There are limits to both what we take from the environment (resources) and to what we return as wastes and emissions.

The environment has a limited capacity to absorb our wastes and emissions.
While the ultimate goal is pollution avoidance, it will always remain that:

1. Accidents happen;

2. Purposeful releases (ex. of treated sewage) are acceptable as long as nature can handle it. (Often nature does a better job than we do, and for free!)

We need to act responsibly, which at a minimum requires us to stay within limits.

But what are these limits? What is nature’s capacity of absorb our wastes and emissions without suffering permanent damage?

It is typically easier to determine the limit of a resource supply than the absorption capacity of a natural system.

Sources – Pathways – Fate

- Point of contact, receptor
The typical story behind environmental problems

Examples of source management:
- Emission alternative (ex. ethanol instead of gasoline)
- Emission reduction (ex. hybrid car, better traffic management)
- Treatment of emission / effluent (ex. catalytic converter, scrubber)
- Target your source (ex. regulate power plants, diesel trucks, or private cars?)

Examples of pathway management:
- Placement and height of a smokestack plume
- Location of sewage outfall in the coastal ocean
- Silted basins along rivers
- Vegetated swales
- Creating buffer zones between farm land and streams
- Additives in lakes to prevent acidification

Examples of receptor management:
- Water treatment before distribution
- Cover protection on historical buildings
- Gas masks on people
- Protective boom to protect a beach from an approaching oil spill

(*) This requires an in-depth understanding of physics, chemistry and biology.
Challenge

Source A -> Receptor 1
Source B
Source C -> Receptor 2
Source D -> Receptor 3
Source E -> Receptor 4

Which source causes which effect? We can rarely tell…
Example: What has caused my cousin’s cancer?

Example of the multiplicity of mechanical transports in a single area

Pathways by which pollutants in urban areas are transported to surface waters
(Behrendt & Boehme, *Point and Diffuse Loads of Selected Pollutants in the River Rhine and its Main Tributaries, Research Report, 1992*)
Example of the multiplicity of transport mechanisms, including the biological food web

Examples of contamination sources

Sign of prosperity in Pittsburgh in 1906 (Carnegie Library of Pittsburgh)


Morning emission in Lebanon, New Hampshire
Examples of effects at receptors

Global distribution of acidity in precipitation

Haze over Newark, New Jersey in summer 2006

MESSINGERS for the Rapid Response Corps in Los Angeles were outfitted with gas masks in the fall of 1997 so that they would not suffer from the effects of the smog. Shortly thereafter, local officials began air-pollution control programs.

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A forest killed by pollution in the Karkonoski National Park in southwest Poland. Combined effects of a toxic soup of many different air pollutants probably caused this damage. (From Cunningham & Saigo, 1997)

Atmospheric acids, especially sulfuric and nitric acids, have almost completely eaten away the face of this medieval statue. Each year, the total losses from air pollution damage to buildings and materials amounts to billions of dollars.
Examples of a single pathway (ocean currents)

Progression of the oil spilled by the Exxon Valdez in March-April 1989

Oil slicks and sheen in Gulf of Mexico from leaky Deepwater Horizon BP well in late May 2010

“Dead Zone” in the Gulf of Mexico (hypoxia) attributed to nutrients carried by the Mississippi River. The ultimate source is agricultural runoff, especially of dissolved organic nitrogen, along the Mississippi River watershed.

Gradual reduction of flood basins along the course of the river, which normally lead to nutrient capture along the way, is a compounding factor.

The satellite picture shows a region in the northern Gulf of Mexico where a phytoplankton bloom now occurs every summer, due to excessive nutrients. This bloom asphyxiates all other forms of life in the sea. The so-called “Dead Zone” now extends over 8,000 square miles.
Contamination versus Pollution – A small technical difference

CONTAMINATION = introduction in the environment of an alien substance
That substance may or may not be harmful.
Contamination refers to the source.

POLLUTION = potential or actual damage or harm caused by the presence of an alien substance in the environment
Pollution refers to the receptor.

It may happen that a contaminant does not pollute:
- it may be harmless,
- it may be transformed into a harmless substance before reaching a receptor,
- it may be diluted down to a benign level that can be assimilated by nature.

PRIMARY POLLUTANT = a substance being emitted
= a substance that we can avoid to emit

*Examples: NO, NO₂, SO₂, VOCs, CFCs*

SECONDARY POLLUTANT = a substance created in the environment as a reaction product from precursor substances
= a substance for which we need to discern the precursors

*Examples: ambient ozone (O₃), sulfuric acid (H₂SO₄), lake algae*

GREENHOUSE GASES
not considered as contaminants since most are also naturally occurring
not considered as pollutants since they do not inflict immediate harm

*Examples: carbon dioxide (CO₂), methane (CH₄)*
A few more definitions

TOXICITY = capacity to cause serious harm, or even death, of people or animals

Some substances are always toxic (ex. Mercury);
Some others only above a certain dose (ex. Zinc).

POINT SOURCES vs. DISTRIBUTED SOURCES

Point sources (ex. discharge pipe, smokestack)
can be singled out and are easier to control.
Distributed sources (ex. traffic emissions, agricultural runoff)
are diffuse and much harder to control.

SYNERGISM

Occurs when the combination of pollutants create a worse effect
than each individually (ex. acid rain and lead emissions from gasoline)

AMELIORATIVE ACTION

Opposite of synergism, occurs when combined effects are less than
individual effects (ex. scavenging effect of VOCs on ozone formation by NO₂)

The primary media of our environment are the atmosphere, surface water and subsurface (soil and groundwater).
Because few substances are confined to a single medium, exchange at interfaces between media must often be considered.
(Hemond and Fechner, *Chemical Fate and Transport in the Environment*, 1994)
### The various scales of the problem:

<table>
<thead>
<tr>
<th>SCALE</th>
<th>USEFUL CONCEPT</th>
<th>APPROACH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Molecular</td>
<td>Particles in a box</td>
<td>Elementary processes (e.g., chemical reactions)</td>
</tr>
<tr>
<td>Local</td>
<td>Continuous fluid around point source</td>
<td>Attention to 'near-field' variations</td>
</tr>
<tr>
<td>Urban</td>
<td>Local sources now seen as many point sources (distributed source)</td>
<td>Aggregate effects; lumping of near-field variations</td>
</tr>
<tr>
<td>Regional, Continental</td>
<td>Uneven distribution of distributed sources</td>
<td>Emphasis on far-field and long-term effects</td>
</tr>
<tr>
<td>Global</td>
<td>Conservation laws (go out from this system!)</td>
<td>Cumulative aspects of processes</td>
</tr>
</tbody>
</table>

### Another possible classification of pollution sources

<table>
<thead>
<tr>
<th>SOURCE</th>
<th>EXAMPLES of SUBSTANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Individual</td>
<td>Cigarette smoke</td>
</tr>
<tr>
<td></td>
<td>Leaky septic tank</td>
</tr>
<tr>
<td>Corporate</td>
<td>Smokestack fumes</td>
</tr>
<tr>
<td></td>
<td>Tainted discharge in nearby stream</td>
</tr>
<tr>
<td></td>
<td>MTBE leak from underground tank at gas station</td>
</tr>
<tr>
<td>Urban</td>
<td>Auto emissions (gaseous &amp; particulates)</td>
</tr>
<tr>
<td></td>
<td>Smog-causing chemicals</td>
</tr>
<tr>
<td>Regional</td>
<td>Agricultural herbicides and pesticides</td>
</tr>
<tr>
<td></td>
<td>Major oil spills</td>
</tr>
<tr>
<td>Continental</td>
<td>Sulfur dioxide causing acid rain</td>
</tr>
<tr>
<td></td>
<td>Chernobyl radioactive fall-out</td>
</tr>
<tr>
<td>Global</td>
<td>Carbon dioxide from power plants and transportation</td>
</tr>
<tr>
<td></td>
<td>CFCs destroying ozone in stratosphere</td>
</tr>
</tbody>
</table>
Scientific approaches

OBSERVATION

In-situ measurements
Primary data, some ‘harder’ (direct, undeniable), some ‘softer’ (inferred)

Usefulness: Evidence of problem, monitoring, compliance

Limitations: Lack of past records, instrumental limitations, spotty coverage

EXPERIMENTATION

Generation of data in test cases

Usefulness: Measurements of chemical reaction rates

Limitations: Inability to experiment on a large scale, real world not a laboratory

THEORY

Derivation of formulas form first principles

Usefulness: Basic relations, rules-of-thumb for preliminary predictions

Limitations: Formulas of limited use, underlying assumptions possibly incorrect

SIMULATION

Use of computer models to predict or ‘fill-in’ situations

Usefulness: Complex systems, prediction before permitting, anticipation of future

Limitations: Only as good as its underlying assumptions (some known, some unknown)

Needless to say: All approaches need to be combined.