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# CALIFORNIA CENTRAL COAST HEALTHY WATERSHEDS PROJECT – PART 1

## Report Cards for Scoring Water Quality Data to Characterize Health and Change


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SWAMP Surface Water Ambient Monitoring Program

California Water Boards

www.waterboards.ca.gov/swamp

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# List of Acronyms

| Term | Definition |
|---|---|
| **Cal/EPA** | California Environmental Protection Agency |
| **CCAMP** | Central Coast Ambient Monitoring Program |
| **CCC** | criterion continuous concentration |
| **CCME** | Canadian Council of Ministers of the Environment |
| **CCRWQCB** | Central Coast Regional Water Quality Control Board |
| **CDFW** | California Department of Fish and Wildlife |
| **CMC** | criterion maximum concentration |
| **COLD** | cold fresh water habitat beneficial use |
| **CSCI** | California stream condition index |
| **CTR** | California Toxics Rule |
| **ERL** | effects range low |
| **EST** | estuarine habitat beneficial use |
| **HBSL** | health based screening levels |
| **HHBP** | human health benchmarks for pesticides |
| **IRIS** | USEPA's Integrated Risk Information System |
| **LC50** | median lethal concentration |
| **LEL** | lowest effect level |
| **MAR** | marine habitat beneficial use |
| **MCL** | maximum contaminant level |
| **MEQ** | magnitude exceedence quotient |
| **MUN** | municipal and domestic water supply beneficial use |
| **NADA** | Non-detects And Data Analysis |
| **NNE** | numeric nutrient endpoint |
| **NOAA** | National Oceanic and Atmospheric Administration |
| **NOEC/NOAEC** | no observed (adverse) effect concentration |
| **NRWQC** | USEPA National Recommended Water Quality Criteria |
| **NSI SQAL** | National Sediment Inventory sediment quality advisory level |

| | |
|---|---|
| **NTR** | National Toxics Rule |
| **NTU** | nephelometric turbidity units |
| **OC** | organochlorine |
| **OPP** | USEPA Office of Pesticide Programs |
| **PAH** | polycyclic aromatic hydrocarbons |
| **PSA** | California Statewide Perennial Streams Assessment |
| **R** | an open source software environment for statistical computing |
| **SQuiRTs** | NOAA Screening Quick Reference Tables |
| **SWAMP** | California Surface Water Ambient Monitoring Program |
| **SWRCB** | California State Water Resources Control Board |
| **TEC** | threshold effects concentration |
| **TEL** | threshold effects level |
| **USEPA** | United States Environmental Protection Agency |
| **USGS** | United States Geological Survey |
| **WQC** | Oregon Human Health water quality criteria |
| **WQI** | water quality index |

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# Executive Summary

The California Central Coast Healthy Watersheds Project utilizes measured and modeled data in a web mapping environment to assess the health of our watersheds. The Central Coast Ambient Monitoring Program (CCAMP) created these tools to generate report cards that quickly convey water quality and habitat conditions for sites, waterbodies and watersheds. Report cards are based on measurements for a large number of parameters assessed relative to specific aquatic life and human health thresholds. The web application allows the user to drill in with increasing levels of detail to identify the locations and causes of water quality problems, and to relate the observed conditions to associated data trends and land management activities.

This report is Part 1 of two documents describing the approach the Central Coast Healthy Watersheds Project has taken to create a web-based data navigator and report card system that can be used for efficient aquatic assessments to guide resource management. Part 1 describes selection of aquatic life and human health thresholds, parameter scoring, methods to combine multiple parameters into health indices, and status and trends assessment at the site level for parameters and indices. Part 2 describes methods for integrating monitoring data with modeled and remotely sensed data, defining land management attributes, connecting site scores to upstream features (catchments, reaches, etc.), connecting watershed attributes (such as land management activities) to downstream site scores, relating health scores to stressors, and finally, displaying health scores in a web-based report card and mapping system.

The data navigator and report card systems are available at www.ccamp.org and provide resource managers, decision makers and the public with immediately available and easily understood information on aquatic resource conditions. The website opens with high level overview maps and index scores that the user can quickly survey to find problem areas or results of interest. Users can then drill down through maps and scores to easily get detailed information on specific parameters and trends. Underlying data sets can be directly downloaded for additional analysis. This system represents a substantial and meaningful improvement over previous database outputs and query tools that require detailed, technical and advance knowledge of problem sites and parameters in order for the user to begin searching for relevant data.

The main elements of this report are summarized below.

## THRESHOLD SELECTION

We have gathered thresholds from a number of sources for chemical, biological, and physical metrics in water and sediment. Threshold sources included the State Water Board's Water Quality Goals, USEPA Water Quality Criteria, USEPA Office of Pesticide Program's Aquatic Life Benchmarks and state and federal agency reports and tables. Thresholds have been selected for most parameters measured by the California Surface Water Ambient Monitoring Program (SWAMP) and a large number of additional parameters. Thresholds are identified for specific water body types (cold water stream, estuarine, marine, groundwater) and beneficial uses (aquatic life, swimmable, drinkable). Note that because the central coast vision goals assessment is designed to identify and protect healthy waters, thresholds are selected to discriminate between negligible and low levels of biological effect (i.e., "threshold effects") rather than between possible and probable impact levels ("probable effects"). The system is adaptable, however, so that assessment programs by other regions, states or counties can select different types of thresholds from our compilation and apply them toward other assessment objectives.

## SITE- AND PARAMETER-LEVEL DATA ASSESSMENT

Our report card scoring approach has been modified from the Canadian Council of Ministers of the Environment (CCME) Water Quality Index (CCME, 2001). At each site, data are evaluated relative to thresholds using the [Magnitude Exceedance Quotient (MEQ) scoring approach](). This approach combines into a single term both the magnitude of each measurement relative to the threshold and the proportion of samples exceeding the threshold, and is scaled to produce final unit-less scores between 0 and 100. MEQ scores are assigned letter grades using the following scoring and narrative categories: Excellent (A: 90 - 100), Good (B: 80 – 89.9), Fair (C: 65 – 79.9), Poor (D: 45 to 64.9), and Very Poor (F: 0 – 44.9). These threshold breaks are similar to those used in the Canadian approach, with the exception that we have provided for an "Outstanding" or "A+" category that does not apply until individual parameter and sub-index scores are aggregated to the level of the overall Aquatic Life health index. We validated the grading system by quantitatively comparing the MEQ grades with those produced by an independent rule-based scoring approach that was based on multiple thresholds, correlations with biological effects, and professional judgment about the condition of sites from which the data were collected.

## COMBINING PARAMETER SCORES INTO HEALTH INDICES

At each site, MEQ scores from multiple parameters are combined into sub-indices. Sub-index scores for basic water quality, toxicity, organic chemicals, metals, and biostimulation are combined into an overarching Aquatic Life Index. The Aquatic Life Index also encompasses a bioassessment sub-index that currently does not aggregate multiple parameters but simply uses the scores of the available bioassessment protocol (e.g., the California Stream Condition Index; Mazor et al. in review), which are then rescaled to the MEQ grade breakpoints. A sub-index for habitat is in development.

Drinking water sub-indices for salts, nitrogen species, organic chemicals, and metals are created by aggregating the MEQ scores of their component parameters, with each parameter assessed relative to human health thresholds. These sub-indices are combined into an overarching Clean Drinking Water Index that applies to both surface and ground waters. An additional sub-index for pathogen indicators (e.g., *E. coli* and fecal coliform) is created to assess risk to recreational beneficial uses, and this sub-index is considered separately from the two overarching indices (Aquatic Life and Clean Drinking Water).

Sub-index scores are also given letter grades. Care was taken to identify the most appropriate aggregation methods for combining parameter scores into sub-indices. For the basic water quality sub-index, parameters such as nutrients, dissolved oxygen and temperature were combined using the arithmetic mean. For the trace metal sub-index, Individual trace metals were combined using the geometric mean to emphasize the influence of the lowest scoring (highest concentration) elements. The toxicity and organic chemical sub-index scores were equivalent to the lowest (worst) score among the component parameters, because any one of these parameters could cause adverse biological effects regardless of the other measures in the sub-index. These aggregations of individual parameter measurements into sub-indices necessarily result in a loss of detail and sensitivity, but the indices are created to provide a broader picture of watershed health. Detail is easily restored when web tool users drill down from index to sub-index to parameter to underlying data.

## CHANGE AND TREND ANALYSIS

We used both linear trend and change point analysis to evaluate changes in parameters over time, and the results are displayed graphically on the www.ccamp.org website for each parameter at each monitoring site. Website maps and tables display arrow symbols for each site at which statistically significant change is detected. We used standard linear trend plotting with the Mann-Kendall test for statistical significance, but realized that in many cases trend lines fail to illustrate important information about water quality changes. Bayesian change point analysis was added so that breakpoints in time series could be quantified and evaluated for statistical significance. Change point analysis is very useful for detecting episodic events such as floods, dry periods or discharge events, and provides distinct points in time when water quality changes might reflect a management action, such as when a new wastewater treatment process comes on line or a certain type of regulated discharge is terminated. Change point analysis is used to provide the breakpoint around which to color score the two-toned arrows used on our website to denote change from one grade to another. Trend and change point analysis are done automatically on the website, and other trend analysis approaches may be applied by the user to data sets that can be easily downloaded from the CCAMP site at any point in the assessment process.

## WEB DISPLAY

The Central Coast Healthy Watersheds website provides access to all data in an open-source geospatial framework, where users can access data by drilling down from hydrologic unit report cards, to water bodies, to sites, and finally to parameters. At all levels, color scoring allows the user to quickly identify problem locations and parameters. **Figure 1** shows an example of this interactive approach to data viewing. Index, sub-index, and parameter scores/color grades are displayed in web format at www.ccamp.org (**Figure 1**).

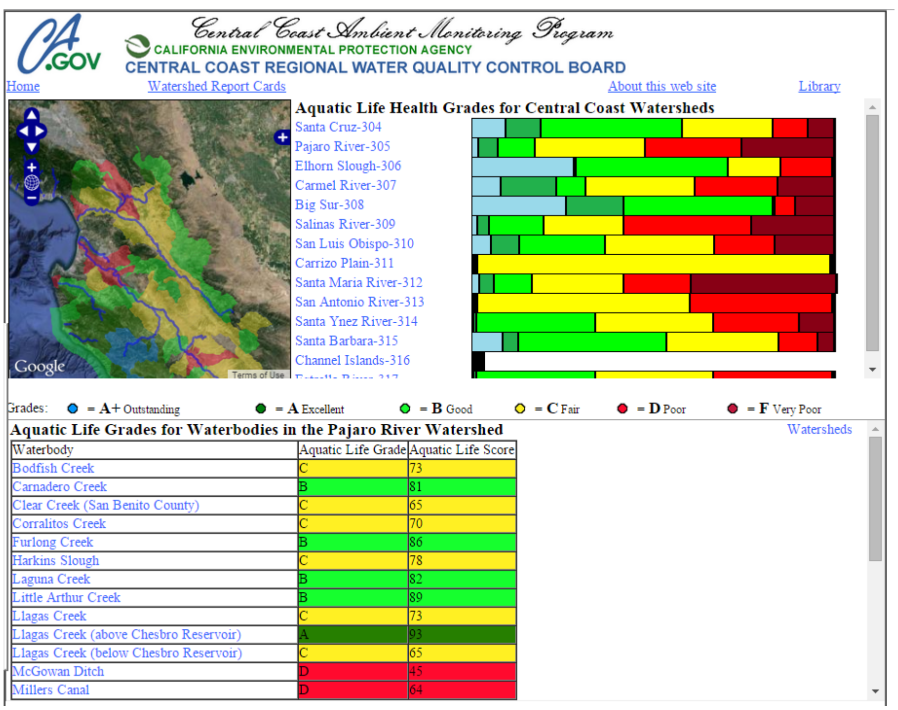



Figure 1. A screenshot from the Healthy Watersheds website (www.ccamp.org)

Please visit the website and spend a few minutes exploring water quality on the California central coast. You will quickly identify issues of interest. You will also likely see results that you might not have anticipated and that you would have had great difficulty finding with other existing database query tools. The remainder of this report provides details on the methods, thresholds, algorithms and approaches that underlie the assessments displayed by the website's data navigator, maps and report card tools.

# Chapter 1: Introduction

Regional Water Board staff has been working since 2007 to realize a "Healthy Watersheds" vision for the California Central Coast. As part of this effort, staff established three measureable goals related to healthy aquatic habitat, proper land management and safe human uses (**Figure 2**). To assess progress made toward achieving these goals, the Central Coast Ambient Monitoring Program (CCAMP) has developed a new web-based tool for synthesizing data from multiple sources into measures of "health." This tool provides a unique new way to view complex data in a user-friendly environment that allows the user to quickly understand where our streams are healthy, and if not healthy, why not.

**Goals for Healthy Watersheds**

**Healthy Aquatic Habitat – By 2025, 80 percent of aquatic habitat will be healthy, and the remaining 20 percent will exhibit positive trends in key parameters.**

**Proper Land Management – By 2025, 80 percent of lands within a watershed will be managed to maintain proper watershed functions, and the remaining 20 percent will exhibit positive trends in key management parameters.**

**Clean Drinking Water – By 2025, 80 percent of surface and groundwater will provide safe drinking water sources and the remaining 20 percent will exhibit positive trends in key parameters.**

Figure 2. Central Coast Water Board Healthy Watershed Goals

In order to address the Region's goals, the online tool summarizes the percent of stream reaches and watershed catchments that are healthy and determines where change is occurring. The website updates routinely and recalculates metrics as new data become available in associated databases. The website update process is code-driven and does not require manual intervention on the part of the project manager. All software has been designed by David M. Paradies, co-author of this document.

This Healthy Watersheds Project identifies numeric thresholds appropriate for aquatic life and human health use protection, scores data relative to these thresholds, and combines multiple parameters into sub-indices and indices of health. Site scores are then linked geospatially to upstream reaches so that appropriate scores can be assigned to watershed catchments. To achieve broader watershed coverage, these scores are combined with indices developed from statewide geospatial datasets and predictive models developed as part of the State's Healthy Watershed Assessment (USEPA, 2013). The statewide assessment is used to aid in scoring the condition of areas where regionally collected data are not available, allowing for health assessment of whole watersheds.

This report is Part 1 of two documents describing the approach the Central Coast Healthy Watersheds Project has taken to accomplish these tasks. Part 1 describes the selection of thresholds for aquatic life and human health, the scoring of parameters, development of indices of health from multiple parameters, and assessing both status and trend at the site level for parameters and indices. Part 2 describes methods for integrating monitoring data with remotely sensed and modeled data that quantify land management attributes, connecting site scores to upstream features (catchments, reaches, etc.), connecting watershed attributes (such as land management activities) to downstream site scores, relating health scores to stressors, and finally, displaying health scores in a web-based report card and mapping system.

# Chapter 2: Thresholds

## THRESHOLD COMPILATION

In order to provide information useful for resource management decision making, water quality monitoring data must be assessed to determine the potential for environmental damage posed by toxic chemicals and other constituents. Potential for environmental impact is frequently assessed by comparing measured constituent concentrations against scientifically defensible threshold values previously shown to be associated with adverse biological effects.

A great many threshold values have been derived over the past 40 years to set benchmarks at various effect levels (e.g., mortality, chronic effects, food web impacts, eutrophication, ecosystem impairment, or human health protection). Many of these thresholds are organized and evaluated at the State Water Resources Control Board's "Compilation of Water Quality Goals" website (www.swrcb.ca.gov/water_issues/programs/water_quality_goals/index.shtml).

For each of many chemicals, there are thresholds for different lengths of exposure, different risk probabilities, different target organisms, and different levels of impact. There are a number of different regulatory criteria and toxicity levels for pollutants in water, proposed guidelines for contaminants in sediment, and site-specific advice for fish tissue consumption. Additionally, there are a large number of chemicals with thresholds only available from the scientific literature, and even more for which there are no thresholds at all. Finding and assigning thresholds appropriate for the goals of a given assessment continue to be substantial challenges for many programs. The accumulation and selection of thresholds here and elsewhere (e.g., Marshack 2011) represent a step forward, but maintaining valid threshold lists will require continuing re-evaluation as new information becomes available.

We compiled thresholds from the Water Quality Goals database, the USEPA Office of Pesticide Program's Aquatic Life Benchmarks database, USEPA Water Quality Criteria, state and federal agency tables, peer-reviewed toxicity studies and a number of other sources. Thresholds were compiled with associated information such as units of measurement, threshold source, applicable water body types (cold water stream, estuarine, marine, ground water, etc.), and beneficial uses (aquatic life support, municipal and domestic supply, water body contact recreation, etc.). This additional information allows our software to apply selected thresholds to appropriate water body types for applicable beneficial uses, so that we can score data for our various metrics of health.

## CRITERIA FOR SELECTING THRESHOLDS

Water quality assessments must consider which of the numerous types of thresholds are appropriate for the resource management questions being addressed. In this assessment, we have evaluated hundreds of thresholds to select those that are consistent with a healthy watershed approach. We have also maintained the more extensive list from which thresholds can be selected for other assessment goals.

It was our goal to select thresholds that were as consistent as possible across parameters, but because threshold sources are so variable, the project employs a set of criteria for threshold selection. For this healthy watersheds assessment, the selected thresholds are intended to distinguish between negligible adverse impacts and possible adverse impacts, rather than between possible and probable impacts. For aquatic life protection, such a threshold ''might be thought of as an estimate of the highest concentration of a substance in water which does not present a significant risk to the aquatic organisms in the water and their uses'' (USEPA 2000). Examples of choosing such thresholds include: selection of Criterion Continuous Concentrations (CCC, based on chronic toxicity) rather than Criterion Maximum Concentrations (CMC, based on acute toxicity); selection of sediment quality guidelines for "threshold effects" rather than "probable effects;" and selection of chronic "no observed effect concentrations" (NOECs or their equivalents) rather than acute "median lethal concentrations" (LC50s) when it is necessary to use thresholds derived from individual peer-reviewed journal articles. In applying these thresholds we also considered the designated exposure duration relative to the frequency of field sample collection, and the statistical reliability demonstrated by threshold evaluation studies.

The selection criteria below drive the tiered selection process described in the following section. In the tiered process, if the type of threshold that best fits the selection criteria is not available for a given parameter, other thresholds are considered.

Criteria for selecting thresholds for this healthy watershed assessment:

1. Thresholds should be ecologically, physiologically, and/or environmentally meaningful, or they should be based on established precedents that were developed with this intent (e.g., federal criteria, state objectives, Maximum Contaminant Levels, sediment quality guidelines, etc.).

2. Thresholds should be at levels that distinguish between negligible adverse impacts and possible adverse impacts, rather than between possible and probable impacts. Higher thresholds may be used as context for evaluating scoring breakpoints.

3. Threshold values for each parameter should be appropriate for the specific matrix, waterbody type, beneficial use and health index (i.e., human health or aquatic life indices). The Marshack (2011) algorithms for threshold selection should be used whenever possible.

4. Similar parameters should be compared to Identical or very similar types of thresholds. For example, all PAHs in groundwater should be compared to the same type of standard. Thresholds for all types of indicators should be based on a similar level of protective intent.

5. Regulatory standards or guidelines protective of chronic effects should be used as thresholds for all parameters for which they are available (e.g., Step 1 thresholds in the Selection Process below). When regulatory standards or guidelines are not available, parameter values should be compared to thresholds that were developed with a similar protective intent (Step 2 or lower thresholds, below).

6. If thresholds are available for sums of like chemicals (e.g., ∑PAH), the summary threshold should be applied to the appropriate summary data in addition to, rather than instead of, thresholds for each available component parameter (e.g., individual PAH compounds such as fluoranthene).

7. Thresholds should be appropriate for the temporal component of the sampling design. Standards based on 1-h average concentrations are probably not protective of more chronic ambient exposures that may being occurring in water bodies between monthly or quarterly sampling events. Four-day standards (e.g., Criterion Continuous Concentrations) may be generally appropriate given typical sampling frequencies. Standards based on life-cycle or very long-term chronic effects are also likely to be inappropriate because monitoring designs can rarely demonstrate that concentrations in the environment persist for similar time spans. Thresholds based on long-term exposures were considered appropriate for municipal and domestic supply parameters because of contaminant persistence in groundwater.

8. Reference conditions or background concentrations should be considered only when established thresholds are unavailable for measured chemicals of potential concern.

## THRESHOLD SELECTION PROCESS

The CCAMP Healthy Watersheds threshold selection follows a step-wise process based in large part on the water quality goal algorithms of Marshack (2011). For each chemical, thresholds were selected according to the stepwise hierarchies described below. If no thresholds for a target parameter were available in an earlier step (tier), then thresholds in the subsequent tier were considered. Some tiers contain multiple thresholds, in which case directions are given for selecting either the lowest (most protective) among equally applicable thresholds or selecting thresholds along a hierarchy within the tier. Because of the large number of thresholds involved and the complexity of managing the selections, we developed a software-aided selection tool based on threshold tiering.

As with regulatory standards, thresholds are selected for the appropriate beneficial use. There are a number of designated beneficial uses related to aquatic organism health, but thresholds are generally lacking or inappropriate for many of them (e.g., Spawning, Rearing or Migration). In this assessment, aquatic organism health-related thresholds were organized by assigning them as appropriate to three beneficial uses: Cold Fresh Water Habitat (COLD), Estuarine Habitat (EST), and Marine Habitat (MAR). Freshwater thresholds (COLD) apply to waters with salinity less than 1‰, saltwater thresholds (MAR) apply to waterbodies with salinity greater than 10‰, and the lower of the two thresholds applies to estuaries (EST) where salinities range from 1 to 10‰. Because central coast estuaries are strongly influenced by tidal and riverine flows and have widely fluctuating salinities, the lower (more protective) of the freshwater or saltwater thresholds was generally applied to estuarine sites regardless of the actual salinity measured when samples were collected.

### Threshold Selection Process for Aquatic Life Protection – Toxic Chemicals in Water

Aquatic life thresholds for freshwater, estuarine, and marine waters are selected using the following process. Many of the original sources for the thresholds listed below (e.g., California Toxics Rule [CTR; USEPA 2000], National Toxics Rule [NTR; USEPA 1998], or National Recommended Water Quality Criteria [NRWQC; USEPA 2014]) provide both freshwater and saltwater criteria, which should be applied appropriately, as described above. California Ocean Plan thresholds apply to MAR, and also apply to EST when lower than freshwater thresholds. Explanations for numbered footnotes are given at the end of this threshold selection process section.

**Step 1**: For each chemical, select the lowest value from the following sources:

- California Toxics Rule, Criterion Continuous Concentration (CCC) (1)
- National Toxics Rule, (CCC) (1)
- Central Coast Water Quality Control Plan (Basin Plan; CCRWQCB 2011) water quality objectives
- Water Quality Control Plan Ocean Waters of California (Ocean Plan; SWRCB 2012) water quality objectives, 6-month median (Table 1) (for saltwater waterbodies)

**Step 2**: If none of the above thresholds are available, select from the following, if available:

- USEPA National Recommended Water Quality Criteria, CCC (chronic) (1)
- Canadian Council of Ministers for the Environment freshwater and saltwater aquatic life guidelines for long-term exposure (CCME 2013)
- California Department of Fish & Wildlife criterion continuous concentration (CDFW 2000) (2)

**Step 3**: If none of the above thresholds are available, select the lowest value from the following sources:

- USEPA Office of Pesticide Programs Aquatic Life Benchmarks for invertebrate chronic effects
- USEPA Office of Pesticide Programs Aquatic Life Benchmarks for fish chronic effects
- USEPA Office of Pesticide Programs Aquatic Life Benchmarks for vascular plant effects, divided by 10 [(3)]
- USEPA Office of Pesticide Programs Aquatic Life Benchmarks for non-vascular plant effects, divided by 10 [(3)]
  (all USEPA 2012)

**Step 4**: If none of the above thresholds are available, select the lowest value from the following sources:

- California Toxics Rule, Criterion Maximum Concentration (CMC) divided by 5 [(1, 4)]
- National Toxics Rule, CMC divided by 5 [(1, 4)]
- National Recommended Water Quality Criteria, CMC divided by 5 [(1, 4)]
- USEPA Office of Pesticide Programs Aquatic Life Benchmarks for fish acute effects, divided by 5 [(4)]
- USEPA Office of Pesticide Programs Aquatic Life Benchmarks for invertebrate acute effects, divided by 5 [(4)]
- California Department of Pesticide Regulation (Luo et al. 2013) benchmark equivalent, lowest acute benchmark, divided by 5 [(4)]

**Step 5**: If none of the above thresholds are available, carefully evaluate published toxicity values and thresholds from other sources, including those below, and select the lowest threshold:

- Ambient Water Quality Guidelines, Canadian Council of Ministers of the Environment (CCME 2003)
- Toxicity values from the ECOTOX Database (USEPA 2000c), with acute LC50 values divided by 10 [(3)]
- Toxicity values from the scientific literature, with acute LC50 values divided by 10 [(3)]
- Other appropriate standards or criteria evaluated on a chemical- and source-specific basis

## Threshold Selection Process for Aquatic Life Protection - Toxic Chemicals in Sediment

**Salinity Step:** Determine whether to apply freshwater (A) or saltwater (B) guidelines as thresholds.

- For inland surface waters (e.g., COLD beneficial use), select freshwater sediment quality guidelines by proceeding through steps 1a, 2a, 3a, and 4a
- For marine waterbodies (MAR) select saltwater sediment quality guidelines by proceeding through steps 1b, 2b, 3b and 4b
- For estuaries (EST) select the lower of the freshwater or saltwater sediment quality guidelines as the threshold

### *A. Freshwater sites (COLD), and in some cases estuarine sites (EST)*

**Step 1a:** Select the appropriate consensus-based threshold effects concentration (TEC) from MacDonald et al. (2003). Note that TECs are based on empirical/statistical rather than mechanistic/theoretical studies and should be applied with care in site-specific assessments. Among available guidelines, TECs best met the intent of this broad-based healthy watersheds assessment.

**Step 2a**: If TECs for the chemical are not available from MacDonald et al. (2003), select the lowest value from the following sources:

- TEC (MacDonald et al. 2000)

- TEL (Smith et al. 1996)
- LEL (Persaud et al. 1993)
- TEC (Stortelder et al. 1989; as cited in MacDonald et al. 2003, Table 5.1)
    - Canadian Interim Sediment Quality Guidelines (CCME 2013)
    - Sediment Effect Concentrations (Ingersoll et al. (1996)

**Step 3a:** If none of the above thresholds are available, select the lowest freshwater LC50 value from acceptable published results of sediment toxicity tests, and divide the LC50s by 10 to approximate chronic effects.

**Step 4a:** If none of the above thresholds or LC50s are available, select the lowest freshwater value from the following sources:

- USEPA National Sediment Inventory Sediment Quality Advisory Level – aquatic life, divided by 10 to approximate chronic or threshold effects (USEPA 1997) (5)
- Apparent Effects Thresholds, divided by 10 to approximate chronic or threshold effects (5)
- WA State Department of Ecology Sediment Quality Standards (WDOE, 1995), divided by 10 to approximate chronic or threshold effects (5)
- WA State Department of Ecology Minimum cleanup levels (WDOE, 1995), divided by 10 to approximate chronic or threshold effects (5)
- Dutch Sediment Target Values (cited in NOAA 2008)

### *B. Saltwater sites (MAR), and in some cases estuarine sites (EST)*

**Step 1b:** Select the lowest value from the following:

- Effects Range Low (ERL, Long et al. 1995, NOAA 1999)
- Threshold Effects Level (TEL, MacDonald, et al. 1996)

**Step 2b:** If none of the above thresholds are available, select the lowest value from the following sources:

- Canadian Interim Sediment Quality Guidelines (CCME 2013)

**Step 3b:** If none of the above thresholds are available, select the lowest saltwater LC50 value from acceptable published results of sediment toxicity tests, and divide the acute LC50s ($\leq$ 10-day) by 10 to approximate chronic effects.

**Step 4b:** If none of the above thresholds or LC50s is available, select the lowest saltwater value from the following sources:

- USEPA National Sediment Inventory Sediment Quality Advisory Level – aquatic life, divided by 10 to approximate chronic or threshold effects (USEPA 1997) (4)
- Apparent Effects Thresholds, divided by 10 to approximate chronic or threshold effects
- WA State Department of Ecology Sediment Quality Standards (WDOE, 1995), divided by 10 to approximate chronic or threshold effects(4)
- WA State Department of Ecology Minimum cleanup levels (WDOE, 1995), divided by 10 to approximate chronic or threshold effects(4)

## Threshold Selection Process for Aquatic Life Protection - Conventional Chemicals in Water

For conventional chemistry, threshold selection involves special treatment of several analytes with unusual properties. For example, temperature, oxygen and pH are all assumed to have acceptable ranges within which no impact is expected, and oxygen and pH also are "double ended thresholds" for which values either above or below the acceptable range can indicate adverse effects. This affects threshold derivation and also involves special considerations for scoring relative to the selected thresholds. Scoring is described in Chapter 3. The conventional chemistry thresholds selected for the Central Coast healthy watersheds assessment are as follows:

**Chlorophyll a (ug/L):** The cold water aquatic life chlorophyll a threshold used for this project is 15 ug/L (NCAC 2004; OAR 2000). The benthic chlorophyll a threshold used in the Biostimulation Index for this project is 44 mg/$m^2$, which represents the 95th percentile of reference sites statewide (i.e., only 5% of reference sites exceeded this concentration) (Fletscher, et al., 2013). This number is applied to both measured benthic chlorophyll a concentrations (where available) and to modeled concentrations resulting as output from the Benthic Biomass Spreadsheet Tool (Tetratech Inc., 2007).

**Dissolved Oxygen (mg/L):** The Central Coast Basin Plan requires that dissolved oxygen concentrations in cold water habitat remain above 7.0 mg/L. Increased photosynthesis from excessive plant and algal material during daylight hours can result in concentrations over 13 mg/l, which is indicative of oxygen supersaturation (Worcester et al., 2010). For this project, oxygen MEQ scores are calculated for both an upper and lower threshold, where measurements under 7.0 mg/L or over 13.0 mg/L contribute to MEQ calculations of Exceedance and Magnitude. Because we do not consider values that fall between these two numbers to be of concern, the calculation for Magnitude only includes excursions outside of these thresholds.

**Dissolved Oxygen Deficit (mg/L):** The California Numeric Nutrient Endpoint (NNE) Benthic Biomass Spreadsheet Tool (Tetratech Inc., 2007; Creager et al. 2006) calculates a modeled estimate of dissolved oxygen deficit resulting from biostimulatory substances. The model inputs include nutrient concentrations, temperature, and several other parameters. A modeled deficit of 1.25 mg/L has been determined to be associated with field conditions of excessive nutrient enrichment in the Central Coast Region (Worcester et al., 2010). This project uses a threshold of 1.25 mg/L for aquatic life protection.

**Water Temperature (°C):** Moyle (2002) describes the upper range of optimum temperatures for steelhead growth at 18°C and temperatures above 23°C as potentially lethal without acclimatization. The threshold for this project is set at 18°C for aquatic life protection. Since this is the upper range of optimum, temperatures approaching 18°C are not of increasing concern. Therefore, only excursions above this threshold are considered in calculation of magnitude.

**Nitrate as N (mg/l):** This project utilizes the Central Coast aquatic life guideline value of 1.0 mg/L as N as the threshold for aquatic life protection (Worcester et al., 2010).

**Ortho-phosphate (as Phosphorus) (mg/L):** Williamson (1994) established a guideline value for orthophosphate-P in the Pajaro River of 0.12 mg/L, below which waters are at low risk for eutrophication. This project utilizes 0.12 mg/L as its ortho-phosphate threshold for aquatic life protection.

**pH:** The pH score is calculated both on upper and lower thresholds, based on the Central Coast Basin Plan cold water objectives of 7.0 to 8.5 pH units. Measurements under 7.0 or over 8.5 contribute to calculations of exceedance and magnitude. Because we do not consider values that fall between these two numbers to be of concern, the calculation for magnitude only includes excursions outside of these thresholds.

**Total Suspended Solids (TSS) (mg/L):** This project utilizes a threshold of 30 mg/L for aquatic life protection. This is a threshold used as an aquatic life criterion by several other states (USEPA, 2006).

**Turbidity (NTU):** This project utilizes a threshold of 25 NTU for aquatic life protection, based on levels that are of concern for visual feeders like steelhead trout (Sigler, et al., 1984).

## Threshold Selection Process for Aquatic Life Protection – Bioassessment Indicators

Existing bioassessment indices have established scoring approaches and associated thresholds. The California Stream Condition Index (Mazor et al., in review) uses grade breakpoints that are nearly identical to those used by the MEQ, with the exception that it does not employ the equivalent of our "seriously impacted" category. The Southern California Index of Biotic Integrity (Ode et al., 2005) utilizes a five-category quantile approach. We describe an approach to adjusting these scores to be consistent with the MEQ approach in Chapter 3.

## Threshold Selection Process for Human Health Protection in Surface Waters and Groundwater – Indicators for Sources of Drinking Water

The Municipal and Domestic Water Supply beneficial use is assigned to almost all freshwater streams in the Central Coast Region (CCRWQCB 2011), and we therefore assess these streams based on municipal supply thresholds, which are appropriate for assessing sources of drinking water. Before being supplied to the public for consumption, water is typically treated by coagulation, settlement, filtration and chlorination. While this treatment removes particles and disinfects, it may not remove dissolved chemicals (unless additional treatment is required). Thus, protecting surface and groundwater for municipal supply requires that thresholds protective of drinking water be applied (except for parameters addressed through standard treatment, such as pathogen indicators).

For surface waters, selection of human health thresholds to protect for sources of drinking water is based on selecting the appropriate value from each of the following four categories, and then selecting the lowest of the four category values. Selection of thresholds for groundwater follows the same process, except where indicated below.

- California Toxics Rule (CTR) and National Toxics Rule (NTR) (*Does not apply to groundwater.*) [(1)]
- Chemical Constituent Objective
- Toxicity Objective (*Applies in all cases to groundwater, but applies to surface water only if there are no CTR, NTR or NRWQC criteria for human health protection.*)
- Taste and Odor-based numeric thresholds

### Step 1: CTR, NTR, NRWQC

(*This step does not apply to groundwater*.)

For each chemical, identify the criteria for human health protection from the California Toxics Rule and the National Toxics Rule, and select the lower of the two. If neither exists for the target chemical, select the USEPA National Recommended Water Quality Criterion (NRWQC) for human health protection. For MUN and COLD beneficial uses, select the value listed for "Human Health Water & Organisms." For EST, MAR and COMM beneficial uses, select the value listed for "Human Health Organisms Only."

If no CTR, NTR or NRWQC values exist for the target chemical, eliminate this category from the selection process.

### Step 2: Chemical Constituent Objective

For each chemical, select the lowest of:

- Numeric water quality objective from the Central Coast Basin Plan (CCWQCB 2011)

- California primary Maximum Contaminant Level (MCL)
- Federal primary MCL
- EST and MAR beneficial uses: California Ocean Plan Objectives for Protection of Human Health – Non-carcinogens (30-day average) (*Does not apply to groundwater.*)
- EST and MAR beneficial uses: California Ocean Plan Objectives for Protection of Human Health – Carcinogens (30-day average) (*Does not apply to groundwater.*)

**Step 3: Toxicity Objective**

*For surface water, include this step only if there are no CTR, NTR or NRWQC values for human health protection.*

For each chemical, select the threshold from the first of the following eight hierarchical sub-categories that has an available value. The sub-categories are marked here with a dark bullet point (●). This step is a composite process wherein some sub-categories have internal choices.

- 1 – California Public Health Goal (Office of Environmental Health Hazard Assessment)
  *If not available, go to sub-category 2.*

- 2 – Cal/EPA cancer potency factor at the one-in-a-million risk level
  *If not available, go to sub-category 3.*

- 3 – California Drinking Water Notification Level based on toxicity
  *If not available, go to sub-category 4.*

- 4 – USEPA IRIS criteria – *Select the lowest of the following two*:
  - One-in-a-million cancer risk estimate
  - Reference dose for non-cancer toxicity (as a drinking water threshold)

  *If none available, go to sub-category 5.*

- 5 – USEPA Health Advisory — *Select the lowest of the following two:*
  - One-in-a-million cancer risk estimate
  - Lifetime non-cancer numeric threshold

  *For sodium*:
  - USEPA Health Advisory – Drinking Water Advisory Table – Health-based Value for individuals on a restricted sodium diet

  *If none available, go to sub-category 6.*

- 6 – USEPA MCL Goals — *Use non-zero numeric thresholds only*
  *If not available, go to sub-category 7.*

- 7 – Other health risk-based numeric thresholds - *Select the first available*:
  - National Academy of Sciences criteria – *Select the lowest of*:
    - One-in-a-million incremental cancer risk
    - Drinking water health advisory or SNARL
  - USGS Health Based Screening Levels (2014) – *Select the lowest of*:
    - Cancer HBSL
    - Non-Cancer HBSL
- USEPA Human Health Benchmarks for Pesticides – *Select the lowest of*:
    - Chronic HHBP (Non-Cancer) in parts per billion (ppb)

- Carcinogenic HHBP in parts per billion (ppb)

  *If none available, go to sub-category 8.*

- 8 – Other
  - California Proposition 65 levels – *Select the lowest of:*
  - No-Significant-Risk Level
  - Maximum Allowable Dose Level
  - Oregon Human Health WQC
  - World Health Organization – Drinking water guideline values

**Step 4: Taste- and Odor-based Numeric Thresholds**

*For MUN designated waters, select the first available numeric threshold from the following hierarchy:*

- California Secondary MCL
- Federal Secondary MCL
- USEPA National Recommended Water Quality Criteria – Organoleptic Effect Criteria (based on taste & odor)
- Taste and odor thresholds published by other agencies or from the peer-reviewed literature

**Step 5: Select the Lowest (most protective) Threshold**

Compare the thresholds selected in each of the four steps above, and select the lowest (most protective) threshold as the final threshold for human health protection in surface and ground water.

## Threshold Selection Process for Pathogen Indicators

Thresholds for pathogen indicators are based on supporting the more protective "water body contact" rather than "non-water body contact" recreational beneficial use of surface waters.

**Step 1**: For each bacterial indicator, select the lowest applicable value from the following sources:

- Central Coast Water Quality Control Plan (CCWQCB 2011) water quality objectives
- Water Quality Control Plan Ocean Waters of California (SWRCB 2012) water quality objectives

**Step 2**: If thresholds are not available from Step 1, select from the following, if available:

- USEPA National Recommended Water Quality Criteria for Recreation (USEPA 2012)

## Threshold Selection Footnotes

(1) Hardness adjustments are made for California Toxics Rule, National Toxics Rule and NRWQC criteria for fresh water aquatic life protection. These include Continuous Concentrations (CCCs) and Criteria Maximum Concentrations (CMCs) for cadmium, copper, zinc, chromium III, lead, nickel, and silver as described in Marshack (2014).

(2) Individual CDFW criteria exist for diazinon and chlorpyrifos (CDFW 2000)

(3) For the purposes of this Healthy Watershed assessment, all cases assume an acute-to-chronic ratio of 10, meaning that dividing acute LC50s (median lethal concentrations) by 10 is assumed to approximate chronic NOECs or NOAECs (no observed [adverse] effect concentrations). This is consistent with USEPA Region 9 advice and many published studies, though literature acute-to-chronic ratios vary widely. The USEPA OPP

aquatic life benchmarks for vascular and non-vascular plants are usually short-term EC50 values (usually < 10-d LC50s with duckweed and unicellular algae, respectively). Since these are both considered acute endpoints, they are divided by 10 to approximate chronic effect levels.

(4) The acute OPP aquatic life benchmarks for fish and invertebrates are calculated from the lowest acute LC50 divided by 2, thus these are further divided by 5 to approximate chronic effects levels. Similar calculations are used to derive the California Department of Pesticide Regulation (Luo et al. 2013) benchmark equivalent, so these are also divided by 5.

(5) USEPA NSI SQAL values were an average of 15.9 times higher (+ 20) than TEC values for 7 chemicals for which both values were available (MacDonald et al., 2003). This suggests that USEPA NSI SQAL values, divided by 10, may be appropriate as thresholds in CCAMP assessments. The 7 chemicals were all OCs and PAHs.

## PEER REVIEW OF THRESHOLD SELECTION PROCESS

The threshold selection algorithms listed above were used to apply threshold values from approximately 40 agency, literature, and web-based threshold sources to a list of over 1200 analytes in an automated Excel-based spreadsheet tool. The selection process algorithms (an earlier draft of the above) and the spreadsheet results were then reviewed by experts in the fields of water quality goals application, pesticide ranking and prioritization, toxicity identification evaluation, and sediment quality guideline application.

This review committee was asked to evaluate:

1. **the overall approach to threshold selection;**
2. **the appropriate application of toxicity-based thresholds;**
3. **the appropriate use of toxicity data from the peer-reviewed literature;**
4. **the balance between USEPA criteria, USEPA pesticide benchmarks and California Department of Pesticide Regulation benchmark equivalents;**
5. **the appropriate selection of sediment quality guidelines; and**
6. **the conceptual agreement between this approach and other approaches currently under development.**

Each of the reviewers sent detailed comments that identified a number of specific issues that were addressed in finalizing the selection process described above. These included comments on the distinctions between various sources of agency-derived criteria, the trade-offs between using thresholds based on acute and chronic toxicity data, appropriate acute-to-chronic ratios, ways to consider data from plant and animal exposures, differences between thresholds derived through formal criteria development programs versus single organism toxicity studies, salinity issues, and analyte-by-analyte evaluations. After revising the selection process to address these comments, we had further discussions with SWRCB staff to apply their experience in the use of water quality goals. We then applied the revised algorithms to the list of analytes and made comparisons between the results from the different processes. Further refinements will be considered as we work with an expanding group of experts applying this system to different assessment needs.

# Chapter 3: Magnitude Exceedance Quotient Scoring Approach

A Water Quality Index (WQI) is a numeric scoring system that represents the overall quality of the water in question, created by combining multiple measures of water quality into a single score. Most indices normalize data relative to threshold concentrations, combine parameters in some type of weighted average, and then break scores into grade categories from "good" to "bad" (Rickwood and Carr, 2007). There have been a number of different WQIs developed over the years for varying purposes, each with its own strengths and weaknesses. Some rely on simple measures of central tendency or percent exceedance. Some are developed from a single set of samples; others from data sets with many measurements of each parameter over time. Some indices are sensitive to changing conditions. Many of these indices rely on a predetermined list of parameters (CCME 2001, Cude 2001, Tsegaye 2006, Sargaonkar and Deshpande 2003). Some but not all of these methods compare measurements to a benchmark or guideline value.

In order to create indices of health for a wide variety of different parameters, different waterbody types and applicable beneficial uses, we sought a scoring approach that: 1) is consistently defined relative to a set of thresholds, 2) does not require a set number of water quality indicators (because of the variable availability of data from site to site), 3) provides a continuous variable between 0 and 100 that can also be assigned to five grade categories; 4) is sensitive both to magnitude and number of exceedances, and 5) is consistent with similar efforts from the literature.

Our scoring approach, called the Magnitude Exceedance Quotient (MEQ), is modified from the Water Quality Index adopted by the Canadian Council of Ministers of the Environment (CCME, 2001). Our focus on "healthy watersheds," and our desire to utilize data from multiple projects with widely varying parameter lists and sample counts, required that we modify the CCME WQI as described in this document. The MEQ scoring approach is employed via software that automatically scans data extracted directly from multiple databases and applies the calculations described here. These calculations support the CCAMP Data Navigator and Healthy Watersheds websites (www.ccamp.org) by grading and color scoring data at the level of the parameter, the sub-index (e.g. toxicity, metals, bioassessment) and the index (e.g. aquatic life, safe human uses).

## THE CANADIAN WATER QUALITY INDEX

A Water Quality Index developed for use in British Columbia has been adopted for use more broadly in Canada (CCME, 2001) and has since become the basis for the Global Drinking Water Quality Index developed by the United Nations Global Environment Monitoring System (Rickwood and Carr, 2007). The United Nations selected the CCME WQI as the basis for its own global water quality index after comparing its features to several other water quality indices from around the globe. One compelling feature was that the CCME WQI requires comparison to a threshold value and can be anchored to the World Health Organization drinking water guidelines (WHO, 2004).

The CCME WQI is a three component score that includes 1) number of threshold exceedances (frequency), 2) magnitude of threshold exceedances (amplitude), and 3) number of parameters that exceed thresholds (scope). The index is calculated for a pre-defined suite of parameters, each of which must have a regulatory objective, guideline or benchmark value to use as the threshold. It is flexible relative to the types of thresholds being used (human or ecological health, deviation from background, etc.). Scores range from 0 to 100. Scoring and narrative categories are: Excellent (A): 95 - 100, Good (B): 80 – 94, Fair (C): 65 – 79, Poor (D): 45 to 64, and Very Poor (F): 0 – 44.

Calculation of the CCME WQI, as shown below, is taken from CCME (2001):

Scope ($F_1$):

$$F_1 = \left(\frac{Number\ of\ failed\ variables}{Total\ number\ of\ variables}\right) X\ 100$$

Frequency (or Exceedance) ($F_2$):

$$F_2 = \left(\frac{Number\ of\ failed\ tests}{Total\ number\ of\ tests}\right) X\ 100$$

Amplitude (or Magnitude) ($F_3$):

First, excursion is calculated, as the factor by which a measurement that fails the test is greater (or less) than its objective (threshold).

When the test value should not exceed the objective:

$$\text{Excursion} = \left(\frac{Failed\ Test\ Value}{Objective}\right) - 1$$

When the test value should not fall below the objective:

$$\text{Excursion} = \left(\frac{Objective}{Failed\ Test\ Value}\right) - 1$$

The Normalized Sum of Excursions (*nse*) is calculated:

$$nse = \frac{\sum_{i=1}^{n} \text{excursion}(i)}{\#\ \text{of tests}}$$

The $F_3$ component, for Amplitude (or Magnitude), is then calculated using an asymptotic function (percentile rank) that scales from 0 to 100:

$$F_3 = \left(\frac{nse}{0.01nse + 0.01}\right)$$

The CCME WQI is calculated as a normalized summation of the three factors:

$$\text{CCME WQI} = 100 - \left(\frac{\sqrt{F1^2+F2^2+F3^2}}{1.732}\right)$$

The division by 1.732 rescales the WQI back to 100, derived by assuming each individual factor can reach a maximum of 100 as shown below:

$$\sqrt{100^2 + 100^2 + 100^2} = \sqrt{30000} = 173.2$$

In California, the CCME WQI has been implemented by several programs, including:

- **The Bay Institute of San Francisco (2003)**
- **Ventura Countywide Stormwater Quality Management Program (VCSQMP 2014)**
- **Orange County Stormwater Program (OCSP 2013)**
- **San Diego Coastkeeper (2010)**
- **San Diego River Watershed Monitoring and Assessment Program (Bernstein 2014)**

Many programs have modified the basic Canadian approach slightly through use of sub-indices and/or minor alterations in scoring thresholds and narrative scoring categories. The San Diego CoastKeepers modified the CCME WQI to include only the frequency and amplitude terms (SDCK, 2010).

## THE CCAMP MAGNITUDE / EXCEEDENCE QUOTIENT

For our purposes, the CCME WQI has two disadvantages which we sought to address through modifications to the basic approach. The first is that the CCME WQI's "Amplitude" component evaluates the amount by which failed tests exceed thresholds, but does not consider the amount by which passing tests are below thresholds. Because we are particularly interested in "health," we wanted to modify this term to evaluate overall magnitude, including measurements lower than the threshold. This is useful in identifying the "best of the best" waters, not just waters that comply with objectives.

The second issue is the "Scope" term. The CCME WQI Scope term is a measure of percent of "failed variables" (parameters), so it scores at the level of the site, not the parameter. We wanted a scoring system that provided scores at the level of the individual parameter, the sub-index, and the index. This better supports our report card and web display concept. In addition, the Scope term is particularly sensitive to small numbers of parameters, and this becomes an issue when creating sub-indices (e.g., pesticides, metals). In these cases, the index value can change substantially based on one or two exceedances, even with a moderately large dataset. Thus, we eliminated the "Scope" term from our index approach (as did the San Diego Coastkeeper [2010]).

We followed the CCME WQI approach for calculating the Magnitude (or "Amplitude" in CCME terminology) and Exceedance (or CCME "Frequency") components of the MEQ with the following modifications.

### Scoring to emphasize "healthy"

In calculating Magnitude, we extended the CCME's Amplitude calculation to all measurements regardless of whether they were above or below the threshold. This has the result of scoring measurements that are better than the threshold as fractions less than one, and allows us to characterize the "best of the best." We did not subtract one from the quotient as done for the CCME WQI because of its effect of driving the fractional component below zero. Instead, we used a straight quotient, similar to other normalized scoring approaches (e.g. Ingersoll et al., 2000; Hunt et al., 2001; Fairey et al. 2001; Vidal & Bay, 2005).

The MEQ calculations are as follows. Because the "scope" component (CCME's $F_1$) has been dropped, the MEQ "exceedence" component is labeled $C_1$ and the MEQ "magnitude" component is labeled $C_2$.

### Calculating the Exceedance component ($C_1$):

Exceedance is calculated the same way as in the CCME WQI:

$$C_1 = \left(\frac{\textit{Number of failed tests}}{\textit{Total number of tests}}\right) \text{ X } 100$$

Note that here and in the CCME WQI, the word "tests" is equivalent to the measurement of one parameter in one sample. If 10 samples were collected from a site, all were measured for a suite of 8 trace metals, and 2 samples exceeded the threshold for zinc, then the $C_1$ value for zinc would be 2/10 X 100 = 20.

## Calculating the Magnitude component ($C_2$):

"Excursion" is calculated as the factor by which a measurement is greater (or less) than its threshold.

Our calculation is as follows for parameters that should not exceed the objective or threshold:

(A) $$\text{Excursion}_{(i)} = \left(\frac{Measurement(i)}{Threshold}\right)$$

For parameters that should not fall below the objective or threshold:

(B) $$\text{Excursion}_{(i)} = \left(\frac{Threshold}{Measurement(i)}\right)$$

The following two steps complete the calculations of the Magnitude ($C_2$) component:

Average Magnitude of Excursions (*ame*) is calculated:

$$ame = \frac{\sum_i^n \text{excursion}(i)}{\text{\# of tests}}$$

The *ame* is then normalized using an asymptotic function (percentile rank) that scales from 0 to 100:

$$C_2 = \left(\frac{ame}{0.01ame + 0.01}\right)$$

## Calculation of the MEQ value:

The Magnitude Exceedance Quotient (MEQ) is calculated at the level of the individual parameter, using a formula similar to that used to calculate the CCME WQI, but modified to eliminate the Scope component. Here $C_1$ is the Exceedance component and $C_2$ is the Magnitude component:

$$\text{MEQ (parameter)} = 100 - \left(\frac{\sqrt{C1^2 + C2^2}}{1.414}\right)$$

Because there are only two factors, 1.414 is used to rescale the quotient back to 100, derived by assuming each individual factor can reach a maximum of 100:

$$\sqrt{100^2 + 100^2} = \sqrt{20000} = 141.4$$

## Additional considerations for certain types of parameters

### *Dissolved Oxygen and pH:*

The MEQ addresses pH and oxygen differently because of their "double-ended" nature, where either low or high measurements may be indications of a problem. We have identified both upper and lower thresholds for pH (7.0 and 8.5) and oxygen (7.0 mg/L and 13 mg/L). These thresholds are regulatory with the exception of the upper limit for oxygen (Worcester et al., 2010). We calculate Exceedance as the sum of the number of excursions over the upper threshold and below the lower threshold. We calculate Magnitude as follows:

If Measurement (i) > Upper Threshold

(C) $$\text{Excursion}_{(i)} = \left(\frac{Measurement(i)}{Upper\ Threshold}\right)$$

If Measurement (i) < Lower Threshold

(D) $$\text{Excursion}_{(i)} = \left(\frac{Lower\ Threshold}{Measurement(i)}\right)$$

$$ame = \frac{\sum_i^n \text{excursion}(i)}{\#\ \text{of tests}}$$

This approach parallels the CCME approach in that a measurement falling anywhere within the accepted range is scored "zero" for excursion; there are no "degrees of good" as there are for other parameters.

### *Water Temperature:*

Water temperatures that are closer to 0° C are not considered to be better than temperatures that are approaching 18ºC, which is considered the "upper end of optimum". As long as temperatures fall below 18ºC, by adhering to Equation C above we are not scoring measurements for "degrees of good", but only for excursions above 18ºC.

### *Low Sample Count:*

The CCME WQI does not score sites with a sample count of fewer than four. In our dataset, many of our upper watershed data are bioassessment scores from the Statewide Perennial Streams Assessment (PSA), which involves a probabilistic design employing a single sampling visit to each randomly selected site. To retain this important dataset in our assessment, it is necessary to score datasets with fewer than 4 samples per site. At sites with low sample counts, a single exceedance can greatly affect the score, even if the magnitude is only slightly over the threshold. In these cases, the exceedence component ($C_1$) is dropped and the MEQ is calculated using only the magnitude component ($C_2$) for any parameters measured less than four times at a site. If the parameter sample count is less than four, the MEQ becomes:

$$\text{MEQ (parameter)} = 100 - C_2$$

Because there is only one component ($C_2$), there is no need to use a rescaling term (e.g. 1.414).

### *Handling data with "logarithmic" distributions:*

Some parameters that have "logarithmic" distributions, including turbidity, total suspended solids, fecal coliform, and *E. coli* can have a few very high measurements relative to an arithmetic mean, and one or two "outlier" scores can strongly affect the MEQ magnitude component. For these parameters we have employed a geometric mean in place of the Average Magnitude of Excursions (ame) in the magnitude component.

$$C_2 = \left(\frac{geomean(e)}{0.01geomean(e) + 0.01}\right)$$

Where geomean(e) = geometric mean of the magnitudes of excursion

***Handling indices and other data with existing scoring approaches:***

Existing biological indices typically have established scoring approaches. For example, the California Stream Condition Index (Mazor et al. in review) uses grade breakpoints that are nearly identical to those used by the MEQ (expressed as proportions rather than percentages), with the exception that it does not employ the equivalent of our "seriously impacted" category: Likely intact (>=.92), possibly intact (0.79 to 0.92), likely altered (0.63 to 0.79), and very altered (0 – 0.63). Consequently, we utilized the scoring for the CSCI with no changes, except to incorporate the equivalent of our "severely impacted" category (0 – 0.45). The Southern California Index of Biotic Integrity (Ode et al., 2005) utilizes a five-category quantile approach: very good (80-100), good (60-80), fair (40-60), poor (20-40), and very poor (0-20). In this case, we redistribute scores so that they reflect the score breaks of the MEQ, using linear interpolation within each grade category. The same method is applied to all modeled data layers coming from the California Healthy Watersheds Assessment project (USEPA, 2013).

## EVALUATION OF MEQ SCORES

MEQ scores are assigned letter grades using scoring breakpoints similar to those employed by the CCME WQI. Scoring and narrative categories for the MEQ are: Excellent (A): 90 - 100, Good (B): 80 – 89.9, Fair (C): 65 – 79.9, Impacted (D): 45 to 64.9, and Severely Impacted (F): 0 – 44.9. The one difference between MEQ and CCME scoring is the breakpoint between good and excellent, which is at 95 for the CCME and at 90 for the MEQ.

Because the MEQ derivation calculations are different than those of the CCME WQI, we wanted to evaluate whether the breakpoints for MEQ scores made sense. We did this in two ways. The first was a comparison to an independent scoring approach, and the second was a best professional judgment review of the scores and their time series relative to other information known about the monitoring sites. To accomplish the first, we compared MEQ grades to "CCAMP Rule" grades originally used by the CCAMP program to score data for website purposes. The Rules used an entirely different scoring approach to produce five grade categories, based on percent exceedance of a series of thresholds (see example in **Figure 3**). The Rules were developed for grading a subset of the parameters that have now also been scored using the MEQ. These included conventional parameters and bacterial indicators. It should be noted that the CCAMP Rules were replaced by the MEQ because of concerns over CCAMP Rule performance. The Rules typically compared a grade boundary threshold to the value at the $90^{th}$ percentile of the data (by definition 90% of the data distribution falls below the $90^{th}$ percentile). As such, the Rules were based only on percent exceedance and did not take into account sample magnitude. For example, in the Rule shown in **Figure 3**, up to 10% of samples could exceed a threshold, even by large amounts, without any consequences to the grade outcome. Also, in many cases the breakpoints between grades established by the Rules were somewhat arbitrary, with many set by halving or doubling published thresholds.

Typically, the parameter threshold used in the MEQ is the same one used as the breakpoint between "C" and "D" grades in the respective CCAMP Rule. For example, the MEQ threshold for nitrate to protect aquatic life is 1 mg/L as N. In the CCAMP Rule, if the 90th percentile nitrate value is < 1 and > 0.3 mg/L, the site scores a "C" (Fair) (**Figure 3**). The rules are often (but not always) structured with breakpoints as empirically-set multiples of the threshold. In other cases, such as nitrate, more than one breakpoint was based on an available standard or experimentally derived concentration. For nitrate, the 1 mg/L breakpoint (between C and D) is based on the Central Coast aquatic life guideline value, set using calculations for nutrient numeric endpoints (NNE) (Worcester et al., 2010). The 0.3 mg/L breakpoint (between B and C) is based on the median nitrate threshold effect relative to invertebrate and algae bioassessment scores (Rollins et al. 2012). The other breakpoints are multiples of one or the other of these values.

**Figure 3. Example of a "CCAMP Rule"**

**This CCAMP Rule is for grading Nitrate-N (mg/L) to assess potential for freshwater aquatic life impacts, based on breakpoints described in the text.**

**If 90th percentile ≥ 2 then "Very Poor"**

**If 90th percentile > 1 and < 2 then "Poor"**

**If 90th percentile > 0.3 and < 1 then "Fair"**

**If 90th percentile > 0.15 and < 0.3 then "Good"**

**If 90th percentile < 0.15 then "Excellent"**

MEQ grades were compared to CCAMP Rule-derived grades for 2,128 site-analyte combinations. **Figure 4** shows relative performance of the MEQ against CCAMP Rules for several individual analytes. In 60% of samples the two approaches produced the same grade, 36% of the grades derived from the MEQ were higher than those derived by the CCAMP Rules, and 4% were lower (**Figure 5**). The vast majority (94%) of MEQ grades were no more than one grade category different than CCAMP Rule grades.

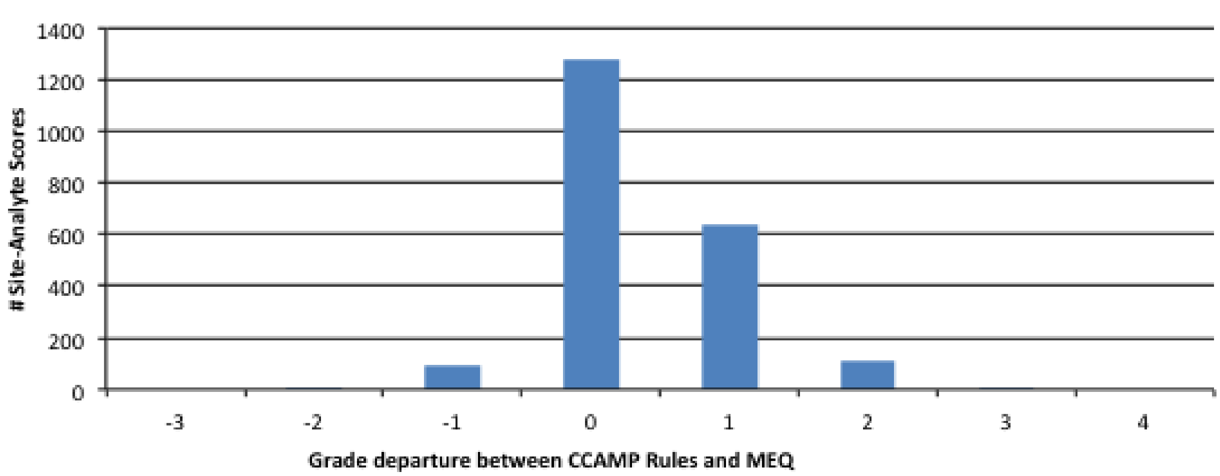
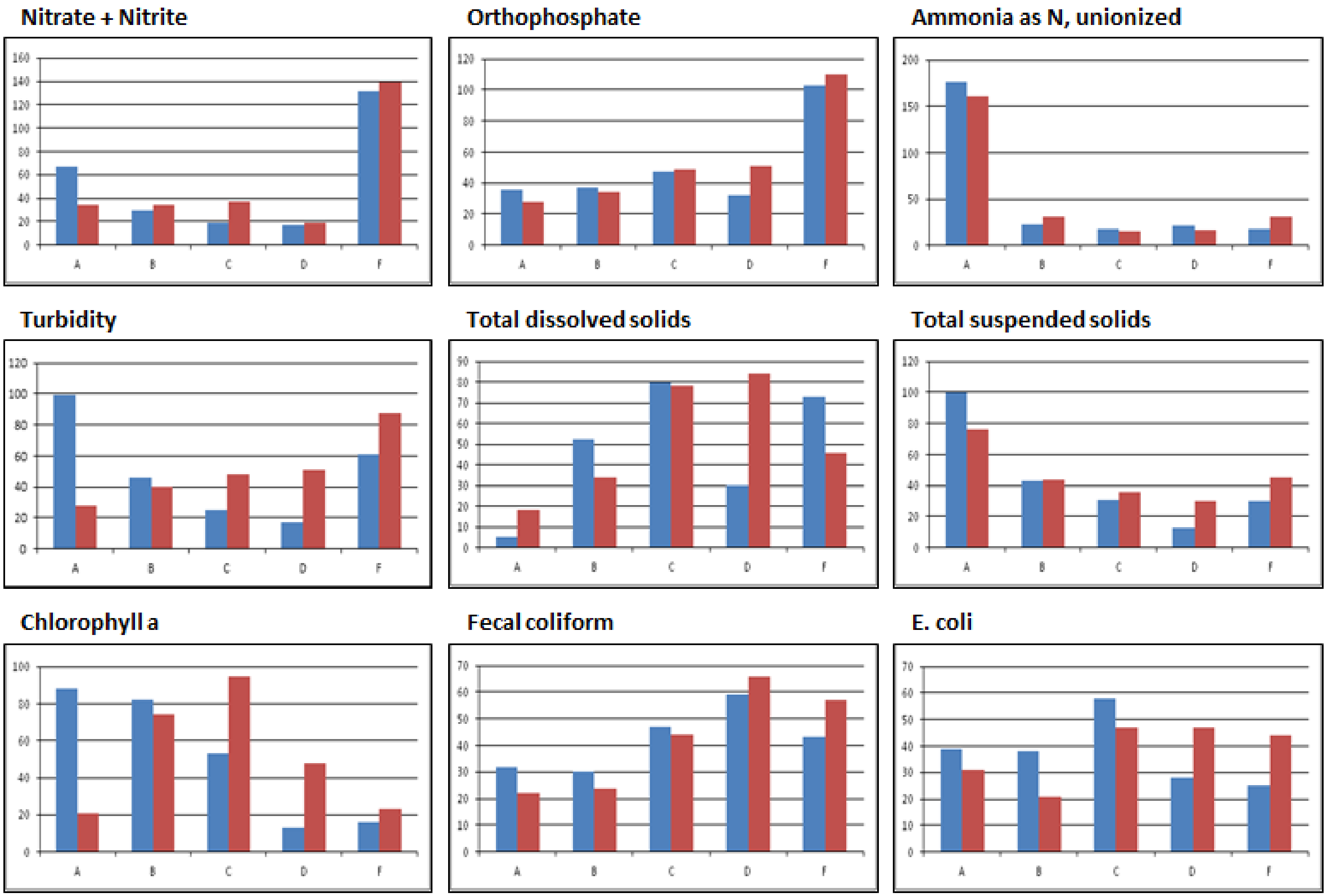



**Figure 4. Deviation between MEQ-based and CCAMP Rule-based grades for conventional parameters (nutrients, bacterial indicators, chlorophyll a and solids). A positive number on the x-axis implies grades derived from MEQ are higher than those from CCAMP Rules. Each integer represents a difference of one grade category.**

For a number of conventional parameters, particularly for turbidity and chlorophyll a, the MEQ tended to assign more sites to higher grade categories (A and B grades) than the Rule based approach, while the Rules tended to assign more sites to the lower grade categories (D and F grades) (**Figure 4**). In the Rules, the "A" score threshold can be quite low, often one-quarter the value of the MEQ threshold or less. For example, for turbidity and chlorophyll a, the "A" score threshold is derived as a reference value from a collection of data that includes western Sierra stream values (EPA 2000), and thus may be low for central coast streams, especially when employed as a 90th percentile. Also, a geometric mean was employed in the MEQ scoring of turbidity for the specific reason that occasional storm events were causing sites with otherwise excellent water quality to score poorly and we wanted to deemphasize the influence of these events in the score, being more concerned about persistent turbidity. Many sites considered to have excellent water quality overall cannot qualify for an "A" score for turbidity under the CCAMP Rule. The difference in scoring between the two approaches may speak more to deficiencies in the previous CCAMP Rules than in the new MEQ approach.

The MEQ scores were also evaluated by reviewing time series data for over 100 sites in a region where the authors had conducted water quality monitoring for over 15 years. This best professional judgment review focused on the presence, distribution and magnitude of very high and low measurements, the affect that sample count, outliers, and exponential distributions had on the resulting grades, and knowledge of disturbance and biological indicators (primarily toxicity and bioassessment) at the various sites.

Figure 5. Comparison of MEQ-based grades (blue bars) and CCAMP rule-based grades (red bars) for several conventional parameters. Grades (A-F) are on the x-axis, number of samples is on the y-axis.



# Chapter 4: Site Scoring

## COMBINING MEQ PARAMETER SCORES INTO A SUB-INDEX

In order to develop an overall score of health at the level of the site, MEQ scores for individual parameters are combined into sub-indices and overall indices of health. The same scoring and narrative categories used for parameters are applied at the index level: Excellent (A): 90 - 100, Good (B): 80 – 89.9, Fair (C): 65 – 79.9, Impacted (D): 45 to 64.9, and Severely Impacted (F): 0 – 44.9.

At each site, MEQ scores from multiple parameters are combined into sub-indices. Sub-index scores are given letter grades. The Aquatic Life Index contains sub-indices for basic water quality, toxicity, bioassessment, habitat, organic chemicals, metals, and biostimulation. Within the Clean Drinking Water Index, sub-indices include nitrogen, salts, metals and organics. Components of the indices are shown in Tables 1 and 2. At this time the CCAMP report cards do not include grades for fish tissue contamination, because our goals emphasize drinking water and aquatic life. We may add thresholds for scoring this data at some point in the future. The SWAMP Bioaccumulation Oversight Group continues to collect fish tissue data and evaluate appropriate thresholds (e.g., Davis et al. 2011).

Table 1. Sub-indices and their component parameters within the Aquatic Life Index.

| Aggregation Method | Component Parameters |
|---|---|
| Basic Water Quality Sub-Index | |
| Arithmetic mean of component parameter scores | Unionized Ammonia<br>Nitrate-Nitrite as N<br>Orthophosphate<br>Turbidity<br>Total Suspended Solids<br>Water temperature<br>pH departure |
| Biostimulation Sub-Index | |
| Arithmetic mean of component parameter scores | Dissolved Oxygen departure<br>Chlorophyll a (ug/L)<br>Filamentous algal mat cover<br>Dissolved Oxygen deficit (predicted)<br>Benthic algal biomass (predicted) |
| Toxicity Sub-Index | |
| Sub-index score equal to lowest component toxicity test score | Invert survival in water<br>Invert reproduction in water<br>Invertebrate survival in sediment<br>Algae cell growth<br>Fish survival<br>Fish growth |

| | |
|---|---|
| Metals Sub-Index | |
| Geometric mean of component parameter scores | Metals in water<br>Metals in sediment |
| Organic Chemicals Sub-Index | |
| Sub-index score equal to lowest component chemical score | Organic chemicals in water *<br>Organic chemicals in sediment * |
| Bioassessment Sub-Index | |
| Existing bioassessment score, redistributed to MEQ grade categories | Aquatic invertebrate bioassessment |

* Chemicals analyzed include all those measured for which we have identified an appropriate threshold

**Table 2. Sub-indices and their component parameters within the Human Health Index.**

| Aggregation Method | Component Parameters |
|---|---|
| Nitrogen Sub-Index | |
| Sub-index score equal to lowest component chemical score | Ammonia<br>Nitrate-Nitrite as N<br>Nitrite |
| Salts Sub-Index | |
| Arithmetic mean of component parameter scores | Boron<br>Chloride<br>Sodium<br>TDS<br>Boron |
| Metals Sub-Index | |
| Sub-index score equal to lowest component chemical score | Metals in water * |
| Organic Chemicals Sub-Index | |
| Sub-index score equal to lowest component chemical score | Organic chemicals in water * |

* Chemicals analyzed include all those measured for which we have identified an appropriate threshold

At present the Bioassessment sub-index only includes bioassessment for benthic invertebrates. It is scored using the approach specific for the bioassessment metric being used and then adjusted to conform to the scoring ranges of the MEQ. If more than one type of bioassessment data is available, the scores are combined using an arithmetic mean. A sub-index for habitat is in development.

The basic water quality and biostimulation sub-indices combine parameters using an arithmetic mean of parameter MEQ scores. Individual metals are combined in the aquatic life metals sub-index using a geometric mean. The geometric mean is a measure of central tendency that emphasizes the lowest-scoring parameters (in this case, the worst scores).

Geometric mean (for trace metal sub-index): $\text{MEQ Index} = \sqrt[n]{(MEQ1)(\text{MEQ2})\ldots(\text{MEQn})}$

For all sub-indices involving organic chemicals or toxicity, the sub-index score is equal to the lowest score of any component. This ensures that the "signal" from a problem parameter is not "diluted" by the large number of parameters measured. The rationale for this is that if the water at a site is toxic to aquatic life or is not suitable for drinking based on any one chemical, the site index score should reflect that directly regardless of other parameters measured.

## COMBINING SUB-INDICES INTO SUMMARY AQUATIC LIFE AND CLEAN DRINKING WATER INDICES

The Aquatic Life Index utilizes a geometric mean to combine sub-indices into a single score of aquatic health. This weights the overall index score towards the lowest scoring sub-indices, because if one or two components are not healthy, that reflects on the overall site health. Note that while the parameters that make up the Clean Drinking Water Index and sub-indices are all indicators of stress (pollutants), the Aquatic Life Index also includes indicators of biological status (bioassessment and toxicity). Aquatic life stressor and status indicators can be evaluated independently by looking at their respective sub-index scores (**Table 1**).

In addition to the basic grading scale already described, we have provided for an "Outstanding" or "A+" category for the Aquatic Health Index that does not apply until individual parameter and sub-index scores are aggregated to the level of the overall Aquatic Life index. These are sites that score 95 or higher overall (**Figure 6**). This additional scoring may provide an approach to designate or otherwise protect "outstanding resource waters." The Clean Drinking Water Index does not include an "Outstanding" category, because the chemical suite tested in water is relatively limited, and it is impossible to know for certain that un-sampled chemicals are not present. The grading scale for the Clean Drinking Water Index is the same as those used for parameters and sub-indices: Excellent (A): 90 - 100, Good (B): 80 – 89.9, Fair (C): 65 – 79.9, Poor (D): 45 to 64.9, and Very Poor (F): 0 – 44.9.

| | | |
|---|---|---|
| A+ | 95 - 100 | |
| A | 90 - 94.9 | |
| B | 80 - 89.9 | |
| C | 65 - 79.9 | |
| D | 45 - 64.9 | |
| F | 0 - 44.9 | |

Figure 6. MEQ summary index grade scale

The Clean Drinking Water Index utilizes a slightly more complex approach to combine sub-indices. In this case, some of the sub-components reflect higher risks to human health than others. The sub-indices that relate to toxins are treated differently than the salts sub-index. The overall Clean Drinking Water Index is scored as the lowest score of the subcomponents involving toxins (nitrogen species, organic chemicals and metals) or the geometric mean of all sub-indices, whichever is lower.

# Chapter 5: Change and Trend Analysis

The primary statistical software used for change analysis and elsewhere in this project is R, a free, open source software environment for statistical computing and graphics. Other open source software used includes Non-detects And Data Analysis (NADA: Lopaka 2013, Helsel 2004). NADA was used for analyses involving censored data (data including non-detects or "less-thans"), including general statistics, change detection and associated graphics.

We employed trend analysis and change point analysis as two different statistical approaches to evaluate patterns in monthly time series data. In some cases these two approaches can produce contrasting results, as when there is an overall increasing trend in a data set that has some change points that mark a decrease. For this assessment, confidence that overall improvement (or degradation) is occurring at a site is strongest when there is agreement between both trend and change analysis, when there is a relatively steep slope to the trend line, and when there is a relatively high percent difference between data before and after change points.

## TREND ANALYSIS

Trend analysis identifies consistent change in a single direction. If a trend line through the data has a slope that is statistically different from zero (horizontal), the trend is significant and is represented on our graphs by a sloping green line (decreasing trend) or sloping red line (increasing trend) (**Figure 7**). The statistical significance of the trend is determined using the Mann-Kendall test, as modified for non-detects using the "Non-detects And Data Analysis" (NADA) package (Helsel 2004), which computes Kendall's tau correlation coefficient and the associated trend line for censored data. The alpha value for this analysis is set at 0.01 (99% certainty) because our data set is large and even trend lines with relatively low slope can be statistically significant at higher alpha values. The higher confidence level makes it more likely that the trends we detect are environmentally meaningful.

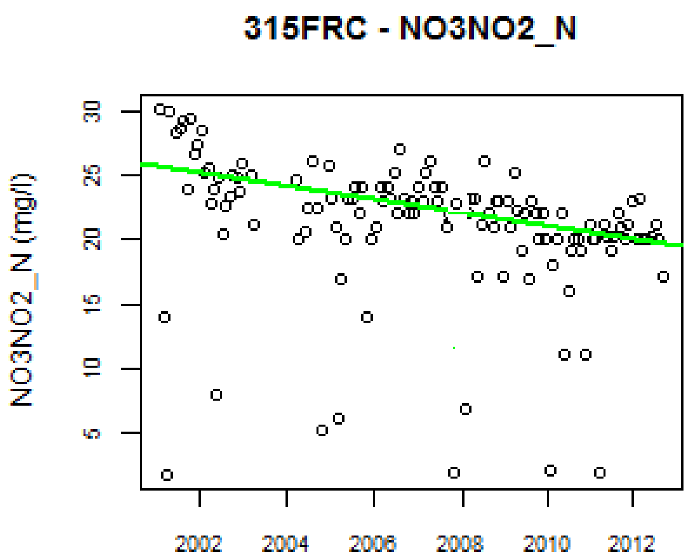



Figure 7. Significant decreasing linear trend for nitrate-N following elimination of greenhouse discharge on Franklin Creek (Site 315FRC)

## CHANGE ANALYSIS

Change point analysis identifies specific points in time when there is a high probability that measurements taken before that point are different from measurements taken after. Change points are identified here in two steps. In the first step, R package Bayesian Change Point Analysis is used to identify candidate change points by segmenting data into contiguous blocks so that the mean within each block is constant. We used a minimum block size of 10 samples to identify candidate change points, which are shown on our graphs as blue vertical lines. This first step may identify none, one, or more than one candidate change point in the data.

In the second step, statistical significance is determined by identifying blue-line candidate change points that meet the following conditions to become a red- or green-line statistically significant change point:

1. **The change point must have at least 15 samples taken before the change date and at least 15 samples taken after.**
2. **A t-test (with alpha ≤ 0.05) must detect a statistically significant difference between the mean of all samples taken before the change date and the mean of all samples taken after.**

Once statistically significant change points are identified, they are prioritized so that each graph has only one vertical green line (for decreasing data values) or one vertical red line (for increasing data values). If there is more than one statistically significant change point for a given parameter at a given site, and all of the change points indicate a change in the same direction, then it is the earliest change point that is highlighted as a green or red vertical line. This is because we want to know the earliest event that could have caused a consistent series of changes. If there are multiple significant change points indicating changes in opposite directions, then the most recent significant change point is highlighted as a green or red vertical line, because in this case we want to know the most recent change and its direction. The remaining blue lines are retained in the graphs because they are useful for highlighting other potential change points that may indicate increasing change in one direction, or points at which data values changed in an opposite direction, possibly indicating episodic events.

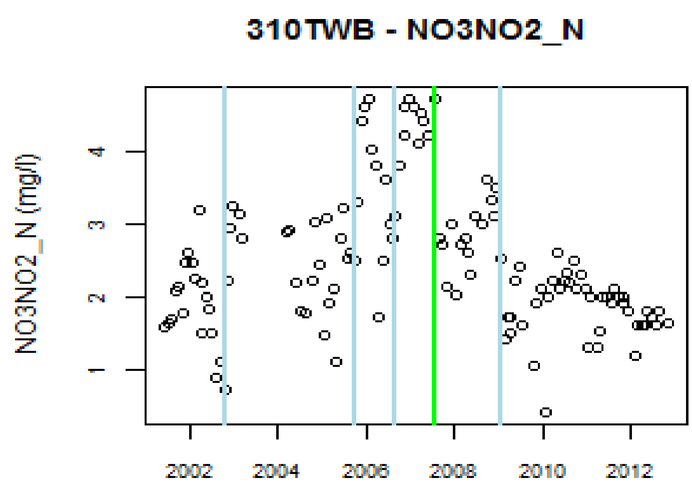



**Figure 8. Significant decreasing change point (in green) for Nitrate-N at Chorro Creek (Site 310TWB), coincident with treatment plant upgrade.**

**Figure 8** shows an example of a significant decreasing change point identified using the described approach. This change occurred following a waste water treatment plant upgrade in 2007. Linear trend analysis would not have detected this important change. This is an example of why we have found change point analysis to be a more useful indication of change for the purposes of this project. In addition, change point analysis provides a discrete date to break the data into "before" and "after" groups, necessary for the MEQ change scoring approach used for our website icons.

In many cases both change and trend lines are statistically significant. **Figure 9** shows both in response to deteriorating conditions below a wastewater treatment plant on San Simeon creek in San Luis Obispo County. This followed a change in treatment from spray fields to percolation ponds.

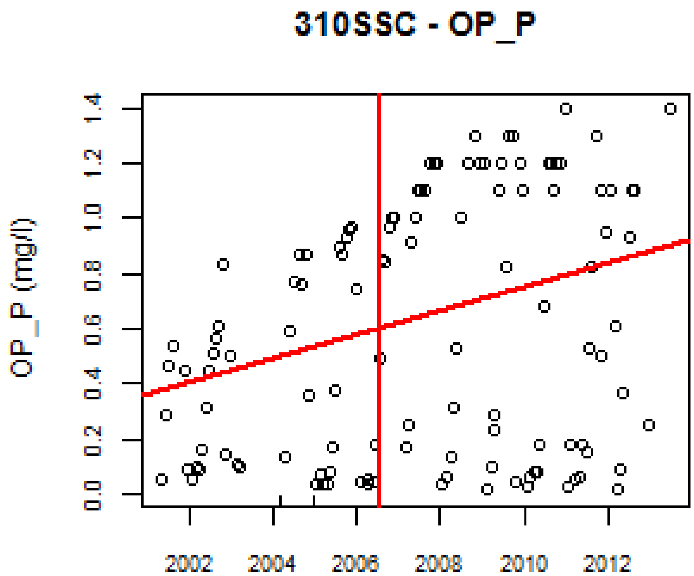



Figure 9. Significant linear trend and change point tests both indicate increases in orthophosphate on San Simeon Creek (Site 310SSC) below a wastewater treatment plant

## DEPICTING CHANGE ON WEB MAPS

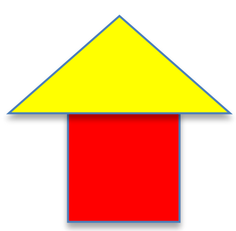


Figure 10. Arrow icon showing improving conditions going from "Poor" to "Fair"

As described in the previous section, our approach to change point analysis includes a test of significance comparing all data for a given parameter that occur before the change point, to all data that follow the change point. The change point provides a specific date to break the data into "before-" and "after-change" groups. Each group can then be given its own MEQ score following the approach described in Chapter 3. We use an arrow "icon" on our web maps that indicate improving or deteriorating trends. **Figure 10** shows an example of an icon, where conditions are improving and the grades have crossed MEQ score boundaries from "Poor" to "Fair" using the same grade scoring approach described in Chapter 3. For example, if the data before the change point scored 51 and the data after the change point scored 69, these scores cross color boundaries and result in the arrow shown in **Figure 10**. Some significant changes, however, may not cross color boundaries, such as when a site improves from a score of 29 to a score of 43. In this case, the arrow icon would be dark red in both segments, since both "before" and "after" groups score lower than the "Poor" to "Very Poor" breakpoint of 45.

## DETERMINING CHANGE FOR INDICES OF HEALTH

Determining change at the level of the index or sub-index requires that scores from all parameters within the index be included in the calculation, whether they have changed or not. Suppose that at a given site one parameter has improved, three have gotten worse and two have stayed the same (**Figure 11**). All of the MEQ scores for parameters during the "before" periods are combined into a sub-index score using the combining approach appropriate for the data type (see **Table 1**). The same is done for all MEQ scores from the "after" periods. For parameters that have not changed, the same MEQ score is used in both calculations. If the resulting index scores cross a color boundary from "before" to "after", we are interpreting that as change at the level of the index.

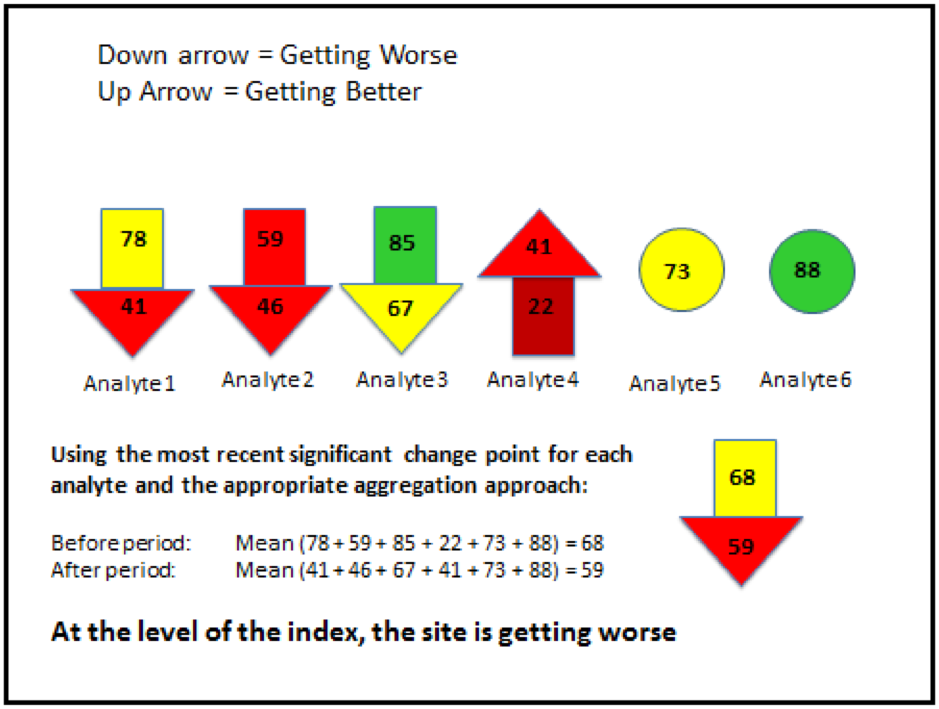



Figure 11. Expressing change at the level of an index.

# Chapter 7: Conclusions

Over the past 15 years, the Central Coast Ambient Monitoring Program (CCAMP) and the affiliated statewide Surface Water Ambient Monitoring Program (SWAMP) have conducted increasingly sophisticated studies to measure water quality, detect changes in aquatic habitat conditions, identify causes of impacts to aquatic life and human health, find sources of pollutants, and evaluate the effectiveness of management programs. Millions of data records have been entered into the California Environmental Data Exchange Network (CEDEN), a system designed to store and manage the data produced by these and partner programs. This report describes web-based tools and assessment methods that are now being used to translate these large data sets into information that is readily available and easily understood by resource managers, decision makers, and the interested public. Readers can access and use these tools on the CCAMP website (www.ccamp.org).

This report's description of the CCAMP automated data navigator and report card system provides background information and transparency for system users as they conduct their own waterbody and watershed assessments using these web-based tools. This report also outlines the CCAMP assessment goals and Regional vision goals that the report card system and data navigator are currently configured to address.

There are seven primary objectives for this CCAMP automated report card system and data navigator:

- **To identify appropriate, scientifically defensible and institutionally accepted thresholds against which to compare measurement parameters to determine levels of watershed health**
- **To build on previously established water quality index algorithms to translate data into threshold-based scores for each measured parameter and field sampling site**
- **To build on previously established rules to translate scores into letter grades and chart colors for immediate interpretation of monitoring results**
- **To aggregate individual parameter scores into higher level indices that provide broad indicators of watershed health and human health risk**
- **To analyze and visually display change in conditions over time**
- **To develop geospatial linkages between monitoring sites and stream reaches so that appropriate scores can be assigned to catchments and watersheds**
- **To combine monitoring-based indices with remotely sensed geospatial datasets and predictive models to holistically characterize watershed condition and associated land management**

This report describes methods to achieve the first 5 of these objectives, and we conclude by summarizing the progress made with each.

## THRESHOLDS

The compilation and evaluation of thresholds was comprehensive, and was closely aligned with the State Water Resources Control Board's Water Quality Goals process. Nearly 10,000 stressor/threshold combinations have been organized in the CCAMP threshold database, and each type of threshold has been evaluated for regulatory status, broad institutional acceptance, scientific defensibility, associated level of environmental protection and applicability to the objectives of CCAMP Healthy Watersheds assessment. The threshold selection process was documented in detail and coded into an automated selection routine to prioritize thresholds for specific assessments. The selection process was reviewed by a group of five experts in the fields of water quality assessment and regulation, and their comments were incorporated into the revised process. The threshold database is currently prioritized for the CCAMP Healthy Watersheds assessment, but can be readily modified to fit state and national programs with a range of assessment objectives. This compilation in itself is a useful contribution to the organization and alignment of water quality monitoring programs, an alignment that has long been complicated by the disparate nature and frequent lack of thresholds needed for consistent data assessment.

## WATER QUALITY INDEX SCORING SYSTEM

The Magnitude Exceedence Quotient (MEQ) water quality index was carefully developed as a modification of the widely accepted Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI). In adopting this approach, numerous candidate indices were evaluated and many mathematical approaches were explored before developing the MEQ index. The MEQ index is an important development because the scoring system can grade at the level of the individual parameter, it can be applied to large and small data sets, and it can be used with a broad suite of parameters having different data distributions (normal, binomial, exponential, double-ended, etc.). This simple but effective threshold-based scoring system provides a consistent and defensible method of translating raw monitoring data into assessment scores that are useful at the parameter level and also easily aggregated into higher level indices.

## GRADING THE SCORES

MEQ scores are turned into report card grades using similar breakpoints as those used by the CCME WQI. The resulting MEQ breakpoints and grades have been validated against a separate rule-based system. The rule-based system was previously developed using multiple thresholds for each parameter and expert judgment about the condition of sites from which monitoring data were collected. This MEQ grading system is a transparent and intuitive way to create easily understood report cards and color-coded maps to quickly convey various watershed health attributes to decision makers.

## HIGHER LEVEL HEALTH INDICES

At many monitoring sites and in many watersheds, a few measured parameters might indicate potential for adverse effects while other constituents are measured below levels of concern. To adequately characterize aquatic habitat condition and potential risks to human health, it is important to combine parameter scores into higher level indices that give a broader picture of overall watershed health. This project combined different parameters into sub-indices (e.g., for toxicity, bioassessment, salts, organic chemicals) using aggregation algorithms appropriate for each sub-index. Parameters were aggregated using arithmetic means for such sub-indices as basic water quality, where each parameter was assumed to have a relatively similar contribution to health risk; geometric means were used for sub-indices such as trace metals so that the lowest scoring parameter scores would be emphasized; and worst parameter scores were used as sub-index values when a single constituent could cause unacceptable impact, as in the case of toxic organic chemicals.

The sub-indices are then aggregated into two over-arching indices: the Aquatic Life Index and the Clean Drinking Water Index. These can be considered similar to broad indicators of economic condition, such as the Index of Leading Economic Indicators. Creating such broad indices requires careful attention to the component parameter lists, the scoring methods, the aggregation algorithms and the grading breakpoints. The indices presented here represent important steps toward quickly conveying scientifically valid and comprehensive information to resource managers and decision makers.

## CHANGE AND TRENDS

While many assessment programs present trend information, the CCAMP system also extensively incorporated statistical methods for calculating and displaying change points. Using R package software and Bayesian change point analysis, the data navigator system identifies both minor and major change points in time series of monitoring data. This is particularly important for assessing the effectiveness of resource management efforts. Change point analysis effectively identifies and graphically displays distinct water quality responses that can be matched with specific management activities, such as treatment plant upgrades or changes in nonpoint-source inflows.

## WEB-BASED DISPLAY

The CCAMP report card and data navigator website (www.ccamp.org) has been extensively renovated and will continue to be upgraded to make most effective use of these new report card and data navigator tools. The website and its analyses, tables and graphics automatically update on a regular basis to import and analyze data from linked databases. The report card opens with map-based and report card-based screens that highlight the highest level indices for all monitoring sites. This allows a quick survey of where problems are occurring and how measurements are changing over time. Users can easily drill down from the report card to the data navigator, to find increasingly specific results including which sites, parameters and measurements are responsible for the watershed scores. This is a substantial and meaningful improvement over previous database output systems that require detailed, technical and advance knowledge of problem sites and parameters in order to begin searching for relevant data. The ccamp.org site allows immediate access to the most important information on whichever scale is of interest to decision makers.

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