Solving Water Quality Problems Worldwide

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Topics

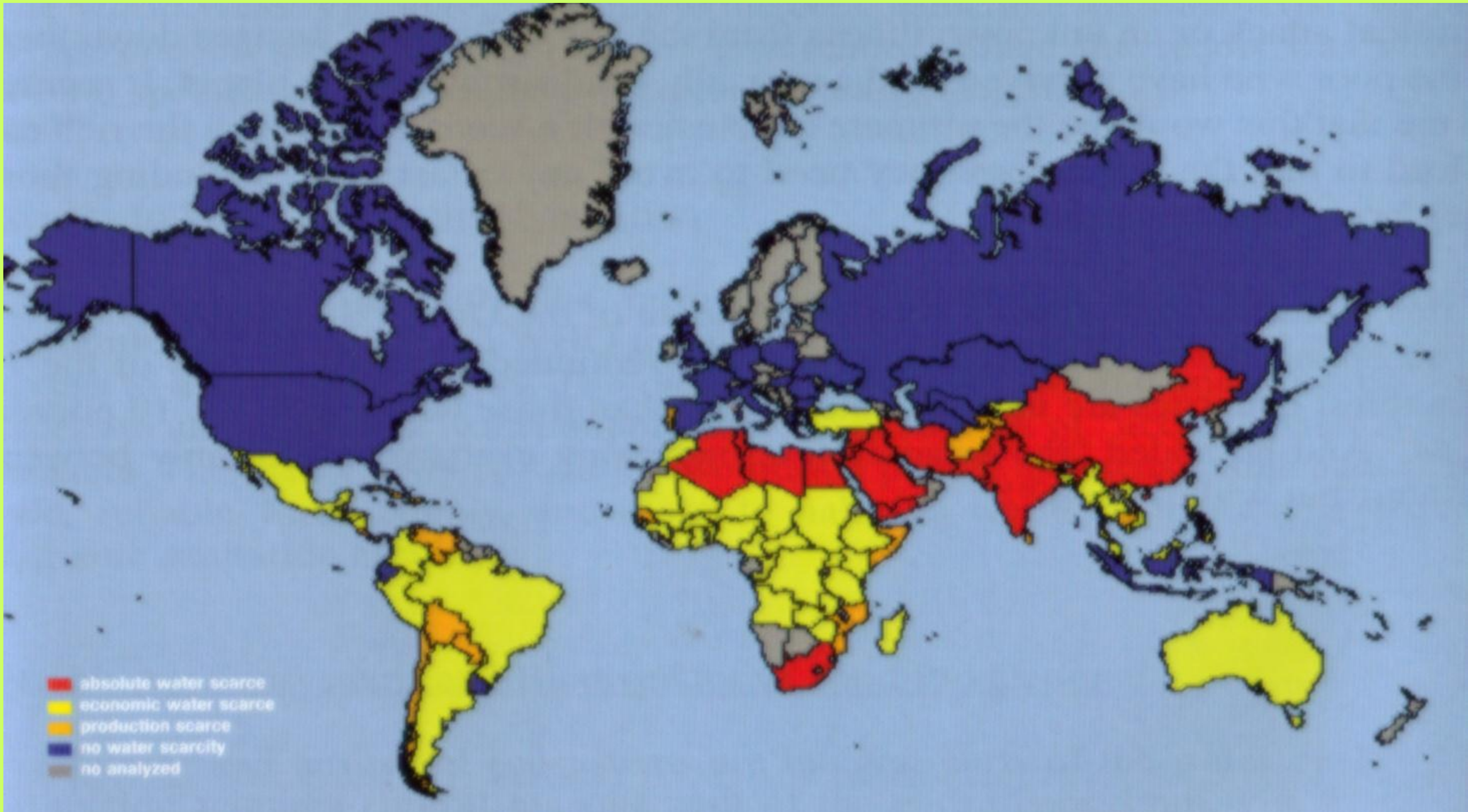
- Is water availability a human right?
- Sources of contamination
- Monitoring contaminants
- Delineation of a worldwide problem
- Good sanitary practices
- Potential solutions

Earth Is a Water Planet

- 3% of the total water available to us is fresh water. Only 0.06% is easily accessible.
- Over 80 countries have water deficits.
- About 1.2 billion people drink unclean water.
- 2.7 billion people will face a water shortage by 2025 (UN estimate).
- Water-related diseases kill 5 -10 million people per year.

H_2O Availability (Technology and Economics-driven Scenario)

- = economic water scarcity
- = absolute water scarcity
- = production scarcity
- = no water scarcity
- = not analyzed



Chemistry for Water, **2006, p 33.**

Why Worry About Water or its Sustainability?

- WATER is the most essential material for human survival, after air.
- Our civilization has managed to pollute surface water and groundwater, necessitating purification for drinking purposes.
- We need to minimize further pollution.

Angkor Temple; A Sad Story (900-1300)

NASA’s radar images revealed the artificial landscape of Angkor: Miles of canals and dikes diverted water from three rivers (Puok, Roluos, and Siem Reap) to the barays (West Baray is 5 miles long and 1.5 miles wide).

Khmer engineers (900-1300) had built a sloping dam from stone blocks that were hewn from laterite (a spongy, iron-laden soil that hardens when exposed to air). Eventually the dam failed, and led to the downfall of the empire (Mega-droughts in 1362 to 1392 and 1415 to 1440 may also have been responsible).

When the water system failed, so did Angkor’s power. Modern societies have to prepare themselves for similar climatic challenges.

Even today, clusters of Khmer homes sit on *spindly stilts* to cope with flooding during the summer monsoon.

Villagers have learned to “walk on water” as it rises near Tonle Sap. Families easily net dinner from their porches.

Nat. Geo., July, 2009, p.49

Water Resources

Drinking water comes mainly from the following sources: rivers, lakes, wells, and natural springs. These sources are exposed to a variety of conditions that can contaminate the water. The failure of safety measures relating to production, utilization, and disposal of a large number of inorganic/ organic compounds can cause contamination of our water supplies.

Contaminants

Since thousands of contaminants can enter our water supplies, it will serve no purpose to list all of them; however, they do cover the whole range of the alphabet, from arsenic to zinc (S. Ahuja, Atlanta ACS meeting, 2005).

The next slide shows some water contaminants that arise from materials that are frequently used to assure a better quality of life.

Sources of Contamination

- Combustion of coal/oil
- Detergents
- Disinfectants
- Drugs (pharmaceuticals)
- Fertilizers
- Gasoline (combustion products) and its additives
- Herbicides
- Insecticides
- Pesticides

How About the United States?

The U.S. is also facing a water crisis. Most experts agree that the U.S. water policy is in chaos. Decision making about allocation, repair, infrastructure, and pollution is spread across hundreds of federal, state, and local agencies.

- Over 700 different chemicals have been found in U.S. drinking water as it comes out of the tap! EPA classifies 129 of these as being particularly dangerous.
- EPA sets standards for approximately 90 of them.

Drugs as Contaminants in Water in the United States

- About 12,500 tons of antimicrobials and antibiotics are administered to healthy animals on U.S. farms each year.
- A 2002 U.S. Geological Survey found pharmaceuticals (hormones and other drugs) in 80% of our streams sampled in 30 states.
- These contaminants are suspected in the rise of fish cancer, deformities, and feminization of male fish.

Rivers and Lakes Pollution in the United States

40% of U.S. rivers are too polluted for fishing, swimming, or aquatic life. Almost 50% of the lakes are too polluted for the same activities.

The Mississippi, which drains nearly 40% of continental U.S., carries an estimated 1.5 million metric tons of nitrogen into the Gulf of Mexico, resulting in a hypoxic coastal dead zone the size of Massachusetts every summer.

What Is Potable Water?

A simple definition of potable water is “any water that is suitable for human consumption.”

National Primary Drinking Water Regulations control water quality in the United States. However, these regulations vary in different parts of the world. The following table lists what one municipality in the U.S. does to monitor potable water quality.

Water Quality in Brunswick County (NC)--2008

Substances	EPA	Detected	Source
TOC		3.2 to 4.4 ppm	Nature
RADIONUCLIDES			
Beta	10 pCi/l	2.48 pCi/l	Nature

Water Quality (cont.)

Substances	EPA	Detected	Source
INORGANIC CHEMICALS	ppm	ppm	
Chlorite	1.0	0.6–1.0	Disinfectants
Chlorine dioxide	0.8	0.0–0.32	Water additive
Fluoride	4	0.26–1.20	Water additive
Nitrate	10	N/A	Disinfectants
Sulfate	250	N/A	Nature
Copper	1.3	≤0.79	Plumbing
Lead	0.015	≤0.003	Plumbing

Water Quality (cont.)

Substances	EPA	Detected	Source
ORGANIC CHEMICALS			
Chloramines	4 ppm	1.6–3.10 ppm	Water additive
Trihalomethanes	80 ppb	0.0–48.0 ppb	Disinfectants
Haloacetic acids	60 ppb	4.0–42.0 ppb	Disinfectants

Water Quality (cont.)

Substances	Detected	Source
UNREGULATED CONTAMINANTS		
Sodium	19.1 ppm	Natural deposits
Manganese*	0.051 ppm	Natural deposits
Iron*	0.10 ppm	Natural deposits
Bromoform*	0.8 ppb	THM component
Bromomethane*	8.7 ppb	THM component
Chloroform*	34.0 ppb	THM component

*Data from 2004.

Other Contaminants of Concern

- MTBE
- Herbicides
- Pesticides
- Fertilizers
- Pharmaceuticals
- Perchlorate
- Mercury
- Arsenic

In Search of Femtogram

In the 1978 Metrochem meeting, I presented a paper "In Search of Femtogram." As you know, a femtogram is 10^{-15}g, or one part per quadrillion—a phantom quantity at that time.

I emphasized the need to analyze ultratrace levels of various contaminants to fully understand their impact on our bodies. Dioxin (2,3,7,8-tetrachloro-dibenzodioxin) can cause abortion in monkeys at the 200 parts-per-trillion (ppt) level. PCBs at the 0.43 ppb level can weaken the backbones of trout.

We have known for some time now that water that we call potable may actually contain many trace and ultratrace contaminants, as exemplified by an analysis of Ottawa drinking water.

GC/MS Analysis of Ottawa Tap Water

Compound	Conc. Detected in Water (ppt)
α-BHC	17
Lindane	1.3
Aldrin	0.70
Chlordane	0.0053
Dibutyl phthalate	29

Odors in Drinking Water

At times, municipal water may have an odor. Frequently, that odor relates to the chlorination of water. (Some people can smell certain compounds at concentrations of 10 parts per trillion or less.)

A musty odor in drinking water may be the result of by-products of blue-green algae.

Chemical Species in River Water

Base Element	Species	Freshwater Conc. (mg/L)	Instrument(s) Used
Chromium	$Cr^{6+,3+}$	6.7	AAS
Arsenic	$HAsO_4^{2-}$	7.9	AAS, ICP-OES
Selenium	SeO_3^{2-}	8.6	AAS
Barium	Ba^{2+}	6.0	AAS, ICP-OES
Mercury	$Hg(OH)_2$	8.0	AAS
Lead	Pb^{2+}, Pb^{+}	7.7	AAS, ICP-OES

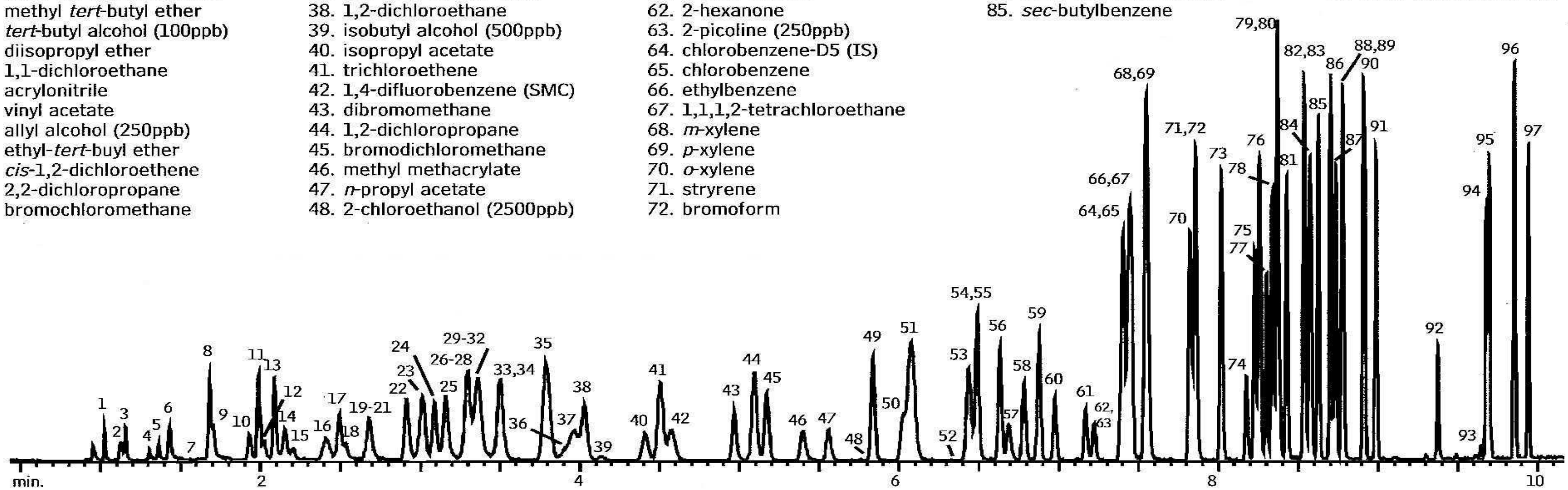
Volatile Contaminants (VOCs)

According to the EPA, the following VOCs are most likely to be found in drinking water:

- Benzene
- Carbon tetrachloride
- Chlorobenzene
- *o*-Dichlorobenzene
- *p*-Dichlorobenzene
- 1,1-Dichloroethylene
- *cis*-1,1-Dichloro-ethylene
- *trans*-1,1-Dichloro-ethylene
- Dichloromethane
- 1,2-Dichloroethane
- 1,2-Dichloropropane
- Ethylbenzene
- Styrene
- Tetrachloroethylene
- 1,2,4-Trichlorobenzene
- 1,1,1,-Trichloroethane
  1,1,2-Trichloroethane
  Trichloroethylene
  Toluene
- Vinyl chloride
- Xylene

VOCs on Rtx-VMS Column

1. dichlorodifluoromethane
2. chloromethane
3. vinyl chloride
4. bromomethane
5. chloroethane
6. trichlorofluoromethane
7. ethanol (2500ppb)
8. 1,1-dichloroethene
9. carbon disulfide (40ppb)
10. allyl chloride
11. methylene chloride
12. acetone
13. *trans*-1,2-dichloroethene
14. methyl *tert*-butyl ether
15. *tert*-butyl alcohol (100ppb)
16. diisopropyl ether
17. 1,1-dichloroethane
18. acrylonitrile
19. vinyl acetate
20. allyl alcohol (250ppb)
21. ethyl-*tert*-buyl ether
22. *cis*-1,2-dichloroethene
23. 2,2-dichloropropane
24. bromochloromethane
25. chloroform
26. ethyl acetate
27. carbon tetrachloride
28. methyl acrylate
29. propargyl alcohol (500ppb)
30. dibromofluoromethane (SMC)
31. tetrahydrofuran
32. 1,1,1-trichloroethane
33. 2-butanone
34. 1,1-dichloropropene
35. benzene
36. pentafluorobenzene (IS)
37. *tert*-amyl-methyl ether
38. 1,2-dichloroethane
39. isobutyl alcohol (500ppb)
40. isopropyl acetate
41. trichloroethene
42. 1,4-difluorobenzene (SMC)
43. dibromomethane
44. 1,2-dichloropropane
45. bromodichloromethane
46. methyl methacrylate
47. *n*-propyl acetate
48. 2-chloroethanol (2500ppb)
49. *cis*-1,3-dichloropropene
50. toluene-d8 (SMC)
51. toluene
52. pyridine (250ppb)
53. tetrachloroethene
54. 4-methyl-2-pentanone
55. *trans*-1,3-dichloropropene
56. 1,1,2-trichloroethane
57. ethyl methacrylate
58. dibromochloromethane
59. 1,3-dichloropropane
60. 1,2-dibromoethane
61. *n*-butyl acetate
62. 2-hexanone
63. 2-picoline (250ppb)
64. chlorobenzene-D5 (IS)
65. chlorobenzene
66. ethylbenzene
67. 1,1,1,2-tetrachloroethane
68. *m*-xylene
69. *p*-xylene
70. *o*-xylene
71. stryrene
72. bromoform
73. isopropylbenzene
74. 4-bromo-1-fluorobenzene (SMC)
75. bromobenzene
76. *n*-propylbenzene
77. 1,1,2,2-tetrachloroethane
78. 2-chlorotoluene
79. 1,3,5-trimethylbenzene
80. 1,2,3-trichloropropane
81. 4-chlorotoluene
82. *tert*-butylbenzene
83. pentachloroethane
84. 1,2,4-trimethylbenzene
85. *sec*-butylbenzene
86. *p*-isopropyltoluene
87. 1,3-dichlorobenzene
88. 1,4-dichlorobenzene-d4
89. 1,4-dichlorobenzene
90. *n*-butylbenzene
91. 1,2-dichlorobenzene
92. 1,2-dibromo-3-chlor propane
93. nitrobenzene (250ppb)
94. hexachlorobutadiene
95. 1,2,4-trichlorobenzene
96. naphthalene
97. 1,2,3-trichlorobenzene



Column: Rtx®-VMS, 20m, 0.18 mm ID, 1.00µm (cat.# 49914)
Conc.: 10ppb in 5mL of RO water unless otherwise noted; ketones at 2.5X
Concentrator: Tekmar LSC-3100 Purge and Trap
Trap: Vocarb 3000 (type K)
Purge: 11 min. @ 40mL/min. (ambient temperature)
Dry purge: 1 min. @ 40mL/min.
Desorb preheat: 245°C
Desorb: 250°C for 2 min., flow 40mL/min.
Bake: 260°C for 8 min.

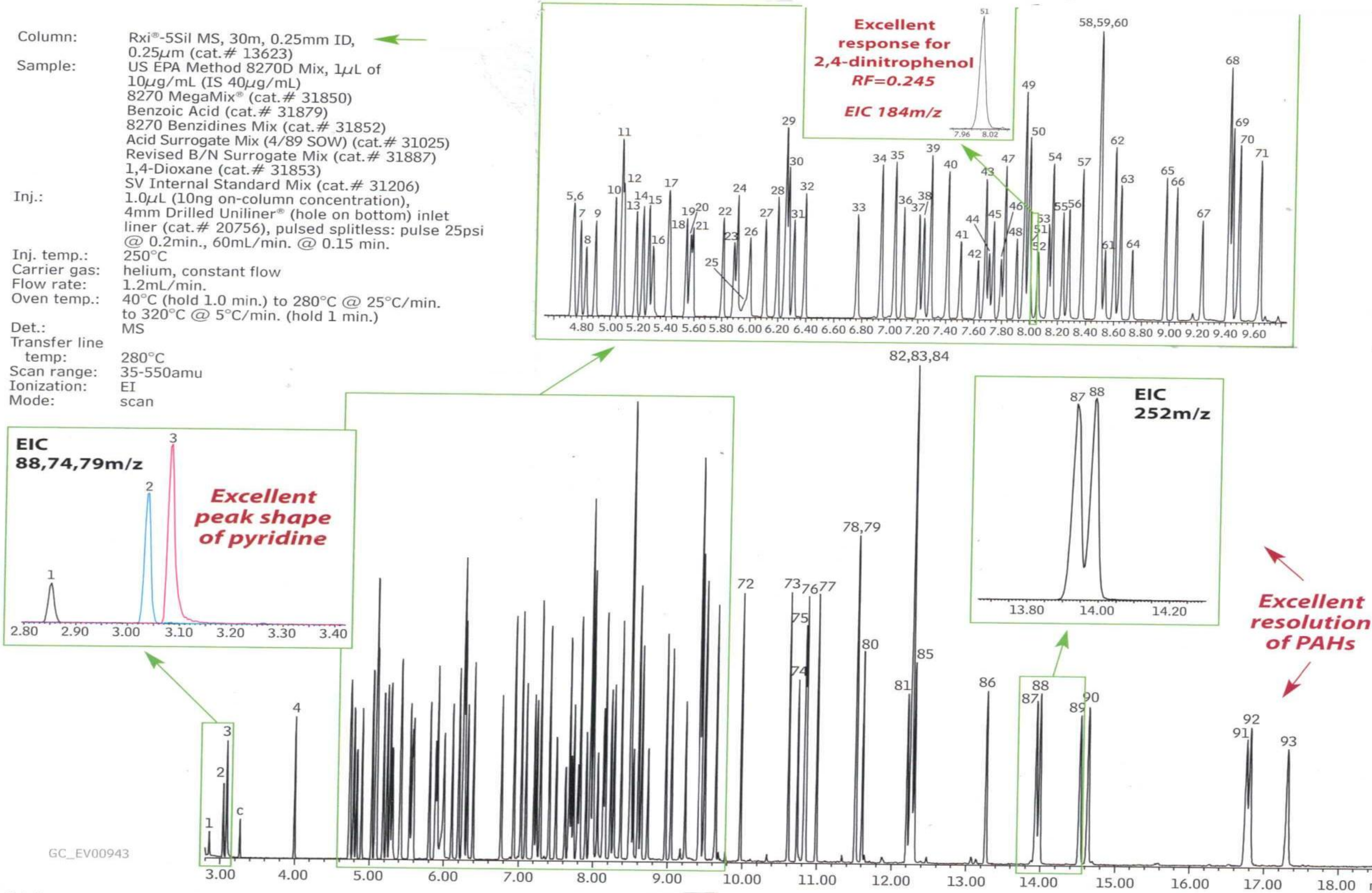
Interface: 0.53mm ID Silcosteel® tubing transfer line 1:40 split at injection port. 1mm ID liner.
Oven temp.: 50°C (hold 4 min.) to 100°C @ 18°C/min. (hold 0 min.) to 230°C @ 40°C/min. (hold 3 min.)
Carrier gas: helium @ ~1.0mL/min. constant flow Adjust dichlorodifluoromethane to a retention time of 1.03 min. @ 50°C.
Detector: Agilent 5973 MSD
Scan range: 35-300amu

Semivolatile Compounds (SOCs)

A number of SOCs can be detected in our water supplies. They are ubiquitous because of anthropogenic activities and they have the potential to accumulate in polar and mountainous regions. They can undergo atmospheric long-range transport via large-scale winds. The EPA has classified certain SOCs as persistent, bioaccumulative, and toxic chemicals.

The next slide shows GC separation of SOCs on an Rxi 5SilMs column.

Column: Rxi®-5Sil MS, 30m, 0.25mm ID, 0.25µm (cat.# 13623)
Sample: US EPA Method 8270D Mix, 1µL of 10µg/mL (IS 40µg/mL)
8270 MegaMix® (cat.# 31850)
Benzoic Acid (cat.# 31879)
8270 Benzidines Mix (cat.# 31852)
Acid Surrogate Mix (4/89 SOW) (cat.# 31025)
Revised B/N Surrogate Mix (cat.# 31887)
1,4-Dioxane (cat.# 31853)
SV Internal Standard Mix (cat.# 31206)
Inj.: 1.0µL (10ng on-column concentration), 4mm Drilled Uniliner® (hole on bottom) inlet liner (cat.# 20756), pulsed splitless: pulse 25psi @ 0.2min., 60mL/min. @ 0.15 min.
Inj. temp.: 250°C
Carrier gas: helium, constant flow
Flow rate: 1.2mL/min.
Oven temp.: 40°C (hold 1.0 min.) to 280°C @ 25°C/min. to 320°C @ 5°C/min. (hold 1 min.)
Det.: MS
Transfer line temp.: 280°C
Scan range: 35-550amu
Ionization: EI
Mode: scan



1. 1,4-dioxane
2. *n*-nitrosodimethylamine
3. pyridine
c. toluene
4. 2-fluorophenol (SS)
5. phenol-d6 (SS)
6. phenol
7. aniline
8. bis(2-chloroethyl) ether
9. 2-chlorophenol
10. 1,3-dichlorobenzene
11. 1,4-dichlorobenzene-d4 (IS)
12. 1,4-dichlorobenzene
13. benzyl alcohol
14. 1,2-dichlorobenzene
15. 2-methylphenol
16. bis(2-chloroisopropyl) ether
17. 4-methylphenol/3-methylphenol
18. *n*-nitroso-di-*n*-propylamine
19. hexachloroethane
20. nitrobenzene-d5 (SS)
21. nitrobenzene
22. isophorone
23. 2-nitrophenol
24. 2,4-dimethylphenol
25. benzoic acid
26. bis(2-chloroethoxy)methane
27. 2,4-dichlorophenol
28. 1,2,4-trichlorobenzene
29. naphthalene-d8 (IS)
30. naphthalene
31. 4-chloroaniline
32. hexachlorobutadiene
33. 4-chloro-3-methylphenol
34. 2-methylnaphthalene
35. 1-methylnaphthalene
36. hexachlorocyclopentadiene
37. 2,4,6-trichlorophenol
38. 2,4,5-trichlorophenol
39. 2-fluorobiphenyl (SS)
40. 2-chloronaphthalene
41. 2-nitroaniline
42. 1,4-dinitrobenzene
43. dimethyl phthalate
44. 1,3-dinitrobenzene
45. 2,6-dinitrotoluene
46. 1,2-dinitrobenzene
47. acenaphthylene
48. 3-nitroaniline
49. acenaphthene-d10 (IS)
50. acenaphthene
51. 2,4-dinitrophenol
52. 4-nitrophenol
53. 2,4-dinitrotoluene
54. dibenzofuran
55. 2,3,5,6-tetrachlorophenol
56. 2,3,4,6-tetrachlorophenol
57. diethyl phthalate
58. 4-chlorophenyl phenyl ether
59. fluorene
60. 4-nitroanaline
61. 4,6-dinitro-2-methylphenol
62. *n*-nitrosodiphenylamine (as diphenylamine)
63. 1,2-diphenylhydrazine (as azobenzene)
64. 2,4,6-tribromophenol (SS)
65. 4-bromophenyl phenyl ether
66. hexachlorobenzene
67. pentachlorophenol
68. phenanthrene-d10 (IS)
69. phenanthrene
70. anthracene
71. carbazole
72. di-*n*-butyl phthalate
73. fluoranthene
74. benzidine
75. pyrene-d10 (SS)
76. pyrene
77. *p*-terphenyl-d14 (SS)
78. 3,3'-dimethylbenzidine
79. butyl benzyl phthalate
80. bis(2-ethylhexyl) adipate
81. 3,3'-dichlorobenzidine
82. benzo(a)anthracene
83. bis(2-ethylhexyl) phthalate
84. chrysene-d12 (IS)
85. chrysene
86. di-*n*-octyl phthalate
87. benzo(b)fluoranthene
88. benzo(k)fluoranthene
89. benzo(a)pyrene
90. perylene-d12 (IS)
91. dibenzo(a,h)anthracene
92. indeno(1,2,3-cd)pyrene
93. benzo(ghi)perylene

c = contaminant

Disinfectants

- To protect public health, disinfectants are used to reduce the number of pathogenic microorganisms in water. Chemical disinfection has been an integral part of drinking water–treatment processes in the United States, since the early 1900s.
- Seventy years later, formation of chloroform ($CHCl_3$) and other volatile halogen-substituted organics in drinking water was identified.
- Alternate disinfectants such as ozone and chlorine dioxide form by-products of their own.
- The EPA regulates disinfection by-products and the permissible levels of disinfectants in drinking water.

Herbicides and Their Degradation Products

Utilization of herbicides is important to agriculture production. History shows the importance of linking water and food to the population’s well-being.

Various studies have been conducted on water samples from around the world to determine herbicide use and concentrations.

To assure better water quality, regulations have been issued related to production practices.

Pharmaceuticals in Sewage Effluents

- A new environmental problem has arisen from the increased use of pharmaceuticals worldwide.
- Over 3,000 chemical substances are used in human and veterinary medicines.
- In the 1970s, the first report of pharmaceuticals in wastewater effluents in surface waters was issued in the U.S. [e.g., Diclofenac has adverse effects on both rainbow trout and vultures.]
- Wastewater treatment plants are major contributors of pharmaceuticals in the water supply.

Endocrine Disruptors

- The problem of endocrine disruptors is gaining greater significance.
- This problem received much attention when the impact of the birth-control pill (ethynyl estradiol) on fish was established.
- Recently, it was reported that liquid formula is the biggest culprit in exposing infants to bisphenol A, a potential hormone-disrupting chemical.

Radionuclides in Surface and Groundwater

- Radioactive compounds pose a double threat from both toxicity and damaging radiation.
- Mining, production, use, and disposal of these compounds provide potential pathways for their release into the environment.
- [It is important to study sources, uses, and regulation of radioactive compounds, including biogeochemical processes that control mobility in the environment.]

Contamination by Mother Nature

Contaminants may also come from Mother Nature, even where the soil has not been influenced by pollutants from human beings. Contaminants from nature include manganese, radionuclides, arsenic, and a host of other chemicals. Let's take a close look at arsenic; it is a major problem.

Worldwide Appeal

I made a worldwide appeal in *C&E News* of June 9, 2003, wherein chemists and chemical engineers were asked to offer suggestions to help rectify the problem of arsenic contamination of groundwater.

My goal was to involve chemists worldwide. The International Activities Committee of the American Chemical Society agreed to support the project. We also had support from IUPAC.

Chemists and chemical engineers from many countries offered to participate in the project to help purify water that is contaminated by arsenic.

IUPAC/ACS Project

This problem is most significant in Bangladesh. We worked with IAC and obtained a small grant from IUPAC that was 50% matched by ACS for the fact-finding trip to Bangladesh and for making a report at CHEMRAWN XV on Chemistry for Water, June 21-23, 2004.

[Dhaka Workshop photos by H. Garelick]

Arsenic Contamination of Water: A Worldwide Problem*

Inorganic arsenic above 10-ppb level can increase the risk of lung, skin, bladder, liver, kidney, and prostate cancers. To address this problem, I chaired a workshop in Dhaka (2005); symposium in Atlanta (2006) & lectured at a UNESCO Meeting, Irvine, CA, 2008; trip to India, Thailand and Cambodia (2009). The workshop in India (2011) will be discussed later.

* S. Ahuja, *Handbook of Water Purity and Quality*, Elsevier, ‘09

Arsenic contamination of groundwater has been reported in a large number of countries throughout the world, including the U.S.

Millions of wells installed in Bangladesh in the 1970s to solve the problem of microbial contamination were not tested for natural contamination by arsenic.

Prolonged drinking of arsenic-contaminated water can lead to arsenicosis that results in a slow and painful death. In Bangladesh, one hundred million people are at risk at levels of 10 ppb or greater. More than 200 million people may be affected by this problem worldwide.

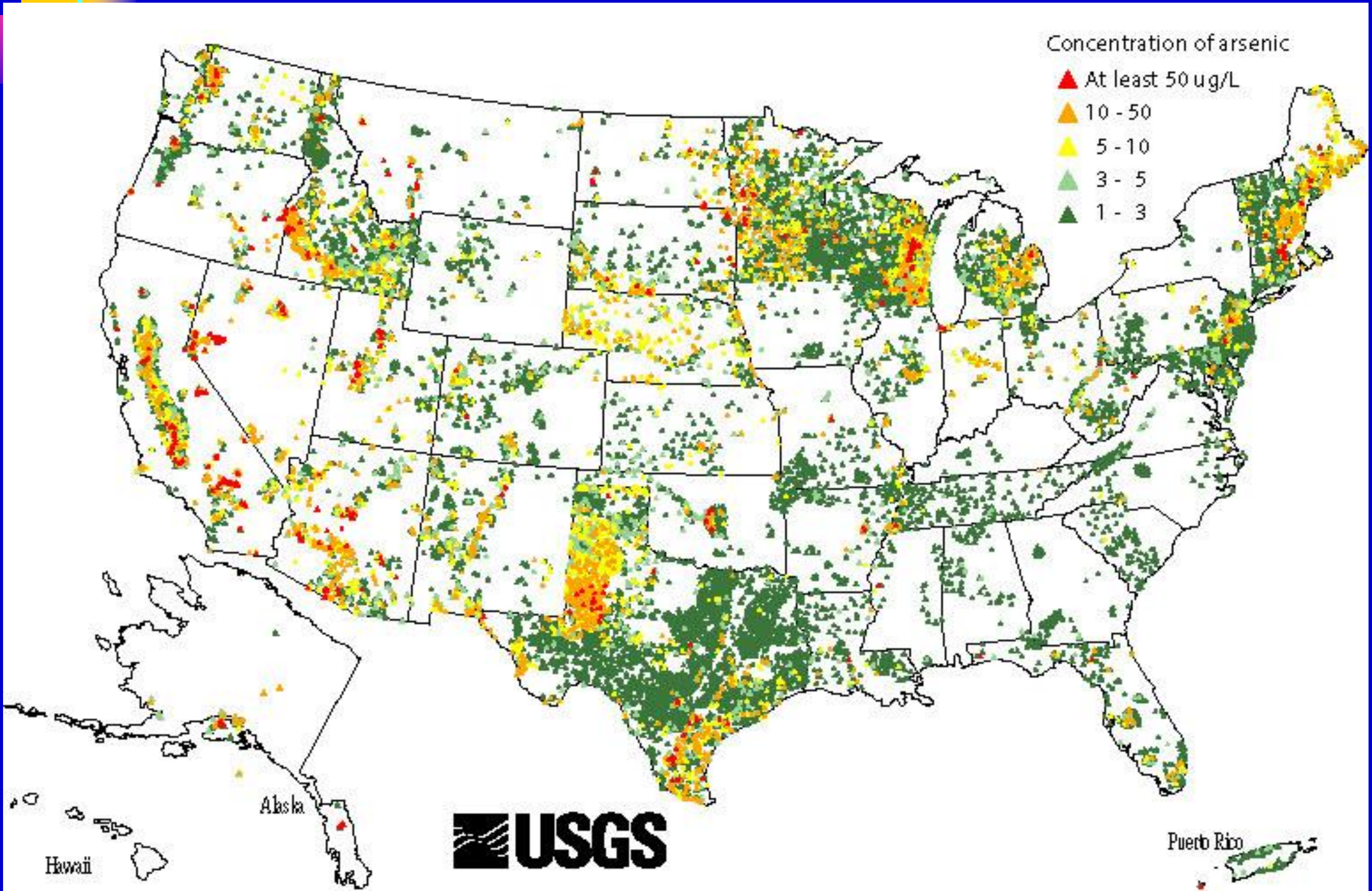
Arsenic Contamination in the United States

- Large areas in the west, Midwest, and north-east U.S. have high arsenic concentrations. In my home state (NC), arsenic has been found in 960 wells statewide since Jan. 2000.
- According to the Wilmington *Star News* of August 18, 2003, "Half the state's [NC] population depends on groundwater."
- Ken Rudo (NC state toxicologist) noted: "for new wells, arsenic test is pretty much <u>not done</u>."

Commercial Uses of Arsenic Compounds in the United States

- Pesticides: monosodium methyl arsonate, disodium methyl arsonate
- Insecticide: dimethylarsenic acid
- Aquatic weed control and sheep and cattle dip: sodium arsenite
- Defoliating cotton bolls: arsenic acid, arsenic pentoxide
- Some pharmaceuticals and decolorizing glass: arsenic trioxide

Arsenic Concentration in Groundwater in the United States

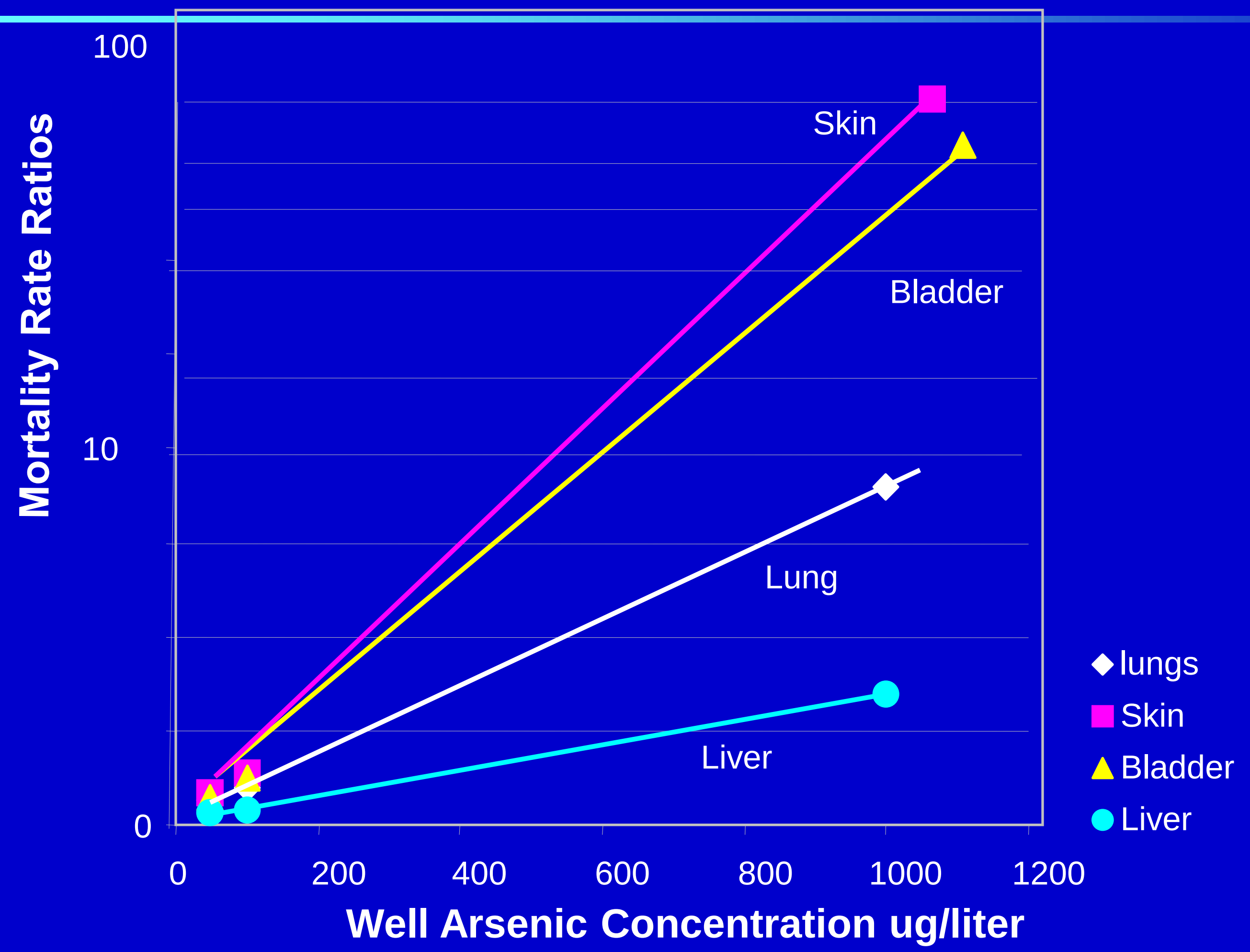


Hands and feet of arsenicosis patient (Photo: J. Malin)


বাংলাদেশ পরমাণু শক্তি


MUM

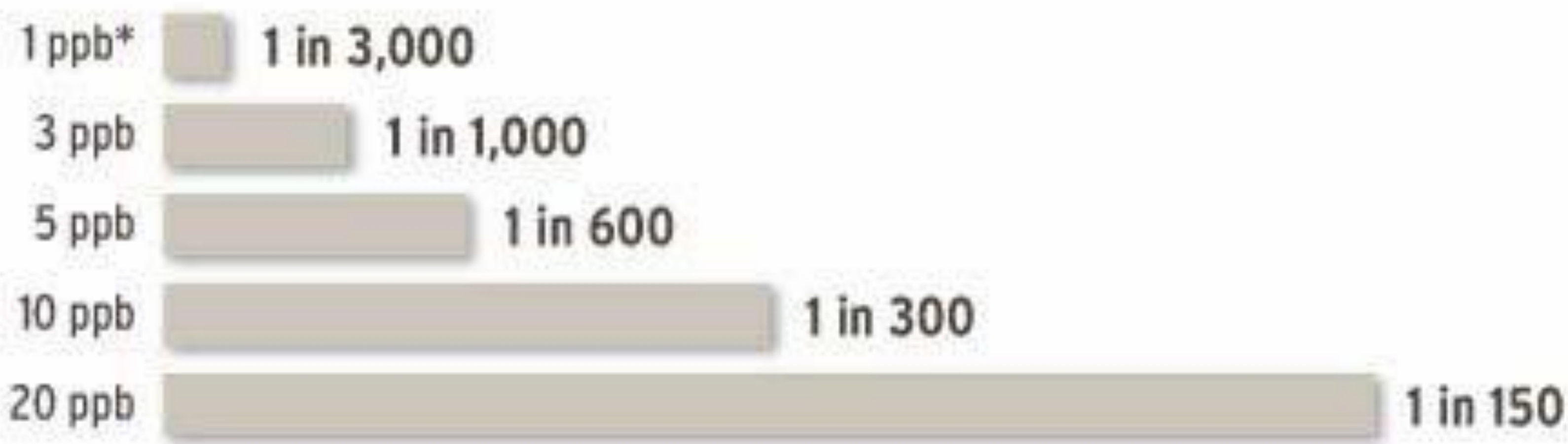
Cancer Mortality Rate Ratios for Males in Taiwan



Risk of Cancer with Arsenic-contaminated Water

ARSENIC IN DRINKING WATER RAISES RISK OF CANCER

Over long periods of time, a small amount of arsenic can cause harm. This chart shows the estimated odds of getting bladder or lung cancer for a person who drinks about a quart of arsenic-laced water a day for 70 years. For women, the chances are slightly lower; for men, slightly higher.

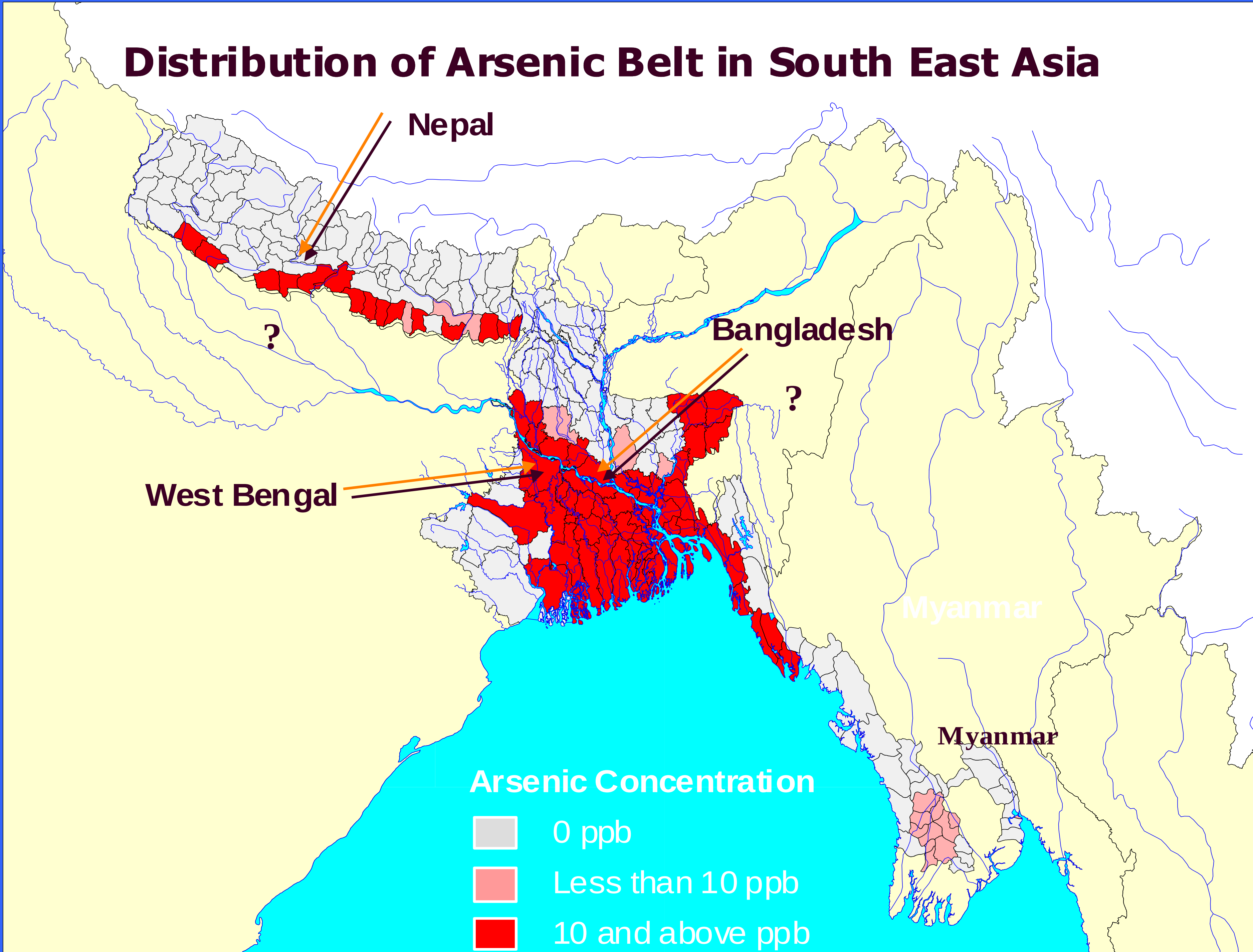


*parts per billion

Source: National Research Council's 2001 study for the U.S. Environmental Protection Agency

The News & Observer

Distribution of Arsenic Belt in South East Asia



Impact of Arsenic in Irrigation Water on the Food Chain*

There is a great potential for the transfer of ground-water arsenic to crops. Green leafy vegetables act as arsenic accumulators, with *arum* (kochu), gourd leaf, *Amaranthus, Ipomea* (kalmi) topping the list.

Speciation of Bangladeshi rice shows the presence of As(III), DMAV, and As(V); greater than 80% is in the inorganic form. More than 85% of the arsenic in rice is bioavailable.

*Chapter 2 in S. Ahuja, *Arsenic Contamination of Groundwater: Mechanism, Analysis, and Remediation*, Wiley, 2008.

Arsenic Source in Bangladesh and India

In Bangladesh and India (West Bengal), the aquifer sediments are derived from weathered materials from the Himalayas. Arsenic typically occurs at concentrations of 2 ppm–100 ppm in these sediments, much of it is sorbed onto a variety of mineralogical hosts including hydrated ferric oxides, phyllosilicates, and sulfides.

* S. Ahuja, *Arsenic Contamination of Groundwater: Mechanism, Analysis, and Remediation*, Wiley, 2008.

Weathering of Arsenopyrite

Important factors that control the oxidation/ reduction of arsenopyrite are moisture, pH, temperature, solubility, redox characteristics of the species, and its reactivity with CO_2/H_2O.

$4\ FeAsS + 13\ O_2 + 6\ H_2O$ ⌦

$4\ SO_4^{-2} + 4\ AsO_4^{-3} + 4\ Fe^{+3} + 12H$

R.R. Brooks et al, *Environ. Pollut*. 4B:109, 1982.

Anaerobic, Metal-reducing Bacteria

These bacteria have been shown to play a key role in releasing arsenic from their host sediments into groundwater (*Nature,* Vol. 430, 68, 2004). Naturally occurring organisms (that have yet to be identified) in the sediments reduce Fe(III) and As(V) to As(III), which is more toxic and more mobile.

Analytical Methods

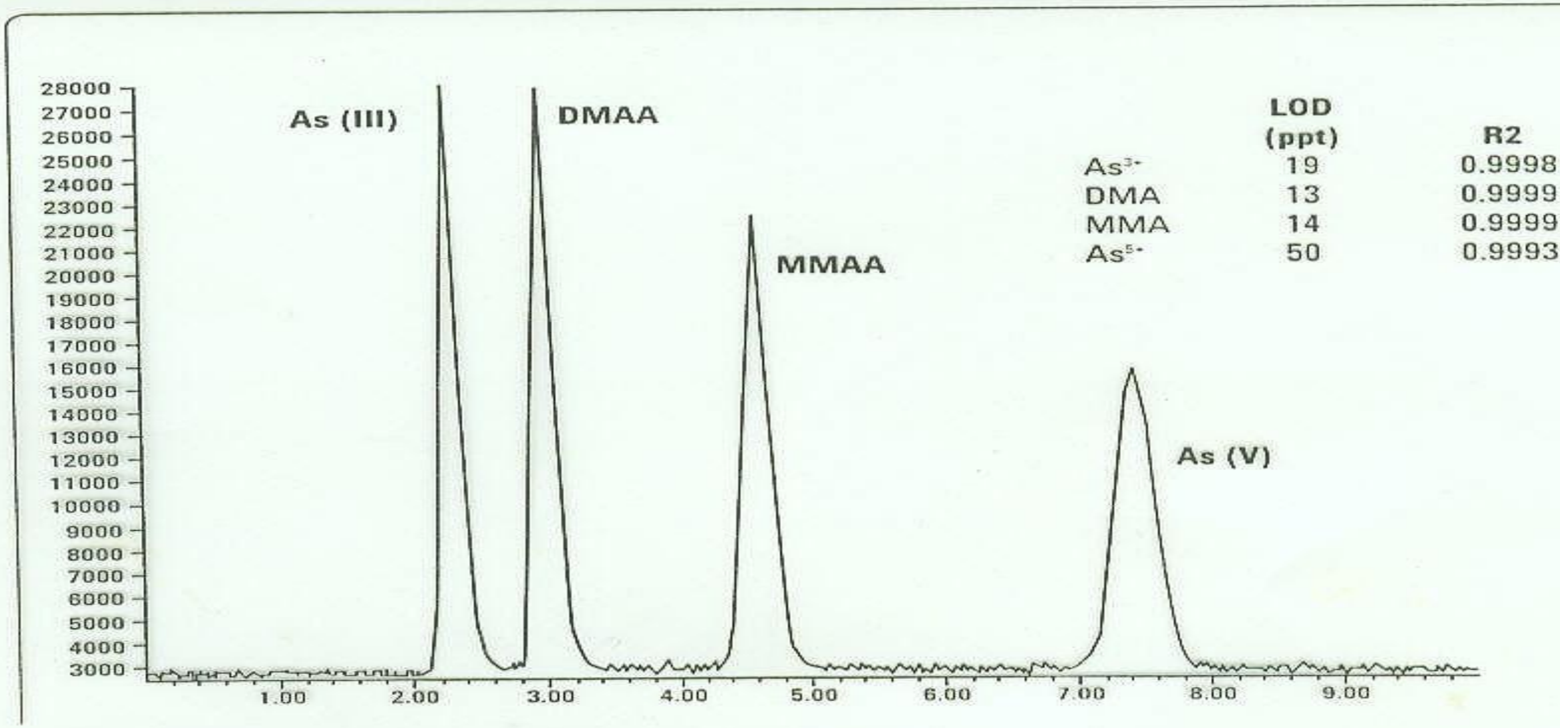
Arsenic can be analyzed in water at 10 ppb or even lower levels (See my *Ultratrace Analysis* book published by Wiley in 1986).

- Flame atomic absorption spectrometry
- Graphite furnace atomic absorption spectrometry
- Inductively coupled plasma-mass spectrometry
- Atomic fluorescence spectrometry
- Neutron activation analysis
- Differential pulse polarography

Speciation and Detection Limits

Speciation of arsenic requires separations based on solvent extraction, chromatography, and selective hydride generation. Detection limits for arsenic down to 0.0006 µg/L can be obtained with inductively coupled plasma mass spectrometry (ICP-MS). HPLC-ICP-MS is currently the best technique available for determination of inorganic and organic species of arsenic. The main problem is the high cost.

Speciation with LC-ICP-MS



Data courtesy of Joseph A. Caruso et al., University of Cincinnati

Field Kits

- Vendors: Merck, Hach, GPL, Wagtech , and Nipsom
- An assessment of the results at the 10-μg/L threshold reveals that large numbers of incorrect results are produced; most of them are false positives.*
- Better kits are needed.

*Chapter 8 in S. Ahuja, *Arsenic Contamination of Ground-water: Mechanism, Analysis, and Remediation*, Wiley, 2008.

Test kit demo. in Bangkok, Thailand.

Remediation with Separation and Chromatographic Methods

- Coagulation with ferric chloride or alum
- Sorption on activated alumina
- Sorption on iron oxide–coated sand particles
- Granulated iron oxide particles
- Polymeric ligand exchange
- Nanomagnetite particles
- Sand with zero valent iron
- Hybrid cation exchange resins
- Hybrid anion exchange resins
- Polymeric anion exchange
- Reverse osmosis

Status in Bangladesh

The Bangladesh government has tried to meet the needs of small families. As a result, they temporarily approved four commercially useful technologies to remove arsenic from contaminated water, on February 25, 2004, :

- ALCAN: Activated alumina
- REED-F: Ion exchange with Ce
- SIDKO: Synthetic iron oxide
- SONO: Composite iron matrix

Groundwater Arsenic-removal Technologies Based on Sorbents

Various options presented by inventors to win the million-dollar Grainger Prize for remediation of arsenic contamination were reviewed by me as an advisor to the National Academy of Engineering.

The two systems that won first and second prize will be described briefly in that order.

Small-scale Household Water Filtration Systems

These systems are based on solid sorbents to obtain potable water. Special emphasis is placed on iron-based filters because they appear to be chemically most suitable for arsenic removal, are easy to develop, and are environmentally benign. Arsenic removal mechanisms based on surface complexation reactions, sorption dynamics, and kinetics are detailed in my book.*

*Chapter12 in S. Ahuja, *Arsenic Contamination of Groundwater: Mechanism, Analysis, and Remediation*, Wiley, 2008.

The SONO unit utilizes Bangladeshi resources, and is one of the most economical techniques.

SONO Filters*: 2001 to April 2010

- 225,000 SONO™ filters installed in Bangladesh, Nepal (1000), and India (100).
- 60–180 liters per day consumed for 2–8 years.
- >750,000 direct beneficiaries.
- >1 billion liters of clean water consumed.
- Cost: <0.0013 taka/liter. 50 takas = $1.

*Chapter13 in S. Ahuja, *Arsenic Contamination of Groundwater ,* Wiley, 2008.

A Community-based System*

- Utilizes activated alumina as a regenerable adsorbent media.
- Serves about 200 households and requires no chemical addition, pH adjustment, or electricity.
- Since 1997, over 150 community-level arsenic removal units have been installed.
- Influent arsenic concentrations ranging from 100 µg/L to 500 µg/L, containing both As(III) and As(V) species, can be purified.
- Exhausted media is replaced and the spent media is taken to a central regeneration facility.

*Chapter13 in S. Ahuja, *Arsenic Contamination of Groundwater ,* Wiley, 2008

Wellhead arsenic removal unit uses activated alumina adsorption column and a coarse sand filter.

Sludge

- An arsenic-laden spent regenerant form is converted to a small volume of sludge that is contained in an aerated coarse sand filter.
- Manufacturer claims the process is sustainable because the treatment residues are not toxic under normal environmental conditions.
- It is also economically sustainable, as the villagers collectively maintain the units by paying a monthly water tariff of about $0.40.

Sanitation Problems Worldwide

- 2.6 billion people have no access to basic sanitation services, and more than 1 million children die of diarrheal disease each year.
- Poor economy in the underdeveloped countries does not permit the best sanitary practices. Unsanitary practices can lead to contamination of both surface and groundwater. Educating the public about this problem would be very helpful.
- Economic assistance from the developed countries would also be very beneficial.

2011 Workshop on Sustainability and Water Quality, New Delhi

- About 10% of the population in India does not have safe drinking water.
- Arsenic and fluoride are big problems.
- West Bengal has a significant problem of arsenic contamination of groundwater.
- Rajasthan has major fluoride problems.
- Ganges and Yamuna, the two holy rivers, are now highly polluted.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Fluoride Removal Plant

We toured a fluoride removal plant near Jaipur, India, that has benefitted the local people immensely. A large number of them came to express their thanks for the plant and to show how their health has improved after the installation of the plant.

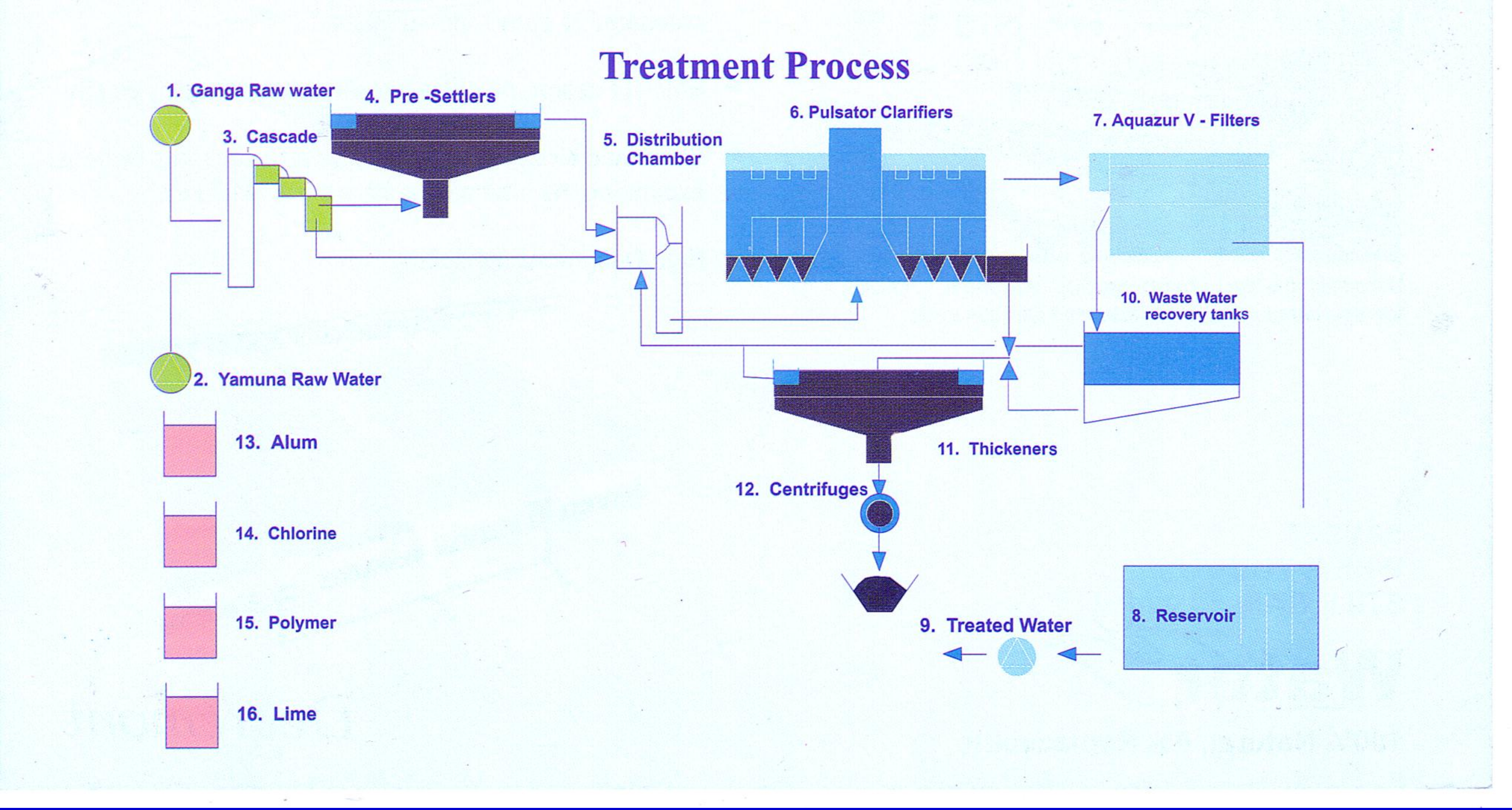
Yamuna

- According to the Central Pollution Control Board (CPCB), the fecal content in the Yamuna River is so high that the river resembles a sewage drain. Two out of five New Delhi residents have pollution-related health problems.
- Based on CPCB's 10-month monitoring of the Yamuna at Nizamuddin, the water is unfit even for bathing or washing.

Yamuna (cont.)

- New Delhi, May 19, 2010 (ANI): The Cabinet Committee on Infrastructure approved the project for laying interceptor sewers along the three major drains in Delhi for abatement of pollution in the Yamuna.
- The sewers will be laid along the Shahdara, Najafgarh, and Supplementary drains.
- The project is expected to cost 13.6 billion rupees (50 Rs = US 1$).

Water Treatment Process Plant



Sonia Vihar
Water Treatment Plant

Total current demand for water	850 MGD
Total supply	670 MGD
Total supply with Sonia Vihar	810 MGD

Water from Yamuna or Ganges can be utilized.

More water treatment facilities and infrastructure are still needed to meet the needs of 15 million people in Delhi.

Recommendations

After consideration of Bangladesh National Policy for Arsenic Mitigation (2004) and inputs from participants of Paris CHEMRAWN conference (2004), Dhaka workshop (2005), ACS symposia in 2006*, UNESCO Conference (2009), and evaluations in India, Thailand, and Cambodia in 2007, 2009, and 2011, the following recommendations seem to be logical for Bangladesh and other Asian countries.

*S. Ahuja, et al. *Science*, 314, 1687, 2006.

Potential Solutions for Asia

1. Piped surface water should be an intermediate to long-term goal. This requires total commitment from local governments and funding agencies.
2. Other surface water options such as sand–water filters, rainwater harvesting, and dug wells should be utilized.
3. Deep tube wells (located, tested, and installed properly).
4. Arsenic-removal filtration systems can work on a small scale; however, their reliability initially or over a period of time remains an issue. Other contaminants in water, including microbial contamination, can affect their performance.
5. Education in water usage and good sanitary practices is essential.

Conclusions

1. Water pollution in our modern society is inevitable.
2. Our vigilance to monitor point and nonpoint source pollution must be significantly improved.
3. We should employ effective safety measures that can prevent further pollution.
4. The needs of various countries are diverse.
5. Most important, we must use sustainable solutions to water quality problems.

Thank you