Dry Creek Watershed: Potential Effects of Contaminants and Emerging Pollutants to Food Web and Salmonids

April 2009

Swee Teh, PhD
Aquatic Toxicologist/Pathologist
1302 Locust Place
Davis, CA 95616

Geologic reports by Wilshire 2009 (NSCARP FEIS/EIR made on behalf of the Clean Water Coalition of Northern Sonoma County) and by Yates 2009 suggested that *"Use of the reservoirs proposed by NSCARP is likely to cause contamination of both surface water and groundwater. Because they are interconnected, surface water contamination, for example by frost-protection spraying and leakage of reservoirs, inevitably leads to groundwater contamination. In addition, if recycled water is used for frost protection, there will be discharges of recycled water runoff along most of the length of Dry Creek and the Russian River where they cross the proposed NSCARP service area. This runoff—including all of the salts, nitrate, dissolved organic carbon, metals and other pollutants contained in the water—flows without dilution to local creeks and the Russian River"*. Furthermore, reports by Johnson 2008 and Yates 2009 further suggested that "*Groundwater salinity in some domestic wells could increase to exceed the drinking water standard or other contaminants present in recycled waste water, including metals, organic compounds, and other currently unregulated "emerging contaminants" would become similarly concentrated and impact local groundwater*".

Based upon these evaluations, the objective of this document is to describe the potential long-term effects of surface and groundwater contamination by NSCARP on the aquatic ecosystems in the Dry Creek Valley. The implications of these effects are presented in this report by briefly describing several studies on the potential impacts of emerging or legacy contaminants to the food web and to targeted fish resources in the Russian River-Dry Creek watershed ecosystem. The role of water chemistry parameters, importantly salinity, is outlined briefly as related to contaminant bioavailability, toxicity to aquatic organisms and ecosystem effects. Emphasis on these factors are presented in a context of potential drivers of structure and function of the Dry Creek ecosystem that may be altered or remain stable in the future and how this will essentially relate to its capability to support important fish resources such as the salmonids Coho salmon (*Oncorhynchus kisutch*), Chinook salmon (*Oncorhynchus tschawytscha*) and steelhead trout (*Oncorhynchus mykiss*).

Water Quality

Salmonids are very sensitive to water pollution and sensitivity may vary during the different life stages. As water quality deteriorates, diminished flows may cause crowding and stress that may lead to disease outbreaks (Spence et al. 1996, Nichols and Foott, 2005). In the Klamath River, water quality conditions are highly stressful to salmonids due to increased stream temperatures, decreased dissolved oxygen, high pH and unionized ammonia formation due to nutrient flow dynamics (http://www.klamathwaterquality.com/fish_health.html). Fish are also exposed to other stressors including climate changes and disease agents (i.e. microbial pathogens) throughout their life stages. In wild habitats, climate change can influence global impacts of microbial pathogens and endemic diseases to fish populations (Gozlan et al. 2006) and water temperature may affect the pathogenesis of many important infectious diseases (Snieszko 1974). Environmental stressors including culture conditions, water quality and pollutants affect fish at all life stages and their susceptibility to disease can be overwhelmed with a variety of environmental and internal factors (Schreck 1981, Schreck et al. 1993). Larval fish are generally more sensitive to contaminant and disease stressors compared to adults (Arkoosh et al. 1998, Rolland 2000, Teh et al. 2003, Varsamos et al. 2006) and that stress during early life stages may trigger stress and consequential effects as juveniles (Varsamos et al. 2006).

Water temperature is the most important factor affecting biochemical and physiological processes of individual organisms which also affects contaminant transformation and excretion. Within normal physiological ranges, temperature increases may enhance bioaccumulation and toxicity of metals with more complex effects to organic contaminants (Newman and Unger 2003). Other water chemistry parameters including salinity, pH, hardness, organic carbon concentration and redox potential (for sediments) are important factors affecting complexation and speciation of chemicals and metals such as mercury, copper and selenium (Alpers et al. 2008). For instance, ammonia toxicity is reduced at low pH as the ionized form (NH_4^+) which is produced at low pH, is less toxic than the unionized NH_3 form. Studies to address the potential adverse effects of ammonia/ammonium on the Bay-Delta ecosystem, including effects to POD populations or pelagic organisms in decline, have been recently formulated.

Food Web

Links between food web complexity and ecosystem stability have been an emerging challenge in research of aquatic organisms that has focused from phytoplankton to zooplankton to fish. Various trophic levels are affected by chemical contaminants beginning at the base of the food chain during uptake of specific contaminants by phytoplankton with subsequent uptake by grazers (e.g. zooplankton). Extrapolating how toxic compounds move through the food web is a challenge since quantitative information on transfers is limited. Because of the complexity of ecosystems, there is an enormous potential for interaction among different levels of the food web under varying environmental conditions (http://www.mdsg.umd.edu/programs/gateway/contaminants/toxicsrpt/bioleffects/).

Fish rely for food from other organisms across the food web and are exposed to a bewildering array of natural stressors and low-levels of complex toxicants throughout their life history. As fish can accumulate pollutants in body tissues as they grow, deleterious effects may become apparent only when concentrations in tissues reach a threshold level after several months or years. Alternately, a toxicant present at low levels may be lethal only to very early life history stages. A decline in population due to contaminants may therefore become apparent only several years after a pollution incident when low numbers of a particular year-class is recorded. As suggested by Johnson, Yates, and Wilshire, contaminants will continue to be introduced into the Dry Creek watershed at high concentrations over the years. The cumulative impacts of contaminants to key organisms and to food web species in the environment or through contaminant-induced changes in nutrient and oxygen dynamics will significantly alter the ecosystem function. Pollutants may directly and/or indirectly affect populations and communities and indirect impacts may either reduce or increase population abundance (Fleeger et al. 2003). Indirect contaminant effects have profound implications in environments with strong trophic cascades (indirect effects mediated through consumer resource interactions) such as the freshwater pelagic system with competitive interactions between 'top–down' (predator influence on lower trophic levels) and 'bottom–up' (nutrient/food/prey influence on higher trophic levels) components. The indirect effects of contaminants across trophic levels in the Russian River-Dry Creek watershed may have profound implications as suggested in an excellent review in Fleeger et al. (2003). As the magnitude of systemic effects of contaminants to the ecosystem and to resident aquatic organisms is broad, complex and difficult to assess, contaminant effects may focus on food webs affecting the species of concern in this water system, i.e. the salmonids Coho salmon (*Oncorhynchus kisutch*), Chinook salmon (*Oncorhynchus tschawytscha*) and steelhead trout (*Oncorhynchus mykiss*). Ideally, a coordinated research program with integrated field and laboratory experiments using a variety of methods and endpoints will address the cause and effects of priority contaminants of concern to these key organisms by testing a series of hypotheses.

Emerging Pollutants

Effluents from wastewater treatment plants are significant sources of ammonium including complex mixtures of contaminants that affect reproductive endocrine function (Kidd et al. 2007). As reviewed in Hoenicke et al. 2007, a growing list of emerging contaminants including flame retardant compounds, pesticide and insecticide synergists, insect repellants, pharmaceuticals, personal care product ingredients, plasticizers, non-ionic surfactants and other manufacturing ingredients have not been previously targeted for analysis but polybrominated diphenyl ether (PBDEs) have been detected in water, sediments or biological tissue samples (clams, striped bass, halibut) from the Sacramento and San Joaquin Rivers. Several of these compounds, particularly PBDEs showed concentrations of environmental implications. Although waterborne concentrations are about two orders of magnitude greater than the thresholds for effects observed in laboratory trials (Fent et al. 2006), these compounds may pose a hazard from synergistic effects of multiple contaminants as found in the San Francisco Estuary (Laville et al. 2004). There is a considerable data gap on the cause and effects of emerging contaminants particularly in fish and other aquatic organisms in the Sacramento delta (Thompson et al. 2007).

Endocrine disrupting chemicals (EDCs) are significantly present in wastewater treatment plants that can interfere with the hormonal systems in humans and wildlife that even extremely low concentrations can cause adverse effects on reproduction and development (Kidd et al. 2007). Chronic exposure of fathead minnow to 5-6 ng/l of 17α-ethynylestradiol (EE2, synthetic estrogen used in birth control pills) resulted to near extinction of this species (Kidd et al. 2007). Even after secondary treatments (chlorination), concentrations of up to 4.05 ng/l of 17ß-estradiol (E2, the natural estrogen) and 2.45 ng/l EE2 in the treatment plant effluent were detected (Huang and Sedlack 2001). Most importantly, subsurface transport of EDCs has been demonstrated as a result of landscape irrigation with treated wastewater (Hudson et al. 2005).

Effects of other contaminants to salmonids

As chinook salmon are obligate pelagic (midwater) feeders, they feed almost exclusively in the midwater zone hence are probably more susceptible to contaminants linked to the food web. As top predators, the Chinook salmon are more affected by pollutants even when the contaminant is toxic only to lower trophic levels (Bacelar et al. 2008).
Among five species of Pacific salmon (chinook, coho, sockeye, chum, pink) collected from the Sacramento River, Skeena River in British Columbia and Puget Sound, the highest levels of all types of contaminants were found in chinook salmon which generally feed higher in the food web than other types of salmon (http://wdfw.wa.gov/science/articles/pcb/index.html). Magnification of polychlorinated biphenyls (PCBs) and major organochlorine pesticides (OCPs) were found in lake trout (*Salvelinus namaycush*) and other food web organisms collected from 17 lakes in Canada and the northeastern United States between 1998 and 2001 (Houde et al. 2008).

Chemical contaminants have been associated with salmon declines in the Pacific Northwest. High levels of PCBs (1300 to 14,000 ng/g lipid, in some cases exceeding the threshold for adverse health effects in juvenile salmonids of 2400 ng/g lipid), dichlorodiphenyltrichloroethanes, DDTs (1800 to 27,000 ng/g lipid), and polycyclic aromatic hydrocarbons, PAHs were found in whole bodies of Chinook salmon in the Lower Columbia River. The stomach contents also showed high contaminant levels indicating that the prey is a significant source of exposure (Johnson et al. 2007a, 2007b).

Low concentrations of anthropogenic chemicals such as insecticides (malathion, carbaryl, chlorpyrifos, diazinon, and endosulfan) and herbicides (glyphosate, atrazine, acetochlor, metolachlor, and 2,4-D) separate or combined in low concentrations (2-16 ppb), can affect aquatic communities composed of zooplankton, phytoplankton, periphyton, and larval amphibians (Relyea 2009). Juvenile chinook salmon exposed to sublethal levels of esfenvalerate or chlorpyrifos either alone or concurrently with infectious hematopoietic necrosis virus (IHNV) showed synergistic effects with endemic pathogens to compromise the survival of wild fish populations through immunologic or physiologic disruption (Clifford et al. 2005).

While copper is a necessary trace element for all living organisms, many studies show that copper in small amounts can be lethal and have many sub-lethal effects in fish and zooplankton. In particular, salmonids and their food sources have very low tolerance for copper and sub-lethal effects may include decreased fish survival, production and increased mortality rates. Furthermore, copper can impair salmon's sense of smell that may interfere with normal salmon migration, and since copper is a biological stress agent; it depresses immune system function and compromises fish ability to fight disease (Woody 2007, http://www.fish4thefuture.com/pdfs/Summary%20WoodyReview%20-%20Copper%20Effects%20to%20Fish%20092107.pdf).

Effects of Salinity

Although recent studies confirm that elevated salinities can cause substantial changes to the biological communities of aquatic ecosystems, impacts of irrigation-induced salinity in freshwater ecosystems have not been extensively investigated. As the Dry Creek habitats may be altered with future water movements and hydrologic modifications, the freshwater ecosystem in the Dry Creek may be threatened by the effects of salinity changes because of potential rising saline groundwater (as a result of NSCARP) and reduced frequency of high-flow events (as a result of Dry Creek bypass pipeline). Salinity changes may affect ecosystem function through alteration of abiotic and biotic processes (Nielsen et al. 2003). It is beyond my ability to stress the underlying effects of salinity and would encourage reviewers to refer to Nielsen et al. 2003 for more information on how salinity may impact not only the aquatic biota but also the physical components of aquatic ecosystems. The CUWA 1994 literature review indicated salinity tolerance of Chinook salmon from spawning → eggs → larval stages in the ranges of 0 to 0.5 ppt. The potential significant effects of increasing salinity due to the NSCARP and Dry Creek bypass pipelines remain to be determined.

Summary

In is undoubtedly consequential that the SCWA's proposed NSCARP and Dry Creek bypass pipeline will result in the contamination of both surface water and groundwater. This contamination will have long-term effects on the Dry Creek aquatic ecosystems. Author of Santa Rosa DCP FEIR, Volume 3, Appendix G.3-Ecological Risk Assessment stated "*Regulatory agencies have not developed standards or adjusted existing standards to address nonregulated chemicals due to insufficient data to evaluate potential effects of exposure to the environment. Any regulation of these chemicals will likely not occur for several years, if at all. Given that many xenobiotics are neither regulated nor monitored in recycled water, it is unknown what, if any, contribution recycled water discharges may contribute to the Laguna or Russian River. Available data suggest that accurate measurements of hormones at levels that may adversely affect fish are difficult to attain, but would be necessary to fully evaluate these chemicals"* is encouraged to review the Technical Report submitted by Hudson et al. 2005 demonstrating subsurface transport of EDCs as a result of landscape irrigation with treated wastewater (Hudson et al. 2005; www.llnl.gov/tid/lof/documents/pdf/327864.pdf).

It is important that NSCARP FEIS/EIR take into consideration the long-term effects of the contamination of ground and surface waters of the aquatic ecosystem in the Dry Creek Watershed. Of importance is investigating the potential relationships among contaminant levels and other relevant factors such as: 1) recruitment potential of aquatic organisms, 2) primary and secondary production, 3) nutrient dynamics, and 4) food web structure. Linking these factors to variabilities in contaminants and hydrology may elucidate their effects to biota and ecosystem integrity. Once these relationships are assessed, water allocation may be used as a strategy to manage salinity impacts to the ecosystem and to the species of concern. Disposal and replacement of contaminated salt waters however, should be regulated to minimize potential contaminant distribution in the system.

Literature Cited:

Alpers C, C Eagles-Smith, C Foe, S Klasing, MC Marvin-DiPasquale, DG Slotton, L Windham-Myers. 2008. Mercury Conceptual Model, Delta Regional Ecosystem Restoration Implementation Plan.

Arkoosh MR, E Casillas, P Huffman, E Clemons, J Evered, JE Stein, U Varanasi. 1998. Increased susceptibility of juvenile Chinook salmon from a contaminated estuary to *Vibrio anguillarum*. Transactions of the American Fisheries Society 127: 360-374

Bacelar FS, S Dueri, E Hernández-García, JM Zaldívar JM. 2009. Joint effects of nutrients and contaminants on the dynamics of a food chain in marine ecosystems. Math Biosci 218:24 - 32

California Urban Water Agencies (CUWA). 1994. Evaluation of potential effects of the proposed EPA salinity standard on the biological resources of the San Francisco Bay/Sacramento-San Joaquin Estuary (Draft). Prepared by R2 Resource Consultants, Inc. for The California Urban Water Agencies, Sacramento, CA, March 7, 1994. Reference No. 5. 65 pp. plus appendices.

Clifford MA, KJ Eder, I Werner, RP Hedrick. 2005. Synergistic effects of esfenvalerate and infectious hematopoietic necrosis virus on juvenile Chinook salmon mortality. Environmental Toxicology and Chemistry 24(7):1766-1772.

Fent K, AA Weston, D Camminada, 2006. Ecotoxicology of human pharmaceuticals. Aquat Toxicol 76: 122–159

Fleeger JW, KR Carman, RM Nisbet. 2003. Indirect effects of contaminants in aquatic ecosystems. The Science of the Total Environment 317: 207 – 233

Gozlan RE, EJ Peeler, M Longshaw, S St-Hilaire, SW Feist. 2006. Effect of microbial pathogens on the diversity of aquatic populations, notably in Europe. Microbes and Infection 8:1358 – 1364

Hoenicke R, DR Oros, JJ Oram, KM Taberski. 2007. Adapting an ambient monitoring program to the challenge of managing emerging pollutants in the San Francisco Estuary. Environmental Research 105: 132-144

Houde M, DC Muir, KA Kidd, S Guildford, K Drouillard, MS Evans, X Wang, DM Whittle, D Haffner, H Kling. 2008. Influence of lake characteristics on the biomagnifications of persistent organic pollutants in lake trout food webs. Environ Toxicol Chem 10:2169 – 2178

Huang CH, DL Sedlak DL. 2001. Analysis of estrogenic hormones in municipal wastewater effluent and surface water using enzyme-linked immunosorbent assay and gas chromatography/tandem mass spectrometry. Environ. Toxicol. Chem. 20(1):133-139.

Hudson B, H Beller, CM Bartel1, S Kane, C Campbell, A Grayson, N Liu, S Burastero. 2005. Environmental transport and fate of endocrine disruptors from non-potable reuse of municipal wastewater Final Report for 03-ERD-065. U.S. Department of Energy, University of California, Lawrence Livermore National Laboratory Contract W-7405-Eng-48.

Johnson LL, GM Ylitalo, CA Sloan, BF Anulacion, AN Kagley, MR Arkoosh, TA Lundrigan, K Larson, M Siipola, TK Collier. 2007a. Persistent organic pollutants in outmigrant juvenile chinook salmon from the Lower Columbia Estuary, USA. Sci Total Environ 374:342 – 366

Johnson LL, GM Ylitalo, MR Arkoosh, AN Kagley C. Stafford, JL Bolton, J Buzitis, BF Anulacion, TK Collier. 2007b. Contaminant exposure in outmigrant juvenile salmon from Pacific Northwest estuaries of the United States. Environ Monit Assess 124:167 – 194

Johnson, Nicholas M., Water Resources Consultant, Potential Water-Supply Impacts to Dry Creek Valley from NSCARP and a Bypass Pipeline, Prepared for Dry Creek Valley Association, December 2008

Kidd KA, PJ Blanchfield, KH Mills, VP Palace, RE Evans, JM Lazorchak, RW Flick. 2007. Collapse of a fish population after exposure to a synthetic estrogen. Proceed. Nat. Acad. Sci. 104:8897-8901

Laville N, S Ait-Assima, F Gomez, C Casellas, M Porcher. 2004. Effects of human pharmaceuticals on cytotoxicity, EROD activity and ROS production in fish hepatocytes. Toxicology 196: 41–55

Newman MC, MA Unger. 2003. Fundamentals of Ecotoxicology. CRC Press, Boca Raton, FL, pp 458.

Nichols K, JS Foott. 2005. Health monitoring of juvenile Klamath River Chinook salmon, FY 2004 investigational report. USFWS California-Nevada Fish Health Center, Red Bluff, CA.

Nielsen DL, MA Brock, GN Rees, DS Baldwin. 2003. Effects of increasing salinity on freshwater ecosystems in Australia. Austalian Journal of Botany 51: 655 – 665

Relyea RA. 2009. A cocktail of contaminants: how mixtures of pesticides at low concentrations affect aquatic communities. Oecologia 159:363 – 376

Rolland RM. 2000. Ecoepidemiology of the effects of pollution on reproduction and survival of early life stages in teleosts. Fish and Fisheries 1: 41-72

Santa Rosa Discharge Compliance Report EIR, Volume 3--Appendix G-3, Ecological Risk Assessment, available at http://ci.santa-rosa.ca.us/departments/utilities/irwp/discharge/Pages/studies_reports.aspx#Final_EIR.

Schreck CB. 1981. Stress and compensation in teleost fishes: response to social and physical factors. Stress and Fish. A. Pickering. London, Academic Press**:** 295-321

Schreck CB, AG Maule, SL Kaattari. 1993. Stress and disease. Recent Advances in Aquaculture. J. F. Muir, Roberts, R.J. Oxford, Blackwell Scientific Publishing**:** 170-175

Spence BC, GA Lomnicky, RM Hughes, RP Novitzki. 1996. An ecosystem approach to salmonid conservation. Funded jointly by the U.S. EPA, U.S. Fish and Wildlife Service and National Marine Fisheries Service. TR-4501-96-6057. Man Tech Environmental Research Services Corp., Corvallis, OR.

Snieszko SF. 1974. The effects of environmental stress on outbreaks of infectious diseases of fishes. Journal of Fish Biolology 6:197-208

Teh SJ, C Wong, V Furtula, FC Teh. 2003. Lethal and sublethal toxicity of didecyldimethylammonium chloride (DDAC) in early life stages of white sturgeon (*Acipenser transmontanus*). Environmental Toxicology and Chemistry 22: 2152-2158

Thompson B, T Adelsbach, C Brown, J Hunta, J Kuwabara, J Neale, H Ohlendorf, S Schwarzbach, R Spies, K Taberski. 2007. Biological effects of anthropogenic contaminants in the San Francisco Estuary. Environmental Research 105:156–174

Varsamos S, G Flik, JF Pepin, SE Wendelaar Bonga, G Breuil. 2006. Husbandry stress during early life stages affects the stress response and health status of juvenile sea bass, *Dicentrarchus labrax*. Fish and Shellfish Immunology 20:83 – 96

Wilshire, Howard; Letter to David Cuneo, SCWA, April 2009

Woody CA. 2007. Summary of copper: Effects on freshwater food chains and salmon - summary prepared by Trout Unlimited for the Alaska State Legislature, September 2007. http://www.fish4thefuture.com/pdfs/Summary%20WoodyReview%20-%20Copper%20Effects%20to%20Fish%20092107.pdf

Yates, Gus; Northern Sonoma County Agricultural Reuse Project, Final Environmental Impact Report: Technical Review of Hydrology and Water Quality Issues, Letter to CWCNSC, April 2009