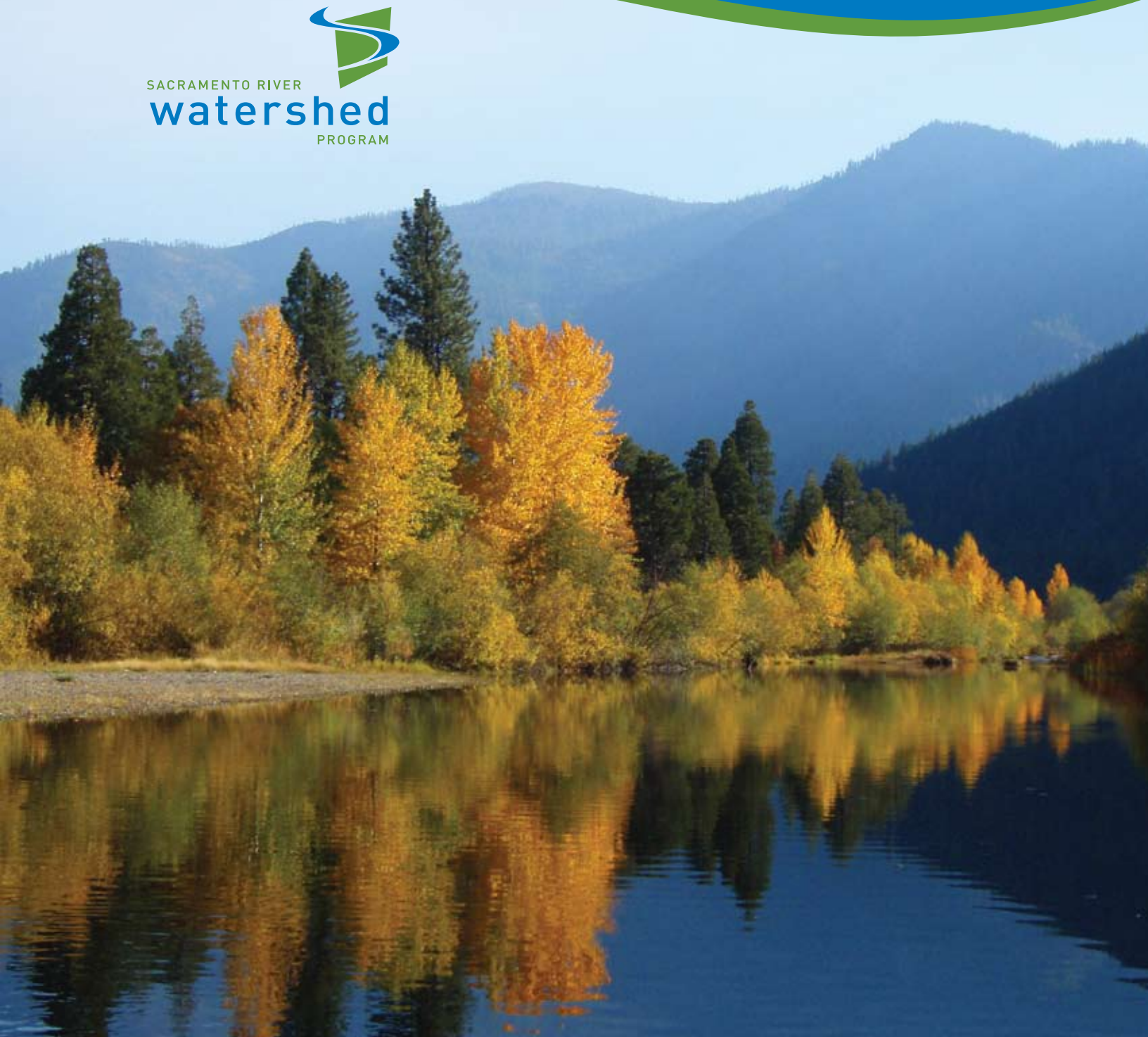
# Sacramento River Basin
## Report Card & Technical Report

FEATHER RIVER WATERSHED

April 2010

SACRAMENTO RIVER watershed PROGRAM



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# List of Acronyms

7DADM..... Maximum seven-day average daily maximum
BDAT ..... Bay-Delta and Tributaries Project
BMI ..... Benthic Macroinvertebrates
CalFire ..... California Department of Forestry and Fire Protection
CalVeg ..... California Vegetation Maps
CDE..... California Department of Education
CVRWQCB ..... Central Valley Regional Water Quality Control Board
CWA ..... Clean Water Act
CWAM ..... California Watershed Assessment Manual
CWHR ..... California Wildlife Habitat Relationships
DC..... Deer Creek
DFG..... California Department of Fish and Game
DO ..... Dissolved Oxygen
DOC ..... California Department of Conservation
DWR..... California Department of Water Resources
EBNFF..... East Branch North Fork Feather River
EEA..... Essential Ecological Attributes
EMS ..... Effective Mesh Size
EPT ..... Ephemeroptera – mayfly, Plecoptera – stonefly, Trichoptera – caddisfly
ESA..... Endangered Species Act
EWA..... Essential Watershed Attributes
FDA..... Food and Drug Administration
FERC..... Federal Energy Regulatory Commission
FRAP..... Fire and Resource Assessment Program
FRCRM..... Feather River Coordinated Resource Management
GIS ..... Geographic Information System
GPP..... Gross Primary Productivity
GRASS ..... Geographic Resource Analysis Support System
HAB ..... Hydrological Area Boundaries
IHA..... Indicators of Hydrologic Alternation
LB ..... Lower Bear River
LCMMP..... Land Cover Mapping and Monitoring Program
LF..... Lower Feather River
LY ..... Lower Yuba River
MFF ..... Middle Fork Feather River
Mg ..... Megagrams
MODIS ..... Moderate Resolution Imaging Spectroradiometer
MS ..... Microsoft
MSLC ..... Multi-Source Land Cover
MSS ..... Multispectral Scanner

MY ..... Middle Yuba River
NASA ..... National Aeronautics and Space Administration
NHD ..... National Hydrography Dataset
NFF ..... North Fork Feather River
NID..... Nevada Irrigation District
NPP..... Net Primary Productivity
NRCS ..... Natural Resource Conservation District
NY..... North Yuba River
PAD ..... Passage Assessment Database
PCB..... Polychlorinated Biphenyl
PG&E ..... Pacific Gas and Electric Company
PONSE ..... Percentage of Native Species Expected
PNS..... Proportion Native Species
PSN..... Net Photosynthesis
QA ..... Quality Assurance
QC ..... Quality Control
QAPP ..... Quality Assurance Policy and Procedures
RES ..... Plant Respiration
RVA..... Range of Variability
RCD ..... Resource Conservation District
RfD..... Reference Dose
RSC..... Relative Source Contribution
SAB..... Science Advisory Board
SNEP..... Sierra Nevada Ecosystem Project
SOP..... Standing Operating Procedures
SRWP..... Sacramento River Watershed Program
SWAMP ..... Surface Water Ambient Monitoring Program
SWRCB ..... State Water Resources Control Board
SY ..... South Yuba River
SYRCL..... South Yuba River Citizen League
TAC..... Technical Advisory Committee
TKN..... Total Kjeldahl Nitrogen
TMDL ..... Total Maximum Daily Load
TRC ..... Tissue Residue Criterion
UC Davis..... University of California, Davis
UP..... Upper Bear River
USDA ..... USDA is US Department of Agriculture
USEPA ..... US Environmental Protection Agency
USFS ..... US Forest Service
USGS..... US Geological Survey
WAF..... Watershed Assessment Framework
WHIP..... Watershed Health Indicators Project

# EXECUTIVE SUMMARY AND REPORT CARD

Diverse interests and communities have varied needs and uses of the Sacramento River Basin and its services. But how do we know if we are keeping this critical place in good shape? How do we measure conditions in the watershed and our own performance toward maintaining and restoring watershed health? This Report Card comprises a key learning component of good watershed management, tying our goals for community and ecosystem well-being with actual conditions that can be measured over time.

The Sacramento River Basin Report Card provides a description of conditions relative to our expectations and goals for the Basin. It is a science-based solution to a social and management need. The Report Card measures aspects of the whole integrated system relative to stakeholder goals. It reports on the system using regionally-important and science-based indicators. Because the indicators are assessed using transparent reference points, they provide a measurement of health that can be assessed in future report cards.

## Background

The natural and human systems of a river basin are often thought of from the point of view of particular components because of economic, regulatory, or social perspectives. For example, water quality and pollutant loads are analyzed and regulated in waterways to meet legal standards, while recognizing ecosystem and economic needs and conditions. The Report Card performs a vital service in this watershed by bringing together the different components into a common framework, with stakeholder involvement, to facilitate discussion of the whole system, including natural and human processes and needs. This allows us to develop an integrated approach to valuing watershed services and approaches, managing for these values while also meeting regulatory needs, and connecting stakeholders to the diverse values of their watershed.

The Sacramento River is the largest river in California, is vital to the state's economy and is a major source of drinking water for residents from Modoc County to San Diego County. It is this vital resource that incited the development of the Sacramento River Watershed Program (SRWP) in 1996, and the more recent Sacramento River Basin Management Plan: A Roadmap for the Future (Roadmap) and Watershed Health Indicators Project (WHIP). Roadmap summarizes key information about six subregions within the watershed providing a picture of watershed health in the Sacramento River Basin. Roadmap and WHIP use the Watershed Assessment Framework (WAF) to articulate a shared vision for each of the subregions by way of watershed forums throughout the watershed. By evaluating and summarizing watershed characteristics and articulating common goals and lists of indicators for the various subwatersheds, Roadmap and WHIP provide an essential foundation for adaptive management of the Sacramento River Basin.

SRWP began work on watershed health indicators in 2004, in response to stakeholder recommendations to expand SRWP monitoring efforts beyond main-stem river water quality monitoring. SRWP held two public workshops and several Monitoring Committee meetings to receive stakeholder input on the approach to develop watershed health indicators for the Sacramento River Basin. SRWP also had several meetings with state and federal agencies leading SRWP to adopt the WAF; an element of the 2006 California Watershed Action Plan.

## Focus Watershed

The focus of this Report Card is the Feather River Watershed, which is the largest tributary to the Sacramento River and the State Water Project's primary watershed. The Feather River Watershed is located in California's northern Sierra Nevada and encompasses a broad variety of terrain, climate, historic use, and flora and fauna. It drains 6,223 square miles of land base from the Sierra Nevada crest westward into the Sacramento River. The

watershed includes the tributary Yuba and Bear rivers, which flow into the Lower Feather River. Below the major dams on all three rivers, salmon and steelhead still return to spawn, though in declining numbers. The focus watershed was divided into 11 commonly-used divisions in the upper (above the lowest dams) and lower watershed (Figure E.1).

## Feather River Watershed

### Subwatersheds and Counties

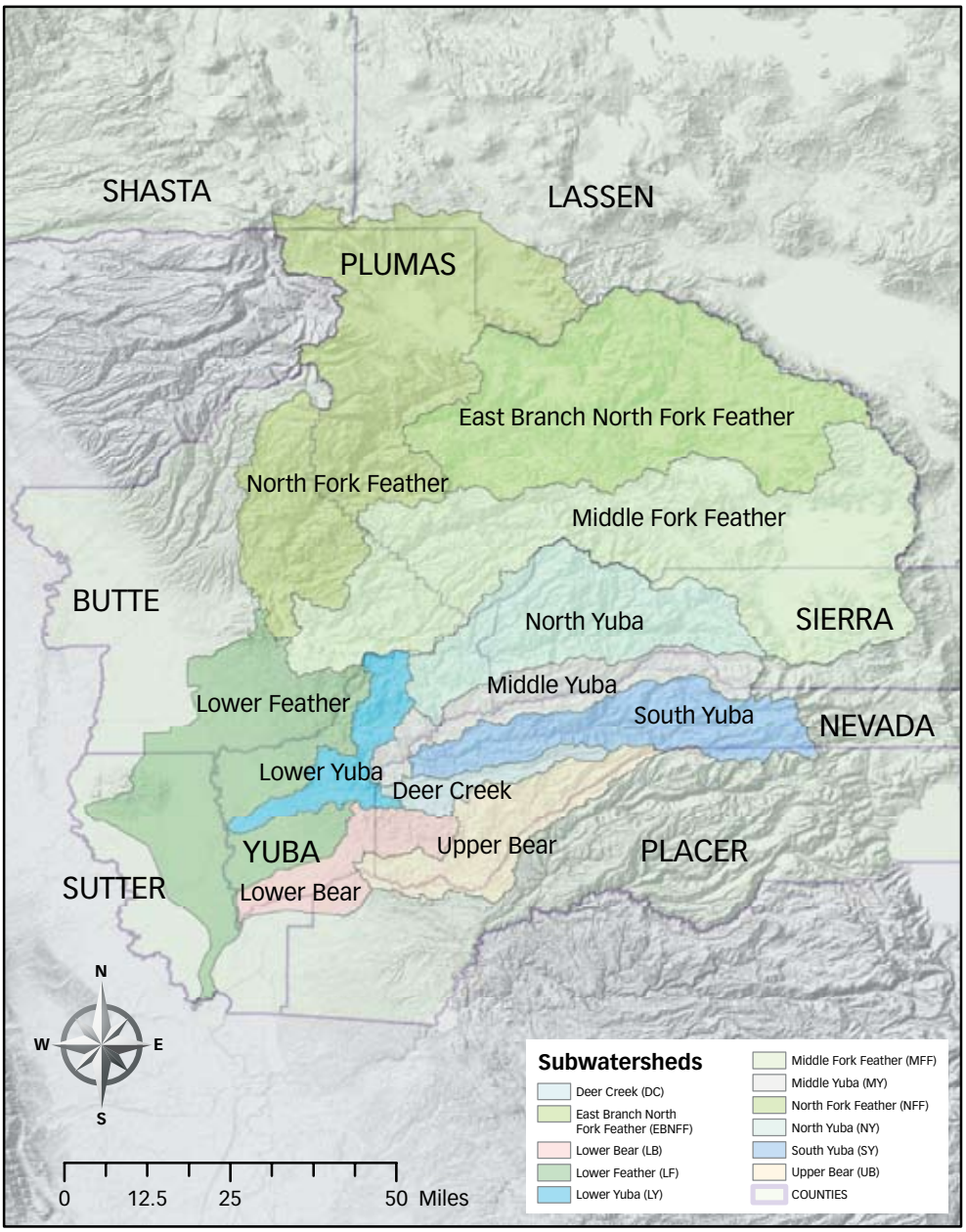


Figure E.1 — Map of the Feather River Watershed, its constituent subwatersheds, and its overlap with counties

The watershed is home to several long-running citizen-based monitoring and restoration programs, including the Feather River Coordinated Resource Management (FRCRM), the South Yuba River Citizens League (SYRCL), Friends of Deer Creek, Wolf Creek Alliance, and the Yuba-Bear Watershed Council. This watershed was chosen as the focus of the first Report Card, because of its size and critical importance to California.

## How To Use The Report Card

The Report Card summarizes the status and trends of key indicators in the watershed to measure watershed condition. The Report Card is organized around stakeholder goals and objectives for the watershed. Indicators were selected that corresponded to these goals and objectives, based on scientific and feasibility criteria. Report Card values (described in detail in section 3) range from 0, reflecting poor condition, to 100, reflecting good condition, for each indicator within each subwatershed. Trends in certain indicators were also calculated, indicated by arrows pointing up, down, or horizontal.

## What Did We Find Out?

Environmental and community conditions are highly variable across the Feather River Watershed and across goals and indicators of condition (Table E.1). Bird populations appear to be doing very well and fire patterns are quite different than they should be. Aquatic communities are struggling in almost all subwatersheds, possibly due to the combination of water and land management that characterizes this watershed. Trends in most cases are either unknown or not detectably changing. Economic condition and carbon sequestration rates are declining, but agricultural practices are improving. Overall the Feather River Watershed is in fair condition, with room for improvement.

### Table E.1 — How well are we meeting goals and objectives for the Feather River Watershed?

| Goals | Measurable Objective | Condition | Trend | Confidence |
|---|---|---|---|---|
| Water quality and supply for natural and human communities | Water quality for aquatic health | 50 | ↔ | Medium-high |
| | Maintain natural stream flows | 55 | n/a | Medium |
| Protect and restore native animals and plants | Native birds | 100 | ↔ | Medium |
| | Native invertebrates | 46 | ↔ | High |
| | Native fish | 49 | ↔ | High |
| | Agricultural/urban development | 90 | n/a | Medium |
| Protect and enhance habitats, ecosystems, and watersheds | Protect aquatic connections | 77 | n/a | Medium-high |
| | Protect landscape connections | 33 | n/a | High |
| | Maintain natural production and nutrient cycles | 82 | ↓ | Medium |
| Maintain and restore natural disturbance | Restore natural fire regimes | 9 | ↔ | Medium |
| | Encourage natural flooding, while protecting people | 50 | n/a | Low |
| Improve social and economic conditions & benefits from healthy watersheds | Enhance wildlife-friendly agriculture | 83 | ↑ | Medium-high |
| | Improve community economic status | 51 | ↓ | High |

Each subwatershed was evaluated for its condition relative to targets for each indicator. The condition score is the average score for all 11 subwatersheds. Trend was evaluated from a combination of trend assessments from each subwatershed. Arrow direction indicates trend direction, horizontal arrows refer to no change, "n/a" means not available. Confidence refers to quantitative or professional assessment of confidence in the result.

# SECTION 1.0

## Introduction and Background


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# 1.0 Introduction / Background

## 1.1 — Why do we need indicators?

Environmental, economic, and social indicators are used world-wide to report on the condition of human, natural, and combined human-natural systems. Indicator frameworks vary depending on what is being measured and on the intended reporting audience. The National Research Council (NRC, 2000) identified two types of frameworks: those that measure the status or condition of the system, and those that seek to identify cause and effect relationships. Many contemporary indicator frameworks incorporate both condition indicators and indicators of pressures or influences. This combination allows for a condition assessment and an evaluation of what may be driving condition. This reflects a common aspect of these frameworks — that they are practical and intended to support decision-making, usually in support of restoration, regulatory, or sustainability goals. This combination allows for evaluation and reporting on system attributes that are important for watershed and regional residents and stakeholders, as reflected in regional and local goals.

For the Report Card, the selection, analyses, and interpretation of indicators were conducted in an open, transparent process, which provides an educational (and networking) opportunity for all involved. Choosing indicators that reflect conditions and understanding how they might change in response to various influences facilitates a better understanding of how actions in a specific region can affect watershed function and processes. The largest watershed within the Sacramento River Basin, the Feather River Watershed, was chosen as the focus for this first phase of evaluating status and trends in watershed condition.

### THE FEATHER RIVER WATERSHED

The Feather River Watershed is located in California's northern Sierra Nevada and encompasses a broad variety of terrain, climate, historic use, and flora and fauna. It drains over 6,000 square miles of landscape, from the Sierra Nevada crest westward into the Sacramento River. It is the largest tributary to the Sacramento River below Shasta Lake. Watershed elevation ranges from ~100 to over 10,000 feet, and annual precipitation varies broadly from more than 70 inches on the wet western slopes to less that 12 inches on the arid east side. Vegetation is diverse and ranges from productive agricultural lands, grasslands, and oak savannah in the west to sparse sage/yellow pine plant communities in the east.

The Plumas and Tahoe National Forests manage over 75 percent of the watershed, while the Sacramento Valley portions are predominantly privately owned and are agricultural. The Upper Feather River Watershed is a rural landscape and includes the small communities of Almanor, Quincy, Nevada City, and Grass Valley. The Lower Feather River Watershed is also predominantly rural, but does include the larger towns of Oroville, Yuba City, and Marysville.

The Lower Feather River Watershed supports salmon (predominantly fall-run; few spring-run), but there are no salmon above Oroville and Englebright dams. The Upper Feather River Watershed has several very active and successful watershed groups and agencies: FRCRM; Feather River, Butte, Nevada, and Sutter County Resource Conservation Districts; SYRCL; Friends of Deer Creek; and the Yuba Bear Watershed Council.

For this focus watershed, we evaluated aspects of the whole system (social, economic, and environmental conditions), at the watershed scale, in order to help us better understand some of the relationships between these conditions and watershed management actions. The value of protecting and restoring watershed condition (and by inference, watershed functions) is in direct proportion to the services well-functioning watersheds provide. Assessing the value of watershed services requires development of the appropriate tools, such as the indicator system described here. We developed the Report Card to describe the status and trend of the conditions in our focus watershed. To the degree that data sources allowed, each of the science-based indicators were assessed relative to social targets.

## 1.2 — Why the watershed?

Watersheds are regions which ultimately drain to a particular water course or body of water (Figure 1.1). Humans have depended on a vast array of resources provided by rivers, tributaries, and surrounding lands for centuries, and historically the prosperity of many societies has been intricately tied to the watershed resources they controlled (O'Conner and Costa, 2004). Yet many human activities can greatly modify natural watershed processes, resulting in altered patterns and function of riverine and adjacent terrestrial ecosystems (Fight et al. 2000). Effective management and conservation of resources and ecosystems relies on knowledge both of watershed processes and how human activities modify them.

Figure 1.1 — Depiction of typical watershed (USEPA 2010)

Typically a watershed is a geographic area defined by the movement of water (precipitation) draining to a common point or waterbody. A more all-encompassing definition of a watershed is one which pertains to both natural attributes (e.g. soil, water, vegetation, animal species) and human uses and conditions (e.g. land use, social structure and organization) within the area. The subtle difference is that the latter definition explicitly includes a relationship to people and how they utilize, manage, and are affected by their environment.

We used this more all-encompassing definition of a watershed, one that includes human social and economic elements, in developing the Report Card. Although still geographically based in the traditional sense of a "watershed," the broader definition facilitated assessment of the degree to which natural process and condition goals are being achieved, knowing that these "watershed" goals are affected by (and perhaps directly correlated with) human social and economic systems and conditions. In using a broader application of the term "watershed," we gained the ability to assess indicators that measure how physical watershed condition(s) interact with economic and social goals (e.g., fishability of streams, fire frequency, primary productivity), and conversely, how economic and social systems and patterns interact with watershed attributes (e.g., species biodiversity, habitat connectivity, water quality).

## 1.3 — How can indicators be used?

Indicators can be used to tell us about status and trends for a variety of attributes of different systems. They help us understand system condition and can inform decisions affecting management and restoration of valued attributes and processes. To be effective, they are usually organized into structures that help users clearly understand their meaning. For example, water characteristics such as temperature, dissolved oxygen (DO), pH, and concentrations of suspended sediments are not necessarily intuitively-understood by a non-technical audience but can be combined into a more user-friendly index of water quality to help regulators and the public understand water quality status and trends and whether there might be a need for particular regulations or investments in infrastructure.

The system we used to develop and organize indicators is called the WAF, which was adopted in 2007, by the state of California as part of a strategy to inform and guide watershed management. It is based upon the US Environmental Protection Agency's (USEPA) Science Advisory Board's (SAB) approach (SAB, Young and Sanzone, 2002). The SAB system provides a framework for organizing indicators into categories termed "essential ecological attributes" (EEAs). The WAF adds social and economic categories to the EEAs and re-frames these attributes as "essential watershed attributes" (EWAs), creating an evaluation framework for the integrated natural and human systems in

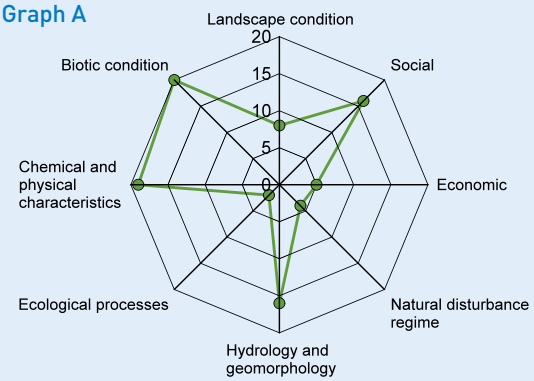
### INDICATORS AROUND THE WORLD

To position this study in a global context, 20 indicator frameworks from around the world were analyzed, including the types of EWAs represented, the types of indicators used, and their coverage of different spatial scales. We found that the attribute categories of chemical/physical condition, biotic condition, hydrology/geomorphology, and social condition were well-represented among the compared frameworks.

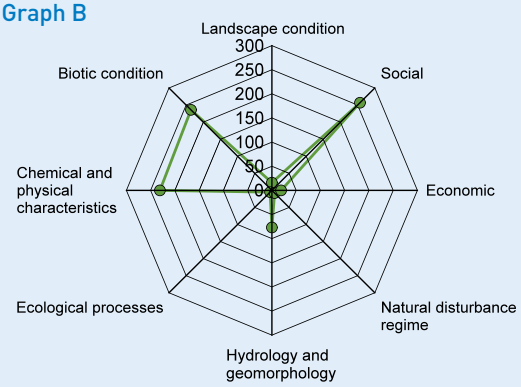
The >900 indicators from all 20 frameworks reviewed were categorized within each of the EWAs of the WAF (e.g. Landscape Condition, Biotic Condition, Chemical and Physical Characteristics, etc.). This categorization allows for comparisons among the different approaches. Graph A shows the number of frameworks with indicators in each WAF attribute category. Graph B shows the number of indicators from all frameworks categorized within each WAF attribute category.

A majority of the indicators among all 20 frameworks analyzed were represented in 4 WAF attribute categories: chemical/physical condition, biotic condition, hydrology/geomorphology, and social condition. The indicator frameworks did not effectively cover the WAF attributes of ecological processes, natural disturbance, economic condition, or landscape condition.

Graph A

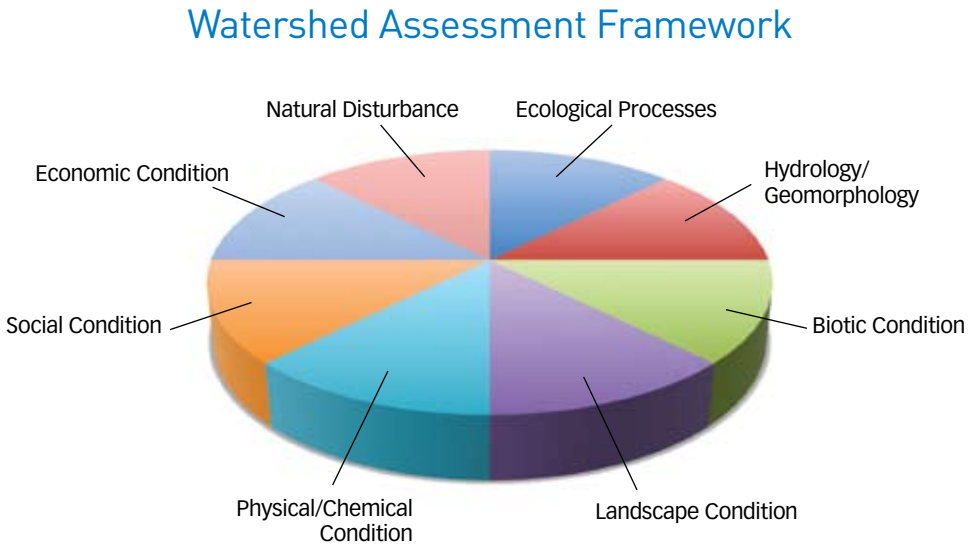



Graph B



watersheds (Figure 1.2). Missing from the SAB approach is guidance for comparing indicator values to a desired or reference condition and guidance for aggregation of normalized values into "scores" for the EWA/EEAs and other possible aggregations. The SAB framework also suggests that indicator information corresponding to measurable objectives can be extracted from the framework, however, how that can occur is not described in any detail. The WAF approach we propose here fills these gaps, describing the use of the framework to organize condition indicators, a normalization approach drawn from the scientific literature, and an approach for both measuring condition in system categories (e.g., EWAs) and performance relative to desired goals and objectives for the system.

**Figure 1.2 — California Watershed Assessment Framework showing Essential Watershed Attributes**




The WAF approach is founded on metrics and indicators (see Appendix A: Glossary of Terms for explanation of what these terms mean) that are organized into a hierarchical structure corresponding to aspects of natural and human systems that are termed system "attributes." The WAF is not the only way to organize these measures of environmental (both human and natural) condition. Information describing ecological, economic and social conditions could also be organized according to the goals that society sets for these conditions.

## 1.4 — Other Report Card Projects in California

Currently in California, more than a dozen efforts are underway to characterize environmental, social, and economic conditions to report to the public, legislators, and federal agencies. These range from the California Water Quality Monitoring Council collaborative work on water quality indicators, to California Department of Transportation's development of an economic valuation method for ecosystem services, to the application of the USEPA SAB's method to watershed conditions (the WAF), rolled-up to regional extents (e.g., this project).

Although no single approach for indicator evaluation and reporting has been chosen for the state, many organizations are selecting indicators that report on regional goals or for specific system attributes.

The organizations in California currently developing and using regional watershed-scale report cards based on the WAF include: SRWP; Los Angeles San Gabriel Rivers Watershed Council; Napa County; Sierra Nevada Alliance; UC Davis; Sonoma Ecology Center; Napa County Resource Conservation District; University of California, Los Angeles; University of Southern California; San Francisco Estuary Project; San Francisco Estuary Institute; The Bay Institute; and the California Department of Water Resources (DWR).

## 1.5 — Sacramento River Basin Report Card

### *1.5.1 Sacramento River Basin Geography*

The Sacramento River and its watershed is California's most precious resource. "The future of California is joined at the hip with the Sacramento River" says University of California geologist, Dr. Jeff Mount. The Sacramento River has always been a "river of life" and never more so than right now.

Located in central northern California, the Sacramento River is the largest river system and basin in the state. The 27,000 square mile watershed includes the eastern slopes of the Coast Ranges, Mount Shasta, and the western slopes of the southernmost region of the Cascades and the northern portion of the Sierra Nevada. The Sacramento River, stretching from the Oregon border to the Bay-Delta, carries 31% of the state's total runoff water. Primary tributaries to the Sacramento River include the Pit, McCloud, Feather, and American rivers.

California's largest watershed provides drinking water for two-thirds of the State including Southern California, supplies farmers and ranchers with the lifeblood of California's agricultural industry, and is a vital organ for hundreds of wildlife species, including four separate runs of Chinook salmon. It is also the home of over two million Northern Californians. From the mountains, to the valley, to the small towns and cities, it is the place where we live, work, and recreate. Fittingly, the health of this watershed directly affects our quality of life. As the state's and the watershed's population continues to burgeon over the next decade, it is important to track watershed conditions and trends. In an effort to help better understand some of the relationships between social, economic,

Figure 1.3 — Sacramento River Basin

and environmental conditions, and watershed management actions, SRWP launched the Report Card in 2008, focusing on the Feather River Watershed for the first evaluation.

### 1.5.2 Subwatershed Geography

#### North Fork Feather River

The North Fork Feather River arises from the snow-clad flanks of Mount Lassen, in Lassen National Park, and flows unimpeded to Lake Almanor, a Pacific Gas & Electric Company (PG&E)-operated hdyro-power reservoir with major recreational use. This subwatershed is home to old-growth conifer forest as well as actively managed/logged public and private forestlands and towns along with hundreds of miles of dirt roads and historic railroad logging grades. From Lake Almanor downstream, the North Fork waters are diverted out of, and then back into, the river to supply the numerous PG&E powerhouses that form the 'Stairway of Power' in the North Fork Feather River Canyon, until entering the State Water Project Oroville Reservoir. The subwatershed is actively monitored by the US Forest Service (USFS), PG&E and other agencies.

#### Middle Fork Feather River

The Middle Fork Feather River arises from the confluence of numerous tributaries of Sierra Valley, the largest montane valley in the Sierra Nevada. The Middle Fork Feather River is one of the original federally-designated Wild and Scenic River systems. The watershed is home to old-growth conifer forest as well as actively managed/logged public and private forestlands, agricultural production and towns along with hundreds of miles of dirt roads and historic railroad logging grades. After providing the bulk of agricultural water supplies in Sierra Valley and Mohawk Valleys, the Middle Fork descends into an un-roaded canyon, popular with flyfishers, backpackers and whitewater enthusiasts. The watershed is actively monitored by the FRCRM, Upper Feather River Irrigated Lands Group and USFS. For the Report Card, the south fork of the Feather River was combined with the Middle Fork. It is a small, high precipitation watershed that is home to old-growth conifer forest as well as actively managed/logged public and private forestlands, towns, an extensive mining legacy, along with hundreds of miles of dirt roads. Little Grass Valley Reservoir, in the upper watershed, provides agricultural and drinking water supplies as well as supporting heavy recreational use.

#### East Branch North Fork Feather River

The East Branch North Fork Feather River stems from eastern Plumas County, south of Honey Lake. The river flows westward through the Plumas National Forest through Indian Valley. It joins the North Fork Feather River near the town of Belden. This subwatershed is

primarily publicly-owned as National Forest. The watershed is home to old-growth conifer forest as well as actively managed/logged public and private forestlands, agricultural production, towns, undammed creeks and rivers, mining legacies, along with hundreds of miles of dirt roads and historic railroad logging grades. The watershed is actively monitored by FRCRM, the Upper Feather River Irrigated Lands Group and USFS.

### *Lower Feather River*

The Lower Feather River originates from Lake Oroville and flows generally south across the Sacramento Valley, east of the Sutter Buttes, past Oroville and Yuba City, and discharges to the Sacramento River approximately 20 miles north of Sacramento. Agriculture is the single largest land use in the subwatershed, making up roughly 60% of all lands. The Lower Feather River is an important habitat for fall- and spring-run Chinook salmon. The Sutter County Resource Conservation District has recently developed a management plan for the subwatershed.

### *North Yuba*

The North Yuba River begins just to the East of Sierra City and flows into the New Bullards Bar Reservoir. The North Yuba landscape is primarily publicly-owned as National Forest. The watershed is home to old-growth conifer forest, actively logged plantations, towns, undammed creeks and rivers, mining legacies, and hundreds of miles of dirt roads. The watershed is actively monitored by the SYRCL and USFS.

### *Middle Yuba*

The Middle Yuba River begins at Jackson Meadows Reservoir, flows through Gold Canyon, and joins the North Yuba just downstream of the New Bullards Bar Dam. Mining operations around Alleghany and Forest City are still active and three dams provide irrigation water and power to nearby communities. The SYRCL conducts watershed monitoring activities.

### *South Yuba*

The South Yuba River begins at Lake Spaulding and joins the North and Middle Yuba Rivers at Englebright Reservoir. Thirty-nine miles of the South Yuba River is designated Wild and Scenic, where the majority of the watershed is either logged or undisturbed hardwood and conifer forest. Like all three Upper Yuba Watershed rivers, the South Yuba has considerable hydraulic mining damage and residue. The watershed is monitored by the SYRCL.

### *Deer Creek*

The headwaters of Deer Creek stem from the Sierra Nevada foothills at 4000' elevation. The creek winds its way though pine forests, oak woodlands, towns and pastures. At 600' elevation and 34 miles from its source, Deer Creek joins the Yuba River. Hydraulic mining debris remains from past gold-mining operations. Friends of Deer Creek conducts water quality monitoring within the subwatershed.

### *Lower Yuba*

The Lower Yuba River originates at Englebright Reservoir east of Marysville and meets the Feather River near Yuba City. The river flows through a floodplain where large quantities of hydraulic mining debris remain from past gold-mining operations. Small tributary creeks flow into the lower Yuba, which becomes narrow and levee constrained when it joins the Lower Feather River.

### *Upper Bear River*

The Bear River rises on the westside of the Sierra Nevada just West of Spaulding reservoir at 5500' elevation. It flows southwest through the Lower Bear Watershed for approximately 65 miles to its confluence with the Feather River. The Upper Bear is fed by natural springs and supports a wild trout fishery. The upper watershed consists of mixed conifer and pine forests. Bear River Coordinated Resource Management Program (CRMP) conducts water quality monitoring.

### *Lower Bear River*

The Lower Bear River is a tributary to the Feather River. The lower watershed is dominated by grasslands and agricultural production. A high volume of mining sediment, in combination with flood-restricting levees, has caused the Lower Bear River to change from wide and shallow to deeply incised. Bear River CRMP conducts water quality monitoring and the US Geological Survey (USGS) conducts mercury studies in the subwatershed.

## *1.5.3. Technical Advisory Committee and Stakeholders*

Advising the formulation of the Report Card has been a team of regional experts participating on a Technical Advisory Committee (TAC). These experts included representatives from DWR, Central Valley Regional Water Quality Control Board (CVRWCB), California Department of Fish and Game (DFG), California Department of Conservation (DOC), and local Resource Conservation Districts (RCD). The initial meeting of the TAC resulted in the identification of the focus watershed and discussion of goals and objectives and selection criteria. The TAC also discussed potential indicators appropriate

for the goals and objectives. Subsequent meetings of the TAC resulted in fine-tuning and narrowing of the goals and objectives, finalizing selection criteria and indicators, and identifying appropriate data sources.

In addition to the TAC, SRWP partnered with a local watershed group, the FRCRM within the Feather River Watershed, to serve as a sounding board, to review material, and provide watershed data to the WHIP team. In November 2008, the FRCRM coordinated a stakeholder meeting in Quincy to provide a forum for the WHIP team to gather information and feedback from local stakeholders regarding the pilot study. SRWP and WHIP Team also presented details of the project and gathered input at a variety of stakeholders meetings throughout the watershed.

### *1.5.4. Report Card Outputs*

There were two outputs of this Report Card project: (1) Feather River Watershed Report Card, which provides a summary of the goals and objectives and corresponding scores for subwatershed conditions along with the trend in condition and level of confidence in findings, and (2) this Technical Report, which includes more detailed information for each of the 16 indicators including:

- Condition score, trend, and level of certainty
- Corresponding goal and objective
- Corresponding WAF attribute
- Description of the indicator
- Explanation of why the indicator is important
- Description of the target or desired condition
- Portrayal of what can influence conditions
- Summary of the data analysis and results
- Explanation about the level of certainty

All of the materials are also available online at http://www.sacriver.org in PDF format and as a "living document" in wiki format.

# SECTION 2.0

## Indicator Selection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# 2.0 Indicator Selection

Two complementary methods were used to select indicators to assess condition and trends. One was to use the WAF to select and organize indicators according to various ecological and social categories, for example landscape condition and economic condition. The other method was to find out about the goals and objectives stakeholders have for the watershed and use those to select and organize indicators. Ultimately, the report card was based on these watershed and regional goals and objectives.

## 2.1 — Goals and objectives

A critical feature of the Report Card is the selection of indicators, which were chosen based on consideration of stakeholder goals and objectives for the Feather River Watershed. Watershed goals and objectives were derived from a broad list of regional and local stakeholder goals and objectives. A comprehensive list of goals and objectives was compiled using three methods to insure that goals pertaining to each EWA were represented. Active watershed stakeholders were surveyed by electronic mail. Goals and objectives were extracted from planning documents and mission statements of various stakeholder organizations, including online documents of state and federal agencies that are active in the region. The project's TAC was presented with the list of compiled goals and asked to add additional goals that were important and missing from the list. These were compiled into a comprehensive list of goals and objectives for the Sacramento River Basin (Table 2.1).

During this process, corresponding objectives were chosen from those found in planning documents beneath goals we used and sometimes using goal statements that in our system were objectives for other goals. Objectives were phrased in a way that enabled them to be measured and evaluated. This made the transition to indicators easier and more transparent.

### Table 2.1 — Regional watershed goals and objectives considered for the Report Card

| Goals | Icon | Objectives |
|---|---|---|
| **A.** Maintain and improve water quality and supply to sustainably meet the needs of natural and human communities | | 1) Protect receiving waters from pollution to comply with current and future water quality regulations |
| | | 2) Maintain water quality for healthy aquatic systems* |
| | | 3) Protect the quality of drinking water supplies |
| | | 4) Maintain and restore natural stream flows for aquatic and riparian communities* |
| | | 5) Maintain water supplies to meet human needs within the watershed |
| **B.** Protect and enhance native aquatic and terrestrial species, especially sensitive and at-risk species and natural communities | | 1) Protect and enhance native fish populations, including anadromous fish* |
| | | 2) Protect and enhance bird populations |
| | | 3) Protect and enhance amphibian populations |
| | | 4) Protect and enhance mammal populations* |
| | | 5) Protect and enhance native invertebrate communities* |
| | | 6) Discourage and reduce invasive, non-native species |
| **C.** Protect and enhance landscape and habitats structure and processes to benefit ecosystem and watershed functions | | 1) Protect and enhance riparian habitat quality |
| | | 2) Protect and enhance wetland habitat quality |
| | | 3) Protect and enhance aquatic habitat connectivity* |
| | | 4) Protect and enhance terrestrial habitat connectivity* |
| | | 5) Maintain and restore stream geomorphic processes |
| | | 6) Optimize primary production and nutrient cycling to support aquatic and terrestrial communities* (for N) |
| | | 7) Manage land-uses to reduce impacts on aquatic and terrestrial habitats |
| **D.** Maintain and restore natural disturbance processes that balance benefits for natural and human communities | | 1) Reduce high severity fire frequency; encourage natural fire regimes that support native communities* |
| | | 2) Reduce flood risk to human communities; encourage natural flood processes that support native communities* |
| | | 3) Reduce greenhouse gas emissions and encourage activities to adapt to climate change |
| **E.** Maintain and improve the social and economic conditions, including benefits from healthy watersheds | | 1) Protect and enhance wildlife friendly agricultural practices* |
| | | 2) Improve grazing management |
| | | 3) Encourage sustainable land use practices |
| | | 4) Improve community economic status in balance with watershed condition* |
| | | 5) Improve community relationship with watershed processes |
| | | 6) The watershed supports sustainable social practices |
| | | 7) Support and improve human uses associated with watershed condition* |
| | | 8) To have widespread community awareness and deep civic engagement in the protection and improvement of watersheds* |

For the Feather River Watershed Report Card, a sub-set of the objectives were chosen (indicated with an asterisk in Table 2.1) based on a combination of how well they met the need for reporting on the condition in this watershed and whether or not data were likely to be available to evaluate the corresponding indicators. This sub-set is shown in Table 2.2.

Table 2.2 — Feather River Report Card goals and objectives

| Goal | Objective |
|---|---|
| A. Maintain and improve water quality and supply to sustainably meet the needs of natural and human communities | 1. Maintain water quality for healthy aquatic systems<br>2. Maintain and restore natural stream flows for aquatic and riparian communities |
| B. Protect and enhance native aquatic and terrestrial species, especially sensitive and at-risk species and natural communities | 1. Protect and enhance native bird populations<br>2. Protect and enhance native aquatic invertebrate communities<br>3. Protect and enhance native fish populations |
| C. Protect and enhance landscape and habitats structure and processes to benefit ecosystem and watershed functions | 1. Protect and enhance aquatic habitat connectivity<br>2. Protect and enhance terrestrial (native upland) habitat connectivity<br>3. Protect and maintain natural variability and rates of primary production and nutrient cycling |
| D. Maintain and restore natural disturbance processes that balance benefits for natural and human communities | 1. Reduce high severity fire frequency to more natural levels; encourage natural fire regimes that support native communities<br>2. Reduce flood risk to human communities and encourage natural flood processes that support native communities |
| E. Maintain and improve the social and economic conditions, including benefits from healthy watersheds | 1. Protect and enhance wildlife friendly agricultural practices<br>2. Improve community economic status in balance with watershed condition |

### 2.1.1 — Cross-walk between goals and objectives and attribute categories

Goals and objectives provide one framework for understanding how well a watershed or similar system is doing, but "system attributes" provide another. For example, you may have a personal *goal* that your cardiovascular system be capable of supporting a long life, which is linked to *objectives* you might set for heart rate, ability to exercise, etc. In this context your cardiac system is an *attribute* or category of organ(s) within your body. Similarly, natural systems can be broken up into attributes that together describe the whole. "Landscape condition" is one of the EWAs used in the WAF and addresses the structural integrity of the terrestrial landscape of the watershed. The other EWAs are: biotic condition, chemical/physical condition, hydrology/geomorphology, ecological processes, natural disturbance, social condition, and economic condition. These are the same attributes as in the USEPA SAB framework, with the addition of consideration of social and economic conditions (columns in Figure 3).

Indicators can be aggregated, or organized, based upon WAF attributes (Figure 2.1, columns), or by the goals and objectives of watershed (Figure 2.1, rows). The linkage between goals and attributes is critical because it allows the application of the WAF to evaluate progress toward regional and watershed goals. Looking more broadly at the future application of the WAF across California, attribute categories should remain constant across watersheds for ease of comparison, as goals and objectives will likely differ at various local levels. Reporting on both attributes and goals allows for comparison of our findings with findings from other watersheds where the WAF is also being used, while also answering local goal assessment needs. This dual reporting capability is an inherent strength of the Report Card's application of the WAF.

**Figure 2.1 — Organization of indicators within a matrix with 2 dimensions: goals and objectives (rows) and EWAs (columns)**

| Goal | Objective | Landscape | Biotic | Physical/ Chemical | Natural Disturbance | Ecological Processes | Hydrology/ Geomorphology | Social Condition | Economic Condition | Score (Objective) | Score (Goal) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| G1 | O1A | X | X | | | | | | | YO1A | $Y_{G1}$ |
| | O1B | | X | | | | | | | YO1B | |
| | O1C | | | | X | | | | | YO1C | |
| G2 | O2A | | X | X | | | | | | YO2A | $Y_{G2}$ |
| | O2B | | | X | | | X | | | YO2B | |
| G3 | O3A | | | | | | | X | | YO3A | $Y_{G3}$ |
| | O3B | | | | | | | | X | YO3B | |
| Score (EWA) | | $X_L$ | $X_B$ | $X_{PC}$ | $X_{ND}$ | $X_{EP}$ | $X_{HG}$ | $X_{SC}$ | $X_{EC}$ | | |

## 2.1.2 — Correspondence between objectives and ecological condition indicators

A description of goals and objectives for the watershed or region being evaluated is central to the application of indicator frameworks in social and management decision-making. It is also extremely important that these objectives be measurable, as the next step is to choose indicators that can be used to evaluate progress toward the objectives and thereby assess progress towards the overall goals. Metrics are also needed for each indicator, if the indicator itself is not easily quantified. For example, water temperature can be an indicator, and is also a quantifiable metric. However, native fish populations can be an indicator, but would need to be quantified through metrics such as adult population size, reproduction rate, or population demographics. A critical and sometimes missing component of indicator system development is an explicit or transparent link between the goals for the system and the indicators chosen to represent the system condition. An example of a goal is to "maintain and improve water quality and supply to sustainably meet the needs of natural and human communities" (Table 2.3). The corresponding objectives are clearly understandable and each of the indicators is measurable.

**Table 2.3 — Relationship between goal, objectives, and indicators**

| Goal | Objectives | Indicators |
|---|---|---|
| A. Maintain and improve water quality and supply to sustainably meet the needs of natural and human communities | 1) Maintain water quality for healthy aquatic systems | i. Periphyton Cover and Biomass |
| | | ii. Surface Water Temperature |
| | | iii. Mercury in Fish Tissue |
| | 2) Maintain and restore natural stream flows for aquatic and riparian communities | i. Flow Patterns and Alteration |

For each goal, objectives have been chosen that can be evaluated with either numeric or narrative approaches. For the indicators above, numeric evaluation is possible, assuming that thresholds or benchmarks are available against which to compare the numeric values.

## 2.2 — Indicator selection criteria

Indicator selection was driven primarily by the project team's knowledge of existing indicators that are feasible to monitor, the availability of corresponding data, the degree to which the indicators are representative of the social and ecological systems, and the likelihood that the indicators would continue to be monitored in the future. The following selection criteria were used for the indicators evaluated for the Feather River Watershed (more detail for the selection criteria is provided in Appendix B):

- Availability of high-quality data
- Data affordability
- System representation
- Ability to detect change over time
- Independence of indicators from one another
- Supports management decisions and actions
- Can be reported and understood in public arenas

Because indicator evaluation scores are often combined in some way, it is important to understand how dependent or independent indicators are from one another to avoid double-counting when possible. Sometimes redundancy and overlap among indicators will be desired in order to triangulate a problem's location. Because natural systems and often the human systems they interact with have many inter-dependencies, maintaining indicator independence is an imperfect science. For Feather River Watershed indicators, overlap among indicators was avoided where possible to simplify aggregation of indicator scores and to make the Report Card more efficient.

## 2.3 — Indicators selected

There are many possible indicators of status and trends for ecosystem condition and human community well-being in the Sacramento River Basin. Some of these have been used in monitoring programs or for previous assessments in the watershed (e.g., the

Lower Feather River Watershed Assessment, 2009, and the State of the Yuba: Shilling, 2004). A list of potential indicators was derived from sources like these, from the expertise of the TAC and regional watershed groups, and from the project team. A subset of the large potential indicator list was selected (Table 2.4) using criteria (Section 2.2) and evaluated in each subwatershed.

### Table 2.4 — Goal and objective-based indicators selected for the Report Card

| Goal | Objectives | Indicators |
|---|---|---|
| A. Maintain and improve water quality and supply to sustainably meet the needs of natural and human communities | 1) Maintain water quality for healthy aquatic systems | i. Periphyton Cover and Biomass |
| | | ii. Surface Water Temperature |
| | | iii. Mercury in Fish Tissue |
| | 2) Maintain and restore natural stream flows for aquatic and riparian communities | i. Flow Patterns and Alteration |
| B. Protect and enhance native aquatic and terrestrial species, especially sensitive and at-risk species and natural communities | 1) Protect and enhance native bird populations | i. Bird Species Diversity |
| | 2) Protect and enhance native aquatic invertebrate communities | i. Proportion of Watershed in Agricultural/urban Development |
| | 3) Protect and enhance native fish populations | ii. Benthic Macroinvertebrates Community Structure |
| | | iii. Fish Community Diversity |
| C. Protect and enhance landscape and habitats structure and processes to benefit ecosystem and watershed functions | 1) Protect and enhance aquatic habitat connectivity | i. Aquatic Habitat Barriers |
| | 2) Protect and enhance terrestrial (native upland) habitat connectivity | ii. Terrestrial Habitat Fragmentation |
| | 3) Protect and maintain natural variability and rates of primary production and nutrient cycling | i. Carbon Stock and Sequestration |
| | | ii. Nitrogen Load/Cycling |
| D. Maintain and restore natural disturbance processes that balance benefits for natural and human communities | 1) Reduce high severity fire frequency to more natural levels; encourage natural fire regimes that support native communities | i. Fire Frequency |
| | 2) Reduce flood risk to human communities and encourage natural flood processes that support native communities | i. Flooding and Floodplain Access |
| E. Maintain and improve the social and economic conditions, including benefits from healthy watersheds | 1) Protect and enhance wildlife friendly agricultural practices | i. Pesticide Application and Organic Agriculture |
| | 2) Improve community economic status in balance with watershed condition | i. School Lunch Program Enrollment |

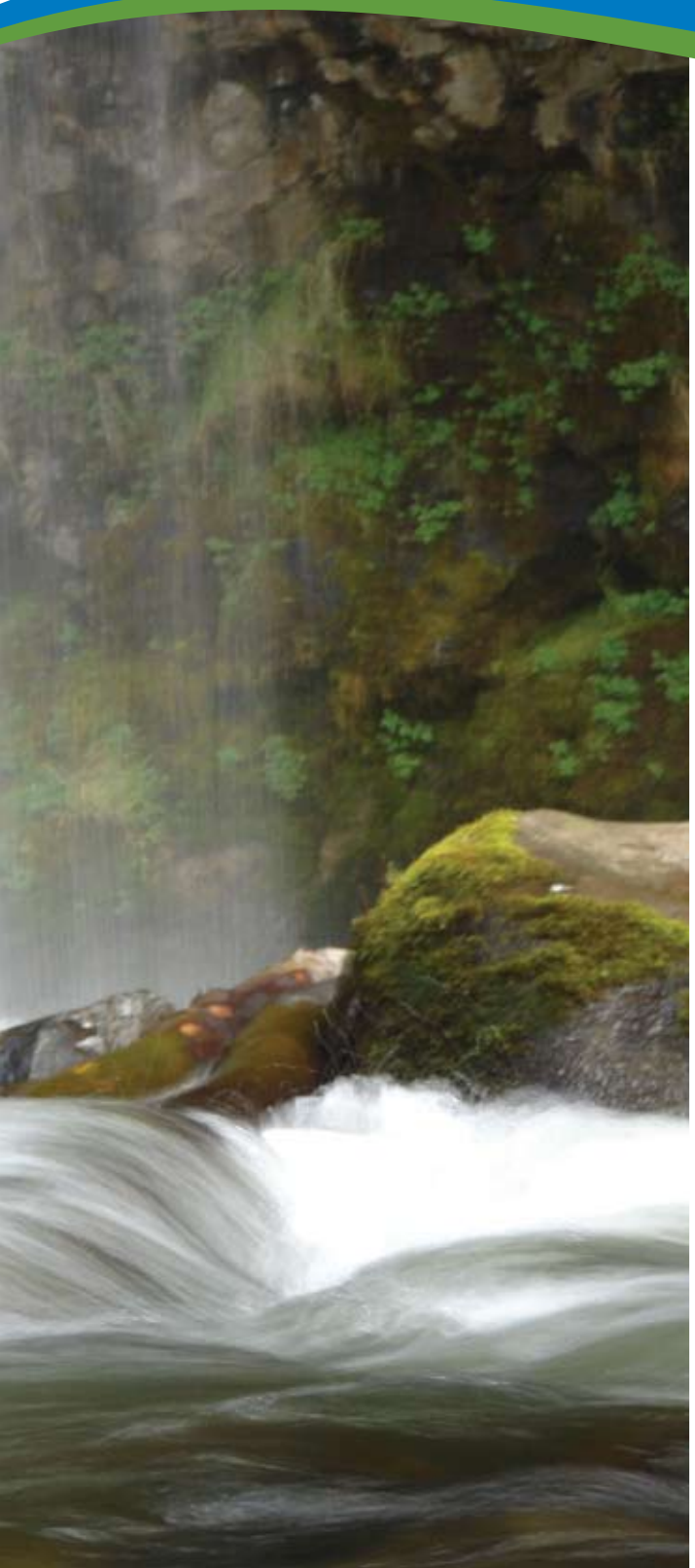
## 2.4 Target and reference condition selection

Comparing indicator condition against a fixed/reference value is a critical requirement for using indicators to inform condition assessments. This fixed value could be an historical condition, a desired future condition, a legal threshold, or some other reference value. It provides the context for interpreting indicator results — a number against which current status and trends can be compared. For instance, a high water temperature or an increasing trend in water temperature only tells us something meaningful about the risk of this condition to fish if we know at what temperature fish will be adversely affected, and whether the current trend is moving closer to or further away from that temperature threshold. A reference value is a quantity/value of an indicator that reflects some threshold, desired goal or target, or historic and/or pristine condition, according to what is most meaningful for the assessment and reporting purpose, and supported by science. The selection of reference values is as important as the selection of the indicator itself because, without this baseline, it is difficult to assess the magnitude of change objectively, whether the magnitude of change is important, or if any efforts at improving conditions are succeeding (National Research Council, 2000).

The term reference condition also may have multiple meanings. Stoddard et al. (2006) suggest that the term "reference condition" is reserved for referring to the "naturalness" of the biota (structure and function) and that naturalness implies the absence of significant human disturbance or alteration. They further propose specific terms to characterize the expected condition to which current conditions are compared: "minimally disturbed condition," "historical condition," "least disturbed condition," and "best attainable condition." A similar concept of reference conditions is considered in the USEPA-SAB reporting framework (Young and Sanzone, 2002): "Reference conditions that attempt to define a 'healthy' ecological system are often derived from either the conditions that existed prior to anthropogenic disturbance or conditions in a relatively undisturbed but comparable system in the ecoregion. Alternatively, reference conditions can be inferred from a combination of historical data, a composite of best remaining regional conditions, and professional judgment."

Ideally, reference conditions will include sites with little or no indication of stressors associated with human disturbance. However, this is not always the case and most landscapes have already been altered. Where undisturbed sites are absent, Stoddard et al. (2006) propose a combination of methods to determine reference conditions: (1) sampling biota from least disturbed sites (reference sites), (2) interpreting historical records to deduce which characteristics occurred at times with substantially less human disturbance, (3) developing models that incorporate the best ecological knowledge, and (4) using best professional judgment.

For each indicator in the Feather River Watershed Report Card, targets are described (Section 3). These range from an estimate of historical condition, to legal guidance for endangered species, to comparisons against the best or worst condition in the watershed. Targets were set for both the good reference condition (score = 100) and for the poor reference condition (score = 0). Indicators were evaluated on this range from poor to good reference conditions.



# SECTION 3.0

## Indicator Generation, Evaluation, Aggregation

This section describes the evaluation of each of the 16 indicators for each of the 11 subwatersheds. It is organized into sections that correspond to goals for the watershed. Within each goal section there are subsections, which are essentially reports for each indicators. The indicator reports have a similar format: background on the indicator, influences on the indicator, target conditions, subwatershed conditions and trends, discussion of confidence in the findings, resolution of the information used, and technical descriptions of where data were obtained and how they were analyzed.


3.1 — Goal A: Water quality and supply . . . . . 32

*3.1.1 — Periphyton Cover and Biomass . . . . . 32*

*3.1.2 — Surface Water Temperature . . . . . 41*

*3.1.3 — Mercury in Fish Tissue . . . . . 52*

*3.1.4 — Flow Patterns and Alteration . . . . . 59*

3.2 — Goal B: Native biota . . . . . 67

*3.2.1 — Bird Species Diversity . . . . . 67*

*3.2.2 — Proportion of Watershed as Agricultural/Urban . . . . 76*

*3.2.3 — Benthic Macroinvertebrates Community Structure . 83*

*3.2.4 — Fish Community Diversity . . . . . 96*

3.3 — Goal C: Habitats and ecosystems . . . . . 106

*3.3.1 — Aquatic Habitat Barriers . . . . . 106*

*3.3.2 — Terrestrial Habitat Fragmentation . . . . . 113*

*3.3.3 — Carbon Stock and Sequestration . . . . . 118*

*3.3.4 — Nitrogen Load/Cycling . . . . . 134*

3.4 — Goal D: Fire and flooding . . . . . 143

*3.4.1 — Fire Frequency . . . . . 143*

*3.4.2 — Flooding and Floodplain Access . . . . . 150*

3.5 — Goal E: Community, social and economic conditions 157

*3.5.1 — Pesticide Application and Organic Agriculture . . . . 157*

*3.5.2 — School Lunch Program Enrollment . . . . . 165*

3.6 — Linkages and relationships among objectives, attributes, and indicators . . . . . 171

# Section 3.1 – Water Quality and Supply

**GOAL: A.** Maintain and improve water quality and supply to sustainably meet the needs of natural and human communities

**OBJECTIVE: 1.** Maintain water quality for healthy aquatic systems

**OBJECTIVE: 2.** Maintain and restore natural stream flows for aquatic and riparian communities

The following indicators were evaluated to measure water quality and supply conditions:

- Periphyton cover and biomass
- Surface water temperature
- Mercury in fish tissue
- Flow patterns and alteration

## 3.1.1 – Periphyton Cover and Biomass

**GOAL: A.** Maintain and improve water quality and supply to sustainably meet the needs of natural and human communities

**OBJECTIVE: 1.** Maintain water quality for healthy aquatic systems

**WAF ATTRIBUTE:** Biotic Condition

### What is it?

Benthic algae are photosynthetic plants which are anchored to benthic sediment, rock, and each other on the stream bottoms or edges of aquatic systems. Together with submerged vascular plants, benthic algae are referred to as periphyton and are indicators of pollution and water quality (Shilling, 2007). Benthic algal cover is a food source for invertebrates which graze on the plant material and in turn the invertebrates are food sources for fish (Finlay et al., 2002) in the rivers, streams, and lakes. Periphyton is a relatively under-studied biological indicator of ecological condition, but it has an ecological connection to temperatures, nutrients, and benthic macroinvertebrates in determining the health of an aquatic system.

## Why is it Important?

"Excessive algae growth" is a water quality concern and pollution indicator in the managed waterways of California and in the Sierra Nevada (Fetscher et al., 2009). It is defined as an amount of algae growth greater than a normal system's output (Shilling et al., 2007). Algae can deplete aquatic systems of nutrients and algal communities can vary compositionally by the nutrients available (Marinelarena and Di Giorgi, 2001). High productivity of algae causes negative downstream effects to benthic DO levels (Lavoie et al., 2003), fixed carbon production, nutrient cycling, pH, food web structures, and health of fish (Shilling et al., 2007). Methylated mercury can be passed up the food chain to pose health risks to wildlife and humans, and bromine-reacted dissolved organic carbon (DOC) compounds (from algal decomposition) in drinking water are human health hazards (Shilling et al., 2007). Watershed questions can be answered by determining algal density and community structures by assessing the locations and severities of nutrients concentrations, of high temperatures which would naturally would be colder, of invasive species, of natural succession through seasonal changes (e.g., flow and temperature), and of land disturbances (e.g., water diversion, fire, or development activities; Shilling et al., 2007).

## What is the target or desired condition?

Periphyton is naturally present in aquatic systems at all times of the year. It does create its own food source during colder temperatures and is distinguishable as a thin, colorless layer on rocks and benthic substrates. The metrics for periphyton used here were percent cover of benthos, dry weight, and ash-free dry weight (weight of organic material). Chlorophyll is sometimes used as a metric for amount of periphyton, but was not available here. For biomass weight measurements, a) the target ash free dry weight scores ranged linearly from the values of $10g/m_2$ = score of 100 to $100\ g/m_2$ = score of 0, and b) the dry weight scores ranged from the values of $20g/m_2$ = 100 to $200g/m_2$ = 0. A target of 0 $g/m_2$ or zero percent cover is not ideal for most aquatic ecosystems, except for very cold and light limited conditions. Metric ranges for this analysis were determined by the UC Davis team from a preliminary pilot study conducted in 2001 & 2002 by Fraser Shilling (Shilling, 2007). For the percent cover metric, 100% cover = score of 0 and 35% = score of 100. The value 35% was chosen as the baseline value because it was the lowest summer maximum percent cover value of any subwatershed in the studied region of the Feather River Watershed and was assumed to represent natural conditions. A linear 1:1 function was used to calculate score, using values for percent algal cover and/or biomass of grams per meter squared. Again, since periphyton is under-studied, there are not published values for the Sierra Nevada, Northern California, or the state of California to use in setting standard maximum and minimum values for periphyton in health aquatic ecosystems. Publications for the region of Lake Tahoe are comparative studies in this discipline, but do not give guideline values.

## What can influence or stress condition?

Algae can be nutrient-limited (Cascallar et al. 2003; McCormick and Stevenson, 1998; Perrin and Richardson, 1997) by nitrogen and phosphorus concentrations, light-limited (Kiffney and Bull, 2000; Quinn et al., 1997a, b), and water temperature limited (Francoeur et al., 1999; Morin et al., 1999; Robinson and Minshall, 1998; Weckstroem and Korhola, 2001). Nitrogen and phosphorus, as nutrients, are readily absorbed by aquatic plants especially at levels greater than the naturally occurring low concentrations in aquatic systems. Nutrients and increased temperatures together will increase periphyton growth rates. Additionally, the riparian corridor on either side of an aquatic system shades and provide an external cooling system for the water. These same concerns of higher temperatures and/or lack of riparian cover and/or nutrient additions to an aquatic system can be due to land use practices or disturbances (Bojsen and Jacobsen, 2003; Cascallar et al., 2003; Chessman et al., 1999; Delong and Brusven, 1998; Giorgi and Malacalza, 2002; Harding et al., 1999; Siva and John, 2002; Winter and Duthie, 1998). Disturbances to the surrounding hillsides can remove riparian trees, remove root systems that hold soils, and add nutrient run-off into the rivers. Finally, seasonal changes in an aquatic system influence channel geomorphology and atmospheric climate and directly affects flows, substrate types, and temperatures. Lastly, a majority of California waterways are controlled by water management systems of dam, diversions, and canals which provide additional pressure on natural regulation of periphyton growth compared to historical conditions.

## What did we find out/How are we doing?

The periphyton scores ranged from 5 (Deer Creek) to 100 (North Fork Feather and East Branch North Fork Feather, Figure 1 and Table 1) for all subwatersheds evaluated. The subwatershed with the lowest score was Deer Creek, which also had the richest data-set in terms of spatial distribution and years sampled. Subwatersheds with the lowest scores are assumed to be under greater stress in the watershed. The highest scores given to the East Branch North Fork Feather and the North Fork Feather were based on one year's data from samples taken over a wide area. Currently, the Feather River and Yuba River are the only regions with percent cover estimates. Deer Creek and the Yuba River are the only regions with biomass measurements.

### Table 1 — Report Card scores for periphyton for subwatersheds

| Goal | Measurable Objective | Subwatershed | Score |
|---|---|---|---|
| A. Maintain and improve water quality and supply to sustainably meet the needs of natural and human communities | 1) Maintain water quality for healthy aquatic systems — periphyton | NFF | 100 |
| | | EBNFF | 100 |
| | | MFF | 87 |
| | | LF | n/a |
| | | NY | 73 |
| | | MY | 27 |
| | | SY | 29 |
| | | DC | 5 |
| | | LY | n/a |
| | | UB | n/a |
| | | LB | n/a |

## Water Quality and Supply

### Periphyton Biomass & Cover

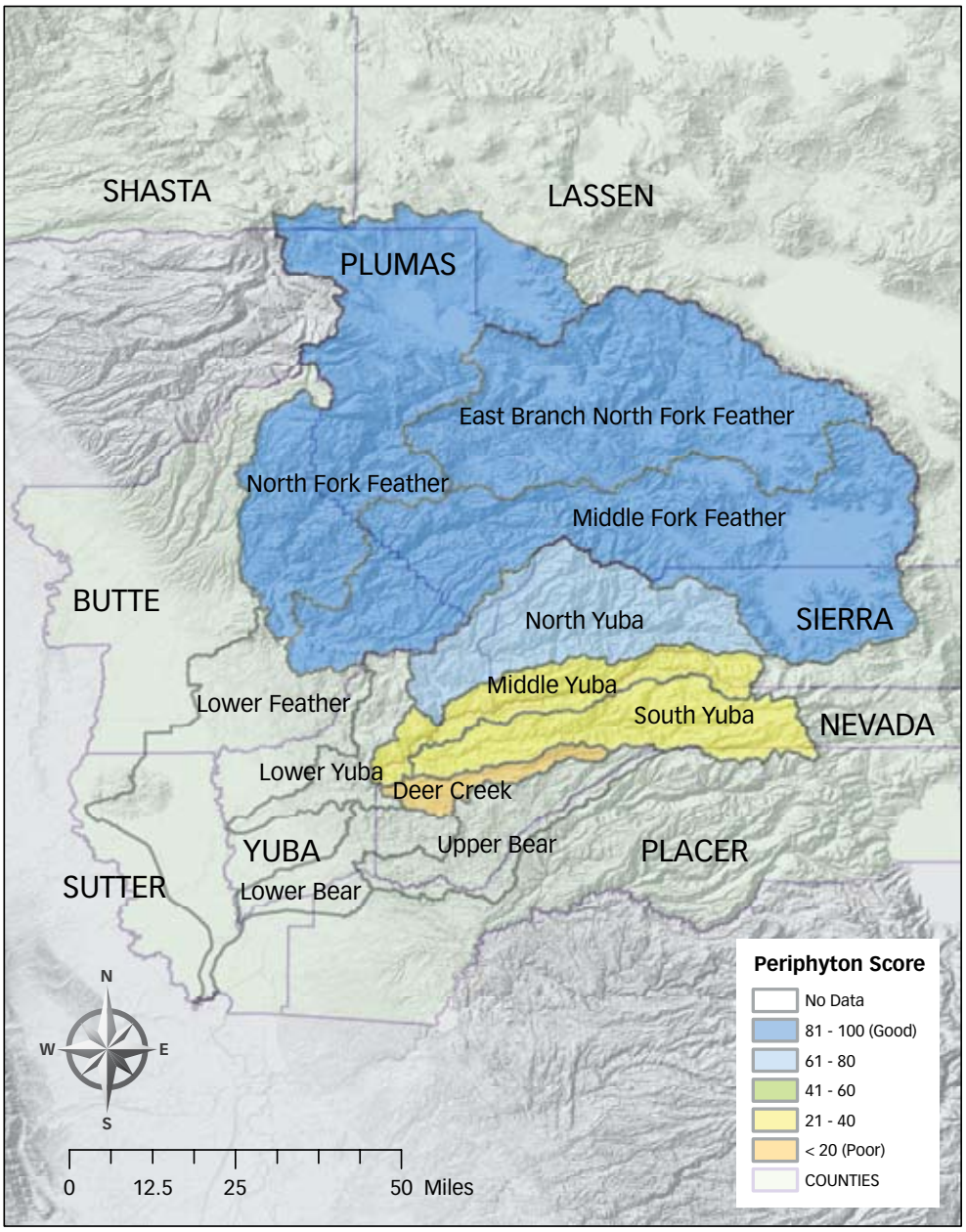



Figure 1 — Periphyton scores distributed across subwatersheds

## Temporal and spatial resolution

The spatial distribution of periphyton data was inconsistent across all subwatersheds. The time scale varied from 2001- 2009 for sampling conducted. A majority of sites in the Deer Creek and Feather subwatersheds were sampled in 2004. The greatest amount of data on a single time-frame were available for Deer Creek with 4 years of consistent sampling conducted, but otherwise there were few sites with replicated years of sampled data at the same site locations. The lowest temporal resolution collected data were collected in the single years 2001-02 and in 2004 at single site locations. The highest resolution of spatial data was found in the Feather subwatershed where 19 locations were sampled in the North Fork Feather, although it was all taken in one year. The overall spatial coverage of the subwatersheds was not very comprehensive for this analysis with data not available in the three lower subwatersheds and was not widely distributed within individual subwatersheds.

## How sure are we about our findings? (Things to keep in mind)

The confidence in the overall finding of the reported values is assessed as a combination of variation in scores and how well the indicator reflects the environmental condition. An overall confidence is rated low for periphyton scores due to an overall relatively small geographic range of sampling, high variability in temporal collection, and lack of repetition of sampling. Therefore, the low overall confidence is given to all of the subwatershed scores with the recommendation that more data be collected in the future with similar protocols. There are two sets of guidance for measuring periphyton in California's watersheds, which are complementary because they address different ways of measuring periphyton: The California Watershed Assessment Manual (CWAM), Volume II (Shilling et al., 2007, http://cwam.ucdavis.edu) and the State Water Resources Control Board (SWRCB) Surface Water Ambient Monitoring Program (SWAMP) periphyton protocol (Fetscher et al., 2009). Nutrients and water temperature are complimentary indicators to periphyton and may be sampled at the same time. Benthic invertebrates can also be reported in conjunction with the periphyton assessments in the determination of potential pollution/perturbation.

Sampling intensity has been low in the subwatersheds, especially in the lower watersheds, where there were no accessible data. Data were collected at different temporal scales for the years ranging from 2001-02 and 2004-09, which led to inconsistencies in comparisons of all sites sampled. Also, periodic sampling (monthly) may not have captured the peak

algae amounts which was the focus of the analysis, the highest sample value for each sampled year. There were metric inconsistencies where almost all watersheds did not have multiple metrics collected to average but within a metric there was consistency in collection methods. No trends or complex statistical analysis could be run due to the inconstancies in data availability. Overall a more robust set of data would be needed to conduct trend analysis for periphyton biomass or percent cover for the Feather River Watershed.

## Technical Information

### DATA SOURCES AND TRANSFORMATIONS

Friends of Deer Creek (http://friendsofdeercreek.org/data.html); SYRCL (http://www.yubashed.org); UC Davis, Fraser Shilling and the Center for Watershed Sciences (http://watershed.ucdavis.edu/research/sierra.html)

Data was acquired for ash free dry weight, dry weight, and percent cover. In the Feather River Watershed, the subwatersheds with periphyton data were the North Fork Feather, Middle Fork Feather, East Branch North Fork Feather, North Yuba, South Yuba, Middle Yuba, and Deer Creek. Data were not available for the Lower Yuba, Lower Feather, Upper Bear, and Lower Bear. The Deer Creek data were collected from 2004 to 2008 (AFDW) at eight locations and was collected in 2001-02 dry weight at one location. The Yuba River data was collected from the years of 2006 and 2008-09, for the percent cover measurements at 14 locations; it was collected at three locations in 2001-02, of which one maximum value was evaluated for each subwatershed for dry weight. The Feather River subwatershed data in 2004 covered three separate types of algae with percent floating mats, percent macrophyte beds, and percent filamentous algae reported individually. The sum of these three percentages were used to get an overall, comprehensive percent cover of periphyton for each site location. The only excluded type of data reported was the percent emergent plants. Also the values were give in mostly whole numbers but for values close to zero, they were recorded as a <5% value. For these values less than five, they were converted to 5%. These "less than" numbers could not be assigned exact values, and for these purposes they were considered to weighted closer to five than to zero due to the idea that periphyton were present versus absent.

For ash free dry weight, the highest values for each site were used for each sampled year to get an overall site peak value for the watershed. For dry weight, maximum values for the subwatersheds as the peak values at each site since only one year's worth of data was available. There was not a most representative metric unit available for all sites and subwatershed score analysis was conducted on the averages of multiple metrics if available. All values were reported as raw values and no conversions were used to extrapolate the values into a different metric type (e.g., from percent cover to biomass).

### Table 2 — Average values for each metric and subwatershed with available data

| Subwatershed Metric Values | Percent Cover (%) | Ash Free Dry Weight ($g/m_2$) | Dry Weight ($g/m_2$) |
|---|---|---|---|
| East Branch North Fork Feather | 35.0 | n/a | n/a |
| Middle Fork Feather | 43.3 | n/a | n/a |
| Middle Yuba | 91.1 | n/a | 27.7 |
| North Fork Feather | 25.9 | n/a | n/a |
| North Yuba | 13.7 | n/a | 17.2 |
| South Yuba | 62.2 | n/a | 167.2 |
| Deer Creek | n/a | 454.3 | 81.6 |

### Table 3 — Basic statistics for ash free dry weights, dry weights (grams per meter squared) and percent cover of periphyton across all sites. 95% C.I. refers to 95% confidence intervals.

Ash Free Dry Weight ($g/m_2$)

| Subwatershed | Number of algal cover samples/year | minimum | maximum | mean | upper 95% C.I. | lower 95% C.I. |
|---|---|---|---|---|---|---|
| Deer Creek | 27 | 22.4 | 2664.8 | 454.3 | 735.1 | 173.4 |

Dry Weight ($g/m_2$)

| Subwatershed | Number of algal cover samples/year | Values |
|---|---|---|
| North Yuba | 1 | 17.2 |
| South Yuba | 1 | 167.2 |
| Middle Yuba | 1 | 27.7 |
| Deer Creek | 1 | 81.6 |

Percent Cover (%)

| Subwatershed | Number of algal cover samples/year | minimum | maximum | mean | upper 95% C.I. | lower 95% C.I. |
|---|---|---|---|---|---|---|
| East Branch North Fork Feather | 5 | 10 | 100 | 35 | 68.7 | 1.3 |
| Middle Fork Feather | 6 | 10 | 65 | 43.3 | 59.1 | 27.6 |
| Middle Yuba | 1 | 91.1 | 91.1 | 91.1 | 91.1 | 91.1 |
| North Fork Feather | 19 | 0 | 90 | 25.9 | 36.3 | 15.5 |
| North Yuba | 6 | 5 | 35 | 13.7 | 23.1 | 4.2 |
| South Yuba | 9 | 6 | 100 | 62.2 | 85.1 | 39.3 |

**CONDITION ANALYSES:**

Each metric was scored under a set range with the final score being extrapolated by the averaging of the multiple metrics, if available. The condition value was determined by averaging the raw values (Table 2). Values for each metric, if more than one metric was available, were averaged to get the final subwatershed score (Table 1, Figure 1). For percent cover, each subwatershed's set of data was plotted to give maximum algal coverage curves. The lowest maximum percent cover value (35%) was set as the lowest threshold and assigned the value of 100. A score of zero was given to 100% cover. Intermediate percent cover values were given correspondingly intermediate scores using a 1:1 linear function. For ash free dry weight, 10 g/m2 was given a score of 100 and 100 g/m2 was given a score of 0. For dry weight, 20 g/m2 was given a score of 100 and 200 g/m2 was given a score of 0. For both dry weight and ash free dry weight, the scores assigned were proportional to the parameter value's distance from these targets.

**Table 4 — Separate scores for each metric used in the final condition analysis**

| Subwatershed Score per Metric | Percent Cover | Ash Free Dry Weight | Dry Weight |
|---|---|---|---|
| East Branch North Fork Feather | 100 | n/a | n/a |
| Middle Fork Feather | 87.2 | n/a | n/a |
| Middle Yuba | 13.7 | n/a | 40.2 |
| North Fork Feather | 100 | n/a | n/a |
| North Yuba | 100 | n/a | 46 |
| South Yuba | 58.3 | n/a | 0 |
| Deer Creek | n/a | 0 | 10.2 |

**TRENDS ANALYSES:**

There was no consistently sampled location across years in any subwatershed, therefore no trends analysis was conducted.

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# 3.1.2 – Surface Water Temperature

**GOAL: A.** Maintain and improve water quality and supply to sustainably meet the needs of natural and human communities

**OBJECTIVE: 1.** Maintain water quality for healthy aquatic systems

**WAF ATTRIBUTE:** Physical/Chemical

## What is it?

Surface water temperature is a constant variable of any waterbody and can be measured and summarized in various ways. Maximum seven day average daily maximum (7DADM) was calculated for each year and for each subwatershed. Each year was represented by the highest seven-day average maximum water temperature within the year. This metric is identical to the Maximum Weekly Maximum Temperature metric in the literature.

## Why is it Important?

One of the consequences of increased withdrawal of river water for human uses is an increase in water temperature due to lowered volume. Increase of river temperatures from their natural levels has far-reaching effects on local ecology, including alteration of community processes and facilitating invasion by exotic species (Poole & Berman 2001). Restoring natural flow regimes and thus natural temperatures is critical to restoring a healthy natural system.

Native salmonid species are of great ecological, economic, and cultural importance to local communities. They also serve as strong indicators of habitat quality and integrity in river systems, particularly with regard to water temperature, sediment load, and barriers to passage. They are well-studied, including behavioral and physiological responses to temperature extremes. The Central Valley spring-run Chinook salmon is listed as a threatened species under the Endangered Species Act (ESA), giving them a high priority for restoration. The main threats to the remaining populations are loss and degradation of habitat. In particular, rising water temperature combined with upstream dams has greatly diminished available juvenile summer habitat. Within the Feather River Watershed, only two populations persist. One, in the Feather River itself, is completely dependent on the Feather River Fish Hatchery to maintain itself. The other, in the Yuba River, is of unknown status. There are occasionally spawning salmon in the Lower Bear River.

Maximum water temperature is a critical part of habitat quality for salmonids. Temperature affects every aspect of salmonid biology, from feeding and growth rates to migration and spawning, and stress levels and survival (Carter 2005). Rainbow trout, for example, are more severely impacted by temperatures in excess of 20°C than by fishing pressure (Runge & Peterson 2008). Upstream diversion of water for human usage increases downstream temperatures, as the lower remaining volume warms more quickly. Due to upstream barriers such as dams, only less-suitable, high-temperature regions are available for spawning and summer feeding. Anthropogenic temperature increases have been identified as key contributors to salmon decline (USEPA 2003).

## What is the target or desired condition?

USEPA suggests as a guideline that a river sustaining salmonid populations should not have 7DADM temperatures over 18°C to avoid impairment of salmon health. Similarly, migratory portions of the river should not exceed Maximum Weekly Maximum Temperatures of 20°C and temperatures greater than 22°C will cause broad mortality (USEPA 2003). For core rearing areas in mid-to-upper parts of the river basin, a maximum of 16°C may be appropriate. Experimental studies indicate that spawning temperatures up to 16.5°C do not have deleterious effects on juvenile salmon, but mortality increases markedly after that point (Geist et al. 2006). These temperature guidelines, along with additional information from Brett et al. (1982), were used to convert monthly maximum 7DADM into a 0-100 scale.

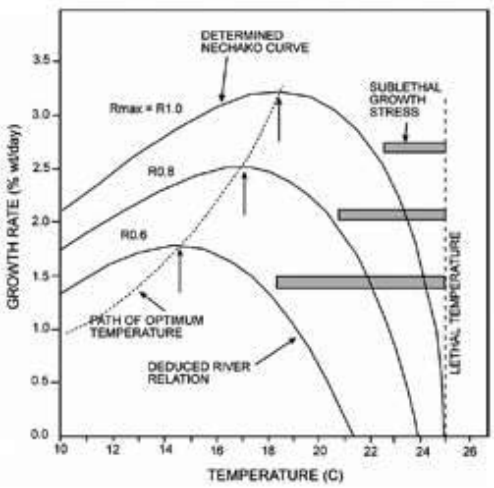



**Figure 1 — Chinook salmon growth curve (Brett et al. 1982)**

Growth rates at different temperatures for three feeding levels (R=0.6, 0.8, and 1.0). Rmax (R=1.0) represents satiation feeding, with R=0.6 closer to natural feeding levels.

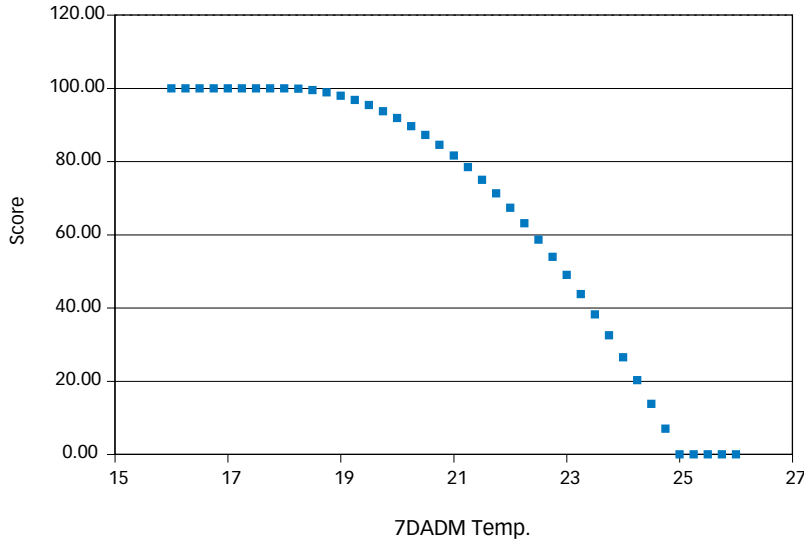
A score of 100 is equivalent to the USEPA's stated protective criteria of 18°C 7DADM for secondary foraging/rearing areas. A score of 0 will be equivalent to 25°C 7DADM, the lethal point for juvenile Chinook salmon. Intermediate scores were scaled using an adaptation of the Brett et al. (1982) growth curve (Figure 1). Only the right side of the curve was used; temperatures below the USEPA protective criterion were still scored as 100. Brett et al. (1982) estimate that natural populations of Chinook feed at roughly 60% of saturation (or R=0.6, the lowest growth curve). Because of daily temperature fluctuation, 7DADM temperatures are equivalent to constant laboratory temperatures roughly 1-2°C colder (USEPA 2003).

The scaling curve is shown in Figure 2. The scaling curve does not exactly match the growth curve, due to the temperature thresholds for 0 (25°C) and 100 (18°C). Temperatures for the growth curve were adjusted upward by 1.5°C to adjust for the use of 7DADM measurements. These scores apply only to summer maximum temperatures.

## What can influence or stress condition?

The major factor which raises water temperature is decreased flow within the river. Low water volume allows the sun to warm the river much faster, and temperatures increase rapidly as the water moves downstream. Prolonged decreased flow (as opposed to seasonal variations) is most often due to human water use; water is retained in reservoirs and diverted to urban centers or for agricultural use, and only a small fraction is released into the original channel. Land-uses can contribute to higher temperatures, including logging, agriculture, and urban development. Increasing temperature due to climate change is another possible factor.

### Figure 2 — Water Temperature Scaling Curve




This curve is approximated from salmonid growth/survival data in Brett et al. 1982. It converts 7-day average daily maximum temperature to a 0-to-100 score. The formula for temperature (x) conversion to score is 100 – r(x-K)2, where r = 2.041 and K = 18°C.

## What did we find out/ How are we doing?

The current states of the subwatersheds are shown in Table 1 and Figure 3. Scores ranged from a low of 20 for the Lower Yuba to 100 for Deer Creek and the Lower Feather. Many of the sampling sites were excluded from analysis due to data limitations. Many sites had only one year of data, sometimes represented by a single point. Most problematic was the prevalence of monthly samples at irregular times, which clearly do not represent temperature maxima. However, there were sufficient daily datasets from each subwatershed to perform trend analyses. Due to the aforementioned data limitations, only current state assessments and annual Mann-Kendall analyses were performed for each subwatershed. More details are available in later tables.

### Table 1 —Report Card scores for water temperature for subwatersheds

| Goal | Measurable Objective | Subwatershed | Score |
|---|---|---|---|
| A. Maintain and improve water quality and supply to sustainably meet the needs of natural and human communities | 1) Maintain water quality for healthy aquatic systems — water temperature | NFF | 90 |
| | | EBNFF | 32 |
| | | MFF | 28 |
| | | LF | 100 |
| | | NY | 87 |
| | | MY | 87 |
| | | SY | 88 |
| | | DC | 100 |
| | | LY | 26 |
| | | UB | 79 |
| | | LB | 82 |

## Water Quality and Supply

### Water Temperature

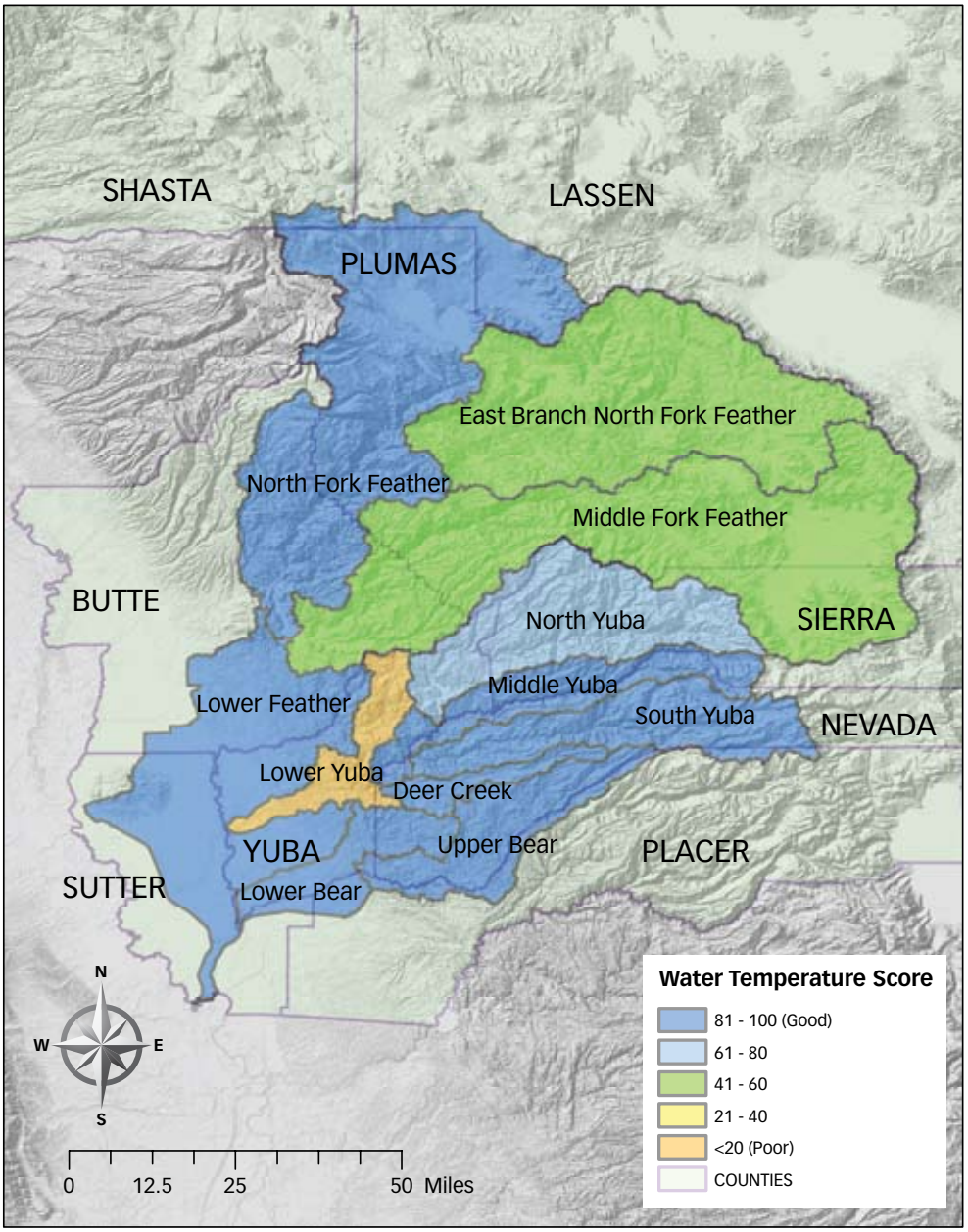



Figure 3 — Water temperature condition scores across subwatersheds

### TRENDS ANALYSIS

The majority of subwatersheds had positive temperature trends, but only one was statistically significant (Table 2). This was the Lower Feather, which had the second highest score for current state. Deer Creek had a significant negative slope, but the limited data available indicate an unreliable trend. Regional Mann-Kendall analysis (section 4.3) was conducted on each subwatershed, using the individual sites as separate regions. Only datasets with three or more years were included, to minimize noise and avoid a disproportionate contribution from the many 2008-2009 datasets. As suggested by the results from the individual regions, the overall trend for the entire watershed was positive but not significant (tau-b = 0.011, p = 0.728).

**Table 2 — Regional Mann-Kendall trend analysis. "Tau-b" is a Mann-Kendall test statistic. "S.N." refers to number of sites.**

| Subwatershed | Tau-b | Significant? | p-value | Slope Magnitude | Years | S.N. | Confidence | Remarks |
|---|---|---|---|---|---|---|---|---|
| DC | -0.150 | Yes | 0.050 | -0.156 | 2001-2009 | 13 | Medium | Many datasets, but false maxima |
| ENFF | 0.149 | No | 0.107 | 0.234 | 1999-2008 | 9 | High | All true maxima |
| LB | -0.326 | No | 0.081 | -0.065 | 1968-2003 | 1 | Low | Insufficient data |
| LF | 0.262 | Yes | 0.026 | 0.195 | 1964-2003 | 4 | Low | Few data, false maxima |
| LY | -0.021 | No | 0.890 | -0.004 | 1973-2009 | 7 | Low | False maxima |
| MFF | 0.000 | No | 0.699 | -0.198 | 2001-2007 | 4 | Medium | Few data, but true maxima |
| MY | 0.105 | No | 0.466 | 0.06 | 2001-2009 | 6 | Low | False maxima |
| NFF | -0.333 | No | 0.564 | -0.184 | 2001-2003 | 3 | Medium | Few datasets, but true maxima |
| NY | 0.042 | No | 0.771 | 0.04 | 2000-2009 | 6 | Low | Few datasets and false maxima |
| SY | 0.020 | No | 0.721 | 0.018 | 1966-2009 | 47 | Medium | Many datasets, some true maxima |
| UB | 0.238 | No | 0.296 | .450 | 2000-2003 | 5 | Low | Few datasets and false maxima |

Most datasets, particularly the true maxima, were gathered within the last 10 years. Consequently, these analyses rely heavily on the significance of recent trends. However, there are some historical monthly datasets available through USGS sites which extend back to the early 1960s. These are shown in Figure 4. There are large gaps in the data, and the temperatures are not true maxima. Nonetheless, in the interest of historical comparison a Mann-Kendall analysis was performed on each site. The results are given in Table 3. Two sites (out of seven) showed significant positive trends, both in the Lower Feather.

Figure 4 — Annual maximum temperature (°C) from seven long-term USGS datasets

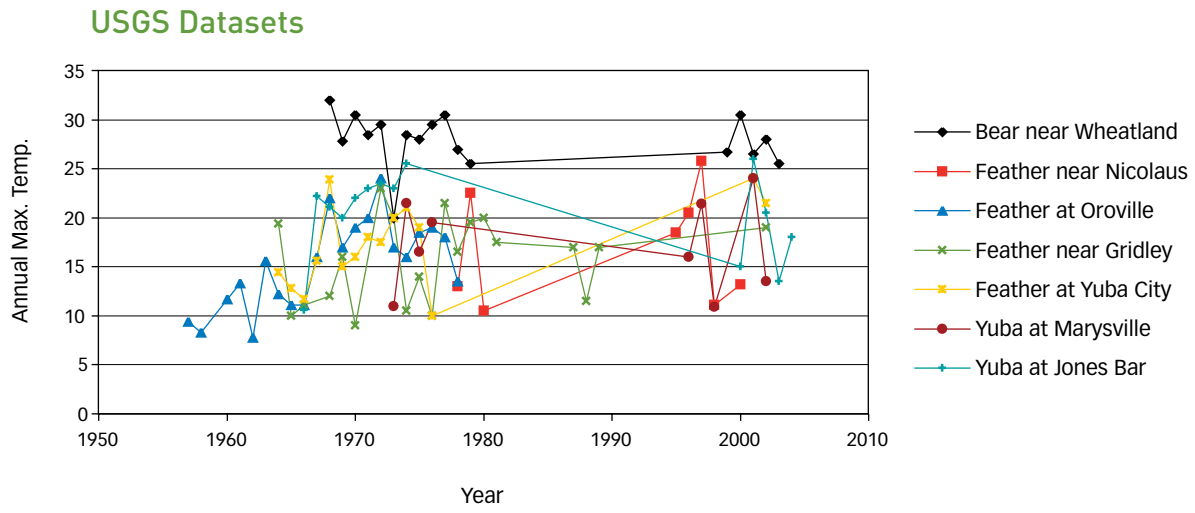



Table 3 — Regional Mann-Kendall analyses for seven USGS datasets. "Tau-b" is a Mann-Kendall test statistic.

| RU | Site | Years | Tau-b | Significant? | p-value | Slope Magnitude |
|---|---|---|---|---|---|---|
| LB | Bear near Wheatland | 1968-2003 | -0.325 | No | 0.082 | -0.084 |
| LF | Feather near Nicolaus | 1978-2000 | 0.071 | No | 0.902 | 0.021 |
| LF | Feather at Oroville | 1957-1978 | 0.481 | Yes | 0.003 | 0.493 |
| LF | Feather near Gridley | 1964-2002 | 0.186 | No | 0.269 | 0.125 |
| LF | Feather at Yuba City | 1964-2002 | 0.467 | Yes | 0.018 | 0.281 |
| LY | Yuba at Marysville | 1973-2002 | 0.000 | No | 0.917 | 0.041 |
| SY | Yuba at Jones Bar | 1966-2004 | 0.066 | No | 0.784 | 0.078 |

## Temporal and spatial resolution

Temperature is monitored throughout the Feather River Watershed, but not consistently over time or space. For example, there are few sites in the very large North Fork Feather and many in the comparatively small South Yuba. In addition, temperatures are collected using a combination of monthly grab samples and continuously monitoring Hobo-temps (thermometers left in the waterways). Continuous monitoring provides the most consistent source of temperature data and indicator calculation, but it is conducted on only a few sites. A critical feature of watershed-wide monitoring would be the establishment of a network of continuous temperature measuring devices that covers all important waterways and times of the year.

## Water Quality and Supply

### Water Temperature

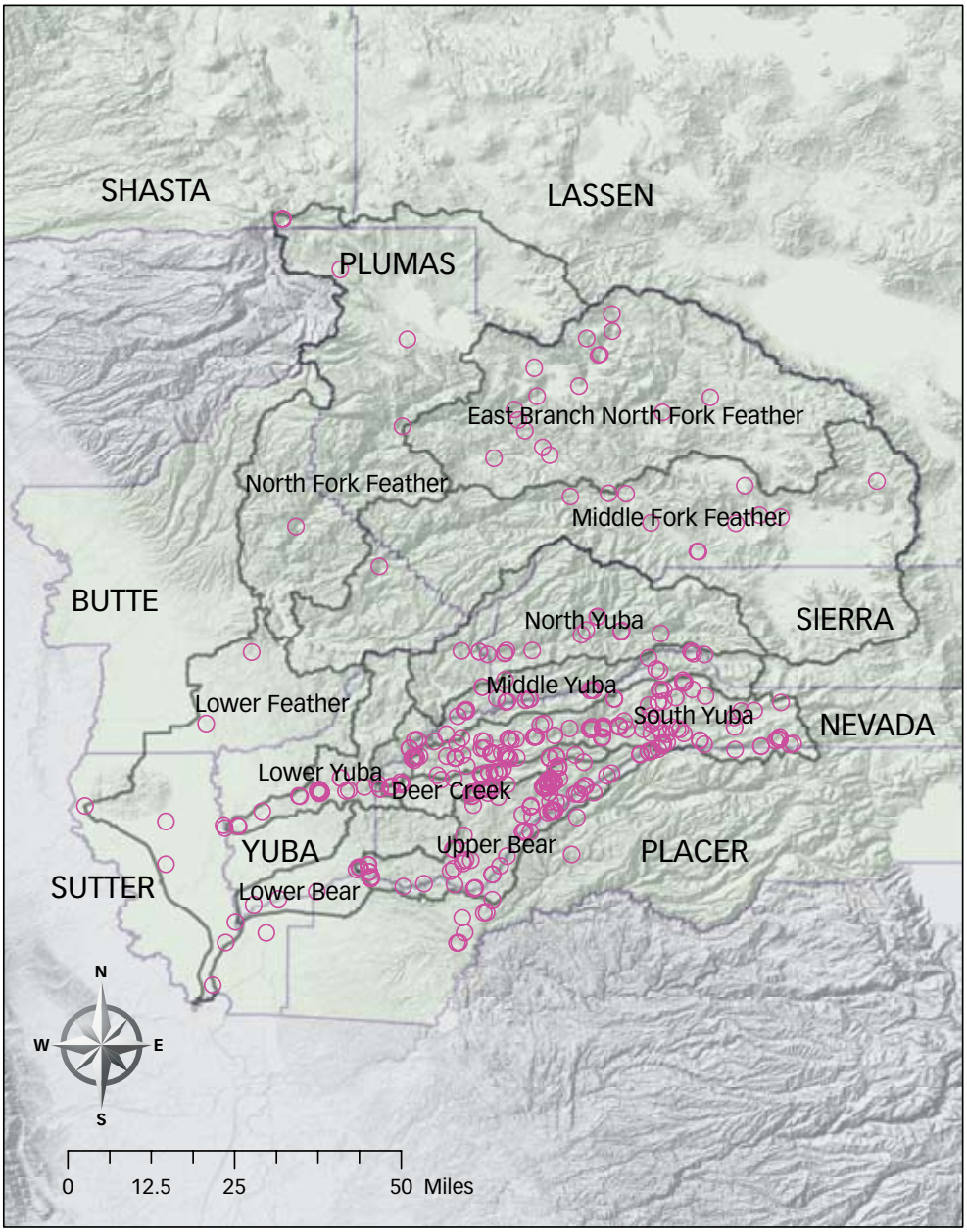



Figure 5 — Distribution of temperature monitoring stations used as sources of data from throughout the watershed

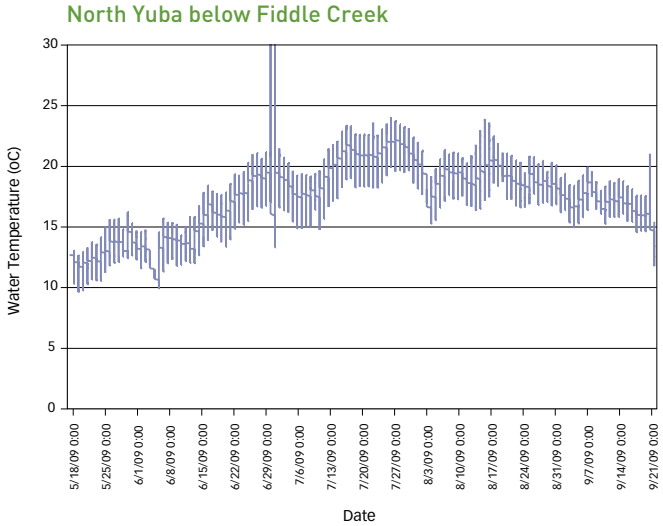
## How sure are we about our findings? (Things to keep in mind)

The overall condition assessment based on 7DADM tells part of the story, but is best calculated based on complete data-sets. Water temperature is a straightforward parameter to measure, but is complicated to interpret. For example, the North Yuba received a lower condition score than the South Yuba (Table 1), but maximum temperatures in the South Yuba (Figure 6B) can get higher than in the North Yuba (Figure 6A, Table 4). Similarly, Deer Creek received a score of 100, but has also experienced high maximum temperatures (Table 4). The most significant problem is the lack of long-term continuous temperature data for all sites. Although continuous data exists for many sites, it is limited to only the most recent years. The majority of sites have only single daily or monthly measurements, which makes it impossible to estimate a reliable maximum temperature. Scores based on these "false maxima" are likely to under-represent temperature problems in the watershed. The lack of reliable long-term time series makes trend estimation difficult as well.

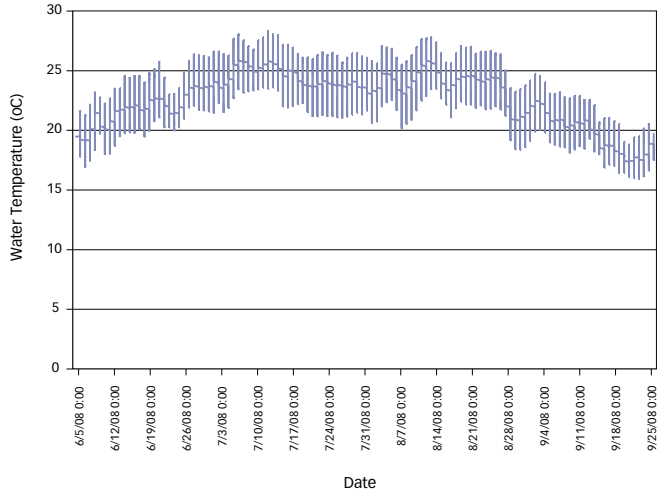
The sites included were not edited to provide balanced spatial resolution, and some monitoring stations may not be representative of the subwatershed. For instance, the Lower Yuba score includes temperatures from Dry Creek. Dry Creek has higher temperatures than the Lower Yuba, and excluding its data would give a final score for the Lower Yuba of 41, not 26. Due to these and other factors, subwatersheds varied broadly in the confidence in findings (see Table 4). Subwatersheds with the lowest confidence scores are: Deer Creek, Lower Bear, Lower Feather, and North Fork Feather. These regions typically had fewer sampling sites, or lacked data for true temperature maxima. Highest confidence subwatersheds are: East Branch North Fork Feather, Middle Yuba, South Yuba, and Upper Bear. Differences in quality of data may explain some of the results, such as the high score for the Lower Feather compared to the Lower Yuba.

**Figure 6 — Sample data from remote electronic thermometers ("Hobo-Temps") in A) the North Yuba River and B) the South Yuba River**

A.



B. South Yuba at Bridgeport




## Technical Information

### DATA SOURCES:

- Feather River: USGS daily temperatures 1957-2009, FRCRM/DWR daily temperatures 2000-2008, Nevada Irrigation District (NID), Federal Energy Regulation Commission (FERC) summer temperatures 2008-2009
- Yuba River: SYRCL monthly data 2000-2009, daily data 2007-2009, USGS daily temperatures 1957-2009, NID FERC summer temperatures 2008-2009
- Bear River: USGS daily temperatures 1957-2009, Nevada Irrigation District (NID), Federal Energy Regulation Commission (FERC) summer temperatures 2008-2009

### DATA MANIPULATION:

Units: Temperature data were converted into Celsius where necessary.

Type of data: Analysis is meant to be on temperature maxima only. Non-maximum data, such as daily averages or single measurements, were treated in one of two ways:

- If data set was inferior or redundant, data were excluded from analysis. Generally excluded were: data sets with only one year of data; data sets with no data within the last 10 years; and false maxima data in regions with 5+ sites with true maxima.
- If data set was desirable (i.e. the particular region or time period had little alternative data), then data were be treated as if they represented daily maxima, but this was noted in the analysis and the data confidence evaluation.
- Unrealistically extreme values (>>30°C) were assumed to be erroneous readings from exposed temperature probes, and were removed.

### TEMPORAL AGGREGATION:

Data were aggregated temporally as follows:

Sub-daily data (i.e. hourly, 15min, etc.): included only daily maximum.

Daily data: Daily maxima were averaged over seven-day periods to form a rolling 7DADM. Standard deviations calculated for each average. Averages started with the seventh day in a series, and then moved forward until the final day. Some averages extended into two months, but the 7DADM was associated with the final day in the average. For months with fewer than seven days of reporting, a shorter average was used, though this was reflected in the standard deviation. Missing days were accommodated in a similar manner, though single missing days were treated as an unbroken average.

Weekly data: Whether this was a single measure of weekly temperature, or a 7DADM point, only the maximum value was used to represent the month. Standard deviation for the maximum point was preserved.

Monthly data: Seasonal Kendall and month-by-month trend analysis were carried out on monthly maxima data, when data permitted. Trends were reported for each season or month, as well as the overall yearly trend.

Annual data: For annual analysis, the Mann-Kendall trend analysis was used on yearly maximum data. Standard deviations were maintained from the 7DADM averages when possible.

Subwatershed aggregation: Data within a subwatershed was assumed to represent independent sampling of the subwatershed, and was used to calculate aggregate scores for that subwatershed. Number of sites was considered when assessing confidence measures.

**Table 4 — Basic statistics for subwatershed condition assessments. "SD" refers to standard deviation; "95% C.I." refers to 95% confidence intervals. "S.N." refers to the number of monitoring sites.**

| Subwatershed Name | Mean 7DADM (°C) | Minimum 7DADM | Maximum 7DADM | SD | S.N. | 95% C.I. | Score | Confidence | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| Deer Creek | 18.38 | 13.12 | 28.89 | 4.36 | 17 | +/-2.07 | 99.70 | Low | False maxima (score could be lower) |
| East Branch North Fork Feather | 23.77 | 17.03 | 29.81 | 3.18 | 18 | +/-1.47 | 31.98 | High | All true maxima |
| Lower Bear | 21.00 | 16.50 | 25.50 | 6.36 | 2 | +/-8.82 | 81.63 | Low | Few data, no true maxima |
| Lower Feather | 18.42 | 11.30 | 24.00 | 5.07 | 6 | +/-4.05 | 99.65 | Low | Few data, no true maxima |
| Lower Yuba | 24.01 | 18.21 | 28.66 | 4.78 | 5 | +/-4.19 | 26.25 | Medium | True maxima, but few data |
| Middle Fork Feather | 23.93 | 17.33 | 29.13 | 4.82 | 5 | +/-4.22 | 28.13 | Medium | True maxima, but few data |
| Middle Yuba | 20.53 | 11.90 | 27.76 | 5.69 | 16 | +/-2.79 | 86.89 | High | Plentiful true maxima |
| North Fork Feather | 20.24 | 14.06 | 26.22 | 6.09 | 3 | +/-6.89 | 89.81 | Low | True maxima, but very few data |
| North Yuba | 20.54 | 16.03 | 24.01 | 3.72 | 6 | +/-2.98 | 86.82 | Medium | True maxima, but few data |
| South Yuba | 20.40 | 10.91 | 29.75 | 4.49 | 56 | +/-1.18 | 88.27 | High | Very extensive sampling, true maxima |
| Upper Bear | 21.17 | 13.09 | 29.68 | 4.15 | 27 | +/-1.56 | 79.44 | High | Good sampling, many true maxima |

**TRENDS ANALYSIS REPORTING:**

The primary values reported were Mann-Kendall trends and Kendall B estimated trend slope, with confidence intervals. When performing regional analysis, trends for subunits were reported along with overall trend. Only time series with 3+ years of data were used for trend analysis.

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U.S. Environmental Protection Agency (USEPA). 2001. "Issue Paper 5: Summary of Technical Literature Examining the Physiological Effects of Temperature on Salmonids." Region 10, Seattle, WA. USEPA 910-D-01-005. 119pp.

# 3.1.3 – Mercury in Fish Tissue

**GOAL: A.** Maintain and improve water quality and supply to sustainably meet the needs of natural and human communities

**OBJECTIVE: 1.** Maintain water quality for healthy aquatic systems

**WAF ATTRIBUTE:** Physical/Chemical

## What is it and why is it important?

Pollution is a major concern for all watersheds, especially those that have been heavily modified and urbanized. Biological and chemical contaminants have a wide range of sources and can exert negative effects on species, ecosystems, and humans (primarily via drinking water and fish consumption). Trace metals such as mercury are natural components of rocks and soil and can enter the aquatic environments as a consequence of weathering and erosion (Garrett 2000). However, following gold-mining in California and global industrialization, unnatural quantities of many elements, such as mercury, were and continue to be released into the riverine and coastal ecosystems, altering natural biological equilibrium (Haynes and Johnson 2000). Anthropogenic activities have altered both the distribution of metals in the environment as well as metal speciation, or biochemical form (Goyer and Clarkson 2001).

Mercury is a trace metal of particular concern because it can exert negative toxic effects on humans and wildlife at low concentrations (Selin 2009). Methylmercury has been shown to cause massive neurological damage because of its ability to cross the blood-brain barrier, while inorganic forms can cause nephrotoxicity (Boelsterli 2007). Mercury primarily enters aquatic ecosystems in inorganic dissolved ionic or particulate form through wet and dry deposition from the atmosphere to water body surfaces, or via runoff from watersheds (Selin 2009). Although mercury occurs naturally in the environment, human activities such as gold mining and recovery, burning fossil fuels and waste, mining and smelting metals, and using mercury in products and industrial processes have added to the amount of mercury in the global environment. Ecosystems near point sources may be characterized by higher mercury concentrations, but due to global transport ecosystems that are far from any point sources may also have high mercury concentrations (Scheulhammer et al. 2007). In the Feather River Watershed, mercury was used in the late 1800's to recover gold mixed in sediments sluiced from mountain-sides during hydraulic mining. Mercury was literally poured into sluice boxes in order to trap small gold particles. The mercury was then burned away to recover the gold. Most of this mercury was lost in the sluicing and in the burning.

Biological magnification is the process by which toxins become more concentrated in organisms at each successive trophic level up the food chain. Due to the tendency for mercury to bioaccumulate and magnify up the food chain, organisms at higher trophic levels on the food chain and with long life spans tend to be at greatest risk (Scheulhammer et al. 2007). Mercury concentrations in the tissues of top predators can be over one million times greater than those in the water column (Selin 2009). Furthermore, the proportion of methylmercury to total mercury increases at each trophic level in the food chain; in predatory fish, almost 100% of the mercury is methylmercury (USEPA 1997, Morel et al. 1998).

The major pathway for human exposure to methylmercury is consumption of contaminated fish. Dietary methylmercury is almost completely absorbed into the blood and is distributed to all tissues including the brain; it also readily passes through the placenta to the fetus and fetal brain (USEPA 2001). Based on available data, human exposures to methylmercury from all media sources except freshwater/estuarine and marine fish are negligible. Therefore, the USEPA methylmercury water quality criterion is a concentration in fish tissue (USEPA 2001).

## What did we find out/How are we doing?

Based on pooled data from fish samples for each subwatershed, 7 of 11 subwatersheds within the Feather River Watershed on average exceed the methylmercury USEPA tissue residue criterion (TRC) safe level for human consumption (Table 1; Figure 1). We can conclude from these basic statistics that human and wildlife consumers of fish in the Feather River may be at risk of methylmercury bioaccumulation and possible toxic effects in these subwatersheds.

The East Branch North Fork of the Feather had the lowest concentrations and highest score and the Deer Creek had the highest concentrations and shared the lowest score, 0, with other subwatersheds.

### Table 1 — Report Card scores for mercury in fish for subwatersheds

| Goal | Measurable Objective | Subwatershed | Score |
|---|---|---|---|
| A. Maintain and improve water quality and supply to sustainably meet the needs of natural and human communities | 1) Maintain water quality for healthy aquatic systems — mercury in fish | NFF | 36 |
| | | EBNFF | 88 |
| | | MFF | 0 |
| | | LF | 0 |
| | | NY | 0 |
| | | MY | 24 |
| | | SY | 0 |
| | | DC | 0 |
| | | LY | 0 |
| | | UB | 0 |
| | | LB | 41 |

## Water Quality and Supply

### Mercury in Consumable Fish

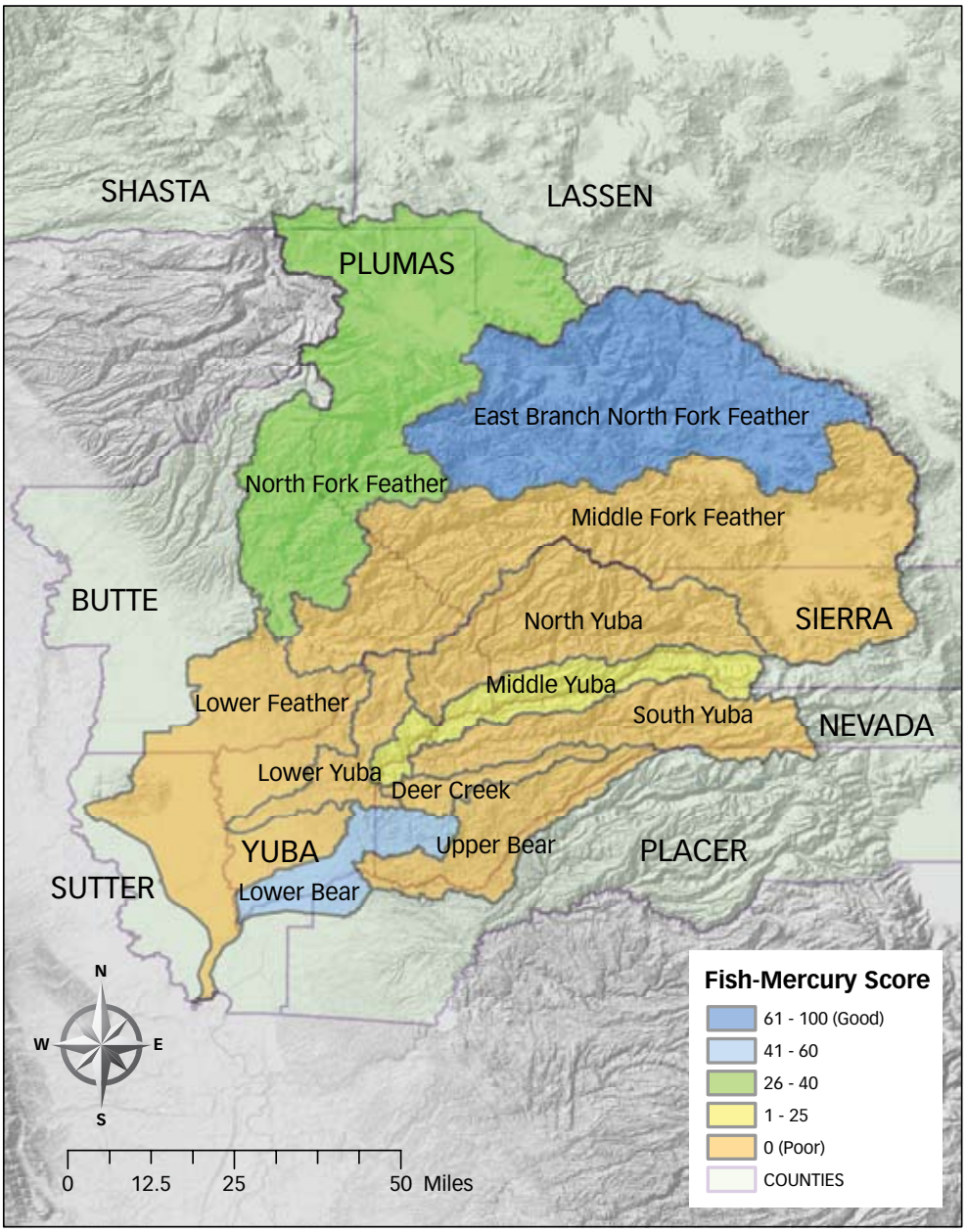
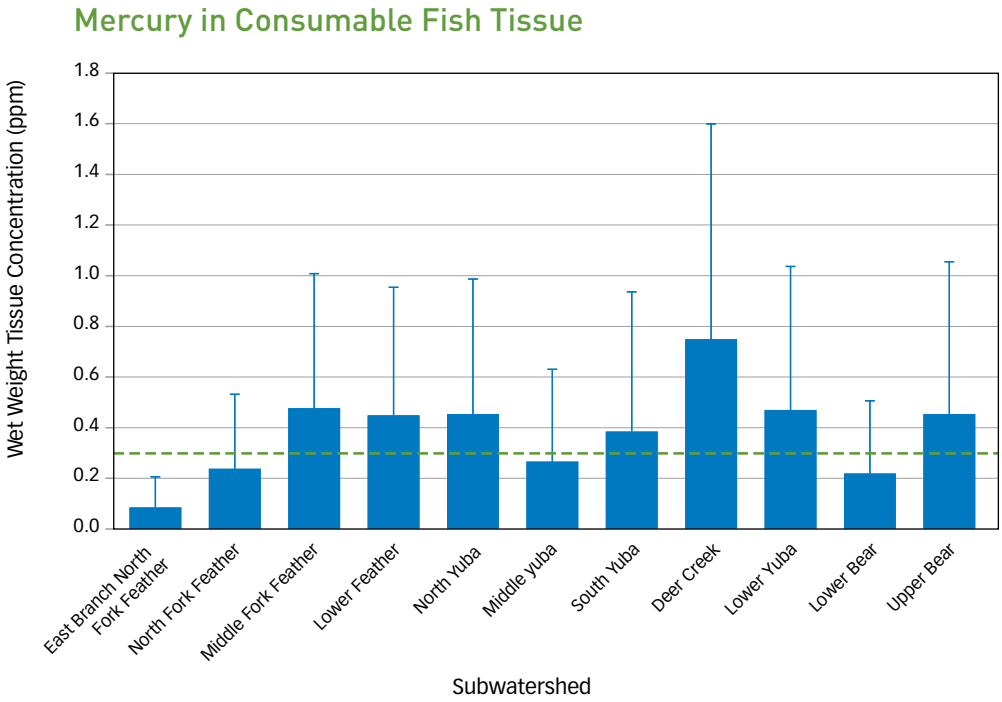



Figure 1 — Subwatershed distribution of scores for mercury in fish tissue

**Figure 2 — Mean + 95% confidence intervals of mercury in fish tissue for each subwatershed. Green line on chart is EPA's 0.3 ppm threshold for fish tissue concentration of mercury.**




## Analysis Confidence

Though some subwatersheds were limited by sample sizes and/or were not normally distributed, most had enough data to consider these statistics robust. Therefore, we have high confidence that mercury levels in fish in many of the Feather River subwatersheds are higher than safe thresholds set by the USEPA. However, there are several considerations to consider when interpreting these data. First, we chose to pool species of trophic levels 3 and 4 in order to roughly estimate the risk of exposure to the average human consumer of fish. However, certain subwatersheds, communities, or individuals may only have access to certain types of fishes or preferentially choose to consume certain species. Therefore, the risk may be very different than the values calculated here and may be either higher or lower. Many previous studies have shown that higher trophic level fish typically have higher concentrations of mercury as well as other persistent pollutants such as polychlorinated biphenyls (PCB). Thus, consumers preferentially eating carnivorous or top predatory fish should be especially cautious if they consume fish in these subwatersheds.

## Technical Information

### DATA SOURCES AND ANALYSIS

All data for mercury concentrations in fish were obtained from the CVRWQB, who maintains a database of concentrations for all water bodies sampled in the Central Valley Region.

Included in this analysis are mercury concentrations in edible-sized fish caught at sites within the designated subwatershed boundaries. Though this data spans several decades, preliminary analyses determined that there were no trends in mercury concentrations in fish tissues over time. To assess current risk to human consumers, we limited our analyses to data for the latest year at each site, except in the event of extremely small samples sizes where we pooled data from the latest five years. We also only included fish above certain minimum sizes (Shilling et al. 2010). We calculated the levels and variation at both the subwatershed and site levels.

**Table 2 — Basic statistics for consumable fish samples in each subwatershed. Colors are coded to indicate distance to target, where red > 0.3 mg/kg, yellow >0.1 mg/kg, and green< 0.1 mg/kg.**

| Hg in fish tissue wet weight (mg/kg) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Subwatershed | N | Min | Max | Median | Mean | 0.95% Upper C.I. | 0.95% Lower C.I. | Score |
| East Branch North Fork Feather | 5 | 0.05 | 0.12 | 0.07 | 0.08 | 0.11 | 0.04 | 88 |
| Lower Bear | 20 | 0.06 | 0.51 | 0.14 | 0.20 | 0.26 | 0.13 | 40 |
| Upper Bear | 77 | 0.06 | 1.50 | 0.40 | 0.41 | 0.54 | 0.40 | 0 |
| North Fork Feather | 78 | 0.02 | 1.23 | 0.12 | 0.21 | 0.27 | 0.16 | 36 |
| North Yuba | 36 | 0.06 | 0.83 | 0.47 | 0.41 | 0.48 | 0.34 | 0 |
| Deer Creek | 27 | 0.15 | 1.17 | 0.70 | 0.68 | 0.77 | 0.59 | 0 |
| Lower Yuba | 60 | 0.02 | 1.58 | 0.38 | 0.42 | 0.51 | 0.34 | 0 |
| Lower Feather | 253 | 0.02 | 3.50 | 0.27 | 0.41 | 0.46 | 0.35 | 0 |
| Middle Fork Feather | 75 | 0.06 | 1.26 | 0.38 | 0.43 | 0.48 | 0.38 | 0 |
| Middle Yuba | 19 | 0.06 | 0.81 | 0.20 | 0.24 | 0.33 | 0.15 | 24 |
| South Yuba | 4 | 0.26 | 0.48 | 0.33 | 0.35 | 0.50 | 0.20 | 0 |

Mercury concentrations in fish were transformed into a corresponding score based on 1) low concentrations of mercury found in certain species (e.g., trout in montane systems) and smaller individuals of edible species and 2) USEPA Reference Dose (RfD), Relative Source Contribution (RSC) and Tissue Residue Criterion (TRC) (USEPA 2001). The quantitative health risk assessment for a non-carcinogen relies on an RfD, an estimate of a daily exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious health effects during a lifetime. The RSC

is used to adjust the RfD to ensure that the water quality criterion is protective, given other anticipated sources of exposure. Finally, the TRC is the concentration in fish tissue that should not be exceeded based on a total fish and shellfish consumption weighted rate. According to the USEPA consumption guidelines (2001), the RfD for mercury is 0.1 g/kg bw/day. After subtracting contributing mercury exposure via marine fish (RSC), the TRC for freshwater/estuarine fish= 0.3 mg methylmercury/kg fish based on an assumed weighted rate of 0.0175 kg fish/day, and resulting in the score of 0. Other consumption guidelines have also been published which suggest levels for safe exposure may be higher, such as the Food and Drud Administration (FDA) at 1.0 mg/kg (FDA 2001). However we chose to scale our scoring system by the stricter USEPA guidelines in order to be conservative and to reflect higher fish consumption rates found along the Sacramento River among communities that my be similar to or may fish in the Feather River Watershed. The highest score cutoff is for the lowest concentrations found in the Sacramento River Basin, 0.05 mg/kg, which may be similar to background.

**SCORING BASED ON:**

After transformation, this corresponds to scores according to the following scale:

- 0 for concentrations > 0.3mg/kg (corresponds to significant human risk via fish consumption)
- 100 for concentrations < 0.05 mg/kg (corresponds to little to no human risk via fish consumption)
- Concentrations between 0.05 mg/kg and 0.3 mg/kg were given a corresponding proportional score using a 1:1 linear transformation.

This transformation allowed us to report the general level of concern for the human consumption of fish in each area.

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# 3.1.4 – Flow Patterns and Alteration

## Current flow patterns compared to historical flows

**GOAL: A.** Maintain and improve water quality and supply to sustainably meet the needs of natural and human communities

**OBJECTIVE: 2.** Maintain and restore natural stream flows for aquatic and riparian communities

**WAF ATTRIBUTE:** Hydrology/Geomorphology

## What is it?

Hydrologic alteration is a measure of how the current flow pattern of a river compares to natural flows. The amount of water in a river changes every day, sometimes a little bit, sometimes a lot. A hydrograph is a daily flow record over an entire year at one location on a river (Figure 1). The hydrograph changes throughout the year as seasons change and as water delivery and power generation schedules change. The natural hydrograph can be drastically different from the current hydrograph. Calculating the degree of hydrologic alteration is a way of quantifying how different the current conditions are from natural conditions.

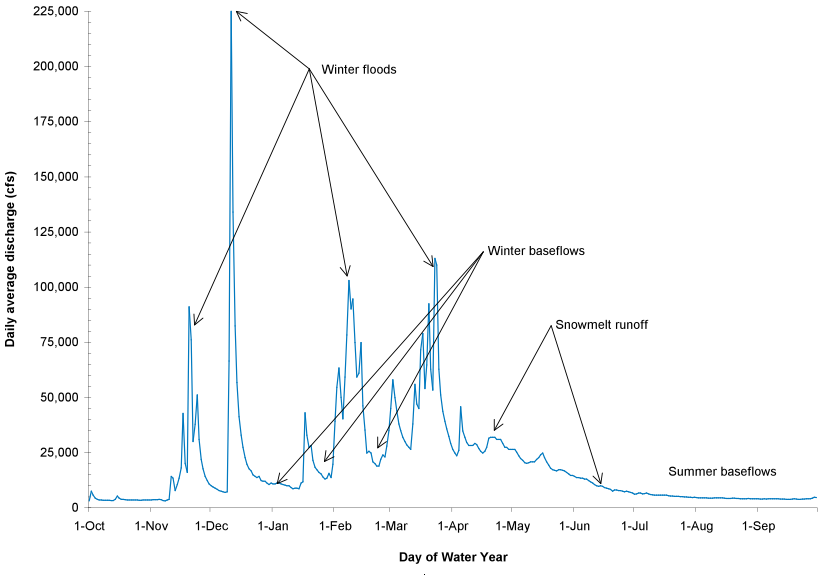


**Figure 1 — The Hydrograph: A hydrograph is a daily flow record over an entire year at one location on a river**

Hydrograph components noted here are winter floods (from individual storm events), winter base flows (what the winter water levels is between storm events) and summer base flows (Kondolf et. al 2000).

## Why is it Important?

The ecological integrity of river ecosystems depends on their dynamic character (Poff et al.1997). The ecosystem in a river or stream lives in balance with the hourly, daily, monthly, and annual changes in water level. The transportation and germination of some plant species depend on flow pulse events, such as a spring storm runoff, followed by gradual receding flows. The flow pulse transports the seeds up onto the river bank and the receding flow provides the young seedling with sufficient moisture while its roots grow deeper where it can access more permanent water sources. If pulse flows from storm events do not occur because they are held back by upstream dams, the downstream reaches do not receive any ecological benefits from that storm. Similarly, macroinvertebrates and fish depend on storm flows for both habitat (such as the creation of cool pools that are safe for rearing young), as well as for the transportation of sediment and valuable nutrients. Maintaining the hydrologic variability of the natural flow regime is essential for the conservation of native riverine biota and maintaining river ecosystem integrity (Richter et al. 1998).

## What is the target or desired condition?

The desired condition for the hydrologic regime is to be as close to the hydrologic regime that existed in the watershed naturally prior to construction of any dams, weirs, or other structures that can attenuate flow, as well as any significant landscape alterations such as roads or change in type and amount of vegetation cover in a watershed. Each watershed has a unique natural hydrologic regime which depends on the type of vegetation in a watershed, the form of precipitation (snow or water), soil and sediment composition, groundwater connectivity, etc. Consequently, it is not possible to have a single hydrologic regime that all watersheds should follow.

## What can influence or stress condition?

As previously mentioned, hydrologic alteration is caused by the presence of dams, weirs, paved surfaces (delivering runoff), road-crossings, and/or other structures that can alter flow. In addition, changes to vegetation cover, channel/floodplain connectivity, and soil composition (e.g., loss of some types of soils from surface erosion) can all contribute to hydrologic alteration because different types of vegetation and soil have different abilities for soaking up and releasing water.

## What did we find out/How are we doing?

The streams and rivers in the Feather River Watershed are moderately to highly altered. The most highly altered subwatersheds are the Lower Yuba and Lower Bear (Figure 1 and Table 1). The factor most strongly driving the hydrologic change in the Yuba and Bear Rivers is the timing of extreme flow events. Spring pulse flows are typical of regulated, i.e., dammed, rivers because reservoirs that are empty from high summer water demand fill up all winter long and in the spring spill more often than early in the rainy season. Spring extreme events may have the same geomorphic (physical) benefits as extreme events in the winter, but the biological benefits of the extreme events can be drastically different for fish and macroinvertebrate populations, depending on the time of year when they occur. In general, the construction of dams has shifted the timing of extreme events from winter to spring.

### Table 1 — Report Card scores for hydrologic alteration for subwatersheds

| Goal | Measurable Objective | Subwatershed | Score |
|---|---|---|---|
| A. Maintain and improve water quality and supply to sustainably meet the needs of natural and human communities | 2. Maintain and restore natural stream flows for aquatic and riparian communities | NFF | n/a |
| | | EBNFF | 69 |
| | | MFF | n/a |
| | | LF | 54 |
| | | NY | n/a |
| | | MY | n/a |
| | | SY | n/a |
| | | DC | 63 |
| | | LY | 40 |
| | | UB | 60 |
| | | LB | 41 |

## Water Quality and Supply

### Flow Alteration

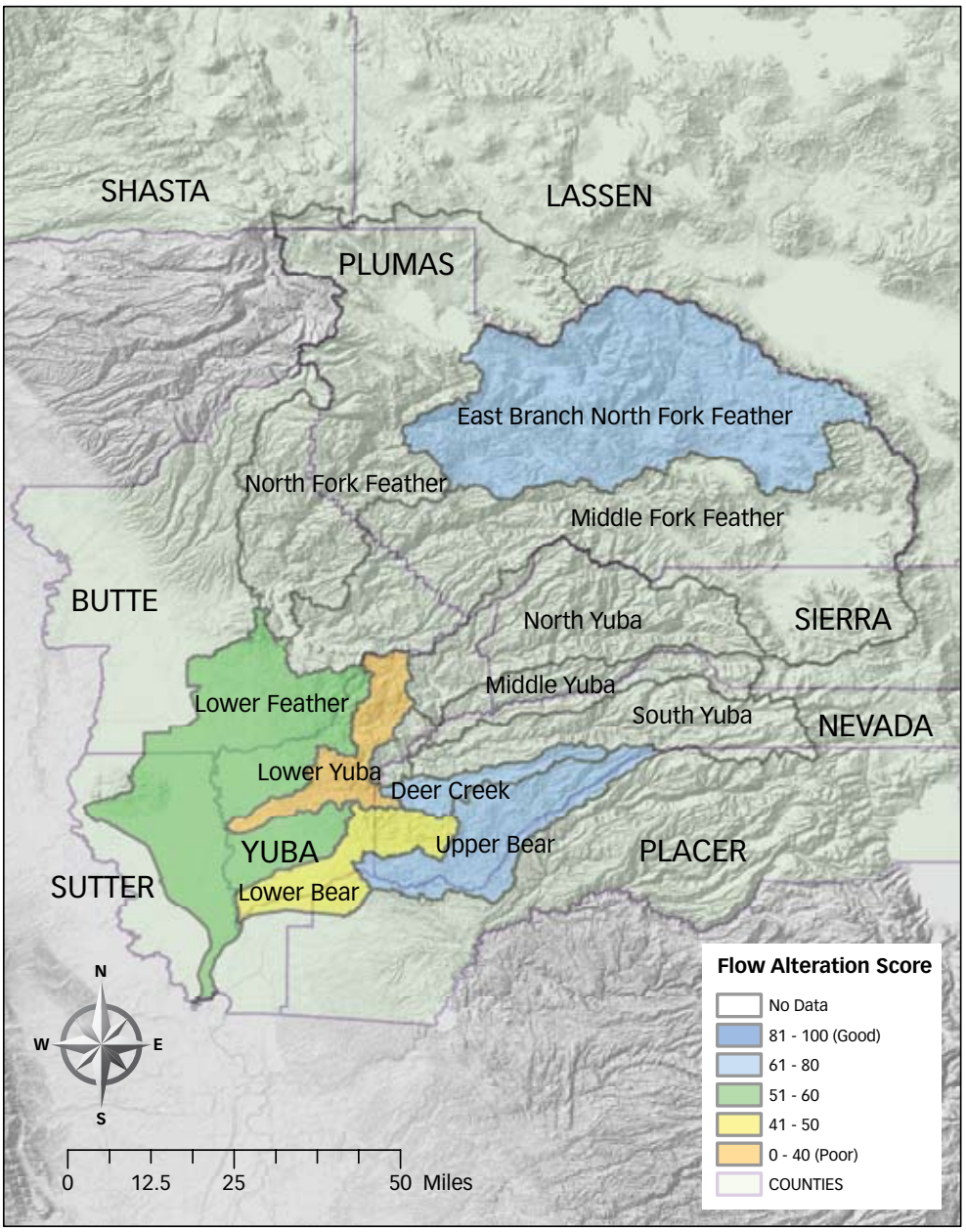


**Figure 2 — Hydrologic alteration scores for subwatersheds with sufficient available data**

One of the least altered of the analyzed subwatersheds is Deer Creek. The most highly altered aspect of the Deer Creek hydrology is the 30-day minimum, i.e., summer base flow. Post-project construction (after the installation of Scotts Flat Reservoir) summer base flows on Deer Creek are abnormally high. Unnaturally high summer flows in Deer Creek are likely a result of agricultural water demand in the lower watershed during the summer

months. The ecological impacts of unnaturally high flows is that it may make summer rearing for sensitive species, such as young fish and frogs, more difficult. In addition, water release from both Lake Wildwood and Scotts Flat can result in massive scour can occur if the water is released too high, too fast.

## Temporal and spatial resolution

The data used in this analysis only represent a small portion of the whole river. A measure of hydrologic alteration at a particular stream gauge site is limited in geographical extent and cannot be representative of the entire watershed. Dams tend to re-set the system by introducing a new flow release schedule and tributaries tend to mask the signal of the main stem hydrology by contributing either a more natural contribution or a more highly altered contribution depending on if the tributary has a dam on it or not. Therefore, the measurement of hydrologic alteration was considered to extend downstream of the gauge site to the first confluence with a major tributary and extend upstream to the location of the first upstream dam (Richter et al. 1998). The result is that there are large areas of stream reaches that are not covered by this analysis, especially in the upper watersheds.

## How sure are we about our findings?

There is no perfect record for the natural flow regime. This analysis is limited by the available historical flow data which was divided up into two time periods; a pre-project period, which was prior to a dam being constructed, and a post-project period, which was after the construction of a dam. Invariably, other landscape changes are also taking place that also influence hydrology such as stream incision, road density and vegetation changes, but this analysis is not sensitive enough to capture these changes. In addition, each river has multiple dams on it making it difficult to select the appropriate pre- and post-project period, which in turn makes it more complex to measure the degree of hydrological alteration. In some cases, especially for the Upper Feather River the gauges were installed at the same time that the dam was constructed, therefore, there is no pre-project flow data, or natural flow record, to compare to current flows. Ideally, naturalized flows for each subwatershed would be generated using hydrologic models and would constitute the baseline that the current flow regime would be compared to. This is a critical data gap and source of uncertainty.

Comparing two different time periods can be like comparing apples to oranges. When working with historical hydrological data that covers a long time frame, say twenty years before a dam was built to twenty years after a dam was built, it is important to remember that other climate-related changes have occurred which may influence the hydrograph. For example, if the twenty years of pre-project data occurred during a drought then the hydrograph does not capture the extent of variability in flow/hydrologic regimes that the watershed can experience. In an attempt to overcome this potential source of error, hydrological analyses take into account different water year types (critical, dry, below normal, above normal, wet) when comparing pre- and post-project hydrology. This analysis uses the complete flow record that was available and as a result does not explicitly look at different water year types.

## Additional Information

### DATA SOURCES

The USGS daily median flows from four gauges in the Feather River Watershed; Bear River (USGS gage 11424000), Deer Creek (USGS 11418500), Yuba River (USGS gage 11421000) and Feather River (Oroville USGS gage 11407000 and Thermalito 11406920) was obtained from the USGS archive at http://water.usgs.gov/usa/nwis. The Feather River data from Thermalito gage and the Oroville gage was combined (summed) from 1967 (when the Thermalito gage was installed) until 2009. These values were combined because most of the water released from Oroville Dam is routed through the Thermalito diversion pool and afterbay and therefore bypasses a 7 mile stretch below the dam known as the low flow channel. The location of the gauges are as follows:

| Gauge Location | USGS gauge number | Lat (DD) | Long (DD) | HU |
|---|---|---|---|---|
| Feather River Thermalito | 11406920 | 39.52083 | 121.6361 | 18020106 |
| Feather River Oroville | 11407000 | 39.52167 | 121.5467 | 18020106 |
| Feather River East Branch Indian Creek | 11401500 | 40.07806 | 121.9269 | 18020122 |
| Yuba River Marysville | 11421000 | 39.17583 | 121.5239 | 18020107 |
| Deer Creek Smartsville | 11418500 | 39.22444 | 121.2675 | 18020125 |
| Bear River Wheatland | 11424000 | 39.00028 | 121.4056 | 18020108 |

### ANALYSES

In order to calculate the degree of hydrologic alteration the historic flow record was divided into two groups, pre-project (before the dam was constructed) and post-project (after the dam was constructed). The construction of the most resent and/or downstream dam was used as the project by which to divide the flow record (Table 2). The pre-and post-project data sets were compared using a program called Indicators of Hydrologic Alteration (IHA version 7.1). Six different hydrograph components were selected to represent the hydrograph from which the degree of hydrologic alteration was calculated (Goa et al. 2009). These hydrograph components were chosen because, selected together, they capture the signature of the hydrograph and reduce information redundancy (measuring the same thing more than once) that can occur when too many hydrograph components are used.

The selected six hydrograph components that were used for this analysis are:

- 30-day minimum, represents base flow or summer monthly flow
- 7-day maximum, represents high flow
- February flow, represents winter monthly flow
- November flow, represents fall to winter monthly flow rate of change
- June Flow, represents spring to summer monthly flow
- March flow, represents the timing of extreme events

**Table 2 — List of pre- and post-project time periods for each subwatershed**

| Subwatershed | Reservoirs | Date of Dam construction | Pre-project period | Post-project period |
|---|---|---|---|---|
| Lower Feather River | Oroville | 1961-1969 | 1909-1960 | 1970-2009 |
| East Branch North Fork Feather River Indian Creek | Antelope Lake | 1968 | 1906-1967 | 1969-1993 |
| South Yuba River | Spaulding | 1913 | | |
| North Yuba River | New Bullards Bar | 1970 | | |
| Lower Yuba River | Englebright | 1941 | 1940-1969 | 1970-2009 |
| Deer Creek | Scotts Flat | 1948, 1965 | | |
| Deer Creek | Anthony House Dam/ LWW | 1970 | 1935-1970 | 1970-2009 |
| Deer Creek | Deer Creek Dam Diversion | 1928 | | |
| Upper Bear River | Rollins | 1965 | | |
| Upper Bear River | Combie | 1928 | 1928-1965 | 1967-2008 |
| Lower Bear River | Camp Far West | 1963 | 1928-1962 | 1963-2009 |

Selection of hydrograph components: The six hydrograph components that were measured using IHA (version 7.1) are called range of variability (RVA) values and they represent six principal component axes (PCA axes) described in an analysis by Goa et al. (2009). Two of the eight IHA parameters selected by Goa at al. (2009) were excluded from this analysis; these were high pulse duration and rise rate. The reason these two parameters were excluded was that they fell into group 4 and 5 respectively of the IHA analysis and only groups 1 and 2 are considered reliable when portions of data are missing in the period of record. In addition, these two parameters explained the least amount of variation in the overall principal components analysis.

Determining the natural range of variability: Each hydrologic characteristic is calculated for a pre-project period which creates a data set that represents a more natural flow regime. The acceptable RVA is between the 25th and 75th percentile determined by the pre-project data set. The pre-project data set is compared to the post-project data set to determine the frequency with which the post-project data set falls within the acceptable range of variability. A positive deviation indicates that annual parameter values for the hydrologic characteristic fell inside the RVA target window more often than expected, a negative value indicates that the annual values fell within the RVA target window less often than expected.

Calculating the degree of hydrologic alteration: The absolute value (distance from zero) of the RVA values for each of the six hydrologic characteristics were averaged to get an overall percent of hydrologic alteration for each subwatershed (Richter et al. 1998).

$$Alteration = \left| \frac{\%\ \text{of values in range} - \text{historic}\ \%\ \text{in range}}{\text{historic}\ \%\ \text{in range}} \right|$$

The degree of hydrologic alteration is considered high, if the average is greater than 60%, low, if it is less than 33%, and medium, if it is between 34 and 59%. The average degree of hydrologic alteration is converted into the report card format by subtracting the absolute value of the average hydrologic alteration from 100. In this way a high degree of hydrologic alteration for an average score of -74, becomes a report card score of 26, a very low grade. Table 3 gives the report card score for each subwatershed.

### Table 3 — Report Card for extent of hydrologic alteration by subwatershed

| Measures of hydrologic alteration at individual stream gauges | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Subwatershed | 30-day minimum (%) | 7-day max (%) | Feb flow (%) | Nov flow (%) | June flow (%) | March flow (%) | Average Hydrologic Alteration (%) | Level of Alteration | Report Card Score |
| Lower Bear | -77 | -41 | -24 | -82 | 100 | -41 | 59 | H | 41 |
| Upper Bear | -33 | -94 | -21 | 11 | 45 | -70 | 40 | M | 60 |
| Deer Creek | 73 | -4 | -10 | -59 | -31 | -45 | 37 | M | 63 |
| Lower Yuba | -61 | -77 | -69 | -23 | -54 | -77 | 60 | H | 40 |
| East Branch North Fork Feather River Indian Creek | 15 | -65 | 15 | -7 | -54 | -31 | 31 | L | 69 |
| Lower Feather | -72 | -58 | -51 | 5 | 33 | -58 | 46 | M | 54 |
| Average Hydrologic Alteration % | 66 | 55 | 38 | 36 | 52 | 55 | 49 | M | 54 |
| PCA axis interpreted by Goa et al. 2009 | Base flow, summer monthly flow | High Flow | Winter monthly flow, rate of change, frequency | Fall to winter monthly flow, rate of change | Spring to summer monthly flow, frequency | Timing of extreme events | | | |

Degrees of hydrologic alteration are considered HIGH if they are greater than 68%, LOW if they are less than 33% and MEDIUM if they are between 34 and 67%

A positive deviation indicates that annual parameter values fell inside the RVA target window more often than expected (e.g.>50% of post dam years), a negative value indicates that the annual values fell within the RVA target window less often than expected (e.g.<50%),

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# Section 3.2 – Native Biota

**GOAL: B.** Protect and enhance native aquatic and terrestrial species, especially sensitive and at-risk species and natural communities

**OBJECTIVE: 1.** Protect and enhance native bird populations

**OBJECTIVE: 2.** Protect and enhance native aquatic communities

**OBJECTIVE: 3.** Protect and enhance native fish populations

The following indicators were evaluated to measure native biota conditions:

- Bird species diversity
- Proportion of watershed in agriculture/urban development
- Benthic Macroinvertebrates community structure
- Fish community diversity

## 3.2.1 – Bird Species Diversity

**GOAL: B.** Protect and enhance native aquatic and terrestrial species, especially sensitive and at-risk species and natural communities

**OBJECTIVE: 1.** Protect and enhance native bird communities

**WAF ATTRIBUTE:** Biotic Condition

### What is it?

There is an abundance of quantitative data about bird populations, thanks to surveys such as Christmas Bird Counts, the Breeding Bird Survey, and other projects. There are long time series for many of these surveys, allowing for trends to be determined. The Feather River Watershed contains seven Breeding Bird Survey routes and three Christmas Bird Counts locations that can be used for trend analysis.

A number of different metrics can be used to assess bird count data including change in species richness, change in diversity (e.g. Shannon index), or trends in abundance in selected bird species such as those from a particular guild or on a recognized watch list (Magurran 2004, Buckland *et al*. 2005). Because there are only a limited number of Breeding Bird Survey transects and Christmas Bird Count locations available in this watershed, in this analysis we look at a community-

level metric, species richness, rather than single-species trends. Analyses of Breeding Bird Survey data suggest that data from at least 14 routes are needed to determine a robust trend for a population of an individual species (Pardieck and Sauer 2007). Seven routes were available in the watershed forcing a focus on a community-level metric such as species richness.

Detectable change in species richness of birds over time was evaluated for each subwatershed. Because raw counts of species totals underestimate richness due to lack of detection of species, a statistical estimator was used to obtain a value for actual species richness (e.g. Coddington & Colwell 1994, Kery & Royle 2008, Magurran 2004).

## Why is it Important?

This indicator helps assess the bird communities in the region, an important and highly visible component of biodiversity. A change in species richness or dominance may reflect overall shifts in processes in the terrestrial ecosystems of the watershed. (O'Connell *et al.* 2000). Of the variety of species diversity metrics, richness was chosen instead of dominance-related metrics such as Shannon's index for a number of related reasons (Weber *et al.* 2004). First, species richness is a metric that is easily communicated to the general public. Second, dominance-related metrics may show confusing results such as decline in counts of abundant species leading to an increase in the value of the metric. Also, species richness may be assessed without the difficulties of measuring population or density. Finally, species richness is a good metric for assessing changes in communities due to declines in species that are widespread but uncommon locally.

## What is the target or desired condition?

The target condition is having a stable or increasing trend in species richness. A target condition based on trend slopes was selected rather than a target condition of a particular species richness value because it would be difficult in practice to establish what a richness value *should be* for a given landscape. Efforts to measure species richness are always mediated through the biases of a particular counting methodology, and any attempt to compare a particular measured value of richness with a predicted value (modeled for instance by combining knowledge of habitat preferences with broad-scale species range maps) will say just as much about the quality of the predictive model as it does about the quality of the actual richness condition. Steady or increasing species richness was the desired condition and hence represented by an indicator score of 100, and a negative trend in species richness to be represented by an indicator score under 100, the value of the score proportionate to the slope of the trend.

## What can influence or stress condition?

Factors that can influence species richness include broad-scale changes in the landscape such as deforestation, conversion to agriculture, and development. Degradation of habitat in the absence of broad-scale landscape changes can also lead to declining species richness, particularly through the extinction of rare species (Weber *et al.* 2004). Conversely, good management of reserves where rare species occur may promote species richness stability (Bohning-Gaese and Bauer 1996).

## What did we find out/How are we doing?

Species richness did not vary appreciably for the nine subwatersheds for which there were data, with all scoring 100. This means that there was no decline in species richness for any subwatershed over the last 10 years.

### Table 1 — Bird community condition scores for subwatersheds

| Goal | Measurable Objective | Subwatershed | Score |
|---|---|---|---|
| B. Protect and enhance native aquatic and terrestrial species, especially sensitive and at-risk species and natural communities | 1. Protect and enhance native bird communities. | NFF | n/a |
| | | EBNFF | 100 |
| | | MFF | 100 |
| | | LF | 100 |
| | | NY | 100 |
| | | MY | 100 |
| | | SY | 100 |
| | | DC | n/a |
| | | LY | 100 |
| | | UB | 100 |
| | | LB | 100 |

## Native Biota

### Bird Species Richness

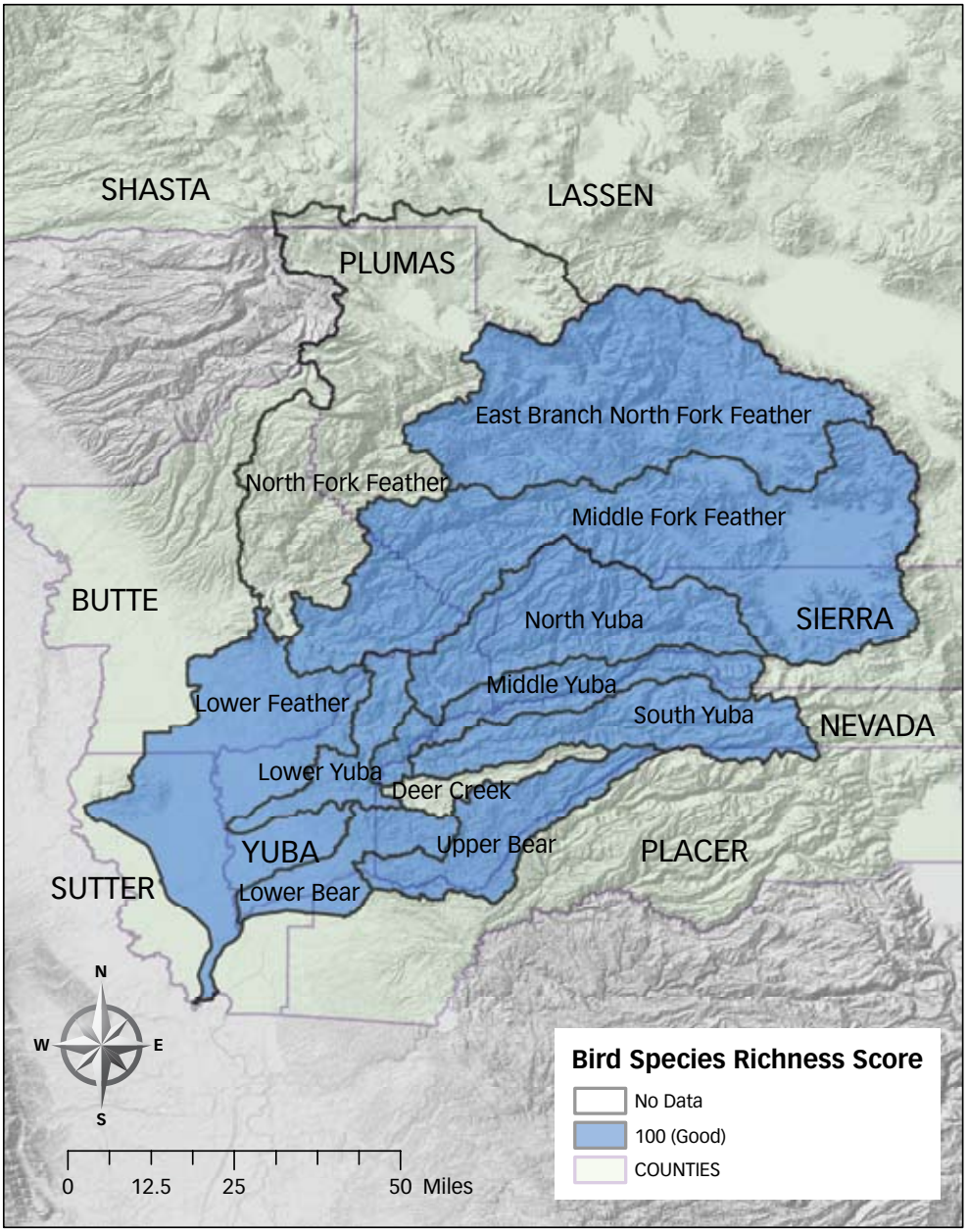
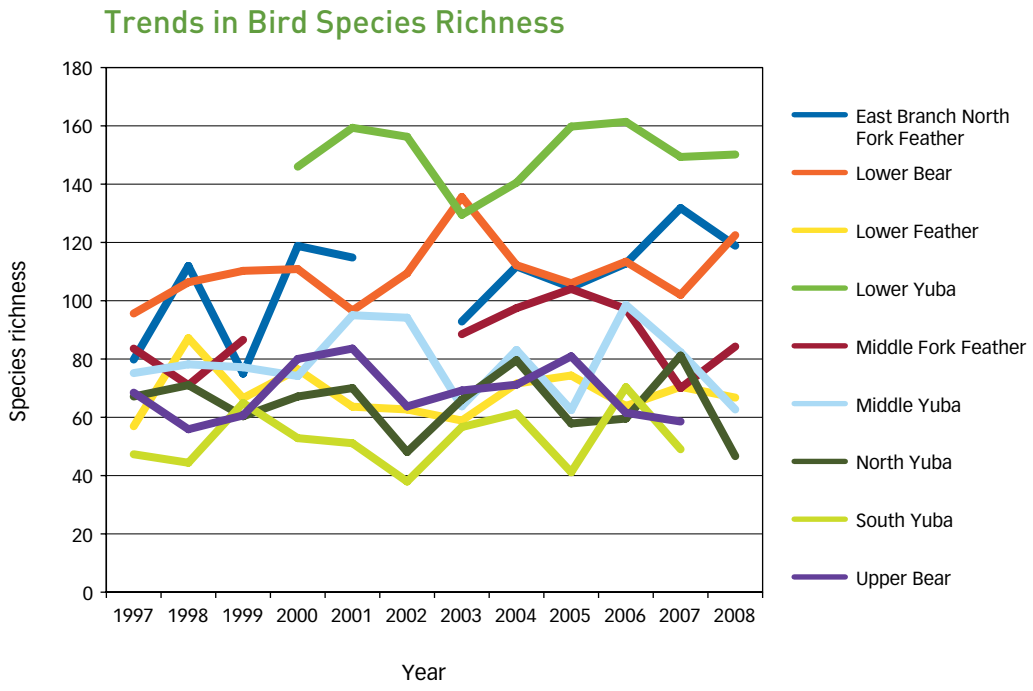



**Figure 1 — Bird community condition score across subwatersheds**

Values for estimated species richness ranged from 41.2 species to 131.8 species for the Breeding Bird Survey transects and from 95.6 species to 161.8 species for the two Christmas Bird Count datasets (Lower Bear and Lower Yuba watersheds). There appeared to be no significant trends in richness for any subwatershed (Figure 2). Gaps occurring in the graph reflect years in which counts or transects were not conducted.

Figure 2 — Bird species richness across Breeding Bird Survey sampling years




Analysis of the significance of trends in species richness were determined (Table 1). None of the subwatersheds show trends whose slopes are statistically-significantly different from zero. Seven of the subwatersheds show slightly to moderately increasing slopes, and therefore these are assigned an indicator value of 100. Of these subwatersheds with an increasing trend, the East Branch North Fork Feather River shows the highest slope (a value of 2.51), and is also the slope which most approaches statistical significance (a p-value of 0.064). Two of the subwatersheds (Middle Yuba and North Yuba) show slightly decreasing slopes. Based on the lack of statistical significance of any of these trends, it was concluded that bird species richness is relatively stable across all the subwatersheds of the Feather River.

## Temporal or Spatial Resolution

Individual Breeding Bird Survey routes are run annually in late May or early June. In California, there are roughly four routes per latitude-longitude block. Each route is 24.5 miles in length, and consists of 50 stops at 0.5 mile intervals. Since 1997, Breeding Bird Survey count data has been available at the individual stop level. The stops are not precisely geo-referenced; in this analysis they have been assigned to subwatersheds using linear referencing techniques in a GIS along the lines describing each route. The Christmas Bird Counts are likewise held annually, from mid-December to early January. Each count is performed in a circle 15 miles in diameter, and species counts are reported spatially only to the whole circle.

## How Sure Are We About the Findings (Things to keep in mind)

The conclusion that bird species richness is stable across the Feather River Watershed seems robust given examination of the time series data. The main caveat is that the species richness can be steady, but lower than historical or natural conditions. Other studies of bird communities over time have documented little change in species richness despite substantial changes to the landscape (e.g. Bohning-Gaese and Bauer 1996, Parody *et al* 2001), so this result may not be that surprising. It would be interesting to examine these data for shifts in community composition over time, which would tell more of a story about changes of pattern of bird diversity across this landscape than simply looking at species richness. But it is conceptually difficult to reduce examination of such shifts to a single graded metric.

The two different data sources are not ideal for examining changes in bird diversity at the subwatershed scale. Both the Breeding Bird Survey and the Christmas Bird Count are designed to provide information about changes in bird populations at a regional to continental scale, much coarser than the scale of our analyses. Moreover, since the Breeding Bird Survey and the Chrismas Bird Count take place at different times of the year, they are in fact sampling different bird communities. We amalgamate them here because we assume that trends in each say something about the condition of the subwatersheds, despite the difference in the bird communities that are sampled.

## Technical Information

### DATA SOURCES & TRANSFORMATIONS

The Breeding Bird Survey data is available from the USGS Patuxent Wildlife Research Center (Sauer *et al*. 2008). Data from seven routes were used in the this analysis (California route numbers 158, 159, 181, 184, 185, 415, and 436). Christmas Bird Count data is available from the National Audubon Society (National Audubon Society 2010). In this analysis we used data from the Grass Valley and Marysville count circles. We omit data from the Sierra Valley count circle because its subwatershed is already covered by Breeding Bird Survey transects. Because data collection methods for the Breeding Bird Survey are much more standardized than the Christmas Bird Count, we only used Christmas Bird Count data where there was no Breeding Bird Survey data for a subwatershed.

The individual Breeding Bird Survey routes that fell within the boundaries of the Feather River Watershed were examined to see if each was run for enough years to make trend analyses meaningful, routes that were run for five or less times over the period 1997 to 2008 being dropped from the analysis. By georeferencing the start point of each route and measuring distances in a GIS along the trace of each route, we were able to assign individual stops within each route to a subwatershed. A total of seven subwatersheds (Upper Bear, Lower Feather, East Branch North Fork Feather, Middle Fork Feather, North Yuba, Middle Yuba, and South Yuba) were covered by the Breeding Bird Survey route segments. For the subwatersheds that did not have Breeding Bird Survey route coverage, we used Christmas Bird Count coverage where available. This allowed coverage of two more subwatersheds, the Marysville count being assigned to the Lower Yuba subwatershed, and the Grass Valley count being assigned to the Lower Bear subwatershed.

## ANALYSES

All statistical analyses were performed in the R statistical computing environment (R Development Core Team. 2009). From the raw species counts in the Breeding Bird Survey and Christmas Bird Count datasets, statistical estimators were used that were available in the *vegan* package (Oksanen *et al*. 2009) in R to derive measures of actual species richness. For the Breeding Bird Survey data, the *specpool* function in *vegan* was used to derive the estimate of richness. The input to this function is a species count by plot matrix; it uses counts of species seen only once or twice as a basis for estimating the richness. The Jackknife 2 estimator in the *specpool* function was used as literature suggests that it is the least biased estimator of the five available in the function (Coddington and Colwell 1994, Palmer 1991). For the Christmas Bird Count counts, the *estimateR* function was used with the Chao estimator; this function differs from *specpool* in that it can provide an estimate based on counts at a single site.

Data collection in the Breeding Bird Survey is standardized through a well-defined protocol, and hence controlled for effort: for instance the observer spends exactly three minutes at each stop counting birds. There is no standard protocol for Christmas Bird Counts. It is common in analyses of Christmas Bird Count data to standardize for levels of effort by dividing raw counts by the number of hours parties spend in the field, but some analyses suggest that this normalization should not be linear (Link & Sauer 1999). In this analysis of the Christmas Bird Count datasets no effort was made to normalize for effort and instead raw counts were used. No literature was found discussing how Christmas Bird Count counts may be normalized for levels of effort if the metric of interest is species richness rather than population levels; moreover, the

*estimateR* function does not allow count entries in the species by plot matrix to have fractional values, which would be the case if entries were divided through by number of party-hours. Experience with Christmas Bird Counts indicates that they are biased towards finding as many species as possible, which may mean that differences in level of effort will have relatively minimal impact on species richness totals.

Trends in species richness were evaluated using the Mann-Kendall method described in section 4.3. Slopes in the trends were derived using Sen's method (Sen 1968). These slopes were converted into an indicator score of 100 because none of the slopes were significantly different from 0.

### Table 1 — Trends in bird species richness, 1997-2008

| Subwatershed | Indicator Value | Data Source | Slope of Trend | Statistical Significance | Confidence Interval for Slope |
|---|---|---|---|---|---|
| Deer Creek | N/A | N/A | N/A | N/A | N/A |
| East Branch North Fork Feather | 100 | Breeding Bird Survey | Increasing – 2.51 | Not significant (p = 0.064) | -0.045 – 5.01 |
| Lower Bear | 100 | Christmas Bird Count | Increasing – 0.94 | Not significant (p = 0.14) | -0.71 – 2.93 |
| Lower Feather | 100 | Breeding Bird Survey | Increasing – 0.12 | Not significant (p = 0.85) | -1.69 – 1.45 |
| Lower Yuba | 100 | Christmas Bird Count | Increasing – 0.49 | Not significant (p =0.60) | -4.00 – 4.46 |
| Middle Fork Feather | 100 | Breeding Bird Survey | Increasing – 0.80 | Not significant (p = 0.47) | -1.68 – 3.07 |
| Middle Yuba | 100 | Breeding Bird Survey | Decreasing – -0.75 | Not significant (p = 0.58) | -2.48 – 1.16 |
| North Fork Feather | N/A | N/A | N/A | N/A | N/A |
| North Yuba | 100 | Breeding Bird Survey | Decreasing – -0.28 | Not significant (p = 0.52) | -2.09 – 1.86 |
| South Yuba | 100 | Breeding Bird Survey | Increasing – 0.95 | Not significant (p = 0.64) | -1.99 – 2.95 |
| Upper Bear | 100 | Breeding Bird Survey | Increasing – 0.13 | Not significant (p = 0.87) | -3.07 – 3.40 |

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# 3.2.2 – Proportion of Watershed as Agricultural/Urban

**GOAL: B.** Protect and enhance native aquatic and terrestrial species, especially sensitive and at-risk species and natural communities

**OBJECTIVE: 2.** Protect and enhance native aquatic communities

**WAF ATTRIBUTE:** Landscape Condition

## What is it?

Land intensively used by humans for agriculture and urban development has direct impacts on the functions of natural ecosystems. The proportions of subwatersheds in use for urban and agricultural activity were combined to produce a measure that reflects the amount of land governed primarily by natural processes and those governed by anthropogenic processes. Regions that are not classified as urban or agriculture may be in use for rural activities that also impact natural ecosystems (Byron and Goldman 1989). To gage the impact of rural human activities, housing unit density is used as a measure of rural disturbance.

## Why is it Important?

Agricultural and urban land uses changes sediment characteristics and loading in adjacent rivers, increases nitrogen loading (Ahearn et al., 2005), modifies in-stream and hyporheic hydrology, delivers pesticides and other chemicals, modifies nutrient cycling and other ecological processes, fragments terrestrial and aquatic habitat, and has caused the loss of productive habitat.

Land that is not currently developed for urban, suburban, rural or agricultural uses provides habitat for native plant and animal communities and provides the opportunity for healthy and natural population dynamics in the community and natural processes. With loss of habitat, the services provided by these communities are reduced and, with fragmentation of the remaining habitat, the impact is even greater. Negative impacts on water quality are correlated with landscape disturbance and, though land-cover is only a general indicator of these impacts, it is regularly updated and made public.

One of the most important ways that developed areas impact streams and watershed processes is through the creation of impervious surface (surfaces that are not pervious or less pervious to water than soil). Recent studies elsewhere in California suggest that the amount and the spatial distribution of impervious area influence hydrologic response (Coleman *et al.,* 2005). The amount of impervious surface development per unit watershed area is one important measure. Past studies have suggested that the range in proportion is from any development at all affecting some aspect of aquatic systems (Booth et al., 2002) to >25% development making a watershed non-supporting to aquatic life (Schueler, 2000). Intermediate development (3-5% impervious cover) has intermediate impacts on aquatic organisms (Stein and Zaleski, 2005).

## What is the target or desired condition?

The desired condition of the landscape, from an ecological health standpoint, is to have no land in use as urban or agriculture. Likewise, any area with no housing units is deemed desirable. These conditions are used as the baseline for the scoring of the regions. This means that an area that has no urban or agricultural landuse and no housing units will have a score of 100. This is not to say that human development activities should be prohibited, but rather to recognize that when development occurs, it invariably brings some level of impact and measuring and tracking that impact is important.

## What can influence or stress condition?

Any sort of development (urban or agricultural) and any sort of human activity on the landscape that disturbs the natural state will impact the overall health of streams in the watershed. Also, any efforts to mitigate existing disturbance will serve to improve the health of the watershed. Inefficient land consumption through low-density development will tend to exacerbate effects to streams. But even dense development can have focused effects on adjacent and nearby streams.

## What did we find out/How are we doing?

The scores for subwatersheds in the foothills and mountains are high due to the low proportion of urban and agricultural land use and the low population density (Table 1 and Figure 1). This status is not likely to change much in the next 10 to 20 years at the subwatershed scale. The scores of subwatersheds in the valley are lower and reflect the high proportion of urban and agricultural land use and the higher population density. These may change in subsequent analyses as cities grow and more areas are farmed on the valley floor. It is anticipated that declines in the indicator will be evident over periods of decades with the lower elevation and flatter watersheds seeing the most rapid declines in the indicator.

### Table 1 — Report Card scores for agricultural/urban development for subwatersheds

| Goal | Measurable Objective | Subwatershed | Score |
|---|---|---|---|
| B. Protect and enhance native aquatic and terrestrial species, especially sensitive and at-risk species and natural communities | 2. Protect and enhance native aquatic communities | NFF | 98 |
| | | EBNFF | 98 |
| | | MFF | 96 |
| | | LF | 67 |
| | | NY | 99 |
| | | MY | 97 |
| | | SY | 96 |
| | | DC | 81 |
| | | LY | 88 |
| | | UB | 88 |
| | | LB | 82 |

## Native Biota

### Agricultural & Urban Development

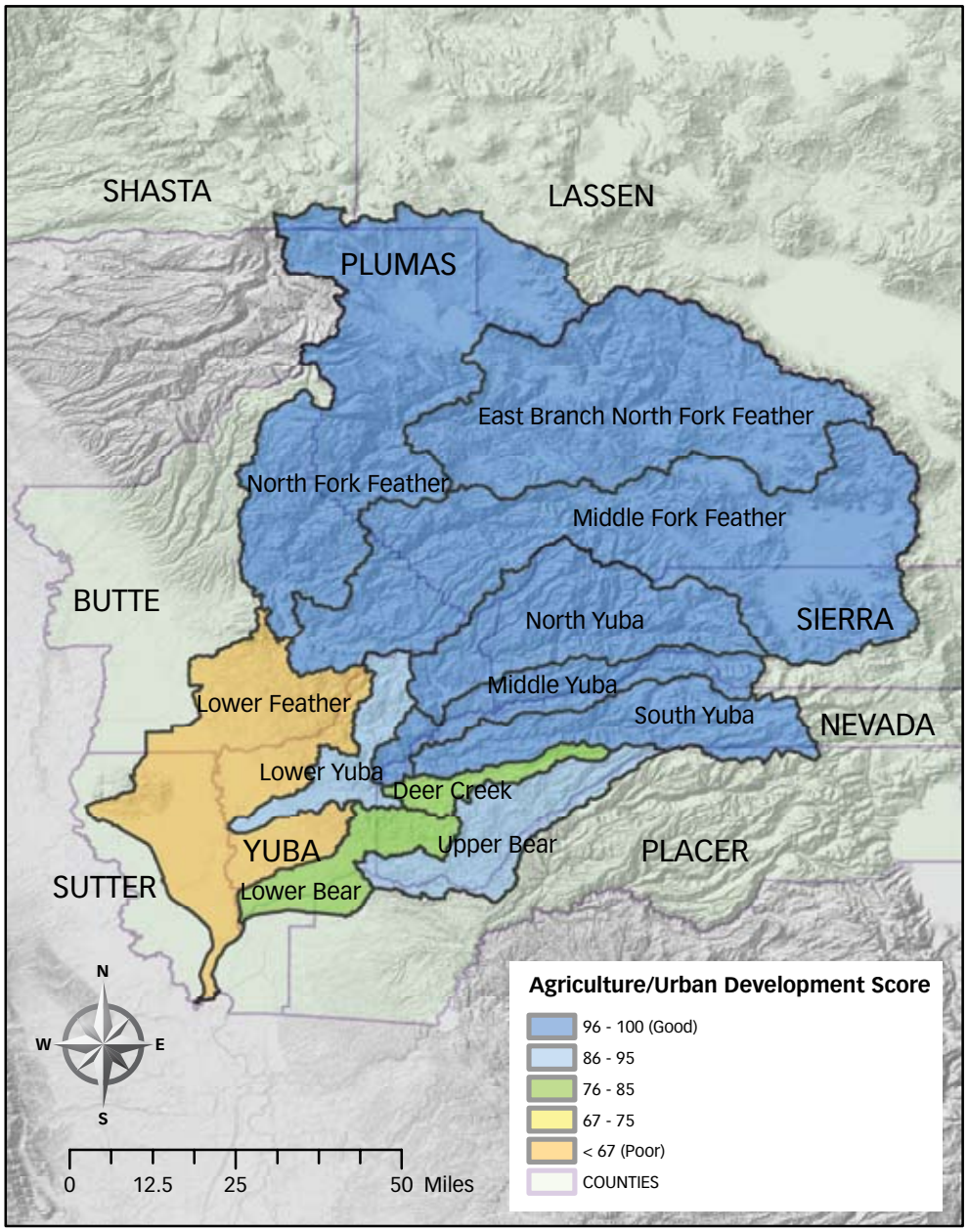



Figure 1 — Agricultural and urban development condition scores for subwatersheds

## Temporal and spatial resolution

Landuse and housing data are spatially continuous for the subwatersheds, meaning that the whole watershed is represented. Temporal resolution for the housing-density data is 10 years as the data are sourced from the US Census. Landuse data are updated on an irregular interval by both the DWR and the CA Dept of Forestry and Fire Protection (CalFire). The nominal time span between landuse datasets is about 6 years.

The relative condition of the subwatersheds must be established over several data collection events. These data can be updated using the decennial census and using the periodic land use assessments provided by both the DWR land use survey and the CalFire Fire and Resource Assessment Program (FRAP) land use survey.

## How sure are we about our findings (Things to keep in mind)

Due to the spatial extent and resolution of the data, confidence in the results is high. However, the Census housing unit density data are from 2000 (to be updated in 2010) and will be more accurate with the inclusion of 2010 Census data in subsequent analyses. One caveat to our finding is that the score is an average of two measures that overlap each other. Proportion of the landscape that is agriculture or urban overlaps with housing unit density in urban areas, essentially double-counting this small part of the total landscape. We used both measures because of the extensive rural development in the watershed.

## Technical Information

### DATA SOURCES:

Landuse data was sourced mainly from DWR (http://www.water.ca.gov/landwateruse/lusrvymain.cfm). The counties used are Placer (1994), Sierra (2002), Yuba (1995), Butte (2004), Plumas (1997). The CalFire data was used to source the Nevada county landuse data (2002, http://frap.cdf.ca.gov/).

The US Census was the source for housing units at the block level and can be accessed as a prepared spatial product from the CalFire FRAP website.

### ANALYSES:

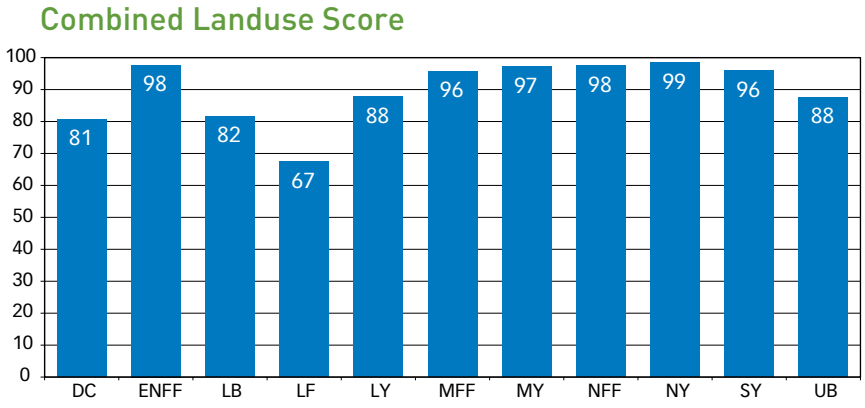
DWR conducts periodic land use surveys of California counties that have substantial agricultural activities. These data were combined into one dataset which comprised portions of Placer, Sierra, Yuba, Butte and Plumas counties. Land use data for Nevada County was sourced from CalFire and processed to a comparable format (converted from raster to vector) and combined with the remaining county data. Landuse categories were combined into three categories including agriculture, urban and other. The proportion of each landuse type was calculated for each planning watershed as well as for the subwatersheds. Housing unit counts from the 2000 Decennial Census were calculated for each planning watershed. These data were used to generate housing unit density (units per acre) for each planning watershed and for each subwatershed (see equations below).

**SCORING:**

The landuse proportion was multiplied by 100 to generate a score between 0 and 100. The housing unit density scores for the subwatersheds were normalized by dividing the calculated density by the maximum observed density (at the planning watershed scale), then multiplying by 100. These two scores were combined by averaging the two values (Figure 2).

- Proportion Ag/Urban Landuse = (Areaurban + Areaagriculture) / Areatotal
- Housing Unit Density = Unit count / Area
- Landuse Score = 100 x (1 – Proportion)
- Housing Score = 100 x (Unit Density / 1.061); 1.061 is the highest observed density (units/acre) at the planning watershed scale.
- Combined score = (Landuse score + Housing score) / 2

**Figure 2 — Combined land-use scores for each subwatershed**



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# 3.2.3 – Benthic Macroinvertebrates Community Structure

**GOAL: B.** Protect and enhance native aquatic and terrestrial species, especially sensitive and at-risk species and natural communities

**OBJECTIVE: 2.** Protect and enhance native aquatic invertebrate communities

**WAF ATTRIBUTE:** Biotic Condition

## What is it?

Freshwater benthic macroinvertebrates (BMI) are small animals without backbones that live on and under submerged rocks, logs, sediment, debris and aquatic plants during some period in their life. BMI include the immature forms of aquatic insects such as mayfly and stonefly nymphs, as well as crustaceans such as crayfish, molluscs such as clams and snails, and aquatic worms.

Many BMI are highly sensitive to changes in their aquatic environment and thus can act as continuous monitors of the condition of the water they live in. Human activities that interfere with or disrupt natural processes in a watershed can have significant impacts on the types and numbers of BMI that live there. We can assess the biological health of a watershed by looking at the types of BMI that either thrive or do not thrive in it. BMI represent an extremely diverse group of aquatic animals, with a wide range of responses to stressors such as organic pollutants, sediments, and toxicants. If only a few types of benthic macroinvertebrates live there, or if the macroinvertebrates present are primarily ones that are insensitive to disturbed systems, there is some kind of problem present.

## Why is it Important?

The best way to assess the ability of a watershed to support living things is to look at those living things. Unlike chemical monitoring, for example, which provides information about water quality at the time of measurement, monitoring of living organisms (biomonitoring) can provide information about past and/or episodic pollution and the cumulative effects of a suite of watershed impacts. BMI represent ideal biomonitors for assessing the overall health of watersheds for a number of reasons:

- They are widespread
- They are easy to collect and identify
- They are relatively sedentary and long-lived, so reflect the longer-term effects of activities within their watershed
- Some species of BMI are highly sensitive to pollution

BMI-related metrics (e.g., taxa richness and diversity, specific taxa pollution sensitivities/ tolerances, etc.) have been used by varied US agencies for many years as "bioindicators" of water quality, providing integrated information on toxic chemical concentrations, DO levels, nutrients, and habitat quality. Beyond their usefulness as bioindicators BMI are themselves an important part of aquatic food chains, especially for fish. Many BMI feed on algae and bacteria, which are on the lower end of the food chain. Some shred and eat leaves and other organic matter that enters the water. Because of their abundance and position as "middlemen" in the aquatic food chain, BMI play a critical role in the natural flow of energy and aquatic nutrients in streams, lakes and wetlands.

## What is the target or desired condition?

The desired condition is to a have rich and diverse community of BMI across the watershed, reflecting maintenance of natural river/stream processes and clean water that allows persistence of particularly sensitive species. A variety of BMI metrics (e.g., diversity, sensitive taxa, functional feeding groups, rare species, etc.) can all be used to provide some assessment of watershed condition and the status of aquatic invertebrate populations. One group of BMI, the "EPT" taxa (Ephemeroptera - mayfly, Plecoptera - stonefly, Trichoptera - caddisfly) are often used because they decrease in richness in the presence of pollution. We selected two key BMI metrics (Total Taxa Richness and EPT Taxa Richness) that are commonly used for assessments of aquatic macroinvertebrate communities and that could also be generated easily using readily available agency monitoring data, and supplemented using information from volunteer groups and university programs that have undertaken BMI sampling in the watershed.

## What can influence or stress condition?

Some BMI taxa require very good water quality, whereas others tolerate a wide range of environmental conditions. Although BMI can move about to some extent and even drift downstream, they generally cannot move quickly to avoid adverse conditions. Deteriorating water and/or habitat quality and pollutants can be expected to kill or at least stress less tolerant BMI taxa and encourage other more tolerant taxa to proliferate. Once BMI are lost from a waterway, they may take years or decades to recover, both because the system is recovering and because they would have to be recruited from elsewhere.

## What did we find out/How are we doing?

In general, most Feather River subwatersheds would seem to currently be in fair condition based on the key BMI metrics that were evaluated across 2004-2008 (Table 1 and Figure 1). Not all subwatersheds had data in 2008, but many had at least some data available between these five years. Average subwatershed condition scores were based on Total Taxa Richness (scoring based on comparison with the most taxa-rich site in the Feather River database) ranged from 30 for the Lower Yuba to 58 for the Middle Yuba (the Lower Yuba score was however based on only 2 samples).

Average scores for EPT Taxa Richness (based on defined target thresholds) ranged from 0 to 100 across the subwatersheds (Table 1). While most subwatersheds had fairly highs scores for the EPT metric Deer Creek, East Branch North Fork Feather and Lower Yuba all had scores of zero. However, Deer Creek values were based only on Level 2 sampling (taxonomic identification at the level of "Family") which would lower its score, and Lower Yuba was based on only two samples. The lower score for East Branch North Fork Feather suggests that further work should be directed there to better determine if this EPT result suggests some current impairment, particularly as our supporting trend analysis indicated a significant decline in Total Taxa Richness for this subwatershed since the mid-1990's, a trend that was also displayed by the Middle Fork Feather. Deer Creek conversely demonstrated a significant positive trend in Total Taxa Richness between 2000 and 2008; this trend is however based on Level 2 sampling only (see *How sure are we about our findings* section).

**Table 1 — Report Card scores for Benthic Macroinvertebrate communities for subwatersheds**

| Goal | Measurable Objective | Subwatershed | Total Taxa Richness Score | EPT Taxa Richness Score | Trend |
|---|---|---|---|---|---|
| B. Protect and enhance native aquatic and terrestrial species, especially sensitive and at-risk species and natural communities | 2) Protect and enhance native aquatic invertebrate communities | NFF | 48 | 93 | ? |
| | | EBNFF | 45 | 0 | ↘ |
| | | MFF | 48 | 47 | ↘ |
| | | LF | n/a | n/a | ? |
| | | NY | 51 | 97 | ? |
| | | MY | 58 | 100 | ? |
| | | SY | 52 | 91 | ? |
| | | DC | 36 | 0 | ↗ |
| | | LY | 30 | 0 | ? |
| | | UB | 44 | 37 | ? |
| | | LB | n/a | n/a | ? |

## Native Biota

### Benthic Macroinvertebrate (BMI) Communities

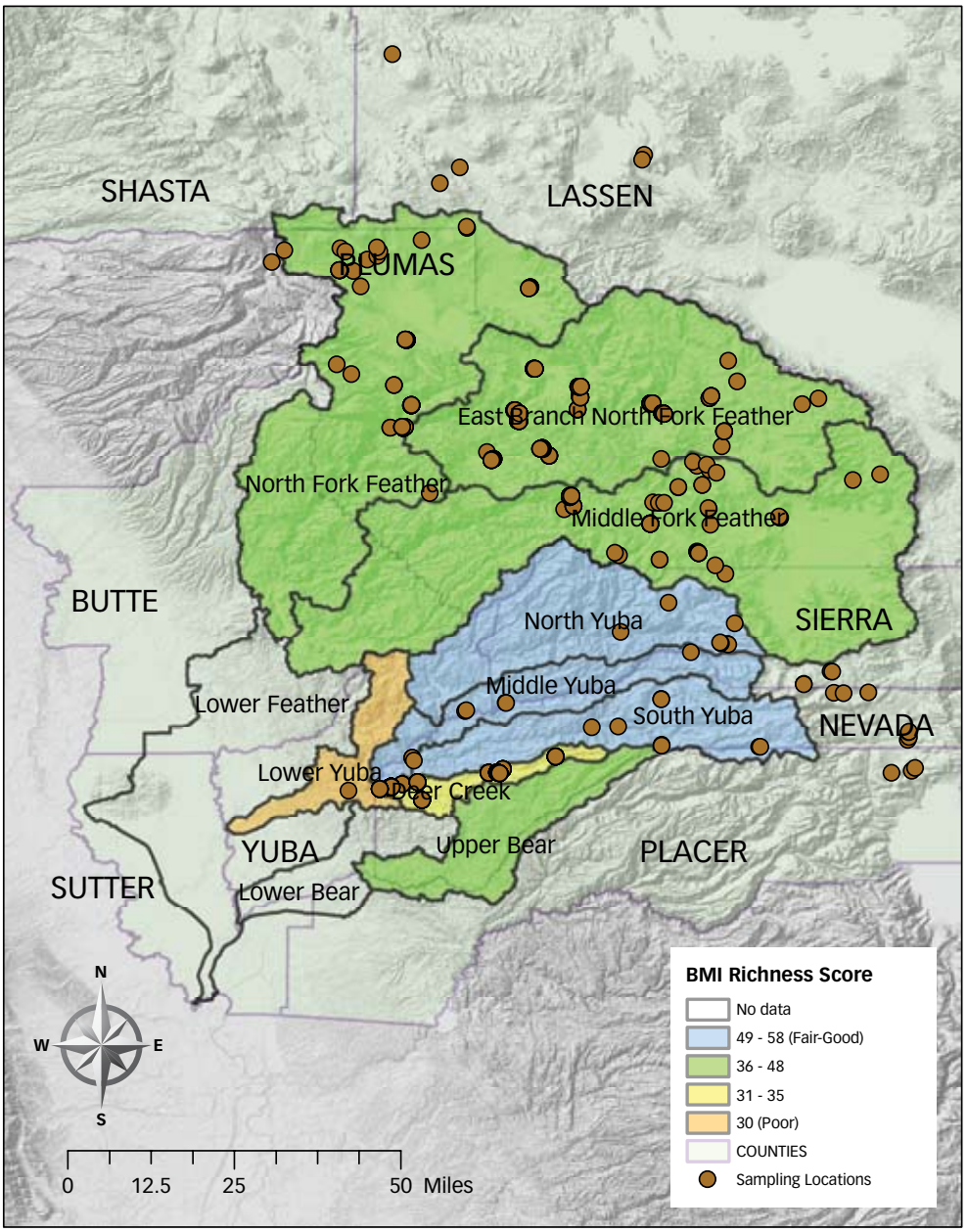



Figure 1 — Subwatershed distribution of Total BMI Taxa richness scores — number of different types of BMI present. Not all sampling locations are represented on the map due to missing spatial coordinates for 2 sites in the Upper Bear and 1 site in the North Yuba.

## Temporal and spatial resolution

Seasonal sampling of benthic macroinvertebrates has occurred at varied sites (Table 2) in the Feather River Watershed as far back as 1995, but early sampling was restricted to the North Fork Feather (which represents the longest time series for the basin). More intensive and widespread sampling has occurred subsequent to 1999, with some level of BMI data available from different monitoring programs for at least nine Feather River subwatersheds (Figure 1).

**Table 2 — Number of samples collected each year for BMI in Feather River subwatersheds since 1995. Note that some of these are replicate samples within a site, and are not necessarily independent sites. Sites represent a mix of Level 2 and Level 3 sampling efforts.**

| Subwatershed | 1995 | 1997 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Deer Creek | 0 | 0 | 0 | 7 | 20 | 22 | 12 | 23 | 24 | 24 | 14 | 25 |
| East Branch NF Feather | 0 | 0 | 70 | 2 | 70 | 0 | 38 | 1 | 0 | 25 | 21 | 0 |
| Lower Yuba | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 |
| MF Feather | 0 | 0 | 21 | 6 | 26 | 0 | 16 | 7 | 2 | 6 | 2 | 0 |
| Middle Yuba | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 2 | 4 | 2 |
| NF Feather | 3 | 3 | 20 | 0 | 20 | 0 | 12 | 2 | 0 | 21 | 6 | 0 |
| North Yuba | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 7 | 1 | 0 |
| South Yuba | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 18 | 6 | 6 | 7 | 4 |
| Upper Bear | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 3 |
| Unknown | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 2 | 18 | 21 | 0 |
| Total | 3 | 3 | 111 | 15 | 136 | 22 | 78 | 57 | 38 | 110 | 82 | 34 |

## How sure are we about our findings?

The data used for this indicator come from a mix of different sampling programs across the Feather River Watershed, some that are agency-based and some that are volunteer-based, with associated "measurement error" uncertainties related to consistency of sampling protocols employed, processing thoroughness and correct identification of BMI taxa (i.e., Level 3 analyses vs. Level 2 analyses — Richards and Rogers 2006). We have attempted to control for this somewhat by using BMI metrics that may be easier to evaluate consistently and do not necessarily require a high level of invertebrate identification expertise (although the value of this information is enhanced with higher levels of taxonomic resolution). In general, however, evaluating the status and trends of BMI can be very challenging and requires consistently sampled and analyzed data over time as macroinvertebrate populations are naturally highly variable both spatially and temporally (seasonally and annually) (USEPA 2006). Our use of a mix of Level 3 and Level 2 sampled sites within our scoring increased both the spatial and temporal extent of our comparative analyses but also increased the uncertainty around the interpretation

of pooled results. We do know that this uncertainty has a directional bias however, as subwatershed evaluations which incorporate Level 2 samples will be biased low (that is they will be conservative estimates, more likely to judge water quality to be poorer).

An additional element of uncertainty for our comparisons relates to our interpretation of the overall sampling frame. For our indicators we have opportunistically mined and pooled BMI data that have been collected by a number of different agencies/groups with possibly different objectives, target populations and sampling frames (e.g., they could have focused on different stream orders, types of streams or times of year). Without specific knowledge of different sample design elements, we have made assumptions about the probability of selecting each site and the appropriate weighting of the observation. As a default for our analyses we have treated each of the BMI sites as though they were a simple random sample from the overall population of streams. This may well be incorrect.

Finally, although BMI community composition is an informative indicator based on the presence of certain types of BMI, the absence of specific types of BMI at specific locations is difficult to interpret. Short-term perturbations may remove sensitive, or most, types of BMI from a location and even after the location has recovered physically and chemically, it may be a long-time before those types return.

**Table 3 — Summary of BMI condition and trend based on Total Taxa and EPT Taxa by subwatershed**

| Subwatershed | Average Taxa Richness | Average EPT Taxa Richness | Report Card Score | | Sampling Effort | Trend |
|---|---|---|---|---|---|---|
| | | | Total Taxa | EPT Taxa | | |
| Deer Creek | 22.0 | 10.7 | 36 | 0 | C | ↗ |
| EB NF Feather | 27.2 | 11.9 | 45 | 0 | B | ↘ |
| Lower Yuba | 18.0 | 11.5 | 30 | 0 | A | ? |
| MF Feather | 29.4 | 15.3 | 48 | 47 | B | ↘ |
| Middle Yuba | 35.1 | 20.9 | 58 | 100 | A | ? |
| NF Feather | 29.5 | 18.5 | 48 | 93 | B | ? |
| North Yuba | 31.2 | 18.8 | 51 | 97 | B | ? |
| South Yuba | 31.7 | 18.4 | 52 | 91 | B | ? |
| Upper Bear | 25.6 | 14.5 | 44 | 37 | B | ? |

As BMI sampling has been inconsistent across the years the subwatershed values for these metrics and derived "report card" scores are the average of the annual estimates from the last 5 years of available data (2004-2008). Sampling effort indicates whether information to derive the score was based on: (A) Level 3 sampling effort only; (B) a mix of Level 3 and Level 2 sampling; or (C) Level 2 sampling effort only. Full statistical summaries for the BMI metrics ( means, 95% C.I., SE, minimum and maximum values for the annual estimates between 2004-2008, as well as for 1999-2004, are presented in the Analysis section - Tables 4 and 5).

## Technical Information

### DATA SOURCES

Data for our BMI community metrics were compiled from past sampling that has been undertaken within varied Feather River subwatersheds by the USFS, DWR, FRCRM, Friends of Deer Creek, UC Davis Center for Watershed Sciences, Wolf Creek Community Alliance, and SYRCL. Data from specific sites were assigned subwatershed identifiers, permitting aggregation of information to that scale.

### ANALYSES

BMI data are available from a variety of groups that have undertaken aquatic sampling in streams throughout the Feather River Watershed. Some of this sampling has been led by government agencies that have undertaken rigorous Level 3 analysis of BMI samples (Harrington 2003, Richards and Rogers 2006), with identification to the taxonomic level of "Genus/species". Other sampling in the Feather River Watershed has been undertaken by citizens groups and university projects which have generally undertaken only Level 2 analyses, with taxonomic identification at the level of "Family". Given differences in how groups have analyzed BMI data historically we sought to capture some simple yet informative BMI metrics that could provide information about the status of BMI communities across the watershed using information from both Level 3 and Level 2 sampling. Data from multiple sources were therefore pooled as possible and summarized for our scoring using two standard metrics of BMI community condition:

1) Total Taxa Richness is the total number of macroinvertebrate taxa (Family/Genera), insect and non-insects at a sampling site. Total Taxa Richness provides an index of the general health of the BMI community and is expected to be higher in subwatersheds with better habitat diversity, suitability, and water quality (Plafkin et al., 1989). Absent a defined California standard for desired BMI total taxa richness in aquatic systems, or alternatively readily available information from a pristine (reference) watershed for comparison, we instead used the highest Total Taxa Richness value obtained at any of the historical sampling sites as a "good" target and gave this the highest score (100); a Total Taxa Richness value of zero was given the poorest score (0). We then used an interpolated straight line function between this range of values to score the average Total Taxa Richness found across the subwatersheds.

To take full advantage of the range of BMI data available from all sampling undertaken across the Feather River Watershed we combined both Level 3 and Level 2 sampling efforts to generate subwatershed averages for Total Taxa Richness and compared this to our defined target (which was based on the best Level 3 sampled site) for the Feather River Watershed. We recognize, however, that this is a biased low interpretation of the Level 2 sites (i.e., more likely to conclude that water quality is poorer in relation to the defined target criteria). Observation of 12 families using the Level 2 sampling implies a minimum of 12 genera, but possibly more. However, without Level 3 sampling we cannot be sure how many more. Hence we use the most conservative estimate and assume only

12 genera were observed, essentially penalizing lower quality observations. We caveated the relative quality of the sampling information available to inform taxa status. For each Feather River subwatershed we indicated if the level of effort at BMI sites across the years was: A) all Level 3 sampling, B) a mix of Level 3 and Level 2 sampling, or C) all Level 2 sampling.

2) EPT Taxa Richness is the total number of EPT taxa (Family and Genera) found within the insect orders Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies). These are insect orders considered particularly sensitive to pollution and habitat disturbance so that the presence and abundance of EPT taxa provides an indication of overall water quality. Sites at which EPT taxa are more prevalent are considered to have cleaner water and provide better habitat conditions. EPT Richness is one of the most commonly used biometrics used to describe macroinvertebrate community structure and to assess possible stream degradation (Resh and Jackson 1993). Although EPT Taxa Richness would be expected to vary regionally, Harrington et al. (1999) suggest a standard (based on Level 3 sampling) that could be used for California streams, where EPT Taxa Richness > 19 indicates good water quality, 12-19 indicates fair water quality, and < 12 indicates poor water quality. We have adopted this standard as a target for desired BMI condition where subwatersheds with an average EPT Taxa Richness of < 12 were scored as 0, those with > 19 were scored as 100 and those with EPT values between 12 and 19 were scored as an extrapolated straight line function between 12 and 19. To take full advantage of the range of BMI data available from sampling undertaken across the Feather River Watershed (including Level 2 sampling efforts) we used the defined EPT threshold criteria consistently across the Feather River Watershed but combined all Level 2 and Level 3 sampling efforts to generate subwatershed averages. Recognizing that the data relating to EPT status would be poorer at Level 2 sites relative to Level 3 sites we used the same categorizations of historical sampling effort in each subwatershed as described for the Total Taxa Richness metric.

For each of our BMI metrics data from all individual sampling sites were aggregated to produce an average annual estimate for each subwatershed in which sampling had occurred. Where there was more than one record per site per year, these were first averaged. For Total Family Richness estimates and confidence intervals were compared to the highest value reported at any site within the historical dataset (61 observed taxa, Sept. 20, Canyon Creek, South Yuba), for EPT Taxa Richness estimates and confidence intervals were compared to a defined threshold of water quality condition. Estimates and associated confidence intervals were transformed to a 0-100 scale. The 95% confidence interval for the estimate is presented, along with the minimum, maximum, and number of observations (n, Table 3). Depending on how sites were selected, it may be better in

the future to first average the results by stream and then average the streams within a subwatershed, but at this point too little replicate information is available per stream to make this a worthwhile approach to consider.

Summaries of statistics for BMI metrics and derived scores are presented for Total Taxa Richness and ETP Taxa Richness in Table 4 and Table 5 respectively. While our assessments determined that there was large site-to-site variability in BMI metrics, the annual means for a subwatershed did not vary as much.

**Table 4 — Average Total Taxa Richness values and derived scores in each of four subwatersheds in two time periods of comparison (1999-2003 vs. 2004-2008)**

| Subwatershed | Mean (Total Taxa) | 95% C.I. | N (years) | Minimum value | Maximum value | Score (mean) | Score (95% C.I.) |
|---|---|---|---|---|---|---|---|
| Deer Creek (1999-2003) | 19.6 | 2.4 | 4 | 17.7 | 21.3 | 32 | 3.9 |
| Deer Creek (2004-2008) | 22.0 | 1.5 | 5 | 20.1 | 23.0 | 36 | 2.4 |
| EB NF Feather (1999-2003) | 32.0 | 0.7 | 4 | 31.4 | 32.5 | 53 | 1.2 |
| EB NF Feather (2004-2008) | 27.2 | 10.4 | 3 | 24.1 | 32.0 | 45 | 17.1 |
| Lower Yuba (1999-2003) | NA | NA | NA | NA | NA | NA | NA |
| Lower Yuba (2004-2008) | 18.0 | 50.8 | 2 | 14.0 | 22.0 | 30 | 29.5 |
| MF Feather (1999-2003) | 36.4 | 8.3 | 4 | 28.6 | 39.4 | 60 | 13.6 |
| MF Feather (2004-2008) | 29.4 | 20.6 | 4 | 17.2 | 45.0 | 48 | 33.7 |
| Middle Yuba (1999-2003) | NA | NA | NA | NA | NA | NA | NA |
| Middle Yuba (2004-2008) | 35.2 | 1.8 | 5 | 32.7 | 36.3 | 58 | 2.9 |
| NF Feather (1999-2003) | 38.3 | 6.4 | 3 | 35.3 | 40.3 | 63 | 10.6 |
| NF Feather (2004-2008) | 31.2 | 22.8 | 3 | 19.5 | 37.5 | 48 | 37.3 |
| North Yuba (1999-2003) | NA | NA | NA | NA | NA | NA | NA |
| North Yuba (2004-2008) | 31.2 | 38.4 | 3 | 20.7 | 49.0 | 51 | 51.2 |
| South Yuba (1999-2003) | NA | NA | NA | NA | NA | NA | NA |
| South Yuba (2004-2008) | 31.7 | 4.6 | 5 | 28.0 | 37.3 | 52 | 7.5 |
| Upper Bear (1999-2003) | NA | NA | NA | NA | NA | NA | NA |
| Upper Bear (2004-2008) | 25.6 | 76.0 | 2 | 19.7 | 31.6 | 42 | 42.0 |

We used these five year blocks to represent reasonable time intervals for BMI reporting purposes. Subwatersheds with NA indicated did not have data collected within the particular time block. Formal trend analysis was undertaken for Total Taxa Richness for a subset of the subwatersheds that had greater than five years of data across the years (not necessarily consecutive, see Trends Analysis section). "95% C.I." refers to 95% confidence intervals.

**Table 5 — EPT Taxa Richness values and derived scores in each of four subwatersheds in two time periods of comparison (1999-2003 vs. 2004-2008)**

| Subwatershed | Mean (EPT Taxa) | 95% C.I. | N (years) | Minimum value | Maximum value | Score (mean) | Score (Lower 95% C.I.) | Score (Upper 95% C.I.) |
|---|---|---|---|---|---|---|---|---|
| Deer Creek (1999-2003) | 10.2 | 1.0 | 4 | 9.6 | 11 | 0 | 0 | 0 |
| Deer Creek (2004-2008) | 10.7 | 0.6 | 5 | 10.3 | 11.5 | 0 | 0 | 0 |
| EB NF Feather (1999-2003) | 15.6 | 5.7 | 4 | 11.0 | 19.5 | 51 | 0 | 100 |
| EB NF Feather (2004-2008) | 11.9 | 4.2 | 3 | 10.0 | 13.2 | 0 | 0 | 59 |
| Lower Yuba (1999-2003) | NA | NA | NA | NA | NA | NA | NA | NA |
| Lower Yuba (2004-2008) | 11.5 | 31.8 | 2 | 9.0 | 14.0 | 0 | 0 | 100 |
| MF Feather (1999-2003) | 21.3 | 4.3 | 4 | 17.3 | 23.0 | 100 | 72 | 100 |
| MF Feather (2004-2008) | 15.3 | 15.3 | 4 | 4.5 | 25.0 | 47 | 0 | 100 |
| Middle Yuba (1999-2003) | NA | NA | NA | NA | NA | NA | NA | NA |
| Middle Yuba (2004-2008) | 20.9 | 3.7 | 5 | 17.0 | 24.0 | 100 | 74 | 100 |
| NF Feather (1999-2003) | 21.8 | 6.5 | 3 | 18.8 | 23.5 | 100 | 47 | 100 |
| NF Feather (2004-2008) | 18.5 | 19.3 | 3 | 11.0 | 26.5 | 93 | 0 | 100 |
| North Yuba (1999-2003) | NA | NA | NA | NA | NA | NA | NA | NA |
| North Yuba (2004-2008) | 18.8 | 16.1 | 3 | 13.4 | 26.0 | 97 | 0 | 100 |
| South Yuba (1999-2003) | NA | NA | NA | NA | NA | NA | NA | NA |
| South Yuba (2004-2008) | 18.4 | 3.4 | 5 | 16.8 | 23.3 | 91 | 42 | 100 |
| Upper Bear (1999-2003) | NA | NA | NA | NA | NA | NA | NA | NA |
| Upper Bear (2004-2008) | 15.0 | 41.3 | 4 | 12.3 | 18.0 | 43 | 0 | 100 |

## Trend Analysis

We attempted to fit a trend line to any dataset with at least five years of data (these did not have to be consecutive). This was done using simple linear regression with "year" as the independent variable and "BMI metric" as the dependent variable. We then tested the hypothesis that the slope of the line was equal to zero (i.e., no trend). Six of the subwatersheds had sufficient data to fit a trend line for the BMI metrics. Three of these subwatersheds displayed significant trends for Total Taxa Richness (Table 5), one of these (Deer Creek) had a positive (upward) trend (Figure 2C), two of these (East Branch North Fork Feather, and North Fork Feather) displayed negative (downward) trends (Figure 2A). For the other subwatersheds there was no evidence of a significant directional (i.e., non-zero) trend. None of the six subwatersheds displayed any significant trends for EPT Taxa Richness (Table 6).

Table 6 — Linear regression estimates for Total Taxa Richness in the six Feather River subwatersheds with at least five years of BMI data. Significant regressions are indicated by a bold asterisk.

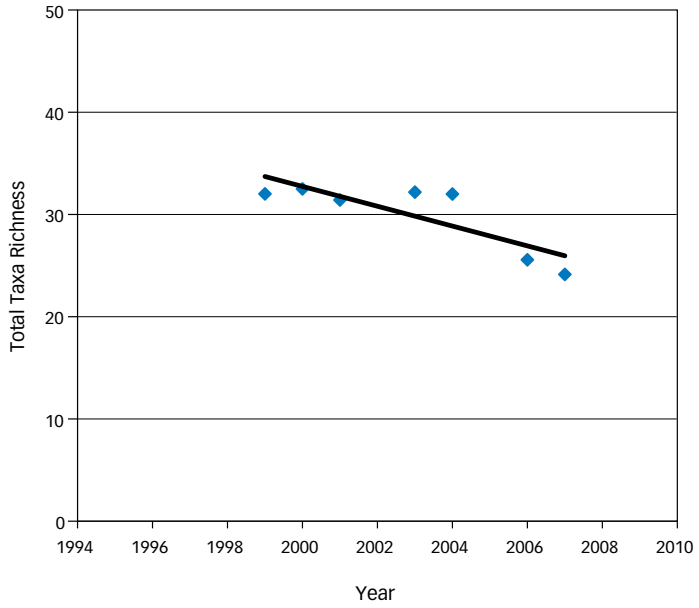
| | Deer Creek | EB North Fork Feather | Middle Fork Feather | Middle Yuba | North Fork Feather | South Yuba |
|---|---|---|---|---|---|---|
| Estimate | 0.536 | -0.969 | -1.408 | 0.658 | -1.462 | 1.445 |
| SE | 0.134 | 0.293 | 1.264 | 0.362 | 0.506 | 1.050 |
| T value | 3.989 | -3.305 | -1.114 | 1.821 | -2.888 | 1.376 |
| P value | **0.005*** | **0.021*** | 0.308 | 0.166 | **0.028*** | 0.262 |
| Trend | **Positive** | **Negative** | No indication of trend | No indication of trend | **Negative** | No indication of trend |

Table 7 — Linear regression estimates for EPT Taxa Richness in the six Feather River subwatersheds with at least five years of BMI data. No significant trends were evident.

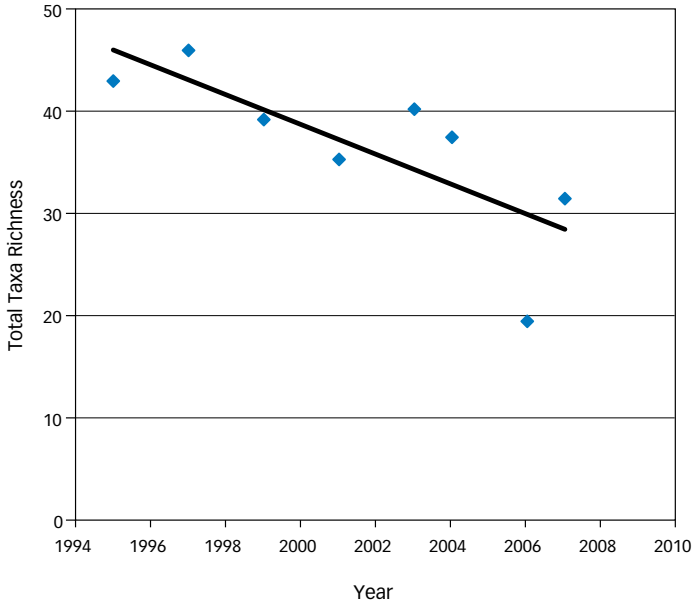
| | Deer Creek | EB North Fork Feather | Middle Fork Feather | Middle Yuba | North Fork Feather | South Yuba |
|---|---|---|---|---|---|---|
| Estimate | 0.077 | -0.492 | -1.406 | -0.133 | -0.551 | 0.75 |
| SE | 0.076 | 0.443 | 0.85 | 1.091 | 0.407 | 0.916 |
| T value | 1.01 | -1.109 | -1.654 | -0.122 | -1.354 | 0.819 |
| P value | 0.346 | 0.318 | 0.149 | 0.91 | 0.225 | 0.473 |
| Trend | No indication of trend | No indication of trend | No indication of trend | No indication of trend | No indication of trend | No indication of trend |

Figure 2 — Annual observations and significant linear trend lines for (A) East Branch North Fork Feather and (B) North Fork Feather (negative trends) and Deer Creek (positive trend)

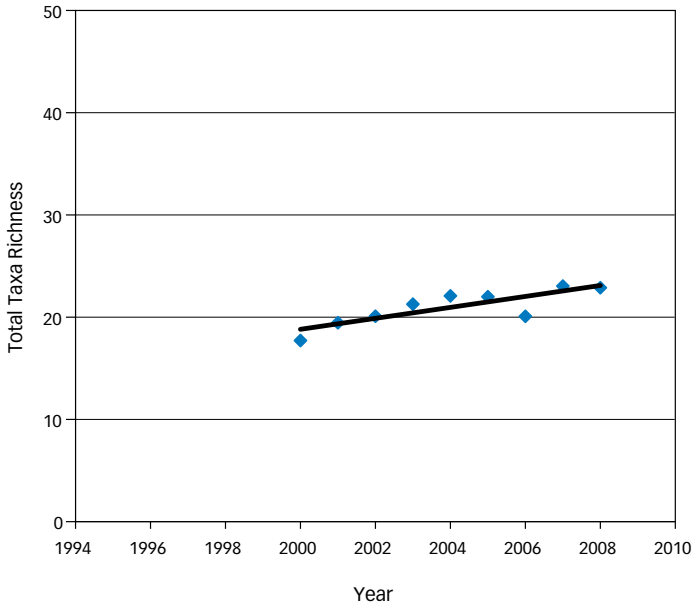
**A.** East Branch North Fork Feather



**B.** North Fork Feather




**C.** Deer Creek



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# 3.2.4 – Fish Community Diversity

**GOAL: B.** Protect and enhance native aquatic and terrestrial species, especially sensitive and at-risk species and natural communities

**OBJECTIVE: 3.** Protect and enhance native fish populations

**WAF ATTRIBUTE:** Biotic condition

## What is it?

The abundance of individual fish and the diversity of fish species present can tell a lot about the conditions in waterways and watersheds. Two metrics of fish community condition were used, based on indicators used by the South East Queensland Ecosystem Health Monitoring Program (Australia, http://www.healthywaterways.org/ehmphome.aspx). These metrics are:

- Percentage of native species expected (PONSE). This is a measure of observed number of fish species (species richness) compared to expected number of species based on expert knowledge and observations in other regions of the river. The primary source for expected species was the Sierra Nevada Ecosystem Project (SNEP), with adjustments based on survey effectiveness (see below under "Data manipulation").
- Proportion native species (PNS). This is the percentage of native species of total fish caught or observed (not species number). This metric assesses what proportion of the community is composed of native species. Native/exotic identity was determined using information from the SNEP report.

In addition to these fish community composition measures, local Chinook salmon population assessment was used for the Lower Feather and Lower Yuba regions. Population is scaled from 0 to 100 by comparing recent six-year geometric mean of abundance to DFG targets for population restoration (Table 1).

## Why is it Important?

Fish are a common and familiar component of freshwater environments, and fish communities reflect a range of natural and human-induced disturbances through changes in abundance and species composition. Ecological assessments based on fish community structure have the advantage over more traditional physical and chemical indices (e.g. conductivity, turbidity, nutrients) in that fish provide an integrated

measure of stream condition due to the mobility, relatively long-life, and high trophic level of the animals involved (SEQ EHMP methods). Low native species presence can be an indicator of high disturbance levels, which disrupt natural community balance and exclude stress-intolerant species and/or non-generalists. Presence of exotic species is also a good indicator of poor ecological health (Meador et al. 2003). Many invasive species are highly competitive generalists, and can exclude local species. In addition, exotics may be able to establish due to altered habitat processes (i.e. higher water temperatures, changes in mean water level) or through direct human introduction (i.e. stocking, discard of aquarium fish).

Native salmonid species are of great ecological, economic, and cultural importance to local communities. They also serve as strong indicators of habitat quality and integrity in river systems, particularly with regard to water temperature, sediment load, and barriers to passage. The Central Valley spring-run Chinook salmon in particular is listed as a threatened species under the ESA, giving them a high priority for restoration. The main threats to the remaining populations are loss and degradation of habitat. In particular, rising water temperature combined with loss of upstream spawning and rearing habitats blocked by dams has diminished available juvenile summer habitat greatly. Within the Feather River Watershed, only two populations persist. One, in the Feather River itself, is completely dependent on the Feather River FIsh Hatchery to maintain itself. The other, in the Yuba River, is of unknown status.

## What is the target or desired condition?

Ideally, native fish communities will be fully intact and contain no invasive or introduced species. A PONSE and PNS of 100 indicate that every expected species was found in the area, and no exotic species were caught.

For Chinook populations, the target condition is taken from DFG's Central Valley targets (DFG 1988). Because the targets are given for the Sacramento Basin as a whole, the five-year geometric mean proportion of total population for the subwatersheds was used to determine a specific restoration target for the Feather and Yuba populations. The target for population for each of the Feather and Yuba was based on the proportion of the total observed returning salmon to the Sacramento River that returned to each of these rivers.

**Table 1 — Target Chinook populations for Feather and Yuba Rivers**

| Sacramento | | Feather River | | Yuba River | |
|---|---|---|---|---|---|
| *Chinook Run* | *Target Population* | *Proportion of Returning Sacramento River Salmon* | *Target Population* | *Proportion of Returning Sacramento River Salmon* | *Target Population* |
| Fall | 450,000 | 0.237 | 106,659 | 0.044 | 19,726 |
| Spring | 23,300 | 0.206 | 4,796 | | |

## What can influence or stress condition?

Primary stressors for native fish communities are habitat degradation, high fine-sediment load, increasing maximum water temperatures, and introduced species. Salmonids are negatively impacted by increased maximum water temperatures, sediment loads, habitat loss, barriers to passage, and predation by black bass and striped bass on their young.

## What did we find out/How are we doing?

Overall scores for all subwatersheds based on fish community composition and abundance of salmon in the lower watershed are given in Table 2.

### *Fish Community Composition*

Survey information was limited, with only a few surveys and years per subwatershed. Most surveys were performed during only a few months per year, so annual aggregation and trend analysis was most appropriate. Although not all surveys were conducted identically, with combinations of electrofishing, snorkeling, and passive monitoring, results could be compared once converted into PONSE and PNS values. No data were available in the Lower Bear subwatershed. Score calculation was straight-forward, with 100 indicating all expected native species detected and no exotic species caught (with 0 indicating the reverse). Current status for each subwatershed was calculated by averaging across all sites for their most recent years. The PONSE and PNS are given in Tables 3 and 4, respectively. The majority of native species caught were Chinook salmon (in the Lower Feather and Lower Yuba) and Rainbow trout (in all subwatersheds).

**Table 2 — Report Card scores for fish community condition for subwatersheds**

| Goal | Measurable Objective | Subwatershed | Score |
|---|---|---|---|
| B. Protect and enhance native aquatic and terrestrial species, especially sensitive and at-risk species and natural communities | 2) Protect and enhance native fish communities. | NFF | 47 |
| | | EBNFF | 64 |
| | | MFF | 63 |
| | | LF | 55 |
| | | NY | 47 |
| | | MY | 51 |
| | | SY | 38 |
| | | DC | 23 |
| | | LY | 48 |
| | | UB | 51 |
| | | LB | n/a |

## Native Biota

### Fish Community Condition

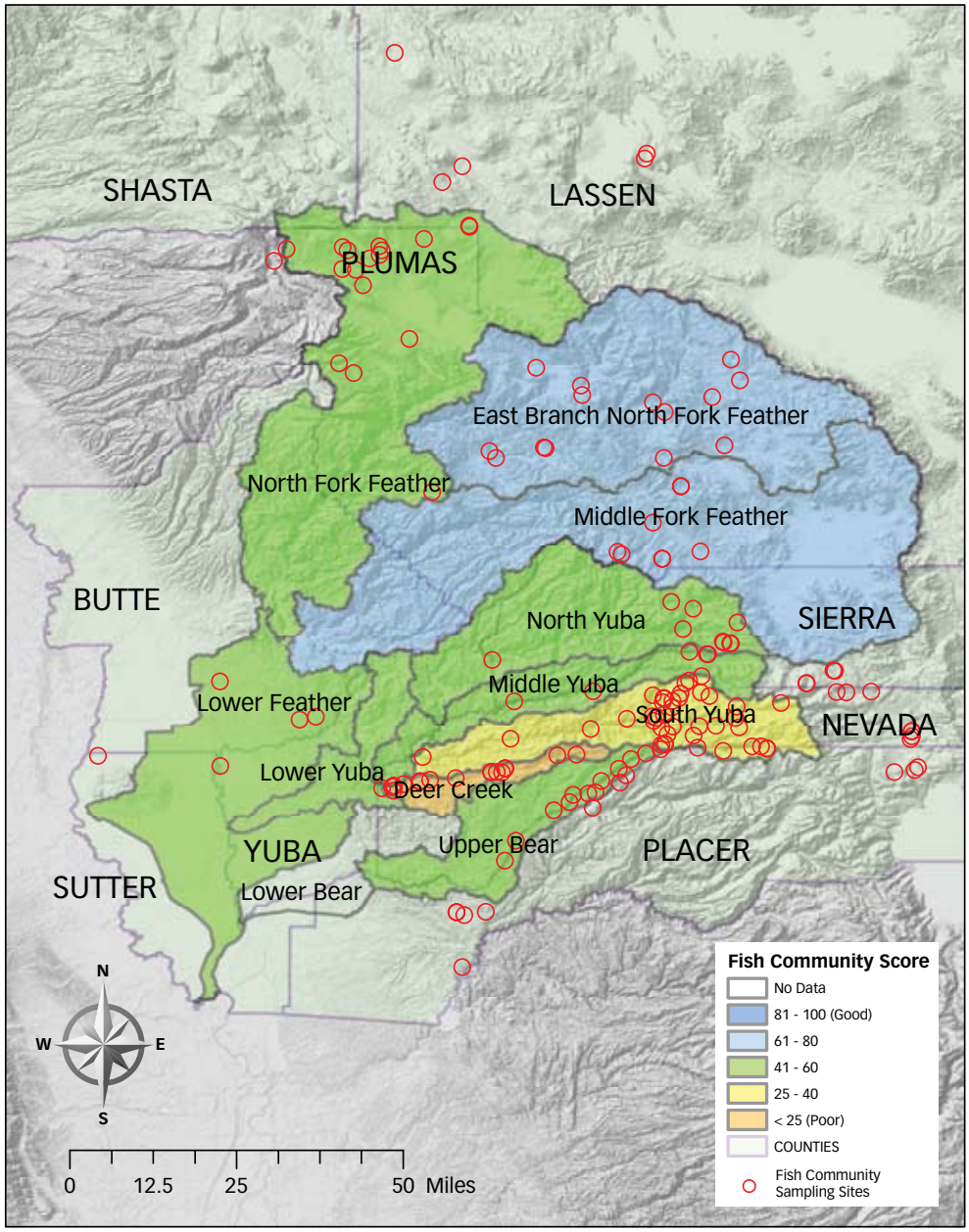



Figure 1 — Fish community condition scores and community sampling sites across subwatersheds. Salmon monitoring occurs on the Lower Feather and Yuba rivers and sites are not shown.

**Table 3 — Percent of native species expected (PONSE) values for subwatersheds. 95% C.I. refers to 95% confidence intervals.**

| Region | Name | PONSE | Minimum | Maximum | N | 95% C.I. |
|---|---|---|---|---|---|---|
| DC | Deer Creek | 0.182 | 0.000 | 0.600 | 11 | +/-0.11 |
| EBNFF | East Branch North Fork Feather | 0.444 | 0.000 | 0.667 | 9 | +/-0.12 |
| LB | Lower Bear | NA | NA | NA | 0 | NA |
| LF | Lower Feather | 0.542 | 0.000 | 1.000 | 6 | +/-0.31 |
| LY | Lower Yuba | 0.600 | 0.200 | 0.800 | 3 | +/-0.39 |
| MFF | Middle Fork Feather | 0.417 | 0.167 | 0.667 | 2 | +/-0.49 |
| MY | Middle Yuba | 0.267 | 0.167 | 0.333 | 5 | +/-0.08 |
| NFF | North Fork Feather | 0.500 | 0.500 | 0.500 | 2 | NA |
| NY | North Yuba | 0.208 | 0.000 | 0.500 | 4 | +/-0.21 |
| SY | South Yuba | 0.175 | 0.000 | 0.500 | 38 | +/-0.05 |
| UB | Upper Bear | 0.250 | 0.000 | 0.500 | 12 | +/-0.09 |

**Table 4 — Proportion native species (PNS) values for subwatersheds. 95% C.I. refers to 95% confidence intervals.**

| Region | Name | PNS | Minimum | Maximum | N | 95% C.I. |
|---|---|---|---|---|---|---|
| DC | Deer Creek | 0.281 | 0.000 | 0.818 | 11 | +/-0.16 |
| EBNFF | East Branch North Fork Feather | 0.826 | 0.000 | 1.000 | 9 | +/-0.21 |
| LB | Lower Bear | NA | NA | NA | 0 | NA |
| LF | Lower Feather | 0.999 | 0.998 | 1.000 | 6 | +/-0.00 |
| LY | Lower Yuba | 0.758 | 0.273 | 1.000 | 3 | +/-0.48 |
| MFF | Middle Fork Feather | 0.847 | 0.694 | 1.000 | 2 | +/-0.30 |
| MY | Middle Yuba | 0.758 | 0.214 | 1.000 | 5 | +/-0.29 |
| NFF | North Fork Feather | 0.437 | 0.144 | 0.731 | 2 | +/-0.58 |
| NY | North Yuba | 0.730 | 0.000 | 0.999 | 4 | +/-0.48 |
| SY | South Yuba | 0.580 | 0.000 | 1.000 | 38 | +/-0.13 |
| UB | Upper Bear | 0.765 | 0.000 | 1.000 | 12 | +/-0.21 |

A Regional-Kendall trends analysis (see section 4.3) was performed on PONSE data from each subwatershed, as well as the overall region. Results are shown in Tables 5 and 6; no significant trends were found.

**Table 5 — Regional-Kendall trend analysis of PONSE values for subwatersheds. "Tau-b" is a Regional-Kendall test statistic.**

| Region | Tau-b | Significant? | p | Slope Magnitude |
|---|---|---|---|---|
| DC | -0.375 | No | 0.480 | 0.000 |
| EBNFF | 0.143 | No | 0.706 | 0.000 |
| LB | Insufficient data | | | |
| LF | 0.282 | No | 0.126 | 0.000 |
| LY | 0.000 | No | 0.712 | 0.000 |
| MFF | Insufficient data | | | |
| MY | -0.250 | No | 0.617 | 0.000 |
| NFF | Insufficient data | | | |
| NY | 0.000 | No | 0.564 | 0.000 |
| SY | 0.000 | No | 0.773 | 0.000 |
| UB | 0.125 | No | 0.724 | 0.000 |

**Table 6 — Regional-Kendall trend analysis of PNS values for subwatersheds. "Tau-b" is a Regional-Kendall test statistic.**

| Region | Tau-b | Significant? | p | Slope Magnitude |
|---|---|---|---|---|
| DC | -0.625 | No | 0.157 | -0.175 |
| EBNFF | -0.429 | No | 0.450 | -0.014 |
| LB | Insufficient data | | | |
| LF | 0.054 | No | 0.810 | 0.000 |
| LY | 0.000 | No | 0.712 | 0.000 |
| MFF | Insufficient data | | | |
| MY | 0.000 | No | 0.617 | 0.000 |
| NFF | Insufficient data | | | |
| NY | 0.333 | No | 0.564 | 0.000 |
| SY | 0.000 | No | 0.773 | 0.000 |
| UB | 0.125 | No | 0.724 | 0.011 |

### *Chinook Salmon Population*

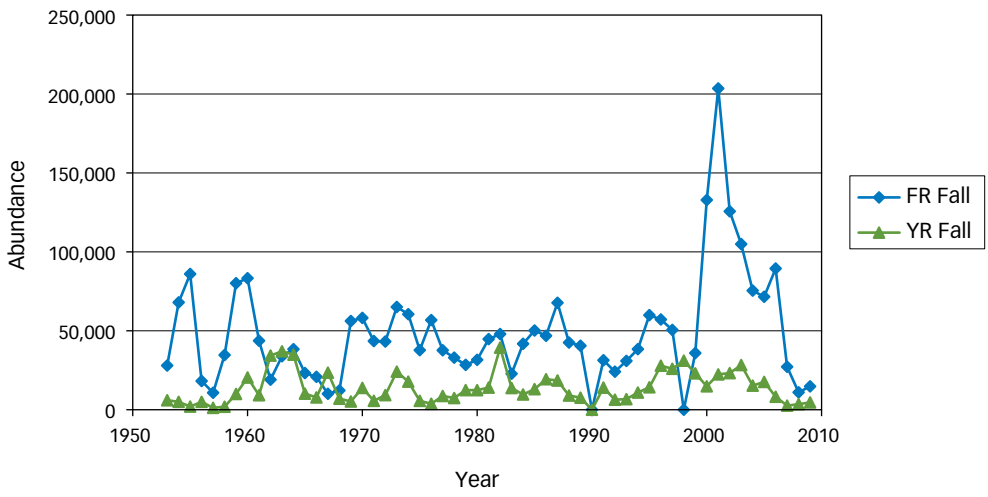
Chinook populations were analyzed in the Lower Feather and Lower Yuba subwatersheds. Although salmon spawn in the Lower Bear River, no regular monitoring of spawning is conducted there. Annual population sizes for the fall- and spring-run Chinook in both rivers are shown in Figures 2a and b. Current condition was calculated as described above, and the scores are given in Table 7. Note that the Feather River fall-run is composed of about 20% hatchery fish, whereas the spring-run is entirely maintained by

hatchery fish. Confidence in these scores is slightly lower, because the data for the most recent years (2006-2009) are considered preliminary. However, these numbers are usually only adjusted slightly so all conclusions should be valid.

Trends were calculated using a Mann-Kendall analysis, and results are given in Table 8. Overall conditions are shown in Table 1, with salmonid scores averaged with the Lower Feather and Lower Yuba fish community scores. Note that the only positive trend was for the spring-run of Lower Feather Chinook. This is despite very low numbers in 2008-2009. The spring-run is an endangered population. Both Feather River populations had a spike in abundance around 2001-2003, and have diminished since. It is unclear whether this is natural variation or due to anthropogenic factors.

**Figure 2 — Chinook fall-run (2A) and spring-run (2B) populations**

**A.**




**B.**

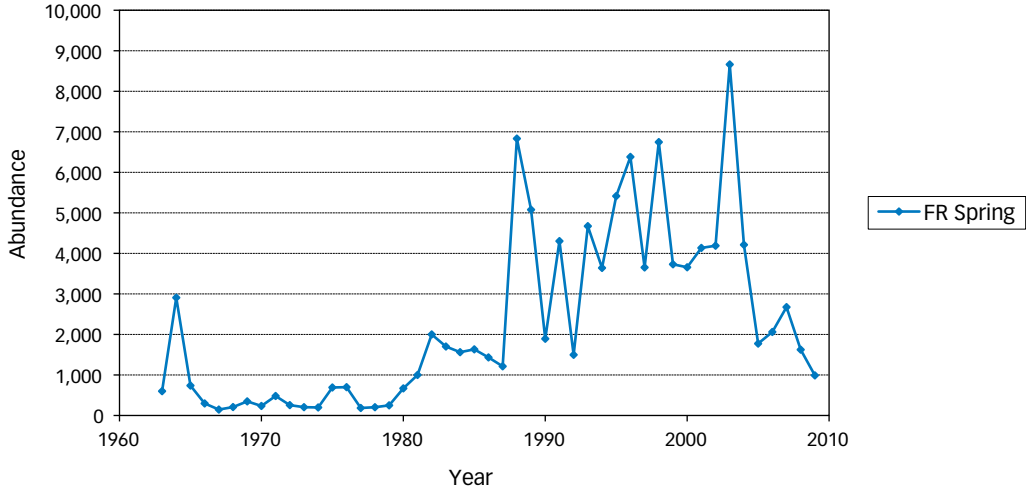


Table 7 — Current state assessment for Chinook populations compared to targets for the populations. 95% C.I. refers to 95% confidence intervals.

| Population | 5-yr Geometric Mean | 5-yr Minimum | 5-yr Maximum | 95% C.I. | | % Hatchery | Target | Score |
|---|---|---|---|---|---|---|---|---|
| | | | | Lower | Upper | | | |
| FR Fall | 30,949 | 11,021 | 89,464 | 13,701 | 69,911 | 31.3% | 106,659 | 29.02 |
| FR Spring | 1,735 | 989 | 2,674 | 1,258 | 2,392 | 100% | 4,796 | 36.17 |
| YR Fall | 5,724 | 2,604 | 17,630 | 2,944 | 11,129 | 0% | 19,726 | 29.02 |

Table 8 — Trend analysis for Chinook populations over last 40 years. "Tau-b" is a Mann-Kendall test statistic.

| Population | Tau-b | Significant? | p | Slope Magnitude |
|---|---|---|---|---|
| FR Fall | 0.137 | No | 0.1425 | 381.6 |
| FR Spring | 0.480 | Yes | <0.0001 | 82.6 |
| YR Fall | 0.171 | No | 0.0641 | 132.4 |

Table 9 — Overall scores and trends for subwatersheds. This score is a combination of scores from the fish community metrics and salmon population estimates. "n.s" means that the trend was not significant. "n/a" means that data were not available.

| Region | Overall Score | Trend |
|---|---|---|
| DC | 23.16 | n.s. |
| EBNFF | 63.50 | n.s. |
| LB | NA | n/a |
| LF | 54.81 | n.s./pos. |
| LY | 48.45 | n.s. |
| MFF | 63.18 | n.s. |
| MY | 51.21 | n.s. |
| NFF | 46.87 | n.s. |
| NY | 46.92 | n.s. |
| SY | 37.76 | n.s. |
| UB | 50.73 | n.s. |

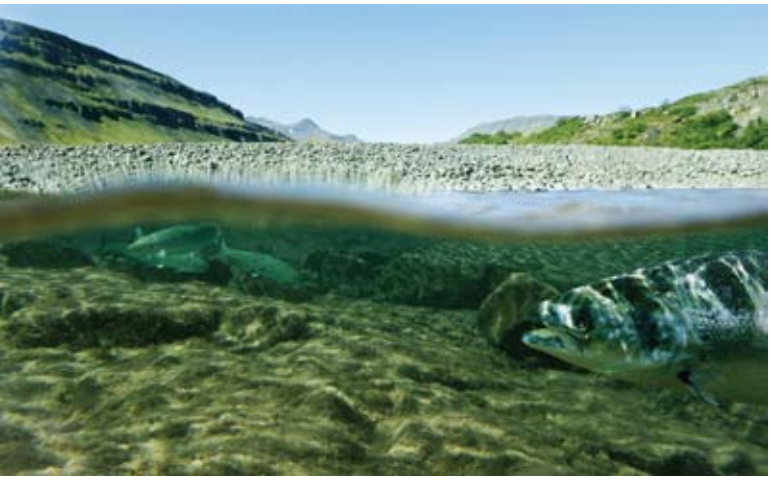
## Temporal and spatial resolution

There is an uneven distribution of fish monitoring sites across the watershed and a tendency for these sites to be associated with FERC relicensing processes and thus rivers with regulated flows and large dams and reservoirs. The highly-regulated South Yuba had a disproportionately large number of sites relative to other subwatersheds. Because of the association of fish community monitoring with FERC re-licensing, most data have been collected recently. Returning salmon have been well monitored in this watershed for many years, though the methods for assessing population health have changed over the years. Currently there is extensive monitoring of returning adults in the lower watershed, but not as extensive monitoring of juvenile rearing, growth, and return to the ocean.

## How sure are we about our findings (Things to keep in mind)

For both fish community and salmon population assessments assumptions were made about targets (species richness and abundance). Modifications of these targets because of habitat variation (fish community metrics) and new estimates of target populations (salmon) would change the corresponding condition scores.

There were sufficient data to be confident about the fish community findings and the spawning salmon abundances to be confident in the trends measured. Longer term monitoring will be needed to estimate trends in fish communities with greater confidence.



## Technical Information

### DATA SOURCES:

DWR fish community survey data on the Feather River (1997-2005, 6 locations)

FRCRM 2001, 2003 electrofishing data (multiple creeks)

NID, FERC survey data on the Yuba and Bear River (2008-2009)

Friends of Deer Creek fish community survey data (2007-2008)

Vaki Riverwatcher 2008-2010

DFG Annual Reports Chinook Salmon Spawner Stocks in California's Central Valley (1953-2009)

### DATA TRANSFORMATION AND ANALYSIS:

#### *Unidentified species:*

Unidentified species were not relevant to PONSE calculation, and were only included in PNS if the native/exotic status was well-defined (i.e. "unidentified sculpin" or "unidentified bass," given that only native sculpins and exotic bass are found in the species lists).

#### *Aggregation:*

Survey data for each site were combined annually, so that each site had only a single data point for each year. Fish abundances from individual surveys were added together to form one "total survey." Subwatershed trends were then determined via a Regional-Kendall analysis across all sites within the subwatershed. Current state was determined by averaging PONSE and PNS scores for the most recent year at each site within the subwatershed. Most datasets included only a few samples per year in a few months, so monthly analysis was impossible.

### *Expected native species:*

Expected native species were determined through a combination of factors. First, a list of species native to the Sacramento River Basin was taken from the SNEP report (SNEP, 1996). Then the subwatersheds were divided into low and high elevation sites, and the native fish were divided accordingly depending on habitat preferences. Elevation decisions were made by estimating whether each subwatershed was primarily lowland/foothills or in the mountainous region of the watershed. Finally, the lists were reduced to only fish that had been caught in at least one of the relevant subwatersheds. This limited the number of expected species to only those known to be found by the electro-fishing surveys employed. Expected species for the Lower Feather were slightly expanded, because the surveys conducted there were more thorough than in other regions. Final expected species lists are given in Table 10.

**Table 10 — Expected species for different subwatersheds**

| Low elevation | |
|---|---|
| LF | Rainbow trout(RBT), Sacramento sucker (SSK), Sacramento pikeminnow (SPM), Speckled dace (SPD), Hardhead (HHD), Pacific lamprey (PLP), River lamprey (RLP), Tule perch (TUP) |
| LY | RBT, SSK, SPM, SPD, HHD |
| DC | RBT, SSK, SPM, SPD, HHD |
| LB | No surveys conducted. |

| High elevation | |
|---|---|
| NFF | RBT, SSK, SPM, SPD, Riffle sculpin (RIS), California roach (RCH) |
| MFF | RBT, SSK, SPM, SPD, RIS, RCH |
| EBNFF | RBT, SSK, SPM, SPD, RIS, RCH |
| MY | RBT, SSK, SPM, SPD, RCH, Lahontan redside (LRS) |
| NY | RBT, SSK, SPM, SPD, RCH, LRS |
| SY | RBT, SSK, SPM, SPD, RCH, LRS |
| UB | RBT, SSK, SPM, SPD, RCH, LRS |

### *Salmon abundance*

The abundances for the most recent years (2006-2009) are considered preliminary. Confidence in current state is accordingly slightly lower.

## Citations

SE Queensland EHMP methods: (http://www.ehmp.org/_uploads/ehmp/FileLibrary/freshw_methodsfishi.pdf)

Meador, M. R., L. R. Brown, and T. Short. 2003. "Relations between introduced fish and environmental conditions at large geographic scales." Ecological Indicators 3:81-92.

Sierra Nevada Ecosystem Project Final Report to Congress. 1996. "Status of the Sierra Nevada". (http://ceres.ca.gov/snep/pubs/)

California Dept. of Fish and Game: Chinook escapement estimate from March 9, 2010

CALFED Vision for Chinook Salmon, February 3, 1997 (http://www.calfish.org/portals/0/Programs/AdditionalPrograms/CDFGFisheriesBranch/tabid/104/Default.aspx)

# Section 3.3 – Habitats and Ecosystems

**GOAL: C.** Protect and enhance landscape and habitats structure and processes to benefit ecosystem and watershed functions

**OBJECTIVE: 1.** Protect and enhance aquatic habitat connectivity

**OBJECTIVE: 2.** Protect and enhance terrestrial (native upland) habitat connectivity

**OBJECTIVE: 3.** Protect and maintain natural variability and rates of primary production and nutrient cycling

The following indicators were evaluated to measure habitat and ecosystem conditions:

- Aquatic habitat barriers
- Terrestrial habitat fragmentation
- Carbon stock and sequestration
- Nitrogen load/cycling

## 3.3.1 – Aquatic Habitat Barriers

**GOAL: C.** Protect and enhance landscape and habitats structure and processes to benefit ecosystem and watershed functions

**OBJECTIVE: 1.** Protect and enhance aquatic habitat connectivity

**WAF ATTRIBUTE:** Hydrology/Geomorphology

### What is it?

The connectivity of aquatic habitat is interrupted by man-made structures which include road crossings, dams, weirs and other management structures (Baxter, Frissell et al. 1999; Gibson, Haedrich et al. 2005). The interruptions vary in nature from complete barriers (a dam with no fish ladder or other accessible passage), to changes that have little or no impact on habitat (Warren and Pardew 1998). This indicator is a count of all stream and river crossings by roads and other barriers (collectively referred to as barriers) per linear kilometer of river in the regions of interest. This provides a statistic that summarizes the amount of interaction between barriers and rivers for each area. Included in these data are barriers generated by the analysis of road and river datasets as well as barriers catalogued by the Fish Passage Assessment.

## Why is it Important?

Locations where roads cross waterways change the natural shape of the river and how it is allowed to flow through the barrier. This can affect sediment transport and deposition and the movement and migration of aquatic species (Forman and Alexander 1998; Warren and Pardew 1998). Natural processes are altered by crossings and higher barrier frequency has a negative impact on many aspects of waterway health. Specifically, increases in the water velocity due to the configuration of a road crossing are inversely proportional to fish movement (Warren and Pardew 1998). A similar metric is used in assessing logging road impacts on fish habitat. In this case, road density is used with the assumption that all crossings have a similar configuration and are proportional to road density (Baxter, Frissell et al. 1999).

## What is the target or desired condition?

The desired condition of the landscape, from an ecological health standpoint, is to have no barriers in the aquatic habitat. This could mean all road crossings or other structures are configured such that they generate no impact on the habitat or movement of aquatic species. Some planning watersheds do not have roads and therefore are the benchmark for scoring the watersheds that do have barriers. Watersheds that have no barriers have a score of 100.

## What can influence or stress condition?

Alteration of road crossings or installation of new crossings (or other barriers) that do not specifically address the need for habitat-friendly design will negatively impact aquatic connectivity. Likewise, the construction of any roads in a watershed can negatively impact connectivity due to increases in runoff, total suspended solids and water chemistry (Byron and Goldman 1989; Forman and Alexander 1998; Ahearn, Sheibley et al. 2005).

## What did we find out/How are we doing?

The barrier scores for each of the 11 subwatersheds ranged between 67 and 82 (Table 1). This score was calculated by comparing the density of barriers within each planning watershed with the highest density measured in the Feather River Watershed (2.99 barriers/km stream), which resulted in a proportional value, which was in turn converted to a score. Reduction in road crossings or other barriers in all regions will improve environmental health and reduce the negative impacts on aquatic habitat connectivity. These data will need to be recalculated as the data sources are updated to provide an indication of temporal trend. Road building, especially in rural areas, is likely to increase the barriers per kilometer of river. No trend was calculated because of the lack of historical information

### Table 1 — Aquatic barrier scores for subwatersheds

| Goal | Measurable Objective | Subwatershed | Score |
|---|---|---|---|
| C. Protect and enhance landscape and habitats structure and processes to benefit ecosystem and watershed functions | 1. Protect and enhance aquatic habitat connectivity | NFF | 82 |
| | | EBNFF | 77 |
| | | MFF | 81 |
| | | LF | 82 |
| | | NY | 82 |
| | | MY | 76 |
| | | SY | 79 |
| | | DC | 69 |
| | | LY | 77 |
| | | UB | 67 |
| | | LB | 79 |

## Habitats and Ecosystems

### Aquatic Barriers

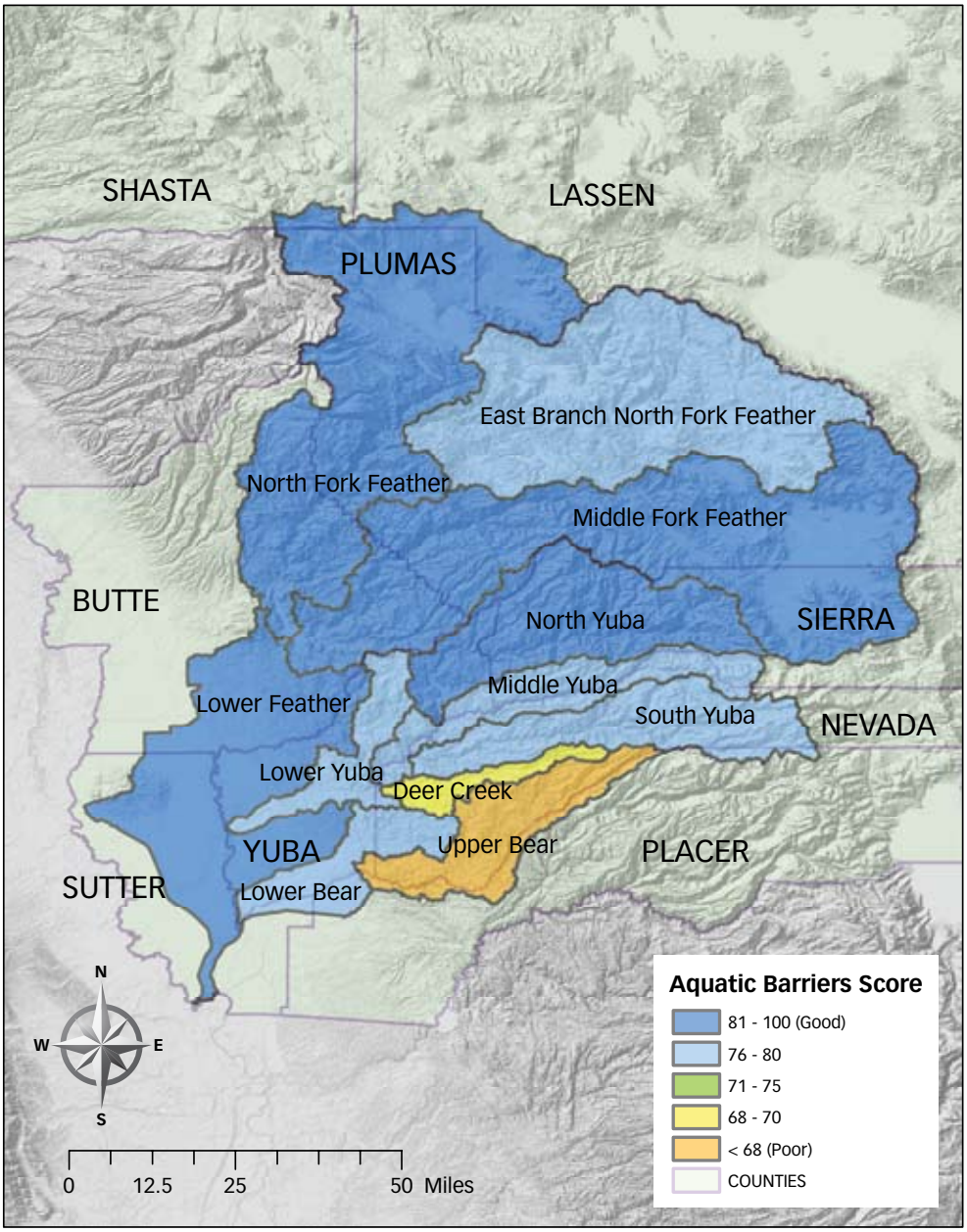
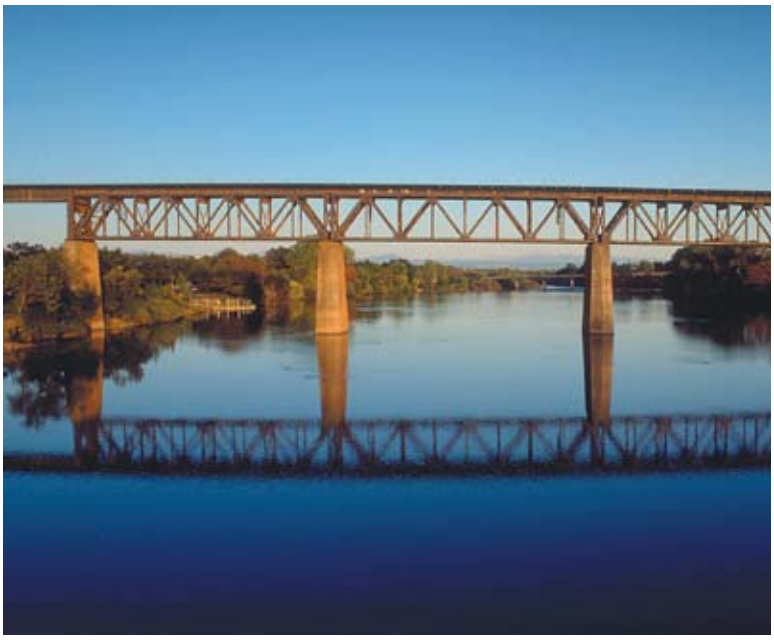



Figure 1 — Distribution of aquatic barriers score across subwatersheds

## Temporal and spatial resolution

River and road data were sourced from the highest-resolution datasets available. Ephemeral streams were removed from the dataset because of inconsistent representations of this stream type data across the watersheds. Road data were combined from two sources, the state of California and the USFS. The USFS data had higher resolution and more detail within the boundaries of the national forests and were used in place of state data. Temporal resolution is unknown as these datasets are irregularly updated.



## How sure are we about our findings (Things to keep in mind)

The road crossings combined with barriers cataloged by DFG provide a detailed dataset from which to derive information. However, no field validation of the spatial data were performed. As such, an assumption was made that each barrier is equally detrimental to fish movement and no barrier completely blocks fish movement. Future analyses of this nature could be further detailed to boost confidence in the indicator. For instance, the different types of road crossing (e.g. culvert, open box, fording and others) exhibit differential impacts on fish movement (Warren and Pardew 1998). Culverts tend to accelerate the water through the crossing, which makes the crossing more of a barrier to fish movement. The configuration of each of the crossings in this analysis is not known and data of this nature would improve the analysis.

## Technical Information

### DATA SOURCES AND TRANSFORMATIONS:

River data was sourced from the USGS National Hydrography Dataset. Ephemeral streams were removed from the dataset prior to analysis. (http://nhd.usgs.gov/). Road data were sourced from both the state of California (http://www.atlas.ca.gov/) and from the USFS (http://www.fs.fed.us/). All roads within national park boundaries originated from USFS. Additional river barrier locations were obtained from DFG Passage Assessment Database (PAD, http://www.calfish.org).

All spatial data were re-projected to Teale Albers NAD 83.

**ANALYSES:**

A road dataset was assembled by selecting the USFS road dataset that fell within the Feather River Watershed, then adding data from the State of California road dataset in areas not included in the USFS dataset. Ephemeral streams and shoreline features (for the major lakes) were eliminated from the NHD stream dataset within the watershed. The crossing data points were generated by intersecting roads and streams across all portions of the analysis area. Barriers cataloged in the Passage Assessment Database by the DFG were also added to the road/stream point dataset. For each planning watershed, the ratio of barriers to total river length (located inside the planning watershed) was calculated. The ratio was also calculated for the entire subbasin.

The barrier density for each subwatershed (BRsw) is compared with the maximum observed density of all planning-watersheds in the Feather River Watershed (BRmax, 2.99 barriers/km). The following equation was used to scale the score between 0 and 100: Score = 100 x (1 - (BRsw/BRmax)), where a score of 100 is the highest score and indicates no barriers.

**Table 2 — Summary statistics for barrier evaluation. "PW in SW" refers to the number of planning watersheds in each subwatershed. "Barrier count" refers to the number of dams and road crossings. Minimum and maximum barriers/km are the lowest and highest densities of barriers in any planning watershed in the subwatershed. "Average barriers/km" and "StDev ..." refers to the average and standard deviation of barrier density across all planning watersheds in each subwatershed. "Score" refers to the indicator score.**

| Subwatershed Name | PW in SW (count) | Barrier Count (SW) | River km | Minimum Barriers/km | Maximum Barriers/km | Average Barriers/km | StDev Barriers/km | Score |
|---|---|---|---|---|---|---|---|---|
| Deer Creek | 8 | 308 | 332.506 | 0.65 | 1.27 | 0.906 | 0.2592 | 69 |
| East Branch North Fork Feather | 75 | 1483 | 2148.072 | 0.11 | 2.99 | 0.690 | 0.3829 | 77 |
| Lower Bear | 10 | 368 | 597.455 | 0.40 | 1.22 | 0.689 | 0.2508 | 79 |
| Lower Feather | 19 | 1435 | 2676.798 | 0.00 | 1.38 | 0.638 | 0.3170 | 82 |
| Lower Yuba | 14 | 409 | 603.028 | 0.20 | 1.44 | 0.814 | 0.3459 | 77 |
| Middle Fork Feather | 98 | 1795 | 3131.308 | 0.00 | 1.60 | 0.651 | 0.3413 | 81 |
| Middle Yuba | 20 | 444 | 608.727 | 0.14 | 1.89 | 0.799 | 0.4073 | 76 |
| North Fork Feather | 86 | 1185 | 2266.707 | 0.00 | 1.92 | 0.532 | 0.3779 | 82 |
| North Yuba | 34 | 594 | 1115.386 | 0.15 | 1.08 | 0.583 | 0.2776 | 82 |
| South Yuba | 25 | 508 | 822.238 | 0.00 | 1.37 | 0.632 | 0.3329 | 79 |
| Upper Bear | 21 | 821 | 836.948 | 0.38 | 1.68 | 0.992 | 0.3657 | 67 |

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# 3.3.2 – Terrestrial Habitat Fragmentation

**GOAL: C.** Protect and enhance landscape and habitats structure and processes to benefit ecosystem and watershed functions

**OBJECTIVE: 2.** Protect and enhance terrestrial (native upland) habitat connectivity both within the watershed and into adjacent watersheds

**WAF ATTRIBUTE:** Landscape Condition

## What is it?

This indicator is a measure of landscape fragmentation using a metric known as effective mesh size. Effective mesh size is based on the probability that two points chosen randomly in a region will be connected, and that barriers like roads, railroads, or urban development do not separate the points (Jaeger 2000, Moser 2007, Girvetz et al., 2008). A high effective mesh size value indicates low fragmentation of the landscape. Fragmentation, or its corollary connectivity, was recently calculated for the whole of California (Girvetz et al., 2008).

## Why is it Important?

Landscape fragmentation is a process by which larger areas become smaller, more numerous and isolated by physical or other barriers. Structural changes in ecosystems, such as fragmentation in vegetative cover, causes functional changes in hydrological, geochemical, and geomorpological processes. At the landscape scale, fragmentation (and its corollary connectivity) for individual taxa may be the most important of physiographic properties, because it is a measure of intactness, which along with habitat type and forage availability describes what individual taxa and biodiversity need across daily to evolutionary timeframes. Landscape fragmentation results in further changes in other structures (e.g., aquatic habitat) and processes, leading to an unraveling of complex systems and loss of resiliency. Species existing in a fragmenting landscape will have different responses to the process. Some will be less able to adapt to the changes leading to a reduction in the probability of survival over time. Ultimately, fragmentation can result in a reduction of biodiversity, a measure of the health of an ecosystem. All landscapes have some degree of natural fragmentation, however a landscape with fewer anthropogenic sources of fragmentation is regarded as healthier and an objective for environmental protection.

Intactness and habitat quality and the connectivity that they help to confer, are closely related to the ecological state of particular landscapes. A place that has undergone a large change in cover (e.g., from grazing or crop irrigation) may attain a different resilient state than the original, natural state. One commonly-proposed adaptation strategy is

improving structural connectivity under different climate change scenarios to increase the likelihood that species ranges can change adaptively over time (Carroll et al., 2009). Providing for biodiversity conservation under climate change and land-use pressure includes protecting connectivity as a landscape attribute to facilitate individual species and community migration.

## What is the target or desired condition?

Natural fragmentation of habitats is an expected characteristic of Sierra Nevada landscapes and is desirable. Fragmentation by roads and other infrastructure and activities is not. Fragmentation affects different species and natural processes differently, meaning that there is no single value of fragmentation that has broad ecological meaning. A target condition (score of 100) was set at the largest measured effective mesh size in any Feather River subwatershed (South Yuba). All other subwatersheds were compared to that value and scores expressed as proportions.

## What can influence or stress condition?

The most direct cause of habitat fragmentation is land-use actions by people. These include housing development, roads & highways, canals, logging, surface mining, agriculture, and recreation. The combination of infrastructure and use of the infrastructure causes the overall disturbance to habitats and landscapes. The decision-making that leads to fragmentation is spread among many private and public bodies and many social and economic benefits are derived from past and current fragmenting structures and activities.

## What did we find out/How are we doing?

The largest average effective mesh size value for the subwatersheds was 221 sq. km, for the South Yuba, which had a score of 100 (Table 1, Figure 1). The lowest score of 2 was for the Lower Bear subwatershed, corresponding to an effective mesh size of 4.9 sq km. The average score for all planning watersheds (~10,000 acre creek drainages) in the landscape was 10.1 indicating that the effective mesh size for most of the landscape is low compared to the maximum observed.

### Table 1 — Report Card for Habitat Fragmentation

| Goal | Measurable Objective | Subwatershed | Score |
|---|---|---|---|
| C. Protect and enhance landscape and habitats structure and processes to benefit ecosystem and watershed functions | 2. Protect and enhance terrestrial (native upland) habitat connectivity both within the watershed and into adjacent watersheds | NFF | 81 |
| | | EBNFF | 23 |
| | | MFF | 44 |
| | | LF | 5 |
| | | NY | 54 |
| | | MY | 27 |
| | | SY | 100 |
| | | DC | 5 |
| | | LY | 11 |
| | | UB | 14 |
| | | LB | 2 |

## Landscape and Habitat Structure

### Fragmentation

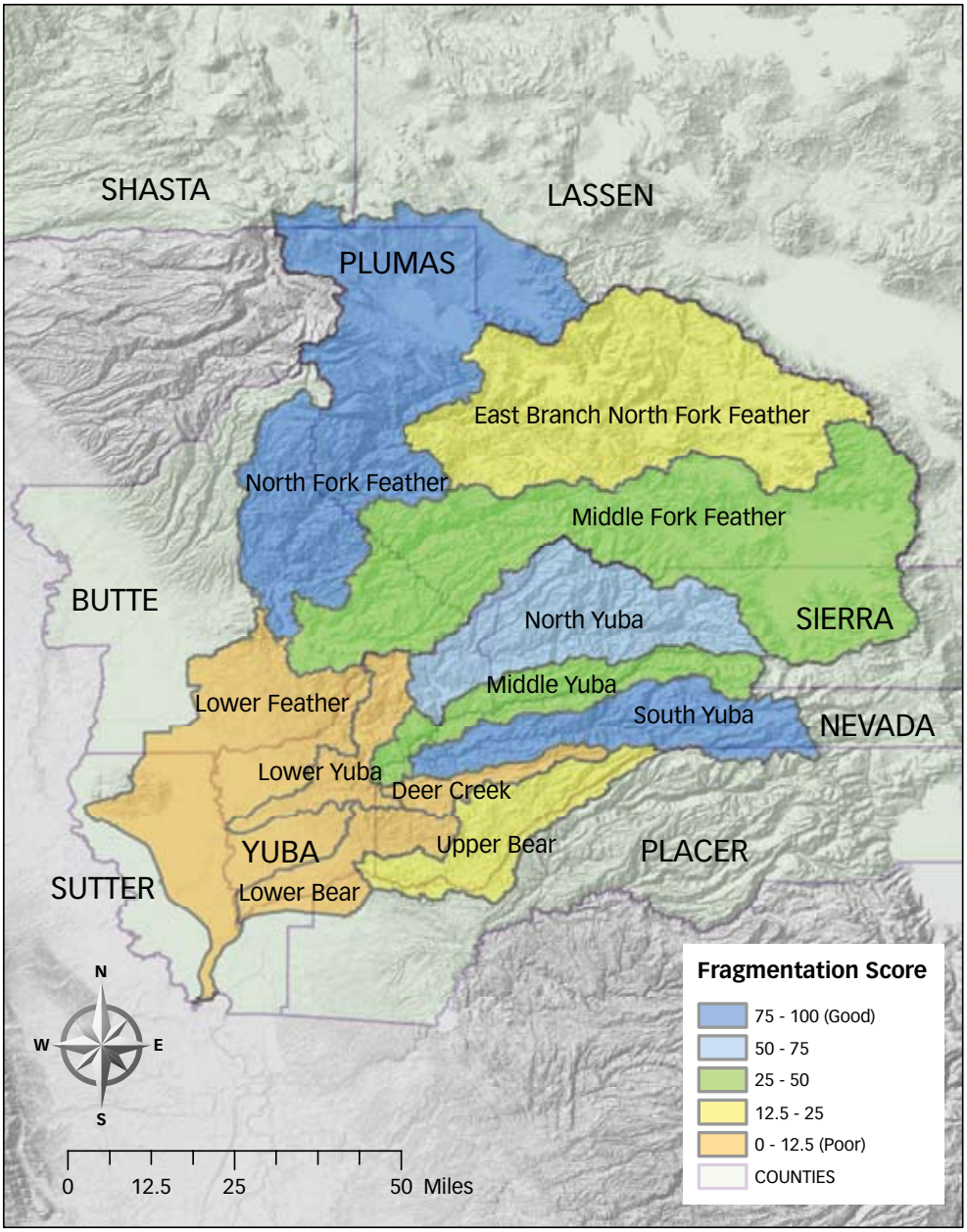


Figure 1 — Distribution of subwatershed landscape and habitat fragmentation scores

## Temporal and spatial resolution

Effective mesh size was previously calculated for the whole of California by Girvetz et al. (2008). The finest-resolution values were available for planning watersheds, which are creek drainages with sizes around 10,000 acres. This calculation has only been done once for the state using roads and other barriers (e.g., urban areas), so temporal resolution is limited to this most recent calculation.

## How sure are we about our findings (Things to keep in mind)

The effective mesh size metric is one estimator of fragmentation. It treats all barriers as identical in their prevention of wildlife movement and inhibiting other ecological flows, though it is more likely that barriers are relatively permeable, rather than absolutely impermeable. There are other fragmentation metrics in the literature relating to the size, shape, and distribution of "patches", which are the pieces of habitat surrounded by roads or other habitats. The measurement itself is very accurate at the planning and subwatershed scale, though there was considerable variation in effective mesh sizes among planning watersheds (Table 2). Overall, this metric provides a good general indication of fragmentation condition, especially in a relative sense within a region or river basin.

## Additional Information

### DATA SOURCES

Effective mesh size data were those described in Girvetz et al. (2008) and were obtained directly from the authors.

### ANALYSES

Effective mesh size (expressed in sq. km) values for individual planning watersheds were aggregated to the subwatershed using area weighted averaging.

The effective mesh size value for each subwatershed was compared to the maximum observed effective mesh size value among all subwatersheds (South Yuba). The following equation was used to generate a score for each subwatershed relative to the maximum observed EMS value: Score = $EMS_{SW}$ / max($EMS_{SW}$), where $EMS_{SW}$ is the area weighted EMS value calculated for the subwatershed and max ($EMS_{SW}$) is the maximum EMS value observed in a subwatershed. The score ranges from 0 (low) to 100 (high).

**Table 2 — Basic statistics for effective mesh size for subwatersheds. "95% C.I. refers to 95% confidence intervals around the mean. "PW" refers to planning watersheds and "SW" refers to subwatersheds.**

| Subwatershed Name | PW in SW (count) | Minimum EMS (sqkm) | Maximum EMS (sqkm) | Mean EMS (sqkm) | 95% C.I. | Score |
|---|---|---|---|---|---|---|
| Deer Creek | 8 | 1.581 | 36.045 | 10.304 | 8.7 | 4.6 |
| East Branch North Fork Feather | 75 | 5.377 | 318.431 | 51.981 | 6.5 | 23 |
| Lower Bear | 10 | 2.778 | 11.429 | 4.911 | 1.6 | 2.2 |
| Lower Feather | 19 | 1.767 | 204.927 | 9.852 | 21.5 | 4.5 |
| Lower Yuba | 14 | 7.463 | 89.939 | 25.050 | 13.1 | 11 |
| Middle Fork Feather | 98 | 9.050 | 438.637 | 97.160 | 22.9 | 44 |
| Middle Yuba | 20 | 7.286 | 156.699 | 60.835 | 18.5 | 27 |
| North Fork Feather | 86 | 2.188 | 730.727 | 179.089 | 36.6 | 81 |
| North Yuba | 34 | 24.091 | 275.046 | 120.255 | 26.9 | 54 |
| South Yuba | 25 | 4.932 | 537.050 | 221.597 | 76.2 | 100 |
| Upper Bear | 21 | 1.317 | 115.992 | 32.009 | 14.1 | 14 |

## Citations

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# 3.3.3 – Carbon Stock and Sequestration

**GOAL: C.** Protect and enhance landscape and habitats structure and processes to benefit ecosystem and watershed functions

**OBJECTIVE: 3.** Protect and maintain natural variability and rates of primary production and nutrient cycling to support aquatic and terrestrial communities

**WAF ATTRIBUTE:** Ecological processes

## What is it?

For this indicator we examine two elements of the carbon budget of the Feather River Watershed, carbon sequestration amounts and net primary productivity. Both are of interest in terms of global change issues, in particular because of the potential for offsetting increases in atmospheric carbon dioxide by storage of carbon in terrestrial carbon pools (Dixon et al. 1994). In this analysis we look at carbon standing stock at a single point in time as a measure of watershed condition, and assess trends in carbon storage by examining changes in net primary productivity detected by satellite remote sensing.

### *Carbon Sequestration*

Research on carbon sequestration has focused on measurements of carbon stocks and carbon flux. Measuring carbon flux requires sophisticated instrumentation making fine-scale studies difficult, but measurement of carbon stock is more amenable to landscape-scale studies. The general approach for carbon stock evaluation is to amalgamate remote sensing-based landscape classifications with vegetation plot data that includes above-ground biomass, litter accumulation on the soil floor, and below-ground carbon to estimate total carbon storage across the landscape. Typical units for the metric are in megagrams (Mg) of carbon per hectare for the stock and Mg C per hectare per year for the flux. In this analysis we use the results from a landscape-scale assessment of carbon stocks in California and compare that to a reference condition that assumes all trees are fully mature.

## Net Primary Productivity

According to NASA, terrestrial biological productivity (or primary productivity) is the single most fundamental measure of "global change" of practical interest for humankind. Primary productivity is the measure of carbon intake by plants during photosynthesis, and this measure is an important indicator for studying the health for plant communities.

Net Primary Productivity (NPP) is the amount of carbon uptake after subtracting Plant Respiration (RES) from Gross Primary Productivity (GPP). GPP is the total rate at which the ecosystem capture and store carbon as plant biomass, for a given length of time.

$$NPP = GPP - RES$$

Photosynthesis is the process in which the energy from the sun converts carbon dioxide (CO2) from the atmosphere and water (or water vapor) to organic sugar molecules (carbohydrates), which are stored in the plants, and oxygen, which we, and other life on earth, consume. The extra water molecules which are derived in photosynthesis are reused by the plant or transpired into the atmosphere. Below is the chemical formula for photosynthesis:

$$6CO_2 + 12H_20(+sunlight) \longrightarrow C_6H_{12}O_6 + 6O_2 + 6H_2O$$

NPP measures the mass of the new plant growth (chemically-fixed carbon) produced during a given interval. Change in NPP may change with vegetation health, so NPP rates were used to analyze the overall trend of carbon uptake in this region over the past ten years. To analyze trend, we downloaded ten years of monthly satellite data from NASA, which are are reported as grams of carbon uptake per meter square per day (gC/m$^2$/day). With monthly data, we ran a Seasonal-Kendall trend analysis, and with annual data, we ran a Mann-Kendall and Regional-Kendall trend analysis.

## Why is it Important?

Humans continue to release CO2 and other greenhouse gases into the atmosphere from the burning of fossil fuels and agricultural practices. Plants cannot convert CO2 into biomass as fast as it is entering the atmosphere, causing a global buildup. These greenhouse gases trap heat from the sun and cause the surface temperature to rise, which has started a chain of events that will have enormous impacts on the globe in the years to come. These changes include glacial melting, sea level rising, and climatic shifting, which in turn can affect the welfare and health of all living things on this planet.

Carbon sequestration is considered an important means to mitigate the impacts of greenhouse gases on climate change (Sedjo & Solomon 1989). Increasing the amount of carbon stored on a watershed may become an important policy goal with economic benefits accruing from the establishment of a carbon offset market (Richards & Stokes 2004).

Forest ecosystems sequester the most carbon of any terrestrial ecosystem, and most United States surveys of carbon storage to date have emphasized storage in forests, usually working with the USFS Forest Inventory and Assessment plots as a base (Woodbury et al. 2007, Blackard et al. 2008). The forests of the Pacific Northwest, including the Sierra Nevada, may have some of the highest potential to store additional carbon of any forests in the world (Hudiburg et al. 2009).

## What is the target or desired condition?

Prior to the industrial revolution, the planet's carbon cycle was closer to a state of equilibrium. While an increase in solar radiation or an increase in planetary volcanism can drastically change the carbon cycle for a relatively short period of time, it has been shown that human activity has adjusted this cycle by adding more carbon and methane into the atmosphere at higher concentrations than any natural occurrence over the last 650,000 years (Siegenthaler et al., 2005). The carbon cycle is a global phenomena, so to return to a desired condition at equilibrium will be a global, population-wide, effort. To select a desired condition at a regional scale, we look at the carbon *holding capacity* for each region and compare it with current conditions.

We take the desired condition to be a landscape where all trees are fully mature; that is, they have grown to the point where additional carbon storage on the landscape in aboveground biomass is limited to the rate of trees dying and new ones growing. Such a landscape is at its maximum potential for mitigating climate change through storage of atmospheric carbon dioxide.

We also selected a target for new carbon sequestration, as indicated by NPP, as an increasing trend, or at least not a declining trend. This means that a significant upward trend is a good condition from a climate mitigation point of view, and a declining trend is a poor condition.

## What can influence or stress condition?

Any changes in plant cover in the landscape will affect the amount of aboveground carbon storage. Most important are changes in forest cover, given that forests have the greatest amount of biomass of any habitat type. Processes that influence forest cover and hence carbon storage include fire, timber harvest, land development, and disturbances such as pest outbreaks as well as forest regrowth (Brown et al. 2004). In a recent study, scientists found that logging was the greatest impact on reduced carbon storage in forests and "no management" of forests resulted in the greatest sequestration of carbon (Nunery

and Keeton, 2010). Fire can also reduce NPP, with reduction depending on fire intensity (Meigs et al., 2009). Remaining and newly-growing plants will tend to grow vigorously, so at the landscape scale, fire temporarily reduces NPP rates.

Regional climate will greatly affect the natural growth of shrubs and trees. Between 2006 and 2009, California experienced three consecutive dry water years. NPP will tend to decline in response to seasonal and drought-related drying. Plants take up CO2 through holes in their leaves called stomata. These will close under very dry conditions in order to reduce water loss by the plant. This means that as conditions dry, rates of carbon sequestration will decline. Because climate change may lead to drier and hotter conditions in many places in California, NPP may decline.

## What did we find out/How are we doing?

There were relatively high scores for carbon standing stock, ranging from 86 for the East Branch North Fork Feather to 96 for Deer Creek (Table 1 and Figure 1). There was significant downward trends in annual NPP for the three the western, lower elevation and agricultural rich, subwatersheds (Lower Bear, Lower Feather, Lower Yuba). Despite the high absolute values of the indicator scores, scores should be as close to 100% as possible, because of the need to reach global greenhouse gas mitigation goals.

**Table 1 — Report Card scores for carbon for subwatersheds**

| Goal | Measurable Objective | Subwatershed | Score | Trend |
|---|---|---|---|---|
| C. Protect and enhance landscape and habitats structure and processes to benefit ecosystem and watershed functions | 3) Protect and maintain natural variability and rates of primary production and nutrient cycling to support aquatic and terrestrial communities | NFF | 94 | n.s. |
| | | EBNFF | 86 | n.s. |
| | | MFF | 88 | n.s. |
| | | LF | 93 | ↘ |
| | | NY | 93 | n.s. |
| | | MY | 89 | n.s. |
| | | SY | 93 | n.s. |
| | | DC | 96 | n.s. |
| | | LY | 91 | ↘ |
| | | UB | 91 | n.s. |
| | | LB | 93 | ↘ |

### *Carbon Standing Stock*

The indicator value is a comparison of current standing stock to a potential maximum, which is based on a combination of underlying vegetation types and canopy closure values. Figure 2 is an intermediate layer which shows carbon storage at a 100 meter pixel-resolution and provides additional detail about the patterns in each subwatershed. Low elevation subwatersheds with a predominance of oak woodlands and chaparral have relatively low levels of carbon storage. There is a mid-elevation zone where carbon storage is particularly high, which is related to the wetter, productive conifer and mixed-conifer/hardwood forest types. On the eastern slope watersheds (Middle Fork Feather, East Branch North Fork Feather) there is a large band with relatively low carbon storage.

## Habitats and Ecosystems

### Carbon Standing Stock

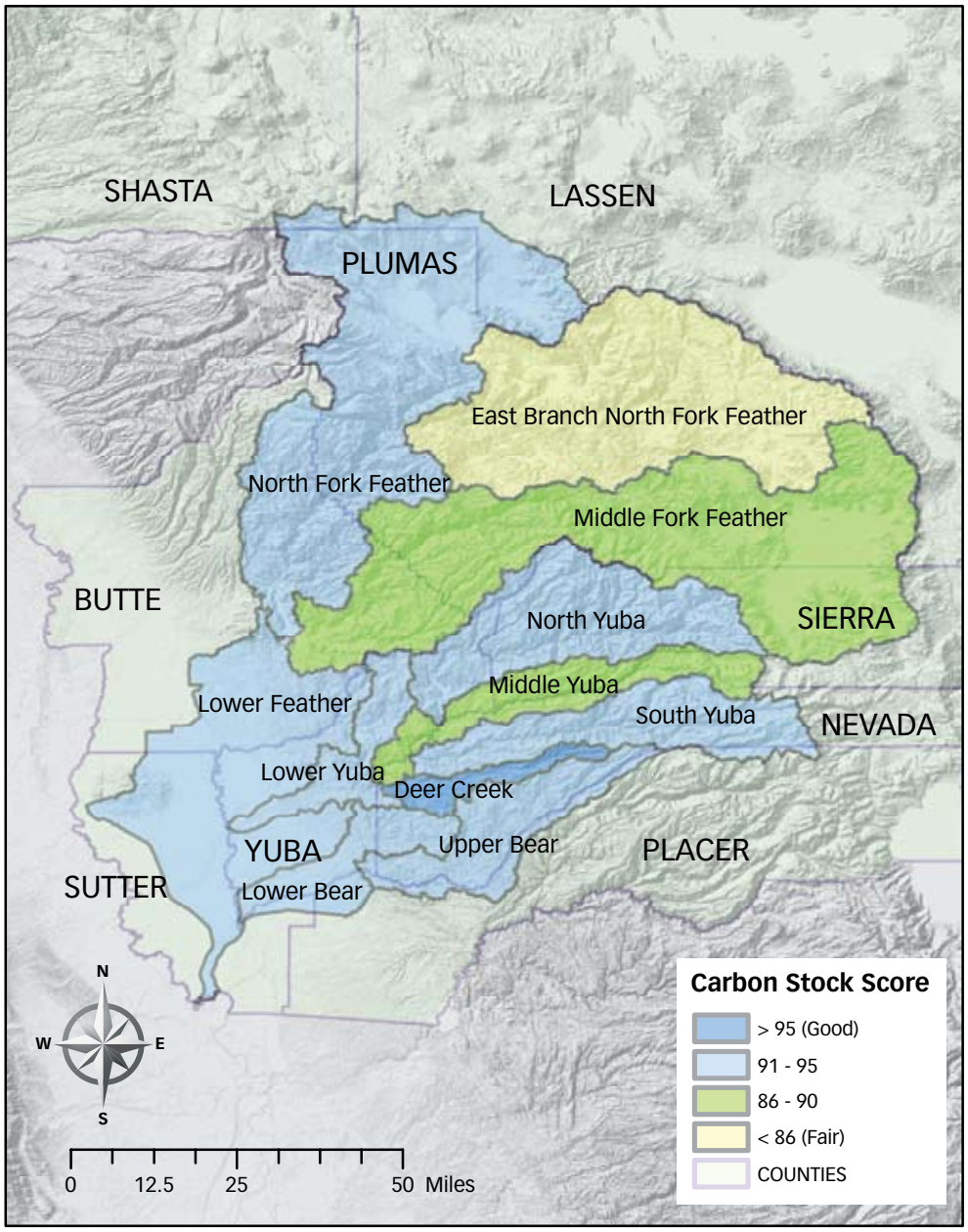



Figure 1 — Carbon stock scores across subwatersheds

## Habitats and Ecosystems

Carbon Stocks

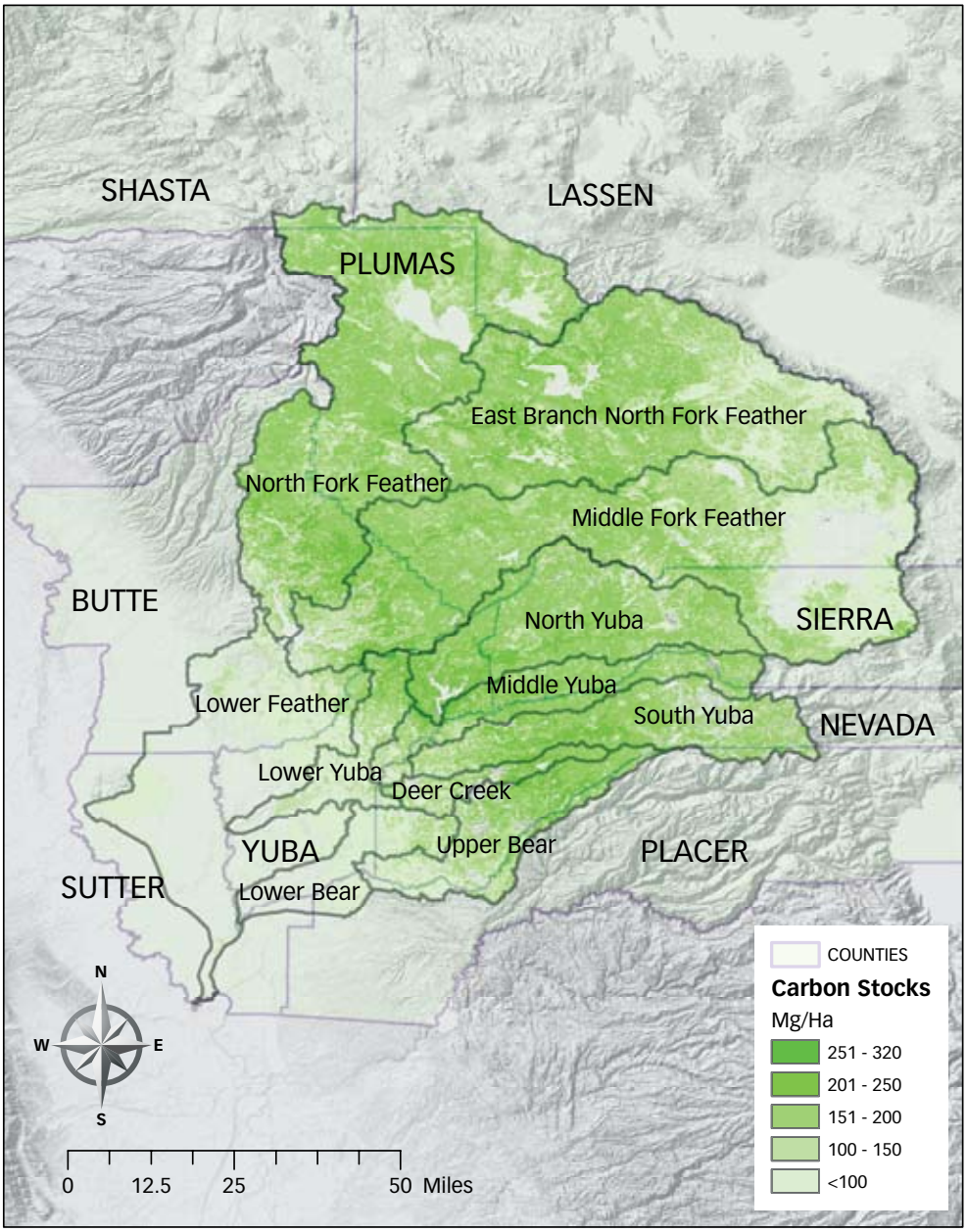



Figure 2 — Actual carbon standing stocks based on vegetation present

## Trend Analysis

To study trends in the carbon budget, NPP was analyzed for each subwatershed. NPP provides a rate of carbon fixation or sequestration into plant material. Ten years of monthly NPP rates were available, allowing for an estimate of change in rate over time. We used the R statistical program to analyze these data, and used custom-made variations of the Kendall package depending on whether the analysis was for monthly or annual data. Kendall's rank correlation measures the strength of monotonic association between two vectors, such as year and data value (see section 4.3 for more information on trends analysis).

### *Monthly Trend*

Monthly-seasonal variation over 10 years (2000 – 2009), was analyzed using a Seasonal Kendall statistical model. Monthly NPP raster data for each subwatershed were aggregated as sum, mean, maximum, minimum, and standard deviation for each subwatershed, and trends across each parameter were calculated for the 10-year analysis period (Table 2).

**Table 2 — Monthly Net Primary Productivity in each subwatershed: trends in the sum, mean, maximum, minimum, and standard deviation (StdDev) of NPP**

| Subwatershed | Trend | | | | |
|---|---|---|---|---|---|
| | Sum | Mean | Max | Min | StdDev |
| *Deer Creek* | | | | | |
| *East Branch North Fork Feather* | | | | | |
| *Lower Bear* | *Negative* | *Negative* | | *Negative* | |
| *Lower Feather* | *Negative* | *Negative* | | *Negative* | |
| *Lower Yuba* | | | | | |
| *Middle Fork Feather* | | | *Positive* | | *Positive* |
| *Middle Yuba* | | | | | *Positive* |
| *North Fork Feather* | | | *Positive* | | *Positive* |
| *North Yuba* | | | | | *Positive* |
| *South Yuba* | | | | | |
| *Upper Bear* | | | | | *Positive* |

We found a negative trend (decline in NPP) in the Lower Bear and Feather subwatersheds (Figure 3 and 4, respectively). Declines in NPP are associated with changes in vegetation type (e.g., replacement of tree canopy by row-crops), increases in temperature, and/or decreases in available water (from irrigation or precipitation. In these subwatersheds, all of these could be occurring. Maximum NPP rates (which occur in the Spring) increased in the Middle Fork Feather and North Fork Feather regions. This could be because Spring temperatures are higher and water is not limiting growth, resulting in higher Spring photosynthesis rates. A positive trend in the standard deviation tells us that the variability between years is increasing for those regions. Most alarmingly, NPP rates have recently

dipped into negative rates in the summer, meaning that there is a net export of carbon dioxide to the atmosphere during these times.

**Figure 3 — Monthly sums of NPP for the Lower Bear subwatershed, showing a statistically-significant downward trend**

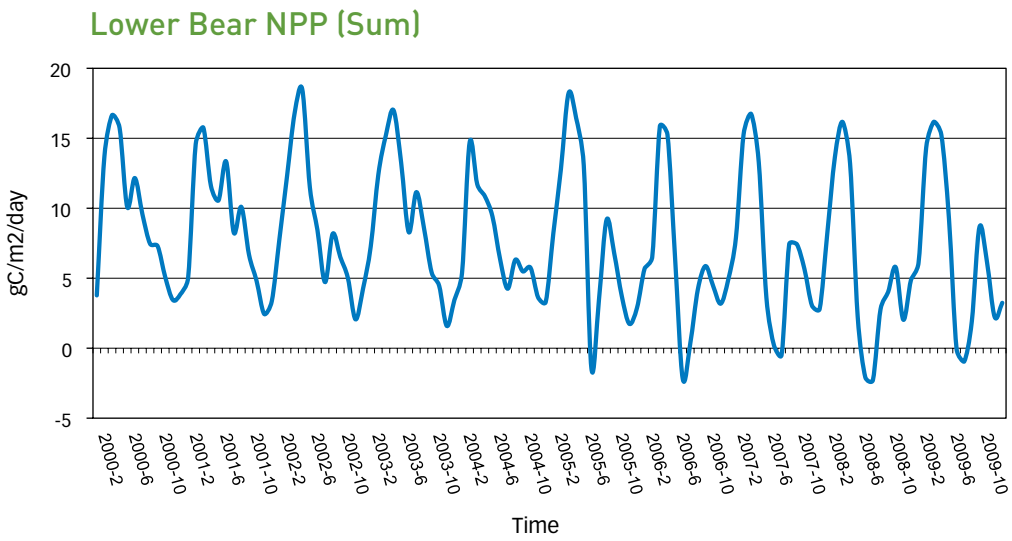
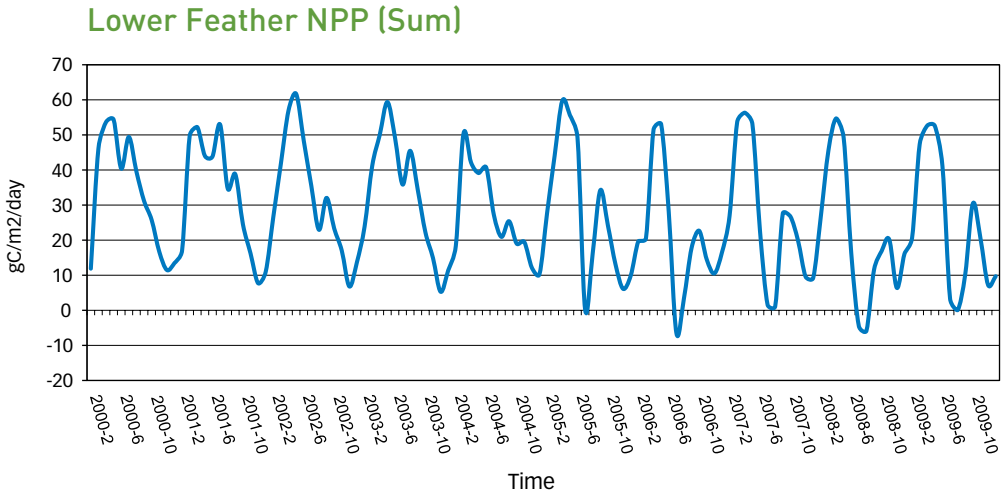



**Figure 4 — Monthly sums of NPP for the Lower Feather subwatershed, showing a statistically-significant downward trend**



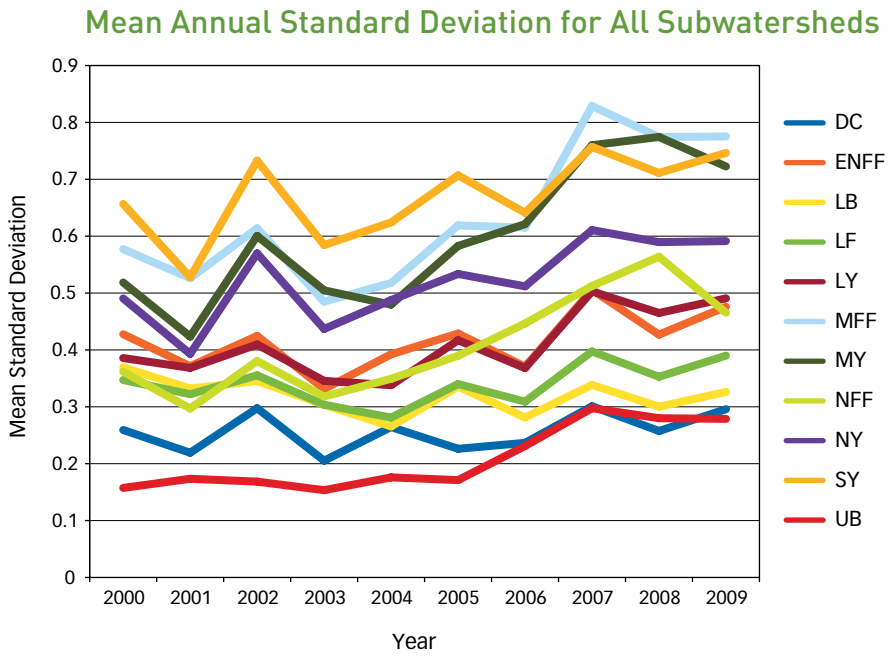
### *Annual Trend*

NPP values were summed for the year for each subwatershed and trends analyzed using the Mann-Kendall and Regional-Kendall statistical tests. These values were aggregated from the monthly NPP values, where the annual sum is the sum across all months, annual mean is the mean across all months, annual maximum, annual minimum, and the mean standard deviation for all months in the year. There were significant declines in the total NPP (sum), mean NPP, and minimum NPP for the Lower Bear, Feather, and Yuba subwatersheds and declines in the minimum NPP for the Deer Creek and Middle Fork Feather subwatersheds. There were also increasing trends in the standard deviation (Figure 5), a measure of variation within the year among months. These results are consistent with the possibility of NPP declining with land-use or climatic drivers. In addition, the increase in variability could be related to warmer springs allowing greater NPP during the peak natural growing season and hotter/drier summers causing declines and even net losses in carbon (negative NPP).

**Table 3 — Annual Net Primary Productivity in each subwatershed: trends in the sum, mean, maximum, minimum, and standard deviation (StdDev) of NPP**

| Subwatershed | Annual Trend | | | | |
|---|---|---|---|---|---|
| | Sum | Mean | Max | Min | StdDev |
| *Deer Creek* | | | | *Negative* | |
| *East Branch North Fork Feather* | | | | | |
| *Lower Bear* | *Negative* | *Negative* | | *Negative* | |
| *Lower Feather* | *Negative* | *Negative* | | *Negative* | |
| *Lower Yuba* | *Negative* | *Negative* | | *Negative* | |
| *Middle Fork Feather* | | | | *Negative* | *Positive* |
| *Middle Yuba* | | | | | *Positive* |
| *North Fork Feather* | | | | | *Positive* |
| *North Yuba* | | | | | *Positive* |
| *South Yuba* | | | | | |
| *Upper Bear* | | | | *Negative* | *Positive* |

Figure 5 — Change in annual mean standard deviations for all subwatersheds




## Temporal and spatial resolution

Carbon standing stock was measured at 100 m resolution with vegetation data that was roughly a decade old. The NPP data were at a 0.1 degree resolution, which is equivalent to roughly 10 kilometers squared, using data that are recent and updated. The standing stock is unlikely to change rapidly over areas the size of the subwatersheds, but for planning watersheds or similar units it may. NPP changes rapidly (daily to monthly) and high time-resolution is required for accurate estimations.

## How sure are we about our findings? (Things to keep in mind)

### *Carbon Stock*

Carbon stock estimation is difficult for a number of reasons, and the results above should be treated carefully. First, because estimation methodology depends upon combining synoptic land cover data from remote sensing platforms with plot-level measurements of carbon in living and dead plant material, it is important that the remote sensing-derived map has accurate information about vegetation height and cover. This is challenging because remotely sensed imagery usually only gives spectral information about the top level of the canopy and not the canopy depth, the latter corresponding more closely to volume of aboveground biomass. Also, plot-level data tends to be focused on forest stands [e.g. the Forest Inventory and Assessment plots (Woodbury et al. 2007)], with shrublands and grasslands being sampled more poorly. Carbon estimation is even difficult at the plot level, since the usual technique for estimating carbon stored in a tree is to measure diameter and height and then refer to a set of allometric equations (e.g. Jenkins et al. 2004) relating tree biomass to those parameters, and these equations may have

been developed from measurements of trees located in a very different landscape than one's study plot.

For this particular analysis of carbon stocks, a couple things to note are the following. First, using the estimator equations in Brown et al. (2004) involves reducing the land cover data to types that are not very specific to California vegetation. It would be best if this assessment was made using equations based on California vegetation types, if these were available. Second, the reference condition assumes that carbon storage will be maximized if all vegetation types are at dense cover. This introduces error because some localities will not support dense forest (e.g. sparsely forested upper elevation rocky areas).

The standard deviation measure, which was calculated from the values of all pixels within each subwatershed, is relatively high, with values ranging from 9.9 to 17.9 (Table 4). This reflects the fact that only four discrete canopy cover classes were used to calculate the carbon values in each pixel, leading to discrete and well spread apart bins in the output values.

**Table 4 — Standard Deviation of the mean in carbon stock estimation per subwatershed**

| Subwatershed | Confidence: Standard Deviation of Carbon Stock Estimate |
|---|---|
| Deer Creek | ± 9.9 |
| East Branch North Fork Feather | ± 17.9 |
| Lower Bear | ± 11.4 |
| Lower Feather | ± 11.9 |
| Lower Yuba | ± 12.2 |
| Middle Fork Feather | ± 15.5 |
| Middle Yuba | ± 11.8 |
| North Fork Feather | ± 15.0 |
| North Yuba | ± 12.7 |
| South Yuba | ± 12.6 |
| Upper Bear | ± 13.2 |

### *NPP*

With regard to NPP, these data were not readily available at the highest resolution provided by NASA. While the GIS processing of the raster data should provide an accurate estimate for calculated parameters, the smallest subwatersheds, for example Deer Creek, contain only a few of the low-resolution data cells that NASA currently provides through their website.

## Technical Information

### DATA SOURCES

The primary GIS data source for the carbon stock calculations was the CalFire Multi-Source Land Cover layer (Fire and Resource Protection Program 2003), which provides 100 meter resolution habitat data for all of California. This dataset was compiled in 2002, by amalgamating the best available local sources for land cover information in California present at that time. Most of these local data sources were made available in the period from 1993 to 1998. Equations for calculating carbon stock were from Brown et al. (2004), using equations orignialy published in Smith et al. (2003).

In February 2000, the Moderate Resolution Imaging Spectroradiometer (MODIS), aboard NASA's Terra and Aqua satellites, began producing regular global estimates for GPP and NPP at a spatial resolution of one square-km. When analyzing data from satellites, the scale, or resolution, which the data is collected can greatly influence the analysis. We downloaded these data from NASA Earth Observations, which provides global NPP data at a 0.1 degree scale (equivalent to approximately 8.5 km east/west and 11 km north/south at the study site). While this analysis could be improved with a finer-scaled dataset, with an average of 16.5 pixels for each subwatershed, this provided enough data to make estimates of general trends. The full dataset available was downloaded, with a temporal scale from February 2000 to January 2010 (120 GIS layers). These data were downloaded as georeferenced .tif files at the highest resolution (0.1 degrees) and as floating point pixel values. Each pixel represents the rate of NPP as grams of carbon uptake per meter squared per day ($gC/m^2/day$), averaged over the 0.1 degree box and for that month.

The downloaded MOD 17 data is a product consisting of 8-day Net Photosynthesis (PSN) and NPP. Annual NPP is the time integral of the PSN product over a year.

These NPP data were used to provide an estimate of NPP for this study region. It has been previously found that areas recently affected by fire can cause the MODIS algorithm which is used to estimate NPP (MODIS 4.1 fPar) to overestimate NPP for many terrestrial ecosystems (*Cheng, et al. 2006*), and therefore, if the specific values were important, another data source should be used to validate MODIS data. Since this study has a coarse spatial resolution with a fairly stable ecosystem, we use these data to analyze the overall trend and assume a consistent variation of NPP estimates.

### DATA TRANSFORMATIONS

We calculated the indicator value for each subwatershed in two steps. First, in a raster calculation we divided the estimated carbon stock layer by the target condition stock layer to produce a fraction giving the percent of maximum carbon storage for each pixel. Second, we averaged the carbon stock values for all pixels within each subwatershed to produce a value for each subwatershed. We calculated a measure of variation for each subwatershed in a similar way by computing the standard deviation of the values of all pixels in each subwatershed.

## ANALYSIS

### *Carbon Stock*

Brown et al. (2004) provided the first comprehensive evaluation of carbon storage and greenhouse gas emissions across agricultural lands, forests, and rangelands in California. We followed their methodology at a watershed scale in this analysis. They used the CalFire, FRAP, Multi-Source Land Cover (MSLC) layer as well as Land Cover Mapping and Monitoring Program (LCMMP) change maps to assess changes in carbon stock in the 1990s, referring to Smith et al. (2003) for measures of carbon content by forest cover type.

In particular, the CalFire MSLC layer provides habitat mapping for the state to 100 meter resolution using the vegetation classification from the California Wildlife Habitat Relationships (CWHR) mapping system (Mayer and Laudenslayer 1988). In addition to the vegetation type, this dataset gives information on vegetation canopy cover and canopy size where source data was available. The methodology in Brown 2004, calls for crosswalking the CWHR vegetation types to 5 forest types given in Smith (2003), namely Douglas fir, hardwoods, redwoods, fir-spruce, and other conifers. Taken together with canopy cover information, the equations in Brown (2004) allow for estimation of the carbon content (Table 5).

**Table 5 — Summary of equations available to estimate carbon standing stock in forest from Brown et al. (2004). In these equations, x is the canopy cover in percent, and y is the amount of carbon in Mg C/ha.**

| Habitat type | Carbon estimation equation |
|---|---|
| Douglas fir | $y = -101 + 96 \ln x$ |
| Fir-spruce | $y = -125 + 83 \ln x$ |
| Hardwoods | $y = -70 + 52 \ln x$ |
| Other conifer | $y = 59 + 2 x$ |
| Redwood/sequoia | No equation provided, instead use carbon values of ~90 Mg C/ha for canopy densities < 40 %, and carbon values of ~300 Mg C/ha for canopy densities > 40% (the graph provides only 4 points because of scarcity of input data) |

For shrublands and grasslands, Brown et al. (2004) use estimates for carbon content derived from other literature. In their report, Brown et al. (2004) do not provide carbon content values for woodlands, so the USDA Forest Service Carbon Online Estimator (NCASI 2010) was used to give carbon estimates for different age classes of blue oak, blue oak woodland being the dominant woodland habitat in the Feather River Watershed.

In a raster GIS, the portion of the MSLC layer that covered the Feather River Watershed was selected and analysis was restricted to the boundaries of the watershed using a raster mask. Using the CWHR habitat types in the MSLC layer and the crosswalk described above, vegetation pixels within the watershed were classified to one of eight vegetation types: either the five forest types listed above, shrublands, grasslands, or oak woodlands. Agricultural lands and developed lands were also masked out. The MSLC layer provides canopy cover information using the four canopy cover classes described in CWHR, namely sparse (10-24% cover), open (25-39%), moderate (40-59%) or dense cover (60% or greater). In pixels where the MSLC layer did not identify a canopy cover value. It was assumed this value was moderate cover. Using the mean values of the canopy cover class intervals, the carbon estimation relationships described above for the eight vegetation types were used to create a lookup table from which each pixel was assigned a carbon content value. All carbon stock GIS calculations were performed in the GIS GRASS (Neteler & Mitasova 2008).

A target condition layer was calculated using the same method, except that instead of taking the canopy cover value to be the actual value from the MSLC layer, dense cover was assigned. Because the carbon estimation relationships all reach their maximum value in the dense cover condition, this forces the output layer to have the maximum stock possible while keeping vegetation types the same for each pixel. The raster data for carbon standing stock and the subwatershed boundaries were intersected to generate a mean value per subwatershed.

### *NPP*

NPP spatial analysis was done with ArcMap 9.3 and a series of Python scripts using the ArcGIS scripting engine. The Feather River Watershed was detailed by a vector polygon, and the zonal statistics aggregated the raster (pixel-based) dataset and summarized the results. A third party product, Hawth's Tools version 3.27, was used to perform raster analysis, specifically the Zonal Statistics, on the set of NPP raster layers. Zonal Statistics produces a data table which includes the summation, minimum, maximum, mean, and standard deviation of the raster NPP values for each subwatershed. These data were then transformed from a column format (where each column represents a montly results) to a "long format," where month is its own column and has subsequent columns for the corresponding data value.

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# 3.3.4 – Nitrogen Load/Cycling

**GOAL: C.** Protect and enhance landscape and habitats structure and processes to benefit ecosystem and watershed functions

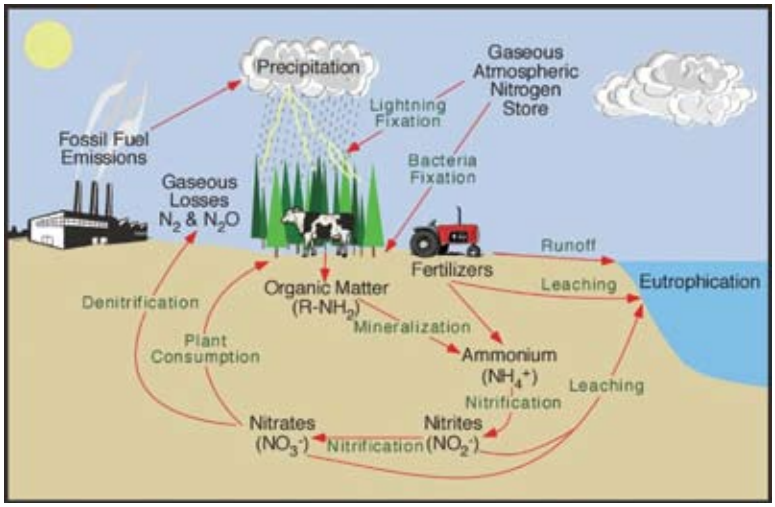
**OBJECTIVE: 3.** Protect and maintain natural variability and rates of primary production and nutrient cycling

**WAF ATTRIBUTE:** Ecological Processes

## What is it and why is it important?

Many macro and micro nutrients are essential to primary productivity, food-web dynamics, and ecological function. In particular, almost all organisms require nitrogen and phosphorus in some form for physiological processes (Ryther and Dunstan 1971, Vitousek et al. 1997b, Carpenter et al. 1998). The availability and forms of these elements play important roles in shaping communities, and organisms are frequently nitrogen or phosphorus limited (Galloway et al. 1995, Vitousek et al. 1997a). However, human alteration of nutrient cycles has resulted in many watersheds being highly enriched in certain elements, specifically nitrogen, phosphorus, and/or sulfur. Among other reasons, this is frequently a result of agricultural practices which use nitrogen and phosphorus enriched fertilizers to increase crop yield (Vitousek et al. 1997a, Vitousek et al. 1997b) or sulfur-based fungicides, which subsequently wash into the riverine systems. While artificial fertilization can increase ecosystem productivity, it can also decrease biological diversity (Tilman 1987). Currently, human activity adds as much fixed nitrogen to terrestrial ecosystems as do all natural sources combined (Vitousek et al. 1997a, Vitousek et al. 1997b). Nutrients, which are necessary for aquatic life, are only toxic at high concentrations, it's the secondary impacts (e.g., low DO, disruption of nutrient cycling) that cause concern (SWRCB 2010). Thus, these natural elements can become a significant form of pollution in aquatic ecosystems by upsetting natural nutrient cycles and can result in eutrophication and fuel harmful algal blooms (Carpenter et al. 1998). Nitrogen is often of the greatest concern as a nutrient pollutant and has as a result more monitoring data. Future comprehensive assessments should strive to also evaluate phosphorus, sulfur, and other nutrients of concern specific to the region of interest.

**Figure 1 — Depiction of a nitrogen cycle and the ways in which human activities alter the natural nitrogen cycle**




Reprinted from University of Waikato, New Zealand (http://sci.waikato.ac.nz/farm/content/nutrientcycling.html).

## What is the target or desired condition?

Nutrients (nitrogen and phosphorus) were consistently one of the top pollutants on the Clean Water Act (CWA) Section 303(d) List to Congress Reports beginning in the early 1990's, but "excess" concentrations of nutrients vary by waterbody type, climate, geologic areas, and other local risk cofactors (e.g., degraded riparian). Therefore, "nutrient criteria" cannot be developed as a single number for the country as a whole due to variability in background conditions and the role of other risk co-factors which affect nutrient processing within ecosystems. Total Maximum Daily Load (TMDL) levels for nutrients are currently being developed by the USEPA and the state of California, however currently specific values for criteria thresholds are not available for subwatersheds of the Feather River. In this Report Card, 0.1 mg/L Total Kjeldahl Nitrogen (TKN, ammonia + organic nitrogen) was used as the target for a good condition (score = 100) and 1 mg/L TKN for a target for poor condition (score = 0). TKN concentrations can be high as a result of human origina and natural organic material inputs into waterways, are indicative of ammonia concentrations, and can lead to increased ammonia and nitrate concentrations and biological oxygen demand. In the Sierra Nevada, they are also the dominant form of nitrogen, as compared to inorganic nitrogen (Coats and Goldman, 2001). (See Table 2, page 138). Once the responsible state and federal agencies set criteria for nutrients such as nitrogen for individual basins, then these scores can be recalculated.

## What can influence or stress condition?

Nitrogen is one of the most essential elements for plant reproduction and growth, therefore the amount of available nitrogen can strongly limit plant productivity. At first glance, nitrogen limitation may be counterintuitive, since 78% of the atmosphere is

composed of nitrogen gas (N2). Yet N2, and most forms of nitrogen found in terrestrial ecosystems, is not directly available to plants. Plants therefore rely on nitrogen fixing organisms to transform N2 into bioavailable forms. Consequently, although nitrogen is abundant, many natural systems are nitrogen limited. To get around this limitation, the Haber-Bosch process ws developed to artificially produce bioavailable nitrogen (ammonia) that can be used in fertilizers to increase productivity in cultivated crops. Fertilizers must be continuously reapplied because crops take up some the added nitrogen, and leaching causes the movement of nutrients out of the soil via irrigation or storm-water runoff. As this nitrogen moves into nearby waterways, it can accumulate and at higher than natural concentrations. High levels of nitrogen in waters can also produce harmful algal blooms. In turn, these blooms can produce "dead zones" in water bodies where DO levels are so low that most aquatic life cannot survive (USEPA 2010). Through these processes along with other sources such as urban effluent and atmospheric deposition, humans have roughly doubled the amount of fixed nitrogen, and this alteration may have drastic impacts on ecological systems (Fig. 1; B. Houlton, personal communication).

## What did we find out/How are we doing?

For subwatersheds with data, the condition scores for nitrogen ranged from 0 (Deer Creek) to 100 (Lower Yuba; Table 1 and Figure 2). All subwatersheds except Deer Creek were evaluated using total Kjeldahl nitrogen concentrations. Friends of Deer Creek have measured concentrations of nitrate (a form of inorganic nitrogen) at >10 mg/L in Lower Deer Creek, the highest reported for the watershed and concentrations that are toxic to animals and contribute to excess periphyton growth.

**Table 1 — Nutrient condition scores, based on total Kjeldahl (organic nitrogen + ammonia) concentrations, for subwatersheds**

| Goal | Measurable Objective | Subwatershed | Score |
|---|---|---|---|
| C. Protect and enhance landscape and habitats structure and processes to benefit ecosystem and watershed functions | 3. Protect and maintain natural variability and rates of primary production and nutrient cycling | NFF | 92 |
| | | EBNFF | 89 |
| | | MFF | 38 |
| | | LF | 94 |
| | | NY | n/a |
| | | MY | n/a |
| | | SY | n/a |
| | | DC | 0 |
| | | LY | 100 |
| | | UB | n/a |
| | | LB | 98 |

## Habitats and Ecosystems

### Nitrogen Cycling

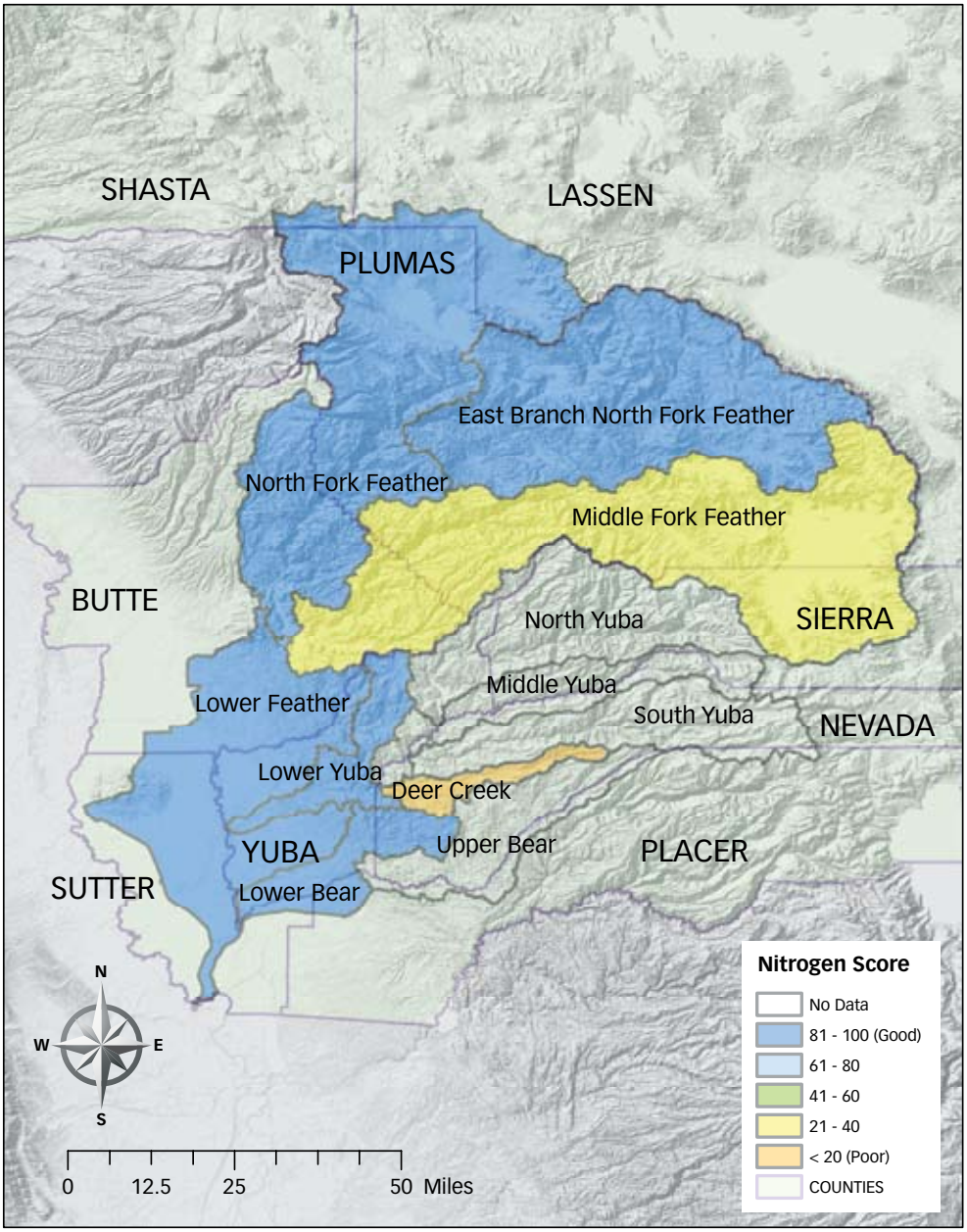



Figure 2 — Subwatershed scores for nitrogen conditions

**Table 2 — Basic statistics for monitored forms of nitrogen in each subwatershed during the latest year in which robust data was collected. All concentrations are in mg/L. "95% C.I." refers to 95% confidence intervals. Total Kjeldahl Nitrogen is total organic nitrogen + ammonia.**

| | | Dissolved Ammonia | | | Dissolved Nitrate + Nitrite | | | Total Kjeldahl Nitrogen | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Subwatershed | Yr | N | Mean | 95% C.I. | N | Mean | 95% C.I. | N | Mean | 95% C.I. |
| EBN Fork Feather 2007 | 2007 | 3 | 0.03 | 0.049 | 3 | 0.005 | | 1 | 0.2 | |
| Lower Bear 2009 | 2009 | 4 | 0.010 | 0.008 | 4 | 0.078 | 0.061 | 1 | 0.120 | |
| Lower Feather 2009 | 2009 | 32 | 0.008 | 0.002 | 32 | 0.048 | 0.016 | 23 | 0.152 | 0.039 |
| Lower Yuba 2009 | 2009 | 4 | 0.005 | | 4 | 0.028 | | 1 | 0.050 | |
| Middle Fork Feather 2007 | 2007 | 29 | 0.098 | 0.088 | 29 | 0.004 | 0.032 | 9 | 0.657 | 0.280 |
| North Fork Feather 2007 | 2007 | 38 | 0.018 | 0.016 | 38 | 0.046 | 0.014 | 9 | 0.171 | 0.092 |

As expected, the types of nitrogen vary across the watershed, primarily with elevation. Nitrate + nitrite concentrations are higher in the lower watershed and North Fork Feather than in other subwatersheds (Figure 3, Table 2) and highest in Deer Creek (data not shown). Ammonia and TKN occur in a different part of the nitrogen cycle and are higher in the upper watershed than the lower, especially in the Middle Fork Feather (Figures 4 and 5, Table 2). All 3 forms of nitrogen measured can vary widely among years (Figure 6) and within years, as is reflected in the sometimes large 95% confidence intervals (Table 2).

**Figure 3 — Mean + 95% C.I. concentrations for dissolved nitrate+nitrite (mg/L) in each subwatershed during the latest year in which sufficient data were available (all years between 2007-2009).**

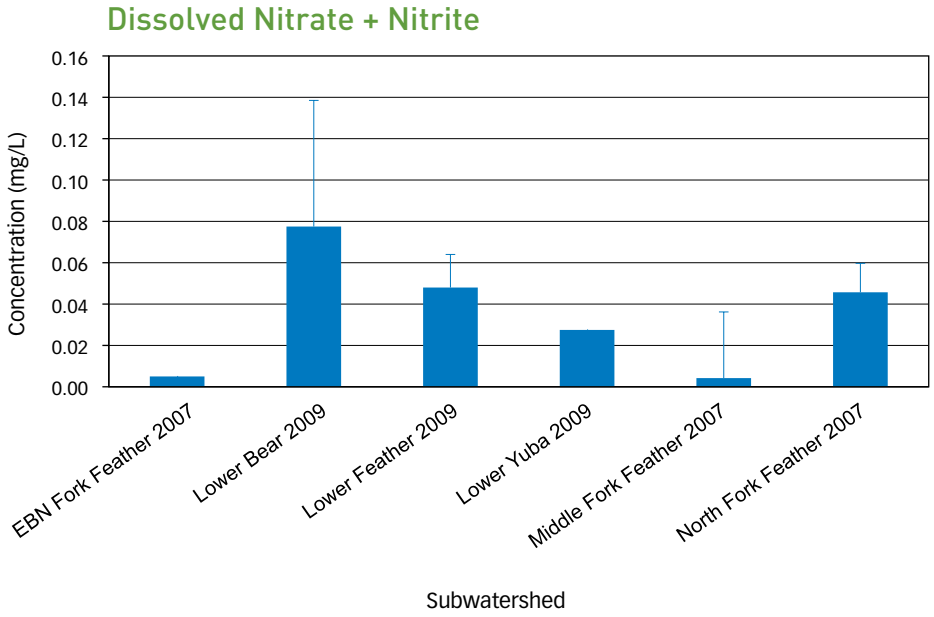


Figure 4 — Mean + 95% C.I. concentrations for dissolved ammonia (mg/L) in each subwatershed during the latest year in which sufficient data were available (all years between 2007-2009).

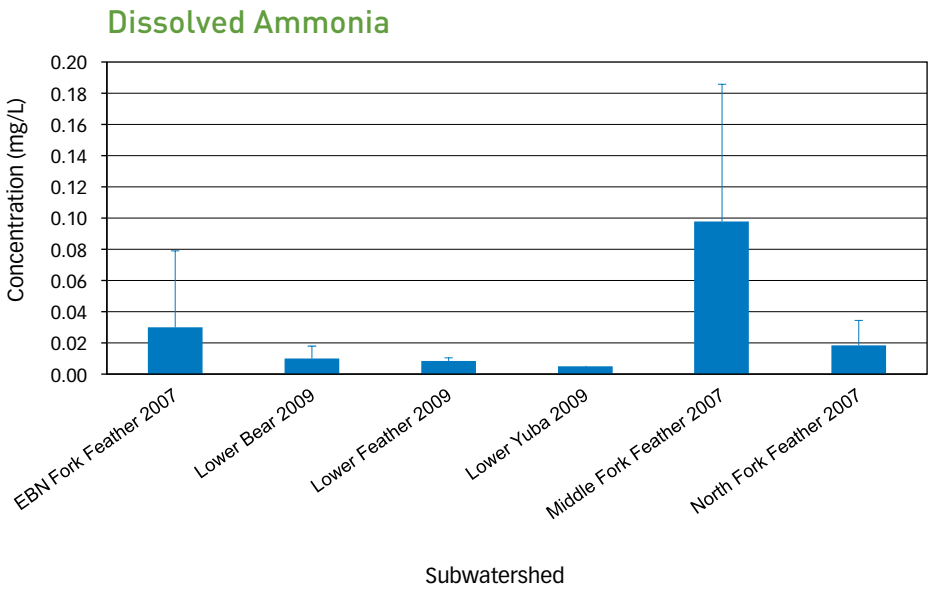



Figure 5 — Mean + 95% C.I. concentrations for total Kjeldahl nitrogen (mg/L) in each subwatershed during the latest year in which sufficient data were available (all years between 2007-2009).

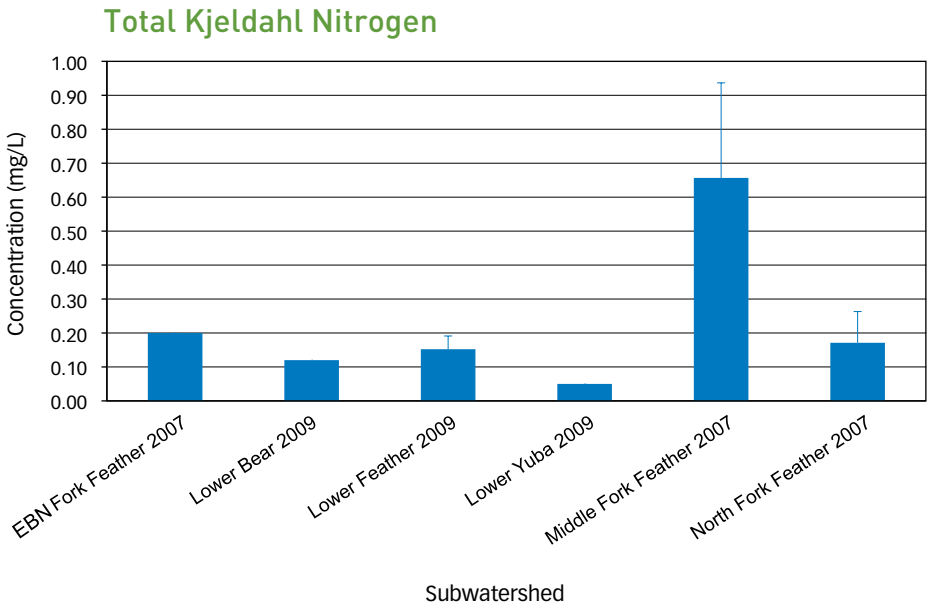
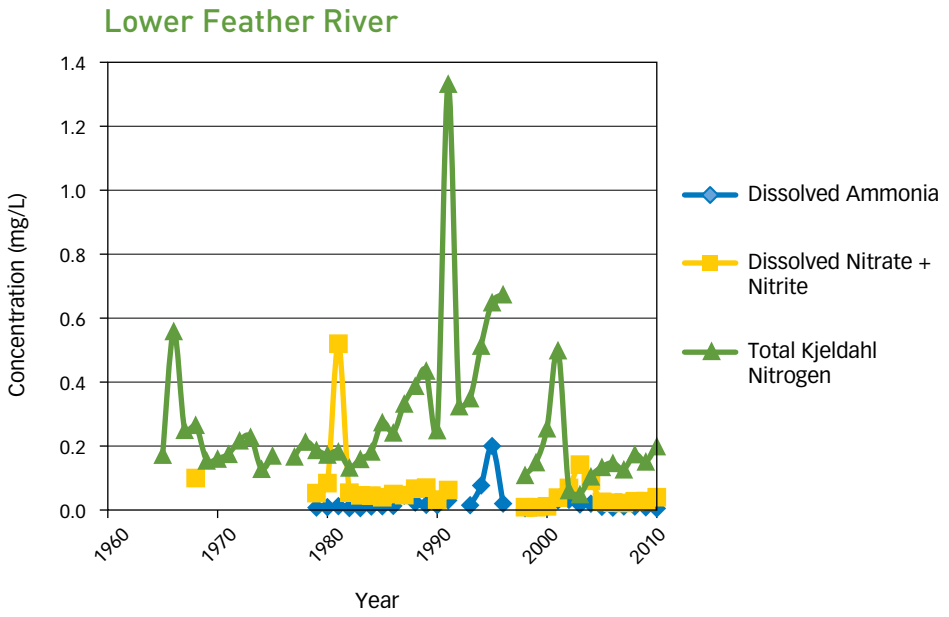


**Figure 6 — Mean concentrations averaged across sites in the Lower Feather River for dissolved nitrate + nitrite, dissolved ammonia, and total Kjeldahl nitrogen (all mg/L) for all years in which data was available**




## Temporal and spatial resolution

Data were available for most subwatersheds at some point in the last several decades, but only a few waterways, such as the Lower Feather River, had long-term data sets, the longest of which are shown in Figure 6. The remainder of the subwatersheds had spatially and temporally sporadic sampling for various forms of nitrogen (and phosphorous). Data were gathered for monitoring sites in 7 of the subwatersheds, covering 1949 to 2010, with most measurements being in the last decade.

## How sure are we about our findings (Things to keep in mind)

We focused our scoring on TKN concentrations — total organic nitrogen + ammonia. Nitrate concentrations are also available for waterways in the watershed, but nitrate concentrations may have less meaning ecologically when considering nutrient cycling, except at very high concentrations such as were found in Deer Creek. TKN includes ammonia, which is a fertilizer and at high enough concentrations is toxic to aquatic life. One waterway was scored based upon nitrate concentrations — Deer Creek, because it has had extremely high concentrations of nitrate in the past (>10 mg/L), concentrations that are toxic to humans in drinking water. In the upper watershed and in the absence of human activities (waste-water treatment, septic systems, livestock), higher concentrations of TKN may be indicative of healthy inputs of organic material into a river, such as the Middle Fork Feather (Figure 5). Because concentrations in this subwatershed were much higher than other subwatersheds, its lower score is a cautionary note rather than a conclusion that conditions are poor.

A large amount of nitrogen and other nutrient data has been collected over the past fifty years in the Feather River Watershed, but the methods, chemical species, and locations of data collection have varied greatly. This makes it difficult to apply statistical tools and determine what, if any longer term trends are occurring in each region. However, since we know nutrients play such an important role in ecosystem dynamics and health, the standardized collection of nutrient data would greatly aid in future watershed assessments. We recommend that both total and dissolved forms of nitrogen, sulfur and phosphorus, as well as flow data be collected across the watershed in a standardized method. These nutrient data coupled with flow data will allow analysis of nutrient flux, which will give a much better indication of nutrient content per area because high variability in flow rates can result in vastly different dilution factors for the concentrations observed. This may obscure trends between sites with different flows, and also may mask true trend within sites when flow rates vary widely between wet and dry seasons. Secondly, if both nitrogen and phosphorus data are collected, N:P ratios can be assessed. This ratio can be very important in determining which nutrients are limiting a system. Since these two nutrient cycles are often inextricably linked and many agricultural areas leach different forms of either or both of these nutrients from fertilizers and, it would be very advantageous to monitor both nutrients in concert with one another. Though some flow and phosphorus data are currently available to conduct these types of analyses in certain regions, due to time constraints of this pilot project we were unable to conduct these analyses.

## Technical Information

### DATA ANALYSIS, TRANSFORMATIONS AND ANALYSIS

Data for 129 sites throughout the watershed was gathered, comprising >6,900 measurements taken by various agencies and non-profit groups of total Kjeldahl nitrogen, dissolved ammonia, and dissolved nitrate + nitrite. Total Kjeldahl nitrogen (TKN) is the sum of organic nitrogen, ammonia ($NH_3$), and ammonium ($NH_4$+). Though other forms of nitrogen data were available (total for each species, DON, etc.), we chose these three as representative of nitrogen condition because they were most consistent. All are reported in mg/L. We calculated basic statistics for each per year for each subwatershed; however, data collection and reporting methods were generally too variable over time to apply more advanced statistical methods with confidence. Concentration values and corresponding scores for each subwatershed were reported for the last year in which robust data is available (all between 2007-2009). Mean TKN concentrations were converted to scores for each subwatershed using 0.1 mg/L as a score of 0 and 1 mg/L as a score of 100, with a linear calculation of score between these concentrations and values.

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# Section 3.4 – Fire and Flooding

**GOAL: D.** Maintain and restore natural disturbance processes that balance benefits for natural and human communities Macroinvertebrates

**OBJECTIVE: 1.** Reduce high severity fire frequency to more natural levels; encourage natural fire regimes that support native communities

**OBJECTIVE: 2.** Reduce flood risk to human communities and encourage natural flood processes that support native communities

The following indicators were used to evaluate fire and flood risk conditions:

- Fire Frequency
- Flooding and Floodplain Access

## 3.4.1 – Fire Frequency

**GOAL: D.** Maintain and restore natural disturbance processes that balance benefits for natural and human communities

**OBJECTIVE: 1.** Reduce high severity fire frequency to more natural levels; encourage natural fire regimes that support native communities

**WAF ATTRIBUTE:** Natural Disturbance

### What is it?

This indicator is a comparison of observed fire frequency to expected fire frequency over a series of decades spanning the last 100 years. Fire return interval, a measure of fire frequency, is a measurable property of terrestrial vegetation that tells us about how natural a fire regime is in an area. This measure is used to score the subwatersheds based on expected fire frequency derived from CalVeg vegetation data.

### Why is it Important?

How many fires occur each year in a particular place is an indicator of the state of the landscape regarding the health of plant communities. Specifically, disease pressure, drought, no-burn management practices

and timber harvest can directly impact the health of a natural landscape which can be observed in wildfire activity. Forests in a region damaged by increases in pest activity, dry from drought, laden with excessive fuel can burn more frequently and in greater extent. Other factors are also important such as fire intensity, and must be considered along with this information.

## What is the target or desired condition?

Fire is a natural part of the Sierra Nevada ecosystem. Historically, fires have naturally ranged from slow-burning under-story fires to raging stand-replacing fires (SNEP, 1996). The target condition for this indicator is for fire patterns and frequencies to oscillate around the central tendency of historical conditions. This is reflected in the vegetation-specific fire return intervals used for this indicator, where return intervals and the corollary frequencies, vary with vegetation type. The undesired condition set for this indicator is both zero fires and greater than twice the natural frequency. Therefore, a score of zero is attained under either of these conditions. A desired trend is for actual fire frequency to return to natural frequencies, depending on the vegetation present and danger to human communities.

## What can influence or stress condition?

Fire is affected by climatic variables such as preceeding year's moisture, El Niño cycles, and the Pacific Decadal Oscillations (Taylor and Beaty, 2005, Norman and Taylor, 2003, Morgan et al., 2008, Skinner et al., 2008). In fact, fire is so strongly determined by these climatic factors that land management seems to play only a minor role in regional fire patterns, except in changing vegetation patterns (through logging), locations of fire suppression (urban development), and soil moisture (thinning and clear-cutting).

## What did we find out/How are we doing?

Fire frequency condition scores for the last decade were low for all subwatersheds, reflecting departure of the current fire patterns from historical conditions (Table 1, Figure 1). Only the Lower Feather subwatershed had anything approaching the historical fire frequencies. In this case, 7 of 19 planning watersheds (smaller creek drainages) had fires in the last decade. Throughout the watershed over the last century, there have been large areas of every subwatershed that has not had a mapped fire.

**Table 1 — Report Card scores for fire frequency for subwatersheds**

| Goal | Measurable Objective | Subwatershed | Score (2000-2007) |
|---|---|---|---|
| D. Maintain and restore natural disturbance processes that balance benefits for natural and human communities | 1. Reduce high severity fire frequency to more natural levels; encourage natural fire regimes that support native communities | NFF | 9 |
| | | EBNFF | 2 |
| | | MFF | 14 |
| | | LF | 39 |
| | | NY | 2 |
| | | MY | 3 |
| | | SY | 4 |
| | | DC | 12 |
| | | LY | 15 |
| | | UB | 0 |
| | | LB | 4 |

### *Trend Analysis*

In order to find out if there was any change in fire frequencies over the century of record for the watershed, number of fires per decade were summed per subwatershed and the Mann-Kendall and Regional-Kendall trends analyses conducted (section 4.3). There were no significant trends for any subwatershed in numbers of fires per decade, where significance was measured as $p < 0.05$. this means that the number of fires per decade is neither increasing or decreasing over the last 100 years in any subwatershed.

## Natural Disturbances

### Fire Frequency

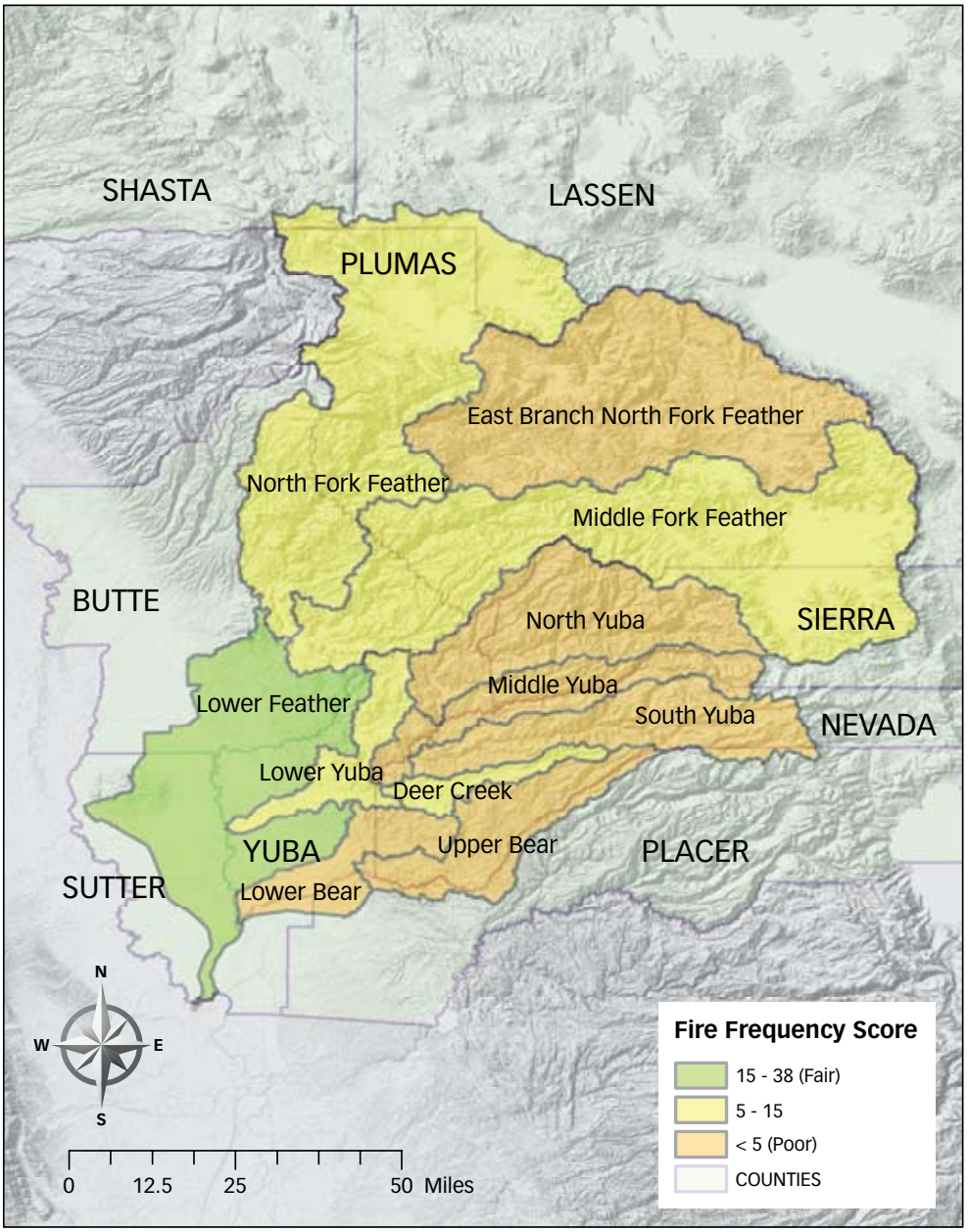



Figure 1 — Fire frequency condition scores for subwatersheds

## Temporal and spatial resolution

Fire data are updated on an annual basis and are available as an online GIS dataset. The fire perimeter resolution is high and fires less than one acre are recorded in the dataset. The CalVeg vegetation data were created in 1979, and were recently updated (2000). The spatial resolution is based on the LandSat Multispectral Scanner (MSS) images with a resolution of 80 meters. The smallest CalVeg areas reported are less than one hectare.

## How sure are we about our findings (Things to keep in mind)

The method used here of evaluating the last decade for condition (2000 – 2007) is prone to one systematic error — if fire frequencies are low or high in that decade for climatic reasons, the score will reflect that. The scores were in fact lower than the equivalent scores for the last century for 9 of the 11 subwatersheds (Table 2), suggesting that the fire frequencies have recently been low. Measuring fire frequency at the decade time scale is also challenged by the presence of vegetation types that would naturally not burn at greater than once every 20-30 years (Table 3). Thus decadal scores calculated in the way we did would tend to be variable.

**Table 2 — Comparison of last decade condition score with the scores for previous century**

| Subwatershed Name | # PW in Subwatershed (count) | Minimum 100-year Score for any PW | Maximum 100-year Score for any PW | Average 100-year Score for all PW | Average Score 2000-2007 |
|---|---|---|---|---|---|
| Deer Creek | 8 | 0 | 32 | 11 | 12 |
| East Branch North Fork Feather | 75 | 0 | 96 | 23 | 2 |
| Lower Bear | 10 | 0 | 66 | 38 | 4 |
| Lower Feather | 19 | 0 | 92 | 13 | 39 |
| Lower Yuba | 14 | 0 | 96 | 31 | 15 |
| Middle Fork Feather | 98 | 0 | 98 | 28 | 14 |
| Middle Yuba | 20 | 0 | 95 | 25 | 3 |
| North Fork Feather | 86 | 0 | 97 | 20 | 9 |
| North Yuba | 34 | 0 | 71 | 15 | 2 |
| South Yuba | 25 | 0 | 95 | 20 | 4 |
| Upper Bear | 21 | 0 | 92 | 30 | 0 |

## Technical Information

### DATA SOURCES:

Fire data were sourced from the CalFire FRAP as a GIS layer that logged each known fire occurrence since 1900. The location and extent are stored as polygons with attributes such as date, cause and cost of fighting the fire (if available). Fire return intervals were obtained from Nagel et al. (2005) and Stephens et al., (2007) and are presented in Table 3. Vegetation classes were acquired from the USFS CalVeg statewide natural vegetation database (http://www.atlas.ca.gov/).

### DATA TRANSFORMATIONS:

The fire return intervals from the literature were converted to expected 10-year and 100-year fire frequency. These values were assigned to the CalVeg vegetation polygons.

**Table 3 — Expected fire frequency by vegetation class**

| Vegetation Class | Fire Return Interval (years) | Vegetation Class | Fire Return Interval (years) |
|---|---|---|---|
| Annual Grass - Forb | 3 | Mixed Conifer - Pine | 8 |
| Barren | 3 | Montane Mixed Shrub | 28 |
| Black Oak | 8 | Mountain Hemlock | 20 |
| Blue Oak | 8 | Mule Ears | 30 |
| Canyon Live Oak | 13 | Perennial Grass | 3 |
| Deerbrush | 28 | Red Fir | 15 |
| Desert Ironwood | 30 | Sagebrush | 30 |
| Greenleaf Manzanita | 28 | Tobacco Brush | 28 |
| Interior Live Oak | 8 | Urban - Agriculture | 3 |
| Jeffrey Pine | 16 | Water | 28 |
| Lodgepole Pine | 25 | Western Juniper | 30 |
| Mariposa Manzanita | 30 | Whiteleaf Manzanita | 30 |
| Mixed Conifer - Fir | 8 | | |

### ANALYSES:

Fire boundary data were located for the watershed. The number of fires was calculated per year for each of the planning watersheds (referred to as observed fire frequency). These values were combined into 10-year and 100-year summaries to compare decadal trends in fire activity over the century. Ten-year and 100-year fire frequency was calculated based on CalVeg vegetation classes using an area weighted average of the vegetation polygons for each planning watershed. Actual frequencies were compared to expected frequencies at the planning watershed resolution.

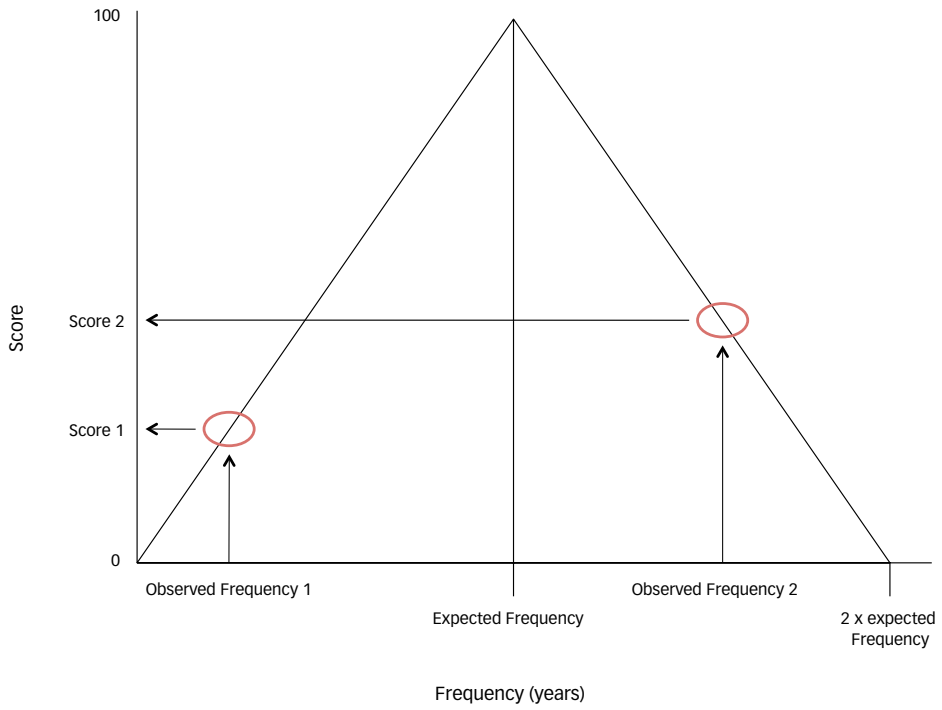
The comparison is standardized by generating a value (score) ranging from zero to 100 depending on how close the observed fire rate was to the expected fire frequency. A linear relationship between observed fire frequency and the score was established from zero to the expected fire rate (Figure 2). This relationship was mirrored for values greater than the expected frequency until the score reached zero (and remained zero for all greater values). The same scoring scenario was used for the 100-year analysis. The set of equations for the scoring follows:

**Table 4 — Scoring scenario for 100-year analysis**

| | |
|---|---|
| a. when observed frequency < 10yr expected frequency | Score = observed 10yr frequency / expected 10yr frequency times 100 |
| b. when 10yr expected frequency < observed < 2 x 10yr FR prob | Score = ((2 x 10yr FR frequency) - observed) / 10yr FR frequency times 100 |
| c. when observed > 2 x 10yr Expected Frequency | Score = 0 |

The scores were calculated for all planning watersheds, then aggregated to the subwatershed scale using an area weighted average score of the planning watershed scores. This was completed for each decade and for the entire century of records.

**Figure 2 — Relationship between score and fire frequency. Two example observed frequencies and corresponding scores are shown.**

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# 3.4.2 – Flooding and Floodplain Access

## Proportion of River with Floodplain Access

**GOAL: D.** Maintain and restore natural disturbance processes that balance benefits for natural and human communities

**OBJECTIVE: 2.** Reduce flood risk to human communities and encourage "wise" development (outside of floodplains); encourage natural flood processes that support native communities

**WAF ATTRIBUTE:** Natural Disturbance

## What is it?

A floodplain is an area adjacent to a river or stream that is periodically inundated with water when the river level rises over the banks. The total floodplain area that is available to a river is a measure of how well a watershed is able to handle a flood and support floodplain vegetation (e.g., cottonwood trees) and aquatic (e.g., fish) communities. Two indicators are used to determine how capable a watershed is at buffering the effects of a flood to downstream areas. The first is informed by two metrics: 1) how much floodplain the river has access to (i.e., what proportion of the area adjacent to a river can be flooded) and 2) what length of the channel is confined by levees. The second indicator is the severity of a 50-year flood event. Fifty-year flood events are when water levels are high enough to significantly flood a river's banks and pose risks to communities.

## Why is it Important?

Riparian floodplain systems are among the most dynamic and complex habitats on earth (Feyrer et al. 2006a). The health of a river and/or stream is very much dependent on the degree of connectivity it has with its floodplain and the number of regular flood events. Flood events provide important hydrologic and geomorphic functions that result in sediment deposition, ground water recharge, point bar formation, and scour events which are necessary for the maintenance, recruitment, and growth of riparian forests (Scott et al. 1997), as well as directly contributing to local productivity and biotic interactions (Lehman et al. 2008). For example, many plant and invertebrate species have developed life history adaptations which make them dependent on flood events for reproduction and/or enable them to exploit seasonal floodplain habitats (Opperman 2008; Stella et al. 2006; Feyrer et al. 2006a). The Sacramento River and tributary streams throughout the basin provide critical spawning and rearing habitat for salmon, trout and other resident fish species.

At the same time it is important to take into consideration the effects that flooding can have on human communities and activities. Towns and cities have traditionally been constructed in the lower reaches of the watershed, where fertile soils for farming are located, but where flooding presents a hazard to human life. For example, Yuba City, Marysville and Oroville have developed parts of the floodplain without adequate planning which has lead to drainage problems and localized flooding of streets and low lying properties. Future growth of cities and towns in the floodplain will put further pressure on floodplains by increasing the height of levees to minimize the risk of flood events, as well as building new levees in currently unconstrained floodplains. Rather than keeping floodwaters out of the floodplain, communities should explore ways to encourage flooding in areas that have habitat benefits for floodplain dependent species and which are not currently heavily developed.

## What is the target or desired condition?

The desired watershed condition is to have sufficient floodplain access to: 1) minimize the risk of flood events to communities; and 2) provide floodplain habitat to aquatic and terrestrial species that are dependent on floodplains for their survival. In addition, low levels of development and infrastructure should be located in areas that are prone to flooding so that channel alteration and construction of levees can be minimized. Given that each watershed has an existing level of development in the floodplain area desired conditions will vary by watershed. The target for the Report Card was likely historic or natural conditions. Identification of a desired condition and/or target is something that communities should decide through the use of zoning and future development plans.

## What can influence or stress condition?

The present day floodplain has been greatly modified through the use of flood control mechanisms including levees, dams, river channelization, and rip-rapping. As a result of these flood control mechanisms, floodplain dependent species in many subbasin watersheds have been impacted or even eliminated resulting in a loss of aquatic and riparian biodiverisity. For example, the cumulative effecst of the Oroville and Shasta dams are thought to be the reason why the Tiger beetle is no longer found in the Lower Feather River Watershed. Because of the dams, the sandy edge river habitat and periods of prolonged flooding that the Tiger beetle needs to survive no longer exist (Knisley and Fenster 2005). In addition, the construction of levees results in the isolation of floodplains from their waterways, which in turn negatively impacts river ecosystem health. Lack of organic material and debris transport from the floodplain into the river channel decreases the available food and habitat for fish and aquatic organisms, thereby reducing fish populations and aquatic productivity. Dams significantly alter the frequency, intensity and duration of floodplain inundation leading to a simplification of the downstream and floodplain vegetation, animal, and fish communities.

## What did we find out/How are we doing?

Combined scores for flooding and floodplain access for the lower elevation subwatersheds are given in Table 1 and shown in Figure 1. With regards to flood frequency, the analysis shows that the size of a 50-year flood was larger prior to the construction of dams in each of the subwatersheds or upstream portions. The explanation for this observation is that dams and reservoirs were built to attenuate floods by holding back large volumes of water in the upper watershed and slowly releasing this water over time. The effect of dam associated flood attenuation on 50-year flood size was most clearly seen in the Lower Feather River where Oroville Dam is located. The results for flood acres show that the lower Yuba has the greatest access to its floodplain and the fewest number of levied river kilometers.

### Table 1 — Subwatershed scores for flooding and floodplain access

| Goal | Measurable Objective | Subwatershed | Score |
|---|---|---|---|
| D. Maintain and restore natural disturbance processes that balance benefits for natural and human communities | 2. Reduce flood risk to human communities and encourage "wise" development (outside of floodplains); encourage natural flood processes that support native communities | NFF | n/a |
| | | EBNFF | n/a |
| | | MFF | n/a |
| | | LF | 43 |
| | | NY | n/a |
| | | MY | n/a |
| | | SY | n/a |
| | | DC | n/a |
| | | LY | 70 |
| | | UB | n/a |
| | | LB | 38 |

## Natural Disturbances

### Flooding and Floodplains

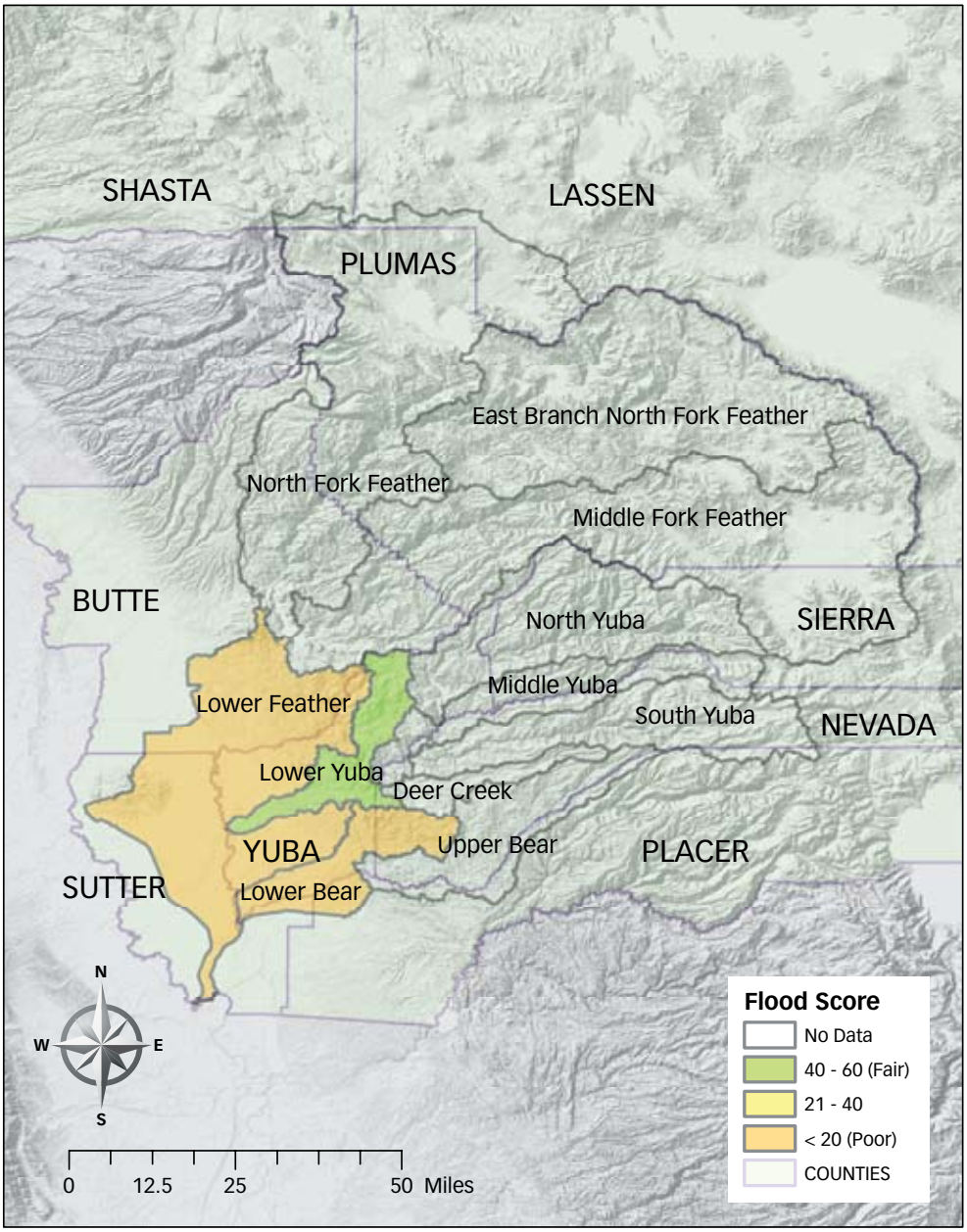


Figure 1 — Flooding and floodplain access score distribution across subwatersheds

Based on analyses, the Lower Yuba has the greatest ability to mitigate the disruptive effects of floods to downstream communities while also providing habitat for floodplain dependent species. Floods are not as strongly attenuated by dams in the Lower Yuba because there are other "natural" mechanisms (i.e., floodplain access) which help to mitigate the risks posed by floods. In other words, even though post-dam 50-year flood events are closer in size to pre-dam 50-year flood events, the lower Yuba has retained the ability to flood its banks in areas that do not pose risks to human communities, thus minimizing the risk of flooding in areas where communities are located. The high degree of floodplain connectivity in the Lower Yuba is an artifact of the hydraulic mining that occurred in the area, where the presence of the Yuba Goldfields made building levees downstream for flood control unnecessary. The river can pool and flood the Goldfields (i.e., fill all the interstitial spaces in the mining debris) which attenuated the flow of water downstream. In addition, hydraulic mining debris prevented the development of infrastructure in some parts of the floodplain, thereby minimizing risk to communities. It is important to note the presence of the Goldfields have ecological ramification with respect to aquatic connectivity and water quality. The Lower Feather ranked second overall, and the Lower Bear ranked last.

## Temporal and spatial resolution

In the Feather River Watershed, data on floodplain access is only available for the lower portions of the watershed, consequently, commentary can only be made on floodplain access and flood risk for the lower part of the Feather River Watershed. In the upper watershed, local flooding will be desired to recharge groundwater (e.g., in montane meadows), improving summer base-flows. Spatial data for flood infrastructure allowed only a snapshot in time, prohibiting any kind of trend analysis.

## How sure are we about our findings?

With regard to flood acre score and levee score, uncertainty is present because it is not known whether further development (i.e., levee construction) has occurred in the subwatersheds since the infrastructure was last mapped. With regard to flood severity, there is moderate confidence in the finding because natural flow data for each subwatershed are not available (i.e., flow data from before any dams were present). Consequently, the flood severity score is likely an overestimate (too high) because the size of the current 50-year flood is substantially smaller than the 50-year flood in the absence of any dams.

## Technical Information

### DATA SOURCES

- USGS 1:100,000 topographic maps
- USGS gauges; Lower Feather: Thermalio (11406920), Oroville (11407000), Lower Yuba (11421000), Deer Creek (11418500), Lower Bear (11424000)
- USFS and DFG meadow data
- CA dam inventory
- State and federal project levees positions were digitized from the Sacramento River LFPZ map (DWR, 2009)
- Flood map for the Butte Basin, Lower Feather River Watershed, was obtained from USGS Open File Report 80-971, June 1981.

### DATA TRANSFORMATIONS

- Data were projected to Teale Albers NAD83
- LFPZ map was geo-referenced in ArcGIS using road-intersections from a geo-referenced USGS quad-map.
- Areas permitted to flood were delineated using levees and boundaries of wildlife areas adjacent to rivers

### ANALYSES

A score was created for each metric: a flood acre score, a levee score, and a flood frequency score. The overall score for a subwatershed is the average of the three metric scores (Table 2), which are evenly weighted. It is not possible to calculate confidence intervals for these metrics because the data are obtained from a single map in the case of levees and floodplain acres or from a single flow gauge in the case of flood severity, consequently there is no sampling error associated with them.

Levee score is the ratio of length of the channel (i.e., in "river-miles") with levees on one or both sides of the river channel to the total length of the channel. Flood acre score is the ratio of the floodplain area that is still accessible to the channel relative to the historical floodplain area that was accessible. Flood severity score is a measure of the size and severity of a 50-year flood post dam relative to the size and severity of a 50-year flood pre-dam.

Levee score: To measure the area available for flooding in the lower watershed the number of river kilometers without levees was compared to the number of river kilometers with levees. The greater the value the fewer river kilometers there are with levees.

Flood acre score: The percentage of the total area that was historically expected to flood that is made up of the area where regular flooding is permitted within the confines of flood management infrastructure (e.g., the entire bypass, the areas between levees and areas designated as wetlands or wildlife areas adjacent to the river).

Flood severity score: A measure of the size and severity of a 50-year flood post-dam construction relative to the size and severity of a 50-year flood pre-dam. A score is obtained using the formula:

$$Score = 1 - \left| \frac{observed - historical}{historical} \right|$$

### Table 2 — Summary of scores for floodplain and flooding access metrics

| Subwatershed | Flood acre score | Levee score | Flood severity score | Overall Score |
|---|---|---|---|---|
| Lower Bear | 0.12 | 0.17 | 0.83 | 0.38 |
| Lower Feather | 0.27 | 0.13 | 0.90 | 0.43 |
| Lower Yuba | 0.79 | 0.65 | 0.66 | 0.70 |

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# Section 3.5 – Community, Social and Economic Conditions

**GOAL: E.** Maintain and improve the social and economic conditions, including benefits from healthy watersheds

**OBJECTIVE: 1.** Protect and enhance wildlife friendly agricultural practices

**OBJECTIVE: 2.** Improve community economic status in balance with watershed condition

The following indicators were evaluated to measure community and social and economic conditions:

- Pesticide application and organic agriculture
- School lunch program enrollment

## 3.5.1 – Pesticide Application and Organic Agriculture

**GOAL: E.** Maintain and improve the social and economic conditions, including benefits from healthy watersheds

**OBJECTIVE: 1.** Protect and enhance wildlife-friendly agricultural practices

**WAF ATTRIBUTE:** Social Condition

### What is it?

Pesticide use can impact terrestrial and aquatic biota and ecosystems, as well as affect human health. For this indicator, relative levels of pesticide use in agricultural areas for the 11 subwatersheds from 2008 are reported. In California, data on pesticide use is reported at a relatively fine spatial scale (a square-mile section) in a time series dating back to 1974. The presence of organic farming is another component of wildlife-friendly agricultural practices (Hole et al. 2005). Measures such as the trend in the number of acres farmed and the amount of sales from organic agriculture suggest the level of adoption of such practices. Therefore, trends in organic agriculture in the watershed from the years 2000 to 2005 are also examined. These

data are reported at the county level (Klonsky and Richter 2007). Our focus on pesticide use and organic agriculture does not exclude consideration of other positive and negative impacts of farming on community and wildlife health.

## Why is it Important?

There is a suite of agricultural practices that enhance the ability of working landscapes to support wildlife communities. There is debate about whether biological conservation is best promoted by a strategy of intensive agriculture together with separate conservation reserves or by a strategy of widespread adoption of wildlife-friendly farming practices such as organic agriculture (Fischer et al. 2008). It is clear that management practices such as reduced use or elimination of chemical pesticides or inorganic fertilizers, appropriate management of the un-cropped landscape, and mixed farming (i.e. integration of crops with livestock) benefit a wide variety of taxa in terms of their abundance and species richness at a local scale (Hole et al. 2005, Chamberlain et al. 2010, Fuller et al 2005). Metrics that capture these practices not only indicate improved health of biological communities, but also suggest synergy between economic and ecological health within the watershed. Adoption of organic farming would indicate broader acceptance of wildlife-friendly agricultural practices, as does reduction in total pesticide load.

## What is the target or desired condition?

This report assumes that the best possible condition for communities and wildlife would be the universal adoption of wildlife-friendly agricultural practices throughout the watershed. Accordingly, this analysis rates "no pesticide use at all" with a score of 100. This analysis assumes the worst possible case as the 95th percentile rate of pesticide use per unit area anywhere in the Sacramento Valley, and assigns this level a score of 0. This also assumes that a rising trend in organic agriculture also reflects approaching the target condition.

## What can influence or stress condition?

Pesticide usage is affected by many factors, including change in the crop mix and the number of acres planted, changes in pest pressure, and differing weather conditions (California Department of Pesticide Regulation. 2009.) Economic demand for organic food is another important driver affecting this condition and reflects social desires for more sustainable agricultural practices that don't harm communities and ecosystems.

## What did we find out/How are we doing?

Given the intensive agriculture in the Sacramento Valley, it is not surprising that the three lower subwatersheds (Lower Feather, Lower Yuba, and Lower Bear) score low on the index of pesticide use (Figure 1 and Table 1). The mid- to upper-elevation subwatersheds either have very low amounts of land in agriculture or have their agricultural land devoted to pasture; in either case, there are relative small amounts of pesticide applied to agricultural land in these subwatersheds. The trend in organic farming, as indicated by trends in organic acreage (Figure 2) and organic crop sales (Figure 3) is either steady or increasing across time, depending upon the county.

## Social Condition

### Wildlife-Friendly Agriculture

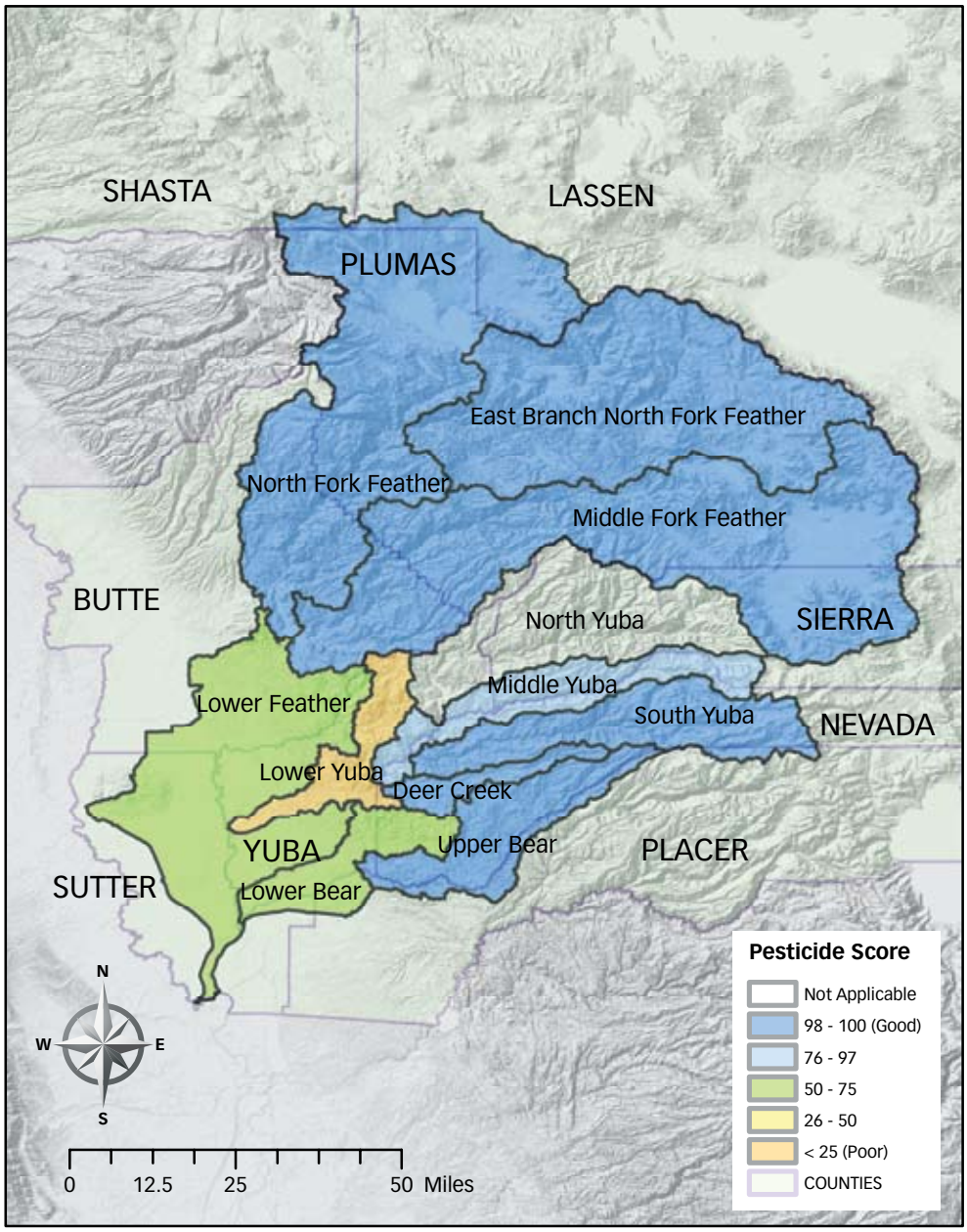


Figure 1 — Pesticide application scores across subwatersheds

**Table 1 — Report Card scores for wildlife-friendly agriculture for subwatersheds. "n/a" refers to data not being available or the trend is unknown.**

| Goal | Measurable Objective | Subwatershed | Score | Trend |
|---|---|---|---|---|
| E. Maintain and improve the social and economic conditions, including benefits from healthy watersheds | 1) Protect and enhance wildlife-friendly agricultural practices | NFF | 99 | n/a |
| | | EBNFF | 100 | ↗ |
| | | MFF | 100 | ↗ |
| | | LF | 51 | ↗ |
| | | NY | n/a | n/a |
| | | MY | 98 | n/a |
| | | SY | 100 | n/a |
| | | DC | 100 | No change |
| | | LY | 17 | ↗ |
| | | UB | 100 | No change |
| | | LB | 62 | n/a |

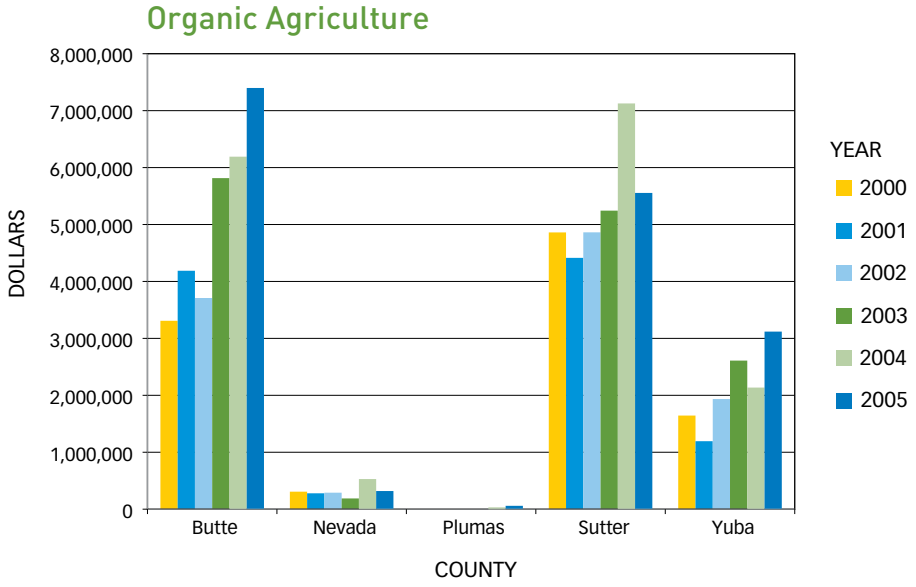


**Figure 2 — Acres in Organic Agriculture**

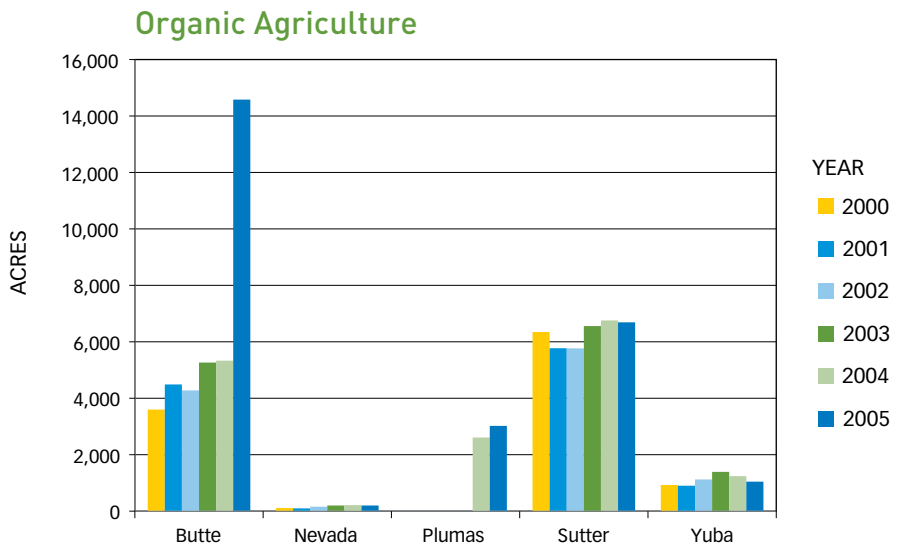


Figure 3 — Organic Agriculture Sales

## Subwatershed Discussion

Deer Creek — Agriculture in this subwatershed consists mainly of mid-elevation vineyards. The indicator score is near the maximum value of 100, which may reflect fallow lands reported as in agriculture, or simply low levels of pesticide application in this crop type in this region. There are several organic vineyards in the Nevada City area, which is reflected in modest amount of organic agriculture from Nevada County reported in Figures 2 and 3. Based on the Nevada County trends, it appears that there is no upward or downward trend in the amount of organic agriculture in this subwatershed, which will have its own environmental impacts not reflected in the score.

East Branch North Fork Feather — Agriculture here is almost entirely based on livestock grazing and hay production, with no significant use of pesticides. The Plumas County data on organic agriculture shows an increase from essentially no acreage at the beginning of the time period to 3,021 acres in 2005, most of which is pastureland. Some fraction of this increase is assignable to this subwatershed, especially in the Indian Valley area.

Lower Bear — Agriculture production in this subwatershed consists of vineyards in upslope regions and rice and deciduous orchards on the valley floor. Of the three valley floor subwatersheds (the others being Lower Feather and Lower Yuba) it has the best rating for pesticide usage, perhaps because of this cropping pattern diversity. It is difficult to assess trends in organic farming because of an unfavorable alignment of county boundaries and the subwatershed boundary for this analysis.

Lower Feather — Of the subwatersheds in the study, this is the one most dominated by agriculture, with a total of 229,247 acres in agriculture. The indicator score shows fairly high levels of pesticide use, though there is a fair amount of variation, presumably across different crop types. In terms of trends in organic agriculture, the counties that most overlap the subwatershed, Sutter and Butte, show substantial increases in crop revenue, and Butte County shows an increase in acreage as well. Major organic crop types include rice, prunes and peaches.

Lower Yuba — This subwatershed has the lowest indicator score (17) of all the subwatersheds. Agriculture in this subwatershed is mostly limited to deciduous orchards, and dominance by this crop type (which receives high pesticide use) probably accounts for the particularly low score. The increase in sales in organic agriculture in Yuba County is likely mostly due to organic rice and kiwi fruit production, though there may be some organic walnut farming within the watershed.

Middle Fork Feather — Like the East Branch North Fork Feather subwatershed, agriculture in this region is essentially limited to livestock and pasturelands, mostly centered on Sierra Valley. There is no significant use of pesticides in this subwatershed. Some of the increase in organic agriculture in Plumas County discussed above may be attributable to livestock management practices in this subwatershed.

Middle Yuba — Agriculture is an insignificant fraction of land cover on this subwatershed and no appreciable pesticide use.

North Fork Feather — Agriculture is an insignificant fraction of land cover on this subwatershed and no appreciable pesticide use.

North Yuba — There is no appreciable agriculture in this subwatershed, and the indicator cannot be calculated here.

South Yuba — Agriculture is an insignificant fraction of land cover on this subwatershed and no appreciable pesticide use.

Upper Bear — Similar to Deer Creek, the agriculture that exists in this subwatershed is dominated by vineyards, and the indicator value is again near the maximum value of 100. There may be some organic vineyards here, but from the Nevada County trend data, organic farming is probably not changing.

## Temporal or Spatial Resolution

Information on pesticide usage is available annually and is reported to each square mile section in the township-range-section geo-referencing system. Information on organic farm production is available annually and is reported for each county.

## How sure are we about the findings (Things to keep in mind)

The results of this analysis are limited by the coarse spatial scale of the data. There is no available dataset describing organic agriculture at any finer spatial scale than the county level, which makes attribution to subwatersheds difficult. Moreover, many practices that comprise wildlife-friendly agriculture such as maintenance of hedgerows and appropriate grazing management are difficult to map, requiring much fine-scale survey work. Another limitation is that this analysis takes no account of differences in toxicity in pesticides, instead lumping them together as total pounds of all products applied. The analysis thus is unable to detect usage of what are considered to be less toxic types of pesticides. However, pesticides are by definition toxic to at least some organisms, and given that an ecosystem consists of complex interactions among many different types of organisms, it is very challenging to grade levels of toxicity in terms of impacts on the overall ecosystem. This analysis also makes no attempt to distinguish between levels of pesticides on a per-crop type basis.

## Technical Information

### DATA SOURCES & TRANSFORMATIONS

The California Department of Pesticide Regulation maintains a pesticide use reporting database dating to 1974 (California Department of Pesticide Regulation. 2009) from which we have extracted the most recent (2008) dataset for the Sacramento River Basin counties (Butte, Colusa, Glenn, Lassen, Nevada, Placer, Plumas, Sacramento, Sierra, Sutter, Tehama, Yolo, and Yuba Counties). Trends in the amount of organic farming at a county scale are reported in Klonsky & Richter (2007). Their summary is derived from reports by county of organic crop sales filed with the California Department of Food and Agriculture and available online (CDFA California Organic Program, no date). Map information describing patterns in major crop type across the entire watershed was derived from the California Augmented Multisource Land-cover GIS dataset (Hollander 2007).

### ANALYSES

The pesticide use data was imported into PostGIS and linked to a spatial dataset of the Public Land Survey System for California using identifiers for the meridian, township, range, and section. Total pounds of pesticides per section were calculated using standard SQL queries. This dataset was turned into a raster at 100 meter resolution in Geographic Resource Analysis Support System (GRASS) GIS for tabulation by subwatersheds. The value for the total pounds of pesticides was averaged over the agricultural regions in each subwatershed using the California Augmented Multisource Landcover layer to delineate agricultural pixels. The standard deviation for the indicator value was calculated from a subsample of the pixels in the 100 meter resolution raster map, the fraction of the subsample being chosen so as to randomly draw on average one pixel per square mile section. Trends in the amount of organic agriculture in each subwatershed were assessed qualitatively based on the relationship between crop type patterns and county boundaries.

The value calculated through GIS operations for the number of pounds of pesticide per section averaged over each subwatershed was linearly transformed to an indicator score from 0 to 100. The score of 100 in this scale was assigned for the condition of zero pounds

of pesticides, and the minimum score of 0 was assigned for the condition of 19,885 pounds of pesticides, which is the 95th percentile value for the total number of pounds of pesticides on any section in the entire Sacramento Valley watershed.

### Table 1 — Levels of Pesticide Use on Agricultural Lands and Trends in Organic Agriculture

| Subwatershed | Indicator Value | Standard deviation for Indicator Value | Trend in Organic Agriculture | Area in Agriculture (ha) |
|---|---|---|---|---|
| Deer Creek | 99.6 | 1.6 | Steady | 300 |
| East Branch North Fork Feather | 99.9 | 4.5 | Moderately rising | 4185 |
| Lower Bear | 62 | 37 | ? | 15091 |
| Lower Feather | 51 | 38 | Moderately rising | 92775 |
| Lower Yuba | 17 | 51 | Moderately rising | 2973 |
| Middle Fork Feather | 100.0 | 3.9 | Moderately rising | 32817 |
| Middle Yuba | 98 | 9.1 | Not applicable | 161 |
| North Fork Feather | 99 | 1.4 | Not applicable | 70 |
| North Yuba | N/A | N/A | Not applicable | 0 |
| South Yuba | 99.5 | 2.1 | Not applicable | 70 |
| Upper Bear | 99.5 | 0.1 | Steady | 988 |

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# 3.5.2 – School Lunch Program Enrollment

**GOAL: E.** Maintain and improve the social and economic conditions, including benefits from healthy watersheds

**OBJECTIVE: 2.** Improve community economic status in balance with watershed condition

**WAF ATTRIBUTE:** Economic condition

## What is it?

Enrollment of children in school lunch programs is considered to be a sensitive measure of poverty at the sub-municipal scale. Children between 6 and 17-years-old are eligible if family income is less than the federal poverty level. Data are available for every school that is participating in the federal program, including schools in the study area, for the last 20 years.

## Why is it Important?

Poverty and income inequities are correlated with reduced life expectancy (Singh and Siahpush, 2006), child well-being (Pickett and Wilkinson, 2007), and academic performance (Caldas and Bankston, 1997). Enrollment in school lunch programs is an extensive (data available for every school), but fairly general indicator of poverty. We can answer questions related to rate of poverty for individual schools (K-12) and change in this rate over at least the last 20 years. Because rates of enrollment are available for each school, correlations can be drawn between this poverty indicator and other municipal or subwatershed condition and trends in condition.

## What is the target or desired condition?

Community economic conditions can affect opportunities and sense of welfare for children and adults. Absent a state or local policy that defines an acceptable level of poverty, this analysis rates 0% enrollment in a school lunch program as a good target score (100) and 100% school lunch program enrollment as a poor score (0). A linear function was used to calculate score, where Score = 100% - % children enrolled.

## What can influence or stress condition?

Poverty is caused by a variety of factors, including employment availability, legacy of poverty, regional economy, and skills for employment. In this region, historic mining, logging, and contemporary agriculture provide much of the land-based income. Over the last few decades, influx of retirees and ex-urban migration has led to changing demographics, including income. Global and statewide economic trends are likely to influence community economic condition. Communities that derive their economic well-being from productivity that is not controlled or commodified by global markets may be less negatively impacted by economic declines.

## What did we find out/How are we doing?

The economic condition score in the last year for which there was complete data (2008) varied by subwatershed (Figure 1 and Table 1), ranging from a score of 32 (Lower Feather subwatershed) to a score of 75 (Upper Bear subwatershed). At the scale of individual schools, enrollment rates varied from 0% to 100%.

The high score for the Deer Creek Watershed suggests that communities in that watershed have lower levels of poverty than other subwatersheds. The low score for the Lower Feather and Middle Yuba watersheds suggests that communities in these watersheds have higher levels of poverty.

**Table 1 — Community economic condition scores and trends for subwatersheds based on school lunch enrollment rates. "?" indicates that trend is unknown for that subwatershed.**

| Goal | Measurable Objective | Subwatershed | Score | Trend |
|---|---|---|---|---|
| E. Maintain and improve the social and economic conditions, including benefits from healthy watersheds | 2. Community economic status | NFF | 52 | ↘ |
| | | EBNFF | 49 | ? |
| | | MFF | 54 | ↘ |
| | | LF | 34 | ↘ |
| | | NY | 64 | ↘ |
| | | MY | 32 | ↘ |
| | | SY | 40 | ? |
| | | DC | 73 | ↔ |
| | | LY | 35 | ↘ |
| | | UB | 70 | ↘ |
| | | LB | 61 | ? |

## Community Economic Condition

School Lunch Program Enrollment

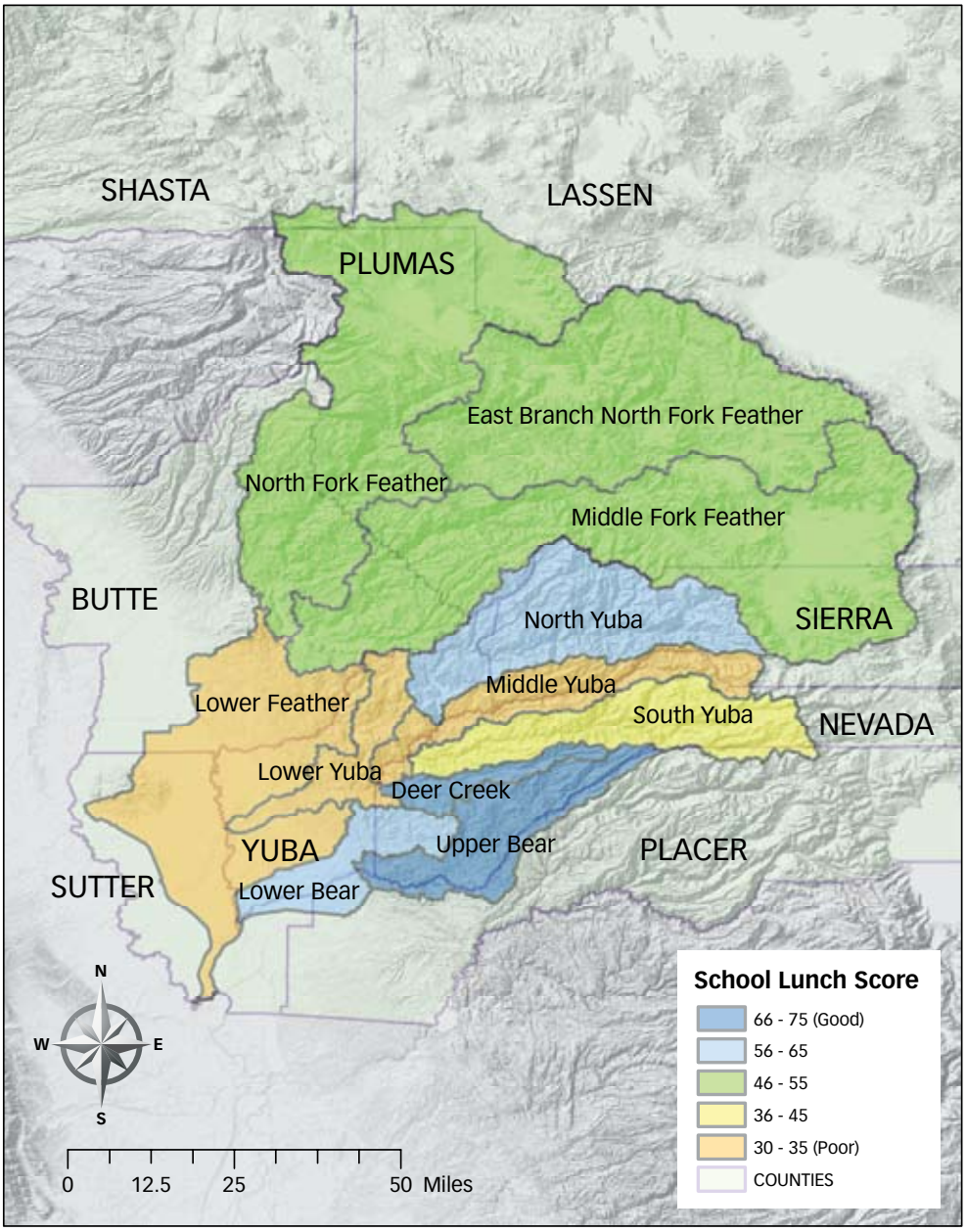
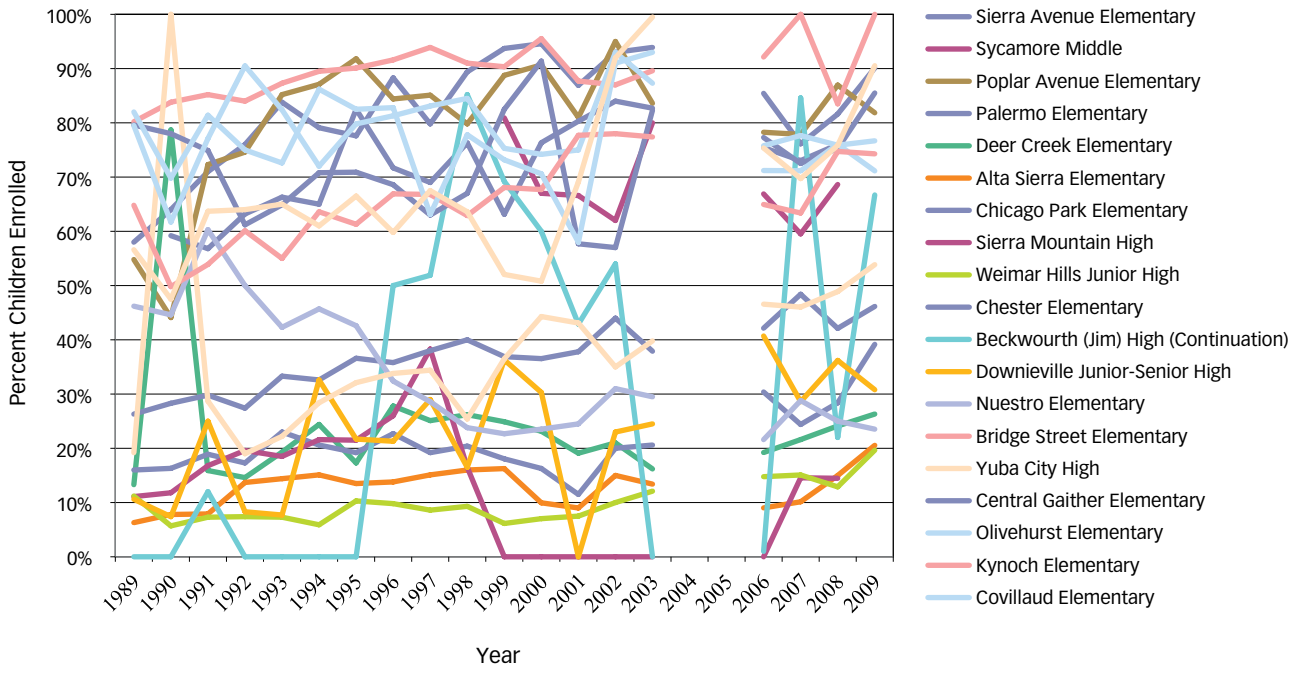



Figure 1 — Distribution of community economic condition scores, based on school lunch program enrollment

### *Trends Analysis*

School lunch enrollment rates at 20 randomly-selected schools were analyzed over the 20-year time period of data (1989 to 2009), excluding 2004 and 2005 data because of rates of enrollment that exceeded 100% for these years (Figure 2). For 11 schools there were statistically-significant increases in enrollment over this time, meaning that community economic conditions were worsening. The trends varied from 0.4% to 2% increases in enrollment per year. For only one school (Nuestro Elementary School in Sutter County) was there a statistically-significant decrease in enrollment (1.5%/year). The remaining schools showed no change in enrollment. An increase in enrollment corresponds to decreasing condition scores (Table 1).

**Figure 2 — Rates of child enrollment in the federal school lunch program for 20 randomly-selected schools in the watershed.**




## Temporal and spatial resolution

Because there are data for every school and every year, spatial and temporal resolution for this indicator is moderate. Annual enrollments are reported for each school participating in the program. Therefore, the assessment can be updated annually, unless monthly data were to be collected from individual schools.

All subwatersheds had at least one school, but there was a wide difference in number of schools between the Lower Feather (51 schools) and the North Yuba (1 school), which affects the calculation and meaning of the average score for each subwatershed.

## How sure are we about our findings (Things to keep in mind)

The data used for this indicator are based on school enrollment figures, reported to the California Department of Education. They are complete for 1989 to 2008, with potential problems with data for certain schools in 2004 and 2005 (e.g., enrollment rates >100%). The precision of these data is likely very high. The calculated average score for each subwatershed reflects the average condition for that area, the 95% confidence interval and minimum and maximum scores reflect the variation around the averages, which can be fairly large (Table 2). One data gap in this analysis is that not all schools or parts of schools enrolled in the Free and Reduced Priced Meal Program have location information that can be used in GIS.

Enrollment is based on a family being below federal poverty level. This means that the metric is not particularly sensitive to geography-specific cost of living variation (Curran et al., 2006; Heflin et al., 2009), which is a limitation in its use. There may also be an effect of peer-pressure on children's desire for enrollment.

Overall our confidence is high in the precision of the indicator, moderate and variable about how well the average value for each subwatershed reflects conditions, and moderate to high for how well the indicator reflects community economic well-being.

**Table 2 — Basic statistics for school lunch program per subwatershed. Minimum, maximum, mean, and 95% C.I. are for percent of children enrolled in each subwatershed. "95% C.I." refers to 95% confidence intervals.**

| Subwatershed | # Schools | Minimum | Maximum | Mean | 95% C.I. | Trend (%/year) | Score |
|---|---|---|---|---|---|---|---|
| Deer Creek | 5 | 15% | 60% | 27% | 15% | N.S. | 73 |
| EBN Fork Feather | 8 | 22% | 100% | 51% | 18% | ? | 49 |
| Lower Bear | 4 | 28% | 52% | 39% | 9% | ? | 61 |
| Lower Feather | 51 | 14% | 100% | 66% | 6% | .61% | 34 |
| Lower Yuba | 6 | 26% | 81% | 65% | 15% | .95% | 35 |
| Middle Fork Feather | 4 | 33% | 67% | 46% | 13% | 1.93% | 54 |
| Middle Yuba | 3 | 59% | 76% | 68% | 8% | 1.01% | 32 |
| North Fork Feather | 4 | 26% | 81% | 48% | 20% | 0.93% | 52 |
| North Yuba | 1 | 36% | 36% | 36% | N/A | 1.11% | 64 |
| South Yuba | 2 | 20% | 100% | 60% | N/A | ? | 40 |
| Upper Bear | 13 | 11% | 70% | 30% | 9% | 0.44% | 70 |

## Technical Information

### DATA SOURCES:

California Department of Education (http://www.cde.ca.gov/ds/sh/cw/filesafdc.asp); USGS Geo-Names Database (http://gis.ca.gov).

### DATA TRANSFORMATIONS:

Data were manually assembled from downloadable files. For school years where the year was given by "88/89" or similar, a new column was created and actual year-dates manually entered corresponding to the end of the school year (e.g., "1989"). Only percent of students receiving "free meals," as opposed to reduced-price, were calculated and used to be consistent over the whole time-span.

### CONDITION ANALYSES:

The percentage of students receiving free meals was extracted from the California Department of Education database for 2008, the last year with complete data. The location of the school was determined using the USGS Geo-Names database in ArcGIS. Each school was attributed with a subwatershed (e.g., North Fork Feather). For each subwatershed, mean, standard deviation, minimum, and maximum percentage of children receiving free lunches were calculated.

### TRENDS ANALYSES:

Random numbers were assigned to each school in the watershed using the Microsoft Excel random number generator. The 20% of schools with the lowest random numbers were chosen for trends analysis, resulting in trends for 20 schools being analyzed. The Mann-Kendall trends analysis was used, using the methods described in Section 4.3.

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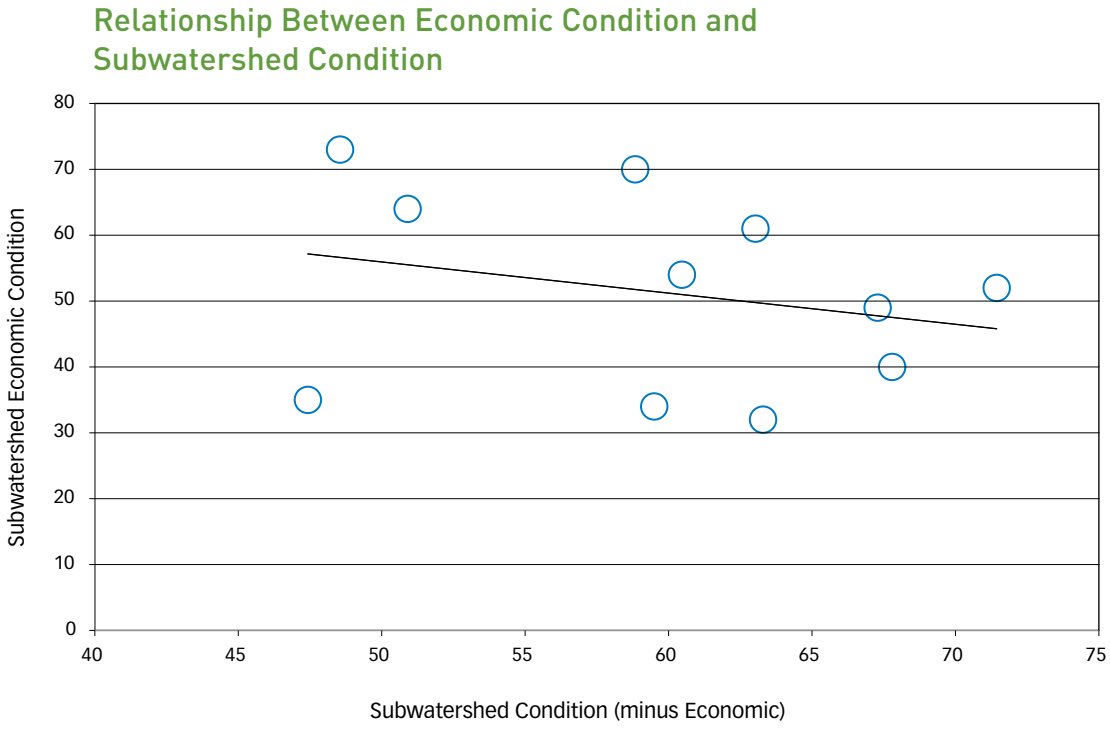
# Section 3.6 — Linkages and relationships among objectives, attributes, and indicators

Not all goals and objectives, or condition indicators are independent of each other and in some cases, one indicates a condition that affects another. Indicators are one method for efficiently characterizing conditions; overlap and directional or causal relationships among indicators may be useful in more integrated understanding of overall watershed condition.

Water temperature (section 3.1.2) is both an indicator and a potential influence on periphyton growth (section 3.1.1), benthic macroinvertebrates (section 3.2.3), and fish communities (section 3.2.4). Water temperature can in turn be influenced by flow alteration (section 3.1.4), and urban & agricultural development (section 3.2.2). Another example is pesticide use (section 3.5.1), which may affect benthic macroinvertebrates (section 3.2.3) and fish communities (section 3.2.4). Pesticide use will be correlated with urban and agricultural development (section 3.2.2).

These inter-dependencies are characteristic of collections of indicators that describe some aspect of integrated systems. They are likely to be tied to other indicators through the relationships among components of the system. Even human well-being may be tied to watershed conditions. When community economic condition is compared to subwatershed condition (minus economic condition), one would hope to find a positive relationship — improved economic condition is positively correlated with good subwatershed condition. In the Feather River Watershed, there is a hint that the opposite relationship applies (Figure 1), that economic conditions are best when subwatershed conditions are poor. This relationship is weak and may not be significant, however, it is not a positive relationship, suggesting that society needs to re-visit its relationship with the systems that provide it with sustenance and well-being.

Figure 1 — Subwatershed economic condition compared to subwatershed condition, minus economic condition



# SECTION 4.0

## General Methods and Principles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# Section 4.0 – General Methods and Principles

This section describes the general principles and methods used for individual indicators. The exact methods used are described in association with each indicator. The sub-sections below discuss the management of data, subwatershed reporting unit strategy, scoring indicators, trends analysis, aggregating scores, and determining confidence in results.

## 4.1 — Reporting and analysis subwatershed units

The reporting and analysis units were based on geographical subregions of the Feather River Watershed, which in the Report Card are called subwatersheds. The Feather River Watershed, a subbasin of the Sacramento River Basin, consists of the watersheds of the Feather, Yuba, and Bear rivers. The logical reporting subregions were fairly predetermined by organizations and agencies working in this region. These areas are divided based on the upper and lower reaches of the river in relation to the major reservoirs on the river. For example, the reaches of the Lower Feather are designated below Lake Oroville, and the Lower Yuba below Englebright Dam. Deer Creek had its own reporting unit based on the availability of data for this Yuba River tributary, and how the subwatershed is influenced from a social and geographical point of view.

The USDA Natural Resource Conservation Science (NRCS) watershed boundary dataset, CalWater, was used to create the reporting regions. The Hydrological Area Boundaries (HAB) provided the boundaries for the East Branch North Fork Feather, Lower Feather, Lower Yuba, Middle Fork Feather, Middle Yuba, North Fork Feather, North Yuba, South Yuba, and Upper Bear. HAB name alone didn't designate the regions, for example, South Honcut Creek, Sutter Bypass, and below Oroville Reservoir, were assigned to the Lower Feather subwatershed and Ute Mountain was assigned to the Lower Yuba. The other two boundaries, the Lower Bear and Deer Creek were constructed using the Hydrological Super Planning Watershed boundaries (HSPW). For Deer Creek, this included the designations HSPW Upper Deer Creek and Lake Wildwood, and for the Lower Bear, these included Upper Dry Creek, Clear Creek, and an undefined region associated with the Bear River. CalWater's planning watershed at the mouth of the Lower Bear was assigned to the Lower Feather, so this region was clipped so that it could properly be assigned to the Lower Bear.

Analyses were conducted for planning watersheds (small creek drainages) within subwatersheds, or for the subwatersheds as a whole. All results were reported at the subwatershed scale (e.g., Lower Feather, South Yuba)

## 4.2 — Scoring: Distance to target/reference and scoring transformations

An important step in turning parameters into indicators is describing the meaning of particular values or ranges of values from an educational or decision-making perspective. For example, surface water temperature is a parameter that can be reported daily or annually, but if reported on its own, may not be overly meaningful. When water temperatures are compared with temperatures important for the salmonid life cycle, then water temperature can be reported as an indicator of condition relative to the needs of fish, this provides a more meaningful context in which to interpret indicator status and trends. A creek with a temperature of 20°C may be fine for recreational use and may support certain fish and wildlife species; however, salmon eggs and fry will be stressed at this temperature, thus the indicator score relative to salmonids may be low for this temperature.

Each indicator status value (or trend) was compared to a reference or standard value (Figure 4.1), and the comparison was used to generate a score. Although it is important to pick a reference value that is meaningful for decision-making, it is just as important to make the choice transparent so that the reference value can be changed in the future if warranted by changes in knowledge, goals or assumptions.

**Figure 4.1 — Example of parameter comparison to goal/standard. This comparison is used to evaluate the indicator status and trend.**

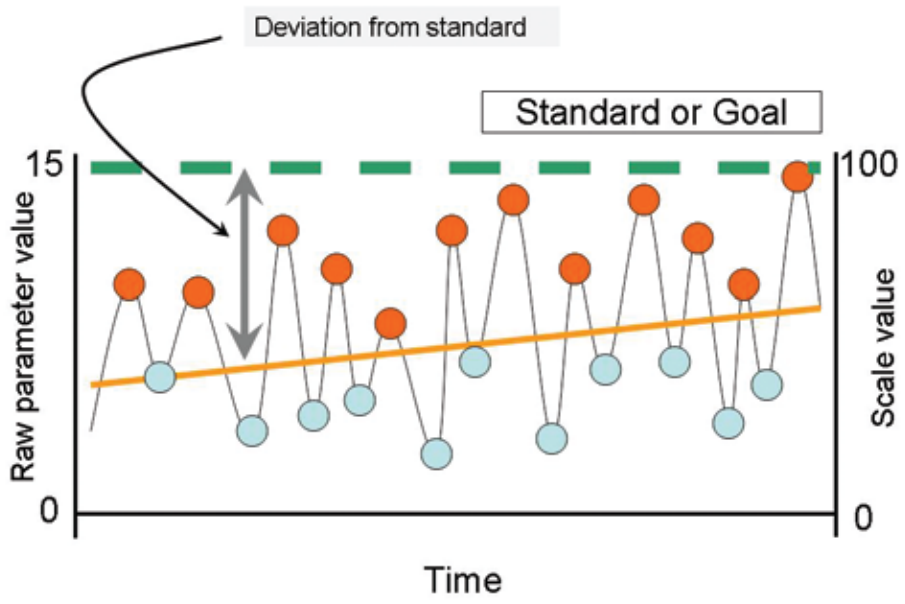
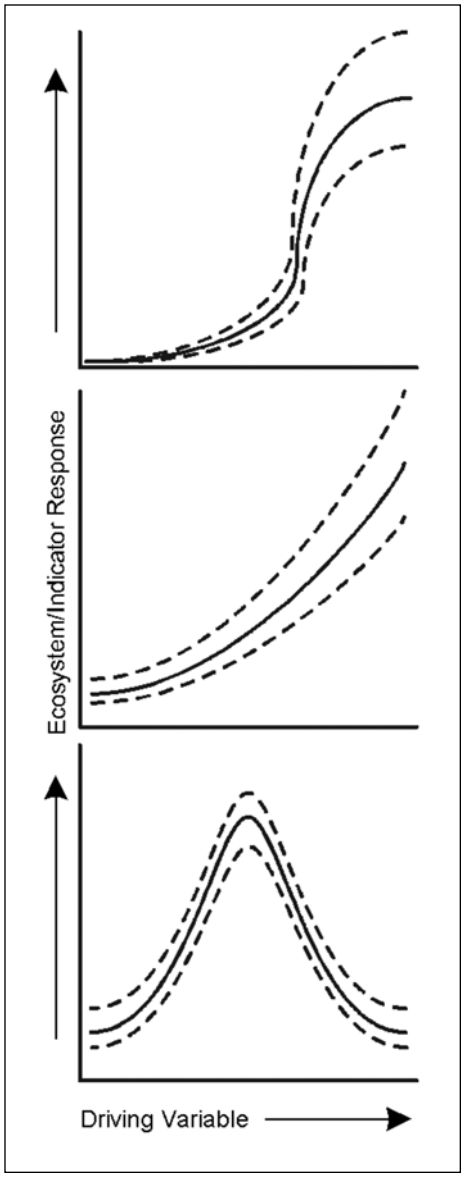


**Figure 4.2 — Relationship between ecosystem or community condition and something affecting that condition (driving variable)**




We chose reference or target conditions specific to the indicator using best available science, goals expressed by stakeholder organizations, and professional opinion. These are all mutable choices and can be regarded as proposals for how indicators can be evaluated.

A very important benefit of taking this step is that scores can be combined across very different indicators (e.g., water temperature and fish tissue mercury concentrations), whereas otherwise this would not be possible. Because all indicator conditions were quantitatively compared to a target, they were all normalized to the same scale — distance to target. Once the normalization takes place, the new values, ranging from 0 to 100, mean the same thing and can therefore be combined.

Because environmental and socio-economic processes and conditions rarely respond to influences in a linear fashion, evaluating indicators relative to reference conditions must take into account these non-linear responses (Figure 4.2). For example, evaluation of water temperature used a non-linear function (section 3.1.2).

Indicator metrics were quantified in their raw or native units (e.g., °C or tons C sequestered), and evaluated on the basis of their separation from the target condition. This target or reference condition is sometimes called the "ideal point" (Malczewski, 1999). The ideal point method was first introduced in the late 1950s and expanded by Milan Zeleny in the 1970s (Pomerol and Barba-Romero 2000). Zeleny (1982) operationalized the measurement of closeness with

$$d_i = f_i^* - f_i\,(x_{ji})$$

Where $d_i d_i$ is the distance of attribute state $x_{ji} x_{ji}$ to the ideal value $f_i^* f_i^*$, i indicates the attribute and j indicates the objective. For the Report Card, indicator distances from target were calculated in their native units and converted to a common scale (0-100) to be compared among disparate indicators, or to be aggregated into composite indices. The common scale conversion was relative to a threshold or objective specific to each indicator and was based on the appropriate linear or non-linear rate of change relationship. For example, there is a linear rate of increase in carbon sequestration with area of vegetative cover, but non-linear effects of temperature on salmonid species.

## 4.3 — Trend/time series analysis

Time series or trend analysis was primarily conducted using the Mann-Kendall statistical test. Trends analyses using the Mann-Kendall tests were conducted using custom programming in R, an open source statistical package. Changes in ecosystem characteristics over time are an important type of analysis and one of the most valuable types of information conveyed with indicators. Somewhat counter-intuitively, they are also rarely conducted using appropriate statistical techniques. Analysis of trend in time series data is necessary to determine if conditions in a subwatershed are improving or deteriorating. One of the most common techniques for determining trend is linear regression. However, linear regression requires certain data characteristics, such as normal distribution of values, which are not easy to assess in small data sets. Distribution-free trend analysis is ideal due to the unknown nature of the data, so non-parametric tests are preferred. Of the various commonly used options, the Mann-Kendall rank correlation trend test is the strongest (Berryman et al. 1988). It is appropriate for data that are not normally-distributed, tolerates missing values, and is relatively unaffected by extreme values or skewed data. Although it is sensitive to autocorrelation, this is only an issue in very long datasets and was not considered for these indicators. The output of the Mann-Kendall analysis is an assessment of the trend slope and its statistical significance.

One weakness of the Mann-Kendall is an inability to adjust for seasonality or cycling in the time series. Almost all environmental data will have daily, seasonal, inter-annual, and/or inter-decadal cycles. This means that one cannot detect change in these data without taking into account and controlling for these cyclic effects. Full decomposition of a time series into its component parts (trend, oscillations, seasonal factors, and disturbances) is not always possible or practical (Jassby & Powell 1990). For these data, the Seasonal-Kendall test can be used to determine whether or not significant changes have occurred over time, while taking into account variation due to seasonal effects (Hirsch *et al*., 1982; Hirsch and Slack 1984; Esterby 1996). It retains the non-parametric strengths of the Mann-Kendall, but performs separate trends analysis for each season and compares the results. For certain indicators, there may have been infrequent data collection (e.g., annual), or only a few years of data collection (i.e., <5 years), in which case a seasonal trends analysis was not conducted and instead the standard Mann-Kendall was used.

Hess et al. (2001) ran simulations for six linear trend analysis techniques, and determined that the strongest are the Seasonal-Kendall test and a *t*-test adjusted for seasonality. France et al. (1992) also found the Seasonal-Kendall to be the strongest option, and the best when seasonality is unknown as well. For non-seasonal data, such as annual data, the Mann-Kendall is probably superior (Hamed & Rao 1998).

When assessing trend within a broad region with multiple sampling sites, the same principle applies as with seasonal data: it is better to compare trends across sites than to combine them into a single time series. The Regional Mann-Kendall is analogous to the Seasonal-Kendall, but compares individual locations rather than seasons (Helsel & Frans 2006). Because it is statistically identical, it has all the advantages of the Seasonal-Kendall. This approach was used frequently for subwatershed analysis.

## 4.4 — Confidence in Report Card findings

The degree of certainty in the Report Card results depends on two conceptual questions: whether good indicators were chosen and how well the data presented for each indicator accurately reflect the real status or trend in the metric(s).

The first of these questions pertains to the indicators themselves and how well they address the objectives or attributes they are meant to represent. Certainty about the indicators depends on four main factors:

- Importance — the degree to which a linkage (functional relationship) controls the outcome relative to other drivers and linkages affecting that same outcome,
- Understanding — the degree to which the performance indicator can be predicted from the defined linkage (functional relationship) and its driver(s),
- Rigor — the degree to which the scientific evidence supporting our understanding of a cause-effect relationship (linkage) is contested or confounded by other information, and
- Feasibility — the degree to which input data necessary to calculate the proposed performance measure can be delivered in a timely fashion (without external bottlenecks) and the amount of effort (relative to other possible indicators) needed to implement the cause-effect linkage in a computer model.

Where possible, confidence findings for each indicator are mentioned in the corresponding sections as they form an important component of overall confidence in the Report Card.

The second question pertains to statistical confidence in the data presented for each indicator. The available data may contain a variety of sources of uncertainty including:

- Measurement error. Random or systematic errors introduced during the measurement process, sample handling, recording, sample preparation, sample analysis, data reduction, transmission and storage (USEPA 2006; Thompson 2002)
- Uncertain/inappropriate interpretation of sampling frame. Errors in inference resulting from opportunistically mining the available data without knowledge of the sampling

frame[1]. For example, macro-invertebrate data may have been collected by several different studies with different objectives and target populations (e.g. they could have focused on different stream orders). Without this knowledge, we must make assumptions about the probability of selecting each site and the appropriate weighting of the observation.

- Sampling error. The error resulting from only examining a portion of the total population (Cochran 1977; Lohr 1999; Thompson 2002), if a census of the population is taken (e.g., school lunch enrolment) then there is no sampling error.
- Process error. Actual variability between spatial or temporal units in the population. This source of variability exists even if a census is taken with no measurement error. This is often referred to as natural variability.

Any of the above sources of uncertainty affects confidence in the estimates of status and reduces the ability to detect trends over time. For some indicators quantification of different sources of uncertainty in the data may be possible, but in many cases there are limitations to providing a qualitative description of the likely sources of error and associated magnitude.

For each indicator, the best available data were aggregated to produce an estimate for each subwatershed. The 95% confidence interval for the metric statistics are presented, along with the minimum, maximum, and number of observations (n). Finally, when possible, the estimates and associated confidence intervals were transformed to a 0-100 scale (as described in section 4.2).

## 4.5 — Spatial scale and aggregation of fine scale data to subwatershed

A desired feature when selecting indicators is that they can be scalable; that is, they are valid across different spatial and temporal scales. For instance, indicators reviewed on a larger (national) scale, can be also useful on the regional and local level. The Indicator Development for Estuaries Manual (US-USEPA, 2008) suggests that, whenever possible, it is always best to try to align local and regional programs with programs at a higher (i.e., national) spatial scale because this allows for future comparisons with data collected over the larger area. For example, the "benthic index", which provides a quantification of the response of benthic communities to stress, is an example of a scalable indicator (Kurtz et al., 2001). Finding scalable indicators is a difficult task because many cost-effective methods to measure and summarize social, economic and ecological data are scale dependent (Hagan and Whitman, 2006).

[1] Sampling Frame: the complete list of sampling units in the target population for a particular study.

Scalability of indicators may be more feasible in nested systems (e.g. South Yuba subwatershed ➔ Feather River Watershed ➔ Sacramento River Basin) than in non-nested ones. For nested systems the issues of sampling and data aggregation are more straightforward because of the direct spatial correlation from one scale to the next. Data can be sampled at one scale finer (e.g., monitoring site) than the question of interest and then "up-scaled" to a larger evaluation or reporting unit (e.g., subwatershed). Sampling and data aggregation in non-nested systems proves more difficult because the emergent properties of the systems are different and simply aggregating data will overlook the synergistic effects of systems (US Forest Service, http://www.fs.fed.us/institute/monitoring/Scale_Overview.htm). In nested natural systems, cross-scale aggregation of environmental indicators may be more realistic than social or economic indicators. In contrast, social and economic indicators may be easier to aggregate when using nested political boundaries (e.g. municipality-county-state).

In the particular case of the US-USEPA SAB reporting framework, the Essential Ecological Attributes (EEAs) were successfully mapped onto structural, functional, and compositional characteristics of ecological systems at a variety of scales in order to assure coverage of different aspects of natural systems (Young and Sanzone, 2002). Furthermore, the EEAs and their subcomponents were checked to determine whether they would be relevant at several geographic scales (ecoregion, 1000 $km^2$; regional landscape, 100 $km^2$; small watershed or ecosystem, 10 $km^2$; reach or stand, <1 $km^2$). Overall, it was found that all the components of the SAB reporting framework were relevant to each geographic scale (Young and Sanzone, 2002), which is important because the SAB approach is the basis for the Watershed Assessment Framework and the Report Card.

Several different nested geographic scales at which aggregated indices can be developed include: (a) whole ecosystem/watershed, (b) primary subsystem habitat types (e.g., uplands, wetlands, in-stream), (c) categories of parameters within habitat types (e.g., wetland water quality), and (d) parameters within habitat types (e.g., in-stream nitrogen concentration). For the Feather River Watershed we reported indicator values and aggregated values to goals and objectives at the subwatershed extent (e.g., North Yuba River). The Report Card provides a method for translating characteristics at the site, reach, or creek drainage scale to the river basin and state scale.

The technique for reporting to the subwatershed level depended on the geographic type of data collected. Many of the datasets such as the water sampling information were collected at point localities, for instance a monitoring station on a stream. In this case, these data were assigned to subwatersheds by a GIS operation of overlaying the points on the polygon boundaries of the subwatersheds, and averaging values within a subwatershed. Some of the datasets, such as the fire history information, were originally represented by vector polygon GIS coverages. These were intersected with a finer-scale polygon layer for analysis based on hydrological planning watershed units that nest into each subwatershed. Values were then reported to the subwatershed level by averaging across all planning units within each subwatershed. Finally, some datasets were developed from raster surface layers such as land cover data which exhaustively covered

the entire watershed. In these cases, the derived data (e.g. carbon stock values) were reported to a subwatershed by averaging the values for all pixels within a subwatershed.

## 4.6 — Temporal scale and aggregation

Estimates of status and trend for a given indicator must also consider temporal aggregation. The temporal scale includes both aggregation within a year and among years.

How the data are summarized within a year depends on the specific data type. Some data are collected frequently throughout the year (e.g., continuous temperature or flow data). In such cases periodic behaviour should be accounted for before aggregation takes place, and these methods are described in detail in section 4.3 (Trend Analysis). For many indicators there is only one record per site per year and there is no aggregation to consider within the year. The temporal scale or resolution of the data can affect its meaning. Higher resolution (i.e., more times at which data were collected) will tend to lead to a more accurate assessment of condition/status and change in condition than a single time-point measurement.

Status refers to the "current state," and most often this refers to the state for a specific year. However, if reporting occurs only every few years the status should reflect the average status since the last report, or the status for some recent time window (e.g., 5 years). In the case of this Report Card, the best and most recent available data were used. In some cases, these data were several years old.

It is insufficient to simply assess the current status, without assessing whether or not a trend exists or vice versa. These two pieces of information together provide far more useful tool for decision makers. It is important to consider the time-frame (i.e., number of years) within which to evaluate trends. In most cases there are insufficient data to allow much choice, but as more data are collected it is possible to have scenarios where the recent trend is much different from the older trend, imagine a shift in the slope from negative before restoration to positive after restoration. It may be necessary to limit the analyses to the more recent years or to weight scores from recent years more heavily. Another strategy is to use piece-wise regression to allow different windows of time to have different slopes. Section 4.3 provides detailed information about how to complete trend analyses.

## 4.7 — Cross-indicator score aggregation

One value of the Report Card is that indicators were normalized to a common scoring scale, 0 (poor condition) to 100 (good condition), where good and poor conditions were defined for each indicator. For goals and objectives that have more than one indicator, it is then possible to combine the indicator scores into an overall score for that goal or objective (see Executive Summary). The steps for doing this included: 1) analyzing individual indicators, 2) transforming indicator values to a single scoring scale, 3) determining the relative importance of each indicator (by default we assumed each was equally important), and 4) averaging the scores for indicators within a goal or objective. In the case of (4), averaging is one way that the scores could be used. Another possibility

would be to selected the lowest score in order to point out the conditions that might need the most attention, or to weight the scores according to a social or management ranking of indicator importance.

Carrying out this type of score aggregation is appropriate for a decision-support device like the Report Card, which is intended to provide a quantitative estimate of how well conditions are performing relative to goals. The scores may seem less relevant to an ecological or economic model where the base parameters units (e.g., tons of nitrogen, $) may be more useful. However, there are few quantitative modeling approaches that can use multiple parameters in their native units to reflect conditions in complex systems like watersheds. It is possible that the normalization approach used for the Report Card can be used to quantitatively reflect conditions of and interactions among watershed components.

## 4.8 — Data management and transformation

Calculating environmental indicators for the watershed required temporal and geospatial data from numerous sources. While some indicators utilized a single data source, others required a combination of multiple sources to provide a complete record. This section describes some of the general data management strategies used in this project. For specific details of the data sources and management strategies used for an indicator, please visit the appropriate section in this report.

The teams from SRWP, UC Davis, FRCRM, ESSA Technologies, and other WHIP stakeholders who had knowledge and expertise of the Feather River Watershed, all participated in identifying and acquiring data for use in the calculation of environmental indicators. For the purposes of management within the team, the data types were divided between point-source monitoring data and GIS based data.

Point-source monitoring data focused on temporal variation across the basin originating from numerous collection sites across the basin. The types of indicators that were point data referenced included fish and birds, benthic macroinvertebrates, temperature, stream flow, periphyton, nutrients, mercury, and school lunch programs. Each had an assigned metric to a specific point in the watershed. The condition data were often averaged across the subwatershed reporting units to calculate an overall subwatershed score. The collection sites were mapped with a GIS to identify the subwatershed of which they were a member, to provide a map visualization for the corresponding indicator reports.

Spatial data analysis was performed across the basin using various GIS based data sources. The indicators which utilized GIS analysis included fire frequency, carbon budget, river flooding, stream road barriers, and fragmentation index. These data were analyzed using the same boundary base layer that identified each of the subbasins.

The acquisition of temporal and spatial data came from the following organizations that had assembled data for the Feather River Watershed.

**NATIONAL ORGANIZATIONS:**

National Aeronautics and Space Administration (NASA)
USDA Forest Service
United States Geological Service (USGS): National Water Information System (NWIS)

**STATE AND COUNTY AGENCIES:**

California Department of Education (CDE)
California Department Fish & Game (DFG)
California Department of Water Resources (DWR)
Nevada Irrigation District (NID)
State Water Resources Control Board Surface Water Ambient Monitoring Program (SWAMP)
Sutter County Resource Conservation District (SCRCD)

**NGO AND ACADEMIC CENTERS:**

Avian Knowledge Network (AKN)
Bay-Delta and Tributaries Project (BDAT)
Friends of Deer Creek
Information Center for the Environment (UC Davis)
South Yuba River Citizens League (SYRCL)
University of California, Davis
Wolf Creek Community Alliance
Yuba Accord River Management Team

Each environmental indicator included one or more data files as well as other corresponding relevant information. These files were shared amongst the indicator team, with careful consideration to version control as these data were analyzed and derivative products were created.

These data were stored in various formats, including text based delimited formats (.csv, .tsv), spreadsheet packages (such as Microsoft Excel and OpenOffice Spreadsheet), personal databases (Microsoft Access), GIS Raster Formats (geoTIFF), GIS Vector formats (such as Shapefiles or Google Earth KML files), and personal geodatabases (Microsoft Access). Temporal metadata were collected in various formats, but most often available as part of a document or report that one could download with the data. When available, source GIS based metadata were stored in a standard FGDC XML format, and utilized by the various GIS packages.

An initial search was performed to identify available data for an indicator and to collect general data attributes, such as the data provider, temporal range, spatial extent, and data representation, including units of measure and data quality attributes. These general attributes were assembled in a shared spreadsheet, which identified all relevant sources of data for the various indicators in the study. These data and metadata were downloaded, organized, and assembled for each indicator. It was often necessary for the data to be manually manipulated to transfer it into a common format. Additional resources which

documented the data were also collected, such as Standard Operating Procedures (SOP), lab/organization identification protocols, Quality Assurance Policy and Procedures (QAPP's), and other documents and reports that reported proper use of these data.

Data transformations were often required, because an indicator would utilize data from multiple sources, and these data were frequently stored in different units of measure and temporal frequencies. The common data elements were extracted and stored to produce a new dataset that combined all sources. Specific description of the data manipulations can be found with each indicator report (Section 3).

The quality of the data was an important consideration when decided if they should be included in the study. Various forms of quality assurance (QA) were performed on these data, especially as additional collection sites or new data sources were added to an indicator. For many data sources, the providers had already performed a rigorous QA on the data, and these data could be used in the state at which they were downloaded. In rare cases, the data was found to be corrupted or have extreme outliers (spatially, temporally, and in terms of a valid data value), and in these circumstance, the data were omitted from the study.

Another QA procedure was performed to eliminate data that was *within* the study area, but was located in canals and diversions since these data points do not represent the natural hydrology of the Feather River. Certain data collected at highly irregular intervals or with an incompatible protocol were also removed from the study.

# SECTION 5.0

## Interpretation

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## 5.1 — Using the Report Card

The Report Card expresses condition scores and condition trends relative to a desired or target state. It uses a 0 (poor) to 100 (good) scale to make it easier to see the gradation in conditions possible. The scores were not put into lumped categories, such as grades, because most people are familiar with percents. A score of 50 means that conditions are approximately in the middle of the range from unacceptable/poor to desired/good. On a school report card, this would be similar to a "C" grade. Multiple metric scores were then aggregated to an indicator and multiple indicator scores aggregated to an objective score. At each step there is necessarily some loss of information, such as natural variability differences among metrics, etc. Therefore, while the most accurate assessments are at the metric or indicator scale, they are less informative about overall watershed condition, whereas the score for a combination of multiple related indicators is less accurate and has higher variability, but may tell us more about overall condition.

For the Report Card, scores were aggregated to the level of objectives, but not goals. The Report Card is designed so that a user can take scores for several associated subwatersheds and aggregate them (e.g., for the Upper Yuba River Watershed), or take scores for several associated indicators and aggregate them to a single subwatershed or larger watershed unit, such as the entire Feather River Watershed.

# SECTION 6.0

## Conclusions and Recommendations

The Report Card is the result of a first application of the Watershed Assessment Framework in California and the Sacramento River Basin. The Report Card itself helps us learn something about the current condition of certain attributes of the Feather River Watershed within the context of stakeholder goals and objectives for watershed health. In *preparing* the Report Card the availability of indicator data for the watershed and the process for evaluating indicators were limiting factors. This section summarizes some of the key conclusions from the Report Card development and offers recommendations based on lessons learned.

## 6.1 — Critical data gaps

Indicator selection and analysis is often complicated by gaps in the necessary information or data. These gaps exist because either the information has *not been collected*, or the information exists but is *not accessible* for any number of reasons. Being aware of the critical data gaps not only helps readers of the Report Card understand the limitations behind the analyses but also provides guidance on any next steps for additional investigations or monitoring. The following summarizes the key issues faced and recommendations regarding various aspects of data availability.

a) Spatial uniformity of data coverage: It is difficult to carry out analyses for a study area using data that are only representative of a small portion of it (i.e., if data have not been collected for the entire study area). Data that have only been collected at a single location in a single subwatershed cannot be used to generate an indicator that is intended to represent condition across all subwatersheds. Expanded spatial coverage of data collection for specific indicators, and availability of such data, would have made analysis more comprehensive. Inadequacy of spatial representation across subwatersheds was especially true for:

*Periphyton.* Data periphyton biomass and percent cover do not exist for the lower watersheds, i.e., Lower Yuba, Lower Bear, and Lower Feather. There were also no data for the Upper Bear. Periphyton data that were available were collected by four independent organizations: Friends of Deer Creek, the SYRCL, Sabra Purdy (UC Davis) and Fraser Shilling (UC Davis). The limited data that were available were fairly patchy and only collected at one or two sites within a subwatershed: Deer Creek, Middle Yuba, South Yuba, and East Branch North Fork and the North Fork of the Feather. As a result, no trends or complex statistical analysis could be run for periphyton across the region.

*Benthic macroinvertabrates.* Given the limited hydrological mapping of the study area, it was not possible to identify stream order for all benthic macroinvertebrate sampling sites. Stream order is a particularly important variable when analysing macroinvertebrate data because the size of stream influences the composition and structure of the macroinvertebrate community. Better resolution of hydrological maps capturing stream order (i.e., capturing 4$^{th}$, 5$^{th}$, and 6$^{th}$ order streams) would have enabled the benthic macroinvertabrate functional feeding groups to be analyzed within a natural continuum of habitat conditions based on ascending stream order.

b) Frequency of data collection: Some data were only collected at a single point in time and therefore only represent a snapshot of the biotic condition. It is not possible to infer a trend (i.e., whether things are getting better or worse) from a single sampling event. For example, a monthly measurement of a process such as water flow which changes continuously limits the level of analysis that is possible as well as limiting the confidence in results. More frequent sampling of select indicators, and having these data available to analysts, would have enabled a more informed analysis. This was especially true for:

*Water temperature.* The most spatially-extensive temperature data available for the study area were collected once a month by volunteers. This is problematic because the fluctuations in water temperature (e.g., the hottest and coldest water temperatures on that day) are not captured. Similarly, you would not know the length of time that water temperatures remained very high or very low. Maximum temperatures are significant for the aquatic ecosystem because high water temperatures that last a long time can cause stress for fish and insects, sometime to the point of death. Temperature measurements taken every 15 minutes using a continuous recording instrument, such as a HOBO data logger, would enable a more reliable and accurate estimation of the extent and duration of maximum water temperatures. Temperature data from a data logger were only available for a small number of sites and for only a short time period, 2008-2009. To determine trends in maximum water temperature, a continuous time series of ten years or more is needed. Consequently, our analyses for the study area only provide a limited sense of how water temperatures have changed over time and we were not able to determine the duration of high temperature conditions during biologically critical times of year. Temperature data are inexpensive to collect using automated data loggers and do not require a lot of complex equipment, therefore improved data collection should be encouraged.

*Economics.* The school lunch program enrolment data are currently only available as an annual statistic (i.e., X number of children, per school, per year). Monthly data on enrolment in the program would allow for detection of changes in poverty at finer scale to see if there are any relationships between poverty and seasonal patterns of employment and migration of workers.

c) Availability of reference standards: Control sites in a pristine watershed would be very useful to determine appropriate standards for watershed condition as measured by an indicator. For example, if a pristine watershed was known to have a certain type of benthic macroinvertebrate community in small streams, we could use this as a benchmark to evaluate the health of benthic macroinvertebrate communities in the study area. A lack of appropriate reference conditions was especially true for:

*Benthic macroinvertebrates.* Information on invertebrate species richness from a 'pristine' watershed would have been extremely valuable for determining how to score subwatershed in our study area. The 'pristine' watershed would have provided a benchmark condition that all subwatersheds could be ranked against.

*Flow.* Historical flow records for the study area have numerous limitations because of incomplete historical records for some subwatersheds. For example, flow data prior to the building of dams in the Upper Feather River (Butt Valley Reservoir, Beldon Reservoir, Rock Creek Reservoir, Cresta Reservoir, Poe Reservoir) do not exist. Collection of flow data for these systems began at the same time the dam was constructed. As a result, we were not able to compare current flows to the natural hydrograph (i.e., what happened before the dams) for

the North Fork of the Feather River. Reconstruction of the naturalized flows for the system (for each of the subwatersheds) would provide a better benchmark to compare existing hydrologic conditions.

d) Consistency in data collection methods: The way data are collected (i.e., how sampling is done) affects the results; if the same metric is sampled in two different ways it is very difficult to compare the results. This was especially true for data available to us on:

*Benthic macroinvertebrates.* The taxonomic level at which an individual bug is identified, typically either genus or family, and rarely down to species, can determine the level of analysis that is possible. The use of a sampling framework across the region with standardized sampling protocols and a wide distribution of sampling locations would have improved the benthic macroinvertebrate analysis because the creation of certain indices is only possible when species-level information is collected.

*Fish.* The method used to sample fish, e.g., electroshocking or snorkeling, determines the number or species and individuals one is able to record. Only one of the fish surveys was thorough enough to look at total community structure whereas the others typically only reported catching 5-6 species (which is probably an artefact of the methodology rather than a true absence of more species).

*Periphyton.* Periphyton data collected using different field and laboratory methods can result in different results. If periphyton are collected using similar protocols, such as the ones in the CWAM (Volume II, http://cwam.ucdavis.edu), or those published by SWAMP, then trend analysis over time and between different watershed would be more reliable. However, even standard protocols like the ones listed have limitations when very large algal masses are encountered.

A few additional data gaps came to light as analyses were conducted:

*Field Data:* There is a need for channel cross-section data in order to determine the stage discharge relationship associated with flooding at different locations (i.e., how much water needs to be flowing through a given location for the riparian area to become inundated). This information would help identify restoration sites where flooding could be allowed without damaging infrastructure.

*Community Awareness:* Public support of ecosystem protection and restoration, public health, and sustainability is a critical feature of a modern society, but it is hard to measure because of the absence of data and data-collection programs. Support begins with awareness. By measuring awareness of watershed health issues, support can be generated for the life-support functions of watersheds.

Addressing the critical data gaps listed above would greatly strengthen the regional analysis as a whole and should serve as a to-do list for those interested in continuing the Report Card analysis into the future. Of utmost priority are:

- Water temperature measurements taken using automated data loggers, set to 15 minute intervals, and placed strategically across the watershed.
- Natural flow data generated using a hydrologic model so that current conditions can be compared to a more reliable and standardized data set.
- Periphyton data collected using standard methods in the upper and lower watershed for the Yuba, Bear and Feather River Watersheds.
- Standardized and regular monitoring of fish and wildlife populations, probably the best indicators of watershed conditions.

The use of standardized protocols and creation of regional data sets will be made possible only with regular communication between research organizations, regulatory agencies, and watershed groups, because in the end, the management decisions that are influenced by the above analysis are only as good as the data that are collected and made available to collaborative efforts such as this.

## 6.2 — Next Steps for the Report Card in the Sacramento River Basin.

Report Cards such as this are a valuable tool for tracking and communicating watershed condition to residents, other stakeholders, and decision-makers, and similar Report Card should be conducted within each major watershed and subregion withen the entire Sacramento River Basin. The basic steps should mirror those used in the Feather River Watershed Report Card (described in the previous sections):

- Articulate stakeholder goals and objectives for the basin.
- Identify the geographic subunits to be assessed (e.g., reporting subwatersheds).
- Select indicators for each objective, using a WAF cross-walk matrix to ensure that the chosen indicators collectively also address all of the essential watershed attributes (EWAs) in the WAF.
- Determine the reference value (target) for each indicator, and the relationship between potential indicator values and scores from 1-100 (i.e. linear or non-linear function).
- Identify the metrics for each indicator, compile and analyze the data, and calculate the score for each indicator in each sub-unit.
- Aggregate the scores across objectives and across sub-units.

Adopting this Report Card process in other watersheds would provide a consistent approach for a broader assessment of watershed condition across California, and the WAF attributes, which would be common across watersheds, would enable comparison among watersheds even if the goals and objectives (and indicators) might differ. The feasibility of aggregation across Report Cards using the WAF attributes could also be explored.

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# APPENDIX A

## Glossary of Terms


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This appendix provides a list of terms useful in communicating effectively and ensuring consistency among California based Watershed Assessment Framework (WAF) Valuation projects. [1] The terms and definitions provided below come from a combination of reports and background documents from both state and federal efforts towards developing ecological condition reporting frameworks for monitoring watershed condition and health.[2]

## Watershed Assessment Framework

The Watershed Assessment Framework (WAF) is in an evaluation framework developed for use at the scale of identified watershed boundaries. The geographical scope of the assessment framework varies, and is based upon the watershed area being evaluated. The concept and use of the WAF was developed by the USEPA's Science Advisory Board and has been adapted to meet watershed monitoring needs and performance measures identified in the California Watershed Management Strategic Action Plan.

The framework provides a scientifically defensible approach for aggregating and assessing a wide variety of environmental, economic and social data. The framework can be used to assist in linking the condition of a watershed's air, water, land, biota, and social structures into a broad framework termed ecosystem condition — the sum total of the physical, chemical, social and biological components of the watershed and how they interact and change over time. The WAF includes evaluation of economic and social conditions at the watershed scale and is a way of integrating consideration of environment, economics, and social conditions in watersheds. The WAF acknowledges that humans and their activities are integral parts of watersheds and their ecosystems.

## Goals & Objectives

*"Goals and Objectives. Ideally, environmental management programs begin with a process to develop goals and objectives that articulate the desired ecosystem conditions that will result from the program(s)." (USEPA SAB Report)*

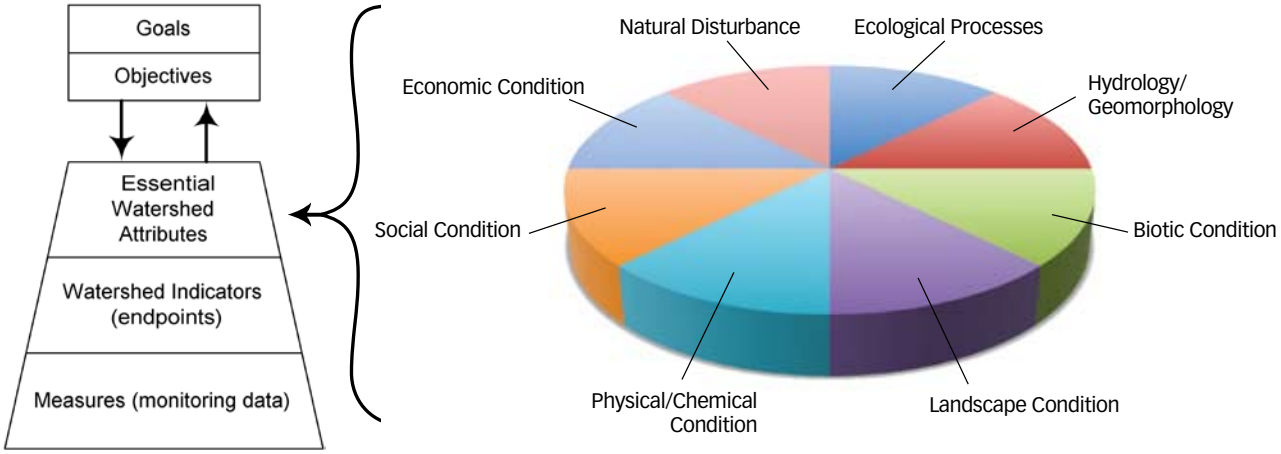
Goals describe desired outcomes for a watershed or similar place, through a particular project or program in a stated timeframe. In the case of the WAF, groups could set goals for the watershed, in which case they would be describing the desired outcomes for the watershed in some stated timeframe.

Objectives are the tactics to the goals' strategies. They describe actions that can be taken to implement or reach goals. Objectives for watersheds can be defined as actions that help reach desired outcomes for particular aspects of watershed condition.

1 http://www.water.ca.gov/watersheds/framework.cfm

2 Developed by Fraser Shilling (UC Davis) based on the index/indicator literature and feedback from Jeff Sharp (Napa County) and Mike Antos (Los Angeles San Gabriel Rivers Watershed Council).

Figure 1 — Watershed Assessment Framework




## Index

Sometimes organizations want to develop a comprehensive understanding of environmental or social health and express that as a single score, which is a composite of several or many indicators. This composite is usually called an index. In terms of the WAF, you could imagine scores for indicators within each essential attribute being composited into an overall attribute score for health assessment based upon a set of identified goals. In this case, the attribute is functioning as an index. The WAF is also an index, composed of the 8 attributes and component indicators, though a single index score for the WAF may be only generally meaningful.

## Essential Watershed Attributes

*"The EEAs and their component categories and subcategories can be used as a checklist to help design environmental management and assessment programs and as a guide for aggregating and organizing information." (USEPA SAB Report)*

The essential watershed attributes (EWA) provide a way to categorize environmental and social processes to facilitate understanding and reporting of condition. The 8 essential attributes identified in the WAF valuation projects is a means to categorize various attributes that describe a watershed and are described below.

Landscape Condition — The extent, composition, and pattern or structure of (non-human) habitats in a landscape.

Biotic Condition — The condition or viability of communities, populations, and individual biota (i.e., at the scale of individual habitat types).

Ecological Processes — Metabolic function of ecosystems - energy flow, element cycling, and the production, consumption, and decomposition of organic matter at the ecosystem or landscape level.

Social Condition — The examination of the organization and development of human social

life within the watershed, including measurements of community and social patterns, and behavior of individuals and groups.

Economic Condition — Measures of community economic well-being and of the production, distribution, and consumption of goods and services within a watershed, including the valuation and of non-market resources that provide individual and community utility.

Chemical and Physical Characteristics — Physical parameters and concentrations of chemical substances present in the environment/watershed (water, air, soil, sediment).

Hydrology/Geomorphology — Characteristics that reflect the dynamic interplay of surface and groundwater flows and the land forms within the watershed.

Natural Disturbance — The historical and/or contemporary function of discrete and usually recurrent disturbances, which may be physical, chemical, or biological in nature, that shape watershed ecosystems.

## Categories

A category is a class of similar concepts, ideas, or things within in an organized and rule-based system to discriminate among classes where the discrimination is based on apparent differences among the categorized objects. EWAs are pseudo-categories in that they contain groups of similar indicators, but are not completely discreet and overlap each other. The EWAs often include sub-categories. Categories are one way to organize information in an overall condition index, like the WAF, where the categories and sub-categories are used to classify related indicators.

## Indicators

*"Ecological Indicators (also called ecological endpoints) are measurable characteristics related to the structure, composition, or functioning of ecological systems. Multiple indicators may be associated with each subcategory in the EEA hierarchy." (USEPA SAB Report)*

Indicators (the backbone of the WAF process) provide a way to collect information about a condition and to report and compare condition over time. Indicators in the WAF are organized within EWAs and are based on metrics or measures of condition, though sometimes indicators and metrics are the same thing.

## Metrics/measures

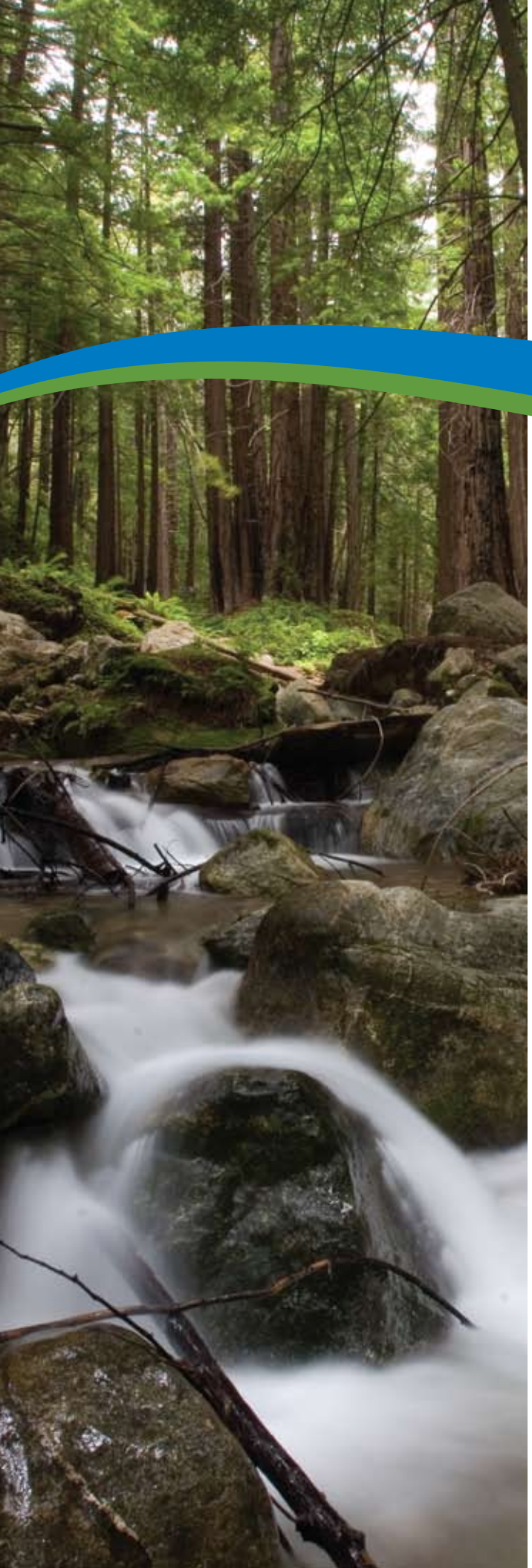
*"Measures. The measures are the specific monitoring variables that are measured in the field and aggregated into one or more ecological indicators." (USEPA SAB Report)*

Metrics/Measures are the building blocks of indicators and thus the foundation of a condition assessment system (e.g., the WAF). Examples of metrics and measures include DO concentration, proportion of successful nests (i.e., produce young) per season for a particular bird species, and fire return interval for a particular plant community within a study area. Each of these measures might fit into an indicator composed of one or more metrics (e.g., "fire dynamics") that in turn is categorized into an EWA (e.g., natural disturbance) or EWA sub-attribute (e.g., fire).

**Figure 2 — Example use of Categories, Indicators and Metrics in a report card format**

Report Card

| Category | Indicator | Metric | Score |
|---|---|---|---|
| Landscape Condition | Development | Impervious surface<br>Fragmentation | 65±13 |
| Biotic Condition | Native fish | Out-migrants<br>Habitat | 43±22 |
| Social Condition | Material relationship to watershed | Fishability | 84±3 |
| Economic Condition | Community well-being | School lunch program enrollment | 71±15 |
| Hydrology/Geomorphology | Erosion | TSS<br>Bed-load movement | 34±8 |
| Ecological Processes | Exotic invasion | Extent<br>Rate of spread | 57±31 |
| Natural Disturbance | Fire | Spread risk<br>Succession/regeneration | 35±16 |
| Chemical/Physical Properties | Toxics | Metals<br>Pesticides | 52±9 |



# APPENDIX B
## Indicator Selection Criteria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## Availability of high-quality data

One of the main obstacles many face when selecting indicators is the lack of available data. Frequently the data for an indicator that may be important are not available. Alternatively, the data might only be available for random points in time or for limited geographical areas. The data might have been collected for one purpose in a particular way that served the original purpose, but for your purposes, it may be inadequate. If new data are needed, the feasibility of collecting them might be limited by the amount of effort required to accurately make the measurement (e.g., actual salmon escapement). Alternate indicators may be considered that have significantly lower cost (e.g., remote-sensing based habitat assessment). For certain indicators, it may be very cost-effective to collect the required metrics (e.g., habitat assessment for a species of concern), but the indicator may not represent the process of concern compared to more expensive indicators (e.g., actual population trends in the species of concern).

Data collection and analysis costs (further described as a separate criterion below) have to be evaluated in relation to the potential cost and societal implications of a proposed action or inaction, i.e., the greater the expected tradeoffs between societal goals, the greater the need for certainty in the environmental outcome. When choosing indicators, it is essential to carefully consider the current availability of data for the indicator, as well as how much data will be available in the future from our own collection and from the efforts of others. The availability of metadata is one criterion for selection of particular data for corresponding indicators. Finally, indicators will be useful and useable in the long-run if there is a process for updating the corresponding database, metadata, and data collection & QA/QC procedures.

## Data affordability

One factor to consider in evaluating indicators is the costs associated with collecting and analyzing data. One consideration in evaluation the costs and benefits is the usefulness of the information for evaluation of management and ecosystem condition. Indicators that are cost-effective, while accurately representing ecosystem characteristics are preferable. The primary guide is that the amount of data required to adequately report on condition and change in condition can be and are being collected with the resources available. The data should also be collected in a standardized way for which there are QA/QC procedures described. For critical indicators (those reflecting important system conditions for which there is no viable alternative), more resources may need to be made available if they are currently inadequate.

## System representation

Another factor to consider in indicator selection is how well the indicator reflects the issue for which it was selected. Frequently, certain indicators are widely recognized to be a useful measure for an issue. Selecting these indicators is usually a 'safe bet'. For example, percent riparian canopy cover is considered a good indicator of riparian conditions because it has been extensively studied and shown to have a good relationship with

stream temperature and the detection of changes can be made easily. Selecting indicators that have been carefully evaluated for their scientific validity means they usually have wider acceptance than those that haven't been studied very much, and they are more likely to allow you to make confident inferences about system condition.

Indicators that are representative of large aspects of system condition and trends are preferable for those that have narrower utility, all else being equal.

Sometimes the condition is itself an important ecosystem driver. For example, surface water temperature is an important ecological variable for understanding the condition of aquatic ecosystems. It is also the target of management actions to benefit these ecosystems, which is another criterion described below. Indicators that can provide important information at both broad and fine spatial scales are likely to be more useful as they can help inform both strategic and site-specific decisions.

## Ability to detect change over time

The ability to report on trends over time is a key function of an indicator. The availability of a data set collected over a period of many years is ideal. Indicators that respond relatively quickly to management intervention and can effectively be used to measure change over time may be preferable to those that require data over long periods of time to observe changes due to management actions. This is especially useful in reference to short-term grants and contracts, or short-term program evaluation, which require performance measures to demonstrate the success or failure of the project. If possible, select indicators whose range of natural variation can be quantified and that permit change detection over short periods of time (2-3 years). At the same time, recognize that many of the processes that we try to improve with restoration programs take decades or longer to change or recover (e.g., salmon population recovery). Indicators for these projects and programs should be stable over these longer timeframes (i.e., decades).

## Independence of indicators from one another

Independence refers to how related indicators are to each other. Road density and %impervious surface are related indicators because roads are often impervious. Indicators that are relatively independent are preferable (e.g., rate of ground water use for irrigation and migration barriers), while recognizing that some critical indicators are related and somewhat dependent on each other (e.g., surface water temperature, flow, stream shading, hydraulic connectivity to groundwater, salmon rearing habitat suitability). The concern about independence is important for designing efficient indicator systems, but is secondary to choosing easily-measured and representative indicators. You may choose related indicators, but you would be constrained in your attempts to use them together to explain condition of a system. For example, if (a) surface water temperature, (b) flow, (c) stream shading, (d) amount of groundwater withdrawal, and (e) salmon rearing habitat were indicators of success for a restoration program, then you could not report changes in these indicators without acknowledging that (a) depends on (b), (c), and (d); (e) depends on (a), (b), (c), and possible indirectly on (d) through (b); and (c) may depend on (b) and (d).

If restoration of riparian shade (c) was a goal in order to benefit salmon rearing (e), then the inter-dependence of some of the other parameters would need to be acknowledged and potentially controlled-for in order to measure the true effect of increased riparian shade on salmon rearing.

## Supports management decisions and actions

Measuring conditions in the environment and in communities can inform policy development and social/fiscal investments. Indicators should be informative in evaluating environmental/social/economic conditions, as well as the influences on these conditions. Another useful characteristics of indicators is that they can be used to evaluate the effects or effectiveness of management actions — be it a state or federal agency or the goals and objectives of a watershed council. Whatever the business of the organization is, indicators should provide information that can be used to assess the effectiveness of the work and efforts of the group. In the past, *activities* were seen as a measure of the effectiveness of an organization. The number of grants awarded, the number of pamphlets distributed, or similar "bean counting" has been used extensively to evaluate an organization's productivity. Environmental performance measures, on the other hand, look at the environmental and social *outcomes* of these activities to determine an organization's effectiveness. This is the reason it is so important to select indicators that are closely linked to management actions and decisions and that can be reported and understood in public arenas

The point of most indicators is to inform a wide audience about conditions in the environment and communities. Indicators should be science-based and easily understood by various kinds of decision-makers (e.g., scientists, public, elected officials). They should be equally presentable in summary form in newspapers and on web sites. Finally, indicators should be based upon reportable technical & scientific information and links easily made between summary presentations and the source data and knowledge.

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