



Technical Balance with Nature

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August 17, 2012

Dr. Brock Bernstein
Workshops Facilitator
State Water Resources Control Board
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Subject: Written Materials for Comprehensive (Phase 2) Review and Update to the Bay-Delta Plan, Workshop 1: Ecosystem Changes and the Low Salinity Zone, September 5-6, 2012

Dear Dr. Bernstein:

The Sacramento Regional County Sanitation District (SRCSD or District) appreciates the opportunity to provide written information, including scientific and technical reports, responding to questions listed in the June 22, 2012 "Notice of Public Workshops and Request for Information; Comprehensive (Phase 2) Review and Update to the Bay-Delta Plan" (Notice). By a subsequent e-mail, you have informed us that the panel identified for SRCSD presenters is the In-Delta Water Interests. At Workshop 1 on September 5 and 6, Dr. Michael Bryan of Robertson-Bryan, Inc. will present on SRCSD's behalf on the topics of water quality, data quality objectives, and a Delta Regional Monitoring Program

It had been SRCSD's understanding that this specific upcoming process would focus on review and update of water quality objectives in the current Bay-Delta Plan that pertain to flow and salinity and similar issues, and that nutrients would be addressed through existing Water Board processes, such as the development of nutrient numeric endpoints. However, it appears that hypotheses regarding toxicants, including ammonia/um, or nutrients in general, will be advanced by some stakeholders as matters requiring the State Water Board's attention during this process. Therefore, SRCSD is submitting information on these issues. With this letter we enclose three technical memoranda, with authors and general subject matter as follows:

Board of Directors Representing:

- County of Sacramento
- County of Yolo
- City of Citrus Heights
- City of Elk Grove
- City of Folsom
- City of Rancho Cordova
- City of Sacramento
- City of West Sacramento

- Stan Dean
District Engineer
- Ruben Robles
Director of Operations
- Prabhakar Somavarapu
Director of Policy & Planning
- Karen Stoyanowski
Director of Internal Services
- Joseph Maestretti
Chief Financial Officer
- Claudia Goss
Public Affairs Manager

- Dr. Michael Bryan, Robertson-Bryan Inc, RMP, pesticides and regional monitoring ;
- Dr. Diana Engle, Larry Walker Associates Inc., direct and indirect effects of ammonia; and
- Cameron Irvine, CH2MHill, data quality objectives, invasive clams, and contaminants.

Each author has a different area of expertise (see enclosed resumes); therefore, scientific discussion in the memoranda includes analysis of the same science or research, but from different scientific disciplines. The authors' varying knowledge of the science/research is complementary, thereby providing the State Water Board members and staff enhanced perspective. SRCSD has always championed the use of

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sound science for decision making, and by submitting this written information it is providing important current scientific information relevant to water quality. We have included recommendations for resolving uncertainty regarding science in the Delta through development of data quality objectives and regional monitoring for adaptive management.

In addition to the three memoranda described above, we are submitting a number of technical documents and other material for the State Water Board's consideration. SRCSD wishes to ensure that all of this material, as well as material SRCSD previously submitted for the 2010 Delta Flow Criteria Informational Proceedings, be included in the administrative record for the Phase II Review and Update to the Bay-Delta Plan. We regret the redundancy if any of these documents is already part of the record. In addition, the video recording of the "Other Stressors Panel" from that 2010 Proceeding is being provided. Lastly, we are providing scientific resources that were submitted to the National Research Council Committee on Delta Sustainability to be included in the administrative record for the Phase II Review and Update to the Bay-Delta Plan.

In addition, we are hand delivering to the State Water Board a hard copy and electronic version of this letter and attached technical memoranda, CD of references in the memos; scientific research provided to the National Research Council in January and December 2010; and a DVD of the video recording of the "Other Stressor Panel" from the 2010 Delta Flow Criteria Informational Proceedings.

Finally, the three memoranda identified above, and other materials provided here, may also be relevant for Workshop 2, and we will separately communicate in regard to SRCSD's participation in Workshop 2.

We again thank you for the opportunity to provide scientific and technical input to inform and prepare the Board members to make science-based decisions when updating the Bay-Delta Plan. If you need further information, please contact me at 916-876-6030 or dornl@sacsewer.com.

Sincerely,



Linda Dorn
Environmental Program Manager

cc: Stan Dean, District Engineer
Prabhakar Somavarapu, Director of Policy and Planning
Terrie Mitchell, Legislative and Regulatory Affairs Manager
Kurt Ohlinger, Chief Scientist
Danielle Wilson, ICF

Attachments: August 16, 2012, Technical Memorandum, Robertson-Bryan, Inc., Dr. Michael Bryan,
Subject: Additional Scientific Information for the State Water Resources Control Board's
Comprehensive (Phase 2) Review and Update of the Bay-Delta Plan

August 15, 2012, Memorandum, Larry Walker Associates, Dr. Diana Engle, Subject: Information for Consideration by the State Water Resources Control Board during the Update/Review of the Bay-Delta Plan

August 16, 2012, Technical Memorandum, CH2MHill, Cameron Irvine, Additional Scientific and Technical Information for the SWRCB Comprehensive (Phase 2) Review and Update to the Bay-Delta Plan

CD References from Technical Memos. References not listed can be found on the Water Boards website from the 2010 Delta Flow Criteria Informational Proceedings
http://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/deltaflow/sac_rcsd.shtml

CD “Scientific Resources Provided to the NRC Committee by Sacramento Regional County Sanitation District, January 24, 2010”

CD “Scientific Resources Provided to the NRC Committee by Sacramento Regional County Sanitation District, December 8, 2010”

DVD video recording of the “Other Stressors Panel” from March 2010 Delta Flow Criteria Informational Proceedings



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TECHNICAL MEMORANDUM

Date: August 16, 2012

To: Linda Dorn, SRCSD
Terrie Mitchell, SRCSD

From: Michael Bryan, Ph.D.

Subject: Additional Scientific Information for the State Water Resources Control Board's
Comprehensive (Phase 2) Review and Update of the Bay-Delta Plan

Introduction

The State Water Resources Control Board (State Water Board) has scheduled informational workshops in advance of its consideration of changes to the Water Quality Control Plan for the San Francisco/Sacramento-San Joaquin Delta Estuary (Bay-Delta Plan). The State Water Board is approaching update of the Bay-Delta Plan in a phased manner. The workshops currently scheduled for September 2012 are intended to elicit input from stakeholder experts with regard to recent scientific and technical information the State Water Board and staff should consider in its update of the Bay-Delta Plan. Specifically, the State Water Board has requested input regarding new or additional scientific information that has been developed or was not fully considered in the 2009 Staff Report¹ or 2010 Delta Flow Criteria Report².

Related to the receipt of information at the scheduled workshops, the State Water Board has requested that workshop participants submit written information, including scientific and technical report summaries, prior to the workshops. This memorandum conveys information concerning specific water quality issues. While we have understood that the State Water Board intends to defer specific water quality constituent concerns such as pesticides and toxicity to the Regional Water Quality Control Boards (i.e., Region 2 and Region 5), this information is provided, as you have requested, for the State Water Board's consideration with regard to its continued coordination and collaboration with the Regional Water Boards and for consideration with regard to any new or revised flow objectives and related purposes.

Issues for Consideration – New Scientific Information

Delta Water and Sediment Quality

As a potential stressor related to the pelagic organism decline (POD), toxicity and contaminants have been the subject of scientific scrutiny, particularly that linked to pesticides. Since adoption

¹ State Water Board. 2009. Periodic Review of the 2006 Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary, Staff Report. Adopted by Resolution 2009-0065. August 4, 2009.

² State Water Board. 2010. Development of Flow Criteria for the Sacramento-San Joaquin Delta Ecosystem. Prepared pursuant to the Sacramento-San Joaquin Delta Reform Act of 2009. Adopted by Resolution 2010-0039. August 3, 2010.

of the 2009 Staff Report, several notable related studies and reports have been published, or will be published in the imminent future.

While the ability to predict future water quality issues related to changing flow objectives is difficult, the State Water Board should consider implementation of a comprehensive monitoring program as part of its supporting implementation program. The following list of citations present tools and recommendations for how such a comprehensive monitoring program could be organized, and thus are worthy of the State Water Board's review and consideration. Citations and brief summaries are provided below.

Johnson, M.; I. Werner; S. Teh; F. Loge. 2010. *Evaluation of Chemical, Toxicological, and Histopathologic Data to Determine Their Role in the Pelagic Organism Decline*. April 20, 2010.

The State Water Board, in collaboration with the Central Valley Regional Water Quality Control Board, contracted with the University of California in the preparation of the above-cited report, often referred to by its short name, the *Contaminants Synthesis Report*. The Contaminants Synthesis Report represents the single most comprehensive gathering of recent and historic contaminant (pesticide, metals, toxicity, histopathology) data for the Delta and nearby surface waters. The report approached the possible role of contaminants through an evaluation of six hypotheses addressing whether contaminants could be wholly or partially responsible for the POD. In general, the study found that there was insufficient data to make definitive conclusions regarding contaminants and the POD. While the study could not completely eliminate contaminants as the cause of the POD, the study concluded that contaminants were unlikely to be a major cause of the POD.

Perhaps more pertinent to the State Water Board's current efforts regarding update of the Bay-Delta Plan or Delta issues generally, the study concluded with a series of recommendations regarding current and future Delta monitoring programs. The studies comprehensive list of recommendations for future Delta monitoring programs stem from the deficiencies the authors encountered with the manner contaminants are currently and have historically been collected. In response to these deficiencies, it was recommended that a long-term monitoring program be developed such that the involvement of contaminants in future phenomena such as the POD could be identified. Such a program would include an element that would allow the rapid identification of new and emerging contaminants. Moreover, toxicity testing should accompany analytical chemistry, and where appropriate, histopathology should be applied to a targeted selection of samples. Toxicant effects are often observable at the cellular level well before effects are observed at population levels.

Hoogeweg, C. G.; W.M. William; R. Breuer; D. Denton; B. Rook, C. Watry. 2011. *Spatial and Temporal Quantification of Pesticide Loadings to the Sacramento River, San Joaquin River, and Bay-Delta to Guide Risk Assessment for Sensitive Species*. CALFED Science Grant #1055. November 2, 2011

The authors of this modeling study performed a risk assessment whereby the spatial and temporal co-occurrence of listed special status species with that of 40 different present-use pesticides were estimated. The modeling investigation estimated pesticide loadings to surface waters from agricultural and urban land uses based on actual pesticide use as recorded in the California Department of Pesticide Regulation's (DPR) pesticide use reporting database. Pesticide loadings from sites of application were estimated based on various environmental fate models, resulting in both spatial and temporal estimates of concentration, and "indicator days" (**Figure 1**), defined as a risk quotient greater than one for at least one pesticide. Risk quotients were expressed as the ratio of the estimated concentration to a toxicity benchmark. Ultimately, the spatial and temporal occurrence of special status species were combined with the indicator day estimates in a manner allowing approximations of toxicological risk (**Figure 2**, shown in terms of 80th percentile co-occurrence estimates). Areas of potential concern are also noted, where high levels of co-occurrence were estimated and monitoring is currently not conducted, or conducted infrequently.

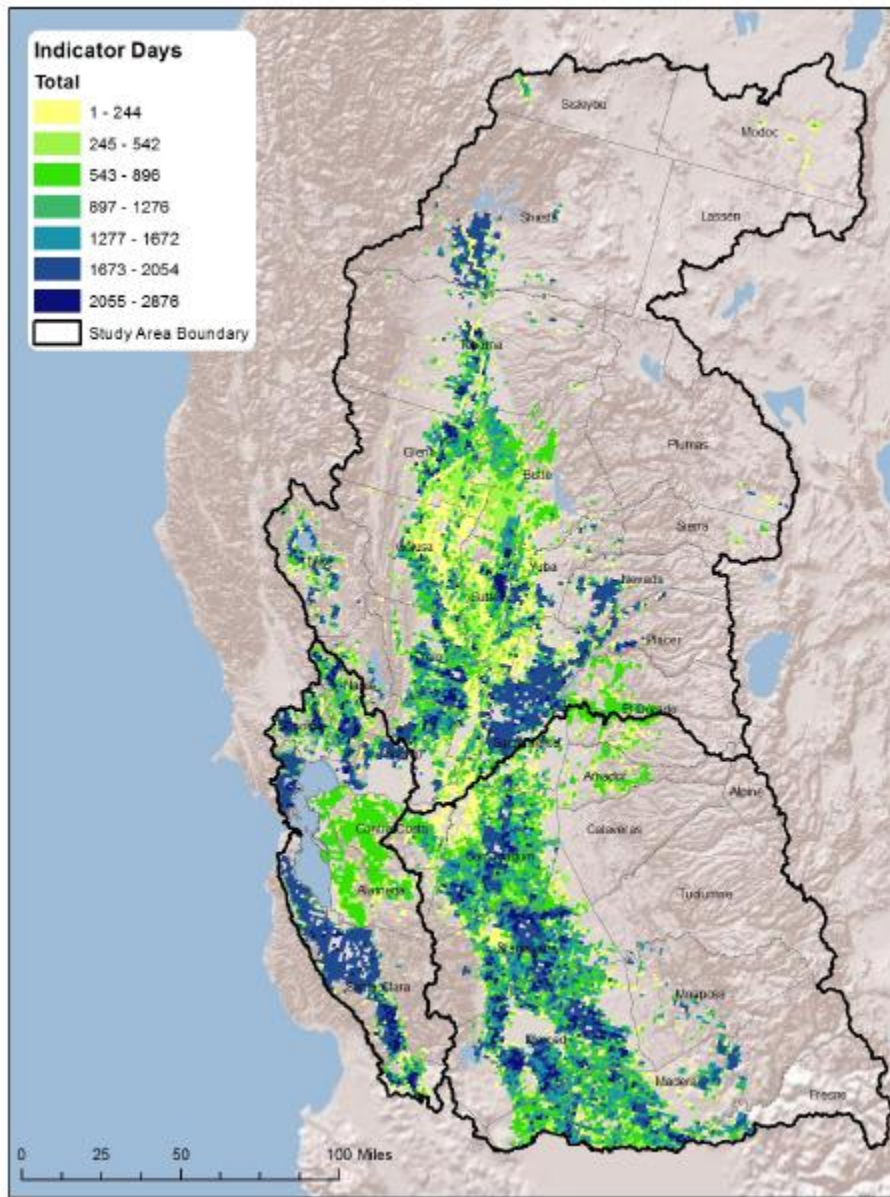


Figure 1: Spatial distribution of total indicator days for the period 2000-2009 (Hoogeweg et al., 2011)

While the presence of an indicator day is not a formal prediction of expected toxicity, the density of indicator days does provide information on potential risk, especially when combined with the occurrence of species of concern. The risk estimates generated provide a logical and intelligent foundation for planning future possible monitoring activities for pesticides and/or pesticide related toxicity.

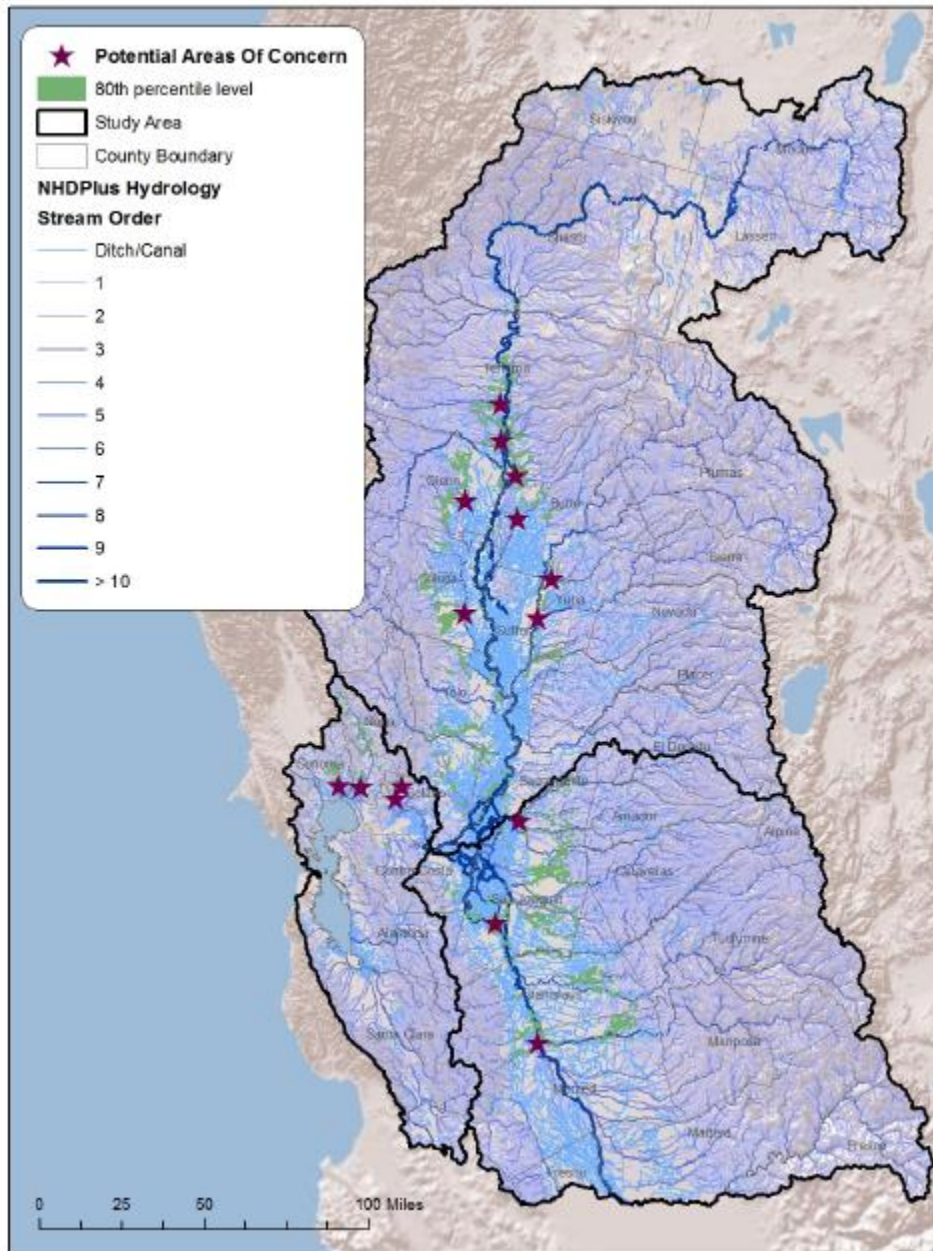


Figure 2: Spatial distribution of 80th percentile co-occurrence estimates and potential areas of concern (Hoogeweg et al., 2011)

Southern California Coastal Water Research Project. *Assessing the Direct Effects of Sediment Contamination in the Sacramento and San Joaquin River Delta*. In preparation. Preliminary findings at:

<http://www.sccwrp.org/ResearchAreas/Contaminants/SedimentQualityAssessment/>

For many hydrophobic contaminants, sediments are long-term integrators of contaminant exposure and as a result, the potential for contaminated sediments to impact aquatic ecosystems is often discussed (see the citation of Johnson et. al.

2010). Until recently, there has been no single comprehensive survey of Delta sediment quality. The Southern California Coastal Water Research Project (SCCWRP) performed such a comprehensive survey in 2007 and 2008. A total of 144 monitoring sites were analyzed for toxicity to the epibenthic arthropod *Hyalella azteca*, of which a subset of 75 were subject to the full sediment quality triad analysis, including sediment chemistry, toxicity, and benthic community composition. Overall, toxicity in sediments was observed to be low, with only 3% of samples found to be acutely toxic (Figure 3). While a final study report summarizing the full sediment quality triad results is pending (expected to be finalized in 2012), concern over Delta sediment quality overall appears to be relatively low.

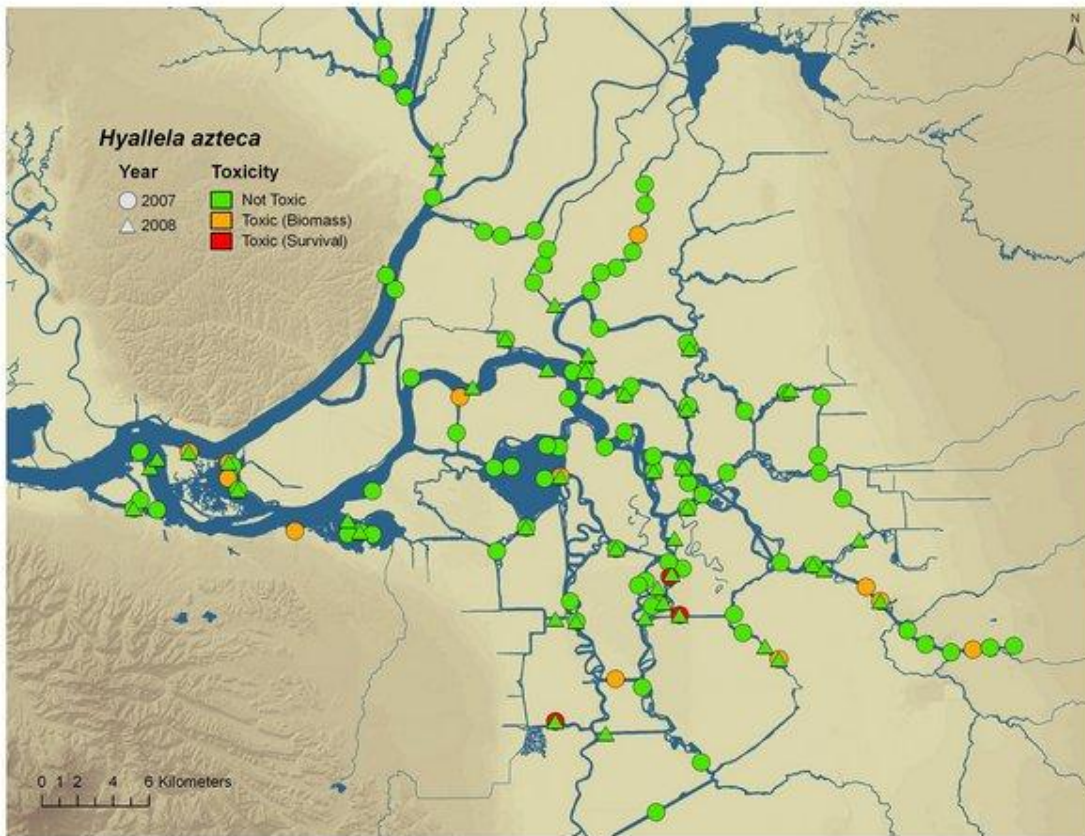


Figure 3: Toxicity to *Hyalella azteca* in Delta sediments, 2007-2008. (SCCWRP, in preparation)

Pyrethroid Insecticides and POTWs

Research in the field of pyrethroids has advanced considerably since preparation of the 2009 Staff Report. Much recent attention has been given to pyrethroid insecticides, including pyrethroids discharged in POTW effluent. Since adoption of the 2009 Staff Report, several notable related studies and reports have been published, or will be published in the imminent future.

While the following summary of recent studies focuses on the issue of pyrethroid insecticides in POTW effluent, it is worthy to note that the most recent research continues to confirm that the prevalence of pyrethroid related toxicity is centered around urban usage and storm water runoff. In response, DPR has recently taken significant and aggressive actions to curtail the environmental impacts of urban pyrethroid usage. Surface water protection rules were adopted by DPR in July 2012 that target the application of pyrethroids for structural pest control and landscape maintenance by professional pest control applicators. In a recently published modeling effort, an 80% reduction in pyrethroid related toxicity units was predicted³.

Weston, B.P.; M.J. Lydy. 2010. Urban and agricultural sources of pyrethroid insecticides to the Sacramento-San Joaquin Delta of California. *Environ. Sci. Tech.* 44:1833-1840.

In this often cited research article, Weston and Lydy present pyrethroid monitoring results, including analysis of POTW effluent for pyrethroids and acute toxicity to *Hyalella azteca*. Pooling of results across three separate POTWs employing varying treatment technologies was necessary for the authors to find a statistical correlation between pyrethroid concentration and expected toxic effect. Nevertheless, no statistical correlation existed when data were reviewed on an individual POTW basis. At times pyrethroids were present in effluent at levels expected to cause substantial toxicity, but no toxicity was evident, and at times substantial toxicity was present, but no pyrethroids were detected.

While the article is often cited out of concern that POTWs may be discharging pyrethroid burdened toxic effluent, the article is in fact most notable for its detection of pyrethroids in final effluent. Pyrethroid insecticides are extremely hydrophobic, and very high levels of removal would be expected. Moreover, the amount of pyrethroid that passes through a POTW would predominantly be associated with suspended solids and organic colloids, and thus be biologically unavailable. This expectation has led others, including Weston and Lydy, to conduct follow-up studies to confirm whether pyrethroids in POTW effluent are truly bioactive.

Presently Unpublished Follow-Up Studies

Robertson-Bryan, Inc. *In prep.* Easterly Wastewater Treatment Plant Water Quality Monitoring Plan: Final Report for Monitoring Pyrethroids in Effluent and Receiving Water.

Any consideration of pyrethroid insecticides in POTW effluent discharged to the Delta must include the work of two critical follow-up studies. The City of Vacaville's Easterly Wastewater Treatment Plant (EWWTP) monitored pyrethroids and acute toxicity to *Hyalella azteca* in influent (chemistry only), effluent and receiving waters. While removal of pyrethroids at the EWWTP was greater than 95%, specific pyrethroids were detected occasionally in final effluent, but they were never found to be acutely lethal, based on the test of significant toxicity (TST). As similarly observed by Weston and Lydy (2010) at EWWTP, actual observed bioassay effects were poorly correlated with actual

³ Jorgenson, B.C. 2011. *Off-Target Transport of Pyrethroid Insecticides in the Urban Environment: An Investigation into Factors Contributing to Washoff and Opportunities for Mitigation*. Dissertation submitted in completion of Ph.D. by Jorgenson, Brant Coberly. University of California, Davis. 2011.

observed effluent concentration when utilizing a concentration addition toxic unit model, where a toxic unit is defined as the ratio of pyrethroid concentration to its 50% lethal concentration (**Figure 4**). The use of whole effluent, total recoverable pyrethroid analytical measurements to predict acute toxicity in *Hyaella azteca* substantially overestimated actual effects. However, accounting for phase partitioning, and the truly bioavailable dissolved pyrethroid fraction of an effluent sample, resulted in improved statistical correlation between predicted and actual effects to *Hyaella azteca*. Such observation highlights the importance of bioavailability when selecting the method of analytical measurement. A final study report is currently in preparation.

Analytical techniques for measuring dissolved pyrethroid fractions currently cannot reliably achieve necessary detection limits. The demonstrated improvement in statistical correlation between actual and predicted toxic effects in EWWTP effluent required calculation of dissolved pyrethroid concentrations through use of phase partitioning theory. This would not have been possible if not for the ongoing research of Parry and Young⁴. Organic carbon normalized pyrethroid distribution coefficients have been measured by Parry and Young for effluent suspended solids collected from the Sacramento Regional County Sanitation District (SRCSD) wastewater treatment plant. Measured distribution coefficients show that nearly all pyrethroid in SRCSD effluent is sorbed to suspended particulate matter, and thus biologically unavailable. While these data remain preliminary, publication is anticipated in 2012.

Such results from EWWTP and SRCSD challenge the simple application of laboratory bioassays, including the use of toxicity identification evaluation (TIE) techniques. Research continues with regard to pyrethroids and POTWs, but the present findings of science remains uncertain.

⁴ Parry, E., and T.M. Young. 2012. Pyrethroid sorption to Sacramento wastewater effluent suspended particulate matter. 40th Annual Winter Colloquium of the Agricultural and Environmental Chemistry Graduate Group.

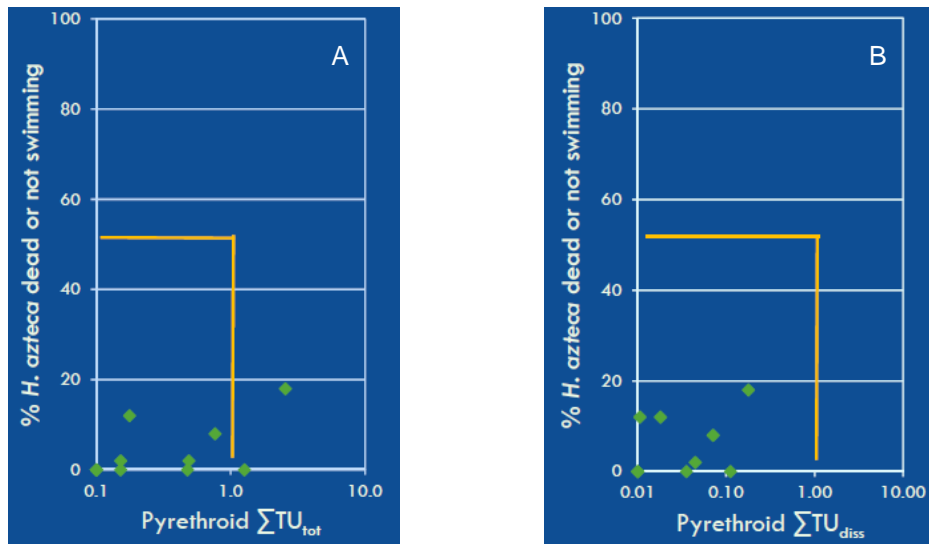


Figure 4: Acute mortality and paralysis in *Hyallolela azteca* bioassays, correlated to the sum of pyrethroid TU's (total recoverable [A] and dissolved pyrethroid basis [B]). The intersection of orange lines represents expected 50% mortality/paralysis at 1 TU. Improved correlation and improved prediction is observed when basing TU calculation on dissolved fraction. (City of Vacaville, in preparation)

Constituents of Emerging Concern

Since adoption of the 2009 Staff Report, several notable studies and reports regarding constituents of emerging concern (CECs) in general, and in the Delta (and its watershed) specifically, have been published.

Anderson, P., N. Denslow, J. E. Drewes, A. Olivieri, D. Schlenk, G. I. Scott and S. Snyder (2012). Monitoring Strategies for Chemicals of Emerging Concern (CECs) in California's Aquatic Ecosystems: Recommendations of a Science Advisory Panel. Southern California Coastal Water Research Project.

In 2009, the SWRCB requested that a “blue ribbon” advisory panel be convened to provide unbiased scientific recommendations for monitoring CECs in oceanic, brackish, and fresh water that receive discharge of treated municipal wastewater effluent and stormwater. This report represents the outcome of the panel process. Contained in the report are:

1. a conceptual, risk-based approach to assess and identify CECs for monitoring in California receiving waters;
2. application of the above framework to identify a list of CECs for initial monitoring;

3. an adaptive, phased monitoring approach with interpretive guidelines that direct and update actions commensurate with potential risk; and
4. research needs to develop bioanalytical screening methods, link molecular responses with higher order effects, and fill key data gaps.

The report focused almost exclusively on treated municipal wastewater effluent and stormwater, and did not address other known sources of CECs (private septic systems, industrial effluents, landfill leachates, discharges from fish hatcheries and dairy facilities, runoff from agricultural fields and livestock enclosures, and land amended with biosolids or manure). Exposure scenarios included an inland freshwater effluent dominated waterbody, coastal embayments, and ocean discharges. For the effluent-dominated freshwater environment, an assumption of no dilution was made, and the list of CECs identified for initial monitoring, based on potential effects to aquatic life, included ten compounds. Because the Delta does not fall into any of the three exposure scenarios, but rather, is an inland freshwater system with substantial dilution available to effluent and stormwater discharges, the reports' findings cannot be easily extended to the Delta. However, it is clear that out of the numerous CECs currently assessed in the report, only a handful may be of concern in the Delta based on current scientific understanding. Considerations of effects of changes in flow on CECs should be limited to those that were identified through the report to have any risk of effects on aquatic life. That said, before an appropriate monitoring paradigm can be established and effectively implemented, standardization of analytical methods used to measure these constituents is needed.

Guo, Y. C., S. W. Krasner, S. Fitzsimmons, G. Woodside and N. Yamachika (2010). Source, Fate, and Transport of Endocrine Disruptors, Pharmaceuticals, and Personal Care Products in Drinking Water Sources in California. Fountain valley, CA, Metropolitan Water District of Southern California and Orange County Water District.

The objectives of this project were to assess the occurrence of a wide range of CECs in drinking water sources to Southern California, including the State Water Project starting from the Delta, to evaluate the impact of treated wastewater discharges, and also to evaluate the fate and transport of these chemicals in the watersheds. Samples were collected quarterly for a year at five Delta locations and analyzed for 50 CECs. As expected, concentrations of target analytes varied by analyte, sample, and location, but virtually every sample had detectable concentrations of at least one analyte. That said, the report acknowledges that “the general consensus is that there is no evidence of human health risk from low levels of the commonly detected [endocrine disrupting chemicals] and [pharmaceuticals and personal care products] in drinking water or drinking water supplies.” Furthermore, the report notes: “standardized analytical methods are needed to ensure high quality data and to be able to compare results from different studies. Currently, approaches from laboratories performing PPCP analysis vary widely on key analytical issues, such as blank contamination and matrix effects.”

Lavado, R., J. E. Loyo-Rosales, E. Floyd, E. P. Kolodziej, S. A. Snyder, D. L. Sedlak, and D. Schlenk. 2009. Site-Specific Profiles of Estrogenic Activity in Agricultural Areas of California's Inland Waters. *Environmental Science and Technology* 43(24):9110–9116.

In this study, researchers collected 101 samples from 16 locations throughout the Central Valley at areas impacted by agriculture, and analyzed the samples using bioassays that measure total estrogenic activity, as well as steroid hormones and nonionic detergents and their metabolites. There were infrequent detections of low concentrations of the trace organic compounds, and the concentrations of compounds frequently associated with feminization effects on fish were far below thresholds for feminization of sensitive species. Estrogenic activity was definitively detected and confirmed at two sampling sites, including the Sacramento River at Walnut Grove. These samples were subjected to fractionation to attempt to determine compounds responsible for the estrogenic activity, and fractions were analyzed for numerous pharmaceuticals, pesticides, and potential endocrine disruptors. However, none of the compounds analyzed for in the study could explain the estrogenic activity that was observed.

Although determination of compounds responsible for estrogenic activity was inconclusive, one of the primary outcomes of the study is the finding that over a large geographic and temporal scale (i.e., throughout the Delta watershed, and at several times over the course of an entire year), concentrations of chemicals known to cause estrogenic effects are predominantly below detection limits. While it is possible that the results of the study are not representative of all areas in the Delta, it is apparent that estrogenic activity is not widespread in the watershed.

Presently Unpublished Follow-Up Studies

Robertson-Bryan, Inc. *In prep.* Easterly Wastewater Treatment Plant Water Quality Monitoring Plan: Final Report for Monitoring Constituents of Emerging Concern in Effluent and Receiving Water.

The City of Vacaville monitored CECs in its Easterly Wastewater Treatment Plant undiluted effluent and its receiving water on a monthly basis for one year. Three events included split samples that were sent to a second laboratory for interlaboratory comparison. Thorough quality assurance/quality control review protocols were developed and implemented on an ongoing basis throughout the study. Concentrations measured in the study were approximately the same or lower than similar studies that have been conducted at other wastewater treatment plants and receiving waters for most compounds. Results indicated that analytes detected in the effluent largely persisted through the near-field environment. Decreased concentrations in the receiving water, downstream of the discharge location, appeared to be primarily related to dilution.

Results of the QA/QC review protocols performed on a monthly basis indicated that close inspection of laboratory QC samples and of the analytical results themselves is critical to a successful monitoring program for CECs. This was because numerous QA/QC problems were encountered for the PPCPs and steroids/hormones testing over the course of the study, including holding time exceedances, unacceptable matrix recoveries,

contamination in field or method blanks, and both false negatives and false positives, mostly attributable to non-standardized sample preparation and analysis methods. Although it is clear that robust, reliable methods for measurement of CECs in wastewater exist, widespread acceptance and use of standardized sample preparation and analysis methods is necessary before an appropriate monitoring and regulatory paradigm can be established and effectively implemented.

Issues for Consideration – Need for a Comprehensive, Scientific Delta Monitoring Program Framework

Far too often, monitoring programs are developed and implemented without sufficient up-front thought and planning related to the purpose of the program (e.g., to assess compliance, to develop an understanding of ecosystem processes/limiting factors, to answer important questions) and how monitoring will be performed to achieve specific objectives in order to answer key questions, thereby achieving the overall program goal or purpose. Regional monitoring and assessment frameworks are often designed around key scientific questions that need to be answered in order to know whether regulatory requirements are adequate and, if not, how regulatory requirements need to be changed to achieve the desired environmental conditions for adequate beneficial use protection.

An effective program of implementation for the new flow objectives will need to rely on current and expanded Delta monitoring programs to provide the State Water Board with the data it needs to judge whether the flow objectives are producing the desired environmental conditions. Although several good Delta monitoring programs currently exist, and should continue, what each individual monitoring program produces has not been effectively integrated, from a scientific perspective, to ensure the programs are, collectively, gathering all the necessary types, frequency, and quality of data needed to answer the key questions that regulators and stakeholders need to have answered relative to Delta conditions and beneficial use protection. More specifically, how flows affect key water quality parameters which, in turn, affect aquatic life, agricultural, and municipal and industrial supply beneficial uses.

A comprehensive, scientific monitoring framework is needed that defines appropriate measures of Delta ecological health and how they are affected by flow, water quality, and species interactions (including those of invasive species). Such a framework would bring an overall “Delta function perspective” to determine how best to coordinate and integrate existing monitoring programs (e.g., Surface Water Ambient Monitoring Program (SWAMP)); Interagency Ecological Program (IEP), the Department of Water Resources’ Municipal Water Quality Investigations (MWQI) program, and California Department of Fish and Game, U.S. Fish and Wildlife Service, and National Marine Fisheries Service fisheries monitoring programs). It also would bring a scientific perspective to how data from these individual programs could be collected and analyzed to address well-defined scientific and regulatory questions that are not being posed by the individual programs.

The Strategic Workplan for Activities in the San Francisco Bay/Sacramento-San Joaquin Delta Estuary, which was prepared and adopted by the State Water Board, Central Valley Regional Water Board, and San Francisco Bay Regional Water Board, identifies the development of a comprehensive monitoring program for the Delta as a priority action. Consistent with the strategic workplan, the Central Valley Regional Water Board issued (June 2012): “*Delta Regional Monitoring Program: A Proposal for a Regional Monitoring and Assessment Framework and its Implementation.*” The impetus for the Delta Regional Monitoring Program (RMP) was, in large part, the pelagic organism decline (POD) observed in the Delta in recent years and the concern that contaminants may be the

cause or a significant contributor to the observed decline. As stated in the strategic workplan, the POD highlighted “...*the need for regularly compiling, assessing, and reporting data that is currently being collected and the need to better coordinate monitoring efforts.*”

The proposal for a Delta regional monitoring program (RMP) for more comprehensively assessing contaminants and toxicity within the Delta is a useful concept that is under development and will likely result in improved efficiency and collaboration for assessing Delta-wide water quality. However, coordination without a comprehensive, scientific Delta monitoring framework to direct such coordination – one that integrates ecological, hydrologic, and water quality data in search of fundamental relationships – will fall short of what is needed. Such a comprehensive framework would need to relate the water quality and toxicity data generated throughout the Delta from the RMP to key measures of ecological health, as monitored by the IEP and the fisheries agencies’ monitoring programs. Cause-effect relationships between ecological parameters and water quality need to be identified when and where they exist so that as water quality changes over time (positive or negative), ecological effects can be better predicted. Our understanding of how Delta inflow and outflow affect water quality needs to be expanded well beyond salinity, to other water quality parameters affecting the Delta’s ecological health. Individual efforts to do so are underway, but are not well coordinated or integrated under an overarching scientific vision of understanding how the Delta’s ecology and water quality is affected, at various time-steps, by flow.

Work by Johnston et al., 2010 (see above) further illustrate the need for a more far-reaching Delta monitoring framework. These researchers compiled, assessed, and reported all available water quality and contaminant data, but could not come to any definitive conclusion regarding the role of contaminants in POD. A factor that likely contributed to this outcome is that the water quality, toxicity, and ecological monitoring programs were not designed and operated in an integrated manner to specifically relate contaminant levels in the Delta to effects at various levels of biological organization, trophic levels, or sentinel species. When programs are not designed to answer specific questions, the data they produce (based on other objectives) are often inadequate to answer said questions.

Both the need and opportunity exists today for the State Water Board to develop a truly comprehensive, science-based Delta monitoring framework that clearly: 1) identifies the regulatory and scientific questions that must be answered to determine best management scenarios for the Delta, and 2) coordinates the implementation of ongoing and modified ecological and water quality monitoring programs to produce and analyze data in a manner that will, to the greatest degree possible, definitively answer these critically important scientific and regulatory questions that have already been posed, but not fully answered.

A comprehensive Delta monitoring program framework would define the water quality and ecological conditions that are desired at key locations throughout the Delta and the monitoring parameters (i.e., ecological and water quality measurements) used to determine achievement of those desired conditions. Initial implementation of Bay-Delta Water Quality Control Plan flow objectives can then be directly evaluated to determine their role in achieving the desired Delta conditions, and the relative sensitivity of various Delta conditions to specific source flows (i.e., flow fractions from the Sacramento and San Joaquin rivers, east-side tributaries, agricultural return flows, and sea water intrusion) and other controlled variables (e.g., cross-channel gate operations, water quality). By providing such a comprehensive, science-based framework, the State Water Board can effectively harness the data-generating power of multiple monitoring programs to produce the information needed to most efficiently evaluate the efficacy of initial flow objectives, and can identify the monitoring and analyses needed to do so.

Through the development (and refinement over time) of conceptual models that include testable hypotheses as part of this framework, the State Water Board will improve its understanding of important causal relationships, including the role flow and other controllable variables play in resulting Delta conditions, and thus will better know how to modify flow objectives as climate change and changes in Sierra hydrology and CVP/SWP operations occurs over time. Through programs such as the environmental monitoring program (EMP), the State Water Board maintains tools to evaluate the effect of proposed flows objectives on water quality characteristics such as salinity. It is recommended, however, that the State Water Board further extend its understanding of flow effects into the arena of contaminants and ecological parameters so that beneficial use protection is holistically considered. For this to occur, a comprehensive Delta monitoring program framework that facilitates the effective integration of efforts from the major ecological and water quality monitoring programs is essential.

Development of a comprehensive Delta monitoring program framework by the State Water Board and other involved agencies and stakeholders should consider the following.

1. Develop an overarching vision and purpose/goal that unites stakeholders and agencies in an integrated, supportable effort.
 2. Develop conceptual models that define our current understanding of Delta relationships among ecological parameters, flow, and water quality and thus define data gaps to be filled and assist in defining the fundamental scientific and regulatory questions to be answered by the program.
 3. Develop a full suite of fundamental questions that stakeholders and agencies seek to have answered by the monitoring data to be collected and analyzed, which have not been adequately answered to date.
 4. Define program objectives that when achieved produce the data/information needed to achieve the program goals.
 5. Define specific monitoring elements, special studies, and pilot projects that constitute actions, with measurable outcomes, that will accomplish the program objectives.
 6. Define the type, amount and geographic extent of specific data that will be needed to effectively address the questions, and which monitoring programs will collect these data. Determine how, if at all, various ongoing monitoring programs need to be expanded/modified to achieve the overall goal.
 7. Define the kinds of analyses that will be performed to address each of the program questions. Knowing how data are to be analyzed is critical to knowing the type, amount, and quality of data to collect.
 8. Define the quality and quantity of data needed to support the analyses to be performed.
 9. Define how the current and planned monitoring efforts and programs will be integrated to produce the data and analyses needed to answer key scientific and regulatory questions.
 10. Define an adaptive management approach that allows the individual monitoring programs to change appropriately and timely in response to new information/findings, changing environmental conditions, and new questions to be answered.
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Additional Scientific and Technical Information for the SWRCB Comprehensive (Phase 2) Review and Update to the Bay-Delta Plan

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DATE: August 16, 2012

The State Water Resource Control Board (SWRCB) asked for two types of information in its June 22, 2012, public notice informing stakeholders and interested parties about the pending Delta-Plan Information Review workshops: 1) scientific and technical information related to ecosystem changes in the low salinity zone (LSZ) of the Delta along with levels of uncertainty and recommended changes to the Delta Plan supported by the new information; and 2) comments on how to address uncertainty, change, and how to implement an adaptive management program (AMP). A response to the latter request for addressing uncertainty is presented here that will improve the quality of data used to inform AMPs and management decisions in the Delta, thus reducing uncertainty. This is presented in the first section as a lens to which all the following new information presented here can be viewed and lessons learned from those investigations.

1. Data Quality

Decision-makers should have sound environmental data. Debate over the validity of scientific studies generally arises 1) when data are of unknown or poor quality or 2) when scientists or decision makers do not agree on how data should be evaluated or applied. Poor quality data can misinform the public and decision makers and waste resources in debates, repeating studies, or in management decisions that do not have the desired effect because they are founded on incorrect information. These problems can be addressed to a large degree with only a moderately increased level of effort during investigation planning stages to develop clear Data Quality Objectives¹ (DQOs).

The DQO process is used to develop performance and acceptance criteria (or DQOs) that clarify study intent, define the appropriate type of data, and serve as the basis for designing a plan for collecting data of sufficient quality and quantity to support the goals of a study. The use of DQOs, typically in a Quality Assurance Project Plan (QAPP), is a requirement of the Data Quality Act for U.S. Environmental Protection Agency (EPA) projects to ensure that management decisions are based on data of known (and acceptable) quality (EPA Order CIO 2105.5 [preceded by EPA Order 5360.1 A2, EPA 2000, and 48CFR 46]).

This process allows for the decision-makers and planning teams to facilitate good communication and project documentation, concentrate on developing the appropriate requirements for collecting data of known quality, clarify vague objectives, and ensure the data will fulfill their intended use, all of which

¹ U.S. Environmental Protection Agency (EPA). 2006. "Guidance on Systematic Planning Using the Data Quality Objectives Process." Office of Environmental Information. Washington, DC. EPA/240/B-06/001.

encourages more efficient peer review and acceptance. Scientific studies can be strengthened by clearly developing sound, comprehensive DQOs. As described by EPA, the DQO process defines criteria that will be used to establish the final data collection design, and consists of:

- The nature of the problem and a conceptual model
- The eventual decisions or estimates to be made
- The type of data needed
- How the data will be used to draw conclusions from the study findings
- Acceptable data quality criteria
- The investigation design that will collect data to meet stated objectives

Including the DQO process into planning documents will serve as an effective tool to help develop performance and acceptance criteria for the collection, evaluation, and use of environmental data in the Delta and to reduce uncertainty by generating data of known quality. The data can be validated and deemed acceptable if they meet the established data quality criteria or rejected if they do not. Validated data minimize uncertainties and help decision-makers develop well supported management approaches. Further, when stakeholders and regulators are included in the development of DQOs as part of planning documents for studies or monitoring programs, debates are less likely because the high-quality and validated data generated have reduced uncertainty and the data uses have already been agreed to by all parties.

In addition to generating high-quality data, the analyses and conclusions made from these data should be peer reviewed. Scientists produce work of varying quality and the confidence that resource managers have in data interpretations can be improved through peer review. However, not all peer reviews are created equal and the impact of peer review on document quality varies. Some peer reviews are very rigorous and have high standards for addressing reviewer comments, as determined by an editor or referee, but some reviews do not have any effect on the author's original conclusions if left to the discretion of the author. The most effective peer reviews solicit comments from peers with appropriate subject knowledge, referees validate the adequacy of responses to comments, and the comments/responses are included as appendices where readers can consider where disagreement exists.

A thorough and critical review of all information to develop a weight-of-evidence conclusion is further recommended to generate a balanced and weighted approach that accounts for differences in data quality, interpretations, and uncertainties. Such integration of data (preferably of known quality) will allow decision-makers to be confident that the foundations of their decisions can withstand technical scrutiny and helps them understand the level of confidence in achieving desired goals.

2. New Scientific and Technical Information Related to Ecosystem Changes in the LSZ

Summaries of new information are provided with brief descriptions of their associated uncertainties and positive attributes that reflect sound science and/or practices. Table 1 highlights the key points of each new study that is discussed.

TABLE 1

Highlights from Additional Scientific and Technical Information

Key Points	Uncertainties	Reference
Invasive Clams		
Grazing by invasive clams has contributed to the decline of phytoplankton biomass and annual phytoplankton blooms.	There is little consideration of this significant driver of ecosystem productivity and conceptual or empirical models that do not take bivalve grazing into account are highly uncertain.	<p>Thompson and Parchaso. 2010. <i>Corbula amurensis</i> Conceptual Model. Prepared for the Delta Science Program.</p> <p>Greene et al. 2011. Grazing impact of the invasive clam <i>Corbula amurensis</i> on the microplankton assemblage of the northern San Francisco Estuary.</p> <p>Thompson et al. 2008. Shallow water processes govern system-wide phytoplankton bloom dynamics: A field study. <i>Journal of Marine Systems</i>.</p> <p>Winder and Jassby. 2011. Shifts in Zooplankton Community Structure: Implications for Food Web Processes in the Upper San Francisco Estuary.</p>
Contaminants/Toxicity		
Guidance is provided for developing monitoring programs for contaminants of emerging concern.	The use of a Science Advisory Panel of experts to recommend a thoroughly vetted strategy for monitoring CECs limits uncertainty in these recommendations. However, there is little consideration of non-point sources, which remain an uncertainty.	Anderson et al. 2012. Monitoring Strategies for Chemicals of Emerging Concern (CECs) in California's Aquatic Ecosystems: Recommendations of a Science Advisory Panel.
Sources of pyrethroid pesticides are reported.	Evaluation of toxicity in effluent is not a relevant exposure when effluent is diluted in receiving waters. Therefore, toxicity data is not relevant for evaluating ecosystem impairment.	Weston and Lydy. 2010. Urban and agricultural sources of pyrethroid insecticides to the Sacramento-San Joaquin Delta of California.
Pyrethroids and organophosphates are reported in the Delta tributaries.	Uncertainties were managed in this study by sampling and testing over a large area to confirm that conclusions are broadly applicable.	Weston et al. in press. Identifying the cause of sediment toxicity in agricultural sediments: The role of pyrethroids and nine seldom-measured hydrophobic pesticides. <i>Chemosphere</i> .
This review article summarizes existing data and proposes a new approach for monitoring aquatic organisms health.	References are generic and may not describe studies or species relevant to the Delta. Greater impact from treated wastewater if portrayed than is warranted based on the available data.	Brooks et al. 2012. Life Histories, Salinity Zones, and Sublethal Contributions of Contaminants to Pelagic Fish Declines Illustrated with a Case Study of San Francisco Estuary.
The study concluded that sufficient high-quality chemical data are not available to make conclusions about the role of specific contaminants in the POD.	Care should be taken in drawing any conclusions about the effect of contaminants on the POD due to limited data.	Johnson et al. 2010. <i>Evaluation of Chemical, Toxicological, and Histopathologic Data to determine their Role in the Pelagic Organism Decline</i> .

TABLE 1
Highlights from Additional Scientific and Technical Information

Key Points	Uncertainties	Reference
Ammonia toxicity testing with a novel test species (<i>Pseudodiaptomus forbesi</i>) is reported .	There are significant concerns over the validity of these test data and the calculated effect levels. Uncertainties could be managed by retesting in accordance with well defined DQOs.	Teh, et al. 2011. Full Life-Cycle Bioassay Approach to Assess Chronic Exposure of <i>Pseudodiaptomus forbesi</i> to Ammonia/Ammonium.
Ambient surface water toxicity is reported.	This study contains good data, but some of the data analyses and conclusions are based on incomplete information.	Werner et al. 2010a. Pelagic Organism Decline (POD): Acute and Chronic Invertebrate and Fish Toxicity Testing in the Sacramento-San Joaquin Delta 2008-2010. Werner et al. 2010b. Monitoring acute and chronic water column toxicity in the northern Sacramento-San Joaquin Estuary, California, USA, using the euryhaline amphipod, <i>Hyalella azteca</i> : 2006-2007.
Sub-cellular effects in delta smelt exposed to ammonia are reported.	Linkages between biomarkers and adverse effects at the whole organism level that would affect survival, growth or reproduction are not clear.	Connon et al. 2011. Sublethal responses to ammonia in the endangered delta smelt

2.1 Invasive Clams

Thompson, J.K. and F. Parchaso. 2010. *Corbula amurensis* Conceptual Model. Prepared for the Delta Science Program.

This peer reviewed Delta Regional Ecosystem Restoration Implementation Plan (DRERIP) conceptual model summarizes existing knowledge of invasive bivalves in the Sacramento-San Joaquin River Delta ecosystem and is an excellent source of information on this much neglected factor which has a potentially great effect on the Delta ecosystem. The Delta is described as a high nutrient, high turbidity estuary with low primary production due to a combination of light limitation and bivalve grazing^{2,3}.

Corbula amurensis (*Corbula*), an invasive clam species now prevalent in portions of the San Francisco Estuary (SFE), is a suspension feeder that can filter and assimilate both phytoplankton and bacteria (<1.2 micrometers [μm]) from the water column.⁴ *Corbula* can withstand a wide range of salinities (~2 to 30 practical salinity units [psu]),⁵ and therefore maintains a high population year-round in the intertidal areas of the Delta (see Figure 1).

The northern part of the SFE has always had low primary production, but declines in primary production following the invasion of *Corbula* in 1986 lead researchers to conclude that suspension feeding by

² Cloern, J.E., 2001. Our evolving conceptual model of coastal the eutrophication problem. Marine Ecology Progress Series, 210:223-253.

³ Thompson JK, Koseff JR, Monismith SG, Lucas LV, 2008 (in press). Shallow water processes govern system-wide phytoplankton bloom dynamics: A field study. Journal of Marine Systems. doi:10.1016/j.jmarsys.2007.12.006

⁴ Werner I, Hollibaugh, JT, 1993. *Potamocorbula amurensis*: comparison of clearance rates and assimilation efficiencies for phytoplankton and bacterioplankton. Limnology and Oceanography, 38:949-964.

⁵ Nicolini MH, Penry DL, 2000. Spawning, fertilization, and larval development of *Potamocorbula amurensis* (Mollusca: Bivalvia) from San Francisco Bay, California. Pacific Science, 54:377-388.

Corbula resulted in the decline in phytoplankton biomass (annual primary production^{6,7} has been reduced from ≈ 100 grams of carbon per square meter per year [$\text{carbon}/\text{m}^2/\text{yr}$] to <20 grams of carbon/ m^2/yr) and the elimination of an annual phytoplankton bloom in the estuary.^{7,8} *Corbula* were reported to clear the water column up to once every 8-16 hours in Grizzly Bay and every 8-24 hours in the channel. High *Corbula* grazing rates in conjunction with relatively high water column vertical mixing rates continually challenge the potential for phytoplankton biomass increase in these shallow systems. This decline of phytoplankton biomass is also correlated with long-term declines of copepod and mysid shrimp populations.

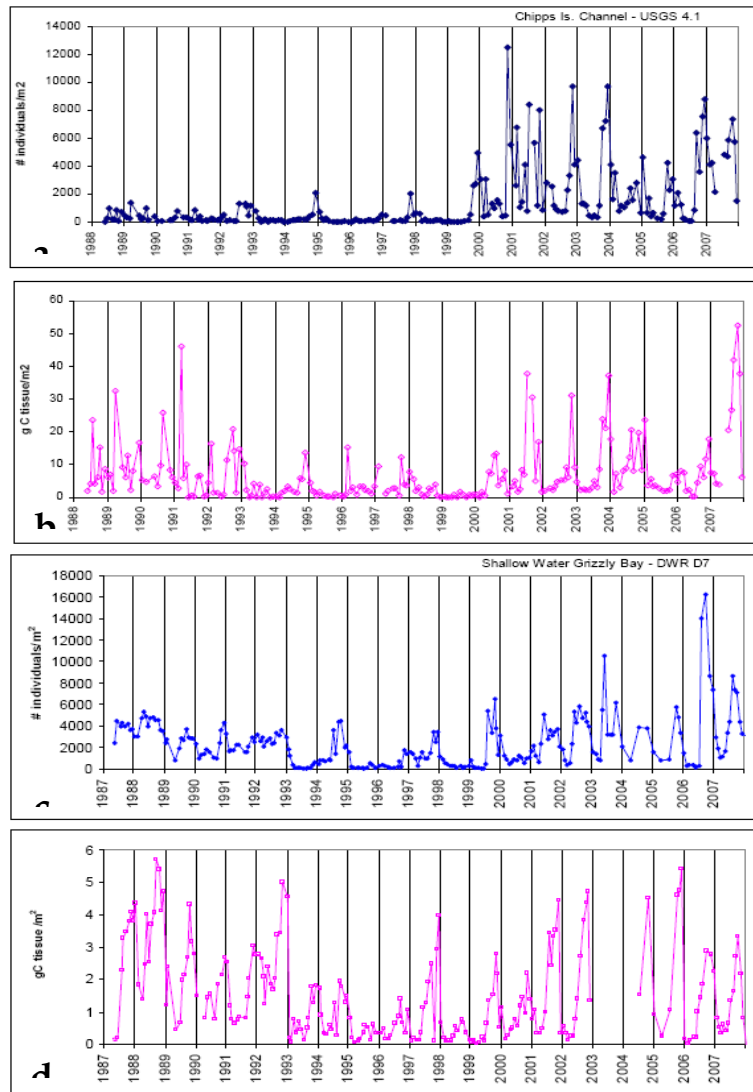


Figure 1: Density and biomass of *Corbula* at the western Delta (a, b) and in Grizzly Bay (c,d). Grizzly Bay data courtesy of DWR CALFED Biomass Study. (reproduced from Thompson and Parchaso, 2010)

⁶ Jassby, A.D., J.E. Cloern, and B.E. Cole. 2002. Annual primary production: patterns and mechanisms of change in a nutrient-rich tidal ecosystem. *Limnology and Oceanography*, 47(3):698-712.

⁷ Alpine, A.E. and J.E. Cloern. 1992. Trophic interactions and direct physical effects control phytoplankton biomass and production in an estuary. *Limnology and Oceanography*, 37 (5):946-955

⁸ Kimmerer, W.J. 2002. Effects of freshwater flow on abundance of estuarine organisms: physical effects or trophic linkages. *Marine Ecology Progress Series*, 243:39-55.

Greene, V.E., L.J. Sullivan, J.K. Thompson, and W.J. Kimmerer. 2011. Grazing impact of the invasive clam *Corbula amurensis* on the microplankton assemblage of the northern San Francisco Estuary. *Mar. Ecol. Prog. Ser.* 431:183-193.

Grazing by the invasive overbite clam, *Corbula amurensis*, may be the cause of substantial declines in phytoplankton biomass and zooplankton in the SFE following its introduction in 1986. *Corbula* cleared 0.5 liters/individual/hour of microzooplankton (ciliates) and 0.2 liters/individual/hour of chlorophyll in this study. The authors conclude that the observed grazing rate may be sufficient for *Corbula* to alter food web dynamics through its predation and would disrupt the links between lower and higher trophic levels (see Figure 2).

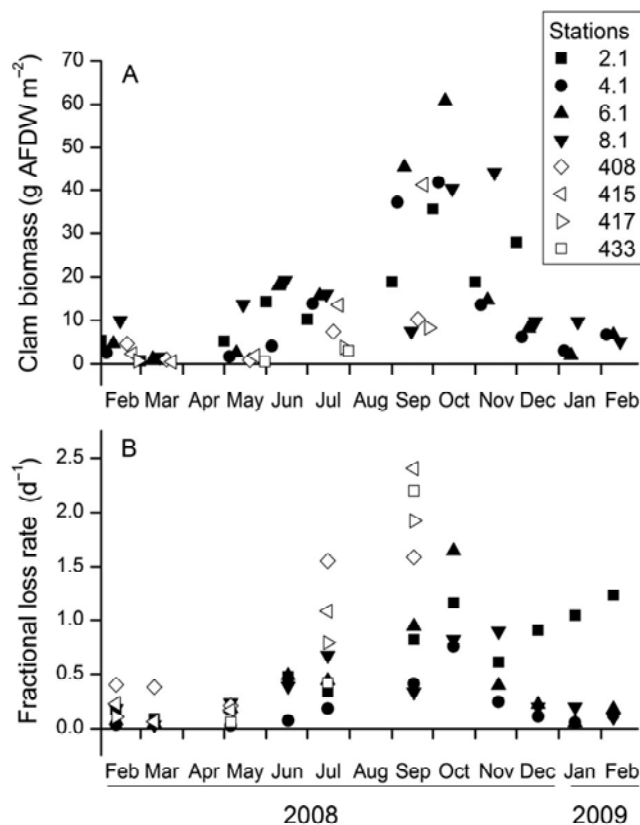


Figure 2: (A) Mean biomass from February 2008 to February 2009 in the low-salinity zone of SFE. (B) Estimated fractional loss rate (d⁻¹) of microzooplankton resulting from grazing. (Note: Solid symbols indicate channel stations and open symbols indicate shoal stations.) (reproduced from Greene et al. 2011).

Thompson, J.K., J.R. Koseff, S.G. Monismith, and L.V. Lucas. 2008. Shallow water processes govern system-wide phytoplankton bloom dynamics: A field study. *Journal of Marine Systems.* 74:153-166.

This study found that phytoplankton bloom occurrence was dependent on shallow-water benthic filter-feeder grazing as well as surface water quality (i.e., turbidity and nutrients). These consumers have great

potential to change the phytoplankton bloom dynamics in the Delta. One reason why benthic bivalves can effectively control phytoplankton biomass is that they are “always” present to some degree. Bivalves' long lives (relative to zooplankton) and large size allow them to survive periods of low food availability and to respond immediately to any increase in phytoplankton biomass. Shallow-water bivalves can be consumed by migratory birds and fish in the fall and winter.^{9 10} However, grazing rates can be high year-round (see Figure 3).

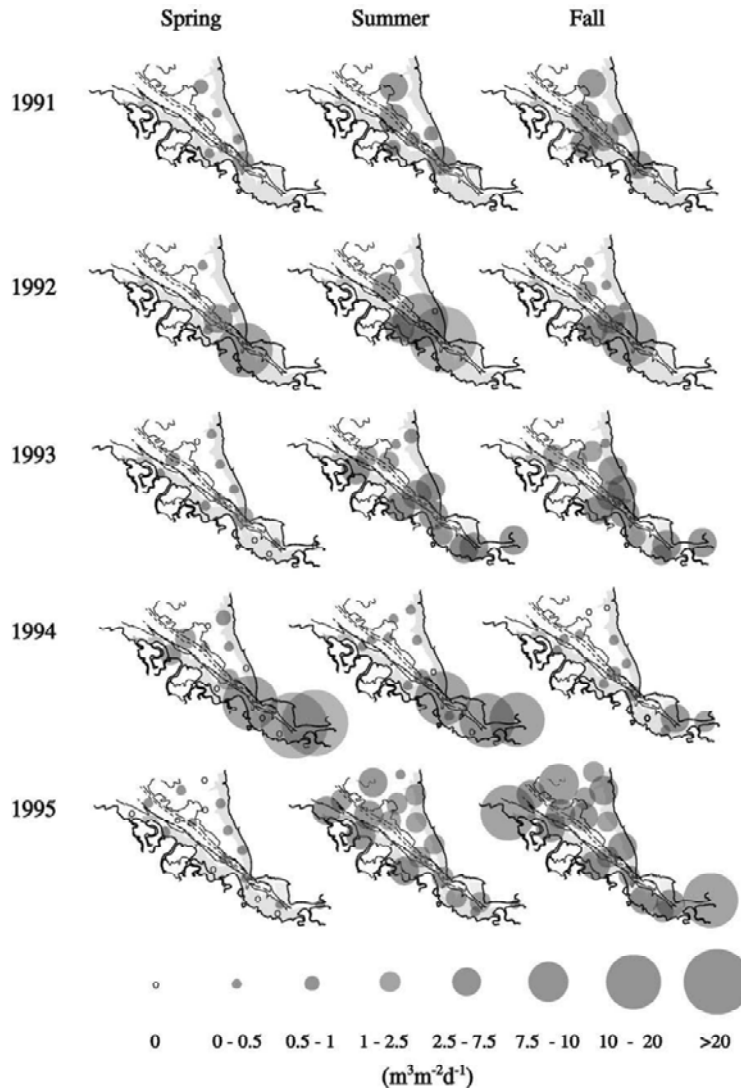


Figure 3: Bivalve grazing rates prior to spring bloom, in mid-summer, and in fall. (reproduced from Thompson et al. 2008)

⁹ Richman, S.E. and J.R. Lovvorn. 2004. Relative foraging value to Lesser Scaup ducks of native and exotic clams from San Francisco Bay. *Ecological Applications* 14 (4), 1217–1232.

¹⁰ Poulton, V.K., J.R. Lovvorn, and J.Y. Takekawa. 2004. Spatial and overwinter changes in clam populations of San Pablo Bay, a semiarid estuary with highly variable freshwater inflow. *Estuarine Coastal and Shelf Science* 59 (3), 459–473.

Winder, M and A.D. Jassby. 2011. Shifts in Zooplankton Community Structure: Implications for Food Web Processes in the Upper San Francisco Estuary. *Estuaries and Coasts*. 34:675-690.

Zooplankton are an important trophic link and a key food source for many larval fish species in estuarine ecosystems. This study documents zooplankton dynamics in Suisun Bay and the Sacramento–San Joaquin Delta over a 37-year period (1972–2008). The zooplankton community experienced major changes in species composition during 1987–1994, largely associated with direct and indirect effects from the introduction of non-native bivalve species coupled with an extended drought period. A step decline in chl-a concentration in the mid 1980s coincided with the invasion of *Corbula*, and concentrations have remained at low levels (Figure 4).

Shifts in zooplankton species composition have also been accompanied by an observed decrease in zooplankton size and food quality as shown in Figure 5. These changes in the biomass, size, and possibly chemical composition of the zooplankton community imply major alterations in pelagic food web processes, including a drop in prey quantity and quality for foraging fish and an increase in the importance of the microbial food web for higher trophic levels.

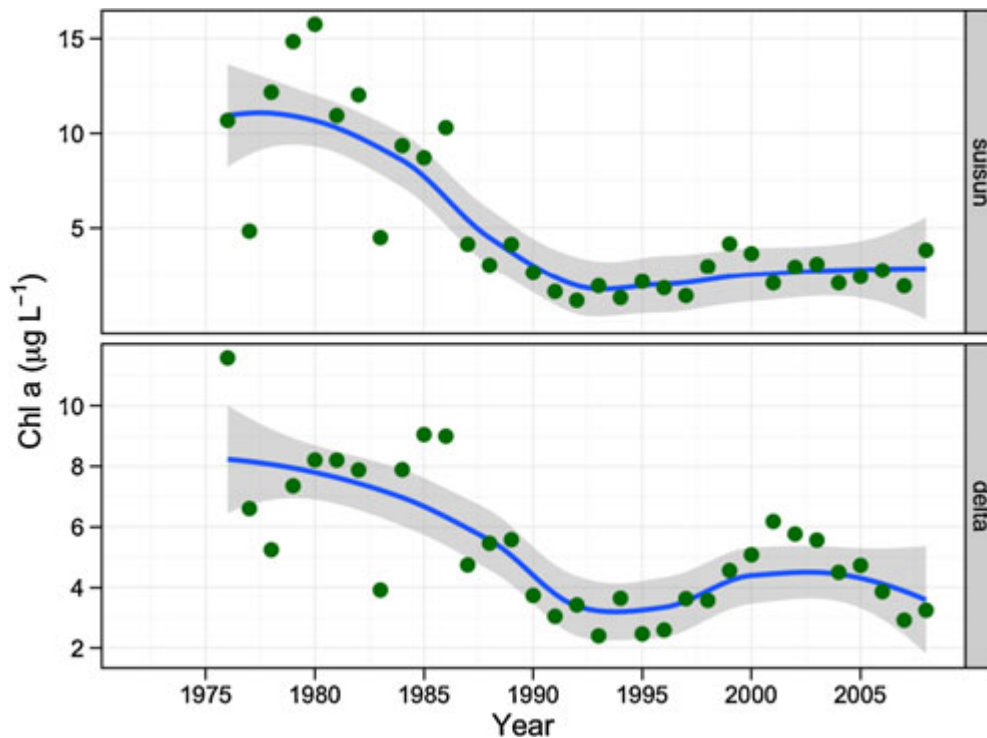


Figure 4: Annual average chlorophyll a concentration by subregion in the upper San Francisco Estuary between 1976 and 2008. Top panel represents the “suisun” and bottom panel the “delta” subregion. The blue line displays a loess fit \pm standard error (shaded area) (reproduced from Winder and Jassby, 2011)

The study found large spatial and temporal changes of the zooplankton community in the Sacramento–San Joaquin Delta and Suisun Bay over the last four decades in both abundances and species composition. Major shifts in the zooplankton community composition coincided with the extended drought during 1987–1994 and explosive colonization of the invasive clam *C. amurensis* at the beginning

of the drought.^{11,12} Food limitation and predation after the population expansion of the overbite clam *C. amurensis* was the likely reason for the decline in the zooplankton community. Many zooplankton, including calanoids, rotifers, and mysids, compete with benthic suspension feeders for phytoplankton^{13,14}.

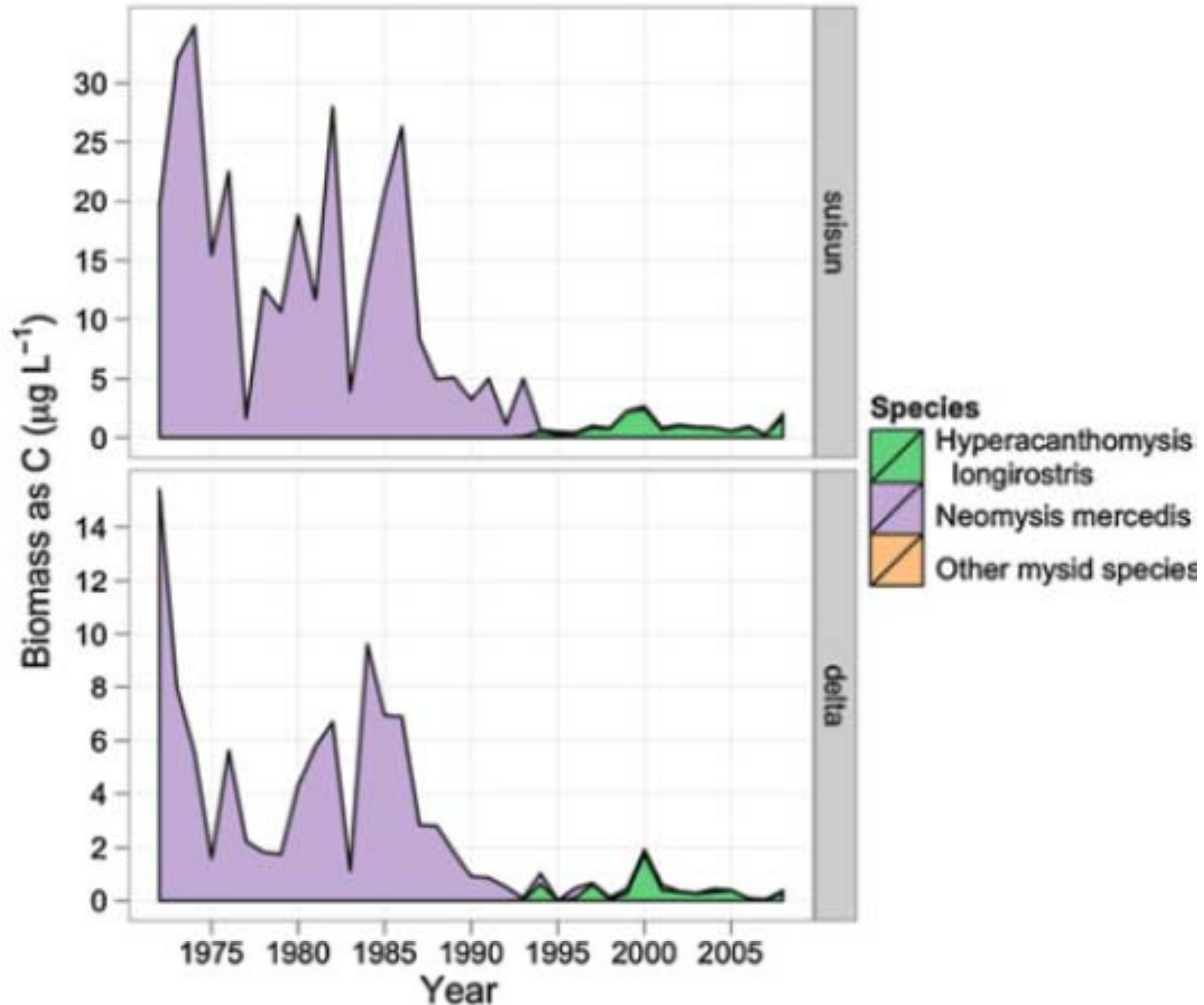


Figure 5: Annual average biomass of mysids species by subregion in the upper San Francisco Estuary between 1972 and 2008. *H. longirostris* was formerly classified as *A. canthomysis bowmani*; other mysids species include *A. aspera*, *A. hwanhaiensis*, *Aliencanthomysis macropsis*, *Deltamysis holmquistae*, *Neomysis kadiakensis*, and unidentified mysids. Top panel represents the “suisun” and bottom panel the “delta” subregion (reproduced from Winder and Jassby, 2011).

¹¹ Carlton, J.T., J.K. Thompson, L.E. Schemel, and F.H. Nichols. 1990. Remarkable invasion of San-Francisco Bay (California, USA) by the Asian clam *Potamocorbula amurensis*. I. Introduction and dispersal. *Marine Ecology Progress Series* 66: 81–94.

¹² Alpine, A.E. and J.E. Cloern. 1992. Trophic interactions and direct physical effects control phytoplankton biomass and production in an estuary. *Limnology and Oceanography* 37: 946–955.

¹³ Murrell, M.C. and J.T. Hollibaugh. 1998. Microzooplankton grazing in northern San Francisco Bay measured by the dilution method. *Aquatic Microbial Ecology* 15: 53–63.

¹⁴ Irigoien, X., J. Titelman, R.P. Harris, D. Harbour, and C. Castellani. 2003. Feeding of *Calanus finmarchicus* nauplii in the Irminger Sea. *Marine Ecology Progress Series* 262: 193–200.

Uncertainties – Invasive Clams

Invasive clams have altered phytoplankton and zooplankton communities in the Delta and continue to consume incredible amounts of algae. It is unclear why there is relatively little discussion over how this has affected the POD, or what can be done to address it. Instead, the discussion has focused on whether or not there is a potential for one form of nitrogen to impair algae productivity over another form of nitrogen. Conceptual and empirical models that are being developed or considered should include the losses of phytoplankton due to grazing by invasive clams using known variables such as filtration rates, growth, abundance, and known preferred habitats (i.e., depth and salinity ranges where they occur). Uncertainty with phytoplankton growth models will be reduced when this significant factor is considered.

2.2 Contaminants/Toxicity

The 2009 staff report includes appropriate recommendations to allow the San Francisco Bay and Central Valley Regional Water Quality Control Boards to continue their efforts on ammonia and toxicity issues. However, the following information and discussion is presented in the event of renewed interest in these topics by the SWRCB.

Anderson, P.D., N.D. Denslow, J.E. Drewes, A.W. Olivieri, D. Schlenk, G.I. Scott and S.A. Snyder. 2012. Monitoring Strategies for Chemicals of Emerging Concern (CECs) in California's Aquatic Ecosystems: Recommendations of a Science Advisory Panel, Technical Report 692 - April 2012.

This technical report was prepared for the SWRCB by a selection of scientific experts charged with identifying potential sources, evaluating the fate and effects of chemicals of emerging concern (CECs), and ultimately providing guidance for developing monitoring programs to assess those chemicals with the highest potential of causing adverse effects in California surface waters. The following are the four products developed to help design a CEC monitoring process:

- A conceptual, risk-based approach to assess and identify CECs for monitoring in California receiving waters.
- Application of the risk-based screening framework to identify a list of CECs for initial monitoring.
- An adaptive, phased monitoring approach with interpretive guidelines that direct and update actions commensurate with potential risk.
- Identified research needs to develop bioanalytical screening methods, link molecular responses with higher order effects, and fill key data gaps.

Uncertainties

Data on CEC concentrations, analytical method development, and effect levels are continuing to improve; however, considerable uncertainty remains on these fronts, as identified by the report authors. This report was focused on treated wastewater point sources while "...agricultural sources were outside of the scope of this panel..." Non-point sources such as livestock facilities, which are known to contribute considerable CECs to receiving waters,^{15,16} may be considered under other efforts, but

¹⁵ Brander, S. 2010. From otoliths to oocytes: a three-tiered investigation into estrogenic and androgenic effects in a California estuary. Presented at the 20th Annual Meeting of the Northern California Regional Chapter of the Society of Environmental Toxicology and Chemistry. May 2010, Berkeley, CA.

should not be ignored. Understanding the uncertainties and formulating a plan to shed light on data gaps is an appropriate approach to move forward to the point where data are sufficient to inform management decisions.

Weston, D.P. and M.J. Lydy. 2010. Urban and agricultural sources of pyrethroid insecticides to the Sacramento-San Joaquin Delta of California. Environ. Sci. Tech. 44:1833-1840.

Weston and Lydy (2010) describe their assessment of potential pyrethroid sources in the Delta. Pyrethroids were found in treated wastewater and urban storm water at concentrations sufficient to cause toxicity to *Hyaella azteca*. Toxicity identification evaluation (TIE) methods confirmed the presence of pyrethroids in effluent and urban storm water. However, the reported toxicity in effluent is not a relevant exposure media for aquatic organisms that are exposed to effluent only after dilution by receiving waters. Further, the potential for pyrethroid loading into receiving waters should be interpreted with caution. For example, pyrethroid measurement errors are compounded by millions of gallons per day of treated wastewater that is discharged, and dilution in the Sacramento River reduces pyrethroids from Sacramento Regional Wastewater Treatment Plant (SRWTP) effluent to concentrations well below levels known to cause toxicity (EC50s range from 1.7-21.1 nanograms per liter [ng/L]). These low ambient concentration estimates are supported by the absence of toxicity in ambient samples from the Sacramento River by Weston and Lydy (2010) and by the lack of acute or chronic toxicity to *H. azteca* in 51 samples from Hood, a monitoring station located about 8 miles downstream of the SRWTP effluent discharge, reported by Werner et al. (2010a). Preliminary data from follow-up testing in 2011-2012 confirm the lack of detectable concentrations of pyrethroids in the Sacramento River downstream of SRWTP and the lack of toxicity to *H. azteca*¹⁷. It should also be noted that Weston and Lydy (2010) reported the highest concentrations of pyrethroids in urban storm drains¹⁸ and surface water of tributaries receiving agricultural drainage.¹⁹ Detailed calculations of pyrethroid loading from suspended sediments in agricultural drains and urban storm water have also been reported²⁰. Likewise, recent work by Weston found that pyrethroids were present and causing toxicity to freshwater invertebrates in Delta tributaries affected by discharges from agricultural drains²¹.

Uncertainties

Although this initial work by Weston and Lydy (2010) added value to the body of research on pyrethroid sources and toxicity in the Delta, there were uncertainties in the early study results and conclusions that need to be addressed to provide sound science for decision-making. For example, a “rough approximation” of pyrethroid loading into the Sacramento River from SRCSD discharge was based on a median concentration that overestimates loads when there were sampling days when no pyrethroids were detected. Detected pyrethroid concentrations reported in SRCSD effluent samples were variable

¹⁶ Jeffries, K.M., E.R. Nelson, L.J. Jackson and H.R. Habibi. 2008. Basin-wide Impacts of Compounds with Estrogen-like Activity on Longnose Dace (*Rhinichthys cataractae*) in two Prairie Rivers of Alberta, Canada. *Env. Tox. and Chem.* 27:2042-2052.

¹⁷ Ohlinger, K. 2011. Pyrethroid pesticides in municipal wastewater: early results. Presented to the Pelagic Organism Decline Contaminant Work Team (POD-CWT). June 22, 2011.

¹⁸ Weston, D. and M. Lydy. 2012. Stormwater Input of Pyrethroid Insecticides to an Urban River. *Env. Tox. and Chem.* 31:1-8.

¹⁹ Weston, D., S. Teh, S. Lesmeister and M. Lydy. 2011. *The Role of Pyrethroid Insecticides in Limiting Prey Availability for Delta Smelt in the North Delta*. Presented to the POD-Contaminant Work Team, on June 22, 2011, Sacramento, CA.

²⁰ Domagalski, J.L., D.P. Weston, M. Zhang, and M. Hladik. 2010. Pyrethroid insecticide concentrations and toxicity in streambed sediments and loads in surface waters of the San Joaquin Valley, California, USA. *Env. Toxicol. Chem.* 29(4):813-823.

²¹ Weston, D.P., Y. Ding, M. Zhang, and M.J. Lydy. in press. Identifying the cause of sediment toxicity in agricultural sediments: The role of pyrethroids and nine seldom-measured hydrophobic pesticides. *Chemosphere*.

among events and for individual pyrethroids during each event. Measured concentrations were also at or near reporting limits where the associated error is highest. Measurements were also based on single grab samples collected during each event. The load calculations compound these potential errors by multiplying them by the millions of liters discharged each day. However, these uncertainties surrounding initial load estimates have been mediated by repeated studies where sampling did not find detectable pyrethroids in surface water samples and there was no toxicity to *Hyalella*. Repeated analyses and specific DQOs to use serial dilutions of effluent samples to evaluate the potential for toxicity in receiving waters are appropriate methods for addressing uncertainty associated with initial results.

Weston, D.P., Y. Ding, M. Zhang, and M.J. Lydy. in press. Identifying the cause of sediment toxicity in agricultural sediments: The role of pyrethroids and nine seldom-measured hydrophobic pesticides. Chemosphere.

Seldom-analyzed but commonly used hydrophobic pesticides were analyzed in 69 sediment samples from Central Valley tributaries receiving agricultural irrigation runoff. Only a few of these pesticides were infrequently found to be present at concentrations contributing to *H. azteca* and *Chironomus dilutus* toxicity (abamectin, fenpropathrin, and methyl parathion), whereas pyrethroids (bifenthrin, lambda-cyhalothrin, cypermethrin, esfenvalerate, and permethrin) and the organophosphate chlorpyrifos were primarily responsible for observed toxicity.

Uncertainties

Uncertainty is managed in this study by reporting data from samples collected over a large area of the Delta. This work also builds upon previous studies that found pyrethroids in Delta tributaries.²²

Brooks, M.L., E. Fleishman, L.R. Brown, P.W. Lehman, I. Werner. 2012. Life Histories, Salinity Zones, and Sublethal Contributions of Contaminants to Pelagic Fish Declines Illustrated with a Case Study of San Francisco Estuary.

This manuscript is largely a review article describing the POD. No new data or compelling data analyses are presented. The importance of organism life histories and environmental variables that affect exposures to contaminants are described as important considerations when evaluating possible adverse effects. Generic and brief conceptual models illustrating how these environmental variables may affect direct sublethal or indirect (i.e., through the food web) toxicity are discussed using the SFE as a case study. The stated goal is to “recast thinking about contaminant effects and criteria for identifying them, and to encourage development of suitable methods of assessment.”

The manuscript should only be considered to provide general information supporting the evaluation of energetic costs as a surrogate for chronic effects in Delta species. While the manuscript seems to focus on a case study of the SFE, many of the references are generic and may or may not describe studies or species relevant to the Delta/SFE. The authors discuss many factors that should be considered in any effects evaluation, but do not adequately describe the relative contributions from various sources and locations. The manuscript contains elements of bias, often framing study descriptions (for inorganic nitrogen, cyanobacterial blooms, and pyrethroids) in a way that implies greater impact from treated wastewater than indicated by the data. The lack of references to invasive clams affecting the POD,²³ or considering them as a confounding factor when interpreting Delta environmental data, is a major oversight. The authors discuss many factors that should be considered in an effects evaluation, but do

²² Amweg, E.L., D.P. Weston, and N.M. Ureda. 2005. Use and toxicity of pyrethroid pesticides in the Central Valley, California, USA. *Environmental Toxicology and Chemistry* 24, 966–972.

²³ Kimmerer, W.J. 1994. Predation by an introduced clam as the likely cause of substantial declines in zooplankton of San Francisco Bay. *Marine Ecology Progress Series*, 113:81-93.

not differentiate toxicity that has been observed between tributaries and the main stem Sacramento River. The location of samples is a very important factor when describing study results and developing a conceptual model.

Uncertainties

Very general statements can be misleading if taken out of this very generic context. Many of the references describe studies or species not specific to the Delta/SFE. Further, it is not clear how developing new assessment methods, as suggested, would improve regulatory decision making. Toxicity tests are a well-proven assessment tool with benefits and limitations, and the debate about the environmental relevance of toxicity test data is ongoing and complex. This longstanding and proven tool should not be discarded in favor of an untested approach.

Johnson M., I. Werner, S. Teh, and F. Loge. 2010. Evaluation of Chemical, Toxicological, and Histopathological Data to determine their Role in the Pelagic Organism Decline

The Central Valley Regional Water Quality Control Board (CVRWQCB) funded an evaluation to determine if there are sufficient water chemistry, toxicity, and histopathological (i.e., tissue) data “to characterize the extent and role of contaminants in the Pelagic Organism Decline (POD).” Experts representing several disciplines from the University of California, Davis, compiled these available data to make comparisons between pre- and post-POD chemical concentrations. They came to an overall conclusion that the available data do not indicate any links between ammonia, pyrethroids, or other chemical stressors and the POD. However, the limited data add uncertainty to these conclusions.

“...while contaminants are unlikely to be a major cause of the POD, they cannot be eliminated as a possible contributor to the decline.”

In general, the study found that there was insufficient high-quality data available to make conclusions about the potential role of specific contaminants in the POD. Data identified from the legal Delta proved to be very limited, leading to the inclusion of data from tributaries as far as 30 miles outside of the legally defined Delta. Therefore, and as stated in the conclusions of the report, care should be taken in drawing any specific conclusions about the effect of contaminants on the POD based on the data found and included in the report.

One conclusion was that delta smelt were not food-limited. This suggests that the food supply has not been reduced by exposure to contaminants or bottom-up effects and can support populations of POD species.

“Stomachs full of food upon capture suggest that delta smelt are not starving. This further suggests that the food supply has not been reduced by exposure to contaminants and can support populations of POD species.”

To the extent possible with the available data, the following conclusions were made:

- Chemicals with available data were not found in higher concentrations during the POD years compared to the pre-POD years.
- There was as much or more toxicity in water samples from the Delta in pre-POD years compared to the POD years.
- The percentage of toxic samples collected from Delta waters was lower than in tributaries (0-7 percent) and less frequent but could indicate a potential for toxicity to prey items utilized by POD species.

- Ammonia was not the focus of this review but there was no correlation between ammonia concentrations and larval delta smelt 7-d survival, where maximum unionized ammonia concentrations were < 0.016 milligrams per liter (mg/L).
- There appeared to be no difference in the percentage of toxic water samples to either *Ceriodaphnia dubia* or *Pimephales promelas* between the 2000-2002 step-decline years and the later POD years.
- There were no toxicity data available to determine if the threadfin shad was relatively less sensitive to chemicals present in the Delta compared to other POD species. Chemical data did not identify the cause of the step-decline in population of threadfin shad followed by the gradual increase in abundance in the subsequent years while other POD species were declining.
- It was considered unlikely that differential exposure of POD and non-POD species to contaminants would account for some species thriving (i.e., inland silverside, bluegill sunfish) in the Delta while POD species are not.
- Several non-POD species were present in the Delta at the same time as POD species. The cursory review of the relative sensitivity of POD and non-POD species to various chemicals found in the Delta during the POD years did not suggest that POD species are more sensitive to chemical toxicants.
- While direct toxicity to POD species was considered unlikely, indirect effects on POD species through toxicity to prey items could not be ruled out. A helpful evaluation of the prey items for POD and non-POD fish suggests different diets may contribute to differential food availability for POD and non-POD species; however, observations that smelt stomachs were full of food refute the potential for bottom-up effects.

The main conclusion drawn from the analyses was that contaminants did not seem to be a major cause of the POD, although they could not be eliminated as a possible contributor to the decline.

Uncertainties

Conclusions in this assessment were hindered by limited or unreliable data. Concentrations below detection limits could not inform risk evaluations when the detection limit exceeded the threshold toxicity effect concentrations. The data quality of other chemicals could not always be determined if collection records were incomplete or unavailable and if samples were improperly collected according to current standards (i.e., pyrethroids)—as expected when data was evaluated over an approximately 10-year period and detection limits have changed as new analytical methods have been developed and refined. This long-term data review emphasizes the importance of thinking ahead to possible data analyses when planning monitoring projects and using DQOs to ensure detection limits are adequate for the planned uses of the data – to the extent possible.

Teh, S., I. Flores, M. Kawaguchi, S. Lesmeister, and C. Teh. 2011. Full Life-Cycle Bioassay Approach to Assess Chronic Exposure of *Pseudodiaptomus forbesi* to Ammonia/Ammonium. Final Report. Submitted to Chris Foe of the Central Valley Regional Water Quality Control Board and Mark Gowdy of the State Water Resources Control Board. August.

This technical report presents the findings of multiple toxicity tests with a novel test organism—the copepod *Pseudodiaptomus forbesi* (*P. forbesi*). Reported toxicity effect levels are presented for chronic reproduction effects and acute survival endpoints. Based on these results, the authors concluded that the concentrations of ammonia in the Sacramento River downstream of Hood are at levels potentially

toxic to *P. forbesi*. However, significant concerns over the validity of these test results have been expressed by reviewers.

Uncertainties

An independent review of the final report by Pacific EcoRisk (PER)²⁴ found that the testing methods were flawed and results were calculated erroneously. For example, using the same statistical software as Teh et al., PER's independent analysis of 31-day reproduction toxicity data resulted in lowest observed effect levels of 1.62 mg/L total ammonia nitrogen (TAN) when the article reported 0.79 mg/L TAN for juveniles. Likewise, independent analyses found a LOEC of >3.23 mg/L TAN for adults when the study reported LOELs of 0.79 and 0.36 mg/L TAN. High variability within many of the test results sheds great uncertainty on the reported results, especially when significant effects are reported despite the lack of clear dose-response relationships. PER comments concluded that:

*“The reviewer is troubled by the absence of any discussion by Teh et al. regarding the variability in their test response data, either between tests or within tests (i.e., inter-replicate variability). Without such acknowledgement, it is left for the non-scientist to assume that the data as presented are definitive. Moreover, it raises the question of whether the data from this study are adequate (or ‘ready’) for use in regulatory decision-making. However, it is important to note that this critical review is not intended to negate Teh et al.’s general observations that ammonia is toxic to naupliar, juvenile, and/or adult *P. forbesi* at elevated concentrations and that this toxicity is strongly influenced by pH. Indeed, the primary question of ‘what are the effects of ammonia on *P. forbesi*’ is relevant and Teh et al.’s study results certainly compel a more thorough examination of this. However, the problems associated with Teh et al.’s experimental methodology for Subtasks 3-3 and 3-4-1 and significant questions regarding the analysis of the resulting data do indicate that the quality of the work should preclude the resulting ‘critical threshold’ data (i.e., NOECs, LOECs, and point estimates [e.g., ECx, LCx, and ICx values]) from being used for regulatory purposes.”*

Comments were provided to the CVRWQCB and Dr. Teh by SRCSD on May 17, 2011. Author responses to SRCSDs comments were provided in a letter to Ms. Linda Dorn of SRCSD on August 31 2011, but these responses did not adequately address SRCSD's comments and inconsistencies persist in the final report. It is recommended that this study be excluded from any SWRCB consideration pending further review and clarification of the reported effect levels. This study would have benefitted from developing DQOs and generating validated data of known quality, as the existing data are of uncertain quality and concerns exist that resource managers who rely on these data will be misinformed.

²⁴ Pacific EcoRisk, Inc (PER). 2011. *A Critical Review of: Full Life-Cycle Bioassay Approach to Assess Chronic Exposure of Pseudodiaptomus forbesi to Ammonia/Ammonium - Final Report Dated August 31, 2011*. Prepared for Larry Walker Associates and the Central Contra Costa County Sanitary District. December.

Werner, I. D. Markiewicz, L. Deanovic, R. Connon, S. Beggel, S. Teh, M. Stillway, and C. Reece. 2010a. Pelagic Organism Decline (POD): Acute and Chronic Invertebrate and Fish Toxicity Testing in the Sacramento-San Joaquin Delta 2008-2010. Final Report. Prepared by Aquatic Toxicology Laboratory, School of Veterinary Medicine, University of California, Davis, California. Submitted to the California Department of Water Resources.

Werner, I., L.A. Deanovic, D. Markiewicz, J. Khamphanh, C.K. Reece, M. Stillway, and C. Reece. 2010b. Monitoring acute and chronic water column toxicity in the northern Sacramento-San Joaquin Estuary, California, USA, using the euryhaline amphipod, *Hyaella azteca*: 2006-2007. Environ. Toxicol. Chem. 29:2190-2199.

Werner et al. (2010a,b) describe a toxicity monitoring program in the Sacramento-San Joaquin Delta from 2006-2009. This research focused on the toxicity of ambient waters to fish and aquatic invertebrates using laboratory and stream-side toxicity testing and used TIE methods to determine whether either pyrethroids or organophosphate insecticides were contributing to ambient toxicity. A total of 752 water samples were collected from 16 sites in the Northern Sacramento-San Joaquin Estuary during 2008-2009. Of these, acute *Hyaella azteca* toxicity (mortality measured over 10 days) was found in only 0.5 percent of samples (4 samples) and chronic toxicity to *Hyaella* (as measured by 10-day growth) was found in only 0.9 percent of samples (7 samples). There was no toxicity to delta smelt, *Hyaella*, or fathead minnows in streamside "in situ" tests. Although some areas within the Delta were identified as "least favorable" / "at times unfavorable" to delta smelt, the authors concluded that ammonia could not be implicated as a primary cause of smelt toxicity and in some cases, toxicity was partly attributable to low turbidity stress. In fact, good survival of larval smelt in water samples from some principal spawning and rearing grounds that had the highest concentrations of ammonia suggests that ammonia does not adversely affect juvenile smelt at these locations. Finally, pilot testing with water from several Delta sites identified low conductivity as a major factor determining survival of *Eurytemora affinis*. The low incidence of toxicity in these ambient samples supports a conclusion that contaminants are not a major driver of the POD.

Delta smelt toxicity from ammonia (lowest reported LD50 of 5.4 mg/L NH₄⁺) were reported to be 1.8 times more sensitive to ammonium and 5-6 times more sensitive to ammonia than fathead minnows. However, current ambient water quality criteria for ammonia¹² are protective of delta smelt (acute criterion range of 3.19 to 5.25 mg N/L under conditions tested; pH of 7.9 and temperatures 20 to 25°C).

Uncertainties

Acute toxicity data do not provide a compelling argument that ammonia/ium is causing adverse effects in the Delta despite statements that there were "Significant correlations between amphipod survival [and ammonia/ium]" This statement applies to correlations of ambient surface water toxicity data from 2006-2009 at individual sites and the data were not compiled across all sites. Further, it does not adequately describe the results in which only one negative relationship (where ammonia/ium was associated with reduced survival) was observed (at Cache-Ulatis), but positive relationships between ammonia/ium and survival were observed at five sites (Sites 323, 504, 804, 915, and Cache-Lindsey). Werner et al. (2010a,b) report that growth measured in the *Hyaella* chronic toxicity tests was not a reliable toxicity endpoint due to variable organism size and effects related to water quality (i.e., conductivity). Therefore, any of the conclusions regarding chronic toxicity to *Hyaella* should be considered qualified due to this limitation, although no such qualification is stated. Despite these limitations, the authors make several conclusions based on the growth endpoint in these chronic tests.

Additionally, the analysis of ammonia discussed in both Werner et al. (2010a) and Werner et al. (2010b) was independent of pesticide analyses and did not consider interactions of contaminants. Ammonia was reported to have significant relationships with *Hyalella* survival and growth, but there was no consideration of the interactive effects from salinity/ions/hardness/conductivity²⁵ or the fact that measured concentrations of ammonia in the samples were below minimum concentrations reported to affect *Hyalella azteca* growth and survival (i.e., 4-day LC50 of 20 to 28 mg N/L; and growth was not reported to be affected by total ammonium concentrations up to 14 to 25 mg N/L²⁶). Given these uncertainties, it would seem more likely that constituents/factors other than ammonia were greater contributors to the observed toxicity. Results for univariate correlations that ignore these other known stressors must be considered in context with other observations to draw conclusions and do not support conclusions about causal relationships.

Connon, R.E., L. Deanovic, E.B. Fritsch, L.S. D'Abronzio, and I. Werner. 2011. Sublethal responses to ammonia in the endangered delta smelt; *Hypomesus transpacificus* (Fam. Osmeridae). *Aquatic Toxicol.* 105(3-4):369-377.

Four-day exposures of 57-day old delta smelt to aqueous concentrations of ammonia (2.5-80 mg/L total ammonia; 0.023-0.439 mg/L unionized ammonia) were generally above actual (i.e., environmentally relevant) concentrations in the Delta. These tested concentrations were at or above the highest concentrations reported by Werner et al. (2010a) of 0.62 mg/L total ammonia and 0.025 mg/L unionized ammonia. This study demonstrated sub-cellular effects (e.g., cell membrane destabilization) from ammonia exposure (NOEC = 5 mg/L total ammonia/ium; 0.066 mg/L ammonia; LOEC = 9 mg/L total ammonia/ium; 0.105 mg/L ammonia), at concentrations above environmentally relevant exposures in the Delta.

Uncertainties

Biomarkers are typically only considered a measure of exposure—essentially where a gene is turned on/off in response to an exposure—but it is not clear what effect this change has on the whole organism (i.e., survival, growth, or reproduction) or population. Dose-responses for several biomarkers were varied and some of the associations between biomarkers and adverse effects were unclear. Organisms can also compensate metabolically and can recover from short-term chemical exposures. These uncertainties can be addressed to a degree by additional study to better understand the linkages between biomarkers and organism-level effects, as the authors recommend.

²⁵ Borgmann, U. 1994. Chronic toxicity of ammonia to the amphipod *Hyalella azteca*; importance of ammonium ion and water hardness. *Environmental Pollution.* 86:329-335.

²⁶ *ibid*