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11.479J / 1.851J Water and Sanitation Infrastructure in Developing Countries
Spring 2007

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Financing Water Supply and Sanitation

Peter Rogers

Guest Lecture – Water & Sanitation Infrastructure in Developing Countries
11.479J / 1.851J – Week 11

Tuesday May 1, 2007

Image removed due to copyright restrictions: photograph of water tap located next to a public urinal and near animals eating garbage.

What's wrong with this picture?

This is "adequate WSS" according to the WHO!

And… Now a Word from Our Sponsors…

Image removed due to copyright restrictions. Cover image for Rogers, Peter, M. Ramon Llamas, and Luis Martinez Cortina, editors. *Water Crisis: Myth or Reality?* Oxford, UK: Taylor & Francis, 2006. ISBN: 978-0415364386.

Rogers, Jalal, and Boyd, **Introduction to Sustainable Development**, Harvard Press, 2006

Rogers, and Lydon, **Water in the Arab World**, Harvard Press, 1994

Rogers, **America's Water**, MIT Press, 1992

Global Burden of Health Showing Percentage of Environmental Contribution by Disease

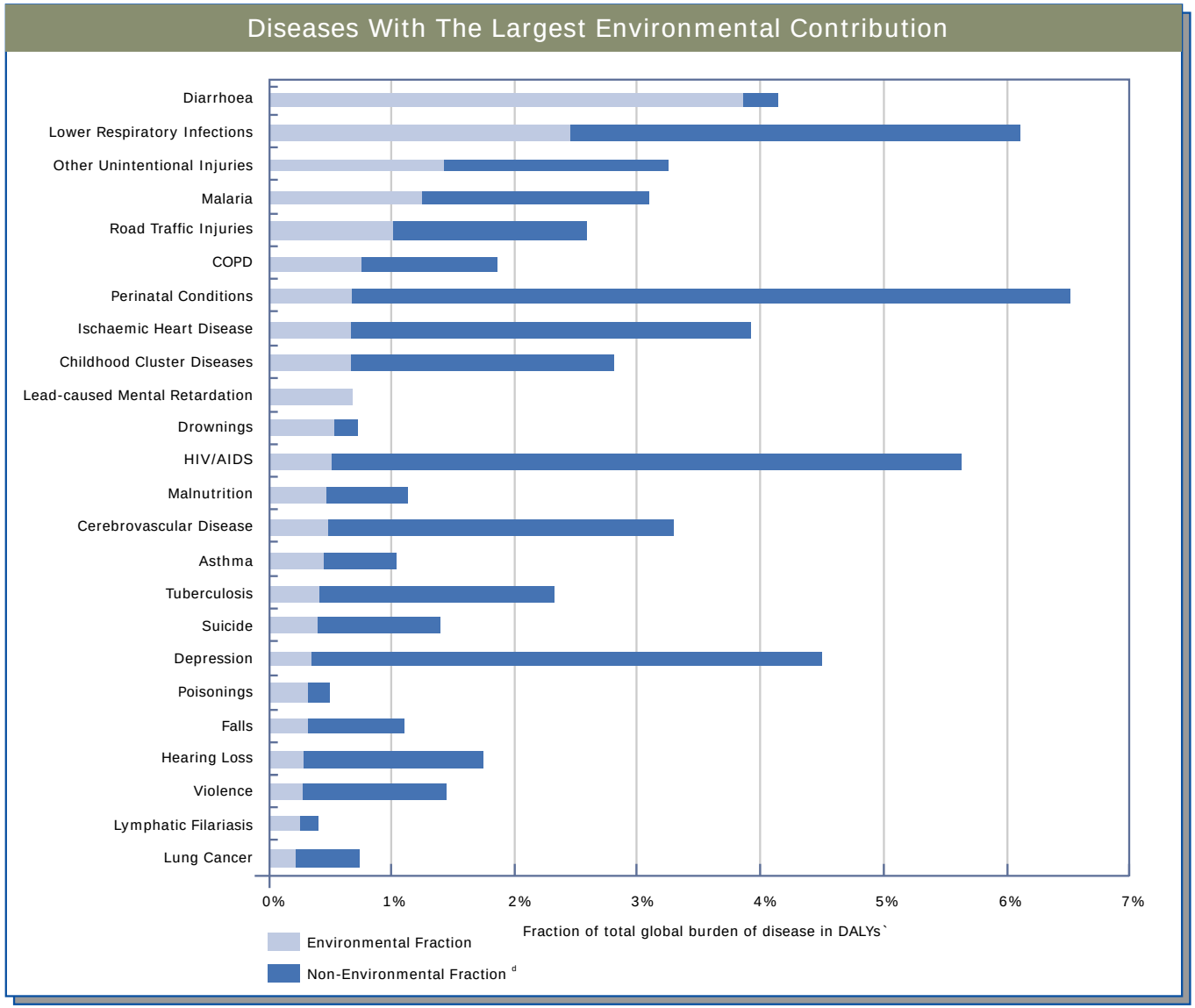
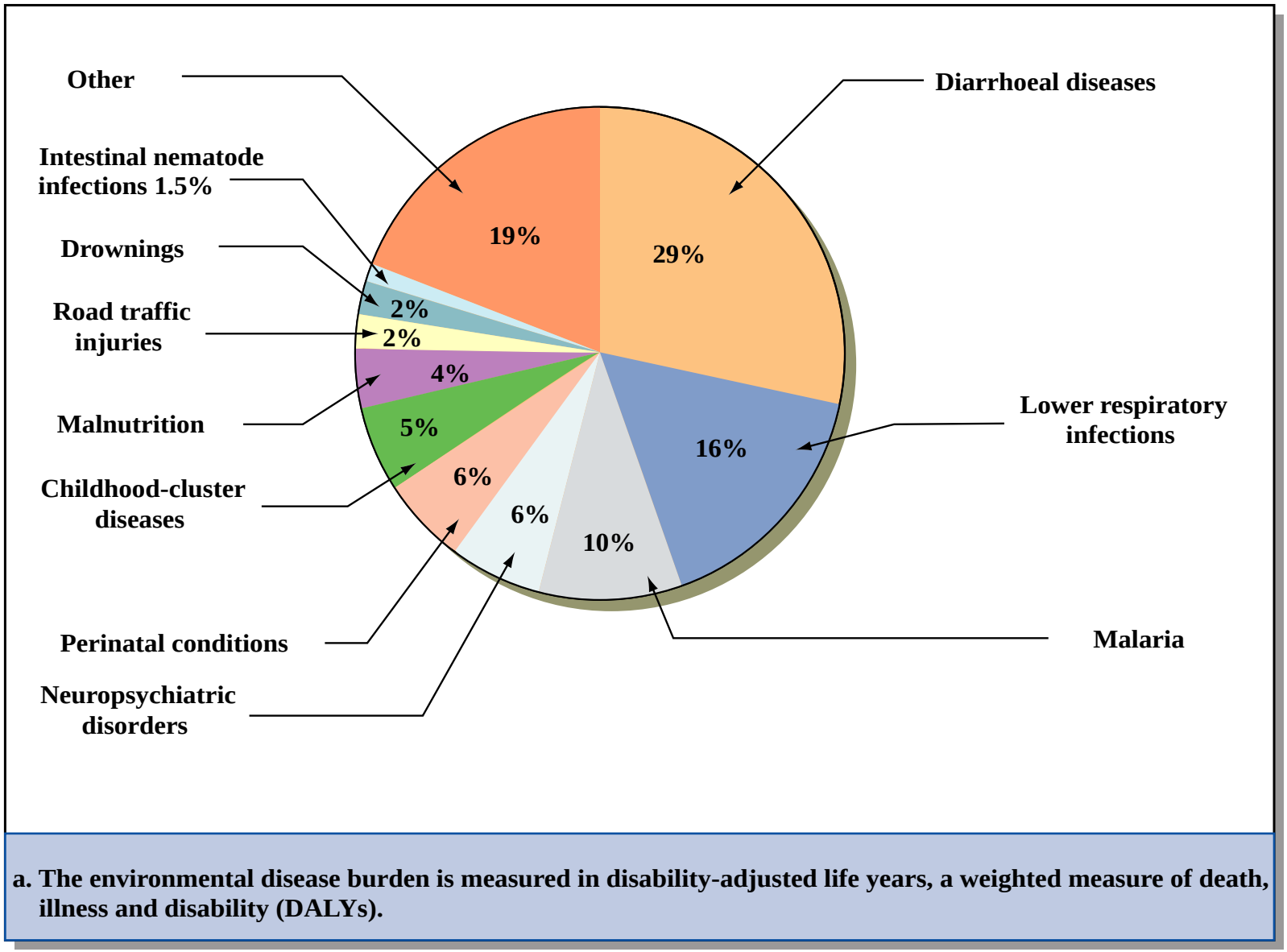


Figure by MIT OpenCourseWare.

WHO, Preventing Disease…, 2006

Reported in Disability Adjusted Life Years (DALYS)

Main Diseases Contributing to the Environmental Burden of Disease, Among Children 0-14 years[2]



a. The environmental disease burden is measured in disability-adjusted life years, a weighted measure of death, illness and disability (DALYs).

Figure by MIT OpenCourseWare.

WHO, Preventing Disease…, 2006, p. 62.

What Constitutes”Other?”

- IF
- Diarrhoeal diseases account for 29%
- Malaria for 10%
- Neuropsychiatric disorders 6%
- Intestinal nematode infections 1.5%
- THEN
- “Other” water related illnesses must be some part of the remaining 19%
  - Ischaemic heart diseases (Hg,…)
  - Childhood cluster diseases (industrial chemicals…)
  - Mental retardation (Pb, Hg,…)
  - Poisonings (As, toxics, etc)
  - Lymphatic filariasis

An old story

Huge needs

- over 1 billion people without safe water, 2 w/o sanitation, 4 w/o sewage treatment
- existing systems are run-down
- needs in developing and transition economies: up to $50bn/year or 1% of GDP

No money

➔ fiscal constraints

➔ official aid stagnant (< $3bn/yr, WB $1bn)

➔ public utilities unable to self-finance or to carry debt

➔ private investment: a relative trickle so far

what can we do?

Janssens, J., (2003)

MOTIVATION FOR PROVIDING SAFE WATER

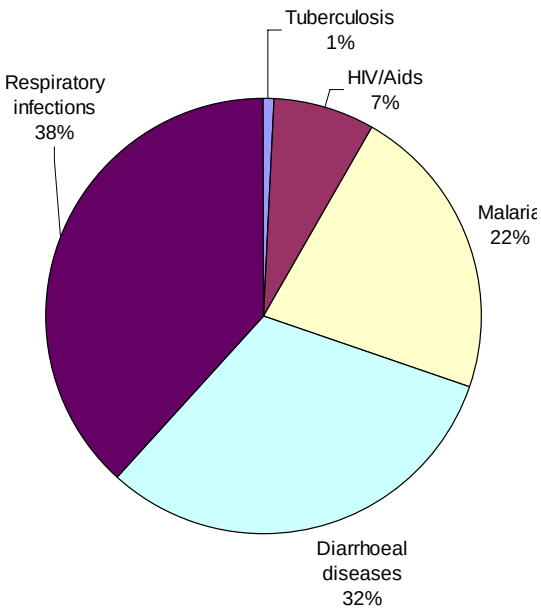
KEEP IN MIND

- Over 1 billion people without safe water
- 2.4 billion without access to adequate sanitation
- 10% of the world's food is grown with water from aquifers which are being depleted faster than the rate of recharge
- In the next 30 minutes about 180 children in developing countries - six children per minute - will have died from disease caused by unsafe water
- What does this mean for ordinary people in the developing world? In many parts of the world, access to water and power distinguishes the poor from the non-poor.

DEATHS BY AGE AND CAUSE (2002)

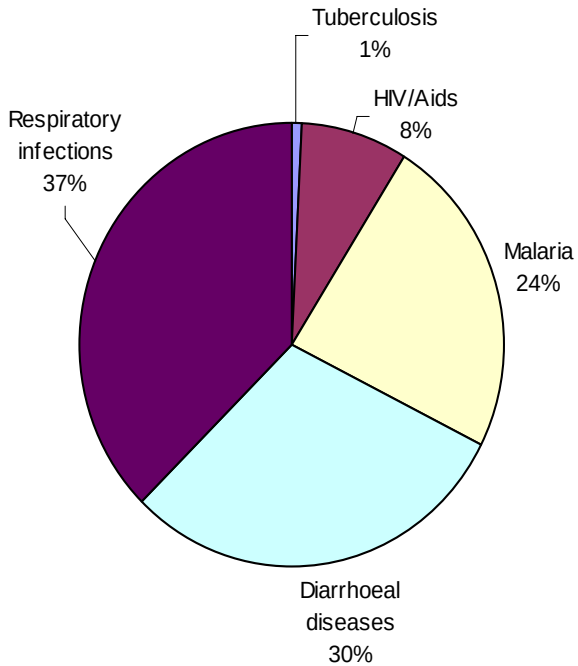
Data for Children (0-4yrs)

World



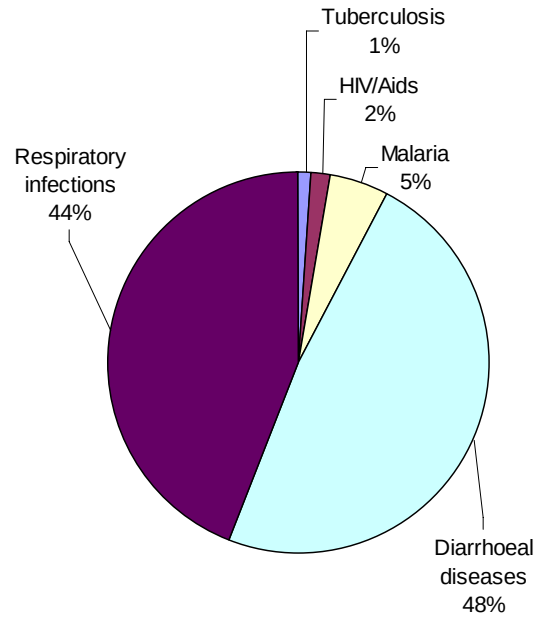
Total: 5,008,054

Developing countries
(high mortality)



Total: 4,528,061

Developing countries
(low mortality)



Total: 428,791

Modified from Evans, Hutton and Haller (2004)

The Environment is not just Water

- In addition to classical water-borne diseases there are many other illnesses caused by anthropogenic water use that may impinge on the aquatic environment or be environmentally mediated in other phases of the environment before ending up in the water
  - For example, long range transport of mercury from coal burning is mediated through the atmospheric part of the environment until it deposits in water courses where it is in turn mobilized by the chemistry in the sediments to enter the human food chain via fish consumption
  - There are many other toxic assaults that have not been adequately studied or assessed

- In addition to the human caused contamination naturally occurring inorganic toxics (arsenic, fluoride, selenium, uranium, etc) may be mobilized by exploitation of water resources
  - For example, in Bangladesh as many as 20-77 million people are at risk from arsenic poisoning due to the mobilization of toxic levels of arsenic due to lowering ground water levels by irrigation and domestic water use pumping.
  - Many of these mechanisms have not been well studied

Environmental Classification of Water-Related Diseases*

Category (1)	Example (2)
1. Feco-oral (waterborne or water-washed)	
Low infective dose	Cholera
High infective dose	Bacillary dysentery
2. Water-washed	
Skin and eye infections	Trachoma, scabies
Other	Louseborne fever
3. Water-based	
Penetrating skin	Schistosomiasis
Ingested	Guinea Worm
4. Water-related insect vectors	
Biting near water	Sleeping sickness
Breeding in water	Malaria
5. Transport of toxic chemicals	Arsenic, mercury, lead, and domestic and industrial water pollutants

*Modified from Table 3 in D.D. Mara and R.G.A. Feachem, "Water- and excreta-related diseases: Unitary environmental classification," *J. Environ. Eng.*, pp. 334–339, April 1999.

TRADITIONAL WATER RELATED DISEASES

Image removed due to copyright restrictions. Graphic of representative waterborne parasitic diseases showing the disease transmission cycle of lymphatic filariasis, malaria, dracunculiasis (guinea worm), and schistosomiasis (blood fluke). See Fenwick, 2006, p. 1079.

Prevalence of water-related diseases in Africa

Condition	Cases in Africa
Malaria	>300 million*
Hookworm	198 million
Ascariasis	173 million
Schistosomiasis	166 million
Trichuriasis	162 million
Lymphatic filariasis	46 million
Onchocerciasis	18 million
Dracunculiasis	<0.1 million

Fenwick, 2006, p. 1078.

***Roll Back Malaria (UN, WHO), 2000.**

Magnitude of Classical Water and Other Environmentally Mediated Diseases Affecting Children

- Global Data (WHO, 2003)
  - Worldwide 40% of the global burden of environmental disease fall on children under 5 years of age
  - 1.6 million under the age of 5 die from diarrhoeal diseases every year
- European Data (Valent et al., 2004)
  - In the under 5 age group diarrhoea attributable to inadequate sanitation and water accounted for 9.6% of the deaths.
  - Over 13,000 deaths per year of children under 15 are from diarrhoeal diseases, with over 12,000 of the deaths in Eastern Europe

MODERN WATER RELATED DISEASES

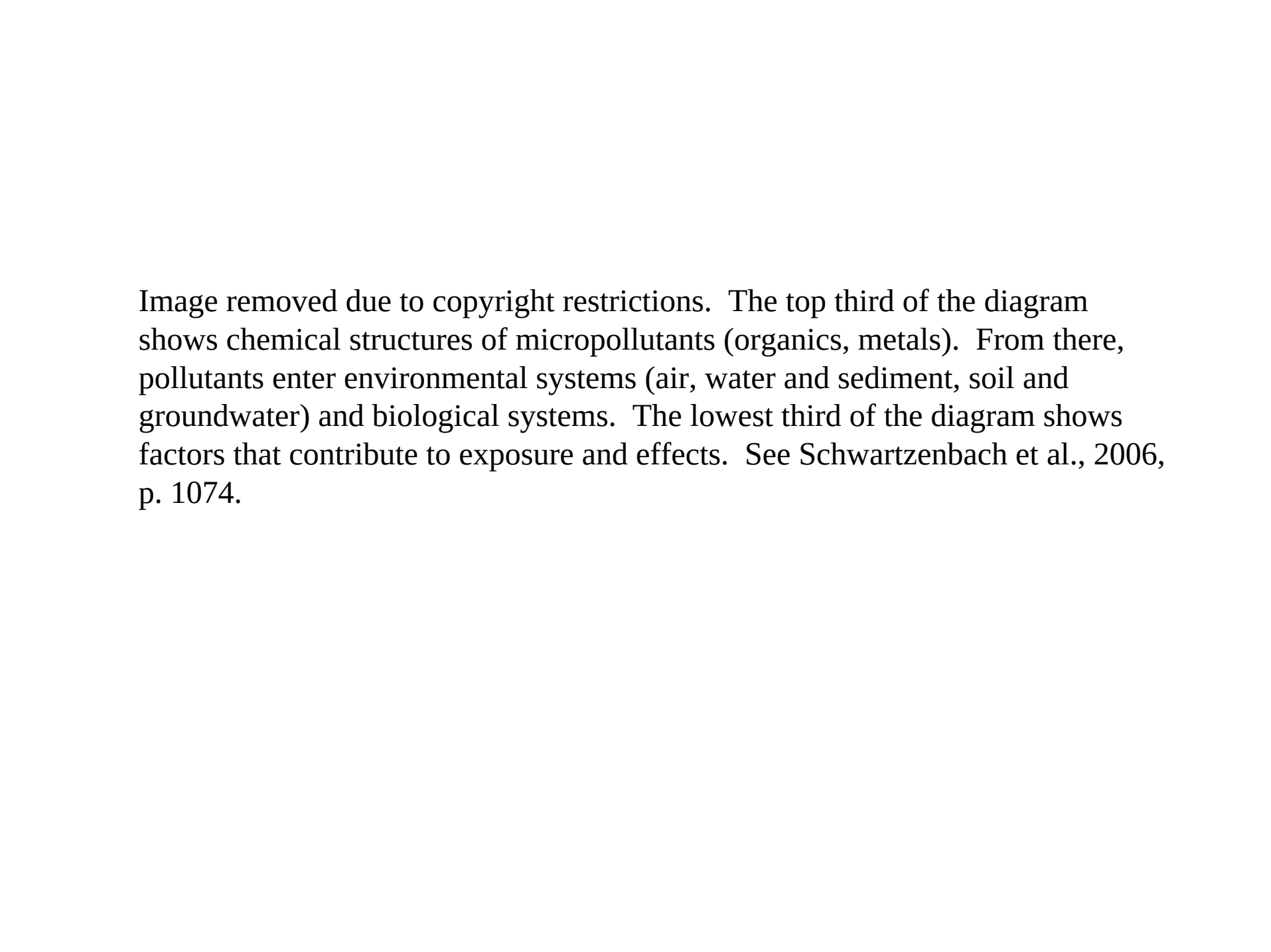


Image removed due to copyright restrictions. The top third of the diagram shows chemical structures of micropollutants (organics, metals). From there, pollutants enter environmental systems (air, water and sediment, soil and groundwater) and biological systems. The lowest third of the diagram shows factors that contribute to exposure and effects. See Schwartzenbach et al., 2006, p. 1074.

Global Mercury Cycle

Units: 100 tons/yr

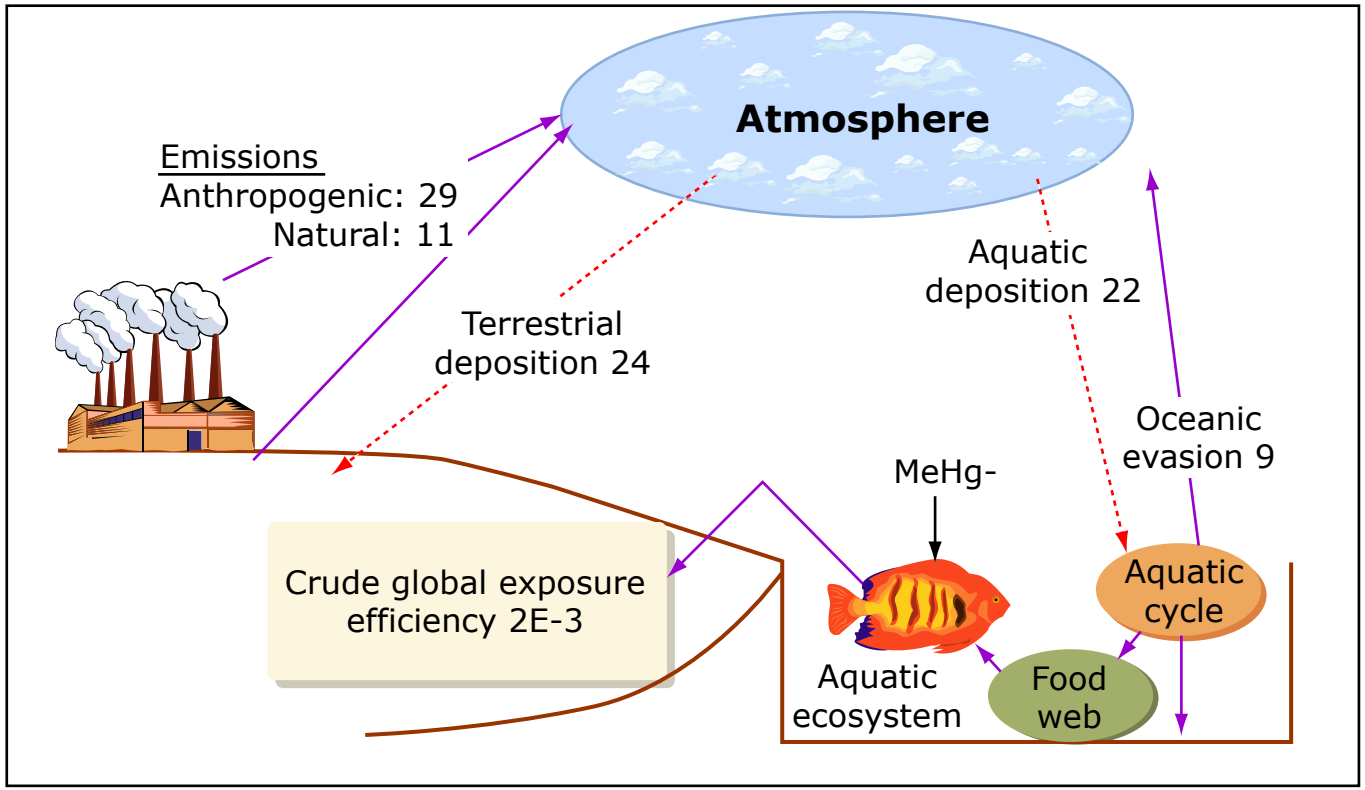


Figure by MIT OpenCourseWare.

Rice and Hammitt, 2005, p. 4.

Global macro-and micropollutant fluxes

Pollutants	10^6 ton/year
Fluxes of macropollutants in world rivers	
Total inorganic nitrogen (~75% anthropogenic)	21
Total phosphorus (60% anthropogenic)	5.1
Anthropogenic inputs of heavy metals to aquatic systems	
Zn, Cr, Ni, Pb, Cu, Cd, Hg	0.3-1
Anthropogenic fluxes affecting water quality	
Global fertilizer production (2000)	140
Global pesticide production	5
Synthetic organic chemicals production	300
Oil Spills (average 1980-2000)	0.4

Schwartzenbach, et al., 2006, p. 1073.

Examples of Ubiquitous Water Pollutants

Origins/Usage	Class	Selected Examples
Industrial Chemicals	Solvents	Tetrachloromethane
	Petrochemicals	BTEX (Benzene, toluene, xylene)
Industrial products	Additives	Phthalates
	Lubricants	PCBs
Consumer Products	Pharmaceuticals	Antibiotics
	Hormones	Ethinyl estradiol
Biocides	Pesticides	DDT, Atrazine
	Nonagricultural biocides	Tributyltin, Triclosan
Geogenic/ Natural chemicals	Heavy Metals and Inorganics	Lead, Cadmium Mercury, Arsenic, Selemium, Fluoride, Uranium
Disinfection by-products	Disinfection by-products	Trihalomethanes, haloacetic acids

Schwartzenbach, et al., 2006, 1073. In the EU 100,000 chemicals have been registered and 30-70,000 are in daily use.

WATER AND HEALTH IN EUROPE

Definition of the three European WHO subregions

52 Member States

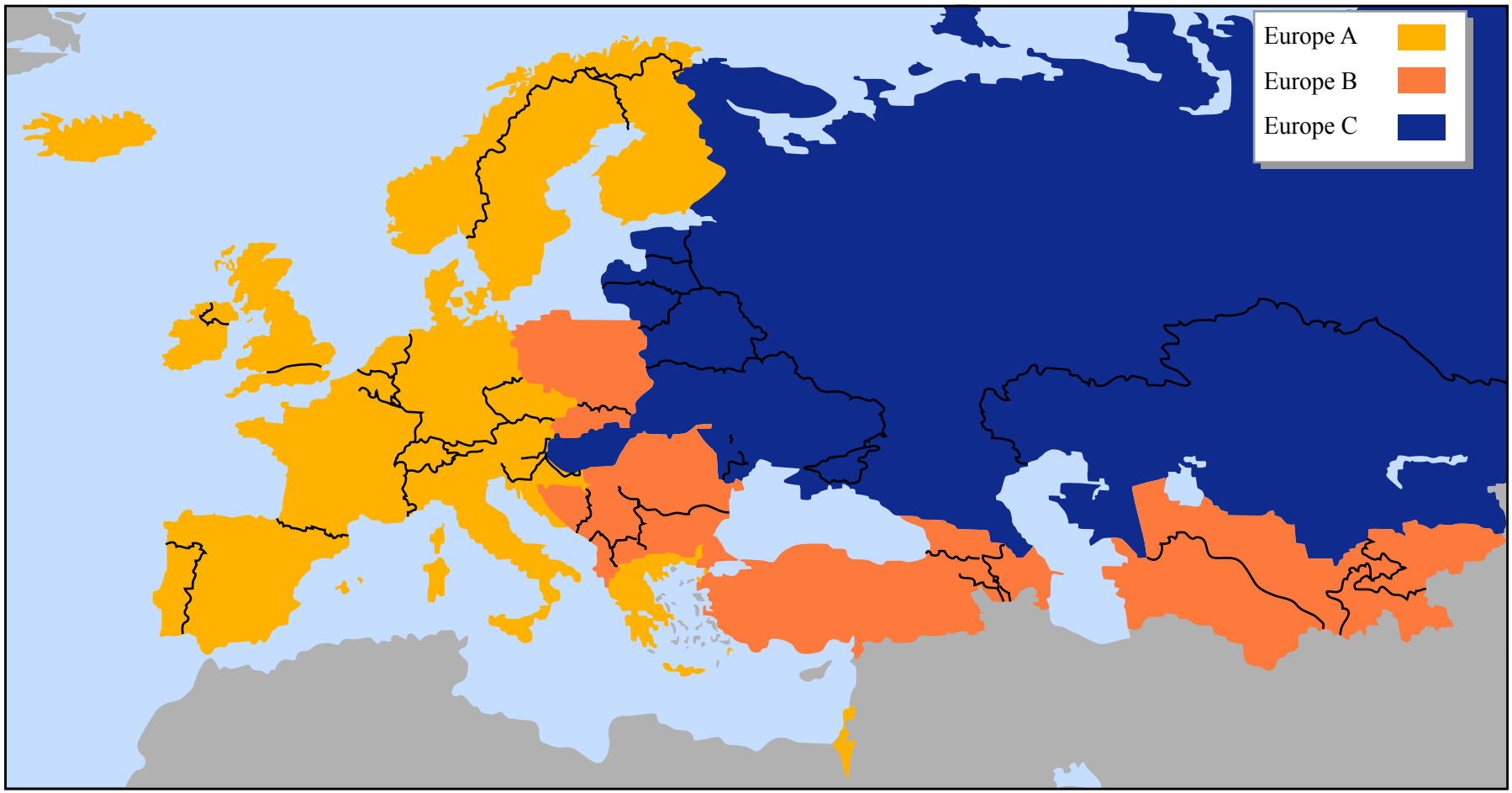
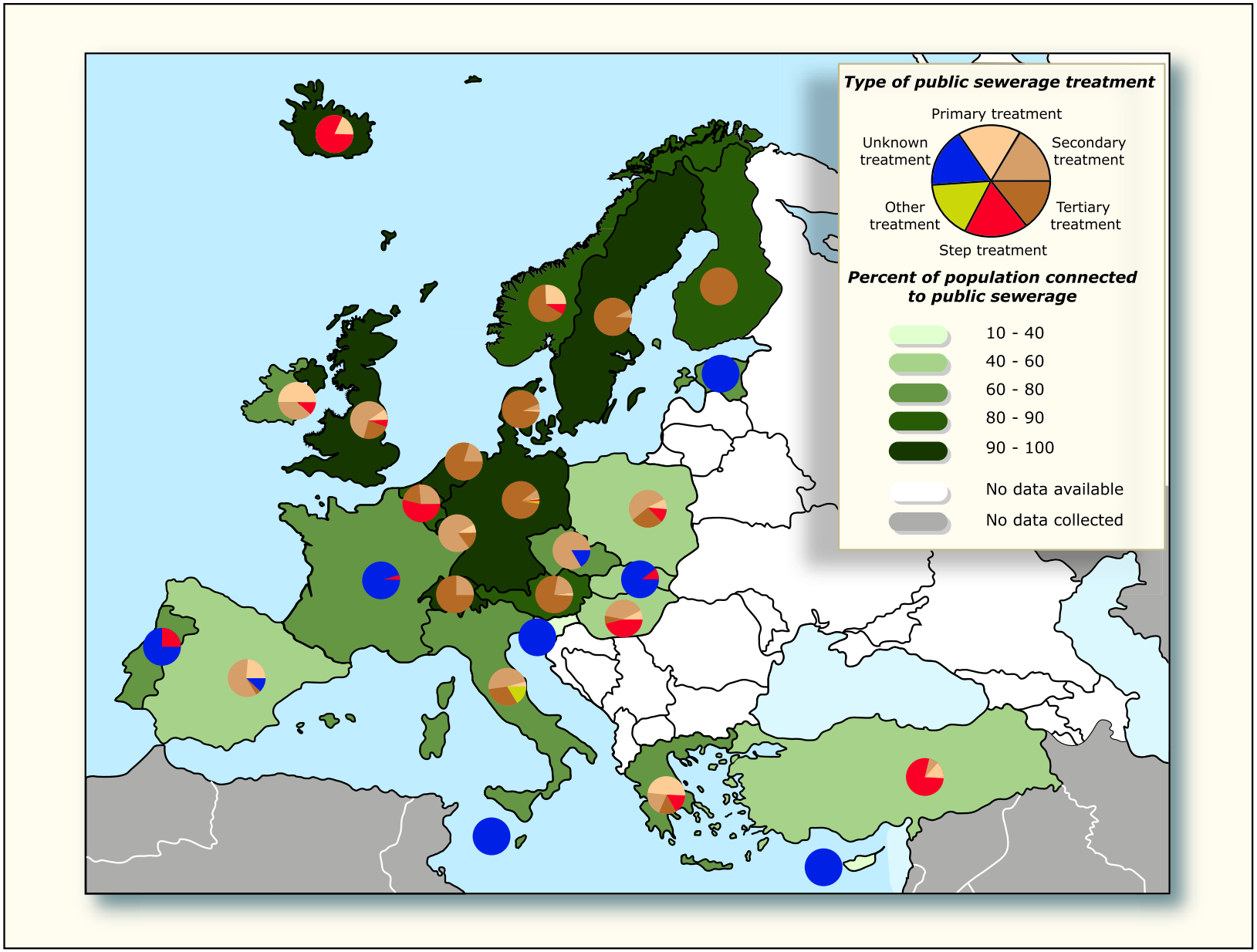


Figure by MIT OpenCourseWare, adapted from Valent et al., 2004, p. 2033.

Valent, et al., 2004, p. 2033

Europe A: very low child and adult mortality
Europe B: low child and adult mortality
Europe C: low child and high adult mortality

Public Wastewater Treatment in Europe



UNEP, 2006

Figure by MIT OpenCourseWare, adapted from United Nations Environmental Programme (UNEP).

Traditional Water Related Diseases in Europe (1986-96)

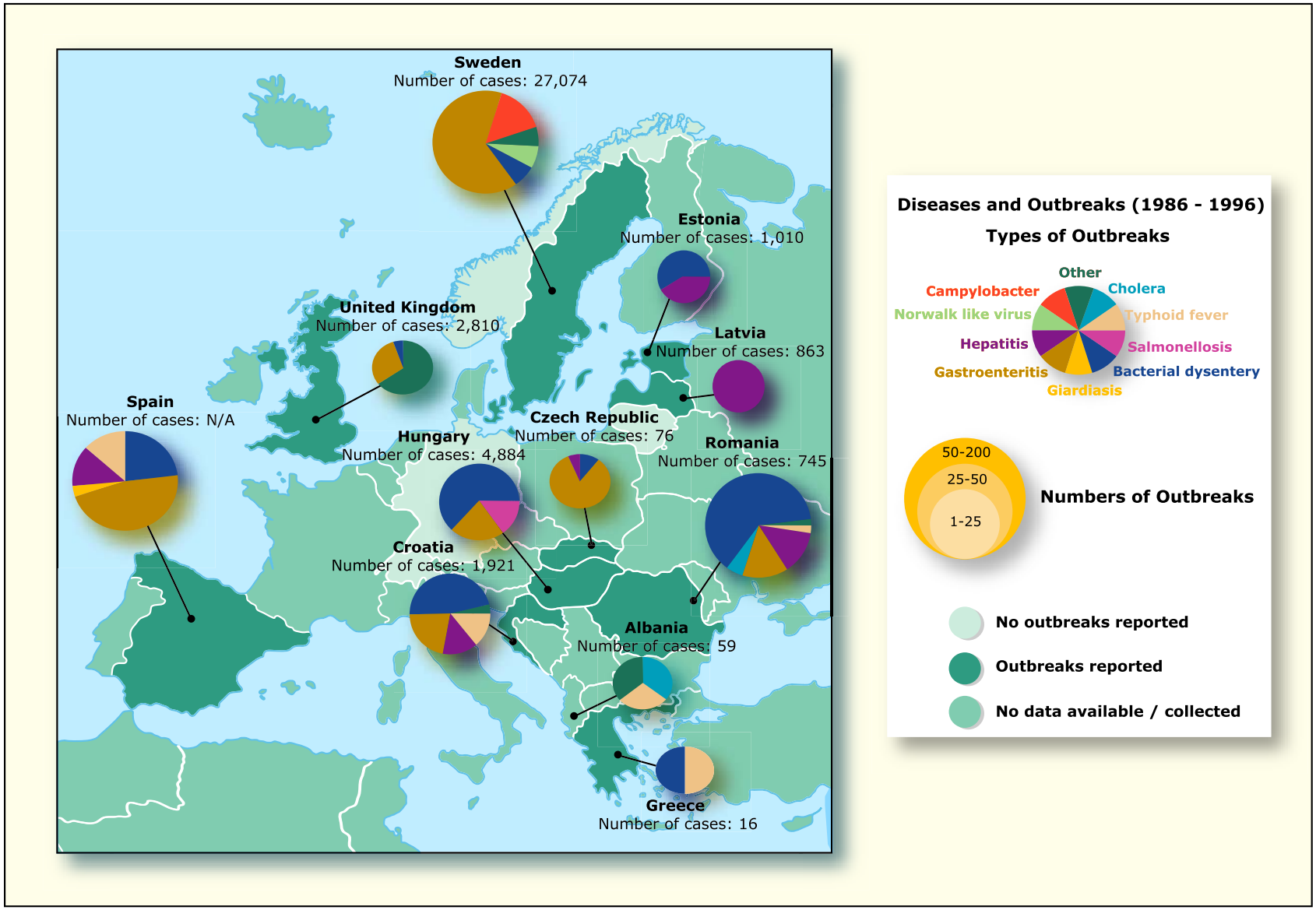


Figure by MIT OpenCourseWare, adapted from United Nations Environmental Programme (UNEP).

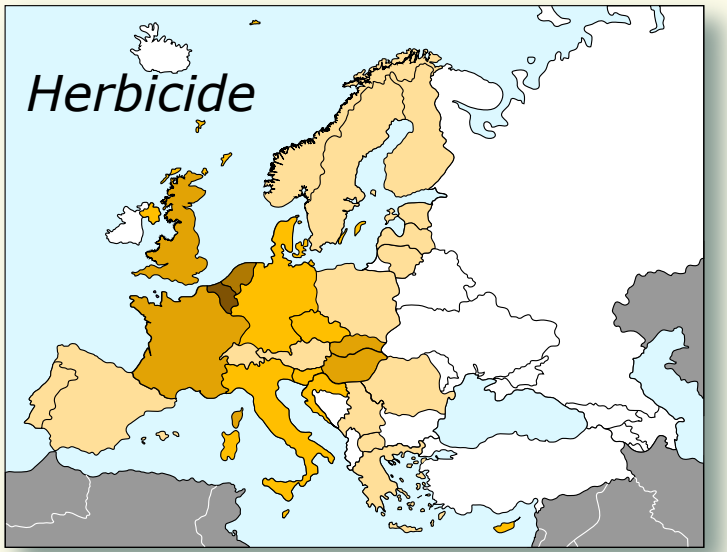
UNEP, 2006

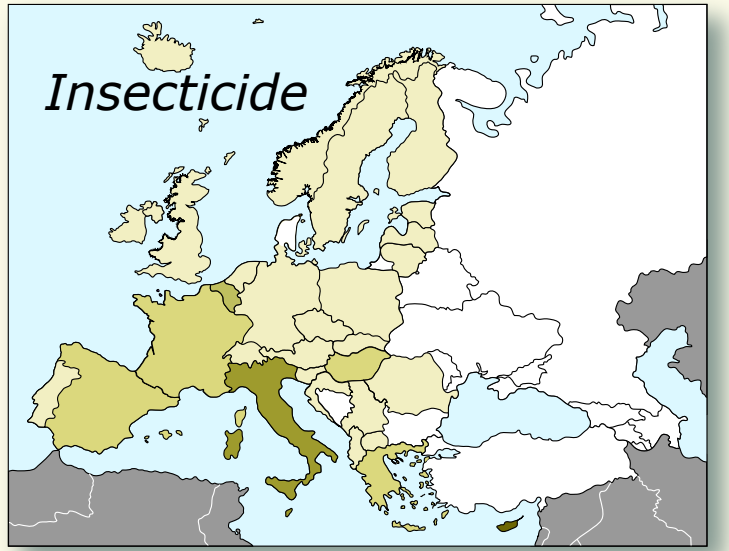
Annual Diarrhoea Deaths and Illness of Children aged 0-14 years in Europe due to Inadequate Water and Sanitation

Region	Deaths		DALYs	
	Number	% of all causes	Number	% of all causes
EUR-A	63	0.2	25,946	0.8
EUR-B	11,876 (10,374-12,831)	7.5	446,763 (390,276-482,710)	5.2
EUR-C	1609 (1,385-1,759)	2.4	77,231 (66,455-84,476)	1.6
Total	63	5.3	25,946	3.5
Total	**13,042**	**5.3**	**549,960**	**3.5**

Valent, et al. 2006, p.2035, using 2001 GBD death estimates and 1990 Global Health Statistics incidence estimates.

Potential Drinking Water Contaminants in Europe, 1998





Herbicide consumption per agricultural land area unit (kg/ha)

0 - 0.5 | 0.5 - 1.0 | 1.0 - 1.5 | 1.5 - 2.0 | >2.0

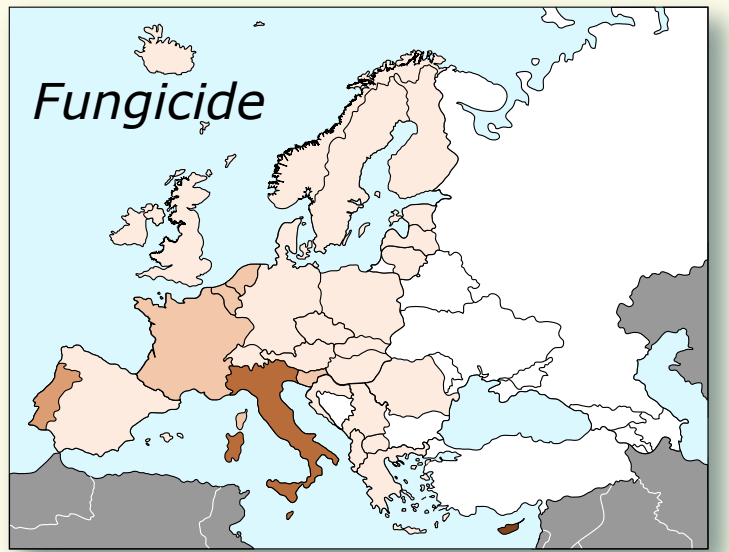
Insecticide consumption per agricultural land area unit (kg/ha)

0 - 0.2 | 0.2 - 0.4 | 0.4 - 0.8 | 0.8 - 1.6 | >1.6

Fungicide consumption per agricultural land area unit (kg/ha)

0 - 1 | 1 - 2 | 2 - 3 | 3 - 4 | >4

No data available | No data collected



UNEP, 2006

Figure by MIT OpenCourseWare, adapted from United Nations Environmental Programme (UNEP).

- Unfortunately, for Europe, the database does not yet exist to provide accurate comparisons of the health burden of the classical waterborne and the environmentally mediated water diseases.

- Data do exist for inadequate water and sanitation infrastructure and for lead, but comprehensive data on other heavy metals, and chemical and other residuals from consumer products, industrial emissions, and agricultural chemicals are lacking

Examples of Environmentally Mediated Diseases

There are many diseases caused by toxics released into the aquatic environment. The cases included here demonstrate the complexity of the analyses and the data requirements. The results of these cases should be considered only indicative of the magnitude of the health and economic consequences of all of the other non-traditional water-related diseases.

1. Mercury: Two case studies from the United States

2. Arsenic: A case study from Bangladesh

Based on:

Glen Rice and James Hammitt, *Economic Valuation of Human Health Benefits of Controlling Mercury Emissions from U.S. Coal-Fired Power Plants*, Northeast States for Coordinated Air Use Management (NESCAUM), 2005.

Transande. L, et al., *Public Health and Economic Consequences of Methyl Mercury Toxicity to the Developing Brain*, Environmental Health perspectives, vol. 113, no. 5, May 2005, pp. 590-596

Arsenic Foundation Inc., 2006. and Feroze Ahmed, et al., 2006.

Conceptual Model of Human Mercury Exposure

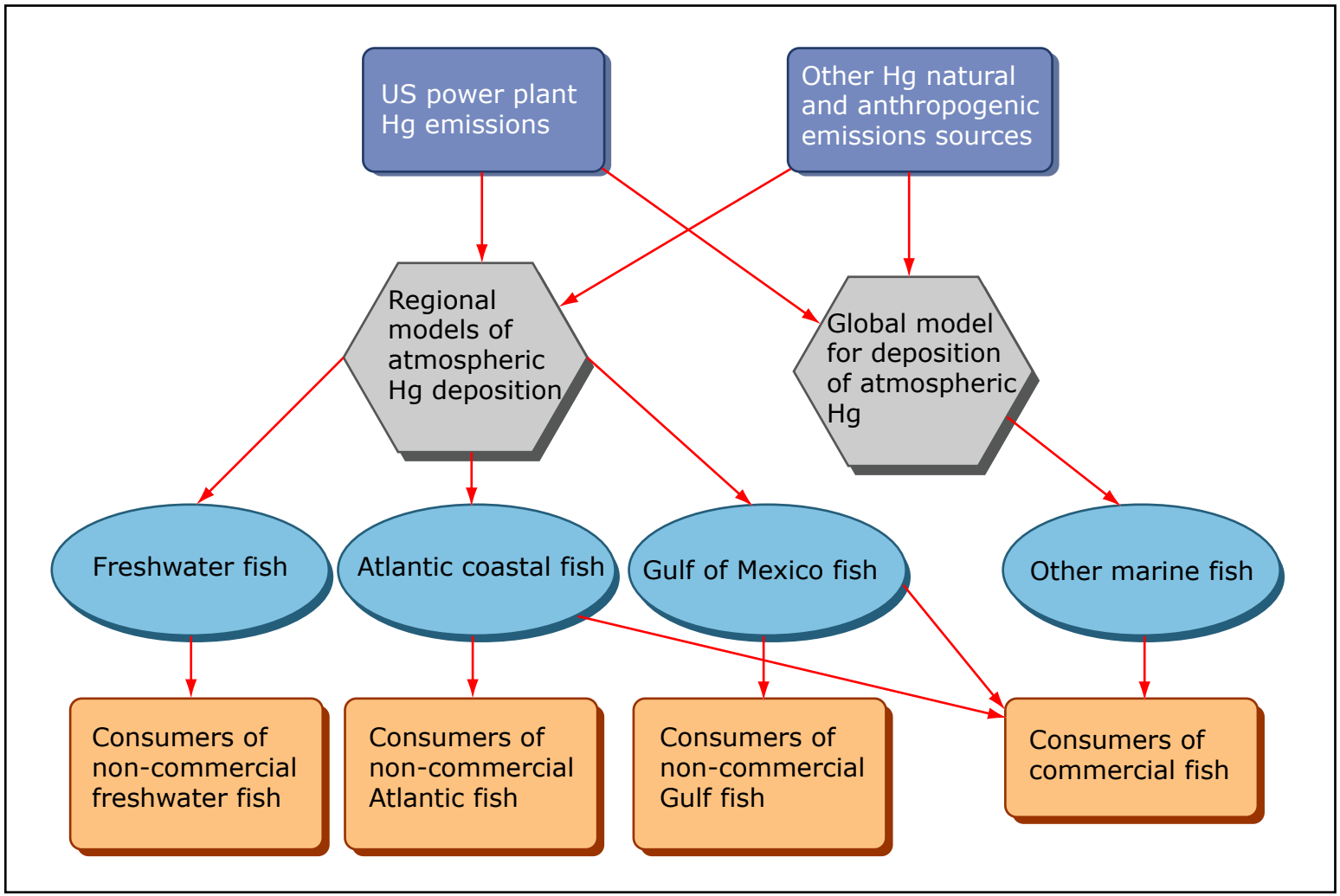


Figure by MIT OpenCourseWare.

Rice and Hammitt, 2005, p. 59

Health End Points due to Mercury Deposition used in US cases

Rice and Hammitt. (2005)

- Neurological Decrements Associated with Intrauterine Methylmercury Exposures
- Myocardial Effects Associated with Adult Methylmercury Exposures
- Elevated Childhood Blood Pressure and Cardiac Rhythm Effects Associated with *In Utero* Methylmercury Exposures

Trasande et al. (2006)

- Used CDC national blood mercury prevalence data
- 416,000-637,000 children predicted to have cord blood level of >5.8 μg/L
- End point was neurodevelopment impacts: loss of IQ

Global Extent of Natural Arsenic Contamination of Drinking Water

Image removed due to copyright restrictions: global map showing aquifers affected by arsenic, arsenic caused by mining operations, and geothermal waters. See Smedley, Kinniburgh 2001.

Chronic Adverse Effects of Arsenic

After a few years of continued low level of arsenic exposure, many skin ailments dyspigmentation (white spots, dark spots), collectively called melanosis appear. Also keratosis (break up of the skin on hands and feet) starts to appear.

After a latency of about 10 years, skin cancers appear.
After a latency of 20 - 30 years, internal cancers - particularly bladder and lung appear.

Source. Arsenic Foundation Inc., 2006

SOME ECONOMIC CONSEQUENCES

URBAN WATER SUPPLY AND SANITATION

- Typically huge poor population, villages within cities!

- 15 of top 20 mega cities (>10 million) globally will be in the poor countries by 2015

- 1975-2015 cities (> 5 million) will go from 11 to 45 in the poor countries

THIS WILL COST A LOT?

Need to add coverage of water to 280,000 and sanitation to 567,000 persons per day from now until 2015 (MGDs). Annual Additional Funding Needed $15 billion in 2000US$

World Bank	$75
Water Aid	$25
Vision 21	$19-34
GWP	$30
IUCN	$20
Price Waterhouse	$180

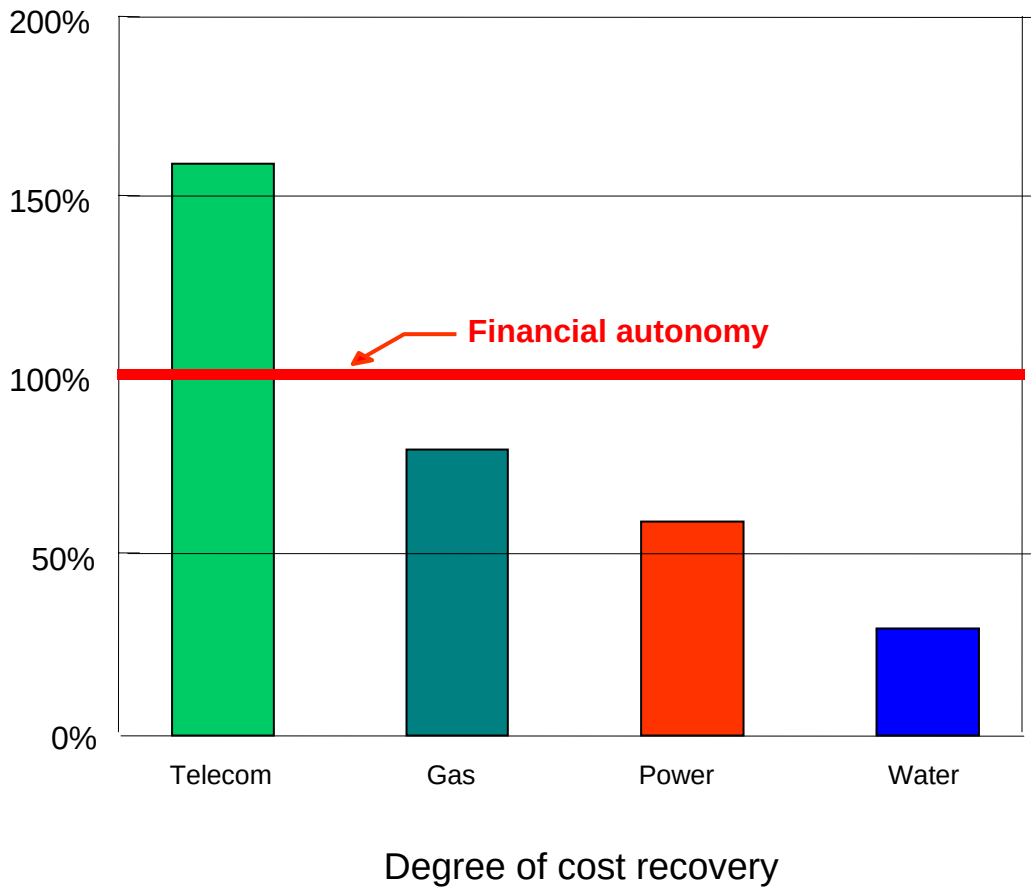
(Source, WSSCC, 2000)

COMPARED TO WHAT?

WHAT ARE THE DIMENSIONS OF THE WSS PROBLEM IN THE US?

- Most utilities for both water and wastewater have problems covering the cost of services
- Many have deferred maintenance due to capital shortages
- About half of the 55,000 drinking water systems and 20% of the 30,000 wastewater systems are privately owned
- Most of these serve populations of less than 10,000
- GAO (2002) estimated that investments between $300 billion and $1 trillion would be needed over the next 20 years
- These costs apparently do not include the costs of the evolving storm water regulations estimated to cost between $23 billion and $170 billion for the Los Angeles Water Board Region over the next 20 years
- During the past decade, about $7 billion per year has been provided by federal and state resources

Reasons NOT TO INVEST in the Water Business…



Source: World Bank, ca 2003.

Annual Investments and Revenue Collection (2001) in $millions

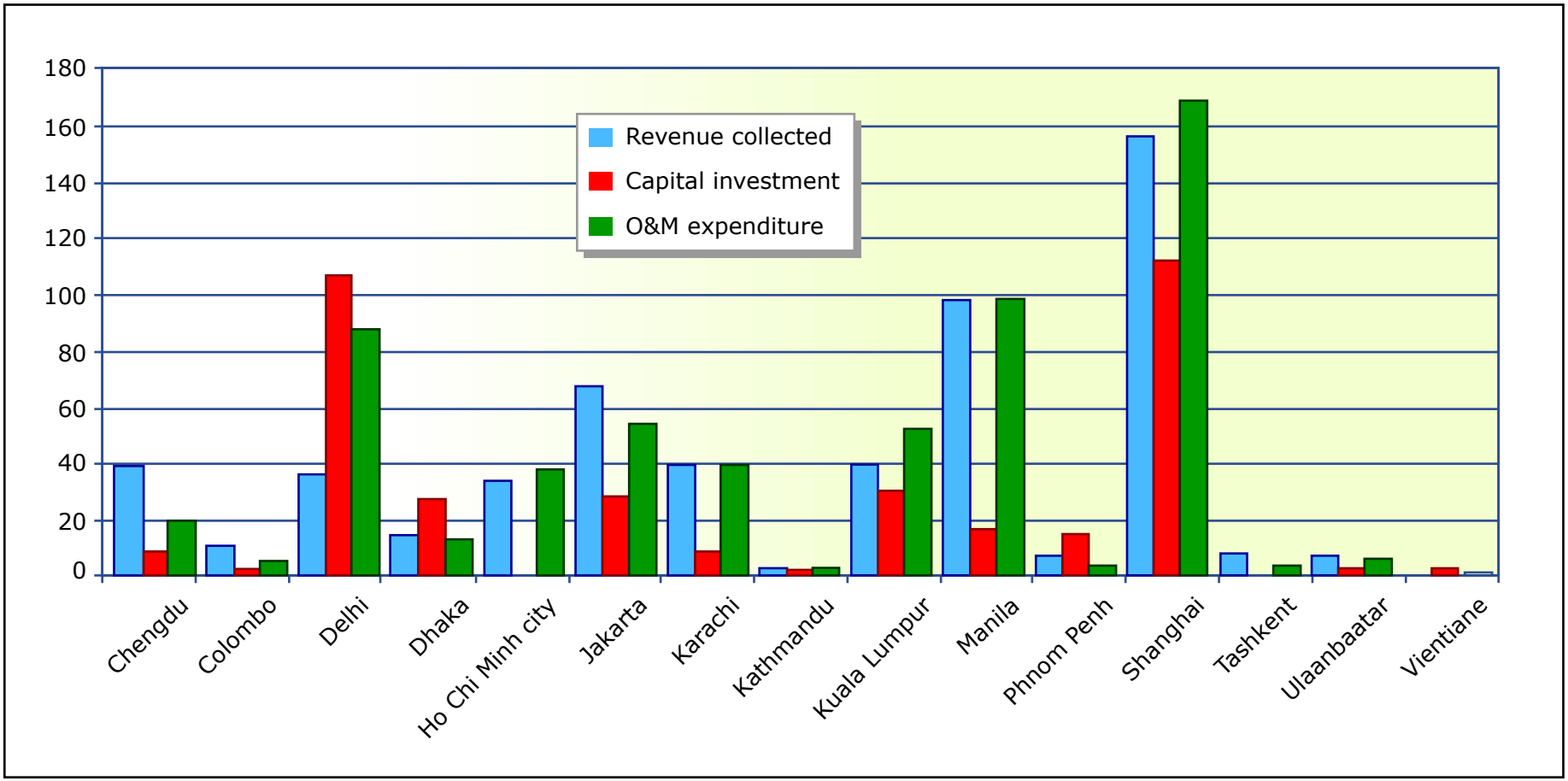


Figure by MIT OpenCourseWare.

Reasons TO INVEST in Water and Sanitation

Look at the Economic and Social Benefits—Do not focus on the Costs!

Classical Waterborne Diseases

Diarrhoea in Europe

Total NPV Costs and Benefits due to Water Supply and Sanitation Improvements for Europe by 2015

Region/ County	Population (m)	Total Cost and Benefits of Interventions (US$m)								
		Intervention 3			Intervention 4			Intervention 5		
		Cost	Benefit	B:C Ratio	Cost	Benefit	B:C Ratio	Cost	Benefit	B:C Ratio
EUR-A	413	222	1614	7.27	235	2050	8.72	656	2357	3.59
EUR-B	238	373	5950	15.95	464	7658	16.50	4602	17037	3.70
EUR-C	223	143	934	6.53	266	1551	5.83	4206	5337	1.27
Total	874	738	8498	11.51	965	11259	11.67	9464	24731	2.61

Intervention 3: Everyone has access to improved water and improved sanitation services
Intervention 4: Intervention 3 + everyone has a minimum of water disinfected at the point of use
Intervention 5: Everyone has access to a regulated piped water supply and sewage connection in their houses

Hutton and Haller, 2004.

SOME CONFLICTING EVIDENCE

- Hutton and Haller (2004) claim benefit cost ratios in excess of 15 for pursuing the water and sanitation MDGs in developing countries (for Europe they range from 11.6 to 2.6)
- Their claim is that, considered as a national investment strategy these choices would dominate all other possible infrastructure investments, and hence, should be top priority for government investment.
- Whittington and Hanemann (2006), however, reviewed the evidence from several willingness-to-pay studies for water and sanitation in developing countries and find, that the benefit cost ratios were all less than one.
- As economists, they warn that investing in social overhead capital (like water and sanitation infrastructure) is largely a matter of faith and that typically when a project does not pass a benefit-cost test, then the water professionals appeal to excessive valuing of health benefits which the local population does not see, or expect, are not willing to pay for, and have not been demonstrated by follow-up project reviews!
- Other economists (Cutler and Miller, 2005) in a longitudinal study of several large US cities claim B/C ratios of 23 for these cities.

Environmentally Mediated Diseases:
Mercury

Trasande's and Rice and Hammitt's US Mercury Studies

Rice and Hammitt. (2005)

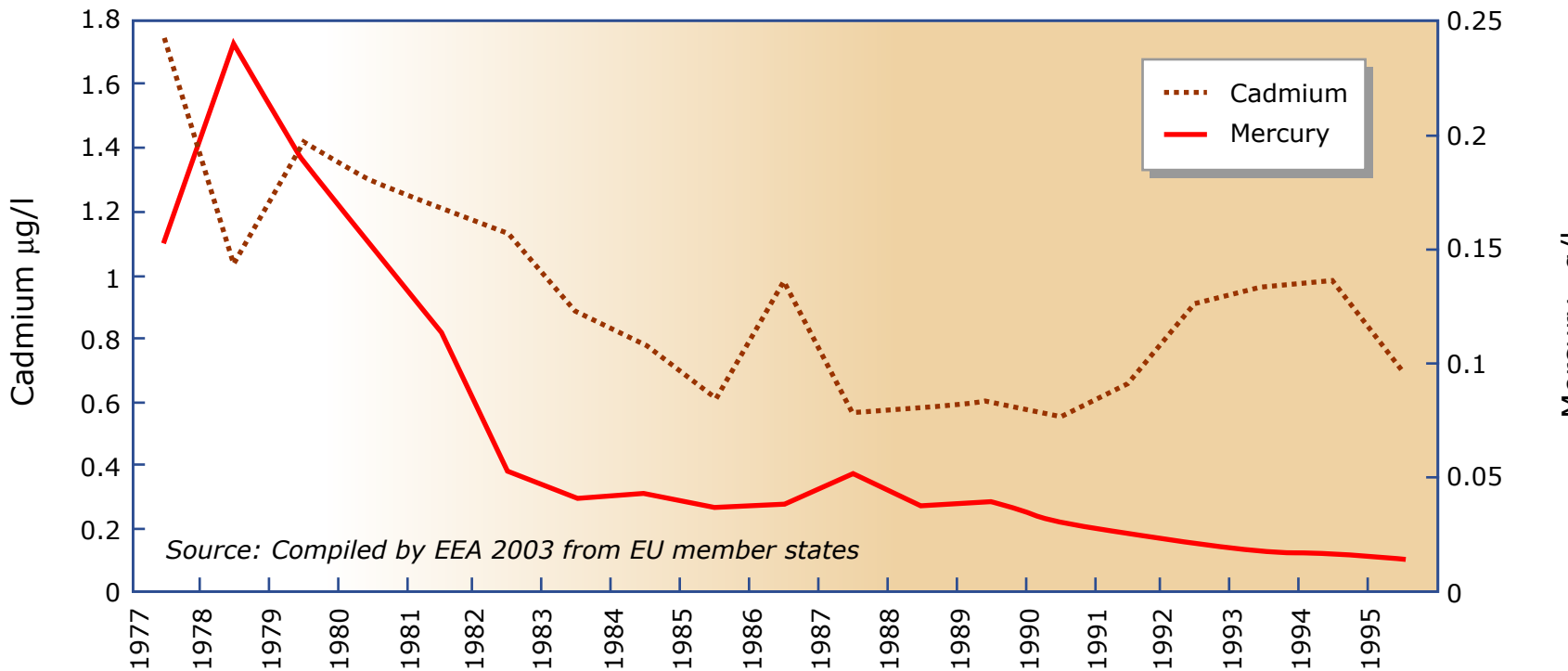
- Annual benefits due to IQ impairment from fetal exposure due to US power plants: $0.075-0.194 billion
- Cardiovascular effects and premature mortality in all fish consumers: $3.3 billion
- This implies a B/C ratio of 4.7 for 50% removal an 5.0 for 70% removal from electric power emissions

Trasande et al. (2006)

- Lost productivity due to IQ impairment $8.7 billion annually ($2.2-43.8)
- $1.3 ($0.1-6.5) billion attributable to Hg from American power plants

It has been estimated that as much as 70% of the atmospheric mercury deposited in North America has origins in China (Weiss, 2004)

Cadmium and Mercury Concentrations for Selected Rivers in Europe



The EU environmental quality standards for cadmium and mercury are 5 µg/l and 1 µg/l as annual averages, respectively. Cadmium data from Belgium, Germany, Ireland, Luxembourg, Netherlands, UK.
Mercury data from Belgium, France, Germany, Ireland, Netherlands, UK.
In less polluted areas in e.g. Nordic countries concentrations of cadmium and mercury are only 10 and 1% of these values.

UNEP, 2006

Figure by MIT OpenCourseWare, adapted from United Nations Environmental Programme (UNEP).

Benefits for Arsenic Reduction in Bangladesh

- Estimated μDALYs/person-year
  - Microbial: 391 (27-2,631)
  - Arsenic: 152 (50-511)
- Exposure: population 20 million
  - Arsenic: 42 mg/liter
  - Fecal coliforms: 3 colony forming units (cfu)/100mL
  - Life expectancy: 62 years
- Total cost of arsenic remediation
  - $11-22 billion[1]
- Total arsenic DALYs = 91,458

Feroze, A. et al. 2006. p.10. [1] World Bank, WSP 2005

IS THERE A ROLE FOR PRICING?

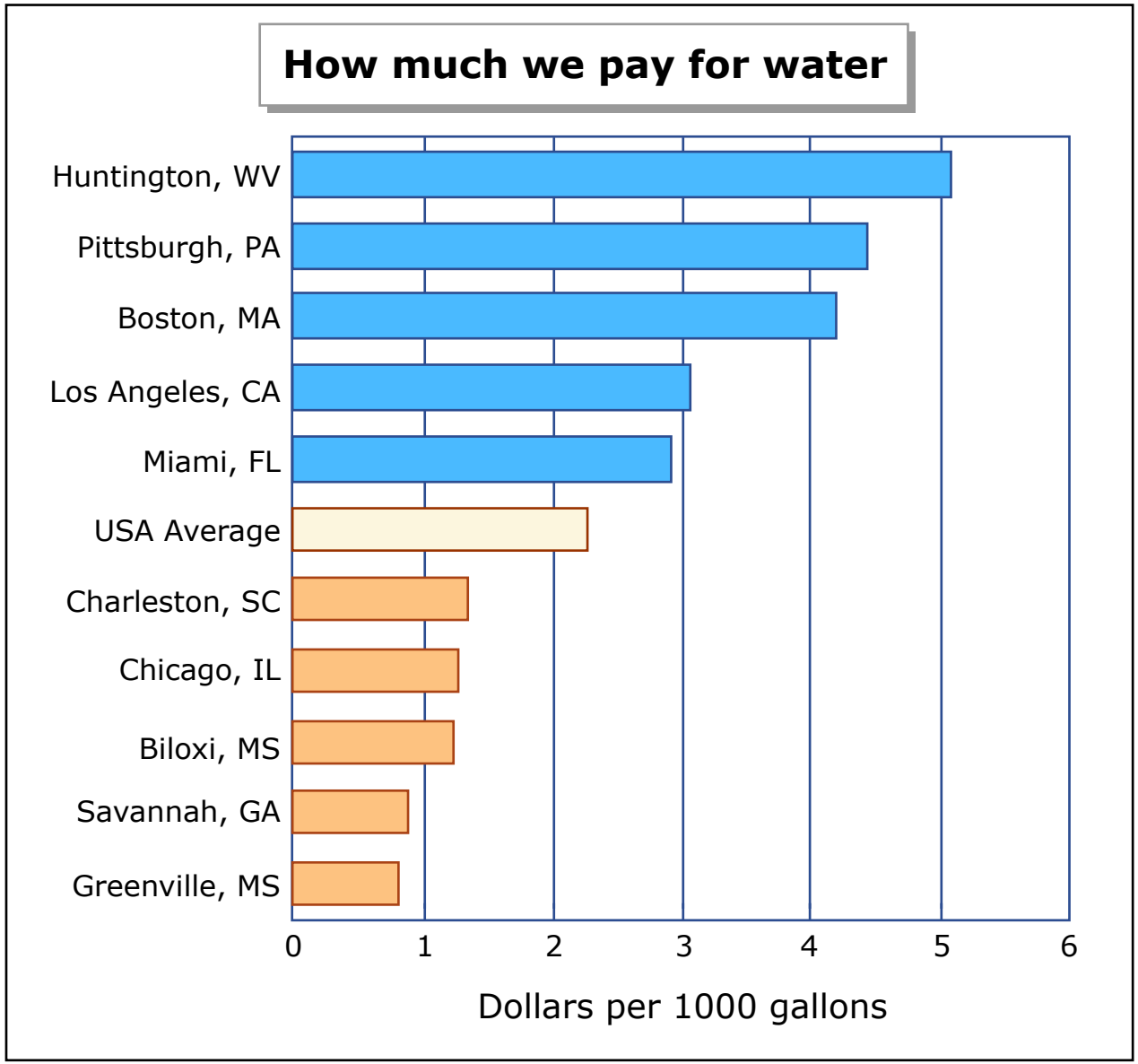


Figure by MIT OpenCourseWare.

$1 per cubic meter = $3.78 per 1000 gal. US Average is $2.26 per 1000 gal. (with sewer costs, $5.54).

Source: *US Water News*, Vol. 21, No. 10, October 2004. (In Europe prices are approx $2 per cubic meter)

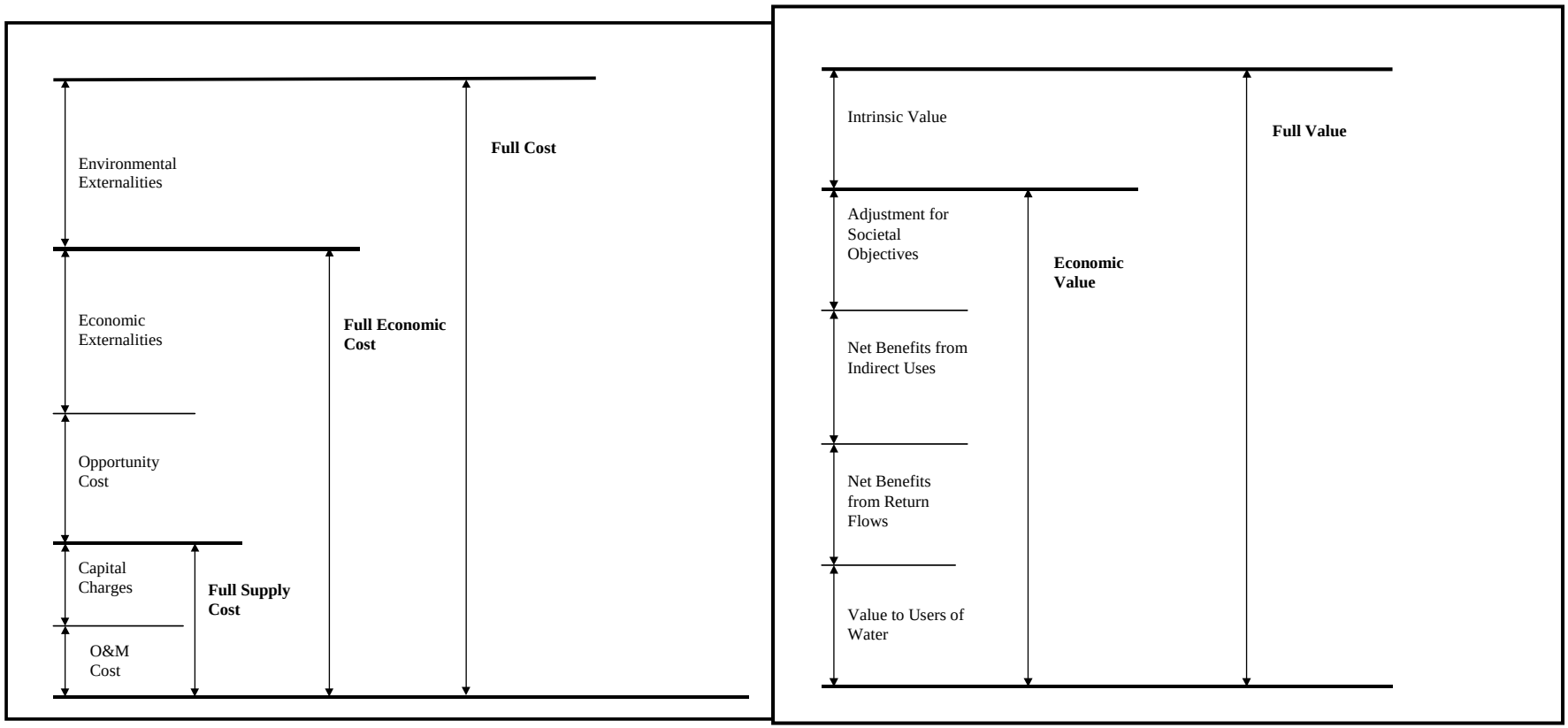
Three important concepts

COST: O&M costs, capital costs, opportunity costs, costs of economic and environmental externalities.

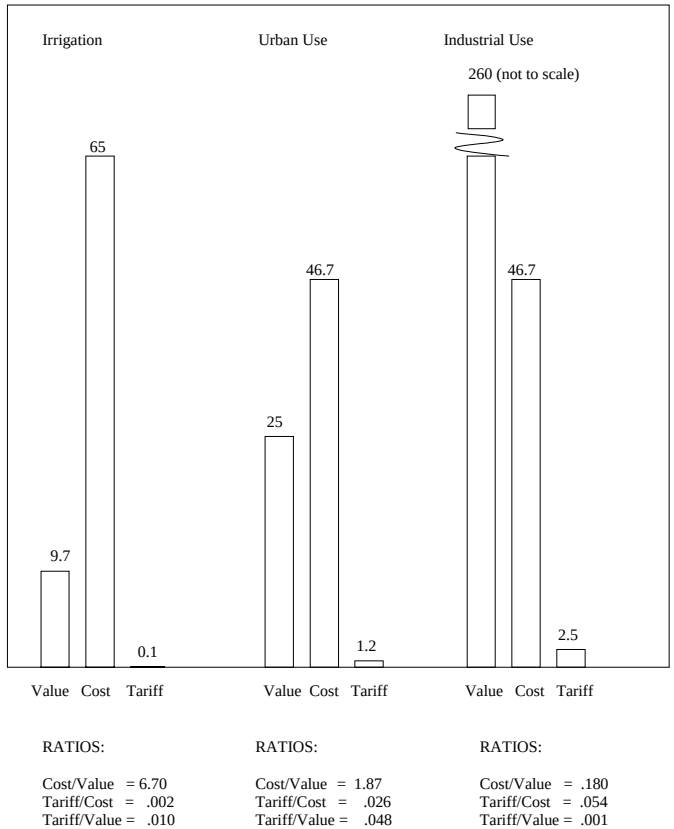
VALUE: Benefits to users, benefits from returned flows, indirect benefits, and intrinsic values.

PRICE: Amount set by the political and social system to ensure cost recovery, equity and sustainability. The price may or may not include subsidies. Prices for water are not to be determined solely by costs or value.

General Principles for Value and Cost of Water



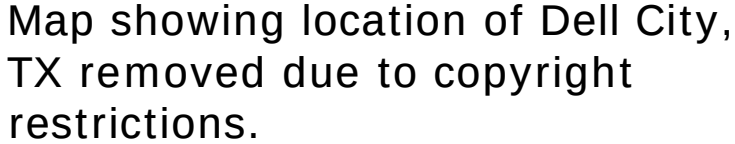
Comparison of Value-in-Use, Costs, and Prices Charged for Three Sectors in the Subernarehka River Basin, India



Source: Rogers, Bhatia, and Huber, (1998)

WHAT ABOUT SUSTAINABILITY?

PUTTING A VALUE ON SUSTAINABILITY: DELL CITY, TEXAS



Protection of Existing and Historic Use of Groundwater in Texas – Legislation, Regulation, and Litigation Dr. A.W. Blair, P.E., Austin, Texas. Paper presented at the University of Arizona, Jan. 31, 2007.

Choices for the Citizens of Dell City

"… groundwater districts across the state will be faced with making difficult and likely unpopular decisions as they manage the state's dwindling groundwater supplies."

Senate Interim Committee on Natural Resources

- Dissolve the district and revert to Rule of Capture
- Ban exportation of groundwater and be litigated into bankruptcy
- Implement a fair and just method to balance the rights of those wishing to use water within the district and those wishing to export water outside of the district

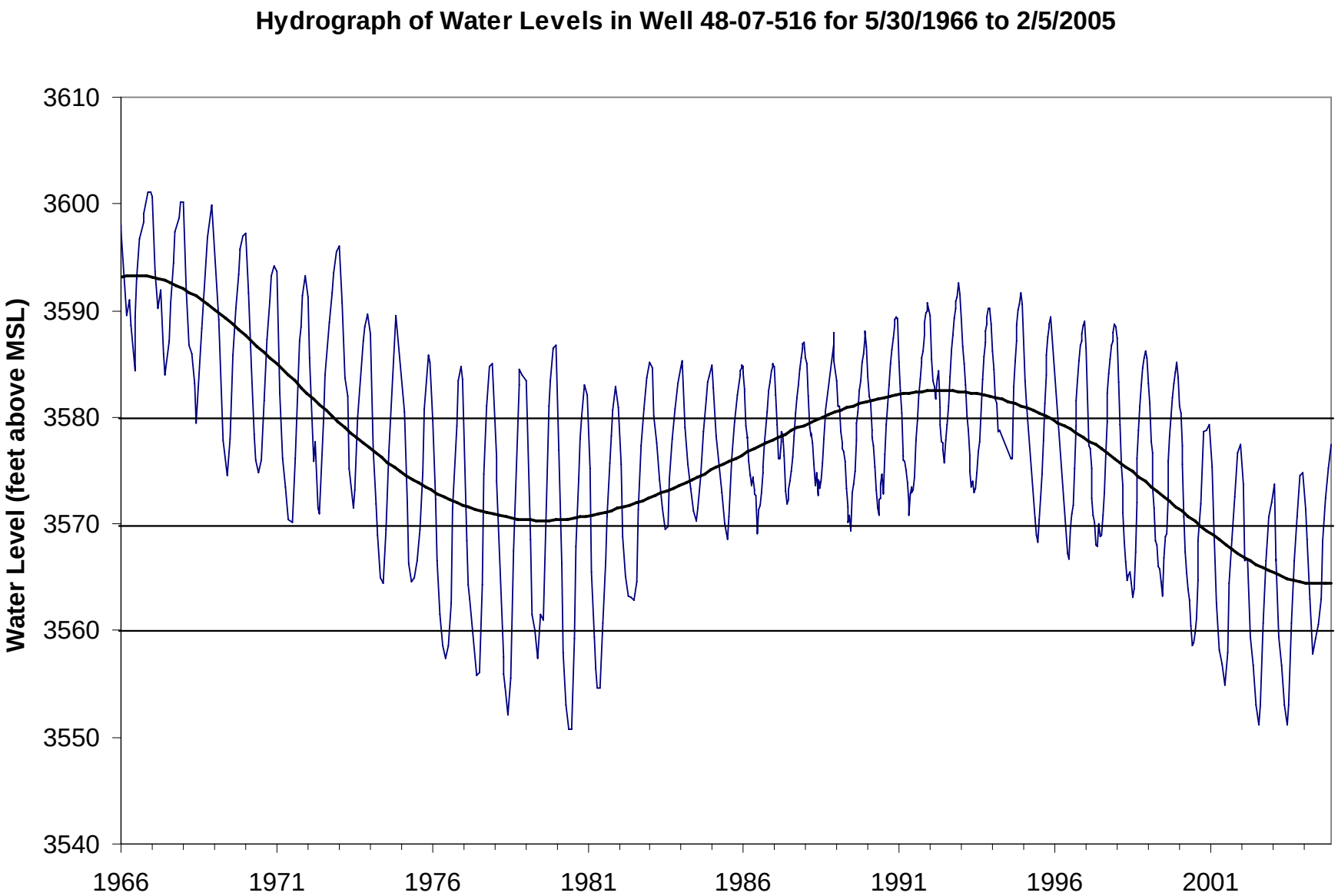
Current Board Approach

The District's Board has chosen that the groundwater resources of the District should be managed in a sustainable manner, allowing for the transfer of groundwater from the District while protecting the current and future uses of groundwater within the District.

Summary of Choices

- All wells greater than 2” discharge are metered and have reporting obligations
- “Sustainable Use” based on index well
- Bi-annual water allocation based on index wells
- Permits based on historically irrigated land (previous 10 years) and current beneficial use (correlative right within historic period)
- Protection of exempt uses, domestic and livestock use (up to 2.5 acre-feet per acre)
- New Permits conditional on water level

Index Well Water Level



Quantifying Sustainability in $

- City estimated that 67,000 acre-ft per year as the sustained yield of the aquifer on a total resource base of 600,000 acre-ft
- El Paso, 90 miles away, willing to build a pipeline for trans-boundary capture of the whole resource
- Water marketers whished to apply the “rule of capture” for their wells
- Value of water in Dell City irrigation $30-50 per acre-ft
- Value of water in El Paso more than $200 per acre-ft

Shadow Value of Sustainability

Water Price $/ac-ft	200	200	400	400
Discount rate	4%	6%	4%	6%
Dell City, SD $1000	65,673	44,535	65,673	44,535
El Paso Benefits	-47,541	-57,549	33,667	11,269
Dell City Sells water	81,541	68,819	163,083	137,639
Shadow value $1000	-15,868	-24,284	-99,410	-93,064

Did Dell City make a wise choice?

TAMPA BAY WATER DESALINATION

$110 million plant went on line in 2004, closed for a $39 million correction of filter clogging problem. Will go on line by 2008 producing water for $2.54 per 1000 gal ($0.67 per cubic meter could be reduced to $0.47 per cubic meter within 30 years).

Uses Tampa Bay water and is located next to Tampa Electric's 2000 MW Big Bend plant with which it shares an outflow channel.

NOTE: the production cost is comparable to current average US water prices