Estuary Structure and Function; Submarine Groundwater Discharge

OCN 623 – Chemical Oceanography
31 March 2015


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Outline

• River-water vs. sea-water concentrations
• Definitions of types of estuaries
• Mixing curves
• The mid-estuary turbidity maximum
• Submarine groundwater discharge
Masses of Materials Entering/Leaving the Ocean

Transport rates are $10^{14}$ g/year

Dissolved solids in global ocean = $470 \times 10^{20}$ g

From Garrels & Mackenzie (1971)
River-water and Sea-water Concentrations

<table>
<thead>
<tr>
<th>Element</th>
<th>Concentration in river-water (µg l⁻¹)</th>
<th>Concentration in sea-water (µg l⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cl</td>
<td>8 × 10³</td>
<td>1.987 × 10⁷</td>
</tr>
<tr>
<td>S</td>
<td>3.7 × 10³</td>
<td>9.28 × 10⁵</td>
</tr>
<tr>
<td>Br</td>
<td>20</td>
<td>6.8 × 10⁴</td>
</tr>
<tr>
<td>F</td>
<td>100</td>
<td>1.4 × 10³</td>
</tr>
<tr>
<td>B</td>
<td>10</td>
<td>4.5 × 10³</td>
</tr>
<tr>
<td>Na</td>
<td>9 × 10³</td>
<td>11.05 × 10⁶</td>
</tr>
<tr>
<td>Mg</td>
<td>4.1 × 10³</td>
<td>1.326 × 10⁶</td>
</tr>
<tr>
<td>Ca</td>
<td>1.5 × 10³</td>
<td>4.22 × 10⁵</td>
</tr>
<tr>
<td>K</td>
<td>2.3 × 10³</td>
<td>4.16 × 10⁵</td>
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<tr>
<td>Sr</td>
<td>50</td>
<td>8.5 × 10³</td>
</tr>
<tr>
<td>N</td>
<td>2.5 × 10²</td>
<td>500</td>
</tr>
<tr>
<td>P</td>
<td>20</td>
<td>70</td>
</tr>
<tr>
<td>Si</td>
<td>6.1 × 10³</td>
<td>1000</td>
</tr>
</tbody>
</table>

Nutrients are different!

\[ \text{RW} \ll \text{SW} \]

\[ \text{RW} \approx \text{SW} \]

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\( a \) Data from Riley and Chester (1971).

\( b \) Salinity = 35%.  

\( c \) Data from Livingstone (1963).
Definitions of “Estuary”

Two major components involved:

• Transition from fresh (river) water to saline (ocean) water
• Tidal influence

One definition:

“An estuary is a semi-enclosed coastal water body that extends to the effective limit of tidal influence, within which sea water is significantly diluted with freshwater from land drainage”
• Estuarine ecosystems includes:

- The **river channel**, to the maximum upstream extent of tidal influence

- The **adjacent coastal waters**, to the maximum extent of freshwater flow

- **Salt marshes and tidal flats** that develop along the shoreline, built up from riverine sediments deposited as river flow rate slows at sea level; subject to daily tidal inundation and exposure

• Estuaries are zones of **mixing**, displaying **strong salinity gradients** from land to sea
Water Movement in Estuaries

- River flow is essentially unidirectional

- As river water meets the sea, tidal oscillation introduces a bi-directional (“in-out”) component to flow
  - This bi-directionality may be throughout the water column (well-mixed estuary)
  - Or there may be predominantly surface outflow and deep inflow (salt-wedge estuary)
River-dominated Estuary

Fig. 112. Idealized map of a typical estuary showing three divisions, lower, middle and upper estuary; the boundaries are transition zones that shift according to season, weather and tides (After Fairbridge, 1980)

Salomens and Forstner (1984)
Fig. 1.2. Estuarine circulation patterns, isohaline structure and typical vertical profiles of salinity and residual velocity in mid-estuary.

**Salt wedge**

**Partially mixed**

**Well mixed**

What factors determine the type of estuary??
Net outflow of water

Actually, evaporation - precipitation

Net inflow of water
Mixing Curves

The Basic Tool for Studying River-Ocean Interactions

Assumes end-members are constant over the flushing time of the estuary
Figure 5.3 Calculated values of partial pressure of CO$_2$ ($p$CO$_2$), based on dissolved inorganic carbon (DIC) and pH data, versus salinity in estuarine waters of the Satilla and Altamaha Rivers (USA). (Modified from Cai and Wang, 1998.)
Fig. 1.6. Model dissolved constituent–salinity relationships in an estuary under steady-state conditions. $C_{FW}$ and $C_{SW}$ are the concentrations of constituent $C$ in the fresh-water and sea-water mixing component, respectively. Line $a$ defines the theoretical dilution line for a non-interactive constituent. Curves $b$ and $c$ indicate relatively widespread estuarine input and removal of $C$, respectively. Curve $d$ is typical of removal occurring only in the upper estuary. Curve $e$ is generated when the rate of removal of $C$ in mid-estuary exceeds the riverine input. Curve $f$ indicates net input of $C$ to the upper estuary coupled with net removal further seaward.
Data from multiple points up-river

Greater impact of mid-estuary input during low flow (summer)

An Example of Seasonal Effects

An Example of Seasonal Effects

Salinity, g/kg

Dissolved phosphate as a function of salinity in the Hudson River Estuary (adapted from Simpson et al. 1975)
Estuarine Turbidity Maximum

Dennison and Abal (1999)
Turbidity maximum is due to both:

1) Chemical flocculation
   - Changes in speciation due to increased salinity
   - E.g., major seawater ions will cause decomplexation of freshwater ion complexes

2) Sediment resuspension
A Mid-estuary Trap for Riverborne Material

Flocculation & resuspension

removal of dissolved riverborne iron, manganese and organic matter

formation of new particulate matter

flux of Mn, Fe, doc to surface water

settling of particles

sediment
Fig. 113. Schematic presentation of types of estuaries. The dots indicate sediment concentration and the arrows the net water movements over ebb and flood. (Postma, 1980). 0–35 are % Salinity (S) isolines. For explanation see the text.
Effects Of The Mid-estuary Turbidity Maximum

1. **Scavenging** of surface-active materials
   - 70-100% of riverine Fe is removed (most at low salinity)
   - 60-80% of humic acids is removed
   - 5% of total DOM is removed

2. Increased **turbidity**
   - Lower primary production
   - Reduction of photochemical reaction rates

3. Enhanced **transport** rates downstream / offshore
   - Enhanced sedimentation rates downstream / offshore
Computation of Annual Mean River Flux

Means of products vs. products of means

<table>
<thead>
<tr>
<th>Month</th>
<th>Conc</th>
<th>Flow</th>
<th>Conc x flow</th>
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<td>3</td>
<td>6</td>
</tr>
<tr>
<td>1</td>
<td>2.4</td>
<td>3.3</td>
<td>7.92</td>
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<tr>
<td>2</td>
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<td>10.36</td>
</tr>
<tr>
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<td>3</td>
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<td>12</td>
</tr>
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<td>2.76</td>
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<td>11</td>
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</tr>
<tr>
<td>12</td>
<td>2</td>
<td>3</td>
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</tr>
</tbody>
</table>

Mean: 2 3 6.39
Surface Runoff

MANY POINTS OF ENTRY
Pollutants that are harmful to Hawaii's reefs can enter the ocean in many ways, including through storm drains and streams. Sediment runoff is a particular problem in some coastal areas, such as along East Honolulu's Maunalua Bay. The pollutants flush into Maunalua via nine major streams that have been altered to speed storm runoff and through dozens of neighborhood drainage systems that eventually empty into the streams or the bay. Other areas with similar sedimentation problems face the same challenge as East Honolulu: How to reduce the amount of dirt and other pollutants washing into the ocean.

Sources: Malama Maunalua, city records

The Honolulu Advertiser