Tidal Effect on Chemical Spills in San Diego Bay

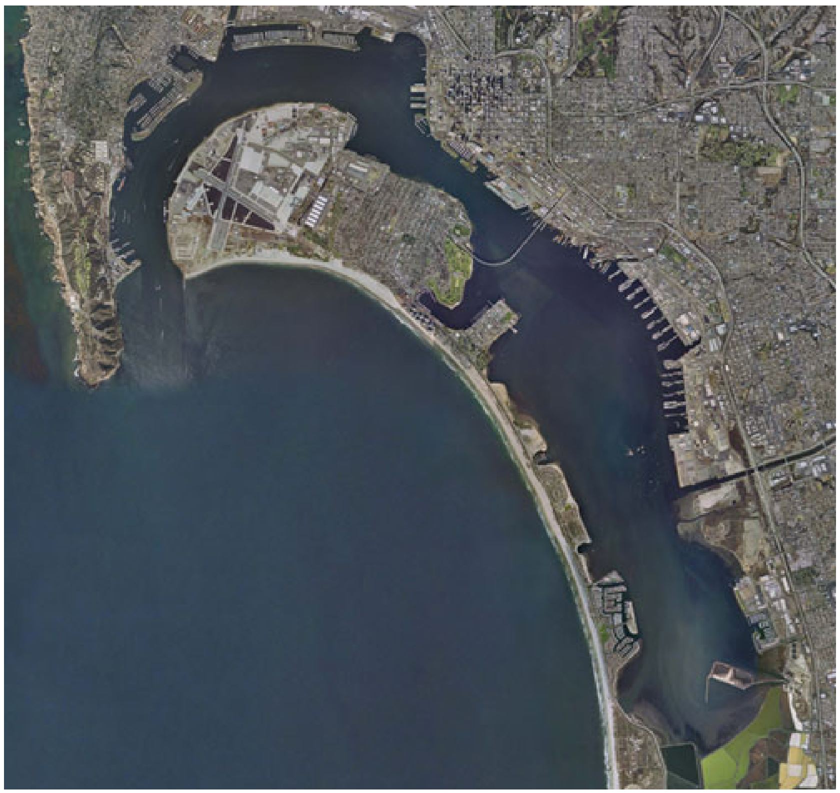
Peter C. Chu, Kleanthis Kyriakidis
Naval Postgraduate School, Monterey, CA, USA

Steven D. Haeger
Naval Oceanographic Office, Stennis Space Center, MS, USA

Mathew Ward
Applied Science Associates, Inc., .Narragansett, RI, USA

First International Conference on Physical Coastal Processes, Management, and Engineering, WIT, Malta, September 14-16, 2009

San Diego Bay



- Importance for Homeland Security
  - Large City
  - Host of a significant part of US Navy
  - Near the Mexican border
- Weak winds
- Tidally driven basin

Homeland Security: Chemical Attack or Accident

(UNCLASSIFIED)

Primary source container being placed into a double-walled secondary container. The inner wall is depleted uranium and the outer wall is stainless steel.

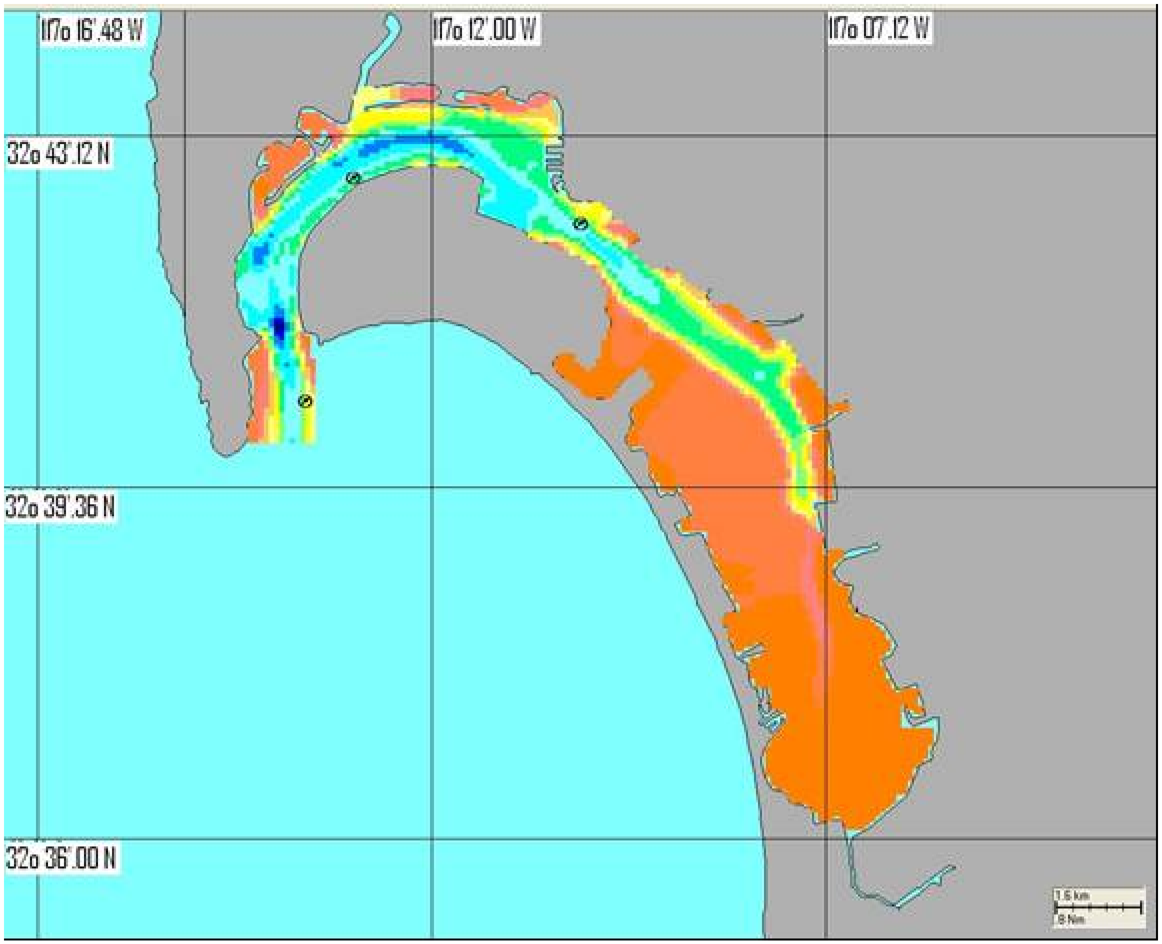
Secondary container being placed into the outer shipping container. The secondary container will be surrounded by laminated plywood in the outer container.

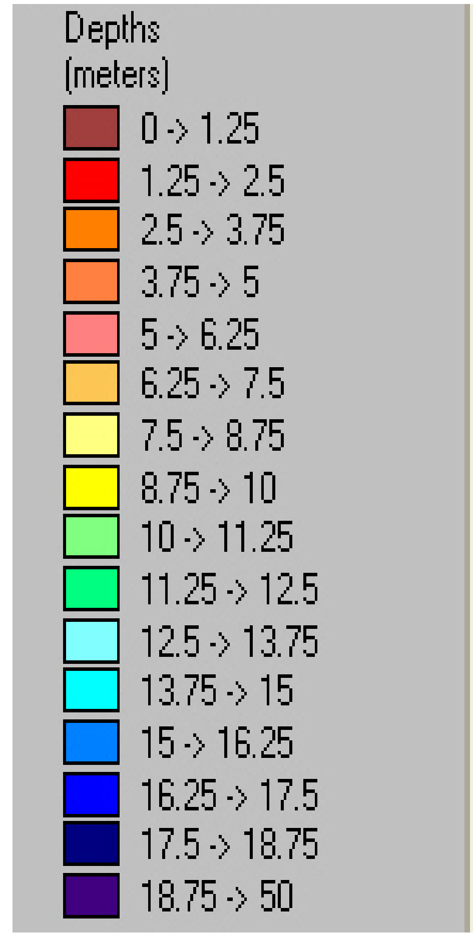
Steel drum outer shipping container with top plywood structure in place.

Completed outer shipping container.

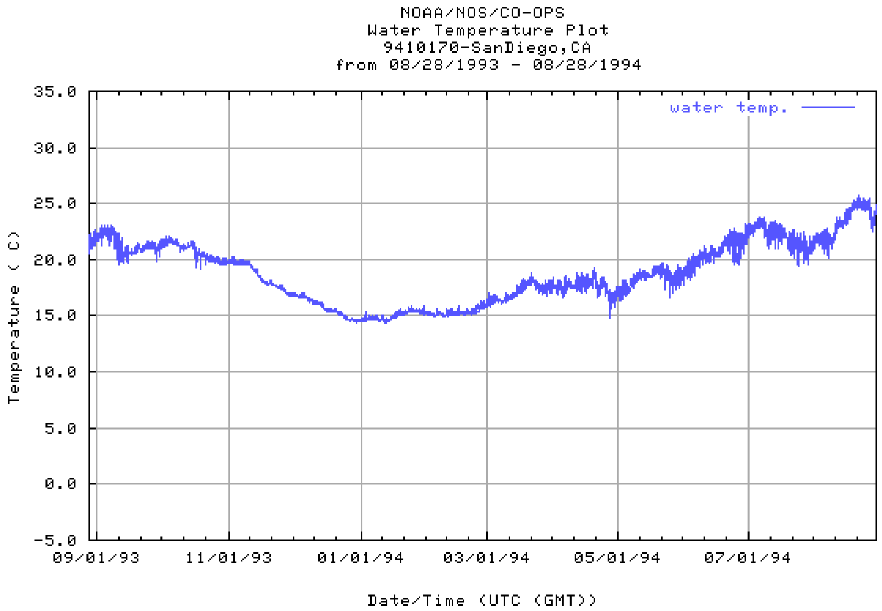
(1) Basic environmental conditions in San Diego Bay

Bottom Topography





Characteristics

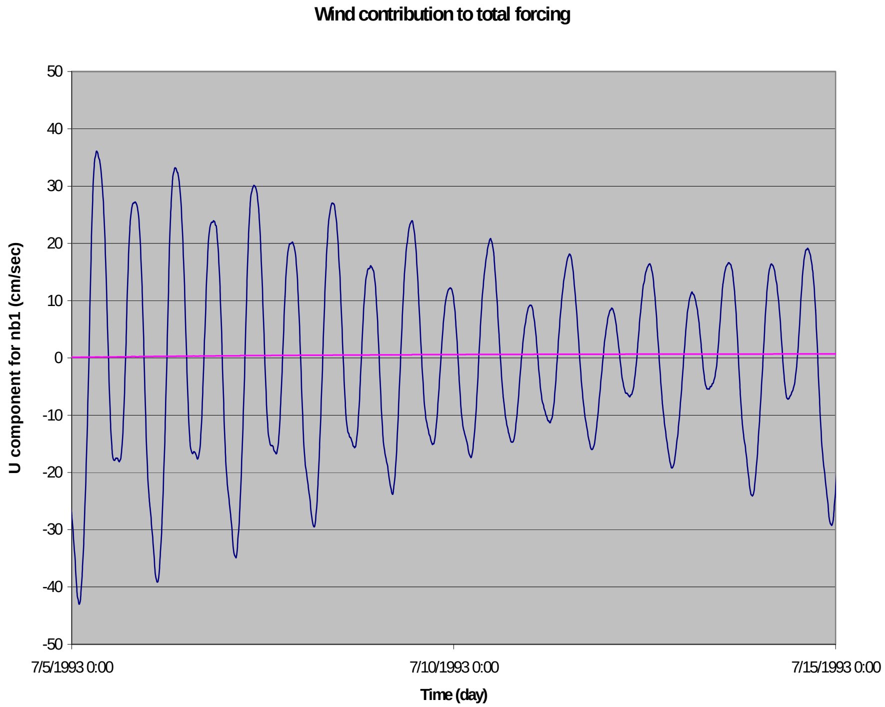


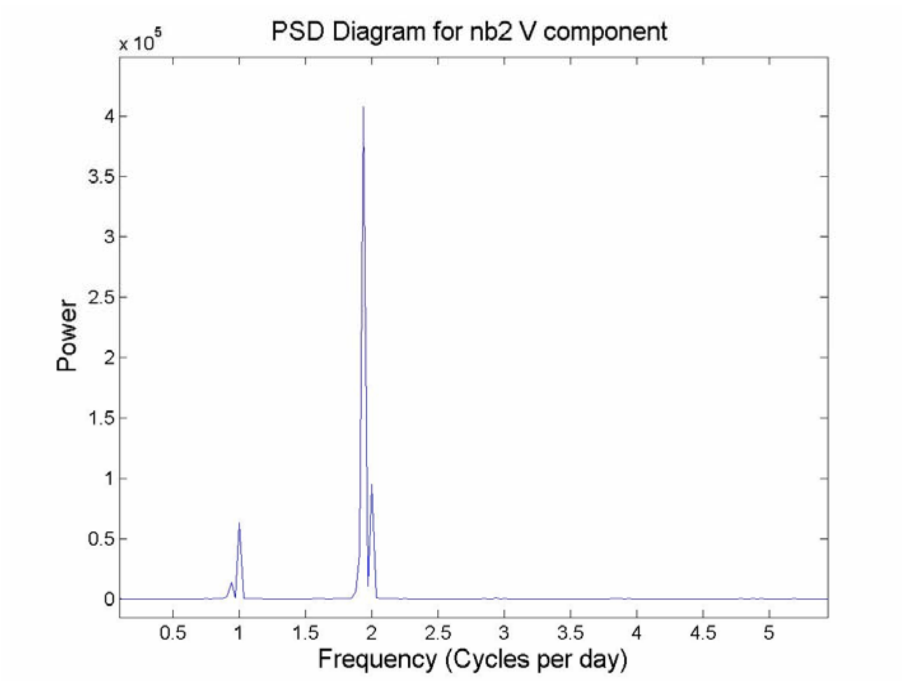
T ~ 21ºC

(range 14º – 26ºC).

S ~ 35 ppt

(range 32.5 - 37.5 ppt)





- Currents produced by tides ("tidal pumping" caused by the flow difference between ebb and flood).

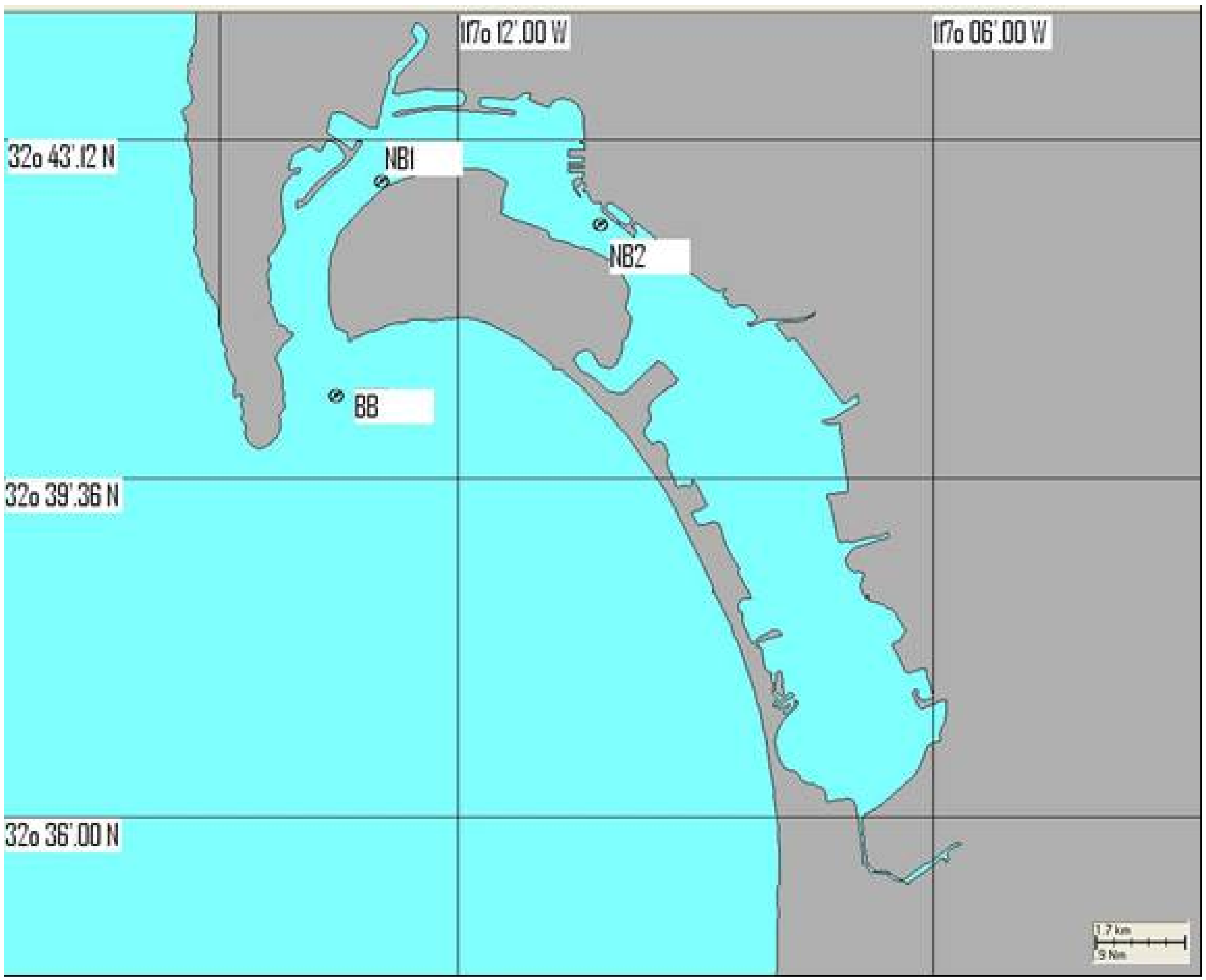
- Winds insignificant effect. Both westerly afternoon winds and easterly morning/ evening winds less than 5 m/sec

- Annual precipitation 0.26 m (in summer negligible – less than 0.005 m) . No significant river inflow

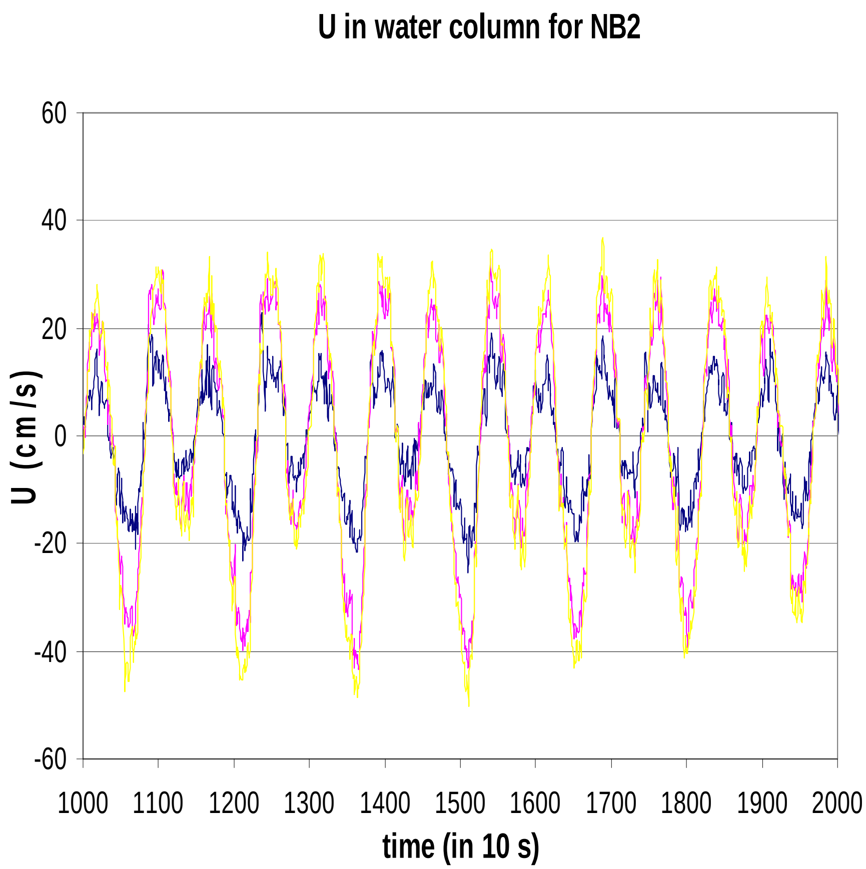
	Name	Amplitude (m)	Epoch (degrees)
1	M2	0.576	148.9
2	S2	0.233	145.9
3	N2	0.136	128.7
4	K1	0.352	210.5
5	O1	0223	195.6
6	NU2	0.027	134.3
7	MU2	0.010	109.7
8	2N2	0.018	108.7
9	OO1	0.010	225.4
10	LAM2	0.004	147.5
11	M1	0.011	194.2
12	J1	0.018	217.9
13	SSA	0.017	272.7
14	SA	0.063	182.0
15	RHO	0.008	189.2
16	Q1	0.041	188.7
17	T2	0.014	145.9
18	2Q1	0.006	180.7
19	P1	0.109	208.8
20	L2	0.013	121.7
21	K2	0.065	139.3

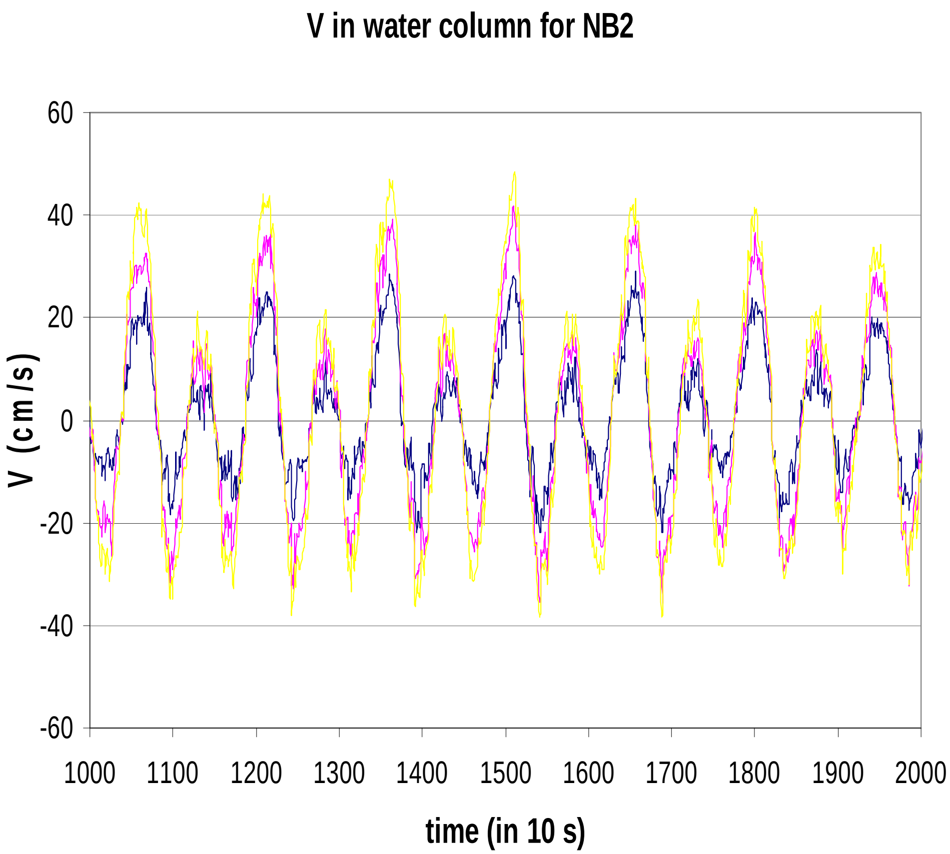
- Semi-diurnal and Diurnal Tides

ADCP Stations (SPAWAR)
Measuring Current Velocity



Currents at NB2 station for surface (yellow), middle depth (purple) and bottom (blue)





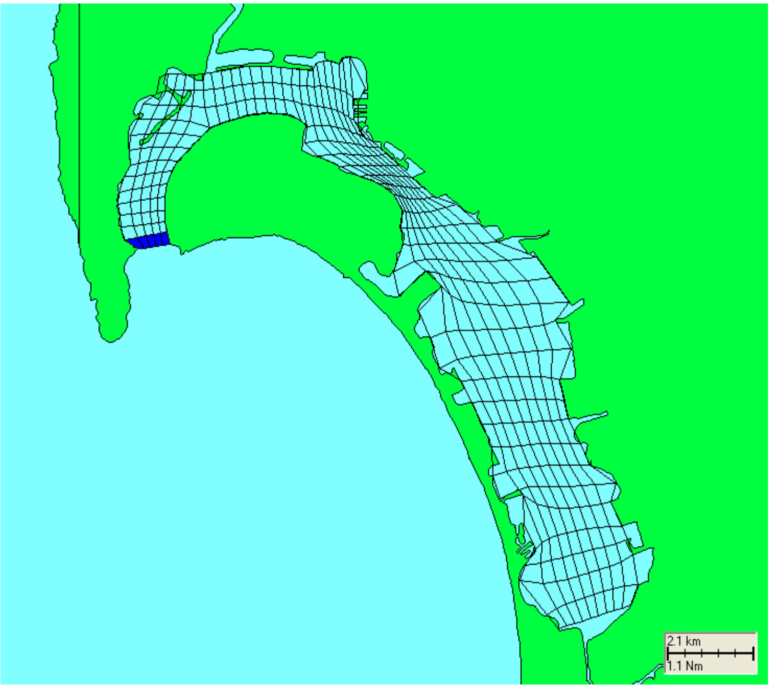
(2) Hydrodynamic modeling

Water Quality Management and Analysis Package (WQMAP)

- **WQMAP** is an integrated modeling system designed to predict hydrodynamic features (current velocity, surface elevation, …) and surface water quality.

Features of WQMAP

- Integrated Geographic Information System
- Grid Generation
- Hydrodynamic Model
- Pollutant Transport Model
- All models use same computational grid
- Applicable within regions such as rivers, lakes, estuaries, bays and coastal seas.



Hydrodynamic model

- Hydrostatic
- Tidal forcing (tidal harmonic at the open boundary from NOAA)
- Land boundaries assumed impermeable (normal component of velocity set to zero).
- At closed boundaries transport of substance (i.e. salinity) is zero.
- At open boundaries, concentration specified during the inflow, using characteristic values.

Basic Equations

$$\frac{d\rho}{dt} + \rho\Delta \cdot \vec{v} = 0$$

$$\rho \frac{d\vec{v}}{dt} + \rho(2\vec{\Omega} \times \vec{v}) = -\nabla p - \rho g\vec{k} + \nabla \cdot \mathbf{T}$$

$$\rho c_p \frac{dT}{dt} - \beta T \frac{dp}{dt} = -\nabla \cdot \vec{q} - \sigma$$

$$\rho = \rho(T, S, p)$$

$$\frac{dS}{dt} = \kappa_s \nabla \cdot (\nabla S)$$

- $\mathbf{T} \equiv \begin{bmatrix} \tau_{xx} & \tau_{xy} & \tau_{xz} \\ \tau_{yx} & \tau_{yy} & \tau_{yz} \\ \tau_{zx} & \tau_{zy} & \tau_{zz} \end{bmatrix}$
- $\vec{q} \equiv$ heat flux
- $c_p \equiv$ specific heat
- $\beta \equiv$ thermal expansion
- $\kappa_S \equiv$ molecular diffusion

Hydrodynamic Model

$$\rho\left[\frac{du}{dt}-\frac{uv\tan\phi}{r}+\frac{uw}{r}\right]+2\Omega\rho(\cos\phi w-\sin\phi v)=-\frac{1}{r\cos\phi}\frac{\partial\rho}{\partial\lambda}+(\nabla\cdot\mathbf{T})\cdot\hat{\lambda}$$

$$\rho\left[\frac{dv}{dt}-\frac{u^{2}\tan\phi}{r}+\frac{vw}{r}\right]+2\rho\Omega\sin\phi u=-\frac{1}{r}\frac{\partial\rho}{\partial\phi}+(\nabla\cdot\mathbf{T})\cdot\hat{\phi}$$

$$\rho\left[\frac{dw}{dt}-\frac{u^{2}+v^{2}}{r}\right]+2\rho\Omega\cos\phi u=-\frac{\partial p}{\partial r}-\rho g+(\nabla\cdot\mathbf{T})\cdot\hat{r}$$

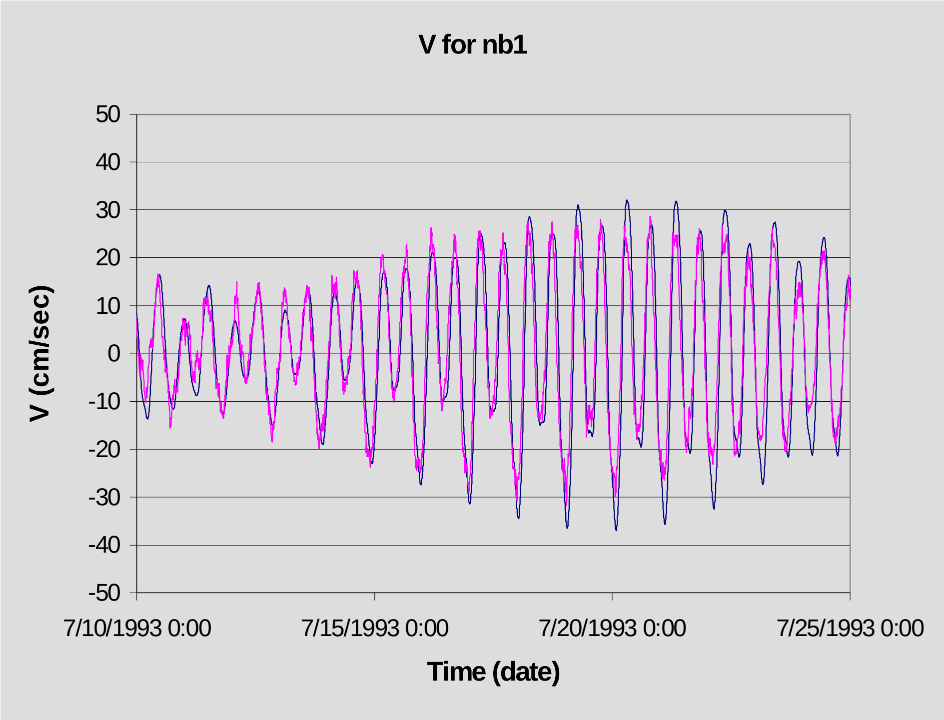
$$\frac{d\rho}{dt}+\frac{\rho}{r\cos\phi}\left(\frac{\partial u}{\partial\lambda}+\frac{\partial(v\cos\phi)}{\partial\phi}\right)+\frac{\rho}{r^{2}}\frac{\partial(r^{2}w)}{\partial r}=0$$

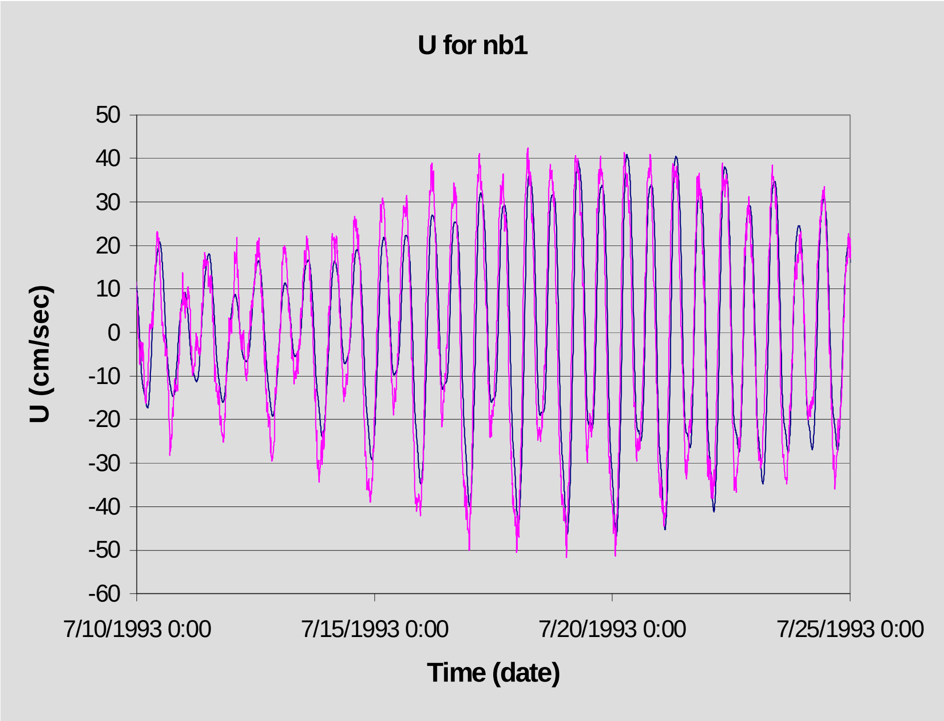
$$\frac{dT}{dt}-\frac{\beta T}{\rho c_{p}}\frac{dp}{dt}=\frac{\nabla\cdot(\kappa\nabla T)}{\rho c_{p}}-\frac{\sigma}{\rho c_{p}},\ \text{where } \rho=\rho(p,T)\ \text{and}$$

$$\frac{d}{dt}=\frac{\partial}{\partial t}+\frac{u}{r\cos\phi}\frac{\partial}{\partial\lambda}+\frac{v}{r}\frac{\partial}{\partial\phi}+w\frac{\partial}{\partial r}.$$

Model Evaluation

Red – Observation, Blue - Modeling





MODEL EVALUATION/ VELOCITY COMPONENTS

- Correlation Coefficient : 0.92
- Relative Root Mean Square Error: 0.09

MODEL EVALUATION/ ELEVATION

	NOAA	SPAWAR
M2 (ampl dif)	+ 2.51 cm	+ 3.83 cm
K1 (ampl dif)	- 0.94 cm	+ 3.73 cm
O1 (ampl dif)	- 0.84 cm	- 2.19 cm
S2 (ampl dif)	+ 0.71 cm	- 1.1 cm
M2 (ph dif)	+ 0.75^{o}	- 1.71^{o}

(3) Chemical Dispersion

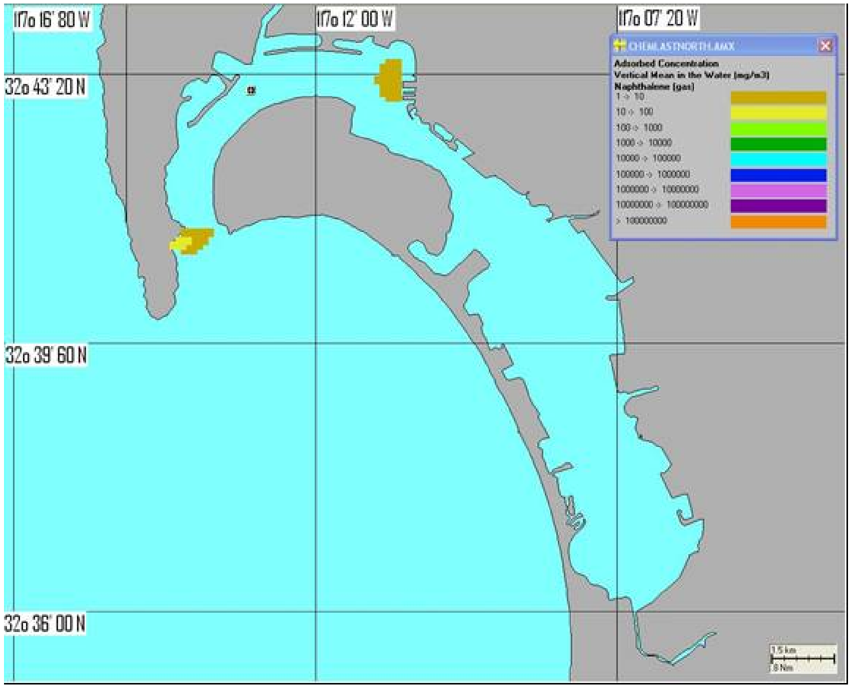
Chemical Discharge Model System (CHEMMAP)

- **CHEMMAP** is a chemical discharge model designed to predict the trajectory, fate, impacts and biological effects of a wide variety of chemical substances three-dimensionally.

CHEMICAL Dispersion SCENARIOS

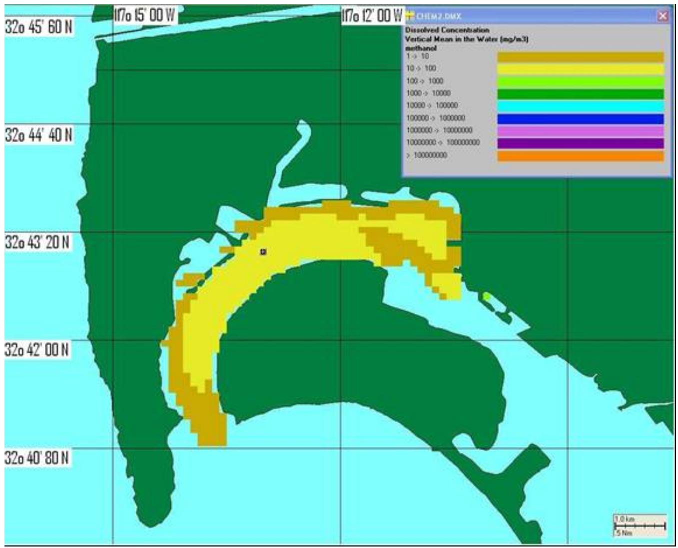
- Released in North and South San Diego Bay)
- Methanol (1 barrel released in depth 1 m).
- Chlorobenzene (200 tons in depth 1 m).

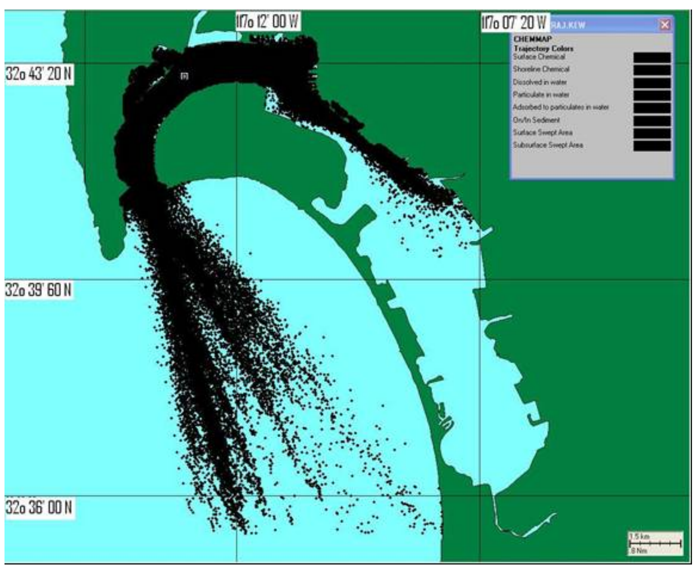
Pollutants Released at North San Diego Bay

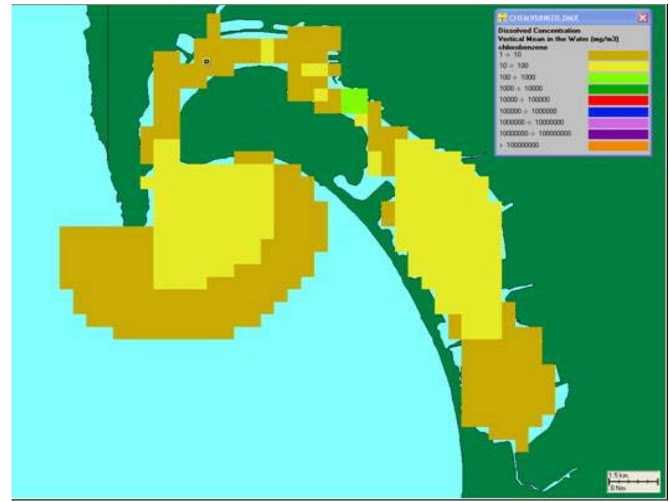


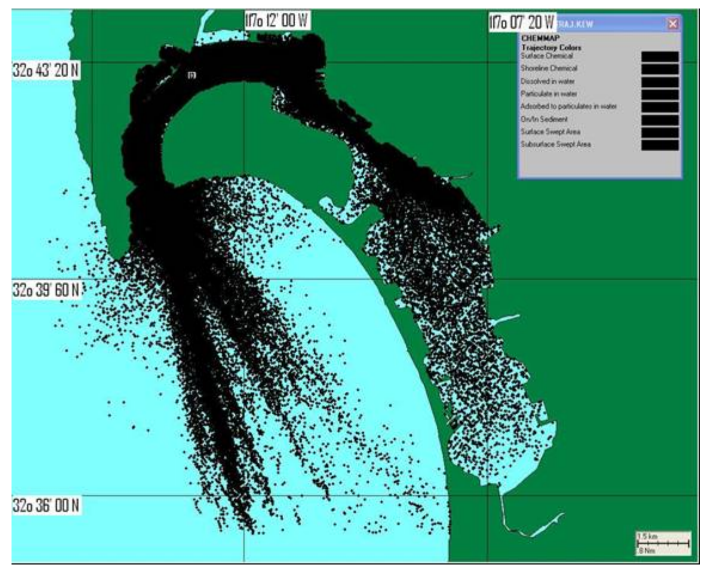
2 days

32 days

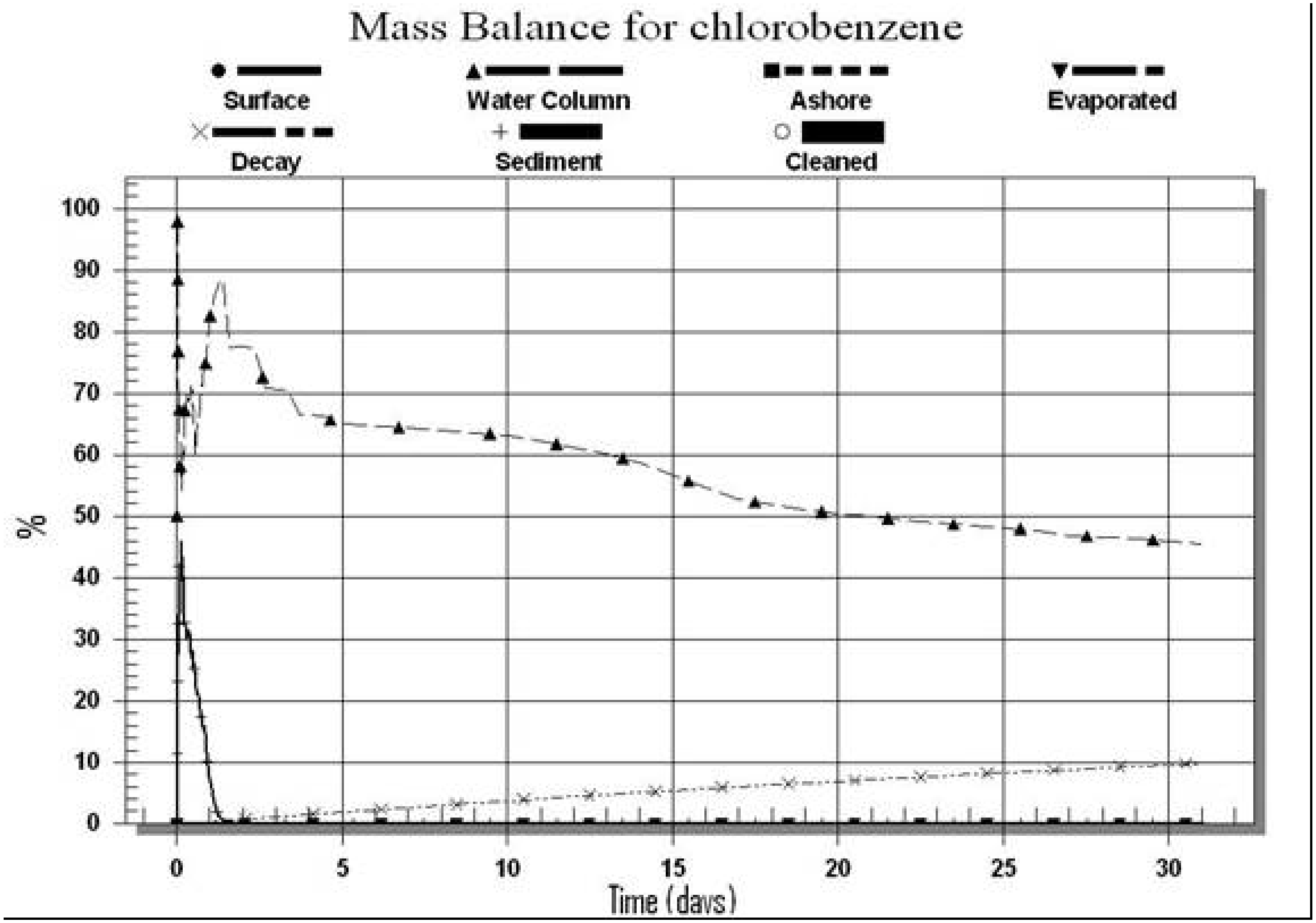




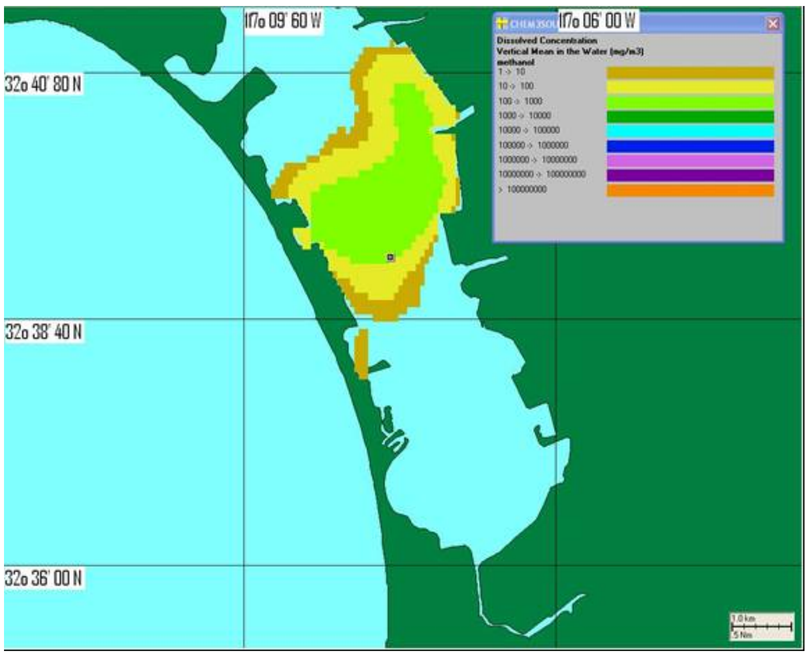




Fast Temporal Reduction of Chemical Concentration



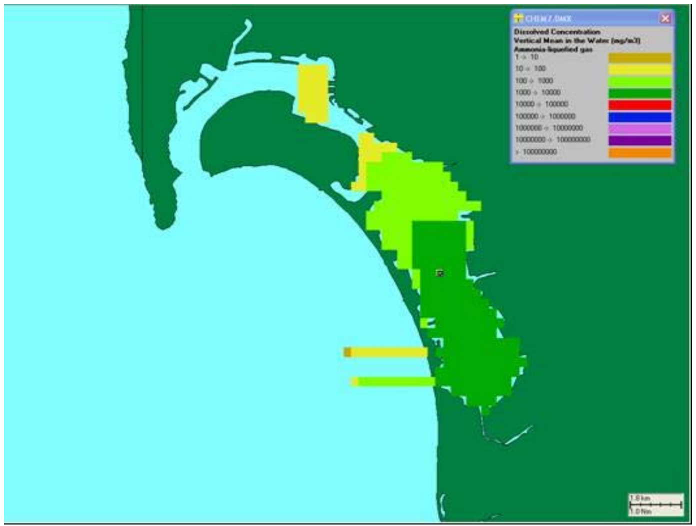
Pollutants Released at South San Diego Bay

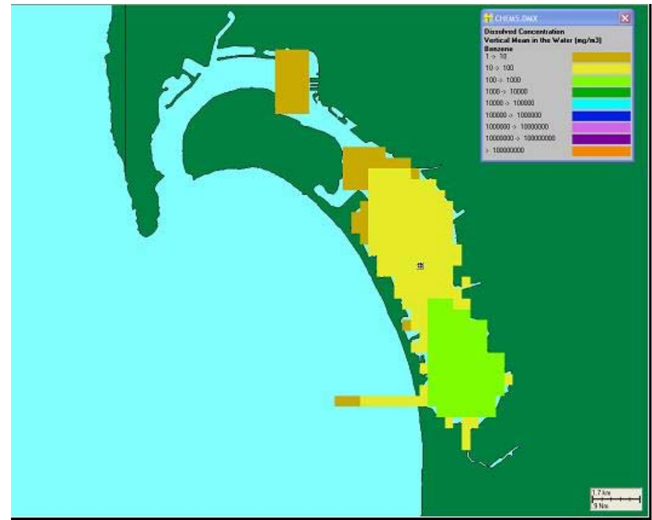


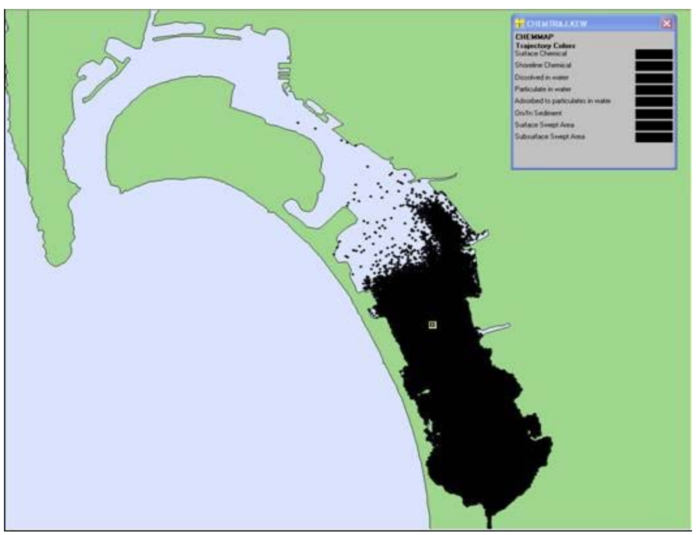
- After 12 hours

15 days

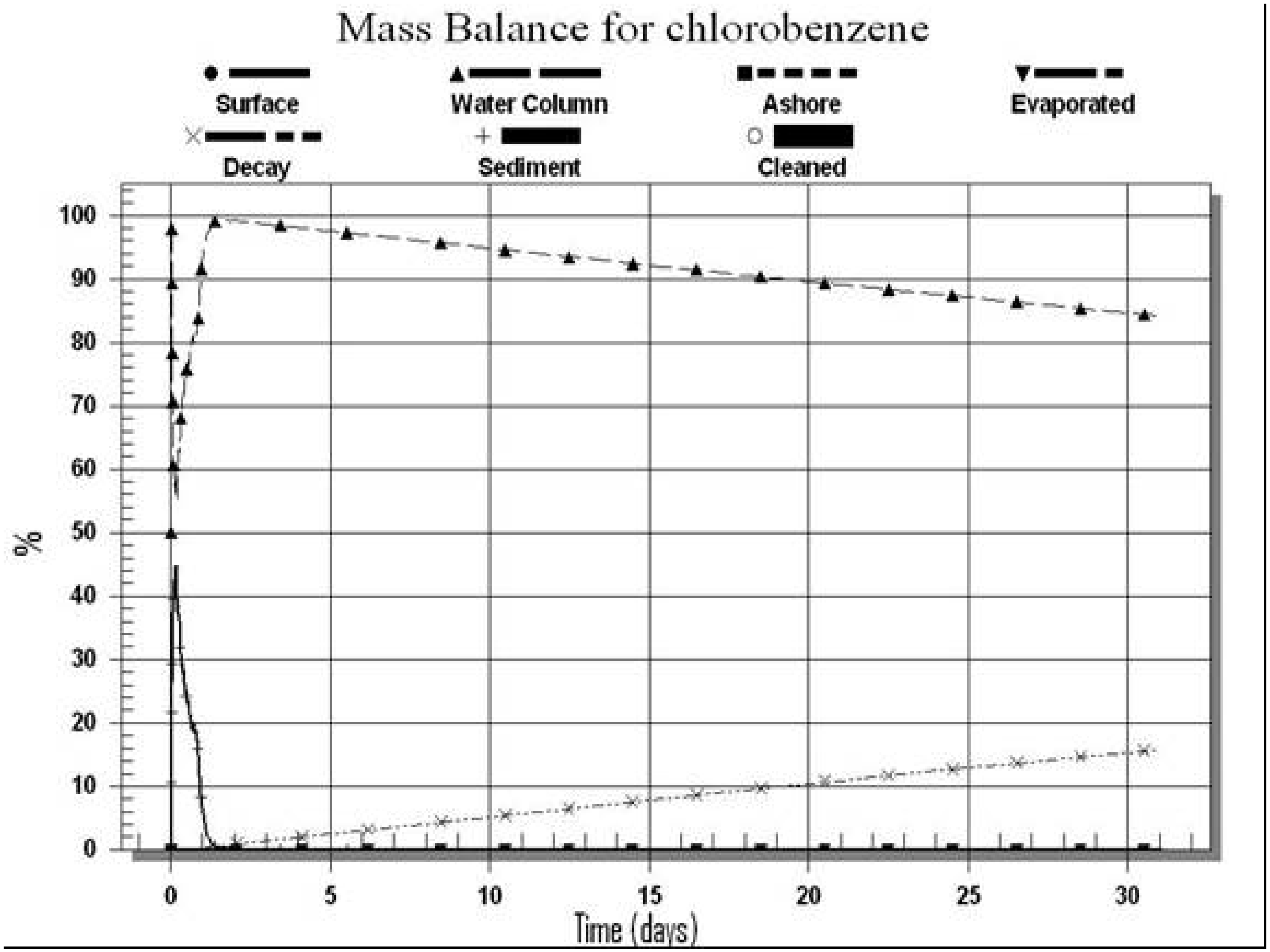
32 days







Slow Temporal Reduction of Chemical Concentration



Conclusions

- Two Types of Chemical Dispersion in San Diego Bay

- Great danger/ vulnerability:

  – In the North San Diego Bay, contamination of city/port, Bay – small reaction time.

  – In the South San Diego Bay, contamination only of Southern part (including Naval Station).

Conclusions

- Hydrodynamic-chemical modeling is very important for harbor safety and waste water management.