Appendix G

Predictive Limnology:

The Likely Nature of Impoundment Ecosystems on the Margins of the Salton Sea

An analysis by San Diego State University

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The Likely Nature of Impoundment Ecosystems on the Margins of the Salton Sea

Analysis of a project proposed by the Pacific Institute

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EXECUTIVE SUMMARY

The impoundment ecosystems proposed by the Pacific Institute would have ecological and recreational values determined primarily by salinity and contaminant levels. As proposed, equilibrium salinities on the order of 3-5 g/L would be quickly (< 6 months) achieved and contaminant levels would be higher than in the current Sea, especially in the impoundment receiving New River waters. Dense submerged and emergent aquatic vegetation would occupy possibly the major part of the impoundments, biting insects would increase in abundance, both fish and birds would be exposed to a greater diversity of parasites, the fishery likely would be poor both for sport fishermen and fish-eating birds, boating would be restricted, and swimming out of the question.

More attractive ecosystem features would develop if salinities of at least 6-8 g/L and lower input of contaminants could be achieved. Salinities of 6-8 g/L might inhibit excessive development of aquatic vegetation. They might limit it to a few forms (e.g. *Ruppia, Najas*) that do not form such dense or as deep-growing beds as do less salinity tolerant potential invaders (e.g. *Hydrilla, Myriophyllum, Typha, Phragmites, Arundo, Schoenoplectus*). Salinities of 6-8 g/L could be achieved by diverting directly to the Salton Sea proper the major portion of inflow waters (> 70 percent, under present hydrologic regimen), including the entirety of the New River flow. Smaller inflows result in longer residence times in the impoundments and hence more evaporative concentration of inflow waters before they overflow into the Salton Sea.

Even with the best design, these impoundments and the eventually fishless Salton Sea proper would together represent much poorer conditions for fish-eating birds, especially the larger ones, and for recreation and economic development than would be provided by a Salton Sea with salinities reduced to 35-38 g/L, even if nutrient inputs were not much reduced.

INTRODUCTION

For roughly 40 years there has been increasing concern for the consequences of the increasing salinity of the Salton Sea, especially for its fish populations and aspects of the natural and human systems partly dependent on them. Analysis of engineering options for dealing with salinity increase and other problems, as well as scientific study of the Sea, accelerated with formation of the Salton Sea Authority (SSA) in 1993 and the establishment in 1997of a U.S. Geological Survey office, now called the Salton Sea Science Office (SSSO), in the region to propose and oversee scientific studies needed for better understanding of the Sea and the consequences for it of different engineering options. Since then many scientific and engineering studies and an analysis of environmental impacts of certain options have been carried out.

In October 2001 a private organization, the Pacific Institute for Studies in Development, Environment and Security, elaborated on earlier comments it had made and put forward "A Proposal to Preserve and Enhance Habitat at the Salton Sea." This has attracted both political and scientific attention because it represents an engineering option with low annual operating costs once built, does not depend on maintenance of current inflows to the Sea, and has some positive ecological aspects.

The essence of the Pacific Institute proposal is to build dikes that will impound low salinity waters at the northernmost and southernmost portions of the Sea and to allow the main body of the lake to become, eventually, a highly saline, fishless lake. At the northern end the dike would be constructed along the –240 ft elevational contour (current depth of about 12 ft), and at the southern end it would be constructed along either the –240 ft or –245 ft (current depth of about 17 ft) contour. These would have maximum depths of 10 ft (northern) and 10 or 15 ft (southern), given a project design that calls for impoundment water levels to be at -230 ft.

According to the Pacific Institute, this project would offer the following benefits:

7. Compatible with water re-allocation efforts
8. Sustainable over the long term
9. Increases diversity of habitats at the Salton Sea
10. Preserves and enhances fisheries in impounded areas
11. Promotes increased recreational and economic development opportunities
12. Compatible with other off-site actions

In November 2001 the Salton Sea Science Office, in response to interest in the Pacific Institute proposal, decided it was desirable to have a formal evaluation of that proposal by independent scientists, and began planning some workshops toward that end. Three principal areas of concern were defined: geological and engineering issues relating to dike construction; likely physical, chemical and biological characteristics of the new impounded ecosystems; and impacts on recreation.

The analysis presented here by SSERG focuses on the second of these areas. We also offer, however, comments on recreation impacts as these will be determined by ecological characteristics of the impoundments and main body of the lake.

This contribution was stimulated by invitations to some members of our group to participate in the SSSO workshops, by the belief that in their general features the nature of the impounded ecosystems are easy to predict on the basis of our collective knowledge, and by SSSO Director Dr. Milt Friend's opinion that such a document could be valuable to the workshop process.

OUR APPROACH

We focus primarily on predicting the general nature of the impoundment ecosystems, recognizing that there would be differences among them due especially to the smaller, shallower, more protected nature of the northern impoundment.

For each of the processes or phenomena involved here, a great deal of additional time could be spent documenting our predictions via literature surveys and small modeling efforts. We do not attempt that here. In general, where we offer an opinion in confident terms, we doubt that more detailed investigation would alter that opinion. We do not attempt many predictions about particular species, about the details of processes, or about short-term (< 6 months post-construction) or fine details of spatial and temporal variations in the system properties. Providing a firm prediction of the 'big picture' is our aim.

We omit value judgments about the overall desirability of the proposed project. Weighing of the pluses and minuses requires attaching of a value to each one of them that is primarily a subjective, non-scientific process.

The sequence in which we treat topics is determined by the fact that the biological components of the impoundment ecosystems will be heavily determined by the physical and chemical properties of those systems.

SOME SYSTEM DIMENSIONS AND FLOWS

At a surface elevation of -230 ft, the Salton Sea would have an area of 233,277 ac and a volume of 6,941,600 ft.

The northern impoundment would include about 2000 ac and 9000 ac-ft of the Sea. These represent about 0.85 percent of the surface area and 0.13 percent of the volume of the Sea, respectively. This impoundment would be fed by the Whitewater River and nearby agricultural drains. Annual inflow from these sources is currently about 80,000 ac-ft/yr with a mean salinity of 2-3 g/L. Residence time would thus be approximately 6 weeks. That is, in 6 weeks the water lost from the northern impoundment, by evaporation and overflow, would be equal to about 6 weeks worth of inflow.

The southern impoundment with a dike at –245 ft would include 26,000 ac and 181,000 ac-ft of the Sea. These represent about 11 percent of the surface area and 2.6 percent of the volume of the Sea, respectively.

With the dike at –240 ft, this impoundment would include 10,500 ac and 47,000 ac-ft. These represent about 4.5 percent of the surface area and 0.68 percent of the volume of the Sea, respectively.

The southern impoundment would be fed by the New and Alamo rivers and nearby agricultural drains. Annual inflow from these sources is currently about 1,100,000 ac-ft/yr with a mean salinity of 2.9 g/L. Residence time would therefore be on the order of 9 weeks for the larger southern impoundment and 2 weeks for the smaller one.

SALINITY

Terminological note: The terms “brackish” and “hypersaline” are terms appropriate for coastal systems where seawater salinity represents a logical standard. In the context of inland waters, however, they have no clear meaning and should be avoided, their popularity notwithstanding.

Salinity will be the single most important factor determining the nature of the impoundment ecosystems. Because of the very short residence times, salinity will drop very quickly, probably within a year after completion of dikes, from Salton Sea salinities (> 42 g/L) to salinities of 3-5 g/L. These will be only slightly higher than salinities of the inflowing rivers.

Exact trajectory for salinity over the first 4-12 months is unpredictable at the moment – and perhaps not of much importance. It would depend a great deal on mixing rates, impoundment configuration, and positioning of outflow points.

Equilibrium salinity (S_e) in impoundments, however, will be a simple function of inflow salinity (S_i), inflow rate (F, ac-ft/yr), and impoundment evaporation rate (E, ac-ft/yr), viz.

$$S_e = S_i F / (F - E)$$

In general this predicts that under likely medium-term scenarios these impoundment systems will have salinities 15-20 percent higher than the waters flowing into them.

For the larger version of the southern impoundment, with an annual inflow of 1,100,000 ac-ft/yr and an evaporation rate of 5.6 ft/yr, equilibrium salinity would be 15 percent higher than salinity of inflows.

If we assume a 200,000 ac-ft reduction in annual inflow, then we would expect equilibrium salinity to be 19 percent higher than that of inflow waters.

For the northern impoundment, with continuation of its annual inflow of 80,000 ac-ft/yr, we would expect equilibrium salinity to be about 16 percent higher than that of inflow waters.

Five factors will tend to produce somewhat higher equilibrium salinities that would be predicted from current inflow salinities.

First, those inflow salinities are likely to increase somewhat as a result of agricultural water management changes already in progress. These include reduction of tailwater runoff, causing agricultural wastewaters to be increasingly dominated by the higher salinity tile drain discharges.

Second, new artificial wetlands and marshes being created along the New and Alamo rivers. These wetlands will be large new surfaces from which water will be lost via evaporation, thus reducing inflow volumes and increasing their salinity.

A third factor would be reduction of input of municipal wastewaters in Mexicali. These have relatively low salinities relative to agricultural wastewaters and eventually are likely to be reclaimed for re-use in Mexico.

The fourth factor will be dissolution of gypsum, or calcium sulfate, that is abundant in the sediments in many places. As the impoundment waters freshen, this will tend to go back into solution, slowing the rate of salinity decline in the impoundment. Gypsum dissolves slowly, however, and much of it is well below the sediment surface where even slower dissolution would occur. Thus gypsum redissolution is not likely to be a large influence on salinity and will probably simply delay slightly the achievement of complete salinity equilibrium in impoundments. During this equilibration period there could be episodes of dissolved gypsum creating high salinity bottom waters that would resist mixing with surface waters. Anoxic, high sulfide conditions lethal to bottom dwelling organisms might develop temporarily. These would be transitional events, however, likely to occur, one would guess, only during the first year or two at the most.

The fifth factor is that evaporation from impoundment surfaces is likely to be higher than from the surface of the Salton Sea. The lower salinity by itself would be expected to increase evaporation by roughly 4 percent relative to that for the present Sea. Greatly increased abundance of shoreline vegetation is likely to result in increased losses from the system via evapotranspiration. Higher surface water temperatures are likely, especially in summer, and these would increase evaporation rates also.

The predicted salinity levels of 3-5 g/L are of particular biological significance. Limnologists conventionally set 3 g/L as the dividing line between fresh and saline waters. This is not entirely arbitrary. Most of the world's fresh waters have a salinity of < 1 g/L and most of its inland saline waters have a salinity of > 5-10 g/L. The nature of lake biota correspondingly changes rather abruptly as one goes from 1-2 g/L to 6-8 g/L. A difference of just a few g/L in this salinity range can cause large changes in the nature of the system, much larger changes than might be produced by going from, say, 8 g/L to 20 g/L.

A corollary of this fact is that temporal variations in salinity in this critical range ideally also need to be taken into account. Imagine two systems one with a salinity more or less constant at 4 g/L, and the other with a salinity that also averages 4 g/L but that fluctuates between 2 and 6 g/L. The biota of these two systems would likely differ markedly. Little information is available to allow even guesses as to how they would differ.

CURRENTS, TURBULENCE AND WAVE ACTION

In the southern impoundment, current speeds, turbulence, and wave action would be greatly reduced relative to present conditions in this part of the Salton Sea. Winds now have a 40 mile fetch over which to exert their influence on water movements in the southern end of the Sea. In the impoundment they would have a fetch of mostly 2-4 miles, at least when coming from the northwest quadrant. Additionally, the high ratio of shoreline (including dike) to surface area would have a dampening effect on current speeds as would the abundant aquatic vegetation (see below). Several consequences would follow from this.

Vertical mixing of the water column would also be greatly reduced in the southern impoundment. This is likely to result in more frequent or more prolonged periods of anoxia in the deeper waters of the impoundment. In the present Sea in summer the nearshore waters generally have higher oxygen levels than do waters at the same depth in the center of the lake. This tendency to poorer vertical mixing will be mitigated to some extent by elimination of vertical salinity gradients. In the present Sea these can be found, especially during calm weather, over southern and southeastern portions of the Sea where the river inflows have flowed out over the top of the higher density saline water. Such density gradients would be non-existent in the new conditions where impoundment waters were only 15-20 percent more saline than inflow waters.

The long, narrow shape of the southern impoundment would tend to increase current speeds in proportion to the degree that inflow and outflow rates were high. Current speed and direction within the lake would be strongly influenced by the number and position of the overflow points. For maximum homogeneity, e.g. of salinity, within the impoundment, overflow points would be located at either end of the lake; for maximum heterogeneity, they would be located on the dike about halfway between the New and Alamo river mouths.

Similar changes would take place in the northern impoundment. They would not be such large ones, however, as this is a smaller, shallower area and usually on the upwind side of the lake.

SEDIMENTS AND SEDIMENTATION

Following construction of dikes all river-delivered sediments would be deposited in the impoundments. At present a large percentage of the fine sediments (silts, clays) carried in can be presumed to be deposited in the deep portions of the Salton Sea.

Retention of fine sediments in the impoundments combined with reduced wave action would likely cause a shift in the nature of shallow water and shoreline sediments from a sandier to a muddier type. Increased abundance of shoreline vegetation, and detritus derived from it, would favor increased organic matter content of nearshore sediments.

Coarse sediments in rivers will continue to be deposited near river mouths, but, especially in the southern impoundment, would be less subject to reworking and redistribution by wave action and currents than coarse sediments are in the present Sea. This may cause the finger deltas of the New and Alamo rivers to build out faster than they are now. By growing toward the dike they would tend to reduce horizontal mixing within the southern impoundment in particular.

ALGAE

Algae would remain an important base of the food webs in the impoundments, though strongly supplemented by production by vascular plants (see below) and with macroalgae assuming a more important role than they have in the present Sea.

Phytoplankton. Phytoplankters that now dominate in the sea are dinoflagellates, diatoms, and raphidophytes. The impoundments would likely be dominated by chlorophytes (green algae) and cyanobacteria (blue-green 'algae'). This shift in composition would result from the fact that few dinoflagellates and raphidophytes tolerate salinities of 3-5 g/L, and the fact that reduced turbulence in the impoundments would make it difficult for diatoms to remain suspended in the photic zone. Their silica frustules make them susceptible to sinking in quiet waters.

Cyanobacteria might have potential for creating blooms toxic to fish and wildlife, as has occurred frequently in other shallow, eutrophic freshwaters but not in waters as saline as the ocean or the Salton Sea. Toxic species of cyanobacteria could appear in the biota without having harmful effects, of course. Indeed some of the cyanobacteria in the present Sea now, as well as some of the dinoflagellates and raphidophytes there, are capable of producing toxins, although there is no hard evidence so far that these have harmed fish or wildlife.

Short water residence times in the impoundments, i.e. high flow-through rates, would seem to diminish the likelihood that toxic species could achieve dense enough blooms to affect fish or wildlife. On the other hand, in embayments of poorly mixed water created by irregular shorelines or bands of aquatic vegetation, the combination of longer residence times, the low ratio of total nitrogen to total phosphorus (TN:TP) in inflow waters, and higher water temperatures ($> 35^{\circ}C$), localized toxic cyanobacterial blooms would be a real possibility.

In the well mixed portions of the impoundments, the short residence times would tend to favor dominance by small phytoplankton species capable of rapid growth. Species present in inflow waters would be especially favored as they would be continuously being inoculated into the impoundments.

Total phytoplankton abundance, measured as biomass per liter, would likely be lower in the impounded areas than in the corresponding areas of the present Sea. At present densities in these shoreline areas are typically much higher than in offshore waters. This would be a consequence of the short residence times and of increased competition for nutrients with macroalgae and vascular plants. In freshwater ponds, large increases in abundance of vascular plants are usually followed by large reductions in phytoplankton abundance.

Macroalgae. Abundance and diversity of macroalgae would be greater in the impoundments than in the present Sea, as a consequence of lowered salinity, reduced wave action, and increased areas of hard substrate. These will include green algae such as *Enteromorpha*, *Cladophora* and other filamentous forms. These would likely form floating mats in quieter areas, attach to solid substrates, including dike faces, and possibly accumulate as drift on shorelines when they die or are pushed there by waves. Stoneworts such as *Chara* or *Nitella,* with rhizoids anchoring them to sediments, may also appear. And microbenthic cyanobacteria would also be able to form thin algal mats on soft and hard substrates just as they do now in the Sea.

Abundance of these macroalgae would likely be controlled by turbidity, which limits the depth of water in which they can grow, by wave action, and by grazing by certain fish, water birds and invertebrates. Reduced current speeds and wave action and reduced phytoplankton abundance would cause turbidity levels to be lower than present ones. Turbidity may be the factor which now limits the existing *Cladophora*, *Chaetomorpha*, and *Enteromorpha* populations to the shallowest waters.

Faces of the new dikes would presumably be of rock or concrete and their great extent would tremendously increase the abundance of attached macroalgae. In the southern impoundment the inner side of the dike generally would experience much less strong wave action than do the dikes along the present southern shoreline of the Sea, allowing larger masses of macroalgae to develop on this inner side.

Periphyton. This term refers to the small algae of various sorts that are found growing on the surfaces of aquatic vascular plants, loosely or tightly attached to them. Such algae represent a food supply for a variety of invertebrates that cannot feed on the vascular plants themselves. Though inconspicuous thesesmall algae can take up nutrients rapidly from the water, thus competing with phytoplankton and the vascular plants themselves. If abundant on plants in the impoundments they would thus tend to have a clarifying effect on the water column by reducing phytoplankton densities.

VASCULAR PLANTS AND VEGETATION

Vascular plants would become much more abundant in the impoundments and along their shorelines than they are along the edges of the present Sea. These would contribute large amounts of plant detritus to the shoreline ecosystem and new habitat for birds in particular. These plants would probably boost overall production of the system and represent an increased food supply for decomposers and detritivores. The detritus would also increase the organic matter content of sediments making them softer and muddier and more subject to anoxia.

Vascular plants are a group especially sensitive to salinity variations in the vicinity of the 3 g/L dividing line between fresh and saline systems. Many species that can thrive at 2-3 g/L cannot tolerate 5-6 g/L. Thus precise prediction of the new assemblages of vascular plants would require precise prediction of impoundment salinities and a thorough review of the literature on the ecophysiology of aquatic vascular plants in the region.

Four distinct categories of vascular plants would be involved in this increase: submerged, floating, emergent, and terrestrial. These are discussed in turn.

Submerged vegetation. These are plants that are rooted in sediments and have all or most of the plant body beneath the water surface. Among species likely to colonize the impoundments would be those in the genera *Ruppia*, *Potamogeton*, *Zannichellia, Hydrilla*, *Najas*, and *Myriophyllum*. *Ruppia* and *Potamogeton* serve as food for some waterfowl species. *Ruppia* beds occurred in the Sea a few decades ago and were favored habitat of the sargo. Submerged vegetation serves as a substrate often colonized by microalgae and by invertebrates. It also provides structural complexity that provides invertebrates and smaller fish some protection from predation by larger fish.

Some submerged species can root in sediments tens of feet deep and thrive there if turbidity is low enough and light levels sufficient. They may produce stands of vegetation that extend only a couple of feet above the sediments or the stands may extend all the way to the surface. By slowing currents and competing with phytoplankton with nutrients, the presence of such plants tends to reduce turbidity thus favoring their occupation of even deeper-lying sediments.

Invasion of the impoundments by the fast growing exotics *Hydrilla verticillata* or *Myriophyllum spicatum* (Eurasian watermilfoil) might occur and would have drastic consequences if it did. *Hydrilla* is reported to grow in salinities up to 7-10 g/L, and *Myriophyllum* in salinities up to 15 g/L. Doubtless neither species grows very well at the upper end of their salinity range.

In clear water systems both species can root at depths greater than 30 feet and form dense stands extending to the surface, as *Hydrilla* did in Lake Murray in San Diego twenty years ago. Both species occur in waters in the Coachella, Imperial and Mexicali valleys, though *Hydrilla* is scarce after years of successful control with grass carp. The California Department of Food and Agriculture and U.S. Department of Agriculture have a program to try to eradicate *Hydrilla* from the state, as it arrived only a few decades ago. If either species established in the proposed impoundments, it likely would be possible to eradicate it, given the size of the impoundments.

Detailed predictions are not possible at this point, but given the predominance of shallow water areas in the proposed impoundments, it is likely that large portions of them, and perhaps even their entirety, would be colonized by submerged vegetation with all the consequences that would follow. Increase in impoundment water clarity resulting from upstream removal of sediments in artificial wetlands would facilitate facilitate invasion of the deepest portions of the impoundments by submerged vegetation.

Floating vegetation. This is likely to be the least significant of the four types of new vegetation that will develop in the impoundments. In quieter areas, tiny floating plants such as duckweed (*Lemna*) and aquatic ferns (*Azolla, Salvinia*) could abundantly cover the surface if salinity is satisfactory. They are probably most important as food for some types of ducks.

Emergent vegetation. Emergent aquatic plants are those that are rooted in the lake bottom or on damp shorelines and whose photosynthetic and reproductive structures extend well above the water surface. Common types are cattails (*Typha*), bulrush (*Schoenoplectus*), common reed (*Phragmites*), and giant reed (*Arundo*). Some such plants can grow in water more than 10 ft deep, if they can get established, can extend more than 10 ft above the water surface, and can grow so densely as to form impenetrable thickets separating open water from upland habitats. *Schoenoplectus* growing in the margins of Lake Miramar in San Diego County is rooted in sediments at a depth of 12 ft. The emergent vegetation that grows along the edges of the lower portions of the New and Alamo rivers is in water often 5-6 ft deep.

Now restricted to the immediate vicinity of the deltas and other inflow points of rivers and streams, emergent vegetation would soon colonize all shoreline areas with sandy or muddy substrates in the impoundments once their salinities were near 3 g/L. These vegetation beds would then tend to expand into deeper water, in large part by vegetative reproduction. This would probably be a slow process that went on for years before plants reached some depth beyond which they could not grow.

It would be likely that this emergent vegetation would come to occupy large portions of both impoundments, making them marsh ecosystems as much as lake ecosystems. The history of Cienaga de Santa Clara in the Mexican portion of the delta gives an idea of what might happen. Once a barren saline depression periodically inundated by ocean water, the whole northern end of the Cienaga became a densely vegetated marsh of *Typha*, *Schoenoplectus*, and *Phragmites* once large volumes of 3 g/L wastewaters from Arizona agriculture began being diverted into this basin. Of course, this is a much shallower system, with maximum water depths on the order of 3 ft, than would be the Salton Sea impoundments.

Development of emergent vegetation in the impoundments would tend to displace submerged aquatic vegetation via competition, most likely for light.

Terrestrial vegetation. The shoreline of the Salton Sea is mostly devoid of terrestrial vegetation, exceptions being those shorelines near points of surface or groundwater inflow. The primary reason for this undoubtedly is the high salinity of soils and soil porewaters near the lake's edge.

Once impoundments were created their fresher waters, together with the infrequent rainfall events of the region, will greatly reduce soil salinity along the shores of the impoundments. This would lead to great increases in the abundance of terrestrial vegetation, which would abut or intermingle with the emergent aquatic vegetation developing in adjacent shallow water areas. Various grasses (e.g. *Distichlis*) and shrubs (*Salicornia*, *Atriplex*, *Pluchea, Baccharis*) would colonize these shore habitats. Salt cedar (*Tamarix*) likely would be the tree species that would most successfully establish in these freshened areas, but other trees such as cottonwood (*Populus*) and willow (*Salix*) might succeed in some areas as well, especially if planted.

Taken together, the submerged, emergent and terrestrial vegetation that would develop along the impoundment shorelines would represent a great 'greening' of the shoreline ecosystem. There would be increased abundances of some invertebrates and birds that can use this vegetation as physical habitat for roosting, nesting, or hiding, as food, or as a place in which to find food. On the other hand, these beds of vegetation displace other elements of planktonic and benthic food webs that are perhaps even more important for good fish production.

INVERTEBRATES

In the impoundments, the species-poor invertebrate assemblage of the Salton Sea would be quickly replaced by a much more diverse assemblage. Key elements of the present food chain, such as the pileworm (*Neanthes*) and barnacle (*Balanus*) would disappear completely, while a few elements might persist, e.g. the copepod (*Apocyclops*), the rotifers (*Brachionus, Synchaeta*), and the amphipod (*Gammarus*).

Large numbers of new species of crustaceans, insects, oligochaete worms, mollusks, flatworms, rotifers and nematodes would colonize the water column, the sediments, and the surfaces of aquatic plants. A long species list could be compiled from studies of other marshes and lakes in California or the Southwest with salinities of 3-5 g/L. But the absolute and relative densities of these new invertebrate species would not be possible to predict. They would depend in part on complex food web interactions, such as predation on invertebrates by fish and bird populations in the new ecosystem.

Increases in the abundance and diversity of shoreline vegetation would be accompanied by large increases and diversity in the abundance of terrestrial invertebrates, especially insects and other arthropods (e.g. spiders, mites), relative to what now can be found along the mostly barren shorelines. Some of these arthropods may feed directly on green plant tissues. Others may be detritivores. Detritus produced by this vegetation will create shallow water sediments and shoreline soils rich in organic matter, and this can serve as the base for detritus-based modules of the overall food web.

The impoundments likely would increase abundance of biting insects in the vicinity of the Sea. These could include mosquitoes (Culicidae), biting midges (Ceratopogonidae), and horse flies (Tabanidae). The aquatic larvae of virtually all mosquitoes are intolerant of salinities as high as those of the Salton Sea and are also very susceptible to fish predation in open waters. But salinities of 3-5 g/L are tolerated by many species of mosquitoes, including *Culex tarsalis,* which is common in vegetated water bodies in the Salton Sea region and a vector of western equine encephalitis.

The structural complexity provided by the stems and foliage of submerged and emergent vegetation would provide mosquito larvae and other invertebrates significant refuge from fish predation. In general fish-inhabited marshes are major breeding grounds for mosquitoes, both in coastal and inland areas.

Biting midges and horseflies breed in damp soils with moderate to high levels of organic matter, often near the margins of bodies of fresh water. Their increase would seem highly probable, but it is not possible to predict whether or not this would be to levels representing a significant nuisance to persons visiting or living near the impoundment areas.

FISH

New Assemblage. The fish assemblages that would develop in the impoundments would be radically different from the present one in the Sea. Corvina, sargo, bairdiella, and long-jaw mudsucker would disappear. Mozambique tilapia would persist as would threadfin shad, mosquito fish, mollies and mullet. Almost all of the freshwater exotics found in the Coachella, Imperial, and Mexicali valleys would eventually find their way into the impoundments and establish permanent populations. These include common carp, catfish, largemouth bass, sunfish, Zill's tilapia, and shiners. The triploid sterile grass carp used for weed control in agricultural drains could also invade though they should not be able to reproduce. It might be predicted that the fish assemblage would be dominated by the tilapias, threadfin shad, carp and catfish, as these feed predominantly near the bottom of the food web. Large mouth bass would become one of the most popular sportfish, if its populations thrived.

The abundances of the different species would exert strong influences on each other and on other components of the impoundment ecosystems via predation, disturbance of the sediments, and, in the case of carp and Zill's tilapia, grazing of macroalgae and aquatic vascular plants.

Fish production on a *per unit area basis* would likely be lower in the impoundments than in the corresponding portions of the present Sea, and very much lower if aquatic vegetation came to occupy more than a minor portion of the impoundment area (e.g. > 20 percent). The major reason for this is that fish presently in these nearshore areas are recipients of food supplies, e.g. plankton, that are produced over the entire area of the Salton Sea. During the warmer half of the year, these food supplies are not consumed in the central 80 percent of the lake because almost all fish move into the nearshore areas.

On the other hand there are some factors that would tend to offset the above to some extent. These would be the greater variety of fish present, and hence of foods utilized, feeding modes, and microhabitats utilized, the lower physiological stress caused by salinity, and perhaps more regular reproductive and recruitment success.

Total fish production *for the region* (excluding aquacultural production) would be drastically reduced as the proposed impoundments would represent, at most, only 12 percent of the area of the present Sea.

Desert pupfish would likely colonize at least the margins of the Salton Sea proper once the other fish were mostly gone. Though stressed by the salinity, the pupfish would have their glory days in the region, perhaps even for a few decades, before even their salinity limits were reached.

Parasites and Disease. At present the fish in the Sea are known to host only a single metazoan parasite, a monogenean fluke (*Gyrodactylus*), and this only rarely. A few microbial ectoparasites (*Amyloodinium*, *Cryptobia*, *Ambiphrya*) are known to infest large percentages of fish, especially juvenile tilapia, at certain times of year. On rare but significant occasions, botulism has been found in moribund tilapia, often associated with *Vibrio* infections.

In the proposed impoundments, all fish would likely be much more heavily infested with metazoan parasites (flukes, cestodes, roundworms, crustaceans). The life cycles of most of these parasites require an intermediate host, usually an insect, crustacean or snail. Few species of such invertebrates are found in the present Sea, but many-fold more would establish populations in the impoundments. This would lead to greater numbers of kinds and perhaps higher infestation rates of parasites on and in impoundment fish. The lower salinity water itself might also improve survival of the free-swimming stages that some of these parasites have.

For example, the introduced Asian fish tapeworm *Bothriocephalus acheilognathi* has been found in shiners and mosquito fish in creeks draining into the Sea. This tapeworm is a harmful parasite of commercial and recreational significance. It uses freshwater copepods as an intermediate host, spreads rapidly, and can cause high mortality of juvenile cyprinid fish.

There is no reason to think, however, that parasite loads would be heavier than they are in these same fish species where they occur in other freshwater or near-freshwater ecosystems in the region.

We cannot predict how the types or degrees of infestation by microbial parasites might change in the impoundments relative to the Sea. The three genera mentioned above are all known to occur in freshwater habitats, aquaria and aquaculture operations. Many other species of microbial parasites may be capable of tolerating a salinity of 3-4 g/L and could appear in the impoundments as well.

Contaminants. Concentrations of contaminants of significance to humans and wildlife would likely be higher in fish in the new impoundments than they are in fish of the present Salton Sea. Principal contaminants of concern would be selenium, pesticides, industrial pollutants, and pathogens. Each contaminant would have its own behavior, and there are many uncertainties, but the big picture seems clear.

In the present system, contaminants entering the Sea at specific points are quickly distributed by currents over and diluted by the whole volume of the Sea. Most fish in the Sea are thus bathed in water and feeding on organisms in water where contaminant concentrations range from extremely low to undetectable. Nevertheless significant levels of selenium, arsenic, and DDE are present in Salton Sea fish.

In the impoundments the fish and their food organisms would be spending their entire lives in what would amount to undiluted, sluggish extensions of the New, Alamo, and Whitewater rivers. Most of the new fish species moreover could move between the rivers and the impoundments, whereas the Mozambique tilapia is the only common species likely to do that now. Fine river-borne sediments on which pesticides might be adsorbed would all be deposited in the impoundments and not distributed over the whole Sea. New species of bottom-feeding fish, such as carp and catfish, thus would be exposed to higher levels of these and any other contaminants that tended to accumulate in sediments. Over time such bottom feeding fish could also bring back into circulation in the food web shallowly buried contaminants that were deposited in prior decades. The occasional pesticide spills (perhaps usually illegal discharges or dumping) upriver that now kill fish mostly only in the rivers, would likely cause mortality in the impoundments as well.

Whereas fish now in the Salton Sea are exposed to water column levels of selenium on the order of 1 ug/L, those in the impoundments would be exposed to the same levels as found in the rivers, viz. 3-6 ug/L. The Pacific Institute proposal acknowledges that selenium-related problems for birds might be exacerbated by resuspension of sediments during dike construction. This, however, would seem a less important mechanism for increased selenium exposure of birds than would be the accumulation of higher selenium levels in the impoundment ecosystem after the dike was completed.

It thus seems certain that fish in the impoundments would have generally higher levels of contaminants than do fish currently in the Sea. This would cause them to pose greater risks to both fish eating birds and to sport fishermen than do the present Salton Sea fish.

In principle, contaminants in inflow waters could be reduced by altered water management practices, both on farm and at wastewater treatment plants, and by constructed wetlands. Exactly what sorts of reductions would be feasible are unknown. Even marked improvements in inflow water quality could occur, of course, and still leave contaminant levels in impoundment fish higher than those now in Salton Sea fish.

AMPHIBIANS AND REPTILES

Soft-shelled turtles have been seen in the New and Alamo rivers and doubtless would colonize the impoundments. Bullfrogs occur in the region, used to be collected for food in the Rio Hardy when it was in better conditions. The African clawed frog is now widespread in southern California and doubtless would colonize the impoundments. Toads and tree frogs might use them for breeding. Abundance of amphibians would be closely tied to the nature of aquatic vegetation present, as this would be needed as critical refuge from piscine and avian predators.

BIRDS

New Assemblage. The avifauna of the Sea would be markedly affected by creating the impoundments and letting the rest of the Sea rise in salinity until all fish disappeared from it. Some types of birds would become more abundant, others less abundant. Changes would reflect changes in habitats and food supplies available. We focus on predicting changes for four major categories of birds.

Users of shoreline vegetation. The predicted large increases in shoreline and shallow water vegetation would lead to large increases in bird species that can use that for nesting, roosting, or feeding. These would include especially rails, bitterns and blackbirds, wrens, and warblers . Once tall salt cedar stands had developed, various herons and egrets would be likely to nest in them. Passerines that glean insects from the foliage of such vegetation would also increase. Ducks, coots, and even geese that can feed on submergent aquatic vegetation would also be more abundant.

Aerial feeders. Production of insects with aquatic larvae and aerial-terrestrial adults is now essentially zero in the Sea. This production would likely be very high in the impoundments. Adults of non-biting midges (Chironomidae) and perhaps mosquitoes (Culicidae) would be especially abundant and likely to attract more swallows, swifts, and nighthawks to the skies above the impoundments.

Feeders on aquatic invertebrates. We distinguish three categories: wading shorebirds (e.g. avocets, stilts, dowitchers, godwits, etc.), beach runners (e.g. sandpipers, plovers), and open water feeders (eared grebes, Wilson's phalaropes, shovelers, ruddy duck, etc.).
We would expect to see reduced abundances in the impoundments of the first two categories as the open shoreline and mudflat areas they utilize would eventually be taken over by dense shoreline vegetation. The open water feeders would probably also be less common as we would predict that the diverse fish assemblage in the impoundments would result in lower overall density of macroinvertebrates of the types these birds feed on.

At least some of these feeders on aquatic invertebrates would be likely to find greatly increased food supplies in the main body of the Sea that would be left to becomes fishless. Once fishless, the dominant invertebrates there would be copepods (*Apocyclops*), water boatmen (*Trichocorixa*) and brine flies (*Ephydra*). Only after salinity became high enough (> 80 g/L?) to eliminate the copepods and waterboatmen would brine shrimp (*Artemia*) become abundant, as the first two are predators on the latter.

Fish-eating birds. In general these would become very much less abundant in the region, even though some individual species might come to have higher densities in the impoundments than they do in the current corresponding portions of the Sea. Fish-eating birds, such as egrets and herons, that like quiet water and are willing to use vegetated marshy areas might become more abundant in the impoundments than they are now along the Sea's southernmost and northernmost shorelines.

The double-crested cormorant and the two pelicans would be likely to become much less abundant even in the areas to be impounded, once the main part of the Sea became fishless. As indicated above, fish production in the areas to be impounded likely will decline. Also, these are open water birds. They cannot swim where there is much submerged vegetation, and at least pelicans generally stay well away from dense emergent shoreline vegetation of any sort, presumably as a way of avoiding predators. The white pelican feeds while swimming in groups in shallow water, and most such shallow waters might have dense submerged vegetation. Areas that the pelicans currently use for loafing – small islands, sand spits, etc., though not Mullet Island – may be colonized by emergent vegetation.

Greater abundance of small fish – mosquito fish, shiners, mollies, and young of the numerous larger species – would likely represent increased food supplies for smaller fish-eating birds, such as terns, black skimmers, and western grebes. They thus might become more abundant. Much would depend on the balance among species and size classes maintained by predation of the larger fish present, such as large mouth bass.

Parasites and Disease. The greatly increased number of invertebrate and fish species in the impoundments that could serve as intermediate hosts for parasitic helminths would likely increase infection rates of birds by those parasites. The importance of this to the health of the bird populations is difficult to judge, however. Most birds would be exposed to these parasites in many of the other aquatic systems they visit for food during the course of a year.

Prediction of changes in the bird disease scenario is difficult. Botulism might be expected to become more frequent as a result of fresher, quieter waters, increased levels of sediment organic matter, higher summer water temperatures, and lower oxygen levels. On the other hand, extensive occupation of shallow water areas by emergent vegetation could work against this.

Contaminants. As indicated above, contaminant levels likely would be higher in fish and invertebrates in impoundments than in fish and invertebrates now in the Sea. Fish-eating and invertebrate eating birds feeding in impoundments thus would be expected to accumulate those contaminants to higher levels than they do now, to the degree that the impoundments would represent their principal source of food over significant parts of the year.

The potential problems in this area are dependent on many unknown factors and would be different for each bird species. Factors include possible improvements in quality of inflow waters, possible tendency of some bird species to cease using areas once they are impounded, possible increased use of impounded areas by other bird species, the specific fish and invertebrate assemblages that develop in the impoundments, the specific behaviors of different contaminants, and so on.

RECREATION

Birdwatching. This is an activity engaged in at the Sea by many thousands of individuals a year, especially at the southern end of the Sea. Construction of the proposed impoundments would not likely have any negative impacts on the quality of the impoundment areas for birdwatching. Positive effects that might be expected would include: increased diversity of birds as a result of development of shoreline vegetation and greater variety of prey populations (invertebrates and fish) in the impoundments; and better access to the shorelines via dikes, especially at the northern end where access is poor.

Along shorelines outside the impoundments and in the Sea's open waters, the diversity of birds would decrease with the disappearance of fish-eating birds. Much larger numbers of invertebrate-eating birds than are there now might be attracted to the Sea, however. Such birds also could remain at the Sea longer during the year because of enhanced invertebrate food supplies.

Since the Salton Sea is already an excellent, nationally recognized location for bird-watching, it would not likely experience even greater popularity in that regard even if certain bird species did become more abundant there.

Fishing. Fishing could be quite good in the impoundments for tilapia, largemouth bass, sunfish, carp and catfish, though it is unpredictable just which of these would establish good numbers of good-sized individuals. Special attractions might include the fact that tilapia sport fisheries do not exist elsewhere in the state and the possibility that largemouth bass would reach record sizes in the impoundments.

That sort of fishery, except for the tilapia, can be found in many other waterbodies in the region and in southern California, however, and fewer fisherman would be willing to travel long distances to take advantage of it. It will no longer be a special, unique fishery capable of generating tales of 30 lb corvina that got away. Rather it would become known as a fishery where contaminant levels were higher than elsewhere for the same species. The accurate perception that the impoundments were sluggish extensions of wastewater drains would probably discourage fishing for many years even after contaminant levels had been reduced – if that ever happened.

Boating and swimming. Boating in the impoundments, because of reduced current speeds and wave size, would probably be safer than in the current sea, and the entirety of the impoundment areas would be accessible to smaller boats. On the other hand lower fish production, invasion by aquatic vegetation, and the considerable number of obstructions (rocks, tree trunks, old man-made structures) in the shallow northern and southern ends of the Sea would render the impoundments much less attractive to boaters in general than is the present Sea. There would be no need for pontoon boat tours for birdwatchers, such as the State Recreation Area currently conducts. Persons with larger, faster boats interested in a quasi-oceanic boating excursions would no longer be attracted.

Swimming would probably be non-existent in the impoundments. Potential bathers would be put off by softer sediments, aquatic vegetation, absence of beaches, and pathogen levels almost certainly higher than those in the present Sea. There are dozens of human pathogens that historically have been detected in the New River, especially near the U.S.-Mexico border. A pathogen not reported from the rivers but that might become of special concern in the summer is the protozoan *Nagleria fowleri* . This enters the nasal passages, travels to the brain, and causes primary amebic meningoencephalitis, a rare but nearly always fatal disease. This ameba does well in fresh waters at very high temperatures. We have heard that cases of this have occurred in the Mexicali valley in summer when young children in agricultural areas use the drainage ditches and other shallow waters as places to play and cool off.

Another deterrent to swimming might be swimmers' itch, a rash caused by penetration of the skin by larval stages (cercariae) of bilharzia-type flukes or trematodes. These flukes have snails as intermediate hosts. The freshened, high calcium waters of the impoundments and the abundant aquatic vegetation would be heaven for several types of snails.

The above contrasts with the present situation. Though swimming in the Sea is less common than it once was along the exposed, sandier shorelines of the present Sea, this has more to do with irrational fears of algal blooms and resultant turbidity and inaccurate press reports than it does with the reality of the situation. Naturally on those specific occasions when there is a moderate to large fish kill nearby or washing up on shore, or when there is a bloom of the surface film-dwelling alga *Pleurochrysis* in progress or when heavy waves have stirred up sediments, swimming is not an attractive option. But most of the year the present Salton Sea is an excellent place for swimming. You can keep your legs still, hold a beer in each hand, and still not sink.

The main part of the Sea where salinity would be allowed to increase over time would remain suitable for both boating and swimming for some decades, though of course boating fishermen would not be interested in it.

Camping. There is a fair bit of both tent camping and mobile home camping around the edges of the Salton Sea, and much of this is associated with birdwatching, desert nature study, scientific excursions by university classes, and just relaxation under the desert stars. More than fishermen and boaters come to the Sea. Very little of this camping takes place along the shorelines of the areas to be impounded, and in general the impoundments – by increasing the abundance of biting insects as well as on non-biting insects likely to swarm to campsite lighting fixtures – would make these areas even less attractive than they are now for camping, unless campsites were a considerable distance – perhaps hundreds of yards - from the water’s edge.

Camping on shorelines of the main part of the Sea would still be attractive to visitors not primarily interested in fishing. Great recession of the shoreline would make these areas less attractive.

New camping areas, or general centers of recreational activity, established near where impoundment dikes intersected the shoreline could enhance recreational values. These could provide easy access of boaters, birdwatchers or fishermen to both impounded areas and the open Sea, especially if means easy transfer of boats over or around dikes were available. These would be areas of high biotic diversity. Those on the west side of the Sea could be tranquil sites free of the hooting and rumbling of nighttime freight trains that run along the east side of the Sea.

ENGINEERING OPTION: EXCLUSION OF NEW RIVER INFLOWS

There are two key negative aspects of the proposed impoundment ecosystems with respect to fishing and other recreational activities associated with them. These are: 1) the taking over of the impoundments by aquatic vegetation well-adapted to the projected salinities, and 2) the high levels of contaminants likely to be present or to develop in the waters and sediments of the impoundments.

For the southern impoundment, the problems arising from these two aspects could be considerably mitigated by diverting all New River flows and a portion of Alamo River flows so that they enter the main body of the Sea directly. This could reduce contaminant inputs to the impoundments and increase equilibrium salinity levels in them so as to inhibit excessive development of aquatic vegetation. Salinities on the order of 6-8 g/L perhaps would be sufficient to do this. They would also be consistent with healthy populations of most, if not all, of the fish species that would be present at 3-5 g/L. Higher equilibrium salinities, e.g. 8-12 g/L, easily could be engineered and might necessary to prevent invasion of *Myriophyllum* in particular. These higher salinities, however, might also eliminate a few of the freshwater fish from the impoundments.

The system described is not unlike that of Laguna Macuata (a.k.a. Laguna Salada; southwest of Mexicali) when it is fully flooded. At those times it supports at least catfish, tilapia, largemouth bass and even small-scale commercial mullet fisheries, and no aquatic vegetation except at its southernmost end where it receives the floodwaters of the Rio Hardy.

Under the current inflow regime, diversion of the New River directly to the Sea would result in a southern impoundment salinity only 35–40 percent higher than that of the New River and other inflows. This salinity increase likely would be insufficient for the objective. If we wanted impoundment salinity to be roughly double inflow salinity then we would have to reduce total inflows to the impoundment to 290,000-300,000 ac-ft/yr. This would be more than a 70 percent reduction of current inflows to this southern shoreline. Hence, the need to consider partial diversion of Alamo River flows directly to the Sea also, perhaps via a pipeline connection to the New River.

The best diversion structure for the New River would be a channel along the southwest shoreline of the southern impoundment. A modest dike or concrete retaining wall built in shallow (4-6 ft deep) water could form one side of the channel and the existing shoreline the other. This channel would extend until it emptied into the Sea proper at or a short ways north of the intersection of the main impoundment dike with the shoreline somewhere south of the old Navy Test Base.

An attractive ecological feature of this diversion structure would be that the shoreline side of the channel would become heavily vegetated with terrestrial, emergent, and, in wider slow-flow areas, even emergent vegetation, just like the banks of the current New River. It would be good habitat for birds and other wildlife, including birdwatchers.

A problematic aspect of allowing essentially only Alamo River water entry into the southern impoundment is that its selenium concentrations seem to be higher than those of the New River, possibly because municipal wastewaters (from Mexicali) make up a higher proportion of total flow in the New than in the Alamo. Not having undergone the evaporative concentration experienced by agricultural wastewaters, or passage through soil, these municipal wastewaters presumably have selenium concentrations on the order of those of the Colorado River. A thoughtful comparison of how the risks associated with the two rivers compare is called for. Of course, if selenium becomes a serious problems for wildlife, it seems most likely to do so in the shrinking main body of the Sea and the invertebrate-eating birds that would use it. In that regard, it would perhaps make little difference which river was the main or only supply for the impoundment. All the selenium of both rivers, most likely, would end up in the Salton Sea proper.

There would also be ways to engineer partial diversion of northern inflows directly to the Salton Sea in order to create northern impoundment salinities on the order of 6-8 g/L.

EVALUATION OF PROPOSED BENEFITS

We quoted at the beginning the benefits that the Pacific Institute claimed for the proposed impoundments, and they are repeated below, with our comments on each. We recognize that the intent of the Pacific Institute was, in part, to put these forward as benefits only relative to benefits (or costs) associated other proposed projects, such as those involving major evaporation facilities and input of additional low salinity waters. Our comments take into account, however, that the proposed benefits will be taken on their face by many as being net benefits claimed in some more absolute sense.

1. **Compatible with water re-allocation efforts.** The impoundments will be compatible with these. But then so would complete desiccation of the Salton Sea and the Colorado River. There is an underlying presumption here that these "re-allocation efforts" are a positive thing or at least a political inevitable. Many of the authors of this review think they are neither and that they will have high environmental and social costs.

2. **Sustainable over the long term.** This is true in the sense that once constructed, annual maintenance and operation costs will be much lower than those for possible projects to restore the entire Sea involving evaporation and replacement waters. It is false in that government policies favoring continued high rates of population growth will prohibit guarantees of any flows into the Salton Sea in the long term. The writing is on the wall. The MWD and CVWD have already filed requests to be given rights to 40 percent of current Salton Sea inflows.

3. **Increases diversity of habitats at the Salton Sea.** This is true but that does not make it good. Those numbed by the rhetoric of political correctness may be pardoned for having forgotten that diversity per se is not a positive – not in society and not in ecology. Putting in 100 acres of date palms on Refuge lands would also increase habitat diversity at the Salton Sea. Convince us that is good!

   The main question to be answered with respect to our re-engineering of habitats at the Sea is what problems would it likely pose to those bird species that have come to rely on the Sea in a major way? This document does not attempt to address that important question.

4. **Preserves and enhances fisheries in impounded areas.** This might be more accurately stated as "Creates new fisheries in impounded areas", as neither preservation or enhancement of what exists now is involved. From the point of view of sport fishermen or fish-eating birds the impoundment fishery would be inferior to the existing fishery. A very large scale, unique fishery would be replaced by a small scale, common type of fishery. Some fishery is preferable to no fishery, of course.

5. **Promotes increased recreational and economic development opportunities.** Yes, small lakes with fish plus a large one without fish offers more such opportunities to the region

than does one large fishless lake. On the other hand, the proposed project would result in a large net *loss* of such opportunities relative to those provided by a Salton Sea restored to lower salinities.

6. **Compatible with other off-site actions.** This is true of other possible restoration projects for the Sea, as well as of the no project alternative, and does not constitute a benefit.