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M E M O

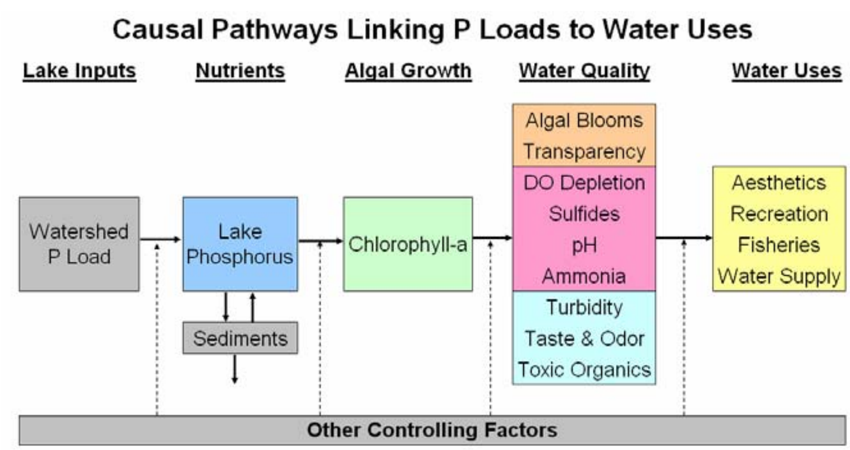
To: Ron Enzweiler, Salton Sea Authority
Subject: SSA's Plan for Revitalizing the Salton Sea to Support Recreational Uses
Date: March 22, 2006

Introduction

This memo summarizes my initial thoughts on the feasibility of SSA's plan for revitalizing the Salton Sea to support recreational uses, as limited by eutrophication. My opinions are based upon review of reports that you provided, some published literature and web sites, attendance at two TAC meetings, tours of the shoreline and watershed, review of monitoring data collected by USBR in 1999 and SSA/USBR in 2004-2005, preliminary mass-balance calculations, and experience with relevant research and restoration projects described at wwwalker.net.

While there are always uncertainties in forecasting responses to implementation of restoration projects, particularly in ones of this scope and given unique features of the Sea, and there are always needs for additional data and analysis, I don't see any "fatal flaws" that should preclude further evaluation of the SSA Plan. I interpret "fatal flaw" to mean a likelihood of failure with respect to restoring recreational water quality, given information reviewed and level of analysis that I am able to provide in this time frame. Assuming that inflows required to sustain the Sea are supplied, there is a greater likelihood of success, especially given the long time frame and components of the SSA plan that can be adjusted in response to actual as opposed to foreseen conditions. The private funding mechanism also promotes efficiency and flexibility for adapting to changing conditions, as compared with typical state or federally funded restoration projects.

The Salton Sea shows all of the classic signs of nutrient enrichment and to an extreme degree. These include elevated nutrient concentrations, algal blooms, low transparency, oxygen depletion, hydrogen sulfide, ammonia, toxic algae, fish kills, etc. This is not unexpected given that the Sea is fed almost exclusively by agricultural drainage and urban wastewater and that it is located in a region with abundant sunlight and warm temperatures that are conducive to algal growth and oxygen depletion. All of these symptoms are linked to excessive algal growth that is in turn linked to excessive phosphorus loadings, as well as other factors, as illustrated below:



The Sea is an ideal environment (sunlight, temperature, nutrients) for algal growth. Monitoring data indicate that algal growth is controlled primarily by phosphorus because other nutrients are present in excess. This is confirmed by the fact that algal density (as measured by chlorophyll-a) is consistent with empirical models that predict chlorophyll-a as a function of Total P concentration. Those models (Jones/Bachman, Carlson) are based upon data from other P-limited lakes and commonly used in eutrophication assessments. So, while other factors also influence the various water quality problems that affect recreational uses, they are fundamentally fueled by phosphorus loads, control of which is a major focus of the SSA plan. As discussed below, control of H_2S is also a major focus of the SSA plan; that problem is also linked to phosphorus.

The USBR (Holdren et al) pointed out that Sea TP concentrations have not changed since the 1960's, despite the fact that the phosphorus loads have approximately doubled. The notion that the Sea TP concentrations have not changed since the 1960's is inconsistent with anecdotal yet undisputed evidence that water quality was much better then, at least enough to foster resort development around the shoreline and to support boating, swimming, water skiing, etc... In my experience, comparisons of modern and historical P measurements and load estimates are typically clouded by changes in investigators, sampling methods, labs, analytical techniques, and load computation techniques, especially over a 30+ year period. While that may or not be the case here, the fact that the Sea once supported recreational uses is an encouraging sign that the goals of the SSA plan are not unrealistic.

Because of the above cause-effect pathways, it is likely that the ~90% reduction in the existing external P load contemplated under the SSA Plan would improve water quality to a significant degree. The question that you have asked is whether there is a fatal flaw in that the plan to revitalize water quality to "recreational" water quality, given the degree of phosphorus control being contemplated. The sub-questions pertain to:

- definition of the "recreational" goal in quantitative terms (equivalent TP concentration, algal bloom frequency, etc.);
- assimilative capacity of the Sea (linkage between TP load and Sea water quality); and
- feasibility of control technology to accomplish the required TP load reductions
- feasibility of technology to control hydrogen sulfide problems

These factors are discussed below.

Phosphorus Goal

A TP concentration of 35 ppb has apparently been selected by the State as a goal in the Salton Sea TMDL process. It is not clear whether that automatically translates to a requirement for the SSA plan. The 35 ppb criterion can be compared with average concentrations of 70 – 110 ppb measured by the USBR 1999 (biweekly sampling) and by SSA/USBR in 2004-2005 (quarterly sampling). Measured average chlorophyll-a concentrations (50 - 120 ppb) are similar to those expected in this phosphorus range, based upon regression equations developed from northern lake data (Bachman & Jones, Carlson, etc).

Achieving a TP concentration of 35 ppb would be expected to provide a mean chlorophyll-a concentration of ~15 ppb and a low frequency of nuisance algal blooms (instantaneous chlorophyll-a > 20-30 ppb). These criteria are within ranges established in other lake restoration projects and consistent with surveys relating water quality measurements to user perceptions of aesthetic and recreational values in other states (e.g., Minnesota, Texas, Colorado).

Phosphorus criteria for recreational use vary regionally and depend to some extent on what users are used to seeing, access to high quality lakes, and how you define "recreational". For example, TP criteria for recreational uses in Minnesota vary from ~15 ppb in the north to ~50 ppb in the south. Northern lakes tend to have relatively high quality because they are mostly deep and have forested watersheds. Southern lakes tend to have relatively low quality because they are mostly shallow and have agricultural watersheds. Lakes are commonly used for contact recreation in both regions of Minnesota, despite the significantly different P concentrations. It would be unlikely, however, that swimmers would flock to a 50 ppb lake in the north because higher-quality lakes are nearby. Similar regional patterns and user "adaptation" were observed in a recent study of Texas reservoirs.

While another Lake Tahoe is clearly not attainable or necessary here, a TP concentration of 35 ppb would provide reasonable assurance that recreational potential would be restored. It should not be interpreted as a red line for failure vs. success. Assuming that the H_2S problem is addressed (see below), significant reductions in P concentration and algal growth would improve aesthetics and recreation potential (especially for shoreline uses, bird-watching, fishing, boating), even the 35 ppb criterion (more appealing for contact recreation) were not achieved. I kayaked on the Sea and visited many ghost resorts on the shoreline in early February. I found the views hypnotizing and was astounded that nobody else was there to enjoy them. I suspect that residents and potential visitors have been traumatized by the stifling sulfide odor in other seasons, as I was in November.

The closest analogy in my experience with respect to goal-setting is Cherry Creek Reservoir, a small impoundment close to Denver intensively used for recreation and located in a region where other recreational lakes are not accessible within reasonable driving times. A mean chlorophyll-a concentration of 15 ppb (expected with SS TP concentration of 35 ppb) was adopted as a restoration goal. While that goal has been achieved (at least as 2000), the reservoir has always been used intensively for recreation, despite the relatively chlorophyll-a concentrations (24 ppb, in 1997-1999). The key difference is that Cherry Creek does not suffer from H_2S problems, control of which will be critical to the success of the SSA plan.

Reductions in nutrients and algal productivity have been shown to decrease fish biomass in harvest in some lakes. This is balanced against beneficial impacts on fish, including changes from less desirable to more desirable species, reduced risk of oxygen depletion leading to fish kills, and improved conditions with respect to pH and ammonia. While the issue should be examined by fisheries experts, it seems unlikely that achieving a mesotrophic state (TP= 35 ppb, Chl-a = 15 ppb) could be viewed has having a net negative impact on the fish community or its predators.

Ammonia toxicity is another water quality problem that is linked to algal productivity and phosphorus loading. Free ammonia concentrations increase with total ammonia concentrations, temperature, and pH. Total ammonia concentrations would be expected to decrease as a consequence of reductions in external total nitrogen load resulting from wastewater diversion, agricultural BMP's, and wetland treatment. Reductions in internal ammonia nitrogen load would be expected to occur as a result of the decrease in organic matter production and decomposition.

Another linkage between algal growth and free ammonia is that the highest pH's (promoting free ammonia) tend to occur during algal blooms (highest chlorophyll-a concentrations), as a consequence of photosynthetic removal of carbon dioxide. This pattern is typical of other lakes and evident in the 2004-2005 monitoring data. Reducing the magnitude and frequency of algal blooms would therefore be expected to reduce free ammonia concentrations, even if total ammonia concentrations did not change. While modeling might be helpful, my initial assessment is that ammonia toxicity would not be a problem if the phosphorus reduction goals were achieved.

Phosphorus Assimilative Capacity

The assimilative capacity can be loosely defined as the external P load expected to produce a given Sea P concentration (or criterion). Modeling studies by the USGS (D. Robertson) showed that SSA's north basin would have a lower assimilative capacity than the existing Sea as a consequence of its smaller volume. Significant reductions in external P load would be required to offset the effects of reduced volume and to reduce the existing Sea TP concentration sufficiently to achieve recreational water quality. These relationships can be explored with relatively simple mass balance models, as described by Robertson and extended below.

The fact that the Sea is not flushed (no outlet) is a minor factor for phosphorus. It is not condemned to hyper-eutrophy because there is no outflow, as long as there is enough inflow to maintain the water level and salinity. Phosphorus loads are effectively trapped in the sediments, due to accretion of organic and inorganic sediment that is enhanced by calcite precipitation (as documented by Orem et al, USGS). While P cycles back and forth between the water column and sediment, the fact that P buildup is generally not observed in the bottom waters during periods with stable stratification (commonly observed in eutrophic stratified lakes) suggests net P releases from the sediments are small. That is a good sign.

Relatively simple mass-balance models can express the relationship between external TP loads and Sea water quality, as measured by Sea TP, chlorophyll-a, algal bloom frequency, and transparency (Tables 1 & 2). These calculations use empirical models calibrated to data from a wide range of freshwater lakes and commonly used in lake eutrophication assessments. While these models have not been widely applied to saline lakes, the predicted TP, chlorophyll-a, and transparency values for the existing Sea are within the range of recent measurements (1999, 2004-2005). Mass-balance modeling by the USGS (D Robertson) have also indicated that the Canfield/Bachman phosphorus retention model (used here) is consistent with existing Salton Sea phosphorus and water budgets. Other, first-order models (e.g. settling velocity concept) may also be applicable and would tend to yield more favorable results (predict lower Sea P concentrations for a given degree of external load control, after calibration to the existing data).

Tables 1 and 2 present steady-state water, salinity, and phosphorus balances for the existing Sea and each basin of the SSA plan under two external loading scenarios corresponding to average inflow concentrations of 200 ppb and 80 ppb, respectively, for all tributaries. The water and salinity budgets are consistent with those proposed by the SSA to provide a stable salinity of ~35 ppt in the north basin and ~22 ppt in the south basin.

Two TP loading scenarios representing different degrees of P control are evaluated. Table 1 indicates that reducing the combined inflow TP concentration to each basin from ~900 ppb to 200 ppb would provide concentrations of 70 ppb and 34 ppb in the south and north basins, respectively. Table 2 indicates that reducing the average inflow concentration to 80 ppb would provide concentrations of 34 ppb and 24 ppb, respectively. My calculations do not reflect potential P removal from the recycle stream by the ozone/filtration scheme being considered. This is not likely to have a large effect on the long-term P balances, but would accelerate the water quality responses to reductions in external P loads and control H_2S odors associated with the deep-water withdrawal and recirculation, as discussed below.

While alternative flow and loading scenarios could be explored, results indicate that inflow treatment down to the 80-200 ppb range would be sufficient to attaining the 35 ppb TMDL goal.

Even if the 35 ppb level were not reached in the South basin, water quality would be considerably improved relative to the existing Sea. Because it will be relatively shallow and rapidly flushed, it is unlikely that south basin will suffer from hydrogen sulfide problems, regardless of the TP concentration.

Monitoring data indicate that the TP residence time in the water column (mass stored in lake / external load) is less than a year. This suggests that Sea TP concentrations would respond relatively rapidly (2 years or so) to reductions in external load if storage and recycling of TP from the bottom sediments were relatively unimportant. Recycling may delay the response until the sediments equilibrate to the new loading and water quality regimes. That time scale is difficult to estimate, but would be limited to some degree by calcite precipitation that is expected to continue, even after reductions in salinity.

There is considerable uncertainty associated with any model forecasts, given the drastic changes in Sea configuration, salinity, flow, loading regime, etc... Further analysis would be required to estimate uncertainty and test sensitivity to alternative model assumptions, as well as to evaluate transitional responses to the predicted changes in inflow and P loads over the next decade or so. Uncertainties in future flow, basin P sources, salinity, potential role of fish in P retention, and other factors introduce additional uncertainty in forecasting the Sea response.

Within reasonable bounds, components of the SSA plan can be operated or modified in response to actual conditions as the project evolves. For example, the technology exists for treating the inflow streams down to concentrations approaching 10 ppb, should that be necessary to achieve Sea water quality objectives, even though the initial calculations indicate that 80-200 ppb would be sufficient to achieve 35 ppb. Similarly, operation of the recirculation stream can be adjusted in response to observed thermal stratification, sulfide buildup, and salinity regimes.

Phosphorus Controls

As discussed above, the fact that technology already exists for treating inflows well below the 80-200 ppb range provides a hedge against uncertainty in predicting Sea response. Both natural and physical/chemical treatment technologies exist for reducing inflow P concentrations below the 80 to 200 ppb range. Under the Everglades restoration effort, full-scale treatment wetlands have reduced TP concentrations in agricultural runoff down to 15 - 30 ppb. Pilot tests of physical/chemical treatment reached concentrations of 10 - 15 ppb. A variety of technologies are commonly used to treat municipal wastewaters down to the 50-200 ppb range. Implementation of lake restoration plans on a global scale is stimulating development of cost-effective technology for removing phosphorus that may be relevant over the extended time frame of the SSA plan.

While cost analysis is beyond the scope of my memo, I understand that cost estimates for CTSS (Chemical Treatment followed by Solids Separation) based on Everglades pilot studies are within the budget contemplated by the SSA. Since inflow P reduction is the cornerstone of the SSA plan, pilot scale testing of chemical treatment, and further cost analyses should be immediate priorities. Even though the technology has been widely applied, pilot studies are absolutely necessary to obtain reliable performance and cost estimates.

Reductions in the existing suspended solids concentrations at the mouths of the tributaries (via BMP's, basin wetlands, and/or sedimentation basins) are necessary to provide cost-effective chemical treatment to remove phosphorus. Existing TSS concentrations in the Alamo and New Rivers (~ 200-300 ppm) are much higher than those tested in the Everglades studies (~5-27 ppm). Assuming that suspended solids can be controlled, chemical dosage requirements to remove phosphorus are likely to be lower in this case, as compared with the Everglades, because of higher target P range (80-200 ppb vs. 10 ppb) and lower dissolved organic carbon content (~10 ppm vs. ~18 ppm). Capital costs would also tend to be lower in this case because of the relatively low variability in streamflow, as compared with the Everglades facilities that had to be designed to handle much larger runoff pulses.

Source controls (BMP's, wetlands, CTSS) should be implemented as soon as possible and preferably before separation of the Sea. While BMP's and wetlands will help to reduce nutrient and suspended solids loads, CTSS appears to be necessary in order to provide average inflow concentrations in the 80–200 ppb range necessary in order to achieve the water quality goals of the SSA plan. The existing monitoring program for the Sea and tributaries should be expanded and continued indefinitely. Otherwise, there will be no way of measuring progress and no signal for guiding the adaptive implementation of the plan.

Hydrogen Sulfide Controls

Excessive hydrogen sulfide (H_2S) production appears to be the major factor limiting potential beneficial uses of the Sea as it exists today and suitability as a habitat for humans, fish, and other wildlife. It also seems to create a significant regional air quality problem. Sulfide production may be enhanced to some extent by high sulfate concentrations, but the primary driving force is likely to be the excessive organic matter generated via photosynthesis, in turn controlled by phosphorus. Both sulfate concentrations and phosphorus loadings would be reduced significantly under the SSA plan.

Dr. Shadlow's one-dimensional hydrodynamic modeling indicates that the smaller north basin will have more stable (possibly permanent) vertical stratification, as compared with the existing Sea, apparently because of smaller wind fetch and resulting reductions in seiche activity and other wind-driven mixing events. Hypothetically, with more stable stratification, H_2S concentrations in the bottom waters would tend to increase relative to existing conditions, assuming that the rate of H_2S production is constant. The latter assumption would not hold in evaluating the SSA's plan that is likely to provide reductions in both algal productivity and sulfate concentrations. Dr. Shadlow's analysis only accounted for increases in transparency potentially resulting from phosphorus control.

The Feasibility Study - Phase I Alternatives Viability Report (October 2005, Science Paper 6) does not discuss calibration procedures for the 1-D model. Figures 3.1 & 3.2 (Pages 13-14) do not convince me that the calibrations are accurate. Perhaps there is additional supporting information on this model. Simplifying assumptions were made in order to simulate seiche activity (inherently a 3-dimensional phenomenon) with a 1-dimensional model. A 3-dimensional hydrodynamic model, coupled with a water quality model (as proposed by Tetra Tech), would be needed to simulate the full plan and evaluate various withdrawal and recycle strategies to control H_2S. Absent such a model, other mechanisms and SSA plan features should be considered in assessing the viability of the SSA plan with respect to H_2S problems, as discussed below.

It is not clear that stable stratification would be "worse" than the existing situation with respect to H_2S and risk of catastrophic surface oxygen depletion. I understand that massive fish kills at the Sea's northern end have been associated with seiche events that transport large quantities of H_2S rich bottom water into localized areas and cause sudden oxygen depletion and atmospheric H_2S releases. Seiche upwelling events can be characterized as "flows" that transport bottom water from far reaches of the Sea into localized surface waters. Seiche upwelling or other wind-mixing events can occur in summer when saturation dissolved oxygen concentrations are low and the thermocline is shallow, so there is a relatively small mass of oxygen in the water column to offset the H_2S load, as compared with turnover events in the fall/winter.

According to the 1-D model, vertical mixing events would be less likely under the SSA plan, particularly during summer. Turnover events may occur (if at all) over the entire Sea and be diluted in a much larger volume of surface water, as compared with localized seiche upwelling. Any turnover events would tend to occur during fall/winter, when water temperatures would be lower, oxygen concentrations in the surface water would be higher because of the higher saturation values, and when the thermocline would be lower. Even if the rate of H_2S generation were constant, the buildup of H_2S concentrations in the hypolimnion would be limited to some extent by diffusion across the thermocline. The higher surface dissolved oxygen concentration and greater epilimnion volume in the fall/winter would reduce the risk of surface oxygen depletion following an H_2S recycle event for a given initial H_2S concentration in the bottom water, as compared with summer mixing events and oxygen depletion occurring in the existing Sea.

If a 35 ppb TP goal were achieved, the corresponding ~65% reduction in Sea TP concentrations would be expected to provide a ~78% reduction in mean chlorophyll-a concentration (Jones/Bachman regression). That would, in turn, reduce the organic load on the bottom waters that is the primary fuel for H_2S generation. The percentage reduction in H_2S generation would tend to be larger than the percentage reduction in organic load because a portion of the oxygen demand is satisfied by the oxygen and nitrate present in the water column when stratification first develops and by diffusion of oxygen across the thermocline.

Aside from phosphorus control, another component of the SSA plan (withdrawal, treatment, and recirculation of bottom waters) is designed to reduce the risk that H_2S will be a problem in the future. This measure could reduce H_2S accumulation in the bottom waters by four potential mechanisms: (1) removal of H_2S from the bottom and subsequent treatment; (2) reduction in vertical density gradients resulting from withdrawal of cool bottom waters; that would promote H_2S oxidation within the Sea by increasing the diffusive exchange of hydrogen sulfide and oxygen across the thermocline; (3) lowering the thermocline (assuming that the recycle stream is heated to surface temperatures before being discharged back into the surface of the north basin) and thereby increasing the volume of oxygenated surface water available to offset H_2S releases; (4) reducing the surface area of the hypolimnion as a consequence of the deeper thermocline.

Based on the morphometry of the north basin, withdrawal of 770 kac-ft/yr (700 kac-ft/yr for the recycle stream and 70 kac-ft/yr for the salt sink) from the bottom would displace the volume between elevations -260 and -279 feet (bottom of basin). With a surface elevation of -231 feet, that would correspond to the water depths between 29 and 48 feet. That would displace about 55% of the hypolimnetic volume, assuming an average thermocline depth of 20 ft. If the withdrawal rate were constant over the year, the volume displacements during the stratified period would be about half of those indicated above. Hydrodynamic modeling is needed to evaluate the net effects on stratification and H_2S buildup.

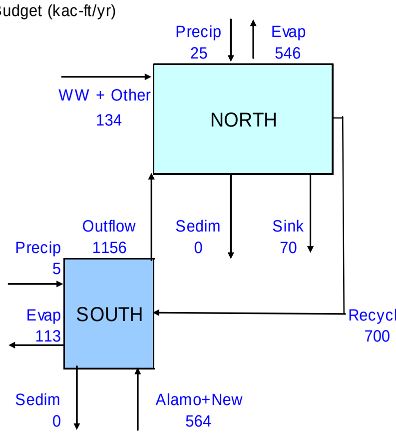
If it turns out that higher withdrawal rates are needed to sufficiently control the stratification and H_2S buildup, one additional option would be to increase the withdrawal rate but return a portion directly to the surface waters of the north basin, since the 700 kac-ft/yr recycle stream is constrained by the need to control salinity in the south basin.

While there is uncertainty in forecasting the net effect of all of the above mechanisms and controls on the H_2S problem, the SSA's Plan is sufficiently viable as to justify further evaluation. The 3-D hydrodynamic and water quality modeling effort will provide substantial additional information. In any case, the Plan should not be rejected based upon pessimistic forecasts derived from the 1-D model, which do not account for several important factors and which I believe over-state the stratification and H2S buildup problems potentially developing in the north basin as a consequence of its smaller surface area relative to the existing Sea.

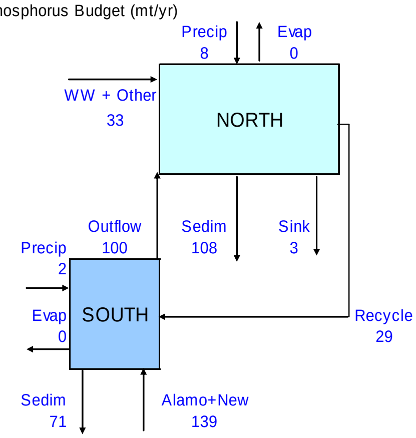
Table 1 – Water & Mass Balances for Inflow TP = 200 ppb

Salton Sea Water & Mass Balances

Water Budget (kac-ft/yr)



Phosphorus Budget (mt/yr)



Model Inputs in Red

			SSA Plan	
		Existing	South	North
Area	mi2	**366**	**32**	**155**
Mean Depth	ft	**31**	**15**	**30**
External Inflow	kac-ft/yr	**1278**	**564**	**134**
Inflow Salinity	ppt	**2.2**	**3.5**	**3.5**
Inflow TP	ppb	**896**	**200**	**200**

Recycle Flow	kac/ft/yr	**700**
Rainfall	in/yr	**3**
Evaporation	in/yr	**66**
Atmos P Deposition	mg/m2-yr	**20**

Predicted Lake Conditions		Existing	South	North	Notes
Lake TP	ppb	95	70	34	Canfield/Bachman Lake P Retention Model
Lake Chl-a	ppb	63	40	14	Jones/Bachman Chl-a vs. TP Regression
Bloom Freq	%	89%	63%	4%	BATHTUB Freq Chl-a > 30 ppb, Lognormal, CV = 0.5
Transparency	m	0.6	0.8	1.8	BATHTUB Secchi vs. Chl-a Model
Salinity	ppt	58	23	35	Mass Balance
H2O Resid Time	yrs	150.5	0.3	3.9	Sea Volume / Outflow
TP Resid Time	yrs	0.60	0.16	0.89	TP Mass in Lake Water Column / Inflow Load

Water Budget (kac-ft/yr)	Existing	South	North
Recycle Inflow		700	1156
External Inflow	1278	564	134
Precipitation	59	5	25
Total Inflow	1337	1269	1315
Evaporation	1288	113	546
Sedimentation			
Total Outflow	48	1156	770
Recycle Outflow			700
Sink			70

Salinity Budget (kmt/yr)	Existing	South	North
Recycle Inflow		30.3	32.7
External Inflow	3.5	2.4	0.6
Precipitation			
Total Inflow	3.5	32.7	33.3
Evaporation			
Sedimentation			
Total Outflow	3.5	32.7	33.3
Recycle Outflow			30.3
Sink			3.0

		SSA Plan	
Salinity Conc (ppt)	Existing	South	North
Recycle Inflow		35.1	22.9
External Inflow	2.2	3.5	3.5
Precipitation			
Total Inflow	2.1	20.9	20.5
Evaporation			
Sedimentation			
Total Outflow	58.3	22.9	35.1
Recycle Outflow			35.1
Sink			35.1

P Budget (mt/yr)	Existing	South	North
Recycle Inflow		29	100
External Inflow	1414	139	33
Precipitation	19	2	8
Total Inflow	1433	170	141
Evaporation			
Sedimentation	1427	71	108
Total Outflow	6	100	32
Recycle Outflow			29
Sink			3

P Conc (ppb)	Existing	South	North
Recycle Inflow		34	70
External Inflow	896	200	200
Precipitation	262	262	262
Total Inflow	869	109	87
Evaporation			
Sedimentation			
Total Outflow	95	70	34
Recycle Outflow			34
Sink			34

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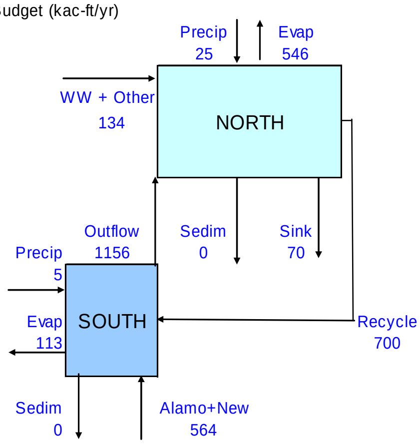
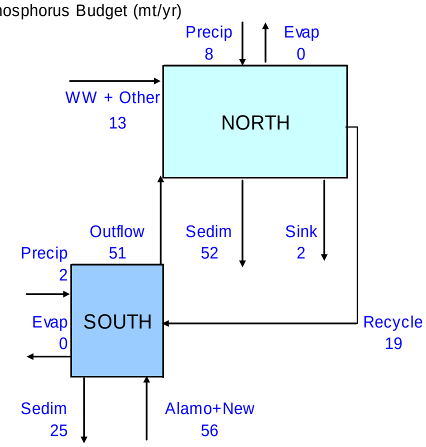
Table 2 – Water & Mass Balances for Inflow TP = 80 ppb

Salton Sea Water & Mass Balances

Water Budget (kac-ft/yr)



Phosphorus Budget (mt/yr)



Model Inputs in Red

			SSA Plan	
		Existing	South	North
Area	mi2	366	32	155
Mean Depth	ft	31	15	30
External Inflow	kac-ft/yr	1278	564	134
Inflow Salinity	ppt	2.2	3.5	3.5
Inflow TP	ppb	896	80	80

Recycle Flow	kac/ft/yr	700
Rainfall	in/yr	3
Evaporation	in/yr	66
Atmos P Deposition	mg/m2-yr	20

Predicted Lake Conditions		Existing	South	North
Lake TP	ppb	95	36	22
Lake Chl-a	ppb	63	15	7
Bloom Freq	%	89%	5%	0%
Transparency	m	0.6	1.7	2.6
Salinity	ppt	58	23	35
H2O Resid Time	yrs	150.5	0.3	3.9
TP Resid Time	yrs	0.60	0.18	1.12

Notes
Canfield/Bachman Lake P Retention Model
Jones/Bachman Chl-a vs. TP Regression
BATHTUB Freq Chl-a > 30 ppb, Lognormal, CV = 0.5
BATHTUB Secchi vs. Chl-a Model
Mass Balance
Sea Volume / Outflow
TP Mass in Lake Water Column / Inflow Load

Water Budget (kac-ft/yr)	Existing	South	North
Recycle Inflow		700	1156
External Inflow	1278	564	134
Precipitation	59	5	25
Total Inflow	1337	1269	1315
Evaporation	1288	113	546
Sedimentation			
Total Outflow	48	1156	770
Recycle Outflow			700
Sink			70

Salinity Budget (kmt/yr)	Existing	South	North
Recycle Inflow		30.3	32.7
External Inflow	3.5	2.4	0.6
Precipitation			
Total Inflow	3.5	32.7	33.3
Evaporation			
Sedimentation			
Total Outflow	3.5	32.7	33.3
Recycle Outflow			30.3
Sink			3.0

		SSA Plan	
Salinity Conc (ppt)	Existing	South	North
Recycle Inflow		35.1	22.9
External Inflow	2.2	3.5	3.5
Precipitation			
Total Inflow	2.1	20.9	20.5
Evaporation			
Sedimentation			
Total Outflow	58.3	22.9	35.1
Recycle Outflow			35.1
Sink			35.1

P Budget (mt/yr)	Existing	South	North
Recycle Inflow		19	51
External Inflow	1414	56	13
Precipitation	19	2	8
Total Inflow	1433	76	73
Evaporation			
Sedimentation	1427	25	52
Total Outflow	6	51	21
Recycle Outflow			19
Sink			2

P Conc (ppb)	Existing	South	North
Recycle Inflow		22	36
External Inflow	896	80	80
Precipitation	262	262	262
Total Inflow	869	49	45
Evaporation			
Sedimentation			
Total Outflow	95	36	22
Recycle Outflow			22
Sink			22

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