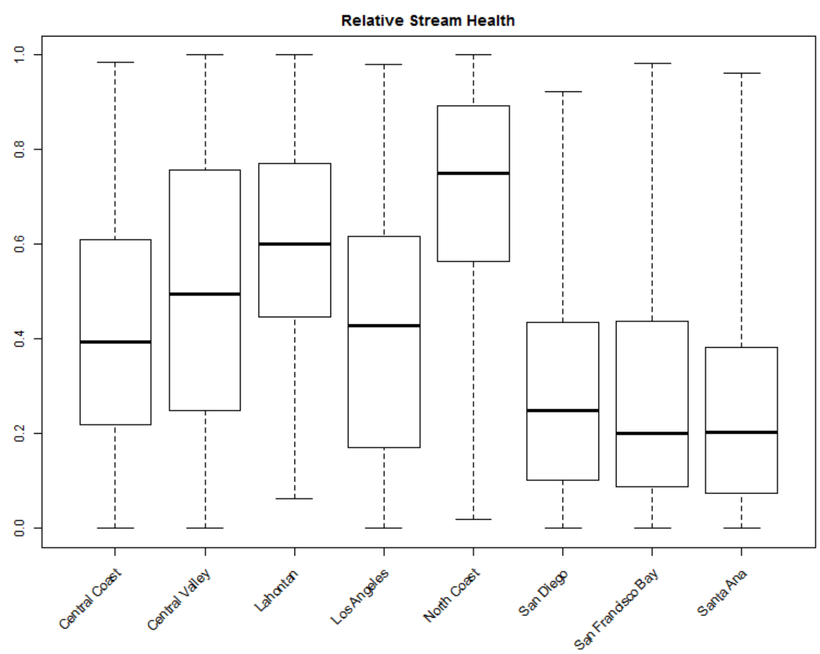

FIGURE 66. RELATIVE STREAM HEALTH INDEX SCORES BY WQCB REGION.

B3 Watershed Vulnerability Indices

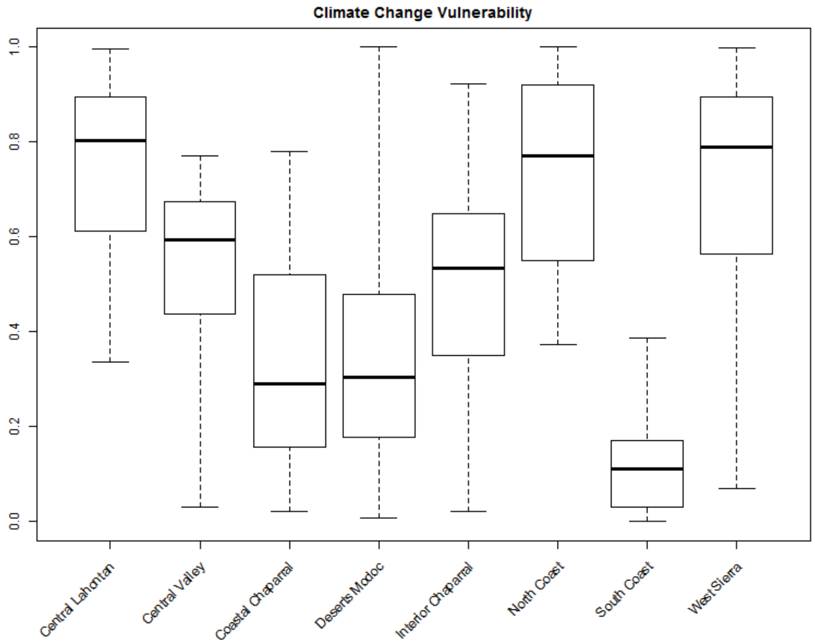

FIGURE 67. CLIMATE CHANGE VULNERABILITY INDEX SCORES BY PSA REGION.

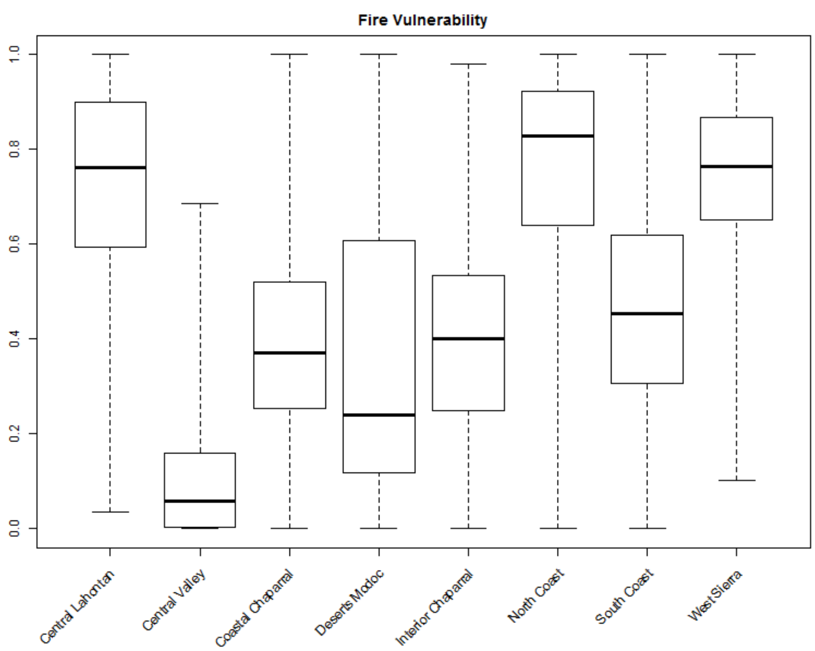

FIGURE 68. WILDFIRE VULNERABILITY INDEX SCORES BY PSA REGION.

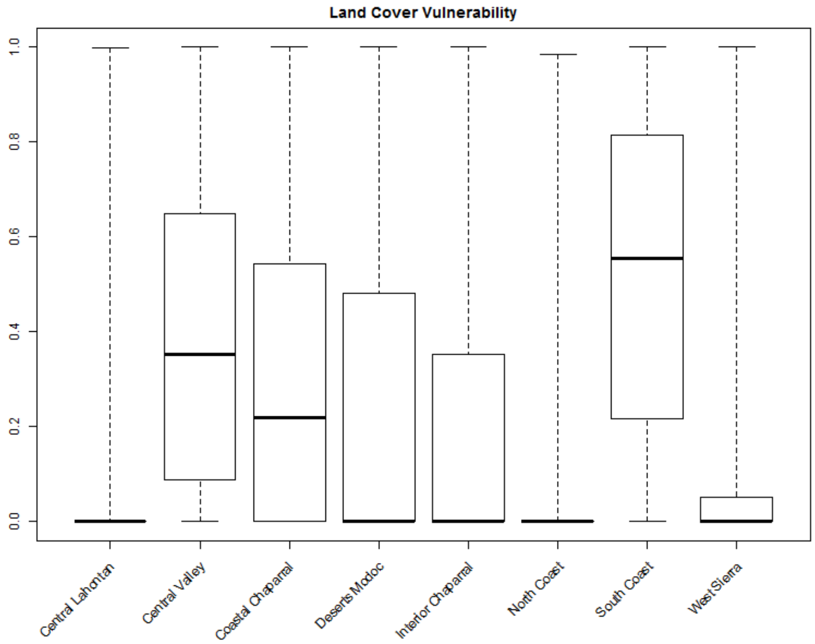

FIGURE 69. LAND COVER VULNERABILITY INDEX SCORES BY PSA REGION.

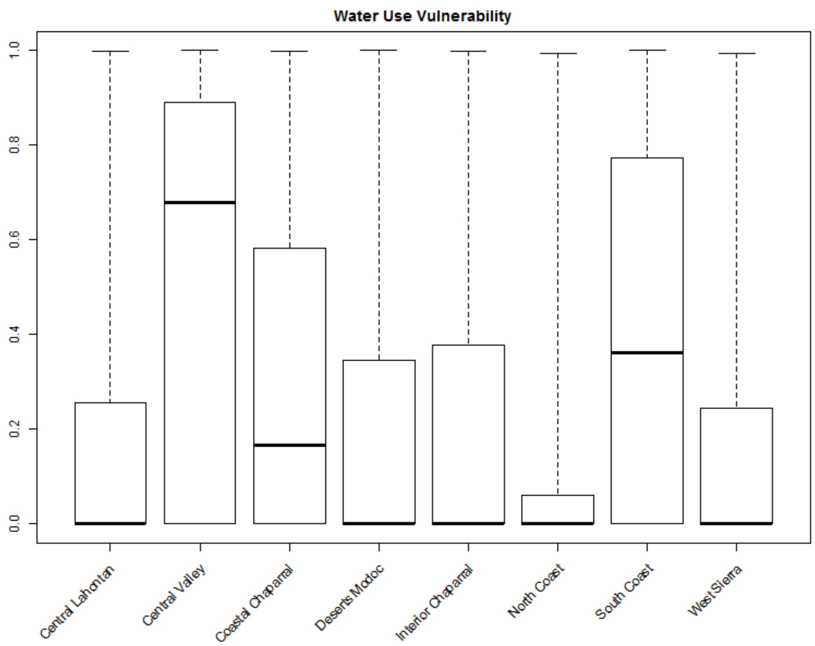

FIGURE 70. WATER USE VULNERABILITY INDEX SCORES BY PSA REGION.

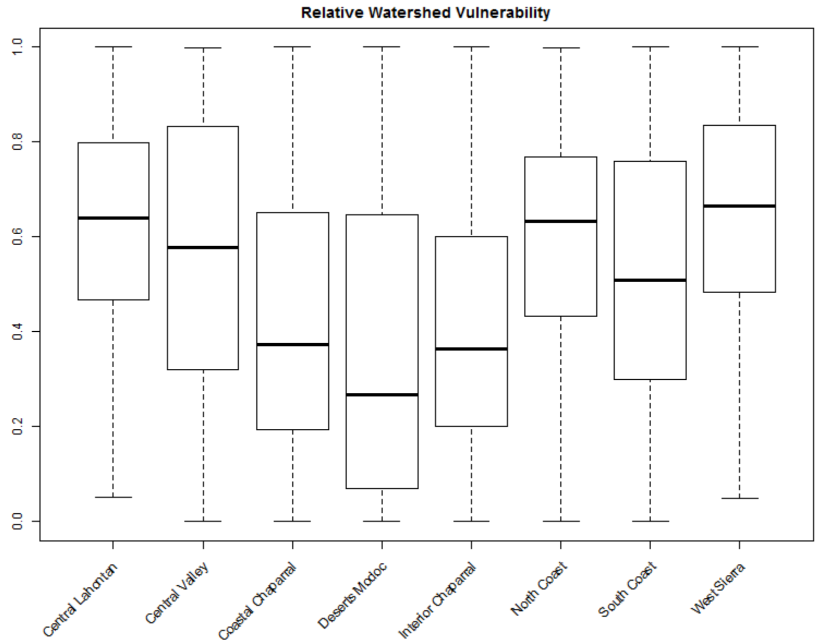

FIGURE 71. RELATIVE WATERSHED VULNERABILITY INDEX SCORES BY PSA REGION.

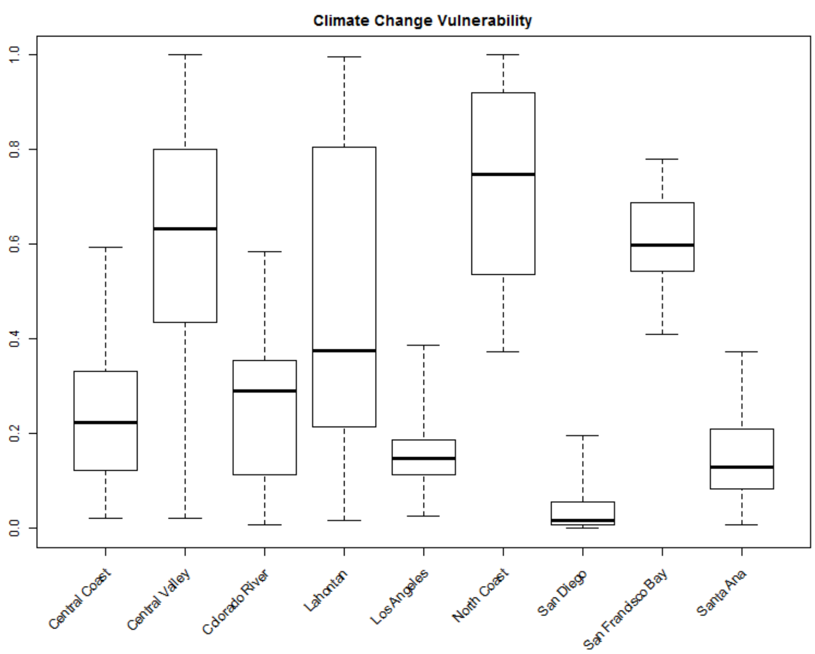

FIGURE 72. CLIMATE CHANGE VULNERABILITY INDEX SCORES BY WQCB REGION.

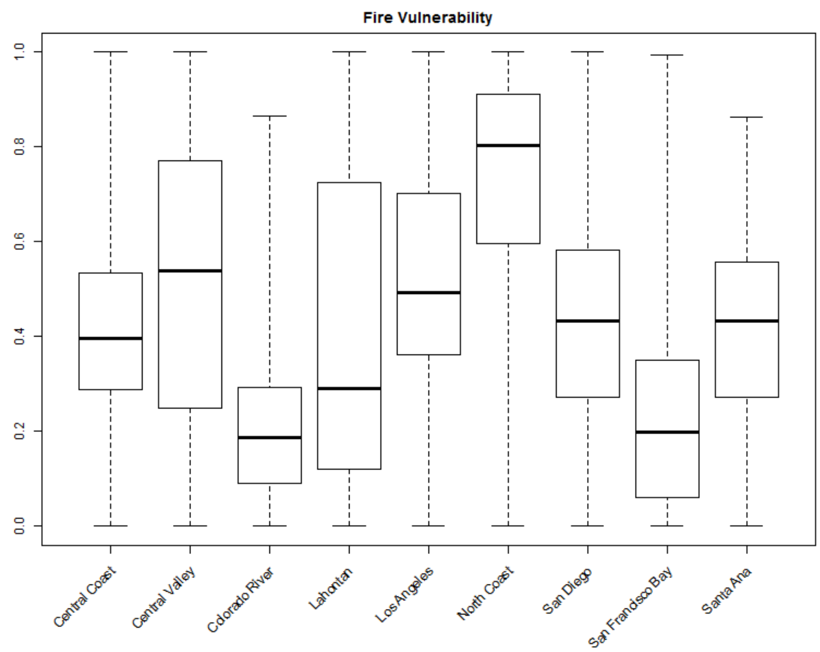

FIGURE 73. WILDFIRE VULNERABILITY INDEX SCORES BY WQCB REGION.

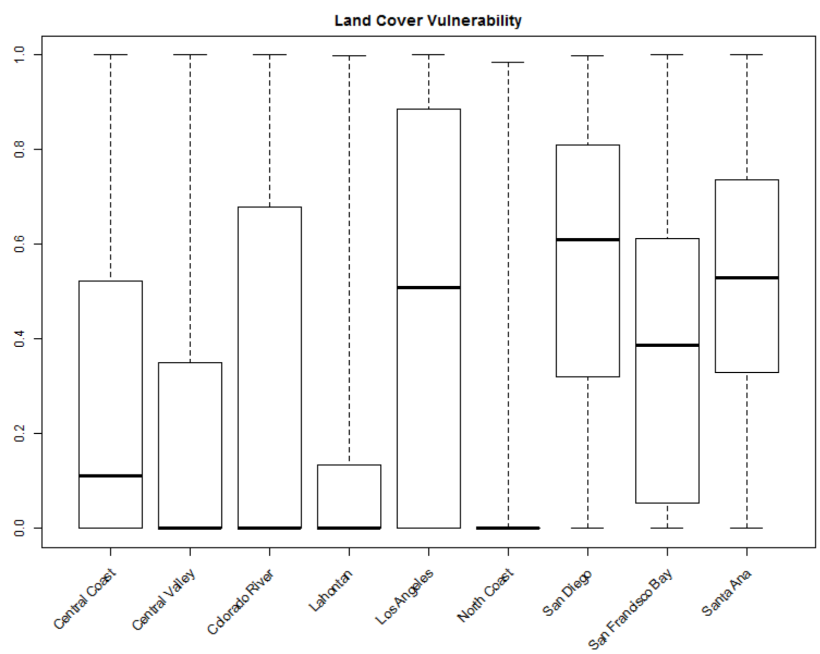

FIGURE 74. LAND COVER VULNERABILITY INDEX SCORES BY WQCB REGION.

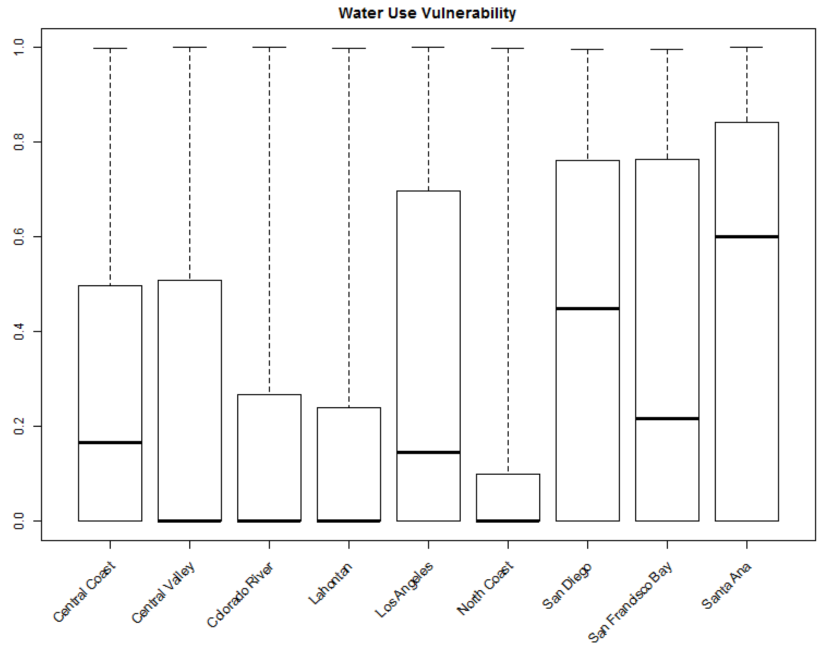

FIGURE 75. WATER USE VULNERABILITY INDEX SCORES BY WQCB REGION

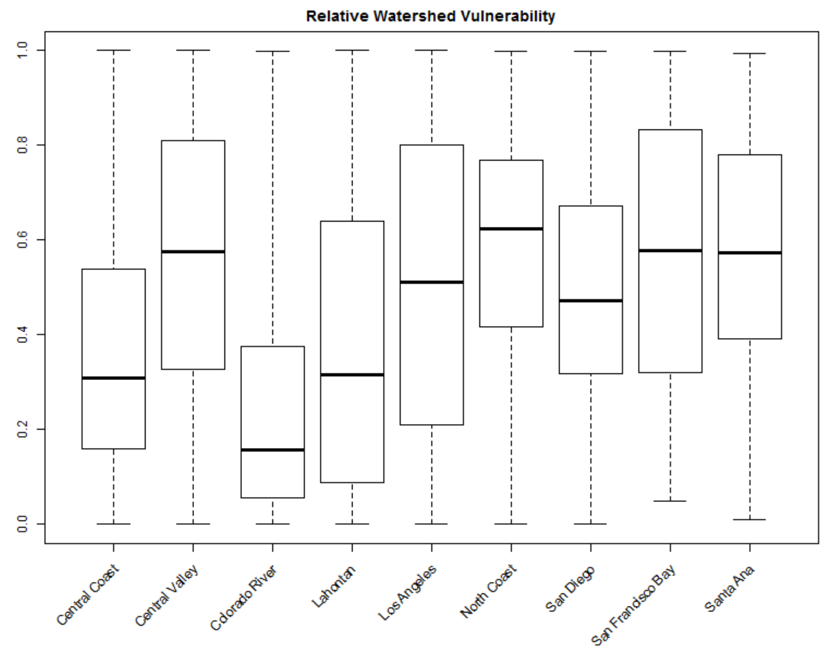

FIGURE 76. RELATIVE WATERSHED VULNERABILITY INDEX SCORES BY WQCB REGION

APPENDIX C STREAM HEALTH INDICATOR MODELING

C1 Introduction

Stream health indicators are quantified for NHDPlus catchments from Boosted Regression Tree (BRT) models. BRTs are a relatively recent approach to modeling ecological relationships that combines two methods: 1) regression tree modeling; and 2) boosting (Elith, Leathwick, & Hastie, 2008).

A regression tree is comprised of a group of leaves that represent possible response variable outcomes and a group of branches connected to each leaf. Each split in the branch network denotes a relationship between a predictor value and a response outcome evident in the training dataset (i.e., a certain predictor value leads to one known outcome or group of outcomes while another predictor value leads to a different known outcome or group of outcomes). Regression trees are constructed to minimize the error between observed and predicted values.

Boosting is a method for improving model predictions by creating multiple submodels for a response variable rather than one single model. Submodels are developed iteratively, with the first submodel fit to minimize prediction errors in the entire dataset, and subsequent submodels focusing on improving predictions for observations that are poorly predicted by existing submodels. A BRT model therefore consists of several regression trees for any one response variable.

BRT models are well suited for modeling complex ecological relationships and have several advantages over traditional statistical methods (e.g., multiple linear regression or generalized linear modeling):

- BRTs can be used to predict several data types (e.g., numeric, categorical, or binary) and can include any combination of data types as potential predictors.
- BRTs are insensitive to outliers in response and predictor datasets. A pre-processing step to evaluate data distributions and remove outliers is therefore not required.
- BRTs capture interactions between individual predictors in the regression tree structure and do not require the use of "interaction terms" as possible predictor variables.
- There is no assumption of a linear relationship between predictor and response variables and nonlinear relationships are accounted for.
- Techniques have been developed to address overfitting that preclude subjective determinations of "significant" predictors.

This Appendix details the methods used for developing BRT models of stream health indicators and BRT model results.

C2 Methods

Preparation of Response Data

Model development was initiated by acquiring and preparing stream monitoring datasets for input as observed response variable outcomes. Monitoring datasets included:

- Physical habitat (PHAB) assessment data for perennial, wadeable streams acquired from the Southern California Coastal Water Research Project (Eric Stein, personal communication)
- Draft California Rapid Assessment Method (CRAM) wetland assessment data acquired from the San Francisco Estuary Institute (Cristina Grosso, personal communication)

- California Stream Condition Index (CSCI) biological assessment data for perennial, wadeable streams acquired from the California Department of Game and Fish (Pete Ode, personal communication)
- Water quality samples for stream monitoring sites acquired from the California Environmental Data Exchange Network (CEDEN) database and the USGS National Water Information System (for the period 1/1/2000 through 12/31/2011)
- Trend presence/absence data for five streamflow variables determined to have ecological significance for California stream gages (see Appendix D for details of streamflow alteration analysis)

From the above datasets, a group of variables were selected as potential indicators of stream health for inclusion in BRT modeling:

- Habitat Condition Variables
  - CRAM Wetland Habitat Assessment Score
  - PHAB Stream Habitat Assessment Score
- Biological Condition Variables
  - CSCI Biological Assessment Score
- Water Quality Variables
  - Median Summer Conductivity
  - Median Summer Nitrate Concentration
  - Median Summer Turbidity
  - Median Summer Temperature
  - Median Summer pH
- Hydrologic Condition Variables
  - Presence of trend in magnitude of large flood peak
  - Presence of trend in duration of small floods
  - Presence of trend in date of small flood peak
  - Presence of trend in frequency of small floods
  - Presence of trend in recession rate of high flow pulses

Habitat and biological variables are multimetric (overall) scores and were selected because they integrate multiple habitat and biology characteristics. Water quality variables were selected on the basis of data availability. Hydrologic variables were selected on the basis of ecological relevance (see Appendix D).

Representative values of stream health variables were calculated for NHDPlus catchments as the median of all samples reported for monitoring sites within catchment boundaries. Only summer season samples were used to calculate median values of water quality variables, defined as April through September, to minimize sampling bias in calculated medians (i.e., due to differences in sampling frequency by season among sites). Table 9 lists the number of NHDPlus catchments with observed stream health data by Perennial Streams Assessment (PSA) Region.

Data distributions of continuous stream health variables (PHAB score, CRAM score, CSCI score, and water quality variables) were reviewed using histograms. Logarithmic or log (x+1) transformations were applied as needed so that all variables were approximately normally distributed. Hydrologic variables are binary (0 for trend absence; 1 for trend presence) and were assumed to follow a binomial distribution.

Table 9. Number of NHDPlus catchments with observed values of stream health variables by PSA Region.

Response Variable	Total	North Coast	Chaparral: Interior	Chaparral: Coastal	Central Valley	Sierra: West Slope	Sierra: Central	South Coast	Desert-Modoc
PHAB Score	482	63 (13%)	36 (7%)	92 (19%)	36 (7%)	44 (9%)	32 (7%)	143 (30%)	36 (7%)
CRAM Score	837	91 (11%)	50 (6%)	316 (38%)	48 (6%)	72 (9%)	68 (8%)	155 (19%)	37 (4%)
CSCI Score	1687	224 (13%)	73 (4%)	303 (18%)	61 (4%)	218 (13%)	192 (11%)	545 (32%)	71 (4%)
Median Summer Conductivity	1531	173 (11%)	134 (9%)	196 (13%)	320 (21%)	130 (8%)	163 (11%)	292 (19%)	123 (8%)
Median Summer Nitrate	1197	164 (14%)	67 (6%)	188 (16%)	112 (9%)	102 (9%)	149 (12%)	270 (23%)	145 (12%)
Median Summer Turbidity	996	127 (13%)	76 (8%)	173 (17%)	144 (14%)	57 (6%)	106 (11%)	197 (20%)	116 (12%)
Median Summer Water Temperature	1598	180 (11%)	128 (8%)	234 (15%)	320 (20%)	134 (8%)	160 (10%)	295 (18%)	147 (9%)
Median Summer pH	1416	163 (12%)	114 (8%)	188 (13%)	300 (21%)	88 (6%)	142 (10%)	270 (19%)	151 (11%)
Trend in Magnitude of Large Flood Peak	940	61 (6%)	144 (15%)	148 (16%)	59 (6%)	243 (26%)	49 (5%)	151 (16%)	85 (9%)
Trend in Duration of Small Floods	940	61 (6%)	144 (15%)	148 (16%)	59 (6%)	243 (26%)	49 (5%)	151 (16%)	85 (9%)
Trend in Date of Small Flood Peak	940	61 (6%)	144 (15%)	148 (16%)	59 (6%)	243 (26%)	49 (5%)	151 (16%)	85 (9%)
Trend in Frequency of Small Floods	940	61 (6%)	144 (15%)	148 (16%)	59 (6%)	243 (26%)	49 (5%)	151 (16%)	85 (9%)
Trend in Recession Rate of High Flow Pulses	940	61 (6%)	144 (15%)	148 (16%)	59 (6%)	243 (26%)	49 (5%)	151 (16%)	85 (9%)

Preparation of Predictor Data

Stream health predictors included in BRT modeling are landscape variables that describe land cover, soils, climate, elevation, topography, geology, and anthropogenic features of NHDPlus catchments (Table 10). Predictors were selected on the basis of data availability and relevance to stream health. A predictor database was prepared by compiling predictor values for all NHDPlus catchments in California at both incremental and cumulative scales. Incremental values reflect within-catchment conditions only. Cumulative values reflect conditions throughout all upstream catchments.

Incremental values of many predictors used in modeling are those reported by the USGS for all NHDPlus catchments in the nation (USGS, 2010). Other sources of pre-calculated incremental values include NHDPlus attribute tables and the National Fish Habitat Action Partnership (NFHAP). Pre-calculated values of some predictors were not available and were quantified from existing geospatial datasets using ArcGIS software (Table 10). Incremental predictor values were aggregated to cumulative values by calculating the mean or sum of incremental values for all upstream catchments. Both incremental and cumulative predictor values were included in BRT modeling.

TABLE 10. LANDSCAPE VARIABLES CONSIDERED FOR STREAM HEALTH MODELING. PREDICTORS INCLUDED IN FINAL MODELS ARE DENOTED WITH AN "I" IF INCREMENTAL VALUES WERE USED AND A "C" IF CUMULATIVE VALUES WERE USED.

Predictor Name	Pre-Calculated	Data Source[a]	Included in Final Models
Stream Length	✓	USGS	-
Stream Density	✓	USGS	I, C
Stream Sinuosity	✓	USGS	I, C
Stream Slope	✓	NHD+	I, C
Stream Order	✓	NHD+	I
Maximum Stream Elevation	✓	NHD+	I, C
Minimum Stream Elevation	✓	NHD+	I
Mean Catchment Elevation	✓	USGS	I, C
Mean Catchment Slope	✓	USGS	I, C
Mean Annual Precipitation	✓	NHD+	I, C
Mean Annual Temperature	✓	NHD+	I, C
Percent Artificially Drained Area	✓	USGS	I, C
Percent Irrigated Area	✓	USGS	I, C
Mean Baseflow Index	✓	USGS	C
Mean Groundwater Recharge	✓	USGS	I, C
Mean Infiltration-Excess Overland Flow	✓	USGS	I, C
Mean Saturation-Excess Overland Flow	✓	USGS	C
Mean Rainfall-Runoff Erosivity	✓	USGS	I
Population Density	✓	NFHAP	I, C
Road Density	✓	NFHAP	I, C
Mean Percent Sand	✓	USGS	-
Mean Percent Silt	✓	USGS	C
Mean Percent Clay	✓	USGS	-
Mean Percent Organic Matter	✓	USGS	I, C
Mean Percent Calcium Carbonate	✓	USGS	I, C
Mean Saturated Hydraulic Conductivity	✓	USGS	-

Mean Soil Erodibility	✓	USGS	C
Mean Electrical Conductivity	✓	USGS	C
Mean Depth to Water Table	✓	USGS	C
Mean Cation-Exchange Capacity	✓	USGS	-
Mean Available Water Capacity	✓	USGS	-
Dominant Hydrologic Soil Group	✓	USGS	-
Dominant Surface Texture	✓	USGS	I, C
Mean Curve Number		NLCD 2006; USGS	I, C
Percent Open Water		NLCD 2006	-
Percent Perennial Ice/Snow		NLCD 2006	-
Percent Developed, Open Space		NLCD 2006	-
Percent Developed, Low Intensity		NLCD 2006	-
Percent Developed, Medium Intensity		NLCD 2006	-
Percent Developed High Intensity		NLCD 2006	-
Percent Barren Land (Rock/Sand/Clay)		NLCD 2006	-
Percent Deciduous Forest		NLCD 2006	-
Percent Evergreen Forest		NLCD 2006	-
Percent Mixed Forest		NLCD 2006	-
Percent Shrub/Scrub		NLCD 2006	-
Percent Grassland/Herbaceous		NLCD 2006	-
Percent Pasture/Hay		NLCD 2006	-
Percent Cultivated Crops		NLCD 2006	-
Percent Woody Wetlands		NLCD 2006	-
Percent Emergent Herbaceous Wetlands		NLCD 2006	-
Percent Natural Land Cover		NLCD 2006	I, C
Percent Urban Land Cover		NLCD 2006	C
Percent Agricultural Land Cover		NLCD 2006	I, C
Percent Riparian Open Water		NLCD 2006	-
Percent Riparian Perennial Ice/Snow		NLCD 2006	-
Percent Riparian Developed, Open Space		NLCD 2006	-
Percent Riparian Developed, Low Intensity		NLCD 2006	-
Percent Riparian Developed, Med Intensity		NLCD 2006	-
Percent Riparian Developed High Intensity		NLCD 2006	-
Percent Riparian Barren Land		NLCD 2006	-
Percent Riparian Deciduous Forest		NLCD 2006	-
Percent Riparian Evergreen Forest		NLCD 2006	-
Percent Riparian Mixed Forest		NLCD 2006	-
Percent Riparian Shrub/Scrub		NLCD 2006	-
Percent Riparian Grassland/Herbaceous		NLCD 2006	-
Percent Riparian Pasture/Hay		NLCD 2006	-
Percent Riparian Cultivated Crops		NLCD 2006	-
Percent Riparian Woody Wetlands		NLCD 2006	-
Percent Riparian Emergent Herbaceous Wetlands		NLCD 2006	-
Percent Riparian Natural Land Cover		NLCD 2006	I, C

Percent Riparian Urban Land Cover		NLCD 2006	-
Percent Riparian Agricultural Land Cover		NLCD 2006	I
Road Crossing Density	✓	USGS	C
Fish Barrier Density		CADFW	I
Dam Density		CADWR	C
Mine Density	✓	NFHAP	-
Toxic Release Inventory Density	✓	NFHAP	I, C
Point Source Density	✓	NFHAP	C
Superfund Site Density	✓	NFHAP	C
Dam Storage Ratio		CADWR	C
Dominant Surface Geology	✓	USGS	I, C

[a]USGS = US Geological Survey NHD+ = National Hydrography Dataset Plus Version 1
NFHAP = National Fish Habitat Partnership NLCD 2006 = National Land Cover Dataset 2006
CADFW = California Dept. of Fish and Wildlife CADWR = California Dept. of Water Resources

Model Development

Development of BRT models for stream health indicators was completed using R software, the *gbm* package (Ridgeway, 2013), and the *dismo* package (Hijmans, Phillips, Leathwick, & Elith, 2013). Key parameters for BRT modeling are the learning rate and tree complexity, which determine the number of regression trees in the full (boosted) model. With too few trees, the model is underfit and does not adequately describe relationships in the data. Too many trees creates an overfitted model that performs poorly on sites not used to build the model.

The optimal number of trees for each BRT model was determined using the k-fold cross-validation (CV) methodology described in Elith et al. (2008). This method randomly divides the full dataset into 10 subsets. Each subset is further divided into a training dataset, used for developing a BRT model, and a validation dataset, used for assessing predictive error. The optimal number of trees is the number that minimizes mean prediction error in the validation portion of the 10 CV subsets, and a final model is developed using the optimal number of trees and the full dataset. Here, the CV method was modified slightly by first setting aside a randomly selected portion (25%) of the full dataset for independent validation of final model predictions.

An initial set of BRT models were developed for stream health variables using all available predictor variables. After developing the initial set of models, relative influence scores for predictors in each model were examined. Relative influence scores describe the importance of an individual predictor relative to predictors. Scores range from 0 to 100, with 100 corresponding to the highest possible influence. Relative influence scores are determined from the number of times a predictor appears in a regression tree and the average improvement in model performance resulting from the presence of the predictor. Predictors with low relative influence (less than 1%) across all models were removed from the dataset. Final BRT models were generated from the trimmed set of predictors. This step was undertaken to simplify final models and remove unimportant/redundant predictors.

Model Evaluation

Three statistics were used to evaluate model fit and predictive performance for continuous response variables (habitat, water quality, and biology):

- Training Correlation – Pearson correlation coefficient for observations in the training dataset and predictions generated by the final model. This is a *goodness-of-fit statistic* for the final model.
- CV Correlation – Mean Pearson correlation coefficient for observations in the 10 CV validation subsets and predictions generated by CV models with the optimal number of regression trees. This is a *predictive performance statistic* for CV models.
- Independent Correlation – Pearson correlation coefficient for observations in the validation dataset and predictions generated by the final model. This is a *predictive performance statistic* for the final model.

Because hydrologic variables are binary (0 for trend absence; 1 for trend presence), the above statistics were not used to evaluate models of hydrologic variables. Their models were instead evaluated using the AUC (area under the receiving operator curve) statistic. AUC values reflect the ability of a model to correctly identify a site with altered flow as altered and a site with unaltered flow as unaltered. An AUC value of 1 corresponds to a perfect model while an AUC value of 0.5 corresponds to a random guess. Three AUC statistics were used here:

- Training AUC – AUC for observations in the training dataset and predictions generated by the final model. This is a *goodness-of-fit statistic* for the final model.
- CV AUC – AUC for observations in the 10 CV validation subsets and predictions generated by CV models with the optimal number of regression trees. This is a *predictive performance statistic* for CV models.
- Independent AUC – AUC for observations in the validation dataset and predictions generated by the final model. This is a *predictive performance statistic* for the final model.

C3 Results

Correlation and AUC statistics for the modeled stream health variables are outlined in Table 11 and Table 12. For all variables, training statistics are greater than CV statistics, indicating that performance suffers from some overfitting. However, the similarity between CV statistics and independent statistics supports the use of the CV methodology to optimize model parameters.

TABLE 11. CORRELATION COEFFICIENTS FOR BRT MODELS OF CONTINUOUS RESPONSE VARIABLES.

Response Variable	Training Correlation	CV Correlation	Independent Correlation
PHAB Score	0.93	0.70	0.72
CRAM Score	0.90	0.75	0.77
CSCI Score	0.81	0.68	0.67
Median Summer Nitrate	0.92	0.74	0.69
Median Summer pH	0.62	0.38	0.40
Median Summer Water Temperature	0.83	0.66	0.73
Median Summer Turbidity	0.82	0.62	0.58
Median Summer Conductivity	0.94	0.84	0.84

TABLE 12. AUC STATISTICS FOR BRT MODELS OF BINARY RESPONSE VARIABLES

Response Variable	Training AUC	CV AUC	Independent AUC
Trend in Magnitude of Large Flood Peak	0.99	0.69	0.69
Trend in Duration of Small Floods	0.90	0.59	0.66
Trend in Date of Small Flood Peak	0.91	0.57	0.60
Trend in Frequency of Small Floods	0.94	0.67	0.56
Trend in Recession Rate of High Flow Pulses	0.91	0.62	0.62

BRT models were reviewed in conjunction with monitoring data characteristics to select a final group of stream health indicators. Factors considered included model performance (training and CV statistics) and the representativeness of monitoring data used for model development. Stream pH was not selected as a stream health indicator due to relatively poor model performance (CV correlation = 0.38). Stream water temperature was also excluded because of concerns over the ability of field data to adequately capture the large temporal variability at any given site and spatial variability throughout the state. Hydrologic response variables were excluded for multiple reasons, including poor model performance (CV AUCs < 0.7), because models did not explicitly account for surface and subsurface water withdrawals, and because many streamflow monitoring sites do not include a sufficient pre-alteration record for accurate trend detection.

Relative influence plots for stream health indicators are shown in Figure 77 through Figure 82. Each plot displays relative influence scores for the 10 most influential predictors of indicator values (i.e., predictors with the top 10 relative influence scores). Influential predictors characterize a combination of natural watershed characteristics and processes and anthropogenic features. While these plots provide some insight into cause-effect relationships between landscape conditions and stream health, BRT models were not explicitly developed to uncover cause-effect relationships. Rather, the goal of BRT modeling was to extrapolate patterns between observed stream health and landscape variables for the purpose of predicting stream health in any NHDPlus catchment in the state. Nevertheless, influential predictors can serve as a starting point for discussion of management approaches to maintain or improve stream health, and predictors with the highest relevance to management efforts are highlighted in red in relative influence plots.

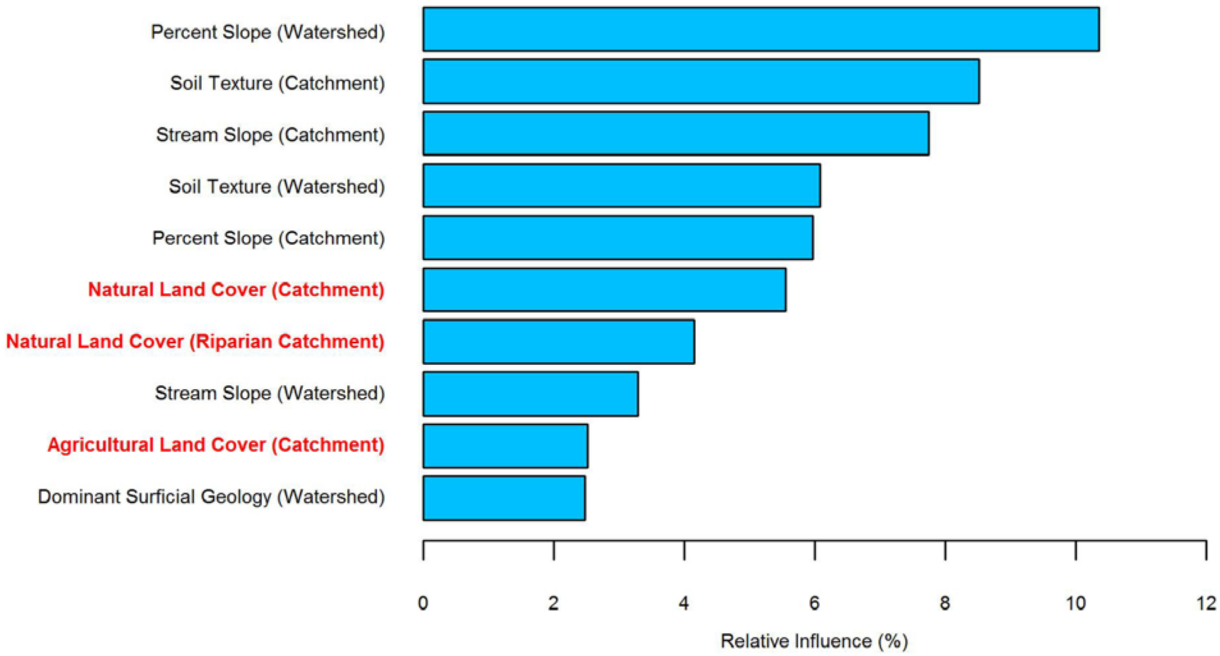

FIGURE 77. RELATIVE INFLUENCE PLOT FOR PHAB STREAM HABITAT ASSESSMENT SCORE.

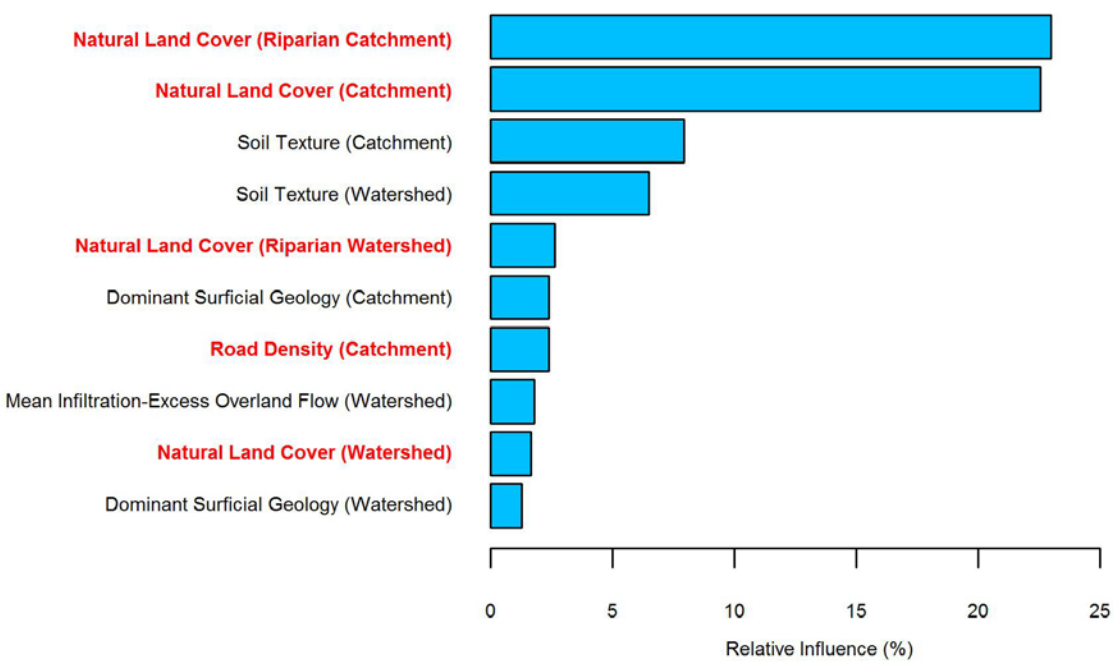

FIGURE 78. RELATIVE INFLUENCE PLOT FOR CRAM WETLAND HABITAT ASSESSMENT SCORE.

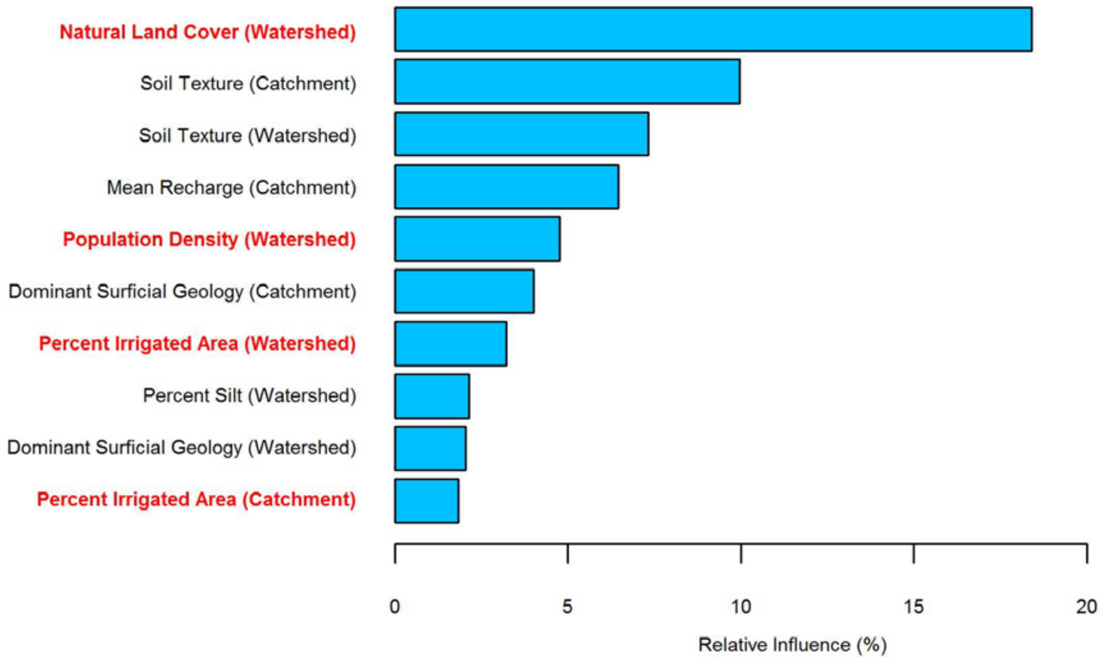

Figure 79. Relative influence plot for median summer nitrate concentration.

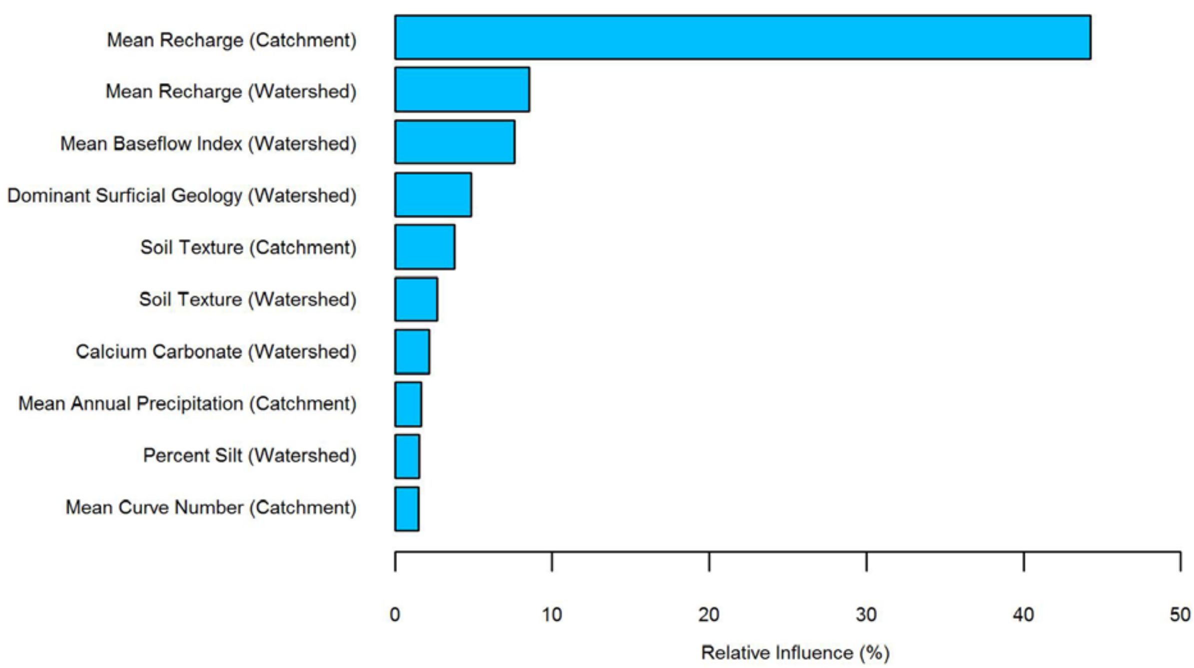

Figure 80. Relative influence plot for median summer conductivity.

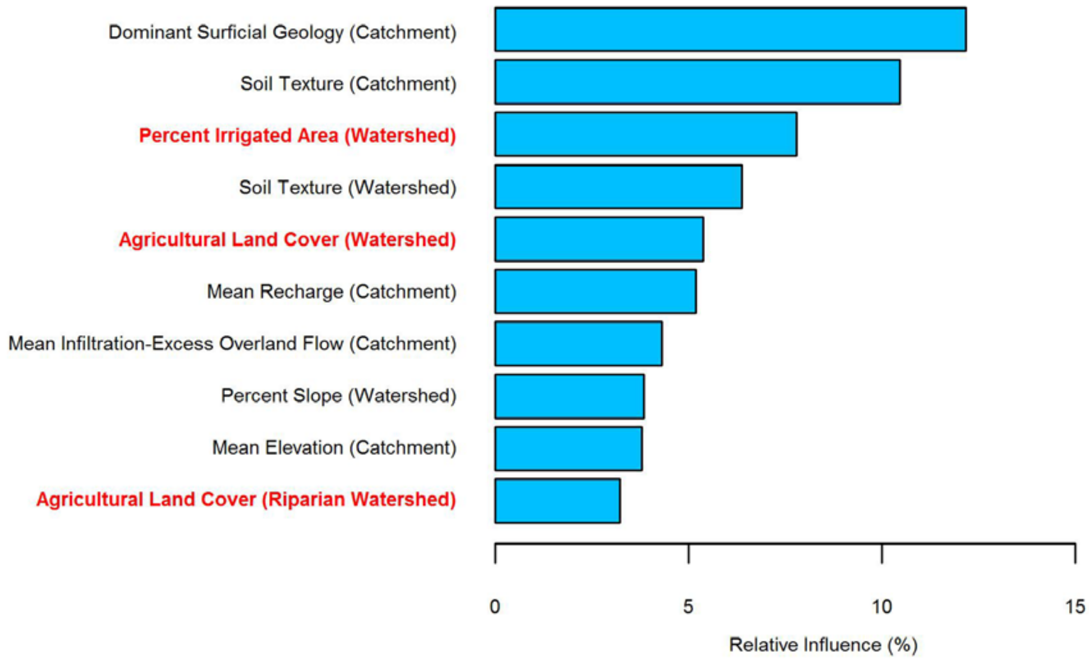

FIGURE 81. RELATIVE INFLUENCE PLOT FOR MEDIAN SUMMER TURBIDITY.

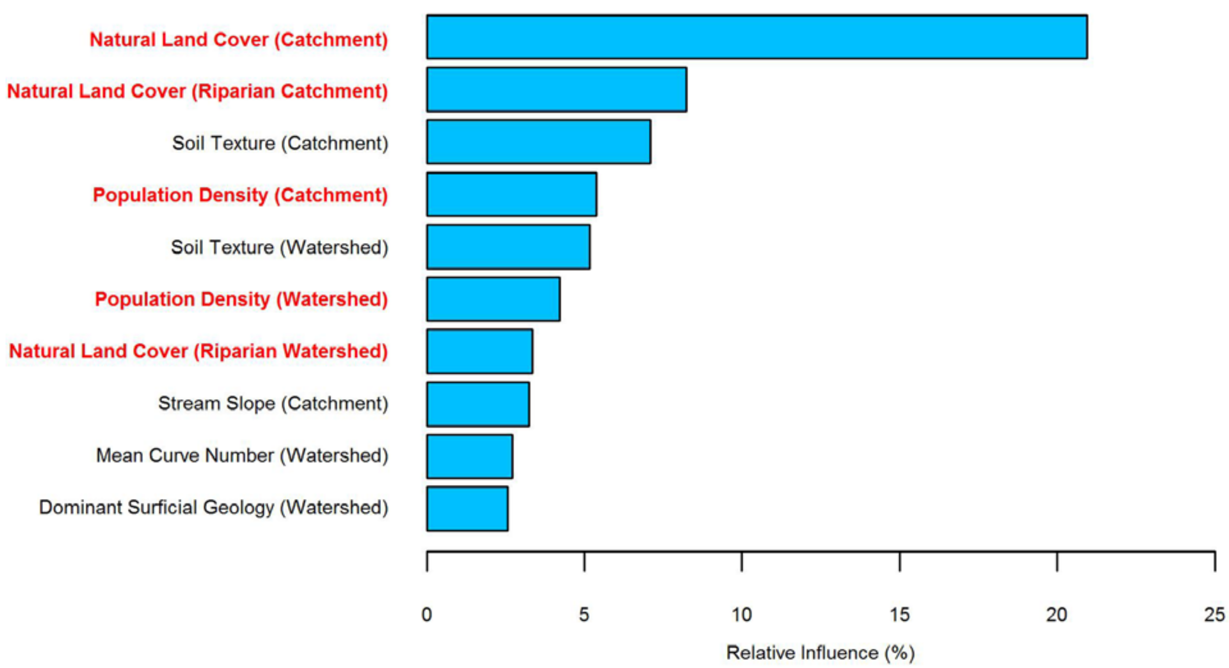

FIGURE 82. RELATIVE INFLUENCE PLOT FOR CSCI STREAM BIOLOGICAL ASSESSMENT SCORE.

APPENDIX D STREAMFLOW ALTERATION ANALYSIS

To inform the selection of stream health indicators, relationships between streamflow alteration and the biological condition of California's streams were examined. Focusing on locations with paired streamflow and biological data, the analysis evaluated whether California Stream Condition Index (CSCI) biological assessment scores were correlated with alteration trends in 67 flow variables. Flow variables with high correlation between trend presence/absence and CSCI scores were included in regression modeling of stream health (see Appendix C).

Data used for flow alteration analysis included CSCI scores for perennial, wadeable streams acquired from the California Department of Game and Fish (Pete Ode, personal communication). Additionally, daily streamflow records were acquired from the USGS National Water Information System for California stream gaging stations with at least 20 years of record. Gaging locations with CSCI scores were identified from reported latitude/longitude coordinates and site names and were included in subsequent analysis.

Daily flow records for 140 gaging locations with CSCI scores were summarized into annual values of 67 streamflow variables describing flow magnitude, timing, duration, frequency, and rate of change using Indicators of Hydrologic Alteration (IHA) Software (The Nature Conservancy, 2009). For each gage, trend analysis was completed on annual values of all 67 IHA flow variables to detect the presence/absence of significant trends over time. Trends were evaluated using the nonparametric Kendall trend test and a threshold significance value (p-value) of 0.05 (i.e., a flow variable was designated as "altered" if the p-value of the trend test exceeded 0.05).

Correlation between CSCI scores and the presence/absence of flow alteration was evaluated for each IHA variable with significant alteration using Spearman's rank correlation coefficient. Correlation coefficients are negative for all flow variables, indicating that lower CSCI scores correspond to altered flow conditions (Table 13).

Flow variables from each flow regime category (magnitude, timing, duration, frequency, and rate of change) were selected for further analysis based on correlation coefficient values. The variables with the highest absolute correlation coefficient for each category were:

- Magnitude of Large Flood Peak Flow
- Duration of Small Floods
- Date of Small Flow Peak Flow
- Frequency of Small Floods
- Recession Rate of High Flow Pulses

The above variables were included in regression analysis to identify relationships between the presence/absence of flow alteration and landscape predictor variables. Further discussion of regression analysis can be found in Appendix C.

Table 13. Spearman rank correlation coefficient values for flow variables with significant trends over time (i.e., p≤0.05). Correlation coefficients describe the strength and direction of the relationship between trend presence/absence and CSCI biological assessment score. Negative values correspond to Lower CSCI scores with the presence of a significant trend.

Flow Regime Category	Flow Variable	Correlation Coefficient
Magnitude	Median Large Flood Peak Flow	-0.34
	Median December Flow	-0.32
	Median December Low Flow	-0.31
	Median June Low Flow	-0.31
	Median June Flow	-0.28
	Median May Low Flow	-0.27
	Median July Low Flow	-0.26
	Median September Low Flow	-0.26
	Median Small Flood Peak Flow	-0.26
	Median October Low Flow	-0.25
	Median January Low Flow	-0.25
	Median July Low Flow	-0.23
	Median January Low Flow	-0.20
	Baseflow Index	-0.22
Duration	Median Small Flood Duration	-0.31
	Number of Zero Flow Days	-0.29
	Duration of High Flow Pulses	-0.29
Timing	Median Date of Small Flood Peaks	-0.34
	Median Date of Large Flood Peaks	-0.26
	Date of Minimum Daily Flow	-0.25
Frequency	Frequency of Small Floods	-0.31
	Frequency of Large Floods	-0.28
	Frequency of High Flow Pulses	-0.26
Rate of Change	Median Recession Rate of High Flow Pulses	-0.30
	Median Rise Rate of Small Floods	-0.30
	Median Rise Rate of Large Floods	-0.29
	Median Rise Rate of High Flow Pulses	-0.29
	Median Recession Rate of Small Floods	-0.25
	Median Rise Rate of Daily Flows	-0.25
	Median Fall Rate of Daily Flows	-0.19

APPENDIX E ACTIVE RIVER AREA DELINEATION

California's Active River Area (ARA) was delineated using an ArcGIS geoprocessing toolbox provided by The Nature Conservancy (Analie Barnett, personal communication). Geospatial data used in the toolbox included NHDPlus Version 1.1 flowline and waterbody shapefiles (US EPA and USGS, 2005) and a National Elevation Dataset 30 meter resolution digital elevation model (DEM). Deviations from default settings of the toolbox are described below:

- ARA Data Preparation Step 1: Flowline Data
  - This step classified NHDPlus flowlines as headwaters, medium-size rivers, and large rivers using the NHDPlus Stream Order attribute. Classified flowlines were subsequently converted to raster format, with the raster cell value equal to size class of the flowline.
  - In our analysis, we classified flowlines as:
    - Headwaters if stream order was 0 or 1.
    - Medium-sized rivers if stream order was 2, 3, or 4.
    - Large rivers if stream order was greater than or equal to 5.
  - Flowlines whose "FTYPE" attribute did not equal "StreamRiver" or "ArtificialPath" were not classified during this step.
- ARA Data Preparation Step 2: Waterbody Data
  - This step classified NHDPlus waterbodies as headwaters, medium-size rivers, and large rivers using the NHDPlus Stream Order attribute. The stream order of each waterbody was determined by finding all flowlines that intersect with each waterbody (using the "Intersect" geoprocessing tool) and then finding the maximum stream order value for each waterbody (using the "Summary Statistics" geoprocessing tool). Classified waterbodies were subsequently converted to raster format, with the raster cell value equal to the class of the waterbody.
  - In our analysis, we classified waterbodies as:
    - Headwaters if maximum intersecting stream order was 0 or 1.
    - Medium-sized rivers if maximum intersecting stream order equal was 2, 3, or 4.
    - Large rivers if maximum intersecting stream order was greater than or equal to 5.
  - Flowlines whose "FTYPE" attribute did not equal "StreamRiver" or "ArtificialPath" were not considered when assigning waterbody classes.
  - The raster produced from this step was merged with the raster produced from Data Preparation Step 1.
- ARA Step 1: Option A – Create Cost Distance Surface, Does Not Fill DEM
  - This step computed three cost distance grids (one for each river class) using a DEM raster and the flowline/waterbody raster. It also generates flow accumulation and slope grids.
- ARA Step 2: Reclass Cost Distance Surface
  - This step classified the cost distance grids produced from Step 1 into binary classes. We used the following thresholds for binary classification:
    - Within the very flat Central Valley ecoregion of California, thresholds were 15, 50, and 65 for headwaters, medium-sized rivers, and large rivers, respectively.

        - Outside of the Central Valley ecoregion, thresholds were 75, 150, and 300 for headwaters, medium-sized rivers, and large rivers, respectively.

- ARA Step 3: Create Moisture Index to Build Wetflats
    - This step used the flow accumulation and slope rasters created in Step 1 to generate a moisture index. No adjustments were made to default tool settings.
- ARA Step 4: Option A – Refine Wetflats and Add to Base Riparian Zones
    - This step used the moisture index created in Step 3 to create a wetflat grid. No adjustments were made to default tool settings.
- ARA Step 5: Generate Non-Headwater Material Contribution Zones and Add to Wetflats and Base Riparian Zones
    - This step added material contribution zones adjacent to flowlines to the ARA. No adjustments were made to default tool settings.
- Final processing
    - We performed the above calculations for inside and outside the Central Valley ecoregion. These two outputs were combined using the Pick geoprocessing tool, with the pick raster defined as an ecoregion boundary raster.

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