14,509

BACWA EXECUTIVE BOARD MEETING

Thursday, September 22 2011, 9:00 a.m. – 12:00 p.m.

HANDOUTS

Handout Packet is available on the BACWA website (www.BACWA.org).

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Executive Board Meeting Agenda

Thursday, September 22, 2011, 9:00 a.m. – 12:00 p.m.
EBMUD Treatment Plant Lab Library
2020 Wake Avenue, Oakland, CA

ROLL CALL AND INTRODUCTIONS (9:00 a.m. – 9:05 a.m.)

PUBLIC COMMENT (9:05 a.m. – 9:10 a.m.)

REPORTS (9:10 a.m. – 9:40 a.m.)

1. Committee Reports
2. Proposition 50 Grant Disbursements Status Report
3. Executive Director Report
4. Executive Board Reports
5. Chair & Executive Director Authorized Actions
    a. Chair authorization for an agreement with Patricia McGovern Engineers (PME) for as-needed technical services, not to exceed $9,500, File 12,555;
    b. Chair task authorization to utilize as needed contract with EOA, Inc. for assistance with e-SMR/CIWQS reporting, not to exceed $9,800, File 12,449;
    c. Executive Director authorization for an agreement with O'Rorke to assist BAPPG with P2 Week outreach, not to exceed $1,500, File 12,556;
    d. Executive Director authorization for an agreement with LWA for BAPPG Copper Algaecide project assistance, not to exceed $4,999, File 12,557;
    e. Chair authorization for Pacific EcoRisk to provide Whole Effluent Toxicity Support, $4,000, File 12,560.

CONSENT CALENDAR (9:40 a.m. – 9:50 a.m.)

6. Minutes from August 25, 2011 BACWA Executive Board Meeting
7. July 2011 Treasurer's Report
8. Contribution from BAPPG for IPM partnership FY2011-12, $10,000, File 12,552
9. CASA Contribution for CWCCG FY2011-12, $43,750, File 12,558
10. CASA Contribution for Pesticides Support, $15,000, File 12,559

OTHER BUSINESS (9:50 a.m. – 12:00 p.m.)

11. Pardee Attendance and Schedule (10 min)
12. Annual Meeting Topics (15 min)
13. NPDES Permit Plant Inspections (30 min)
14. Whole Effluent Toxicity Policy Updates and Next Steps (30 min)
15. SF Bay Regional Water Quality Control Board Meeting (30 min)
16. Informational Item: SFPUC/NOAA Quantitative Precipitation Information Proof-of-Concept Study (15 min)

NEXT REGULAR MEETING

The next meeting of the Board will be October 11 through the 13 (Pardee). The next regularly scheduled meeting will be November 17.

ADJOURNMENT (12:00 p.m.)

BAPPG Committee Report to BACWA Board

Meeting Date: September 22, 2011
Prepared By: Sarah Scheidt, City of Sunnyvale
BAPPG Committee Chair

Project Updates

Project	Update	Completion Date
P2 Week	BAPPG's will reuse previous posters, of which there is a surplus. Posters were distributed during the August 3rd BAPPG meeting. $1,500 budget will be used for Facebook advertisements with a "toilet is not a trash can" message. See attached ads. [Project Leads: Jen Jackson (EBMUD) and Melody LaBella (CCCSD)]	September 2011
Copper	BAPPG will develop a factsheet on copper algaecides used in pools, spas, and fountains. The Project Scope has been finalized and a PO and EDAR have been submitted for approval. [Project Leads: Catherine Allin (City of Millbrae) and Mike Auer (Union Sanitary District), and Jen Jackson (EBMUD)]	September 2011 - ongoing
Pesticides	A letter was sent to the Office of Environmental Health Hazard Assessment on behalf of BAPPG and BACWA supporting the proposed Green Chemistry Toxics Inventory Clearinghouse (TIC) regulation. [Project Lead: Jen Jackson, (EBMUD)]	September 2011
Pharmaceuticals	The Fall 2011 Edition of PERSpective, the quarterly newsletter from CalPERS, contained an updated pharmaceutical disposal article with a link to the Baywise.org and No Drugs Down the Drain websites. The article clarified that in California; the Regional Water Boards advocate no flushing of any used pharmaceuticals. The previous newsletter indicated that certain pharmaceuticals could be flushed according to EPA guidance. BAPPG members with backing from the Regional Board reached out to the editors and succeeded in having this important clarification published. [Project Leads: Jen Jackson, EBMUD, Karin North (City of Palo Alto) and Melody LaBella (CCCSD)]	September 2011
	BAPPG was alerted in June that SB 431 contained language that could hamper extended producer responsibility efforts related to pharmaceuticals. BAPPG worked with CA Product Stewardship Council (CPSC) on the problems in the bill. CPSC has members statewide that could lobby the republican author without damaging relationships with him, whereas Bay Area agencies might be perceived differently. City of Roseville stepped up and worked with the author and co-author to remove one section of the bill that was problematic. Has passed both houses of the legislature and has been enrolled for the Governor's consideration. Great example of how our membership with CPSC is very beneficial to wastewater agencies.	September 2011
General P2	The City of Millbrae Pollution Prevention Program won the Regional Board's Dr. Teng Chung Wu Pollution Prevention Award. The award was presented September 14, 2011. [Project Lead: Catherine Allin (City of Millbrae)]	September 2011

Next BAPPG Meeting

October 5, 2011, 10am – 12 pm
Elihu Harris State Building
1515 Clay Street, 2nd Floor, Room 2
Oakland, CA

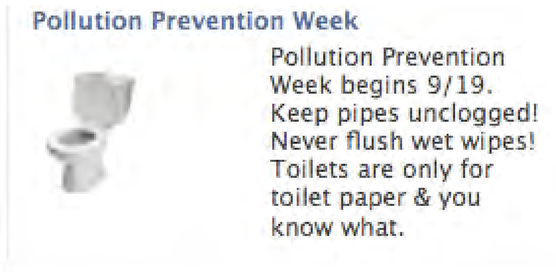
Attachment:

1. **Facebook P2 Week ads**

BAPPG Committee Report to BACWA Board

Attachment

P2 Week Facebook Ads



Collection Systems Committee Report to BACWA Board

September 15, 2011
From: Andy Morrison, Committee Chair
Prepared By: Andy Eggleston

Committee Request for Board Action:

None.

Highlights of New Items Discussed and Action Items

CCTV - Panel Discussion

Staff from four agencies, namely the Union Sanitary District, City of Redwood City, Oro Loma Sanitary District, and Vallejo Sanitation and Flood Control District, served on a panel at the September 8 committee meeting, to present their agencies' strategies on the use of CCTV in managing their collection systems and preventing sanitary sewer overflows (SSOs). Their presentations were followed by an extensive question and answer session during which meeting participants discussed details of CCTV inspection schedules, applications, equipment, contracting, staffing, and data storage and review.

Changes to Statewide SSS WDR

State Water Board staff continue to summarize and categorize the 2,500 comments received on the proposed revisions to the statewide Sanitary Sewer System (SSS) Waste Discharge Requirements (WDR). State Water Board staff have indicated they will share these summaries prior to drafting their responses, giving commenters an opportunity to make sure that their comments were interpreted correctly. A two to three week window for this review is expected to be prompted by notification via email in mid-October.

In addition, the workshop previously scheduled for November 2, 2011 is now expected to be postponed until the middle of January 2012, with adoption in March.

State Water Board Enforcement Actions

State Water Board staff have been conducting inspections of collection systems to evaluate their compliance with the SSS WDR. As reported in the State's August 2011 SSO Reduction Program Annual Compliance Report, ten inspections were conducted in 2010. Most of these inspections were unannounced, and primarily of medium to large collection systems in northern California. One enforcement proceeding for the City of San Jose required City staff to prepare a very detailed and lengthy (40 pages) follow-up technical report based on two SSOs. A four-page, single-spaced list of requested information had been provided to the City by State Water Board staff for this technical report, (the list was provided to committee members and can be made available to others upon request). San Jose staff indicated that preparation of the technical report involved more than 100 hours of staff time.

Sewer System Management Plan (SSMP) Audits

Jim Fischer with the State Water Board's Office of Enforcement has accepted an invitation to attend the November Collection Systems Committee meeting, to share his thoughts with Committee members about SSMP audits and other issues related to sanitary sewer overflows (SSOs). Claudia Villacorta of the Regional Water Board is expected to attend to provide her perspective as well.

Next BACWA Collection Systems Committee Meeting

The next committee meeting is scheduled for Thursday, October 6, 2011 at the Boy Scouts facility in San Leandro.

Permits Committee – Report to BACWA Board

Reporting Date: 9/15/11
Executive Board Meeting Date: 9/22/2011
Committee Chair: Jim Ervin

Committee Request for Board Action: Reach consensus on an approach for negotiating SMR Water Quality Objective "order of magnitude" reporting with Regional Water Board staff.

Upcoming Permits/Permit Amendments – Sept – Hayward Marsh (USD, EBDA, & East Bay Parks District)
Hayward Marsh permit issues: All contentious issues in the Hayward Marsh permit are resolved. The permit is scheduled to be adopted on 14 Sept. Discharger is satisfied that the ammonia limit can now be met. The permit will require completion of a revised mixing zone study to satisfy EPA concerns. A Basin Plan Amendment will be adopted to designate a new set of beneficial uses for Hayward Marsh prior to permit adoption. The REC 1 beneficial use will be deleted since the Marsh is fenced and not accessible by the public.
Report from Regional Water Board Staff: Miriam Zech is moving to the Water Board DOD group and will be replaced by a staff member from the Toxics group. Claudia Villacorta will be taking over the enforcement section from Gina. The permit group is still short three staff members. As staff assignments change, new case managers will notify dischargers by letter.
Status Update on "Staggered Sampling" rule. New language in the Attachment H permit amendment for pretreatment reporting adopted in April 2011 mentions that dischargers "should" stagger influent and effluent sampling to account for detention time through the facility. BACWA sent a letter to Regional Water Board staff confirming the optional nature of this approach on 12 May. Lila confirmed at the Permits meeting that Water Board understands the technical and logistical challenges associated with collecting staggered samples. The wording "should" is meant to be advisory, not a requirement.
Status Update on "Order of Magnitude" reporting rule: A requirement to regularly evaluate organic priority pollutants and Antimony, Thallium, and Berylium and report if they are detected within one order of magnitude of the Water Quality Objective was transmitted by letter from Water Board to BACWA agencies in March 2011. BACWA requested clarification. Lila confirmed at Permits meeting that the new "order of magnitude" language will not be included in new or reissued permits going forward. However, at the Regional Water Board hearing the next day the issue was further discussed. Water Board members indicated possible desire to drop Water Quality Objective reporting from SMRs completely. **The Permits Committee requests that BACWA Board provide direction for further discussions with Regional Water Board staff.**
Status Update on Federal Dental Amalgam rule: Lila Tang has agreed to send a letter to USEPA on their proposed rule under development. She has been working collaboratively with the BACWA Permits Committee on this issue.
eSMR Transition: The next eSMR User Group web-based meeting will be 22 September at 10 AM. • TheTri-TAC special session and Webinar on eSMR was held on 1 September. From the session we learned that the new eSMR version 2.5 software will be released in 2012. The updated software will incorporate DMR reporting so that both SMR and DMR reports can be submitted electronically together.
Nutrients Update: Permits committee was informed that BACWA is using HDR to develop a "Core Nutrients Strategy" to plan and respond to the Bay Area Numeric Nutrient Endpoint (NNE) project. A revised version of the NNE project literature review as released in September. The NNE workplan should be released by December 2011. A SFEI/RMP Nutrient Strategy meeting will be held on 15 September.
WET (Toxicity) Policy: State Board workshop was held on 22 August 2011. State board presented 3 state-wide toxicity policy alternatives. So far, all of the alternatives incorporate numeric limits for toxicity. Two of the alternatives include use of a monthly median. And, so far, all alternatives only allow use of the TST method for toxicity evaluation. • Staff is aiming to present a revised Toxicity Policy to the Board during the December meeting and hopes to have adoption of the policy in early 2012. • BACWA members will meet with Board Member Tam Doduc on 14 Sep, and then meet with State Board staff on 7 October to discuss incorporation of the IC25 method into the policy. CASA is also holding a meeting in Oakland on 16 Sept to discuss the three policy alternatives.
Next BACWA Permits Committee Meeting: Tuesday, October 11th, 2011, at EBMUD Plant Library.

Recycled Water Committee Report to BACWA Board

September 14, 2011

Prepared By: Cheryl Muñoz
Committee Chair

Committee Requests for Board Action:

None.

Business Discussed and Action Items:

Business	Discussion
BAIRWMP and Prop 84 Updates	BAIRWMP Updates • Planning Grant o Consultant interviews for the BAIRWMP update that includes outreach and web/database management were held on 9/13/11. The selection should be announced by the beginning on October. • Prop. 84 Implementation Grant o Now that the grant has officially been awarded for the 10 recycled water projects, project workplans, schedules and budgets need to be updated. o The draft DWR grant agreement template has been posted on DWR's website for review.
Legislative/Regulatory Updates	Title XVI update • The Bureau of Reclamation announced on 8/1/11 that 13 Bay Area Recycled Water Coalition agency projects have been awarded $2.12 million to fund feasibility studies that assess the opportunity for reclamation and reuse of wastewater and naturally impaired ground and surface water. • The Coalition is working with Senator Feinstein on an authorization bill. Presentation on WateReuse Association's Development of a Recycled Water Statute • Eric Rosenblum, the RW Committee's representative to the WateReuse Association's Legislative/Regulatory Committee, gave a presentation on the Association's plans to draft a new recycled water statue or "Law of Recycled Water". • The purpose is to provide a transparent process and clean approach to re-thinking the regulations rather than implementing a series of smaller "fixes" in numerous sections that would distinguish recycled water from the legislative framework for the discharge of waste. It would also advance a structure for maximizing the use of recycled water while protecting public health.
Committee Project Updates	BACWA Agencies Recycled Water Use and Uses Assessments • Preliminary spreadsheet and survey responses were presented indicating that 13 agencies responded on behalf of 18 agencies. Will contact non-responding agencies for data. • Goal is to complete the assessment project by early October. Recycled Water Presentation for the RWQCB (Region 2) • RWQCB staff are planning a presentation to update their Board on the

	status of recycled water trends and activities at their 11/9/11 meeting. The RW Committee plans to assist staff with the presentation and incorporate data from the "Recycled Water Use and Uses Assessment". Recycled Water Irrigation Guide • Project kick-off meeting expected to be held on 9/20/11 at the San Jose/Santa Clara Water Pollution Control Plant from 2-4:30 pm.
Other Items	• WateReuse Association Workshop titled "Whose Water is it Anyway? Water Rights and Recycled Water" will be held at Sacramento Regional County Sanitation District on 11/2/11.
Next RW Committee Meeting	Wednesday, 10/5/11 from 10:00 am to 12:00 pm EBMUD Headquarters, 4th Floor Conference Rooms A/B

Grant Disbursement Summary to Date (August 10, 2011)
Bay Area Integrated Regional Water Management (IRWM) Prop 50 Grant

Agr. No.	Implementing Agency	Project Title	DWR Proj. No.	Max. State Grant Funds by Project	Grant Funds Invoiced to date	Paid by DWR to date	DWR Retention	Admin[2] Funds Rec'd by BACWA	Funds paid out to date	Payable as of this date	Total Paid and Payable
1	Contra Costa Water District	Regional Intertie (VFDs)	1	**500,000.00**	**499,999.59**	**499,999.63**	0.04		495,803.20	0.00	495,803.20
		BACWA Admin	16	15,625.00	8,508.22	6,428.56	(714.28)	15,625.00			
2	East Bay Municipal Utility District	Reg. Conservation Outreach	2	**250,000.00**	**250,000.00**	**250,000.00**	0.00		2,396,885.69	0.00	2,396,885.69
		California WaterStar Initiative -	3	525,000.00	0.00	0.00	0.00				
		New Business Guidebook Pilot	4	75,000.00	0.00	0.00	0.00				
		Richmond Adv Recycling	8	**2,127,600.00**	**2,127,600.00**	**2,127,600.00**	0.00				
		BACWA Admin	16	46,875.00	25,524.65	19,285.69	(2,142.85)	46,875.00			
3	City of Redwood City	Redwood City Recycled WP	5	**972,800.00**	**972,800.00**	**972,800.00**	0.00		978,759.11	469.45	979,228.56
		BACWA Admin	16	15,625.00	8,508.22	6,428.56	(714.28)	15,625.00			
4	City of Palo Alto	Mt.View-Moffett Recycl WP	6	**972,800.00**	**972,800.00**	**972,800.00**	0.00		965,858.13	2,745.43	968,603.56
		BACWA Admin	16	15,625.00	8,508.22	6,428.56	(714.28)	15,625.00			
5	Santa Clara Valley Water District (& San Jose)	Reg. Conservation Outreach	2	**125,000.00**	**125,000.00**	**125,000.00**	0.00		98,910.69	0.00	98,910.69
		South Bay Adv Recycl WTP	7	2,934,600.00	0.00	0.00	0.00				
		BACWA Admin[3]	16	31,875.00	10,524.65	5,785.69	(642.85)	31,875.00			
SJ	City of San Jose	BACWA Admin for SCVWD[3]	16	**15,000.00**	**15,000.00**	13,500.00	(1,500.00)	15,000.00	7,000.00	6,500.00	13,500.00
6	North Coast County WD (& SFPUC)	Pacifica Recycled Water Proj	9	744,400.00	744,400.00	0.00	0.00		0.00	1,928.56	1,928.56
		BACWA Admin[3]	16	10,625.00	3,508.22	1,928.56	(214.28)	10,625.00			
SF	S.F. Public Utilities Comm	Reg. Conservation Outreach	2	**297,550.00**	**297,550.00**	**297,550.00**	0.00		242,045.00	51,612.13	293,657.13
		BACWA Adm for Reg.Consrv	16	31,250.00	17,016.43	12,857.13	(1,428.57)	31,250.00			
		BACWA Admin for NCCWD[3]	16	**5,000.00**	**5,000.00**	4,500.00	(500.00)	5,000.00			
SOL	Solano Co. Water Agency	Reg. Conservation Outreach	2	**50,000.00**	**50,000.00**	**50,000.00**	0.00		45,000.00	5,000.00	50,000.00
7	North Marin Water District	North Marin Recycled Water	10	**244,550.00**	**244,550.00**	**244,550.00**	0.00		241,750.47	281.67	242,032.14
		BACWA Admin	16	9,375.00	5,104.93	3,857.14	(428.57)	9,375.00			
8	Zone 7 Water Agency	Reg. Conservation Outreach	2	**60,000.00**	**60,000.00**	**60,000.00**	0.00		806,428.56	0.00	806,428.56
		Mocho GW Demin Project	11	**740,000.00**	**740,000.00**	**740,000.00**	0.00				
		BACWA Admin	16	15,625.00	8,508.22	6,428.56	(714.28)	15,625.00			
9	Marin Municipal Water District	Reg. Conservation Outreach	2	**200,000.00**	**200,000.00**	**200,000.00**	0.00		478,187.05	0.00	478,187.05
		Direct Installation HET Prog	12	366,800.00	311,894.35	280,704.92	(31,189.44)				
		BACWA Admin	16	9,375.00	5,104.93	3,857.14	(428.57)	9,375.00			
10	Montara Water & Sanitary District	Groundwater Exploration Project	13	**37,100.00**	**37,100.00**	**37,100.00**	0.00		33,390.00	1,285.71	34,675.71
		BACWA Admin	16	3,125.00	1,701.64	1,285.71	(142.86)	3,125.00			
11	Alameda County Water District	Reg. Conservation Outreach	2	**60,000.00**	**60,000.00**	**60,000.00**	0.00		655,803.56	0.00	655,803.56
		Alameda Creek Phase 2 Fish	14	**600,000.00**	**600,000.00**	**600,000.00**	0.00				
		BACWA Admin	16	15,625.00	8,508.22	6,428.56	(714.28)	15,625.00			
12	Sonoma Valley County Sanit. Dist.	Sonoma-Napa Marsh RWP	15	366,800.00	269,322.36	242,390.12	(26,932.24)		246,247.26	0.00	246,247.26
		BACWA Admin	16	9,375.00	5,104.93	3,857.14	(428.57)	9,375.00			
		Grand Total		**12,500,000.00**	**8,699,147.74**	**7,863,351.70**	**(69,550.19)**	**250,000.00**	**7,692,068.74**	**69,822.96**	**7,761,891.70**

Notes: 1. BACWA Administration Costs invoiced, paid and retained to date: 136,131.44 102,857.03 (11,428.56)

3. Reimburse SFPUC and San Jose for Admin Costs until reimbursement = $80k then pay SCVWD & NCCWD

2.Admin funding = $152,250 in upfront funding plus grant check deductions.

9/19/2011

Director's Report to the Board

August 20, 2011 – September 18, 2011
Prepared for the September 22, 2011 Executive Board meeting

A. Organizational Developments

- ***Financial.*** The Executive Director (ED) and Assistant Executive Director (AED) continued to work with the accounting department to prepare corrected invoices for member billings. The June (end of year) Treasurer's Report was finalized and a draft of the annual audit reviewed.
- ***Communications.*** The ED prepared and sent the September electronic newsletter and finalized the Annual Report text.
- ***Other.*** The ED and AED began preparations for the annual Pardee retreat. The ED met with Regional Water Board and BACWA representatives to develop an agenda and background materials for the joint meeting on September 23.

B. Regulatory Affairs

- ***Mercury/PCBs Watershed Permit.*** At the August 29 Aquatic Science Center (ASC) meeting the ED requested an update on the status of the risk reduction project undertaken by CDPH to fulfill the mercury permit requirements. This update is expected at the December meeting and should inform future permit discussions. The general topic of permit reissuance will be discussed at the September 23rd and October 11th meetings with the Regional Water Board.
- ***Selenium.*** No new developments; draft criteria expected from EPA in late 2011 or early 2012.
- ***Nutrients.*** HDR completed two of the three topic papers (which are attached to this report) after incorporating feedback from the review workgroups. The third topic paper is expected to be available later this month. The ED also worked with HDR and others to develop a conceptual proposal for BACWA's support of and involvement in a technical Nutrient Management Strategy. The proposal and the draft Strategy were distributed to the Executive Board on September 16. The Strategy was presented to a small group of stakeholders at an RMP Nutrient Workgroup meeting on September 15. A revised Strategy is expected to be made available to a broader group – including the Numeric Nutrient Endpoint Stakeholder Advisory Group – in October.
- ***e-SMR Transition.*** The ED worked with EOA and SFEI to finalize a scope of work to develop and implement recommendations to ensure the storage and accessibility of historic ERS and current e-SMR data. This issue is also on the agenda for BACWA's September 23 meeting with the Regional Water Board and more information is available in those meeting materials.
- ***Sanitary Sewer Overflow Waste Discharge Requirements.*** No new developments.
- ***Whole Effluent Toxicity Policy.*** The ED worked with LWA to organize and facilitate a meeting with State Water Board member Tam Dudoc on EC25/IC25. A follow-up meeting with State Board staff is scheduled for October 7. The meeting with Ms. Dudoc was unanticipated, so additional authorizations are necessary to enable LWA and Pacific EcoRisk to continue their support. The ED and BACWA WET workgroup also attended a small meeting of statewide POTW representatives to discuss alternatives to the State Board's proposed policy. Any recommendations from that meeting will be shared with the BACWA Board.

- ***Permits.*** BACWA's comment letter on the Hayward Marsh permit garnered attention at the September Regional Water Board meeting. The Regional Water Board has agreed to dispense with the "order of magnitude" threshold for priority pollutant reporting, but the other reporting requirements still need to be finalized. This issue is on the agenda for BACWA's September 23 meeting with Regional Water Board staff; more information is available in those meeting materials.

C. COLLABORATIONS

- ***IRWMP/Prop 84/Prop 50.*** The ED and AED continue working with project manager Brian Campbell on next steps for Proposition 84, which include collecting advance payments, establishing internal accounting controls, and preparing agreements with DWR and local project sponsors. The ED and Recycled Water Committee Chairs participated in the review process for selecting a firm to update the IRWMP.
- ***Climate Change.*** A small workgroup of BACWA members met August 30 to discuss climate change adaptation. A summary of that meeting is attached.

MEETINGS

- September 23: Joint BACWA/Water Board Staff meeting
- October 5: BAPPG Meeting
- October 6: Collection Systems Committee Meeting
- October 11: Permits Committee Meeting
- October 12: Laboratory Committee Meeting
- October 12: Regional Water Board Meeting
- October 11-13: Pardee Retreat
- October 19: AIR Committee Meeting
- October 21: RMP Steering Committee Meeting
- October 26: BAMI Meeting

ATTACHMENTS

1. Modeling Topic Paper
2. POTW Impacts Topic Paper
3. August 30, 2011 Climate Change meeting notes

The Utility of Water Quality Modeling for San Francisco Bay

Nutrient Strategy Development Project

September 16, 2011

1. INTRODUCTION

This paper was prepared for the Bay Area Clean Water Agencies (BACWA), a joint powers agency whose members collectively provide municipal sanitary services to more than seven million people in the San Francisco Bay Area. BACWA's mission is to provide an effective voice for its members' role as stewards of the San Francisco Bay environment through leadership, science, and advocacy. One of BACWA's goals is to ensure that environmental regulations and policies reflect the best available scientific, technical and economic information and that these regulations and policies balance environmental, social, and economic sustainability.

Long-term water quality monitoring indicates that many portions of San Francisco Bay have experienced marked increases in chlorophyll-a, a pigment found in all green plants including phytoplankton. The exact causes of this change are unknown, but may include changes in light regimes, changes in ecosystem function resulting from invasive species, and coastal influences. Often the availability of nitrogen is the factor that limits phytoplankton growth in estuaries. However, San Francisco Bay ambient nutrient concentrations are relatively high, and have not changed significantly in recent years. While Bay nutrient concentrations are on par with those of other nutrient-impaired estuaries, such as the Chesapeake Bay, the San Francisco Bay has typically been considered resilient to the effects of nutrient loads and has not experienced similar water quality impairment. Concern exists, however, that changes in factors other than nutrient concentrations may lead to nutrient-related impairment.

As sources of nitrogen and phosphorous – the natural end products of wastewater treatment – BACWA member agencies recognize that, should current trends continue, they will play a key role in efforts to reduce nutrient loading. Before undertaking potentially substantial investments to reduce nutrient loading, BACWA agencies have an obligation to their ratepayers to ensure that these investments are necessary to improve water quality, and will not have other unintended environmental impacts. BACWA has engaged consultant assistance to support the development of technical information to determine whether nutrients are impairing the estuary. While this question has not yet been answered, BACWA is also developing a framework for protecting the Bay in an informed way.

BACWA's objective with respect to nutrients is to support the development of scientifically based regulations that will result in water quality improvements while balancing environmental and economic objectives. To this end, BACWA is developing information on the technical aspects of nutrient management as well as potential future regulatory framework. While BACWA's priority is to understand the estuary sufficiently to know whether nutrients are causing impairment, information is also being developed to support regulatory strategy development, should it be needed.

This modeling topic paper is the first in a series of three topic papers. All three topic papers are scheduled to be reviewed and completed in October 2011. Descriptions of the other two remaining topic papers are provided below:

- Impacts of Potential Wastewater Treatment Plant Upgrades: Describe to BACWA member agencies the implications of transitioning from secondary to nutrient removal treatment. In particular, this topic paper (1) describes a range of facility requirements and the potential impact on POTW operations, (2) presents a basis for a range of unit costs, and (3) addresses the unintended consequences related to the conversion from secondary to nutrient removal treatment.

- Regulatory Framework: This topic paper will characterize the unique challenges posed by nutrient management regulatory requirements for municipal dischargers and to outline appropriate discharge permitting structures for practical, technically achievable, and affordable compliance.

1.1 Purpose

The purpose of this topic paper is to initiate the development of a BACWA model development framework, which may be presented to the State Water Resources Control Board (SWRCB) and the San Francisco Regional Water Quality Control Board (RWQCB) as a potential methodology for developing the "cause and effect" model required by the Numerical Nutrient Endpoint Project.

1.2 Background

The United States Environmental Protection Agency (USEPA) has delegated authority of implementing the Clean Water Act in California to the California State Water Resources Control Board (SWRCB). In turn the SWRCB has worked with Regional Water Quality Control Boards (RWQCB) to develop water quality objectives, which are used to assess the condition of the State's water bodies, for regional basin plans as well as SWRCB statewide plans. Towards that end, the SWRCB and RWQCBs are developing a conceptual approach to nutrient water quality objectives, using a nutrient numeric endpoint (NNE) framework. The NNE framework is based on the concept that biological response variables or indicators are better suited to evaluating beneficial use impairment rather than using pre-defined nutrient concentrations. The NNE approach permits a weight of evidence approach with multiple indicators rather than just one or two nutrient concentration values alone and thus provides greater scientific validity and defensibility.

The San Francisco Bay RWQCB is working with the SWRCB, the Southern California Coastal Water Research Program (SCCWRP) and the San Francisco Estuary Institute (SFEI) to develop NNEs for the San Francisco Bay (SFB) Estuary. One of the first steps in that process was to provide funding to SFEI to perform a literature review and data gaps analysis. This work has been completed with the issuance of a technical report by SFEI (McKee et al., 2011) detailing their findings. A key recommendation of the report was the need to develop load-response models that can simulate the ecological response of the Bay to nutrients and other important co-factors.

2. UTILITY OF MODELS

Besides the McKee et al. (2011) recommendation for the development of a load-response model (and the necessary research and data collection necessary to support its development) for use in the NNE process, a nutrient based eutrophication model of SFB could help water quality and natural resource managers better understand and respond to nutrient-related hypotheses and questions being posed by bay scientists and academics and/or environmental groups. For example, at the recent Regional Monitoring Program (RMP) workshop on nutrient science and management in San Francisco Bay held on June 29, Jim Cloern presented an analysis of long-term trends in SFB water quality, which indicated that over the past 25-30 years, there has been a 32% increase in chlorophyll-a in the Suisun Bay portion of north SFB, a 72% increase in San Pablo Bay and a 105% increase in annual chlorophyll-a in south SFB. South SFB has also seen a 213% increase in June-October chlorophyll-a levels and a 4% decline in bottom DO. Jim Cloern closed his presentation with a slide showing an analysis of the long-term trend in chlorophyll-a in South San Francisco Bay and projecting future conditions (Figure 1) and asked the question, "Will San Francisco Bay's water quality become impaired by nutrients?" A nutrient-based water quality model of SFB may help to answer this question.

It is important to remember, however, that the SFB Estuary has been and continues to be an estuary in a state of flux. This is particularly true when it comes to salinity-induced changes in benthic filter feeders in Suisun Bay, which may have contributed to the low levels of phytoplankton during the 1976-1977 drought (Nichols, 1985); the invasive clam *Potamocorbula amurensis* in San Pablo and Suisun Bay (Alpine and Cloern, 1992), which appear to contribute to reduced phytoplankton biomass in north SFB, and more recently invasive predators that have reduced suspension feeding bivalves in south SFB (Cloern et al., 2006). Therefore, it may be unreasonable to assume that a single water quality model framework would be able to directly address water quality issues in SFB that are perturbed by random changes in ecosystem function and trophic structure (i.e., invasive species). A model could be constructed, however, that would be able to answer, at least in a relative sense, "What if?" questions. For example:

- Can the water quality model, using the 35% reduction in light attenuation that has resulted from the 22% reduction in suspended sediments explain the 32% increase in chlorophyll-a reported by Cloern (2011)?
- What will future phytoplankton levels in south SFB be if turbidity decreases another ten percent over the next five years and all else remains the same?
- What will future phytoplankton levels in south SFB be if benthic filter feeders decline another ten percent over the next five years and all else remains the same?
- If turbidity decreases ten percent and benthic filter feeders decline ten percent over the next five years, how much would point source loads of nitrogen need to be reduced to maintain current levels of phytoplankton biomass?
- How might future reductions in algal growth due to the implementation of nutrient reduction management efforts in south SFB affect light availability for submerged aquatic vegetation (SAV)?

Once such a model is constructed it can also be used as the cause-effect ecosystem model recommended by the authors of the NNE literature review and data gaps analysis, as well as a tool that would permit local water quality and natural resource managers to judge the efficacy of various management scenarios.

The use of mathematical models and their utility to addressing environmental problems is not new. Beginning with the seminal work of Streeter and Phelps (1925) and Velz (1939), mathematical modeling has long been utilized to analyze potential environmental outcomes. These early models were developed for streams and provided a framework for evaluating the oxidation of organic matter, mainly organic carbon, and its impact on dissolved oxygen. The models included inputs of point sources and recognized the importance of benthic oxygen demand and photosynthetic oxygen production. These models were expanded in the late 1950's and 1960's to include a theoretical basis for reaeration (O'Connor and Dobbins, 1958) and extension to estuaries (O'Connor, 1962) and time-variable applications (O'Connor, 1967). Subsequent model developments expanded from biological oxygen demand-dissolved oxygen (BOD-DO) to include nutrients, phytoplankton and dissolved oxygen (DiToro et al. 1971, 1973, Thomann et al., 1974, 1975, Thomann and Fitzpatrick, 1982).

Water quality models are generally based on and have been used to understand cause and effect relationships, i.e., oxidation of organic matter and resulting drawdown of dissolved oxygen concentrations; inter-relationships between nutrients, primary production, phytoplankton biomass, and dissolved oxygen; and the deposition of organic matter to the sediment bed, its subsequent decomposition or diagenesis and the flux of resulting end-products back to the overlying water column.

Water quality models have continued to evolve, adding new state-variables and processes (refined algal growth models (Laws and Chalup, 1990, Los et al., 2008), sediment nutrient diagenesis and flux (DiToro and Fitzpatrick, 1993) and suspension feeder bivalves (Meyers et al., 2000)) and increasing spatial resolution (Cerco, 1995, Cerco, 2000). This evolutionary process has been driven by both advances in research science and recognition that additional processes need to be incorporated in models in order to provide a better calibration/validation of the model outputs to observed data. The needs of the latter have also been used to focus additional data collection and monitoring (e.g., forms of organic matter, attention to nutrient concentrations at the coastal or oceanic boundaries of estuaries, sediment oxygen demand, nutrient flux and denitrification rates, etc.) and research efforts (filtration and assimilation rates of benthic filter feeders (ex., Werner and Hollibaugh, 1993), pH-enhanced release of phosphorus from the sediment bed (Seitzinger, 1991)).

Water quality models have also been used by water quality and natural resource managers as a tool to define the impacts of various pollutant sources (point vs. nonpoint), to assess required levels of pollutant control (i.e., total maximum daily loads or TMDLs), to evaluate planning alternatives for water quality management, including nutrient trading programs, and to assess future water quality conditions and how long it may take for a waterbody to reach a new equilibrium after a management action is implemented.

McKee et al. (2011) identified the need for development of models that link response indicators to nutrient loads or "load-response" models for San Francisco Bay. McKee et al. stated that two general categories of models be developed: (1) air, oceanic and watershed loading model(s), which estimate the amount of nutrients and sediment reaching the SF Bay estuary and where they originate, and (2) an estuary water quality model, which would simulate the ecosystem response to nutrient loads and other management controls. The latter model would be a system-wide dynamic simulation that would predict phytoplankton biomass/community response to nutrients and management controls. Further McKee et al. recommend that the development of a complex system-wide ecosystem model should follow the testing out of key concepts, processes and assumptions in smaller, simpler models.

3. MODELING FRAMEWORK FOR SAN FRANCISCO BAY

3.1 Conceptual model

The first step in the development of a "cause and effect" water quality model for San Francisco Bay should be the development of a conceptual model (CM) of the Bay. Generally CMs have been developed for contaminated waste sites and via a series of diagrams, figures and narrative text express the inter-relationships between contaminants and the physical, chemical, and biological processes that transport contaminants from sources to receptors. However, a nutrient-based CM should also be considered for San Francisco Bay (SFB). It is recommended that a regional workshop be conducted that invites Bay-area scientists, regulatory agencies and stakeholders that would look to develop a consensus CM for the SFB system. With that in mind, this paper presents a nutrient-eutrophication "strawman" CM, as well as a modeling "strawman", for the Bay, which is based on historical and current information available in the scientific literature, that might help facilitate discussions at the regional workshop.

Although under optimum conditions (temperature, light, residence time, and zero predation) algal growth rates can be as high as 1-2 doublings per day, conditions for algal growth in the natural environment are seldom at optimal conditions. Reasons for the non-optimal conditions have to do with seasonal variations in:

- temperature, which affects algal growth and respiration rates,
- background suspended solids and dissolved organic matter, which contribute to turbidity,
- high rates of freshwater inflow and weak or non-stratified conditions, which affect either residence time in the estuary itself or residence time in the photic zone (i.e., surface waters) of the water column, and
- both pelagic (zooplankton) and benthic (bivalve suspension feeders) grazers, which consume phytoplankton biomass.

In the past, the SFB system has not appeared to support a level of algal biomass commensurate with observed levels of available nutrients (Cloern, 1982, Alpine and Cloern, 1988). The reasons for the low levels of algal biomass in various regions of the SFB estuary were hypothesized to be related to light-limitation or turbidity in north SFB (Cole and Cloern, 1984, Cloern, 1987), grazing by benthic filter feeders in south SFB (Cloern, 1982) and low residence time due to either freshwater inflows in north SFB (Cloern et al., 1985) and strong vertical mixing by tides in south SFB (Cloern, 1991). Recent data analysis, however, suggest that the SFB system may be changing. Cloern et al. (2006) documented a regime shift from 1999-2005 wherein the following were observed: larger spring algal blooms, unusual blooms during other seasons, and an increase in the annual baseline minimum chlorophyll-a. These changes have been hypothesized (Cloern et al., 2006) to be related to reductions in sediment inputs, which have resulted increases in water column transparency and light availability, reductions in benthic filter feeder biomass due to predation by bottom feeding flatfishes, and potentially due to import from the Pacific Ocean during coastal upwelling events.

In the SFB system, besides the transport of nutrients and phytoplankton biomass within the system, freshwater inputs and estuarine circulation also have a direct effect on the growth of phytoplankton. This is due to their combined effect on residence time. Jassby (2005) showed the importance of the San Joaquin River discharge on chlorophyll-a concentrations in the San Joaquin River at Vernalis and Mossdale. He noted that chlorophyll-a levels are lower at higher discharges or flows because phytopankton are flushed out of the system faster than they can grow. At low flows with longer residence times phytoplankton can accumulate within the river because their growth rates are now greater than the flushing rates and, therefore, chlorophyll-a levels are able to increase.

Freshwater inflows and estuarine circulation also affect vertical mixing, which in turn can influence phytoplankton growth. Cloern (1991) demonstrated, from both data analysis and a simple one-dimensional (1-D) vertical model of phytoplankton growth versus vertical turbulence, the importance of vertical stratification and, therefore, residence time on phytoplankton biomass in south SFB. Huzzey et al. (1990) also noted the importance of residence time to bloom development in south SFB, wherein they measured three periods of significant biomass accumulation over the northeast shoal in south SFB. They noted that the end of each bloom episode coincided with the occurrence of a large lateral (shoal-to-channel) flow event. When the residence time was long in the northeast shoal a large bloom was able to develop, until the lateral flow event flushed the region.

Besides freshwater and estuarine circulation that transport nutrients and phytoplankton biomass and that influence phytoplankton growth by affecting residence time, there are other physical, chemical, and biological processes that affect nutrients, phytoplankton and dissolved oxygen within SFB. Numerous researchers have investigated and reported on these processes over the past several decades in an effort to explain the relatively low levels of phytoplankton biomass and primary productivity within the SFB system (Cloern, 1982, Cole and Cloern, 1984, Cloern et al., 1985, Cloern, 1987, Alpine and Cloern, 1988, Cloern, 1991), as well as to explain historical and recent changes in phytoplankton biomass and primary productivity in the SFB system (Cloern et al, 2006, Cloern et al, 2007). Based on a review of this and other literature, it appears that the following processes are influencing phytoplankton biomass within the SFB system:

- Turbidity or light-availibility – related to suspended solids transported in the estuary from the Sacramento and San Joaquin Rivers as well as due to tidal and wind-induced resuspension of bottom sediments,
- Losses due to filtration – related to benthic filter feeders, including native and invasive species, such as *Potamorcorbula amurensis*, and
- Recent reductions in benthic filter feeders and zooplankton – related to high fish predation and new invasive species.

Therefore, the proposed CM model for SFB should include, at a minimum, the following environmental forcings and physical, chemical, and biological processes: freshwater inflows and associated nutrient loadings; estuarine circulation; phytoplankton growth and respiration as affected by temperature, light availability and nutrients; suspended solids, since they strongly influence light availability for phytoplankton growth; and phytoplankton grazing losses due to zooplantkon and benthic filter feeders. While in the past nutrient availability and nutrient cycling may not have been important to understanding phytoplankton dynamics within the bay, since light limitation had a greater impact on phytoplankton growth, both should be part of the CM. The reason for including nutrient cycling is that it can be used to help develop a total nitrogen balance for the bay, which may be important in future efforts to develop waste load allocations, should such efforts become necessary with the development of the NNEs.

3.2 Modeling Components

Based on the above CM, the first component of the modeling strawman or modeling framework (Figure 2) is a hydrodynamic model. It is important to have a hydrodynamic model not only to compute the movement and transport of nutrients and phytoplankton biomass, but also to reliably predict estuarine circulation, including the physical effects of winds and tidal mixing on vertical stratification and lateral transport between the intra-tidal flats and the deep channels of the SFB system. Computation of estuarine circulation, including vertical stratification and lateral transport, is important to the computation of residence time and, therefore, to the computation of phytoplankton productivity and dissolved oxygen. A number of hydrodynamic models have been constructed for the Bay and will be discussed later in this paper.

The second component of the modeling strawman is the water quality model. The water quality model is potentially comprised of three submodels (Figure 2): a nutrient-based water column eutrophication submodel; a sediment diagenesis and nutrient flux submodel; and a suspension feeder submodel. The eutrophication submodel should include state-variables for nutrients, phytoplankton, and dissolved oxygen and should include processes that affect phytoplankton growth, such as temperature, light, and available nutrients, as well as the effects of suspended solids on light, and the effects of zooplankton and benthic filter feeders on net phytoplankton growth. The latter (zooplankton/benthic filter feeders) could be accomplished either by directly including these processes as state-variables in the model or via spatially - and time-varying loss rates based on site-specific data analysis and the literature.

Modern eutrophication models (e.g., Chesapeake Bay, Long Island Sound, New York Bight, Massachusetts and Cape Cod Bays, etc.) include various nutrient state-variables (organic and inorganic and dissolved and particulate forms of nitrogen, phosphorus and silica) and processes or kinetics that describe the relationships between phytoplankton and nutrients and nutrient recycling (i.e., nutrient uptake by phytoplankton, nutrient regeneration resulting from algal death and grazing by zooplanton and benthic filter feeders, and nutrient cycling resulting from hydrolysis and mineralization). These models also include a sediment nutrient diagenesis/flux sub-model (or sediment flux model – SFM) to account for the deposition of phytoplankton biomass and detrital organic matter, its diagenesis or decomposition in the sediment bed, and the flux of resulting end-products back to the overlying water column. The SFM framework also accounts for the loss of nitrogen from a system via sediment nitrification/denitrification ($NH_4 \rightarrow NO_3 \rightarrow N_2$ (gas)). Seitzinger (1988) has estimated that sediment denitification can account for the loss of 15-70% of the nitrogen input to an estuary. HydroQual (2000), in a system-wide mass balance for the Massachusetts Bays system found that denitrification accounted for about a 50% loss of nitrogen delivered to the sediment bed and about 13% of the annual inorganic nitrogen delivered to the Bays from coastal input from the Gulf of Maine, POTWs and atmospheric deposition.

Only a few of today's eutrophication models (Chesapeake Bay and Jamaica Bay) actually include state-variables for zooplankton and suspension feeders. Most other models parameterize the effects of zooplankton or benthic grazing by specifying spatially- and time-varying loss rates based on literature and data analysis. While utlimately, it may be desireable to include a state-variable based suspension feeder bivavle model in the water quality model, as a first step in the model development process, it is recommended that only zooplankton state-variable be included and that the suspension feeders be represented by spatially - and time-varying loss rates based upon the available data and literature information. This in part due to the fact that the SFB benthic community has been strongly influenced by invasive species (both the native suspension feeder population that has been replaced by invasive suspension feeder communities, as well as predatory invasive species that have fed on native and invasive suspension feeders and reduced suspension feeder biomass). Building this somewhat stochastic process into a deterministic modeling framework would be very challenging at best and pehaps beyond the state-of-the-science.

The proposed nutrient-based eutrophication model for SFB is shown in Figure 3 and contains state-variables and kinetic processes that include phytoplankton biomass as carbon (C) and chlorophyll-a, zooplankton biomass, various forms of organic and inorganic nutrients (nitrogen (N), phosphorus (P) and silica (Si)), detrital organic carbon, dissolved oxygen (DO), and suspended sediments. Processes include nutrient uptake by phytoplankton and nutrient losses via respiration, death and grazing by zooplankton and benthic filter feeders. Other processes include nutrient recycling (hydrolysis and mineralization), oxidation of organic carbon, atmospheric reaeration, effects of suspended solids and dissolved organic matter on light-attenuation. The SFM is also included in the eutrophication model framework.

It is important to note, that the proposed eutrophication model is not meant to capture HAB (Harmful Algal Blooms) phytoplankton blooms. With the exception of a few well understood and regional HABs (ex., *Alexandrium fundyense* in the Gulf of Maine (McGillicuddy et al., 2005) and cyanobacterial blooms in the Black Sea (Roiha et al. (2010)) modeling of the development and spread of HAB blooms is generally beyond the state-of-the-science. In addition, as suggested by Cloern et al. (2005), the dinoflagellate bloom that occurred in September, 2004, while perhaps intensified in SFB by local climatic and physical conditions, may have been seeded by high dinoflagellate biomass in the coastal waters off SFB. Therefore, it would be necessary to develop large-scale coastal hydrodynamic and eutrophication/HAB models in order to set boundary conditions (or seed concentrations) for SFB. Instead, it may be more feasible to investigate the use of linked deterministic-empirical models for SFB. For example, Lane et al. (2009) developed a logistic regression model for the prediction of toxigenic *Pseudo-nitzcshia* blooms in Monterey Bay. The logistic model considered chlorophyll-a, silicate, and season-specific temperature, upwelling index, river discharge, and/or nitrate. Predictive power for bloom cases was shown to be > 75%. Similarly, Anderson et al. (2010) used a logistic Generalized Linear Model for the prediction of toxigenic *Pseudo-nitzcshia* blooms in Chesapeake Bay. Small-threshold blooms (≥10cells/mL) were explained by time of year, location, and variability in surface values of phosphate, temperature, nitrate plus nitrite, and freshwater discharge. Medium- (100 cells/mL) to large threshold (1000 cells/mL) blooms were further explained by salinity, silicic acid, dissolved organic carbon, and light attenuation (Secchi) depth. If similar logistic relationships could be developed for SFB, then the proposed water quality model could be used to compute the concentrations of the environmental variables that go into the logistic model, which in turn could estimate potential HAB biomass or risk of HAB blooms.

Besides developing logicistic models for HAB prediction, logistic models or other forms of regression model might also be developed for estimating SAV. For example, Kemp et al. (2000) used logistic and classification and regression tree (CART) models to explore relationships between SAV and water quality in Chesapeake Bay. They found that salinity zone-specific models were most successful in predicting the presence of SAV in shallow waters areas as related to water quality in adjacent main channel water quality stations. These models indentified total suspended solids (TSS) as the most important variable in low salinity areas, TSS and chlorophyll-a as most important in mesohaline areas and dissolved inorganic nitrogen as most important in higher salinity areas. Again if similar regression models can be developed for SFB, then the proposed water quality model could be used to compute the concentrations of the environmental variables that go into the regression models, which in turn could estimate potential increases in SAV biomass and/or areas of potential SAV recovery.

3.3 Data Requirements

The development of a scientifically defensible model, be it a hydrodynamic model, water quality model, or ecosystem model requires a substantial investment in the collection and analysis of field and laboratory data with which to calibrate and validate the model. Ideally, the data sets to be used for model calibration and validation should span a number of years that encompass varying environmental conditions (e.g., average, wet and dry freshwater inflows). Calibrating and validating a model against varying environmental conditions provides confidence in the robustness or skill of the model and provides greater confidence in model projections of future conditions in response to management actions.

The data requirements to parameterize and calibrate/validate the proposed modeling system for SFB are substantial. For the hydrodynamic model the data requirements include:

Model Forcings

- Estimates of freshwater inputs: riverine (Sacramento and San Joaquin), POTW and industrial discharge rates, stormwater runoff, precipitation
- Meteorological: solar radiation, air temperature, relative humidity, barometric pressure, winds, etc.
- Boundary tides or water elevations, salinity and temperature

Model Calibration/Validation

- Water levels – tide gauges
- Salinity and temperature – longtitudinal and vertical casts
- Current speed and direction – Acoustic Doppler Current Profilers (ADCPs)

Most of these data can be obtained from continuous recorders. Data records should be from several weeks to several months in duration and should capture high and low flow events.

The data requirements for the water quality model are more extensive in terms of the types of data needed for both model inputs, parameterization and calibration/validation and include:

Model Inputs:

- Transport fields (advection and dispersion) – provided by the hydrodyanmic model
- Nutrient loading estimates: riverine, oceanic exchange, POTW and industrial effluent, stormwater runoff, agricultural runoff, and atmospheric inputs for various nutrient forms
- Suspended solids loading estimates: riverine, oceanic exchange, POTW and industrial effluent, stormwater runoff, and agricultural runoff
- Solar radiation, fraction of daylight, winds
- Grazing rates: depending upon whether zooplankton and benthic filter feeders are state-variables or not – spatially and time-varying rates of grazing or filtration rates

Model Parameterization and Calibration/Validation

- Water column concentrations of phytoplankton biomass (chlorophyll-a) and species composition, nutrients (N, P, Si, C) and various nutrient forms, DO and suspended solids
- Measures of primary production and community respiration
- Light attenuation or extinction coefficients – turbidity or secchi depth
- Sediment oxygen demand and nutrient flux, including rates of denitrification
- Sediment composition – solid-phase and pore water nutrients
- Zooplankton and benthic filter feeder biomass and species composition.

Generally, these data are collected as discrete samples and for the water column data are monitored on a bi-weekly to monthly basis. Sediment nutrient flux and composition can be monitored on a quarterly to semi-annual basis. Zooplankton should be monitored on a monthly to seasonal basis and benthic biomass on a seasonal or semi-annual to annual basis.

4. REVIEW OF EXISTING MODELS AND DATA FROM SAN FRANCISCO BAY

4.1 Hydrodynamic Models

A number of hydrodynamic models have been constructed for SFB. The oldest of these models was a version of the RMA2, two-dimensional (2-D) time variable finite element model applied by the USACE (Pankow, 1988) to evaluate dredged material disposal. The model extended southward from Benicia and included San Pablo Bay and central and south SFB. The model was subsequently extended upstream to include Suisun Bay by the USACE (Hauck et al., 1990). The next oldest model is the Delta Simulation Model – DSM developed by the California Department of Water Resources (DWR) in the early 1990's (replaced in 1997 by DSM2). It is a 1-D, unsteady, open-channel flow model. Its main focus is on the San Joaquin Delta, but it does include Suisun Bay. The next of the 2-D models of the SFB system was developed by Uncles and Peterson (1995, 1996). The Uncles-Peterson (U-P) model has vertical structure (surface and bottom layers) and the upper terminus of the model is at the confluence of the Sacramento and San Joaquin River and the model extends southward to include south SFB (Figure 4a). The model was calibrated, using surface salinity data from seven stations, for a 22-year period (1967-1988). More recently Lionberger and Schoellhamer (2009) validated the hydrodynamic model for water year 1999 (October 1998-September 1999) and extended the model to include a sediment transport submodel and performed a calibration using data from water year 1999. Other 2-D models include MIKE-21, developed by the Danish Hydraulics Institute and applied by URS (2007) for the Brake Pad Partnership to evaluate the fate and transport of copper from brake pad wear debris in SFB (Figure 4b). Recently the DWR, the University of California-Berkley and the Lawrence Berkeley National Lab has been working on a 2-D adaptive mesh model of SFB and the Western Delta. Unlike the U-P model, the MIKE-21 and REALM models do not have vertical structure.

A number of three-dimensional (3-D) models of the Bay have also been constructed. These 3-D models include:

- TRIM/TRIM3D (Figure 5a) – developed by the USGS. The original TRIM model is a structured, depth-averaged (2-D) tidal hydrodynamic model developed by Ralph Cheng (USGS) and Vincenzo Casulli (Trento University, Italy). The model includes south, central and north SFB. A 3-D version of the model was developed and applied to SFB by Gross et al. (2010). Both models have been well calibrated to observed water levels, flow and salinity and temperature data collected by NOAA, DWR and the USGS. The model is proprietary.
- UnTRIM (Figure 5b) – developed by Mac Williams et al. (2007). The UnTRIM Bay-Delta model is an unstructured 3-D hydrodynamic model that extents from the Pacific Ocean through the entire Sacramento-San Joaquin Delta. The model has been well calibrated to observed water levels, flow and salinity and temperature data collected by NOAA, DWR and the USGS. The model is proprietary.
- SUNTANS (Figure 5c) – developed by Stanford University. SUNTANS is an unstructured 3-D hydrodynamic model of the SFB system. The model extends from the Pacific Ocean up to the confluence of the Sacramento-San Joaquin Rivers. The model has been partially calibrated and is open-source (i.e., publically available).
- Delft3D-FLOW (Figure 5d) – developed by Deltares (formally WL | Delft Hydraulics). The USGS and Deltares have been working together to build a 3-D time-variable hydrodynamic/sediment transport/morphological model of the SFB system. The model extends from Point Reyes to Sacramento and Vernalis. The model can run in either 2-D or 3-D mode. Deltares has recently put the FLOW module of Delft3D into the public domain.

One potential concern of the 3-D hydrodynamic models is the lengthy run times associated with some of them. For example, the TRIM3D model runs in 1/10th real time. So to simulate one-year of hydrodynamics would require about one month to simulate. Potentially this could present a problem for running water quality models on the same computational grid, since water quality models generally have 2-4 times as many state-variables and require many more model runs to calibrate and validate.

4.2 Water Quality Models

First, it is important to note that at the present time, there is no coupled hydrodynamic/ nutrient-based eutrophication model of SFB. The most likely reason for this is that, in general, nutrients have not been a factor in limiting phytoplankton growth in the system. Cloern and Dufford (2005) analyzed data for the period 1992 to 2001 and found that nitrogen and silica were limiting only 4% and

1% of the time, respectively, with light limitation occurring 74% of the time. However, a number of researchers studying SFB have also constructed simple analytical, statistical or 1-D mathematical “process” models in an attempt to verify various hypotheses that have been proposed to explain phytoplankton dynamics in SFB. For example, Cloern (1987) used data analysis and analytical solutions to evaluate the effect of turbidity on phytoplankton biomass and productivity in SFB. Subsequently, Cloern (1999) developed a simple index of the relative strength of light vs. nutrient limitation using analytical models that describe growth rate as a function of light and nutrients. This index supported the hypothesis phytoplankton growth in north SFB is light limited; similarly phytoplankton growth in south SFB is largely light limited but there are a few occasions during the spring bloom when nutrients become limiting. Cloern (1991) used a 1-D model (phytoplankton biomass, light, zooplankton and benthic grazing, algal sinking and vertical mixing) to demonstrate the importance of the rate of vertical mixing induced by tidal stirring on phytoplankton bloom dynamics. Cloern (1982) also put together a 1-D model (phytoplankton, zooplankton and benthic grazing) that suggested that benthic filter feeders were controlling phytoplankton biomass in south SFB during the summer and fall. More recently, Lucas et al. (2009) used a pseudo-two-dimensional model (two 1-D, vertically resolved water columns – one deep and one shallow) to look at the importance of lateral transport from the productive shallow water shoals can result in the accumulation of phytoplankton biomass in the adjacent deep, unproductive channel.

Lucas et al. (1999) used the depth-averaged TRIM hydrodynamic model of SFB to evaluate transport-related mechanisms affecting phytoplankton biomass accumulation and spatial distribution on a system-wide level. Based on model simulations they concluded that tidal-timescale processes, both physical and biological, can determine whether a bloom will occur. As was the case with most of the 1-D models described in the previous paragraph, nutrients were not included in the 2-D water quality model framework.

Finally Smith and Hollibaugh (2006), using a box model approach, developed water, salt and nutrient budgets for San Francisco Bay for the time period 1990-1995. Due to organic nutrient data limitations, the nutrient budgets were only constructed for dissolved inorganic nitrogen (DIN) and dissolved inorganic phosphorus (DIP). Based on their analysis, they estimated that wastewater treatment plant effluent accounted for approximately 50% of the nutrient loading to the bay during the winter months and about 80% of the summer loading.

4.3 Water Quality Data

There appears to be a reasonable water column water quality data set with which to parameterize and calibrate a nutrient-based eutrophication model of SFB. Kimmerer (2004) provides an excellent overview of the physical, biological and chemical data available for SFB. Long-term monitoring data are generally available and are good for physical data (temperature and chemistry), biological data (phytoplankton, zooplankton, benthos, and fish) and water chemistry (inorganic nutrients and suspended solids). However, Kimmerer reports that there are some major data gaps (microzooplankton, macrobenthos, and benthic microalgae). A significant portion of the available data is available on-line and has been collected by a number of state (DWR, Interagency Ecological Program (IEP), Department of Fish and Wildlife (DFW)) and federal agencies (USGS and NOAA). A few of these programs contain data sets that go back far in time. For example, the USGS data base contains salinity, temperature, chlorophyll-a, suspended sediment, and inorganic nutrient (NH3, NO2, NO3, PO4, and SiO2) data back to 1969 and dissolved oxygen data back to 1971, although there are some gaps in certain years. There are limited measurements of total Kjeldahl nitrogen, dissolved organic nitrogen, total phosphorus in the IEP Bay-Delta monitoring database. A number of references report measurements of primary production in the Bay (Peterson et al., 1975, Cole and Herndon, 1979, Cole and Cloern, 1984,) and model estimates (Caffrey et al., 1998, Jassby et al., 2002, Cloern et al, 2007).

There are also some measurements of sediment nutrient flux and sediment nutrient composition although they are limited in both space and time. The earliest measurements were performed by Hammond et al. (1985) at two stations (one shoal and one channel) in south SFB using in situ flux chambers. They measured sediment oxygen demand (SOD) and fluxes of ammonia and silica, using replicate measurements. Caffey (1995) measured rates of ammonia remineralization, porewater ammonia and solid phase nitrogen and carbon at five sites in south SFB and four in north SFB four times between November 1991 and January 1993. Caffrey et al. (1998) measured weekly benthic respiration at two sites (one shoal and one channel) during the 1996 spring (February-May) algal bloom. Grenz et al. (2000) also reported on weekly benthic SOD and nutrient fluxes of N, P, and Si at two stations in south SFB during the 1996 algal bloom.

A key area where information needed for a water quality modeling of the SFB system is deficient is nutrient loadings. This issue was identified by McKee et al. (2011) in their NNE literature and data gap report. They pointed out "estimates of nutrients loads from external sources and pathways are poorly understood. For the most part, published load estimates are outdated by one or even two decades and were either based on data collection methods that were not designed for loads estimation, were based on assumptions that provided guesses at best or were based on data sets that have now been substantially improved with ongoing collection through time." (McKee et al., 2011). This is an area where BACWA can provide information concerning their effluent flows and concentrations to at least update one source of nutrients to the Bay. Additional efforts will need to be expended to develop reliable nutrient loading estimates from the Sacramento-San Joaquin Delta, stormwater runoff, exchange with the Pacific Ocean and atmospheric loadings directly impinging onto the water of the Bay.

5. COSTS AND LESSONS LEARNED FROM OTHER U.S. ESTUARINE MODELING STUDIES

Before providing site-specific conclusions and recommendations for SFB, a brief overview of monitoring and modeling costs associated with and lessons learned from other estuarine modeling studies in the United States follows:

- **Chesapeake Bay.** Chesapeake Bay is in addition to SFB one of the most monitored estuaries in the United States. It is certainly one of the most modeled estuaries in the United States if not the world. Modern water quality sampling, supported by the USEPA, began in 1985. The number of sampling stations has varied over the years, but the most recent sampling program (Figure 6) includes about 150 stations (mainstem Chesapeake and the James, York, Rappahannock, Potomac, Patuxent, Patapsco, Chester, Choptank, Nanticoke, Wicomico and Pocomke Rivers that are tributary to Chesapeake Bay – see Figure 6). There are 14 annual cruises, which sample phytoplankton, zooplankton, SAV, benthic invertebrates and water chemistry. Sediment oxygen demand and nutrient flux are also sampled at 10 stations four times a year (seasonally). The current program costs about \$3.9 M annually and funding is split 50-50 between the states and federal government. Funding to support watershed and hydrodynamic/ water quality modeling has varied between \$1-2.5 M/year over the years. Currently most of the funding for modeling has been allocated to the watershed model and to run management scenarios with the Bay water quality model. **The Bay water quality model has been used to develop nutrient and sediment TMDLs for the Bay and to assist in the development of a Use Attainability Analysis (UUA) for the Bay**, since there are portions of the Bay that do not meet the most protective of the USEPA dissolved oxygen criteria for marine organisms. Model computations and analysis of sediment cores have shown that this is in part due to the particularly deep thalweg that runs up the center of the Bay. **Given its depth and the vertical stratification that occurs during the summer months, it appears that hypoxia is a natural occurrence in this deeper portion of the Bay.**

- **Long Island Sound.** Summer hypoxia is an annual occurrence in the central and western portion of Long Island Sound. During especially stratified years, there are limited occurrences of anoxia in the extreme western Sound. Currently, the USEPA Long Island Sound Study office provides about $850 K/year in funding to monitor water quality in the Sound. The State of Connecticut also provides some costs sharing funds. The monitoring program includes 47 active stations (Figure 7) and sampling includes phytoplankton, zooplankton and water chemistry. The program was initiated in 1991. The development of a Long Island Sound water quality model was begun in 1988 with a laterally-averaged, 2-D segmentation. Further model improvements and refinements were conducted during the early 1990s with increased spatial resolution and coupling to a 3-D time-variable hydrodynamic model of the Sound. The latest version of the model was funded by the NYC Department of Environmental Protection (NYCDEP) and extends the model domain to include the New York Bight. This was done to move the boundary conditions well away from the area of interest in the Sound as well as to permit the NYCDEP to evaluate management alternatives for its 14 wastewater treatment facilities that discharge into the New York Harbor complex. **The Long Island Sound water quality model was used to develop a nitrogen TMDL for the Sound in 2001. The water quality model has also been used as a tool by managers of POTWs in developing a nutrient trading strategy for the Sound.** The water quality model was also used in a re-assessment of the 2001 nitrogen TMDL that is part of the adaptive management plan incorporated within the 2001 TMDL document.
- **Boston Harbor and the Massachusetts Bays System.** As a result of a court-ordered mandate issued in 1991, the Massachusetts Water Resources Authority (MWRA) initiated the construction of a 1,080 MGD secondary treatment facility and a 15.3 km wastewater effluent outfall from Boston Harbor into northern Massachusetts Bays. As part of the treatment plant and outfall permit, MWRA was required to perform water quality monitoring of Massachusetts and Cape Cod Bays to establish ambient water quality conditions prior to the outfall going on-line. The initial sampling began in 1992 and included 21 near-field (outfall) and 22 far-field monitoring stations (Figure 8). Sampling included phytoplankton, zooplankton, water chemistry (at up to five depths in the vertical) and some measurements of primary production, sediment oxygen demand and nutrient flux. Program expenditures for monitoring were between $2.5-3.5 M. In 1994, MWRA provided funding to develop a hydrodynamic/water quality model of the eutrophication processes in Boston Harbor and the Massachusetts Bays system, in particular, to investigate the potential impacts of the relocated Deer Island facility wastewater on Boston Harbor and Massachusetts and Cape Cod Bays. Initially, the model was calibrated to a 3-years pre-outfall data set. During the calibration effort, the model identified the importance of nutrient input in the Massachusetts Bays system from the Gulf of Maine and led to the modification of the existing monitoring program to include a monitoring station near the northeastern boundary of Massachusetts Bay. **A nitrogen mass balance was also conducted that indicated that approximately 92% of the total nitrogen loading to the Massachusetts Bays system was due to import from the Gulf of Maine and that MWRA only contributed about 3% of the total N loading to the Bays.** A yearly update of the Bays Eutrophication Model, as the water quality model is known, is actually written into the

MWRA permit, as is on-going monitoring. Future costs for monitoring are projected to be ~$1.5 M; this is due to a reduction in the sampling plan to 14 stations, sampled nine times/year. Ongoing modeling efforts are about $100 k/year.

6. CONCLUSIONS AND RECOMMENDATIONS FOR DEVELOPMENT OF A SFB MODELING FRAMEWORK

6.1 Conclusions

A strawman Conceptual Model of the SFB system has been developed. The key features or processes of the CM include: freshwater inflows and associated nutrient loadings; estuarine circulation; phytoplankton growth and respiration as affected by temperature, light availability and nutrients; suspended solids, since suspended solids strongly influence light availability for phytoplankton growth; and phytoplankton grazing losses due to zooplantkon and benthic filter feeders. A strawman modeling framework has also been proposed. The components of the modeling framework include: a hydrodynamic model that can predict advective transport and vertical stratification and a nutrient-based eutrophication model that includes a sediment diagenesis and nutrient flux submodel and potentially a suspension feeder submodel.

A generic monitoring program that provides data to parameterize and caibrate and validate both the hydrodynamic and water quality models has also been outlined. While much of the required data are already being collected by ongoing regional monitoring efforts (ex., the USGS monitoring program, which measures temperature, salinity, chlorophyll-a, suspended solids, extinction coefficient, and nutrients baywide, the CA Department of Fish and Wildlife's zooplankton monitoring program, which includes North SFB but does not include Central and South SFB, and the DWR's benthic monitoring program, which includes North SFB but does not include Central and South SFB), additional data collection and monitoring efforts are required. These will be discussed in the recommendations section below.

6.2 Recommendations

It is believed that sufficient information, data, and scientific analyses are available with which to begin the process of model development, calibration and validation. However, it is also believed that this work should be conducted in a phased approach, starting simple, building on existing knowledge and modeling frameworks and continuing to refine the model framework, both ecosystem-wise and spatially over time as our understanding of the Bay continues to improve and as data gaps are filled with additional monitoring and research efforts.

With respect to additional monitoring and data needs, there are some key data that should be collected before proceeding with actual modeling of the SFB system. Perhaps, the most important of these are:

- the collection of effluent water quality parameters (organic and inorganic nutrient forms and suspended solids). While there are some data available for some of the SFB POTWs, most of the effluent data are limited to measurements of inorganic nitrogen. Sampling should be extended to include organic nitrogen and/or total nitrogen as well as the inorganic forms (NH_4 and NO_2+NO_3). Additional data should include BOD_5 and BOD_u and some limited measurements of total phosphorus and PO_4. These data could be collected on a monthly basis and would likely be an inexpensive part of the total data collection/monitoring program.

- zooplankton and benthic biomass monitoring should be extended to Central and South SFB. Zooplankton data (biomass/species composition) could be collected on a monthly basis, while benthic data (biomass/species composition) could be collected on a seasonal to annual basis and would likely be a moderate portion of the annual monitoring program.
- development of a monitoring program to provide estimates of nutrient and chlorophyll-a inputs from coastal waters. This would require utilization of ADCPs at two to three locations near the mouth of SFB in order to develop estimates of net inflow and outflow between coastal waters and SFB. It would also require vertical measurements of nutrients and chlorophyll-a at the locations of the ADCPs over a tidal cycle several times per year. The combination of both the ADCP and nutrient/chlorophyll-a data would then be analyzed in order to develop temporal estimates and timing (i.e., coastal upwelling events) of nutrient and/or chlorophyll-a loadings to the bay from coastal waters. This is likely to be a moderate to high cost of the monitoring program.
- nutrient and flow data that can be used to estimate nutrient loadings from nonpoint source inputs (e.g., stormwater and watershed sources) and to support development of watershed loading models. These data should be collected over a series of storm events, both large and small. This is likely to be a moderate cost item.

Less important, but still relevant, data collection/monitoring efforts would include seasonal measurements of sediment oxygen demand and nutrient flux at several locations within SFB and some measurements of atmospheric nutrient deposition, both dryfall and wetfall.

The first two steps in the phased modeling approach should be: (1) development of a modern, comprehensive estimate of nutrient loadings entering the SFB estuary (recommended data collection efforts necessary to develop these estimates have been listed above), and (2) convening a Modeling Workshop, which would include SFB and nationally recognized scientists and water quality modelers to develop a CM of the Bay (or to validate the one presented above) and to develop a modeling framework and approach for the Bay.

In order to facilitate discussions at the Modeling Workshop, an initial model framework and approach has been developed and is presented below. It is recommended that this framework and approach be used as a “Modeling Strawman” at the Modeling Workshop.

It is a given that calibrating a eutrophication model requires a large number of iterations. This is largely due to the number of adjustable model coefficients that are incorporated in eutrophication models: phytoplankton growth rates and temperature and light optimums, phytoplankton respiration and sinking rates, Michaelis-Menton constants for nitrogen, phosphorus and silica, zooplankton and benthic filter feeder grazing rates, nutrient mineralization and hydrolysis rates, reaeration rates, suspended solids settling and wind-induced resuspension rates, etc. While, previous work and 1-D process models of SFB that have been reported in the literature may provide some guidance for the choice of algal growth and respiration rates and zooplankton and benthic filter feeder rates, it is likely that model calibration will still require a large number of trial-and-error simulation runs. If one were to utilize a very highly resolved spatial resolution grid of the SFB system, the associated runtimes for the water quality model may significantly lengthen the time required to calibrate the water quality model. Therefore, it seems prudent to start the modeling effort with a fairly simple spatial grid. It is recommended that the Uncle-Peterson (U-P) model and model grid (Figure 4a) be used as the basis for the eutrophication model. The structure of the U-P model, with its ability to represent the SFB shoal and channel areas would allow it to represent the effects of benthic filter feeder grazing (shoals) and potentially the importance of tidally driven stratification and mixing in the deeper channel portions of the eutrophication model. The fact that the U-P model is well calibrated should enable it to be extended to other years of interest or conditions of interest to the water quality modelers. The fact that it has been used for sediment transport calculations is also a benefit, as output from the sediment transport component of the U-P model could be used to help calibrate the suspended solids state-variable in the water quality model that would be used to develop spatially - and time-variable extinction coefficients key to the eutrophication model (used to determine light attenuation).

The framework proposed for the water quality or eutrophication model (Figure 3) includes state-variables for phytoplankton biomass as carbon and chlorophyll-a (potentially multiple groups based on seasonal or nutrient related processes), various forms of nutrients (dissolved organic, particulate organic, and inorganic) N, P, and Si, detrital organic carbon (as detrital carbon and phytoplankton carbon affect dissolved oxygen concentrations), dissolved oxygen, suspended solids and zooplankton and the effects of benthic filter feeders on phytoplankton biomass. While a few existing eutrophication models do include benthic filter feeders as a state-variable, it is recommended that initially they not be included directly as state-variable, but rather be treated as an exogenous variables or forcing function based on observed biomass data and literature-based filtering rates. The proposed model framework could be further simplified by eliminating the phosphorus system. A rationale for this is based on an analysis of SFB inorganic nitrogen, phosphorus and silica data for the period 1992 to 2001 performed by Cloern and Dufford (2005). Their analysis indicated that phosphorus was not a limiting nutrient in SFB, while nitrogen and silica were found to be limiting 4% and 1% of the time, respectively with light limitation occurring 74% of the time. However, as reported by Cloern et al., (2006) turbidity has been decreasing in the SFB system and, therefore, light limitation appears to be decreasing and it is possible that nutrient (nitrogen or silica) limitation may occur in the future on a more frequent basis. A potential reason for leaving the phosphorus system in the model framework concerns the potential adaptation of a uniform modeling framework for SFB and the Sacramento-San Joaquin Delta in the future. It is in the Sacramento-San Joaquin Delta where phosphorus controls may be of interest to water quality managers.

A recommended approach for calibration of the water quality model would be to select two or three recent years with differing hydrologic conditions (i.e., wet, dry and average) and perhaps one or two historical years (perhaps the early to mid-90s) that represent different levels of benthic suspension feeders for model calibration. The reason for recommending this approach is to investigate the ability of the model to differentiate phytoplanton biomass under differing residence times and affects of benthic filter feeders. After completing the loading analysis for these years, the model could be run and output evaluated to see how the model performs spatially (north SFB vs. south SFB) and temporally against observed phytoplankton biomass (chlorophyll-a) and water column concentrations of inorganic nutrients. A calibration for sediment oxygen demand and nutrient flux will be less rigorous due to the paucity of data, but should still be evaluated as part of the overall calibration process. The evalution of the model’s calibration of inorganic nutrients would help provide confidence that the nutrient loading estimates are valid, while the evalution of model calibration of chlorphyll would help provide confidence that the significant processes (light and grazing pressure) that affect phytoplankton biomass (and ultimately dissolved oxygen) are well represented.

Models outputs of phytoplankton biomass, dissolved oxygen, nutrients and light attenuation could be used either directly as recommended primary indicators (phytoplankton, dissolved oxygen) or as secondary indicators (light) or post-processed to provide information to formulate emphirical relationships or logistic regression models between nutrients and indicators/co-factors (e.g., nutrients and chlorophyll-a to ephiphytes and light attenuation to SAV or nutrients to chlorophyll-a and light attenuation and together with water temperature and vertical stratification to risk of HAB bloom) as identified in the NNE literature review and data gaps identification document (McKee et al., 2011).

Once initial calibration efforts are successful, the spatial resolution of the Bay can be improved by moving to the more spatially-refined 3-D hydrodynamic models of SFB. Additional processes or state-variables (benthic filter feeders and/or SAV) can be incorporated into the eutrophication model framework as additional monitoring and field and laboratory studies are completed.

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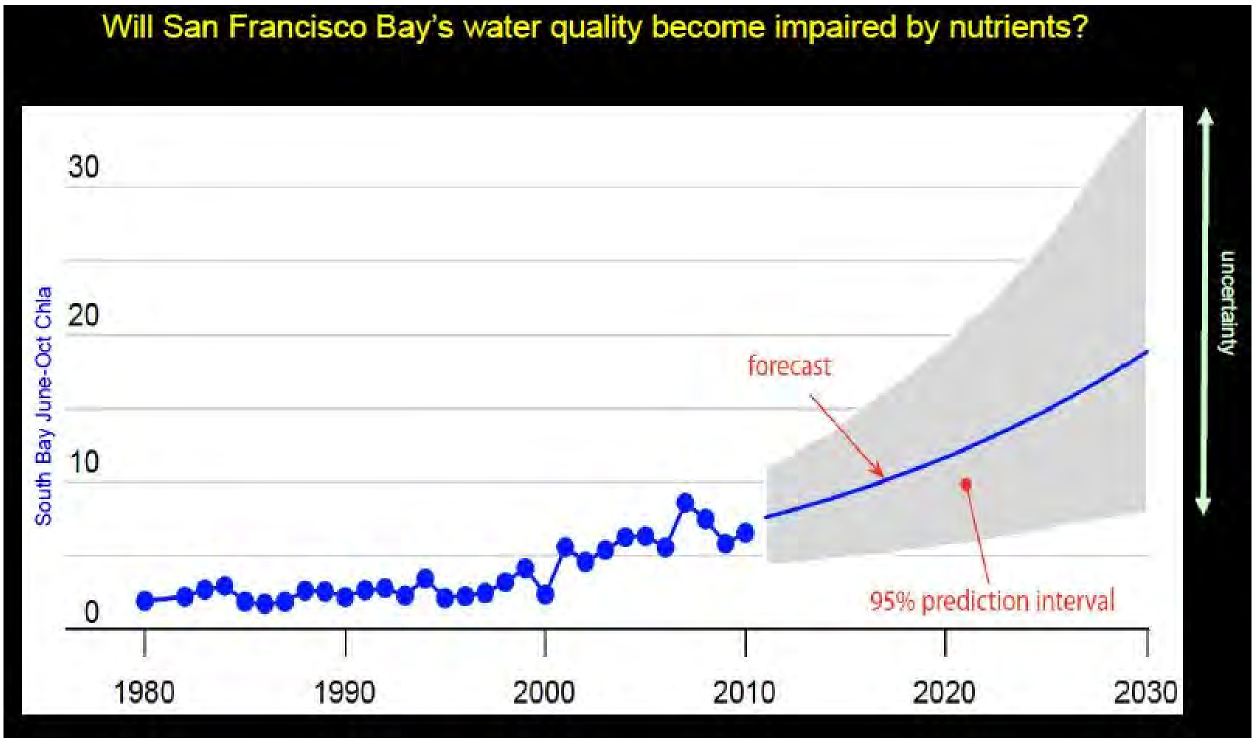


Figure 1. Long-Term Trend in Chlorophyll-a in South San Francisco Bay and Future Trend (from Cloern (2011)

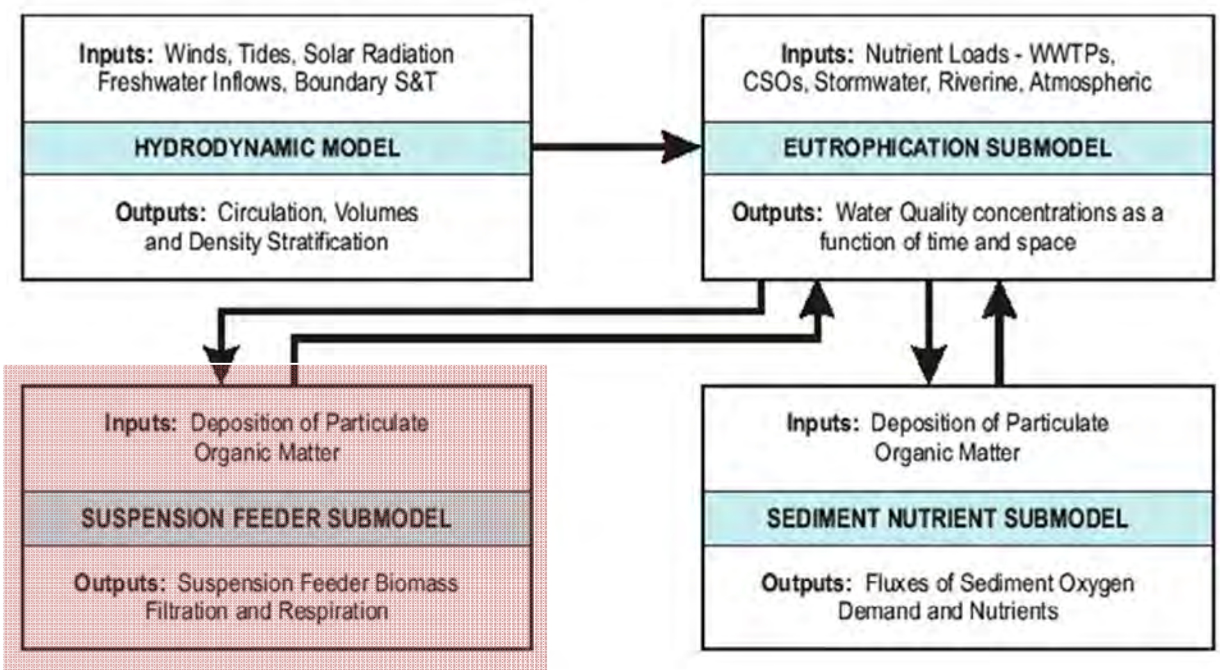


Figure 2. Modeling Framework

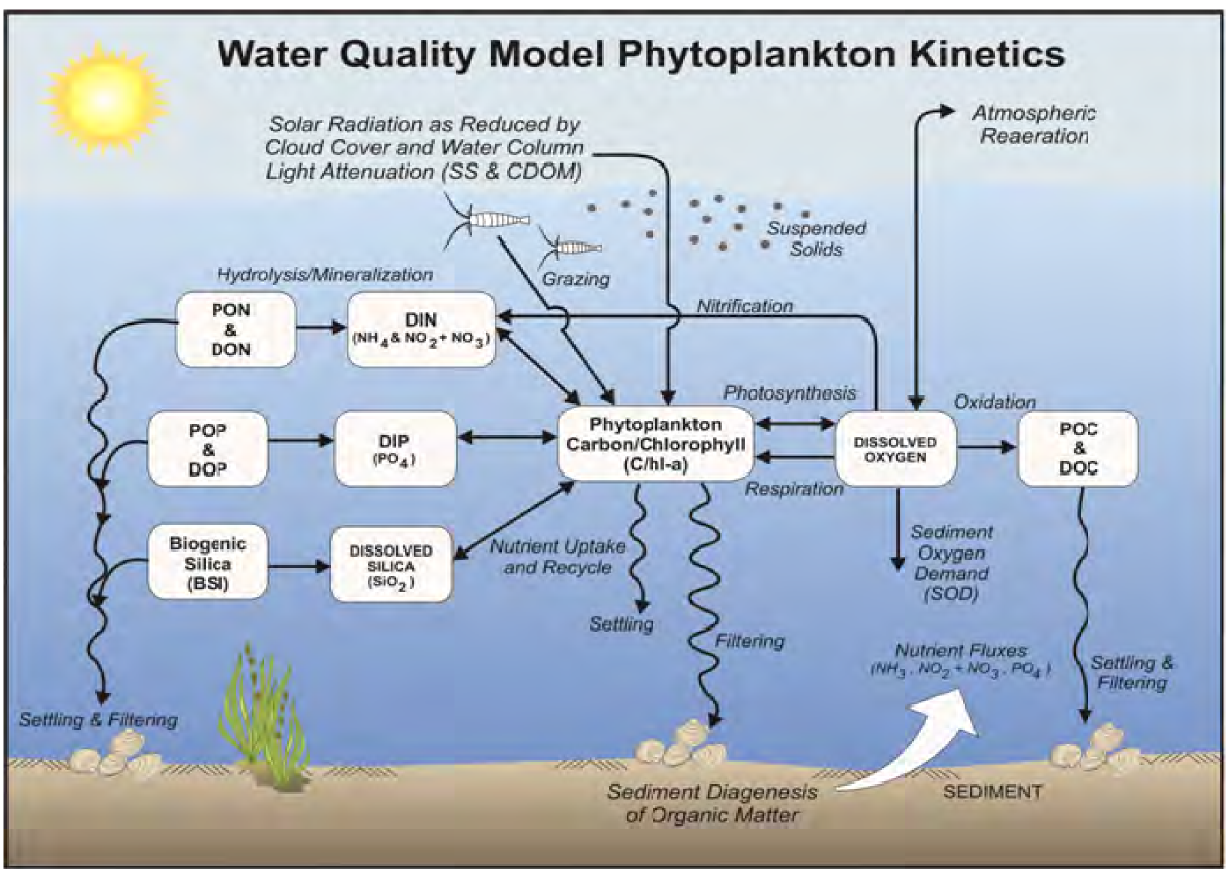
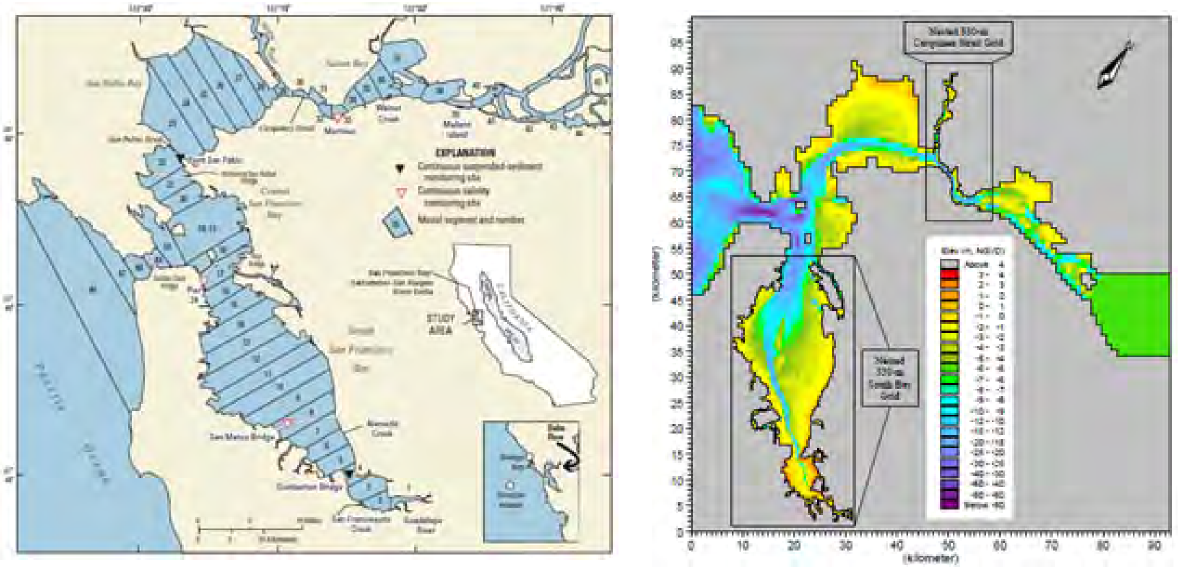
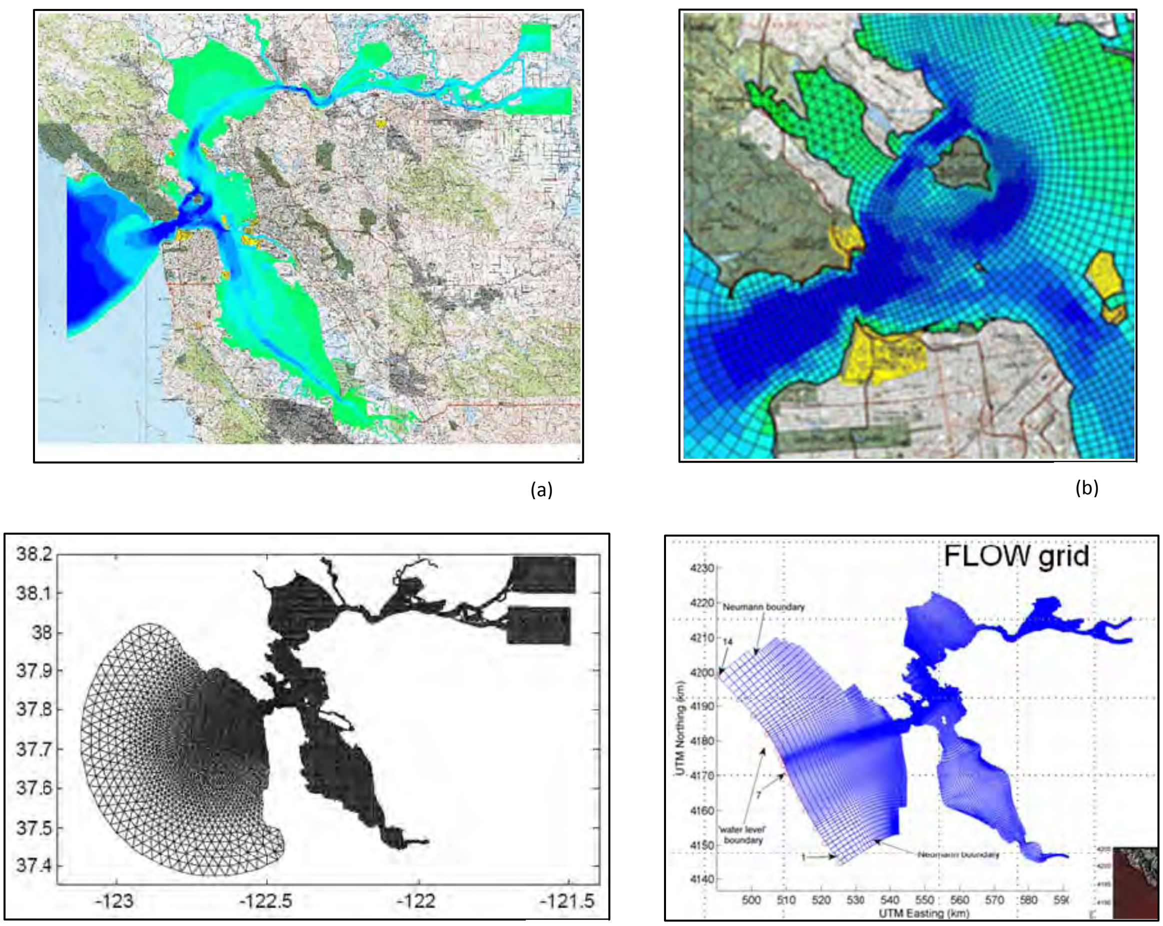


Figure 3. Eutrophication Modeling Framework



(a) (b)

Figure 4. Two-dimensional hydrodynamic models of San Francisco Bay: (a) Uncles-Peterson and (b) Mike-21



(a) (b) (c) (d)

Figure 5. Three-dimensional hydrodynamic models of San Francisco Bay (a) TRIM/TRIM3D, (b) UNTRIM (vicinity of Golden Gate Bridge, (c) SUNTANS, (d) Deltf3D-FLOW.

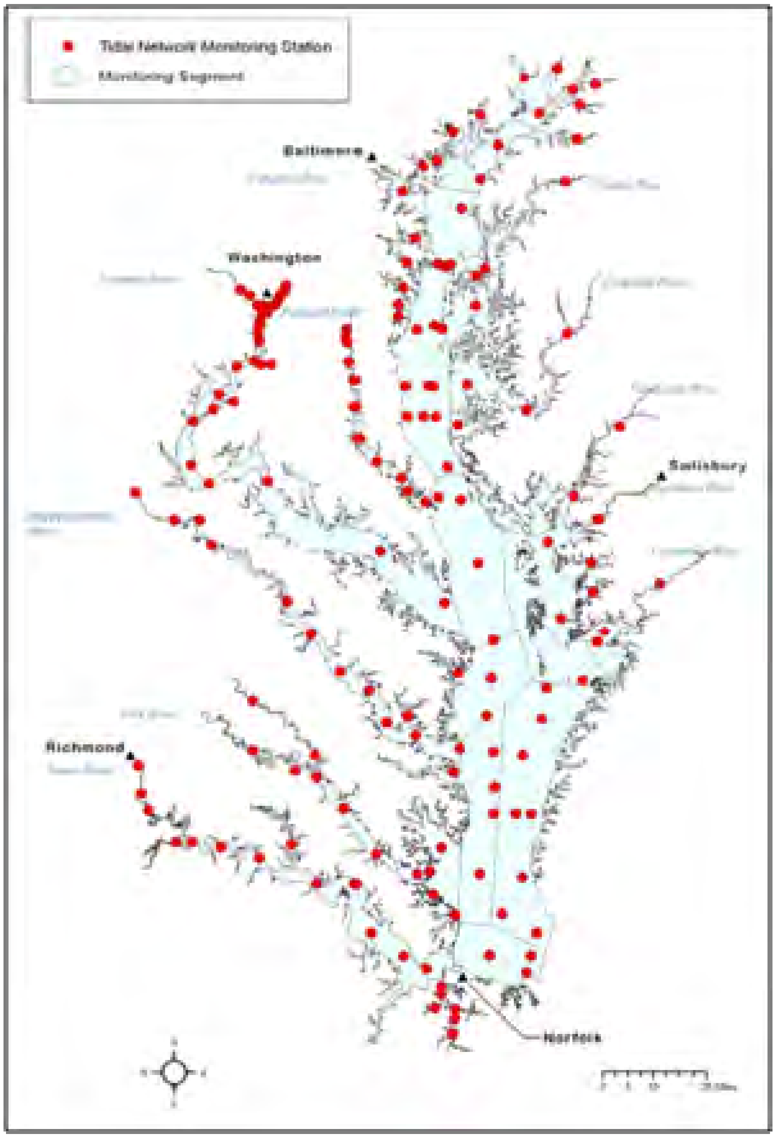


Figure 6. Chesapeake Bay

Figure 7. Long Island Sound

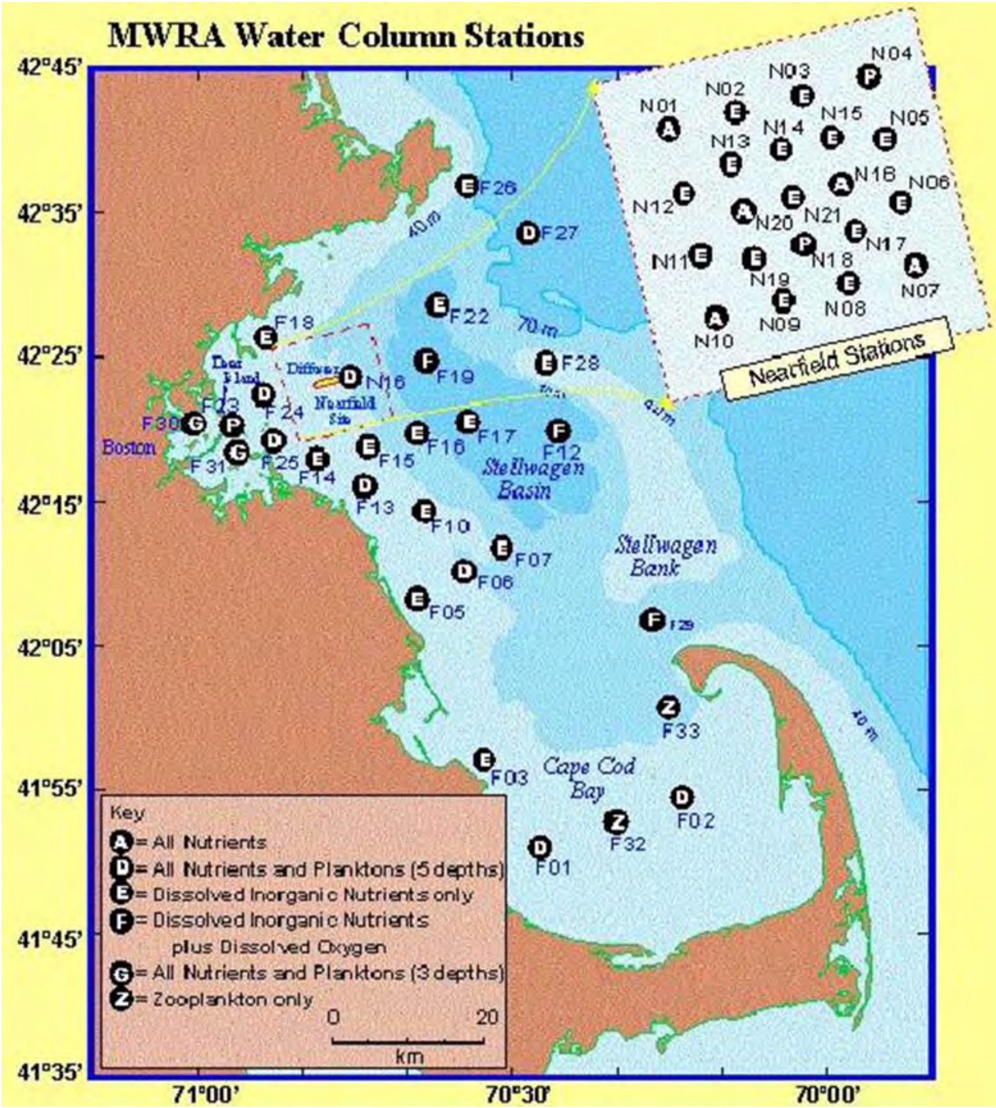


Figure 8. Massachusetts and Cape Cod Bays

Impacts on POTWs Transitioning from Secondary to Nutrient Removal Treatment

Nutrient Strategy Development Project
September 16, 2011

1. INTRODUCTION

This paper was prepared for the Bay Area Clean Water Agencies (BACWA), a joint powers agency whose members collectively provide municipal sanitary services to more than seven million people in the San Francisco Bay Area. BACWA's mission is to provide an effective voice for its members' role as stewards of the San Francisco Bay environment through leadership, science, and advocacy. One of BACWA's goals is to ensure that environmental regulations and policies reflect the best available scientific, technical and economic information and that these regulations and policies balance environmental, social, and economic sustainability.

Long-term water quality monitoring indicates that many portions of San Francisco Bay have experienced marked increases in chlorophyll-a, a pigment found in all green plants including phytoplankton. The exact causes of this change are unknown, but may include changes in light regimes, changes in ecosystem function resulting from invasive species, and coastal influences. Often the availability of nitrogen is the factor that limits phytoplankton growth in estuaries. However, San Francisco Bay ambient nutrient concentrations are relatively high, and have not changed significantly in recent years. While Bay nutrient concentrations are on par with those of other nutrient-impaired estuaries, such as the Chesapeake Bay, the San Francisco Bay has typically been considered resilient to the effects of nutrient loads and has not experienced similar water quality impairment. Concern exists, however, that changes in factors other than nutrient concentrations may lead to nutrient-related impairment.

As sources of nitrogen and phosphorous – the natural end products of wastewater treatment – BACWA member agencies recognize that, should current trends continue, they will play a key role in efforts to reduce nutrient loading. Before undertaking potentially substantial investments to reduce nutrient loading, BACWA agencies have an obligation to their ratepayers to ensure that these investments are necessary to improve water quality, and will not have other unintended environmental impacts. BACWA has engaged consultant assistance to support the development of technical information to determine whether nutrients are impairing the estuary. While this question has not yet been answered, BACWA is also developing a framework for protecting the Bay in an informed way.

BACWA's objective with respect to nutrients is to support the development of scientifically based regulations that will result in water quality improvements while balancing environmental and economic objectives. To this end, BACWA is developing information on the technical aspects of nutrient management as well as potential future regulatory framework. While BACWA's priority is to understand the estuary sufficiently to know whether nutrients are causing impairment, information is also being developed to support regulatory strategy development, should it be needed.

This topic paper is the second in a series of three topic papers. All three topic papers are scheduled to be reviewed and completed in October 2011. Descriptions of the other two topic papers are provided below:

- Modeling: The modeling topic paper presents a conceptual model of the relationships between phytoplankton biomass, nutrients, and physical and biological drivers in the San Francisco Bay (SFB) Estuary. The paper also presents a strawman approach for developing a nutrient based eutrophication model of the SFB Estuary.

- Regulatory Framework: This topic paper will characterize the unique challenges posed by nutrient management regulatory requirements for municipal dischargers and to outline appropriate discharge permitting structures for practical, technically achievable, and affordable compliance.

1.1 Purpose

The purpose of this topic paper is to provide information to BACWA member agencies on the implications of transitioning from secondary to nutrient removal treatment. Furthermore, the topic paper attempts to establish a dialogue with regulators that illustrate the complexity associated with transitioning from secondary to nutrient removal treatment. In particular, this topic paper (1) describes a range of facility requirements and the potential impact on POTW operations, (2) presents a basis for a range of unit costs, and (3) addresses the unintended consequences related to the conversion from secondary to nutrient removal treatment.

1.2 Background

The majority of the BACWA member agency public owned treatment works (POTWs) currently provide secondary treatment. Secondary treatment is a combination of solids and organics removal, followed by disinfection prior to discharge. For some POTWs, a more advanced level of treatment is required for the removal of nutrients, such as nitrogen and in some cases phosphorus. A few BACWA member agencies provide nutrient removal, but most provide secondary treatment to achieve the numerical pollutant limits derived for the San Francisco Bay Basin Plan.

The nutrients of interest include, but are not limited to ammonia, nitrite, nitrate, total nitrogen (TN), phosphate, and total phosphorus (TP). The Regional Monitoring Plan (RMP), Regional Water Quality Control Board (RWQCB), and other stakeholders are focusing on nitrogen species for the San Francisco Bay. The scientific literature suggests that elevated nitrogen loads, not phosphorus, might be negatively impacting the San Francisco Bay. However, phosphorus to nitrogen ratios are a component of algae speciation, so phosphorus is also discussed throughout the paper.

A compilation of typical influent, secondary treatment and various nutrient removal effluent characteristics is provided in Table 1.

Table 1. Annual Average Treatment Level Objectives *

Treatment Location	Ammonia (mg N/L)	Total Kjedahl Nitrogen (ammonia + Org N) (mg N/L)	Nitrite + Nitrate (mg N/L)	Total N (mg N/L)	Total P (mg P/L)
Influent (Raw Sewage)	20-30	30-40	<1	30-40	4-8
Level 1 (Secondary Treatment Effluent)	20-30	25-35	<1	25-35	4-6
Nutrient Removal					
Ammonia Removal	<1	1-3	20-25	20-30	4-6
Level 2 (Conventional TN/TP Removal)	<1	1-3	8-12	10-15	0.5-1
Level 3 (Advanced TN/TP Removal)	<1	1-3	3-6	4-8	0.1 – 0.3
Level 4 (Limit of Technology (not including RO)) **	<1	1-3	<1	<3	<0.1
Level 5 (RO)	<1	<2	<1	<2	<0.02

Notes:

* Regional Monitoring Plan Workshop on June 29, 2011 at David Brower Center, Berkeley, CA and Falk et al. (2011)

** Limit of Technology values from Bott and Parker (2010)

1.2.1 Nitrogen Removal

The removal of nitrogen during wastewater treatment is primarily achieved by (a) assimilation of nitrogen into biomass and (b) biochemical oxidation/reduction processes that convert organic nitrogen and ammonia to nitrogen gas through a two-step process. The two-step process is commonly referred to as nitrification and denitrification. Besides nitrification and denitrification pathways, the anammox step simultaneously removes ammonia and nitrite to form nitrogen gas. The nitrogen cycle, illustrating several nitrogen removal pathways, is presented in Figure 1.

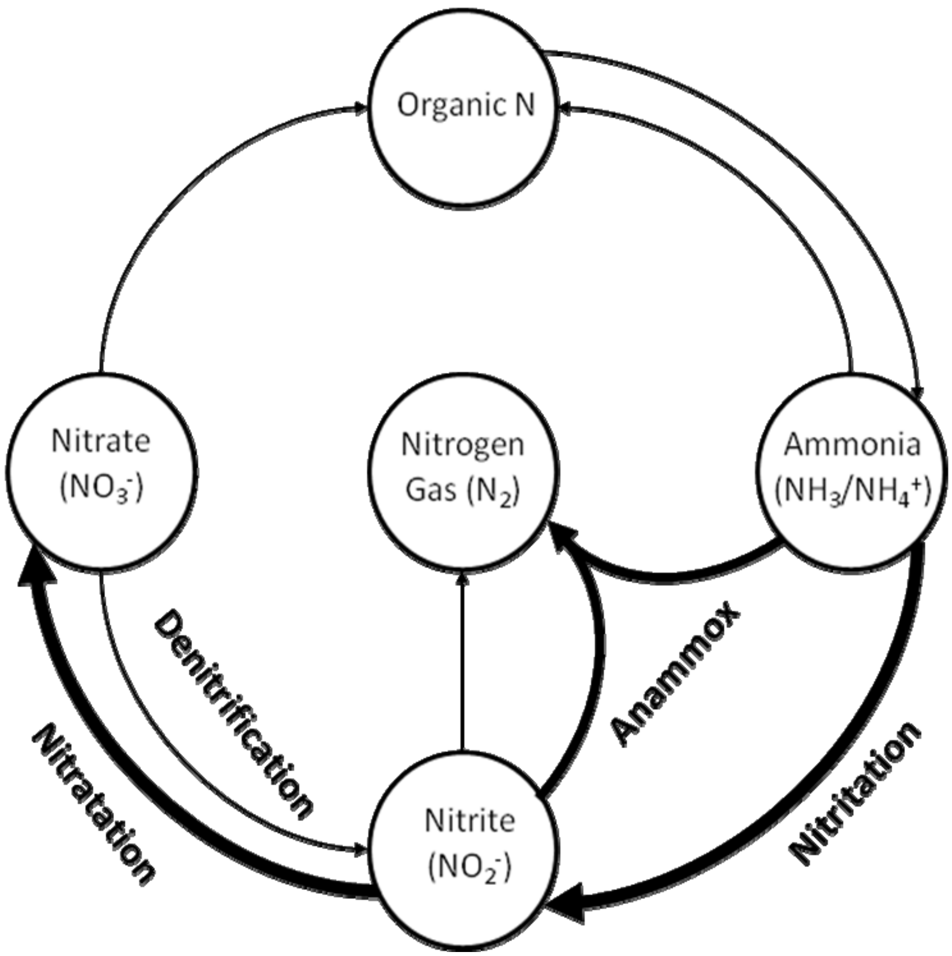


Figure 1. Primary Biological Nitrogen Transformations.

1.2.1.1 Nitrification/Denitrification

Nitrification is a two-step process where ammonia (NH_3/NH_4^+) is first oxidized to nitrite (NO_2^-) (nitritation), followed by nitrite oxidation to nitrate (NO_3^-)(nitratation). The two-step process is carried out by nitrifying organisms and is commonly referred to as nitrification. The overall process stoichiometry is as follows:

$$NH_4^+ + 2O_2 \rightarrow NO_3^- + H_2O + 2H^+ \qquad (1)$$

The nitrate end-point of nitrification can be followed by denitrification if the treatment objective is to remove nitrogen. Denitrification is a biological process where denitrifying bacteria reduce nitrate first to nitrite, followed by subsequent reduction to nitrogen gas. Denitrification requires a carbon source (such as biochemical oxygen demand (BOD)). Overall, the process stoichiometry with methanol as the carbon source is as follows:

$$6NO_3^- + 5CH_3OH + CO_2 \rightarrow 3N_{2(g)} + 6HCO_3^- + 7H_2O \qquad (2)$$

Combined nitrification and denitrification configurations are used in activated sludge wastewater treatment plants to remove nitrogen. A more detailed discussion on nitrification/denitrification, as well as the various treatment configurations can be found in the Water Environment Federation (WEF) Nutrient Removal Manual (2010).

1.2.1.2 Anammox

Although effective at nitrogen removal, the inherent disadvantage in the conventional nitrification/denitrification approach is that each step requires energy. A more energy efficient emerging approach is anaerobic ammonia oxidation (anammox). Anammox is a two-step process that initially requires nitritation where the ammonia is oxidized to nitrite (nitritation):

$$NH_4^+ + 1.5O_2 \rightarrow NO_2^- + H_2O + 2H^+ \tag{3}$$

The nitritation step typically stops at equal parts ammonia-N:nitrite-N. The subsequent second step simultaneously removes the ammonia and nitrite to form nitrogen gas (anammox step relying on the special anammox bacteria) as follows:

$$NH_4^+ + NO_2^- \rightarrow N_{2(g)} + 2H_2O \tag{4}$$

The primary benefits of the anammox processes compared to conventional activated sludge for nitrogen removal is reduced power consumption (about 60% less per pound N removed), little or no required external carbon source, low yield (<0.15 lb TSS/lb N), and greatly reduced CO_2 emissions.

Although promising, the anammox technology is currently limited to the return stream from the dewatering facility (i.e., centrate/filtrate). Within a POTW, the return stream constitutes about 15 to 25 percent of the nitrogen load fed into the activated sludge process. Anammox is limited to the return stream as it requires relatively warm waters (≥30 C) to ensure that Equation 3 stops at nitrite. At relatively cooler water temperatures (about 20 C), Equation 3 proceeds all the way to nitrate (Equation 1) and subsequently must go through the denitrification pathway to remove N (Equation 2).

1.2.2 Treatment Levels for BACWA Member Agencies

An illustration of the current treatment levels provided by BACWA member agencies is provided in Figure 2.

A recently released United States Environmental Protection Agency (USEPA) report signals that nutrient over-enrichment may be a serious threat to estuaries nationwide (USEPA, 2010). Given that the impacts of nutrient over-enrichment are a case specific phenomena, there is an on-going effort to determine whether over-enrichment is a threat to the San Francisco Bay, and in turn whether BACWA member agencies currently performing secondary treatment should convert to nutrient removal treatment. If nutrient removal is ultimately required, there are various nutrient removal treatment levels that could be selected. A more detailed discussion of the impacts of treatment level selection is provided in Section 3.1.

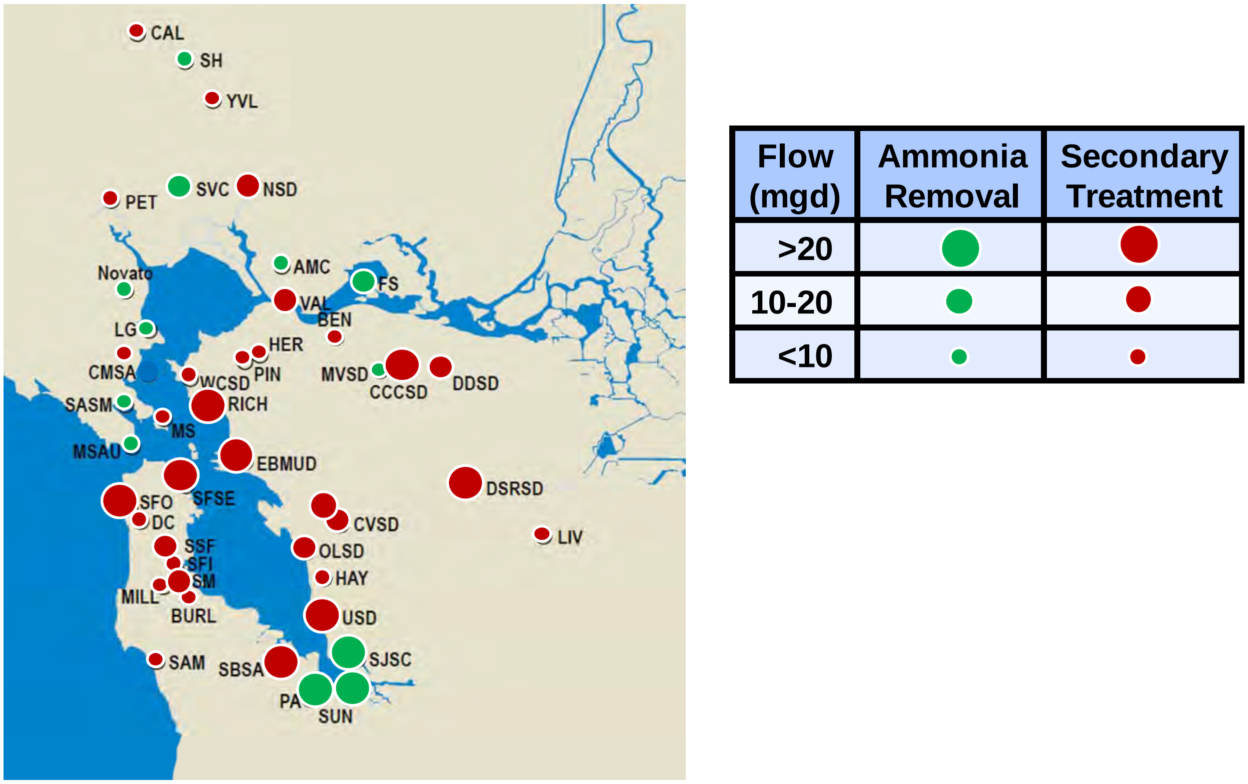


Figure 2. Current POTW Treatment Levels of BACWA Member Agencies

1.2.3 Facility Needs to Convert from Secondary to Nutrient Removal

The conversion from secondary to nutrient removal treatment will most likely require additional treatment facilities. The extent of additional treatment facilities is POTW specific. For example, a POTW that is constrained by footprint (space limitations) might implement different technologies than those with available space. The additional treatment facilities that might be required for a POTW to convert from secondary to nutrient removal treatment include:

- Expansion of secondary treatment facilities
  - Aeration basin volume (to meet nitrification oxygen demand and increase sludge age to grow nitrifiers)
  - Additional blower capacity (to meet nitrification oxygen demand)
  - Additional secondary clarifiers (to accommodate increased solids loading)
  - New pumps for internal recirculation to denitrify
- Chemical feed
  - Alkalinity feed for stable nitrification
  - External carbon source for denitrification
- New unit processes (dependent on permit structure)

2. Basis for Development of Unit Cost Estimates

The cost associated with retrofitting a particular POTW from secondary to nutrient removal treatment is case specific, as previously described, which makes it difficult to estimate general retrofit costs for a wide range of facilities. Therefore, several case studies were used as points of reference to develop a potential range of unit costs, including:

- Sacramento Regional County Sanitation District (High Purity Oxygen) (HDR, 2011c)
- Master Plans (Napa Sanitation District (Brown and Caldwell/Carollo, 2011); Delta Diablo Sanitation District (HDR, 2011a); Hampton Roads Sanitation District (HRSD) (HDR, 2011b))
- Water Environment Research Foundation (WERF) Sustainability Report (Falk et al., 2011)
- Florida Nutrient Numeric Criteria (NNC)(Reardon, 2010)

In addition to cost, permit limits can also span a wide range. The WERF Sustainability Report (Falk et al., 2011) discharge limits, as shown in Table 1, were used to discuss the impact of permit limits on both unit and operation costs. Level 1 treatment represents secondary treatment. Levels 2 through 4 are representative of nutrient removal permits being issued nationwide. Additionally, Levels 2 through 4 reflect the November, 2007 petition for rulemaking submitted by the National Research Defense Council (NRDC) to the USEPA. The NRDC petition claims that Levels 2-4 are achievable using current technology (barring reverse osmosis). Level 5, the most stringent nutrient level objective, would require an advanced membrane technology, such as reverse osmosis (RO) for treating 50% of the flow. Level 5 treatment objective is based on the recently released WERF report by Bott and Parker (2010), whereby they performed treatment performance statistics on 22 different POTWs doing nutrient removal treatment. Their results suggest that a nutrient removal POTW cannot reliably meet Level 4 objectives.

3. Results and Discussion

This section will explain the basis for the wide range in unit costs, the impact on operations and maintenance, ancillary benefits associated with nutrient removal, convergence of technology, and the potential for sidestream treatment for POTWs that transition from secondary to nutrient removal treatment.

3.1 Factors Impacting Unit Cost

The following factors result in a wide range of unit cost:

- Averaging period for permit compliance
- POTW specific variables
    - Economy of scale
    - Existing plant capacity
    - Existing secondary treatment process technology
    - Land availability and constraints
    - Existing solids management

The permit compliance averaging period impacts the extent of treatment facility requirements. California permits are based on maximum day effluent limits for toxic compounds, such as ammonia (see Sacramento Regional County Sanitation District 2010 Discharge Permit). The POTW must be designed to meet this worst-case scenario over a calendar year. In the case of Sacramento Regional County Sanitation District (SRCSD), their recently issued permit will result in a facility sized to address the 2.2 mg N/L ammonia maximum day limitation. This type of limit results in an inefficient POTW with respect to energy consumption because all the pumps/blowers are designed for the worst-case scenario (e.g. maximum day conditions). This condition varies significantly from what pumps/blowers experience on an average day-to-day basis. Additionally, the maximum day condition eliminated some options from consideration. Had the permit been structured for maximum month (such as 2.2 mg N/L ammonia on a calendar month), the increase in air activated sludge basins and pumps could have been less.

A seasonality based permit compliance averaging period typically separates wet and dry weather periods. This approach is attractive as it excludes sizing treatment facilities for peak wet weather events. During a significant precipitation event, the POTW is subjected to peak flows with subsequently less hydraulic residence time within the POTW. Less time for treatment that can in turn negatively impact discharge levels. Additionally, the receiving water body is typically less sensitive to nutrient loads during the wet weather period. The treatment objectives can in turn be less stringent than the dry weather period when the receiving water is more sensitive to nutrient loads.

The POTW specific sub-variables from the bullet list above highlights the discrepancies amongst POTWs and how they might influence the amount of equipment, concrete, and/or pumps required as POTWs transition from secondary to nutrient removal treatment. The economy of scale relates to the size of the POTW in terms of flow. The unit cost for an upgrade with identical facility requirements is indirectly related to POTW size. As for plant capacity, this relates to how close influent flows and loads are to the design capacity. For example, a plant operating at 50 percent design capacity will likely require minimal or no basin expansion, whereas a plant operating at or near design capacity will require basin expansion (nearly double) of the activated sludge process.

The existing secondary treatment technology will play a significant role in cost as some technologies are not easily upgraded to nutrient removal. For example, a high purity oxygen (HPO) process will most likely require conversion to air activated sludge (AAS). Although some basins/tanks may be salvaged, the footprint requirements increase to levels such that space might not be available on-site. The increase in footprint for AAS at SRCSD is anticipated to be about 3.5 times greater than HPO. For landlocked POTWs, a technology with a more compact footprint than AAS might be required or, in extreme cases, additional land may need to be acquired. One such compact technology is a membrane bioreactor (MBR), which requires more cost and requires more energy than AAS. A database compiled by Dave Reardon (HDR) suggests that AAS meeting a Level 2 treatment objective **Error! Reference source not found.**requires between 2,500 to 3,750 KiloWatt-hour/million gallons (kWh/MG) treated, whereas a MBR meeting comparable treatment objectives requires between 3,500 to 6,000 kWh/MG treated.

3.2 Unit Cost for Conversion from Secondary Treatment to Nutrient Removal

The unit cost associated with transitioning from secondary to nutrient removal treatment is broken up into a Greenfield[1] POTW and a compilation of case studies for POTW retrofits. For a Greenfield plant, the WERF Sustainability Report by Falk et al. (2011) was used as it provides both total project capital cost and operations for a nominal 10 mgd flow POTW as shown in Table 2. The increase

[1] A Greenfield plant refers to an undeveloped tract of land for constructing a POTW.

in total project capital costs with increased treatment is due to the fact that additional unit processes are required to meet the more stringent treatment levels. As for operations cost, the increase relates to the fact that additional energy (i.e., for aeration, chemicals, pumping, and mixing) and chemicals are required to meet treatment objectives. The removal of ammonia over total nitrogen requires more energy. The oxygen transfer rates improve the transition from ammonia removal to total nitrogen removal (about 10 percent). Additionally, a portion of the aeration is recovered under total nitrogen removal which translates to roughly 10-20 percent savings in aeration. However, a larger footprint is required for total nitrogen removal over solely ammonia removal. The chemicals are necessary to compliment the biological treatment limitations from Level 3 onwards.

Table 2. Total Project Capital and Operations Costs for a 10 mgd WWTP (Falk et al., 2011)[i]

Level (Treatment Performance)	Total Project Capital Cost ($/gpd) [ii]	Total Project Capital Cost (Million $) [ii]	Operations Cost ($/MG Treated) [iii]	Operations Cost ($1,000/yr) [iii]	Total Present Worth Project Costs (Million $) [iv]
1 (Secondary Treatment)	9.3	93	250	910	110
2 (8 mg N/L; 1 mg P/L)	12.7	127	350	1,260	150
3 (4-8 mg N/L; 0.1-0.3 mg P/L)	14.4	144	640	2,350	180
4 (3 mg N/L; <0.1 mg P/L)	15.3	153	880	3,200	210
5 (1 mg N/L; <0.02 mg P/L)	21.8	218	1,370	4,990 **	300

Notes:

i The total project capital cost is for a Greenfield plant.

ii The total project capital cost are the equipment cost, construction, and administration “soft” costs

iii Operations cost = energy and chemical cost. Labor and maintenance costs are excluded

iv The assumed discount rate was 5 percent at an escalation rate of 3.5 percent (capital, energy, non-energy)

Information gathered from the case study reports listed in Section 2 provides a wide range of unit cost for upgrading treatment plants to nutrient removal. Table 3 presents the range of conversion unit cost for upgrading three types of treatment configurations. Specific examples from treatment plants in the case study reports are listed for reference along with challenges and designs unique to each cost range. The width in unit cost variability is largely due to the case specific nature of each conversion as discussed in Section 4.1.

Table 3. Unit Cost Conversion from Secondary Treatment to Nutrient Removal

Technology	Plant Name	Conversion Unit Cost ($/gpd)	Comment
Trickling Filter/ Activated Sludge	Summary	3.2 – 4.7	Only 1 available data set
	Delta Diablo Sanitation District	3.2 – 4.7	HDR Master Plan (2011a) to leverage existing tankage and add membranes for a membrane bioreactor
High Purity Oxygen	Summary	0.3 - 12 [i]	Lower range for 10-20% NH3 load reduction; upper range for 2010 Adopted NPDES Permit
	Sacramento Regional County Sanitation District (SRCSD)	0.3 - 3.2	10-20% NH3 load reduction (HDR, 2011c)
	SRCSD	1.8 - 5.7	50-60% NH3 load reduction (HDR, 2011c)
	SRCSD	2.7 – 3.4	80-95% NH3 load reduction (HDR, 2011c)
	SRCSD	6.9 – 12	2.2 mg N/L ammonia Maximum Day; 10 mg N/L nitrate Monthly Average (HDR, 2011d)
Activated Sludge	Summary	2.1 – 16	Lower range for POTW with ponds storage; upper range for RO
Activated Sludge	Napa Sanitation District	2.1 – 4.1	Brown and Caldwell/Carollo Master Plan (2010).
Activated Sludge	Atlantic Treatment Plant [ii]	2.7	Includes methanol feed and enhancement facility (NEF), construction space (HDR, 2011b)
Activated Sludge	Boat Harbor Treatment Plant [ii]	6.6	Significant site constraints includes methanol feed and NEF (HDR, 2011b)
IFAS	James River Treatment Plant [ii]	7.4	Includes methanol feed and NEF (HDR, 2011b)
Activated Sludge; no primaries	Chesapeake Elizabeth Treatment Plant [ii]	5.4	NEF used existing gravity thickener structure (HDR, 2011b)
Modified Ludzack-Ettinger Process	Williamsburg Treatment Plant [ii]	3.8	Plant receives high strength brewery waste, includes methanol feed and NEF (HDR, 2011b)
Modified Ludzack-Ettinger Process	Bench-top Study	3.4	Falk et al. (2011) – Level 1→Level 2 (Garden Variety TN/TP removal)
5-Stage Bardenpho/Filtration	Bench-top Study	5.1	Falk et al. (2011) – Level 1→Level 3 (Advanced TN/TP removal)
5-Stage Bardenpho/ Tertiary Denit Filter	Bench-top Study	6.0	Falk et al. (2011) – Level 1→Level 4 (Advanced TN/TP removal)
5-Stage Bardenpho/RO	Bench-top Study	13	Falk et al. (2011) – Level 1→Level 5 (Advanced TN/TP removal)
Modified Ludzack-Ettinger Process	Florida Nutrient Numeric Criteria	8.2	Reardon et al. (2010) – For plants making changes to meet Florida NNC
5-Stage Bardenpho/RO	Florida Nutrient Numeric Criteria	165	Reardon et al. (2010) – For plants implementing Reverse Osmosis to meet Florida NNC

Notes:

i Lower range only accounts for 10-20 percent NH3-N load reduction

ii Hampton Roads Sanitation District (HRSD) Plant Upgraded to 5-stage Bardenpho process with nitrification enhancement facility (NEF), construction cost only.

3.3 Impact of Conversion from Secondary to Nutrient Removal Treatment on Operations and Maintenance

Various areas of operations and maintenance are impacted with the transition from secondary to nutrient removal treatment. A few of these areas are discussed below.

3.3.1 Solids Production

The removal of ammonia by nitrification requires a longer solids retention time (SRT) than required for secondary treatment (on the order of 10 days versus 2 days). By increasing the sludge age, the solids yield (i.e., lb TSS/lb BOD) is reduced, and in turn, less waste activated sludge is sent to solids processing. The extent of solids reduction is shown in Figure 3. This results in a reduction in chemical demand and energy associated with treating the solids waste.

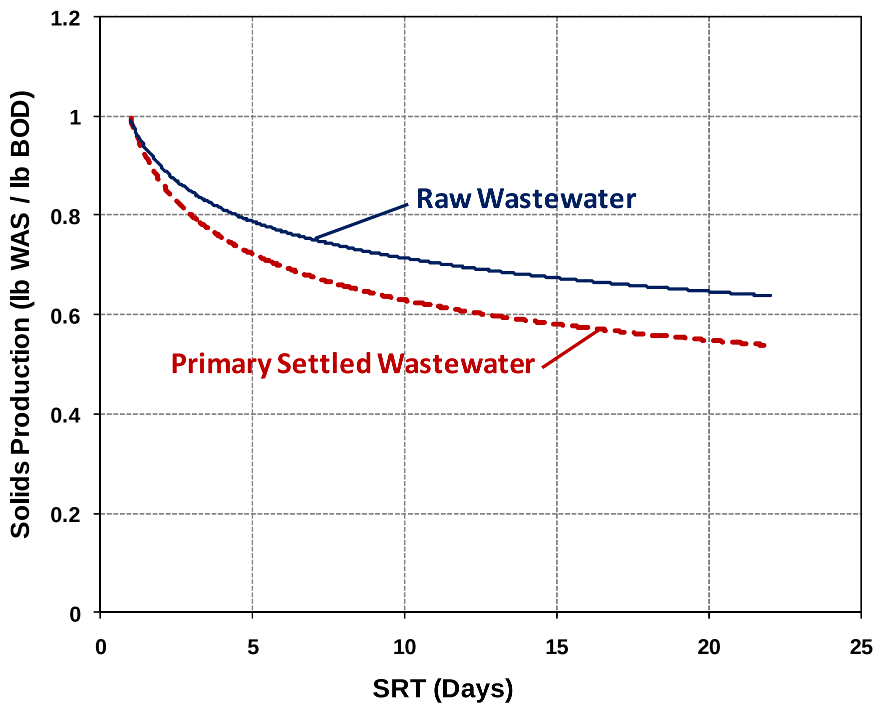


Figure 3. Effect of Sludge on Solids Residence Time (Adapted from Benjes, 1980).

3.3.2 Foaming

An increase in SRT required for nitrification can also promote the growth of floating bacteria. These bacteria have a tendency to induce foam and can accumulate on the reactor's surface. The use of anaerobic/anoxic selectors for biological P removal and denitrification can assist in suppressing foam inducing organisms as they are typically obligate aerobes.

There are several foam control strategies that have results ranging from marginal to complete control. One such foaming control approach is to implement surface wasting using a weir instead of the typical mechanical wasting approach. The collected foam can be thickened and stabilized (e.g., using a dissolved air flotation and lime stabilization) and eliminated from the process train without negatively impacting the anaerobic digesters. Converting a basin from mechanical wasting requires the construction of break walls, which incurs an additional expense. A less intrusive approach is the addition of floc settling chemicals (e.g., polymer) in the clarifier clearwell. The polymer can overcome the effects of filaments on sludge settling. Although effective, this strategy is costly from an operations standpoint and would require detailed analysis on polymer selection. Another approach is the use of a SRT controller that can reduce the sludge age so that it is sufficient for nitrifiers but too short for foam inducing organisms to thrive.

3.3.3 Disinfection

Chlorine added for disinfection rapidly reacts with ammonia (chloramination) to produce monochloramine (NH_2Cl) as follows:

$$NH_4^+ + HOCl \rightarrow NH_2Cl + H_2O + 2H^+ \quad (5)$$

The removal of ammonia in a nutrient removal plant will result in free chlorine being present over monochloramine as the disinfectant. Although free chlorine is a more effective disinfectant than monochloramine, it produces more undesirable disinfection by-products (DBPs). Examples of DBPs include nitrosodimethylamine (NDMA), trihalomethanes (THMs), and haloacetic acids (HAAs).

Rather than converting from chlorine to a different disinfectant (e.g., UV), several variations of chlorine disinfection can be considered. For example, controlled chloramination and sequential chlorination, can be used to disinfect and reduce DBP formation potential. Controlled chloramination entails adding external ammonia to meet the demands associated with Equation 5. Sequential chlorination is a variation on chlorine disinfection that is a two-step process for POTWs with filtration. The first step is free chlorine addition before filtration, followed by ammonia addition after filtration to form monochloramines (Maguin et al., 2009). The rationale for the two step process is to minimize NDMA and the formation of THMs/HAAs by limiting the amount and reaction time of free chlorine. This process was created and first used at the Sanitation Districts of Los Angeles County.

An additional free chlorine demand concern with converting to ammonia removal and/or total nitrogen removal is nitrite breakthrough. Rather than oxidizing the ammonia all the way to nitrate (Figure 1), incomplete nitrification can lead to nitrite production. The presence of nitrite is a concern as the free chlorine demand is 5 pounds free chlorine per lb nitrite (Cowman and Singer, 1994). The increased demand relates to the fact that nitrite rapidly reduces free chlorine and it accelerates chloramines decomposition (Skadsen, 1993). This unintended consequence associated with transitioning from secondary nutrient removal treatment can prove costly in operations. The extent of increased free chlorine demand will be plant specific as it is a function of nitrite breakthrough.

3.3.4 Labor

The conversion to nutrient removal treatment increases complexity and in turn requires more operators. The longer sludge age associated with activated sludge under nutrient removal lends itself to a more robust process than the shorter sludge ages of conventional activated sludge secondary treatment. However, the nitrifying microorganisms that govern the sludge are more sensitive to process upsets than the microorganisms that perform secondary treatment. As a result, the operators must be more experienced and skilled in dealing with the nitrifying populations associated with activated sludge under nutrient removal.

A nutrient removal plant requires more labor to operate and maintain the supplementary equipment associated with nutrient removal (e.g., pumps, mixers, chemical feed, etc.). The extent of increased labor is heavily dependent on the level of treatment. For example, the amount of labor required to meet the Level 2 and Level 4 objectives in Table 1 is significantly different. In the case of Level 2, the only change from secondary treatment is converting the conventional activated sludge process to one that performs nutrient removal. In contrast, Level 4 requires conversion from conventional activated sludge to a more sophisticated and complex activated sludge process than Level 2, a high-rate clarifier, denitrifying filters, and an external carbon source to meet low level nitrate levels.

The external carbon source (e.g., methanol) required of the more advanced treatment levels (e.g., TN < 6 mg N/L) is not only a chemical burden, but also a safety concern. Methanol is commonly used as the external carbon source which is explosive. As a result, the operators must be trained in handling methanol as the regulations are in-line with an automobile gas station.

3.3.5 Sustainability

The WERF Sustainability Report (Falk et al., 2011) investigated where a point of "diminishing returns" is reached where the sustainability impacts of increased levels of nutrient removal outweigh the benefits of improved water quality. Within the report, greenhouse gas (GHG) emissions were measured along with potential algal production as a water quality surrogate. The distribution of GHG emissions for pumping/mixing, aeration, cogeneration, N_2O emissions, chemical manufacturing/delivery/use, deep well injection (Level 5), and sum of CH_4 emissions and biosolids hauling is provided in Figure 4.

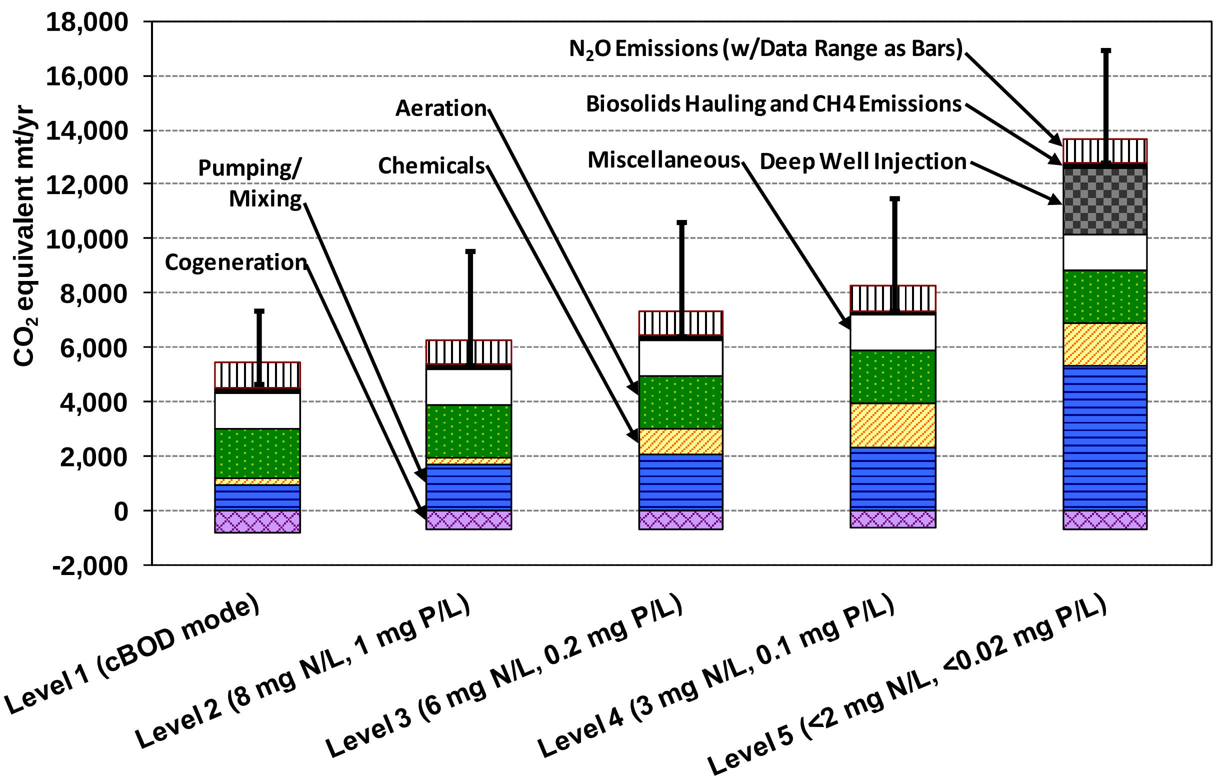


Figure 4. GHG Emissions Distribution per Treatment Level

The three largest contributors to GHG emissions are all energy related: aeration, pumping/mixing, and deep well injection (Level 5). The steady increase in emissions from Levels 2 to 4 is due to chemical demand for methanol to fuel denitrification, alum, and polymer. More chemicals are required for tertiary add-on solids separation processes with more advanced treatment. For example, the use of high rate clarification (assume dose of 50 mg/L alum; 2 mg/L polymer) increases chemical demand from Level 3 to Level 4 or 5. The least significant variables were methane and biosolids hauling.

Besides GHG emissions, the impact on the receiving water body using the water quality surrogate is potential algal production. The algae production results in Figure 5 are on the primary y-axis (left-hand side) along with the GHG emission equivalents on the secondary y-axis (right-hand side). The algal savings are 95% from Level 1 to 3. Both Levels 4 and 5 remove an additional 4 percent (99 percent total removal with respect to Level 1) with a corresponding doubling of GHG emissions from Level 3 to 5.

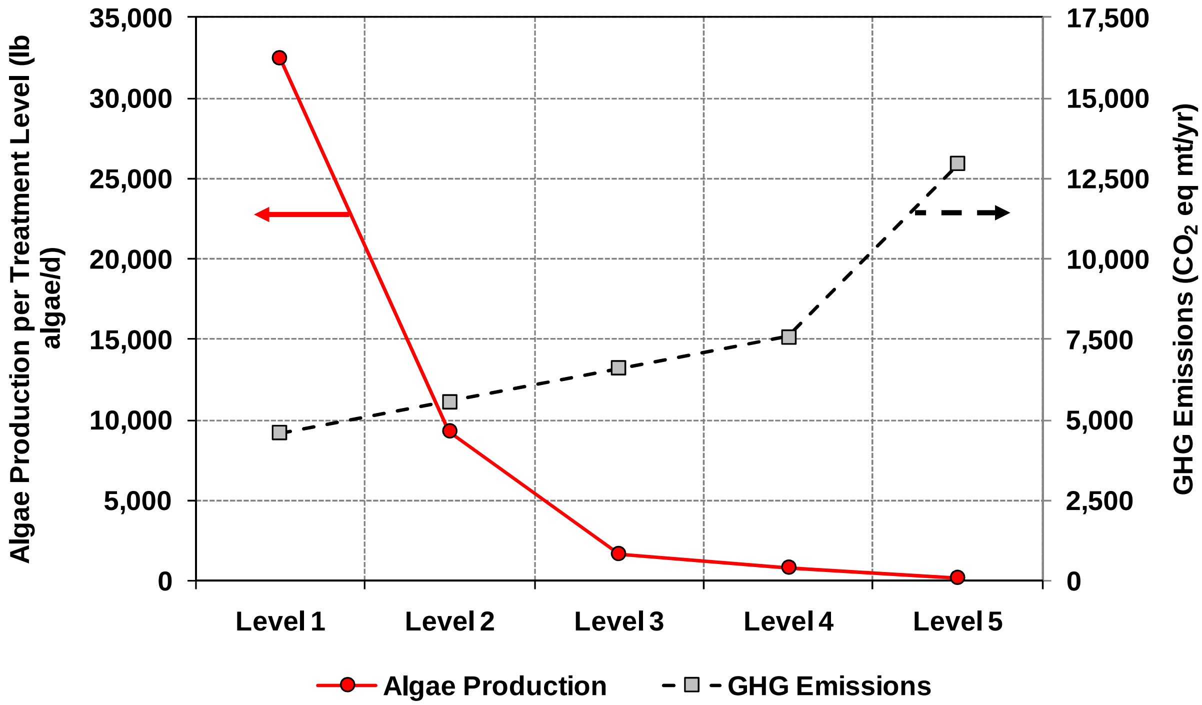


Figure 5. GHG Emissions and Algae Production per Treatment Level

The overall message from the WERF Sustainability Report is that a combination of Level 3 treatment complimented with best management practices on non-point sources might be a more sustainable approach than solely regulating point source discharges for achieving comparable water qualities.

3.4 Ancillary Benefits of Nitrogen Removal

The longer sludge age associated with the conversion of secondary to nutrient removal treatment will provide ancillary benefits as follows:

- Reduced effluent biochemical oxygen demand (BOD) and total suspended solids (TSS) loads
- Lower biomass yield (lb TSS produced per lb BOD feed) as sludge age is inversely related to yield (Figure 3)
- Improved removal of trace organic compounds (TrOCs) (Horz et al., 2004)
- Improved removal of heavy metals (Stasinakis et al., 2003)
- Improved secondary clarifier effluent filterability (Leu et al., In press; Chan et al.; In press) and lower levels of particulate-associated Coliform (Emerick et al., 2000)

- Improved process stability from the anaerobic/anoxic zones serving as a selectors (Jenkins et al., 2004)

3.5 Convergence of Technology – Reclaim or Discharge

As National Pollution Discharge Elimination System (NPDES) permits continue to be more stringent with respect to numerical limits as well as the averaging period for permit compliance (e.g., maximum day ammonia limits), a situation can arise where the treatment requirements for reuse are less stringent than discharging to the receiving water body. This is a common issue nationwide for POTWs. In many cases, the NPDES permit would require a complex activated sludge process with an external carbon source, denitrifying filters, and other unit processes to meet the discharge objectives. In contrast, the treatment requirements for unrestricted Title 22 reuse in California require secondary treatment, followed by filtration and disinfection (albeit more stringent disinfection).

Although meeting the unrestricted Title 22 reuse requirements might be easier than meeting the NPDES permit, there are additional costs associated with identifying potential reclaimed water users, building a reclaimed water distribution system, and managing treated effluent during the wet season when recycled water demands are typically at their lowest. The incorporation of these costs will provide a normalized comparison to assist in decision making.

Under such situations, the utility will need to determine which option provides the most value to their rate payers.

3.6 Emerging Sidestream Nutrient Removal Technologies

The removal of nitrogen within the main plant flow is proven, well understood, and documented. The advent of more stringent permits has led researchers to consider various locations in the plant for nutrient load reduction. In particular, the dewatering centrate/filtrate return stream (referred to as the sidestream) for plants with digesters constitutes between 15-25 percent of the N load and the majority of the P load.

There are several technologies that can remove either N or P from the sidestream. For nitrogen removal, the technologies are either biologically or chemical/physical. The biologically based technologies include, but are not limited to the following:

- Activated sludge technology to treat the sidestream (e.g., sequencing batch reactor)
- SHARON (partial nitritation followed by denitrification using an external carbon source)
- Anammox (partial nitritation followed by anammox bacteria using ammonium/nitrite simultaneously to form nitrogen gas)

Of the listed options, the topic paper will focus on anammox as it requires the least amount of energy, has the smallest footprint, and does not require an external carbon source. Although there are currently no full-scale anammox installations in the United States, the technology is established in Europe and Asia with more than a dozen installations. An image of the Rotterdam, Netherlands anammox reactor is provided in Figure 6.

Figure 6. Anammox Reactor at Rotterdam WWTO, NL

For chemical/physical removal of N, ammonia stripping is an older/proven technology. Ammonia stripping is rarely applied to POTWs anymore due to the amount of chemicals and the required stripping tower. A novel technology (Ammonia Recovery Process (ARP) by ThermoEnergy®) is emerging that uses the chemistry associated with ammonia stripping and increases the pH to greater than 10 standard units (su) to volatilize the ammonium. Rather than strip out ammonia gas in a stripping tower, the ARP technology mists the stream to increase surface area and applies a vacuum pressure all within an enclosed vessel to draw out the ammonia gas. An image of an ARP reactor is shown in Figure 7. Once separated, the ammonia gas is condensed back to the liquid form using sulfuric acid to form reagent grade ammonium sulfate. The ammonium sulfate is then sold as a fertilizer (40% ammonium sulfate) and in turn creates a revenue source.

Figure 7. Image of an ARP Reactor by ThermoEnergy®

For POTWs performing biological P removal, the presence of P in the sidestream constitutes the majority of the P load within the main plant flow. Historically, the P leaving the digesters has a tendency to form struvite crystals that can deposit on piping/pumping and be problematic for operations. Rather than consider struvite crystals as a nuisance, manipulation of water chemistry can facilitate the formation of struvite crystals within a unit process to separate the crystals. Struvite crystals are a formation of ammonia magnesium phosphate (MAP). An image of a MAP reactor provided by Ostara® and the corresponding crystals are provided in Figure 8. Like the ARP technology, the MAP crystals create a revenue source.

Figure 8. Image of a MAP Reactor from Ostara ® (Left) and the MAP Crystal from Ostara ® (Right)

A summary table of the three discussed sidestream technologies is provided in Table 4. The strength in all three technologies is that they provide BACWA member agencies an opportunity to proactively remove a portion of nutrient load with minimal investment compared to the main plant flow. However, the unit cost on a per gallon basis is more expensive than the main plant flow. For example, the range of values in Table 3 is $2.1-16/gpd for AAS, whereas the Anammox/ARP are both between $20-50/gpd. Despite the expensive start-up costs, there is a subsequent operations savings benefit. A planning level cost-benefit analysis is recommended for any POTW considering sidestream treatment.

Table 4. Sidestream Emerging Technologies Unit Cost

Technology	Unit Cost	Revenue Stream Potential	Comment
Anammox	$20 - 50 / gpd treated [i] ($ 0.3 – 1.6/lb N) [ii]	-	Reduces aeration demands in main plant flow; reduces overall plant wide greenhouse gas emissions
ARP by ThermoEnergy ®	$20 - 50 / gpd treated [i] ($ 0.3 – 1.6/lb N) [ii]	$1-2/gal	Operations cost dependent on water chemistry (ability to raise/drop pH), not N load. Reduces aeration demands in main plant flow.
Struvite Reactor (e.g., Ostara ®) [iii]	$0.7-1.4/lb P Removed	$100-250/ton for POTW in revenue	Suffers from economy scale. Currently limited to plants >40 mgd practicing biological phosphorus removal.

Notes:
i The gpd treated is based on the sidestream average annual flow
ii Assumes a 20-yr period and a sidestream concentration of 500 – 1,000 mg N/L
iii A struvite reactor is only applicable for facilities that both perform biological P removal and have anaerobic digestion with dewatering.

4. Summary and Conclusions

As BACWA and its member agencies start to prepare for the potential for more stringent nutrient discharge requirements, it is critical that they understand their implications. This topic paper attempts to inform BACWA and its member agencies about the following implications associated with transitioning from secondary to nutrient removal levels of treatment:

- Factors that govern unit cost
    - Nutrient permit limits/structure
    - POTW specific variables
- Impact of conversion on operations and maintenance
- Ancillary benefits of transitioning from secondary to nutrient removal treatment
- Convergence of technology where reclaimed water is more viable than meeting discharge permit limits
- Emerging sidestream technologies as a tool to proactively remove a portion of the nutrient load at a minimal cost relative to the main plant flow.

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BACWA Climate Change Adaptation Work Group

August 31, 2011, 3:00 pm – 5:00 pm
EBMUD 375 11th Street, Oakland, CA Conference Room 7A/B

Meeting Summary

ATTENDEES
David Behar (SFPUC), Alicia Chakrabarti (EBMUD), Amy Chastain (BACWA), Stephanie Cheng (EBMUD), Mike Connor (EBDA), Rich Currie (Union Sanitary District), Zeynep Erdal (CWCCG), Matt Krupp (City of San Jose), Jon Loiacono (SFPUC), Randy Schmidt (CCCSD)

INFORMATION SHARING
EBMUD
- The agency has prepared a climate report for water and wastewater that details climate change impact predictions and that includes some descriptions of adaptation measures.
- They are coordinating with BCDC/NOAA on a report on the impact of rising tides and are providing data on their infrastructure to inform this report.

SFPUC
- Parts of the city, especially in the Mission Bay area, are susceptible to flooding.
- The city plans to install backflow protection devices on their outfalls, Bay water is currently overtopping weirs on occasion.
- One of the city's oceanside interceptors is being threatened by erosion. The regulatory and public relations steps, including obtaining a Coastal Commission permit, necessary to protect this interceptor have been challenging to take.

Union Sanitary District/EBDA
- The district has tried to engage the water districts and municipalities in its jurisdiction to undertake a study focused on protecting the shoreline.
- EBDA is protected by a levee that is need of maintenance that has already been breached and is vulnerable to being breached again.

City of San Jose
- Is studying climate change impacts as part of their master planning effort.
- Concerns exist about having to pump effluent. The City has investigated converting old drying beds to wetlands to use as storage.

CCCSD
- The district has surveyed all levee structures to identify those vulnerable to failure.
- They are preparing a master plan and a plan for a "plant of the future," that take into account sea level rise and drought.
- Concern exists that current flood control channels are not being maintained and could contribute to flooding at the plant.

GENERAL DISCUSSION POINTS

- Collecting information on what wastewater agencies are currently doing and planning for could help make this issue real.
- Illustrative examples could be used to leverage funds.
- Standardizing assumptions across utilities could be helpful. It is important to be thoughtful about the science and the conditions to which agencies are adapting.
- Some wastewater utilities cannot wait for other agencies to take action (ex. SFPUC), but are finding that they must take steps to protect infrastructure without regional plans or support.
- It would be helpful to agencies to share information about their respective assumptions and strategies. Consider a white paper and workshop. Potential consultants include URS and Moffat-Nickels.
- Look to Seattle and New York for examples of wastewater vulnerability studies and technical suggestions.
- A Joint Policy Council comprised of ABAG, BAAQMD, BCDC, and MTC are currently meeting to discuss regional strategies. A water/wastewater/aquatic ecosystem protection perspective on this council could be valuable.
- The Bay Area IRWMP is currently being updated to incorporate climate change impacts as required by the State. Second round Proposition 84 funding may be available for some wastewater projects.

NEXT STEPS

1. Attendees to send A. Chastain documents to share with the group. A. Chastain will create an online library of these documents for the group.
2. A. Chastain/ A. Chakrabarti to schedule a second meeting in September to discuss goals and project scopes.
3. A. Chastain, A. Chakrabarti and M. Connor to develop draft scopes of work with a white paper for the group to review. Potential topics to be covered include current and projected impacts to wastewater utilities attributable to sea level rise and storm surges, measures and currently underway at plants to address these impacts.

BACWA BAY AREA CLEAN WATER AGENCIES

Executive Board Meeting Minutes

Thursday, August 25, 2011, 9:00 a.m. – 2:00 p.m.
HDR, Inc., San Francisco Office
575 Market Street, Suite 700 94105

ROLL CALL AND INTRODUCTIONS

Executive Board Representatives: Ben Horenstein, Chair (East Bay Municipal Utility District); Laura Pagano, acting Vice-Chair (San Francisco Public Utilities Commission); Jim Kelly (Central Contra Costa Sanitary District); , Rich Currie (East Bay Dischargers Authority); Kirsten Struve (City of San Jose).

Other Attendees: Andy Morrison (Union Sanitary District), Margaret Orr (Central Contra Costa Sanitary District); Jim Ervin (City of San Jose); Greg Baatrup (Fairfield-Suisun Sewer District); Kevin Kennedy (HDR Engineering); Pete Talbot (HDR Engineering); Holly Kennedy (HDR Engineering); Dave Clark (DHR Engineering); Monica Oakley (RMC); Tom Hall (EOA) Amy Chastain (BACWA).

PUBLIC COMMENT

There were no public comments.

REPORTS

Committee Reports, agenda item 1, were included in the meeting handout packet and attendees were invited to elaborate on their reports or field questions. Rich Currie requested more information about the Bay Behavior Campaign and the Executive Director (ED) provided a brief summary of that effort. Mr. Currie also noted that the distributor language in the pharmaceutical take-back bill mentioned in the BAPPG report had been removed. There was a brief discussion of the Tri-TAC electronic workshop to be held on September 1.

For **agenda item 2**, the **Proposition 50 Grant Disbursements Status Report** was included in the meeting handout packet. The ED noted that DWR has been invoiced for approximately 75% of the funds to date.

For **agenda item 3**, the **Executive Director's Report**, there were no questions about the report. The ED mentioned that fifteen tickets are currently available to the Executive Board for the State of the Estuary Conference.

For **agenda item 4, Executive Board Reports**, BACWA Executive Board members were invited to share any items of interest including information about meetings that were attended by BACWA representatives this month.

- Mr. Currie gave an update on the Hayward Marsh permit renewal: EPA commented on the permit, the coliform limit stayed the same despite the applicable beneficial use changing from REC1 to REC2, sampling will be required for four PAH compounds, a new dilution study will have to be conducted, and there is concern that the dilution credit for ammonia will be limited because of concerns about toxicity and the size of the mixing zone. Mr. Currie also reported that EBDA is conducting a peak flow study.
- Jim Kelly reported that CCCSD is still negotiating their permit and one issue that has arisen relates to permitting discharges during repairs.
- Kirsten Struve reported that she attended the RMP steering committee meeting and that there is an ASC meeting in September.
- Laura Pagano reported that SFPUC is investigating higher than normal toxicity and that the current accelerated monitoring requirements make conducting a TIE/TRE simultaneously challenging.

- Dave Williams reported that the ASC is still working on developing a strategic plan and that one proposal has been to keep ASC and SFEI as separate legal entities, but to have the Boards be identical. There was general support for this approach, although there is a legal question of the whether the Board can be comprised of non-JPA signatories.
- Ben Horenstein reported that EBMUD continues to deal with acute toxicity issues.

Under **agenda item 5, Authorized Actions**, Mr. Kelly raised the issue of responding to the State's draft Whole Effluent Toxicity Policy and asked whether the current BACWA effort is sufficient. The ED will consider whether a special meeting is required and will place this issue on the September Executive Board meeting agenda.

CONSENT CALENDAR

Mr. Kelly moved to approve **agenda items 6, 7 and 8**, Ms. Pagano seconded, Mr. Currie abstained, and the motion carried unanimously.

OTHER BUSINESS

For **agenda item 9, ASC Representation**, the ED explained that Mike Connor requested to be replaced on the Board. Ms. Pagano will take Mr. Connor's position. The Executive Director will investigate whether she can sit on the Board as Mr. Williams may not be able to in the future because of a scheduling conflict.

For **agenda item 10, Pardee Retreat**, the ED reminded everyone that the retreat is scheduled for September 13 through the 15. She will send out the draft agenda to the Board and asked that they think about the invitee list.

The ED and Chair introduced **agenda item 11, Facilitated Nutrients Discussion**, by reminding the Executive Board that, several months ago, the Regional Water Board expressed an interest in having BACWA take a leadership position regarding the nutrient issue broadly in the San Francisco Bay. The purpose of the discussion, to be facilitated by HDR, is to develop a proposal or framework for this effort to present to the Regional Water Board on September 23. HDR then lead a discussion about nutrient regulation and control in the San Francisco Bay.

The meeting adjourned at 2:20 p.m.

BACWA EXECUTIVE BOARD ACTION REQUEST

AGENDA NO.: 8

FILE NO.: File 12,554

MEETING DATE: September 22, 2011

TITLE: Contribution to BASMAA for IPM Partnership 2011-12

☒ **MOTION**______________ ☐ **RESOLUTION**_____________

RECOMMENDED ACTION

Authorize contribution to BASMAA from BAPPG, in an amount not to exceed $10,000.00, to continue support for the Regional Integrated Pest Management (IPM) program during Fiscal Year 2011-12.

SUMMARY

This contribution from BAPPG supports the Regional Integrated Pest Management (IPM) Our Water Our World program, which has been a partnership between BAPPG and BASMAA since 2006. The purpose of the Our Water, Our World (OWOW) program is to raise awareness of the connection between pesticide use and water quality and provide information to consumers at the point-of-purchase about integrated pest management (IPM) and less-toxic alternatives. BASMAA manages collection and disbursement of funds for this program.

FISCAL IMPACT

This project was included in the BAPPG FY 2011- 2012 budget and workplan.

ALTERNATIVES

BACWA procurement policies do not require consideration of alternatives because the contract value is less than $50,000.

Attachments:

1. 12,554 BASMAA Invoice $10,000

BASMAA
Bay Area Stormwater Management Agencies Association
P.O. Box 2385
Menlo Park, CA 94026

Invoice

Date	Invoice #
8/26/2011	25

Bill To
Amy Chastain Bay Area Clean Water Agencies PO Box 24055, MS702 Oakland, CA 94623

Description	Amount
BAPPG - IPM Partnership Program XIII	10,000.00
Please remit to above address.	**Total** **$10,000.00**

BASMAA is a 501(c)(3) non-profit corporation. BASMAA Tax payer ID number is 26-4061031.

BACWA EXECUTIVE BOARD ACTION REQUEST

AGENDA NO.: 9

FILE NO.: 12,558

MEETING DATE: September 22, 2011

TITLE: Contribution to CASA for CWCCG 2011-12

☒ **MOTION**____________ ☐ **RESOLUTION**____________

RECOMMENDED ACTION

Authorize contribution to CASA, in an amount not to exceed $43,750.00, to continue support for the California Wastewater Climate Change Group (CWCCG) during Fiscal Year 2011-12.

SUMMARY

This contribution from WQAS/CBC supports the ongoing efforts of the California Wastewater Climate Change Group (CWCCG). CASA manages collection and disbursement of funds for this program. The fiscal year 2011-12 fee has been prorated based on the terms of the agreement with CH2M Hill for consultant support covering a 10.5 month period of service.

FISCAL IMPACT

This project was included in the WQAS/CBC FY 2011- 2012 budget and workplan.

ALTERNATIVES

BACWA procurement policies do not require consideration of alternatives because the contract value is less than $50,000.

Attachments:

1. 12,558 CASA Invoice $43,750

Subject: FW: CWCCG invoice for pledge
Attachments: INVOICE CC-BACWA.pdf

From: Debbie Welch [mailto:dwelch@casaweb.org]
Sent: Tuesday, August 30, 2011 11:34 AM
To: Amy Chastain
Subject: CWCCG invoice for pledge

Amy,

On behalf of the wastewater community's statewide climate change effort, CASA is most appreciative of the collaborative support of BACWA's membership.

CASA as the agent for the California Wastewater Climate Change Group has executed a contract with CH2M Hill for the work of Dr. Zeynep Erdal as the Group's Program Manager. The CASA Executive Board decided that the agreement would conclude with the Association's fiscal year end June 30, 2012. Therefore, the current agreement is for a period of 10.5 months. BACWA's 2011-2012 pledge of $50,000 for the year has been pro-rated to $43,750 for the shortened timeframe and the invoice is attached.

Please do not hesitate to contact if you have questions or concerns about the CWCCG program. Thank you again for your support.

Sincerely,
Debbie Welch
California Association of Sanitation Agencies
1215 K Street Suite 2290
Sacramento, CA 95814
P:(916) 446-0388
F:(916) 231-2141
www.casaweb.org
Ensuring Clean Water for California

INVOICE

California Association of Sanitation Agencies
1215 K Street, Suite 2290
Sacramento, CA 95660
Federal Tax I.D. 68-0018896

DATE: AUGUST 30, 2011

TO

Bay Area Clean Water Agencies
c/o East Bay Municipal Utility District
PO Box 24055, MS702
Oakland, CA 94623
c/o Amy Chastain achastain@bacwa.org

SHIP TO

INVOICE NUMBER	PAYMENT TERMS
11126302CWCCG	Due on receipt

DESCRIPTION	TOTAL
CWCCG Program Management Pro-rata based on 10.5 months of service through June 30, 2012	$43,750.00
TOTAL DUE	$43,750.00

Thank you

Make all checks payable to CASA
Ensuring Clean Water For California

BACWA EXECUTIVE BOARD ACTION REQUEST

AGENDA NO.: 10

FILE NO.: 12,559

MEETING DATE: September 22, 2011

TITLE: Contribution to CASA for Pesticide Registration Regulatory Support

☒ **MOTION**______________ ☐ **RESOLUTION**_____________

RECOMMENDED ACTION

Authorize contribution to CASA, in an amount not to exceed $15,000.00, to support the Tri-TAC Pesticide Regulatory Support during Fiscal Year 2011-12.

SUMMARY

For several years BAPPG has engaged TDC Environmental to provide regulatory support on the issue of pesticide registration to ensure that POTW issues and concerns are considered in the process. This support has benefitted POTWs on a statewide and national level because BAPPG used TDC's expertise to generate comment letters for Tri-TAC and NACWA on issues such as nanosilver and pyrethroids registration. Last year, per the BACWA Executive Board's request, a working group from Tri-TAC began efforts to generate statewide support for this work. This contribution to CASA, which is managing a larger and broader contract with TDC, is the result. Other, confirmed, contributions to this effort are: CASA - $15,000; SCAP - $13,500; NACWA - $10,000; and CWEA - $2,000. While CASA will manage the contract, TDC will report to the Tri-TAC Pesticide Workgroup, which includes BACWA representatives.

FISCAL IMPACT

This project was included in the WQAS/CBC FY 2011- 2012 budget and workplan.

ALTERNATIVES

BACWA procurement policies do not require consideration of alternatives because the contract value is less than $50,000.

Concept Paper[1]
Improving Quantitative Precipitation Information for the San Francisco Bay Region

1. Regional Need for Accurate QPI

Public utility and water resource managers require accurate and timely quantitative precipitation information (QPI) in order to make appropriate decisions regarding infrastructure and resources (see Johnson 2010 for a detailed summary of QPI needs in the Russian River watershed). Water utilities in the City of San Francisco, as well as surrounding counties (Bay Area Integrated Water Management Plan, IWRMP), are often negatively impacted by both long and short-duration heavy rainfall events. These negative impacts result from a combination of inadequate quantitative precipitation estimation (QPE) and short-term quantitative precipitation forecasts (QPF) at sufficient spatial and temporal resolution, limiting critical information needed by water resource managers to take appropriate action in advance and during heavy rainfall events.

Comment from Greg Braswell of San Francisco Public Utilities at AGU fall meeting (Dec 2010)

One consequence of extreme rainfall in the region is that the associated runoff can overwhelm the water treatment system, leading to discharge of untreated water into the ocean or Bay. These events trigger major fines, $25 per gallon in some cases. With adequate lead time and accuracy in QPI, water system managers have the potential to reduce or even eliminate some of these adverse events, thereby improving water quality and reducing major fines.

Comment from Chris Delaney of Sonoma County Water Agency at HMT-West Annual meeting (Oct 2010)

Provision of reliable water supply, protection against flooding and restoration of salmon runs in the Russian River basin depend on accurate information regarding precipitation amount and timing, as well as antecedent conditions, such as soil moisture and ground water levels. With better QPI, decisions regarding water releases from dams in the watershed can be optimized to meet the competing demands for this major resource.

These comments emphasize that benefits of improved QPI are many and substantial. A wide variety of water management responses can be made given improved weather nowcast and increased forecast lead frames. The time frames range from real-time (current) updates on weather and river flow conditions, to short- and near-term seasonal forecasts, and ultimately to long-term climatic-type forecasts. Depending on the water management purpose there are various actions which might be taken to maximize performance and/or to mitigate adverse impacts of too much or too little water. For example, increases in forecast lead time provide opportunity of homeowners to relocate house contents which reduces damages. These damage reductions count as direct benefits and taken across many households can add up to the millions of dollars.

Accurate QPI requires a combination of a robust observational network to accurately measure precipitation and other atmospheric variables in the complex terrain of the region as well as modern Numerical Weather Prediction (NWP) methods agile enough to ingest the observational data (data assimilation) and provide short-term QPF and nowcasting with high spatial and temporal resolution. The situation over complex terrain is especially challenging, given the low density of observations, as well as the complex microphysical processes resulting from the interaction of precipitation producing processes with orography. As uncertainties associated with observations, numerical models, and other tools can only be reduced but never eliminated, it is also important to estimate and clearly communicate to the users uncertainties in the current and forecast conditions for best decision making. Ensemble forecasting, where a number of numerical forecasts are produced to represent not only the most likely but also alternate scenarios, is a fast-developing, new field designed to offer additional information to help water managers make the best decisions in the presence of unavoidable uncertainties.

[1] Cifelli, R., L. Johnson, M. Ralph, D. Reynolds, A. White: 2011. **Improving Quantitative Precipitation Information (QPI) for the San Francisco Bay Region.** NOAA/ESRL Physical Science Division, Boulder, CO. February 2011. Technical Contact: Rob.Cifelli@noaa.gov, Administrative Contact: Marty.Ralph@noaa.gov

2. Role of NOAA HMT

The aim of NOAA's Hydrometeorology Testbed (HMT; http://hmt.noaa.gov/) is to accelerate the development and prototyping of advanced hydrometeorological observations, models, and physical process understanding, to foster infusion of these advances into forecasting operations of the National Weather Service (NWS), and to support the broader user community's needs for advanced QPI. The over arching goals are to more accurately map extreme precipitation and increase the forecast lead times, NOAA has conducted precipitation research in California for over a decade. HMT started a regional implementation in the area starting in 2004 following several pilot studies extending back to the late 1990s (see http://hmt.noaa.gov/field_programs/hmt-west/ for more information). Recently, HMT has been extended to the Pacific Northwest and is anticipated to begin in the Southeast. HMT is led by NOAA/ESRL's Physical Sciences Division (PSD) with partners across NOAA, other agencies and universities.

The HMT addresses these requirements through development and deployment of advanced monitoring instrumentation and observational networks, data assimilation and analysis, and prediction modeling and forecasting tools. Through extensive testing and validation, the HMT approach has matured so that the proven techniques are being deployed to support real-time monitoring and forecasting operations. Major activities focus on QPF, QPE, snow information, hydrologic impacts, climate, and decision support tools. HMT was developed with recommendations from a broad scientific and forecast-user community (Ralph et al. 2005a).

HMT research has shown that improving QPE over complex terrain, including the San Francisco Bay Region, requires a dedicated effort involving the collection of new observations (in situ and remote), the incorporation of these observations into state-of-the-art data assimilation, numerical modeling, and ensemble forecasting algorithms that account for capabilities and limitations of the observations, and the evaluation of the outputs against verification data. HMT research has led to improvements in QPE algorithms for operational radar networks such as NEXRAD (Matrosov et al. 2007; Martner et al. 2009; Gourley et al. 2009; Qi et al. 2010). However, challenges remain due to limitations in the NEXRAD network design (including areal coverage), the existence of shallow rainfall processes illustrated in Figure 1 ("non bright-band," or "NBB rain") that generates 25-35% of seasonal rainfall along the west coast (White et al. 2003, Neiman et al. 2005, Martner et al. 2008) and sharp precipitation gradients resulting from topography. Incorporating high-resolution polarimetric gap-filling radar data, low-cost vertical profiling radars and additional rain gages is a key strategy to address these issues.

Another major challenge is predicting precipitation, known as Quantitative Precipitation Forecasting (QPF). HMT has documented current QPF performance (Ralph et al. 2010), finding that the extreme events are often the most difficult to predict, especially in terms of precipitation amount. Some of the reasons for this are that current numerical models struggle to represent the aforementioned NBB rain, as well as the vertical air motions that generate clouds and precipitation, and include errors in wind speed, direction and water vapor transport. These weaknesses in current numerical forecasts are partly a result of

- spatial resolution being too course to adequately represent crucial details in the complex mountainous terrain of the region,
- use of cloud microphysics parameterizations that are optimized for conditions on a national scale rather than for this unique region (including the City of San Francisco), and
- relative sparseness of meteorological observations over the ocean where key storm attributes are not adequately monitored as they approach the coast.

It has also been found that the extreme precipitation events in the region are most often associated with land-falling atmospheric rivers (ARs; Ralph et al. 2006). Finally, the analysis of QPF skill focused on 24-h accumulations, while the shorter timescales needed for the Bay Area applications, are that much more challenging.

As part of a project to establish an HMT-West legacy in California, NOAA researchers are establishing a permanent, state-of-the-art observing network across the state that will help monitor storms as they strike the coast and move inland. Initial sites in this network already are providing data that can be compared with forecast models, which allows for adjustments in predictions of the strength and position of the storms, conditions that are crucial to determining when and where the most extreme precipitation will occur. This Enhanced Flood Response and Emergency Preparedness (EFREP) project, sponsored by the California Department of Water Resources (CA DWR), also involves atmospheric and hydrologic modeling, specialized display systems, and the development of decision support tools. This proposal adds to this new statewide observing network in California by focusing on filling important gaps in the existing operational NEXRAD network for the San Francisco and the North Bay regions; extending weather radar measurements offshore at the appropriate, low-level scanning angles; and developing new data assimilation, numerical modeling, and ensemble forecasting techniques capable of fully utilizing the observations from the existing and newly developed networks to provide probabilistic QPF (PQPF) information on the sub-kilometer scales for the 0-6 hour time scale.

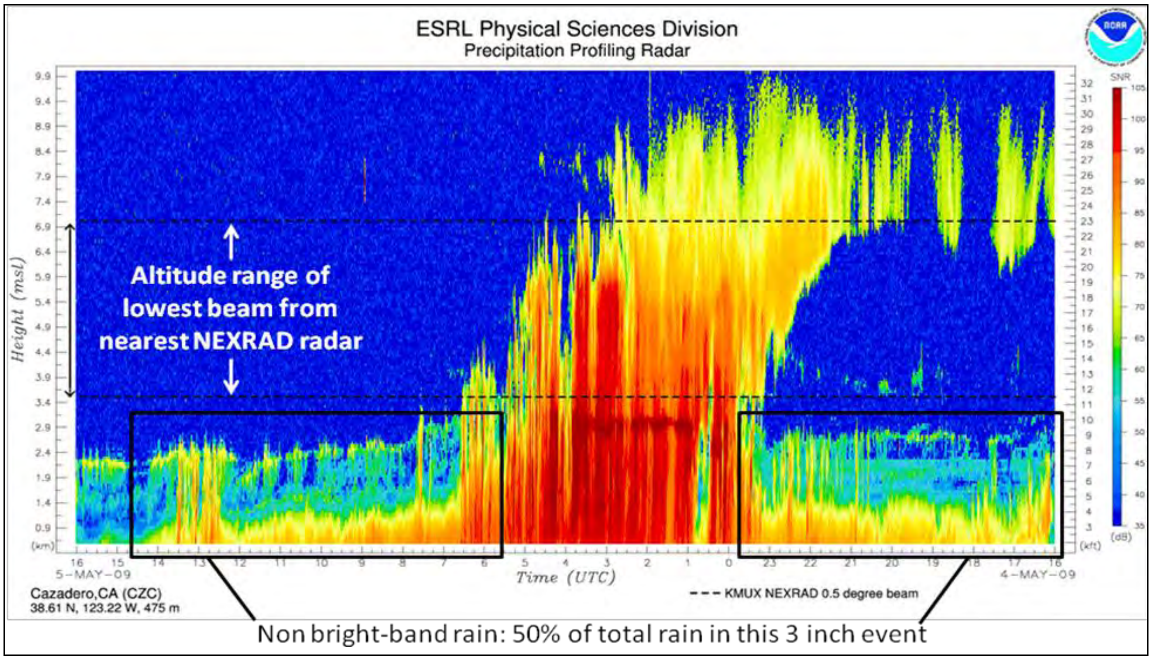

Figure 1. Recent example of vertical profiling radar observations from NOAA/PSD-HMT showing shallow NBB rain that occurred below the lowest beam of the nearest NEXRAD radar, but contributed 50% of the storm total rainfall. This type of rainfall contributes roughly 25-35% of the annual rain in coastal California (Neiman et al. 2005), and presents a major challenge to current operational QPE methods (Martner et al. 2008). These gaps can be filled using a combination of additional rain gages; smaller, specialized scanning radars to fill in gaps between gages; and inexpensive, vertical-profiling radars to ensure the scanning radar data are interpreted properly.

3. Plan to Address Regional QPI

Improving QPI for the San Francisco Bay Region, including the City of San Francisco, Marin, and Sonoma Counties, can be achieved using a combination of observations, data assimilation, modeling, nowcasting, and smart tool components. We refer to this approach as HMT-MAPS: Monitoring, Assimilation, Prediction, and System Integration. This effort can leverage existing HMT, HMT-West Legacy network and tools sponsored by CA DWR, and proposed new instrumentation and modeling efforts for the Russian River Watershed (White et al. 2010), including gap-filling radar. The plan outlined in White et al. 2010 was later incorporated into the Russian River Pilot Study for Integrated Water Resources Science and Services (IWRSS; Johnson, 2010). Extending the scope of the proposed Russian River watershed activities to include the City of San Francisco, Marin County, and other parts of the San Francisco Bay Region would be straightforward and could be implemented at reasonable cost and in a timely fashion.

Herein, NOAA/PSD's Water Cycle Branch proposes several options that range in scope and cost. These options are designated as "Phases". The tiered approach is outlined in Figure 2. At this stage of concept development, the cost estimates should be considered rough order of magnitude (ROM) estimates, and can be refined as needed. The phases are intended to be implemented sequentially (although some tasks could be performed in parallel), and the ROM cost shown for each phase is an increment above the cost of the previous phase. As described below, each phase includes HMT-MAPS components to incrementally improve QPI. Phase 1 represents a prototype solution based on existing equipment and resources. It is designed to be implemented quickly and at relatively low cost. Phases 2 and 3 represent more robust solutions but require a longer time line and higher cost due to the necessary procurement of new radar equipment, and evaluation of new tools (data assimilation, down-scaling of forecast model time and space scales, and nowcasting of precipitation fields). Each phase would include an evaluation period subsequent to the implementation phase to analyze the results and quantify the added value of the observations/products/services (described below). Analysis of the data and results will be accomplished using verification tools and techniques developed through the ongoing collaboration of the multi-agency Developmental Testbed Center (DTC) and HMT (http://verif.rap.ucar.edu/eval/hmt/2011/). Sensitivity analyses of the results will also be performed using the Multi-sensor Precipitation Estimator (MPE; OHD 2010) and Q2 (Qi et al. 2010) QPE algorithms. The results of the evaluations would be summarized in a document to be presented to the regional stakeholders and would include recommendations for future work. *As noted above, all proposed phases leverage surface rain gauge/disdrometer, soil moisture, GPS integrated water vapor, 915 MHz wind profiler, and existing scanning radar assets that are already in place and/or planned for Sonoma County as outlined in White et al. (2010) and summarized below*.

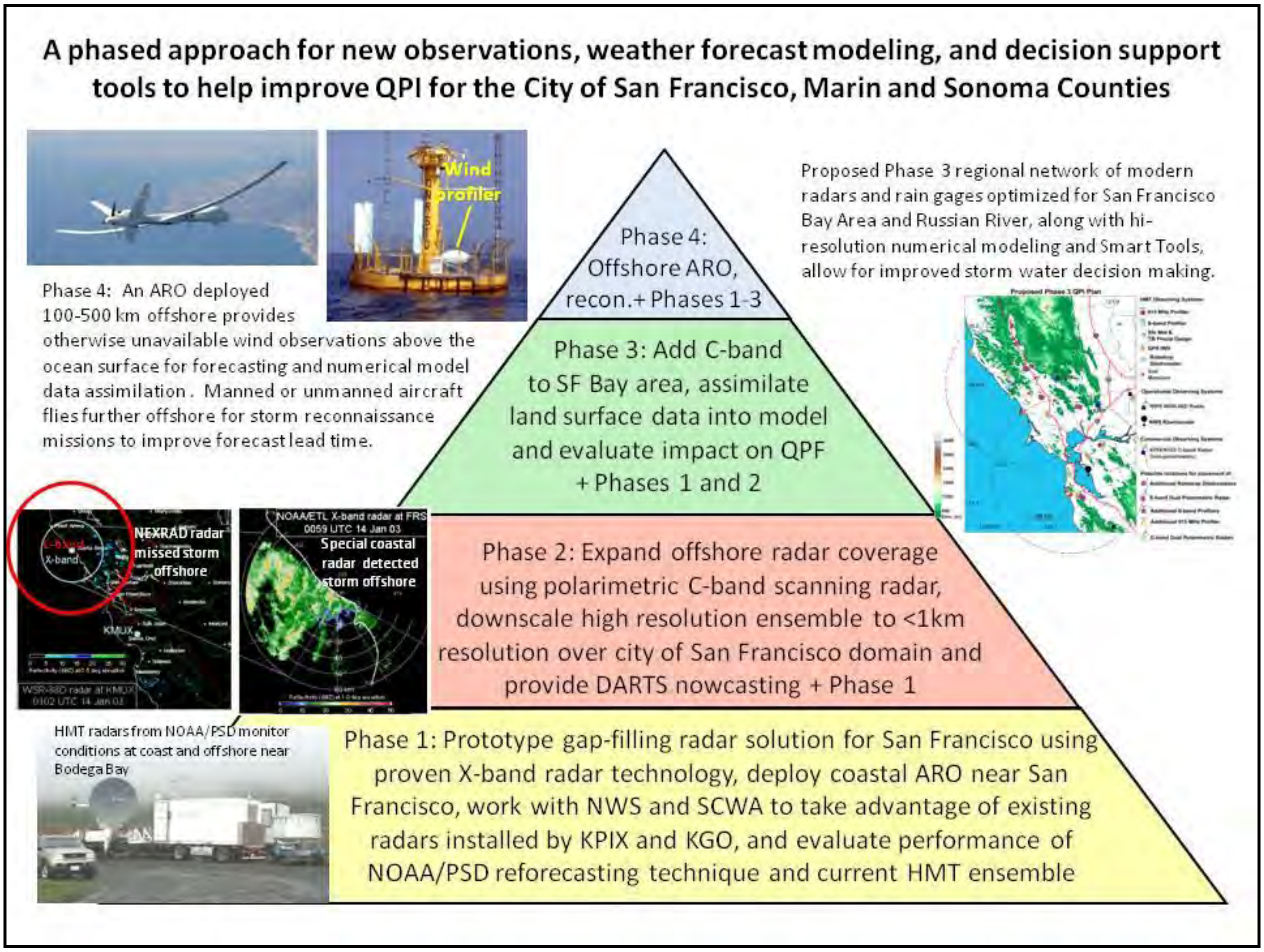

Figure 2 Schematic diagram of QPI plan implementation strategy and timeline for the City of San Francisco and North Bay region. Time periods marked as "Evaluation" represent analysis of data collected during the previous phase implementation phase.

4. Phase 1 Solution –"San Francisco Bay Initial Prototyping" ($1.9 million)

In addition to the assets proposed for Sonoma County in White et al. (2010), this solution includes (see Figure 3):

- Monitoring:
  - Evaluate current capabilities using available data like KPIX with NEXRAD and MPE and gages. Determine the limitations of these. Create HRAP (or smaller) grids of QPE and allow users to evaluate for use in urban drainage design studies.
  - Deployment for one winter season of NOAA ESRL's X-band dual-polarimetric radar near San Francisco (Mt. Pise is a possible location);
  - Deployment for one winter season of an atmospheric river observatory near Half Moon Bay.
  - Deployment of a disdrometer and S-band profiler for one winter southeast of the X-band radar;
- Assimilation:
  - Analyse the "dividing streamline" in AR conditions relative to San Francisco Bay Area extreme precipitation.
  - Incorporate X-band dual polarimetric radar data into operational NWS MPE and FFMP algorithms and demonstrate improved flash flood guidance in the San Francisco Bay Region.
- Prediction:
  - Develop high resolution QPF products from the HMT-DWR WRF ensemble/High Resolution Rapid Refresh (HRRR) Model. Expected increase in lead time is 6 hours.
- System Integration:
  - Disseminate the QPE / QPF gridded precipitation fields as input for the San Francisco storm water drainage hydrologic model. Demonstrate this linkage and document results for the urban runoff modeling.

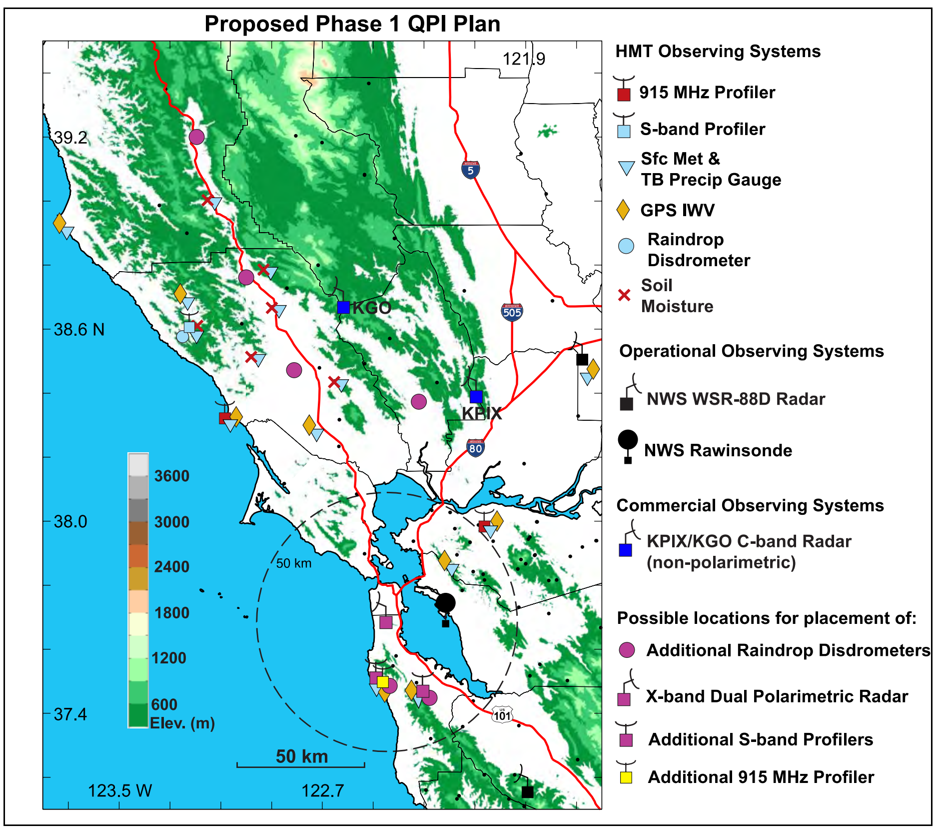

Figure 3. Proposed QPI instrumentation for Phase 1. The dashed circle indicates the approximate maximum extent of X-band radar observations.

The purpose of the X-band radar is to provide robust rainfall estimation using dual-polarimetric algorithms (Matrosov et al. 2005), and building on HMT-West findings regarding drop-size distributions (Martner et al. 2008). Although the range of the X-band is limited to ~40 km, the radar can observe precipitation at low levels that are often missed by NEXRAD (see Figure 4). The S-band profiler and disdrometer would be used to validate the assumptions used in the radar rainfall algorithms and to adjust the radar data through a vertical profile of reflectivity (VPR) correction (Matrosov et al. 2007; Qi et al. 2010). As shown in Figure 2, the X-band QPE would be focused on the City of San Francisco and southern Marin County. The TV radars (KGO and KPIX) would provide rainfall estimation over the Russian River in Sonoma County. The ARO would allow for determination of whether a dividing streamline exists and is directly related to heavy rain over San Francisco. Past research (e.g., Ralph et al. 2003) has shown that wind direction profoundly influences the exact position of rain shadowing, and thus heavy precipitation. It is quite likely that the mountains just south and southwest of San Francisco can produce this effect, but it needs to be proven and in doing so, a specific threshold wind direction would be identified. Regardless, an accurate 5 minute resolution bias corrected radar estimate for the next 1 hour is needed.

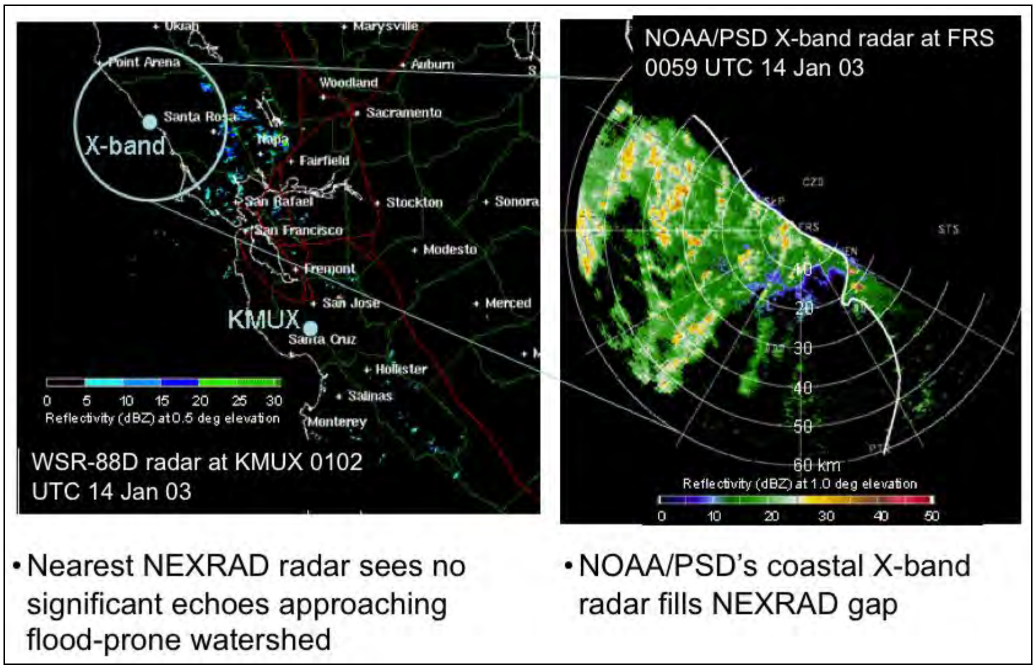

Figure 4. Comparison of precipitation observed by NEXRAD (left) and. X-band radar observations (right) for 14 January 2003 ~01 UTC. The lack of echo coverage in the NEXRAD image is due to the radar beam overshooting the low-level precipitation.

The PQPF products would be 4 times per day at 3-km resolution for the SF Bay area and made available for 60-min intervals out to 6 hrs lead time. The resulting precipitation forecast maps would be tailored to the San Francisco Bay Region, including the City of San Francisco, Sonoma County, and Marin County. The rainfall thresholds shown in Table 1 illustrate the type of information used for warnings. Almost all these thresholds up through 1 hr will have a dominant convective nature to it. Most likely up through 3 hr will be frontally forced. This means high resolution 5 min updates like FFMP with bias corrected rain rates will be critical along with high res extrapolation of radar QPE for short term QPF (see Blier at al 2005). It is anticipated that Phase 1 could be implemented starting in the winter 2011-2012 and could be used to demonstrate the technical feasibility of more advanced solutions (as proposed in Phases 2-4 below).

Table 1 Type of information used for warnings

Duration	10Y Intensity (in/hr) 1973	10Y Intensity (in/hr) New	25Y Intensity (in/hr) 1973	25Y Intensity (in/hr) New
5 Min	2.95	3.05	3.45	3.67
10 Min	2.40	2.43	2.80	2.92
15 Min	2.00	1.93	2.33	2.33
30 Min	1.32	1.34	1.51	1.62
1 Hr	0.85	0.86	1.05	1.04
2 Hr	0.58	0.63	0.72	0.75
3 Hr		0.52		0.63
6 Hr		0.37		0.44
12 Hr		0.25		0.30
1 Day		0.16		0.20

Table 1 (cont)

In general, these watersheds are characterized by urbanized valleys or bayside alluvial plains surrounded by with steep, less-developed or undeveloped uplands. Valley flooding tends to occur when large, widespread storms follow several days of rainfall.

The most widespread flood damages occur in urbanized, low-gradient lower reaches as the capacity of natural or engineered channels is exceeded and floodwaters spread through urban neighborhoods (Figure 3-2). In low-lying areas near the Bay, flooding may be exacerbated by high tides and storm surges which back up riverine flows.

Watershed	*County*	*Area (square miles)*	*Area Subj to Floodi (acres)*
Alameda Creek	Alameda	676	140
Corte Madera Creek	Marin	25	862
Coyote Creek	Santa Clara	356	16,253
Green Valley and Suisun Creeks	Solano	115	239
Guadalupe River	Santa Clara	176	11,854
Napa River	Napa	416	693
Novato Creek	Marin	44	5,473
Petaluma River		148	5,415
San Francisquito Creek	San Mateo & Santa Clara	49	1,108
San Leandro and San Lorenzo Creek	Alameda	128	712
San Mateo Creek	San Mateo	38	50
San Pablo and Wildcat Creeks	Contra Costa	65	3,824
Sonoma Creek	Sonoma	241	506

5. Sonoma County Plan Proposal Overview ($1.1 million) The Sonoma County plan involves integration of local TV station radar imagery as a component of the HMT-MAPS. Filling the gaps in the weather radar coverage is expected to provide improved nowcasting of rainfall occurrence and increase forecast lead times out to 3 hours.

- Monitoring:
    - Calibrate KPIX and KGO[2] TV station radars and stream data into NWS forecast office to support operational forecasting.
    - Install 4 surface disdrometers in the Russian River Watershed to determine the optimal radar reflectivity-rainfall (i.e., Z-R) relation(s) to apply to the TV radar data during precipitation events.
- Assimilation:
    - Incorporate TV radar data into operational NWS MPE and interface with NWS Flash Flood Monitoring and Prediction (FFMP) architecture, which currently ingest gridded precipitation fields – extend for advanced QPE/QPF.
    - Create reforecast database using an operational forecast model that would enable implementation of a modern precipitation forecasting method downscaled to the Russian River watershed.
- Prediction:
    - Link precipitation grids to hydrologic runoff models (i.e. the NOAA OHD distributed model and the USACE HEC model). Demonstrate this linkage for selected events and prototype for real-time operations. Expected increase in lead time is 3 hours.
- System Integration:
    - Create a research infusion team to implement key IWRSS/HMT findings into NWS operations;
        - Options for data and models interoperability
            - HEC CWMS to CHPS interoperability
            - USACE SF District reservoir operations
            - SCWA water management database, models and DSS tools
            - DWR CDEC interface.
    - Develop detailed multi-year scoping and feasibility plan to address long-term information requirements in the Russian River watershed; and
        - SCWA water management
            - Hydrologic Index for Rule 1610 operations (drought threshold)
            - Flood mitigation – (short-term (flash flood), mid-term forecasts)
            - Conjunctive use model – with USGS

6. Phase 2 Solution - "North Bay and Initial Offshore/Upwind Sampling" ($8 million)

In addition to the assets proposed for Phase 1, the Phase 2 solution includes (see Figure 5):

- Monitoring:
    - Deployment of a C-band dual-polarimetric radar near Fort Ross in Sonoma County; and
    - 3 S-band profilers in the Russian River watershed.
- Assimilation:
    - Incorporate the C- and S-band radar reflectivity data into the HMT data assimilation system.
    - Develop high resolution land surface flood monitoring data set (e.g. compatible with NWS FFMP).
- Prediction:
    - Nowcasting of precipitation fields at very high temporal and spatial resolution.
    - Development of higher resolution (compared to Phase 1) QPF products from the WRF ensemble/HRRR. Expected increase in lead time is 12 hours.

[2] The KGO radar on Mt. St. Helena is not operating because of significant damage to the radar caused by lightning on 19 December 2010. KGO has not yet determined when the radar will be repaired.

- System Integration:
    - Disseminate the regional precipitation weather data to agency partners such as the NWS WFO-Monterey and the San Francisco Department of Public Works.
    - Disseminate improved NWS FFMP flash flood guidance to regional stakeholders for improved situational awareness during heavy precipitation events.

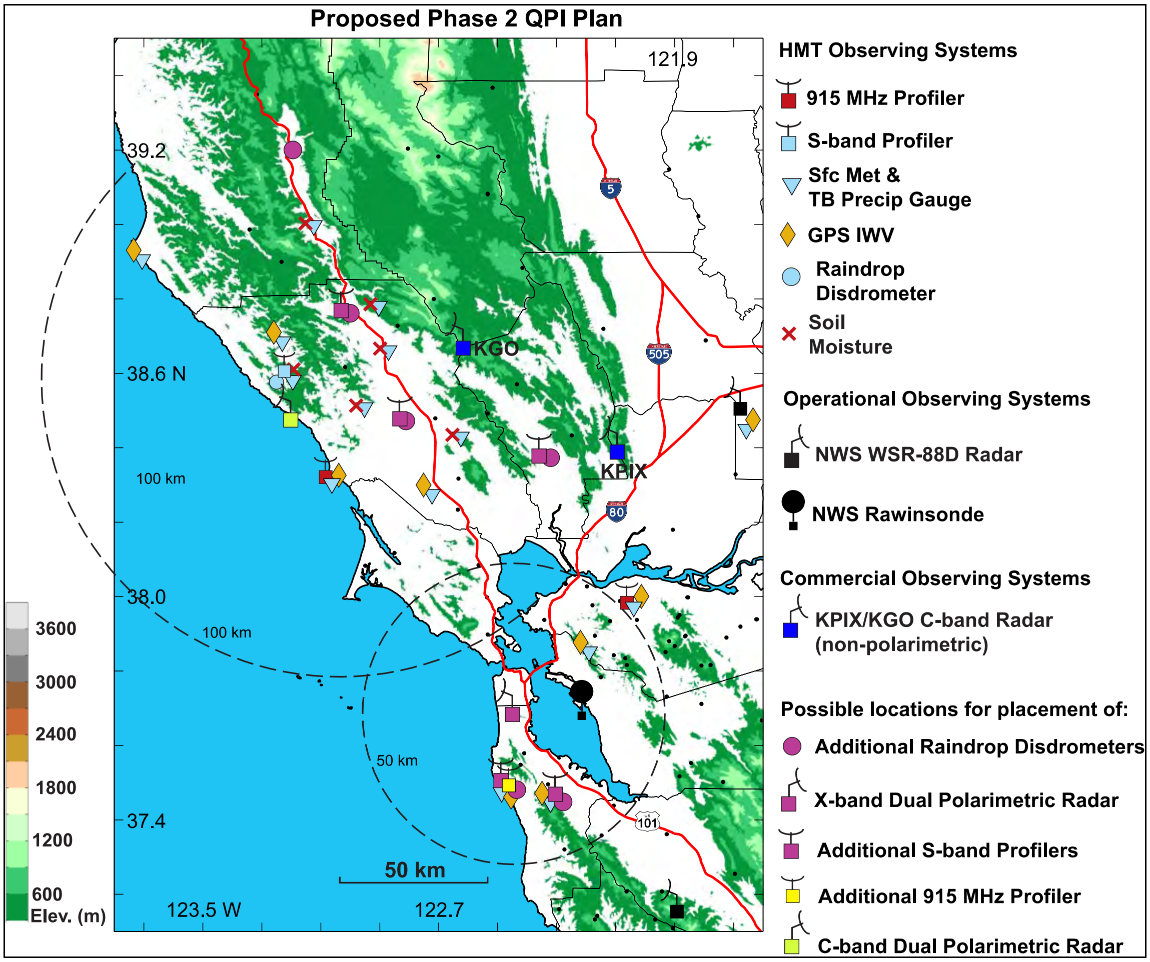

Figure 5. Same as Fig. 2, except for Phase 2. Outer dashed circle represents the approximate 100 km range ring from the proposed C-band radar located near Fort Ross. The coverage domain for this radar is mostly off-shore due to terrain blockage east of the radar site.

The C-band radar would serve three purposes: 1) provide precipitation information out to > 100 km offshore to give forecasters a "heads-up" on potential impacts in advance of low level precipitation moving onshore; 2) provide input for nowcasting algorithms as well as more "up-stream" data assimilation information for the WRF (compared to Phase 1); and 3) support development of accurate QPE off shore as well as along the coast of Sonoma, Marin, and Mendicino counties. The S-band profilers in the Russian River watershed would provide important VPR information to correct QPE estimates from the KPIX and KGO television station radars. Improvements in storm lead time tracking by radar would gain 4 hours lead time; numerical modeling could extend lead times out to 12 hours. For improved PQPF forecasting, a finer, 1-km WRF ensemble will be set up embedded into the 3-km HMT-DWR ensemble, focusing on the SF Bay area. For the initialization of the fine scale ensemble, all special observing systems implemented in Tier-1 will be utilized along with the routinely available observing systems. It is anticipated that the 1-km fine resolution analysis and WRF ensemble will be updated every hour and precipitation output will be made available for 30-min intervals. For improved runoff and hydrologic forecasting, the numerical analysis fields will include not only atmospheric but also land surface conditions (e.g. NWS FFMP system). Methods to utilize short range ensemble forecasts in the data assimilation step will also be investigated. The nowcasting would be used to bridge the gap between QPE and the short term WRF PQPF. The nowcasting would be based on the DARTS methodology (Ruzanski and Chandrasekar 2010) developed at Colorado State University and is intended to provide QPF out to 1 hour at the native resolution of the radar data (< 500m) with update intervals of < 10 minutes.

7. Phase 3 Solution - "Regional Offshore/Upwind Sampling" ($13.5 million)

In addition to the assets proposed for Phases 1 and 2, the Phase 3 solution includes (see Figure 6):

- Monitoring:
  - Deployment of a C-band dual polarimetric radar near San Francisco.
  - Deployment of the X-band dual polarimetric radar in the Russian River Basin.
- Assimilation:
  - Integrate QPE estimation with the NWP data assimilation system.
  - Apply 3D- or 4D-VAR techniques for ensembles.
- Prediction:
  - Increase the resolution of the numerical analysis and WRF ensemble to sub-kilometer scale (~300 m) over a selected region of the Bay area. Expected increase in lead time is 12 to 24 hours.
- System Integration:
  - Provide the high resolution QPE, QPF and PQPF products to the hydromet data dissemination system for use by NWS, State and local agency partners.

The C-band radar deployment near San Francisco is intended to provide more advanced warning of precipitation approaching the region from southerly or southwesterly directions as shown in Figure 7 (a preferred direction for atmospheric rivers – Neiman et al 2002, Ralph et al. 2003, Ralph et al. 2005b; Junker et al. 2008) compared to the X-band proposed in Phases 1 and 2. In Phase 3, the X-band deployment is shifted to Sonoma County to provide high resolution QPE in the lower portion of the Russian River Watershed. For further improvements to the PQPF guidance, the resolution of the numerical analysis and WRF ensemble will be enhanced to sub-kilometer scale (~300 m) over a selected region of the Bay area. Furthermore, QPE estimation will be made part of the NWP data assimilation system. All QPE and other measurements made available in Phase 2 will be directly assimilated using advanced 3D- or 4D-VAR techniques enhanced with ensemble information (hybrid data assimilation), with precipitation being one of the analyzed variables. These enhancements are expected to lead to major improvements in both the quality and the utility of QPI, including QPE and PQPF. <u>Lead times of 12 to 24 hours are to be expected.</u>

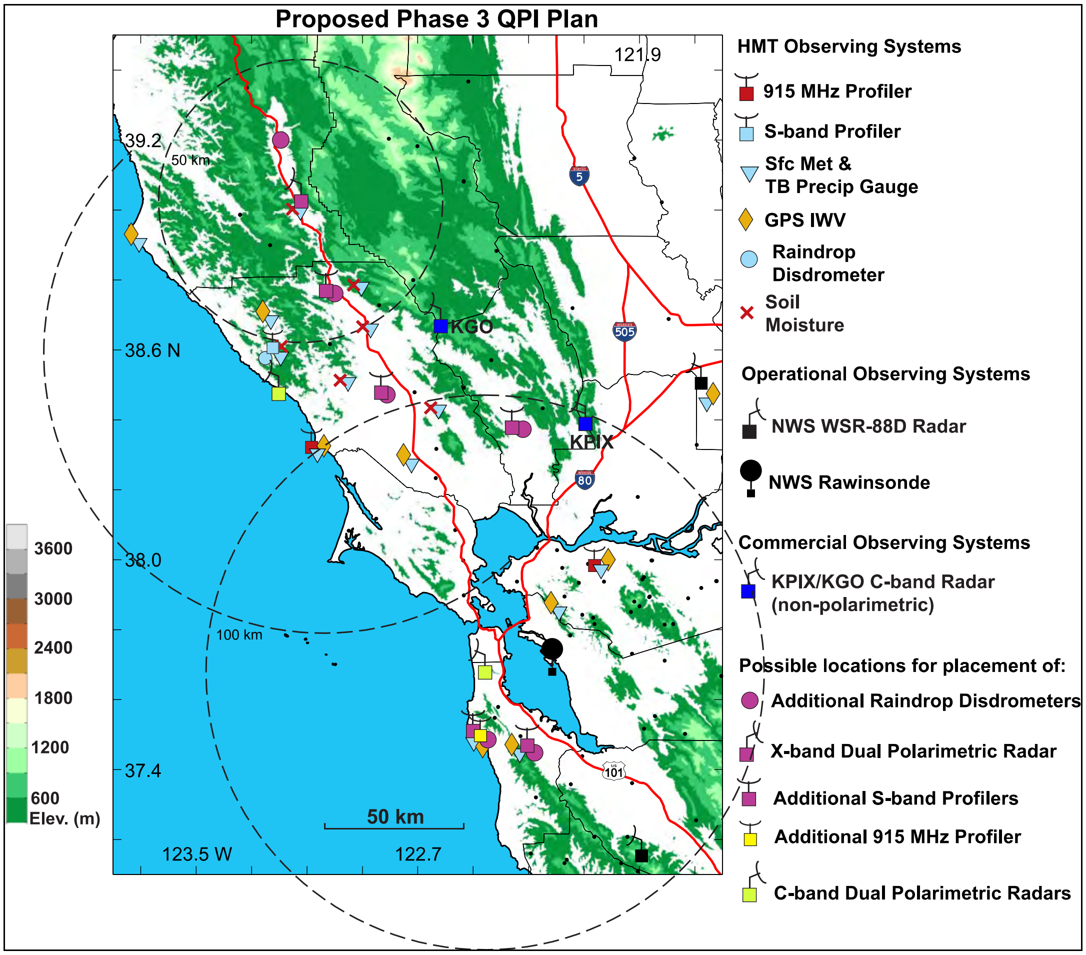

Figure 6. Same as Fig. 2, except for Phase 3. Dashed lines indicate 100 km range rings for C-band radars at Fort Ross and San Francisco as well as 50 km range ring for the X-band radar located near Hopland in Sonoma County.

8. Phase 4 Solution: "Offshore observing platforms" (>$15 M total for 3-5 years of development and testing)

The potential exists to further revolutionize observations to meet these challenging requirements by fielding observations offshore. Overcoming the fundamental challenge of operating on or above the ocean represents a major technical hurdle. Phases 1-3 provide observational solutions that are ground based or satellite based. Phase 4 literally places observing platforms on or over the ocean just west of the Bay Area. Past studies have shown the value of airborne observations (Figure 8), and emerging technological innovations in radar may make mounting a wind profiler on a buoy a true possibility. <u>This would enable essentially an offshore ARO capability and provide storm warning lead times of 24 to 72 hours</u>.

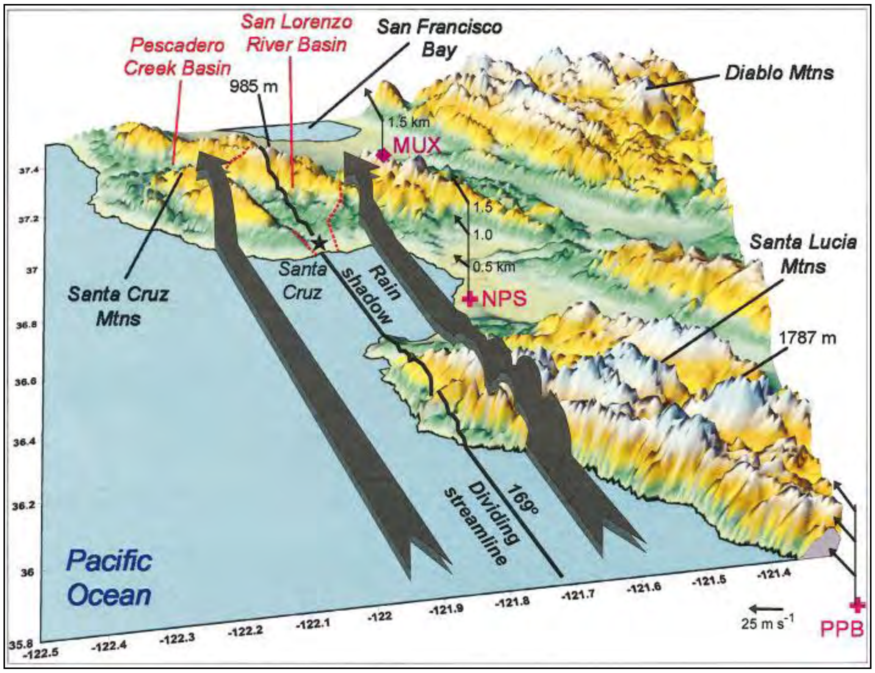

Figure 7. Illustration of a moist airstream approaching the coast south of San Francisco, i.e., an atmospheric river, that is being influenced by the complex terrain of the region. These influences include the creation of a "dividing streamline" that separates rain shadowed regions downwind from those that will receive the brunt of the storm's heavy precipitation. In this event, record flooding occurred on Pescadero Creek, while the San Lorenzo watershed received less rainfall since it was in the rain shadow and thus flooding there was less severe (Ralph et al. 2003)

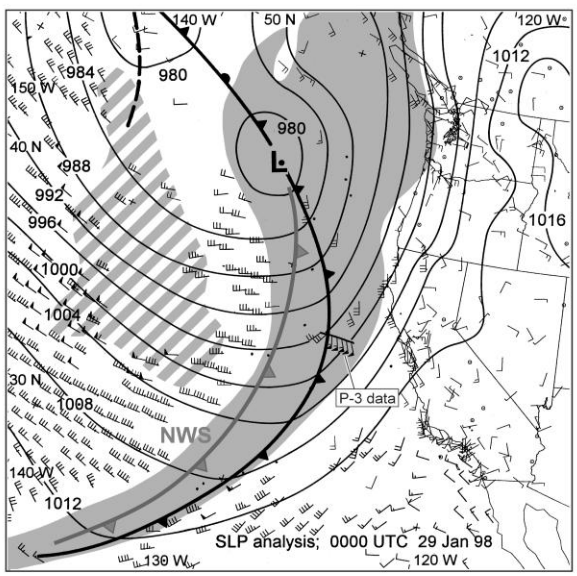

Figure 8. Illustration of uncertainties in the offshore position of the cold front (bold black line with triangles) in a land-falling Pacific winter storm just offshore of the San Francisco Bay Area. The NOAA P-3 research aircraft observed the cold front (and its associated atmospheric river) roughly 200 km east of where satellite-based analysis suggested it was located (gray-shaded front). This translates to the heavy rain arriving several hours prior to when it would have been expected. Surface fronts, sea level pressure (contours; mb), winds (barbs) and cloudy area (solid shading). Winds observations are from several sources; surface observations over land; over the ocean they are

primarily from cloud-tracking by satellite and are at altitudes of 900-700 mb; from the P-3 aircraft. Hatched shading denotes region of strong surface winds observed by SSM/I satellite.

- Buoy-mounted wind profiler/offshore ARO: Past efforts led to a test of this possibility on a buoy. The main advance was the development of software to account for buoy motion and evaluation of potential problems with sea clutter. Two main engineering hurdles were not overcome at that time, i.e., hardening the equipment for operation in the ocean environment, and providing adequate power. While it was deemed technically feasible to harden the equipment for operation in the ocean environment, the power requirements were not seen as resolvable. However, recently the possibility has arisen for a new low-power approach to wind profiling. While promising, this new method, called "FMCW" remains to be demonstrated. Thus, the offshore ARO element of Phase 4 requires significant further development and testing, and includes risk that the technology may not be feasible.
- Airborne reconnaissance: During the CALJET/PACJET experiments, NOAA's P-3 research aircraft was deployed off the west coast and observed ARs before they reached the coast. In one particularly strong AR, the P-3 detected that the strongest part of the storm was approaching the coast near the Bay area several hours prior to what was being predicted at the time. Through radio communications, these data were provided to NWS, and contributed to the issuance of a rare "severe storm watch" ahead of the actual landfall of a line of heavy rain, high winds and severe thunderstorms. This led to a concept for a "NEXRAD-in-the-sky," i.e., a radar on an airplane. Since that time, it has also become feasible to use simpler aircraft to release dropsondes into storms offshore. These descend slowly from the aircraft to the sea and provide data nearly identical to what is provided by balloon soundings launched regularly from land, and that is a foundation of current weather prediction (the absence of these offshore is one of the major reasons west coast storm prediction is so challenging).

These observations could be made with an offshore ARO roughly 100-500 km west of the coast, and by aircraft in similar regions and even broader areas (Figure 9). Both have the potential to allow earlier detection of key meteorological conditions associated with strong ARs. Through assimilation of these data into specialized numerical model runs, it would also be likely that these data could help with numerical weather predictions, especially since assimilation of vertical profile information is known to be much more effective than assimilating measurements of conditions at the earth's surface.

Neither of these solutions within Phase 4 is inexpensive, but they each could be "game changers" for west coast prediction of high-impact precipitation events in the Bay Area. Development of these methods for this region would serve as an example that could be applied to other vulnerable regions, such as Portland, Seattle and Los Angeles.

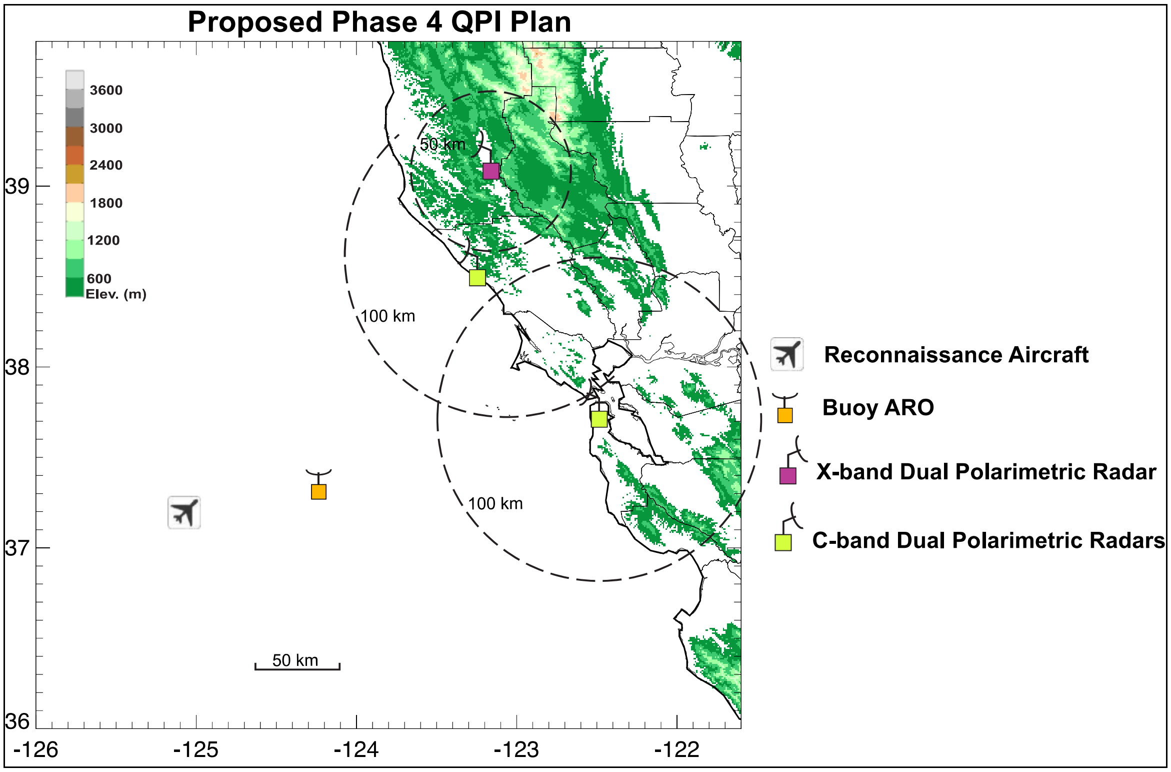

Figure 9. Same as Fig. 2, except for Phase 4. Only the proposed scanning radar deployments are shown.

9. Benefits

Water management responses for a spectrum of weather and climate forecast time frames are summarized in Table 2; these relate to benefits which might be obtained per the time frames. The time frames range from real-time (current) updates on weather and river flow conditions, to short- and near-term seasonal forecasts, and ultimately to long-term climatic-type forecasts. Depending on the water management purpose there are various actions which might be taken to maximize performance and/or to mitigate adverse impacts of too much or too little water.

One example of benefits is associated with increased lead time. A flood warning system yields direct and indirect, tangible and intangible benefits due to increased mitigation time available prior to the onset of flooding. The direct tangible benefit - the inundation damage reduction - can be computed with standard expected damage computation procedures, using modified depth-damage functions that include mitigation time as an independent variable and accounting for improvements to the efficiency of response due to the implementation of the flood warning system. A study by Carswell et al (2004) described how these damage reduction benefits are estimated. An example is the benefits expected with increasing flood forecast lead time from 12 hours to 24 hours which would allow a homeowner to move belongings and avoid $5000 in damages to contents (Table 3). Projecting over 10,000 homes and assuming 80% participation, the total benefits would be $40 million.

Beyond the short term, a wide variety of water management actions can be informed by better precipitation monitoring and forecasting. For reservoir operations there is a competition between storage space reserved for flood storage and use of that storage for conservation purposes to supply municipal, irrigation, hydropower and environmental enhancement purposes. There are fundamental trade-offs between competing purposes, and considerations of timing of storage and releases play an important role in efforts to maximize aggregate benefits across all water users.

Table 2 Water management responses and benefits for forecast leads

Time Frame / Purpose	Nowcast (0 min – 3 hrs)	Near Real-time (6 hr – 24 hrs)	Short-term (1 day – 3 days)	Near-term (1 wk – 3 mon)	Mid-term (6 mon – 2 yrs)	Long-term (5 years+)
Water Supply	Status assessment; Intake operations	Intake and outlet operations	Reservoir FBO; Emergency conservation	Delivery sched.; Reservoir FBO; Conservation	Over-year drought mit.; Conservation	Capacity devel; Demand mana; Climate adapt.
Hydro-Power	Release operations	Reservoir FBO	Reservoir FBO; Demand sched.	Reservoir FBO; Demand sched.	Over-year drought mit.	Capacity devel.; Climate adapt.
Flood Mitigation	Flood status assessment	FF warning; Response deploy; System opt.	Flood warning; Response deploy; Reservoir FBO	Flood warning; Response deploy; Reservoir FBO	Over-year storage allocation	Flood frequency; Capacity devel; Climate adapt.
Ecosystem Enhancement	Status assessment	Threat assess; River & Reservoir FBO	Threat assess; River & Reservoir FBO	Threat assess; River & Reservoir FBO	Threat assess; Capacity devel; Drought mit.	Ecosystem & Capacity devel; Climate adapt.
Water Quality	Status assess; Real-time control	WW capture & treatment	Threat assess; Sys. optimize	Threat assess; Capacity devel; Sys. optimize	Threat assess; Capacity devel; Sys. optimize	Capacity devel; Climate adapt.
Recreation	Weather status; Warning	Event scheduling	Reservoir FBO	Reservoir FBO	Capacity development	Capacity development
Fire Mitigation	Weather status; Warning	Weather status; Warning	Threat assess; Mitigation deployment	Threat assess; Mitigation deployment	Threat assess; Mitigation deployment	Mitigation planning; adaptation

Phase 1 | Phases 2 & 3 | Phase 4

Table 3 Residential damage reductions with lead time

Depth (ft)	Lead Time (hrs)						
	0	1	8	12	24	36	48
1	0	2	5	6	8	8	9
3	0	3	7	8	13	14	15
5	0	3	7	8	13	15	17
10	0	5	12	14	20	25	29
20	0	5	12	13	20	25	29

Note: Values shown are reductions in damage as percentage of $100K contents value. (adapted from Carswell et al 2004)

10. Summary

The City of San Francisco and agencies in the San Francisco Bay region require accurate QPI information to accommodate critical water management needs. Leveraging of NOAA assets and CA-DWR investments that are currently in place and planned as part of HMT-West, high quality QPI for the area can be achieved at reasonable cost through a combination of state-of-the-art observations, data assimilation, modeling, and decision support efforts (HMT-MAPS). The plan outlined herein is based on a phased approach. The phases build successively from prototype solutions (Phase 1), with observations concentrated near-shore that can be implemented relatively quickly to demonstrate the concept feasibility, to solutions that incorporate observations from farther offshore (Phases 2 and 3). These more sophisticated solutions employ more advanced implementations of HMT-MAPS, including new approaches to assimilate the observational data and provide Nowcast/QPF information at high spatial and temporal resolution (see Tables 4 - 6). A 0.5.-1.0 year time period, subsequent to the implementation of each phase, will be used to quantify the added value of the observations and products associated with each solution. The tiered approach is outlined in Figure 2. The ROM costs for these efforts over 10 years are:

- Phase 1 – Russian River Basin and City of San Francisco Initial Prototyping ($3M , 1 year)
- Phase 2 – North Bay and Initial Offshore/Upwind Sampling (+$8M/$12M; $2m/yr for 4 years)
- Phase 3 – Regional Offshore/Upwind Sampling (+$12M/$24M; $4m/yr for 3 years)
- Phase 4 – Offshore observing platforms (+$16M/$40M; $4M/yr for 4 years)

This plan takes advantage of more than a decade of research, prototyping and implementation of a statewide network. These past and ongoing investments (exceeding $50 M over 10 years) have created the knowhow and expertise to recommend the solutions described herein, to do so with confidence in their feasibility and ultimately their execution. Implementing these solutions would create a 21st Century capability for this key region, helping to meet a range of critical demands for water information, and serving as a model for other, similar regions.

The NOAA HMT team would be joined by the NWS Office of Hydrologic Development in developing and deploying the San Francisco Bay QPI system. The OHD will provide expertise in various aspects of radar-rainfall sensing, multi-sensor data assimilation, ensemble forecasting and verification. The OHD is also leading efforts for development of a National Water Center which will serve as a research and development nexus for next-generation hydrometeorological monitoring, modeling and decision support services for the nation.

Table 4 Monitoring assets associated with each implementation phase.

Phase	**Observational Sensors**									
	G-D	Coastal ARO	S-Profs	X-Band	C-band North	C-band South	KPIX	KGO	Off-shore ARO	Aircraft Recon
SC Proposal	X		X				X	X		
Phase 1	X	X	X	X			X	X		
Phase 2	X	X	X	X	X		X	X		
Phase 3	X	X	X	X	X	X	X	X		
Phase 4	X	X	X	X	X	X	X	X	X	X

G-D=gauges and disdrometers

Table 5 Assimilation and Prediction assets associated with each implementation phase.

Phase	Prediction and Assimilation Components								
	Refore-cast	Hydro tracking and/or model	Existing HMT ensembl e	Hi-Res ensembl e	Land Surface Assim	Nowcast	Assim radar data into MPE-FFMP	3D-4D NWP assim	Assim radar data into NWP
SC Proposal	X	X					X		
Phase 1	X	X	X				X		
Phase 2	X	X		X	X	X	X		X
Phase 3	X	X		X	X	X	X	X	X
Phase 4	X	X		X	X	X	X	X	X

Table 6 System Integration assets associated with each implementation phase.

Phase	Implement IWRSS Findings	Russian River Plan	Disseminate adv. QPE/QPF grids	Disseminate FFMP	Disseminate regional precip/WX data	Disseminate hi-res QPE/ QPF/PQPF
SC Proposal	X	X				
Phase 1		X	X			
Phase 2			X	X	X	
Phase 3			X	X	X	X
Phase 4			X	X	X	X

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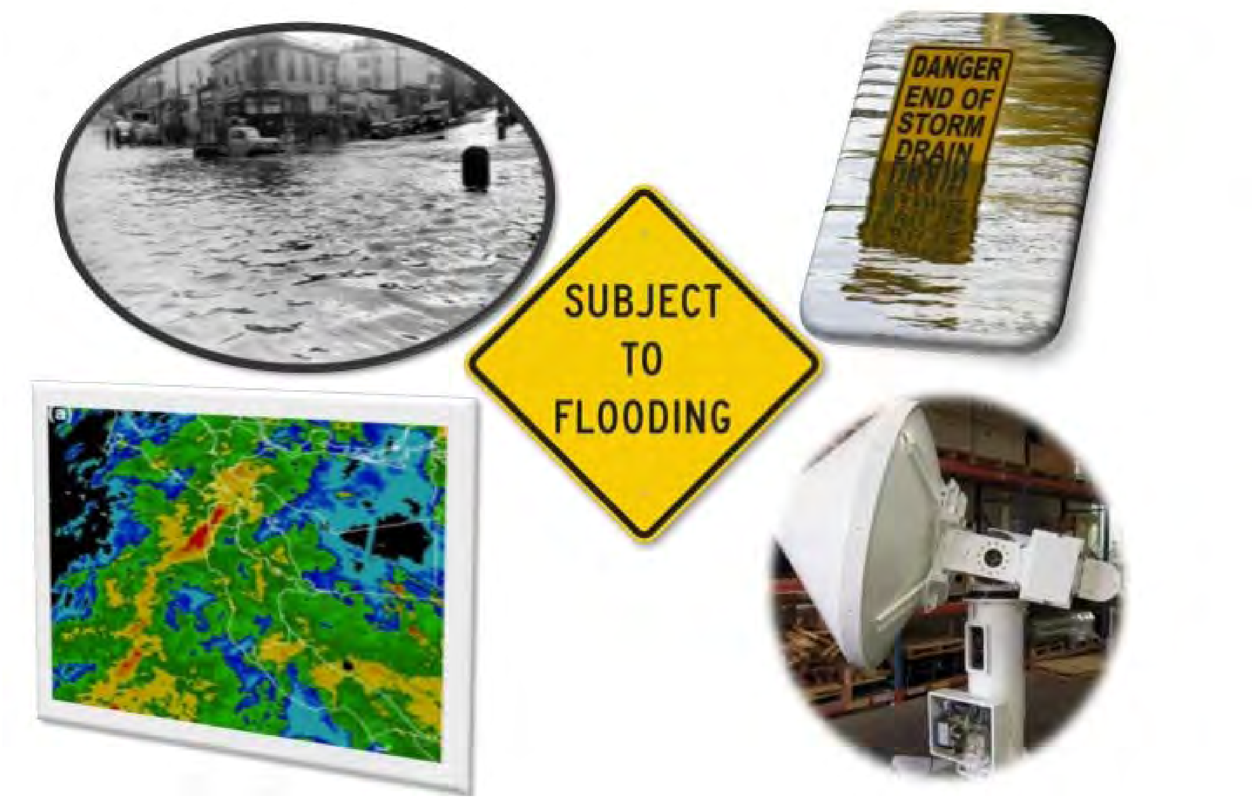
A Vision for Improving Precipitation Monitoring and Prediction in the San Francisco Bay Area



National Oceanic and Atmospheric Administration
Hydrometeorology Testbed Program

29-Aug-11

Vision: *Provide San Francisco Bay area stakeholders with state of the art "city block" scale quantitative precipitation information (QPI) that can be used to minimize urban flooding, reduce or eliminate combined sewage discharges into San Francisco Bay, and greatly improve water quality.*

Challenge: The lack of accurate, high resolution data and reliable forecasts on precipitation events in the San Francisco Bay region causes major problems for water managers. An example illustrates the problem. The City of San Francisco's sewer division must manage mixed sanitary and storm runoff flows to prevent overflows into the bay and ocean which result in beach closures and monetary penalties. The lack of timely and accurate precipitation data and forecasts for high impact short-duration events limits their ability to optimize the storage-transport system to minimize adverse impacts. Limitations of precipitation monitoring and forecasting impact many other jurisdictions in the San Francisco Bay region in similar ways.

Proposed Solution: Information on advances made by the highly successful NOAA Hydrometeorology Testbed (HMT; http://hmt.noaa.gov/) project has prompted several San Francisco Bay water managers to ask if the approach can be extended from a few test areas to encompass the entire San Francisco Bay region. A state-of-the-art monitoring and prediction system (MAPS) for the Bay area could be achieved through strategic placement of additional precipitation radars and other instrumentation such as automated rain gauges, and integration of these data into advanced atmospheric models. This would provide a region-wide basis for accurately measuring and tracking precipitation at high time and space resolution (i.e., city block scale information updated every 1-2 minutes); radars pointing offshore over the ocean could provide early lead time on incoming heavy rain be it water-laden air masses known as atmospheric rivers (http://hmt.noaa.gov/news/2010/122010.html) or strong convective cells bringing short but heavy burst of rain stressing the drainage system. Together with NOAA's advanced precipitation nowcasting and forecasting modeling systems providing high resolution precipitation forecasts out to 12 hours, it is expected that substantial benefits from MAPS could be realized for enhanced flood warnings and for other water management purposes.

To achieve a state-of-the-art MAPS in the San Francisco Bay area, the HMT is recommending a Proof-of-Concept (PoC) to identify QPI gaps and determine the added benefit of advanced hydrometeorological sensors, software and system deployment to Bay area stakeholders. Outcomes of the PoC would inform a 4-phase MAPS implementation paced over eight years. Resources for instrumentation, software hydromet sensors, and software and system deployment would range from $3M in year 1 to $4M to $8/year in years 2 to 5; total system development and deployment costs would be in the $40M range.

- Phase 1a –City of San Francisco and Russian River Basin PoC
- Phase 1 - Install gap-filling radars and integrate into gridded high resolution QPE grids
- Phase 2 – North Bay and Initial Offshore/Upwind Sampling + high resolution forecasting
- Phase 3 – Regional Offshore/Upwind Sampling and San Francisco networked radar system for high resolution monitoring and nowcasting
- Phase 4 – Offshore Observing Platforms

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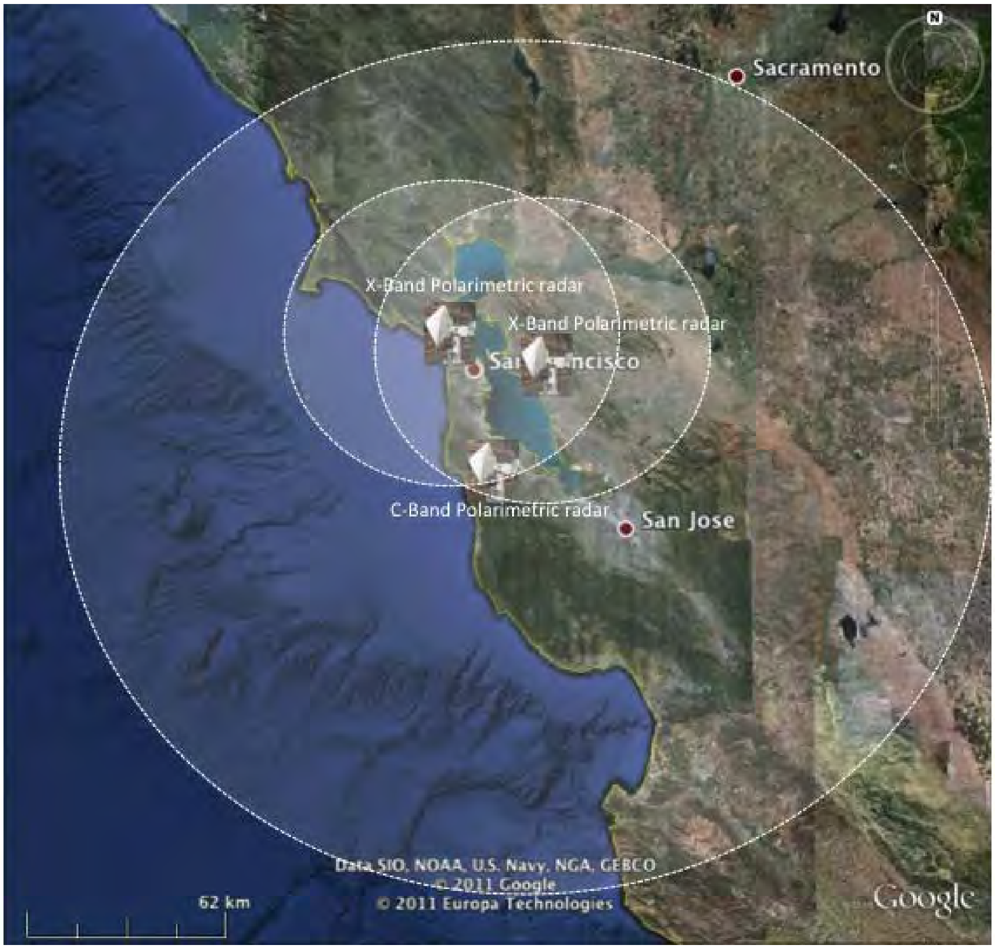
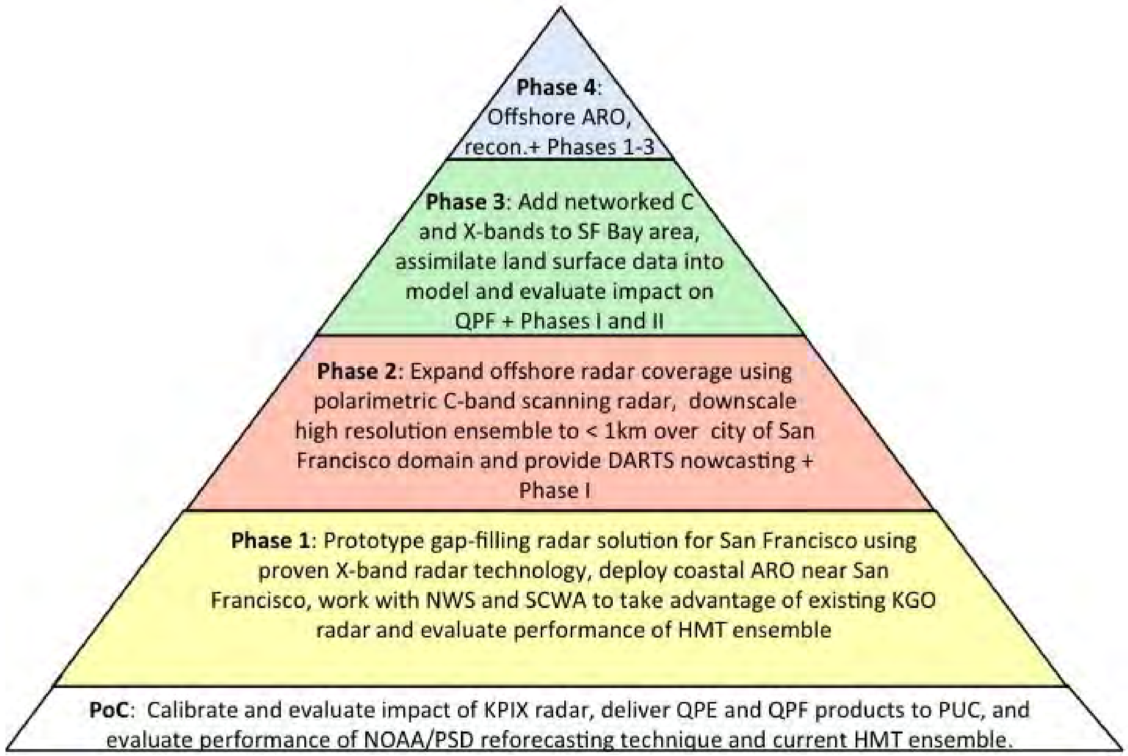
29-Aug-11



Proposed networked radar system over San Francisco as part of Phase 3. White circle indicates approximate 150 km range for the C-band and 40 km range for the X-band radars. C-band provides 3-4 hour lead time and the X-bands provide high resolution (1-2 minute update and city block scale) precipitation monitoring and nowcasting. In addition to providing high resolution QPI, the networked radar system eliminates single point of failure problems that currently impact NEXRAD. Other instrumentation as part of Phase 3 is not shown.



A Proof-of-Concept (PoC) and 4-phase approach for new observations, assimilation, prediction and systems integration to improve San Francisco Bay Region QPI.