Water Quality

Overview of Water Quality
Water Quality

• Measure of what the water carries
  – Sediment
  – Oxygen and Oxygen Demanding Substances
  – Nutrients
  – Xenobiotics

• Varies from place-to-place, time-to-time

• Requires monitoring or proxies
What is Pollution?

• An undesirable quantity of some constituent
  – Many are “natural” but enriched
• Human-defined
  – Related to ecosystem change, aesthetics, health
  – Driven by perception as well as science
• There are few well-defined functional thresholds for pollutants
  – Precautionary principle
  – Over-reaction and management costs
  – One size fits all (e.g. Numeric Nutrient Criteria)
What is Water Pollution

• Any physical, biological, or chemical change in water quality that adversely affects living organisms can be considered pollution.
  – **Point Sources** - Discharge pollution from specific locations.
    • Factories, Power plants
  – **Non-Point Sources** - Scattered or diffuse, having no specific location of discharge.
    • Agricultural fields, Feedlots, Logging Operations
Point Sources

• Easy to find
• Easy to regulate
• Easy to treat
• Easy to monitor

Non-Point Sources

• Hard to measure
• Hard to control
• Hard to treat
• Hard to monitor
Some Sources

• Surface Water
  – Urban runoff
  – Agricultural Runoff
  – Industrial Effluent
  – Chemical/Oil Spills
  – Municipal Effluent
  – Air fallout
  – Acid-mine drainage
  – Logging operations
  – Mills
  – Atmospheric deposits

• Groundwater
  – Gas tank leaks
  – Landill leaching
  – Agricultural Seepage
  – Saltwater Intrusion
  – Mine waste piles
  – Atmospheric deposits
Monitoring Water Quality

- **Total Maximum Daily Load**
  - Load = Mass of Pollutant (per day)
  - Total = In All Forms over All Flows
  - Water body specific
  - Pollutant specific
  - “Concentration that will not cause an imbalance in flora and fauna” or “Failure to meet designated use”
  - Hard to specify with scientific certainty
  - Requires legal defense
Categories of Potential Water Pollutants

- Organic Matter (sewage, garbage)
- Pathogens (cholera, giardia, E. coli)
- Organic chemicals (pesticides)
- Nutrients (P and N from fertilizers)
- Heavy Metals (mercury, lead etc. from urban runoff)
- Acids (mine tailings, industrial spills)
- Sediment (construction sites, erosion)
- Heat (power plant cooling systems)
- Radioactivity (gypsum stack runoff, military runoff)
Oxygen-Demanding Wastes (Biochemical Oxygen Demand)

• Water with an oxygen content > 6 ppm will generally support desirable aquatic life.
  – Water with < 2 ppm oxygen will support mainly detritivores and decomposers.

• Oxygen is added to water by diffusion from wind and waves, and by photosynthesis from green plants, algae, and cyanobacteria.
  – Oxygen is removed from water by respiration and oxygen-consuming processes.

• Natural low oxygen environments exist in wetlands (abundant organic matter and bacteria)
Oxygen-Demanding Wastes

- **Biochemical Oxygen Demand (BOD)** - Amount of dissolved oxygen consumed by microorganisms in degrading organic matter.
- **Effects of BOD on rivers depend on volume, flow, and temperature**
Oxygen Sag

Clean Zone
Trout, perch, bass; mayfly, stonefly, caddis fly larvae

Decomposition Zone
Trash fish; leeches

Septic Zone
Fish absent; sludge worms; midge and mosquito larvae

Recovery Zone
Trash fish; leeches, isopods

Clean Zone
Trout, perch, bass; mayfly, stonefly, caddis fly larvae

Dissolved oxygen

Biochemical oxygen demand

Oxygen sag

2 ppm

8 ppm

Direction of flow

Zone of Organic Matter Decomposition
Oxygen Sag in Time

Dissolved Oxygen in Mill Pond Spring Run
August 2007

Dissolved Oxygen (mg/L)
Insect Guides to Water Quality

• Insects are relatively immobile long-lived components of aquatic ecosystems
• Water quality changes rapidly, and along many axes (DO, nutrients, contaminants)
• Insects INTEGRATE the aquatic environment providing a useful indicator of water quality
  – Some insects are pollution “sensitive”
  – Others are pollution “tolerant”
  – Composition can be used to diagnose “health”
Pollution Tolerance

Stoneflies
(Plecoptera)

Mayflies
(Ephemeroptera)

Caddisflies
(Trichoptera)

Damselfly
(Zygoptera)

Amphipods
(Anisoptera)

Blood worms
(Chironomid)
Stream Condition Index

- Quality of aquatic invertebrates
  - Composition
  - Abundance
  - Diversity
  - Scores from 0 to 50
- Quality of stream habitat
  - Vegetation and periphyton survey
A Problem of Geography

• All Federal (that is “navigable”) waters have the same DO standard
  – The Suwannee River has very high levels of dissolved organic matter naturally
  – There are numerous wetlands that contribute to the flow (naturally low DO)
  – The river has gentle gradients

• The priority water quality issue for the Suwannee is DO
  – Misplaced concern
  – Limitations of the one-size-fits-all approach to regulation
Nutrients and Eutrophication

• Lake Trophic State
  – Oligotrophic - Bodies of water that have low nutrient concentration and therefore clear water and low biological productivity.
  – Eutrophic - Bodies of water that are rich in nutrients and, consequently, organisms and organic material.

• Eutrophication - Process of increasing biological productivity (usually via the addition of nutrients).
  – Effects on water body primary productivity (fertilization)
  – Depletes dissolved oxygen
  – Leads to significant changes in ecological dynamics
  – May have human health consequences
Eutrophication

- **Def:** Excess C fixation
  - Primary production is stimulated. Can be a good thing (e.g., more fish)
  - Can induce changes in dominant primary producers (e.g., algae vs. rooted plants)
  - Can alter dissolved oxygen dynamics (nighttime lows)
    - Fish and invertebrate impacts
    - Changes in color, clarity, aroma
Leibig’s **Law of the Minimum**

- Some element (or light or water) limits primary production (GPP)
- Adding that thing will increase yields *to a point*; effects saturate when something else limits

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**Lost yield potential**
What Limits Aquatic Production?
Nutrient Dose-Aquatic Systems

- Phosphorus limitation in shallow temperate lakes
- Nitrogen limitation in estuarine systems
Nitrogen Inputs → Algal Density → Chlorophyll Violations
River Flow → Algal Density → Carbon Production
Harmful Algal Blooms → Algal Density
Carbon Production → Sediment Oxygen Demand
Sediment Oxygen Demand → Frequency of Stratification
Frequency of Stratification → Frequency of Hypoxia
Frequency of Hypoxia → Shellfish Survival, Number of Fishkills
Shellfish Survival → Fish Health
Lake Apopka
Hypereutrophic
TN = 2,700 mg/m$^3$
TP = 230 mg/m$^3$
ChlA = 130

Aerial photo showing a boat crossing the algae-dominated waters at Lake Apopka in 1995.

© 2003 St. Johns River Water Management District
Lake Sheeler
Oligotrophic
TN = 70 mg/m³
TP = 4 mg/m³
ChlA = 1 mg/m³
Eutrophication may stimulate the growth of algae that produce harmful toxins.

Red Tide

Microcystis bloom
It’s Not What People Like to See...
Cultural Eutrophication

Narrative Nutrient Criteria
"in no case shall nutrient concentrations of a body of water be altered so as to cause an imbalance in natural populations of aquatic flora or fauna."

Or,
It’s hard to define, but you know it when you see it.
Nutrient Loads to the Land

<table>
<thead>
<tr>
<th>Landuse</th>
<th>Nitrogen Load</th>
<th>Phosphorus Loads</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crops</td>
<td>350 kg/ha/yr</td>
<td>40 kg/ha/yr</td>
</tr>
<tr>
<td>Pasture</td>
<td>125 kg/ha/yr</td>
<td>25 kg/ha/yr</td>
</tr>
<tr>
<td>Lawn</td>
<td>280 kg/ha/yr</td>
<td>20 kg/ha/yr</td>
</tr>
<tr>
<td>Forest</td>
<td>25 kg/ha/yr</td>
<td>2+ kg/ha/yr</td>
</tr>
</tbody>
</table>
N Concentrations in Springs

- Background NO$_3$ is ~ 100 ppb (0.1 mg/L)
- Karst landscape is inherently vulnerable to NO$_3$ loading and transport
- Unconfined aquifer areas are best sites for irrigated agriculture
  – = FERTILIZERS
Protected Lands and Recharge

Florida Land Cover

- Water
- Conserved Lands
- Agricultural Production Lands
- Urban Lands

Florida Natural Areas Inventory Data
Inorganic Pollutants

• Metals
  – Many metals such as mercury, lead, cadmium, and nickel are highly toxic.
  – Highly persistent and tend to bioaccumulate in food chains.
    • Lead pipes are a serious source of drinking water pollution.
  – Mine drainage and leaching are serious sources of environmental contamination.
Inorganic Pollutants

• Nonmetallic Salts
  – Many salts that are non-toxic at low concentrations can be mobilized by irrigation and concentrated by evaporation, reaching levels toxic to plants and animals.
  – Leaching of road salts has had detrimental effect on many ecosystems.

• Acids and Bases
  – Often released as by-products of industrial processes.
Salts in the Environment

A. Drinking Water Supply to Baltimore, Maryland

B. Hudson River Valley, New York

C. White Mountains, New Hampshire
Organic Chemicals

• Thousands of natural and synthetic organic chemicals are used to make pesticides, plastics, pharmaceuticals, pigments, etc.

• Two most important sources of toxic organic chemicals in water are:
  – Improper disposal of industrial and household wastes.
  – Runoff of pesticides from high-use areas.
    • Fields, roadsides, golf courses
Sediment

- Human activities have accelerated erosion rates in many areas.
  - Human-induced erosion and runoff contribute about 75 billion metric tons of suspended solids to world surfaces each year.
- Sediment can either be beneficial (nourish floodplains) or harmful (smother aquatic life).
Erosion and Sedimentation in western Kenya
A New Pollution

- Hormones, medicines, etc. that are not treated during conventional treatment.
- Prozac, birth-control hormones, pain killers
- The effects of these in the environment is really unknown. A class of compounds called endocrine disruptors is of growing concern because of the effects they can have on the reproductive success of fish and amphibians.
Current Status of Water Quality

• Areas of Progress
  – **Clean Water Act (1972)** established a National Pollution Discharge System which requires a permit for any entity dumping wastes in surface waters.
    • In 1999, EPA reported 91.4% of all monitored river miles and 87.5% of all accessed lake acres are suitable for their designated uses.
    • Most progress due to municipal sewage treatment facilities. Cuyahoga River in 1969.
  – **Florida Water Resources Act (1972)** established the Water Management Districts, the “local sources first” doctrine, the minimum flows and levels mandate and science-based watershed management entities
    • Administer TMDLs, MFLs, CUPs, 404-permits, wetland mitigation
    • Extensive scientific expertise (SJRWMD has over 50 PhD level scientists on staff)
Diffuse Pollutants - Not Controlled
Stream and River Impairment

- Siltation: 45
- Nutrients: 37
- Pathogens: 27
- Pesticides: 26
- Organic Enrichment: 24

- Agricultural: 72
- Municipal: 15
- Storm Sewers/Runoff: 11
- Resource Extraction: 11
- Industrial: 7
- Hydrologic Modifications: 7
- Silviculture: 7
Areas of Progress

• In 1998, EPA switched regulatory approaches. Rather than issue standards on a site by site approach, the focus is now on watershed-level monitoring and protection.
  – States are required to identify waters not meeting water quality goals and develop total maximum daily loads (TMDLs) for each pollutant and each listed water body.
  – Often the designation of a TMDL is highly political.
Remaining Problems

• Greatest impediments to achieving national goals in water quality are sediment, nutrients, and metals, especially from **non-point** discharges.
  – About three-quarters of water pollution in the US comes from soil erosion, air pollution fallout, and agricultural and urban runoff.
  – Single cow produces 30 kg manure/day.
    • Some feedlots have 100,000 animals.
Narrative vs. Numeric Criteria

- Nutrients were historically regulated based on “narrative criteria”
  - Shall not cause an imbalance in the native flora and fauna
  - This is an inherently reactive system
- EPA proposed (1/14/2010) to regulate nutrients in Florida (and elsewhere) based on “numeric criteria”
  - Preemptive protection
  - Recently finalized...LAW of the State of Florida
Numeric Criteria for Lakes

Numeric criteria proposed for lakes. A lake is a freshwater body that is not a stream or other water course, with some open water free from vegetation above the water surface.

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Baseline criteria</td>
<td>Modified criteria&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chlorophyll &lt;sub&gt;α&lt;/sub&gt; (μg/L)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Total N (mg/L)</td>
<td>Total P (mg/L)</td>
<td>Total N (mg/L)</td>
<td>Total P (mg/L)</td>
<td></td>
</tr>
<tr>
<td>Colored lakes&lt;sup&gt;c&lt;/sup&gt;</td>
<td>20</td>
<td>1.23</td>
<td>0.050</td>
<td>1.23 – 2.25</td>
<td>0.050 – 0.157</td>
</tr>
<tr>
<td>Clear lakes, alkaline&lt;sup&gt;d&lt;/sup&gt;</td>
<td>20</td>
<td>1.00</td>
<td>0.030</td>
<td>1.00 – 1.81</td>
<td>0.030 – 0.087</td>
</tr>
<tr>
<td>Clear lakes, acidic</td>
<td>6</td>
<td>0.500</td>
<td>0.010</td>
<td>0.500 – 0.900</td>
<td>0.010 – 0.030</td>
</tr>
</tbody>
</table>

<sup>a</sup>If chlorophyll <sub>α</sub> is below the criterion in column B and there are representative data to calculate ambient based, lake-specific, modified TP and TN criteria, then DEP may calculate such criteria within these bounds from ambient measurements to determine lake-specific, modified criteria.

<sup>b</sup>Chlorophyll <sub>α</sub> is an indicator of phytoplankton biomass (microscopic algae) in a water body, with concentrations reflecting the integrated effect of many of the water quality factors that may be altered by human activities.

<sup>c</sup>Colored lakes are distinguished from clear lakes based on the amount of dissolved organic matter they have free from turbidity. Dissolved organic matter concentration is reported in Platinum Cobalt Units (PCU). Colored lakes have values greater than 40 PCU and Clear lakes have values less than or equal to 40 PCU.

<sup>d</sup>Alkaline lakes are distinguished from acid lakes based on their concentration of CaCO<sub>3</sub>. Alkaline lakes have greater than 50 mg/L CaCO<sub>3</sub>, while acid lakes have values less than or equal to 50 mg/L CaCO<sub>3</sub>.
Adopted Criteria for Streams and Springs

Numeric criteria proposed for rivers and streams, defined as free-flowing surface waters in defined channels, including rivers, creeks, branches, canals (outside south Florida), and freshwater sloughs.

<table>
<thead>
<tr>
<th>Watershed region*</th>
<th>In-stream protection value criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total N (mg/L)</td>
</tr>
<tr>
<td>Panhandle</td>
<td>0.824</td>
</tr>
<tr>
<td>Bone Valley</td>
<td>1.798</td>
</tr>
<tr>
<td>Peninsula</td>
<td>1.205</td>
</tr>
<tr>
<td>North Central</td>
<td>1.479</td>
</tr>
</tbody>
</table>

*See Further Information section for a map of these regions.

Nitrate (NO$_3^-$-N) + nitrite (NO$_2^-$-N) shall not surpass a concentration of 0.35 mg/L as an annual geometric mean more than once in a 3-year period, nor surpass as a long-term average of annual geometric mean values.

Total N and total P criteria for streams on a watershed basis are also applicable to clear streams.
Next Time...

- More on nutrients and ecosystem metabolism