TESTIMONY/COMMENTS OF CAMERON A. IRVINE REGARDING RENEWAL OF WASTE DISCHARGE REQUIREMENTS AND THE NPDES PERMIT (NO. CA0077682) FOR SACRAMENTO REGIONAL COUNTY SANITATION DISTRICT, SACRAMENTO REGIONAL WASTEWATER TREATMENT PLANT BEFORE THE CENTRAL VALLEY REGIONAL WATER QUALITY CONTROL BOARD

On behalf of the

SACRAMENTO REGIONAL COUNTY SANITATION DISTRICT (SRCSD)

I am Cameron Irvine, R.P. Biol. (No. 1197). I have over 15 years of environmental assessment and toxicity experience in a variety of geographies. The focus of my recent work has been ecological risk assessment, whole effluent toxicity testing for NPDES dischargers, and participating in aquatic ecotoxicology studies. After earning a B.Sc. in biology at the University of Saskatchewan, for the next four years I worked as a biologist conducting environmental assessments at mining sites and leading a watershed-restoration project to improve rainbow trout spawning habitat. I then returned to school to complete a Masters Degree in Environmental Toxicology. In 2004, I began my current position as an ecological risk assessor/ecotoxicologist with CH2M HILL in Sacramento, California. A copy of my resume describing my education and experience is attached.

My work experience has focused on evaluating the effects and potential effects of stressors on organisms in the environment. I have led field investigations to evaluate the impacts of mining activities on aquatic and terrestrial communities, studied factors limiting the recruitment of rainbow trout then implemented watershed-scale restoration efforts to restore habitat and increase the survival of overwintering juveniles, authored risk assessments at numerous superfund sites across the United States to identify the potential risks to aquatic and terrestrial wildlife from contaminants, conducted extensive Toxicity Reduction Evaluation (TRE) studies to identify and successfully reduce toxicity from treated wastewater, and participated in the design, implementation, and reporting of aquatic toxicity investigations.

I am the principal investigator and author of the Sacramento Regional Wastewater Treatment Plant (SRWTP) 2004-2007 *Ceriodaphnia dubia* Chronic Toxicity Reduction Evaluation, where we found that apparent effluent toxicity was caused by an artifact of the sampling system. I have also been involved in multiple studies, on behalf of SRCSD, as a technical liaison between academic institution investigators and the Central Valley Regional Water Quality Control Board (CVRWQCB) to investigate the potential for ammonia/ium and effluent associated toxicity to algae and delta smelt in the Sacramento River, as well as pyrethroid source-evaluation studies at SRWTP. In 2008, I co-authored the Sampling and Analysis Plan – with principal researcher Inge Werner (UC Davis) and the CVRWQCB, to conduct effluent-ammonia toxicity studies with delta smelt. In addition, as a member of the Pelagic Organism Decline – Contaminant Work Team (POD-CWT), I have continued to participate in reviews and contributed to comments submitted on Delta toxicity studies on behalf of SRCSD. In 2008, I was a planning committee member of the CalFed Ammonia Workshop in Sacramento, and I participated in the workshop as a panelist.

Documents I have prepared include the following:

CH2M HILL. 2009. Summary of the Chronic Ceriodaphnia dubia Whole Effluent Toxicity Reduction Evaluation at the Sacramento Regional Wastewater Treatment Plant 2004–2007. October. Prepared by CH2M HILL for the Sacramento Regional County Sanitation District.

- This investigation identified that chronic toxicity to *C. dubia* was caused by a sampling artifact, and that the reported toxicity was not necessarily indicative of the toxicity in effluent discharged to the Sacramento River. High numbers of bacteria were growing in the treated effluent composite samples due to a sub-optimal configuration of the autosamplers. This conclusion was based upon sampling and testing, which identified the autosamplers as the source of toxicity. Toxicity was not present in the secondary treated effluent. The toxicant was confirmed and then the toxicity was successfully removed by reconfiguring the samplers. Confirmation steps included isolating toxic and non-toxic bacteria from samples and inoculating non-toxic samples to reintroduce toxicity.

Werner, I., ***C. Irvine****, and C. Foe. 2008a. The Effects of Wastewater Treatment Effluent-Associated Contaminants on Delta Smelt. Ammonia Toxicity Sampling and Analysis Plan. Final. July.*

- This document describes the rationale and methods for conducting toxicity tests to determine the toxicity of effluent-ammonia to delta smelt in 2008. These methods have continued to be used by Dr. Werner in subsequent investigations that continued in 2009 and 2010.

Engle, D., J. Walker, S. McCord, ***C. Irvine****, and C. Williams. 2009. Sacramento River Ammonia Pilot Study Results. August. Prepared by Larry Walker Associates and CH2M HILL for the Sacramento Regional County Sanitation District and distributed to the Pelagic Organism Decline – Contaminant Work Team.*

- This pilot study collected effluent and ambient water samples in the Sacramento River to assess potential fate and transport, and to identify sources of nutrients. No additional sources were identified. Ambient total ammonia concentrations measured during this pilot study were well below water quality criteria (USEPA 1999).

Ballard, A., R. Brewer, F. Brewster, C. Dahm, ***C. Irvine****, K. Larsen, A. Mueller-Solger, A. Vargas. 2009. Background/Summary of Ammonia Investigations in the Sacramento-San Joaquin Delta and Suisun Bay. Distributed by CalFed for the March 2009 Ammonia Workshop.* http://www.science.calwater.ca.gov/events/workshops/workshop_ammonia.html

- This summary of current information on ammonia/ium in the Delta was prepared for, and distributed to, participants of the March 2009 CalFed Science Ammonia Workshop. Multiple studies conducted to evaluate effects of ammonia in the delta identified that current and historical total ammonia concentrations in the Delta were well below the EPA (1999) ambient water quality criteria for the protections of life. Ambient concentrations were also well below the reported no-effect concentrations for acute toxicity to delta smelt.

The above documents accurately provide my analyses and opinions.

My opinions herein are based on my education, background and experience, including years involved with various Delta science activities and reviews of reports that have been made available to me, including the following:

a. Existing toxicity and effluent data support the conclusion that treated wastewater discharged from SRWTP does not pose a potential for toxicity to aquatic organisms in the receiving environment. Direct toxicity to Delta species has been evaluated as a potential cause of the Pelagic Organism Decline (POD) for many years, although no direct causal relationships have been shown. Effluent toxicity reported in Whole Effluent Toxicity (WET) tests with SRWTP effluent only occur at concentrations exceeding ambient and environmental relevant conditions in the Sacramento River. In addition, effluent-ammonia toxicity tests with delta smelt, *H. azteca* toxicity tests, and copepod toxicity tests have only resulted in toxicity at concentrations well above those that occur in the receiving environment.

b. Toxicity data with novel test species should be interpreted carefully, and with a comprehensive understanding of the available information and limitations of those data. I have been involved in delta smelt toxicity studies since 2008 when SRCSD began a partnership with Dr. Inge Werner (UC Davis) and the CVRWQCB to evaluate whether ammonia from SRWTP posed a potential risk to delta smelt. These acute toxicity studies have conclusively demonstrated that ammonia and effluent from SRWTP in the receiving environment are below concentrations that cause toxicity to larval delta smelt in the Sacramento River (Werner et al. 2009a, 2009b, 2010a). I support these recent delta smelt bioassays conducted by the UC Davis Aquatic Toxicology Lab; although, I qualify this endorsement of toxicity testing with a novel species by saying that early testing by the Werner lab was not as reliable as recent tests with delta smelt larvae. The methods for delta smelt toxicity testing have been under development since at least 2006. Early test data often had poor control survival and I do not consider those results as reliable as recent testing using more refined methods. Antibiotic application for all tested fish was initiated in 2009 and significantly improved the reliability and survival in controls. In addition, it was found that low-EC (salinity) and low turbidity were found to adversely affect delta smelt from the hatchery when they were tested in ambient water samples (Werner et al. 2010b). Therefore, it is important to have multiple controls, including a low-EC/low-turbidity control, matched to ambient conditions for appropriate interpretation of delta smelt toxicity testing in ambient waters (including those using effluent diluted with ambient river water).

c. Understanding the environmental relevance of toxicity data is important for properly interpreting the significance of any results. Pyrethroid insecticides have been a topic of recent considerations as a potential contributor to the POD. Pyrethroids can be present in some, but not all effluent samples from SRWTP, as shown by Weston and Lydy (2010). I supported that study through planning, sample collection, coordinating paired toxicity testing and chemical analysis, and document reviews on behalf of SRWTP. It is important to know that pyrethroids have only been found to be toxic in effluent concentrations that are not environmentally relevant. SRWTP effluent is diluted, on average, 50:1 in river water. Accounting for actual dilution in the Sacramento River reduces pyrethroids from SRWTP effluent to concentrations well below levels known to cause toxicity to highly sensitive invertebrates (i.e., *Hyalella azteca*).

d. I caution the use of draft or provisional data prior to final reports and complete data reviews. As reports are finalized, or peer reviewed manuscripts are published, they tend to increase in reliability and credibility; although, even final products can still contain errors or there can be differences in data interpretation among experts. An example of this from recent Delta ammonia toxicity discussions can be found in a report by Werner et al. (2006), initially reporting a relatively low ('effect level' of >0.02 mg/L unionized ammonia) during the early stages of delta smelt toxicity testing of ambient waters in the Delta. A thorough data review identified multiple assumptions and data concerns that cast significant doubt on the original reported effect level (Werner et al. 2008a,b). Future testing improved the exposure design to reduce test artifacts in these earlier bioassays. The unreliable draft data, however, were reiterated by POD researchers at meetings and conferences in 2007 and 2008. Similarly, preliminary data presentations by Teh et al. (2009) only reported the calculated effect levels of ammonia/ium for copepods. A review of the final data, when it became available in Werner et al. (2010b), clearly showed that some bioassays did not produce dose responses that could be interpreted with confidence (i.e., point estimates of effects were outside of the range of tested concentrations and there were high mortalities in all tested concentrations except for one).

In addition to the above, I have reviewed select sections of the Tentative NPDES Permit (No. CA0077682) for Sacramento Regional County Sanitation District, Sacramento Regional Wastewater Treatment Plant, issued by the Central Valley Regional Water Quality Control Board on September 3, 2010, at the request of SRCSD. My opinions on specific permit provisions or references are based on my education, background and experience and include the following:

The proposed permit includes a proposed study to develop procedures for conducting WET testing using *Hyalella azteca*. In my opinion, the proposed study requirement, without further clarification, would be extensive and resource intensive. Based on my past experience, method development studies need to include acceptability criteria, interlaboratory variability, and other specified elements for consideration in WET method development (e.g., test duration and toxicity endpoints that will be measured). Further, in my opinion, methods development studies are more appropriately undertaken by large government agencies such as USEPA, the United States Geological Survey, or a consensus body of experts such as the American Society of Testing and Materials (ASTM).

The proposed permit also includes references to recent studies and/or presentations suggesting ambient toxicity to *Pseudodiaptomus forbesi* (copepod). In my opinion, data that have not been peer reviewed, finalized, and confirmed should be viewed with caution. It is my opinion that these preliminary data may be of interest, but should have little weight in any scientific discussion until finalized, validated by confirmation testing, and any significant data gaps filled.

The proposed permit includes references to a number of studies pertaining to ammonia and toxicity issues within the Delta. My reviews of select studies are provided further below.

Additionally, I have reviewed many technical Delta science documents on behalf of SRCSD and, in some cases, prepared comments on the draft reports that have been incorporated into those submitted by SRCSD in response to requests for comments.

Effluent and Ammonia Toxicity to Delta Smelt

I have been involved in delta smelt toxicity studies to evaluate the potential effects from SRWTP effluent and ammonia since these tests began in 2008. My role as a technical liaison between academic institution investigators, the CVRWQCB, and SRCSD required me to review and comment on work plans, draft reports and final report describing these data and I am intimately familiar with them. A summary of my comments and conclusions regarding these reports is provided below:

Werner I., L.A. Deanovic, M. Stillway, and D. Markiewicz. 2009a. Acute Toxicity of Ammonia/um and Wastewater Treatment Effluent-Associated Contaminants on Delta Smelt. Final Report to the Central Valley Regional Water Quality Control Board, Rancho Cordova, CA.

Two 7-day acute toxicity tests with delta smelt exposed to up to 8 mg/L total ammonia and 36% effluent-ammonia were conducted with larval delta smelt (55-days old) in 2008. Mixtures of effluent and ammonia were made in Sacramento River water (collected upstream of the SRWTP discharge at Garcia Bend). Test I did not result in significantly reduced delta smelt survival in the maximum tested concentrations: up to 4 mg/L of ammonia added to river water and 2 mg/L ammonia from effluent (equal to 9% effluent) (Table 4-1 from Werner et al. 2009a). These concentrations are well above typical ambient ammonium levels in the Sacramento River downstream of the SRWTP outfall.

The second test (Test II) also showed no effects to delta smelt at ammonium concentrations up to 8 mg/L; although, the acceptability of this second test has been debated. Multiple controls were used in these delta smelt bioassays to adequately understand fish responses to stressors. There was a hatchery control that must have at least 60% survival to meet the test acceptability criteria. There was also a low-EC/low turbidity control and a reference site sample (in this case from the Sacramento River at Garcia Bend) that was used for dilution water. Test II had lower than 60% survival in the low-EC control, but survival was above 60% in both the Garcia Bend reference sample and the hatchery control. Because samples with effluent-ammonia are compared to the Garcia Bend reference sample, and this sample had relatively good survival exceeding the low-EC/low turbidity control, the confounding effects from low-EC/low turbidity were offset by better water quality in the ambient samples. This test would be acceptable based on the un-amended sampling and analysis plan (Werner et al. 2008a) and would be consistent with POD-CWT ammonia subcommittee discussions on the appropriate analysis methods.

The Werner et al. (2009a) report was finalized prior to POD-CWT meetings where appropriate analysis methods were determined. As such, the second delta smelt test was reported as invalid in this report. The rationale for invalidating this second test was partly based on an addendum to the Werner et al. (2008a) sampling and analysis plan, which was intended to define a wider range of test concentrations for Test II, but contained criteria contrary to the main sampling plan document. Acceptable or not, Test II did not show any acute effects to larval smelt from total ammonium concentrations up to 8 mg/L. Likewise, SRWTP effluent concentrations up to approximately 36% did not have significantly affect delta smelt survival (Table 5-1 from Werner et al. 2009a). These no-effect concentrations are well above ammonium and effluent concentrations found in the Delta.

Table 4-1. Percent survival of 55-d old delta smelt larvae after a 7-d test initiated 6/05/08; SRWT= Sacramento Regional Wastewater Treatment Plant; se=standard error of the mean; shaded cells indicate significant ($p<0.05$) reduction in survival compared to the appropriate control.

Treatment	Survival (%)[1]	
	mean	se
Sacramento River at Garcia Bend (SRGB)	66.3	8.8
SRGB + 0.25 mg/L NH_3/NH_4^+ from NH_4Cl	62.5	8.0
SRGB + 0.50 mg/L NH_3/NH_4^+ from NH_4Cl	64.1	11.4
SRGB + 1.00 mg/L NH_3/NH_4^+ from NH_4Cl	64.2	8.3
SRGB + 2.00 mg/L NH_3/NH_4^+ from NH_4Cl	72.3	5.2
SRGB + 4.00 mg/L NH_3/NH_4^+ from NH_4Cl	61.2	7.1
SRGB + 0.25 mg/L NH_3/NH_4^+ from SRWTP	81.4	3.7
SRGB + 0.50 mg/L NH_3/NH_4^+ from SRWTP	45.8	4.2
SRGB + 1.00 mg/L NH_3/NH_4^+ from SRWTP	62.6	4.3
SRGB + 2.00 mg/L NH_3/NH_4^+ from SRWTP	64.9	10.1
Low EC Control	81.3	7.1
Hatchery Water Control	91.7	3.4

[1] The Low EC Control consisted of hatchery water diluted with distilled water to match SRGB conductivity.

Table 5-1. Percent survival of 43-d old delta smelt larvae after a 7-d test initiated 7/17/08; SRWT= Sacramento Regional Wastewater Treatment Plant; se=standard error of the mean; shaded cells indicate significant ($p<0.05$) reduction in survival compared to the appropriate control.

Treatment	Survival (%)[1,2]	
	mean	se
Sacramento River at Garcia Bend (SRGB)	65.0	8.7
SRGB + 1.0 mg/L NH_3/NH_4^+ from NH_4Cl	47.5	6.3
SRGB + 2.0 mg/L NH_3/NH_4^+ from NH_4Cl	60.0	7.1
SRGB + 4.0 mg/L NH_3/NH_4^+ from NH_4Cl	75.0	2.9
SRGB + 8.0 mg/L NH_3/NH_4^+ from NH_4Cl	40.0	12.9
SRGB + 0.5 mg/L NH_3/NH_4^+ from SRWTP	55.0	5.0
SRGB + 1.0 mg/L NH_3/NH_4^+ from SRWTP	50.0	4.1
SRGB + 2.0 mg/L NH_3/NH_4^+ from SRWTP	47.5	4.8
SRGB + 4.0 mg/L NH_3/NH_4^+ from SRWTP	60.0	5.8
SRGB + 8.0 mg/L NH_3/NH_4^+ from SRWTP	42.5	13.1
Low EC Control[2,3]	52.5	8.5
Hatchery Water Control	80.0	4.1

[1] The Low EC Control consisted of hatchery water diluted with distilled water to match SRGB conductivity.

[2] Low EC Control showed significantly lower survival compared to the hatchery water control, but not compared to SRGB.

Werner I., L.A. Deanovic, M. Stillway, and D. Markiewicz. 2009b. Acute Toxicity of Ammonia/um and Wastewater Treatment Effluent-Associated Contaminants on Delta Smelt - 2009. Final Report to the Central Valley Regional Water Quality Control Board, Rancho Cordova, CA.

A single 7-day acute toxicity test with delta smelt exposed to up to 8 mg/L total ammonia and 38% effluent was completed in 2009 (Table 3-1 in Werner et al. 2009b). In this test, there was significantly increased mortality in 8 mg/L total ammonia spiked into river samples and compared with reference site, and at 4 mg/L total ammonia (as a mixture of approximately 18% effluent in river water). These tests did not show effects to delta smelt at environmentally relevant concentrations of total ammonia and effluent.

Table 3-1. Percent survival of 47-d old delta smelt larvae during a 7-d test initiated 6/11/09(Experiment III): SRWTP = Sacramento Regional Wastewater Treatment Plant: SRGB = Sacramento River at Garcia Bend; SE=standard error of the mean: shaded cells indicate significant ($p<0.05$) reduction in survival compared to SRGB; * indicates significantly lower survival than in the corresponding treatment containing NH_4Cl (two-tailed test).

Treatment	Mean Measured Total Ammonia/um (mg/L)	Mean Un-ionized Ammonia (mg/L)	Percent Effluent		96-hr Survival (%)		7-day Survival (%)	
			Mean	SE	Mean	SE	Mean	SE
SRGB	0.10	0.002	-	-	92.0	3.4	73.5	10.6
2.00 mg/L NH_3-N from NH_4Cl	1.90	0.038	-	-	91.5	3.4	73.9	5.1
4.00 mg/L NH_3-N from NH_4Cl	3.84	0.071	-	-	91.5	3.4	65.3	5.7
6.00 mg/L NH_3-N from NH_4Cl	5.66	0.091	-	-	95.8	2.4	77.1	4.0
8.00 mg/L NH_3-N from NH_4Cl	7.71	0.116	-	-	76.5	9.1	32.4	9.7
2.00 mg/L NH_3-N from SRWTP	1.96	0.039	9.0	0.3	95.8	2.4	75.0	5.9
4.00 mg/L NH_3-N from SRWTP	3.92	0.081	18.3	0.5	85.5	7.0	41.5	10.2
6.00 mg/L NH_3-N from SRWTP	5.85	0.092	28.1	0.8	81.1	7.8	36.0*	9.0
8.00 mg/L NH_3-N from SRWTP	7.78	0.139	37.9	1.0	33.5*	12.1	6.3*	4.0
Low EC Control	0.17	0.002	-	-	95.8	4.2	85.2	7.1
Hatchery Water Control	0.20	0.004	-	-	95.6	2.5	82.4	9.9
Hatchery Water - No Antibiotics	0.21	0.003	-	-	83.7	9.0	81.6	11.0

Werner, I., L.A. Deanovic, M. Stillway, and D. Markiewicz. 2010a. Acute Toxicity of SRWTP Effluent to Delta Smelt and Surrogate Species. Draft Final Report Submitted to the Central Valley Regional Water Quality Control Board on August 23, 2010.

Three 7-day acute toxicity tests with larval delta smelt (47 and 48 days old) exposed to up to 28% effluent-ammonia were completed in 2010 (Tables 4a, 4b, and 4c in Werner et al. 2010a). No adverse effects to delta smelt and rainbow trout exposed to 28% effluent; 6.12 - 7.82 mg/L ammonia/ium, and 0.076 - 0.144 mg/L ammonia. These concentrations overlap previously determined effect levels for delta smelt and indicate that there is substantial variability in effluent and/or smelt sensitivity.

Table 4 a. Percent survival of 48-d old delta smelt larvae during a 7-d test initiated April 22, 2010; SRWTP = Sacramento Regional Wastewater Treatment Plant; SRGB = Sacramento River at Garcia Bend; SE=standard error of the mean.

Treatment	Mean Measured Total Ammonia/um (mg/L)	Mean Un-ionized Ammonia (mg/L)	96-h Survival (%)		7-day Survival (%)	
			Mean	SE	Mean	SE
SRGB	0.11	0.002	95.8	4.2	95.8	4.2
4.5% SRWTP	1.10	0.022	95.5	2.6	93.2	4.4
9 % SRWTP	2.13	0.041	97.7	2.3	95.6	2.5
18 % SRWTP	4.22	0.075	100.0	0.0	97.7	2.3
28 % SRWTP	6.58	0.106	97.5	2.5	95.4	2.7
Low EC Control	0.19	0.003	95.6	2.5	93.6	2.2
Hatchery Water Control	0.24	0.006	100.0	0.0	95.8	2.4

Table 4 b. Percent survival of 47-d old delta smelt larvae during a 7-d test initiated May 20, 2010; SRWTP = Sacramento Regional Wastewater Treatment Plant; SRGB = Sacramento River at Garcia Bend; SE=standard error of the mean.

Treatment	Mean Measured Total Ammonia/um (mg/L)	Mean Un-ionized Ammonia (mg/L)	96-h Survival (%)		7-day Survival (%)	
			Mean	SE	Mean	SE
SRGB	0.08	0.003	79.9	7.8	75.4	10.2
4.5% SRWTP	1.31	0.039	85.4	6.3	77.6	8.3
9 % SRWTP	2.54	0.064	82.8*	3.9	73.7*	4.0
18 % SRWTP	5.04	0.100	81.4	6.3	74.4	10.5
28 % SRWTP	7.82	0.144	84.0*	2.4	70.3*	1.5
Low EC Control	0.18	0.008	97.5	2.5	90.5	5.5
Hatchery Water Control	0.20	0.004	86.3	4.6	84.2	2.6

*significantly different from Low EC Control.

Table 4 c. Percent survival of 48-d old delta smelt larvae during a 7-d test initiated June 17, 2010; SRWTP = Sacramento Regional Wastewater Treatment Plant; SRGB = Sacramento River at Garcia Bend; SE=standard error of the mean.

Treatment	Mean Measured Total Ammonia/um (mg/L)	Mean Un-ionized Ammonia (mg/L)	96-h Survival (%)		7-day Survival (%)	
			Mean	SE	Mean	SE
SRGB	0.08	0.001	100.0	0.0	91.3	3.7
4.5% SRWTP	1.06	0.015	100.0	0.0	84.8	4.5
9 % SRWTP	2.06	0.028	97.9	2.1	87.5	5.4
18 % SRWTP	3.91	0.047	96.2	3.8	92.3	7.7
28 % SRWTP	6.12	0.076	98.1	1.9	93.5	2.2
Low EC Control	0.16	0.002	97.9	2.1	95.8	4.2
Hatchery Water Control	0.19	0.003	97.9	2.1	95.8	2.4

AQUA-Science. 2010. Effects of Sacramento Regional Wastewater Treatment Plant Effluent on the 7-day Survival and Growth of Juvenile Rainbow Trout (*Oncorhynchus mykiss*). Prepared for SRCSD. August.

Rainbow trout toxicity tests with effluent were conducted with split samples also used by Werner (2010). These results support those from Werner (2010) that indicate there were no adverse acute (survival) or short-term chronic (growth) effects to juvenile rainbow trout at concentrations over 20 times the average percent effluent and ammonia levels found in the Sacramento River at the time of this testing.

<u>Toxicity of Delta Surface Waters to Fish and Invertebrates</u>

Recent investigations have focused on finding a potential link between the POD and toxicants; particularly ammonia. Of particular interest have been toxicity testing method developments at the UC Davis Aquatic Toxicology Lab (ATL). The ATL designed and is continually refining delta smelt acute toxicity testing methods that have provided insight on the sensitivity of delta smelt to ammonia and other toxicants. However, due to these developing methods it is not necessarily appropriate to compare data among years, and it is wise to consider past data in light of the current understanding. For example, early delta smelt testing in 2006 used static renewal methods that allowed ammonia to accumulate in the exposure beakers (Werner et al. 2006).

This testing artifact led to a premature conclusion about the sensitivity of smelt to ammonia. Refined testing methods using flow-through exposures to maintain concentrations in ambient samples began in 2007 to address this test design-induced artifact (Werner et al. 2008b). Recognition that delta smelt are highly sensitive to low turbidity and low conductivity (EC) led to the inclusion of additional controls in 2008 and 2009 testing so that there are now controls for

1) low EC, 2) low turbidity, and 3) low EC/low turbidity in addition to 4) a hatchery water control. An additional control for 5) antibiotics also began with the use of medications to help increase control survival. The performance of (or lack of) appropriate controls for each test should be carefully considered in the evaluation of delta smelt toxicity data.

Larvae delta smelt, one of the species of concern for the POD, are reported to be as sensitive to ammonia as salmonid species (Werner et al. 2009a,b), which are considered the most sensitive fish species. Because rainbow trout (a salmonid that lives its entire life in fresh water) are protected by the National Recommended Water Quality Criteria for ammonia/ium (USEPA 1999), delta smelt will also be protected by these criteria. Despite ambient ammonia concentrations not exceeding USEPA acute or chronic criteria, there have been variable survival rates reported for delta smelt exposed to ambient Delta surface water (Reece et al. 2009). As mentioned above, reports that chronicle method development and attempt to interpret environmental data should be interpreted with caution. Correlations do not indicate causation, especially in ambient samples where many parameters are not measured. Analyses have also reported that in 2007 "*Turbidity and EC/salinity were the two most important factors determining survival of delta smelt larvae overall*" (Werner et al 2008b). The cause of variable toxicity results continues to be investigated, although species sensitivity testing (where serial dilutions of ammonia in culture water or in river water) support the conclusion that ammonia toxicity does not occur at ambient concentrations (Reece et al. 2009; Werner et al. 2009a,b).

Werner I., L. Deanovic, D. Markiewicz, M. Stillway, N. Offer, R. Connon, and S. Brander. 2008b. Pelagic Organism Decline (POD): Acute and Chronic Invertebrate and Fish Toxicity Testing in the Sacramento-San Joaquin Delta 2006-2007. Final Report. 30 April.

Previously reported in:

Werner, I., L. Deanovic, D. Markiewicz, M. Stillway, J. Khamphanh, R. Connon, N. Offer, J. Krause, T. Ha. 2006. Progress Report. Pelagic Organism Decline (POD), Acute and Chronic Invertebrate and Fish Toxicity Testing. Progress Report. UC Davis – Aquatic Toxicology Lab.11 August.

Werner, I., L. Deanovic, D. Markiewicz, M. Stillway, J. Khamphanh, R. Connon, N. Offer, J. Krause, T. Ha. 2007. Progress Report. Pelagic Organism Decline (POD), Acute and Chronic Invertebrate and Fish Toxicity Testing. Progress Report III. UC Davis – Aquatic Toxicology Lab. 30 September.

Juvenile and larvae delta smelt toxicity testing methods development by the UCD-ATL began in 2006 and 2007 with ambient water samples testing from the Sacramento-San Joaquin Delta. Results in 2006 and 2007 yielded contradictory results (Figures 1 and 2). Results of 96-hour bioassays in 2006 suggested that delta smelt may be highly sensitive to ammonia. However, this relationship was questioned, due to the low strength of the correlation (r^2=0.27), the heavy weight of one sample, and because ammonia concentrations, which changed throughout the test, were plotted based on maximum concentrations measured during the static renewal test rather than ambient concentrations.

Delta smelt survival also showed significant correlations with electrical conductivity and the age of fish used for testing (9-90 days). A problem with assuming that correlations indicate causation of toxicity with ambient samples is that any number of unmeasured toxicants may be a cause of toxicity and could correlate with another measure, like unionized ammonia. However, the error in this 2006 analysis was attributing toxicity to a measurement that changed throughout the test as ammonia was produced as an animal waste product. The ranges of unionized ammonia concentrations determined from samples over the test duration were highly variable and did not provide a consistent exposure (Figure 3). The wide range of concentrations seemed to be from ammonium generated within the test beaker that was not removed with the static renewal method – where once daily water changes replaced only a portion of the water sample. It is not known what caused toxicity to smelt in these tests with ambient surface water because toxicity identification evaluations that would have identified the toxicant(s) were not conducted. More comprehensive chemical analyses and multivariate statistics might also identify a cause of toxicity, but a simple correlation between one water quality parameter and a toxicity endpoint in likely samples containing a variety of chemicals does not allow for a conclusion of causation.

Delta smelt testing in 2007 used a continuous flow method to exchange water in the exposure tanks; this method change seemed to improve the removal of ammonia as it was generated. In contrast to the 2006 results, 2007 bioassays did not show any relationship between 7-day delta smelt survival and unionized ammonia concentrations (Figure 2) even higher than those measured in 2006. Of the 42 surface water grab samples collected in 2007 (seven locations sampled on six occasions), only two from the lower Sacramento River resulted in significantly reduced survival of delta smelt compared to controls. These data were insufficient to conclude that there was a potential for toxicity to delta smelt from ammonia discharged from SRWTP. Therefore, additional studies were planned for the subsequent years to clarify these results.

Figure 1. 2006 Delta smelt larvae survival (4-day) as a function of maximum unionized ammonia (calculated as mg/L NH_3 at 16-18°C) in static renewal exposures. Symbols indicate different sample dates and fish ages tested; unpublished data, UCD-ATL (Werner et al. 2006).

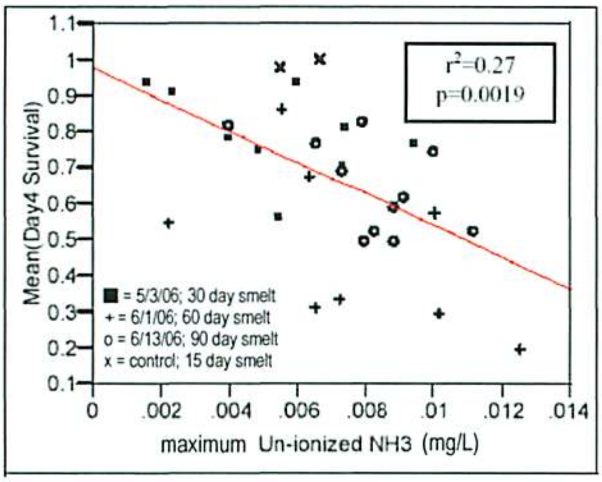


Figure 2. 2007 Delta smelt larvae survival (7-day) as a function of maximum unionized ammonia concentrations (calculated as mg/L NH_3 at 16-18°C) in flow-through exposures with samples from various Delta locations and dates (Werner at al. 2007).

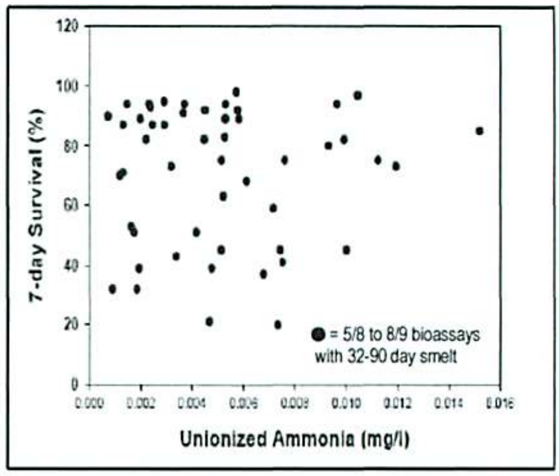
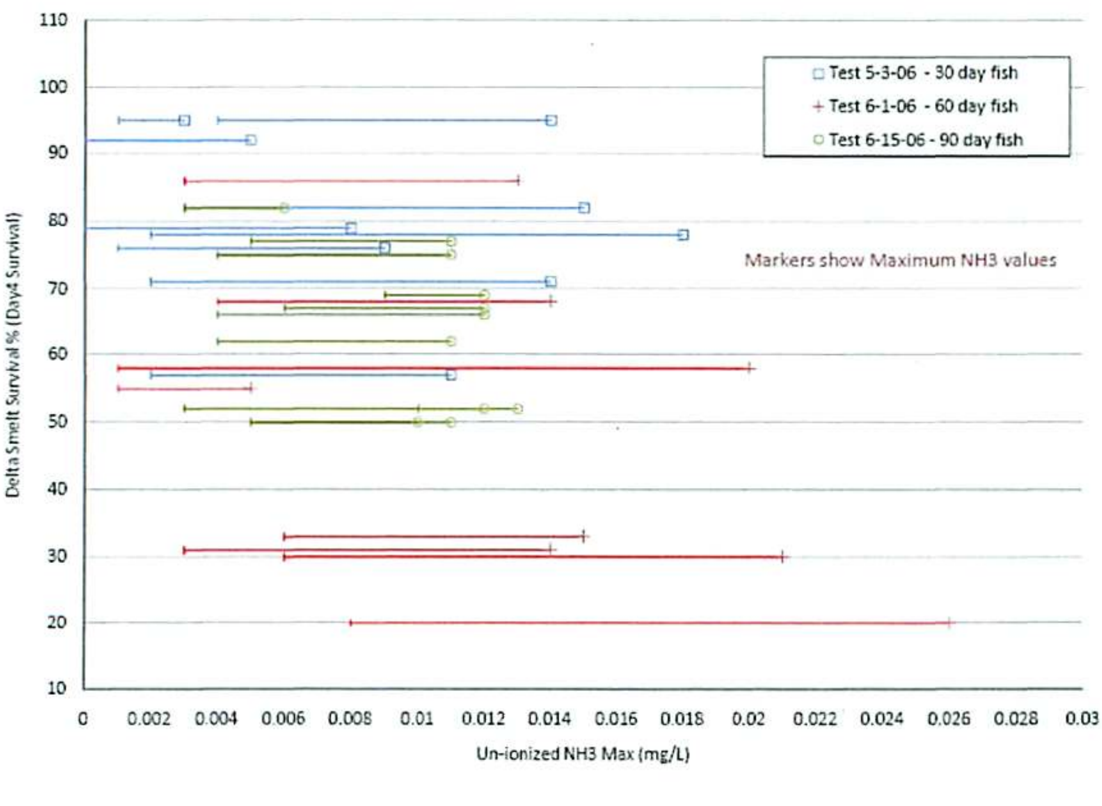


Figure 3. 2006 Delta smelt larvae survival (4-day) as a function of measured unionized ammonia ranges (calculated as mg/L NH_3 at 16-18°C) from sampling through testing (Werner et al. 2008a).



Werner I., D. Markiewicz, L.A. Deanovic, R.E. Connon, S. Beggel, S.J. Teh, M. Stillway, and C. Reece. 2010b. Pelagic Organism Decline (POD): Acute and Chronic Invertebrate and Fish Toxicity Testing in the Sacramento-San Joaquin Delta 2008-2010. Final Report.

Previously reported in:

Werner, I., L. Deanovic, D. Markiewicz, M. Stillway, J. Khamphanar, N. Offer, R. Connon, and S. Beggel. 2008b. Pelagic Organism Decline (POD): Acute and Chronic Invertebrate and Fish Toxicity Testing in the Sacramento-San Joaquin Delta 2008-2010, Progress Report. September.

Reece, C., D. Markiewicz, L. Deanovic, R. Connon, S. Beggel, M. Stillway, and I. Werner. 2009. Pelagic Organism Decline (POD): Acute and Chronic Invertebrate and Fish Toxicity Testing in the Sacramento-San Joaquin Delta 2008-2010, Progress Report III. September.

Werner et al. (2010b) describes a two-year (2008-2010) toxicity monitoring program in the Sacramento-San Joaquin Delta that continues studies started in 2006 and 2007 (Werner et al., 2008b). This research focused on the toxicity of ambient waters to fish and aquatic invertebrates using laboratory and stream-side toxicity testing.

Toxicity testing with *H. azteca* in 2008 and 2009 resulted in few acute (survival) or chronic (growth) effects in the 752 water samples collected from 16 sites in the Northern Sacramento-San Joaquin Estuary. Acute *H. azteca* toxicity (mortality measured over 10 days) was found in only 0.5% of samples (4 of 752). Samples from Hood (downstream of the SRWTP discharge) were not acutely toxic to *H. azteca*. Toxicity Identification Evaluation (TIE) methods used to identify if either pyrethroids or organophosphate insecticides were contributing to ambient toxicity to *H. azteca* identified pyrethroids in 7of 16 samples where acute TIEs were conducted. Pyrethroid insecticides are commonly used in agricultural and urban settings, and have been suspected to be the cause of infrequent toxicity to *H. azteca* in Delta surface water samples. This invertebrate lives on the surface of sediments and is extremely sensitive to pyrethroids. Increased mortality in Delta surface water was infrequently observed after the addition of a chemical that increases the toxicity of pyrethroids and decreases the toxicity from organophosphate (OP) insecticides. This increased toxicity, indicating that pyrethroids were present in the samples, accounted for only 2% of the tested samples in 2006-2007 and 0.5% of samples in 2008.

Chronic toxicity to *H. azteca* (as measured by 10-day growth) was found in only 0.9% (n=7) of samples. However, the authors stated that growth was not a reliable toxicity endpoint due to the confounding effects of variable organism size at test initiation, food content variability in ambient water samples, and low growth in laboratory controls due to the lack of particulate organic matter (POM) present in ambient samples. Any of the conclusions regarding chronic toxicity to *H. azteca* should be qualified due to this limitation. However, the authors went on to make numerous conclusions based on chronic toxicity to *H. azteca*, despite the recognized limitation with this endpoint. Ambient samples from Hood never caused chronic toxic to *H. azteca*. TIEs identified the presence of pyrethroids in more samples than showed toxicity, indicating that pyrethroids were often present below toxic concentrations. A total of 64 samples (8.5%) showed evidence of pyrethroids and 36 samples (4.8%) contained OP insecticides, for a total of 100 samples (11.3%).

Toxicity in the ambient surface water samples was also evaluated for links to ammonia. These data do <u>not</u> provide a compelling argument that ammonia/um is causing adverse effects in the Delta to epibenthic invertebrates despite statements that there were "*Significant correlations between amphipod survival [and ammonia/ium]*" and "*Amphipod growth negatively correlated with total ammonia/um . . . .*" These statements only apply to correlations of ambient surface water toxicity data at individual sites from 2006-2009 and not data compiled across all sites. Hood was not one of the sites where there was a correlation between survival and ammonia/ium.

In addition to the one negative relationship (where ammonia/ium was associated with reduced survival) at Cache-Ulatis, there were five sites with positive relationships between ammonia/ium and survival (Sites 323, 504, 804, 915, and Cache-Lindsey). One (Site 910) showed a positive correlation between ammonia/ium and growth, while many of the 22 sites did not show significant correlations with ammonia. Wherever effects are noted, it must be considered that these were ambient samples, many of which contained pesticides contributing to toxicity. Results for simple correlations (between two variables) that ignore other known stressors in ambient surface water should be considered with caution. Finally, the report does not indicate that maximum ambient total ammonium concentrations (0.26 mg/L) were well below the EPA chronic criterion for test conditions (23 ± 2°C and pH ranging from approximately 7.4 to 8.2 = a range of chronic water quality criteria from 0.89 to 3.1 mg/L), which is protective of chronic effects to *H. azteca*.

Delta smelt toxicity testing with ambient samples indicated that there was no potential for acute toxicity to delta smelt from ambient concentrations of ammonia/ium. Werner found maximum ambient concentrations of 0.26 mg/L total ammonia (at Site 405) and 0.025 mg/L unionized ammonia (Cache Slough near the confluence with Lindsey Slough) during all 2006-2010 sampling. These maximum ambient concentrations were below delta smelt effect levels for unionized ammonia (0.066 mg/L NOEC; 0.067 mg/L LC_{10}; 0.105 mg/L LOEC; and 0.147 mg/L LC50) and total ammonia (5.0 mg/L NOEC; 4.0 mg/L LC_{10}; 9.0 mg/L LOEC; and 12 mg/L LC50).

Toxicity monitoring with larval delta smelt resulted in the finding that ammonia could not be implicated as a primary cause of smelt toxicity; although, water quality at Hood and in the San Joaquin River at Rough and Ready Island were "*least favorable*"/ "*at times unfavorable*" to smelt. The authors grant that this toxicity to smelt may "*in some cases be partly attributable to low turbidity stress*." Low conductivity (salinity/EC) was also an important parameter influencing delta smelt survival. Including a combined low EC/low conductivity control in delta smelt testing was also determined to be important for interpreting ambient toxicity tests—a control that was absent from smelt toxicity tests prior to 2009.

Smelt survival (7-day) in ambient water samples from Hood ranged from 20-46% in 2008 while controls ranged from 27-88%. Good survival of larval smelt in water samples at several sites with high ammonia (e.g., Deep Water Shipping Channel and Cache Slough) indicates that ammonia does not adversely affect larval smelt survival in these principal spawning and rearing grounds. Smelt survival was good (52-92%) at the Deep Water Shipping Channel (Light 55) and only slightly lower (59-71%) in Cache Slough. Acute toxicity to delta smelt in samples at Hood during two of four sampling events might suggest that toxicants were present in the samples. However, during one of these tests, the low-EC control was only 37%. Further, these Hood test results are also qualified [significantly] because low-EC and low-conductivity controls were separate.

Smelt survival (7-day) in 2009 was only significantly different from the low EC/low conductivity control in one sample in one of five[1] ambient water samples from Hood (4/28/09; 55% ambient water survival vs. 85% control), while the remaining sample survival ranged from 20-71% survival and were not significantly different from controls. A new test modification implemented in 2009 was the addition of antibiotics to all treatments to improve control survival. This antibiotic treatment seemed to improve control survival and increased the reliability of delta smelt toxicity tests conducted in 2009 and later.

In situ toxicity monitoring found no toxicity to delta smelt, *H. azteca,* or fathead minnows. These tests were conducted in streamside exposure chambers with flow through river water at Hood and Rough and Ready Island (in the lower Sacramento River confluence with the San Joaquin River). Delta smelt testing *in situ* was problematic, due to variable and low control survival (ranging from 4-62% at Hood). However, delta smelt survival at Hood was better than control survival over 7-day exposures on five test events (ranging from 6-35% better survival in ambient water); and survival was approximately the same in the other test event (only 3% lower than the control). The report only states that smelt survival was poor in controls and ambient water, but many of the control survivals in these *in situ* tests were as good or better than laboratory-based delta smelt testing controls prior to 2009.

Pilot testing with *E. affinis* in water from several Delta sites identified low conductivity as a major factor determining survival. These 96-hour exposures to ambient surface water from the Sacramento River Deep Water Channel (Light 55), the Sacramento River at Grand Island (Site 711), Upper Cache Slough, and Hood resulted in greater survival of *E. affinis* in each ambient sample than in the corresponding conductivity-adjusted control.

Werner, I. 2009. Effects of ammonia/ium and wastewater effluent associated contaminants on Delta Smelt. Presented at the 18-19 August CVRWQCB Ammonia Summit.

An arguable conclusion that EPA (1999) acute and chronic ambient water quality criteria may not be protective of delta smelt—depending on the pH, temperature, and EC—was presented by Werner at the 2009 Ammonia Summit. Bioassays to determine delta smelt sensitivity to ammonia have been conducted at environmentally relevant pH and temperatures and have not shown adverse effects to delta smelt at concentrations that occur in the Delta. These test data (i.e., Werner et al. 2008b and 2010b) clearly indicate that ambient concentrations of ammonia are well below total ammonia and unionized ammonia concentrations that cause adverse effects. Speculation that EPA criteria are not protective are based on unrealistic conditions where maximum ammonia/ium concentrations, maximum pH, and maximum temperatures co-occur. The most conservative assessment to evaluate the potential for toxicity to delta smelt is to compare the lowest NOEC for unionized ammonia (0.066 mg/L) with the highest measured unionized ammonia concentration in the Delta (0.025 mg/L). Ambient concentrations do not exceed this no-effect level, and there is even a greater margin for safety when ambient concentrations are compared to the lowest threshold effect level (0.105 mg/L).

[1] A total of 6 sampling and testing periods were performed in 2009. This summary excludes the first test where control survivals were exceedingly low (2-19%).

Zooplankton Toxicity

Teh, S., M. Lu, C. Teh, S. Lesmeister, I. Werner, J. Krause, and L. Deanovic. No date [2008]. Toxic effects of surface water in the upper San Francisco Estuary on *Eurytemora affinis*. Final Report. Submitted to the San Luis and Delta-Mendota Water Authority.

This study presents the findings from a pilot study using a novel test species, *E. affinis*, to assess the toxicity of ambient Delta surface waters to copepods. Samples from three separate sampling events in April and May 2008 were tested. Toxicity was found to be variable with some samples causing significantly reduced survival compared to controls. Detected chemicals included diuron, pyrethroids, and PAHs. Hood was one of the sites with relatively higher toxicity and the report speculated that ammonia and the detected chemicals were likely candidates affecting *E. affinis* survival. The report does not compare any of the organic chemicals with literature toxicity reference values to determine their potential for effects. However, there is considerable discussion of ammonia.

While the report recognizes that the highest measured unionized ammonia concentration in this study (0.025 mg/L at Hood) was "approximately 4 to 50 fold less than the concentrations that cause 50% survival in fish and invertebrates," the report goes on to hypothesize about the possibility of chronic effects, which were not evaluated. Evaluation of the unionized and total ammonia concentrations data indicates that there was no relationship between either total ammonia or unionized ammonia and *E. affinis* survival in the Sacramento River in this study (Figures 4 and 5). Further, toxicity testing methods development by Werner et al. (2010b) found that conductivity was a significant factor affecting copepod survival in pilot tests with ambient Delta water samples. Therefore, there is no support for the speculative conclusion in this report that interactive effects between ammonia and other chemicals caused acute toxicity to *E. affinis* in the Sacramento River at Hood.

Figure 4. 96-hour E. affinis Survival and Total Ammonia Concentrations in the Sacramento River at Hood and Site 711 (Teh et al. 2008).

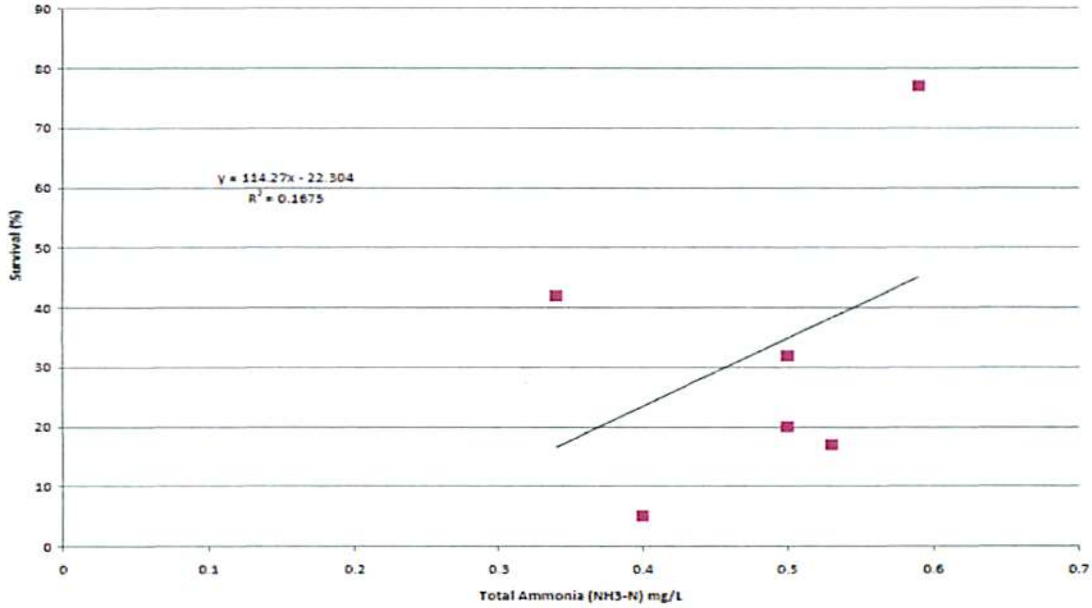
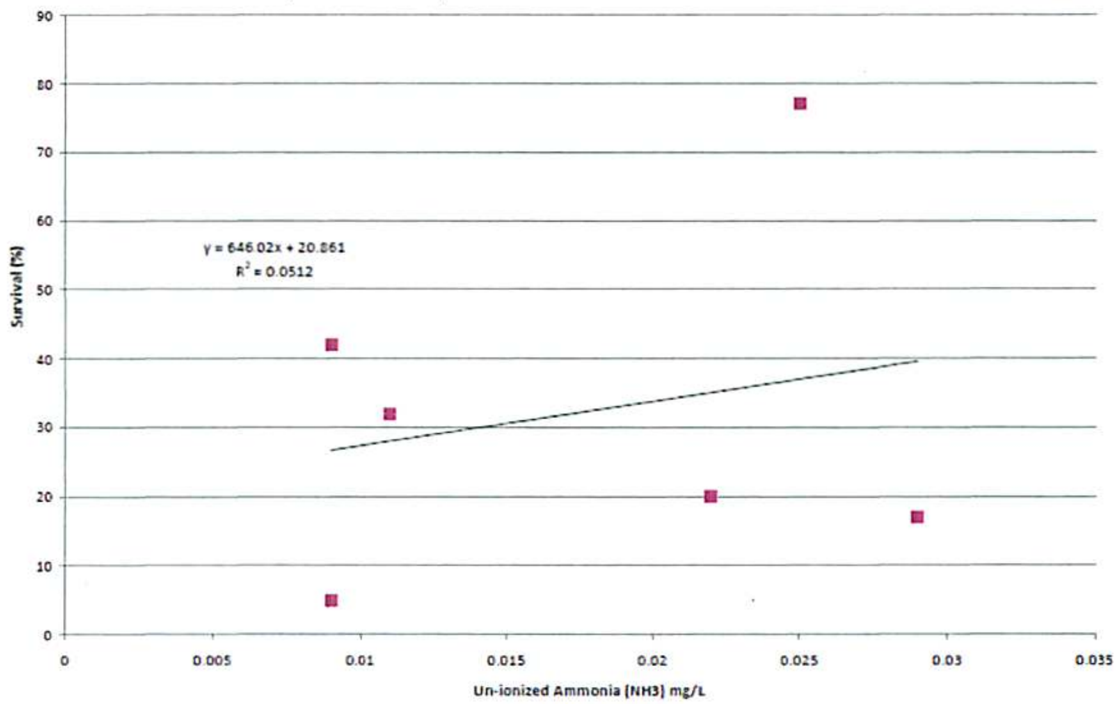


Figure 5. 96-hour *E. affinis* Survival and Unionized Ammonia Concentrations in the Sacramento River at Hood and Site 711 (Teh et al. 2008).



Teh, S., S. Lesmeister, I. Flores, M. Kawaguchi, and C. Teh. 2009. Acute Toxicity of Ammonia, Copper, and Pesticides to *Eurytemora affinis* and *Pseudodiaptomus forbesi*. Presented at the 18-19 August 2009 Ammonia Summit at the CVRWQCB.

I was witness to this presentation and have unanswered questions regarding the findings that are reported. However, it is not appropriate to comment on data that has not been finalized and is not available for review. My comments are provided for data that are available for review in other reports.

Teh, S., I. Flores, M. Kawaguchi, S. Lesmeister, C. Teh, and C. Foe. 2010a. Full life-Cycle Bioassay Approach to Assess Chronic Exposure of *Pseudodiaptomus forbesi* to ammonia/ammonium. Presented at the 6 July 2010 POD-CWT meeting.

I reviewed and commented on the work plan for this study and was witness to the presentation of preliminary data. However, I have unanswered questions regarding the findings that are reported and it is not appropriate to comment on data that has not been finalized or available for review. My comments are provided for data that are available for review in other reports.

Teh, S., S. Lesmeister, I. Flores, M. Kawaguchi, and C. Teh. 2010b. Acute Toxicity of Ammonia, Copper, and Pesticides to *Eurytemora affinis*, of the San Francisco Estuary. Final Report. IN. Werner et al. 2010b. Pelagic Organism Decline (POD): Acute and Chronic Invertebrate and Fish Toxicity Testing in the Sacramento-San Joaquin Delta 2008-2010. Final Report to the CVRWQCB.

Note that this report is also available in Appendix A of the UCD-ATL Progress Report III (Reece et al. 2009).

This report presents 96-hour toxicity testing with ammonia, copper, chlorpyrifos, bifenthrin, cyfluthrin, and permethrin to determine effect concentrations in lab water. Ammonia testing was repeated over a range of pH values (8.1, 7.6, and 7.2) intended to bracket environmentally relevant concentrations, and at 20°C. All other testing was completed at pH of 8. These data provide good insight into the acute sensitivities of *E. affinis* to ammonia and other chemicals of concern.

It should be noted, however, that testing with a non-standard species can require multiple test iterations to determine if anything other than the contaminant concentration is contributing to the effect. Werner (2010b) referred to these as 'pilot' tests for this reason and found that low conductivity was a major factor determining survival of *E. affinis* in ambient surface water testing. Tested ammonia concentrations (4-30 mg/L) were outside of the environmentally relevant range. It is important to recognize that these high concentrations were selected to elicit a dose-response and not for their environmental relevance. Also note that results are based on nominal (spiked) concentrations and have not been verified by measurements; although, this final report states that concentrations "*will be verified.*" A final qualification on these data, which is not stated in the report, is that toxicity estimates (i.e., LC10 and LC50 concentrations) for total ammonia and unionized ammonia at pH 7.6 were calculated as point estimates outside of the tested concentrations. These data should be qualified as such, or considered unacceptable, and tests should be repeated at more appropriate concentrations. This is an important point because the error associated with these estimates of toxicity levels is very high, especially in the ammonia/ium test where only one of the five concentrations had any surviving organisms.

The report concludes by stating that these data indicate that "it is likely that the toxicities observed in *E. affinis* in 2008 may have been due, in part, to the presence of these chemicals in examined ambient waters." This statement seems to only apply to copper concentrations in the five samples with reported chemistry data in 2008 testing (Teh et al. 2008). Copper concentrations (2.16-4.14 mg/L) in all five reported samples were above the LC10 (1.42 mg/L), while three of these were equal to or above the LC50 (3.48 mg/L). However, it should be noted that this comparison between ambient concentrations and effect concentrations was based on total copper concentrations. The USEPA (2007) ambient freshwater quality criteria for copper requires calculating the free copper ion (part of the dissolved fraction) for evaluating potential toxicity. The free copper ion is the bioavailable fraction responsible for causing toxicity. Water quality parameters required for the calculating the free copper ion in surface water (i.e., dissolved organic carbon, major cations, major anions, and sulfide) were not reported by Teh et al. The California Toxics Rule (CTR) standards for copper are also based on the dissolved fraction. Therefore, the applicability of the reported effect concentrations for total copper in ambient waters is unclear, due to the lack of data needed to interpret these results in light of the current standards.

Maximum measured ambient unionized ammonia (0.029 mg/L) and total ammonia (0.59 mg/L) in the study did not exceed the conservative *E. affinis* 96-hour LC10 concentrations (0.46 mg/L unionized ammonia and 7.01 mg/L total ammonia at pH 8.1; 0.08 mg/L unionized ammonia and 5.02 mg/L total ammonia at pH 8.1) for the relevant pH ranges (7.7-8.3). Copper concentrations at Hood were not reported. Therefore, comparisons between effect concentrations and measured ambient concentrations do not indicate a potential risk to *E. affinis* in the Sacramento River from ammonium or unionized ammonia.

Johnson, M. I. Werner, S. Teh, and F. Loge. 2010. Evaluation of Chemical, Toxicological, and Histopathologic Data to determine their Role in the Pelagic Organism Decline. Prepared for the Central Valley Regional Water Quality Control Board. April.

Johnson et al. (2010) conducted comparisons between pre- and post-POD chemical concentrations in the Delta and came to the overall conclusion that available data do not indicate any links between ammonia, pyrethroids, or other chemical stressors and the POD. However, limitations in the available data restrict the confidence in their conclusions.

Toxicity was more commonly identified in tributaries than in the rivers like the Sacramento River, which receives treated wastewater from the SRWTP. The authors did not know how transit times and dilution would affect the toxicity of these waters when they entered POD species habitats. This report includes references to the Werner et al. (2008b) analysis of 2006-2007 ambient toxicity testing with *H. azteca* which states that ammonia-N and unionized ammonia had significant effects on amphipod growth in ambient waters.

However, this is not a balanced assessment of the data. The more complete 2006-2009 *H. azteca* toxicity data showed a mix of negative and positive correlations between ammonia concentrations among sites and *H. azteca* toxicity (Werner et al. 2010b). These conclusions are based on simple correlations with one parameter that may indicate a correlation, but not causation. Pesticides were also present in these ambient samples (Werner et al. 2010b). Accordingly, univariate correlations that ignore multiple known stressors should be considered with caution. Finally, Werner et al. (2010b) indicates that the chronic toxicity endpoint for *H. azteca* (growth) is not a reliable measure due to the confounding effects of variable organism size at test initiation, food content variability in ambient water samples, and low growth in laboratory controls due to the lack of POM present in ambient samples.

Another important finding was that studies evaluating stomach contents of delta smelt found that they were full of food. This information contradicts hypotheses suggesting that an altered Delta food web (through invasive species, nutrient additions, or flow manipulation) has restricted the food available for delta smelt, thereby contributing to the POD.

Pyrethroid Toxicity in Effluent

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. Technol. 44 (5), pp. 1833-1840.

Recent pyrethroid studies have shown that toxicity can occur at extremely low levels. However, the levels of pyrethroids detected in SRWTP effluent are not of sufficient magnitude to cause toxicity to the most sensitive species in the Sacramento River. Weston and Lydy (2010) describe the results of a study designed to identify pyrethroid sources in the Delta. The authors report that pyrethroids were sometimes found at or near their detection limit in SRWTP effluent samples, and that TIE methods were consistent with a pyrethroid cause of toxicity. It is important to note that tests with SRWTP effluent did not show any correlation between pyrethroid concentrations and effects ($r^2 = 0.004$). For this reason, it is not clear what the relative contribution of pyrethroids was to the observed toxicity in any of the 100% effluent samples. Complete TIE testing to determine the proportion of toxicity from pyrethroids or other constituents was not conducted in all samples. Enzymes used in two of the six tests found from approximately 0-70% of the toxicity to *H. azteca* from 100% effluent was due to pyrethroids.

Weston and Lydy (2010) calculated a “rough approximation” of the pyrethroid loading in the Sacramento River from SRWTP discharge, but there was considerable uncertainty associated with this estimate. Detected pyrethroid concentrations reported in SRWTP effluent samples were quite variable among events and for individual pyrethroids during each event. Measured concentrations were also at or near reporting limits where the associated error is highest. Measurement error rates are demonstrated by the variable (±30%) ability of the analysis method to recover known quantities of pyrethroids spiked into quality assurance/ quality control samples. Measurements were also based on single grab samples collected during each event. Load calculations compound these potential errors by multiplying them by the millions of liters discharged each day.

Finally, there is very little potential for toxicity in the Sacramento River due to pyrethroids discharged in SRWTP effluent. Recent pyrethroid studies have shown that toxicity can occur at extremely low levels. However, the levels of pyrethroids detected in SRCSD effluent are insufficient to cause toxicity to the most sensitive species in the Sacramento River. Accounting for dilution of the effluent at the time of sampling indicated that concentrations

(0-0.53 ng/L) would be well below those that have the potential to cause effects (pyrethroid EC50s reported in Weston and Lydy [2010] ranged from 1.7-21.1 ng/L). Note that permethrin accounted for the majority (36-82 %) of the summed pyrethroid concentrations in samples where pyrethroids were detected. However, permethrin is the least toxic pyrethroid, with an EC50 of 21.1 ng/L, and would not have likely contributed greatly to toxicity. These low ambient concentration estimates are supported by toxicity data 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 reported by Werner et al. (2010b). Dilution series bioassays by SRWTP (conducted by Pacific EcoRisk) also demonstrated that effluent toxicity was attenuated in effluent concentrations much higher than the percent of effluent in the Sacramento River after accounting for dilution.

Cameron A. Irvine

Aquatic Ecologist / Ecological Risk Assessor

Education
M.S., Environmental Science (EcoToxicology), Wright State University, 2003
B.Sc., Biology, University of Saskatchewan, 1994

Professional Registrations
Registered Professional Biologist of British Columbia (1999, RPBBC No. 1197)
College of Applied Biologists of British Columbia (2001)

Relevant Experience
I am an aquatic ecotoxicologist/ecological risk assessor with over 15 years of environmental and toxicity assessment experience. I have performed environmental assessments throughout North America, managed a watershed-scale stream restoration project to benefit freshwater fisheries in British Columbia, and contributed to the development of *in situ* toxicity testing methods. Recently, I successfully completed a multi-year toxicity reduction evaluation (TRE) identifying a novel invertebrate toxicant in treated wastewater. In relation to the Sacramento-San Joaquin Delta, I have been supporting special studies being conducted by the Central Valley Regional Water Quality Control Board (CVRWQCB) and various research agencies (e.g., UC Davis, UC Berkeley, SFSU) and working in conjunction with Drs. Werner, Weston, and Dugdale for the past three years. During these studies I have jointly developed study plans, reviewed and discussed results, and commented on the technical merits of delta smelt toxicity testing, ammonium uptake preference by algae, and pyrethroid source evaluations. As a member of the POD-CWT since 2007, and as a committee member for the March 2009 ammonia workshop, and contributor to the August ammonia summit I have come to understand the pelagic organism decline (POD) issues related to toxicity, and am intimately familiar with studies investigating potential Sacramento Regional Wastewater Treatment Plant (SRWTP) impacts on the POD. Highlights from my career include:

- Collaborating with regional dischargers and regulatory staff to investigate potential factors contributing to the pelagic organism decline (POD) in the Sacramento-San Joaquin Delta.
- Development of lab and field-based (*in situ*) toxicity testing of various exposure pathways and media with aquatic invertebrates and fish.
- Completing a multi-year toxicity reduction evaluation (TRE) identifying a novel invertebrate toxicant in treated wastewater.
- Design, permitting, and implementation of a landscape-scale rainbow trout habitat restoration project.
- Field ecological and wildlife investigations pertaining to population assessments, habitat use, mark and recapture, tissue sampling, and radio telemetry.
- Habitat assessments, wetland delineation, surface hydrology, and surveying.
- Supporting the USEPA's ecological risk assessment at one of the largest contaminated sediment superfund sites in the Western US.
- Conducting aquatic ecological risk assessments at two radionuclide and heavy metal contaminated legacy sites.

- Project management, public relations, sampling design, and remote field operations.
- Familiarity with state and federal regulations and tools pertaining to Superfund and ecological assessment: Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA); Superfund Amendments and Reauthorization Act (SARA); Natural Resource Damage Assessment (NRDA) and Net Environmental Benefits Analysis (NEBA); Section 7 of the federal Endangered Species Act (ESA); Section 404 of the Clean Water Act (CWA); and, the California Environmental Quality Act (CEQA).

PROJECT EXPERIENCE
Environmental Toxicology

Project Manager: Special Studies and Permit Support for the Sacramento Regional County Sanitation District, Sacramento, CA. Technical advising, review, and special study coordination for SRWTP related to pelagic organism decline (POD) data requests from the Central Valley Regional Water Quality Control Board (CVRWQCB). Meeting coordination and attendance to evaluate and present SRCSD interests to POD parties (e.g., POD Contaminant Work Team and CVRWQCB). Contribute technical comments and review regulatory activities and requests related to the POD and potentially affecting permit negotiations, especially related to ammonia/ammonium.

Project Manager: Toxicity Reduction Evaluation (TRE) for the Sacramento Regional Wastewater Treatment Plant, Sacramento, CA. Extensive data review and statistical analysis of influent, process, and effluent data to identify potential toxicants to compliance whole effluent toxicity (WET) testing species. Study design and coordination to identify toxicant sources. Implementing controls to reduce toxicity to *Ceriodaphnia dubia* from bacteria in composite autosamplers. Reporting toxicity results and TRE coordination with the CVRWQCB and laboratory resources.

Research Associate: Field Investigations Supporting a Baseline Risk Assessment for the Naval Air Station Patuxant River, MD. Sampling and analysis investigations were performed to support a baseline ecological risk assessment and further evaluate the potential for risks to ecological receptors. Sediment and surface water samples were collected from areas concern. Concurrent *in situ* toxicity testing was performed in sediment and water column exposures to evaluate the potential for risks from NAPL and DNAPL contaminants of potential ecological concern. These tests formed one of several lines-of-evidence in this basin-wide assessment.

Research Associate: Nyanza Chemical Waste Dump Superfund Site. Manchester, NH. Roy F. Weston, Inc. This study was designed to evaluate *in situ* stressors and sediment toxicity in the Sudbury River system, Ashland, MA. Survival of and bioaccumulation of contaminants in sediment and water column invertebrates were evaluated with *in situ* field testing protocols to identify organism exposure and effects from VOCs, SVOCs, and metals. The combination of *in situ* exposures, comprehensive chemical sampling, and hydrologic measurements were critical for providing site characterization information to elucidate exposure-effects relationships. These RI/FS results helped direct decisions to implement pump and treat groundwater cleanup at this site.

Ecological Risk Assessment

Ecological Risk Assessor: Upper Columbia River. Seattle, WA. USEPA. The Upper Columbia River watershed is under investigation due to legacy discharges from a metals smelting facility. Supporting the USEPA review and oversight of a baseline ecological risk assessment (BERA) evaluating the potential for ecological risks over several hundred miles of the Upper Columbia River watershed. Conduct data analyses and co-authoring guidance documents on behalf of USEPA, reviewing and commenting on the screening ecological risk assessment (SLERA), draft BERA Work Plan, quality assurance project plans (QAPPs), and interim reports, coordinating meetings and liaise between the principal responsible party, regulators, and participating parties, including first nation stakeholders. Oversight was also performed on behalf of the USEPA during novel sturgeon sediment toxicity testing at the University of Saskatchewan.

Ecological Risk Assessor: United Heckathorn Superfund Site. Richmond, CA. USEPA. Ecological remedial goals were developed for this site where legacy pesticide processing had contaminated sediments with DDT and dieldrin. Empirical and mechanistic models were developed with site-specific sediment and tissue concentrations. These models estimated sediment concentrations that would have no or minimal effects on fish and on wildlife that consume fish or other biota exposed to sediment.

Ecological Risk Assessor: Hanford 100-B/C Area Pilot Screening Ecological Risk Assessment, Richland, WA. DOE/Bechtel-Hanford Inc. A screening-level ecological risk assessment (ERA) was performed as part of this pilot risk assessment for the Hanford 100-B/C Site. This ERA evaluated chemical exposures to media and tissues and radionuclide concentrations in exposure media against DOEs Biota Concentration Guides. Multiple lines-of-evidence were evaluated where data were available for each receptor (Exposure media-based point-by-point comparison to single chemical toxicity benchmarks; tissue-based point-by-point comparison to single chemical toxicity benchmarks; refined dietary exposure based comparison to single chemical toxicity benchmarks; site-specific histopathology; site-specific community indices). Each LOE contributed to the overall WOE for determining the potential for risk to receptors.

Ecological Risk Assessor: Effects of Radiation on Ecological Receptors. White Paper. DOE/Bechtel-Hanford Inc. Evaluated the basis of protection offered by existing radiation dose guidance: long-term (chronic) radiation screening levels for terrestrial and aquatic biota established by the International Atomic Energy Agency (IAEA). Aquatic and terrestrial invertebrates and wildlife, and terrestrial plant receptor groups potentially present at the Hanford Site were included in this review of past and current literature. No-effects and low-effects doses of published radiation-effects data were compiled from studies reporting molecular/genetic, behavioral, pathological, reproductive, growth, mortality, and population-level effects classes. Based on this literature evaluation, the acute and chronic exposure guidelines established by IAEA would be protective of Hanford Site special-status species.

Ecological Risk Assessor: Rocky Flats. Aquatic Exposure Units Comprehensive Ecological Risk Assessment, Golden, CO. Kaiser-Hill. Contributed to methodology and template development of the Aquatic Exposure Units ERA of the Rocky Flats Comprehensive Risk Assessment. Radionuclide and chemical contaminant concentrations were evaluated for each aquatic drainage following site remediation to human health PRG levels. Regulatory and multiple stakeholder involvement were managed in a truncated time-line to complete this complex ERA involving a large support team.

Sampling and Analysis Task Manager: Baseline Risk Characterization Sampling and Analysis, Guyama, Puerto Rico. Chevron Philips Puerto Rico Core, Inc. Developed a sampling and analysis plan to collect site sediment, water, and benthic invertebrates for chemical analyses and definitive toxicity testing. Results of chemical analyses supported a baseline risk assessment with site-specific dietary concentrations for wildlife exposure modeling. Toxicity testing evaluated the potential for risk from water and sediment media and helped to develop media-specific protection goals (MSPGs) for surface water and sediment. Tests integrated interactive effects of all media contaminants, including those of uncertain toxicity. Conclusions of no potential for ecological risk contributed to accelerated closure at this facility.

Ecological Risk Assessor: Site-Wide Screening-Level Risk Characterization, Guyama, Puerto Rico. Chevron Philips Puerto Rico Core, Inc. Performed an ecological risk assessment where complete soil and aquatic exposure pathways were identified at the site and exposure to terrestrial plants, soil invertebrates, aquatic life, and birds were considered as part of a site closure plan. Data evaluation required extrapolating groundwater based chemical analysis to estuarine harbor water after modeling potential dilution factors. Soil sampling data were also separated between isolated source areas within the site to better characterize and identify the extent and magnitude of potential contamination and risks to soil invertebrates and plants. Focused evaluation of potential risk drivers found that rapid environmental breakdown and metabolic detoxification of some organic chemicals would reduce dietary exposures to wildlife so that risks were unlikely.

Data Analyst: Terrestrial Wildlife Exposure Model (TWEM). U.S. Army Center for Health Promotion and Preventative Medicine. Performed database QA/AC, application beta testing, and prepared application overview and use lessons as part of application development for this risk assessment tool. This component of the U.S. Army Risk Assessment Modeling System was developed for the Center for Health Promotion and Preventive Medicine (CHPPM) to help calculate wildlife exposure to contaminants of potential ecological concern. A prototype of this application was presented with other related applications at a workshop during the 25th Annual SETAC North America World Congress in Portland, OR, 2004.

Ecological Risk Assessor: Screening-Level Ecological Risk Assessment for the Frontier Fertilizer Superfund Site, Davis, CA. USEPA Region 9. Performed a screening-level ecological risk assessment at a former agricultural supply site where pesticides and other organic contaminants were of primary concern. Information relevant to ecological risk assessment was extracted from a complex third party database prior to data QA/QC and calculation of screening exposure point concentrations. Wildlife exposure modeling, threatened and endangered species considerations, and thorough literature review for toxicity benchmark values were performed.

Ecological Risk Assessment Team Member: Site-wide Ecological Risk Assessment for the UNOCAL Guadalupe Oil Field, CA. Performed an ecological risk assessment for this site-wide screening-level ecological risk assessment. Calculated estimates of potential risks from petroleum-derived materials and non-petroleum contaminants in order to support technically defensible risk management decision-making at a 2,700-acre site along the Central California coast. Thorough statistical analysis helped to characterize potential ecological risks from an immense geographical information system (GIS) based data compilation for numerous wildlife receptors and special-status species at the site. Risk estimates were integrated across multiple plant and animal receptors, including threatened and endangered species, in terrestrial and wetland habitats. Habitat specific risk analysis for each receptor was evaluated in a spatial context with the use of GIS. Overall risk conclusions for a given wetland/waterbody or zone-section were based on results for all receptors in their respective habitat. Additional, statistical analyses provided insight into the relative risk contributions of a variety of contaminant sources at site.

Ecological Risk Analyst and Author: Screening Level Ecological Risk Assessment at Hill AFB, UT. Performed a screening ecological risk assessment as part of annual monitoring at a thermal treatment unit (TTU). Complete exposure pathways were identified for plants and invertebrates from soil, and to plants from groundwater. Organic and inorganic compounds analyzed in site soils and groundwater were evaluated for potential risks to terrestrial receptors. Spatial analysis of potential risk drivers was used to determine that no potential risk to receptors was anticipated.

<u>Ecology</u>

Project Biologist and Co-manager: Nulki-Tachick Watershed Restoration Project, Vanderhoof, BC. Saik'uz First Nation. Executed an integrated watershed approach to investigate the ecological and biophysical factors affecting rainbow trout (*Onchorhynchus mykiss*) spawning and rearing in the Nulki-Tachick lakes watershed of central British Columbia. Mark and recapture studies and spawning surveys directed habitat restoration in critical areas to remediate forestry and land-use impacts. Designed and implemented Juvenile trout rearing habitat restoration using large woody debris, boulders, culvert removal/replacement with riffle creation, riparian bank stabilization, and related permitting. Draft horses were used to place large woody debris and boulders, bioengineered bank stabilization structures reduced sedimentation from seven banks, riparian fencing were erected in livestock grazing areas, and collaboration with timber licensees in road deactivation and stream crossing modifications were part of restoration activities. Local First Nation residents were trained as fisheries and restoration technicians to foster a sense of stewardship for their natural resources. The Nulki-Tachick Watershed Restoration Project workplan was achieved within the target budget of CDN $1.2 million and earned regional recognition as a successful project jointly operated by a First Nation, Government, and Industry.

Aquatic Ecologist: McArthur River Uranium Mine, Saskatchewan, Canada. Cameco Corporation. Developed a baseline environmental monitoring program for the McArthur River Uranium Mine in Northern Saskatchewan to quantify several indicators of environmental quality, improve the ability to predict contaminant loading in the receiving environment, and measure adverse environmental effects. Developed sampling and analyses plans and conducted baseline aquatic investigations for an environmental impact assessment (EIA). Lead field investigations to assess fish tissue chemistry and community structure, chemical analyses on sectioned lake sediment core samples, and water quality sampling. Stream and lake benthic invertebrate communities were also sampled to provide a measure of community diversity relating to ecosystem integrity.

Aquatic Ecologist: Cigar Lake Uranium Mine, Saskatchewan, Canada. Cameco Corporation. Co-authored reports, conducted field investigations, and responded to provincial review panel comments regarding baseline fisheries resources, chemical data, and a proposed tailings management facility.

Aquatic Ecologist: Rabbit Lake Mine, Key Lake Mine, Saskatchewan, Canada. Cameco Corporation. Developed sampling and analyses plans and conducted aquatic investigations for status of the environment (SOE) reports. Lead field investigations to assess fish tissue chemistry and community structure, chemical analyses on sectioned lake sediment core samples, and water quality sampling. Stream and lake benthic invertebrate communities were also sampled to provide a measure of community diversity relating to ecosystem integrity as part of environmental effects monitoring (EEM) programs.

Aquatic Ecologist: Cluff Lake Uranium Mine, Saskatchewan, Areva (formerly Cogema Resources). Assisted in study design and conducted baseline aquatic effects monitoring data collections which integrated physical, biological, and toxicological components for a tailings management area expansion EIA.

Aquatic Ecologist: McClean Lake Uranium Mine, Saskatchewan, Areva (formerly Cogema Resources). Conducted reconnaissance investigations to determine areas suitable for fish habitat enhancement, rare plant surveys, and developed an index to environmental baseline data.

Site Assessment Environmental Scientist and Study Author: Carson River Nevada Superfund Site Mercury Evaluations, U.S. Environmental Protection Agency, Region IX, San Francisco, CA Authored a sampling and analysis plan for this remedial investigation phase work at this mercury containing tailings contaminated at the Carson River Superfund Site, Nevada. The studies will be used as input into the design of remedial actions.

Environmental Monitor: Managed Vegetation Dust Control Mitigation at Owens Dry Lake, CA. Los Angeles Department of Water. Saltgrass (*Distichlis spicata*) was planted as a large-scale dust control measure in over 2000 acres of the Owens Dry Lake area. Soil reclamation from a subterranean drip irrigation system was monitored daily throughout the spring, 2004, to determine when soil conditions were favorable for the survival of replanted vegetation and to focus replant efforts. A GIS data tracking system was initiated to allow daily updates to a spatial presentation of monitoring data, which was distributed to the replanting team.

Environmental Monitor: Hickman Bridge Scour Countermeasures Project, Waterford, CA. Stanislaus County Department of Public Works. Monitored construction activities to maintain environmental permit compliance for the protection of migratory Chinook salmon and valley elderberry longhorn beetle habitat. Coordinated site activity discussions with resource agencies (California Department of Fish and Game; California Department of Transportation; California Regional Water Quality Control Board; California Department of Water Resources) to ensure compliance and assess new information acquired during activities on-site.

Project Biologist: Prairie Dog Colony Assessment, Pinedale, WY. Genesis Laboratories. Conducted population assessments and black-tailed prairie dog colony delineation in Wyoming pasture. Populations were assessed using palm-OS based GPS tools as part of a biological survey and inventory program for the Bureau of Land Management.

Professional Organizations/Affiliations
Association of Professional Biologists of British Columbia /College of Applied Biologists (CAB)
Society of Environmental Toxicologists and Chemists - North America (SETAC-NA) and Northern California Chapter (Nor-Cal SETAC)
Chair of the Peer Review Sub-Committee of the SETAC-NA Technical Committee (SNA-TC)

Honors and Awards
1999 – 2002 Wright State University Tuition Fellowship and Graduate Research/Teaching Assistantship
1993 – University of Saskatchewan Honors Scholarship
1992 – University of Saskatchewan Biology Club Scholarship

Specialized Computer Skills
Designed and administered an environmental biology and chemistry database for mining facilities in northern Saskatchewan (Microsoft Access). Data manager for the Institute of Environmental Quality. Microsoft Office - Excel, Word, Access, and PowerPoint; SYSTAT 9; ESRI Arcview (GIS); Sigma Plot 10.

Professional Training
First Aid and CPR-Level C with AED Certification (current)
OSHA Hazardous Materials Health and Safety 40-hour (current)
Site Safety Coordinator (current)
Natural Resources Liability and Asset Management Workshop (2005)
Construction Site Safety (2004)
Radiation Safety Training (2002)
Laboratory Animal Care Training (2002)
Whole Effluent Toxicity (WET) Introductory Course (1999)
Wilderness First Aid (1999)
First Aid Transport Endorsement (1999)
Watershed Habitat Restoration Workshop, Pt. Hardy, BC (1998)
Backpack Fish Electroshocking; Crew Supervisor (1997)
ATV Rider Safety Course (1994)
PADI Open Water Diver Certification (1992)

Languages
English
Conversational Spanish

Publications and Presentations

Sample, B. and **C.A. Irvine**. In Press. Radionuclides in Animal Tissues. Chapter XX. In N. Beyer, Ed. Environmental Contaminants in Biota: Interpreting Tissue Concentrations. Second Edition. Taylor and Francis.

Sample, B., **Irvine, C.**, Gustavson, K., and Lin, Sharon. 2010. Developing Remediation Levels to Address Ecological Risk at the United Heckathorn Superfund Site. Poster. Presented at the 31st Annual Meeting of SETAC North America. Portland, OR.

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Irvine, C.A., M. Maidrand, J. Miller, M. Miller, R. Parales, and B. Sample. 2008. A Toxicity Reduction Evaluation Identifying Bacterial Chronic Toxicity to Ceriodaphnia dubia from a POTW Effluent. Platform. Presented at the 29th Annual Meeting of SETAC North America. Tampa, FL.

Werner, I., **C. Irvine**, and C. Foe. 2008a. The Effects of Wastewater Treatment Effluent-Associated Contaminants on Delta Smelt. Ammonia Toxicity Sampling and Analysis Plan. Final. July.

Maidrand, M.B., **C.A. Irvine**, J. Miller, M. Miller, and B. Sample. 2008. Is Your Sampling System Causing Effluent Toxicity? Poster. Presented at WEFTEC, Chicago, IL.

Maidrand, M, J. Miller, M. Miller, **C.A. Irvine,** and B. Sample. 2006. Weight of Evidence that Chronic *Ceriodaphnia dubia* Toxicity in a POTW Effluent is of Biological Origin. Poster. Presented at the 27th Annual Meeting of SETAC North America. Montreal, ON.

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Sample, B. and **C.A. Irvine.** 2006. A Review and Analysis of Ecological Dose-Effects from Radiation Exposure. Poster. Presented at the 27h Annual Meeting of SETAC North America. Montreal, ON.

Irvine, C., Sample, B., 2005. A Review and Analysis of Ecological Dose-effects from Radiation Exposure. App. J, 100-B/C Pilot Project Risk Assessment Report, DOE/RL-2005-40, Draft A, Richland, WA, USA.

G.A. Burton Jr., M.S. Greenberg, C.A. Rowland, **C.A. Irvine**, D.R. Lavoie, J.A. Brooker, L. Moore, D. Raymer, and R.A. William. 2005. *In situ* exposures using caged organisms: a multi-compartment approach to detect aquatic toxicity and bioaccumulation. Environmental Pollution. 20:133-144.

American Society for Testing and Materials (**ASTM**) Draft Standard. In Review. 2004. Standard Guide for Assessing Freshwater Ecosystem Impairment Using Caged Fish and Invertebrate Assays. Report No. ASTM E47 XXXX-200X

Burton, G.A. Jr., L.T. H. Nguyen, C. Janssen, R. Baudo, R. McWilliam, B. Bossuyt, M. Beltrami, A. Green. 2005. Field validation of sediment zinc toxicity. Env. Tox. & Chem. 24:3. 541-553. (Research Associate).

Arenal, C.A., C.L. Tsao, B.E. Sample, and **C.A. Irvine**. 2004. Poster. Ecological Risk Assessment for the COB Energy Facility, Bonanza, Oregon: Air Emissions and Process Wastewater Application. Presented at the World Congress and 25th Annual Meeting of SETAC North America. Portland, OR.

Irvine, C.A, G.A. Burton Jr., and M.S. Greenberg. 2003. Colloid influence on *D. magna* feeding and tissue residues following contaminant exposure. Platform. Presented at the 24th Annual Meeting of SETAC North America. Austin, TX.

Irvine, C.A. and S. McIntosh. 2002. Nulki-Tachick Watershed Restoration Project: 1995-2000 Project Summary. Prepared for Forest Renewal British Columbia and Ministry of Environment, Lands and Parks. (Author, Project Co-manager, Principal Biologist). 56 pp.

Irvine, C.A, G.A. Burton Jr., M.S. Greenberg. 2002. The Influence of Colloids on the Toxicity of Cadmium and Fluoranthene to Freshwater Invertebrates. Poster. Presented at the 23rd Annual Meeting of SETAC North America, Salt Lake City, UT.

Burton, G.A. Jr., **C.A. Irvine**, J.P. Johnson, R.A. McWilliam, M.S. Greenberg, and B.A. Schwab. 2002. Weight of Evidence Sediment Quality Assessment: Don't Expect Concordance. Platform. Presented at the 23rd Annual Meeting of SETAC North America, Salt Lake City, UT.

Irvine, C.A, G.A. Burton Jr., M.S. Greenberg, and J.P. Johnson. 2002. Effects of Aqueous Colloids on Feeding and Bioconcentration in *Hyalella azteca* and *Daphnia magna* Exposed to Fluoranthene and Cadmium. Poster. Presented at the 5th International Symposium on Sediment Quality Assessment, Chicago, IL.

Burton, G.A. Jr., **C.A. Irvine**, J. Johnson, R.A. McWilliam, and M.S. Greenberg. 2002. Using Multiple Lines of Evidence to Assess Sediment Quality. Poster. Presented at the 5th International Symposium on Sediment Quality Assessment, Chicago, IL.

Johnson, J.P., G.A. Burton Jr., **C.A. Irvine**. 2002. The Impacts of Aircraft Deicing Fluid on Lytle Creek (Wilmington, OH) Using *In Situ* Laboratory Approaches. Poster. Presented at the 5th International Symposium on Sediment Quality Assessment, Chicago, IL.

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McWilliam, R.A., G.A. Burton Jr., **C.A. Irvine**, J. Johnson, B. Schwab. 2002. Separating Natural and Anthropogenic Stressors Using *in situ* and Laboratory Approaches. Poster. Presented at the 11th Annual Meeting of SETAC Europe, Vienna, Austria.

Irvine, C.A. 2001. The Influence of Colloid-Bound and Dissolved Phases of Metals and Organic Contaminants to the Toxicity of Freshwater Invertebrates. Awarded a personal research grant (Wright State University) of $800.00 by Sigma Xi.

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Ministry of Environment, Lands and Parks. (Author, Project Co-manager, Principal Biologist).

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Terrestrial & Aquatic Environmental Managers Ltd. 1996. 1995 Fish Analytical Results for the Waterbury Lake Study Area. Prepared for the Cigar Lake Mining Corporation. (Author).

Terrestrial & Aquatic Environmental Managers Ltd. 1996. Aquatic and Terrestrial Baseline Investigations and Impact Assessment of the Box and Athona Gold Mines Project, Northern Saskatchewan. Prepared for the Greater Lenora Resources Corporation. (Biologist, Co-Author).

Canadian Wildlife Service. 1992. 1992 North American Waterfowl Management Plan Central Flyway Waterfowl Banding Report, Spiritwood, Saskatchewan. Environment Canada, Saskatoon. (Crew Leader, Primary Author).

Canadian Wildlife Service. 1991. 1991 North American Waterfowl Management Plan Central Flyway Waterfowl Banding Report, Yorkton, Saskatchewan. Environment Canada, Saskatoon. (Crew Supervisor, Co-Author).

GRANTS

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Supplemental Information

Years Experience Prior to CH2M HILL: 10
CH2M HILL Hire Date: 21 July, 2003

Last Employee Update: 09/20/2010