Arsenic in Drinking Water: An Overview of U.S. Regulation and Removal Technologies

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Presentation

- Safe Drinking Water Act & Arsenic Rule
- Compliance Status
- Treatment Options
- Arsenic Treatment Technology Demonstrations and Results

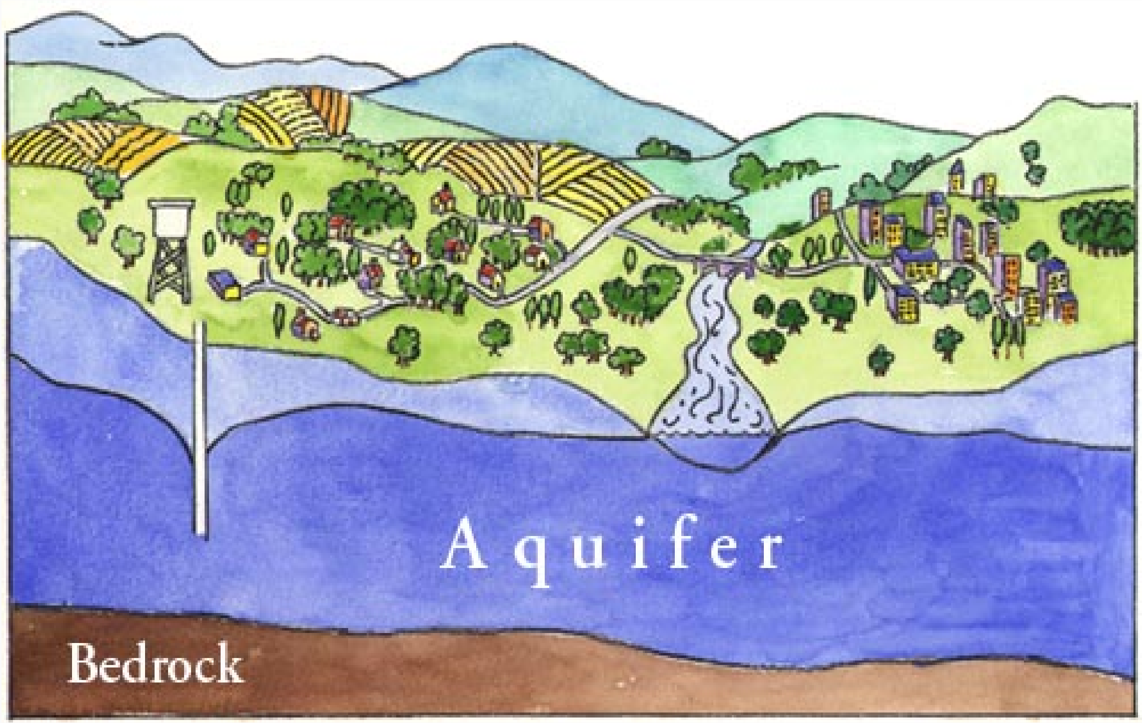
U. S. Safe Drinking Water Act

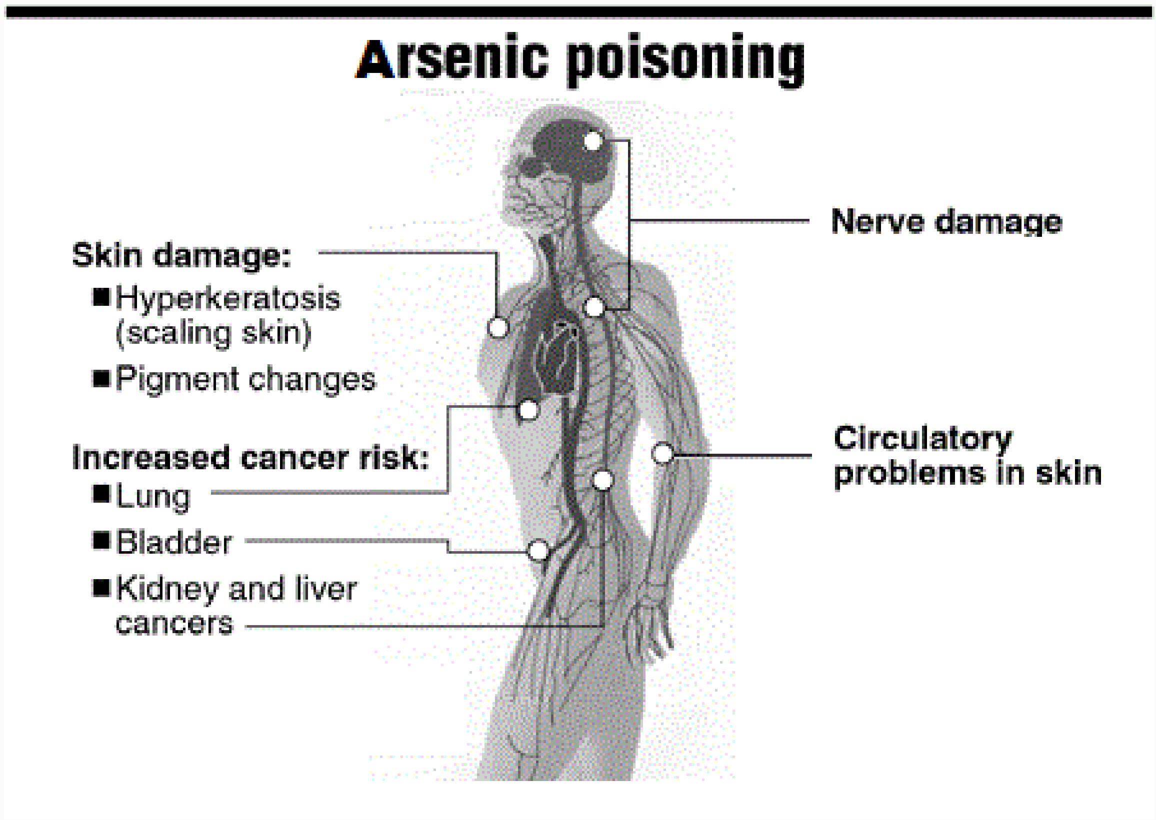
- Requires on-going consideration of contaminants in drinking water that, if controlled, offer reduction of health risk.
- Regulations include standards (maximum contaminant levels), analytical methods and reporting, recommended treatment technologies.

U. S. Safe Drinking Water Act

- Public Water Systems (PWS) serve 15 connections or 25 people for at least 60 days/year

- Types of PWS:
  - Community Water Systems (CWS) 15 connections or 25 people serving year-round residents
  - Non-Community Water Systems
    - Non Transient (NTNCWS) -- serves 25 of same persons for 6 months/yr
    - Transient (TNCWS)-- serves 25 persons/day for 60 days/yr


Aquifer
Bedrock

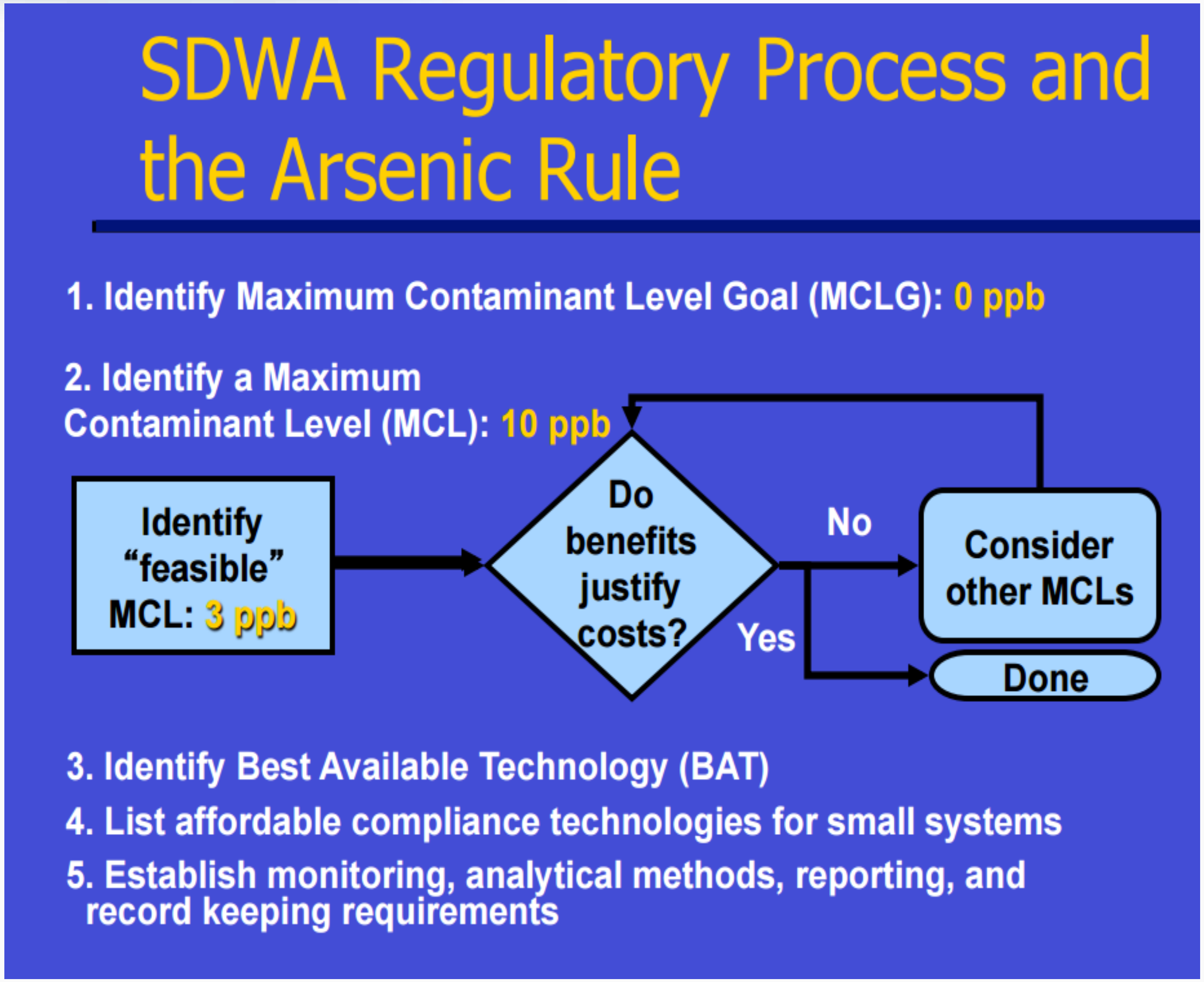

Arsenic poisoning
Nerve damage
Skin damage:
■ Hyperkeratosis (scaling skin)
■ Pigment changes
Increased cancer risk:
■ Lung
■ Bladder
■ Kidney and liver cancers
Circulatory problems in skin

History of U.S. Arsenic Regulation

- 1942 – First standard for arsenic (50 ppb)
- 1975 – EPA standard promulgated (50 ppb)
- 1996 – Congress mandates research strategy and standard revision
- 1998 – Research strategy published
- 1999 – NAS recommends lowering standard
- 2000 – EPA proposes standard of 5 ppb
- 2001- Extensive re-evaluation of benefits and cost of proposed rule
- **October, 2001** –Administrator sets new standard (10 ppb) and initiates $20 million for technical assistance and advanced technologies development
- 2003 – Rule text revised to express standard as 0.010 mg/L
- 2006 – Rule effective date and enforcement begins
- 2015 – Rule compliance exemptions expired

Arsenic Rule Benefit-Cost Analysis

MCL Option	Economic Analysis ($million)	
	Quantified Benefits	Costs
3	$213.8 - $490.9	$792.1
5	$191.1 - $355.6	$471.7
10	**$139.6 - $197.7**	**$205.6**
20	$46.1 – $53.8	$76.5


SDWA Regulatory Process and the Arsenic Rule
1. Identify Maximum Contaminant Level Goal (MCLG): 0 ppb
2. Identify a Maximum Contaminant Level (MCL): 10 ppb
Identify "feasible" MCL: 3 ppb
Do benefits justify costs?
No
Yes
Consider other MCLs
Done
3. Identify Best Available Technology (BAT)
4. List affordable compliance technologies for small systems
5. Establish monitoring, analytical methods, reporting, and record keeping requirements

Arsenic Rule

- Applies to systems that serve communities or residents on a daily basis.

- Water systems monitor according to the Standard Monitoring Framework.
  - If running annual average > than MCL, then MCL violation.

- Compliance monitoring is at point-of-entry into the distribution system.

Arsenic Rule BAT and SSCT

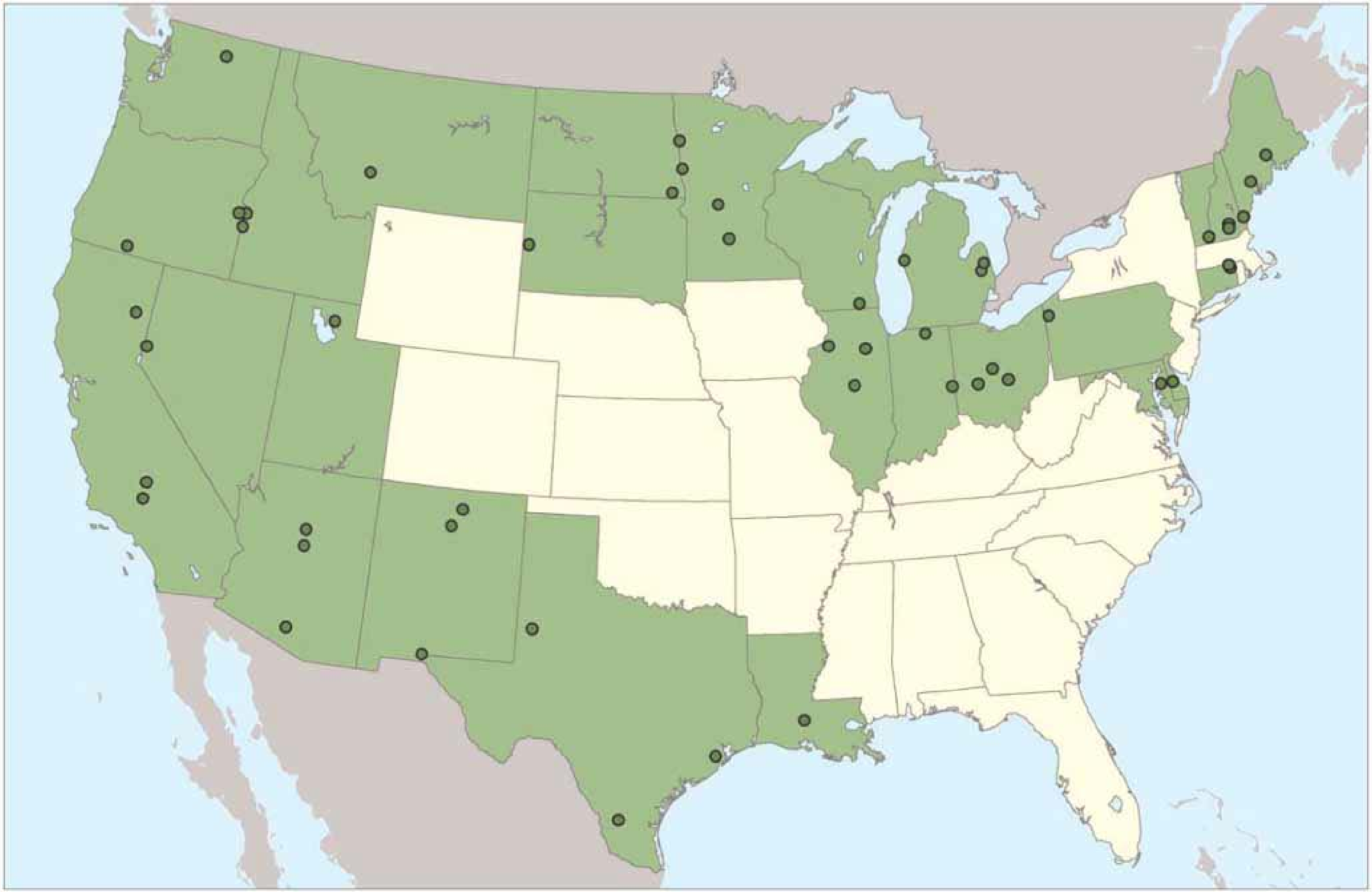
Technology	BAT	SSCT
Mod. lime softening	**yes**	**1,2,3**
Mod. coagulation/filtration	**yes**	**1,2,3**
Anion exchange	**yes**	**1,2,3**
Coag.-assisted microfiltration	**no**	**2,3**
Oxidation-filtration (greensand)	**yes**	**1,2,3**
Activated alumina	**yes**	**1,2,3**
Reverse osmosis	**yes**	**2,3**
Electrodialysis reversal	**yes**	**2,3**
POU reverse osmosis	**no**	**1,2,3**
POU activated alumina	**no**	**1,2,3**

1 = 25 to 500, 2=501 – 3,300, 3 = 3,301 – 10,000

Arsenic Standard Compliance Status

- There are 68,228 systems subject to the rule.
  - 63,914 systems serve ≤ 10,000 persons.
  - 45,417 have arsenic related treatment processes
- The total number of systems with an arsenic MCL violation:
  - **2008 - 967**
  - **2014 - 538**
- 296 systems with arsenic MCL violations have one or more bilateral compliance agreements or administrative orders.
- As of January 2015, 4 systems with exceptions became MCL violations or enforcement actions.

Arsenic Treatment Technology Demonstration Sites



Arsenic Demonstration Program

Technologies – Arsenic Demo Program	Number
Adsorptive Media (26 sites)	28
Iron Removal	10
Iron Removal w/ Adsorptive Media	4
Coagulation/ Filtration	4
Ion Exchange	2
Reverse Osmosis	1
POU – RO	1
POE – Adsorptive Media	1
System/Process Modification	1

Arsenic Chemistry

Arsenic species- pH dependent

As (III) - $H_3AsO_3^{0}$, $H_2AsO_3^{-1}$, $HAsO_3^{-2}$

As (V) - $H_3AsO_4^{0}$, $HAsO_4^{-1}$, AsO_4^{-2}

What is the significance of arsenic speciation?

As (V) more effectively removed than As (III) by most treatment technologies.

Other important WQ parameters
pH, Fe, Mn, PO4, SiO2

Arsenic III Oxidation

Effective!

- Free Chlorine
- Potassium Permanganate
- Ozone
- Solid Oxidizing Media (MnO$_2$ solids)

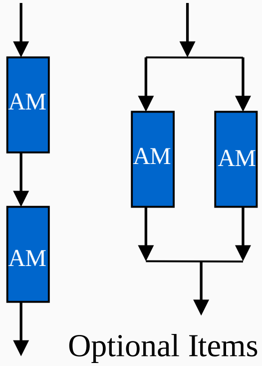
Ineffective

- Aeration
- Chloramine
- Chlorine Dioxide
- UV Radiation + Sulfide

System Designs – As Demonstration Program

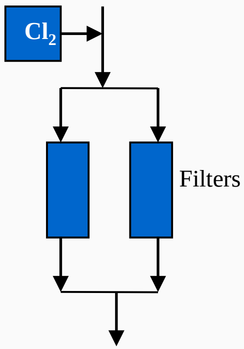
Adsorptive Media Systems

Series **Parallel**

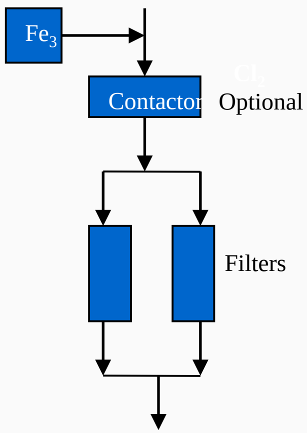


Optional Items
- •pH Adjustment
- •Backwash Tank

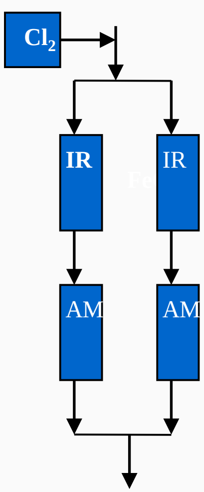
Iron Removal System



Coagulation/ Filtration System



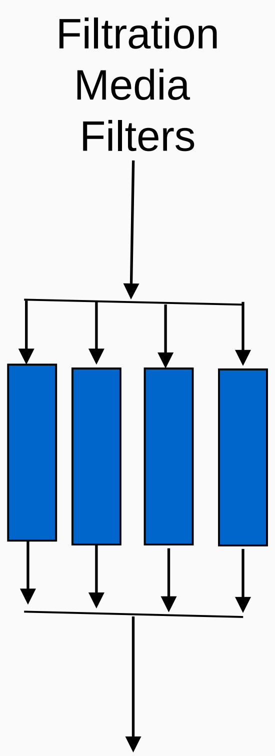
Iron Removal + Adsorptive Media System

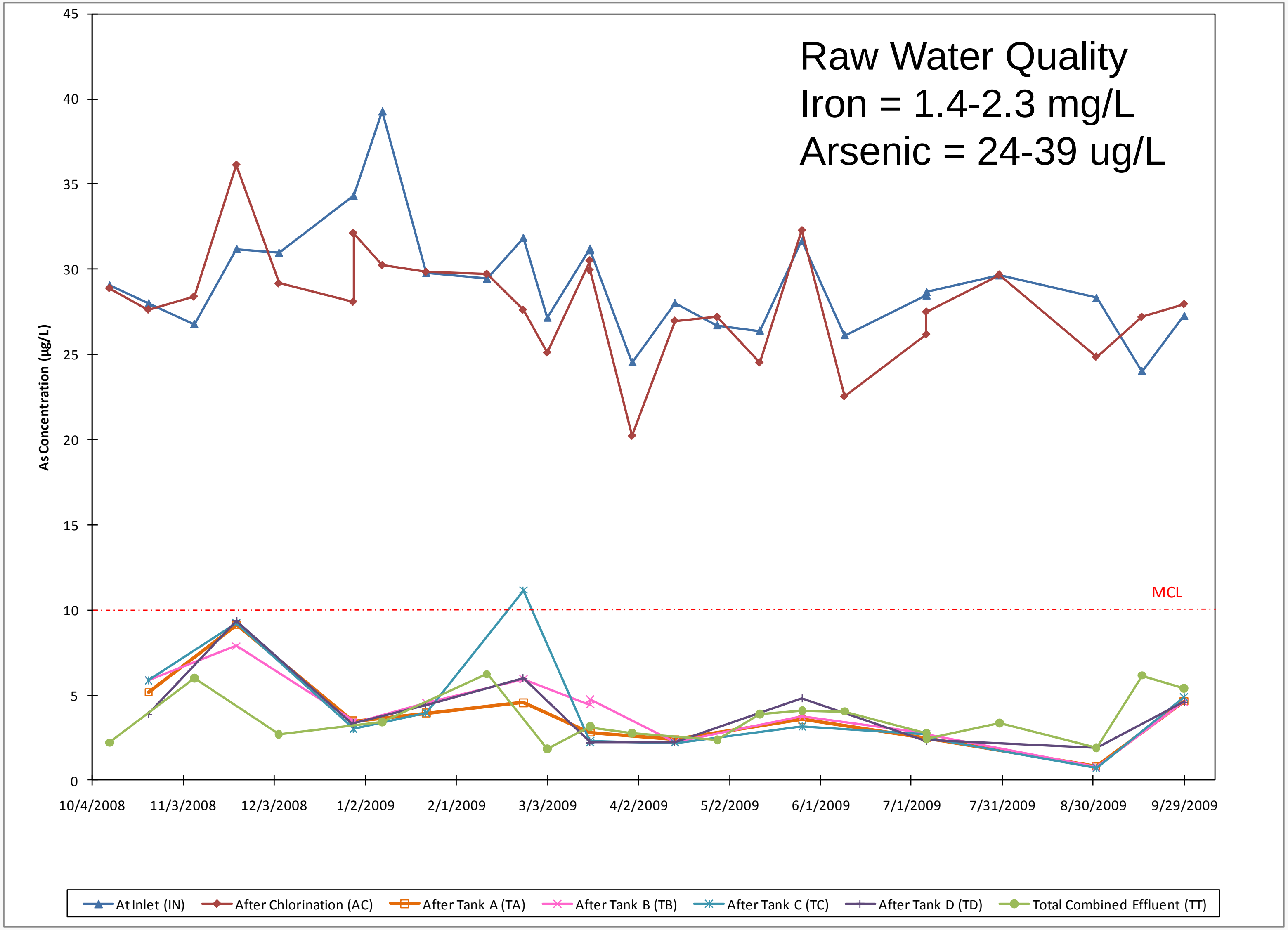


System Performance

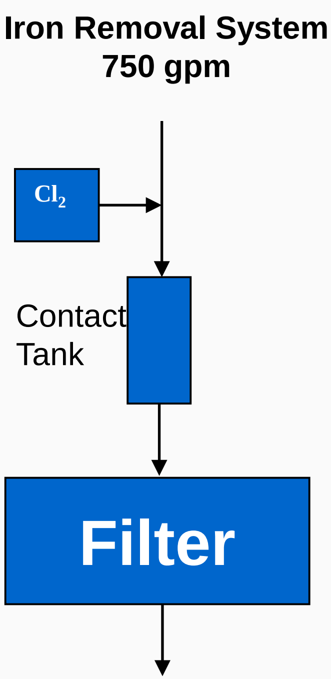
IR & C/F Systems

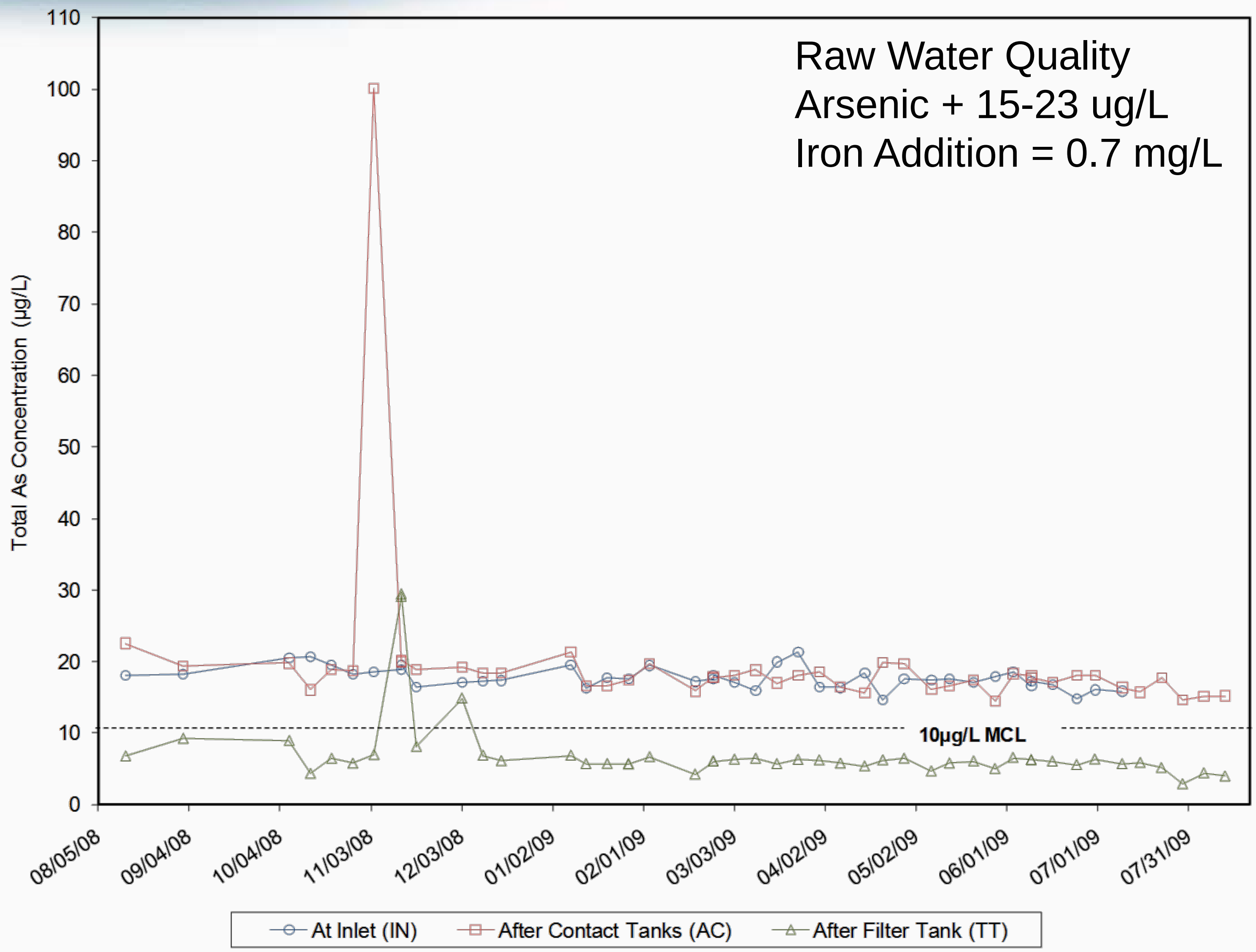
Iron Removal System (60 gpm - School)





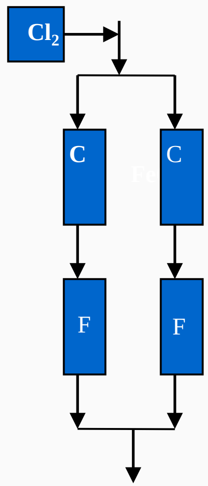
C/F System (750 gpm – CWS)

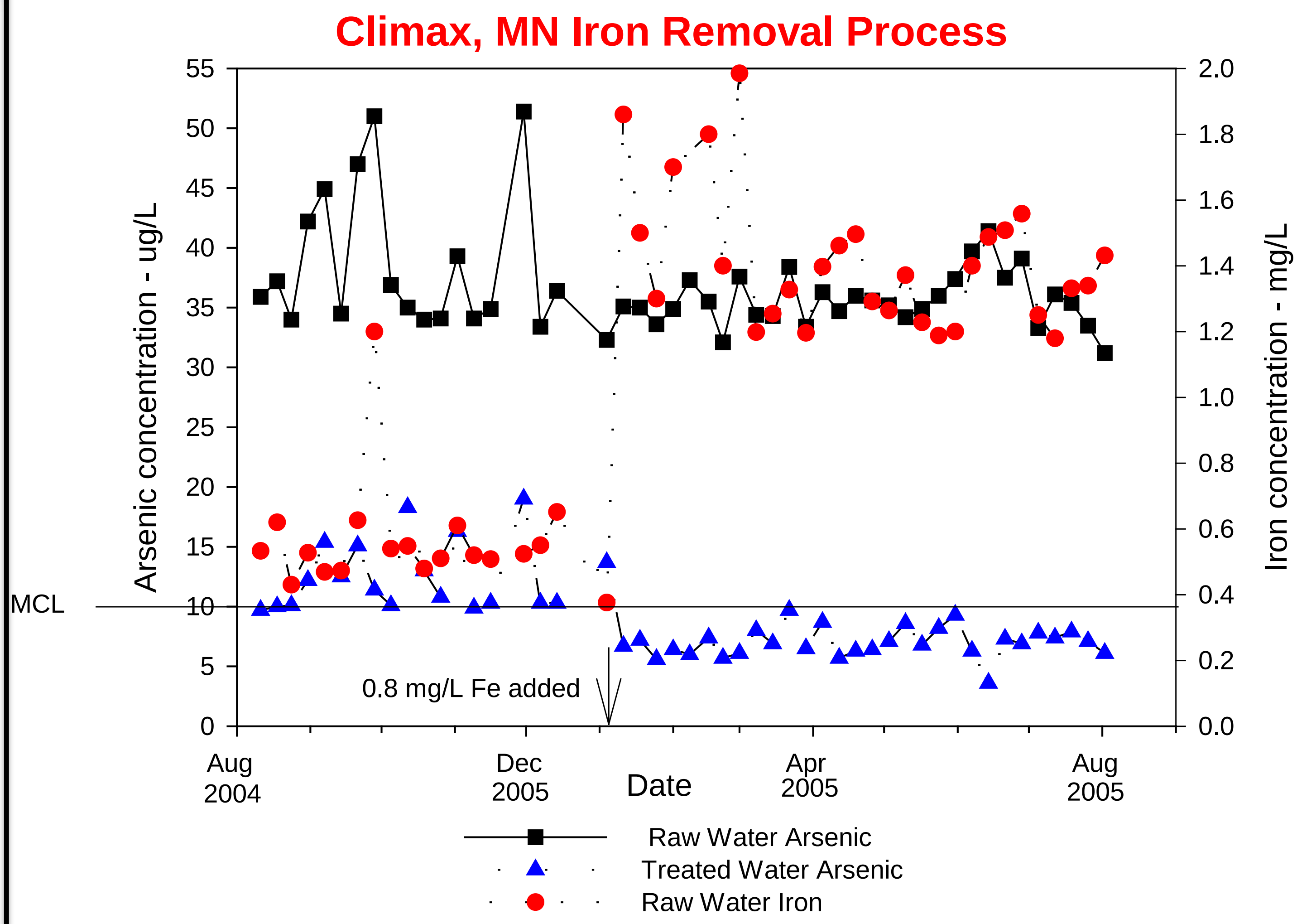




Iron Removal Process Converted to C/F

Iron Removal – C/F System
140 gpm





Raw Water – As III

AM Systems

SU System

WS System

BL System

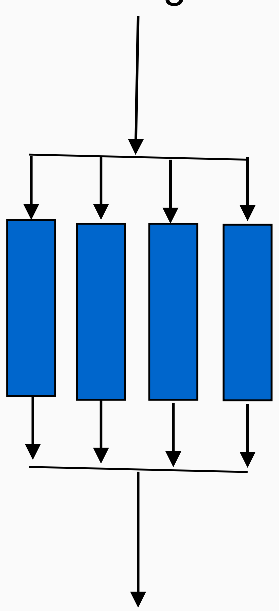
VV System

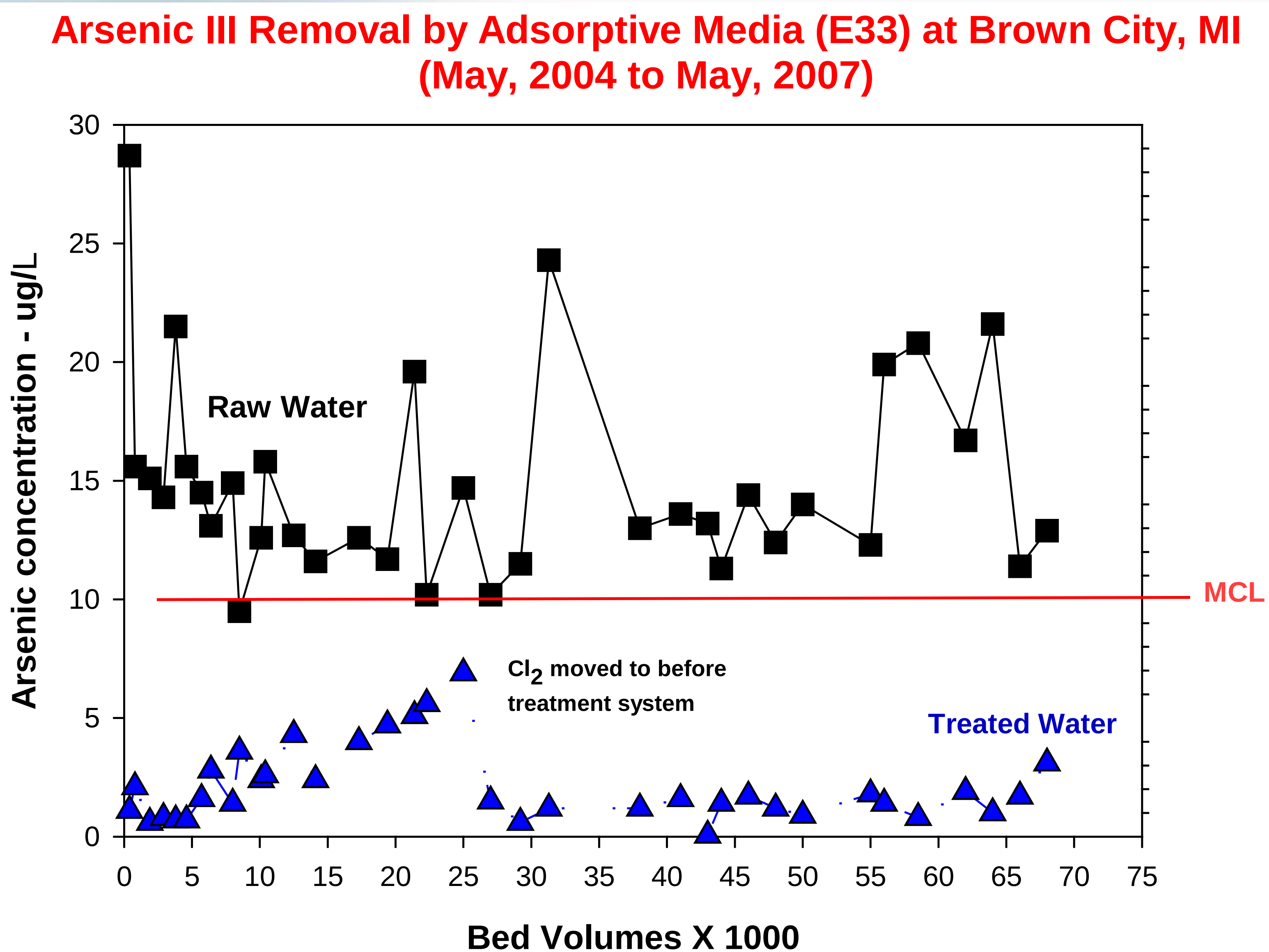
KF System

BW System

BR System

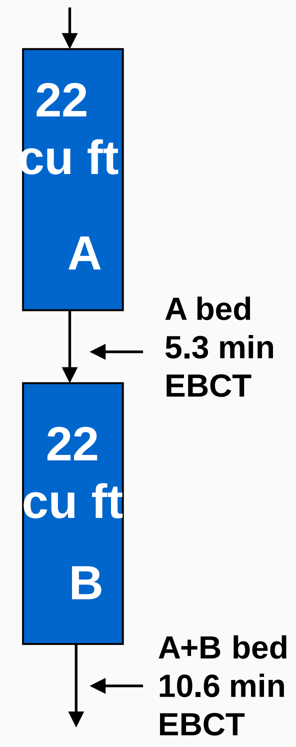
AM System Performance

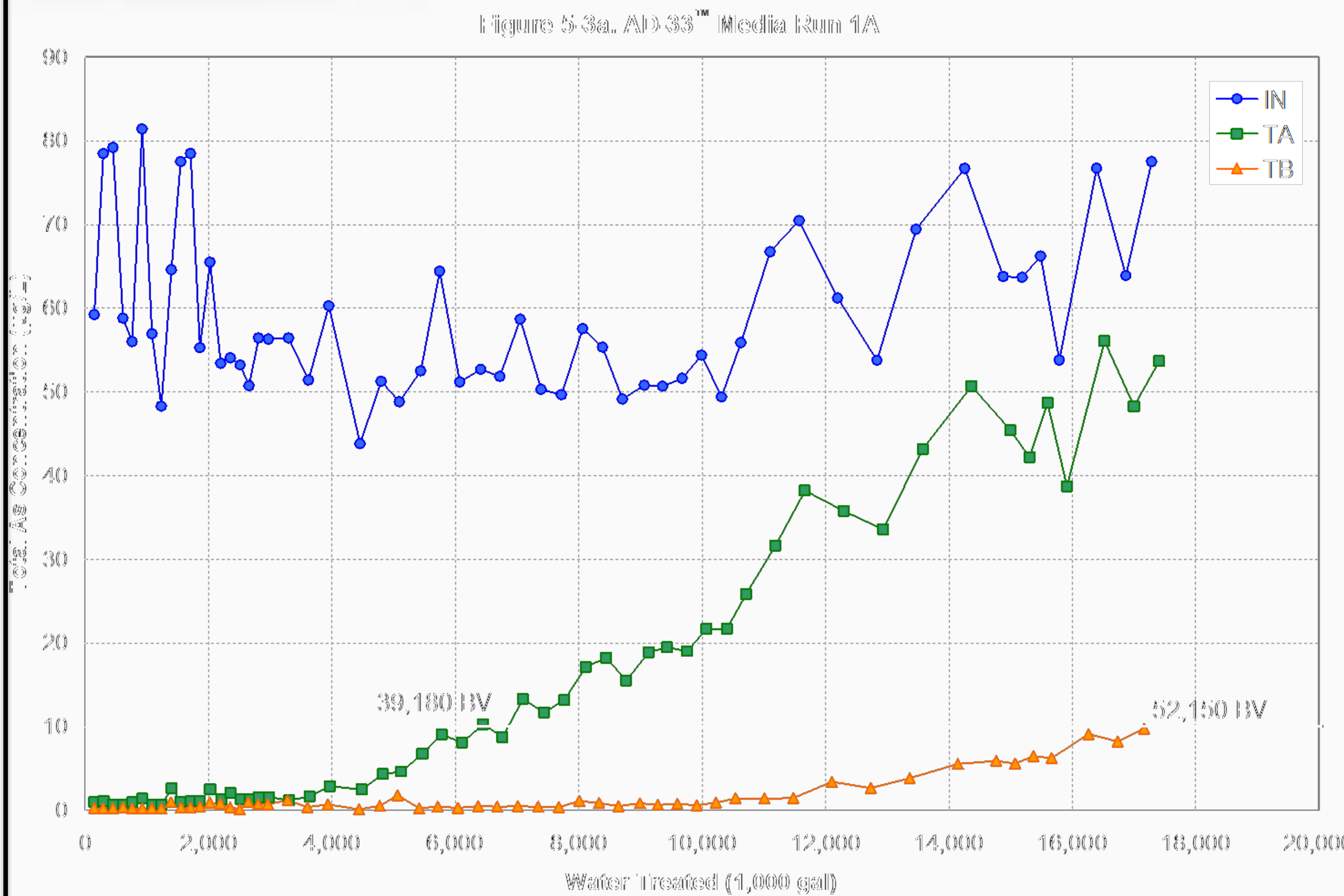




AM System Performance

Series Design
31 gpm





System Costs

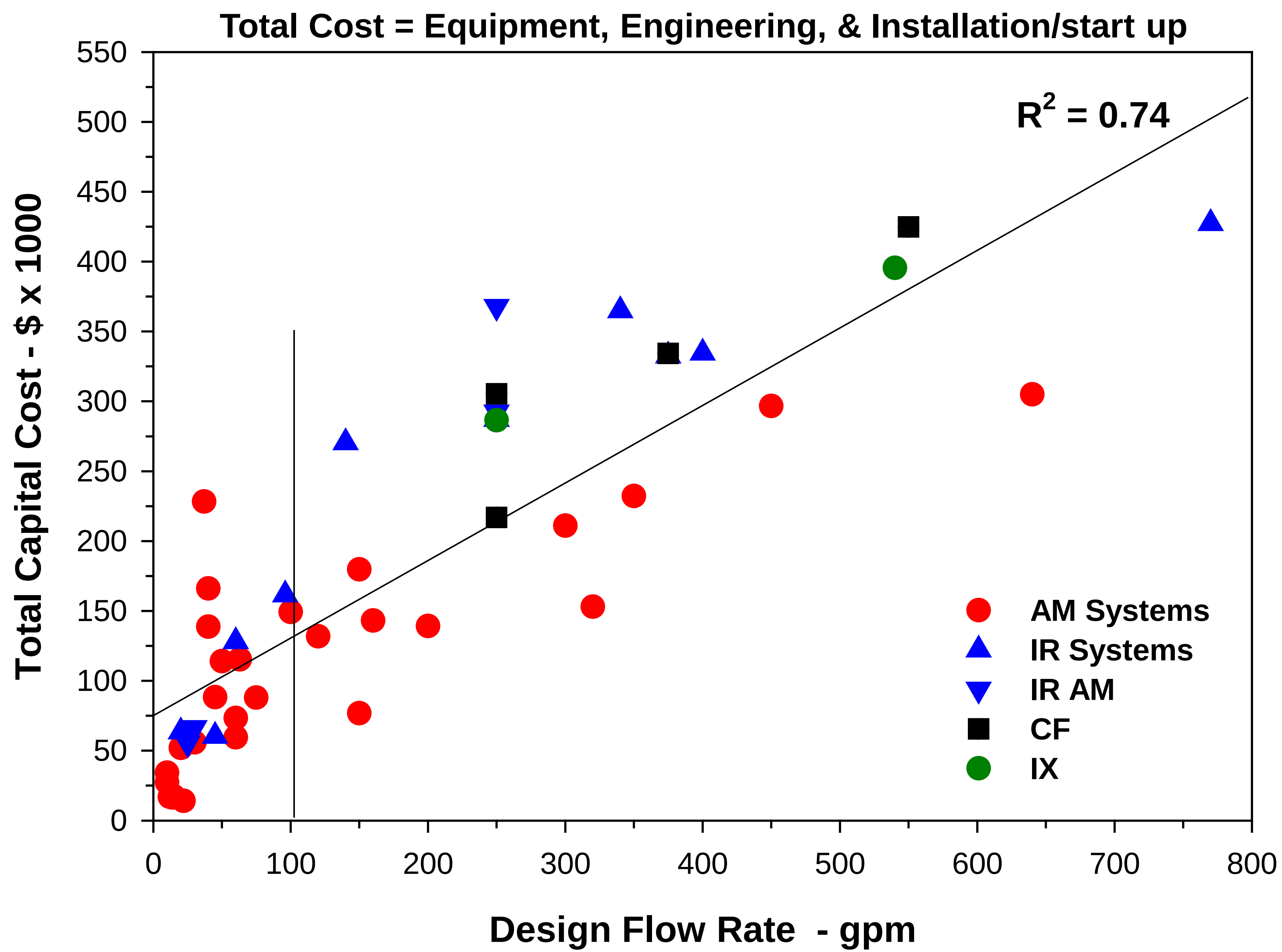
- Capital
- O/M

Systems Capital Costs

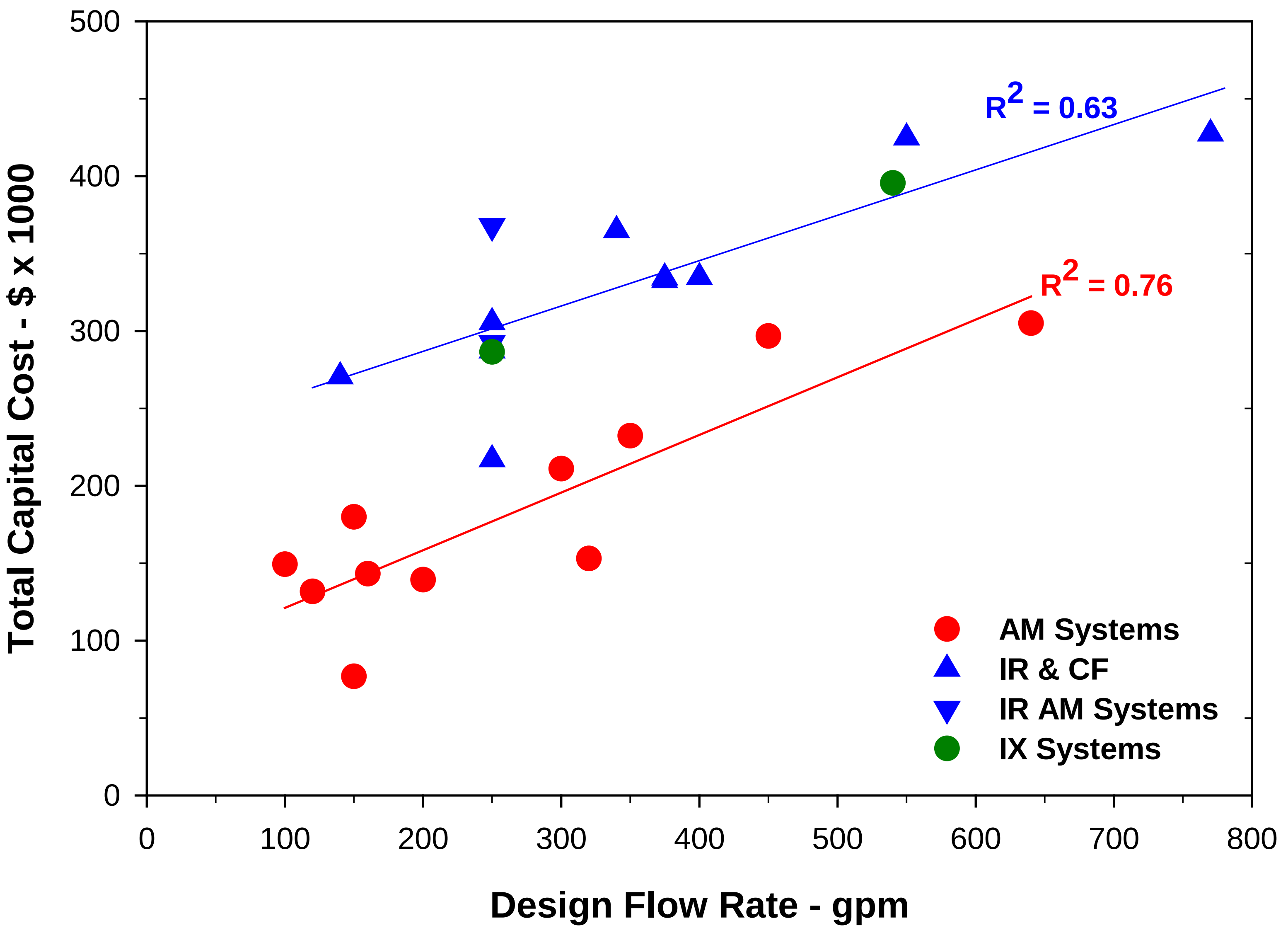
Capital Cost Funding Sources

Capital Costs – EPA Funds
Equipment
Engineering
Installation
Capital Costs – Utility Funds
Site Improvements - Building
Residual Disposal Items – Sewer, pond, etc.

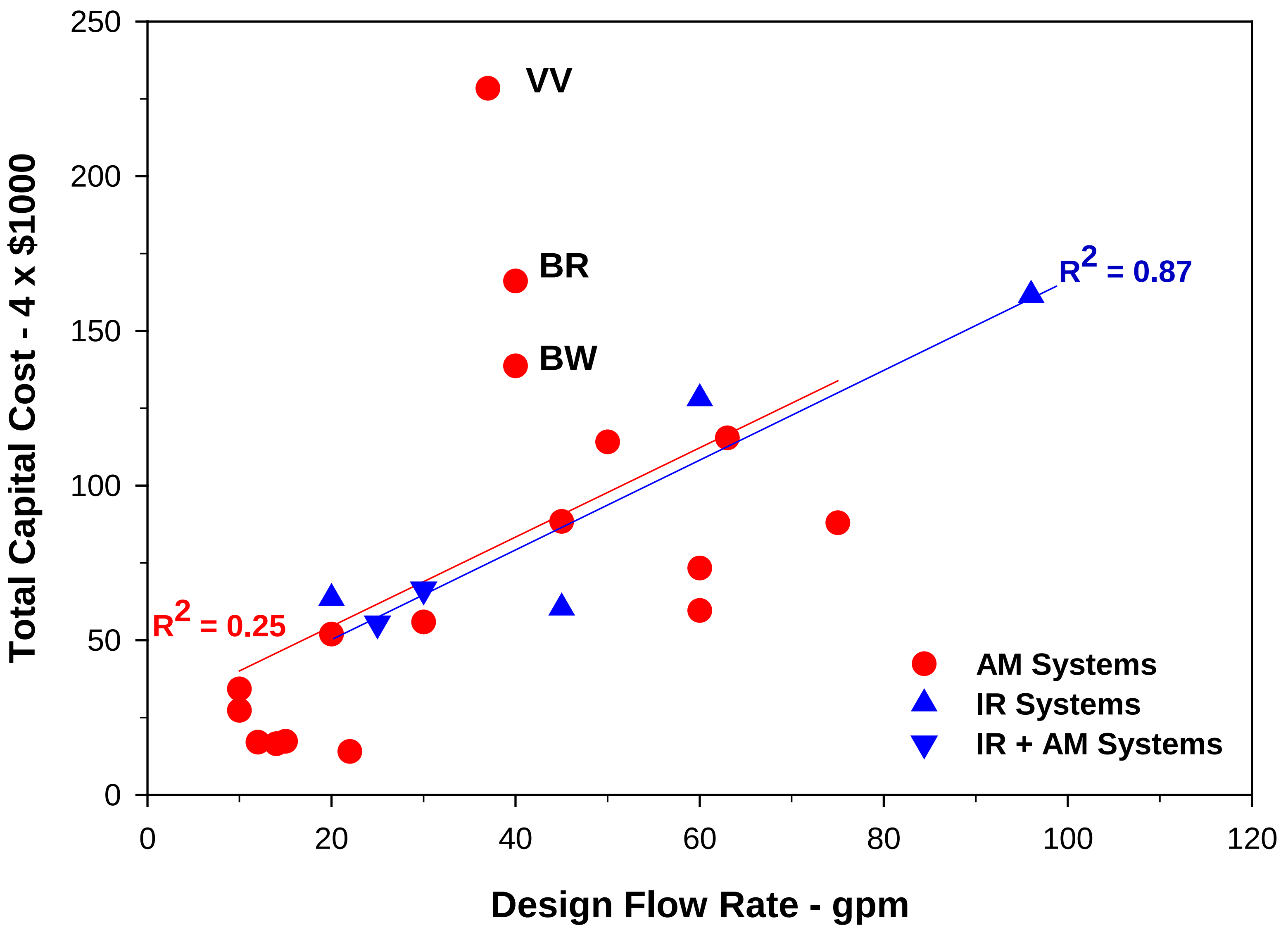
Capital Costs -Total



Capital Costs - > 100 gpm Systems



Capital Costs - < 100 gpm Systems



Total Capital Cost Categories

Total Capital Costs – EPA Funds
• Equipment
• Engineering
• Installation

Cost Categories - Percentages

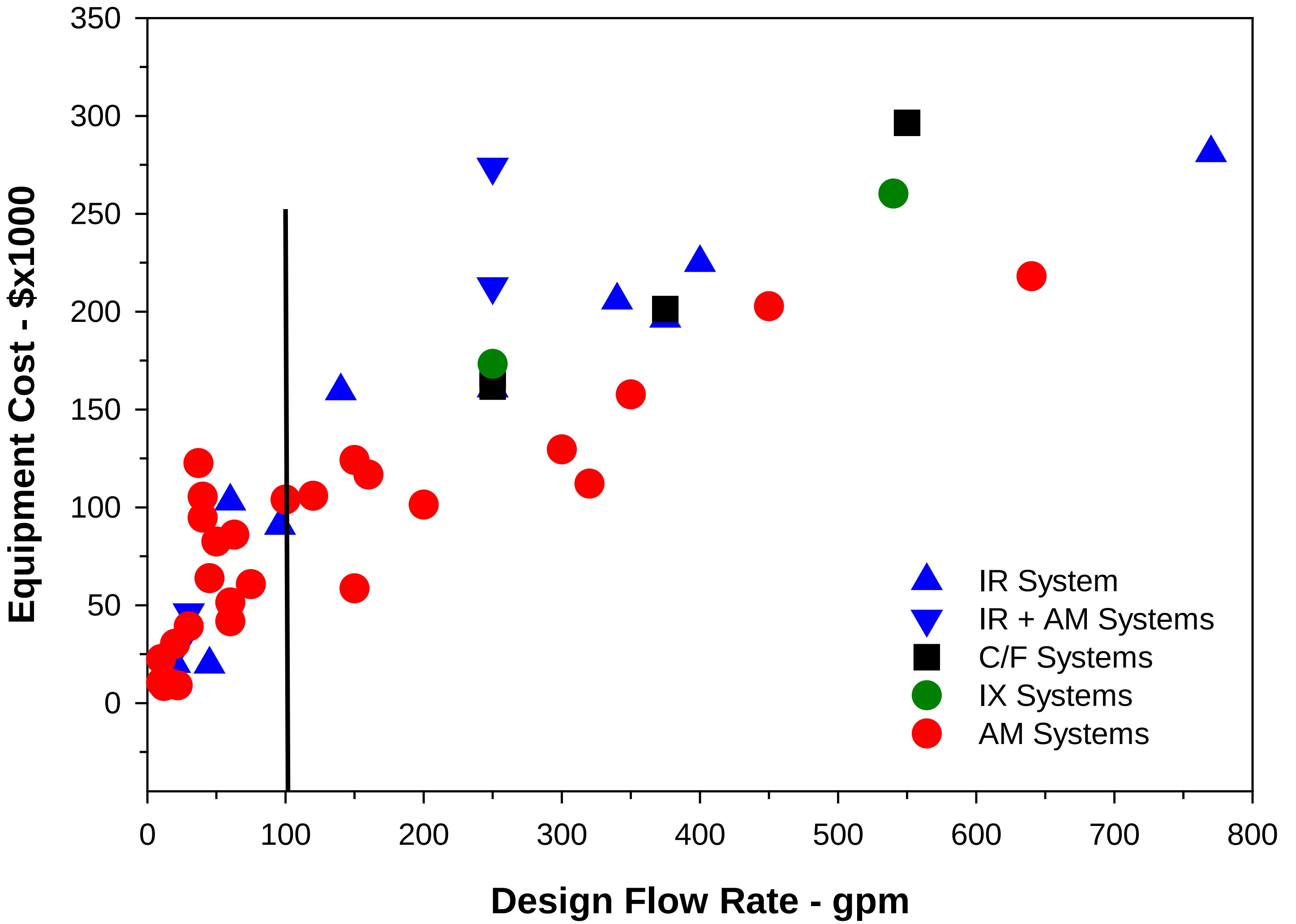
Systems	Equipment %	Engineering %	Inst & Start Up %
AM (All)	67	15	18
AM - <100 gpm	64	17	18
AM - >100 gpm	72	11	17
Other (All)	61	14	24
All Systems	**65**	**14**	**20**

Approximately 2/3 of Total System Cost is for Equipment

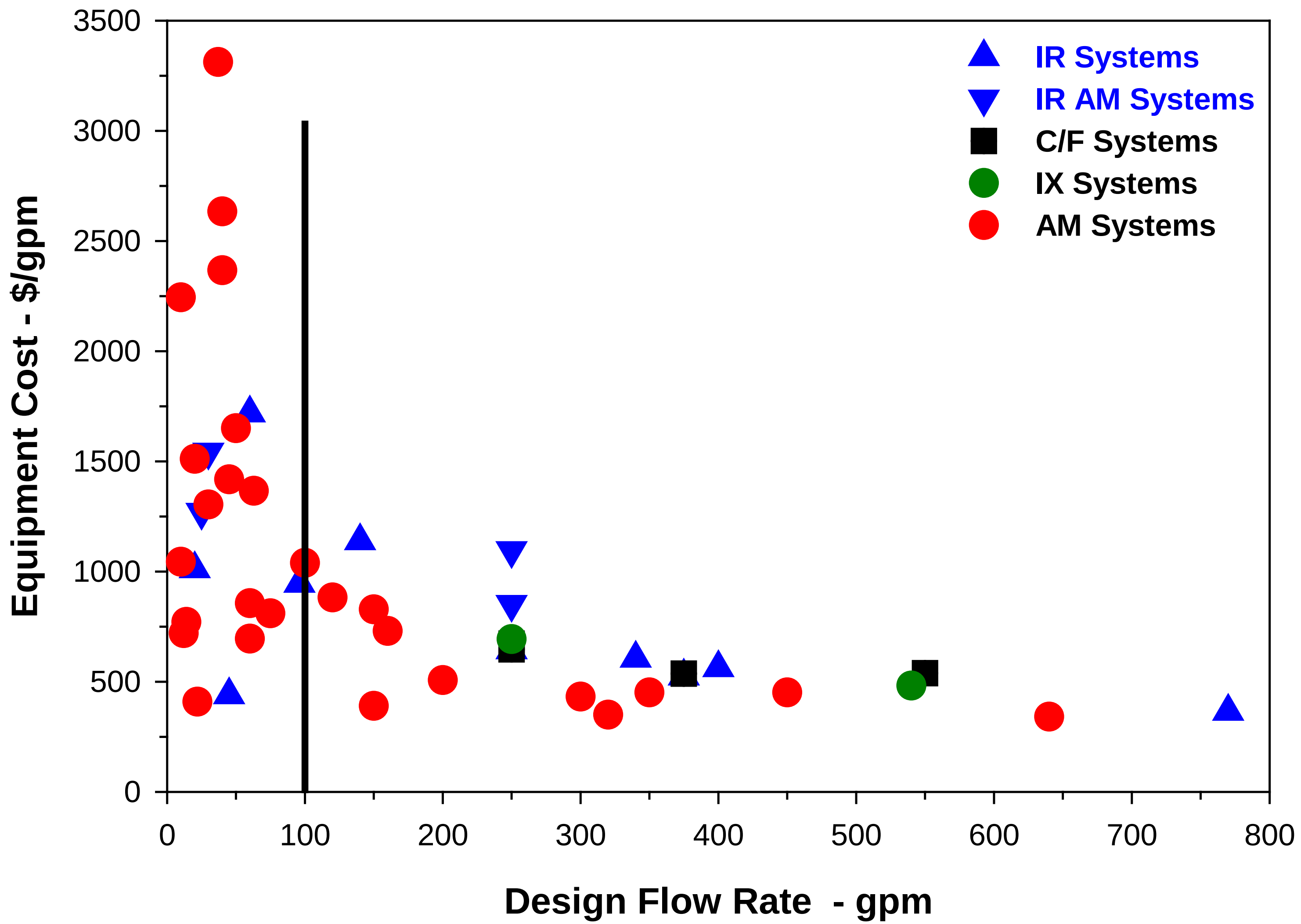
or

Total Cost = 1.5 (Equipment Cost)

Equipment Costs: Total vs Size (gpm)



Equipment Costs: $/ gpm vs Size ($/gpm)



AM Equipment Cost

System Cost Variables	Range/Number
System design	Series vs parallel
Tank size/number	
Tank material	4 – FRP, CS, SS, Polyglass
Media products (Costs)	9 ($40 - $559/cf)
EBCT min/tank	1 - 16
Instrumentation	
Valves	Automatic vs manual
pH adjustment	7
Backwash holding tanks	3

Water Systems – Tanks Cost

KF System

RFP

BW System

Carbon Steel

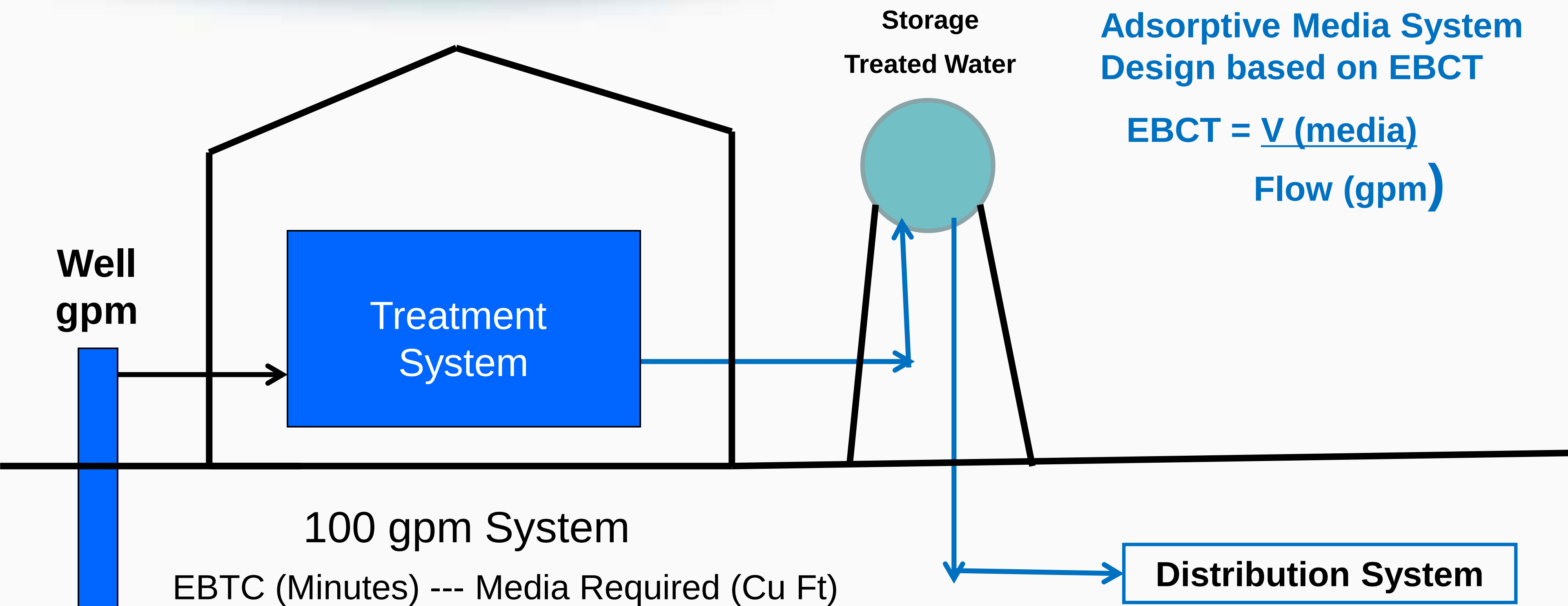
BR System

Stainless Steel

AM System – EBCT Variable

Adsorptive Media System Design based on EBCT

$$EBCT = \frac{V\ (media)}{Flow\ (gpm)}$$

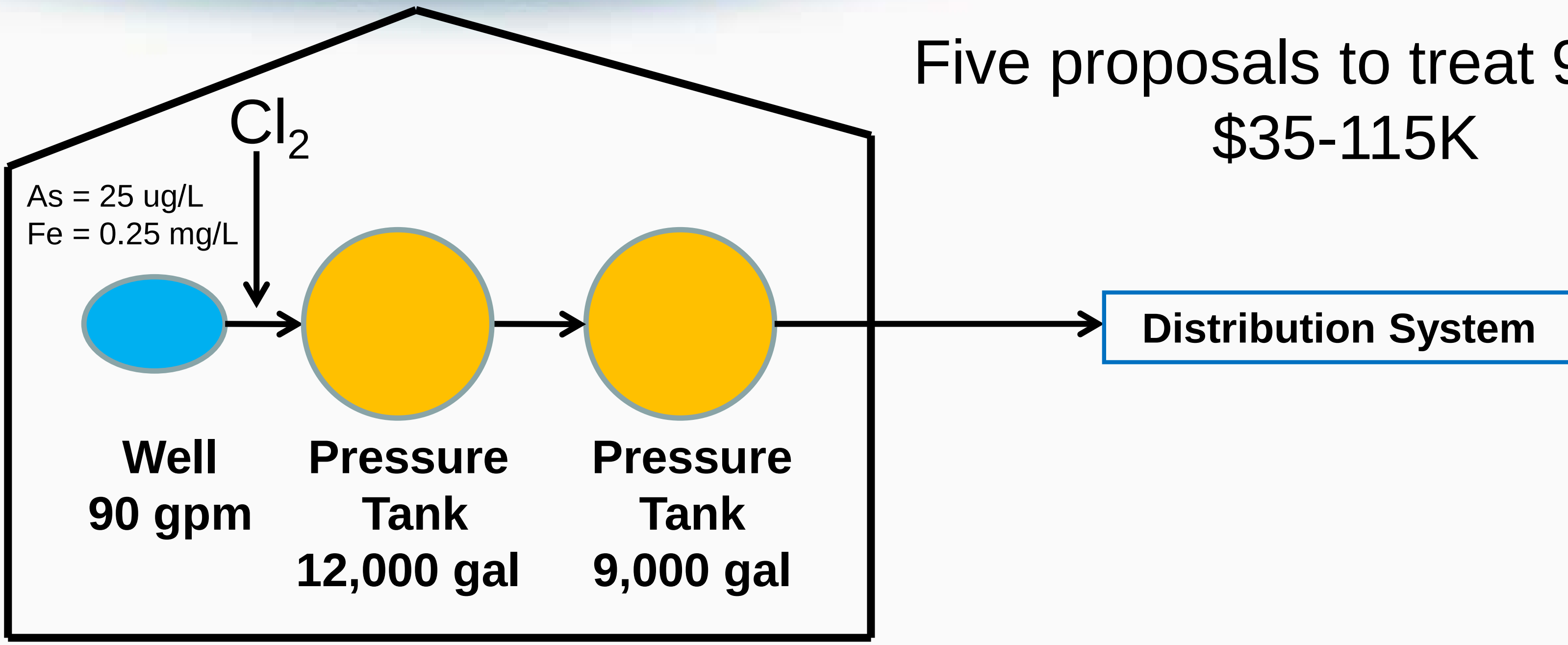


100 gpm System

EBTC (Minutes) ---	Media Required (Cu Ft)
1.5 Min ---------------	20
3.0 Min ---------------	40
5.0 Min ---------------	67
10. 0 Min -------------	133

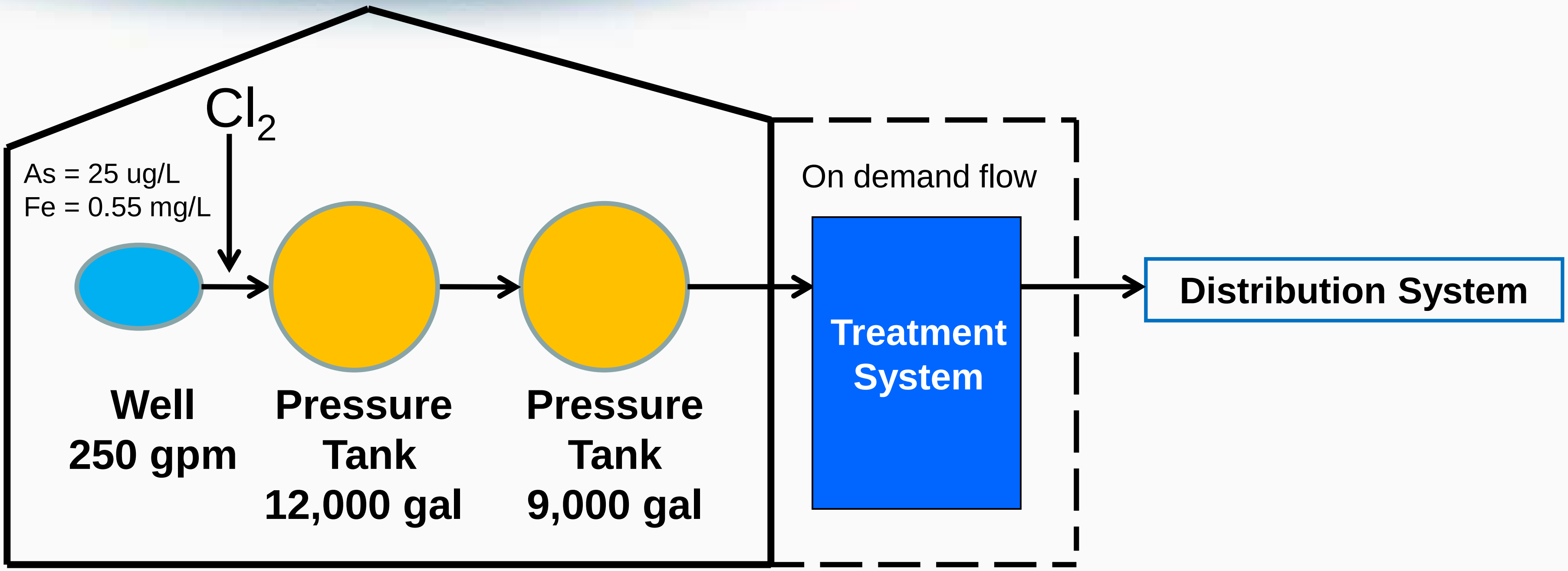
AM System – Serves 480 people

Five proposals to treat 90 gpm
$35-115K



Pressure tank

AM System – Serves 480 people



Decision – Place system after storage/pressure tanks to treat on demand flow where average flow was 32 gpm.

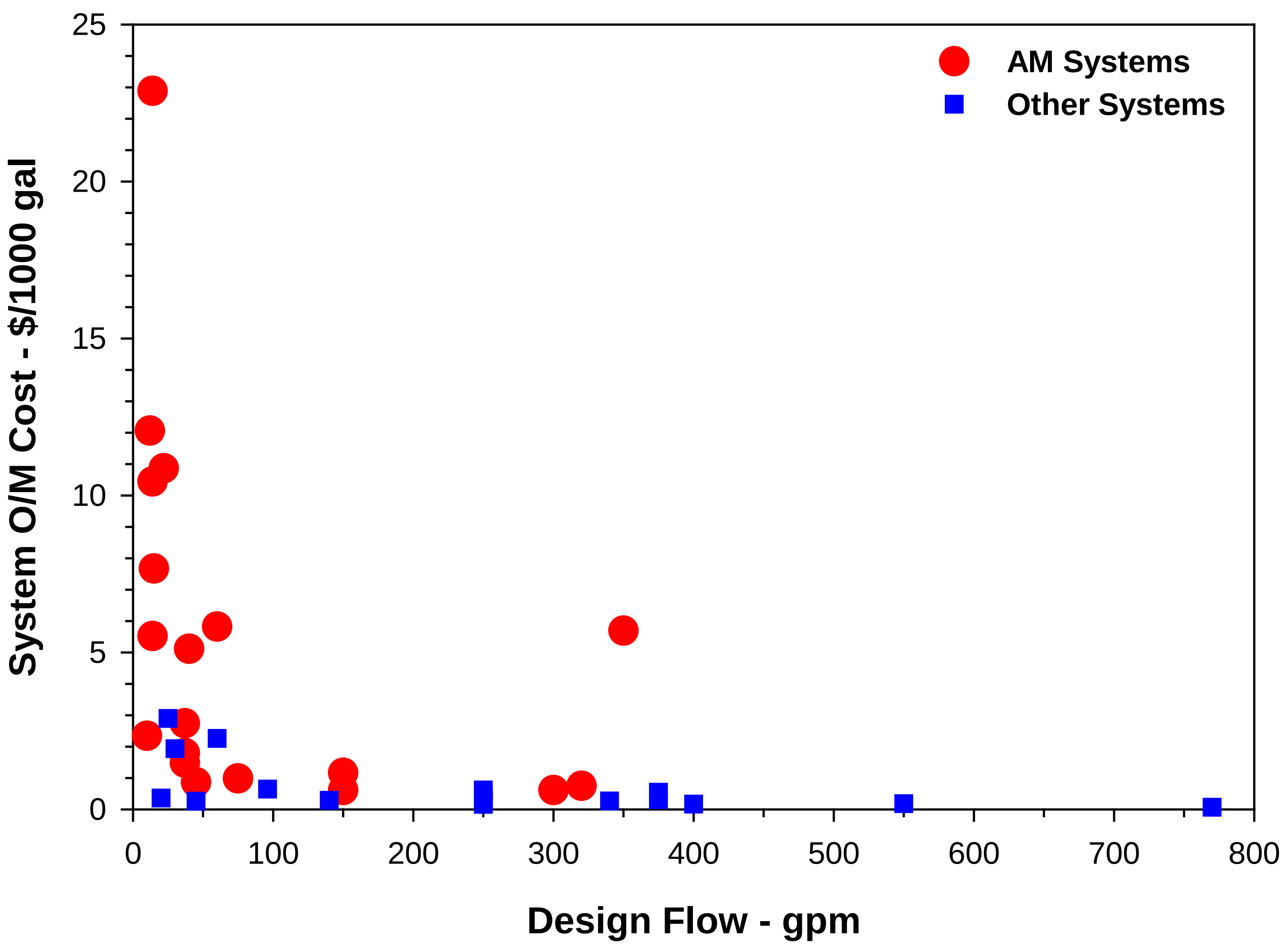
Series system reconfigured to parallel system to handle a State required 165 gpm peak flow.

O/M System Costs

O/M Costs

Based upon data collected during performance evaluation studies that lasted from 1 to 5 years

O/M Costs - $/1000 gal treated water



Comparison of O/M Costs of All Demo Systems

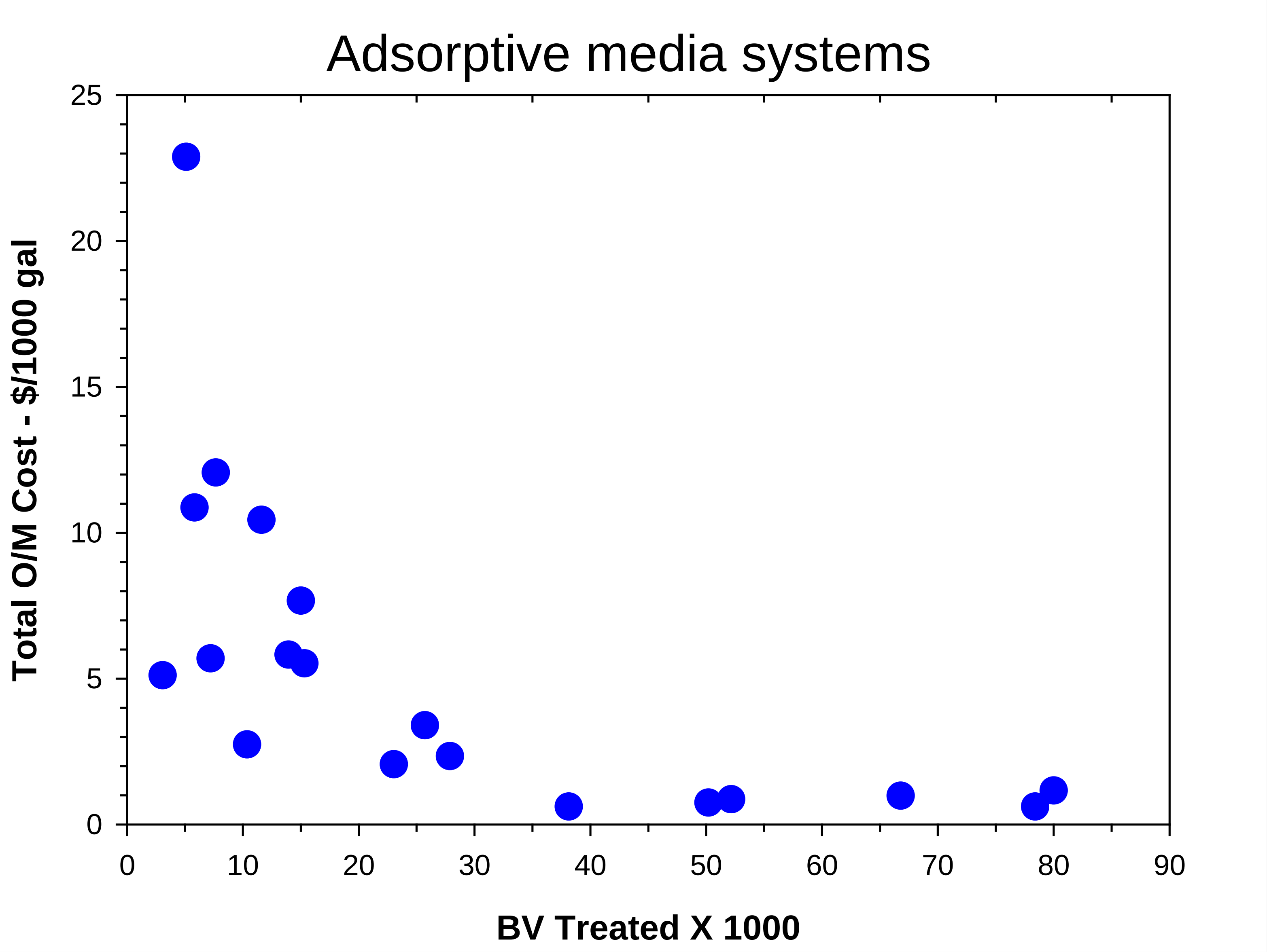
Technology	Total O&M (Avg)	Media Replacement Cost	Chemical Cost	Electricity Cost	Labor Cost
Systems<100 gpm					
AM	**6.47**	**5.58**	0.08	0.03	0.78
IR/CF	**1.39**	NA	0.14	0.10	**1.15**
Systems>=100 gpm					
AM	**1.76**	**1.57**	0.01	0.01	0.17
IR/CF	**0.28**	NA	0.04	0.05	**0.19**
IX	**0.49**	NA	0.39	0.06	0.04

Note: O/M cost of AM systems based upon 15 systems having to replace media during performance evaluation studies

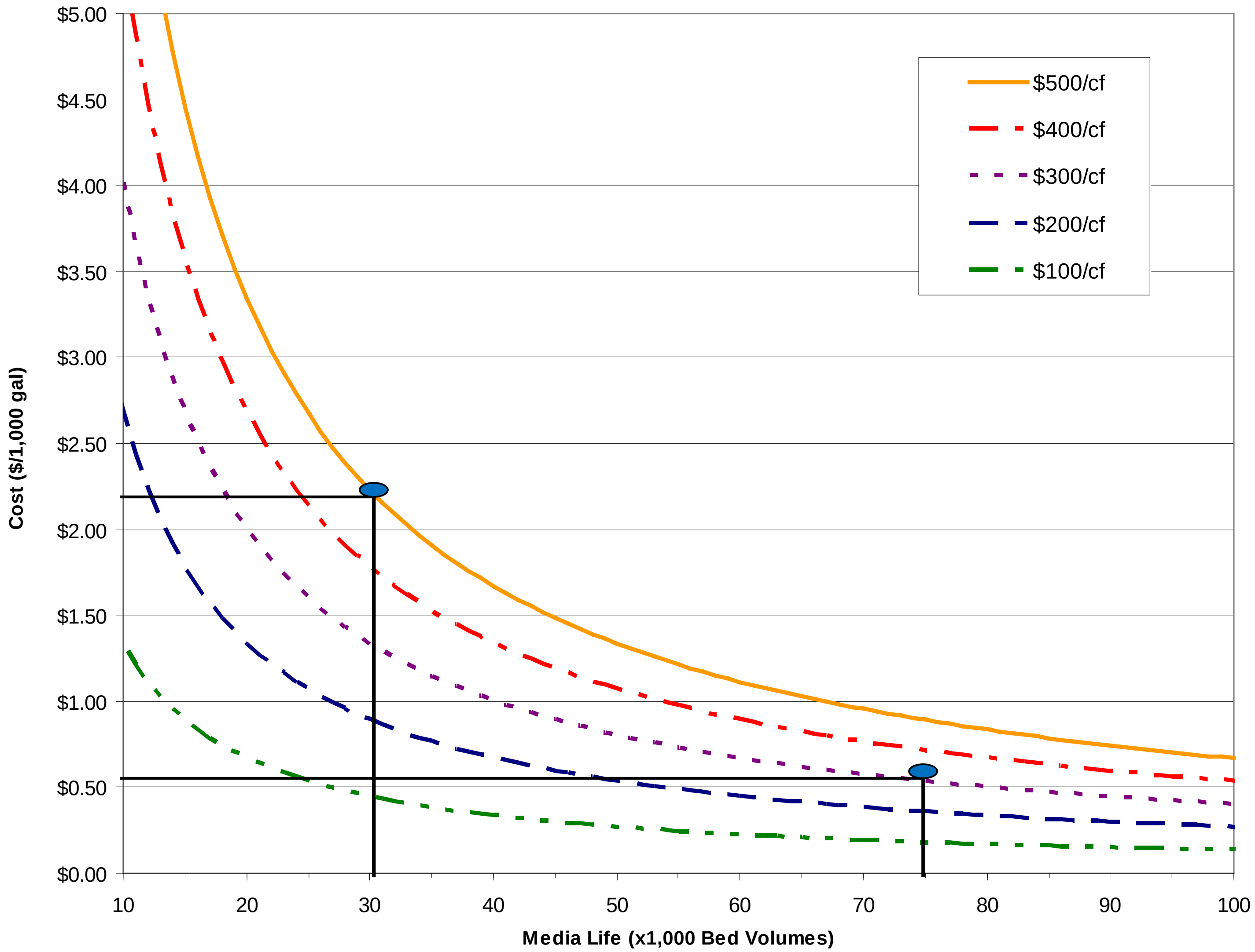
O/M Costs of Systems w/ Media Change Out (15 Systems)

Cost Categories	% of Total (Avg)	Min %	Max %
Media Replacement	**81**	**49**	**98**
Chemical (Cl_2, pH Adj.)	2	0	9
Power (Electricity)	<1	<1	8
Labor	8	1	41

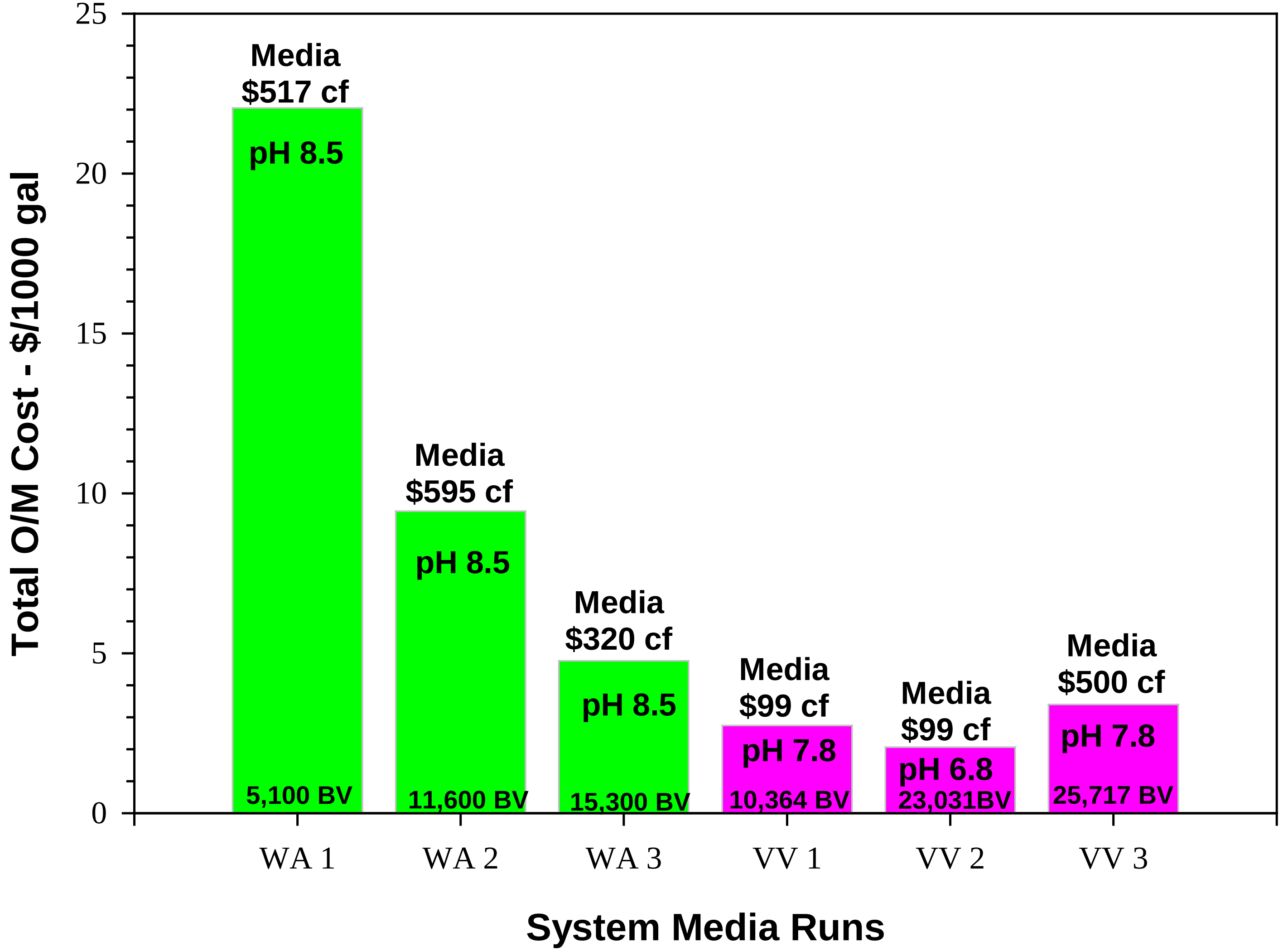
AM O/M Cost ($/1000) vs BV Treated Water



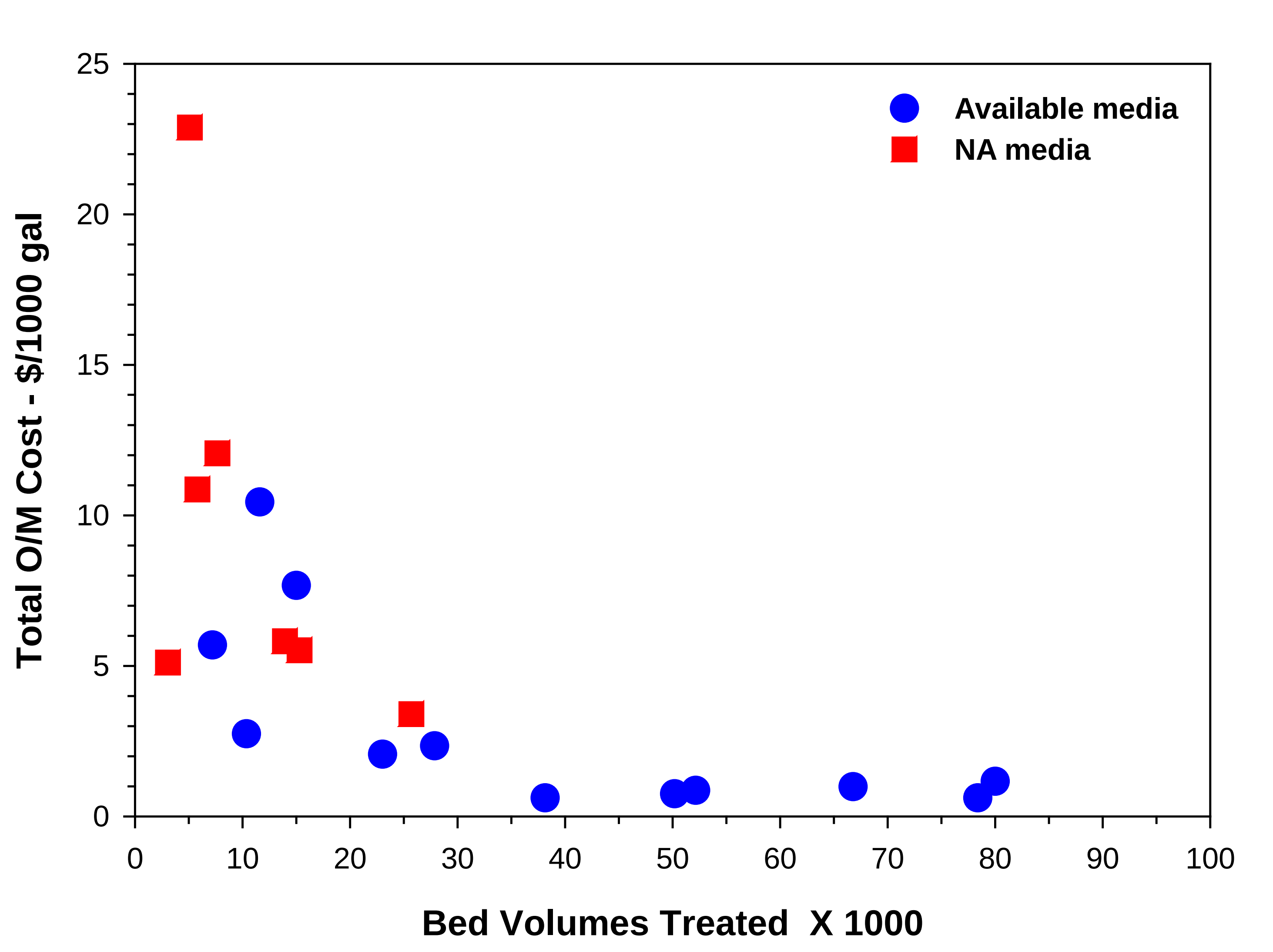
AM Media Cost



Reducing Media Cost



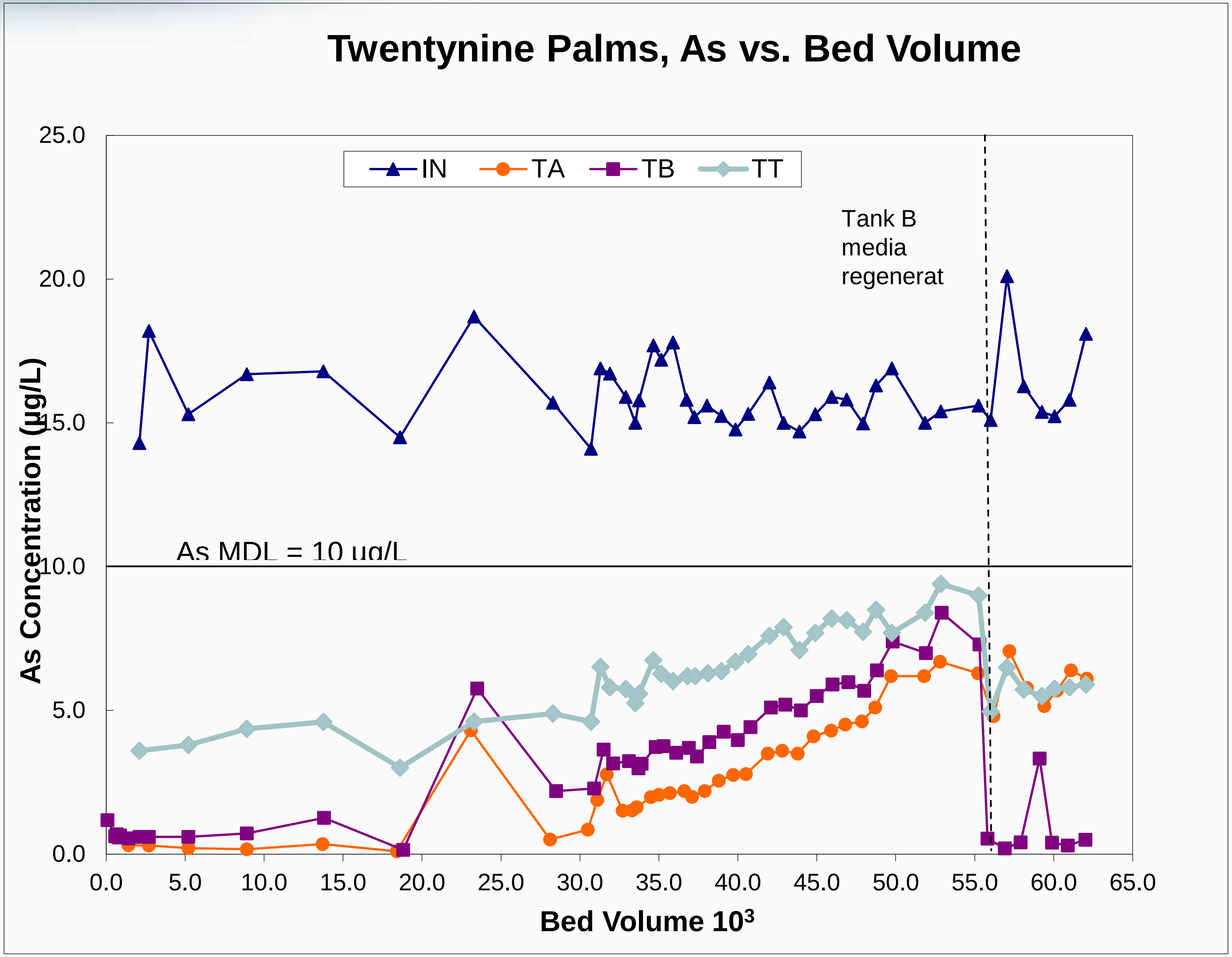
Impact of Media Performance



Regeneration of Media

Extend life of media replacement
by
on-site regeneration of exhausted media

AM Regeneration



Regeneration saving around $10,000

Summary – Capital Costs

System Capital Costs

- Total capital costs varied widely for all sizes and types, but particularly for the very small (< 100 gpm) AM systems. The AM equipment costs are impacted by many design features including tank material, EBCT, media cost, valving and instrumentation.

- Equipment is a major cost component (2/3) of total capital cost of a treatment system.

- For > 100 gpm systems, total capital cost of adsorptive media systems slight low than other types of arsenic removal systems.

O/M Costs – Summary

O/M Costs

- O/M costs of AM systems are generally higher than IR, C/F and IX technology.
- Media change out of AM systems accounts for around 80% of O/M cost. Thus, media performance and cost is the major factor in determining total O/M of AM system.
- AM systems have reduced their O/M costs by switching to a lower cost, higher performance AM media product.
- Some AM systems have converted to C/F system that have lower O/M costs.
- Regeneration of media has potential to lower O/M cost for larger systems.

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