Arsenic in Drinking Water

Dr. John T. O'Connor, PE
H_2O'C Engineering

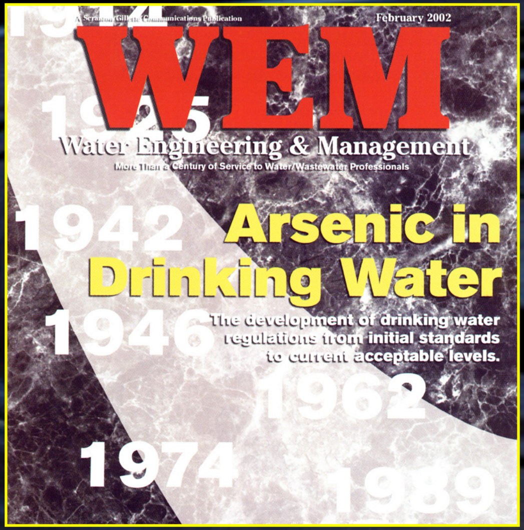
Arsenic in Drinking Water

Part 1. Development of Drinking Water Regulations

Part 2. Human Exposure and Health Effects

Part 3. Occurrence of Arsenic in U.S. Waters

Part 4. Arsenic Removal Methods



***Water Engineering and Management*,**

Volume 149, Numbers 2, 3, 5, 6

February, March, May, June 2002

Arsenic Species

Arsenous Acid, $H_3AsO_3 \longrightarrow 3H^+ + AsO_3^-$

Trivalent Arsenic, As (III) - arsenite ion

Arsenic Acid, $H_3AsO_4 \longrightarrow 3H^+ + AsO_4^-$

Pentavalent Arsenic, As (V) - arsenate

In the most severe case of Arsenic poisoning on record, tens of thousands of people in Bangladesh, India, have reported cancer and lesions all over their bodies, mainly on the hands and feet.
Photos courtesy of Richard Wilson and Harvard University (http://phys4.harvard.edu/~wilson/arsenic_project_pictures2.html)

Arsenic in Drinking Water

Part 2: Human Exposure and Health Effects

Arsenicosis

Arsenic Health Effects

Organ System	Problems (after Dhaka [Bangladesh] Medical College, 1998)
Skin	Symmetric hyperkeratosis of palms and soles, melanosis or depigmentation, Bowen's disease, basal cell carcinoma and squamous cell carcinoma.
Liver	Enlargement, jaundice, cirrhosis, non-cirrhotic portal hypertension
Nervous System	Peripheral neuropathy, hearing loss
Cardiovascular System	Acrocyanosis and Raynaud's Phenomenon
Hemopoietic System	Megalobastosis
Respiratory System	Lung cancer
Endocrine System	Diabetes mellitus and goiter

Linkage of Arsenic to Cancer

2001:

The Johns Hopkins University researchers report the exposure of cell lines to low levels of arsenic trioxide results in a decrease in the activity of the enzyme, telomerase. This enzyme maintains the length of chromosomal ends (telomeres).

The progressive decrease in the length of the telomeres after each healthy cell division could lead to the formation of cancerous cells.

Lung and Bladder Cancer Risk

Table 1: Theoretical Maximum Likelihood Estimates of Excess Lifetime Risk of Lung Cancer and Bladder Cancer for U.S. Populations Exposed at Various Concentrations of Arsenic in Drinking Water (Incidence per 10,000 people)

	Bladder Cancer		Lung Cancer	
Arsenic, µg/L	Females	Males	Females	Males
3	4	7	5	4
5	6	11	9	7
10	12	23	18	14
20	24	45	36	27

CCA-Treated Lumber

By 2004, USEPA will not allow chromated copper arsenate (CCA) products for specified residential (consumer) uses.

Arsenic MCL

1942: USPHS - 50 μg/l arsenic - cardiovascular damage

1975: USEPA begins reevaluating 50 μg/l MCL

1989: USEPA misses deadline for setting MCL

1996: Safe Drinking Water Act Amendments require USEPA to promulgate a revised MCL by January 1, 2001;

- missed deadline extended to June 22, 2001

H2O'C ENGINEERING

Arsenic MCL

1999: NRC - 50 μg/l needs lowering "as quickly as possible"

2000 (June): USEPA proposes a revised MCL of 5 μg/l; requests comments on 3, 10 and 20 μg/l

2000 (Dec): Clinton Administration approves 10 μg/l MCL

2001 (Mar): USEPA Admin. Christine Whitman withdraws MCL

H2O'C ENGINEERING

USEPA Proposes 5 µg/l MCL

2000:

USEPA considers 3 to 20 *µ*g/l and proposes 5 *µ*g/l MCL for arsenic

Mining, wood preserving and *drinking water industry groups* voice strong opposition on economic grounds

Western states strongly object, citing compliance costs for small communities

H2O'C ENGINEERING

USEPA MCL Set at 10 µg/l

2001 (January)

Clinton administration approves recommended 10 µg/l arsenic MCL beginning March, 2001;

- **same standard used by European Union**

WHO (International Drinking Water Standards, 1971) provisionally recommended 10 µg/l "because of the lack of suitable testing methods"

Based on health concerns alone, WHO arsenic standard "would be lower still"

New Administration Opposes MCL

2001 (February)

Congressional opposition voices outrage over hastily drawn, “midnight” regulation.

Mining and wood-preserving industries initiate lawsuit attacking USEPA’s “science”

Albuquerque, NM; El Paso, TX plus smaller utilities join industries suit.

Senator Pete Domenici (R-NM) introduces bill to void the arsenic standard

USEPA MCL Withdrawn

2001 (March)

New USEPA Administrator withdraws 10 *μ*g/l arsenic standard citing concern over costs

President Bush calls for decision based on "sound science"

Christine Todd Whitman initiates 'independent review' by a new, *select* NRC panel.

Arsenic health risk assessment due in August, 2002.

In Search of "Sound Science"

2001 (April)

USEPA reorganizes *National Drinking Water Advisory Committee*; asks panel to conduct a cost-benefit analysis

Senate bill introduced to amend SDWA to require water systems to notify customers if their water contains arsenic and at what level

H2O'C ENGINEERING

From the Frying Pan...

2001 (September)

NAS-NRC releases updated arsenic risk report:

risks of bladder and lung cancer from arsenic in drinking water were previously underestimated

increased evidence that arsenic causes high blood pressure and diabetes

panel estimates that 3 *μ*g/l of arsenic in drinking water would pose a 1 in 1,000 risk of bladder or lung cancer

Back to Square 10

2001 (October)

USEPA Administrator rescinds March decision; embraces 10 μg/l MCL

Potential for future MCL reduction to 3 μg/l

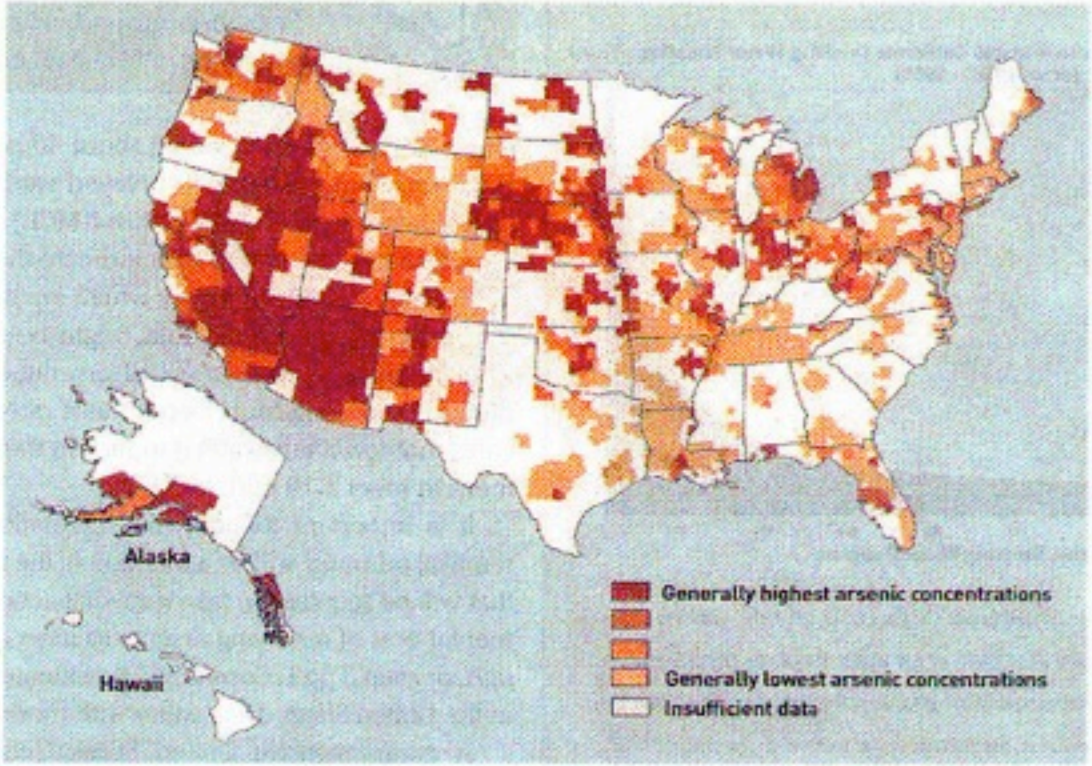
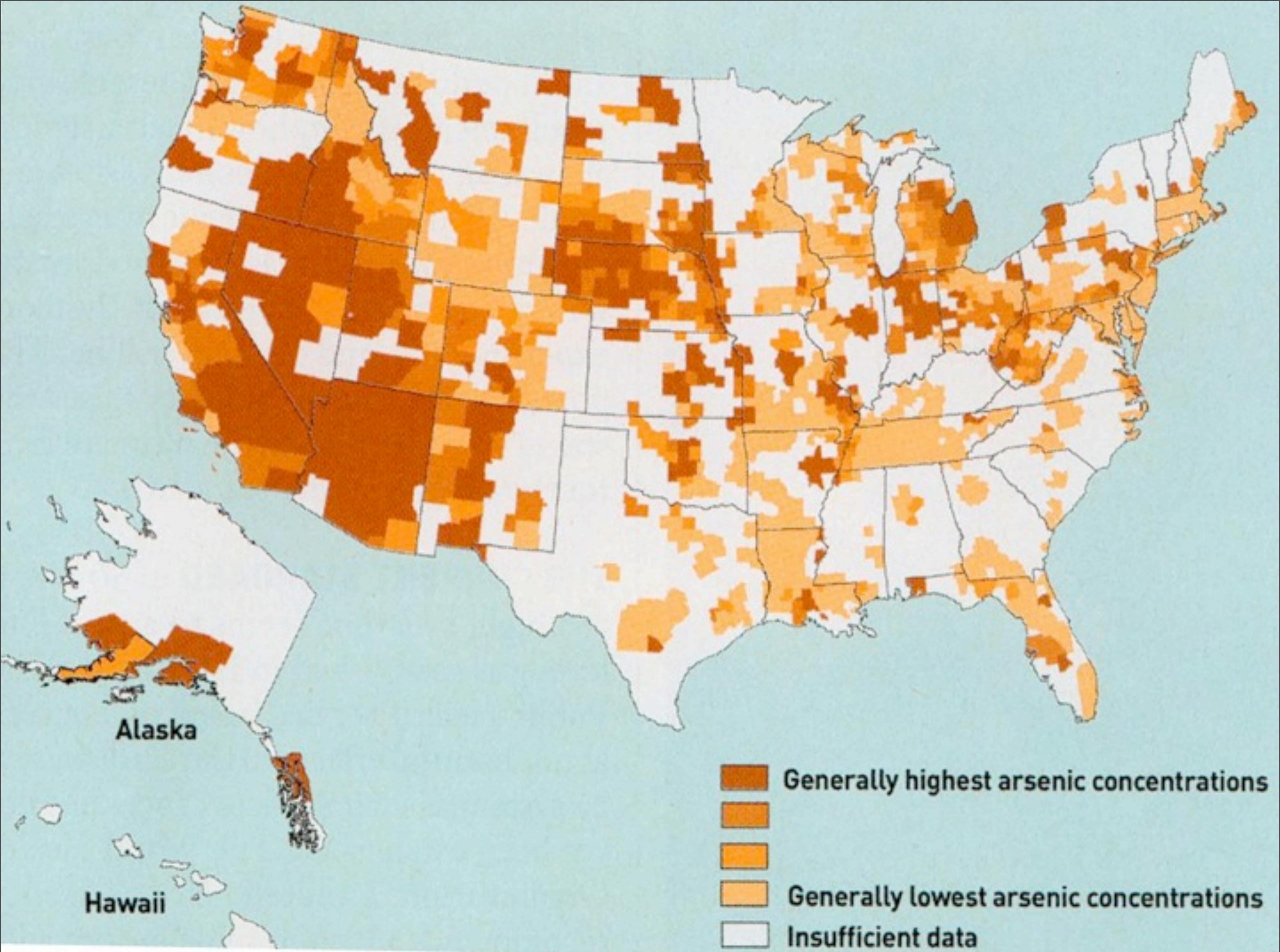


Image courtesy of United States Geological Survey

Arsenic in Drinking Water

Part 3: Occurrence of Arsenic in U.S. Waters


Alaska
Hawaii
Generally highest arsenic concentrations
Generally lowest arsenic concentrations
Insufficient data

Utilities Affected

5,125 groundwater systems < 10,000

75% already have treatment

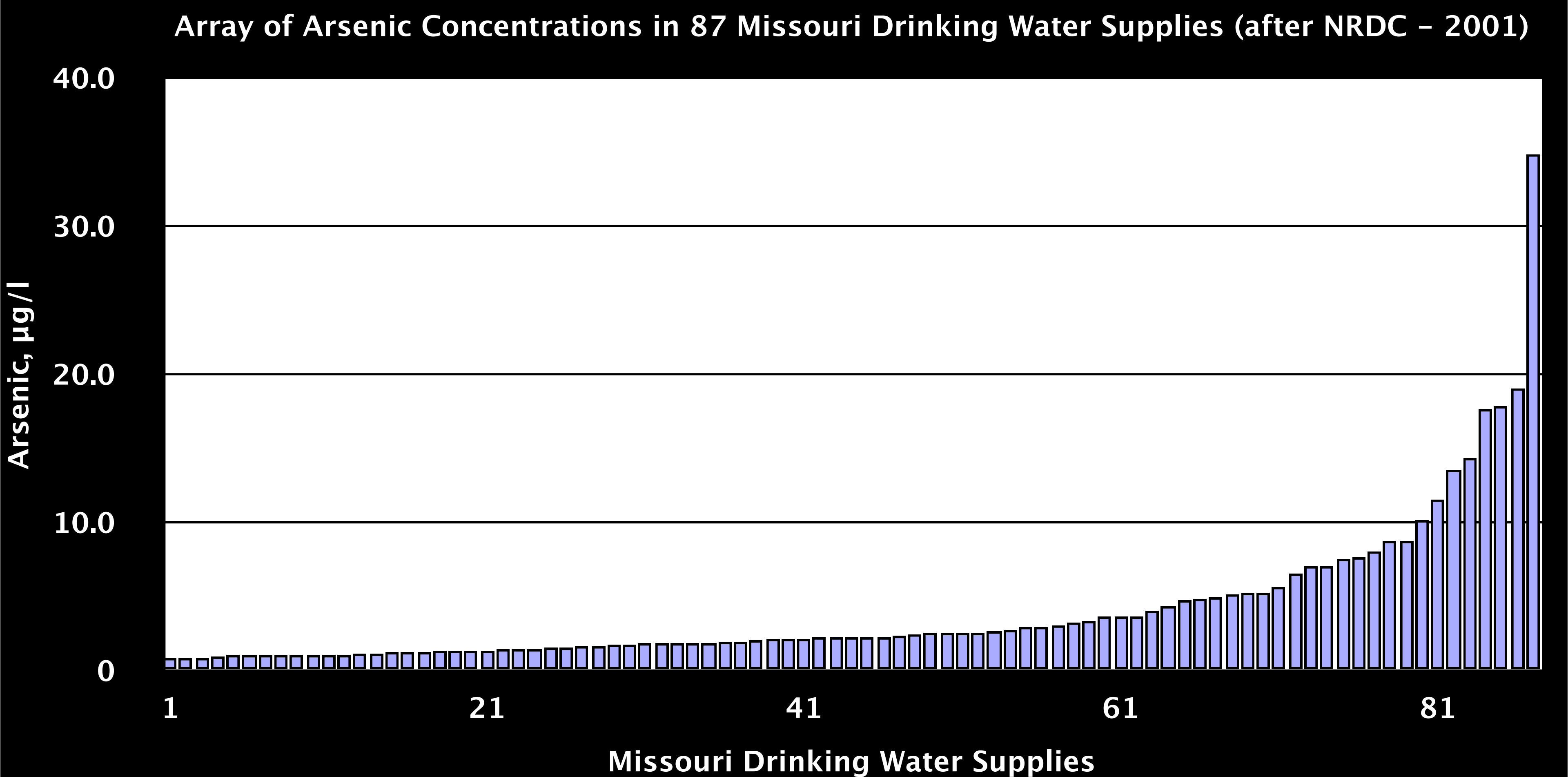
180 groundwater systems > 10,000

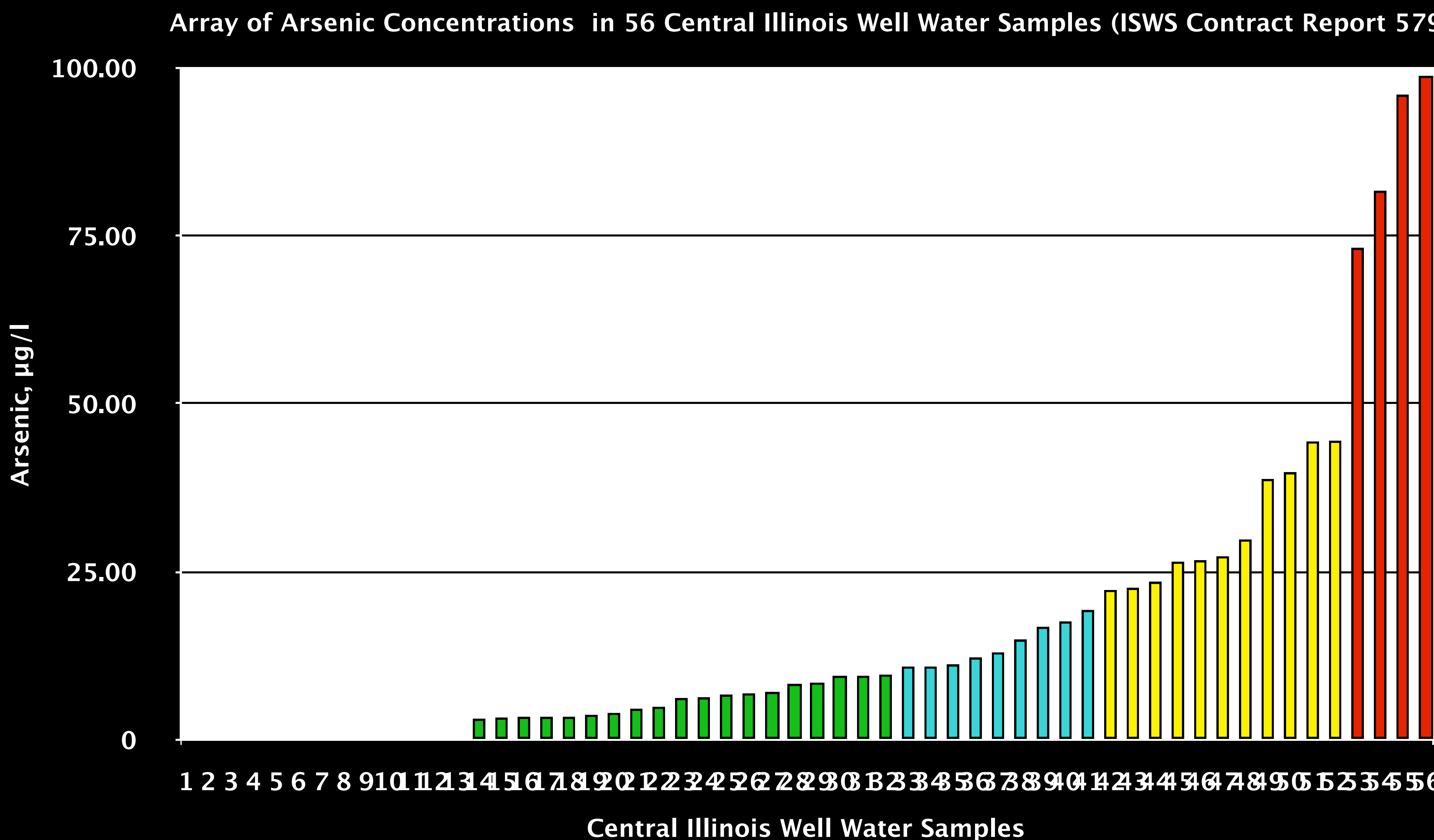
Primarily western states:

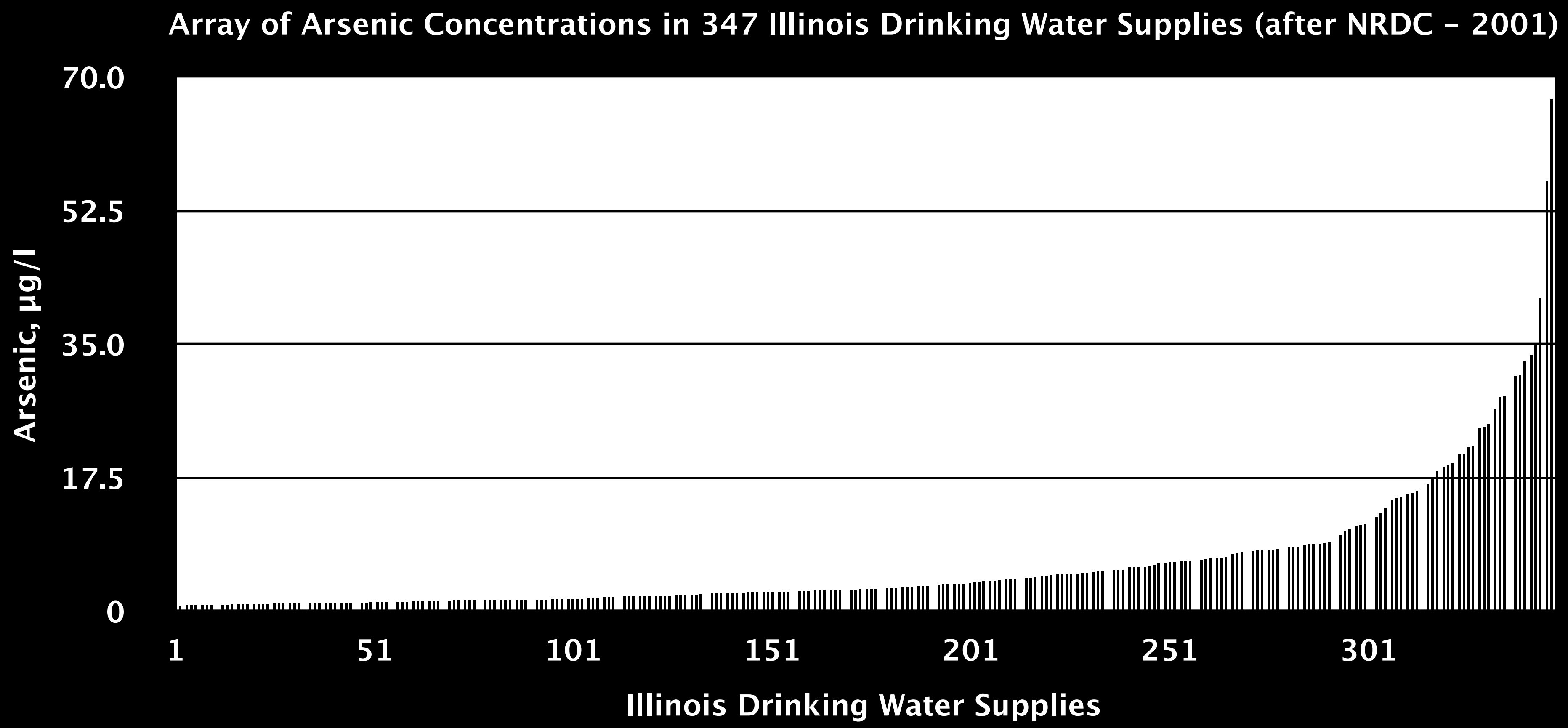
New Mexico, Nevada, California, Utah, Idaho, Oregon

Midwest:

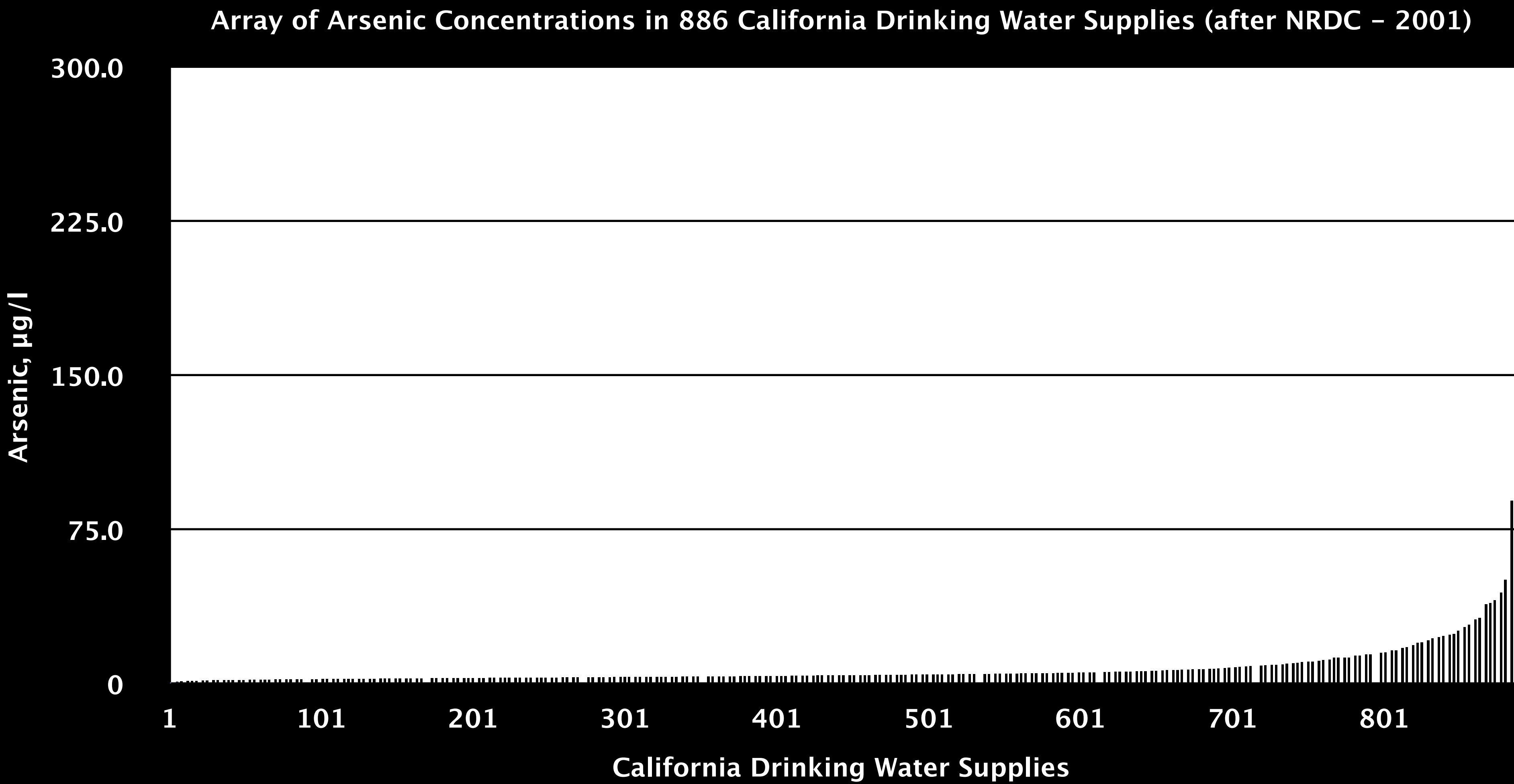
Nebraska, Illinois, Indiana, Michigan


Array of Arsenic Concentrations in 87 Missouri Drinking Water Supplies (after NRDC - 2001)
40.0
30.0
20.0
10.0
0
Arsenic, µg/l
1
21
41
61
81
Missouri Drinking Water Supplies

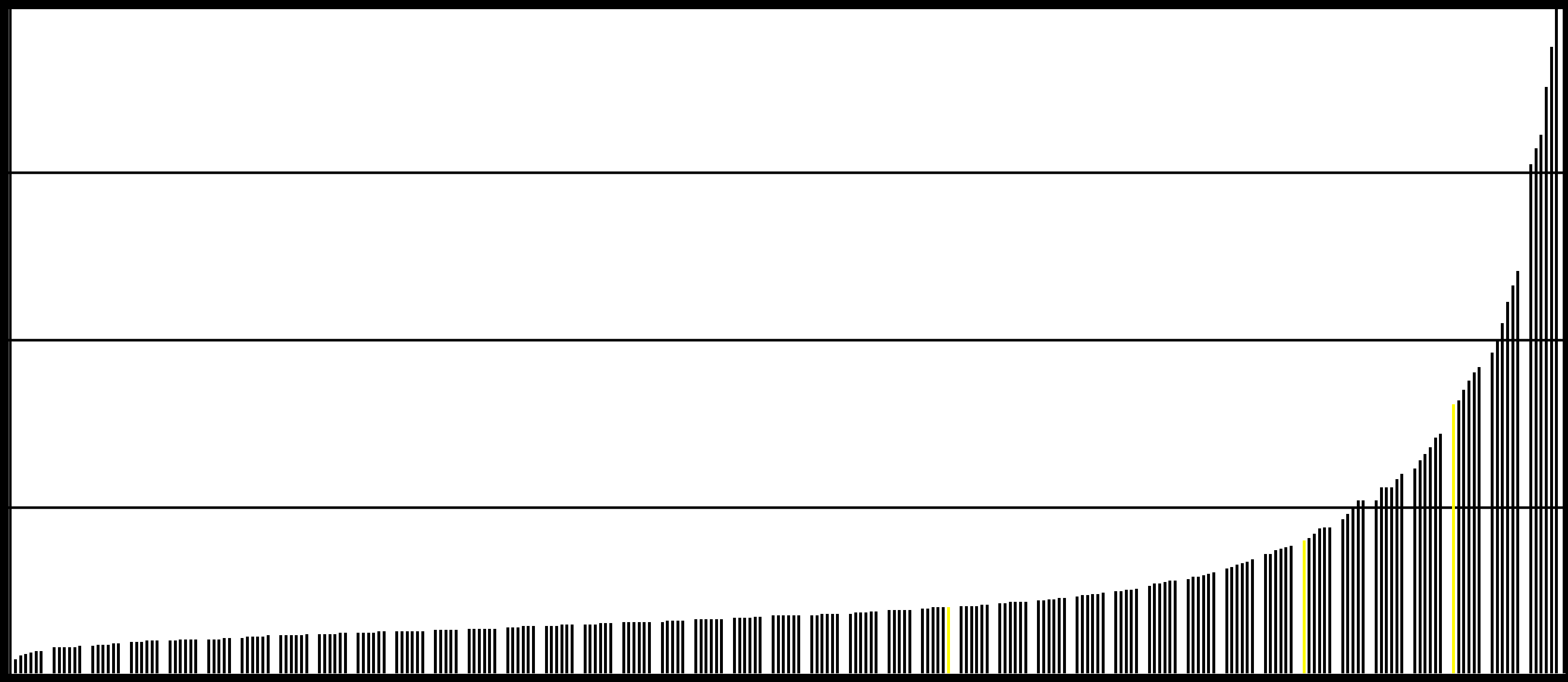

Array of Arsenic Concentrations in 56 Central Illinois Well Water Samples (ISWS Contract Report 579
Arsenic, µg/l
100.00
75.00
50.00
25.00
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56
Central Illinois Well Water Samples

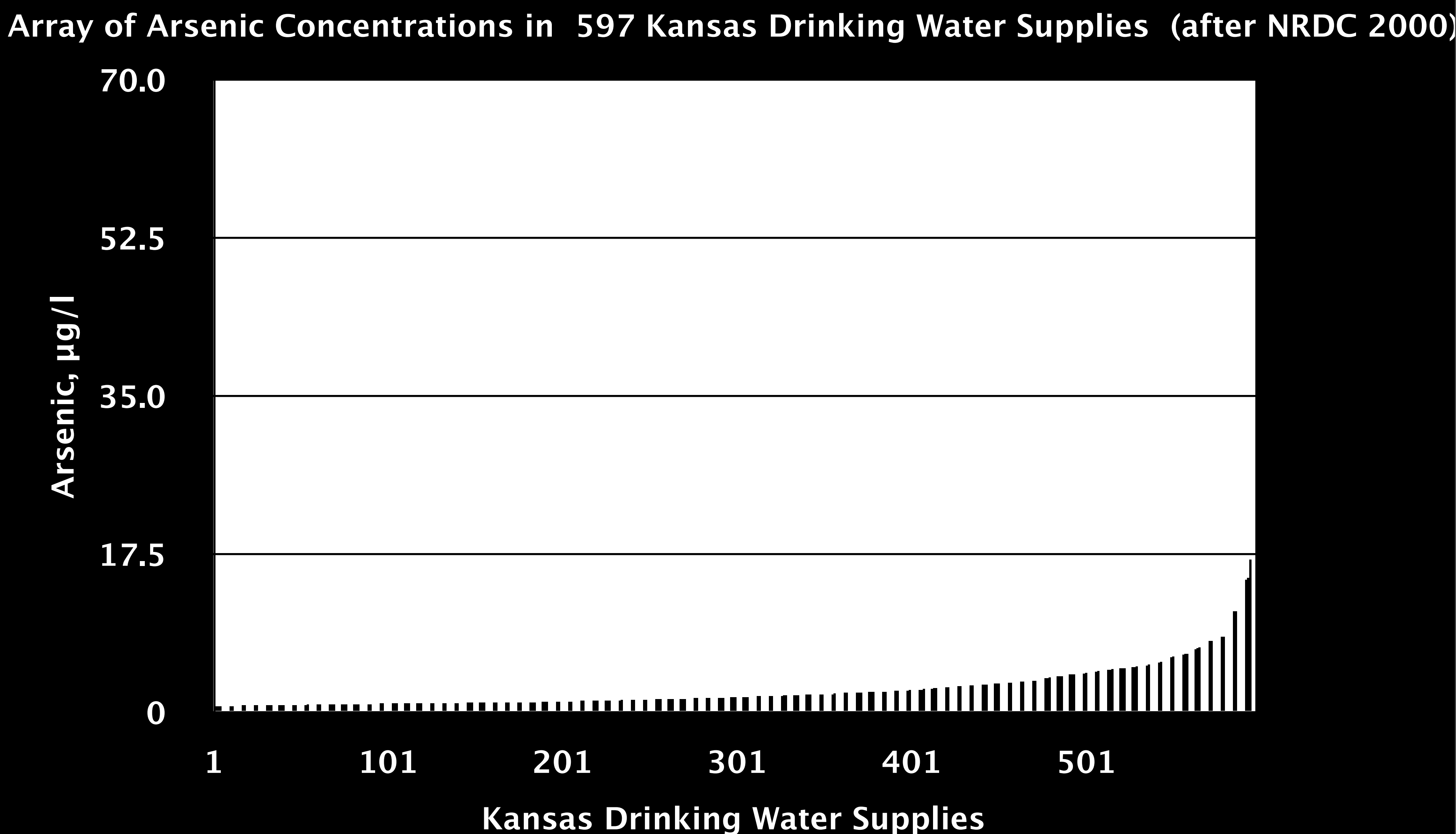


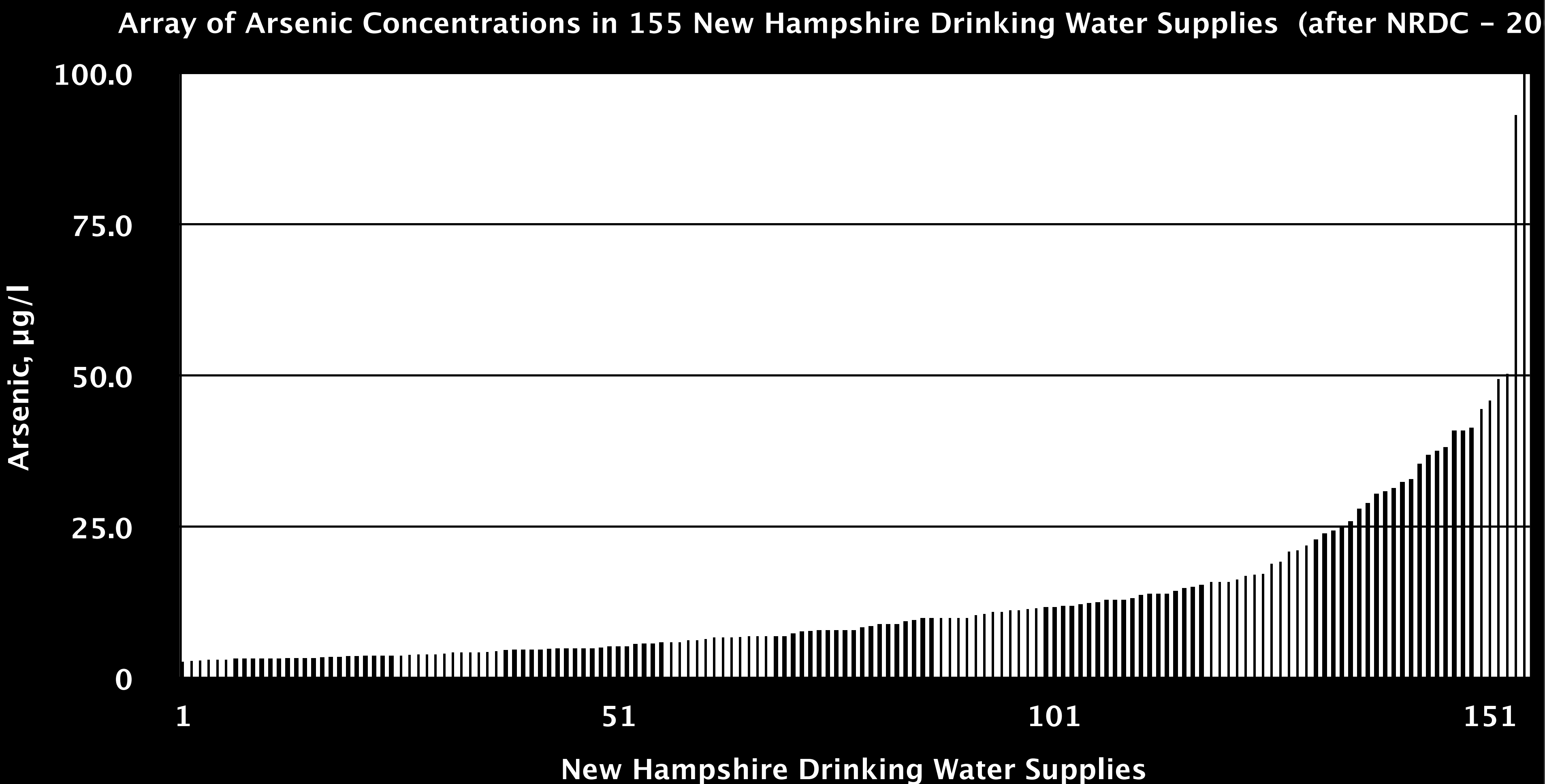
Array of Arsenic Concentrations in 347 Illinois Drinking Water Supplies (after NRDC - 2001)
70.0
52.5
35.0
17.5
0
Arsenic, µg/l
1
51
101
151
201
251
301
Illinois Drinking Water Supplies

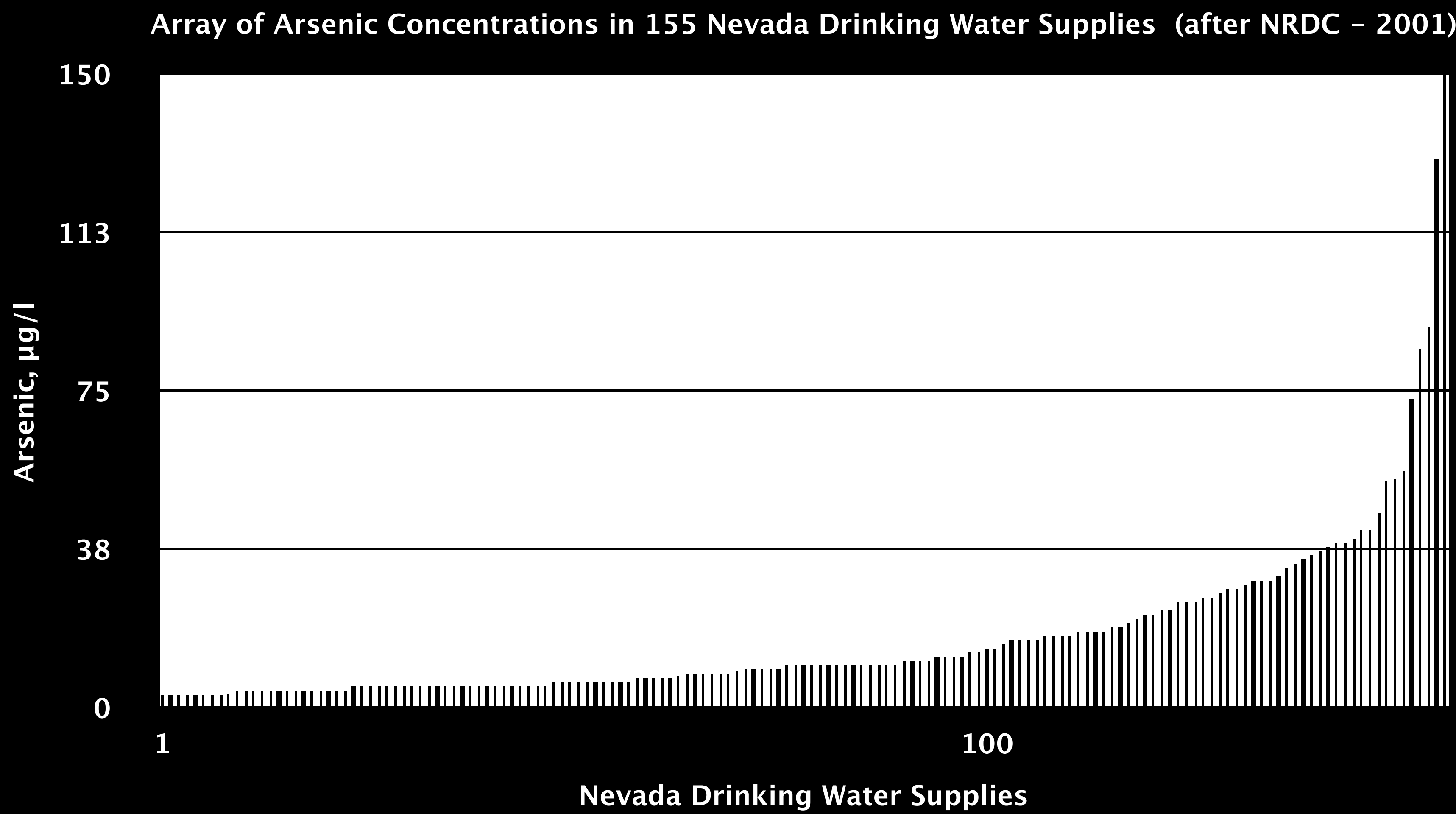


Array of Arsenic Concentrations in 886 California Drinking Water Supplies (after NRDC - 2001)
300.0
225.0
150.0
75.0
0
Arsenic, µg/l
1
101
201
301
401
501
601
701
801
California Drinking Water Supplies

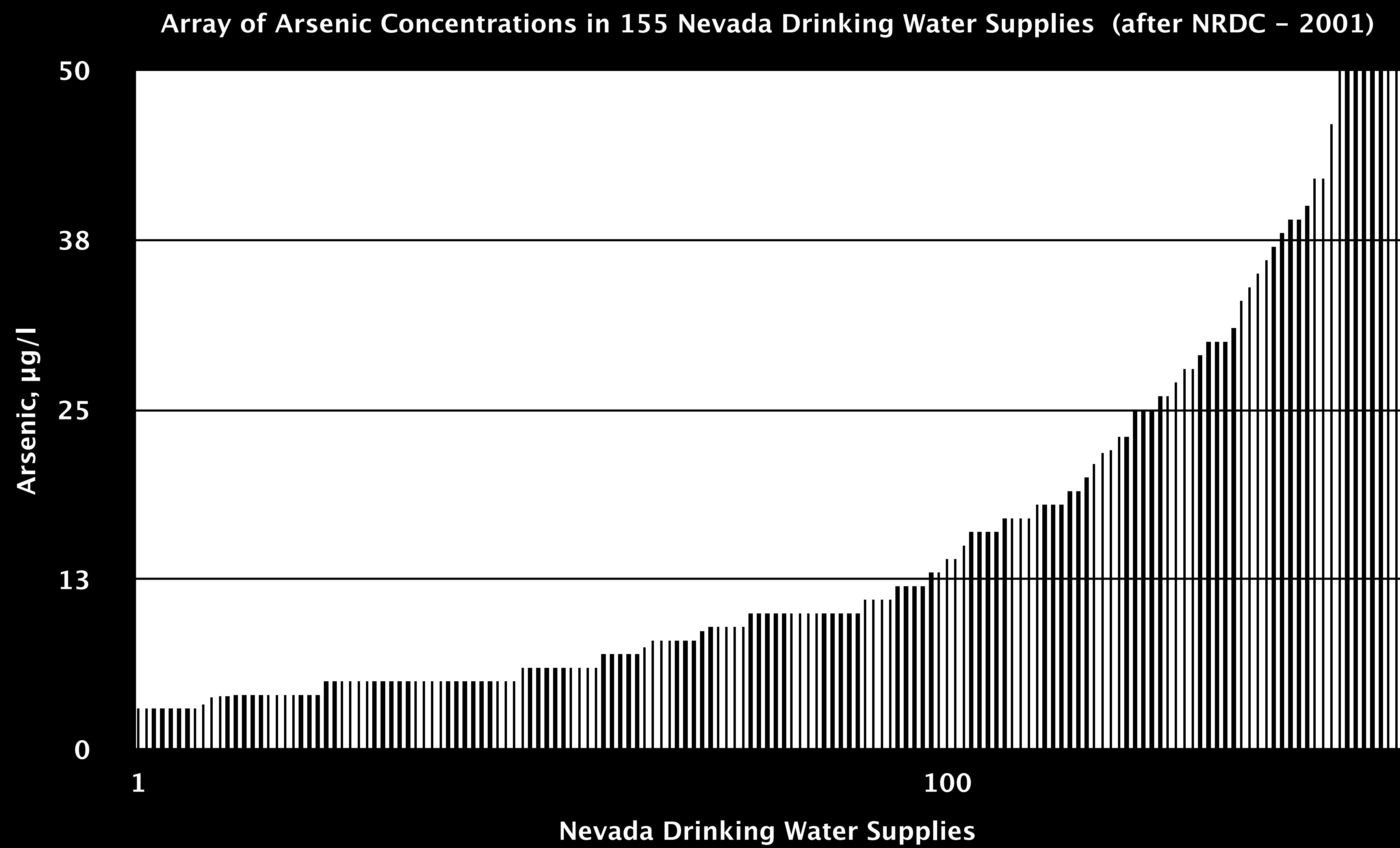



Array of Arsenic Concentrations in 597 Kansas Drinking Water Supplies (after NRDC 2000)
70.0
52.5
35.0
17.5
0
Arsenic, µg/l
1
101
201
301
401
501
Kansas Drinking Water Supplies


Array of Arsenic Concentrations in 155 New Hampshire Drinking Water Supplies (after NRDC - 20
100.0
75.0
50.0
25.0
0
Arsenic, µg/l
1
51
101
151
New Hampshire Drinking Water Supplies

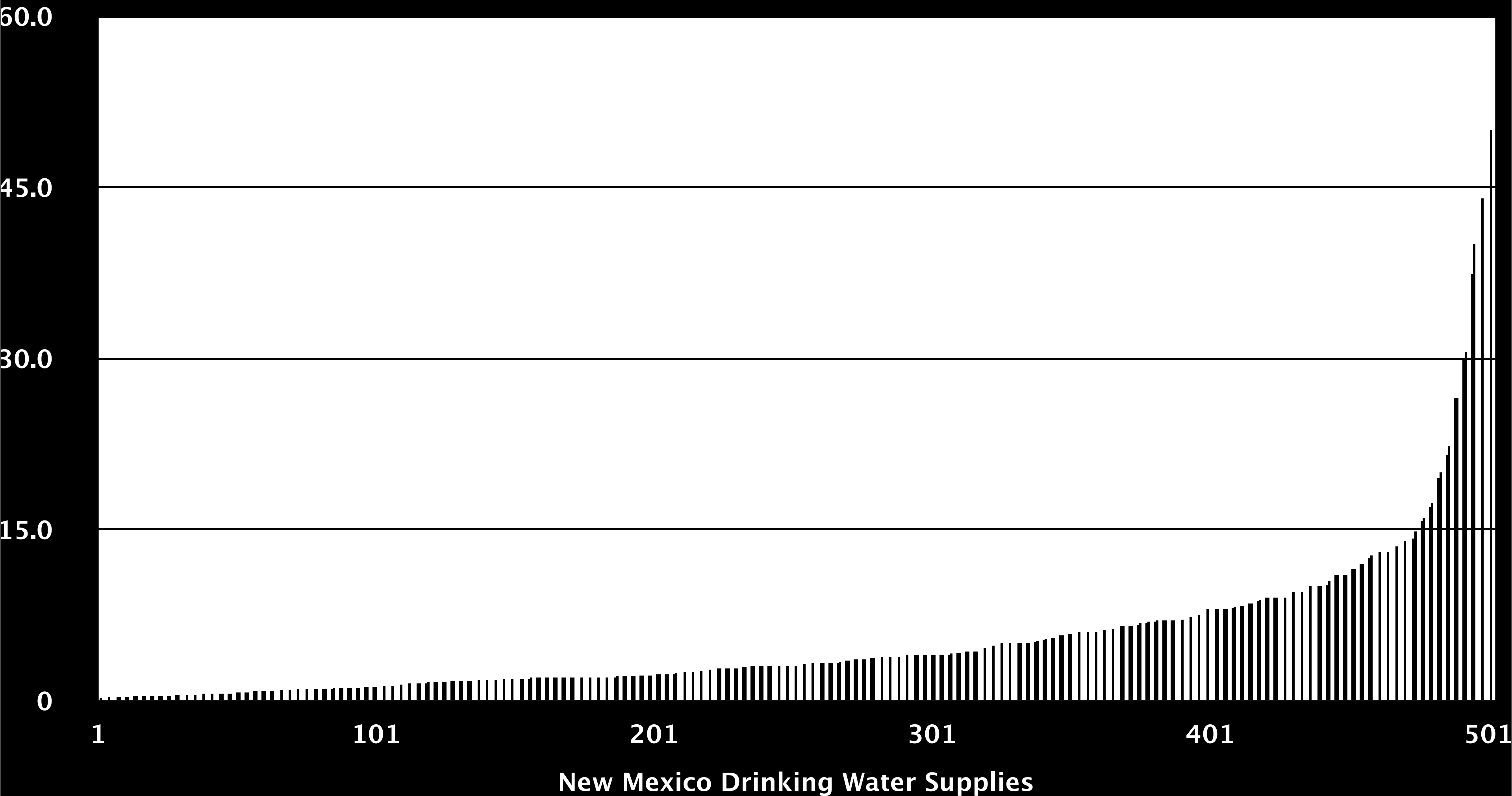


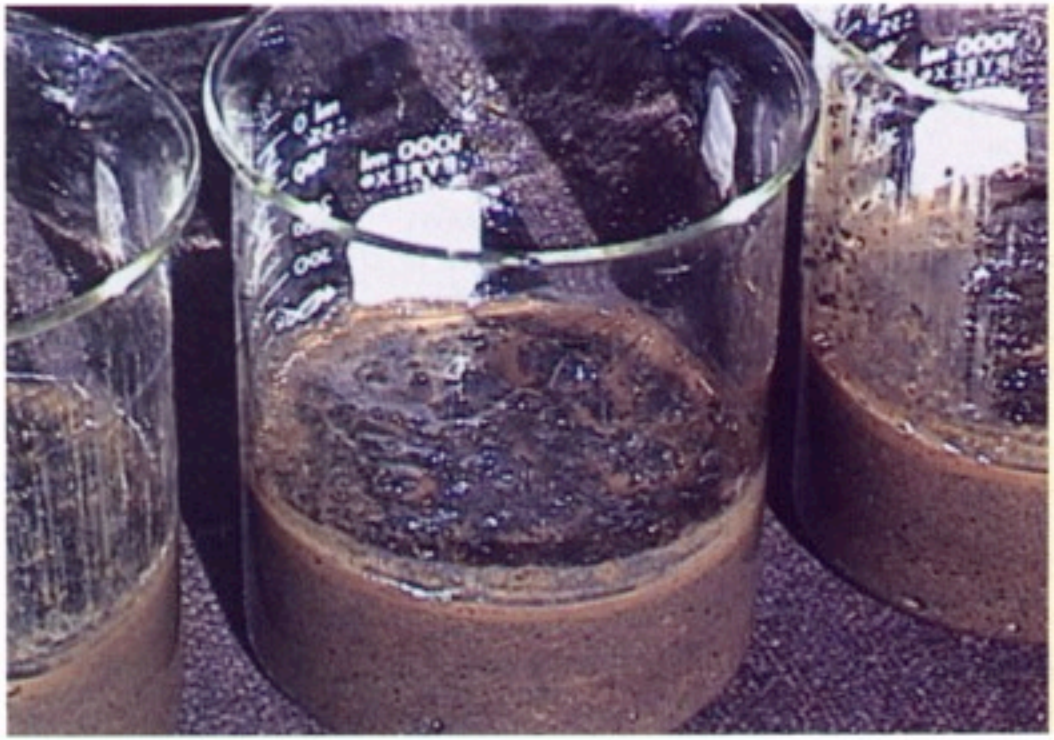
Array of Arsenic Concentrations in 155 Nevada Drinking Water Supplies (after NRDC - 2001)
150
113
75
38
0
Arsenic, µg/l
1
100
Nevada Drinking Water Supplies



Array of Arsenic Concentrations in 155 Nevada Drinking Water Supplies (after NRDC - 2001)
50
38
25
13
0
Arsenic, µg/l
1
100
Nevada Drinking Water Supplies

Array of Arsenic Concentrations in 503 New Mexico Drinking Water Supplies (after NRDC - 2001)





Studies have confirmed that arsenic is removed effectively by precipitation with iron.

Arsenic in Drinking Water

Part 4: Arsenic Removal Methods

Arsenic Removal Technologies (as confounded by USEPA)

Precipitative Processes
- Coagulation/Filtration, a.k.a.
  - Iron/Manganese Oxidation
  - Coagulation- Assisted Microfiltration
  - Enhanced Coagulation
- Lime Softening

Adsorptive Processes
- Activated Alumina
  - Iron Oxide-Coated Sand
- Ion Exchange

Membrane (Processes
- Microfiltration
- Ultrafiltration
- Nanofiltreation
- Reverse Osmosis
- Electrodialysis Reversal

Alternative (Adsorptive) Technologies
- Oxidation Filtration
- Sulfur-Modified Iron
- Granular Ferric Hydroxide
- Iron Filings

H2O'C ENGINEERING

USEPA-Designated
Best Available Treatment Processes

Conventional Treatment

Aeration / Filtration — Adsorption on Fe, Mn Oxides

Coagulation/Filtration — Adsorption on Aluminum Oxides

Lime Softening — Adsorption on Fe, Al, Mg Oxides

Adsorption Media

Activated Alumina — Adsorption on AlO_2 at pH 6

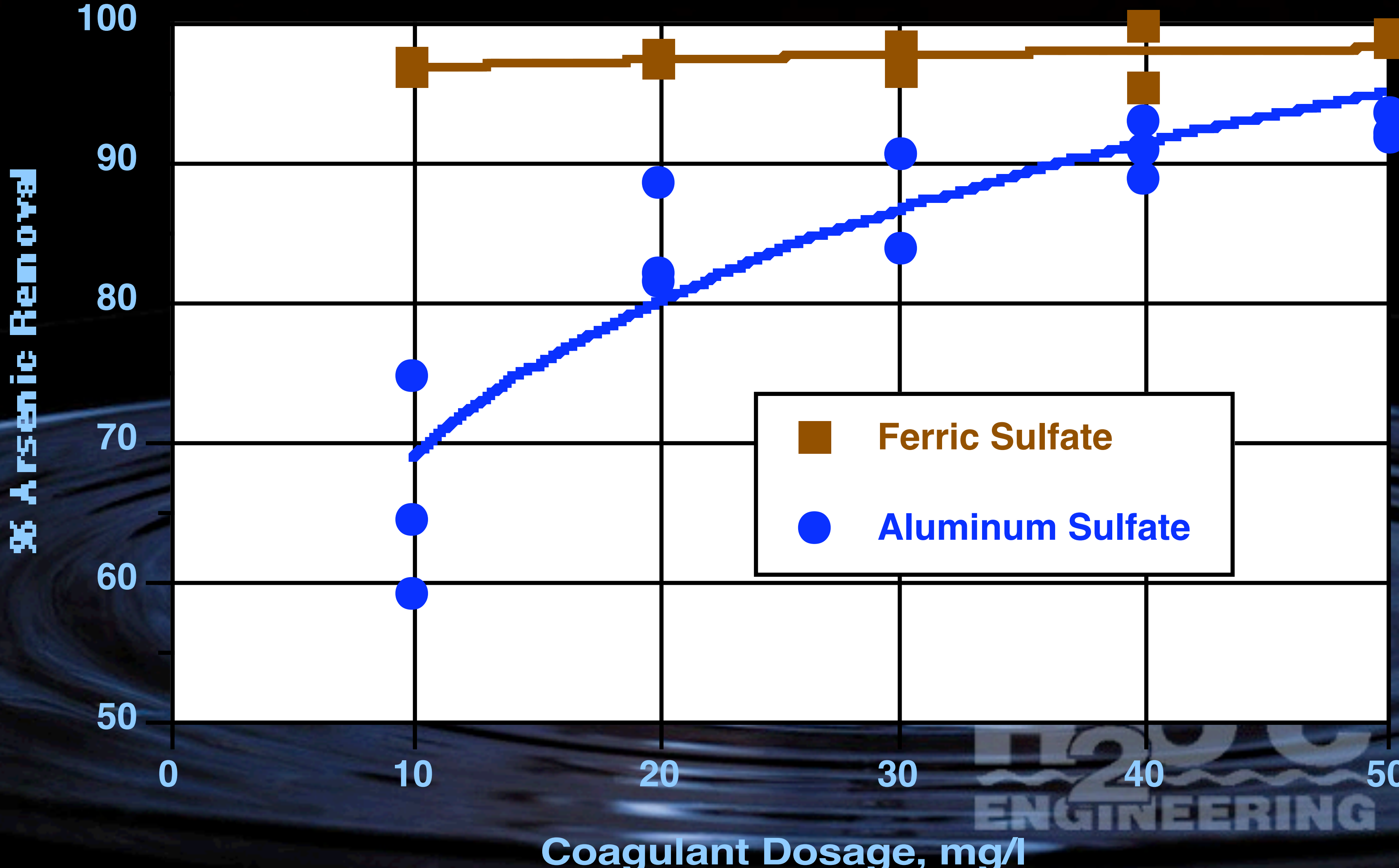
Anion Exchange — Strongly Basic Anion Exchange Resin

Membrane Processes

Reverse Osmosis; Electrodialysis Reversal

Arsenic Removal by Coagulation and Filtration

(Gulledge and O'Connor, J.AWWA, 1973; 65, 8, 548)

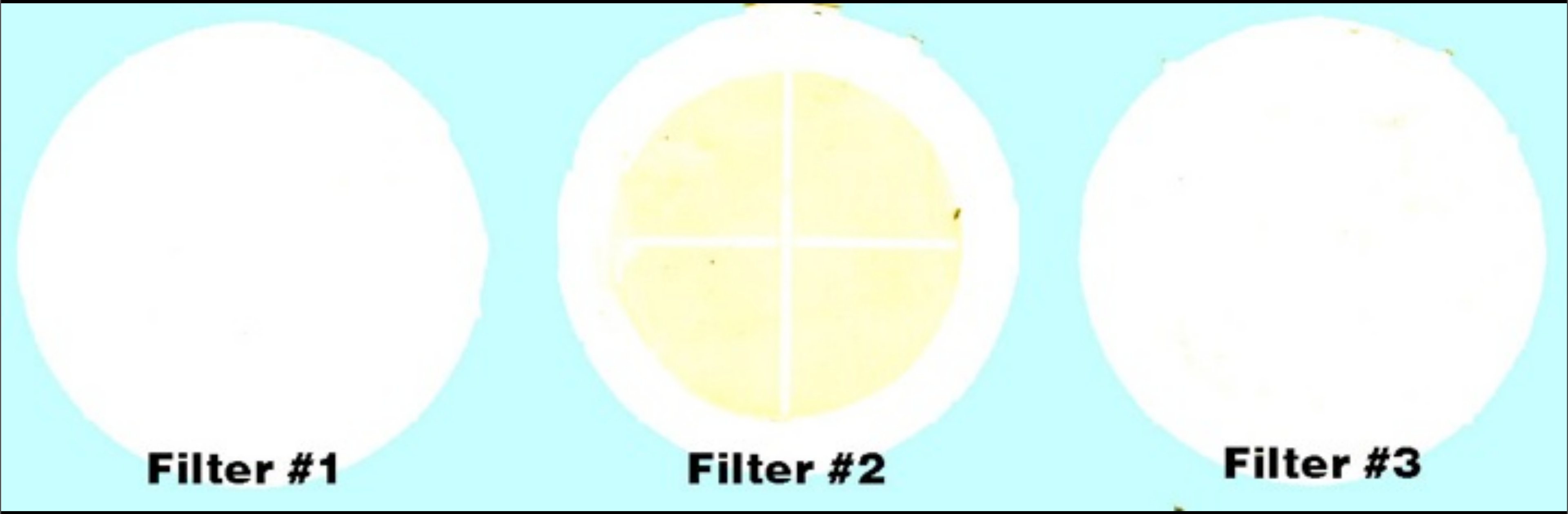


Removal of Fe, Mn from Groundwater: Aeration, KMnO4, Greensand Filters


NSF
CAIROX

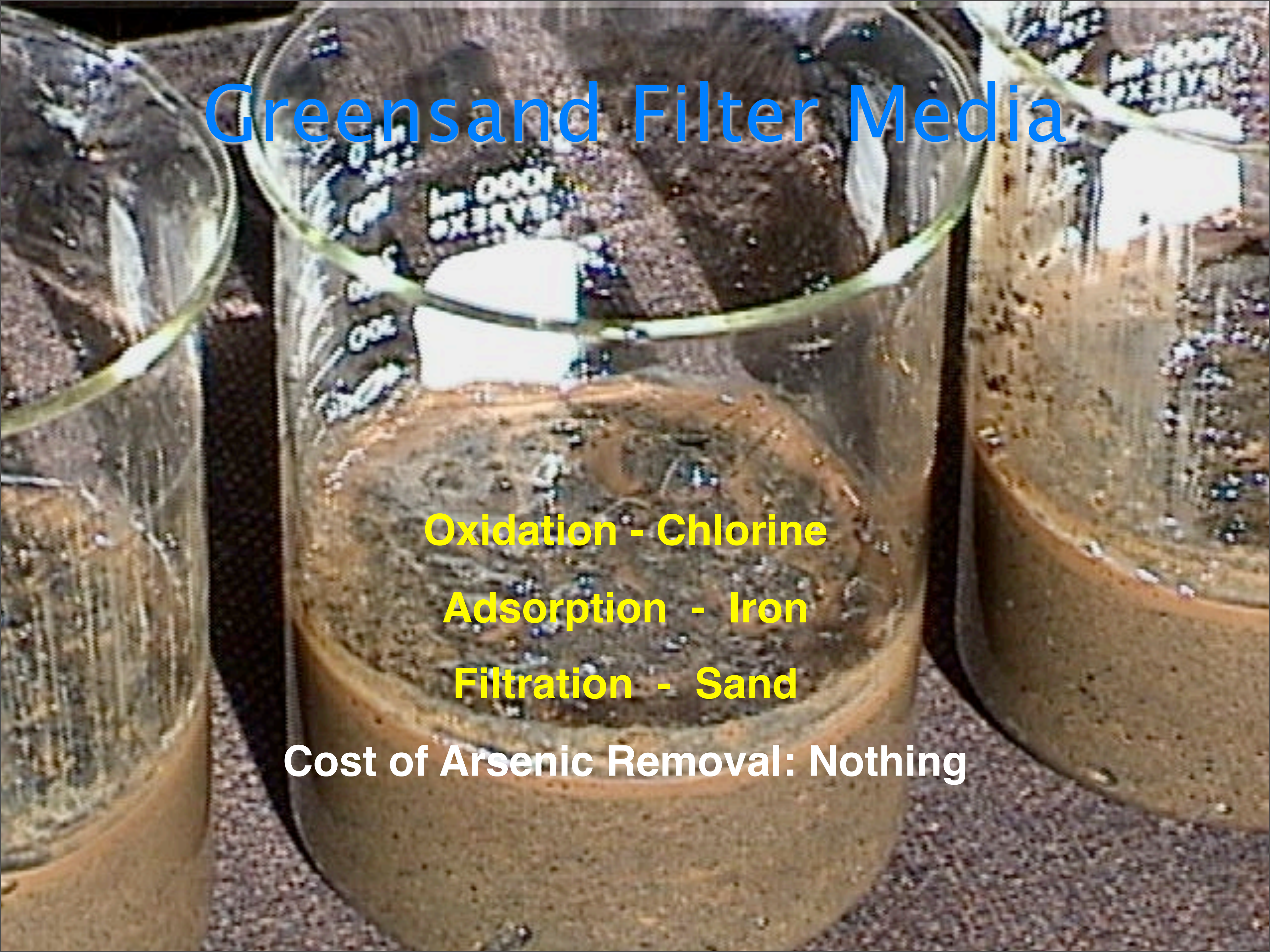

Arsenic
reduced
from 20 to
< 3 µg/l

Monitoring Filter Performance




Greensand from Filter
Mudball

Greensand Filter Media



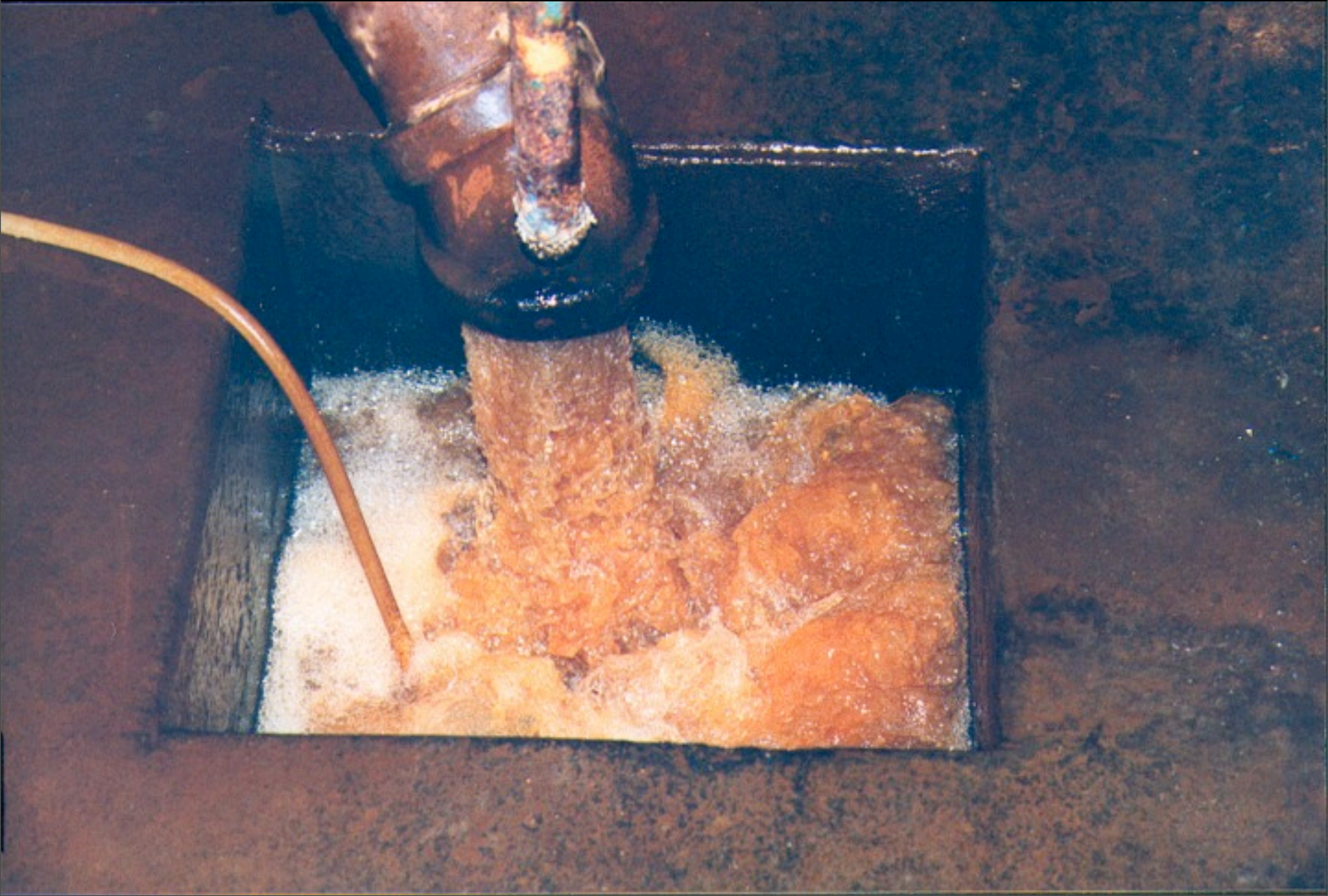
Oxidation - Chlorine

Adsorption - Iron

Filtration - Sand

Cost of Arsenic Removal: Nothing

Arsenic in Filter Backwash



Backwash Water Disposal

Arsenic recovered in $Fe(OH)_3$ sludge

POE / POU Treatment Devices

Utilities would:

- own, operate and maintain the POE/POU devices;
- ensure compliance with the MCLs;
- seek revisions to local ordinances to require consumers to provide access to the installed devices.

Frequent sampling, additional staff may be required.

Pilot testing on the source water would be required.

H2O'C ENGINEERING

USEPA Places Limitations on Small Communities

Coagulation / filtration, lime softening, reverse osmosis and electrodialysis reversal
are not designated as BAT for systems with fewer than 500 service connections.

USEPA has defined "small system compliance technologies (SSCTs)"
limiting arsenic removal technology for smaller communities based on the presumption that they will not be able to provide "appropriate" operation and maintenance.

H2O'C ENGINEERING

Proprietary Media for Arsenic

‘Package plants’ with proprietary media:

Filtronics “Electromedia”

media backwashed and continually reused

General Filter’s GFH (granular ferric hydroxide)

media replaced after exhaustion

University of Missouri-Columbia (Dr. Stanley Manahan)

triple reverse burn (TRB) char

prepared from a sub-bituminous coal

Arsenic Removal Costs

USEPA estimated costs to meet 10 µg/l MCL

Capital Cost:	**$900 million***
Annual O&M:	**$118 million**
Annual Monitoring & Administration:	**$2.7 million**
Average Annual Water Bill Increase:	**$32**
(all 4,100 affected systems)	
Annual Water Bill Increase:	**$58-327**
(~2,500 affected systems serving < 3,300)	

*Does not consider other treatment benefits;
selection of alternate sources;
use of least costly treatment processes.

H2O'C ENGINEERING

Arsenic in Drinking Water

Summary

New Arsenic MCL: 10 *µg/l*

Compliance Date: January 23, 2006

Potential Health Effects: Skin damage; diabetes; problems with circulatory systems; possible increased risk of lung/bladder cancer

Sources of Arsenic in Drinking Water: Mining, erosion of natural deposits; leaching of CCA-treated lumber; runoff from orchards; glass & electronics production wastes

Arsenic Removal Technologies: Precipitative, Adsorptive, Membrane Processes, Alternative (GFH, SMI)

www.epa.gov/safewater:

- **Implementation Guidance for the Arsenic Rule**
- **Arsenic Small System's Treatment Technology Design Manual (draft)**
- **Draft Guidance for Implementing a POU or POE Treatment Strategy**
- **Technologies and Costs for Removing Arsenic from Drinking Water**
- **Using DWSRF Funds to Comply with the New Arsenic Rule**

Dr. John T. O'Connor, PE

H_2O'C Engineering 2401 Tahoe Court Columbia, MO 65203-1444 www.h2oc.com

877-22-WATER

573-446-5595

john@h2oc.com