Tidal Effect on Chemical Spills in San Diego Bay

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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

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

$T \sim 21^\circ C$
(range $14^\circ - 26^\circ C$).

$S \sim 35$ 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.
<table>
<thead>
<tr>
<th>Name</th>
<th>Amplitude (m)</th>
<th>Epoch (degrees)</th>
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<tbody>
<tr>
<td>M2</td>
<td>0.576</td>
<td>148.9</td>
</tr>
<tr>
<td>S2</td>
<td>0.233</td>
<td>145.9</td>
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<tr>
<td>N2</td>
<td>0.136</td>
<td>128.7</td>
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<tr>
<td>K1</td>
<td>0.352</td>
<td>210.5</td>
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<tr>
<td>O1</td>
<td>0.023</td>
<td>195.6</td>
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<td>Q1</td>
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<td>145.9</td>
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<tr>
<td>2Q1</td>
<td>0.006</td>
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<td>0.109</td>
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<tr>
<td>L2</td>
<td>0.013</td>
<td>121.7</td>
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<tr>
<td>K2</td>
<td>0.065</td>
<td>139.3</td>
</tr>
</tbody>
</table>

- Semi-diurnal and Diurnal Tides
ADCP Stations (SPAWAR)
Measuring Current Velocity
Currents at NB2 station for surface (yellow), middle depth (purple) and bottom (blue)

U in water column for NB2

V in water column for NB2
(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

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

\[
\frac{d \vec{v}}{dt} = -\nabla p - \rho g \vec{k} + \nabla \cdot \mathbf{T}
\]

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

\[
\rho = \rho(T, S, p)
\]

\[
\frac{dS}{dt} = \kappa_S \nabla \cdot (\nabla S)
\]

\[\mathbf{T} \equiv \begin{bmatrix}
\tau_{xx} & \tau_{xy} & \tau_{xz} \\
\tau_{yx} & \tau_{yy} & \tau_{yz} \\
\tau_{zx} & \tau_{zy} & \tau_{zz}
\end{bmatrix}\]

- $\vec{q}$ ≡ heat flux
- $c_p$ ≡ specific heat
- $\beta$ ≡ thermal expansion
- $\kappa_S$ ≡ molecular diffusion
Hydrodynamic Model

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

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

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

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

\[
\frac{dT}{dt} - \frac{\beta T}{\rho c_p} \frac{dp}{dt} = \nabla \cdot (k \nabla T) - \frac{\sigma}{\rho c_p}, \text{ where } \rho = \rho(p,T) \text{ and }
\]

\[
\frac{d}{dt} = \frac{\partial}{\partial t} + \frac{u}{r \cos \phi} \frac{\partial}{\partial \lambda} + \frac{v}{r} \frac{\partial}{\partial \phi} + w \frac{\partial}{\partial r}.
\]
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°  - 1.71°
(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

Mass Balance for chlorobenzene

- Surface
- Water Column
- Ashore
- Evaporated
- Decay
- Sediment
- Cleaned

Time (days)

%
Pollutants Released at South San Diego Bay

- After 12 hours
Slow Temporal Reduction of Chemical Concentration

Mass Balance for chlorobenzene
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.**