Restoration of the Salton Sea

Volume 1: Evaluation of the Alternatives

Appendix 1J: Selenium Risk Evaluation of Salton Sea Restoration Alternatives

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Selenium Risk Evaluation of Salton Sea Restoration Alternatives:
by James G. Setmire, Hydrologist

After a lengthy study and review process, the Salton Sea Authority (SSA) selected eight preferred alternatives for restoration of the Salton Sea. The basic concepts for these alternatives are presented in a July 2004 document prepared by Tetra Tech, Inc. At the request of the SSA, a group of scientist will review these alternatives to determine: 1) impact of eutrophication; 2) nutrient and dissolved oxygen concentrations; 3) selenium risks to wildlife; and 4) the presence of any “fatal flaws” or serious defects in any of the proposed alternatives. The latter are conditions that pose a grave threat to the biota in the water bodies or conveyances formed by these alternatives or pose a threat to local inhabitants. This paper focuses on the risk of selenium contamination in the various flow components of each of the alternatives.

In 1998, the United States Congress enacted Public Law 105-372 authorizing the Secretary of the Interior to complete studies that:

1) Permit the continued use of the Salton Sea as a reservoir for irrigation drainage;

2) Reduce and stabilize the overall salinity of the Salton Sea;

3) Stabilize the surface elevation of the Salton Sea;

4) Reclaim, in the long term, healthy fish and wildlife resources and their habitats; and

5) Enhance the potential for recreational uses and economic development of the Salton Sea.

The Salton Sea Authority and the U.S. Bureau of Reclamation (USBR) developed and implemented a plan to obtain necessary water-quality and biological data and information on the Salton Sea to formulate a Salton Sea Restoration Project. Based on the data obtained from these studies, the SSA refined the original Departmental goals as follows:

1. Preserve the Sea as a repository for agricultural runoff

2. Provide a large marine lake with stable elevation

3. Improve water quality: salinity

4. Improve water quality: nutrient/other constituents

5. Maintain and improve habitat

6. Achieve water-quality and habitat objectives in a timely manner

7. Respond to inflow changes

8. Increase recreational and economic potential

9. Address air quality concerns

10. Provide high safety rating/low risk of failure

11. Overcome institutional barriers/public acceptance

12. Achieve reasonable cost/high probability of financing

These more detailed goals are to be accomplished under three possible inflow constraints or scenarios.

A. The anticipated QSA schedule that includes water releases to mitigate effects to the Salton Sea over the next 15 years;

B. The QSA schedule with the mitigation water terminated in 2006 and the sale of additional water to generate restoration funds; and

C. A schedule that would reduce average inflow to about 800,000 acre-feet per year.

Based on the modified Department of the Interior goals and the constraints imposed by the QSA, the SSA has identified eleven preferred Salton Sea Restoration Alternatives identified below.

1) Alternative 1, Mid-Sea Dam with North Marine Lake – North Marine Lake filled by extending the New and Alamo River channels on the NE and SW peripheries of the Sea. The northern freshwater lake is separated from a smaller hyper-saline pond by a constructed dam:

2) Alternative 2, Mid-Sea Dam with South Marine Lake - South Marine Lake separated from a northern hyper-saline pond by a constructed dam;

3) Alternative 3, Concentric Ring Dikes with Cascading Reservoirs - Cascade Concept with Concentric Waterways by diverting water from the New and Alamo River to concentric rings constructed around the Sea. Hyper-saline ponds would form at the northern and southern depressions. Wetlands and halophyte areas would be constructed to separate the hyper-saline ponds from the concentric rings;

4) Alternative 4, Revised Salton Sea Authority Alternative - North Lake with mid-seas dam and outer pool with pump back from Marine Lake;

5) Alternative 5, Mid-Sea Barrier with North Marine Lake - North Marine Lake with a permeable membrane separating the fresher water in the northern end from the higher saline water in the northern end. Similar to alternative 1, with extensions of the New and Alamo Rivers feeding the North Marine Lake, but with no elevation control;

6) Alternative 6, Mid-Sea Barrier with South Marine Lake - South Marine Lake separated from the northern hyper-saline pond by a permeable barrier with no elevation control but with split diversion of New River to the hyper-saline pond;

7) Alternative 7, Mid-Sea Barrier with South Marine Lake and Habitat Ponds - South Marine Lake separated from the northern hyper-saline pond by a permeable barrier with no elevation control but with split diversion of New River to the hyper-saline pond. Treatment facilities on both the New and Whitewater Rivers would remove selenium and nutrients and discharge water to freshwater habitat/shallow ponds;

8) Alternative 8, Revised Evolving Sea - Version of the Pacific Institute's proposal to create brackish water impoundments in northern and southern ends of the Salton Sea;

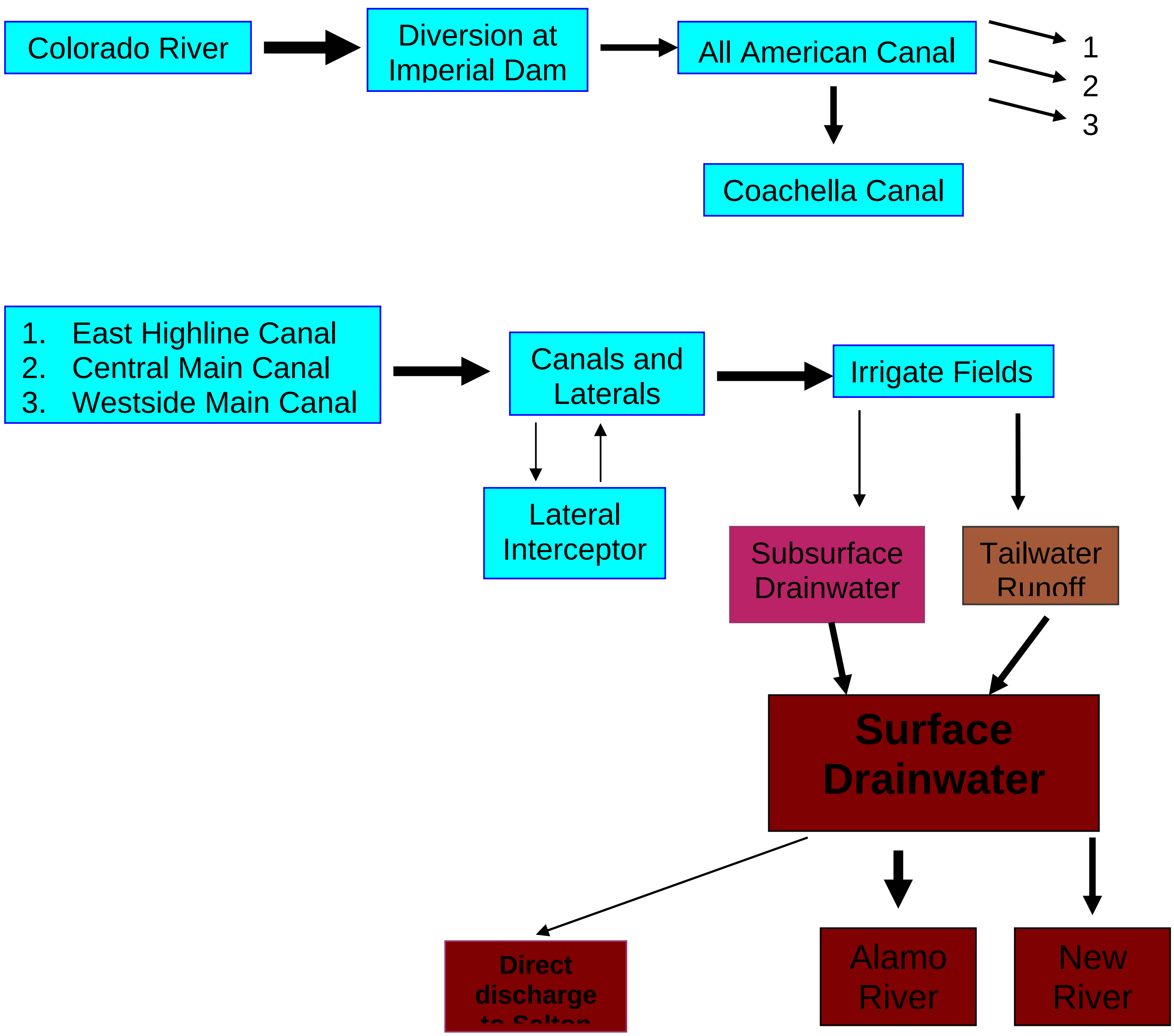
8C) Alternative 8C, Revised Evolving Sea with Marine Lake - Evolving Salton Sea with no elevation or salinity controls leading to increasingly hyper-saline areas forming in the northern and southern depressions. Large areas of Salton Sea bottom sediments would be exposed to wind erosion.

Approach

A rendering of each alternative into a modified flow chart will be developed for each alternative to identify the major system components. The selenium risk to wildlife in each component will be evaluated.

The flow chart below of the Imperial Valley is shown to clarify the various sources of water entering the Salton Sea from irrigated agriculture in the Imperial Valley.

Flow Chart for Agricultural Water Tributary to the Salton Sea



1. East Highline Canal
2. Central Main Canal
3. Westside Main Canal

Water quality characteristics are: Dissolved solids = 686 mg/L, chloride = 98 mg/L, NO_3 = 0.22 mg/L, ammonium concentration = 0.03 mg/L, chloride = 98 mg/L, and **selenium = 2 ug/L** (Setmire and Schroeder, 1998). These are good approximations of selected constituent concentrations for Colorado River water used to irrigate fields in the Imperial Valley. It also is a rough approximation in terms of dissolved solids, chloride and selenium concentrations for tailwater runoff depending on the point in the irrigation cycle.

Subsurface Drainwater/ Tilewater

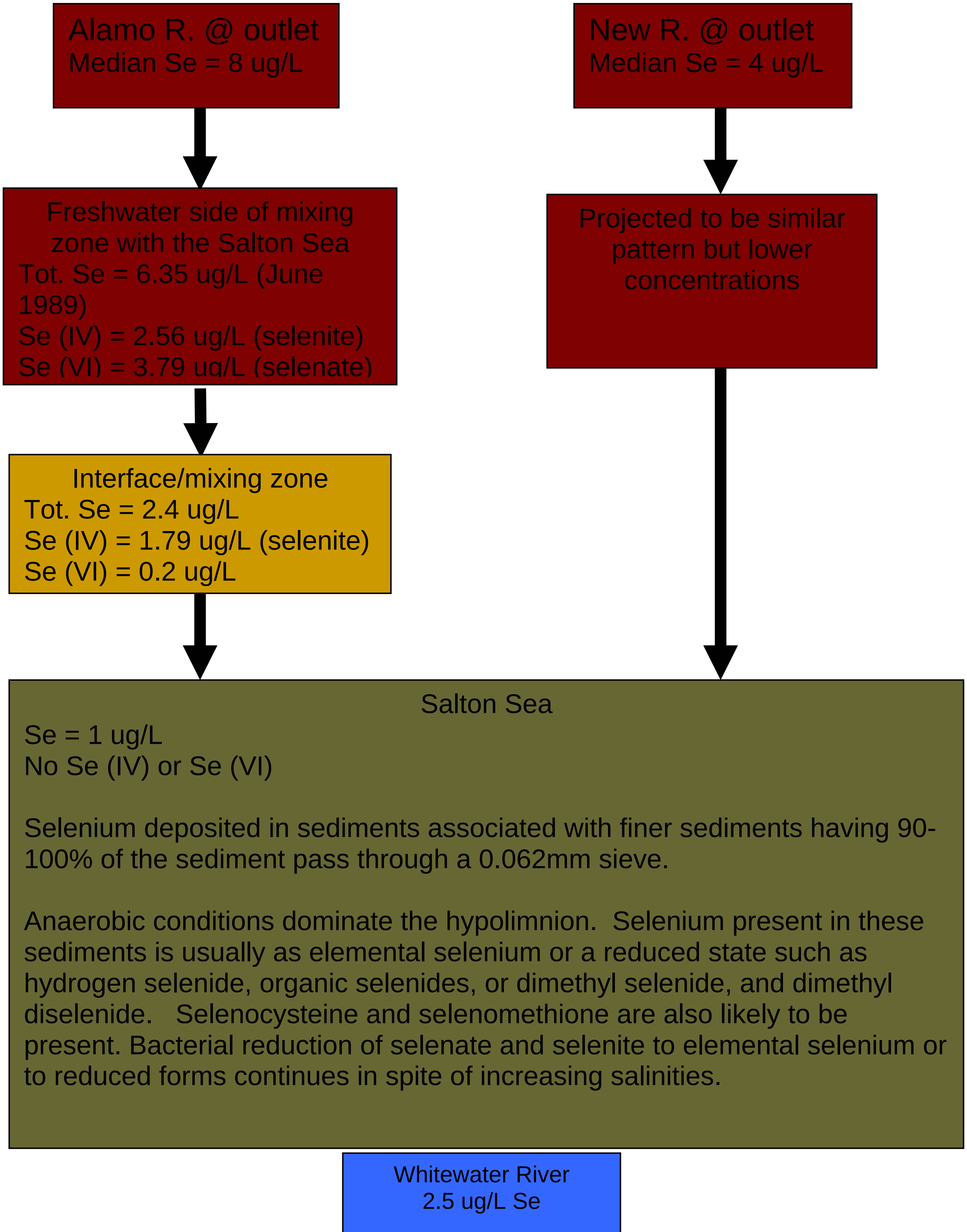
Subsurface drainwater in samples collected from 304 sumps and gravity tile outlets during August 1994 and January 1995 had selenium concentrations ranging from 1 to 311 ug/L with a median concentration of 28 ug/L (Setmire and others, 1998). The dissolved solids concentration = 6448 mg/L, NO_3 = 1.1 mg/L, ammonium concentration = 0.07 mg/L and the chloride concentration = 1200 mg/L.

Surface Drainwater

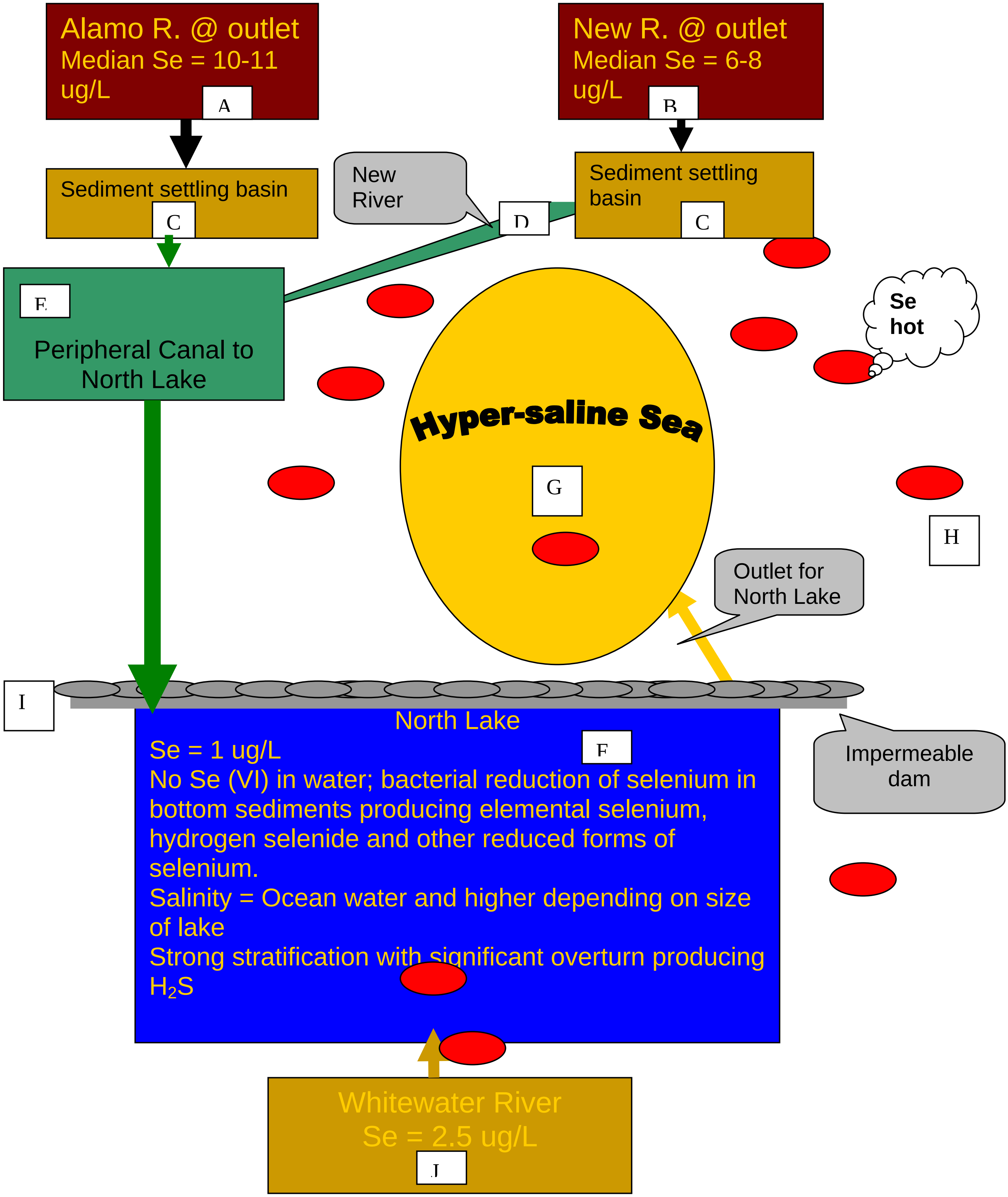
Surface drainwater concentrations of selected constituents from 48 surface drain locations in the Imperial Valley were: dissolved solids = 2025 mg/L, NO_3 = 4.95 mg/L, NH_4 = 0.19 mg/L, chloride = 420 mg/L, and **selenium = 6 ug/L**.

Bottom sediments of 48 surface drains in the Imperial Valley had **a median selenium concentration of 0.5 ug/g** while 270 soil cores from Imperial Valley fields had **a median selenium concentration of 0.2 ug/g**. The selenium to chloride concentration ratio is used to determine sources and sinks for selenium and to show when oxidation/reduction reactions or biological activity affects selenium concentrations. The Se/Cl ratio in the East Highline Canal is about $2X10^{-5}$. In subsurface drainwater, the median Se/Cl ratio is $2.3 X10^{-5}$. In the Alamo River at the Outlet to the Salton Sea, the Se/Cl ratio is $1.6X10^{-5}$ showing that some selenium is lost to the biota and sediments of the surface drains and the New and Alamo Rivers. Selenium in the soils of the Imperial Valley average 0.2 ppm whereas in the surface drains and rivers, the concentration is 0.5 ppm. The increase indicates a loss of selenium to the sediments of the rivers and drains. In the Salton Sea, the ratio is $0.007X10^{-5}$ showing that the Salton Sea is a major sink for selenium.

Salton Sea Flow Chart - Present Conditions



Alternative 1, Mid-Sea dam with North Marine Lake



Alternative 1, North Marine Lake

Flow chart components of the North Marine Lake

A. Alamo River at Outlet

Water-quality Effects: As tailwater and operational loss (excess water needed to deliver the requested volume to the point of irrigation) are minimized to provide for the water transfer, dilution of the higher concentrated subsurface drainwater will decrease and the selenium concentration in the Alamo River at its outlet to the Salton Sea will increase. A 20 percent reduction in tail water and operational loss would produce selenium concentrations ranging from 8 ug/L to 10 to 11 ug/L and 6-8 ug/L respectively in the Alamo and New Rivers.

If at some point, all tailwater and operational loss is eliminated and flow from Mexicali also significantly reduced, the New and Alamo Rivers will be composed almost entirely of subsurface drainwater. The selenium concentration in the Alamo River will approach the median concentration of 28 ug/L found in sumps and gravity tile outlets throughout the Imperial Valley. The dramatic increase in selenium concentration in the New and Alamo Rivers will be matched by the decrease in phosphorus concentrations. Little to no phosphorus is found in subsurface drainwater.

Other chemical components of subsurface drainwater such as dissolved solids concentration likewise will increase. Boron is already elevated in the Salton Sea at about 10 mg/L and is present at elevated concentrations in subsurface drainwater.

The drains directly discharging to the Salton Sea provide habitat for the endangered desert pupfish. Data collected from 13 drains and presented in Schroeder and other, 1993 indicate that sailfin mollies had selenium concentrations ranging from 3 to 6 ug/g which according the J. Bennett (personal communication, 1996) are at levels of concern for warm-water fish. Mollies from the other two drains had selenium concentrations exceeding the 6 ug/g threshold, above which there is increased risk of teratogenesis and embryo mortality (J. Bennet, personal communication, 1996). As previously discussed, water conservation in the Imperial Valley will result in an increase in selenium levels in drains. This increase will result in higher levels of selenium than previously measured and, therefore, a significant threat to the endangered desert pupfish.

Hydrologic Effects: Water in the Alamo River is regulated by a number of drop structures along the rivers course from the International Boundary near Mexicali where only a few cubic feet per second of water cross under the All-American Canal and into the United States. The drop structures provide an energy release for the overall decrease in elevation from near Sea Level at the International Boundary to around –227 ft MSL where the Alamo River discharges to the Salton Sea. The drop structures maintain a flow rate of about 1.5 ft/s that prevents scour and erosion but keeps the finer sediments in suspension.

The North Marine Lake alternative specifies that large sediment basins with spillways will be constructed below the diversions structures for the New and Alamo Rivers. These ponds will also have flow velocities less than 1.5 ft/s to deposit sediments. At a 20 percent reduction in tailwater and operational loss, these basins will be highly eutrophic and have elevated selenium concentrations. They will be freshwater systems and have the same phytoplankton, algae and benthic invertebrates as the New and Alamo Rivers. There will be significant algal growth in the basins and bioaccumulation of selenium in the food chain. As tailwater and operational loss are reduced, selenium concentrations will increase. Phosphorus concentration will decrease and if carried to the point where tailwater is the only component of the Alamo River at the Outlet, eutrophication will also decrease due to lack of phosphorus. At that point, some of the selenium removal pathways will disappear and the water borne selenium concentration will be elevated. Although the phytoplankton route will decrease, bacterial reduction of selenate and selenite will continue and uptake by benthic organisms will be ongoing. If there is no significant stratification, selenium will remain available for uptake by benthic organisms, producing significant biomagnification in the food chains and placing upper trophic level organisms at risk for selenium toxicity. No direct toxicity should occur to fish, but the significance of bioaccumulation and biomagnification was shown in an evaluation of 23 NIWQP case studies in “four of the study areas where the 75th percentile for surface waters was >10 ug/L, all (100 percent) had 75th percentile values for bird eggs above the embryotoxic threshold (Seiler and Skorupa, 1995). The LOAEL for selenium in water is 50-100 ug/L for fish and amphibian eggs/larvae (NWIQP Information report No. 3,) so selenium levels could approach half of that threshold for direct toxicity.

B. New River Near Westmorland (Outlet to the Salton Sea)

Water-quality Effects: The New River will likely experience a greater increase in selenium concentration than the Alamo River. If Mexicali utilizes more of the water in the New River for cooling towers and other uses, the volume of water crossing the border will decrease. The New River is an anomaly in that agricultural discharge actually improves the quality of the river in terms of organic loading. A reduction in flow of lower selenium water crossing the border from Mexico translates to less dilution of subsurface drainwater and overall higher selenium concentrations in the New River.

Drop structures were constructed in the New River for the same purpose as the Alamo River, to prevent erosion by reducing the energy of the water to carry sediment. The flow rate in the New River is about 1.5 ft/s determined by time-of-travel study conducted by Setmire, 1984. There also is a drop structure below the International Boundary near the All American pipe crossing to aerate the water and improve the quality of the water in the river. The Citizen’s Congressional Task Force on the New River constructed this rock weir.

C. Sediment Basins

Water–quality effects: Sediment basins are also planned for construction on the Alamo and New Rivers at the outlets to the Sea. The same effects described for the Alamo Sedimentation Basin will occur for the New River except for the effects of the lower selenium water crossing the International Boundary at Calexico. If there is significant municipal effluent, then phosphorus concentrations will remain high and the final outcome will differ from that of the Alamo River. Depending on the P levels, the basins will continue to be eutrophic and have a greater likelihood that anaerobic conditions will persist in the bottom sediments. The degree to which phosphorus will be removed from water crossing the International Boundary is only speculative. It is likely that the source of phosphorus from untreated or partially treated municipal effluent will continue to some extent. Coupled with a 20 percent reduction in tailwater and operational loss from water conservation practices in the Imperial Valley, selenium concentrations in the New River at its Outlet to the Salton Sea will increase to 6-8 ug/L from their current level of 4ug/L. Continued reduction of tailwater and operational loss will drive the selenium concentrations higher toward the median of 28 found in subsurface drainwater in the Imperial Valley.

Selenium concentrations in the water of the Alamo River sediment basin will have increase to over 2 times the existing 5 ug/L criteria for the protection of aquatic life. This basin will receive the total load of selenium, nutrients and salts from the Alamo River. There will be significant wildlife utilization of these basins that will encompass all trophic levels from primary producers to higher-level consumers. Shorebirds utilizing the extensive habitat along the southern end of the Salton Sea will now utilize the available habitat afforded by the sediment basins. The bioaccumulation and biomagnification graphs for concentration of selenium and dietary thresholds in food chain organisms of the rivers and drains in the Imperial Valley (Setmire and others, 1993, Setmire and Schroeder, 1998)(see attached figures for selenium in biota) will increase significantly and place birds feeding on those organisms in the freshwater food chain in the category of “Possible threat to water-bird survival.” Because the sediment basins will be highly eutrophic, selenium uptake, bioaccumulation, and biomagnification in the food chain will increase. Although some loss selenium via selenite adsorption on fine particles will occur, the anaerobic processes that remove selenium from the water of the Salton Sea will not be present because of the shallow depth, will not sequester selenium in the sediment basins to the same extent as in the Sea. Even though many of the food chains are short, fish feeding on invertebrates in the sediment basins will have selenium concentrations at the chronic exposure criterion of 7.9 ug/g dry weight threshold.

Previous work has indicated that there is a mixture of both selenate and selenite in the Alamo River before it mixes with the saline water of the Salton Sea (Setmire and others, 1993). The presence of both of these compounds in the sediment basins will add to the exposure pathways for selenium toxicity. With the existing shorebird habitat along the southern end of the Sea left dry, black-necked stilts and other shorebirds will utilize available areas in the sediment basins for feeding. Fish-eating birds (piscivorous birds) will also utilize the basin and be at risk to selenium toxicity.

There is a continuum of concentrations and effects in the sediment basins as tail water and operational loss are reduced. Water in the basin will be highly eutrophic at the 20 percent reductions, but at some point, phosphorus concentrations will drop sufficiently to cause the Trophic State Index to decrease and the water to be less eutrophic. As the water becomes less eutrophic and selenium concentrations increase, less selenium will be removed by the biota and sequestered in the bottom sediments. The degree to which this occurs is dependent on magnitude and length of stratification. Food chain bioaccumulation of selenium will increase and cause reproductive problems in biota at the top of the food chains. Even though selenium concentrations will be many times the current level, it would not be directly toxic to algae, benthic invertebrates or fish.

D. Peripheral Canal – Extension of Alamo River from the Delta to the North Lake

The peripheral canal will be concrete lined and maintain a high enough flow velocity to prevent sedimentation. Combining these two rivers into a single peripheral canal will require construction of a large enough canal that will convey a wide range of discharges, some due to the irrigation cycle and other from periodic flooding from tropical storms. The peripheral canal will be designed to pass floods at the 95% level. The flow rate and concrete lining to reduce sedimentation will help to reduce the selenium threat to biota in spite of elevated selenium concentrations in water**.**

The same situation applies to the extension of the New River, whether it has its own peripheral canal or connects to the Alamo peripheral canal.

E. North Marine Lake – Water Near Ocean Salinity

Water-quality Effects: The North Marine Lake will receive the entire selenium and nutrient loads from the Imperial Valley in an area 40 percent the size of the current Salton Sea. It is possible that a small percentage of the selenium load will be removed in the sediment basins, but the inflowing water will not only have a significant selenium load, but will also have a high selenium concentration. The same mechanisms that are removing selenium from the water in the Salton Sea – uptake by phytoplankton, reduction reactions, and bacterial metabolism will occur in the North Marine Lake. The North Marine Lake also has the highest detected selenium concentrations in the bottom sediments of the Sea (Levine Fricke Recon and Schroeder and Setmire). These sediments will no longer be deeply buried, but will be exposed to aerobic conditions, which along with wave action will cause bottom and surface water to mix. Reduced selenium will become available to phytoplankton in the water column. Areas previously anaerobic and without benthic invertebrate colonization will be exposed to higher selenium concentration and organisms that will bioaccumulate and biomagnify selenium in the food chain. Van Derveer and Canton (1997) evaluated data from 27 studies and determined that selenium concentration in sediment is a “reliable predictor of adverse biological effects and that a preliminary toxic threshold existed at about 2.5 mg Se/Kg (10 percentile for effects and that adverse effects are always observed at selenium concentrations greater than 4 ug/g." Bottom samples collected at 11 sites in the Salton Sea by Schroeder, Setmire, and Roberts in July of 1998 had a median selenium concentration of 2.7 mg/kg with a minimum concentration of 0.58 and a maximum concentration of 11 mg/kg (see the attached figure for location). The median concentration of 2.7 mg/kg is 6.5 times greater than the maximum zero-response (NOAEL) boundary for birds nesting at shallow terminal ponds. As selenium concentrations increase in the smaller and shallower North Marine Lake, conditions will be ripe for severe contamination of birds feeding on prey items from the North Marine Lake. Increased selenium concentration, slowly decreasing phosphorus concentrations, lower salinity and shallower water make predicting actual effects difficult to predict. Fish and their larval forms living in the North Lake and birds feeding on fish that in turn have fed on zooplankton, or benthic invertebrates are all part of the equation. Based on past studies at the Salton Sea and on studies at other sites where selenium is elevated in agricultural drainwater, it is logical to conclude that selenium concentrations in the food chain will increase and birds feeding on this resource at great risk to survival

The North Marine Lake will have a lower salinity than the present day Salton Sea that should enable the fishery to thrive without the stress of high salt levels. In spite of the lower salinity, the larger fish-eating birds will be at great risk to selenium toxicity. In the present Salton Sea, selenium is reduced to elemental selenium, selenides and other complexes that remain sequestered in the deeper parts of the Sea (see attached figures). Although higher selenium concentrations tend to be associated with finer sediments and detritus, selenium compounds are distributed in the bottom sediments throughout the entire Sea. In the North Marine Lake, all of the new deposits will be in an area only 40 percent of the size of the existing Sea. Schroeder, Setmire, and Roberts found the highest concentrations of selenium in bottom sediments off of the Whitewater River delta in 1998 and Levine Fricke Recon found highest concentrations off of Desert Shores in 2000. Although the same mechanisms for selenium removal will be available in the North Lake, different dynamics of mixing and overturn could reduce the present day removal rates and produce higher selenium concentration in water.

Setmire and others, 1993 show a graph of selenium concentrations and dietary thresholds in food chain organisms of the Salton Sea, 1988-1990 (Modified from Heinz et al., 1987,1989) (see attached figures of selenium bioaccumulation and biomagnification). With existing conditions, this graph shows that pileworms have particularly high levels of selenium, some as high as 12 ug/g dry weight. Fish feeding on these organisms will bioaccumulate selenium to even higher levels and water-birds feeding on these fish are at risk for survival. With the entire load of selenium entering the North Marine Lake, selenium concentrations in the lower trophic level organisms will increase, placing higher food chain organisms including both fish and birds at risk.

As more water to urban southern California as a result of water conservation in the Imperial Valley, selenium concentrations will increase and phosphorus concentrations will decrease. As mentioned above, this is a continuum of increasing selenium concentration, decreasing phosphorus concentrations and a possible (decades) decrease in the eutrophic state of the North Marine Lake. The degree to which the eutrophication of the North Marine Lake is reduced is still in question, and depends upon the release of phosphorus from the bottom sediments and reductions in municipal effluent from Mexicali. Although the algal smell problems and fish kills associated with depleted dissolved oxygen in the water column might decrease, the toxicity of selenium to the biota will increase and fish and bird reproductive impairments will increase significantly. **(Caveat – recent predictions of long-term stratification and a single large mixing event of bottom water high in hydrogen sulfide suggest a major disaster to the biota in the North Marine Lake and possible a threat to nearby residents)**

F. Hyper-saline Sea

Water-quality Effects: The hyper-saline pond is the remnant of the Salton Sea. It is the outflow receptor for salt to keep North Marine Lake salinity in check with evaporation. The hyper-saline component of the North Marine Lake alternative will significantly increase in salt concentration. Although most of the selenium removal mechanisms, both bacterial and chemical continue to function at higher salinities (bacterial removal of selenium was found in the Dead Sea by Oremland (2001), there will be periods where the food chains are altered and selenium uptake by benthic invertebrates and other food chain items will be hazardous to birds utilizing them as a food source. Brine shrimp, brine fly larva and other salt tolerant biota will continue to feed on these organisms found in the hyper-saline pond. Shorebirds will feed on larval forms around the periphery of the hyper-saline pond and bioaccumulate selenium present in the water. Even though the kinetics of selenite reduction are favorable, selenium does evapoconcentrate (selenium in irrigation water evpoconcentrates to levels as high as 360 ug/L in the Imperial Valley) so that concentrations in the pond could be higher than any other water body in the Imperial Valley.

G. Whitewater River

Contains water from agricultural activities in the Coachella Valley as well as storm water runoff from the surrounding mountains and urban runoff from Palm Springs. Selenium concentrations in the Whitewater River average about 2.5 ug/L.

H. Residual Pools

Left behind as the hyper-saline sea shrinks and the North Marine Lake reaches its target elevation of –235 ft MSL, these ponds will contain elevated concentrations of selenium.

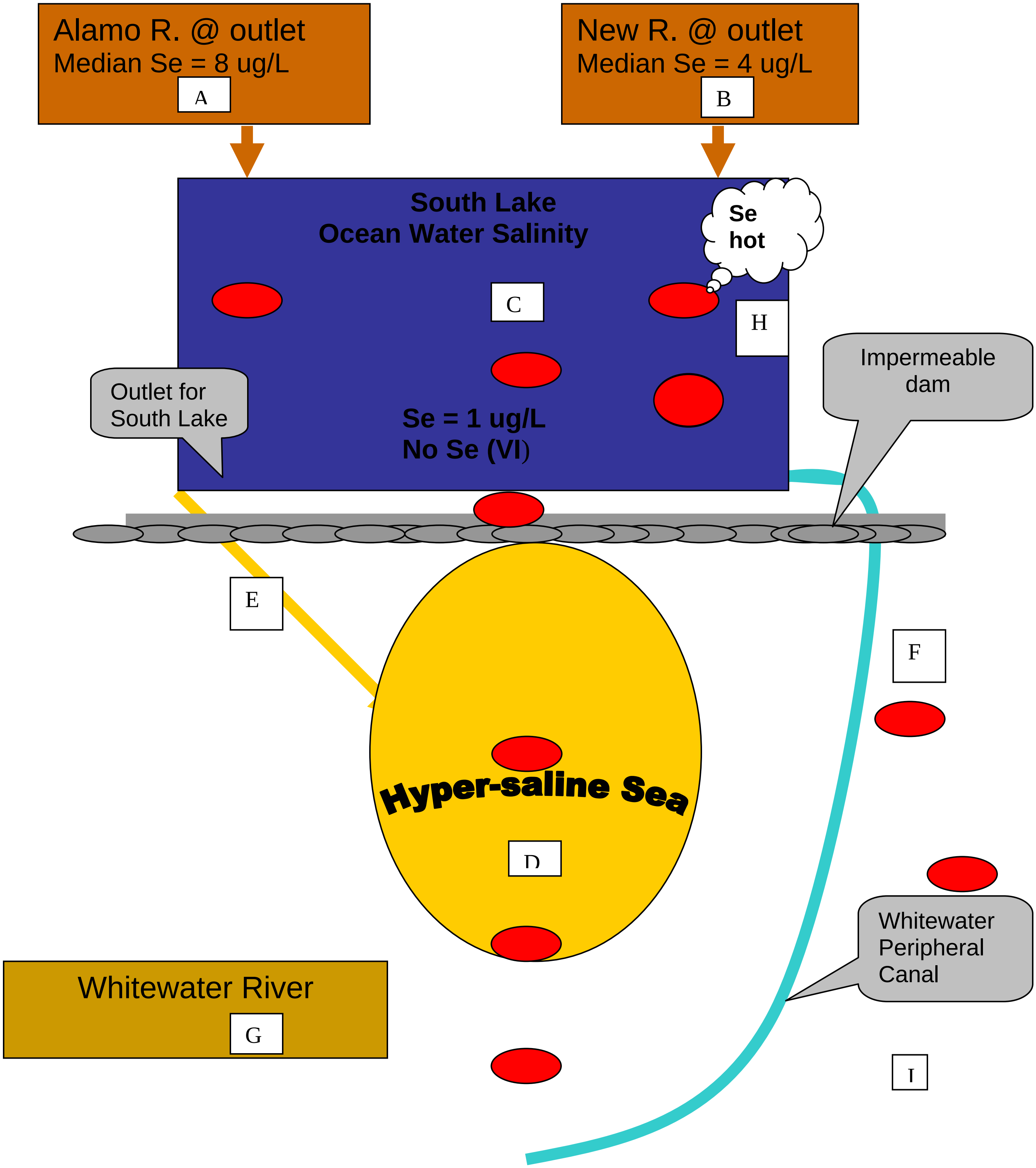
Water-quality Effects: Evaporative concentration will increase selenium and salinity concentrations. Some of these residual pools will form in areas where selenium was deposited at high concentrations in the bottom sediments of the Salton Sea. These residual pools will be colonized by a wide range of larval forms of insect larvae (water boatman, brine fly larvae, etc.) and provide a hazardous food source for shore birds and water-birds feeding in these small pools.

Hydrologic Effects: periodic flooding and the low annual rainfall will contribute to the continual formation of these residual pools. Other pools might form from the geothermal activities on the southern end of the Sea.

I. Impermeable Dam

Constructed to separate the North Marine Lake from the hyper-saline Sea. The rock substrate will be habitat for attached algae, barnacles and other biota.

Alternative 2, Mid-Sea Dam with South Marine Lake



Alternative 2, Mid-Sea Dam with South Marine Lake

Flow chart components of the South Marine Lake

A. Alamo River at Outlet

Water-quality Effects: As tailwater and operational loss (excess water needed to deliver the requested volume of water to the point of irrigation) are minimized to provide for the water transfer, dilution of the higher concentrated subsurface drainwater will decrease and the selenium concentration in the Alamo River at its outlet to the Salton Sea will increase. Currently the total dissolved solids concentration in the Alamo River at the Outlet is 2020 mg/L and the selenium concentration is 8 ug/L. Tailwater and operational loss comprise 77 percent of the water in the Alamo River at the Outlet (Setmire and Schroeder, 2000). A 20 percent reduction in this component translates to 62 percent dilution water in the Alamo River. Applying this reduction to the mixing equation produces a total dissolved solids concentration of 2862 mg/L for the Alamo River at the outlet. Similarly, the selenium concentration increases to 12 ug/L. A 50 percent reduction in dilution water translates to a total dissolved solids concentration of 4,230 mg/L and a selenium concentration of 18 ug/L.

If at some future point, all tailwater and operational loss is eliminated and flow from Mexicali also significantly reduced, the New and Alamo Rivers will be composed almost entirely of subsurface drainwater. The selenium concentration in the Alamo River will approach the median concentration of 28 ug/L found in sumps and gravity tile outlets throughout the Imperial Valley. The dramatic increase in selenium concentration in the New and Alamo Rivers will be matched by the decrease in phosphorus concentrations. Little to no phosphorus is found in subsurface drainwater.

Other chemical components of sub surface drainwater such as dissolved solids concentration likewise will increase. Boron is already elevated in the Salton Sea at about 10 mg/L and is present at elevated concentrations in subsurface drainwater.

The drains directly discharging to the Salton Sea provide habitat for the endangered desert pupfish. Data collected from 13 drains and presented in Schroeder and other, 1993 indicate that salifin mollies had selenium concentrations ranging from 3 to 6 ug/g which according the J. Bennett (personal communication, 1996) are at levels of concern for warm-water fish. Mollies from the other two drains had selenium concentrations exceeding the 6 ug/g threshold, above which there is increased risk of teratogenesis and embryo mortality (J. Bennet, personal communication, 1996). As previously discussed, water conservation in the Imperial Valley will result in an increase in selenium levels in the drains and in the New and Alamo Rivers to concentrations two to four times the current levels. Bioaccumulation of higher concentration selenium will cause concentrations in sailfin mollies and desert pupfish to increase above the 6 ug/g threshold for increased teratogenesis.

As selenium concentrations in the drains and rivers increase, primary producers will bioaccumulate selenium to higher concentrations and biomagnification will increase accordingly. As water-borne concentrations increase, the risk to birds feeding in the drains will also increase. The attached figures show the risk to wildlife in the freshwater system. The observed concentrations will be shifted upward by a factor of at least two causing a greater risk to wildlife feeding on these organisms. Even though the selenium concentration in water will be 12 ug/L and higher, it is not directly toxic to fish or invertebrates. As selenium is incorporated into the food chain, the concentrations will exceed the Lowest observed adverse effect level (LOAEL) for fish and wildlife via bioaccumulation. Black-necked stilts (a moderately selenium sensitive species for which there is abundant data) are one of the birds that will be affected by this increase. Current levels are at the threshold but as selenium concentrations increase, reproductive impairment or reduction in hatching success will occur.

The minimum total-response (EC100) for birds nesting at shallow terminal ponds is a selenium concentration of 1.0 ug/g in the bottom sediments. Currently, the median selenium concentration in drains and the rivers is 0.5 ug/g. As selenium concentrations increase in water, concentrations in bottom sediments will also increase due to bacterial reduction to elemental selenium, hydrogen selenide and organic selenide compounds.

A typical freshwater food chain in the drains and rivers of the Imperial Valley might be phytoplankton **>** zooplankton **>** aquatic insects **>** forage fish **>** water birds and turtles. Ruddy ducks, American coots and Northern shovelers have geometric mean selenium concentrations of 11.7, 10.3, and 19.1 ug/g (Setmire and others, 1993). These birds feed on benthic invertebrates, filamentous or tubular algae, and zooplankton. With water conservation and increased selenium concentrations, these birds will accumulate selenium to a greater degree than concentrations previously measured. Shorebirds such as black-necked stilts accumulate selenium by feeding on benthic invertebrates or by ingestion of sediment during feeding.

Hydrologic Effects: Water in the Alamo River is regulated by a number of drop structures along the rivers course from the International Boundary near Mexicali where only a few cubic feet per second of water cross under the All-American Canal and into the United States. The drop structures provide an energy release for the overall decrease in elevation from near Sea Level at the International Boundary to around –227 ft MSL where the Alamo River discharges to the Salton Sea. The drop structures maintain an overall flow rate of about 1.5 ft/s that prevents scour and erosion but keeps the finer sediments in suspension. The total suspended solids concentration in the Alamo River at the Outlet is 357 mg/L (Holdren and Montano, 2000).

B. New River Near Westmorland (Outlet to the Salton Sea)

Water-quality Effects: The New River will likely experience a greater increase in selenium concentration than the Alamo River. If Mexicali utilizes more New River water for cooling towers and other uses, the volume of water crossing the

International Boundary will decrease substantially. The New River is an anomaly in that agricultural discharge actually improves the quality of the river in terms of its organic loading (Setmire, 191984). The selenium concentration in the New River water crossing the border averages between 1 and 2 ug/L (Setmire and others, 1993). This low selenium water dilutes the selenium in irrigation drainwater in much the same way as does tailwater and operational loss. The selenium concentration in the New River at the Outlet is 4 ug/L. Reducing the low selenium volume crossing the border coupled with conservation of tailwater and operational loss will likely double the selenium concentration to 8 ug/L.

The same food chains, birds and fish found in the Alamo River at the Outlet are found in the New River at the Outlet. The diversity of benthic invertebrates at the New River Outlet is similar to that of the Alamo River at the Outlet. Bioaccumulation and biomagnification of selenium in the New River will produce concentrations less than the projected concentrations in the Alamo River at the Outlet, but will be similar to current concentrations in biota.

Hydrologic Effects: Drop structures were constructed in the New River for the same purpose as the Alamo River, to prevent erosion by reducing the energy of the water to carry sediment. The flow rate in the New River is about 1.5 ft/s, determined by a time-of-travel study conducted by Setmire, 1984. Recently, a rock structure was constructed below the International Boundary near the All American pipe crossing to aerate the water and improve the quality of the water in the river. During hot summer months, the dissolved oxygen concentration in the water entering the United States at Calexico can be zero due to the high organic loading caused by the inadequately treated municipal effluent from Mexicali.

C. South Marine Lake

Water-quality Effects: Similar to the North Marine Lake Alternative, the South Marine Lake will receive the entire loading of nutrients, selenium and other constituents from the New and Alamo Rivers in an area less than half of the size of the current Salton Sea. Selenium in the water in the Alamo River at its interface with the South Marine Lake will have been reduced to selenite, so that no selenate is entering the South Marine Lake. The mixing zone between the rivers and the Lake are moved considerably farther to the northwest than the current location. Much of the shorebird habitat in the large embayments along Garst Road both on the east and west sides of Red Hill will be left dry. These areas are very shallow and have afforded excellent habitat to a variety of shorebirds and water-birds. With current discharges, the South Marine Lake will be highly eutrophic. Selenium will be removed from the water column by a several processes including uptake by phytoplankton, bacterial reduction to elemental selenium, hydrogen selenide and organic selenides. As the water in the South Marine Lake stratifies, anaerobic conditions will form in the hypolimnion providing the ideal conditions for reduction of selenite and detrital selenium compounds. Selenium from the inflowing water will be removed initially keeping the selenium concentration near 1 ug/L in the water column. However, the uptake and bioaccumulation of selenium by primary producers will likely increase due to the higher inflowing concentrations.

Selenium will enter the food chain in a number of ways. As mentioned, uptake by primary producers brings selenium into the food chain. As zooplankton feed on phytoplankton, selenium begins to biomagnify in the food chain. Overturn of anaerobic bottom water causes zero to low dissolved oxygen concentrations in the water column and drastic die-off of phytoplankton populations. Bacteria in the sediments break down the plankton and selenium-reducing bacteria convert selenium to elemental selenium, hydrogen selenide or a number of organic selenides. When these reactions occur in areas where benthic invertebrates (short term turnover and return to aerobic conditions) are established, selenium is accumulated from the sediments during feeding. Uptake of selenium by aquatic and benthic invertebrates and fish is correlated with selenium concentrations in bottom sediments. Investigations by Zhang and Moore 1996, Malloy et al. 1999 and Hamilton et al. 2001 found excellent correlations between selenium concentrations in benthic invertebrates and sediment concentration. Food chain bioaccumulation and biomagnification as shown in the attached figures indicate the hazard to higher trophic organisms from ingestion of selenium. With higher concentrations of selenium in the inflowing water, selenium will be more abundant in the food chain.

The most prominent food chains in the Salton Sea are (1) phytoplankton > zooplankton > pileworm > forage fish > predatory fish > fish-eating bird, and (2) a shorter chain: phytoplankton > zooplankton /pileworm > water bird (Setmire and others, 1993). These food chains have changed as the tilapia, corvina and other fish have died-off. While once abundant, fish in the current Salton Sea are virtually absent. The goal of the South Marine Lake Alternative is to bring back the fishery by lowering the salinity. The outflow from the South Marine Lake to the hyper-saline pond provides the needed balance to maintain a lower salinity from the freshwater inflows of the New and Alamo Rivers. The food chains listed above should return as the salinity is lowered and fish reintroduced.

The reduced size of the South Marine Lake compared to the Salton Sea coupled with the increased selenium concentration in the inflowing water will produce higher selenium concentrations in the biota of the South Lake. In the past, selenium concentrations in the birds of the Salton Sea were elevated: American coot = 12.3 ug/g (7.9-21 ug/g); Black-necked stilt 21.7 ug/g (19.0-27 ug/g); double crested cormorants = 24.5 ug/g (18-42 ug/g. Northern shoveler = 19.3 ug/g (9.1-47 ug/g, Ruddy duck = 11.7 ug/g (5.2-41 ug/g). This is a broad range of birds that have utilized the Salton Sea in the past and hopefully birds that will return as the South Lake's salinity is lowered. These ranges and concentrations reflect elevated selenium in the food chain as well as indicate the effects of biomagnifcation of selenium. Additionally, each species differs in its sensitivity or tolerance to selenium contamination. For example, avocets tolerate 4X the selenium concentration before embryo teratogenesis than ducks and about 2X the value for stilts (Skorupa 1998). The feeding level in the food chain also is important. The eared grebes feed upon smaller fish lower in the food chain than the double crested cormorants that that have twice the mean selenium concentration from feeding on larger fish. Overall, Heinz (1996) estimated that 10 ug/g is a good estimate for an embryotoxic selenium threshold, although there is a wide variation among species that is thought to be related to salinity tolerance or even more specifically to sulfate tolerance (Skorupa, 1998).

The main question is whether or not the increased selenium concentration in the inflow to the South Marine Lake will result in greater bioaccumulation rates and therefore greater exposure to organisms higher in the food chain. Even though the selenium concentration in the water stays at 1 ug/L, greater uptake by phytoplankton and food chain biomagnification will likely increase selenium concentrations in the biota. With concentrations already at levels of concern or for some at threat to survival, any increase will probably cause a reduction in hatching success for sensitive to moderately tolerant species and for more sensitive species, some level of embryo teratogenisis.

As water conservation measures become more widespread in the Imperial Valley, selenium concentrations in the inflowing water will increase toward the median selenium concentration of 28 ug/L found in subsurface drainwater in the Imperial Valley. A wide range of possible flow volumes to the North or South Marine Lakes is within the range of probability. As has been mentioned in the discussion of the North Marine Lake Alternative, there is a point in the continuum of water conservation where phosphorus concentrations will decrease sufficiently that eutrophication might begin to decrease? The Salton Sea water is high in sulfate. Although there is competition between selenate and sulfate for uptake by some phytoplankton, selenate reduction begins in the surface drains and by the time the water discharges to the Salton Sea there is selenite and no selenate. Sulfate and selenite have different pathways for uptake by phytoplankton (US EPA draft criteria for selenium, 2004). Whether uptake by phytoplankton or bacterial reduction, selenium will be available to the biota at higher concentrations than before, placing more sensitive birds at risk and increasing the probability of reproductive impairment or hatching success The point at which this process ends depends on the political/socio/economic struggle between water for urban/suburban use and water for agriculture.

Hydrologic Effects: Flow models and the eutrophication models will provide information about the stratification of the South Marine Lake and the frequency and effects of turnover. The South Lake will be subject to any flooding that occurs from San Felipe Creek, which in the past 30 years has experienced at least one major flood – tropical storm Kathleen.

D. Hyper-saline Sea

Water-quality Effects: The hyper-saline pond is the remnant of the Salton Sea. It is the outflow receptor for salt to keep the South Marine Lake salinity in check with evaporation. The hyper-saline component of the South Lake alternative will significantly increase in salt concentration. Although most of the selenium removal mechanisms, both bacterial and chemical continue to function at higher salinities (bacterial removal of selenium was found in the Dead Sea by Oremland (2001), there will be periods where the food chains are altered and selenium uptake by benthic invertebrates and other food chain items will become sufficient to prove hazardous to birds utilizing them as a food source. Brine shrimp, brine fly larva and other salt tolerant organisms will continue to feed on these organisms found in the hyper-saline pond. Shorebirds will feed on larval forms around the periphery of the hyper-saline pond and bioaccumulate selenium present in the hyper-saline water. Even though the kinetics for selenium oxidation or reduction are often favorable, selenium can nevertheless be reduced by bacterial processes. Selenium can also evapoconcentrate, levels as high as 360 ug/L are found in subsurface drainwater in the Imperial Valley, so that concentrations in the hyper-saline pond could be higher than any other water body in the Imperial Valley.

Hydrologic Effects: The Whitewater River will deliver water to the South Marine Lake, but cannot be sized to contain flooding that can occur from the mountains and canyons in the Palm Springs and La Quinta areas. Much of the desert area in the pocket of Palm Springs, Rancho Mirage, La Quinta and Indio has been urbanized and the rainfall runoff characteristics of the desert drastically altered so that desert thunderstorms could produce significant flooding that would impact the hyper-saline pond, beginning new cycles of changing salinity and biota.

E. Outlet from South Marine Lake to Hyper-saline Pond

Canal from the South Lake to the northern hyper-saline pond will provide an outflow for the South Lake so that salinity control can be maintained. The canal will provide habitat from in the transition from the marine habitat of the South Lake to the hyper-saline pond.

F. Impermeable Dam

Constructed to separate the South Marine Lake from the hyper-saline Sea on the north. The rock substrate will be habitat for attached algae, barnacles and other biota.

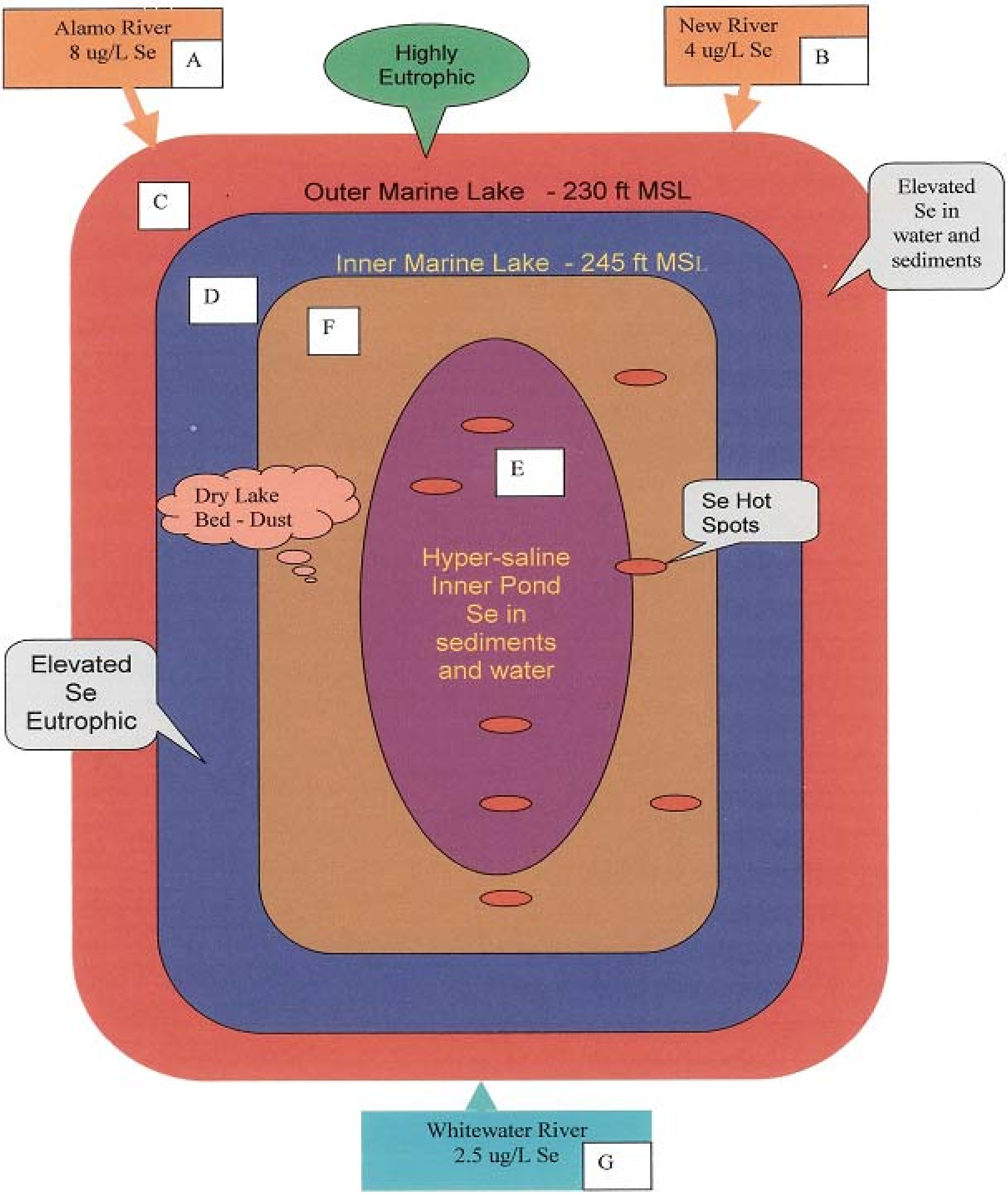
G. Whitewater River

Water quality effects: The selenium concentration in the Whitewater River Is about 2.5 ug/L. It will add to the selenium load of the South Marine Lake, but not substantially. Any sediment from the Coachella Valley should be deposited prior to reaching the South Lake. Historically, elevated concentrations of DDE have been found in some of the drains in the Coachella Valley.

H. Residual Pools

As in the North Marine Lake alternative, these residual pools will form in the dray areas around the hyper-saline pond. The highest selenium concentrations in bottom sediments were found off of the Whitewater River delta and in the area near Desert Shores. Any pools forming in these areas would have very high concentrations of selenium and colonization by invertebrates, brine fly larva and other insect larva will provide a highly toxic selenium diet for birds feeding on the biota in these pools.

Alternative 3, Concentric Ring Dikes with Cascading Reservoirs



Alternative 3, Concentric Ring Dikes with Cascading Reservoirs

Flow chart components of the Concentric Ring Dikes Alternative

A. Alamo River

Same as discussion for other alternatives. The delta area will be further from the existing delta due to the elevation change from –227 to –230. The embayments along Garst Road and the east and west sides of Red Rock will be dry. These areas were about one foot in depth and provided excellent habitat for shorebirds and water birds. The present day Sea has a mixing zone in the delta of the river where the selenium concentration is diluted by the1 ug/L water of the Sea. There will be no dilution of the inflowing river water in the delta of the Alamo River.

B. New River

Same as above.

C. Outer Marine Lake

The outer Marine Lake at an elevation of –230 ft MSL will received the entire load of selenium and nutrients from the Alamo, New and Whitewater Rivers. It will be a shallow system along the periphery of the outer ring where the intense sunlight of the desert environment will cause extensive proliferation of algae and drastic swings between day and night time dissolved oxygen concentrations. Selenium will be incorporated into the algae, phytoplankton and benthic organisms and place the birds at risk for reproductive depression. The New River delta has often had outbreaks of botulism and other diseases that do not occur in the saline environment of the present day Sea. The sediment load of the New and Alamo Rivers will be deposited in this outer ring and will have elevated selenium concentrations. Significant evaporation will also occur in the outer ring, concentrating selenium to higher levels than the inflowing water. Selenium concentrations in the sailfin mollies were elevated in the present-day Salton Sea. The connectivity of the drains for desert pupfish will place this endangered species at risk due to the bioavailability of selenium.

D. Inner Marine Lake

The inner ring will experience many of the same problems as the outer ring, though it will not have the shallow feeding areas. Selenium concentrations in the water should decrease somewhat as phytoplankton die and provide an organic source for the bacteria. Selenium will be reduced to elemental selenium, hydrogen selenide and organoselenide compounds. Bottom sediments in parts of the inner ring already are elevated in selenium concentration and may become oxidized by the more frequent aerobic conditions (?) and increase their bioavailability. It would seem reasonable to predict that the large fish in the inner ring will have elevated selenium concentrations and place the fish eating birds at risk.

E. Hyper-saline Inner Pond

Same as discussions provided in the other alternatives.

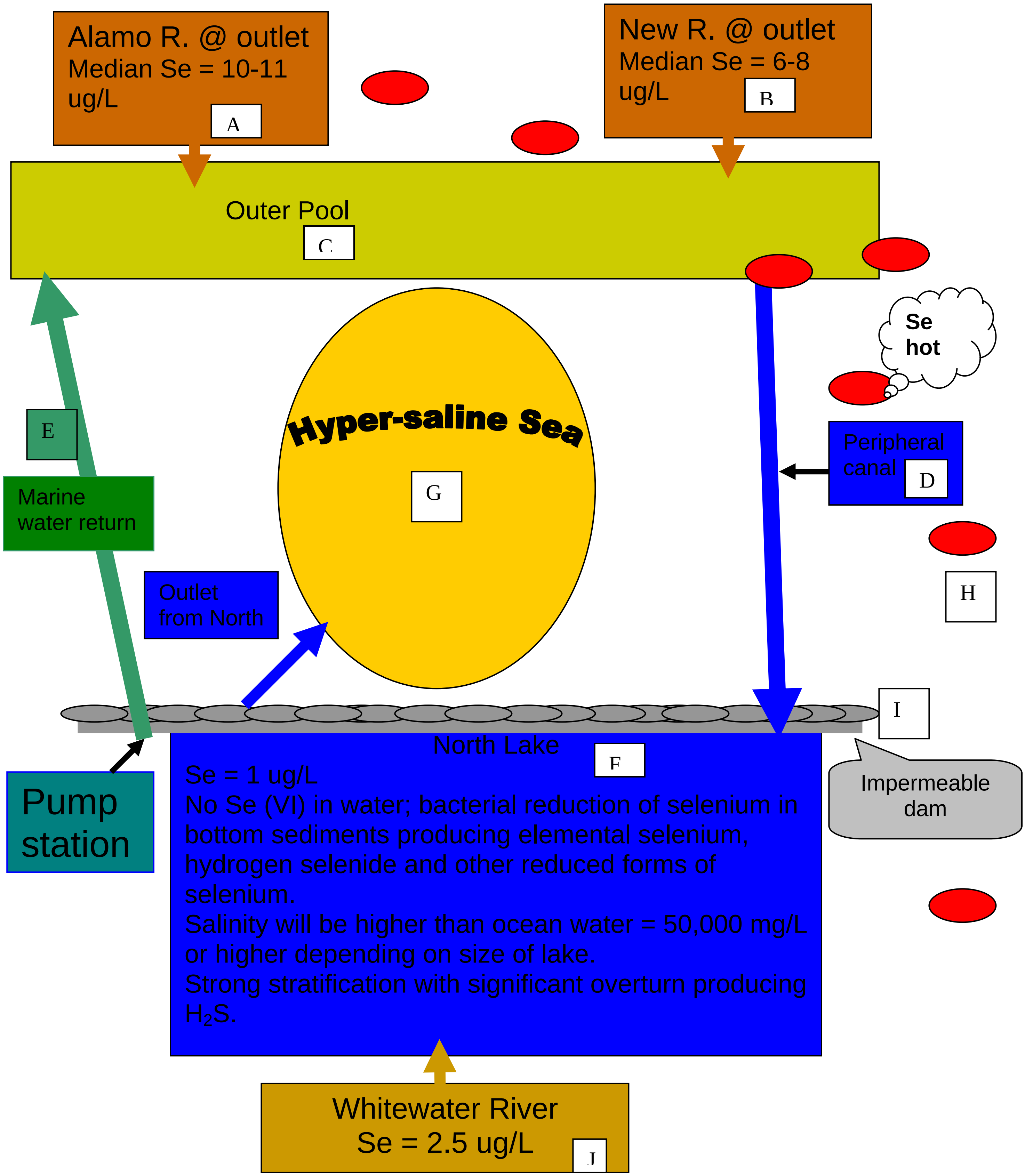
F. Dry Lakebed

With decreasing inflow to the system, there will be significant areas of dry lakebed exposed. Problems with blowing dust would be a problem.

Selenium Hot Spots

Will be the same as in other alternatives.

Alternative 4, Revised Salton Sea Authority Alternative



Alternative 4, Revised Salton Sea Authority Alternative

Flow chart components of the Revised Salton Sea Authority

A. Alamo River at Outlet

Will be the same as for North Lake Alternative #1&2.

B. New River at Outlet

Will be the same as for North Lake Alternative #1&2.

C. Outer Pool

If 1K cfs of water at 50 K dissolved solids from the North Lake is mixed with 1.5 K cfs of water at 2.5 K dissolved solids from the New and Alamo Rivers, the dissolved solids concentration in the Outer Pool = 21,5 K. If water conservation is achieved by a 20 percent reduction in tailwater and operational loss, the selenium concentration in the Alamo River is about 10 ug/L and in the New River about 7 ug/L. When mixed with water having 1 ug/L from the North Lake, the selenium concentration in the Outer Pool will be between 5 to 6 ug/L. The Outer Pond will be eutrophic with salt tolerant biota. Selenium will be incorporated into phytoplankton and be accumulated by the benthic organisms. The Outer Pool may not stratify, therefore the selenium in the Outer Pond will not be sequestered, but will remain in the biota and accumulate in the food chain. Saltwater fish will be present in the Outer Pond and will bioaccumulate selenium to levels that will be a threat to fish-eating birds.

D. Peripheral Canal – same as previous discussions

E. Marine water return – similar to Peripheral Canal, but with marine organisms

F. North Lake – same as previous discussions of North Marine Lake

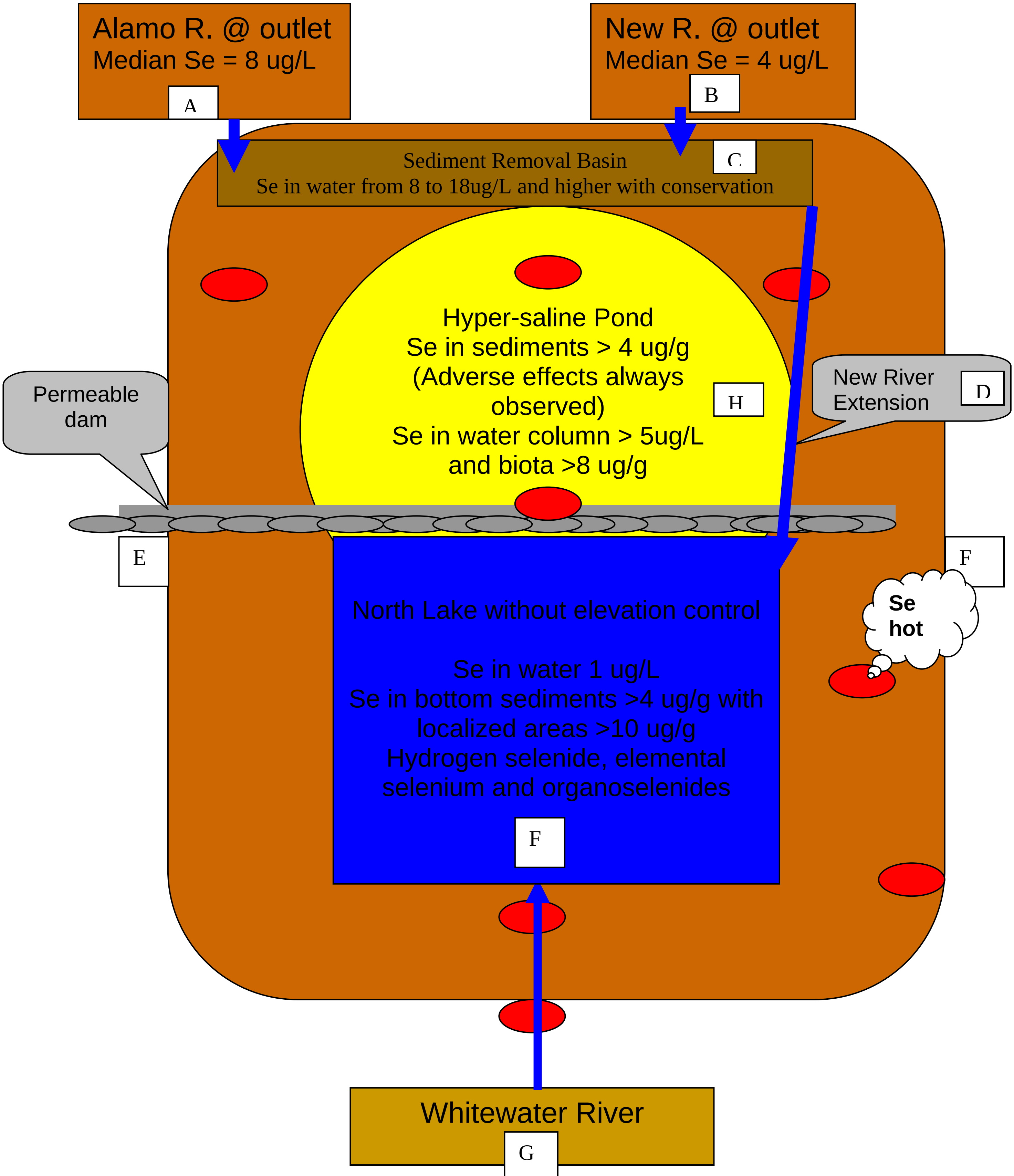
G. Hyper-saline Sea – same as previous discussions hyper-saline Sea

H. Selenium hot spots – same as in previous discussions

I. Impermeable Dam

J. Whitewater River – same as in previous discussions

Alternative 5, Mid-Sea Barrier with North Marine Lake



Alternative 5, Mid-Sea Barrier with North Marine Lake

A. Alamo River– same as previous discussion of other alternatives.

B. New River – same as previous discussions of other alternatives.

C. **Sediment Removal Basin** - Sediment removal ponds also will be the same as other options with selenium in water from 8 to 18 ug/L and higher with increased water conservation. Significant threat to biota in these basins due to elevated selenium in water and in food chain.

D. New River and Alamo River peripheral canal – High flow rate and concrete lining to reduce sedimentation will help to reduce selenium threat to biota in spite of elevated selenium concentrations in water**.**

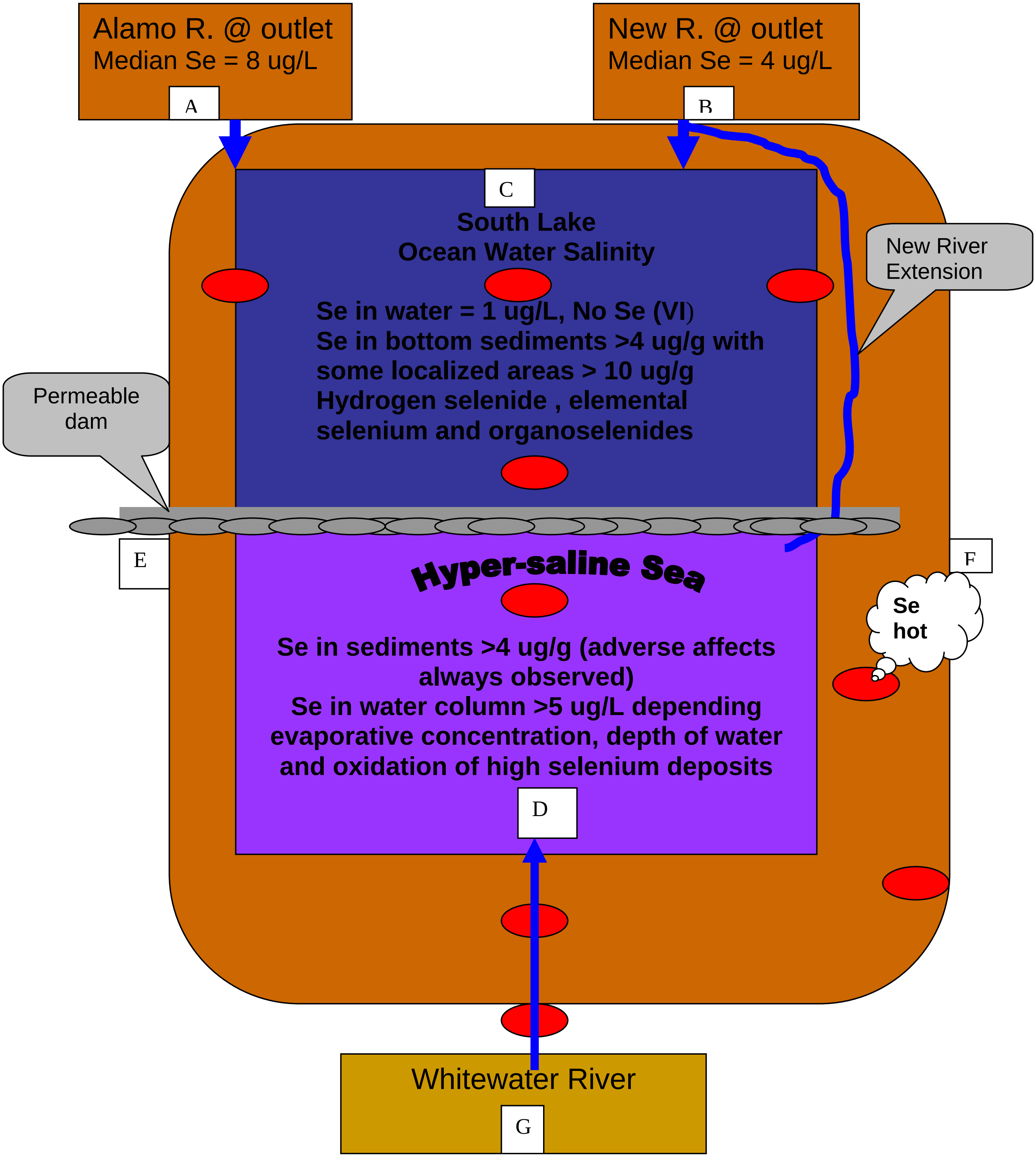
E. Permeable Dam – Allows water elevation on both sides of the dam to equilibrate and slow movement nutrients in water across the barrier to the Hyper-saline pond.

F. North Marine Lake – no elevation control so the lake will be shallow and there will be no connection to existing marinas. Selenium will continue to be removed from the water column by bacterial processes as well as uptake by phytoplankton. Removal by anaerobic processes in the bottom sediments will keep the selenium in water to 1 ug/L. There will be elevated areas of selenium in the bottom sediments to concentrations greater than 4 ug/g with localized areas greater than 10 ug/g. There will be the possibility of oxidation of selenium in shallow areas of high selenium accumulation (depending on possible redistribution by wave action) and increased bioaccumulation and risk to biota.

G. Whitewater River – continued contribution of lower concentrations of selenium to the North Lake.

H. Hyper-saline pond - will be similar to the other alternatives. The biota in the pond will have selenium at concentrations greater than the 8 ug/g threshold. Shorebirds feeding on invertebrates could possibly have selenium concentration in their eggs as high as 10 ug/g, the level Heinz (1996) estimated to be the embryotoxic threshold. Selenium in the sediments likely will be greater than 4 ug/g, a level where adverse affects on biota are always observed. Selenium concentrations in the water will be greater than 5 ug/L and depending on evaporative concentration and depth of the water could be higher as water conservation continues to decrease the dilution of subsurface drainwater in the inflowing water.

Alternative 6, Mid-Sea Barrier with South Marine Lake



Alternative 6, Mid-Sea Barrier with South Marine Lake

Flow chart components of the South Marine Lake Alternative

A. Alamo River and Sediment Removal Ponds

Same as previous discussion of other the alternatives. Sediment removal ponds also will be the same as other options with selenium in water from 8 to 18 ug/L and higher with increased water conservation. Significant threat to biota in these basins due to elevated selenium in water and in food chain.

B. New River

Will be same as previous discussions of other alternatives

C. South Marine Lake

No elevation control so the south lake will shrink as will the north hyper-saline lake – water levels will equilibrate. Rich habitat areas along the southern end of the current Sea will be lost as the river deltas move seaward. Connectivity with the drains will be lost which is a serious problem for the desert pupfish. As tailwater and operational loss are conserved and the flow in the drains reduced, selenium concentrations in the drains will increase and the desert pupfish will be at risk for reproductive failure as concentrations exceed the 6 ug/g threshold above which there is increased risk of teratogenesis and embryo mortality for warm water fish. Without connectivity, the pupfish may not survive the fluctuating flows in the drains.

Selenium concentrations in the water entering the South Marine Lake will continue to increase as water is conserved. The composition of inflowing water will begin to approach that of subsurface drainwater. Bacterial processes in the sediments of the South Marine Lake will continue to reduce selenium to elemental selenium, hydrogen selenide and various organoselenide compounds. These compounds will accumulate in the hypolimnion and pose a threat to fish in the overlying water if there are long periods of stratification followed by a major mixing. Food chain bioaccumulation and biomagnification of selenium will increase to higher levels than the current Sea placing biota in the North Marine Lake at risk for reproductive failure. The levels in the food chain will increase to greater than the10 ug/g threshold for possible threat to survival. Fish higher in the food chain and the larger fish-eating birds will be at greatest risk.

D. Hyper-saline Pond

Will be similar to the other alternatives although with the added inflow from the New River will maintain a lower salinity than in the other alternatives. The lower salinity will maintain conditions where the biota in the pond will have selenium at concentrations greater than the 8 ug/g threshold. Shorebirds feeding on invertebrates could possibly have selenium concentration in their eggs as high as 10 ug/g, the level Heinz (1996) estimated to be the embryotoxic threshold. Selenium in the sediments likely will be greater than 4 ug/g, a level where adverse affects on biota are always observed. Selenium concentrations in the water will be greater than 5 ug/L and depending on evaporative concentration and depth of the water could be higher as water conservation continues to decrease the dilution of subsurface drainwater in the inflowing water.

E. Permeable dam

Allows water on both sides to equilibrate in surface elevation and slowly increase chemical concentrations on both sides of the dam.

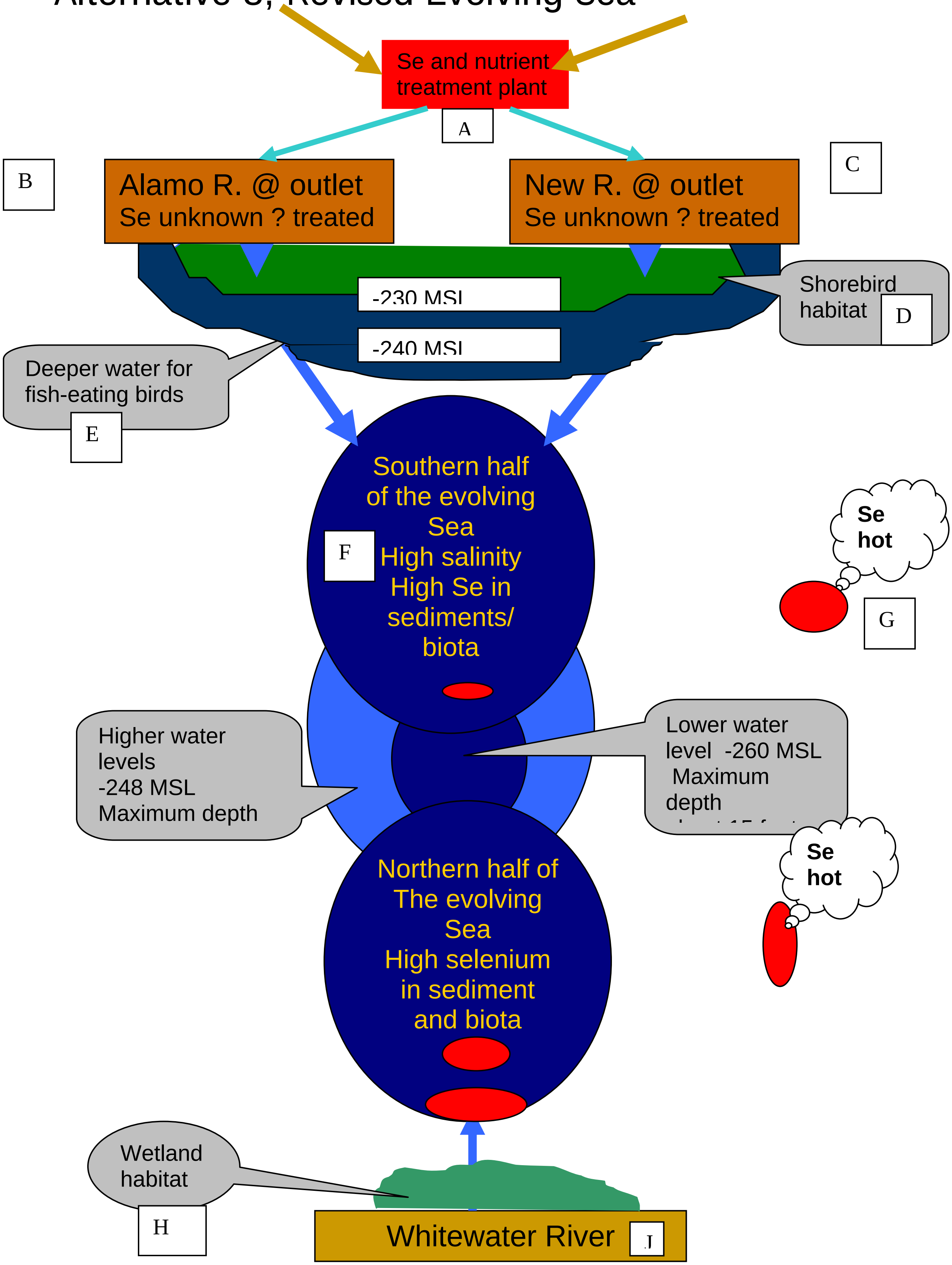
F. Selenium Hot Spots

Will be same as discussed in other alternatives. There will be more sediment exposed, especially in areas where the highest selenium concentrations were measured such as the Desert Shores and the delta of the Whitewater River. These residual ponds will have greater potential for contamination to birds feeding on diverse organisms inhabiting these ponds.

Alternative 7, Mid-Sea Barrier with South Marine Lake and Habitat

Alternative number 7 is similar to 6 except it involves a selenium/nutrient treatment plant with no description of the processes for removal. It is difficult to determine the effectiveness of such a treatment plant and what issues the treatment plant might raise that could be problematic. Assuming the technology is effective at reducing selenium and nutrients, the new shallow habitat pond with no selenium would not present any risk to wildlife utilizing the habitat. The Marine Lake would likely have selenium concentrations at 1 ug/l in the water for some time. Because the sediments would be the same as in Alternative 6, major overturn would bring reduced selenium compounds into the water column and would pose a problem to biota in the lake. If the lengthy stratification and single mixing event scenario that has been presented the selenium load in the sediments would gradually decrease as it is released to the atmosphere as dimethlyselenide or hydrogen selenide, The hyper-saline lake and the residual ponds would have the same conditions as alternative 6. The ability of the treatment plant to remove selenium and/or phosphorus remains questionable. The Kent SeaTech technology holds some promise, but more research is needed before larger trials can be attempted, let alone full project implementation.

Alternative 8, Revised Evolving Sea



Alternative 8, Revised Evolving Sea

Flow chart components of the Revised Evolving Sea Alternative

A. Selenium and Nutrient Treatment Plant

Several different systems are mentioned: Kent Sea-Tech, gravel filters, and ABMet. Most systems that have been developed deal with a higher initial selenium concentration than in the Alamo or New Rivers. Many technologies have worked in the laboratory, but few make their way to full scale implementation. For natural systems, full scale usually means loss of control over variables, the needed size is huge and unmanageable, and the selenium is not lost, but rather converted into a different form that still has to be dealt with. The Kent Sea-Tech operation has merit for phosphorus removal and can produce a marketable product. It relies on the uptake of selenium by algae that in turn are fed upon by fish in controlled tanks. At projected flows of 400 to 900 thousand acre-ft/yr with a mean projected flow of about 790K acre-ft/yr. The selenium load would be about 8-9 tons/year or at 6ug/g/fish equals about 950,000 three pound fish to be sold or disposed or. Since 6 ug/g is the human health advisory, fish would have to be harvested before reaching that limit if some product is desired from the fish.

The treatment plant would also have to remove phosphorus to control eutrophication in the upper and lower freshwater impoundments. If the flow is reduced to 790 K acre-ft/yr, the phosphorus load would be reduced from its current concentration and load to one that would produce a lower eutrophic state in the shallow and deep impoundment.

B. & C. Alamo and New Rivers at Outlet

The selenium concentration in the Alamo River at the Outlet after treatment is unknown, but would have to be at 1 ug/L to be protective the wildlife from bioaccumulation and biomagnification.

D. Shallow impoundment (shorebird habitat)

If the eutrophication is significantly reduced and the selenium is at 1 ug/L, there will be some accumulation of selenium in the bottom sediment of the shallow impoundment. However, with aerobic conditions in the shallow water, the concentrations that result should be protective for the shorebirds due to a fairly short food chain and minimal bioaccumulation.

E. Deep water impoundment

In the deep water impound, some stratification will occur and reducing conditions will cause some reduction of what little selenium is in the water to elemental selenium and various reduced forms. Nevertheless, the accumulation of selenium in the food chain should be minimal and no reproductive impairment will occur.

F. Southern half of the evolving Sea

As the Sea recedes, the constituents in the water will concentration by evaporation. Coupled with the selenium already in the sediments where many of the highest concentrations detected might become available to the brine shrimp and brine fly larvae and could be problematic to birds feeding on this prey.

Alternative 8C, Revised Evolving Sea with Marine Lake

Based on the possibility of long-term stratification of the North or South Marine Lakes followed by a major mixing event that would destroy all biota in the Lake, Dr. Amrhein of UC Riverside has presented a revised alternative #11 detailing a 27,000 acre water body on the south end of the Sea. The size of the Lake is based on the estimated minimum inflow that is necessary to sustain agriculture. That inflow is the amount of subsurface drainwater that is being discharged to the Sea and in that sense the only obligation that the irrigation district has to discharge to the Salton Sea.

The resulting South Marine Lake would be deep enough to provide an anaerobic zone during stratification where bacterial processes would continue remove selenium from the water column of the inflowing water.

Dr. Amrhein's proposal seemed to have significant merit. If the "fatal flaw" presented by the modeling runs that Geoff Schladow presented holds true, then the alternative presented by Dr. Amrhein appears to be the most logical alternative available.

Executive Summary From Eutrophication/Selenium Viability Workshop, July 25-27, 2005

A workshop was held July 15-27, 2005 at Lake Tahoe to evaluate the current preferred alternatives for the Salton Sea. A group of professionals with extensive experience in eutrophication, selenium and water-quality issues were invited to provide this review. The group included Geoff Schladow of UC Davis (eutrophication and geochemical modeling), Chris Amrhein (geochemical cycling) and Michael Anderson (eutrophication modeling) of UC Riverside, Chris Holdren (limnology and geochemical modeling) and Paul Weghorst (Project Manager of the Salton Sea Value Engineering Study) USBR Denver, CO, Dale Robertson (eutrophication and hydrodynamic modeling) of the USGS, and Jim Setmire (selenium cycling in the Salton Sea) USGS/USBR (retired). Also attending were Michael Cohen of the Pacific Institute in Boulder, CO and Doug Barnum of the Salton Sea Science Office in La Quinta, CA.

The goal of the meeting was to evaluate the role of selenium, eutrophication and dissolved oxygen concentration for each of the 11 preferred alternatives. Information from this evaluation will be incorporated into the Salton Sea Restoration Project -Value Planning Study – Treated Foundation Alternatives Cost Estimates spreadsheet and the Salton Sea Restoration Project, Feasibility Study – Phase 1, Value Planning Study currently in draft form.

Paul Weghorst indicated that alternatives containing a dam across the middle of the Sea need a more robust construction to provide for a loss of life risk of less than 1 in 1000. He also provided the Alternatives and Associated Component Construction Costs spreadsheet. The major components of each alternative were identified and given an overall weighting. Within each component a Draft Weighted Criteria Matrix was developed. A weight was assigned to each criterion in the matrix, a value selected and a score computed.

The scores were compiled for each of the elements and the alternatives were ranked. This ranking is based on the alternatives having no “fatal flaws.” The primary goal of the Lake Tahoe meeting was to develop a risk analysis of each alternative to determine if any fatal flaws existed and to characterize the selenium, eutrophication; and dissolved oxygen concentration conditions in the surviving alternatives. The group was also to develop revisions to the value-planning matrix and to determine the type of fishery that would be sustainable.

To evaluate the alternative, the volume of water that would be used for evaluation had to be determined. A probability curve was presented that showed the predicted range of inflow to the Salton Sea. It was indicated that the Coachella discharge depends on groundwater for its contribution to the volume in the Salton Sea. The New River which discharges water at the International Boundary at Calexico could lose up to 90 percent of its flows across the border. This flow would be lost as Mexico developed power plants that utilize water for cooling along with optimizing other uses of their water. A reduced flow of municipal effluent and/or brine would comprise the resulting flow coming into the Imperial Valley and the Salton Sea. The flow distribution model that was presented is based on historical and projected range of flows coming to Salton Sea. The major component of uncertainty is in the amount of tailwater. The amount ranges from 0.426 to 0.716 million acre-feet per year depending on the group making the calculation. Jim Setmire indicated that chloride and/or dissolved solids concentrations in subsurface drainwater and concentrations in the flow of the Alamo River at the Outlet can be used to develop a mixing equation. The results indicate that about 77 percent of the flow is dilution water (tailwater and operational loss).

Jim Setmire looked at selenium in the different components of the preferred alternatives. He indicated that water conservation by means of tailwater conservation and lateral interceptors to reduce operational loss would cause an increase in selenium concentration in the water entering any of the preferred alternatives. A 20 % reduction in tailwater would increase the selenium concentration in the Alamo River at the Outlet from 8 to 10 or 11 ug/L and from 4 to 6-8 ug/L in the New River. A 50 percent reduction would result in a selenium concentration of 18 ug/L in the Alamo River and a dissolved solids concentration of 4200 mg/L. The effects of these increases would be seen in the sediment ponds that are integral to the North Marine Lake options. Increased selenium concentrations in highly eutrophic water would elevate the bioaccumulation of selenium in the food chain. Because selenium also biomagnifies in the trophic ladder, fish and birds feeding on these biota will be at greater risk than current conditions. For example, data presented in Schroeder and others, 1993 indicated that sailfin mollies had selenium concentrations ranging from 3 to 6 ug/g which according to J. Bennett (personal communication, 1996) are at levels of concern for warm-water fish. Mollies from two other drains had selenium concentrations exceeding the 6 ug/g threshold, above which there is increased risk for teratogenesis and embryo mortality. As water is conserved, selenium concentrations will increase to 11ug/L, 18 ug/L or higher causing mortality to sailfin mollies and, therefore, to desert pupfish. Food items will have selenium concentrations greater than the 4 ug/g area of concern for dietary exposure and be at levels greater than 8 ug/g where there is a threat to survival.

The water conveyances such as the peripheral canals will be concrete lined and maintain relatively high velocities to prevent sedimentation and will not likely pose much threat to biota. Water in the marine lakes, both north and south, will have elevated selenium concentrations in the inflowing water. Phytoplankton will incorporate selenium and enter the food chain in the epilimnion. Selenium concentrations in the food chain will be elevated sufficiently to cause concern to larger fish-eating birds. Anaerobic bacteria in the sediments of the lakes will continue to remove selenium from the water column and form hydrogen selenide, elemental selenium and organoselenide compounds. These compounds could be problematic under the scenarios presented by Geoff Schladow.

Selenium in bottom sediments were highest in the North Lake samples collected by Levine Fricke Recon and also by Schroeder, Setmire and Roberts in July of 1998. Elevated selenium was found in samples collected off of Desert Shores and also seaward of the Whitewater River Delta. Several researchers have found that selenium concentration in sediment is a “reliable predictor of adverse biological effects and that a preliminary toxic threshold existed at about 2.5 ug/g and that adverse affects were always observed at selenium concentrations greater than 4 ug/g" (Van Derveer and Canton (1997).

As water inflow decreases and the marine lake and hyper-saline pond decrease in size, residual pools will form in exposed areas from seepage and precipitation. Selenium in these pools will concentrate by evaporation or oxidation of high selenium sediments and cause significant problems to the wildlife feeding on the thriving food chains that will develop in these ponds. The hyper-saline pond will have periods where selenium concentrations in larval forms is very high and birds feeding on these food items will be at risk.

Geoff Schladow who has been working on modeling phosphorus and phosphorus resuspension in the Salton Sea using one-dimensional thermodynamic models. He has used this and other models to determine eutrophication and its effects in lakes around the world. For the Salton Sea he developed and ran a number of simulations using a one-dimensional thermodynamic model to determine the events and hydrologic factors driving stratification and mixing. Although the current Salton Sea has a number of minor and short-lived stratifications during the year, the major stratifying occurs near June as a thermocline develops. There is a tilting of the thermocline due to seiches in the Sea. The model predicts that a shrinking lake will mix all year round with 2-3 month periods of stratification at 14 meters. A clearer Sea will be more homogeneous and have a different mixing pattern. A shrinking Lake will have full mixing year round with 2-3 month periods of stratification at 14 meters. There will be 60 days during the year when there is stratification and cold water for tilapia (below 10 degrees at the surface).

A large shallow sea has large number of cold days and increased risk to tilapia, but a smaller sea also is more uniform. During winter when the Sea is mixed it can get colder and colder. Since the surface is at thermal equilibrium with air, in summer slight micro thermoclines develop but breakdown as mixing occurs.

In a turbid Sea half of the size, there is a diffuse metalimnion. At half the size as a result of a dam in the middle of the Sea, a much sharper thermocline develops and stays strongly stratified for a longer time. There will only be one mixing event during the year.

Other lakes when cut in half did not change the pattern of the stratification and mixing cycle. Wind, convective cooling and sheer are the mixing forces behind stratification and mixing. The effect of cooling on mixing does not change the number of days the Sea stays stratified nor does wind stirring affect number of days. Sheer production is a function of the size of the system, which means there is a drastic change as the Sea is cut in half by a dam. There is a1 order of magnitude reduction in energy of mixing. Reducing the sheer means less energy for mixing. When wind moves waves and the surface layer is stratified, the upper water goes one way and bottom water tilts or goes the other way creating a shear. The Marine Lake (half of the Sea) is stable and will not mix. The North or South Marine Lake will have anoxic conditions most of the year and produce vast amounts of hydrogen sulfide in the hypolimnion. When The Sea finally mixes the massive amount of hydrogen sulfide will kill of all of the fish in the Marine Lake. The reduced compounds (ammonia, hydrogen sulfate and hydrogen selenide) will use up all of the oxygen in the lake and hydrogen sulfide gas, ammonia, and hydrogen selenide will emanate from the lake and potentially be strong enough to kill people downwind of the Sea.

Michael Anderson observed difference in predicted zones of sediment accumulation within the Salton Sea. The North basin accumulates more sediment compared to the South basin. There is a small area of deposition in the south area. Erosion, transport and deposition are the major processes moving detrital material in the Sea. Surface area and mean depth are the only factors needed to determine the depositional areas. The current Sea has an accumulation of 12.1 %, North Marine Lake with Dam = 27.4 -35 %, South Marine Lake with Dam = 28-35%, North Marine Lake without elevation = 0-57%. For a shallow sea there is no accumulation of sediment, only erosion and transportation.

Dale Robertson presented data on the increase in load versus response to changes in concentration. He used the BATHTUB and WiLMS models to show these. His modeling results used no particulate phosphorus for reduced flows. Every scenario that he ran showed that concentration should go up with smaller Sea. A deep evolving Sea has the same curve and shows that there might be less eutrophication and phosphorus. He found that there is a dimensionless factor and that the curve is the same and dependent only on the volume. When loading fraction is same as the volume then there is no change. If there is smaller volume then concentration goes up. If you decrease the load more than the volume then the concentration goes down. He showed changes in concentration for each of the preferred alternatives. However, the dimensionless factor remained the same – the phosphorus concentration varied with the fraction of the volume of the current Salton Sea. He found that phosphorus concentrations will increase for most of the preferred alternatives even under decreased inflows resulting from tailwater conservation.

Chris Amrhein showed results from studies conducted on hydrogen sulfide production in the Salton Sea. He indicated that bacteria mediate hydrogen sulfide reactions as it diffuses out of the sediments and back to sulfide. There also is fixation of carbon by sulfate oxidizing bacteria. There is sulfate oxidation of $H_2S + CO_2$ by bacteria and fixation of carbon by sulfate oxidizing bacteria. Phytoplankton adds more organic matter for the internal sulfate cycle. The Salton Sea is a bacterial dominated lake. The same processes occur for selenium and ammonia. Nutrient loading fuels these reactions, but the Sea is still dominated by the bacterial cycle.

Risks

1. H_2S and NH_3 kill quickly.
2. Se kills slowly.
3. Hot/cold is uncomfortable.
4. Eutrophication looks bad.

Currently, flux measurements of H_2S based on porewater sulfide concentrations predict that 75,000 metric tons of H_2S per year are generated based on summer measurement. This amount can also be based on maximum decomposition rates of algal biomass. If the algae that are produced were degraded by anaerobic sulfate composition, there would be 78,000 metric tons of of H_2S per year. If all of the total inflowing P was converted to algal biomass and degenerated anaerobically producing H_2S, the subsequent release of hydrogen sulfide in one event would be catostrophic to the biota, the fish as well as to local residents depending on the prevailing winds.

At the end of his presentation, Dr. Amrhein suggested that a new version of model be run to confirm the results presented by Dr. Schladow and to determine the best size and depth of the Lake proposed by Dr. Amrhein.

Attachments:

Selenium in Sediments

270 soil cores representing 15 Imperial Valley fields

Median Se conc. = 0.2 ppm (min = 0.1 max = 1.3 ppm)

Bottom sediment - 48 surface drains in Imperial Valley

Median Se conc. = 0.5 ppm (min = 0.1 max = 1.7 ppm)

Se in bottom sediment of surface drains excellent correlation with % material finer than 0.062mm (sand/silt break)

Salton Sea bottom sediment – 11 sites

Median Se conc. = **2.7** ppm (min = 0.58 max = 11 ppm)

Selenium changes in Alamo River Delta and Salton Sea

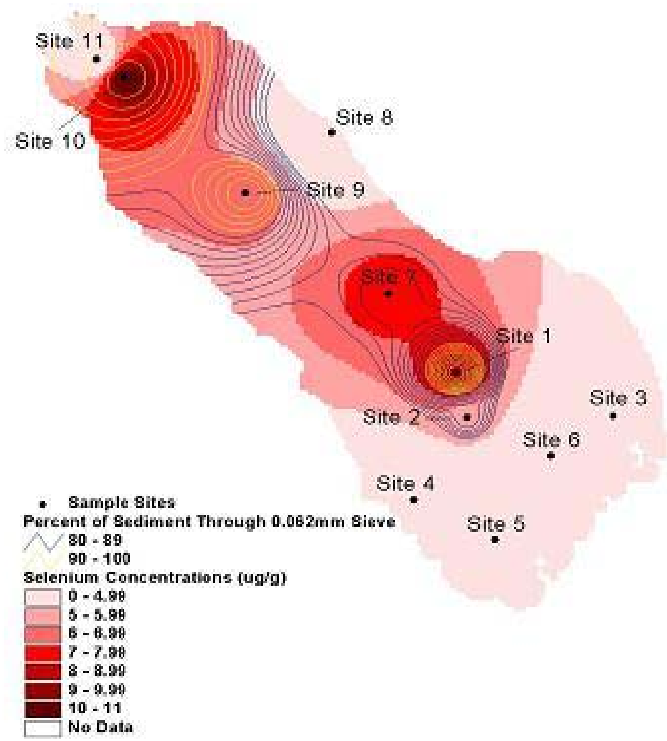
Selenium speciation – special sample June 1989

River side of interface had total Se = 6.35 ug/L
2.56 ug/L in +4 selenite state
3.79 ug/L in +6 selenate state

At interface had total Se 2.4 ug/L (method reporting limit)
1.79 ug/L in +4 selenite state
0.2 ug/L in +6 selenate state

Salton Sea water = 1 ug/L, none in +6 state

Salton Sea Selenium/particle size contour map



Selenium in Bird Livers

60% of eared grebes had Se > 30 ug/g (DW)

40% of species had Se >30 ug/g (DW) associated with high biological risk (Skorupa)

33% of double-crested cormorants had Se > 30 ug/g (DW) and had highest mean Se conc. of 24.5 ug/g

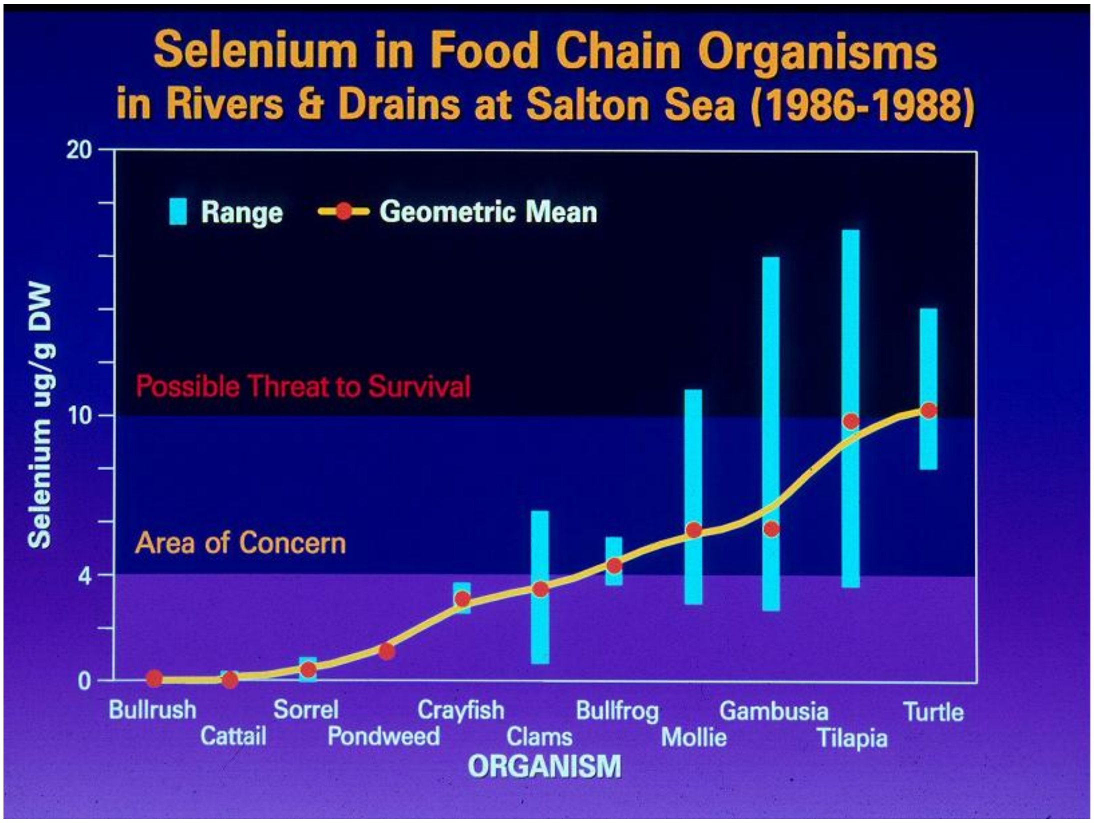
10% of northern shovelers had Se > 30 ug/g (DW) and had highest individual Se conc. of 47 ug/g

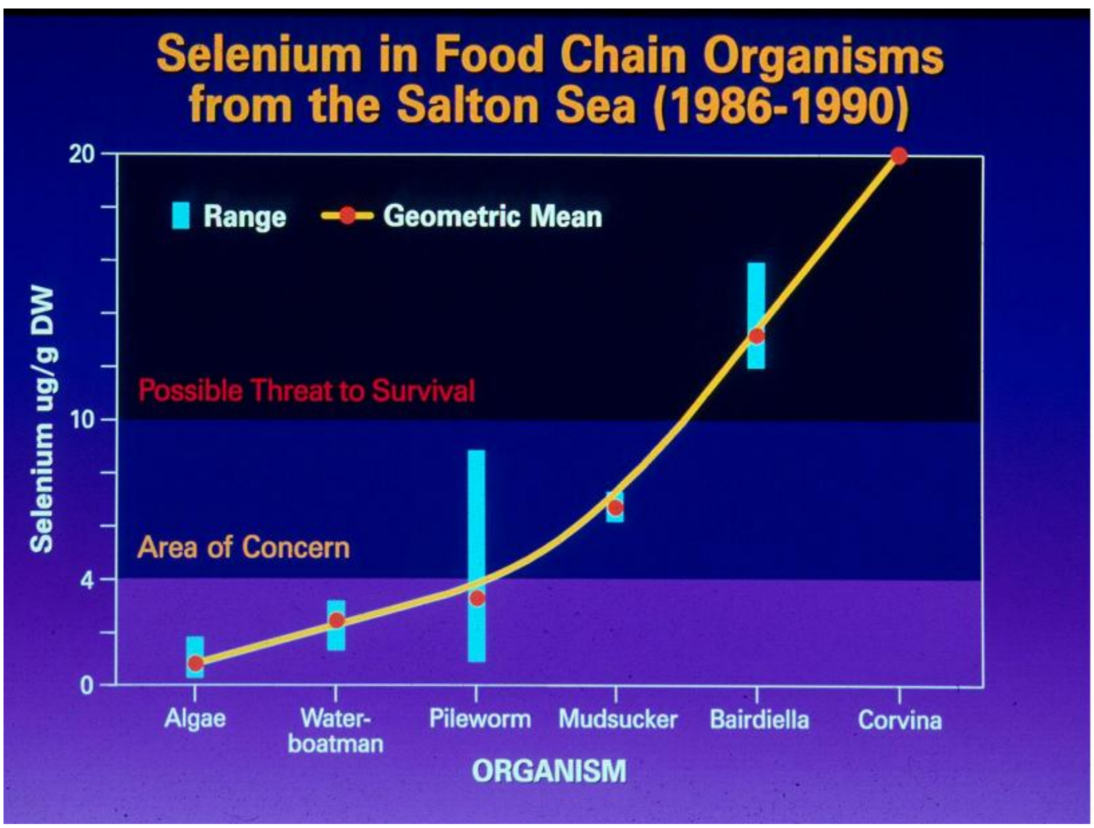
Selenium in Fish in the Salton Sea

Concentrations in ug/g wet weight (edible

Fish	River mouth	Salton Sea
Croaker	2.1(3.7)*	2.32 (n/a)*
Corvina	2.73 (2.9)*	2.3 (3.6)*
Tilapia	1.89 (n/a)*	2.39 (n/a)*

*California Toxics Monitoring Program


Selenium in Food Chain Organisms
in Rivers & Drains at Salton Sea (1986-1988)
Range
Geometric Mean
Possible Threat to Survival
Area of Concern
Selenium ug/g DW
20
10
4
0
Bullrush
Cattail
Sorrel
Pondweed
Crayfish
Clams
Bullfrog
Mollie
Gambusia
Tilapia
Turtle
ORGANISM


Selenium in Food Chain Organisms
from the Salton Sea (1986-1990)
Range
Geometric Mean
Possible Threat to Survival
Area of Concern
Selenium ug/g DW
20
10
4
0
Algae
Water-
boatman
Pileworm
Mudsucker
Bairdiella
Corvina
ORGANISM