Rubbish, Stink, and Death: How Engineers Invented Water Quality Modeling and How It Might Inform Climate Change

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OUTLINE

- The Historical Development of Civil Engineering
- The Roots and History of Environmental Engineering
- The Evolution of Water Quality Modeling and Management
- The Future
  - Developing economies
  - Climate Change
HISTORY OF ENGINEERING

MILITARY ENGINEERS ↔ CIVIL(IAN) ENGINEERS
(Battlements, Weaponry) (Buildings, Roads, Aqueducts)

Scientific Revolution (1600-1700)
Industrial Revolution (1800-1900)

MECHANICAL
(Steam Engines, Vehicles)

CHEMICAL
(Explosives, Food, petroleum)

ELECTRICAL
(Lighting, Power)

CIVIL & ENVIRONMENTAL
(Infrastructure)

Structural
Geotechnical
Construction
Transportation

Environmental
Water resources
What distinguishes CEE from other areas of engineering?

- We are broad
- We plan and manage (big systems)
- We deal directly with the government, the public sector, and society
- We are outdoors oriented
- We own our companies

We are the Builders... of Cities
THE HISTORY OF ENVIRONMENTAL ENGINEERING

Where and why did society begin to care about water quality?

Jared Diamond (Pulitzer Prize)
“Guns, Germs and Steel”

A book about water quality:
“Rubbish, Stink and Death”
19th Century London

Migration from farms to cities

World’s largest city (1831-1925)
Water and Sanitation Infrastructure

- Water supply: Mostly wells
- Waste disposal:
  - Mostly cesspits
  - Some sewers into the Thames
- No waste treatment!!!
Aesthetics Ecosystem Public health

Rubbish Stink Death

health
The Great Stink of 1858

- Unusually warm summer
- Oxidation of sewage created anaerobic conditions (no dissolved oxygen) in the Thames estuary
- Generated hydrogen sulfide gas (rotten egg smell)
Smell Was So Bad That Parliament and Law Courts Closed
Disease

- Pre-Enlightenment: Superstition
- 19th Century Cholera Epidemics
- Miasma Theory of Disease

Pollution "smells" \[\Rightarrow\] ERGO Disease must be "airborne"
A London Board of Health Hunting after Cases Like Cholera.
The Ghost Map

John Snow

Broad Street Pump
King Cholera
Mans the Pump

Germ Theory
Pasteur
Huge Sewer Construction

BUILT BY CIVIL ENGINEERS!
Roots of Water Quality Modeling

- At first, London relied on tidal flushing
- Then needed additional waste treatment
- How much waste treatment do we need???
URBAN POINT SOURCE DESIGN PROBLEM (Late 19th & Early 20th Centuries)

WATER-QUALITY MODEL:

\[ c = f(W, \text{physics, chemistry, biology}) \]
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\[ c = f(W, \text{physics, chemistry, biology}) \]

\[ c = \frac{1}{\alpha W} \]

**CONCENTRATION**
How polluted the system is

**LOADING**
The rate of pollutant discharge

**ASSIMILATION FACTOR**
How physics, chemistry and biology convert the loading rate into concentration
MODELING MODES

SIMULATION MODE:
Given load \( W \) and assimilation factor \( a \),
\[
c = \frac{1}{a W}
\]

ASSIMILATIVE CAPACITY DESIGN MODE:
Given desired concentration \( c \) and assimilation factor \( a \),
\[
W = a c
\]

ENVIRONMENTAL MODIFICATION DESIGN MODE:
Given desired concentration \( c \) and given load \( W \),
\[
a = \frac{W}{c}
\]
MODELS GIVE YOU THE BIG PICTURE

AN ELEPHANT IS LIKE A SNAKE
AN ELEPHANT IS LIKE A BRUSH
AN ELEPHANT IS LIKE A ROPE
AN ELEPHANT IS LIKE A TREE TRUNK
THE COMPUTER MODEL TIES EVERYTHING TOGETHER

CHEMISTRY

BIOLOGY

THE MODEL

PHYSICS
THE PRE-COMPUTER ERA
(1925-1960)

Problems: Untreated Sewage Effluent
Pollutants: BOD/Dissolved Oxygen
Systems: Streams/Estuaries (1D)
Problems: *Multiple* Sewage Effluents
Pollutants: BOD/Dissolved Oxygen
Systems: Streams
Estuaries (1D/2D)

The “systems approach”
AFTER 1945: KA-BOOM
1950’s: THE DREAM
1960’s: THE REALITY

EUTROPHICATION

“Overfertilization due to excess nutrients”
BIOLOGY
(1970-1977)

Problems:
Eutrophication

Pollutants:
Nutrients

Systems:
LAKES, Estuaries, Rivers
Problems: Toxics and Acid Rain

Pollutants: Organics, Metals, Acid

Systems: Sediments, Ecosystem
TODAY
(1995-present)

- Clean Water Act
- Computing Advances
- Quality of Life
WATERSHED MANAGEMENT (1995-present)

Problems:
- Temperature
- Eutrophication
- Pathogens
- Toxics

Pollutants: Heat, BOD, Nutrients, Toxics, Bacteria

Systems: Watershed, Receiving Water, Groundwater, Atmosphere
A Golden Age of Water Quality Management & Modeling
Water is the oil of the 21\textsuperscript{st} Century
Quantity and Quality
Clean Water is More Valuable than Dirty Water
• A Growing Middle Class
  • Quality of Life
  • Tourism
ECONOMIC EVOLUTION AND ENVIRONMENTAL CONCERNS

DEVELOPED ECONOMY

SURVIVAL

QUALITY OF LIFE TOURISM TRADE

RUBBISH SMELLS DEATH

PRIMITIVE ECONOMY

SUSTAINABILITY
CLIMATE CHANGE & WATER QUALITY

Rubbish, Stink, Death
(and Heat, and Rain and Wind)

- Biological Impacts
- Chemical Impacts
- Physical Impacts
- How Models Can Help
TEMPERATURE IMPACT ON MICROORGANISMS

Growth rate vs. $T$ (°C)

Doubling of rate

10 °C increase

This is why we refrigerate.
TEMPERATURE IMPACT ON BIOLOGY
SPECIES TOLERANCES

Growth rate vs. $T \, (^{\circ}C)$
BLUEGREEN ALGAE
AKA CYANOBACTERIA

- Form unsightly scums
- Cannot be eaten
- Some are highly toxic
HIGHER ORGANISMS:
THE SALMONID IN THE COAL MINE

- Highly sensitive to temperature
- And chemistry and biology
- Some are endangered
- Recreational value (S. Africa)
- Commercial value (aquaculture)
RIVER TEMPERATURE MODEL

- Atmospheric longwave radiation
- Water longwave radiation
- Conduction and convection
- Evaporation and condensation

AIR

WATER

SEDIMENTS

GROUND WATER

SOLAR SHORTWAVE RADIATION
Simulation Results

Ref: Gooseff et al. 2002
Impact of Climate Change

Ref: Gooseff et al. 2002

* HADLEY GCM
CHEMICAL IMPACTS
Oxygen: The Breath of Life

Dissolved Oxygen Concentration (mg/L)

0 2 4 6 8 10 12 14 16 18 20

Highly supersaturated
Saturated (T = 15°C)
Gamefish suffer
Coarse fish suffer
Anoxia (Smells)
OXYGEN SATURATION IN WATER TEMPERATURE EFFECT

$T(^\circ F)$

$T(^\circ C)$

$S$ (mg/L)

freshwater ($S = 0$ ppt)

saltwater ($S = 35$ ppt)
OXYGEN SATURATION IN WATER PRESSURE (ELEVATION) EFFECT

\[ \text{Os (mg/L)} \]

\[ T(\degree\text{C}) \]

\[ T(\degree\text{F}) \]

Sea level

1.6 km

3.2 km

4.8 km (3 miles)
PHYSICS
It’s not just temperature

- High flows
- More severe storms
- Low flows
- Less snow pack
- Longer dry periods
HIGH FLOWS

- Higher erosion
- Loss of topsoil
- Suspended solids
- Nutrients
- Siltation and habitat
- Light extinction
HIGH FLOWS

- Urban settings
- Stormwater overflow
- Shanty towns
- Disease transmission
LOW FLOWS

- Less snowpack
- Less baseflow
- Warmer groundwater
- Shallower rivers
- Less dilution
LOW FLOWS

- Estuaries
- Saltwater intrusion
- Organism shifts
HOW CAN MODELS HELP

- Holistic perspective
- What ifs
- Consciousness raising
- Management
- Planning
- Consensus building
Who nabbed Al Capone
AKA Scarface

Accountants!!!
If you want to catch a crook

Follow the money!

If you want to save the planet

Follow the physics, the chemistry and the biology
THE END