Segment 3: opportunities, best practices and lessons-learned for enhancing the science-policy interface

Science-Driven Management Decision-Making in Formulating Sewage Treatment Strategy

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Coastal Eutrophication in the world

- Enrichment of Nutrients (e.g. C, N, P, Si) in coastal waters,

Eutrophication symptoms or impact:

- Harmful algal blooms
- Excess algal biomass
- Hypoxia/anoxia in the bottom layer
In coastal oceans, nitrogen, phosphorus or silica limits phytoplankton biomass.

Sunlight

Euphotic zone

Nutrients: Low

Nutrients: Abundant
Sources of Nutrients:
Global population and fertilizers
Environmental Impact from Nutrients

Nutrient Increase

River → Algal Biomass Increase

Sinking → Decomposition

Sea

$O_2$ Decrease
Widespread occurrences of harmful algal blooms

GlobalHAB
Global Harmful Algal Blooms

Science and Implementation Plan

Changjiang-East China Sea

Zhujiang-South China Sea
Anthropogenic influenced “Dead zones” is expanding

Hypoxia <2 mg/L

Fig. 1. Global distribution of 400-plus systems that have scientifically reported accounts of being eutrophication-associated dead zones. Their distribution matches the global human footprint (the normalized human influence is expressed as a percent [42]) in the Northern Hemisphere. For the Southern Hemisphere, the occurrence of dead zones is only recently being reported. Details on each system are in tables S1 and S2.
Global Ocean Is Losing its Breath

Science 2018

Declining oxygen in the global ocean and coastal waters
Mississippi River: Average annual concentrations


~100 µM

Years

μg at/l

Nitrate
Silicate
Northern Gulf of Mexico:
a large area of hypoxia “dead zone” (20,000 km$^2$) (<2 O$_2$ mg/L)

Science 281, 1998
Nitrogen, Phosphorus fertilizers in China

The graph shows the usage of nitrogen and phosphorus fertilizers in China from 1980 to 2010. The x-axis represents the years, and the y-axis represents the tonnage in millions. The graph indicates a significant increase in the usage of both fertilizers over the years.
Persistent Cyanobacterial Blooms in Dianchi Lake in Kunming
Cyanobacterial blooms shut down the city water supply for weeks

### Taihu Lake

Cyanobacteria have a long history of acquiring remarkable adaptions, such as nitrogen fixation and gas vesicles that keep them afloat and enable them to outcompete diatoms and green algae for light and nutrients. They can lie dormant in extreme conditions—surviving droughts and freezing—then come to life when conditions improve. Cyanobacteria are “very tough,” Paarl says. “They’re the cockroaches of lakes.”

To control Taihu’s “little green pests,” the government in the nearby city of Wuxi crafted an aggressive recovery strategy. The plan promised tough emissions standards for phosphorus and nitrogen for factories near Taihu and requires the installation of facilities that remove nutrients from sewage. Nutrient-rich agricultural runoff would be stemmed by banning chemical fertilizers, pesticides, and detergents that contain phosphorus or nitrogen. The amount of clean water pumped from Taihu is projected to reach 1 million tons per day by the end of 2008, and industries in Wuxi must meet a water-recycling rate of 78% by 2010.

“Don’t be in doubt that Taihu is going to be a challenge,” says Paarl. Degradation of the lake’s water quality was a slow-motion train wreck that played out over several decades. It may take many more years to banish the blooms and bring back the Taihu Beauty of yore.

—Lucie Guo

Lucie Guo is a freelance writer based in Boston.
Green Algal Blooms in Qingdao where Olympic sailing game will take place July 2008
Scores of PLA soldiers remove masses of algae from a beach in Qingdao, where the Olympic sailing events are scheduled to take place from August 9. (Photo: Bloomberg) (from SCMP, 4 July 2008)
A soldier walks through blue-green algae near a beach in Qingdao, Shandong province. (Source: Bloomberg) (from SCMP, 4 July 2008)
Large areas of harmful algal blooms and hypoxia in Changjiang-East China Sea

Spring

Summer

Li et al., 2002
Pearl River Watershed

Nitrogen (N) and Phosphorus (P) fertilizers over time in the Pearl River Watershed.
Population, GDP and Wastewater in Guangdong

- Population (10^4)
- GDP (10^8)
- Waste (10^4 T)

Graphs showing changes from 1985 to 2005.
Pearl River Estuary

- The 2nd largest river in China
- The 13th largest river in the world
- 2,200 km long
- 454,000 km² drainage basin
- 100 million people

South China Sea

Hong Kong
Zhujiang Estuarine Coastal Waters:
HAB and Hypoxia events

Chl-a

Hypoxia

Bottom
Harbour Area Treatment Scheme (HATS):
The Strategy of Sewage Treatment in Hong Kong started in 2001
Strategic Sewage Disposal Scheme (SSDS) before 2001
Chemically Enhanced Treatment Plant (CEPT)
Sewege Collecting Pipe Tunnel under bedrock
4 options by International Review Panel (IRP 2000)
Harbor Area Treatment Scheme (HATS) started in 2001

HATS Catchment Area

1.85 million m³ sewage effluent of Hong Kong
Harbour Area Treatment Scheme (HATS):

Sewage treatment strategy

One of the most important coastal infrastructure in Hong Kong
Harbor Area Treatment Scheme (HATS):

All 4 options require:

- Short outfalls
- Upgraded treatment facility to tertiary or biological removal of inorganic nutrients, nitrogen or phosphorus

This triggers an important scientific question: which nutrient should not be added to the recipient water?
HATS: short outfalls with biological treatment (Biological Aerated Filter)

An important management decision:
removal of nitrogen or phosphorus?

Science-Policy Making Interface

An important scientific question:
Which nutrient is the most limiting in the recipient waters
Environmental Impact Assessment Ordinance, Hong Kong

Assessment Philosophy

Assessment should rely on the concept of assimilative capacity of the receiving water body and water quality objectives.
Ecosystem Buffering

 anthropogenic input → Ecosystem Buffering Capacity → Impacts:

- Excessive algae
- Red tides
- Low DO waters
- OA

Seasonality: Dry and Wet Spatial and Temporal Variability

Drivers → Processes → Factors → Biology

- Climatic events
  - Monsoons
  - River outflow
  - Tidal cycles
  - Rainfall
- Circulation
  - Stratification
  - Mixing
- Light
- Salinity
- Temperature
- Nutrients
- Nutrient Ratios
- Algal Growth
  - Nutrient utilization
  - Nutrient Limitation
  - DO consumption
Ecosystem Buffering Capacity:

The most limiting nutrient
determine phytoplankton biomass and $O_2$
consumption

The Most Limiting Nutrient

The Minimum Law: the nutrient that is the least by elemental ratio is the first nutrient to limit cellular biomass.

Cellular N:P = 16 : 1
How does a N/P ratio indicate which nutrient is the most limiting

N:P < 16:1, N is limiting
N:P > 16:1, P is limiting
In general,

Nitrogen is considered to be the nutrient enrichment causing eutrophication in the coastal waters.

What about Hong Kong waters:
NO₃ at Humen (a river mouth of the Pearl River)
Monthly Average of total inorganic nitrogen during 1991-2000 (Yin 2002)
Yes, there is nitrogen over-enrichment in the Pearl River estuary

- **Nitrogen (N)**
  - High (100 µM) in the Pearl River vs 30 µM in marine fertile waters
  - Excess in HK southern waters in summer
  - Low in winter

- In fact, N concentration has increased at least 3 times during the past 3 decades
Monthly Average of chl $a$ during 1991-2000 (Yin 2002)

![Map of the study area with Chl $a$ concentration graphs for Western waters, Southern Water, and Mirs Bay.]

- **Western waters**: Chl $a$ concentration is generally below 20 ug/L.
- **Southern Water**: Shows higher Chl $a$ concentration with peaks in certain months.
- **Mirs Bay**: Similar to Western waters, with Chl $a$ concentration below 20 ug/L.

The graphs display the monthly average of Chl $a$ concentration from 1991 to 2000, with data from Yin (2002).
Monthly Average of Dissolved O$_2$ during 1991-2000

Dissolved O$_2$ does not drop to hypoxia!

O$_2$ (mg l$^{-2}$)

Month
Findings:

➢ Algal biomass is not as high as expected from high nitrogen;

➢ Dissolved O$_2$ remains above 2 mg/L most of the time - no seasonal hypoxia (low oxygen waters) has been found

Western waters

Southern Water

Mirs Bay

Shenzhen, Guangdong

Macau

Lantau Isl.

New Territories

Lingdingyang

Pearl River

South China Sea

Pearl River

Shenzhen, Guangdong

New Territories

Lingdingyang

Macau

Lantau Isl.

HK Isl.

Southern Water

Mirs Bay

Western waters

Southern Water

Mirs Bay

New Territories

HK Isl.

Lingdingyang

Macau

Lantau Isl.

22° 30' N

23° 00' N

113° 30' E

114° 00' E

114° 30' E

0

20

40 Kilometers

Shenzhen, Guangdong

South China Sea

N

Pearl River

Southern Water

Mirs Bay

Western waters

Southern Water

Mirs Bay

New Territories

HK Isl.

Lingdingyang

Macau

Lantau Isl.

22° 30' N

23° 00' N

113° 30' E

114° 00' E

114° 30' E

0

20

40 Kilometers

Shenzhen, Guangdong

South China Sea

N

Pearl River

Southern Water

Mirs Bay

Western waters

Southern Water

Mirs Bay

New Territories

HK Isl.

Lingdingyang

Macau

Lantau Isl.

22° 30' N

23° 00' N

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114° 00' E

114° 30' E

0

20

40 Kilometers

Shenzhen, Guangdong

South China Sea

N

Pearl River

Findings

- Nutrients are low in winter
- Phosphorus is potentially the most limiting nutrient in summer
  - for phytoplankton biomass
  - the amount of DO consumption
High N:P ratios (>16:1) imply:

1) Phosphorus appears to be the most limiting nutrient

2) There is excess N, and therefore, removal of N does not help reduce nutrient-caused impact
Scenario 1-Dry Season:
large capacity, less concern

- Potential N limitation
- but low nutrient levels
- Physical dilution dominant over biological processes

Low N/P ratios
Low in all nutrients
Scenario 2-Spring: N to P-limitation – P may be a concern

P-limitation
High N, Low P

N-limitation
Low in all nutrients
Scenario 3-Summer:

P-limitation - P is a concern

Shenzhen, Guangdong

High N, Low P

Low Nutrients

P-limitation  N-limitation
HATS: short outfalls with biological treatment (Biological Aerated Filter)

Removal of N – is not cost effective

An important management decision: removal of nitrogen or phosphorus?

Removal of P is more effective

An important scientific question: Which nutrient is potentially the most limiting in the recipient waters
HATS: Short outfalls-biological treatment

An important management decision: removal of nitrogen or phosphorus?

120亿 HK$ difference

If P is the most limiting nutrient, N removal is not economic environmentally
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