Considerations for Pilot Testing of Arsenic Treatment Processes

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Introduction

- ~5,000 public water systems have at least once source of water with arsenic (As) > 10 ug/L
  - Most are systems which rely upon ground water as source of supply
- Must achieve compliance with new MCL by 1/06
  - As treatment will be technically challenging
  - As treatment will be costly

Challenges

- Utilities which rely upon ground water don’t treat water at present
- Construction and operation of treatment facilities is expensive
- Utilities don’t have technical expertise to design or operate treatment plants
- As treatment processes are in early stage of development
  - Design guidance are not well established
  - O&M requirements not well documented
  - Few qualified engineers or operators with As treatment experience
- Uncertainties & challenges can be addressed by conducting pilot testing of treatment processes

Status of As Treatment Operations

Process	**Level of Maturity**	**Pilot Testing Need**
Oxidation	High	No
Adsorption	Medium	Yes
Coagulation/Filtration	Medium	Yes
Ion Exchange	High	No
Membrane Processes	RO – High μ & n-filtration – Medium	No Maybe
Residuals Management	Low	Maybe

Objectives of Presentation

- Provide guidance in design & operation of pilot testing processes
  - Determine when pilot testing is needed
  - Identify factors to be considered in design of pilot testing programs
  - Considerations in operation of pilot test
  - Identify limits of information that can be gained from pilot test

- Focus is on adsorption & coagulation/filtration studies

Objectives of Pilot Testing

- Develop design data
  - Performance
  - Cost
- Develop O&M data
  - Complexity
  - Cost
- Provide operator training
- Develop confidence in performance of prototype
  - Important for public & regulatory acceptance

General Considerations - 1

- Site - often determined by utility, but not always (e.g. AwwaRF projects with utility participation)
- Site considerations
  - Water quality - As, pH, competing/interfering constituents
  - Other utilities - electric, gas, sewer
  - Disposal options - treated water & residuals
  - Access - both for equipment & for operators
  - Security
  - Housing for operators

General Considerations - 2

- Who should do testing?
  - Utility
  - Consultant
  - Vendor
  - University
- Scale of testing - lab scale vs. field scale
  - Depends on objectives
- Design of pilot test facility
- Operation of pilot test facility
- Analytical considerations

Lab Scale vs. Field Scale

Lab Scale	**Field Scale**
• Less costly	• Will produce design data
• Can control variables better	• Representative of field conditions
• Can investigate more variables	• Provides O&M training & experience
• Appropriate for fundamental studies	• Many logistical challenges

Pilot Testing of Adsorption Processes

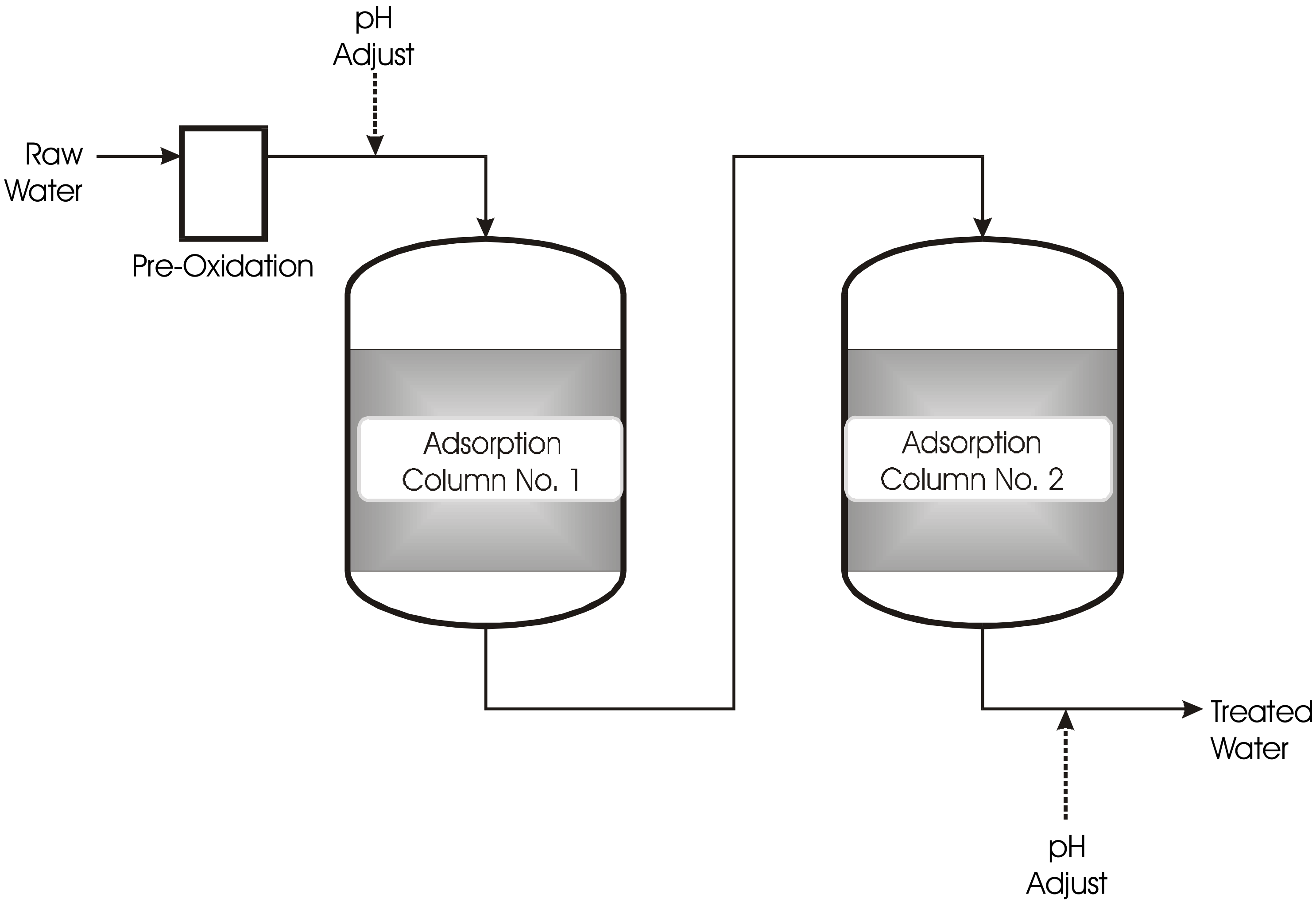
- Scale of design
- Variables to be tested
- O&M Protocol
- Duration of test

Determination of Adsorbent Performance

- Batch tests - Isotherm studies
  - Rapid
  - Qualitative comparison of capacity, selectivity & effects of interferences
- Column tests
  - Long duration - Costly and difficult

- Pre-oxidation is important

Adsorption System Design



Scale of Adsorption Pilot Tests

- Advantages of lab scale tests (< ~.5gpm)
  - Fewer logistical challenges
  - Less costly - primarily due to smaller equipment
  - May be able to use Rapid Small Scale Column Testing (RSSCT) procedure - Reduced duration
- Advantages of field scale tests (> ~10 gpm)
  - Uses equipment similar to prototype
    - More reliable scaling to prototype
    - Experience with O&M challenges
    - Experience with residuals
    - Operator training

Variables of Interest in Adsorption Tests

- Media type
  - Capacity (no. of bed volumes (BVs) treated)
- Process kinetics
  - Establish EBCT ($V_{empty\ bed}/Q$)
  - Surface loading (Q/A)
- Solution chemistry
  - pH
  - Competing constituents (Si, PO_4^{3-}, V, SO_4^{2-}, Fe, Mn, etc.)
  - Treated water quality

Nambe Pueblo Well House

- Columns located in well house
- Fed by adjacent water tank
- Disposal of treated water was problem
- Secure location but requires assistance of operator for access

Nambe Pueblo Buffalo Well

- Fluctuating water level in adjacent tank caused variable flow. Resolved by adding booster pump

Nambe Pueblo Buffalo Well

El Paso Canutillo Well Field

- Pilot testing of GFH at ambient pH (~8.0) & 6.8
  - pH adjusted by CO_2
- Other columns testing E-33 & SANS (not shown)

Zia Pueblo Field Tests

- Points to note
  - Security concerns
  - Can’t operate during winter
  - Disposal of treated water
  - Remote location complicates O&M
  - No utilities

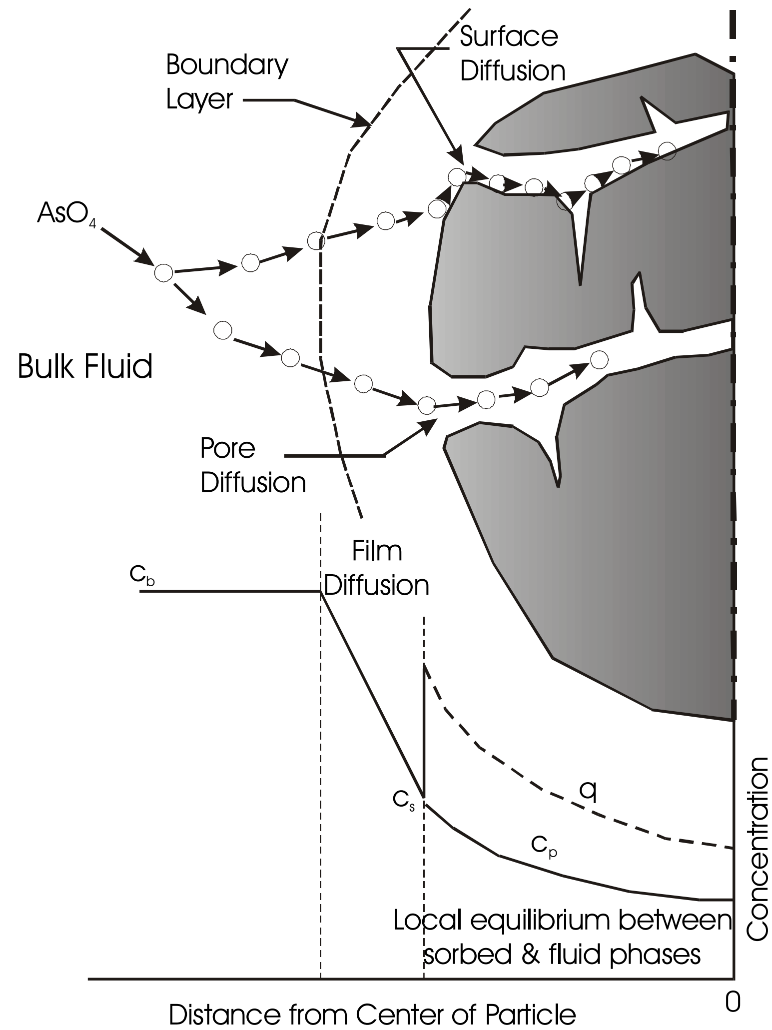
Rapid Small Scale Column Tests (RSSCT)

- Adsorption process consists of sequence of steps
  - External transport
  - Film transport
  - Internal transport
  - Bonding to surface
- Theoretical modeling of adsorption process for GAC led to recognition that often the internal transport (pore & surface diffusion are rate limiting steps
- RSSCT leads to accelerated testing through use of smaller radius media - reduced internal transport resistance

Transport Mechanisms

(from Crittenden et al., 1987)

- Bulk transport to boundary
- Film transport across boundary layer
- Internal transport
  - Pore diffusion
  - Surface diffusion



Application of RSSCT to Design

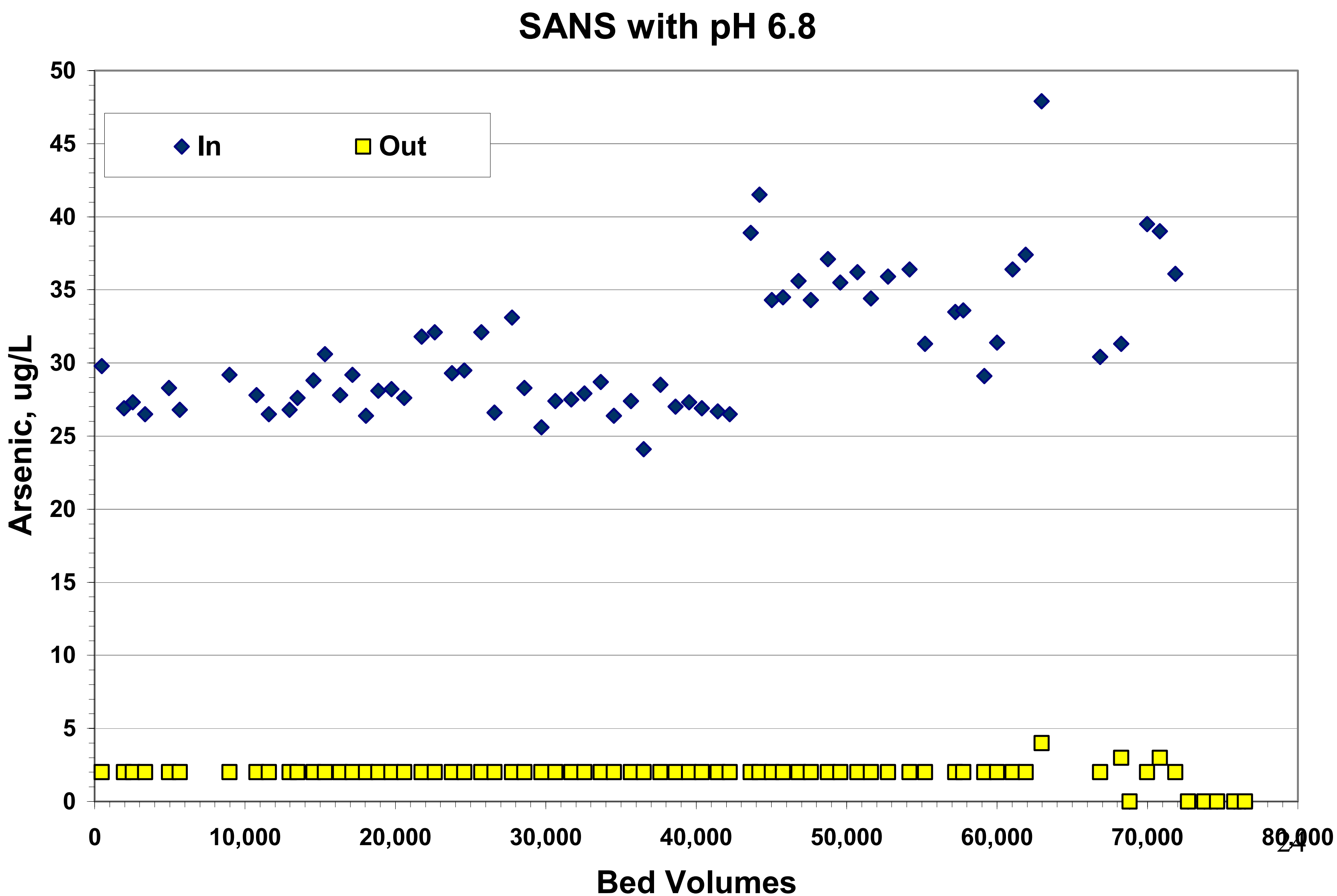
- Conduct batch studies to determine Freundlich constants (K & 1/n)
  - Needed for equilibrium capacity determination
- Measure internal mass transport parameters with Differential Column Tests
  - Use HSDM model to analyze results
  - Determine dependence of particle size on D_s
- Determine X in scaling equation:

$$\frac{EBCT_{SC}}{EBCT_{LC}} = \left[\frac{R_{SC}}{R_{LC}}\right]^{2-x} = \frac{t_{SC}}{t_{LC}}$$

Laboratory Columns

- Example:
  - 2.5 cm x 10 cm col., V = 50 mL
  - 5 min EBCT
  - 10,000 bed volumes = 35 d
  - Requires 500 L of water
- Problem:
  - New media can treat to 10^5 BVs(?)
  - Challenges of column tests:
    - Time
    - Cost
    - Manpower

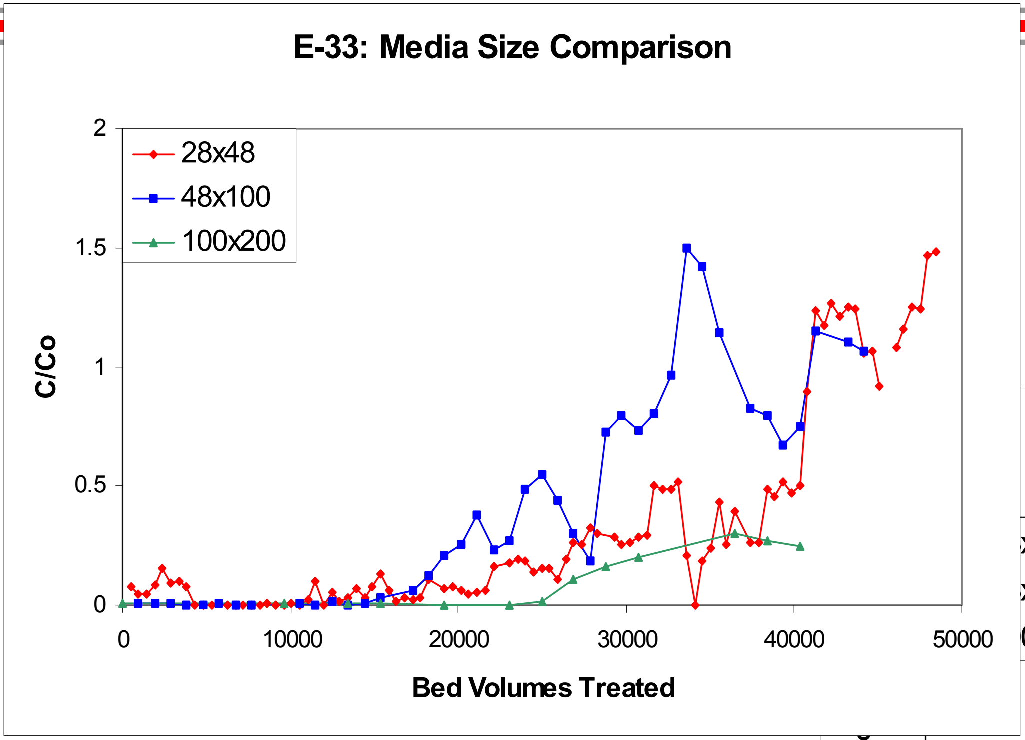
The Problem With Column Studies: El Paso Results

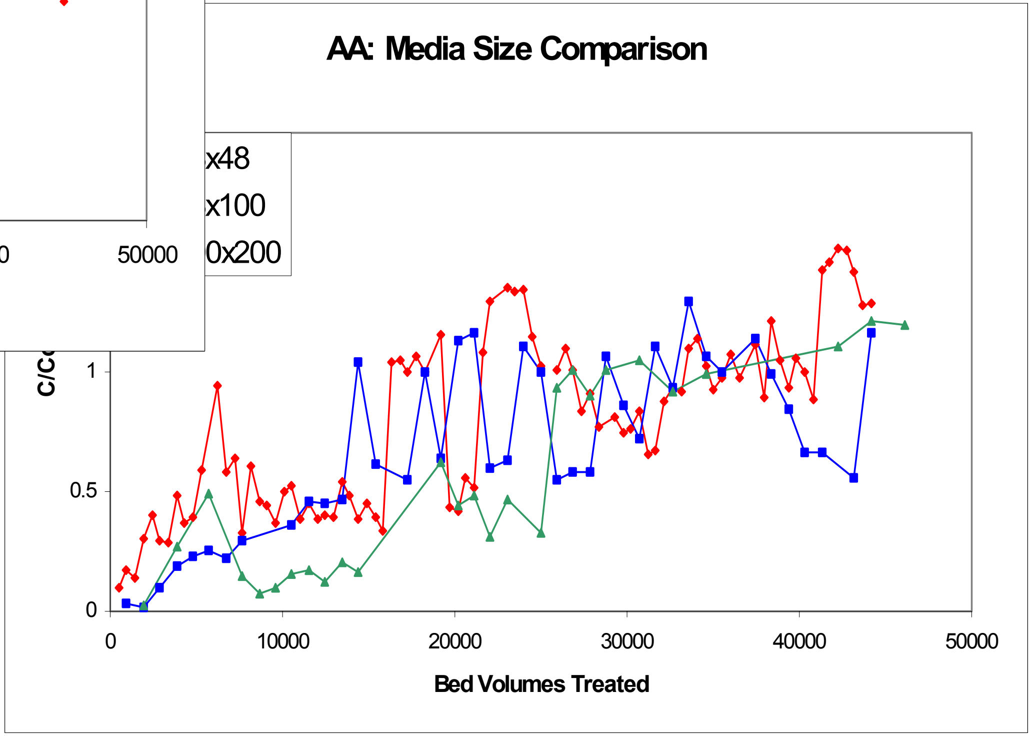


Lab Scale Columns

100x200 Mesh Column

RSSCT Results



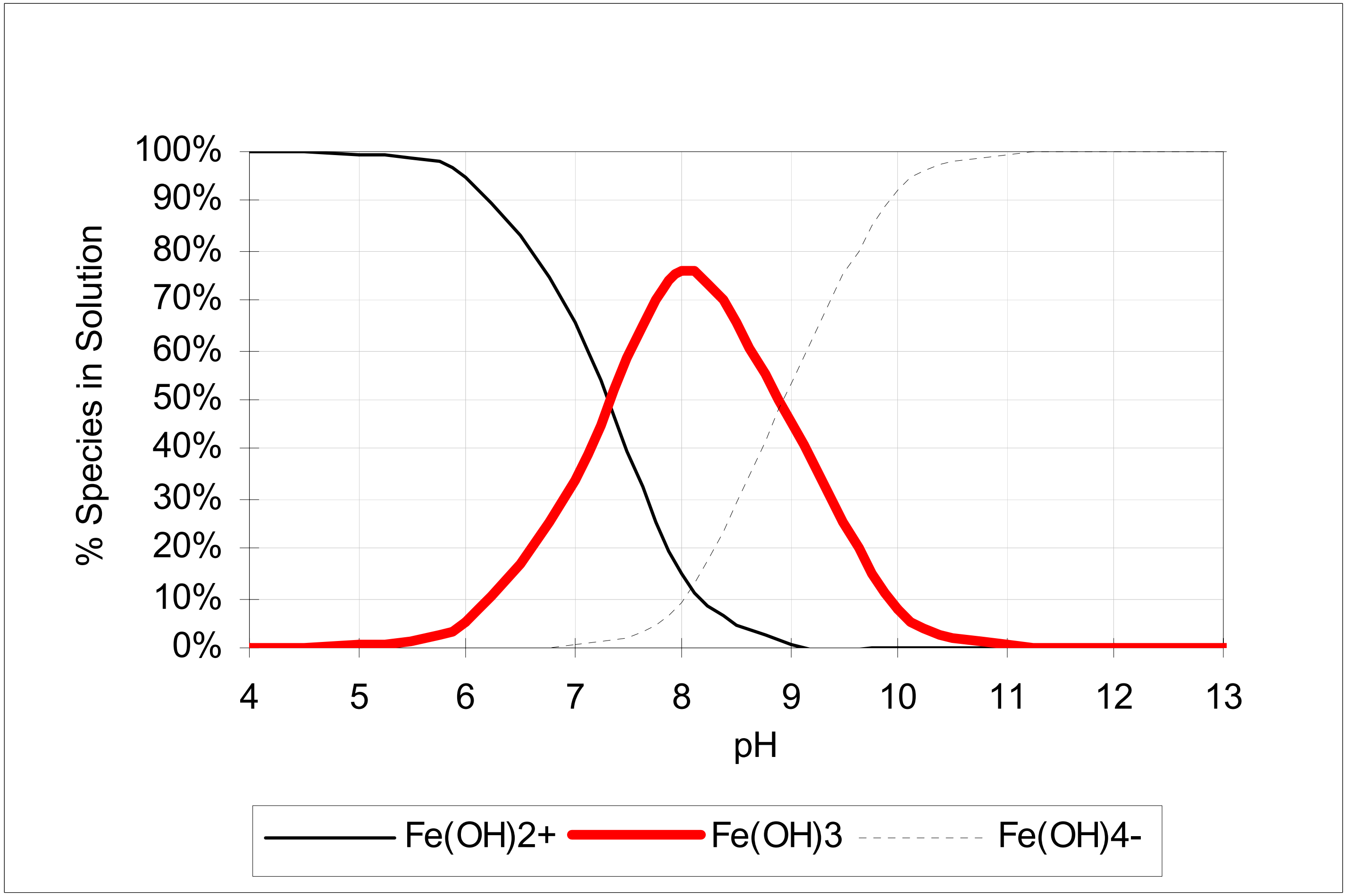


Objectives of Coagulation/Filtration Testing

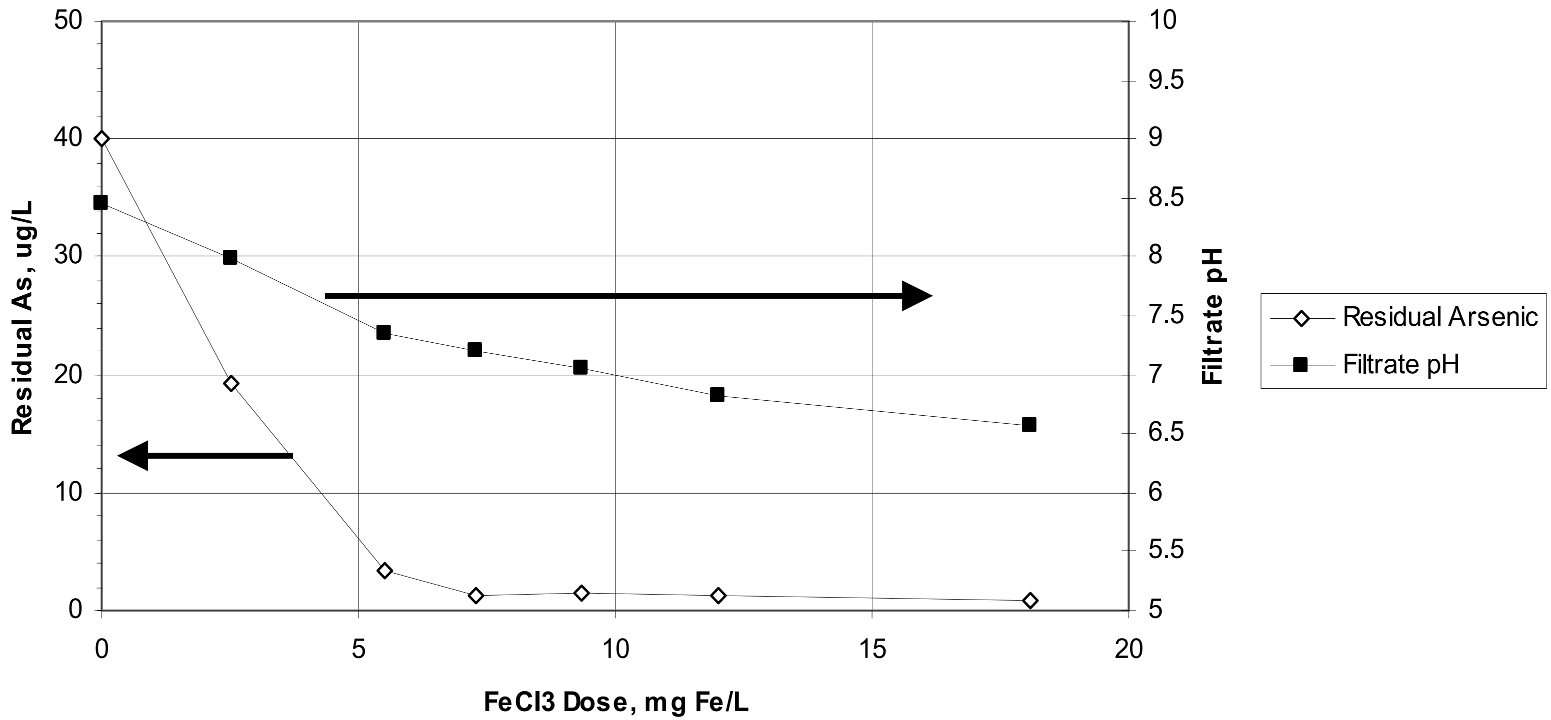
- Coagulant Dose vs pH for effective As removal
- Want to minimize solids loading to filter
- Want to maximize filter run time
- Want to maximize filter loading or flux rate
- As removal can be effectively coupled with iron and manganese removal

- Laboratory testing used to establish general criteria
- Due to dependence on equipment size, limited value of lab scale pilot tests

Surface Charge of $Fe(OH)_3$: pH < 7.3 for As Removal

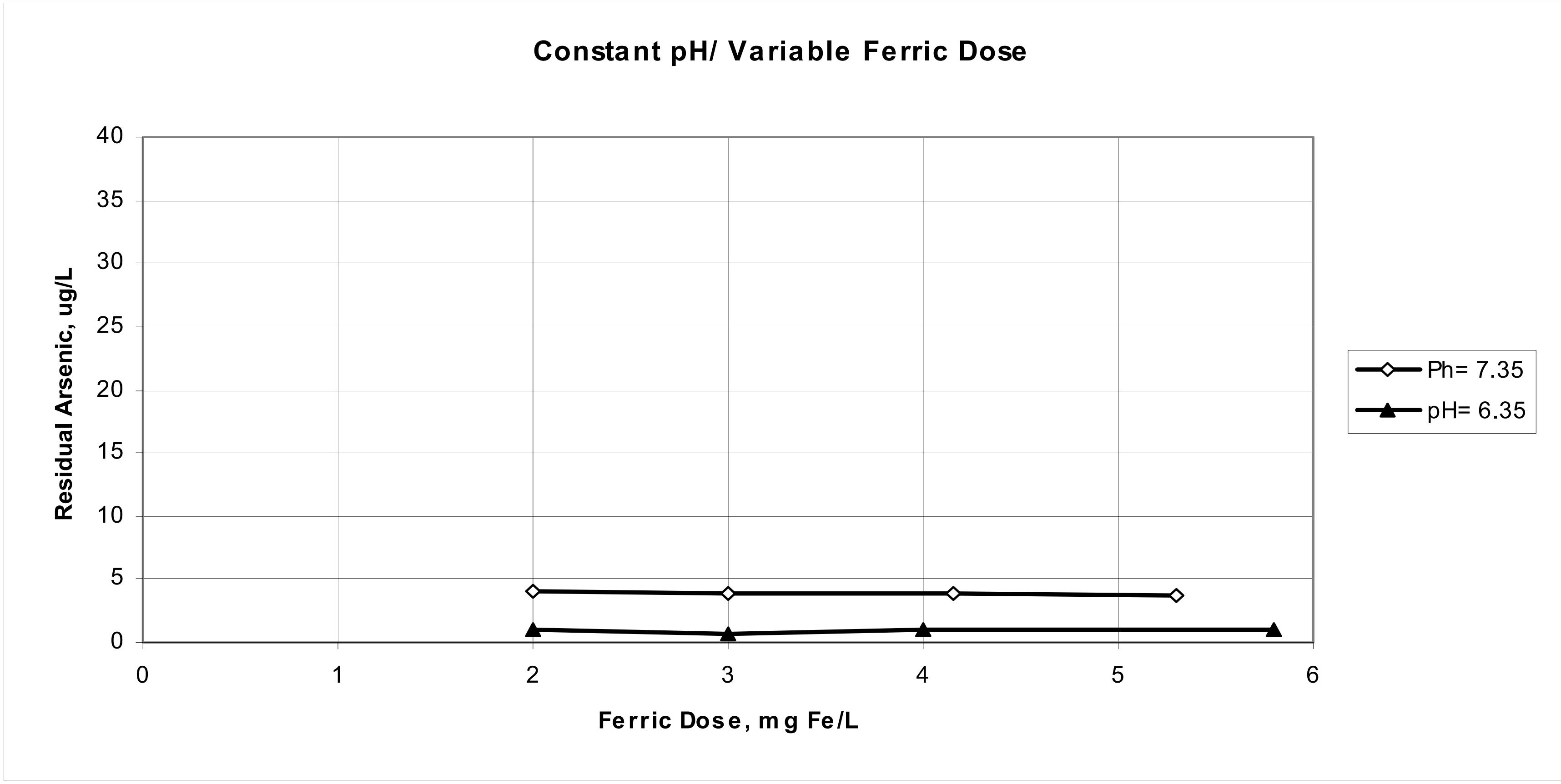


$FeCl_3$ Dose vs Arsenic Removal: Albuquerque NM



After Clifford, 1999

pH More Important Than $FeCl_3$ Dose



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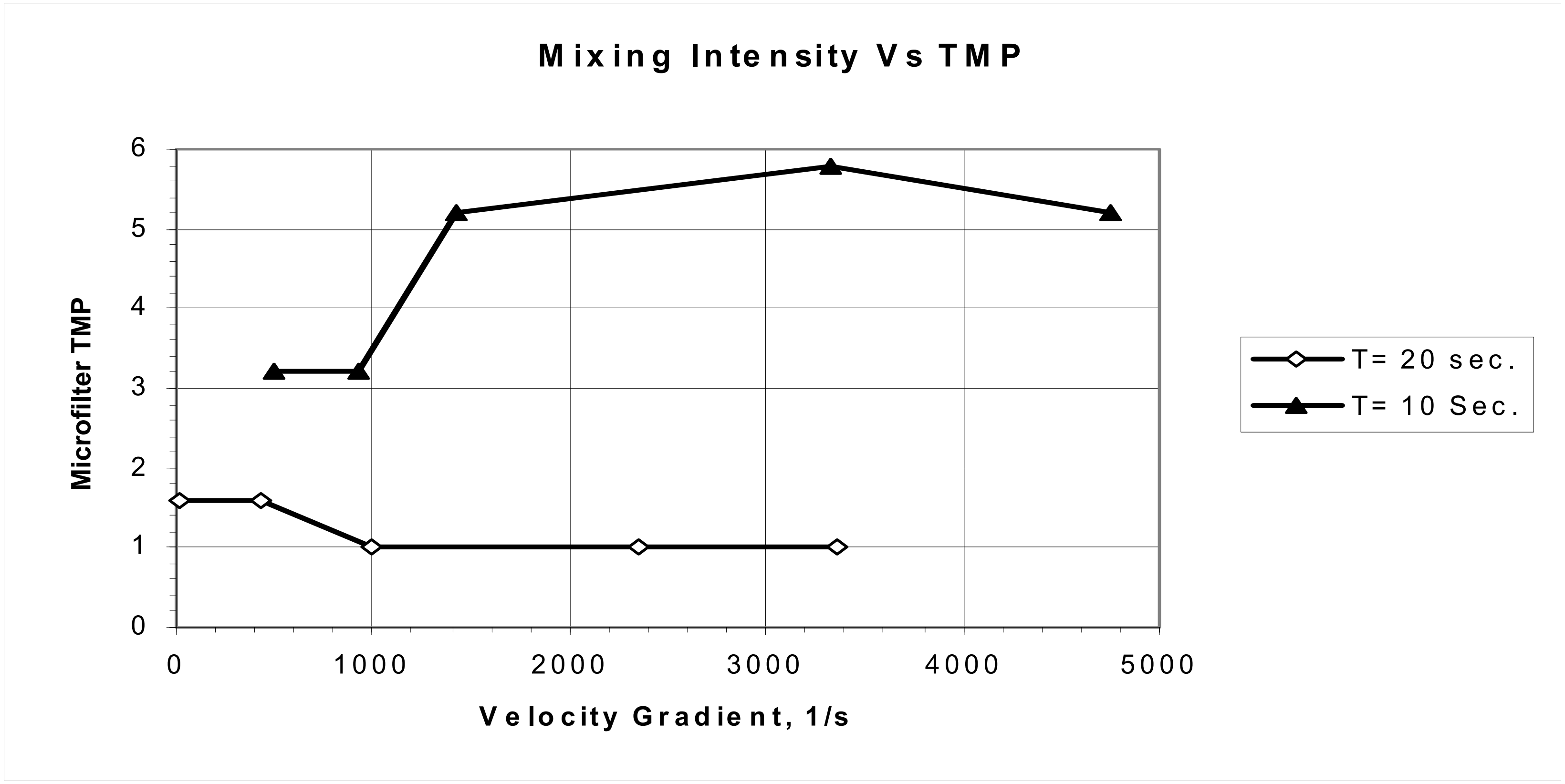
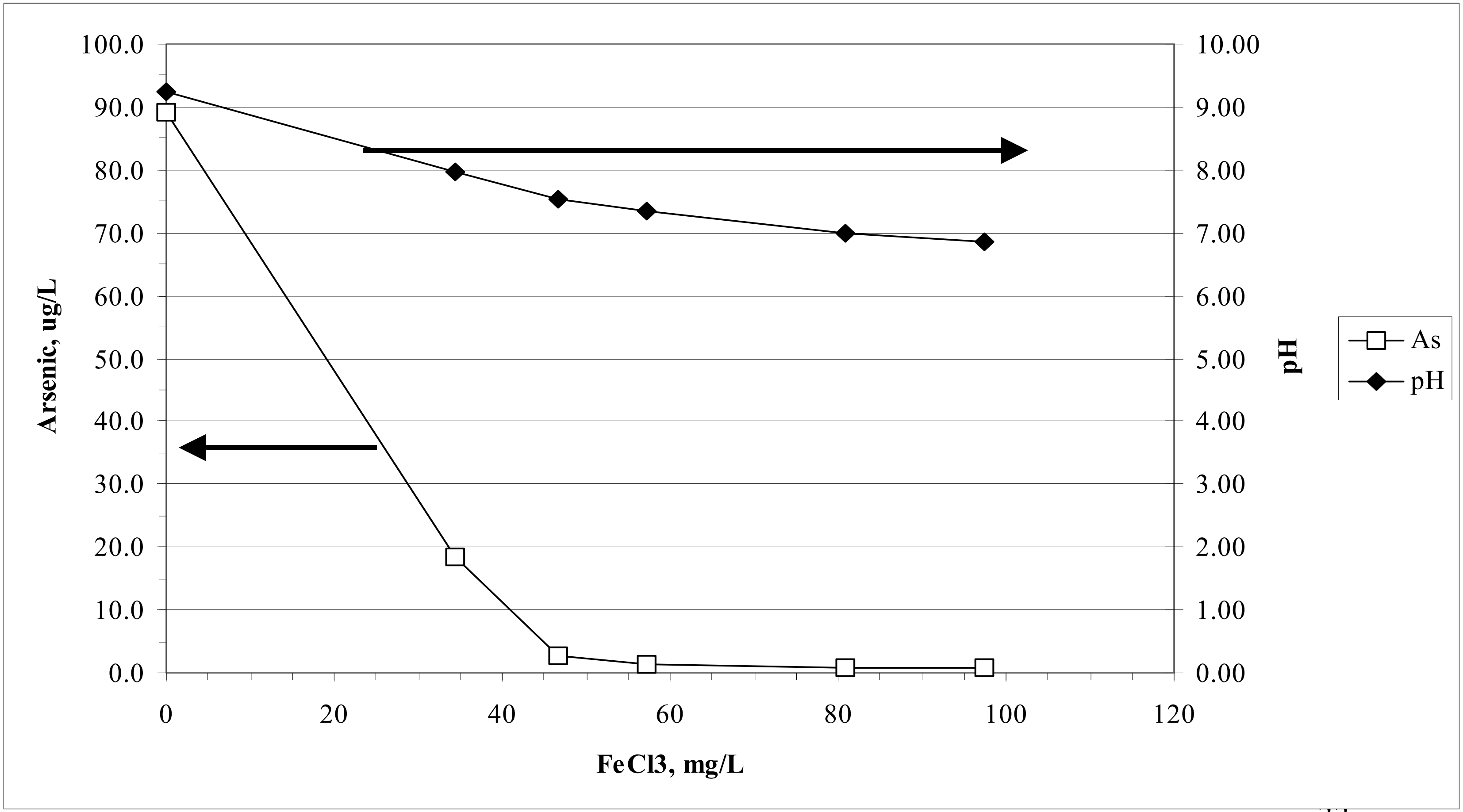
Coagulation Time & Mixing Intensity are Less Important

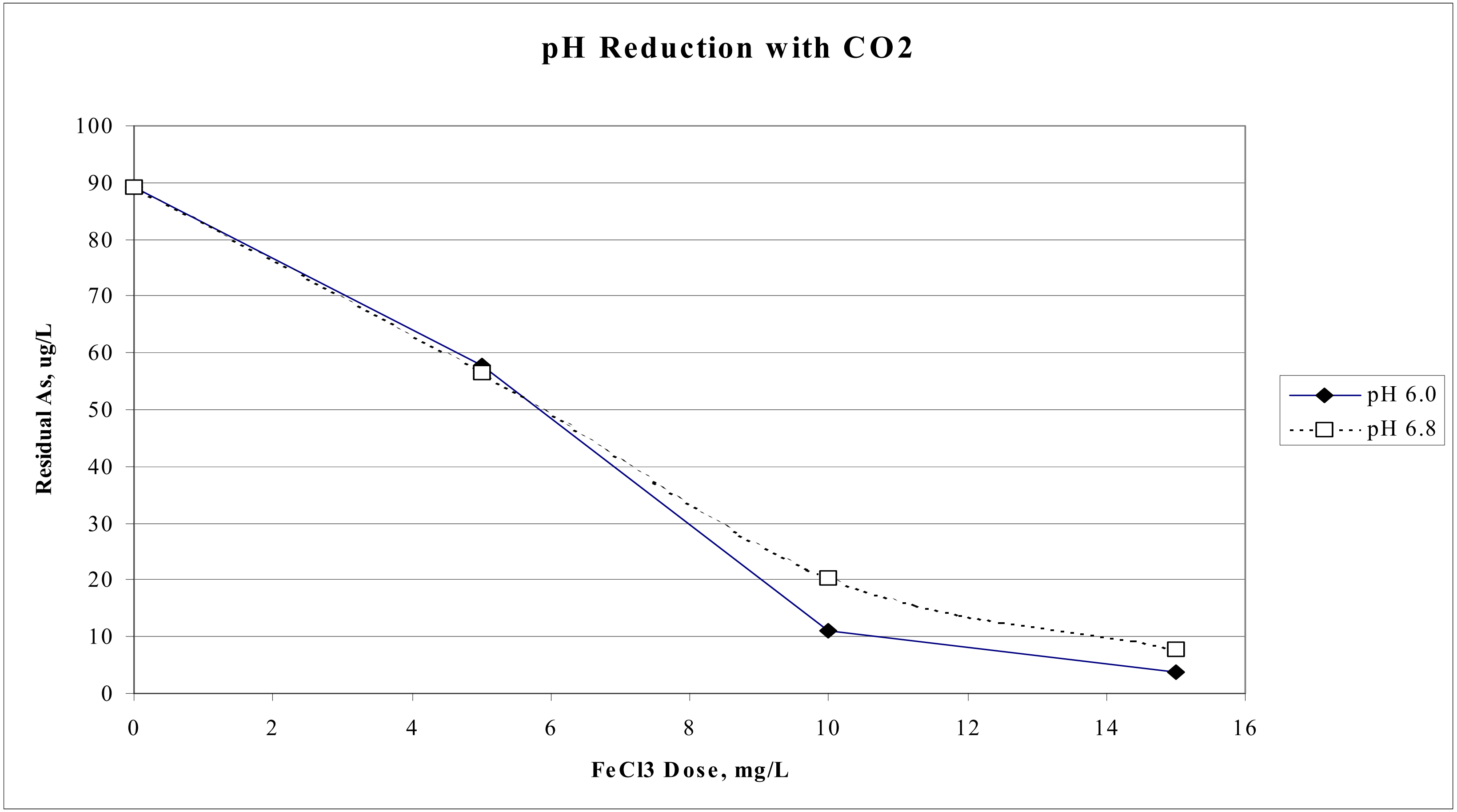


After Clifford, 1999

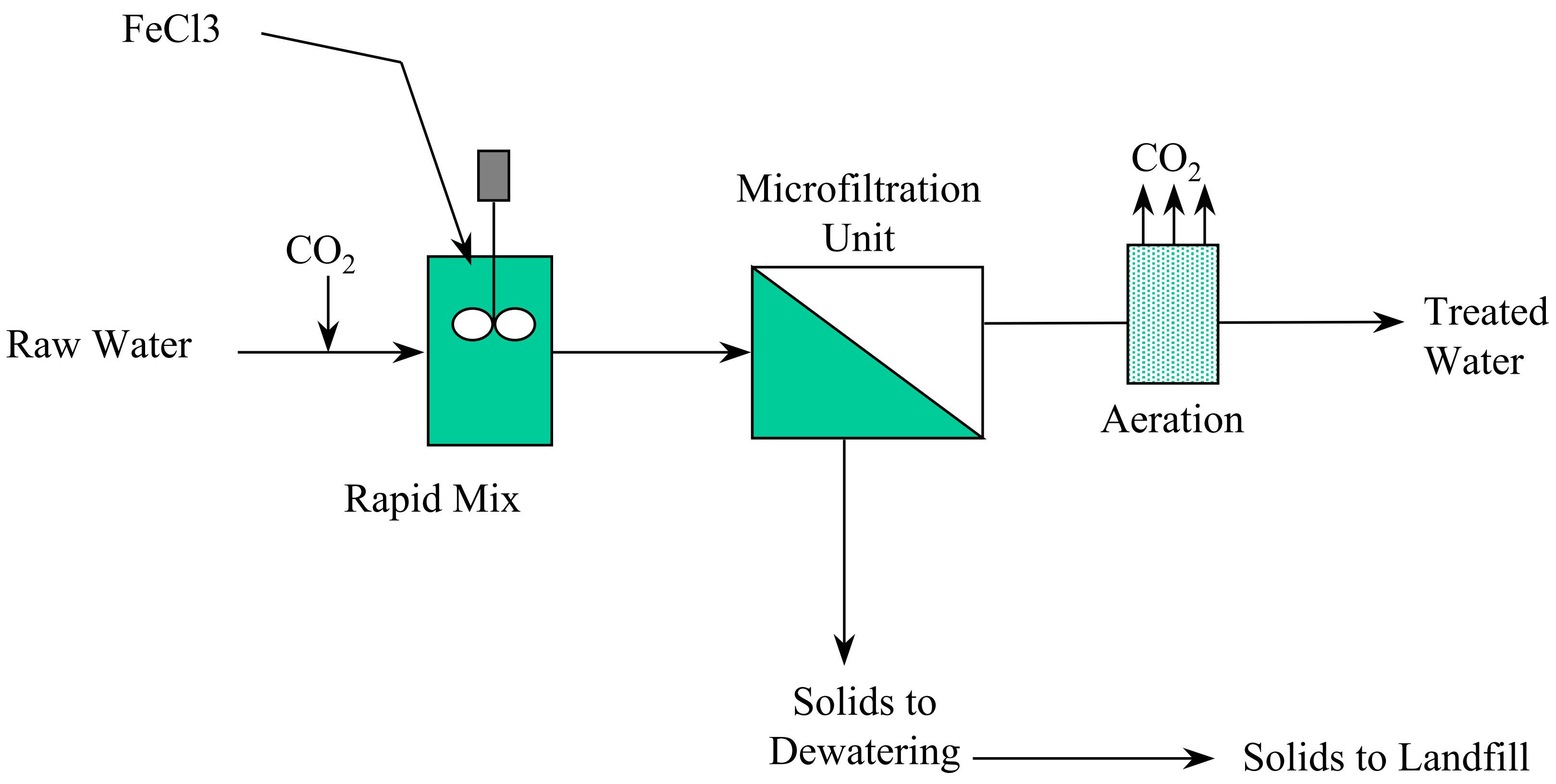
Ambient pH: $FeCl_3$ vs As Leakage NAS Fallon



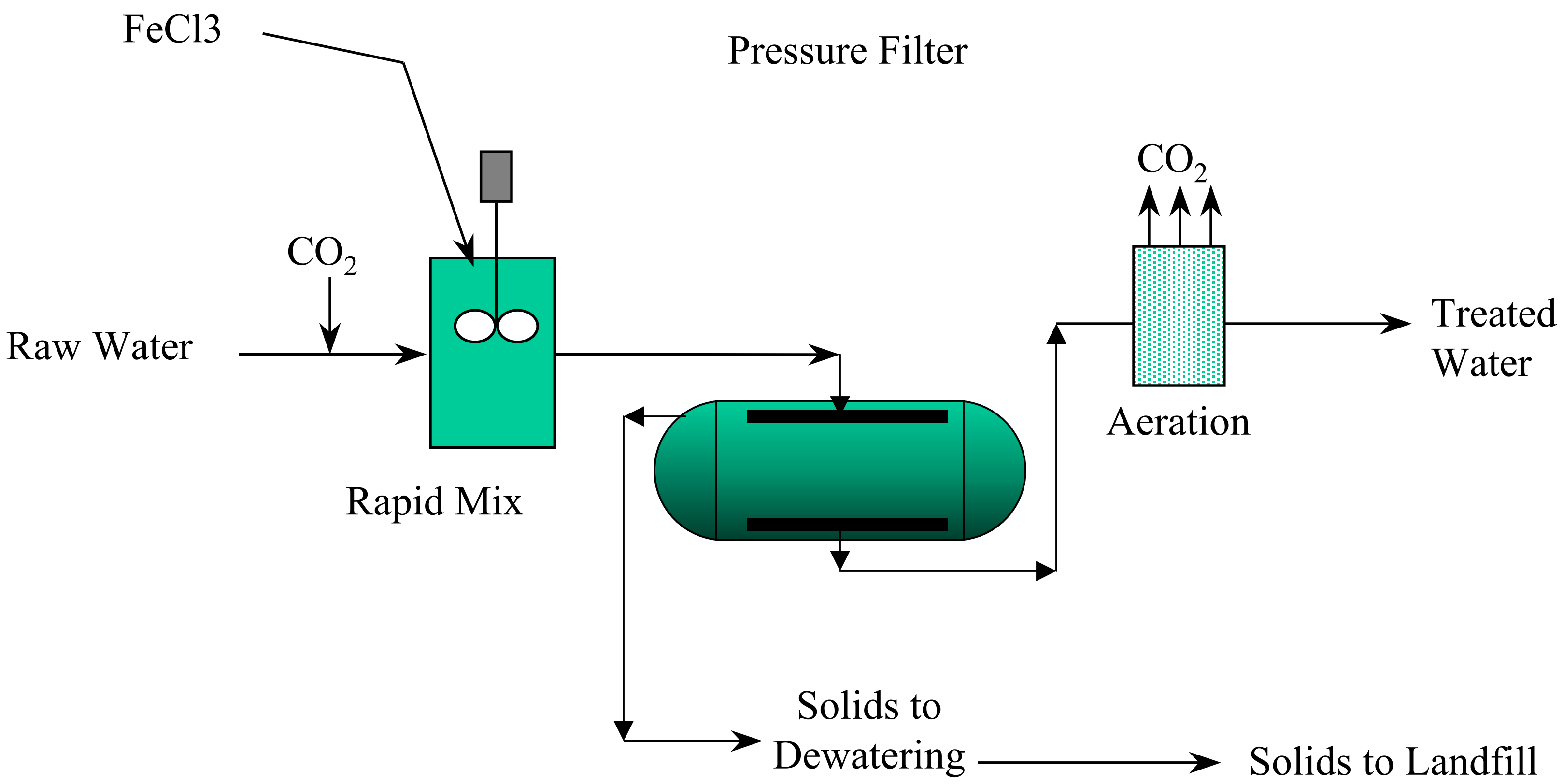
pH 6.8: $FeCl_3$ vs As Leakage NAS Fallon



Coagulation/ Microfiltration Schematic



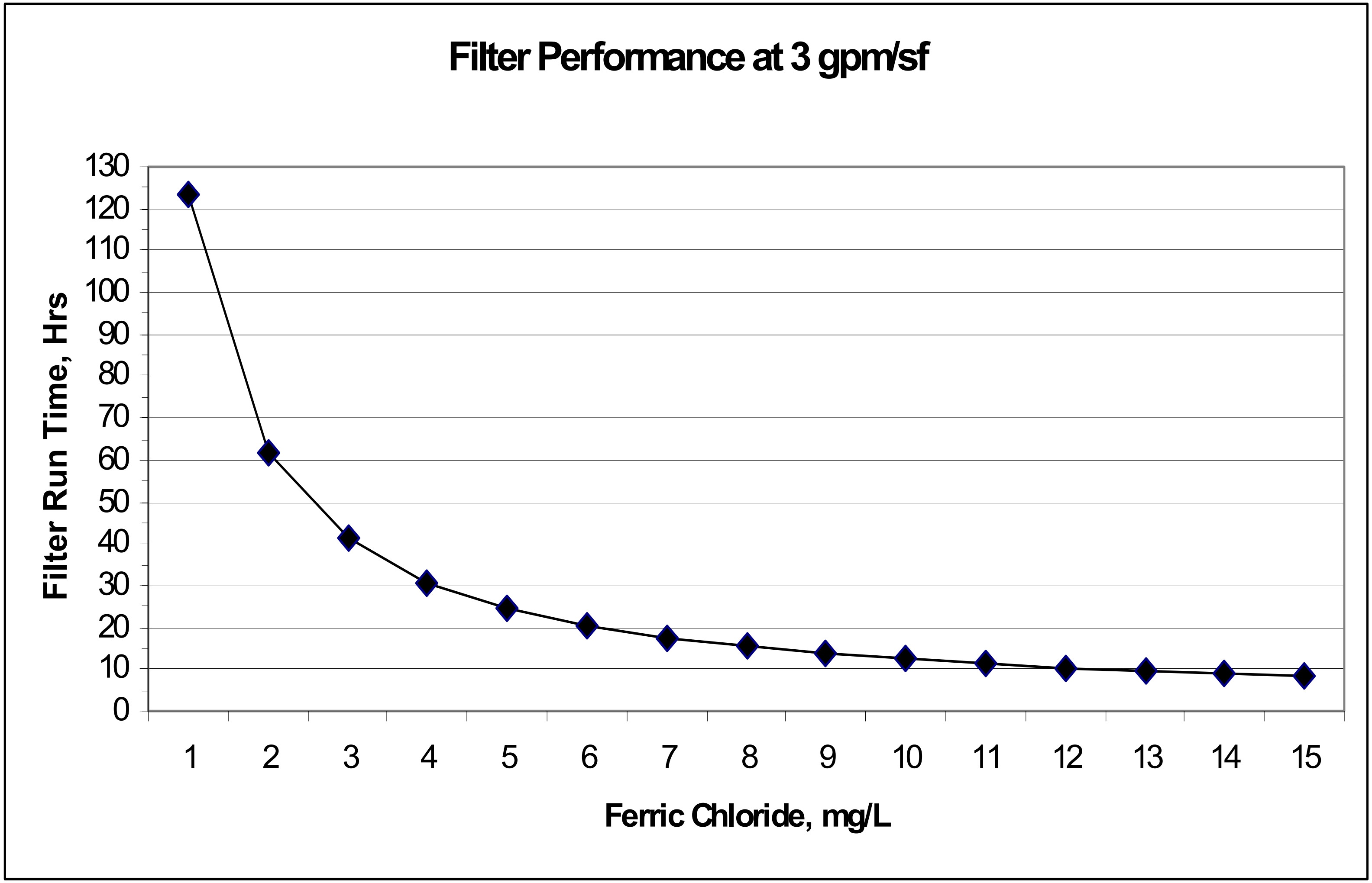
Schematic of Coagulation/ Filtration



Calculation of Filter Loading Limitation

- Rule of Thumb, no more than 10 mg/L of $FeCl_3$
- Limit Solids Loading to 0.1 lbs/ft^2
- May need to add sedimentation

Direct Filtration Performance.



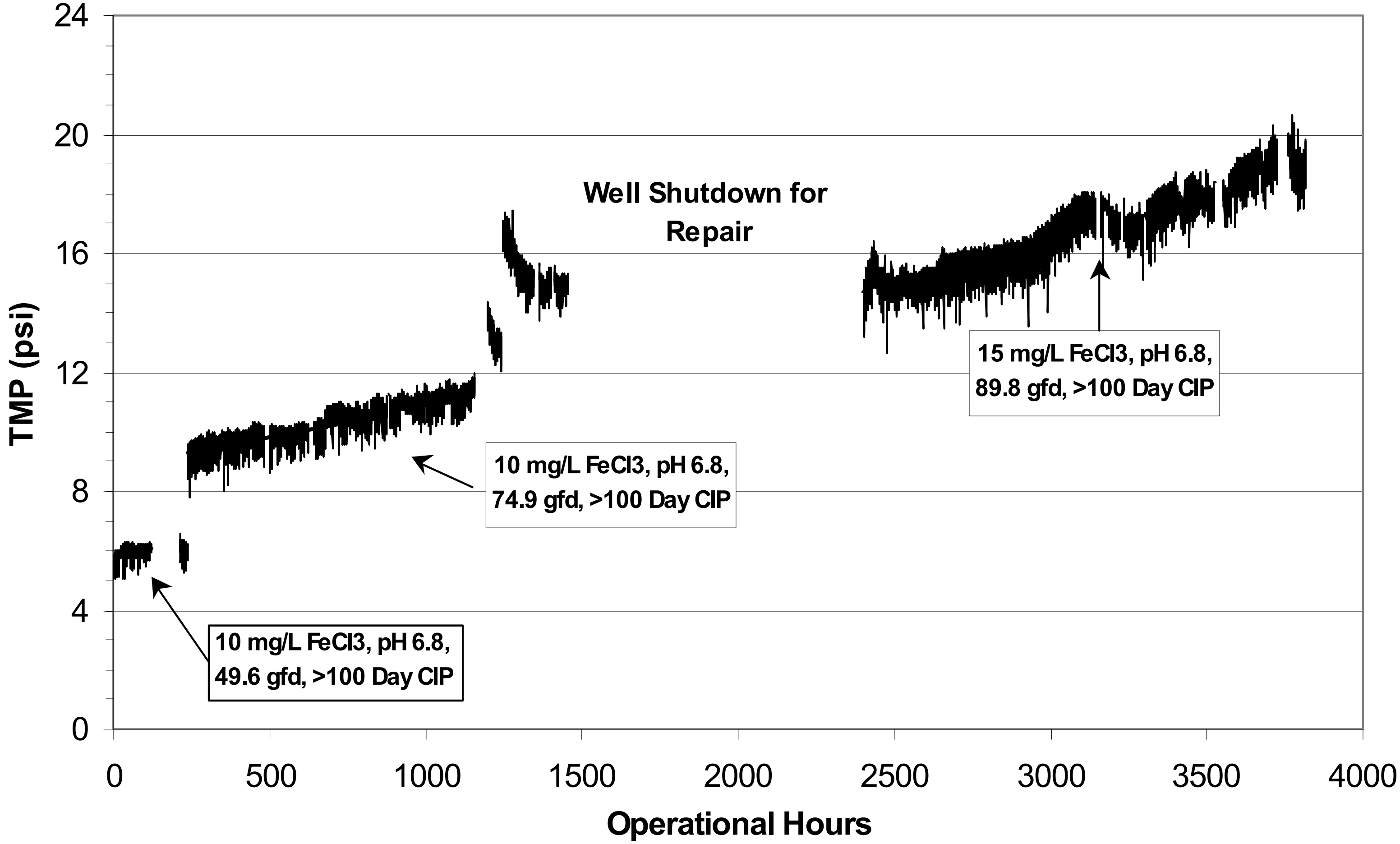
C/MF Pilot Goals

- Optimize membrane flux
  - Higher flux = less membrane area = lower cost
- Optimize chemical cleaning frequency
  - 30 days minimum
  - Citric acid used
- Optimize backwash frequency
  - Typically 20 to 30 minutes
- Duration: at least 3 months to observe fouling of membranes

El Paso C/MF Pilot Studies

El Paso $Fe(OH)_3$ Dose

El Paso
Pall Performance



C/F Pilot Goals

- Optimize backwash frequency
  - want >24 hours
- Maximize filter loading rate, gpm/sf
  - want 4 to 8 gpm/sf
- Duration: 4 to 6 weeks

Analytical Considerations - 1

- Field measurements
  - Electrochemical methods - pH, Elect. Cond., T, Eh
  - Field test kits - Fe, Mn, O_2 (not As)
  - Field separation of As(III) & As(V)
- Sample preservation (see Standard Methods)
  - Metals (incl. As) - HNO_3 to pH < 2
  - Anions - Refrigerate
  - As(III)/As(V) - EDTA complexation

Analytical Consideration - 2

- Analytical methods
  - As analyses
    - ICP-MS
    - Hydride generation AA
    - GFAA
    - (Not ICP-OES)
  - Anions - Ion chromatography
- Lab selection
  - Quality
  - Turn around time
  - Price
  - Location
- Do not change labs or methods in middle of pilot test!!

Conclusions

- Pilot testing is valuable but costly
- Adsorption column tests are necessarily of very long duration but can be relatively simple
  - Column tests are a pain-in-the-patoot!
- Coagulation/filtration process requires more elaborate equipment but shorter duration
- Site characteristics are very important
  - Availability of water, utilities, & disposal options
  - Accessibility & security
- Successful testing is very dependent on quality of operator