Restoration of the Salton Sea

Volume 1: Evaluation of the Alternatives

Appendix 1K: Selenium Risk to Aquatic Birds

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Introduction

The Salton Sea (Sea) is a large saline body of water occupying a closed basin (no outlet) in a portion of a geological formation known as the Salton Trough in southern California. The Sea is about 35 miles long, 9 to 15 miles wide, with 120 miles of shoreline surrounding its 380 square mile surface (Cohen *et al.* 1999). The Sea's elevation in 1999 was -227 feet below msl. The sea's average depth is about 31 feet, with a maximum depth of 51 feet, and it contains about 7.3 million acre feet (maf) of water.

The Salton Sea is a congressionally authorized repository for irrigation drainwater from the Imperial and Coachella Valleys. The Sea also has high recreational and wildlife habitat values. The Sea receives about 1.3 maf of inflow annually and annually looses about this amount from evaporation. Most of the annual inflow is irrigation drainwater with less than eight percent coming from annual precipitation within the basin (Cohen *et al.* 1999). There are three water quality issues associated with the Salton Sea: salinity, nutrient loading, and selenium. Approximately four million tons of dissolved salts, 15,000 tons of nutrients (Cohen *et al.* 1999), and about 9 tons of selenium (Setmire and Schroeder 1998) enter the Sea annually.

Since its most recent filling in 1905, the Sea has experienced several periods of fluctuating water levels. However, as economic pressures change and the need for domestic water in southern California continues to increase, it appears that a prolonged period of reduced inflow is currently underway. High evaporative loss (5-6 feet annually) and reduced inflow in the future will lead to reduced volume and surface area with increasing salinity levels.

This report addresses selenium risks potentially associated with nine basic proposed restoration alternatives. The issues of salinity and nutrient loading are addressed in other reports. Selenium concentrations within the New, Alamo, and Whitewater Rivers, and in the Salton Sea have received much attention in the past relative to potential Salton Sea restoration alternative projects. Numerous workshops have been conducted by the U.S. Geological Survey's Salton Sea Science Office to address such issues. These workshops have identified a number of potential alternatives to have fatal flaws involving the use of river waters in support of project elements. The same types of flaws may exist with the nine alternatives being considered by the Bureau of Reclamation (Reclamation) in Phase 1 of the proposed study. This report documents an assessment of selenium risks to fish-eating and invertebrate-eating birds associated with the current proposed restoration alternatives.

Selenium

Selenium is a naturally occurring semi-metallic trace element with biochemical properties similar to sulfur. Selenium is an essential trace nutrient necessary for normal metabolic functions. Because of its similarities to sulfur, selenium is readily incorporated into an organism's body during protein synthesis and other metabolic pathways. One of the interesting features of selenium is the narrow margin between nutritionally optimal and potentially toxic dietary exposure concentrations for vertebrates (U.S. Department of Interior 1998). The toxic effects result from the incorporation of selenium—rather than sulfur—in amino acids, and the subsequent alteration of protein structure and impaired enzymatic function (Amweg *et al*. 2003). Effects of selenium toxicity (selenosis) range from hair/feather loss to death, with reproductive impairment and/or teratogenesis (deformed embryos) a common concern in wildlife studies.

Selenium is an important consideration in aquatic fish and wildlife studies because of bioaccumulation. Bioaccumulation is an accumulation process involving the biological sequestering of a substance with an organism. Sequestering results in the organism having a higher concentration of the substance than the concentrations in the organism's surroundings. Although selenium can be acquired through the gills or skin, dietary exposure is the dominant uptake pathway in animals (Hamilton 2004). The largest "step" in the bioaccumulation process occurs when selenium concentrations go from parts per billion (ppb) in water to parts per million (ppm) in plants and invertebrates. As additional layers, or trophic levels, of fish and wildlife feed on the levels below, selenium can reach concentrations resulting in reproductive impairment or death. Extensive selenium studies over a range of conditions and locations permit the development of selenium effect levels tied to various medium concentrations (Table 1).

The Salton Sea currently supports a salinity regime that generally dictates the fate of chemical constituents entering the sea via drain water. For example, a significant proportion of total selenium concentrations in the New and Alamo Rivers are in the selenite (+4 oxidation state) and selenate (+6 oxidation state) oxidation states. These states are water soluble, but are generally less available (particularly selenate) for higher organisms to use (Figure 1). For example,

Table 1.—Selenium effect levels (U.S. Department of the Interior 1998). Several authors have published similar guidance with minor variations in values. All indicate a small range of values between “no effect” and “toxicity threshold” levels.

Medium	No Effect	Level of Concern	Toxicity Threshold
Water (ppb, total recoverable)	<1	1-2	>2
Sediment (ppm, dry weight)	<1	1-4	>4
Dietary (ppm, dry weight)	<2	2-3	>3
Waterbird eggs (ppm, dry weight)	<3	3-6	>6
Warmwater fish (ppm, whole body dry weight)	<3	3-4	>4
Coldwater fish (ppm, whole body dry weight)	<2	2-4	>4

organic selenides are the most bioavailable forms (i.e., can enter metabolic pathways with minimum or no alteration) while selenates are among the least bioavailable forms (i.e., require reduction for metabolic processing). However, selenate and selenide are readily taken up by plants and microorganisms and transformed into various organic selenides (Fan *et al.* 2002). Elemental selenium and inorganic and organic selenides are relatively water insoluble, but can absorb to particulates within the water column.

Total selenium concentrations in the Salton Sea water column are in the 1-2 µg/L range, with virtually none of the selenium in the selenate (highly oxidized) form (Setmire *et al.* 1993). However, existing food chains—as depicted in Figure 2—pose hazards to area water birds because of bioaccumulation of selenium through the pileworm to fish to fish-eating bird linkages. Pileworms accumulate selenium from the Sea’s sediments.

Sediments currently function as a sink where selenium is sequestered away from most non-sediment linked food chains.

Current Conditions

In order to understand possible future scenarios for the Sea, it is necessary to first understand current conditions as they relate to selenium and the risk of bioaccumulation in area wildlife, and then how conditions would likely evolve if no restoration actions are taken to maintain current resources associated with the Sea. Selenium enters the Imperial and Coachella Valleys in Colorado River water imported via the All-American Canal as irrigation water. Although selenium concentrations in Colorado River water are low (~2.0 µg/L), the concentration is increased through evaporation of water applied to irrigate fields (Figure 3). Tile drains collect wastewater from beneath the fields and convey it—with tailwater from fields and canal seepage—in open drains which either empty into tributaries

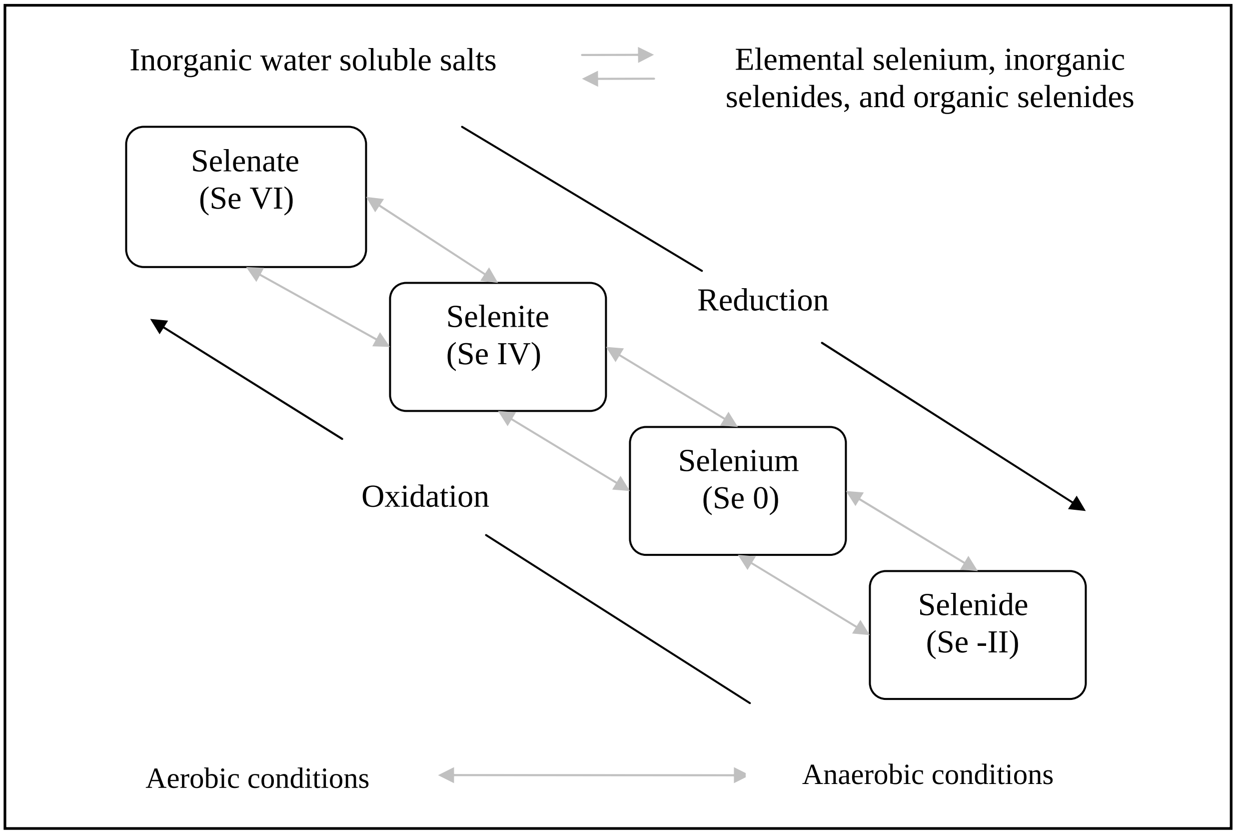

Figure 1.—Selenium exhibits a complex chemistry in natural systems. The above schematic depicts the general relationships between the four valence forms or oxidation states of selenium. As implied, forms can be readily converted to other forms under the proper chemical and/or biological conditions.

of the Sea (e.g., New, Alamo, and Whitewater Rivers), or into the Sea directly (e.g., Trifolium Drain). Elevated concentrations of selenium from tile drains are diluted in open drains and tributaries before discharge to the Sea (Figure 3). Selenium concentrations are further reduced in the Sea's water column by specialized bacteria (Setmire *et al*. 1993) (see also Figure 2 for movement and bioaccumulation of selenium after entering the Sea).

The Salton Sea, the deltas or interfaces between the Sea and tributaries and drains entering the Sea, and the open drains themselves all serve as fish and wildlife habitat. There is one native fish species (Federally endangered desert pupfish) and approximately 15 introduced fish species inhabiting the Sea, and its drains and tributaries (Setmire *et al*. 1993). However, it is the abundance and diversity of birds that identifies the Salton Sea as important wildlife habitat. Estimates of birds using the area range between 375 and 400 species, with 93 nesting species recorded. The Yuma clapper rail and brown pelican remain on the Federal endangered species list. About one-third of the remaining Yuma clapper rail population use the freshwater drains in the area, and up to 5,000 brown pelicans occasionally spend the summer in the Salton Sea area. Wintering birds include

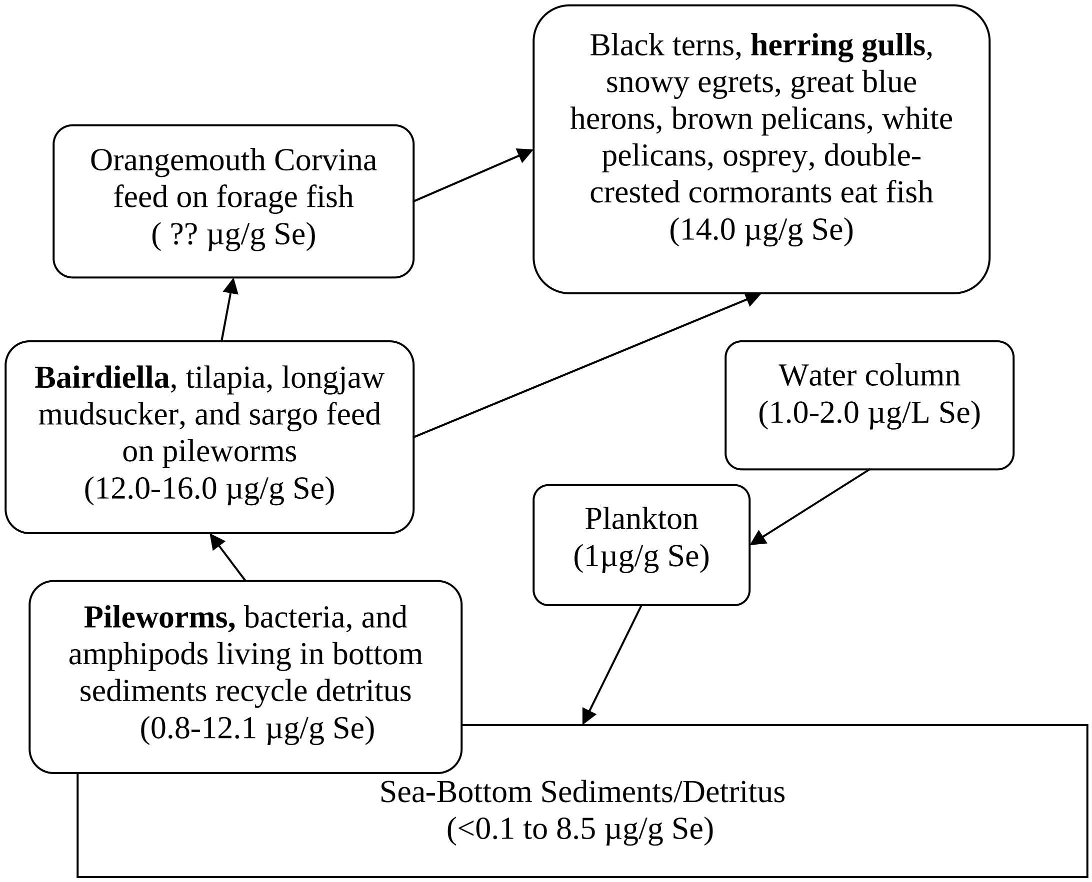

Figure 2.—Selenium in the Salton Sea's water column and/or sediments can be bioaccumulated as it moves through aquatic food chains. Concentrations in parentheses have been reported by Setmire *et al*. (1993), or others, for the organisms in bold.

some 25 species of waterfowl, grebes, shorebirds and others. Eared grebe numbers have been estimated as high as two million birds. It has been estimated that 50 percent of the birds using the Pacific Flyway make annual stops at the Salton Sea.

Methods

Reclamation's Technical Service Center's Ecological Planning and Assessment Group (D-8210) is conducting an assessment of the potential for increased selenium bioaccumulation in both fish-eating and invertebrate-eating birds resulting from the proposed Salton Sea restoration alternatives. D-8210 is evaluating each alternative to determine if restoration features would likely result in an increase in selenium available to aquatic birds using the Salton Sea and/or associated wetlands.

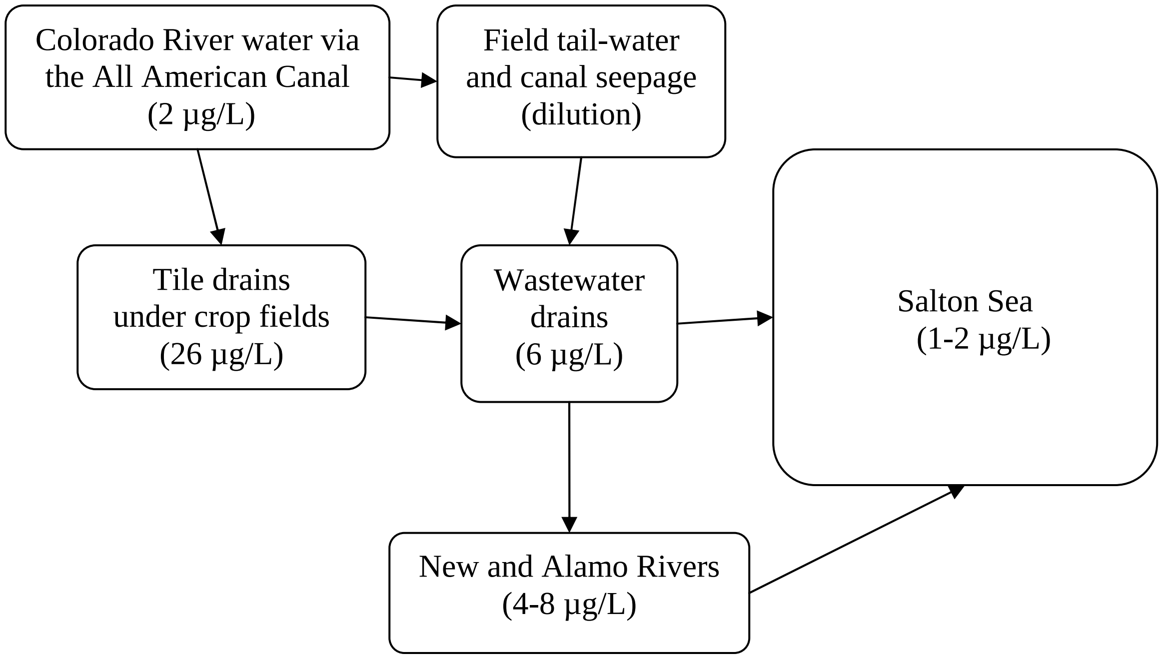

Figure 3.—Approximate mean selenium concentrations at various sites within the Salton Sea system under current conditions (Setmire *et al*. 1993).

The assessment relies on available information addressing bird species' use of the area, selenium cycling and movement through the Salton Sea system, and engineering design specifications for various restoration features, plus nutrient and contaminant information generated from a Salton Sea Science Office workshop to be conduced to address nutrient and contaminant issues.

The information obtained above is being used to develop a conceptual model of selenium bioaccumulation risk to aquatic birds under conditions likely to result from the nine proposed alternatives. This approach can be used to rank alternatives from low to high potential risk of increased bioaccumulation of selenium in aquatic birds.

This approach makes multiple assumptions that are addressed below before the assessment results are presented.

Alternative Assessment: Assumptions

The cycling of selenium within the Salton Sea system involves a number of complex interactions between physical, chemical, and biological components. Some of these interactions are understood, and others are not. More uncertainty surrounds attempts to predict responses from alternative actions that are little more than concepts. Thus, in order to conduct a viability assessment on the selenium risk to aquatic birds, it is first necessary to define a series of assumptions that serve to establish boundaries for the Salton Sea system and how its components are anticipated to respond to reduced inflow in the future.

These assumptions attempt to characterize, to the extent possible, a standard against which we will assess selenium risk, and the parameters that may affect the concentrations of selenium in future alternative components. We begin the definition of assumptions with a discussion of a standard we suggest using to measure the risk of bioaccumulation. The discussion then moves into a characterization of alternative components, beginning with drainwater. Specifically, we define selenium levels, or at least the direction of the trend in future selenium levels in alternative components. We then move the discussion to features that would receive and hold the drainwater. Although restoration alternatives continue to evolve, most cover a narrow assortment of potential features. In general, these features include some type (size varies) of marine lake, a hyper-saline or brine basin, and then an assortment of constructed and "naturally" occurring wetlands. The following discussion treats each of these system components in a general manner, and then addresses each of the current nine alternatives to determine how the various system components would be affected by elements within each alternative.

Finally, the above information is used to assess potential effects to aquatic birds feeding on fish and/or invertebrates produced in alternative features. This is a difficult task in light of the uncertainty that surrounds alternatives. There are also data gaps that are addressed at the end of this report, that also make predictions difficult. For these reasons a conservative approach has been selected. The assessment is based on the potential ability of features to increase the selenium risk level above existing levels. Existing selenium levels in area food chains appear to be at a threshold of causing negative impacts to selenium-sensitive and moderately-sensitive species. Any increase above these levels would be cause for concern.

The Risk Standard

Selenium can bioaccumulate in aquatic food chains until it reaches levels that can adversely affect fish-eating and invertebrate–eating birds. Effects from selenium bioaccumulation can range from no effect through reproductive impairment to death depending on concentration. For example, reproductive toxicity is exposure responsive meaning the higher the concentration, the greater the effect. Because a great many variables interact on and within the food chain, it is difficult to predict a response based only on various selenium concentrations in water, sediments, primary and secondary producer, etc. Because of these uncertainties, egg concentrations have become the assessment standard for selenium risk in birds. The embryo is the most selenium-sensitive stage in a bird's life cycle, and egg concentrations avoid the uncertainties mentioned above for various environment l concentrations, and permit the identification of a reproductive toxicity threshold.

The reproductive toxicity threshold for bird eggs is about 10 µg/g dry weight (Heinz 1996). At this concentration, the most sensitive indicator of reproductive toxicity—reduced egg viability (hatchability)—begins to appear and can be measured. The 10 µg/g is a general value for all birds with some species exhibiting reduced egg viability at lower concentrations, and some at higher concentrations. For example, Skorupa (1998) has calculated the threshold for reduced egg viability for black-necked stilts at 6 µg/g. Deformed embryos (teratogenesis) do not usually appear until higher egg concentrations occur. For example, Skorupa (1998) has calculated the EC_{50} (median effective concentration) for teratogenesis in the following species: dabbling ducks = 31 µg/g, black-necked stilts = 58 µg/g, and American avocets = 105 µg/g.

This assessment attempts to characterize, to the extent possible, the risk of increased bioaccumulation of selenium in both fish-eating and invertebrate-eating birds from various features associated with nine proposed restoration alternatives. The negative impacts of interest from increased bioaccumulation of selenium deal with egg viability (hatchability). Egg viability is the most sensitive measure of reproductive impairment and can be determined from statistical studies of egg clutch viability and selenium levels within the eggs. Reduced hatchability reduces potential recruitment into local and regional populations.

A potential increase in bioaccumulatiion is important because aquatic birds using the Salton Sea may be on the threshold of reproductive toxicity from area selenium levels. Bird eggs from the Salton Sea had selenium concentration of 1.6-35 µg/g (Setmire *et al*. 1993), and black-necked stilts—a species moderately sensitive to selenium—experienced an estimated 5 percent reduction in egg viability linked to selenium in 1993 (Bennet 1998, Skorupa 1998).

In this assessment, the risk of reduced egg viability has been loosely tied to anticipated selenium concentrations in water and sediments of individual restoration alternatives. It is assumed that these concentrations would be reflected in selenium bioaccumulation in area food chains. While this approach permits an assessment of alternatives, it is a very generalized approach that lacks predictive precision. There are too many uncertainties surrounding future selenium concentrations too permit a more quantitative approach at this time. However, the approach can be used to compare relative differences in alternatives at this level of planning.

The above information is used to assess potential effects to aquatic birds feeding on fish and/or invertebrates produced in alternative features. This is a difficult task in light of the uncertainty that surrounds alternatives. There are also data gaps that are addressed at the end of this report, that also make predictions difficult. For these reasons a conservative approach has been selected. The assessment is based on the potential ability of features to increase the selenium risk level above existing levels. Existing selenium levels in area food chains appear to be at a threshold of causing negative impacts to selenium-sensitive and moderately-sensitive species. Any increase above these levels would be cause for concern.

Risk levels are qualitative and loosely linked to selenium concentration in water and sediments. Levels include:

- low water = ≤ 1 µg/L, sediment = ≤ 1 µg/g
- moderate water = 1-2 µg/L, sediment = 1-2.5 µg/g
- high water = 2-5 µg/L sediment = 2.5-4 µg/g
- high hazard water = > 5 µg/L sediment = > 4µg/g

These qualifiers can be further defined. A low risk level would indicate a low probability of reduced egg viability caused by selenium levels in water and/or sediments, and the expected increases in primary producers and subsequent trophic levels of the food chain. A moderate risk level indicates that some reduction in egg viability may occur, but that increase would require detailed study to quantify. Some species nesting at the Salton Sea are likely experiencing conditions that place them in the moderate risk level for reduced egg viability (e.g., black-necked stilts). A high risk level for bioaccumulation of selenium resulting in reduced egg viability would indicate that measurable reduction in egg hatchability in several species was highly probable. Finally, a high hazard risk level would indicate that reduced egg viability is a common condition in aquatic nesting birds, and some level of teratogenesis may be occurring.

Alternative Components

Tributaries and Drains

One of the major considerations when speculating on the future conditions of various alternative features is the source of future water and its characteristics. In the future, surface wastewater drains would likely carry less water with higher concentrations of constituents such as selenium. This would occur because of economic pressures that dictate irrigation water be applied to the most productive soils able to produce the most valuable crops. For example, lettuce (a valuable crop) is grown on highly permeable soils while Bermuda grass (less valuable crop) is grown on less permeable sites (Setmire *et al.* 1993). Less permeable sites produce greater amounts of tail water. If such sites are taken out of irrigation, less tail water would be available for dilution of tile drain water.

This assessment assumes that dilution water, consisting of tailwater and other operational waters, would experience significant future reductions in volume. These reductions would affect the concentrations of constituents in drainwater conveyed through major tributaries and drains to the Salton Sea. Basically, constituents such as selenium would increase to approach concentrations similar to those in subsurface drainwater as the proportion of dilution water in surface drainage decreases and the proportion of subsurface drainwater increases (Figure 4). Sediment concentrations of selenium would also increase as water concentrations increase. Finally, selenium concentrations in food-chain biota would increase reflecting the assumed increases in sediments and transported drainwater.

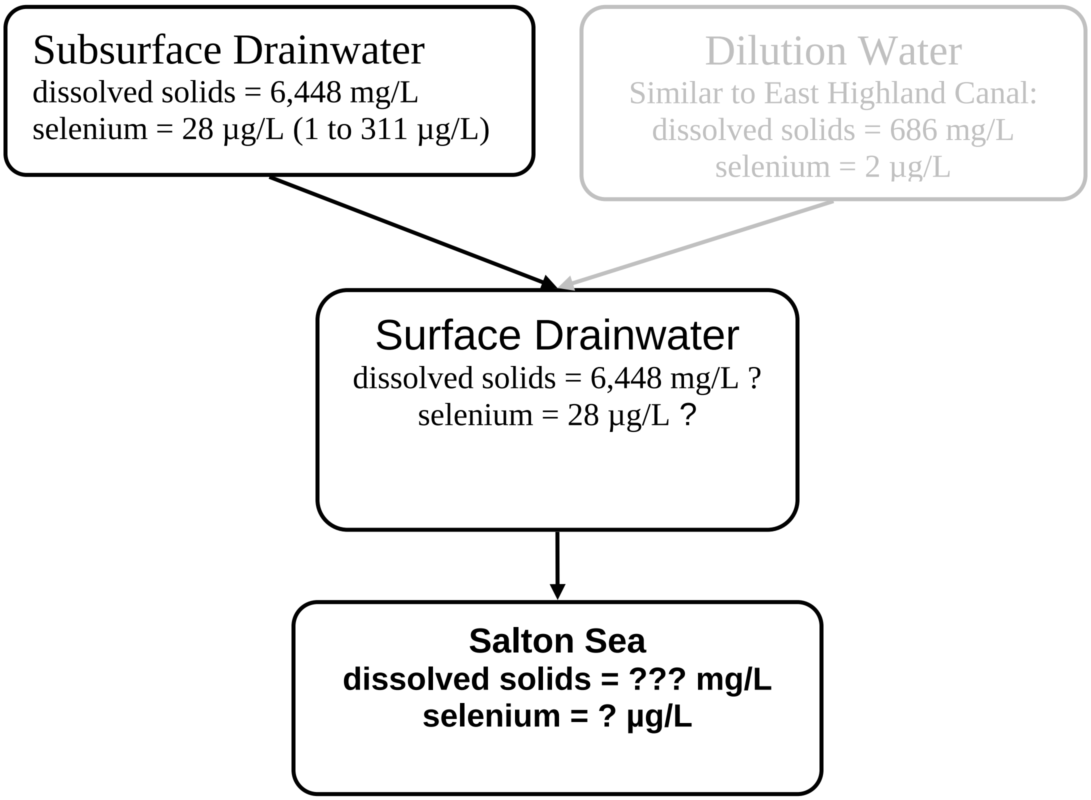

Figure 4.—The future reduction in inflow to the Salton Sea would be dictated by economics and would likely come from a reduction in dilution water. Concentration levels are unknown but as dilution water is reduced, selenium concentrations in surface drainwater would come to resemble concentrations in subsurface drainwater.

Tributaries and drains deliver the drainwater to alternative features. Tributaries also provide shallow freshwater wetland habitat for a variety of fish, amphibians and reptiles, aquatic birds, and mammals (Setmire *et al.* 1993, 1995). Vegetation associated with tributaries varies in coverage and diversity (Setmire *et al*. 1995), and common species include common reed, salt cedar, cattails, and others. Aquatic invertebrates, such as waterboatman, are abundant in tributaries and their outlets. There is currently one native species (desert pupfish) and some 15 introduced fish species using the Salton Sea and its tributaries. Large numbers of tilapia, carp, mosquitofish, sailfin molly, longjaw mudsucker, redfin shiner, and pupfish utilize the tributaries. Both fish-eating birds such as great blue herons, and invertebrate-eating birds such as the endangered Yuma clapper rail make extensive use of these sites.

Although there are many similarities among tributary sites in terms of habitat resources and wildlife use, potential effects of increasing selenium concentrations are discussed below on a site-specific basis.

Alamo River

The Alamo River enters the United States at the International Boundary near Mexicali, Mexico, and passes through the Imperial Valley before terminating in the Salton Sea. The river supports wetland habitat and fish and wildlife similar to those described above.

The river delta (beyond the outlet to the Sea) currently provides a mixing zone where selenium concentrations (e.g., selenate and selenite totaling 8 µg/L) entering the Sea are diluted and reduced (e.g., selenite totaling about 1-2 µg/L). The delta currently supports an extensive area about one foot in depth that provides feeding, loafing, and roosting habitat for a variety aquatic birds (Setmire pers. comm.).

Dissolved solids concentration at the river's outlet to the Sea is currently at about 2020 mg/L with selenium concentrations at 8 µg/L. As discussed above, these concentrations would increase as dilution water is reduced. For example, dilution water currently comprises about 77 percent of Alamo River water at the outlet to the Sea (Setmire pers comm.). A 20 percent reduction in dilution water would result in a dissolved solids concentration of 2862 mg/L and 12 µg/L selenium, while a 50 percent reduction in dilution water would result in 4,230 mg/L dissolved solids and 18 µg/L selenium. A worst-case scenario would result in elimination of dilution water with the Alamo River carrying subsurface drainwater. Subsurface selenium concentrations range from 1 to 311 µg/L (median = 28 µg/L, n = 304) (Setmire *et al*. 1995).

The median selenium concentrations in river sediments is currently about 0.5 ug/g (range = 0.1 to 1.7, n = 47) (Setmire *et al*. 1995). Selenium sediment concentrations would likely increase as water concentrations increase. Bacterial reduction would yield elemental selenium, hydrogen selenide, and organic selenides (Setmire pers. comm.).

Selenium concentrations would increase in biota as increased levels of selenium become available through water column- and sediment-based food chains.

New River

The New River also enters the United States at the International Boundary near Calexico, and passes through the Imperial Valley before terminating in the Salton Sea. The river currently supports a selenium concentration of about 4 µg/L.

In terms of habitat value and fish and wildlife use, the New River it is similar to the Alamo River. The New River delta in the Salton Sea has experienced outbreaks of avian botulism in recent years.

The New River may experience a greater increase in selenium concentrations in the future. The river picks up untreated sewage and other contaminants near Mexicali. Drainwater actually improves water quality in the New River as it passes through the Imperial Valley. If Mexicali implements plans to increase river water use, less low selenium water would be available to mix with agricultural drainwater. The combination of reduced flows crossing the international border and reduced dilution water from the Imperial Valley may increase selenium levels reaching the Salton Sea

Whitewater River

The Whitewater River carries drainwater from the Coachella Valley and storm water runoff from the surrounding mountains and urban areas. The Whitewater River currently supports a selenium concentration of about 2.5 µg/L. The Whitewater River provides habitats similar to those described for the Alamo River, and supports similar species. The river's delta supports marshes used for feeding and loafing.

Drains

Numerous surface drains in the Imperial and Coachella Valleys carry drainwater from irrigated fields to tributaries for transport and disposal in the Sea, or many drains empty directly into the Salton Sea. Selenium concentrations in surface drains range from 2-52 µg/L, with a median value of 6 µg/L (n = 49) (Setmire *et al*. 1995).

Drains provide varying qualities and quantities of wetland habitat supporting area fish and wildlife, including the endangered desert pupfish.(Setmire *et al.* 1993, 1995).

Marine Lake

The concept of a marine lake with salinity concentrations supporting a re-established marine fishery is a common element of most Salton Sea restoration alternatives. Depending upon alternative, the marine lake can vary in location (north versus south basin), size, and water sources. The marine lake would be less saline and it would be smaller, i.e., generally shallower, with less surface area and reduced shoreline, than the current Sea.

Physical-Chemical Considerations

A marine lake would occupy about 30 to 50 percent of the area currently covered by the Sea, and receive all future inflow from some combination of the Alamo, New, and Whitewater Rivers, plus drains that currently empty directly into the Sea. Although a marine lake would occupy an area previously occupied by the Sea, selenium conditions may differ substantially in the new lake. These differences include, but may not be limited to:

- Higher selenium concentrations in incoming drainwater. As dilution water is reduced, selenium concentrations would increase above the current 4-8 µg/L.

- The same mechanisms—phytoplankton uptake, reduction, and bacterial metabolism—that currently remove selenium from the Sea's water column would be present in the marine lake.

- Selenium concentrations in bottom sediments under the north lake are among the highest recorded. These sediments would no longer be deeply buried. There is uncertainty as to whether some portion of this reduced selenium in sediments would enter the water column (via wave action and/or other mixing) and become available via aerobic conditions.

There is currently a large potentially available supply of selenium sequestered in Salton Sea sediments. The fate of this selenium supply in future restoration activities is extremely important, but difficult to predict. Setmire (pers. comm.) cites a study by Van Derveer and Canto (1997) who found that sediment selenium concentration to be a reliable predictor of adverse biological effects. A preliminary toxic threshold for selenium existed in 27 reviewed studies at 2.5 µg/g, and adverse effects were always observed at concentrations > 4 µg/g. Current Sea sediment selenium concentrations range from < 1.0 to 8.5 µg/g (Vogl and Henry 2002), and 0.58 to 11 µg/g (median 2.7 µg/g of 11 samples) (Setmire pers. comm.). Although selenium in Salton Sea deep bottom sediments are generally believed to be physically unavailable to biota, it is clear that there are areas of bottom sediment supporting selenium concentrations that if available—would be within the level on concern identified above, and above.

Selenium is currently reduced (under anaerobic conditions) and sequestered in the bottom sediments of the Salton Sea, resulting in a water column concentration of about 1-2 µg/L. It is unknown if current reducing mechanisms would be adequate to deal with increased selenium levels from incoming drainwater, and perhaps increased availability of selenium currently sequestered in bottom sediments, in a new system that is smaller, shallower, perhaps more aerobic, and a less saline marine lake.

Several sediment-related issues—in terms of increasing bioavailability of selenium—were recently identified by the Salton Sea Ecosystem Restoration Plan (SSERP 2005a):

- Changes in nutrient content of drainwater (e.g., a reduction in phosphorus with a reduction in dilution water) may reduce eutrophication and anaerobic conditions in deep water—such conditions could promote selenium oxidation and increase its bioavailability.

- A shallower marine lake may mix more often resulting in bottom sediment aeration and re-suspension—such conditions could promote selenium oxidation and increase its bioavailability.

- A smaller northern marine lake may increase exposure of water to the highest sediment selenium levels in the Sea—such conditions may increase selenium bioavailability.

There are also alternative sediment/selenium considerations:

- A shallower marine lake that is well mixed by wind action may enhance eutrophication through re-suspension of particulate phosphorus—such conditions may facilitate anaerobic conditions and ensure selenium trapping in bottom sediments.

- A marine lake reduced in size may reduce mixing and stabilize thermal stratification—such conditions may facilitate anaerobic conditions and ensure selenium trapping in bottom sediments.

The issues surrounding the fate of selenium in Salton Sea sediments likely produce the most uncertainty associated with the study of any potential restoration alternatives.

Selenium (generally in its elemental form and as various selenides) is currently physically trapped (i.e., sequestered) in the Sea's sediments by gravity (precipitation of particulates to sediments) and anaerobic conditions. The lack of oxygen prevents the colonization of deep, organically rich sediments by benthic invertebrates. Selenium in deep sediments is thus unavailable to biota, and one of the two most important pathways for selenium bioaccumulation does not exist except in a narrow band of shallow aerobic sediments around the Sea's shoreline and other similarly shallow sites. It has been speculated selenium concentrations in the water column could increase to as much as 400 µg/L if not held as reduced insoluble compounds in Salton Sea sediments (Schroeder and Orem 2000 in SSERP 2005a).

Given the above uncertainties, the following assumptions are identified for the purposes of this analysis:

- Selenium concentrations in drainwater would increase as dilution water is reduced.

- Smaller marine lakes would experience extensive stratification, and would be less prone to sediment re-suspension and wind/wave mixing (Anderson pers. comm.).

- Salinity concentrations would continue to increase until they reach a level that negatively affects the current assemblage of primary producers.

- Phosphorus would continue to increase from present conditions until a state of very low inflow is reached (Robertson pers. comm.).

- Either salinity or phosphorous levels, or both, may act to reduce current primary producers in the future.

Although the above assumptions define a system in which selenium is trapped in bottom sediments of deep eutrophic marine lakes, the uptake and bioaccumulation of selenium by primary producers would likely increase because of higher concentrations entering the system from tributaries and drains (Setmire pers. comm.). In addition, it is reasonable to assume that either salinity or phosphorous, or both, may act to reduce current primary producers at some time in the future. Such a reduction may result in an increase in selenium within the water column. Either of these potential conditions would translate into a high risk level of increased selenium bioaccumulation for aquatic birds.

Biological Considerations

When speculating on the effects of future restoration alternatives on fish-eating birds, we must first assume that the marine fishery that currently (now historically) exists in the Salton Sea will disappear in the near future. Even if the concentration of salts slows, as speculated by Holdren and Montãno (2002) the combined stressors of high levels of un-ionized ammonia, high temperatures, low dissolved oxygen levels and high sulfide levels (associated with algal blooms) would likely persist and challenge the continued existence of a marine fishery. The fishery, except for desert pupfish, will likely collapse in the Sea in the near future and no longer exist as known today. Without a Sea fishery, fish-eating bird numbers would decline, although some fish would persist in the drains and tributaries. Until the Sea fishery disappears, fish-eating birds would likely be exposed to increased levels of selenium and selenium bioaccumulation.

A limited fishery would likely persist in the rivers and surface drains that carry water. Currently, surface drains support desert pupfish, tilapia, sailfin mollies, mosquitofish, carp, longjaw mudsucker, and redfin shiners (Setmire *et al.* 1993). Some fish samples taken from drains exceed the dietary threshold levels of concern for selenium (Table 1). These fish are fed upon by great blue herons, great egrets, green-backed herons, snowy egrets, and others. However, because of the increased concentrations of selenium carried by these water bodies, selenium concentrations in fish would increase and pose additional risk to fish-eating birds using these sites for foraging.

If management chooses to establish a marine fishery in a future marine lake, the bottom sediment linkage to future food chains should not be re-established. For example, there are two major routes of selenium bioaccumulation in aquatic food chains—sediments and the water column (Hamilton and Lemly 1999). Some organic selenides are likely incorporated into a plankton-based food chain, but this would be a minor pathway.

The most important food-chain pathway resulting in bioaccumulation of selenium to levels of concern in fish-feeding birds originates in sea-bed sediments. Assimilated selenium is deposited and accumulates in sea-bed sediments as microorganisms die and become detritus. Pileworms, bacteria, and amphipods living in the sediments acquire selenium from the sediments and pass it on to the next trophic level. An intentional link to bottom sediments in any future fishery should be avoided if possible.

Hypersaline-Brine Basin

A hypersaline or brine basin is a common component for all alternatives because there would continue—at some level—a future need to dispose of irrigation drainwater. This feature would likely function, and have characteristics similar to, evaporation basins in the San Joaquin Valley. As inflows decrease and salinity concentrations increase the hypersaline basin could evolve into a salt lake similar to Mono Lake in California, or the Great Salt Lake in Utah (Cohen *et al.* 1999). As salinity levels increase, eggs and larva of fish and pileworms would have difficulty surviving (45-50 parts per thousand—ppt salinity), and without reproduction, these populations would disappear. The current sediment-detritus based food chain (Figure 2) would be broken and selenium bioaccumulation in area fish-eating birds may be reduced. With the collapse of the fishery, the numbers of fish-eating birds using the area would shift to the marine lake—if it is part of the future and supports a viable fishery. Copeopods and amphipods would also experience reproductive failure as salinity levels continue to increase. As salinity levels continue to rise, an algae-brine shrimp-brine fly community would be established similar to other salt lakes, and some evaporation ponds in the Central Valley of California. Other scenarios may also develop depending upon restoration efforts as discussed below.

Any brine basin would rapidly increase in salinity concentration following construction. Biota currently occupying Sea water would disappear as described above and be replaced by a low diversity, but potentially high biomass community of brine shrimp, brine fly larva, and a few other salt-tolerant species. Although bacterial and chemical selenium removal mechanisms would function under increasingly saline conditions (Setmire pers. comm.), selenium levels would increase through evaporation. Invertebrate-feeding aquatic birds would be attracted to biota within the brine basin, and selenium would bioaccumulate in these shorten food chains.

Sediments and Constructed Wetlands

As the Sea and/or features of future restoration alternatives recede from reduced water supplies, the exposure of bottom sediments associated with a reduced Salton Sea would create several potentially significant selenium issues. Currently, the upper 30 centimeters of bottom sediments contain selenium, with concentrations ranging from < 1.0 mg/kg to 8.5 mg/kg (Vogl and Henry 2002). Selenium in the bottom sediments (anaerobic conditions) likely occurs in the elemental form with perhaps some organic selenides associated with organic detritus (Figure 5). The saline water column supports around 1-2 µg/L of selenium in the predominantly selenite form (Setmire *et al*. 1993). These conditions (i.e., deep saline water over sediments) currently permit the Sea to act as a sink sequestering selenium in sediments where its availability to the system is physically limited.

The exposure of bottom sediments as the Sea recedes would create a very different—aerobic and fresh(er) water—environment for selenium. Reduced selenium in sediments would be exposed to oxidizing conditions as sediments are exposed to the recurring wetting and drying in depressions and basins (creation of ephemeral wetlands) in the historic sea floor. This wetting would occur from natural precipitation (limited) and the seepage of water from local drains (e.g., Trifolium, Vail, etc.) and small streams such as San Felipe Creek, or from dust control efforts. Bottom sediments contain high concentrations of selenium that would likely become available as selenate and perhaps selenite through contact with oxygen and water. Sites with moist substrates or standing water would likely support aquatic plants.

Selenite is taken up faster and in greater quantities than is selenate by aquatic plants (Hamilton 2004). Thus wetlands that may occur and/or may be constructed

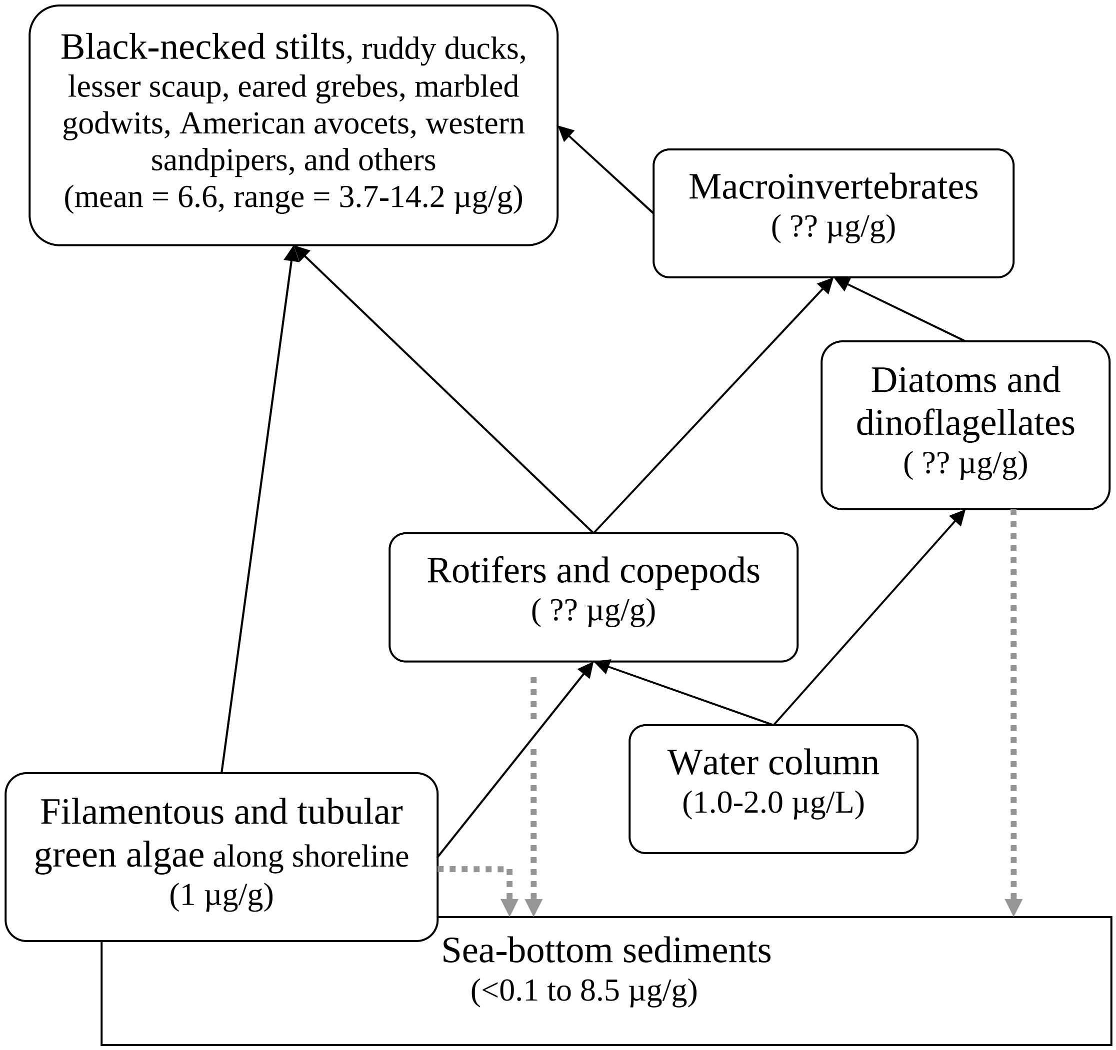

Figure 5.—Selenium in the Salton Sea's water column and/or sediments can be bioaccumulated as it moves through the aquatic food chain to invertebrate-eating birds. Selenium concentrations in parentheses have been reported by Setmire *et al*. (1993), for the organisms in bold, with stilt egg selenium concentration from Bennett (1998). About 13 percent of stilt nests were affected by hatching failure attributed to selenium food-chain bioaccumulation.

on the exposed Sea sediments would potentially combine an abundant selenium source (sediments) with aerobic conditions (shallow water) to support aquatic plants and potentially create an additional selenium pathway to aquatic birds.

The existing selenium in sediments would likely be a difficult issue to deal with regardless of the restoration approaches taken. Our best model of dealing with selenium contamination remains Kesterson Reservoir. Beginning in 1978, subsurface drainwater began flowing into Kesterson Reservoir from irrigated fields in the San Joaquin Valley. In 1983, the first signs of selenium bioaccumulation were detected and the reservoir was closed and filled beginning in 1985 (Presser and Piper 1998). Between 1981 and 1985, an estimated ~11 tons of selenium were input into the reservoir, with an estimated ~ 2.6 tons retained within the sediments. Ephemeral ponds created by winter rains in post-closing/fill soils are monitored, and have contained up to 1,600 µg/L of selenium. In 1996, aquatic invertebrates contained up to 60 µg/g selenium, some of the highest values for selenium recorded since original sampling of Kesterson began (Presser and Piper 1998). Although only one example, this example indicates selenium in Salton Sea sediments, and the potential for bioaccumulation in food chains, are issues that will likely be with us for some time.

Various forms of constructed wetlands are proposed for various alternatives. Wetlands range from sediment removal basins to habitat ponds to outer pools around marine lakes. Freshwater constructed wetlands would function similar to rivers and drains (flow-through systems), or terminal basins in the area. Wetlands that receive untreated water would experience increasing selenium concentrations. For example, Gao et al. (2003) evaluated selenium movement in a flow-through experimental constructed wetland receiving drainwater from the San Joaquin Valley. Most selenium in water was removed with plants playing an important role, and sediments functioning as a sink. Under such conditions, it is reasonable to assume that selenium concentrations in all food-chain biota would increase including fish-eating birds and invertebrate–eating birds. Selenium levels in various members of these feeding guilds are currently at the level of concern, and higher.

Alternative Assessment: Results

The current suite of nine restoration alternatives is evaluated below. To reduce redundancy, the discussion makes frequent reference to material presented in the previous sections. Each alternative component (e.g., sediment basins) that would potentially provide habitat to fish-eating and/or invertebrate-eating birds, is discussed and then evaluated in terms of increased risk of bioaccumulation of selenium in food chains. A summary table addressing each component and the overall risk rating is presented for each alternative.

Alternative components are presented as they would be supplied by water from the Alamo, New, and/or Whitewater Rivers. The tributary rivers and drains are not directly evaluated for selenium risk. However, as discussed previously, selenium concentrations in the rivers and drains are assumed to increase as dilution water from irrigation operations declines. It is reasonable to assume that sediment concentrations in rivers and drains would also increase as water concentrations increase. In addition, it is reasonable to assume that selenium concentrations in all food chain biota would increase, including fish-eating and invertebrate-eating birds.

Alternative 1A—Mid-Sea Dam with North Marine Lake

A detailed description of this alternative can be found in the most recent Phase 1 Value Planning Report and similar documents.

Sediment Basins

Sediment basins in this alternative would receive all sediments, selenium, and other water constituents carried by the Alamo and New Rivers. There is no sediment basin planned for the Whitewater River under this alternative. The basins would quickly become highly eutrophic from salts and nutrients carried by river water. They would also support the same phytoplankton, algae, benthic invertebrates, and other biota present in the Alamo and New Rivers. It is assumed that these sediment basins would—to some degree—function as constructed wetlands.

Water selenium levels would increase from their current concentrations of 8 µg/L in the Alamo River and 4 µg/L in the New River. As explained previously, the magnitude of increase is dependent on the magnitude of reduction of dilution water in irrigation operations, and the resulting reduction in drainwater entering the Salton Sea. As selenium concentrations increase in drainwater, and the basins function as constructed wetlands, selenium concentrations would also increase in sediments.

Selenium would bioaccumulate in food chains via pathways currently present in the rivers. Algae and phytoplankton will serve to move selenium from the water column to higher trophic levels, and benthic invertebrates will serve a similar function in sediments. Both fish-eating and invertebrate-eating birds will likely be affected by both pathways. As the south brine pool component of this alternative recedes, and the Salton Sea National Refuge dewaters, sediment basins (and the residual pools discussed below) would likely receive increased use by aquatic birds seeking alternative feeding sites.

The combination of higher selenium levels and increased use would result in this alternative component becoming a significant risk to local wildlife. As drainwater inflows decrease, selenium concentrations would likely reach and exceed 10µg/L, and could reach subsurface drain levels which currently support a median concentration of 28 µg/L. Skorupa (1998) calculated that black-necked stilts—a species generally considered moderately sensitive to selenium—needed a water selenium concentration of 4 µg/L to produce eggs, with concentrations of 6 µg/L and above, exhibiting reduced egg viability. Ducks, which would also use these areas, are considered more sensitive to selenium.

Any type of constructed wetland using untreated river water would likely develop into a significant selenium hazard (i.e., high hazard risk level) to fish-eating and invertebrate eating aquatic birds.

Diversion/Conveyance Canal

This alternative includes diversion structures and a conveyance canal designed to intercept and carry the entire flows of the Alamo and New Rivers north to the north marine lake. The canal would be routed around the southwest corner of the present sea shore and then north along the west side of the Sea. Diversion would likely occur upstream from the current outlets of both rivers thus dewatering delta habitats currently used for feeding, loafing, and roosting.

The canal would be concrete lined and carry sufficient flow to prevent sediment deposition. The selenium concentration in canal water upstream of sediment basins would be the same as carried in the Alamo River. The risk of bioaccumulation to fish-eating birds in this canal reach would be high, but low for invertebrate-eating birds because of the perceived lack of sediment deposition (concrete lining) and flow rate.

The selenium concentration in canal water downstream of the sediment basins is unknown, but would likely be less than the concentrations entering the basins. As discussed above, the sediment basins would function as constructed wetlands and facilitate the bioaccumulation of selenium in wetland biota and aquatic birds using the sites. Because of this activity, selenium levels in waters leaving the sediment basins should be lower than levels entering them. Regardless of selenium levels in canal water downstream from the sediment basins, the lack of sediment deposition and flow rates in this canal reach indicate that the risk of selenium bioaccumulation is low for invertebrate-eating birds. However, the risk to fish-eating birds would be high.

At present (August 2005), it is unknown how the conveyance canal would affect designated desert pupfish critical habitat in San Felipe Creek and pupfish using drains along the assumed canal route. It is assumed that drainwater would be conveyed beneath the canal via siphons. However, the fate of drainwater beyond the siphons is unknown. . If for some reason, drains discharge directly into the canal, then their sediment, nutrient, and selenium loads would be added to canal water. If drain flows are somehow routed to the south brine basin, then their water may serve to create and/or augment residual pools forming in the receding Sea floor. These uncertainties need to be addressed.

Exposed Sea Bed w/Residual Pools

Ephemeral and/or semi-permanent pools would likely form in the exposed sediments of the Sea floor as it recedes**.** Residual pools may receive periodic or sustained water supply from limited local precipitation, seeps, and/or discharge from drains that have historically emptied directly into the Sea. Dust control efforts may also contribute water to such sites. Depending upon where they form, how long they persist, and the level of evapo-concentration that occurs, residual pools could support very high selenium concentrations.

Wetting and drying cycles can be important factors contributing to selenium mobilization and potential toxicity (SSERP 2005b). Selenium in dry exposed sediments would likely be in reduced forms and biologically unavailable. The addition of water to such sediments would favor oxidation and make selenium available to biota.

As the Sea recedes, aquatic birds would shift feeding activities to any available wetland type that provides food. The more food, the more concentrated the feeding activity. Although the area coverage of residual pools may be small when compared to other features, there is the potential for such sites to produce highly toxic situations (i.e., high hazard risk level) for invertebrate-eating aquatic birds.

North Marine Lake

The north marine lake would occupy about 40 percent of the area currently covered by the Sea, and receive all future inflow from the Alamo, New, and Whitewater Rivers. There may be some reduction in selenium levels as water passes through sediment basins proposed for the Alamo and New Rivers, but no sediment basin is planned for the Whitewater River under this alternative. Some bottom sediment sample sites in this area have produced the highest selenium levels recorded from sediments (Setmire pers. comm.).

Assumptions addressing future marine lakes have been previously identified. For the purposes of analysis, it is assumed that primary producers would continue to remove selenium from the water column to a level of 1-2 µg/L, or somewhat higher until salinity levels reach a level that disrupts and/or reduces the current assemblage of micro-organisms (including bacteria). The decline of the current assemblage of primary producers would likely result in an increase in selenium concentrations.

This disruption, and increased selenium levels in the water column, would likely continue until salinity levels stabilize at a lower level.

Although these conditions appear similar to current conditions in the Salton Sea, the uptake and bioaccumulation of selenium by primary producers would likely increase in the future as selenium concentrations increase in incoming drainwater. In addition, as speculated above, increasing salinity levels may act to reduce current primary producers at some time in the future, and result in increased selenium in the water column. These projected conditions would translate into a high risk level of increased selenium bioaccumulation for aquatic birds. The high risk level for selenium bioaccumulation would continue until salinity levels stabilize and conditions resemble a marine lake. Once stabilized, selenium risk levels would likely return to a moderate level.

South Brine Basin

The south brine basin would rapidly increase in salinity concentration. Biota currently occupying Sea water would disappear as salinity increases and be replaced by a low diversity, but potentially high biomass community of brine shrimp, brine fly larva, and a few other salt-tolerant species.

Invertebrate-eating aquatic birds would feed on biota within the brine basin. Selenium would bioaccumulate in these shorten food chains. As the south brine pool recedes, and the Salton Sea National Refuge dewaters, any water supporting potential food would likely receive increased use by aquatic birds seeking alternative feeding sites.

The combination of higher selenium levels and increased use would result in this alternative component becoming a significant risk to local wildlife and is therefore assigned a high hazard risk level for invertebrate-feeding birds. .

Selenium Risk

The risk of increased bioaccumulation to area aquatic birds from components associated with Alternative 1A is estimated in Table 2.

Alternative 2A—Mid-Sea Dam with South Marine Lake

A detailed description of this alternative can be found in the most recent Phase 1 Value Planning Report and similar documents.

Table 2.—Estimate of aquatic bird risk from increased selenium bioaccumulation in component-supported food chains under Alternative 1A. Overall risk rating based on components' size, and water and sediment estimated selenium concentrations.

Alternative 1A Component:	Acres	Water Concentration (ppb)	Sediment Concentration (ppm)	Aquatic Bird Risk Level	
				Fish-Eating	Invertebrate-Eating
Sediment Basins	10	4-10+	2.5-4	High Hazard	High Hazard
Conveyance Canal	85	4-10+	NA	High	Low
Residual Pools[1]	630	> 10	> 4	NA	High Hazard
North Marine Lake	94,000	2-5	> 4	High-Moderate	High-Moderate
South Brine Basin	75,000	> 5	> 4	NA	High Hazard
Overall Risk Rating[2]				High-Moderate	High Hazard

[1] Residual pool area estimated at 1 percent of exposed sea bed estimate from Table 9, Phase 1, Value Planning Study.
[2] Overall risk determined from a qualitative consideration of feature area, selenium concentration, and potential availability.

Sediment Basins

This alternative differs from the previous one in that the marine lake is located at the south end of the present Sea. A sediment basin would receive all sediments, selenium, and other water constituents carried by the Whitewater River. There is no sediment basin planned for the Alamo and New Rivers under this alternative. The basin would quickly become highly eutrophic from salts and nutrients carried by river water. The basin would also support the same phytoplankton, algae, benthic invertebrates, and other biota present in the Whitewater River.

Water selenium levels would increase from their current concentrations of 2.5 µg/L in the Whitewater River. As explained previously, the magnitude of increase is dependent on the magnitude of reduction of dilution water in irrigation operations, and the resulting reduction in drainwater entering the Salton Sea. Depending on implemented design, the sediment basin may accumulate a large portion of drainwater selenium in sediments, vegetation, and biota.

Selenium would bioaccumulate in food chains via pathways currently present in the Whitewater River. Algae and phytoplankton would serve to move selenium from the water column to higher trophic levels and benthic invertebrates would serve a similar function in sediments. Both fish-eating and invertebrate-eating birds would likely be affected by both pathways. As the north brine pool component of this alternative recedes, and marshes associated with the river's outlet dewater, the sediment basin (and the residual pools discussed below) would likely receive increased use by aquatic birds seeking alternative feeding sites.

Although the Whitewater River carries relatively (compared to the Alamo and New Rivers) lower selenium concentrations, these concentration levels would increase as dilution water is reduced. The combination of higher selenium levels and increased use would result in this feature becoming a significant risk (i.e., high hazard risk level) to local wildlife.

Diversion/Conveyance Canal

This alternative includes a diversion structure and a conveyance canal designed to intercept and carry the entire flow of the Whitewater River southeast to the south marine lake. The canal would be routed along the northwest shoreline in a southeast direction until it empties into the south marine lake.

The canal would be concrete lined and carry sufficient flow to prevent sediment deposition. The selenium concentration in canal water upstream of sediment basins would be the same as carried in the Whitewater River. Even though selenium concentrations would be higher than current levels, the risk of bioaccumulation to invertebrate-eating aquatic birds in this canal would be low because of the perceived lack of sediment deposition (concrete lining) and flow rate. The risk to fish-eating birds would be high.

Exposed Sea Bed w/Residual Pools

As discussed previously, ephemeral and/or semi-permanent pools would likely form in the exposed sediments of the Sea floor as the Sea recedes**.** Residual pools may receive periodic or sustained water supply from limited local precipitation, seeps, and/or discharge from drains that have historically emptied directly into the Sea. Dust control efforts may also contribute water to such sites. Depending on where they form, how long they persist, and the level of evapo-concentration that occurs, residual pools could support very high selenium concentrations.

As the Sea recedes, aquatic birds would shift feeding activities to any available wetland type that provides food. The more food, the more concentrated the feeding activity. Although the area coverage of residual pools may be small when compared to other features, there is the potential for such sites to produce highly toxic situations (i.e., high hazard risk level) for invertebrate-eating aquatic birds.

South Marine Lake

The south marine lake would occupy a smaller portion of the area currently covered by the Sea, and receive all future inflow from the Alamo and New Rivers. There are no sediment basins planned for the Alamo and New Rivers under this alternative.

Assumptions addressing future marine lakes have been previously identified, and would hold for this component. It is assumed that primary producers would continue to remove selenium from the water column to a level of 1-2 µg/L, or somewhat higher until salinity levels reach a level that disrupts and/or reduces the current assemblage of micro-organisms (including bacteria). The decline of the current assemblage of primary producers would likely result in an increase in selenium concentrations. This disruption, and increased selenium levels in the water column, would likely continue until salinity levels stabilize at a lower level.

Although these conditions appear similar to current conditions in the Salton Sea, the uptake and bioaccumulation of selenium by primary producers would likely increase in the future as selenium concentrations increase in incoming drainwater. In addition, as speculated above, increasing salinity levels may act to reduce current primary producers at some time in the future, and result in increased selenium in the water column. These projected conditions would translate into a high risk level of increased selenium bioaccumulation for aquatic birds. The high risk level for selenium bioaccumulation would continue until salinity levels stabilize and conditions resemble a marine lake. Once stabilized, selenium risk levels would likely return to a moderate level.

North Brine Basin

The north brine basin would rapidly increase in salinity concentration. Biota currently occupying Sea water would disappear and be replaced by a low diversity, but potentially high biomass community of brine shrimp, brine fly larva, and a few other salt-tolerant species.

Sediments within the north basin of the current Sea support some of the highest selenium concentrations recorded for the Sea.

Invertebrate-eating aquatic birds would feed on biota within the brine basin. Selenium would bioaccumulate in these shorten food chains. As the north brine basin recedes, any water supporting potential food would likely receive increased use by aquatic birds seeking alternative feeding sites.

Selenium Risk

The risk of increased bioaccumulation to area aquatic birds from features associated with Alternative 2A are estimated in Table 3.

Table 3.—Estimate of aquatic bird risk from increased selenium bioaccumulation in feature-supported food chains under Alternative 2A. Overall risk rating based on components' size, and water and sediment estimated selenium concentrations.

Alternative 2A Components:	Acres	Water Concentration (ppb)	Sediment Concentration (ppm)	Aquatic Bird Risk Level	
				Fish-Eating	Invertebrate-Eating
Sediment Basins	4	4-10+	2.5-4	High Hazard	High Hazard
Conveyance Canal	100	4-10+	NA	High	Low
Residual Pools[1]	480	> 10	> 4	NA	High Hazard
South Marine Lake	110,000	2-5	> 4	High-Moderate	High-Moderate
North Brine Basin	74,000	> 5	> 4	NA	High Hazard
Overall Risk Rating[2]				High-Moderate	High Hazard

[1] Residual pool area estimated at 1 percent of exposed sea bed estimate from Table 9, Phase 1, Value Planning Study.
[2] Overall risk determined from a qualitative consideration of feature area, selenium concentration, and potential availability.

Alternative 3A—Concentric Ring Dikes with Reservoirs

A detailed description of this alternative can be found in the most recent Phase 1 Value Planning Report and similar documents.

Outer Brackish Lake

Under this alternative, an outer brackish-ring lake would encircle the outer edge of what constitutes the current Sea. The lake would be held in place by an interior dike that would impound water at a maximum depth of about 15 feet. This outer-ring lake would receive all sediments, selenium, and other water constituents carried by the Alamo, New, and Whitewater Rivers, plus all drains that now empty directly into the Sea. No sediment basins are planned for this alternative.

Several factors would cause water selenium levels to be elevated in this shallow eutrophic lake. First, as discussed previously, selenium concentrations in drainwater will increase as drainwater inflows decrease. Selenium concentrations will reach and exceed 10 µg/L, and could reach subsurface drain levels which currently support a median concentration of 28 µg/L. In addition, evaporation would further concentrate selenium levels in shallow basins. Second, the Alamo river delta currently serves as a mixing zone where incoming selenium concentrations are diluted and reduced. This area would be reduced in size and function with the new outer ring lake. As water levels in the outer lake fluctuate with changes in inflows, sediments would be first dried and then rewetted. Alternating wetting and drying would favor oxidizing conditions and make selenium in sediments more available. Finally, because of the shallow depth and reduced salinity of the outer ring lake, mixing may be an important factor in the re-suspension of selenium from sediments, and an increase in aerobic conditions.

Selenium would bioaccumulate in food chains via pathways currently present in the Sea. Algae and phytoplankton would serve to move selenium from the water column to higher trophic levels and benthic invertebrates would provide a similar function in sediments.

Both fish-eating and invertebrate-eating birds would likely be affected by both pathways.

Some stratification for short periods may occur. However, if stratification is less extensive, then oxidation may play an important role in selenium cycling. Fish may accumulate selenium levels higher than currently observed. As the water level in the outer lake fluctuates with changes in inflow, the Salton Sea National Refuge would experience various degrees of dewatering, and the outer brackish lake would likely receive increased use by aquatic birds seeking alternative feeding sites. The combination of higher selenium levels and increased use would result in this feature becoming a significant risk (i.e., high hazard risk level) to local wildlife.

The risk to area wildlife includes the endangered desert pupfish which currently uses wastewater drains that empty directly into the Salton Sea. Pupfish may use the Sea to move between drains (Sutton 2000, 2002). Under this alternative, they would use the outer ring lake for movement purposes. Such use may expose pupfish to higher selenium concentrations than currently experienced in drain habitat, and/or increased predation from a re-established fishery.

Inner Marine Lake

An inner marine-ring lake would be constructed within the outer brackish-ring lake as part of this alternative. Construction and depth would be similar to the outer ring lake. The lake would be held in place by an interior dike that would impound water at a maximum depth of about 15 feet. This inner ring lake would receive water as dike overflow from the outer brackish lake.

Most of the factors resulting in higher selenium levels for the outer ring lake would also apply to the inner lake. In addition, sediments deeper in the current Sea generally support higher selenium levels. The major difference between the two lakes appears to be their source water. The inner ring lake would receive water with selenium levels representative of the outer ring.

The pathway from water to algae to aquatic invertebrates to invertebrate eating birds would still be present, but with reduced risk to some birds because of limited shallow water suitable for foraging. Shallow-water waders such as black-necked stilts, avocets, and other shorebirds would find deep water unsuitable for foraging. However, other birds such as dabbling and diving ducks (e.g, northern shovelers and ruddy ducks) would likely forage in ring lakes.

If shallow water is limited, the selenium risk to invertebrate-eating wading birds would be reduced in the inner marine lake. However, the combination of higher selenium levels and increased use would still result in this feature becoming a significant risk (i.e., high hazard risk level) to local wildlife.

Central Brine Basin

A centrally located brine basin would occupy what is now the deepest portions of the Sea, inside the proposed inner marine-lake dike. The central brine basin would receive inflow as dike overflow from the inner marine lake. The basin would fluctuate in coverage as inflow fluctuates, alternately exposing sediments to drying and wetting conditions. Such conditions (as discussed below) may increase selenium concentrations. Evaporation would also serve to increase selenium levels.

The central brine basin would rapidly increase in salinity concentration. Biota currently occupying Sea water would disappear and be replaced by a low diversity, but potentially high biomass community of brine shrimp, brine fly larva, and a few other salt-tolerant species. The central brine basin would likely acquire characteristics similar to a very large evaporation pond. Invertebrate-eating aquatic birds would feed on biota within the brine basin. Selenium would bioaccumulate in these shorten food chains, and this feature would present a significant risk (i.e., high hazard risk level) to area wildlife.

Exposed Sea Bed with Residual Pools

As discussed previously, ephemeral and/or semi-permanent pools would likely form in the exposed sediments of the Sea floor as the Sea recedes. Residual pools may receive periodic or sustained water supply from limited local precipitation, seeps, and/or discharge from drains that have historically emptied directly into the Sea. Dust control efforts may also contribute water to such sites. Depending on where they form, how long they persist, and the level of evapo-concentration that occurs, residual pools could support very high selenium concentrations.

As the Sea recedes, aquatic birds would shift feeding activities to any available wetland type that provides food. The more food, the more concentrated the feeding activity. Although the area coverage of residual pools may be small when compared to other features, there is the potential for such sites to produce highly toxic situations (i.e., high hazard risk level) for invertebrate-eating aquatic birds.

Selenium Risk

The risk of increased bioaccumulation to area aquatic birds from features associated with Alternative 3A are estimated in Table 4.

Table 4.—Estimate of aquatic bird risk from increased selenium bioaccumulation in component-supported food chains under Alternative 3A. Overall risk rating based on components' size, and water and sediment estimated selenium concentrations.

Alternative 3A Components:	Acres	Water Concentration (ppb)	Sediment Concentration (ppm)	Aquatic Bird Risk Level	
				Fish-Eating	Invertebrate-Eating
Residual Pools[1]	390	> 10	> 4	NA	High Hazard
Outer Brackish Lake	41,000	> 5	> 4	High Hazard	High Hazard
Inner Marine Lake	40,000	2-5	> 4	High Hazard	High Hazard
Central Brine Basin	112,000	> 5	>4	NA	High Hazard
Overall Risk Rating[2]				High Hazard	High Hazard

[1] Residual pool area estimated at 1 percent of exposed sea bed estimate from Table 9, Phase 1, Value Planning Study.
[2] Overall risk determined from a qualitative consideration of feature area, selenium concentration, and potential availability.

Alternative 4A—Revised Salton Sea Authority Design

A detailed description of this alternative can be found in the most recent Phase 1 Value Planning Report and similar documents.

Outer Pool

Under this alternative, an outer pool would encircle the outer edge of what constitutes the current Sea from just east of the outlet of the Alamo River, southwest around the southwestern corner of the current Sea, and then northeast along the western shore to join a north marine lake. The pool would be held in place by an interior dike. This outer pool would receive all sediments, selenium, and other water constituents carried by the Alamo and New Rivers, plus all drains that now empty directly into the Sea. The Whitewater River would empty directly into the north marine lake. No sediment basins are planned for this alternative. This outer pool differs from a previous proposal for an outer ring lake in that it is not only smaller, but would contain circulated water. A pumping plant east of the Alamo River outlet would move water from a north lake canal into the outer pool, providing some measure of circulation.

Several factors would cause water selenium levels to be elevated in this shallow eutrophic lake. First, as discussed previously, selenium concentrations in drainwater would increase as drainwater inflows decrease. Setmire (pers. comm.) estimates that a 20 percent reduction in dilution water would result in selenium concentrations of 10 µg/L in the Alamo River and 7 µg/L in the New River. Mixing river water with circulating pool water (at 1-2 µg/L) from the north marine lake component of this alternative would yield pool water selenium concentrations of about 5-6 µg/L. These values would likely increase as dilution water is reduced further. Second, the circulating pool would not stratify, thus permitting benthic invertebrates to occupy suitable sediments. Selenium in sediments would not be sequestered, but would circulate within the system's biota. Finally, because of the shallow depth and reduced salinity of the outer pool, mixing may be an important factor in the re-suspension of selenium from sediments.

Selenium would bioaccumulate in food chains via pathways currently present in the Sea. Algae and phytoplankton would serve to move selenium from the water column to higher trophic levels and benthic invertebrates would function similarly in sediments. Because of higher water column selenium concentration, fish may accumulate selenium levels higher than currently observed. Both fish-eating and invertebrate-eating birds would likely be affected by both pathways. This component is therefore rated at the high hazard risk level for bioaccumulation of selenium in local food chains, and the aquatic birds that depend on them.

The risk to area wildlife includes the endangered desert pupfish which currently uses wastewater drains that empty directly into the Salton Sea. Pupfish may use the Sea to move between drains (Sutton 2000, 2002). Under this alternative, pupfish would use the outer pool for movement purposes. Such use may expose pupfish to higher selenium concentrations than currently experienced in drain habitat, and increased risk from predation from re-establishment of a fishery.

North Marine Lake

The north marine lake would occupy a smaller portion of the area currently covered by the Sea, and receive all future inflow from the Alamo and New Rivers. There are no sediment basins planned for the Alamo and New Rivers under this alternative.

Assumptions addressing future marine lakes have been previously identified, and would hold for this component. It is assumed that primary producers would continue to remove selenium from the water column to a level of 1-2 µg/L, or somewhat higher until salinity levels reach a level that disrupts and/or reduces the current assemblage of micro-organisms (including bacteria). The decline of the current assemblage of primary producers would likely result in an increase in selenium concentrations. This disruption, and increased selenium levels in the water column, would likely continue until salinity levels stabilize at a lower level.

Although these conditions appear similar to current conditions in the Salton Sea, the uptake and bioaccumulation of selenium by primary producers would likely increase in the future as selenium concentrations increase in incoming drainwater. In addition, as speculated above, increasing salinity levels may act to reduce current primary producers at some time in the future, and result in increased selenium in the water column. These projected conditions would translate into a high risk level of increased selenium bioaccumulation for aquatic birds. The high risk level for selenium bioaccumulation would continue until salinity levels stabilize and conditions resemble a marine lake. Once stabilized, selenium risk levels would likely return to a moderate level.

Conveyance Canal

This alternative includes a conveyance canal designed to intercept and carry north marine lake water to a pumping plant where it would be introduced into the outer pool. The canal would be routed around the southeast side the present sea shore to the previously described pumping plant. The canal would be concrete lined and carry sufficient flow to prevent sediment deposition. The selenium concentration in canal water is assumed to be similar to north marine lake water which the canal would carry, or about 1-2 µg/L, or perhaps slightly higher (but see above discussion of increased concentrations).

The perceived risk to invertebrate-eating aquatic birds using canal water is low because of low water born selenium concentrations, the perceived lack of sediment deposition (concrete lining), and flow rate. Fish in the canal would pose a high level of risk for fish-eating birds.

South Brine Basin

The south brine basin would rapidly increase in salinity concentration. At some point, biota currently occupying Sea water would disappear and be replaced by a low diversity but potentially high biomass community of brine shrimp, brine fly larva, and a few other salt-tolerant species.

Invertebrate-eating aquatic birds would feed on biota within the brine basin. Selenium would bioaccumulate in these shortened food chains. As the south brine pool recedes, and the Salton Sea National Refuge dewaters, any water supporting potential food would likely receive increased use by aquatic birds seeking alternative feeding sites.

The combination of higher selenium levels and increased use would result in this feature becoming a significant risk to local wildlife and is therefore assigned a high hazard risk level for invertebrate-feeding birds.

Exposed Sea Bed with Residual Pools

Ephemeral and/or semi-permanent pools would likely form in the exposed sediments of the Sea floor. Residual pools may receive periodic or sustained water supply from limited local precipitation or seeps from the outer pool dike. Dust control efforts may also contribute water to such sites. Depending on where they form, how long they persist, and the level of evapo-concentration that occurs, residual pools could support very high selenium concentrations.

As the Sea evolves or restoration alternatives are implemented, aquatic birds would shift feeding activities to any available wetland type that provides food. The more food, the more concentrated the feeding activity. Although the area coverage of residual pools may be small, there is the potential for such sites to produce highly toxic situations (i.e., high hazard risk level) for invertebrate-eating aquatic birds.

Selenium Risk

The risk of increased bioaccumulation to area aquatic birds from features associated with Alternative 4A is estimated in Table 5.

Table 5.—Estimate of aquatic bird risk from increased selenium bioaccumulation in component-supported food chains under Alternative 4A. Overall risk rating based on components' size, and water and sediment estimated selenium concentrations.

Alternative 4A Components:	Acres	Water Concentration (ppb)	Sediment Concentration (ppm)	Aquatic Bird Risk Level	
				Fish-Eating	Invertebrate-Eating
Outer Pool	26,000	> 5	> 4	High Hazard	High Hazard
North Marine Lake	94,000	2-5	> 4	High-Moderate	High-Moderate
Conveyance Canal	18	2-5	NA	High	Low
South Brine Basin	68,000	> 5	> 4	NA	High Hazard
Residual Pools[1]	440	> 10	> 4	NA	High Hazard
Overall Risk Rating[2]				High Hazard	High Hazard

[1] Residual pool area estimated at 1 percent of exposed sea bed estimate from Table 9, Phase 1, Value Planning Study.
[2] Overall risk determined from a qualitative consideration of feature area, selenium concentration, and potential availability.

Alternative 5A—Mid-Sea Barrier with North Marine Lake

A detailed description of this alternative can be found in the most recent Phase 1 Value Planning Report and similar documents.

Sediment Basins

Sediment basins would receive all sediments, selenium, and other water constituents carried by the Alamo and New Rivers under this alternative. There is no sediment basin planned for the Whitewater River. The basins would quickly become highly eutrophic from salts and nutrients carried by river water. They would also support the same phytoplankton, algae, benthic invertebrates, and other biota present in the Alamo and New Rivers.

The sediment basins in this alternative would likely be identical to the sediment basins in Alternative 1A. The reader is referred to that discussion for details. The combination of higher selenium levels and increased bird use would result in this component becoming a significant risk (i.e., high hazard risk level) to local wildlife.

Diversion/Conveyance Canal

This alternative includes diversion structures and a conveyance canal designed to intercept and carry the entire flows of the Alamo and New Rivers north to the north marine lake. The canal would be routed around the southwest corner of the present sea shore and then north along the west side of the Sea. Diversion would likely occur upstream from the current outlets of both rivers thus dewatering delta habitats currently used for feeding, loafing, and roosting.

The conveyance canal in this alternative would likely be identical to the canal in Alternative 1A. The reader is referred to that discussion for details. As described under Alternative 1A, this component would pose a low risk level for invertebrate eating birds, but a high risk level for fish-eating birds.

At present (August 2005), it is unknown how the conveyance canal would affect designated desert pupfish critical habitat in San Felipe Creek and pupfish using drains along the assumed canal route. It is assumed that drains would be routed under the canal via siphons, and their water would discharge into the north marine lake—a component in this alternative—or the south brine basin. If drain flows are routed to the marine lake and brine basin, this water may serve to create and/or augment residual pools forming in the receding Sea floor.

North Marine Lake

This alternative is very similar to Alternative 1A, except that a permeable barrier, rather than an impermeable dam, would be used to separate a north marine lake from a south brine basin. It is assumed that the two impoundments would be similar in size. This means that the north marine lake would be shallower than previously discussed marine lakes. The north marine lake would receive all future inflow from the Alamo, New, and Whitewater Rivers, plus drainwater from drains that currently empty directly into the Salton Sea.

Assumptions addressing future marine lakes have been previously identified. For the purposes of analysis, it is assumed that primary producers would continue to remove selenium from the water column to a level of 1-2 µg/L, or somewhat higher until salinity levels reach a level that disrupts and/or reduces the current assemblage of micro-organisms (including bacteria). The decline of the current assemblage of primary producers would likely result in an increase in selenium concentrations.

This disruption, and increased selenium levels in the water column, would likely continue until salinity levels stabilize at a lower level.

Although these conditions appear similar to current conditions in the Salton Sea, the uptake and bioaccumulation of selenium by primary producers would likely increase in the future as selenium concentrations increase in incoming drainwater. In addition, as speculated above, increasing salinity levels may act to reduce current primary producers at some time in the future, and result in increased selenium in the water column. These projected conditions would translate into a high risk level of increased selenium bioaccumulation for aquatic birds. The high risk level for selenium bioaccumulation would continue until salinity levels stabilize and conditions resemble a marine lake. Once stabilized, selenium risk levels would likely return to a moderate level.

South Brine Basin

The south brine basin would rapidly increase in salinity concentration. Biota currently occupying Sea water would disappear and be replaced by a low diversity, but potentially high biomass community of brine shrimp, brine fly larva, and a few other salt-tolerant species.

As salt and selenium concentrations increase over time, it is assumed that the brine basin would assume characteristics, and risks, similar to large evaporation ponds operated in the San Joaquin Valley. Invertebrate-eating aquatic birds would feed on biota within the brine basin. Selenium would bioaccumulate in these shortened food chains. As the south brine pool recedes, and the Salton Sea

National Refuge dewaters, any water supporting potential food would likely receive increased use by aquatic birds seeking alternative feeding sites.

The combination of high selenium levels and increased use by invertebrate-feeding birds renders this feature a high hazard risk for invertebrate-eating birds.

Exposed Sea Bed with Residual Pools

Ephemeral and/or semi-permanent pools would likely form in the exposed sediments of the Sea floor as the Sea recedes**.** Residual pools may receive periodic or sustained water supply from limited local precipitation, seeps, and/or discharge from drains that have historically emptied directly into the Sea. Dust control efforts may also contribute water to such sites. Depending on where they form, how long they persist, and the level of evapo-concentration that occurs, residual pools could support very high selenium concentrations.

As the Sea recedes, aquatic birds would shift feeding activities to any available wetland type that provides food. The more food, the more concentrated the feeding activity. Although the area coverage of residual pools may be small when compared to other features, there is the potential for such sites to produce highly toxic situations for aquatic birds. Because of the potentially high levels of selenium that may occur in these features, and the potential for concentrated feeding, this feature is rated as a high hazard selenium risk level.

Selenium Risk

The risks of increased bioaccumulation to area aquatic birds from features associated with Alternative 5A are estimated in Table 6.

Alternative 6A—Mid-Sea Barrier with South Marine Lake

A detailed description of this alternative can be found in the most recent Phase 1 Value Planning Report and similar documents.

Sediment Basin

A sediment basin would receive all sediments, selenium, and other water constituents carried by the New River. There is no sediment basin planned for the Alamo and Whitewater Rivers under this alternative. The basin would quickly become highly eutrophic from salts and nutrients carried by river water. The basin would also support the same phytoplankton, algae, benthic invertebrates,

Table 6.—Estimate of aquatic bird risk from increased selenium bioaccumulation in component-supported food chains under Alternative 5A. Overall risk rating based on components' size, and water and sediment estimated selenium concentrations.

Alternative 5A Components:	Acres	Water Concentration (ppb)	Sediment Concentration (ppm)	Aquatic Bird Risk Level	
				Fish-Eating	Invertebrate-Eating
Sediment Basins	10	4-10+	1-2.5	High Hazard	High Hazard
Conveyance Canal	85	4-10+	NA	High	Low
Residual Pools[1]	680	> 10	> 4	NA	High Hazard
North Marine Lake	83,000	2-5	> 4	High-Moderate	High-Moderate
South Brine Basin	81,000	> 5	> 4	NA	High Hazard
Overall Risk Rating[2]				High-Moderate	High Hazard

[1] Residual pool area estimated at 1 percent of exposed sea bed estimate from Table 9, Phase 1, Value Planning Study.
[2] Overall risk determined from a qualitative consideration of feature area, selenium concentration, and potential availability.

and other biota present in the New River. As with other sediment basins discussed previously, it is assumed that this feature would function as a constructed wetland.

The sediment basins in this alternative would likely be identical to the sediment basins in Alternative 2A. The reader is referred to that discussion for details. The combination of higher selenium levels and increased bird use would result in this component becoming a significant risk (i.e., high hazard risk level) to local wildlife.

Diversion/Conveyance Canal

This alternative includes a diversion structure and a conveyance canal designed to intercept and carry the entire flow of the New River northwest to the north brine basin. The canal would be routed along the southwest shoreline in a northwest direction until it empties into the north brine basin.

The conveyance canal in this alternative would likely be identical to the canal in Alternative 1A. The reader is referred to that discussion for details. As described under Alternative 1A, this component would pose a low risk level for invertebrate eating birds, but a high risk level for fish-eating birds.

The concerns expressed for pupfish and pupfish critical habitat in San Felipe Creek under Alternative 2A also apply here.

Exposed Sea Bed with Residual Pools

Ephemeral and/or semi-permanent pools will likely form in the exposed sediments of the Sea floor as the Sea recedes. Residual pools may receive periodic or sustained water supply from limited local precipitation, seeps, and/or discharge from drains that have historically emptied directly into the Sea. Dust control efforts may also contribute water to such sites. Depending on where they form, how long they persist, and the level of evapo-concentration that occurs, residual pools could support very high selenium concentrations.

As the Sea recedes, aquatic birds would shift feeding activities to any available wetland type that provides food. The more food, the more concentrated the feeding activity. Although the area coverage of residual pools may be small when compared to other features, there is the potential for such sites to produce highly toxic situations for aquatic birds. Because of the potentially high levels of selenium that may occur in these features, and the potential for concentrated feeding, this feature is rated as a high hazard selenium risk level.

South Marine Lake

The south marine lake would receive all future inflow from the New River, plus drainwater from drains that now empty into the Salton Sea. This alternative is very similar to Alternative 2A, except that a permeable barrier, rather than an impermeable dam, would be used to separate a south marine lake from a north brine basin. It is assumed that the two impoundments would be similar in size. This means that the south marine lake would be shallower than previously discussed marine lakes. The south marine lake would receive all future inflow from the Alamo River, plus drainwater from drains that currently empty directly into the Salton Sea.

Assumptions addressing future marine lakes have been previously identified. For the purposes of analysis, it is assumed that primary producers would continue to remove selenium from the water column to a level of 1-2 µg/L, or somewhat higher until salinity levels reach a level that disrupts and/or reduces the current assemblage of micro-organisms (including bacteria). The decline of the current assemblage of primary producers would likely result in an increase in selenium concentrations.

This disruption, and increased selenium levels in the water column, would likely continue until salinity levels stabilize at a lower level.

Although these conditions appear similar to current conditions in the Salton Sea, the uptake and bioaccumulation of selenium by primary producers would likely increase in the future as selenium concentrations increase in incoming drainwater. In addition, as speculated above, increasing salinity levels may act to reduce current primary producers at some time in the future, and result in increased selenium in the water column. These projected conditions would translate into a high risk level of increased selenium bioaccumulation for aquatic birds. The high risk level for selenium bioaccumulation would continue until salinity levels stabilize and conditions resemble a marine lake. Once stabilized, selenium risk levels would likely return to a moderate level.

North Brine Basin

The north brine basin will receive flows from the New and Whitwater Rivers, plus drainwater that now flows directly into the Salton Sea. The basin would rapidly increase in salinity concentration. Biota currently occupying Sea water would disappear and be replaced by a low diversity, but potentially high biomass community of brine shrimp, brine fly larva, and a few other salt-tolerant species.

Invertebrate-eating aquatic birds would feed on biota within the brine basin. Selenium would bioaccumulate in these shortened food chains. As the north brine basin recedes, any water supporting potential food would likely receive increased use by aquatic birds seeking alternative feeding sites.

The combination of high selenium levels and increased use by invertebrate-feeding birds renders this feature a high hazard risk for foraging birds.

Selenium Risk

The risk of increased bioaccumulation to area aquatic birds from components associated with Alternative 6A are estimated in Table 7.

Table 7.—Estimate of aquatic bird risk from increased selenium bioaccumulation in component-supported food chains under Alternative 6A. Overall risk rating based on components' size, and water and sediment estimated selenium concentrations.

Alternative 6A Components:	Acres	Water Concentration (ppb)	Sediment Concentration (ppm)	Aquatic Bird Risk Level	
				Fish-Eating	Invertebrate-Eating
Sediment Basins	7	4-10+	1-2.5	High Hazard	High Hazard
Conveyance Canal	60	4-10+	NA	High	Low
Residual Pools[1]	670	> 10	> 4	NA	High Hazard
South Marine Lake	89,000	2-5	> 4	High-Moderate	High-Moderate
North Brine Basin	76,000	> 5	> 4	NA	High Hazard
Overall Risk Rating[2]				High-Moderate	High Hazard

[1] Residual pool area estimated at 1 percent of exposed sea bed estimate from Table 9, Phase 1, Value Planning Study.

[2] Overall risk determined from a qualitative consideration of feature area, selenium concentration, and potential availability.

Alternative 7A—Mid-Sea Barrier with South Marine Lake and Habitat Ponds

A detailed description of this alternative can be found in the most recent Phase 1 Value Planning Report and similar documents.

Diversion/Conveyance Canal

This alternative includes a diversion structure and a conveyance canal designed to intercept and carry a portion of flows from the New River through a sediment removal basin and a selenium treatment facility, before delivering the treated water to constructed habitat ponds. The remaining untreated flow from the New River would be transported via canal to a north brine basin. All flow with associated sediments, selenium, and other water constituents from the Alamo River would discharge into the south marine lake. All Whitewater River flows would be treated via sediment basin and selenium treatment facility before entering constructed habitat ponds. Any excess water would drain into the north brine basin.

The conveyance canal in this alternative would likely be similar to the canal in Alternative 1A. The reader is referred to that discussion for details. As described under Alternative 1A, this component would pose a low risk level for invertebrate eating birds, but a high risk level for fish-eating birds.

The concerns expressed for pupfish and pupfish critical habitat in San Felipe Creek under Alternative 1A also apply here.

Sediment Basins

Sediment basins would receive all sediments, selenium, and other water constituents carried by the Whitewater River, and a portion of these components from the New River. There is no sediment basin planned for the Alamo River under this alternative. As discussed previously under other alternatives with similar features, the basins would quickly become highly eutrophic from salts and nutrients carried by river water. The basins would also support the same phytoplankton, algae, benthic invertebrates, and other biota present in the Whitewater and New Rivers. As with other sediment basins discussed previously, it is assumed that these features would function as constructed wetlands.

The sediment basins in this alternative would likely be identical to the sediment basins in Alternative 6A. The reader is referred to that discussion for details. The combination of higher selenium levels and increased bird use would result in this component becoming a significant risk (i.e., high hazard risk level) to local wildlife.

Habitat Ponds

Two habitat pond complexes—one associated with the Whitewater River in the north and one associated with the New River in the south—would be constructed on the exposed sea bed as the Sea recedes. It is assumed that these ponds would be lined with geotextile fabric to prevent the infiltration of selenium and other constituents from the sea bed into the pond. Pond water would be treated in a selenium removal facility before delivery and use.

Management goals for the habitat ponds have not been determined at this time. Such sites, if properly managed, may serve the function of "alternative habitat", similar to alternative habitat associated with some evaporation pond operations in the San Joaquin Valley. In theory at least, such sites can provide food items with low selenium levels that serve to dilute items with higher levels. For the purposes of this analysis, it is assumed that such sites would support food chains that could be used by area fish-eating and invertebrate-eating birds. If water and sediment selenium levels in the constructed habitat ponds can be maintained at < 1 µg/L and < 1µg/g respectively, then these sites would pose little (low level) additional selenium risk to aquatic birds.

Exposed Sea Bed with Residual Pools

Ephemeral and/or semi-permanent pools would likely form in the exposed sediments of the Sea floor as the Sea recedes**.** Residual pools may receive periodic or sustained water supply from limited local precipitation, seeps, and/or discharge from drains that have historically emptied directly into the Sea. Dust control efforts may also contribute water to such sites. Depending on where they form, how long they persist, and the level of evapo-concentration that occurs, residual pools could support very high selenium concentrations.

As the Sea recedes, aquatic birds would shift feeding activities to any available wetland type that provides food. The more food, the more concentrated the feeding activity. Although the area coverage of residual pools may be small when compared to other features, there is the potential for such sites to produce highly toxic situations for aquatic birds. Because of the potentially high levels of selenium that may occur in these features, and the potential for concentrated feeding, this feature is rated as a high hazard selenium risk level for invertebrate-eating birds.

South Marine Lake

The south marine lake would receive all future inflow from the Alamo River, plus drainwater from drains that now empty into the Salton Sea.

Assumptions addressing future marine lakes have been previously identified. For the purposes of analysis, it is assumed that primary producers would continue to remove selenium from the water column to a level of 1-2 µg/L, or somewhat higher until salinity levels reach a level that disrupts and/or reduces the current assemblage of micro-organisms (including bacteria). The decline of the current assemblage of primary producers would likely result in an increase in selenium concentrations.

This disruption, and increased selenium levels in the water column, would likely continue until salinity levels stabilize at a lower level.

Although these conditions appear similar to current conditions in the Salton Sea, the uptake and bioaccumulation of selenium by primary producers would likely increase in the future as selenium concentrations increase in incoming drainwater. In addition, as speculated above, increasing salinity levels may act to reduce current primary producers at some time in the future, and result in increased selenium in the water column. These projected conditions would translate into a high risk level of increased selenium bioaccumulation for aquatic birds. The high risk level for selenium bioaccumulation would continue until salinity levels stabilize and conditions resemble a marine lake. Once stabilized, selenium risk levels would likely return to a moderate level.

North Brine Basin

The north brine basin would receive some flows from the New River, plus drainwater that now flows directly into the Salton Sea. The basin would rapidly increase in salinity concentration. Biota currently occupying Sea water would disappear and be replaced by a low diversity, but potentially high biomass community of brine shrimp, brine fly larva, and a few other salt-tolerant species.

Invertebrate-eating aquatic birds would feed on biota within the brine basin. Selenium would bioaccumulate in these shortened food chains. As the north brine basin recedes, any water supporting potential food would likely receive increased use by aquatic birds seeking alternative feeding sites.

The combination of high selenium levels and increased use by invertebrate-feeding birds renders this feature a high hazard risk for foraging birds.

Selenium Risk

The risk of increased bioaccumulation to area aquatic birds from components associated with Alternative 7A are estimated in Table 8.

Table 8.—Estimate of aquatic bird risk from increased selenium bioaccumulation in component-supported food chains under Alternative 7A. Overall risk rating based on components' size, and water and sediment estimated selenium concentrations.

Alternative 7A Components:	Acres	Water Concentration (ppb)	Sediment Concentration (ppm)	Aquatic Bird Risk Level	
				Fish-Eating	Invertebrate-Eating
Conveyance Canal	70	4-10+	NA	High	Low
Sediment Basins	5	4-10+	1-2.5	High Hazard	High Hazard
Habitat Ponds	260	< 1	< 1	Low	Low
Residual Pools[1]	670	> 10	> 4	NA	High Hazard
South Marine Lake	89,000	1-2	> 4	High-Moderate	High-Moderate
North Brine Basin	76,000	> 5	> 4	NA	High Hazard
Overall Risk Rating[2]				High-Moderate	High Hazard

[1] Residual pool area estimated at 1 percent of exposed sea bed estimate from Table 9, Phase 1, Value Planning Study.
[2] Overall risk determined from a qualitative consideration of feature area, selenium concentration, and potential availability.

Alternative 8A—Evolving Sea with Habitat Ponds

A detailed description of this alternative can be found in the most recent Phase 1 Value Planning Report and similar documents.

Diversion/Conveyance Canal

This alternative includes a diversion structure and a conveyance canal designed to intercept and carry flows from the New River through a sediment removal basin and a selenium treatment facility, before delivering the treated water to constructed habitat ponds. All flow with associated sediments, selenium, and other water constituents from the Alamo River would discharge into receding Salton Sea. All Whitewater River flows would be treated via sediment basin and selenium treatment facility before entering constructed habitat ponds. Any excess water from either constructed habitat operation would be discharged into the receding Salton Sea, or used for dust control.

The conveyance canal in this alternative would likely be similar to canals described for other alternatives, and the reader is referred to those discussions. This component would pose a low risk level for invertebrate eating birds, but a high risk level for fish-eating birds.

Sediment Basins

Sediment basins would receive all sediments, selenium, and other water constituents carried by the New and Whitewater Rivers. There is no sediment basin planned for the Alamo River under this alternative. As discussed previously, under other alternatives with similar features, the basins would quickly become highly eutrophic from salts and nutrients carried by river water. The basins would also support the same phytoplankton, algae, benthic invertebrates, and other biota present in the Whitewater and New Rivers. As with other sediment basins discussed previously, it is assumed that these features would function as constructed wetlands.

Water selenium levels would increase from their current concentrations of 2.5 µg/L in the Whitewater River and 4 µg/L in the New River. As explained previously, the magnitude of increase is dependent on the magnitude of reduction of dilution water in irrigation operations, and the resulting reduction in drainwater entering the Salton Sea. Depending upon implemented design, the sediment basins may accumulate a large portion of drainwater selenium in sediments, vegetation, and biota.

Selenium would bioaccumulate in food chains via pathways currently present in the Whitewater and New River. Algae and phytoplankton would serve to move selenium from the water column to higher trophic levels and benthic invertebrates will serve a similar function in sediments. Both fish-eating and invertebrate-eating birds would likely be affected by both pathways. As the north brine pool and south marine lake recede, and marshes associated with both rivers' outlets dewater, sediment basins (and the residual pools discussed below) would likely receive increased use by aquatic birds seeking alternative feeding sites.

The combination of higher selenium levels and increased use would result in this feature becoming a risk to local wildlife. This feature is assigned a high hazard selenium risk level for both fish-eating and invertebrate-eating birds.

Habitat Ponds

Several habitat complexes—including both shallow and deep-water sites—have been conceptualized for this alternative. The following description follows the ponds proposed for Alternative 7A above. Any habitat ponds constructed planned for the exposed sea bed, but without geotextile fabric linings should be carefully reconsidered. Considerations are discussed below.

Two habitat pond complexes—one associated with the Whitewater River in the north and one associated with the New River in the south—would be constructed on exposed sea bed as the Sea recedes. It is assumed that these ponds would be lined with geotextile fabric to prevent the infiltration of selenium and other constituents from the sea bed into the pond. Pond water would be treated in a selenium removal facility before delivery and use. Management goals for the habitat ponds have not been determined at this time.

For the purposes of this analysis, it is assumed that such sites would support food chains that could be used by area fish-eating and invertebrate-eating birds. If water and sediment selenium levels in the constructed habitat ponds can be maintained at < 1 µg/L and < 1µg/g respectively, then these sites would pose little (low level) additional selenium risk to aquatic birds.

Any plans for habitat ponds that do not include geotextile fabric linings, or deep excavation to "clean" soils, should be seriously considered before implementation. This section has repeatedly highlighted the uncertainties associated with selenium currently sequestered in sea-bed sediments. Before any habitats are constructed, extensive sampling of sediments should be conducted to determine selenium content. Because habitat complexes would be supplied with treated water, created habitats may support different selenium cycling and food-chain pathways than currently exist in the area. Caution should be exercised until such cycles and pathways are understood.

Exposed Sea Bed with Residual Pools

Ephemeral and/or semi-permanent pools would likely form in the exposed sediments of the Sea floor as the Sea recedes**.** Residual pools may receive periodic or sustained water supply from limited local precipitation, seeps, and/or discharge from drains that have historically emptied directly into the Sea. Dust control efforts may also contribute water to such sites. Depending on where they form, how long they persist, and the level of evapo-concentration that occurs, residual pools could support very high selenium concentrations.

As the Sea recedes, aquatic birds would shift feeding activities to any available wetland type that provides food. The more food, the more concentrated the feeding activity. Although the area coverage of residual pools may be small when compared to other features, there is the potential for such sites to produce highly toxic situations for aquatic birds. Because of the potentially high levels of selenium that may occur in these features, and the potential for concentrated feeding, this feature is rated as a high hazard selenium risk level for invertebrate-eating birds.

Central Marine/Brine Basin

The receding Salton Sea would receive all future inflow from the Alamo River, plus drainwater from drains that now empty into the Salton Sea. For the purposes of analysis, it is assumed that primary producers would continue to remove selenium from the water column to a level of 1-2 µg/L, or somewhat higher until salinity levels reach a level that disrupts and/or reduces the current assemblage of micro-organisms (including bacteria). The decline of the current assemblage of primary producers would likely result in an increase in selenium concentrations.

The basin would rapidly increase in salinity concentration. Biota currently occupying Sea water would disappear and be replaced by a low diversity, but potentially high biomass community of brine shrimp, brine fly larva, and a few other salt-tolerant species.

Invertebrate-eating aquatic birds would feed on biota within the brine basin. Selenium would bioaccumulate in these shortened food chains. The risk of selenium bioaccumulation in invertebrate-eating birds would at the high hazard level for this component.

Selenium Risk

The risk of increased bioaccumulation to area aquatic birds from components associated with Alternative 8A is estimated in Table 9.

Table 9.—Estimate of aquatic bird risk from increased selenium bioaccumulation in component-supported food chains under Alternative 8A Overall risk rating based on components' size, and water and sediment estimated selenium concentrations

Alternative 8A Feature:	Acres	Water Concentration (ppb)	Sediment Concentration (ppm)	Aquatic Bird Risk Level	
				Fish-Eating	Invertebrate-Eating
Conveyance Canal	15	4-10+	NA	High	Low
Habitat Ponds	Unknown	< 1	< 1	Low[1]	Low[1]
Residual Pools[2]	700	> 10	> 4	NA	High Hazard
Marine/Brine Basin	162,000	> 5	> 4	NA	High Hazard
Overall Risk Rating[3]				Low	High Hazard

[1] Low risk level assumes geotextile fabric lining for all constructed wetlands designated as "habitat". Construction on sea bed without lining would move risk level to high hazard.

[2] Residual pool area estimated at 1 percent of exposed sea bed estimate from Table 9, Phase 1, Value Planning Study.

[3] Overall risk determined from a qualitative consideration of feature area, selenium concentration, and potential availability.

Alternative 9A—No Salton Sea with Reclaimed Land

A detailed description of this alternative can be found in the most recent Phase 1 Value Planning Report and similar documents.

Exposed Sea Bed with Residual Pools

It is unclear how water would be managed under this alternative. We must assume that that the water used for irrigation would be drainwater from tributary rivers and drains emptying into the Salton Sea. As drainwater declines in volume, the Sea would recede exposing bottom sediments and/or land suitable for growing some type of crop. Drainwater would carry high concentrations of salt and selenium, and only be suitable for irrigating salt-tolerant crops.

These activities would favor the formation of ephemeral and/or semi-permanent pools. Such residual pools may receive periodic or a sustained water supply from these irrigation activities. Other potential water sources include limited local precipitation, seeps, and/or discharge from drains that have historically emptied directly into the Sea. Dust control efforts may also contribute water to such sites. Depending on where they form, how long they persist, and the level of evapo-concentration that occurs, residual pools could support very high selenium concentrations.

Although the area coverage of residual pools may be small when compared to other features, there is the potential for such sites to produce highly toxic situations for aquatic birds. Because of the potentially high levels of selenium that may occur in these features, this feature is rated as a high hazard selenium risk level for invertebrate-eating birds.

Central Marine/Brine Basin

The central brine basin would receive any remaining water from any irrigation activities that may occur on reclaimed Sea-bed land. The waste water from such operations would be highly concentrated in terms of salinity and selenium.

Increased selenium levels in biota inhabiting the brine basin would increase the risk of reproductive impairment to invertebrate-eating birds foraging in this brine basin. The selenium risk level for this feature is therefore defined as high hazard for invertebrate-eating birds.

Selenium Risk

The risk of increased bioaccumulation to area aquatic birds from components associated with Alternative 9A is estimated in Table 10.

No Action

The future of the Sea without restoration actions has been discussed in detail elsewhere in this report, and is only briefly addressed here. It is assumed that salinity levels in the Salton Sea would quickly reach levels that preclude the support of a viable fishery within the Sea. Use of the Sea by fish-eating birds would decline. Some fish-eating birds would continue to use the rivers and drains

Table 10.—Estimate of aquatic bird risk from increased selenium bioaccumulation in component-supported food chains under Alternative 9A. Overall risk rating based on components' size, and water and sediment estimated selenium concentrations.

Alternative 9A Components:	Acres	Water Concentration (ppb)	Sediment Concentration (ppm)	Aquatic Bird Risk Level	
				Fish-Eating	Invertebrate-Eating
Residual Pools[1]	820	> 10	> 4	NA	High Hazard
Marine/Brine Basin	50,000	> 5	> 4	NA	High Hazard
Overall Risk Rating[2]				Low	High Hazard

[1] Residual pool area estimated at 1 percent of exposed sea bed estimate from Table 9, Phase 1, Value Planning Study.

[2] Overall risk determined from a qualitative consideration of feature area, selenium concentration, and potential availability.

that support fish populations. Although the numbers and diversity of fish-eating birds would decline, those birds that do continue to use the area would be at risk of increased bioaccumulation of selenium. Invertebrate-eating birds would also experience increased risk of selenium bioaccumulation. A No Action Alternative would likely involve mitigation measures to reduce or remove the effects of increasing selenium levels on invertebrate-eating birds.

Exposed Sea Bed with Residual Pools

Ephemeral and/or semi-permanent pools would likely form in the exposed sediments of the Sea floor as the Sea recedes. The effects from this type of feature have been previously described under all alternatives.

Central Marine/Brine Basin

The central marine/brine basin would receive any remaining water from any irrigation activities in the area. The water would have high salinity and selenium levels. As discussed under marine lakes and brine basins for the proposed restoration alternatives, salinity would increase until it reaches a level that the current assemblage of micro-organisms that reside in the Sea is disrupted and/or reduced. This disruption would also include bacteria that currently play a critical role in sequestering selenium in bottom sediments. Bacteria would be affected either through a reduction in organic food supply, or directly by salinity levels. Our knowledge of these organisms is limited so the actual salinity levels at which such a disruption would occur, or its length are unknown. It is further assumed that selenium levels in sea/brine water would increase in response to the disruption of the micro-organism assemblage. Increasing selenium levels would increase the risk level for invertebrate-eating birds.

As the Sea continues to increase in salinity, the invertebrate community would begin to resemble communities inhabiting evaporation basins. It is assumed that selenium levels would remain elevated or increase, adding to the risk of reproductive toxicity for invertebrate-eating birds. The selenium risk level for this feature is therefore defined as high hazard for invertebrate-eating birds.

Selenium Risk

The risk of increased bioaccumulation to area aquatic birds from components associated with a No Action Alternative is estimated in Table 11.

Table 11.—Estimate of aquatic bird risk from increased selenium bioaccumulation in component-supported food chains under a No Action Alternative. Overall risk ratings are based on components' size, and water and sediment estimated selenium concentrations.

Alternative 9A Components:	Acres	Water Concentration (ppb)	Sediment Concentration (ppm)	Aquatic Bird Risk Level	
				Fish-Eating	Invertebrate-Eating
Residual Pools[1]	Unknown	> 10	> 4	NA	High Hazard
Marine/Brine Basin	160,000	> 5	> 4	NA	High Hazard
Overall Risk Rating[2]				Low	High Hazard

[1] Residual pool area estimated at 1 percent of exposed sea bed estimate from Table 9, Phase 1, Value Planning Study.
[2] Overall risk determined from a qualitative consideration of feature area, selenium concentration, and potential availability.

Discussion

This report attempts to objectively review the risk of increased bioaccumulation of selenium in fish-eating and invertebrate-eating aquatic birds using the Salton Sea. The risk standard used to evaluate restoration alternatives is selenium levels in eggs. Specifically, the selenium level in bird eggs is 10 µg/g dry weight, a level that appears to be a general threshold for reduced egg viability (hatchability) (Heinz 1996). Some birds are more sensitive and some are less sensitive to selenium, but 10µg/g is a useful value for risk assessment. Limited data for the Salton Sea indicates that the current risk level is moderate, with black-necked stilt egg selenium concentrations ranging from 1.6 to 35 µg/g (geometric mean = 4.3 µg/g) (Setmire *et al.* 1993). The reduced egg viability threshold for stilts is 6.0 µg/g (Skorupa 1998).

Reduced egg viability is the most sensitive measure of selenium reproductive toxicity in birds. Teratogenesis or deformed embryos is also a precise, but more severe measure of reproductive toxicity, and occurs at higher egg selenium levels.

For example, Skorupa (1998) calculated the EC_{50} for teratogenesis in dabbling ducks at 31 µg/g, for stilts at 58 µg/g, and for avocets at 105 µg/g. Unfortunately, we do not have threshold values for teratogenesis.

The selection of reduced egg viability as a selenium risk standard focuses our attention on the breeding season. Although birds can rapidly accumulate selenium from their local environment, they can also rapidly eliminate it once exposed to background concentrations. Although up to 400 species of birds have been recorded at the Salton Sea, a much lower number of fish-eating and invertebrate-eating birds breed at the Salton Sea. These species are the focus of concern.

Selenium Risk

Salinity and selenium concentrations in drainwater entering the Salton Sea, or any of the proposed component features of restoration alternatives, will increase as dilution water (tailwater) is reduced. Selenium bioaccumulation will increase. Because a marine fishery appears to be a challenging management goal, this assessment has focused on invertebrate-eating birds. Anticipated increases in selenium concentrations—regardless of their oxidation state—would increase the risk of selenium bioaccumulation in invertebrate-eating birds. We do not completely understand the bio-concentration mechanisms in natural systems, but laboratory studies indicate that most forms of selenium pose risks. For example, "…Besser *et al.* (1993) reported that the bio-concentration factor for algal accumulation of selenium from water in the absence of sediment was 5,300-15,700 for selenomethionine, 1440-1600 for selenite, and 428 for selenate, and for daphnids these bio-concentration factors were 30,300-229,000, 570-3600, and 293, respectively." (Hamilton and Lemly 1999). Bioaccumulation will likely increase in invertebrate-eating birds.

Alternative Risk Summary

All proposed alternatives including No Action, would increase selenium risk levels (Table 12). Two component features account for anticipated increased selenium risk. First, most alternatives contain a marine lake component. The Salton Sea—a very large marine lake—currently deals with selenium through a complex assemblage of micro-organisms. This assemblage includes anaerobic bacteria which reduce (e.g., selenate to elemental selenium) and facilitate the sequestering of incoming selenium into bottom sediments. Selenium concentrations of 4-8 µg/L in tributary waters are diluted and reduced to 1-2 µg/L in Sea water. It is reasonable to assume that increasing salt concentrations in Sea water, or future marine lakes, would adversely affect and disrupt the existing assemblage of micro-organisms.

Table 12.—Estimates of future selenium risk to fish-eating and invertebrate-eating birds under nine proposed Salton Sea restoration alternatives and the No action Alternative

Alternative	Selenium Risk Level to Aquatic Birds	
	Fish-Eating Birds	Invertebrate-Eating Birds
No Federal Action	Low[1]	High Hazard
Mid-Sea Dam with North Marine Lake (Alternative 1A&B)	High-Moderate	High Hazard
Mid-Sea Dam with South Marine Lake (Alternative 2A&B)	High-Moderate	High Hazard
Concentric Ring Dikes with Cascading Reservoirs (Alternative 3A&B)	High Hazard	High Hazard
Revised Salton Sea Authority (Alternative 4A&B)	High Hazard	High Hazard
Mid-Sea Barrier with North Marine Lake (Alternative 5A&B)	High-Moderate	High Hazard
Mid-Sea Barrier with South Marine Lake (Alternative 6A&B)	High-Moderate	High Hazard
Mid-Sea Barrier with South Marine Lake and Habitat Ponds (Alternative 7A&B)	High-Moderate	High Hazard
Evolving Sea with Habitat Ponds (Alternative 8A&B)	Low[1]	High Hazard
No Salton Sea with Land Reclaimed for Agriculture (Alternative 9)	Low[1]	High Hazard

[1] Assumes no fishery exists now or would exist in the future.

The anticipated disruption of the existing micro-organism assemblage would include the anaerobic bacteria responsible for selenium reduction—either directly through increasing salt concentrations, or indirectly through their food source. Water selenium levels would increase during this micro-organism disruption phase. Higher selenium levels would be bioaccumulated in remaining invertebrates and passed on to invertebrate-eating birds. The selenium risk level during this period would be high to high hazard. Once salinity returns to target levels (e.g., < 40 ppt), it is assumed that a marine lake would return to selenium concentrations of 1-2 µg/L, and the selenium risk level for invertebrate-eating birds would move to moderate.

The second component of most alternatives that would increase selenium risk levels is the hyper-saline or brine basin. It is anticipated that these basins would progress through similar changes in micro-organism assemblages as outlined for marine lakes. The major difference between the two basins is that the salt levels in the brine basins do not decrease, and therefore would not return to the moderate selenium risk level. It is assumed that the brine shrimp-brine fly dominated assemblage would pass higher selenium levels on to invertebrate-eating birds. The risk for this component is high hazard for invertebrate-eating birds.

Selenium Risk in Fish-Eating Birds

Table 12 summarizes the selenium risk to fish-eating birds from the nine proposed restoration alternatives and No Action. Of these 10 alternatives, five would some day result on a moderate selenium risk level for fish-eating birds. When this would happen is unknown. The current fishery is either gone or will some be gone from the Sea. A completely new fishery would have to be established once conditions in a marine lake can support fish.

Of the five remaining alternatives, the Concentric Ring Dikes with Cascading Reservoirs and the Revised Salton Sea Authority Alternative are predicted to create a high hazard level of selenium risk for fish-eating birds. This risk level is associated with the ring lake features and the anticipated aerobic conditions created that would favor increased selenium concentrations. The final three alternatives receive a low selenium risk level for fish-eating birds because no fishery is anticipated under these alternatives.

Mitigation for fish-eating birds using the rivers and drains, and any constructed wetlands such as sediment removal basins, would likely be necessary under all 10 of the proposed alternatives. As selenium levels rise in rivers and drains , increased bioaccumulation in fish and fish-eating birds is likely.

Selenium Risk in Invertebrate-Eating Birds

As indicated in Table 12, all 10 alternatives are expected to increase the selenium risk for invertebrate-eating birds.

Although the marine lake component of some alternatives would some day return to a moderate risk level as outlined above for both fish-eating and invertebrate-eating birds, the uncertainties associated with brine basins result in a high hazard risk for invertebrate-eating birds.

Recommendations

The physical, chemical, and biological processes that interact in selenium cycling in natural systems are complex. Some issues are understood and others are not. The literature indicates that while there are commonalities in selenium cycling, there are also site-specific issues that must be understood before selenium concentrations and their bioaccumulation in aquatic food chains can be adequately addressed. Further research appears warranted for the Salton Sea. The following questions are offered to stimulate discussion and further research.

- How will micro-organisms (including anaerobic selenium reducing bacteria) respond to increasing salt concentrations in marine lakes and in hyper-saline/brine basins?

- The last comprehensive selenium study was completed in the early 1990's. What are current conditions?

- What conditions—in terms of primary producer communities—will the interactions of increasing salt levels and increasing eutrophication produce in the future?

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