NMS Science Program Update

• Background
• Program Update
• Permit 2 directions

D Senn, Z Zhang, A Chelsky, T Winchell, E Nuss, A King, E King, I Wren¹

and MANY regional collaborators

¹ Bay Keeper
Collaborators

SFEI
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USGS-Menlo Park
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Does SFB have nutrient problems?
- now?
- future?

How can impacts be mitigated or prevented?
- $5-10$ billion question

N and P loads place SFB in upper ~90%ile of estuaries worldwide (g m$^{-2}$ d$^{-1}$)

Cloern et al., in prep

And those loads are increasing…
Dissolved Inorganic Nitrogen (DIN) Loads ($NH_4^+ + NO_3^-$)

Change (Jan 2000 - Jun 2017) ~ 25%
Does SFB have nutrient problems?
- now?
- future?

How can impacts be mitigated or prevented?
- $5-10$ billion question

**SFB doesn’t use most of its nutrients**

1. High turbidity
2. Strong tidal mixing
3. Filter-feeding clams

**Ecosystem health**

- Nutrients (N,P)
  - Large algae blooms
  - Low DO
  - Harmful algae, toxins

**Bay-wide Loads**
- N: 50,000 kg d⁻¹
- P: 5,000 kg d⁻¹

- 65% WWTP
- 20% Delta/Ag
- 15% Stormwater

**Ecosystem health**

**Nutrients (N,P)**

- Historical: Resistant to classic eutrophication symptoms
- Recently: Evidence of changing response to nutrients

**Large loads place SFB in upper ~90%ile of estuaries worldwide (g m⁻² d⁻¹)**

Cloern et al., in prep

- e.g., Cloern et al., 2007, 2010
Nutrient Management Strategy

• What nutrient loads can SFB (subembayments) assimilate without adverse impacts?

• What management actions would be effective at achieving protective nutrient loads or concentrations?

Tools/Approaches

• Monitoring
• Numerical Models
• Assessment Framework/Criteria
• Special Studies: Mechanistic/Quantitative Linkages to nutrients
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| HABs // Toxins | 
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| Permit 1 | Permit 2 |

| Future Scenarios | 
|---|---|
| Permit 1 | Permit 2 |

| Coastal Effects | 
|---|---|
| Permit 1 | Permit 2 |
Modeling (12/2018)

Hydrodynamic and Water Quality Model Calibration and Application in San Francisco Bay

Prepared by:
- Emilia Suarez
- Shandao Deng
- Brady Velleman
- Andilie Chiriyi
- Taylor Yurdakul
- Ming Wu
- Elizabeth Magann
- and David Siver

Monitoring // Moored Sensors (12/2018)

Nutrient Moored Sensor Program: Program Update

Authors:
- Tyler Velleman
- Shandao Deng
- Erich Sung
- and David Siver

Oxygen & Habitat (10/2018)

Dissolved Oxygen in South San Francisco Bay: Variability, Important Processes, and Implications for Understanding Fish Habitat

Prepared by:
- Lisa MacIntosh
- Philip Seaward
- Lori Comwell
- Eric Haller
- Taylor Schneider
- Taylor Walker
- and David Siver

Trends: chlorophyll (12/2018)

Evaluating the Utility of General Additive Models for Tracking San Francisco Bay Water Quality Over Time

Jan Reimer, Marcus Bea, Percy Alblas, Theresa Murphy, and David Siver
Numerical Models

Hydrodynamic model
(Transport)

\[ \text{Transport} = \text{advection} + \text{dispersion} + \text{mixing} \]

Biogeochemical model
(In-situ)

\[ \text{In-situ} = \text{production} + \text{grazing} + \text{mortality} \]
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Potential Adverse Impacts of Nutrients in SFB

Anthropogenic Nutrient Loads N, P

Increased phytoplankton biomass

Low DO in Margins: sloughs, creeks, wetlands

Low DO Deep Subtidal

Aesthetics

Recreation

Habitat

Fisheries

SFEI 2014, Sutula et al. 2017
Modeling related Management Questions

• Source apportionment: What are the nutrient sources to habitats?

• Predict responses: numerous physical/biological forcings and their influence on nutrient-related responses?
  – Responses: chl, DO, HABs
  – Forcings: loads, tides, wind, suspended sediments, salinity/stratification ($Q_{\text{fresh}}$), upwelling, light, etc.

• Dose:Response -- How will the system respond to incremental increases/decreases in nutrient inputs?

• If nutrient reductions are needed, how will the system respond to various management alternatives?
Model Development and Application

Management Scenarios

Environmental Scenarios

Hydrodynamics
Transport & Mixing

Applications

Water Quality

Physics

Model Development
Model Development and Application

- Management Scenarios
- Environmental Scenarios
- Turbidity
- Light Field
- Phyto: community
- Grazers
- Phyto: biomass
- Dissolved oxygen
- Sediment Flux
- Nitrif.
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- Hydrodynamics
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How well does the model capture...

Phytoplankton biomass/blooms
- Timing...Magnitude...Locations
- Factors controlling loss and gain

Nutrient levels and fate

Dissolved Oxygen

Across a range of conditions and responses
Dissolved Inorganic Nitrogen

Chlorophyll-a

Dissolved Inorganic Nitrogen

2013-01-28
What observational data do we need to inform management decisions?

- Assess current condition
- Predict/anticipate changes
- Establish quantitative linkages
- Calibrate models
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Ship-based monitoring, with USGS

- chlorophyll
- salinity
- temp
- light attenuation
- suspended particles

- Phytoplankton
- Nutrients
- Toxins, harmful algae
High-frequency observations DO, chl, OBS, fDOM, salinity, T

NMS Observation Program

Ship-based monitoring, with USGS

DO, chl, OBS, fDOM, salinity, T
High Frequency Mooring data:
- Dissolved Oxygen
- chl-a
- Other parameters
Jan-Dec 2017: Dumbarton Bridge

What factors regulate blooms magnitude, timine, duration?

Where do blooms develop?
Jan-Dec 2017: Dumbarton Bridge

What factors regulate blooms magnitude, timing, duration?

Where do blooms develop?

USGS, discrete
What monitoring network is needed to detect and describe ‘events’ with sufficient reliability/accuracy?
Past studies have shown high phytoplankton biomass along shoals. (Thompson et al., Cloern et al. 1985)

Is sampling in the channel sufficient to get things right?

Thompson et al 2008
BigBloom

Example ‘new stations’ (e.g., moorings)

Current USGS stations

Elapsed time: 0.00 days

Dilution

Days since release

18: Point Blunt
21: Bay Bridge
23: Hunter’s Point
25: Oyster Point
27: San Francisco Airport
29: S. of San Mateo Bridge
31: Coyote Hills
33: Dumbarton Bridge
35: Mowry Slough
Next Generation SFB NMS Observation Program

- Ship-based water column sampling
- Mooring, existing (SFEI)
- Mooring, existing, other groups
- Proposed New mooring
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Potential biomass ~30-40 µg/L

Cloern et al 2007
Potential biomass ~30-40 µg/L
1. When did changes cease to be statistically significant? Is the trend now negative (and significant)?

2. How does chl-a vary in other regions of SFB?

3. How do other relevant nutrient-related indicators changing over time? DO, gross primary productivity, nutrients, suspended sediments?

4. What trend magnitudes can realistically be detected? How long will it take to detect a sustained change?

5. What physical or biological factors could be causing or contributing to observed changes in water quality indicators?
Evaluating the Utility of General Additive Models for Tracking San Francisco Bay Water Quality Over Time

Ian Wren, Marcus Beck, Perry de Valpine, Rebecca Murphy, and David Senn

December 2018
San Mateo Bridge (s27): Other parameters

(GPP not shown)
San Mateo Bridge (s27)

Spring/Summer chl-a

Fitted averages with 95% confidence intervals: Mar 1-Aug 31

Summer bottom DO (mg/L)

Fitted averages with 95% confidence intervals: Jul 1-Aug 31
Potential Adverse Impacts of Nutrients in SFB

Anthropogenic Nutrient Loads N, P

Increased phytoplankton biomass

Altered phytoplankton communities

Harmful algal blooms and toxins

Poor food resource

Aesthetics

Recreation

Habitat

Fisheries

SFEI 2014, Sutula et al. 2017
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HABs and PhycoToxins in SFB: Science/Management Questions

1. Water Quality / Habitat Quality: Substantial HABs // phycotoxin threat?
   a. Sensitive population(s)? Biota? Humans?
   b. Current vs. Future Conditions? Δ Physical forcings → Δ HA+phycotoxin severity?

2. What factors regulate HA abundance and toxicity in SFB? transport, in situ production

3. Role of SFB nutrients: N,P → frequency or severity of HA events?

4. Protective nutrient loads, with respect to HAs and phycotoxins?

- Light availability
- Temperature
- Salinity
- Mixing
- Nutrients
NMS Observation and Forecasting Program

- Ship-based monitoring, with USGS

- Mussels

Phytoplankton: Microscopy, Sequencing (qPCR)

- Naturally occurring mussels
- Floating docks, readily-accessible
- Bi-weekly sampling (Sep 2015-present)
- Domoic Acid, Saxitoxin, Microcystin
Mussel Toxin concentrations, 9/2015-3/2018

Symbol colors correspond SFB region's in map

Saxitoxin (ppb) (800ppb)

Domoic Acid (20,000ppb)

Microcystin (10ppb)
• Multiple phycotoxins regularly detected in biota
  - *Domoic Acid* Low
  - *Microcystin* Moderate/Elevated
  - *Saxitoxin* Low/Moderate/Elevated
  - *Okadaic Acid* (Peacock et al 2018) Moderate/Elevated

• Regularly detect phycotoxins in water (particulate, dissolved)

• Regularly detect multiple HA taxa

Lighter shade: [tox] < LOQ
Grey: [tox] < LOD
Transport and fate across subembayments

How local are nutrient pathways?

How much exported to coast?
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Export to the Coastal Ocean:

- 35 – 85% of loads, average 55%
- Significant nutrient source to coastal ocean

Full Bay Budget
Overview...Major NMS progress over first 4 years of Permit #1

• Enhanced Monitoring/Observation network
  – New analytes (e.g., toxins)
  – New approaches: high-frequency data, moorings; mussels

• Major steps forward on Numerical Modeling
  – Physics/transport
  – Nutrient Loads and Transformations
  – Source tracking
  – Phytoplankton blooms

• Shift in perspective / understanding of condition
  – Everyday conditions for classic metrics or ‘responses’ parameters appear to be ok
  – Other (newer) issues require continued attention
    • Lower South Bay algal production and DO
    • Ambient conditions related to Harmful Algae and algal toxins
    • Exports to Coast
    • ‘Not Everyday conditions’...Future scenarios, Events
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Major Focus Areas or Challenges Ahead – Science Program 2019-2024

1. Building and Maintaining essential ‘Tools’
   - Monitoring: What/Where/When → wise and timely decisions
   - Modeling: Predicting, Forecasting, Uncertainty

2. Identifying safe or protective loads and concentrations

3. Assessing risk of “events” – present, and future

4. Testing mechanistic linkages to nutrients:
   - HABs and toxins
   - Low DO in sloughs

5. Effects of Bay nutrients on coastal water quality?
Reports and Work Products

Nutrient Strategy work products are available below, organized by Work Element. This list is regularly updated as new reports become available in draft and final versions.

### Annual Reports
- 2015 NMS FY2015 Annual Report
- 2016 NMS FY2016 Annual Report
- 2017_NMS_FY2017_AnnualReport

### Work Element 1: Nutrient Program Administration
- 2013 Nutrient Strategy Nov 2012
- 2016 NMS Science Plan Report Sep 2016

### Work Element 2: Define the problem
- 2011 SFBay Nutrient Numeric Endpoint Development Lit Review
- 2014 Nutrient Conceptual Model Draft Final
- 2014 Suisun Synthesis I
- 2014 External Nutrient Loads to SP Bay
- 2016 Nutrient sources, sinks and transformations in the Delta (MainReport Jan 2016)
  - Link to technical appendices (Nutrient sources, sinks and transformations in the Delta)
- 2016 Summary and Evaluation of Delta Subregions for Monitoring and Assessment
  - Link to technical appendices (Summary and Evaluation of Delta Subregions for Monitoring and Assessment)
- 2016 Suisun Synthesis II: Influence of Nutrient Forms and Ratios on Phytoplankton Production
- 2017 Nutrient Forms Ratios Workshop Report
  - Other workshop materials (panel charge, presentations, reading list, etc.)

### Work Element 4: Establish Guidelines
- 2011 SFBay NNE Development Lit Review
- SF Bay AP Meeting Summary Feb 2014
- Proposed Workplan for Assessment Framework Development
- Assessment_Framework_January2016_report
- 2018 Lower South Bay Dissolved Oxygen and Fish Surveys

### Work Element 5: Monitoring Program Development and Implementation
- 2014 Monitoring Program Development Plan Aug 2014
- 2014 Algal Pigment Final Report
- 2014 Moored Sensor Yr1 Progress Report
- 2017 NMS Observation Program Design

### Work Element 6: Modeling Strategy
- 2014_Model Development Plan to Support SFB Nutrient Management Decisions.pdf
- 2014_Detailed Modeling Workplan.pdf
- FY2016 Modeling Plan
- 2017 Load Update and Load Reduction Scenario Runs (See Section 6)
- 2017_SFBay_Interim_Model_Validation_Report
- 2018_June_Delta_Suisun_Biogeochemical_Model_ProgressReport

### Work Element 7: Control Strategies
- 2017 Conceptual Nutrient Trading Program for San Francisco Bay (See Section 7, Freshwater Trust)
- 2017 Reducing Nutrients in San Francisco Bay through WWTP Sidestream Treatment (Y Shang [EBMUD])
- 2017 Treatment Wetlands Opportunities Screening Report
Modeling

Hydrodynamic and Water Quality Model Calibration and Application in San Francisco Bay

Prepared by:
- Eileen Naoi
- Thierry Ouerghi
- Rusty Houde
- Andrew Glotov
- Taylor Werdell
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- Fiona Meier
- and David Sear

SAN FRANCISCO ESTUARY INSTITUTE AND THE AQUATIC SCIENCE CENTER

Monitoring // Moored Sensors

Nutrient Moored Sensor Program: Program Update

Authors:
- Tyler Werdell
- Claire Thompson
- Erik Hug
- Keri Levinson
- Josephine Vargas
- David Sear

12.14.18

Oxygen & Habitat

Dissolved Oxygen in South San Francisco Bay: Variability, Important Processes, and Implications for Understanding Fish Habitat

Prepared by:
- Lisa Mohrhan
- Philip Johnson
- Jodi Low 
- James Holben
- Molly Sprague
- Safe Madrona
- and David Sear

SAN FRANCISCO ESTUARY INSTITUTE and the AQUATIC SCIENCE CENTER

Trends: chlorophyll

Evaluating the Utility of General Additive Models for Tracking San Francisco Bay Water Quality Over Time

December 2018

Authors:
- Manuel Baier
- Piers Eakin
- Teresa Romney
- and David Sear
Collaborators

**SFEI**
Z Zhang, E Nuss, T Winchell, E King, A Chelsky, Ali King, D Senn

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NMS Steering Committee, NMS Planning Subcommittee, and Stakeholders

SFEI staff, Collaborators, and Technical Advisors
What future conditions are plausible?

What future scenarios should we manage toward preventing?

Dissolved Inorganic Nitrogen (μM)

Physical / Biological Drivers
What future conditions are plausible?

What future scenarios should we manage toward preventing?

What are these axes?

What events can move them?

Potential future state

Path with little or no nutrient management actions

Path with some nutrient management actions, to decrease future risk
Current conditions

- Low light
- Brief, infrequent stratification
- Low seeding and low growth of harmful species
- High clam grazing rates

Future conditions

- Higher Light
- Longer Stratification
- Higher seeding and growth of harmful species
- Low clam grazing rates
Current conditions

- Low light
- Brief, infrequent stratification
- Low seeding and low growth of harmful species
- High clam grazing rates

Change / Scenario

- Decreased sediments
- Climate change: flow/salinity
- Restore salt ponds & wetlands
- Higher water T
- Top Down: Species changes

Future conditions

- Higher Light
- Longer Stratification
- Higher seeding and growth of harmful species
- Low clam grazing rates

SFEI 2014
Current conditions

- Low light
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Change / Scenario

- Decreased sediments
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Future conditions

- Higher Light
- Longer Stratification
- Higher seeding and growth of harmful species
- Low clam grazing rates

Potentially sensitive to climate-change
Suspended sediments...Dumbarton Bridge (Lower South Bay)

Susceptible to major changes?

☑ 1. High turbidity

☑ 2. Strong tidal mixing

☑ 3. Filter-feeding clams

Schoellhamer et al. 2015
SFEI 2015
**Stratification Modeling**

**Stratification:** when surface waters are distinct and isolated from water lower down.

**Hypothesis:** persistent stratification enables phytoplankton blooms

**Typical in SF Bay:**

Flood tide mixes / Ebb tide stratifies
0.444 and $\frac{ds}{dx} = 0.1$ psu/km
0.444 and $ds/dx = 0.133$ psu/km
0.444 and $\frac{ds}{dx} = 0.200$ psu/km
0.333 and $\frac{ds}{dx} = 0.100$ psu/km
Now let’s look at GPP...Station 32, 1992-early2018

GPP (mg C m\(^{-2}\) d\(^{-1}\))

- Points = calculated GPP based on observed chl-a, \(k_{\text{ext}}\), and \(I_o\)
- Black curve = GAM fit to daily GPP
- Red curve = annual cumulative GPP/365 (units of mgC/m\(^2\)/d)

Chl (\(\mu g/L\))

- Points = observed chl-a
- Curve = GAM fit

NOTE: To address differences in data density across years (and stations, later), annual cumulative GPP was calculated based on the GAM fit values. See subsequent slides
Same as slide 13 and 15, but linear y-axis for GPP (some data outside axis limits)

GPP (using biweekly/monthly data same as earlier)

Chl (µg/L)

k_ext (1/m)  Daily Dumbarton
GPP (using biweekly/monthly data same as earlier)

Chl (µg/L)

k_ext (1/m) Daily Dumbarton
Nutrient Management Strategy

- What nutrient loads can SFB (subembayments) assimilate without adverse impacts?
  - Nutrient Loads, Cycling/Losses/Transformations
  - Biological Responses
  - Dose : Response
  - Condition Assessment: Criteria, Observations

- What management actions would be effective at achieving protective nutrient loads or concentrations?

Focus Areas
- Phytoplankton Blooms & DO
- Harmful Algae & Toxins
- Coastal Exports

Tools/Approaches
- Monitoring
- Numerical models
- Assessment Framework/Criteria
- Special Studies: Mechanistic/Quantitative Linkages to nutrients
Ship-based water column sampling

Mooring, existing

Proposed New mooring

Mussel toxins: existing, proposed new

Underway measurements, biweekly/monthly cruises

Lateral high-frequency mapping
What can we learn, mechanistically, about HAs in SFB using long-term data?

- source?
- internal growth?
- resident population(s)?
- Predictors?

Develop and ‘Test’ conceptual models (HA taxa A, B, C)

Example Harmful Algae Detections (SFB)

Density (cells/mL)

Karlodinium
Karenia
Dinophysis
Pseudo-nitzschia
Alexandrium

Sutula et al 2017

Frequency or abundance of HA

Frequency or Abundance

H\textsubscript{0} indicator(s) of favorable growth conditions

Factor 1
Factor 2

LSB
Suisun
Central
Delta

A
B
C

frequency or abundance of HA

A
B
C

cells/mL
time

time

Factor 1
Factor 2
Microscopy: Dates/Locations of Presence/Absence

- San Pablo Bay
- Central Bay
- South Central Bay
- South Bay
- Far South Bay
- Lower South Bay

Underlined: HA of concern
Others: Potential HA (?)
Focusing on *Alexandrium*...

...frequent co-occurrence with *Prorocentrum* and *Heterocapsa*
Densities (cells/mL)

- **South Bay** (s27+nearby)
- **Far South Bay** (s32+nearby)
- **Lower South Bay** (s34+s36)
**Densities (cells/mL)**

- *Alexandrium, Prorocentrum, Heterocapsa:*
  
  ...Commonly appear together
  - during/after major freshwater flow events
  - during elevated chl-a (blooms)

  ...*Alexandrium* reach non-trivial densities
  - comparable to coastal CA events (~$10^4$-$10^5$ cells / Liter)
  - but comprise small proportion of overall biovolume
Alexandrium measurements; Coastal CA sites

Alexandrium measurements: SFB, 1992-2013

Alexandrium measurements: SFB, 1992-2013
Pseudo-nitzchia: Coastal CA sites, Jan2014-Aug2018

Pseudo-nitzchia: SFB, 1992-2013

cells/L
Example Harmful Algal Bloom (HAB) forming species and toxins

**When are toxins produced?**

*When they are stressed...e.g.,*

- Salinity, Temperature
- Nutrients (e.g., ± P, - Si, ±N)
- Light conditions

**Domoic Acid**
(Amnesic Shellfish Poisoning)

**Microcystin toxins**
(hepatotoxin)

**Saxitoxin**
(Paralytic Shellfish Poisoning)

**Alexandrium spp.**

**Pseudo-nitzschia spp.**

**Microcystis spp.**
Pseudo-nitzschia (cells / L)

- Central Bay
- South Central Bay
- South Bay
- Far South Bay
- Lower South Bay
NMS Modeling Focus Areas

- Coastal Exchange
- Scenarios and Risk
- Core Modeling
- LSB sloughs, creeks
- Suisun/Delta