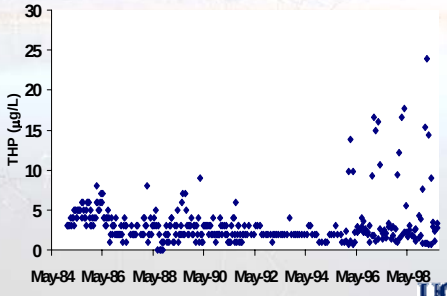
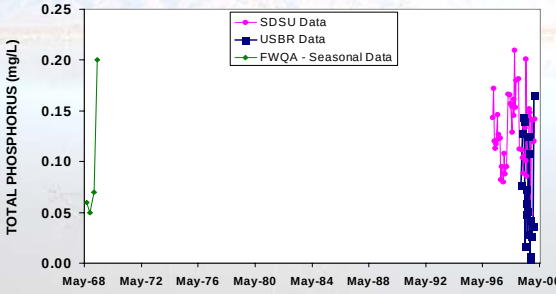
WHAT WE KNOW, WHAT WE DON'T KNOW, AND WHAT WE NEED TO KNOW ABOUT THE SALTON SEA

Geoffrey Schladow
Department of Civil & Environmental Engineering
UC Davis

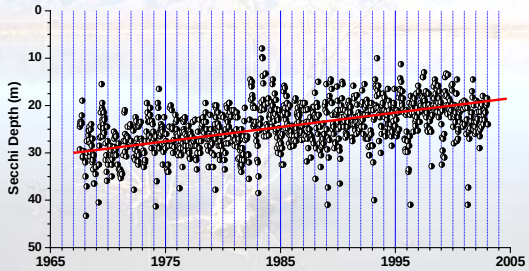
LAKE TAHOE TOTAL HYDROLIZABLE PHOSPHORUS



SALTON SEA TOTAL PHOSPHORUS



LAKE TAHOE SECCHI DEPTH



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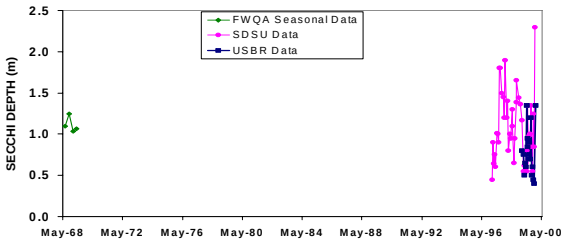
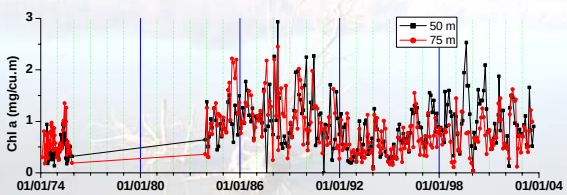


LAKE TAHOE CHLOROPHYLL *a*



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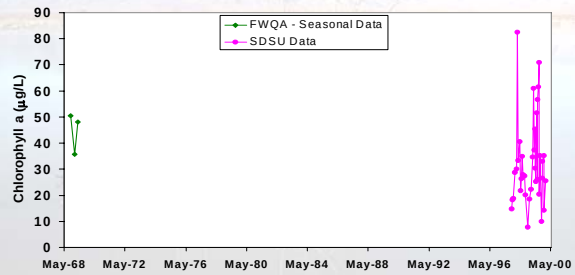
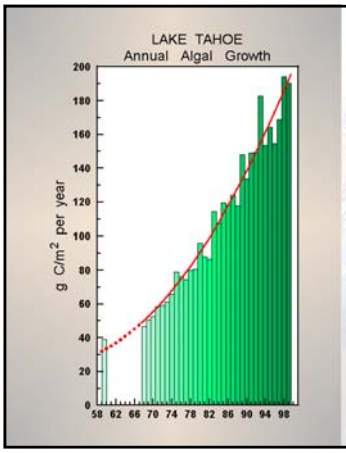
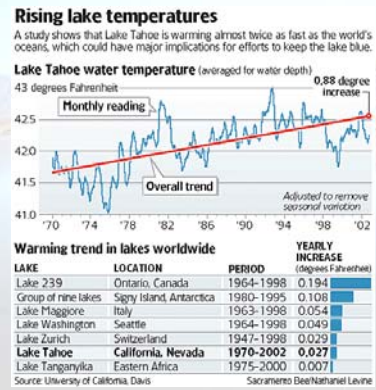




LAKE TAHOE PRIMARY PRODUCTIVITY



LAKE TAHOE CLIMATE CHANGE

LAKE TAHOE HAS:

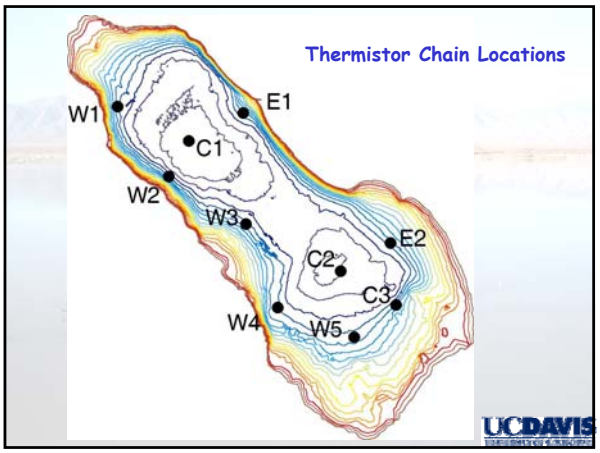
- A LONG-TERM, CONTINUING DATA SET
- AN ONGOING SCIENCE PROGRAM DESIGNED TO ADDRESS CRITICAL UNCERTAINTIES
- A MODELING FRAMEWORK THAT INTEGRATES AND EXTENDS THE DATA, AND PROVIDES A PREDICTIVE CAPABILITY
- A SCIENTIFICALLY DEFENSIBLE BASIS FOR ADAPTIVE MANAGEMENT

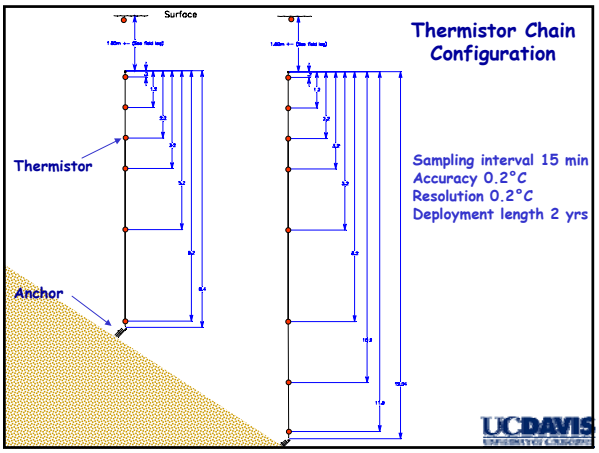
AS A CONSEQUENCE, LAKE TAHOE STANDS A GOOD CHANCE OF ACQUIRING THE ~$1B REQUIRED FOR RESTORATION. THE SAME MAY BE SAID OF OTHER MAJOR RESTORATION PROGRAMS, e.g. EVERGLADES, CHESAPEAKE BAY, CALFED.

CAN THE SAME BE SAID FOR THE SALTON SEA?

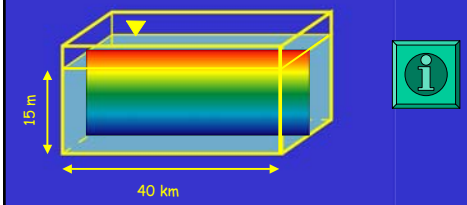
IN WHAT FOLLOWS I WILL PRESENT A SUMMARY OF WHAT IS KNOWN ABOUT THE PHYSICAL ENVIRONMENT, WATER QUALITY AND EUTROPHICATION IN THE SALTON SEA, THE CRITICAL GAPS IN OUR KNOWLEDGE, AND A STRATEGY FOR ADDRESSING THE DEFICIENCIES.

- PHYSICAL ENVIRONMENT/TEMPERATURE
- EUTROPHICATION/WATER QUALITY
- STATE OF MODELS
- A MONITORING & RESEARCH PLAN

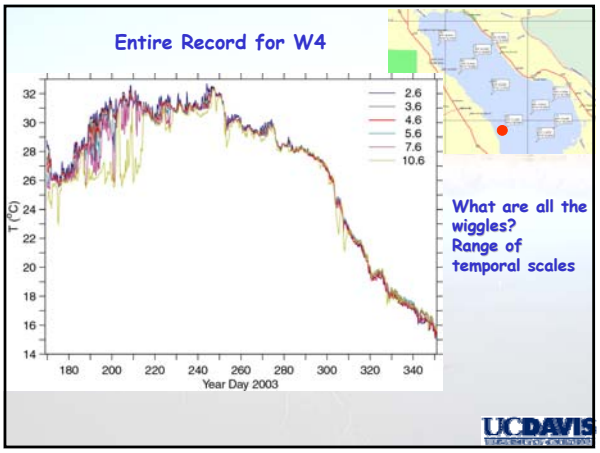


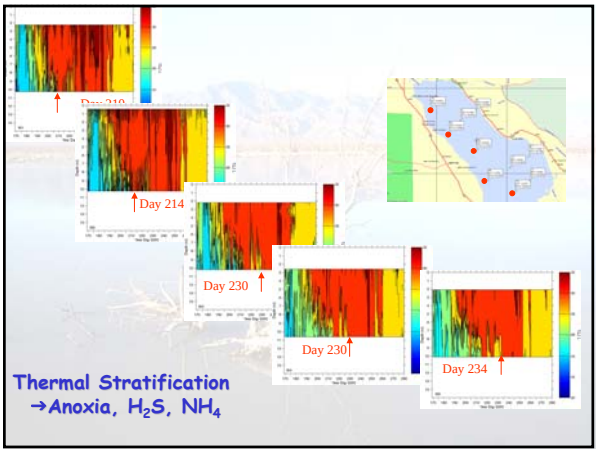


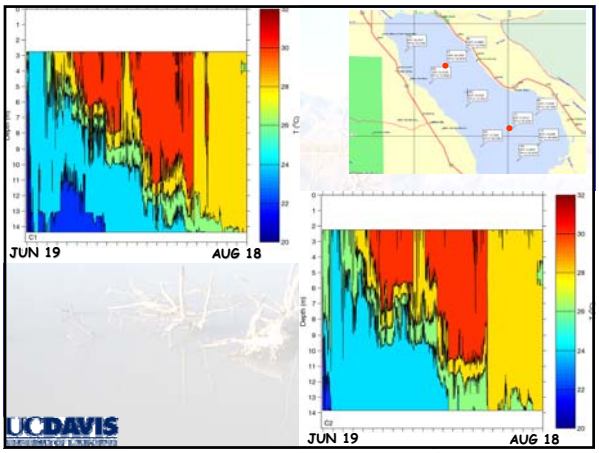
The temperature measured by a thermistor will change according to diurnal processes, weekly weather changes, seasonal differences. They will also change due to internal waves.



Simple internal waves in a rectangular basin







Summary

- Continuous data (of any kind) provides insight into the complexity of natural systems. Temperature is the easiest and cheapest type of data, and yields important insights into hydrodynamics and water quality.
- Real-time data would open the possibility of "informed" sampling of other variables, rather than "blind" sampling".
- The period of persistent thermal stratification in 2003 varied with position. At center ~ 70 days (with epilimnion continually deepening). At margins (10 m) it can be as low as 40 days. In 1997, persistent stratification commenced in mid-March, ended in July (120 days).
- What is it in the littoral zone where most fish are located?
- Intermittent thermal stratification (hours-days) can occur outside this period. A changed future Sea will have a different stratification regimen. What are the water quality affects of this?

IS THERE A CAUSAL CONNECTION BETWEEN THERMAL STRATIFICATION AND FISH KILLS?

IN HIGHLY EUTROPHIC WATER BODIES, THERMAL STRATIFICATION LEADS TO THE ISOLATION OF THE HYPOLIMNION FROM SOURCES OF DISSOLVED OXYGEN, AND THE ACCUMULATION OF OXYGEN DEPLETING SUBSTANCES (BOD, COD, SOD)

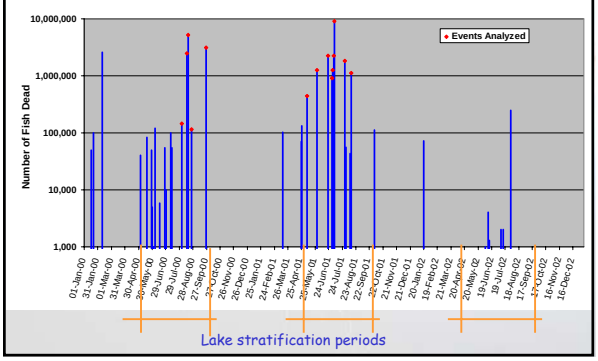
THIS PRODUCES:

- ANOXIC BOTTOM WATER
- HIGH HYDROGEN SULFIDE CONCENTRATION
- HIGH AMMONIA CONCENTRATION

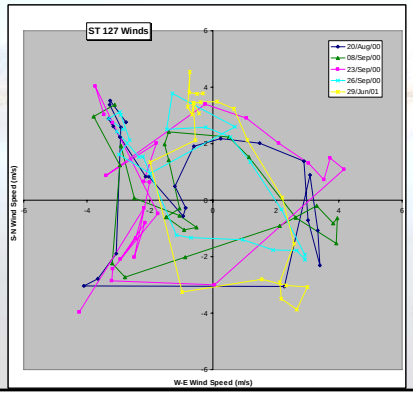
ALL OF WHICH CAN LEAD TO MORTALITY

IS THIS DIRECTLY RELATED TO THE EPISODIC EVENTS THAT LEAD TO MASSIVE FISH KILLS?

Fish Kills in the Salton Sea



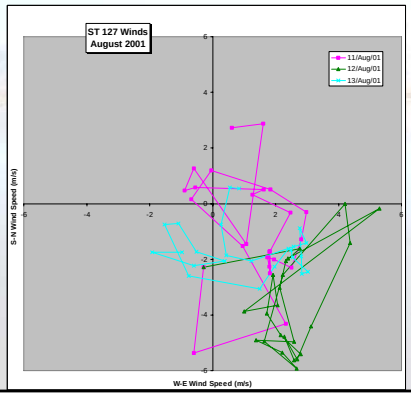
Wind Data Analysis



WIND ROTATION:

- Daily basis
- Clockwise

Wind Data Analysis

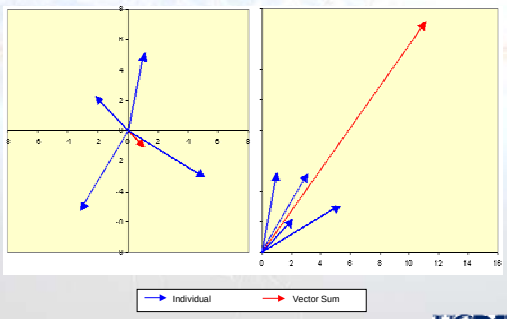


BEFORE FISH KILLS:

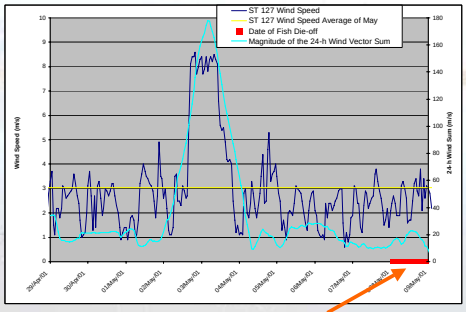
- Strong winds
- Sustained direction

Wind Data Analysis

24-h ACCUMULATED WIND:

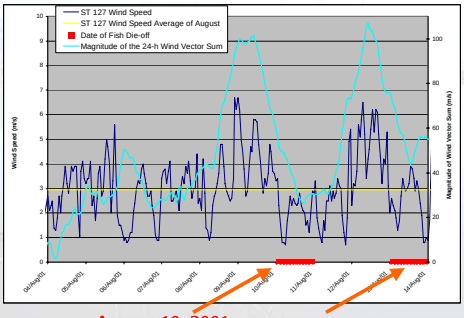


RESULTS



May 8, 2001
442,100 dead fish

RESULTS



August 10, 2001
43,300 dead fish

August 13, 2001
1,133,870 dead fish

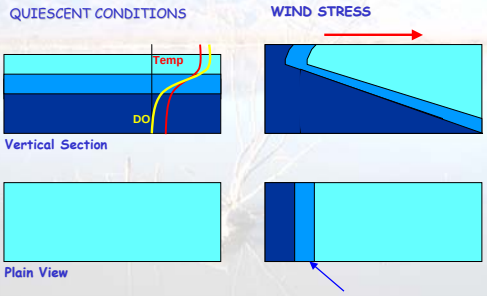
RESULTS

- 12 out of 14 major fish kills follow a 24-h accumulated wind peak > 90 m/s.
- 9 out the 12 die-offs that followed an accumulated wind peak were reported within 2 days after the peak. The remaining three occurred between 2 and 5 days after the peak.

Upwellings in a Stratified Water Body

QUIESCENT CONDITIONS

WIND STRESS

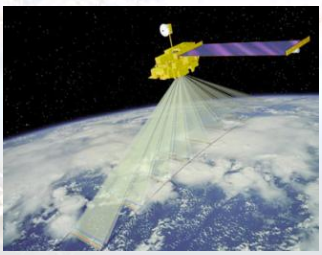


Surface Temperature Mapping

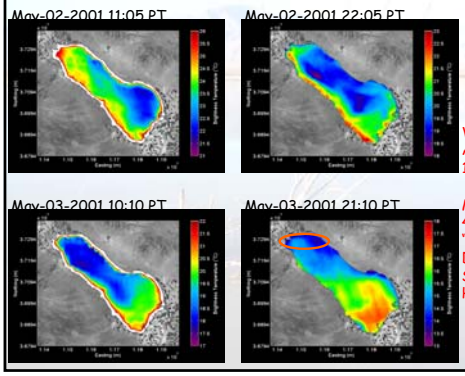
MODIS – MODerate Resolution Imaging Spectroradiometer

1000m resolution (TIR)

0.5 day repeat time



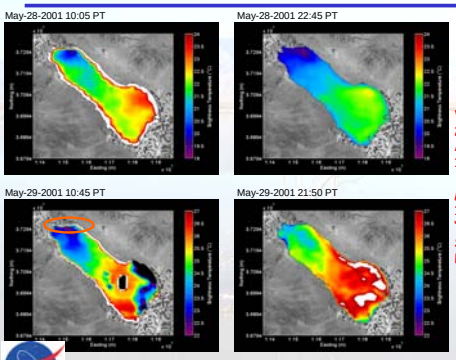
RESULTS



Wind from N-NE
Accumulated wind = 180 m/s

May 8
442,100 dead fish.
"North end, Desert Shores to State Park Headquarters"

RESULTS



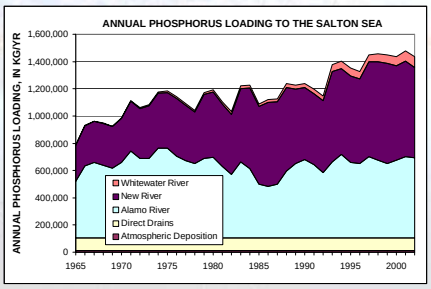
Wind from N on May 26-28
Accumulated wind = 100 m/s

May 29
1,269,200 dead fish.
"North end, Desert Shores to Mecca Beach"

SUMMARY

- Wind-driven upwellings in stratified water bodies can change the water quality at a particular location within hours .
- Major fish kills are observed to occur within 1 to 5 days of peaks in the accumulated wind speed in 12 out of the 14 cases analysed.
- Locations of fish kills consistent with location of upwelling
- The interaction between wind, thermal stratification and water quality is very direct during these "extreme events". What happens during mild upwellings? If a future "shallow lake" is not stratified, is fish habitat improved? Is stratification good or bad?

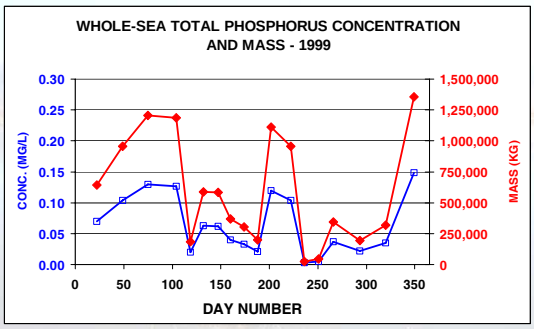
EUTROPHICATION AND THE CONNECTION TO PHOSPHORUS



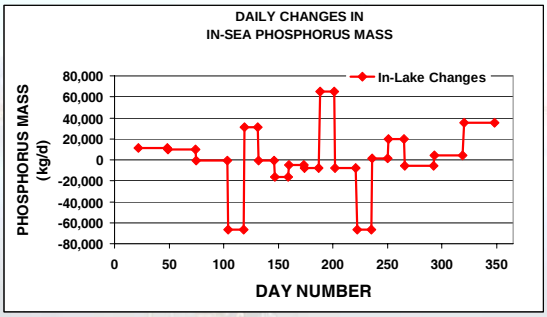
WHAT IS "KNOWN" ABOUT PHOSPHORUS IN THE SALTON SEA

1. Since 1965 there has been a 75% increase in P loading, but no significant change in Chlorophyll concentration
2. Despite anoxic conditions, data do not show the "classical" lake response of high orthophosphate in the hypolimnion
3. This is consistent with orthophosphate being bound as hydroxyapatite (Holdren)
4. Phosphorus concentrations in pore water are about 10 times higher than that in the overlying water (Anderson & Amrhein)

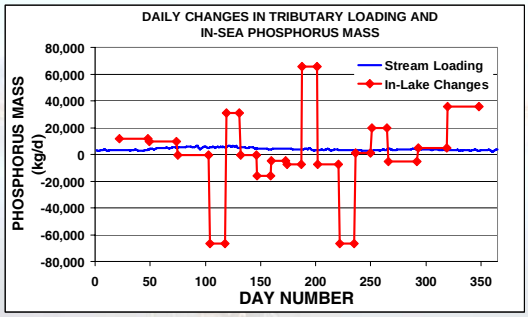
   → "diffusive flux" of Phosphorus into Sea, but still less than external loading



Data from Holdren



Data from Holdren

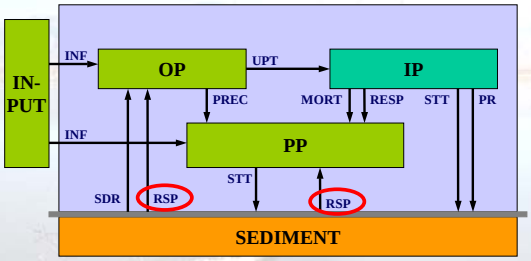


Data from USGS, Holdren

- The rates of phosphorus loading are episodic and are an order of magnitude larger than the external stream-borne phosphorus flux
  - → clearly <u>not</u> a "diffusive" process
- There are rates of phosphorus removal that are equally large

Hypothesis – phosphorus (and other nutrient) additions occur episodically due to sediment resuspension events under high wind/wave conditions. This "internal load" exceeds the "external load"

Salton Sea Conceptual Model - P



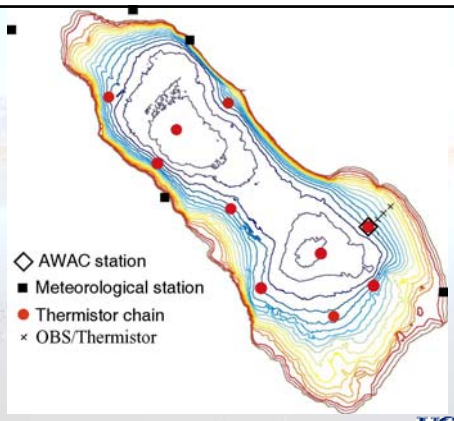
*NOTE: INF=Inflow, UPT=Uptake, RESP=Respiration, MORT= Mortality, PR=Permanent Removal, PREC=Precipitation, STT=Settling, RSP=Resuspension, SDR=Sediment Release

THIS CONCEPTUAL MODEL WAS USED AS THE BASIS OF TWO NUMERICAL MODELING STUDIES OF THE SALTON SEA

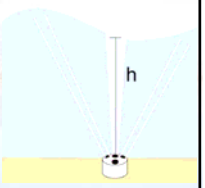
IS THE CONCEPTUAL MODEL RIGHT?

IT IS CRUCIAL THAT WE KNOW.

IF IT IS CORRECT, INFLOW CONTROL WILL SHOW LITTLE IMMEDIATE BENEFIT TO THE SEA. THE FUTURE SEA MAY NOT FULFILL EXPECTATIONS



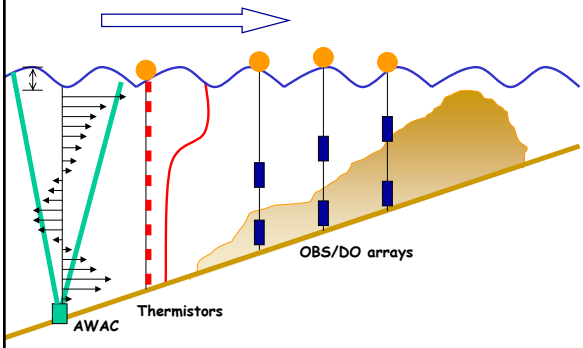
AWAC Acoustic Waves And Currents



Simultaneously measures (1) wave height and direction, and (2) velocity profile through the water column

ONSET THERMISTOR – measures temperature continuously

YSI WIPED OBS/DO/TEMP/COND PROBE – measures changes in suspended sediment concentration continuously



This experiment will provide data for better quantifying the mechanism of sediment resuspension, both for the Salton Sea and for lakes in general – this is the most extensive experiment of its kind.

What will still need to be done, is to understand the actual sediment/porewater chemistry. We do not know what biogeochemical processes are occurring, and how they might change under altered conditions (lower salinity, more frequent/less frequent mixing).

HISTORY OF NUMERICAL MODELS OF THE SALTON SEA

COOK (2000) – 3D HYDRODYNAMIC MODEL

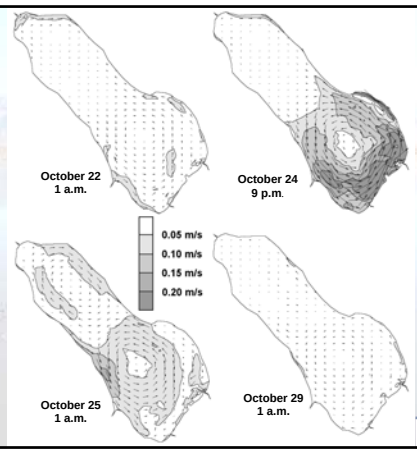
ROBERTSON & SCHLADOW (2004) – EMPIRICAL WATER QUALITY (EUTROPHICATION) MODEL

SCHLADOW et al. (2004) - 1D HYDRODYNAMIC AND WATER QUALITY (EUTROPHICATION) MODEL

COOK (2000) – 3D HYDRODYNAMIC MODEL

Pros - fair agreement for currents under non-stratified conditions
- able to compare different configurations

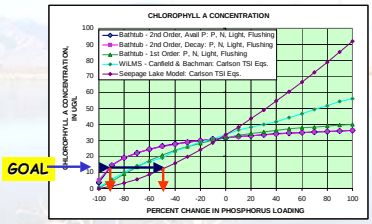
Cons – poor agreement for stratified conditions
- extremely long run times (days/month)
- poor spatial resolution (because of speed)
- no water quality



ROBERTSON & SCHLADOW (2004) – EMPIRICAL WATER QUALITY (EUTROPHICATION) MODEL

Pros – simple models designed to examine watershed impacts on trophic status.
- widely used in TMDL practice

Cons – not process-based
- rely on "universal regressions"
- provide no time response information



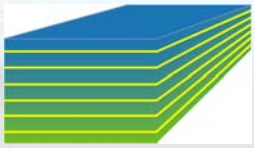
SCHLADOW et al. (2004) - 1D HYDRODYNAMIC AND WATER QUALITY (EUTROPHICATION) MODEL

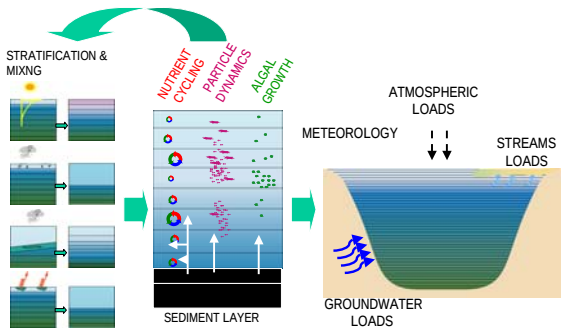
Pros – process based (reliant on best available process descriptions
- models the main processes for WQ
- very fast (minutes/year)
- provides time trajectory of change

Cons – gives no information on circulation
- reliant on best available process descriptions

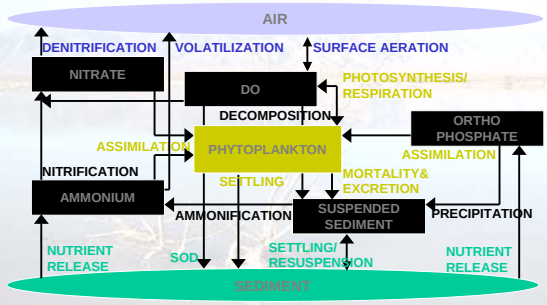
DLM-WQ

- One Dimensional (1-D) Model
- Process Based and Deterministic
- Composed of
  - Hydrodynamic/Thermodynamic Model - Physical Mixing
  - Ecological Model - Biological Growth and Chemical Reactions
  - Sediment Resuspension Model

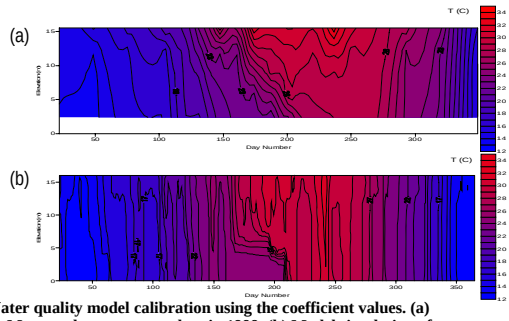




Schematic of Ecological Model

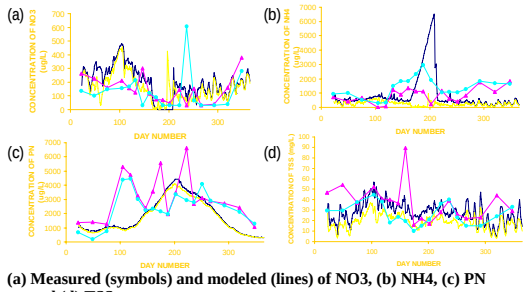


Model Calibration and Validation



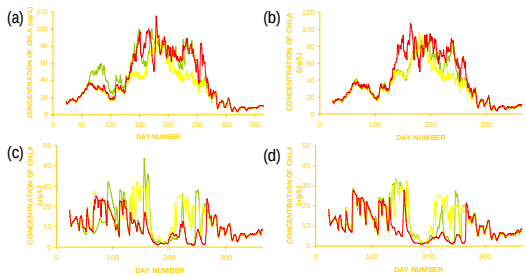
Water quality model calibration using the coefficient values. (a) Measured temperature data in 1999, (b) Model simulation of temperature.

Model Calibration and Validation



(a) Measured (symbols) and modeled (lines) of NO3, (b) NH4, (c) PN and (d) TSS

Chlorophyll *a* Response to External P Load Reduction

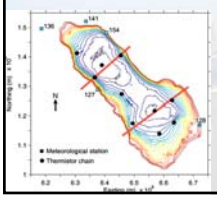


(a) Comparison of Chlorophyll a concentrations at the surface (50%) , (b) at the surface (90%), (c) at the bottom (50%) and (d) at the bottom (90%)

DATA REQUIREMENTS OF THE SALTON SEA

FOR 3 YEARS IN CONJUNCTION W/FISH SAMPLING:

1. 2-MONTHLY MONITORING FOR NUTRIENTS, TEMPERATURE, DO, CHL*a*, LIGHT, H_2S, MAJOR CATIONS/ANIONS, ALGAL SPECIES ALONG 2 TRANSECTS AND IN STREAMS.
2. SEDIMENT PROFILES FOR H_2S, NH_4, PO_4, TP, AND CHARACTERIZING MICROBIAL COMMUNITY ALONG 2 TRANSECTS
3. CONTINUOUS TEMPERATURE, DO AND OBS MEASUREMENTS AT EXISTING THERMISTOR CHAIN NETWORK.
4. UPGRADE UP TO THREE CONTINUOUS STATIONS TO REAL-TIME OUTPUT USING SPREAD SPECTRUM RADIO MODEM
5. ACQUIRE ADP CURRENT DATA AT 6 SITES FOR 1 YEAR



6. AT 6 MONTHLY INTERVALS, PERFORM HIGH FREQUENCY WATER COLUMN PROFILING AND SAMPLING FOR 24 HOURS.UPGRADE "TARGET" TO ALLOW FOR CONTINUOUS WATER SAMPLING.
7. REMOTE SENSING DATA FOR TEMPERATURE, CHLOROPHYLL AND SURFACE VELOCITY MAPPING.

ANALYSIS REQUIREMENTS OF THE SALTON SEA

1. COLLECTED DATA MUST BE ANALYZED JOINTLY TO DEVELOP A TESTABLE CONCEPTUAL MODEL OF THE SEA. SIX MONTHLY SCIENCE WORKSHOPS TO FACILITATE THIS
2. CONCEPTUAL MODEL FORMS BASIS OF NUMERICAL MODELS
3. NUMERICAL MODELS TESTED AGAINST DATA, AND IDENTIFY DATA GAPS AND CONCEPTUAL MODEL FAILURE

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MODEL REQUIREMENTS OF THE SALTON SEA

1. USE DATA COLLECTED TO PROPERLY CALIBRATE AND VALIDATE 1-D WATER QUALITY MODEL.
2. DEVELOP A 3-D HYDRODYNAMIC AND WATER QUALITY MODEL, BASED ON EXISTING PUBLIC DOMAIN MODELS SUITABLE FOR SHALLOW LAKE ENVIRONMENTS.
3. USE NUMERICAL MODELS TO CONFIRM AND/OR ADAPT CONCEPTUAL MODEL, TO GUIDE FUTURE MONITORING (AT A REDUCED SCALE), AND TO ADVANCE THE RESTORATION PLAN.

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