Martha Sutula
marthas@sccwrp.org

Raphael Mazor
raphaelm@sccwrp.org

BIOSTIMULATORY SCIENCE PRODUCTS

Scientific Foundation for Assessment of Eutrophication in California Waterbodies (TR871)

Biostimulatory operating assumptions

Wadeable Stream Eutrophication Synthesis (TR 1048)

Conceptual model and review of indicators

Scientific bases for numeric targets

Part II

- Aquatic life related uses (including **Mazor et al. in prep**)
- Human related uses

Scientific Basis for Biostimulatory Thresholds

Wadeable Streams

Good Light Penetration

Poor Light Penetration

Evidence from CA biointegrity stress-response (Mazor et al in prep, Fetscher et al. 2014)

Benthic Chla

AFDM

% Cover

TN and TP

TN and TP

Sestonic Chla

Other State Literature Sutula et al. TR 1048

Benthic Cyanobacteria Cell Density & Toxins

Diel DO

Diel DO

DO, pH, Sestonic Cyanobacteria Cell Density, Particulate Toxins, tissue toxins

Non wadeable Streams

Basin Plan WQO, Statewide Guidance, Other State Literature Sutula et al. TR 1048

Wadeable Streams Aquatic Life Response and Biostimulatory Thresholds

Response

- Benthic Chl-a
- Benthic Ash-free Dry Mass
- Macroalgal Cover
- Sestonic Chl-a
- Dissolved oxygen
- pH
- Particulate cyanoHAB cell count and toxins
- CyanoHAB tissue toxin concentrations
- SPATT
- CSCI and ASCI or component metrics

"Statewide bioassessment indices can be used as assessment endpoints from which to derive ranges of biostimulatory targets protective of aquatic life"

Causal

- TN, TP

Raphael Mazor Will Summarize Science Linking These Indicators to "Goals" for CSCI and ASCI

[See Mazor Presentation on Biostimulatory Stress-Response Models]

Comparisons of CA Wadeable Stream Thresholds By Approach

- Protection endpoints for CSCI and ASCI
- Percentile of range of biostimulatory values at reference sites (90th shown here)
- Change point analyses

Table 4.1 Range of TN, TP thresholds, Benthic Chl-a, AFDM associated with protection of CSCI and ASCI_H at a relative probability of 90% confidence, at varying levels of percentile of reference, from 30th to 1st. compared to reference distribution and taxon-specific changepoints for eutrophication factors. Red text highlights reference distributions that are higher than the derived Ref10 threshold, or taxon-specific change-points that are below the derived Ref10 threshold. SBA: soft-bodied algae. BMI: Benthic macroinvertebrates. n: number of reference sites.

Benchmark	Total N	Total P	Chl-a	AFDM	% cover
Derived thresholds- CSCI					
Eutrophication threshold for Ref30	0.34	0.024	14	12	10
Ref10	0.59	0.104	28	20	13
Ref01	1.95	0.401	65	37	26
Derived thresholds- ASCI					
Eutrophication threshold for Ref30	0.13	0.026	24	17	18
Ref10	0.32	0.080	43	30	20
Ref01	1.67	0.394	122	80	33
Reference distributions					
90th percentile - Statewide (n=524)	0.25	0.058	31	27	39
- Chaparral (n=76)	0.24	0.075	34	20	42
- Central Valley (n=1)	0.16	0.027	23	13	41
- Deserts and Modoc (n=38)	0.51	0.104	46	35	50
- North Coast (n=106)	0.14	0.030	22	15	29
- South Coast (n=115)	0.31	0.039	34	62	43
- Sierra Nevada (n=164)	0.15	0.058	24	17	35
Taxon-specific changepoints					
Diatom Increasers	0.44	0.082	47	18	17
Diatom Decreasers	0.38	0.048	11	11	18
SBA Increasers	0.58	0.075	26	19	16
SBA Decreasers	0.17	0.034	36	15	23
BMI Increasers	0.65	0.091	71	31	68
BMI Decreasers	0.65	0.080	31	20	28

Comparisons of CA Wadeable Stream Thresholds to

Changepoint Literature Values (other states)

Nutrient Criteria (other states)

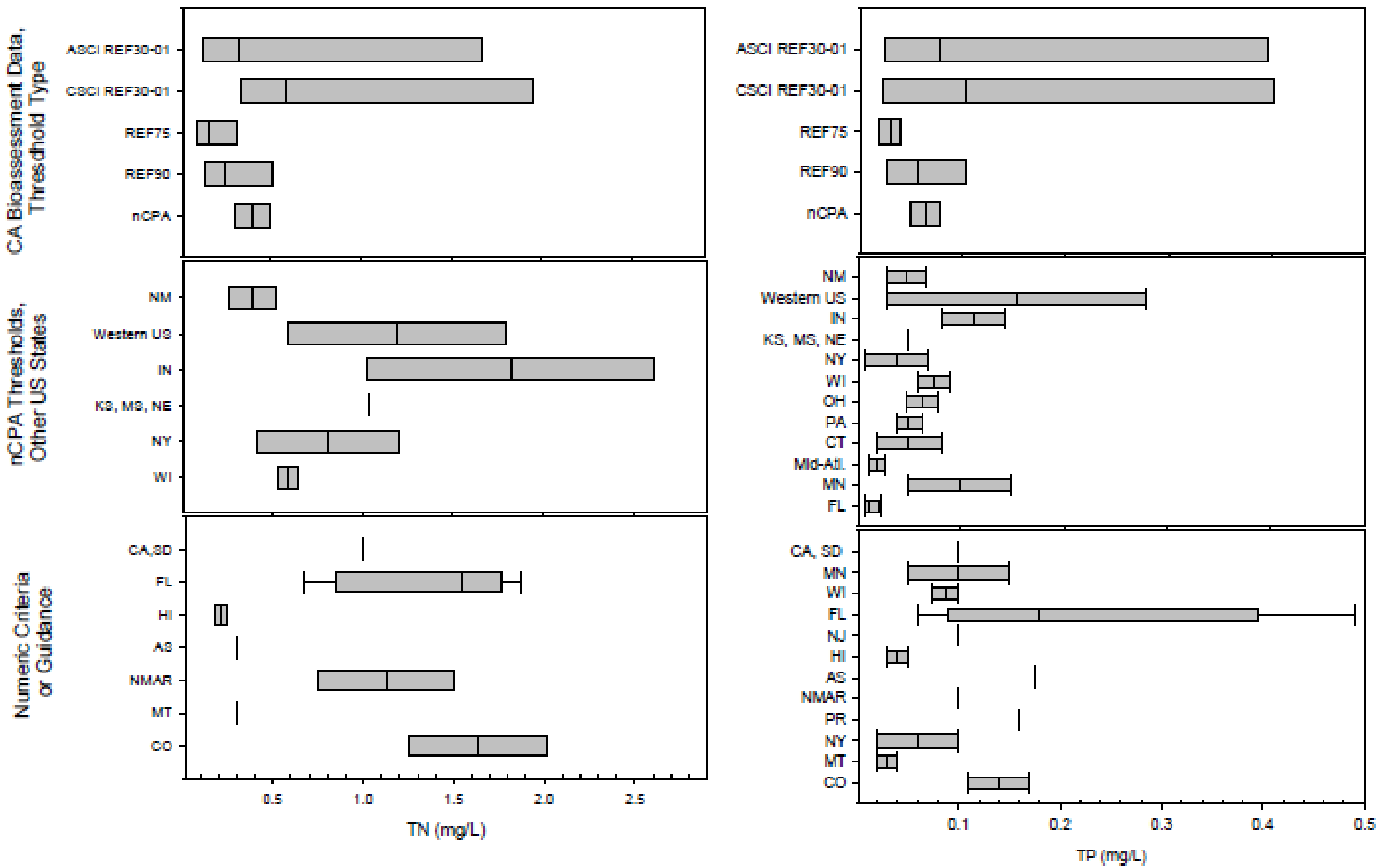
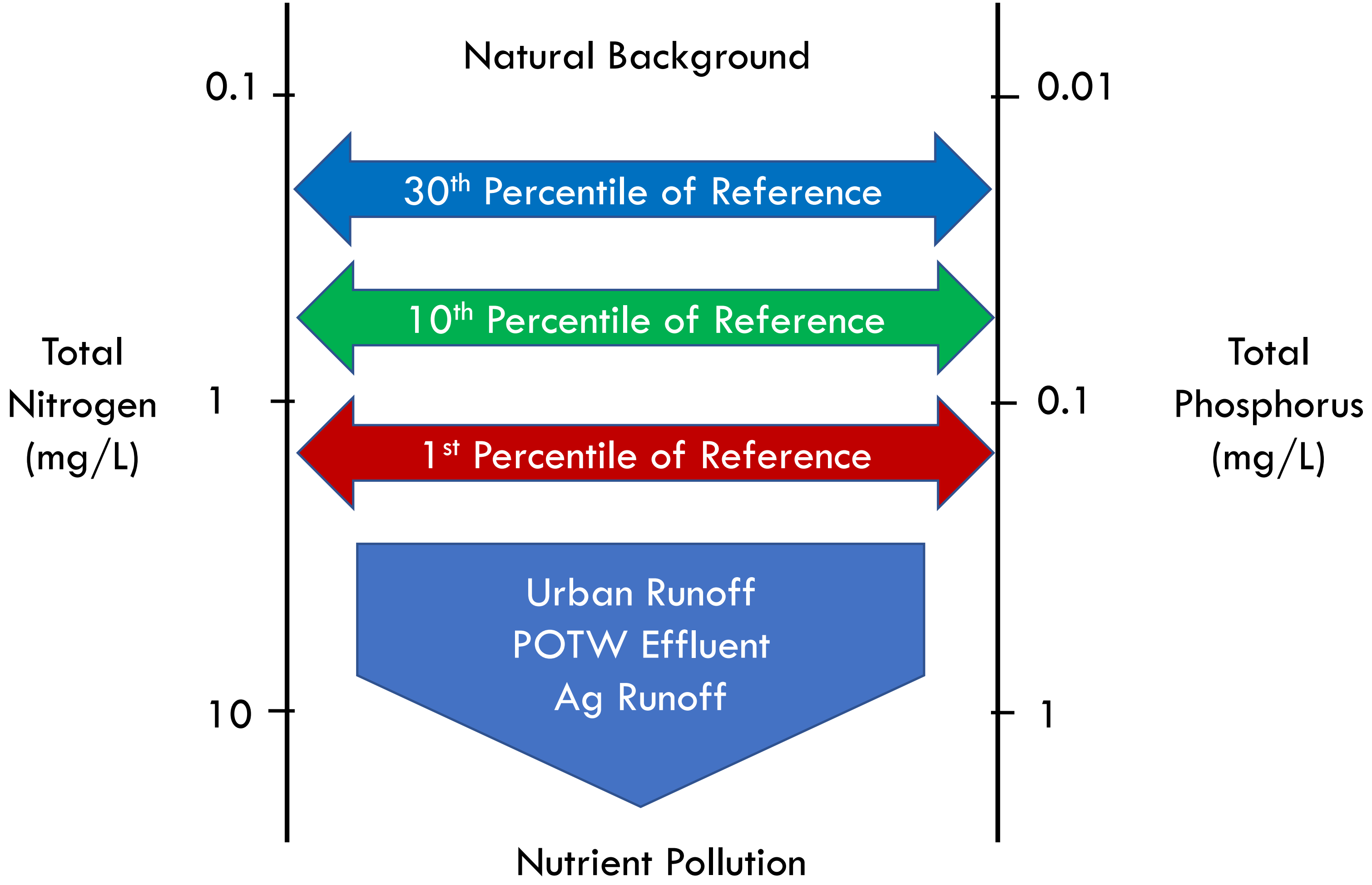


Figure 4.1 Ranges of literature derived TN (left panel) and TP (right panel) thresholds relative to adopted state criteria. Top panel represents threshold derived from CA wadeable stream bioassessment data (Mazor et al. in prep, Fetscher et al. 2014). In ASCI and CSCI REF30-01 bars, mean represents REF10. REF75th and 90th are the ecoregional ranges, while the mean line represents the statewide mean. Middle panel represents published studies of change point analyses (nCPA) for other states/territories and includes a variety of stream types including wadeable and nonwadeable streams. Bottom panel summarizes adopted criteria. Ranges in bar represents adopted criteria for different stream types or classes. NMAR = Northern Mariana, AS =American Samoa, PR= Puerto Rico

Thresholds that Associated with Levels of Protection of Aquatic Life Are Extremely Low Relative to Urban/Ag Runoff and POTW Wastewater



Aquatic Life Derived Benthic Chl-a Also Within Range of Other State Literature

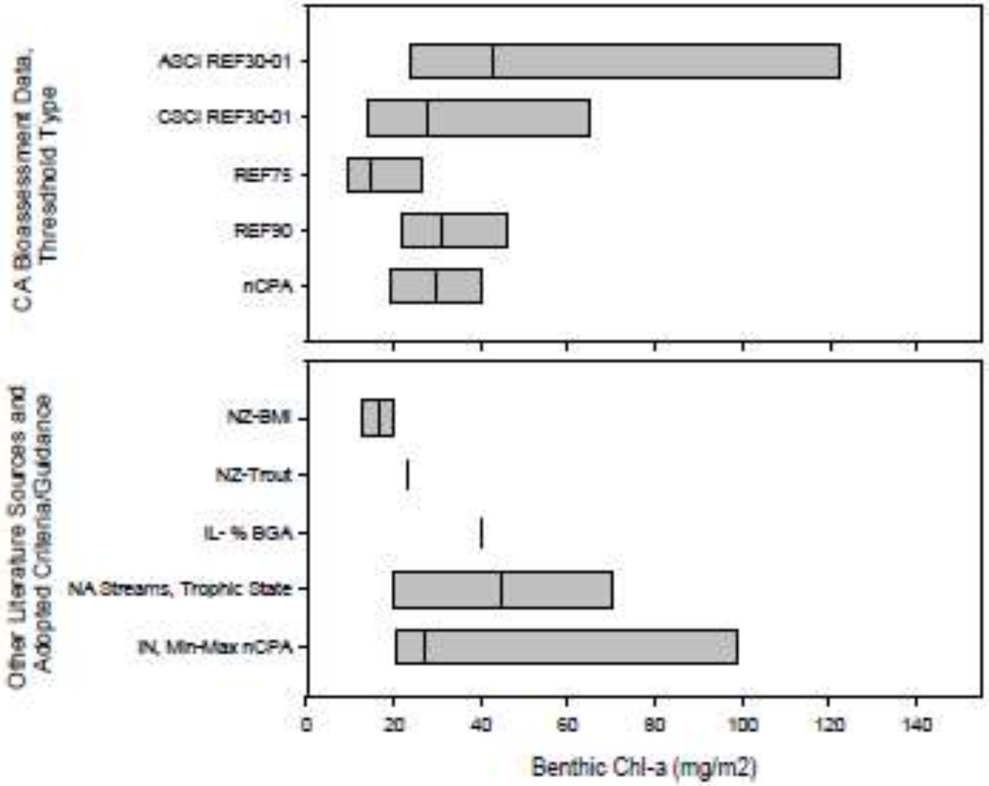


Figure 4.2 Threshold benthic chl-a ranges for CA wadeable stream bioassessment data (top panel; Mazor et al. in prep and Fetscher et al. 2014), compared to other literature values protective of aquatic life (bottom panel). Mean of ASCI and CSCI REC30-01 bars represents REF10. REF75th and 90th show the ecoregional range and the statewide mean line. Change point analyses =nCPA. Thresholds protective of BMI and trout in New Zealand (NZ) are mean values; IL thresholds are protective against > 10% BGA. North American (N.A.) trophic state range represent boundaries of oligotrophic and eutrophic streams, while IN values represent min, mean and max change points for BMI, algae and fish.

AFDM May Have Issues with False Positive at Low End of Disturbance Gradient

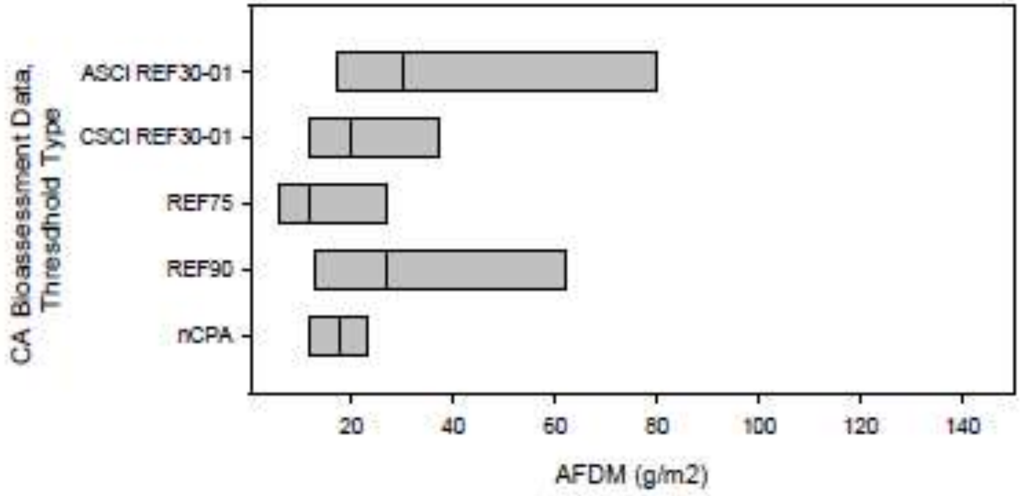


Figure 4.4 Ranges of AFDM of aquatic life thresholds derived from California wadeable stream bioassessment data (Mazor et al. in prep, Fetscher et al. 2014). In ASCI and CSCI REC30-01 bars, mean represents REF10. REF75th and 90th is the ecoregional range, while the mean line represents the statewide mean. Change point analyses are designated as nCPA.

Wadeable Streams Aquatic Life Response and Biostimulatory Thresholds

Response

- Benthic Chl-a
- Ash-free Dry Mass
- Macroalgal Cover
- Sestonic Chl-a
- Dissolved oxygen and pH
- Diel DO Variability
- Particulate cyanoHAB cell count and toxins
- CyanoHAB tissue toxin concentrations
- SPATT
- CSCI and ASCI or component metrics

Causal

- TN, TP

Thresholds for other response indicators are derived from other literature, existing basin plans, state guidance, or are "placeholders" for emerging science

Basis for Stream Water column Chl-a Thresholds: Quick Snapshot

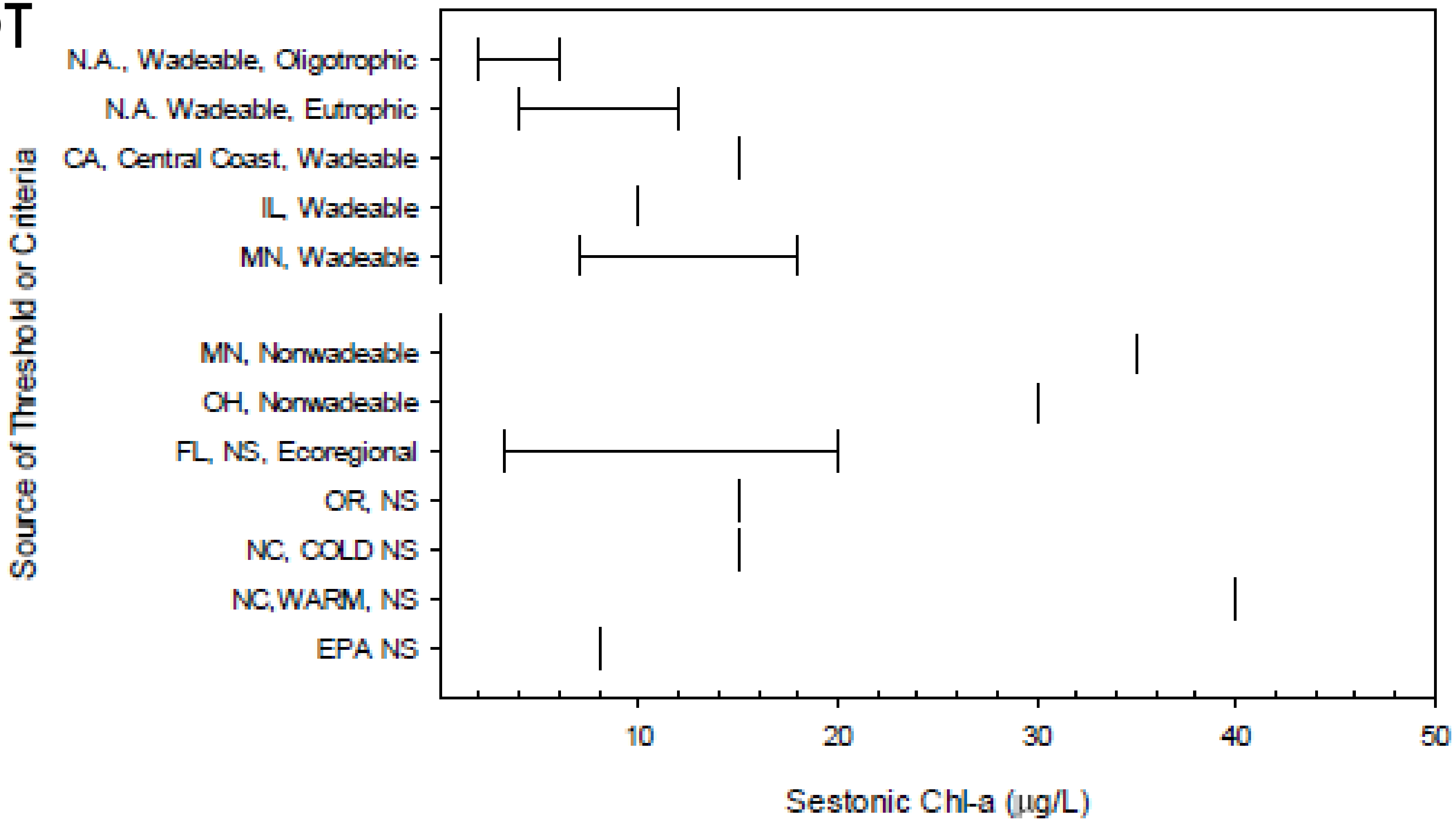


Figure 4.5. Ranges of literature derived Sestonic Chl-a thresholds and adopted state criteria for wadeable versus nonwadeable streams. All threshold criteria sources above orange line are for wadeable streams and nearly all from peer-reviewed literature sources. The exception is the CA Central Coast Regional Water Board, which adopted 15 µg/L to interpret their biostimulatory objective, based on peer-reviewed literature sources. Below the line includes literature sources or adopted criteria for either non-wadeable streams or streams and rivers where the type is not specified (NS).

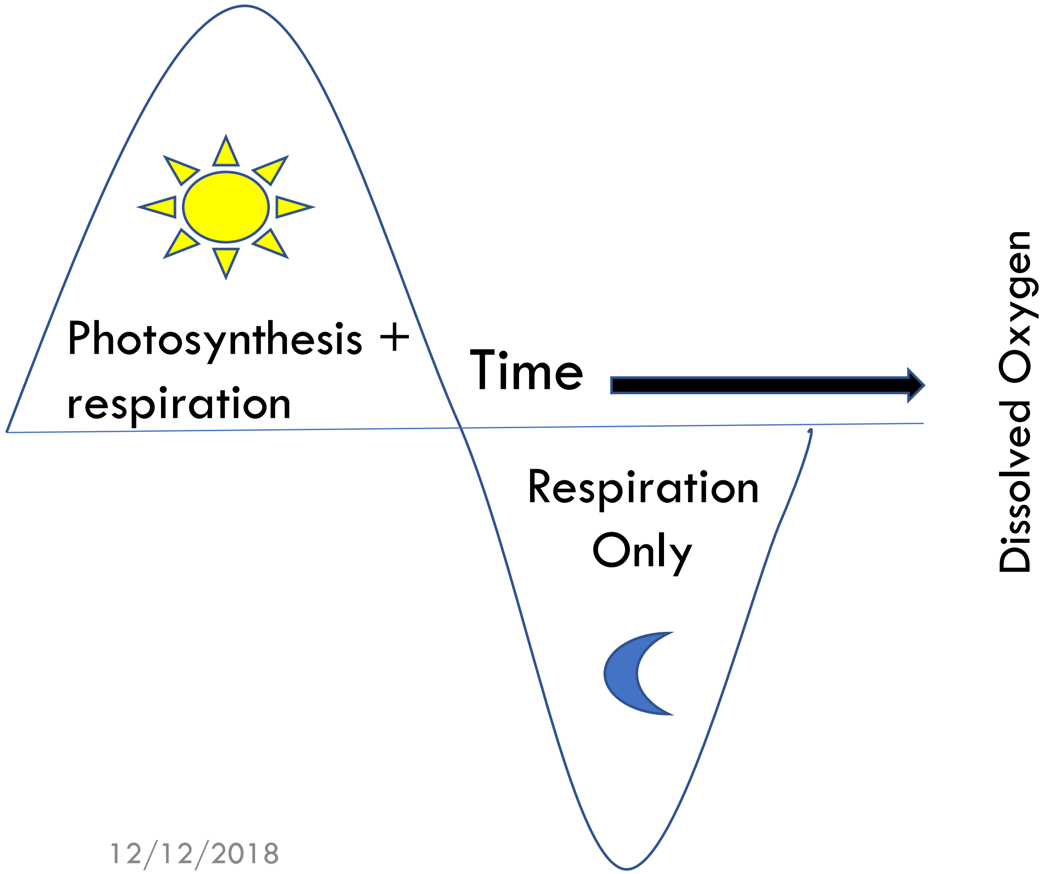
Basis for Stream Water column Chl-a Thresholds: Quick Snapshot

Table 3.9 Summary of sestonic chlorophyll-a values from peer-reviewed literature-based sources. Single sample = SS

Region	Type	Protection Endpoint	Threshold			
			Chl-a(ug/L)	TN (mg/L)	TP (mg/L)	Source
Central Coast California	wadeable streams	Literature	15, SS	--	--	Worcester et al. (2010)
North American Streams and Rivers	Oligotrophic Mesotrophic Eutrophic	Reference based approach, based on data distribution of full disturbance gradient	< 10, SS 10-30, SS >30, SS	<0.70 0.70-1.5 >1.5	<0.025 0.025-0.075 >0.075	Dodds et al. (1988)
North American temperate rivers and streams	Oligotrophic Mesotrophic Eutrophic	Autotrophic state boundaries calculated from reference distributions of TN and TP	2-6, SS 4-12, SS	0.285 0.714	0.029 0.071	Dodds (2006)
Minnesota	Wadeable COLD	Fish community, BMI taxa richness, diel DO range, TP inflection point	7, mean	--	0.050	Heiskary and Bouchard (2016)
	Wadeable WARM		18, mean	--	0.100	
	Large Rivers		35, mean	--	0.150	
	Blue Earth River (large river)	Inflection point in % blue green algae	<20, SS	--	0.1	Carlton et al. 2009
Ohio	Large rivers	Fish IBI 24-hour diel range (±3.5 mg/L DO) BOD (< 2.5 mg/L)	<30 protective	--	0.130	Miltner et al. (2010)
Illinois	Wadeable streams, open canopy (ag dominated)	Inflection point with TP	< 10, SS	--	0.07	Royer et al. 2008
Red River Basin (Arkansas, Louisiana, New Mexico, Oklahoma, and Texas)	Large river	Inflection points with TN and TP	< 10, SS	0.9-2.11	0.11-0.23	Haggard et al. 2013
Oregon Rivers	Rivers and streams	Not specified	< 15, SS	--	--	OAR, 2000
North Carolina	COLD lakes and rivers WARM lakes & rivers	Not specified	< 15, SS < 40, SS			NC 2002
EPA Rivers and Stream Criteria			< 8			EPA 2000

DO and pH Diel Variability

- For DO and pH, the diel variability is linked to fish and invertebrate impacts, is an easier endpoint to model mechanistically, and requires a shorter timeframe to monitor to assess



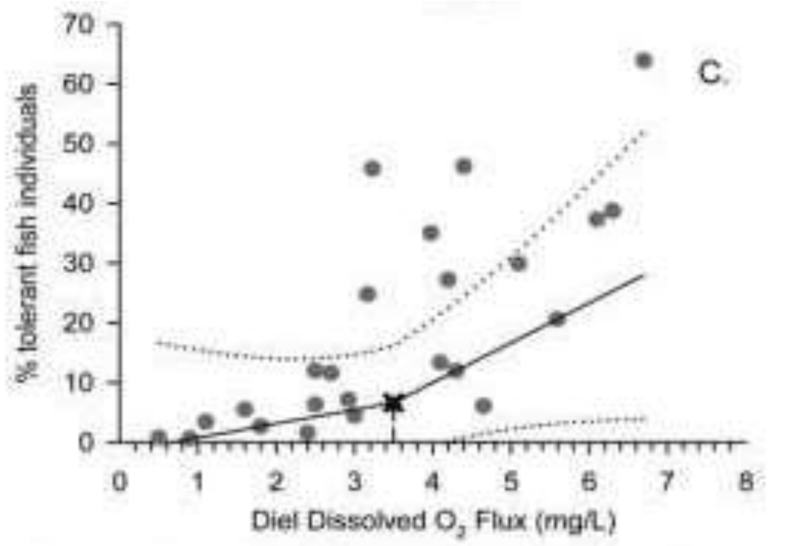


Figure 3. Examples of 75^{th}-percentile additive quantile regression smoothing (AQRS) showing data sets with upper and midpoint lower thresholds (% sensitive fish individuals, Central region, biomonitoring data) (A) and midpoint threshold only (% intolerant fish individuals, Central region, biomonitoring data) (B), and upper breakpoint only (% tolerant fish individuals, River Nutrient Study) (C).

Summary of Thresholds Values for DO Diel Variability

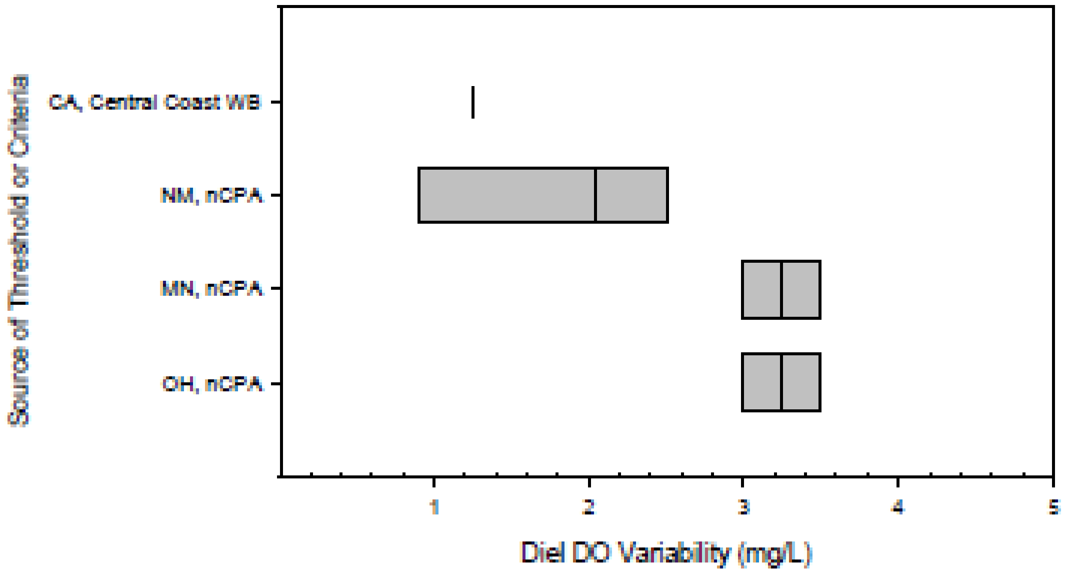


Figure 4.6 Ranges of literature derived diel variability thresholds (California versus other states) relative to adopted state criteria. Ranges of NM, MN, and OH are from change point (nCPA) analyses.

Table 3.12 Summary of diel DO thresholds and associated TN and TP protection thresholds from peer-reviewed and grey literature-based sources.

Region	Type	Protection Endpoint	DO Diel Variability Threshold (± mg/L)	Nutrient Thresholds (mg/L)		Source
				TN	TP	
Central Coast, California	Screening Value	O2 deficit associated with NO3 biostimulation	1.25	1 mg/l NO3[6]	--	Worcester et al. (2010)
	COLD	Reference or near reference that always met either COLD or WARM DO objectives	2.0			
	WARM		3.0			
New Mexico	Volcanic	BMI Changepoint median 90th percentile of reference	-- 2.51	 0.36	 0.059	Jessup et al. (2015)
	Flat	BMI Changepoint median 90th percentile of reference	1.21 2.04	 NS	 0.099	
	Steep	BMI Changepoint 90th percentile of reference	-- 0.085	 0.30	 0.035	
Minnesota	Wadeable COLD	Fish community, BMI taxa richness.	3.0	--	0.050	Heiskary and Bouchard (2016)
	Wadeable WARM		3.5	--	0.100	
	Large Rivers		4.5	--	0.150	
Ohio	Wadeable Streams	High quality Management	3.0 3.5	0.44 DIN 1.1 DIN	0.04 0.1	Miltner (2010)
	Large rivers	Fish IBI change point	3.5		0.130	Miltner et al. (2010)

Wadeable Streams Human Uses (Water Resources, Consumption, & Recreation) Thresholds

Primary Lines of Evidence

- Macroalgal Percent Cover: REC2
- CyanoHAB particulate toxins: MUN, REC1
- CyanoHAB tissue concentrations: COMM, AQUA, SHELL
- DOC and trihalomethane: MUN

Supporting Lines

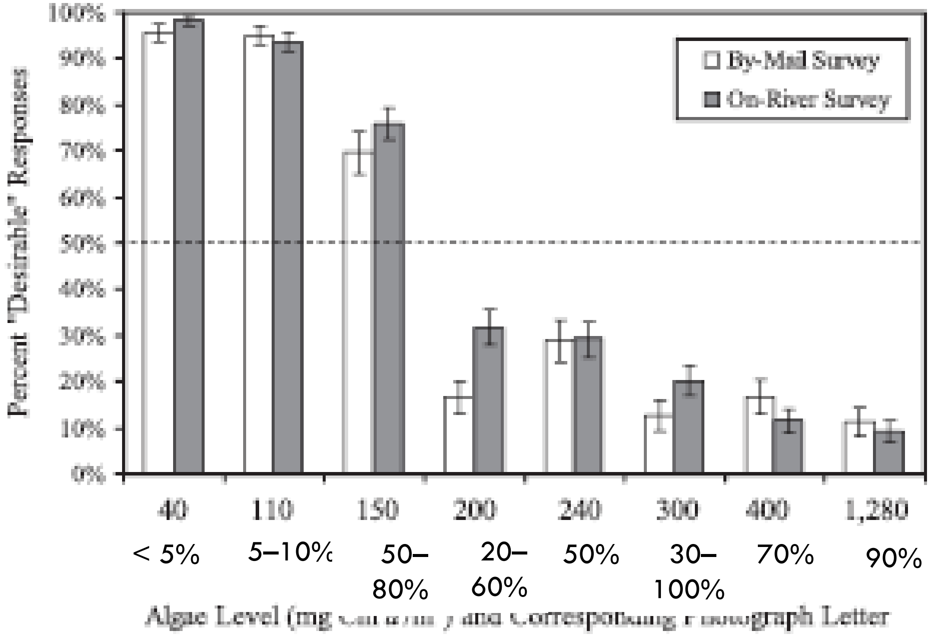
- Cyanotoxin SPATT: MUN, REC1

Causal Lines

TN and TP

Macroalgal Percent Cover Impacts to Recreational Use

- Aesthetic nuisance conditions are caused by the fraction of stream surface covered by visible periphyton mats, especially filamentous green algae and in particular Cladophora.
- Basis for thresholds:
  - Welch (1988) > 20 % is nuisance to aesthetics; 100 to 150 mg m2 benthic chla
  - Suplee et al. (2009) and Jakus et al (2017) recreational user survey; strongly tied to Cladophora mat cover (also drives up biomass), less “generic cover”, > 20%, > 150 mg m2
  - West Virginia: > 25% cover undesirable for > 50% of respondents (Responsive Management 2012)



We strongly suspect that CA biomass estimates are NOT comparable with that of other states

Would be worthwhile doing a comparison of methods AND refinement of Fetscher et al. (2009) to improve quantitative estimate of organic matter accumulation

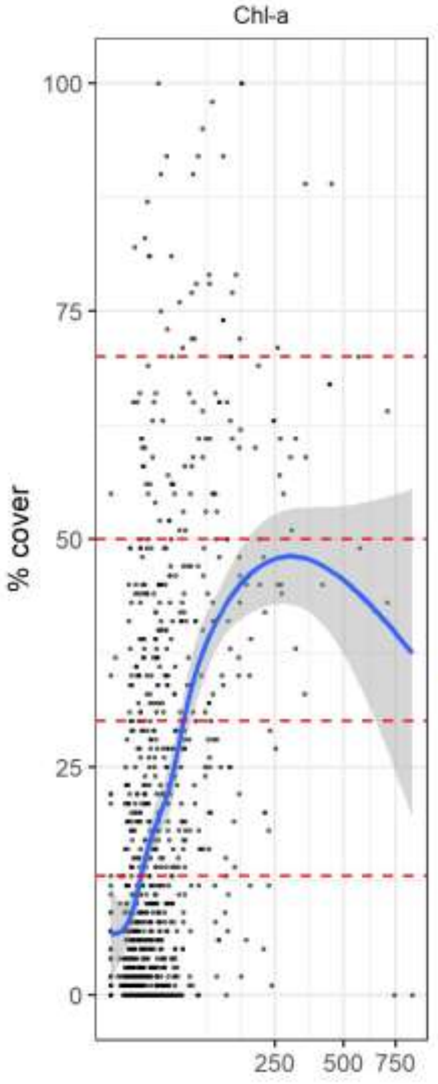
REC-2 Thresholds Are Roughly Comparable to Aquatic Thresholds for % Cover and Benthic Chl-a

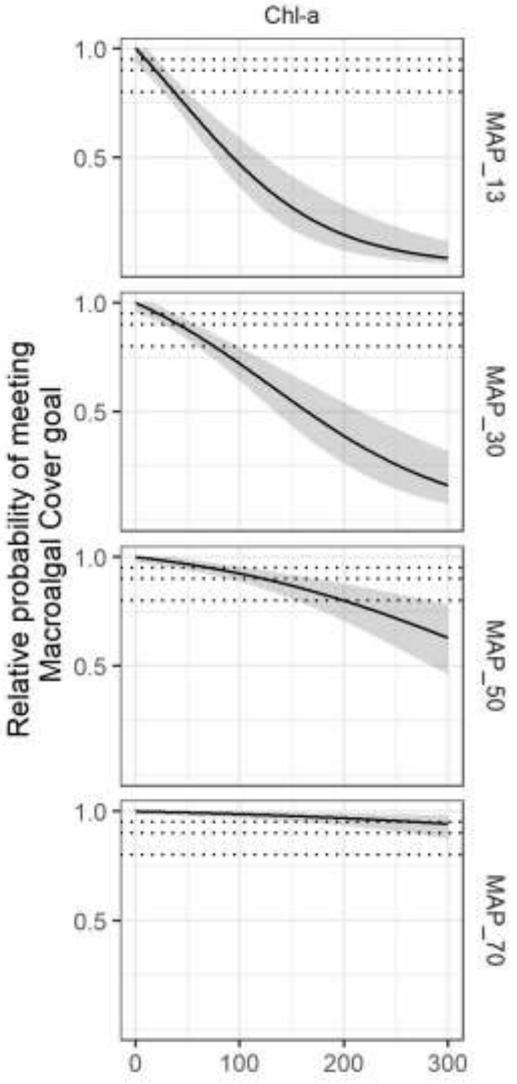
Comparison of Cover Targets: Aquatic Life Versus Recreational Use (Literature-Based)

CSCI- 90% Prob REf10	ASCI- 90% Prob REf10	Literature Recreational Use
13%	21 %	> 20 to 25% Cover

Comparison of Biomass Thresholds (mg/m-2) with 90% Prob. Of Meeting Aquatic Life Versus Range of % Cover Goals*

CSCI-REf10	ASCI-REf10	13% Cover	30% Cover	50% Cover
28	58	19	41	123





* Numbers are provisional, pending model validation

Human Uses: Basis for Cyanotoxin Thresholds….

- Primary Line
  - Particulate cyanoHAB cell densities and toxins (CCHAB triggers, Table 3.16)
  - CyanoHAB toxin concentrations in tissues (OEHHA 2012)

- Supporting Line
  - SPATT Toxin (Kudela et al. references)

Table 3.16. CCHAB trigger levels for cyanotoxin impacts to human health (from MyWaterQualityPortal.ca.gov).

	Caution Action Trigger	Warning TIER I	Danger TIER II
Primary Triggers [a]			
Total Microcystins [b]	0.8 μg/L	6 μg/L	20 μg/L
Anatoxin-a	Detection [c]	20 μg/L	90 μg/L
Cylindrospermopsin	1 μg/L	4 μg/L	17 μg/L
Secondary Triggers			
Cell Density *(Toxin Producers)*	4,000 cells/mL	--	--
Site Specific Indicators of Cyanobacteria	Blooms, scums, mats, ect.	--	--

[a] The primary triggers are met when ANY toxin exceeds criteria.
[b] Microcystins refers to the sum of all measured microcystin variants. (See Box 3)
[c] Must use an analytical method that detects ≤ 1μg/L Anatoxin-a.

Table 3.15 California Office of Environmental Health Hazard Assessment (OEHHA) recommended cyanotoxin action levels under selected scenarios (from OEHHA 2012).

	Microcystins[1]	Anatoxin-a	Cylindro-spermopsin	Media (units)
Human recreational uses[2]	0.8	90	4	Water (μg/L)
Human fish consumption	10	5000	70	Fish (ng/g) ww[3]
Subchronic water intake, dog[4]	2	100	10	Water (μg/L)
Subchronic crust and mat intake, dog	0.01	0.3	0.04	Crusts and Mats (mg/kg) dw[5]
Acute water intake, dog[6]	100	100	200	Water (μg/L)
Acute crust and mat intake, dog	0.5	0.3	0.5	Crusts and Mats (mg/kg) dw[5]
Subchronic water intake, cattle[7]	0.9	40	5	Water (μg/L)
Subchronic crust and mat intake, cattle[7]	0.1	3	0.4	Crusts and Mats (mg/kg) dw[5]
Acute water intake, cattle[7]	50	40	60	Water (μg/L)
Acute crust and mat intake, cattle[7]	5	3	5	Crusts and Mats (mg/kg) dw[5]

[1] Microcystins LA, LR, RR, and YR all had the same RfD so the action levels are the same.
[2] The most highly exposed of all the recreational users were 7- to-10-year-old swimmers. Boaters and water-skiers are less exposed and therefore protected by these action levels. This level should not be used to judge the acceptability of drinking water concentrations.
[3] Wet weight or fresh weight.
[4] Subchronic refers to exposures over multiple days.
[5] Based on sample dry weight (dw).
[6] Acute refers to exposures in a single day.
[7] Based on small breed dairy cows because their potential exposure to cyanotoxins is greatest. See Section VI for action levels in beef cattle.

DOC and Trihalomethane (THM): MUN

- Trihalomethanes (THMs) are byproducts of drinking water treatment that result from the chlorination or bromination of certain dissolved organic carbon (DOC) compounds.
  - Known and suspected carcinogens
  - EPA (2003) suggested 0.080 mg/L total THM in potable water distribution system
- Algal blooms in wadeable streams leak DOC. The Stage I Disinfection Byproducts Rule requires removal of DOC by water treatment plants when the source water concentration exceeds 2 mg/L DOC, a limit easily exceeded during benthic algal blooms
- CALFED (2004) has an objective of 3 mg/L organic carbon in source water

Wadeable Streams Human Uses (Water Resources, Consumption, & Recreation) Thresholds

Primary Lines of Evidence

- Macroalgal Percent Cover: REC2 *
- CyanoHAB particulate toxins: MUN, REC1 ‡
- CyanoHAB tissue concentrations: COMM, AQUA, SHELL ‡
- DOC and trihalomethane: MUN *

Supporting Lines

- Cyanotoxin SPATT *

Causal Lines

TN and TP †

† Potential thresholds based on changepoint or prescribed probability of meeting Macroalgal % Cover Goals

* Literature Values

‡ CCHAB Voluntary Listing Guidance, EPA Health Effects documentation

Key Findings, Part II: Thresholds for Aquatic Life and Human Uses

- Strong empirical evidence for aquatic life-related thresholds for nutrients and organic matter indicators
  - Thresholds are validated with significant increased risk to AL indicators
  - Empirical evidence supported by literature that describes mechanistic basis for relationships
  - Thresholds vary based on confidence level and stringency of approach (e.g. aquatic protection endpoints REF30, REF10, REF1), but all within a fairly narrow range

- Thresholds to protect human uses rely to a greater degree on literature, existing basin plans and guidance

Other Issues Not Currently Addressed In Synthesis, But Would Like to, With More Policy Context

- How should thresholds be applied? Statistics matter!
    - Mean vs maximum vs minimum?
    - Duration of effects?
    - Minimum number of samples to estimate effect?
- Whether or how to use multiple lines of evidence
- Seasonality
    - wet versus dry weather
    - Winter dry versus summer dry
- Analytical variability versus threshold significant digits
- Temporal variability of nutrients in reference streams
- Relevance of indicators and thresholds for protection of downstream uses
- Biostimulatory thresholds were biointegrity constrained by landscape development

What Else?

Water Board Charge Questions:

Scientific Bases for Assessment, Prevention, and Management of Biostimulatory Impacts in California Wadeable Streams, Sutula et al, SCCWRP TR 1048

- Comment on the synthesis of thresholds, in particular:
  - Are the conclusions of the review of thresholds appropriate?
  - The literature review produced less information on organic matter or nutrient thresholds that are linked to human protection endpoints than for aquatic life. Are there additional literature sources that could be used to improve this?
- Are there technical ways to address stakeholder concerns?