Evaluation of Permeable Reactive Barrier Performance: A Tri-Agency Initiative

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Site Characteristics

Site	Date Installed	PRB Type*	Capture Zone* (ft)	
USCG Site NC	1996	CRB/FS	140 x 25	Cr, CVOC
Denver Fed Ctr	1996	F&G/FS	1300 x 24-31	CVOC
Y12, ORNL	1997	CRB/Pilot	20 x 22-30	U, Tc, NO3
Monticello, UT	1999	F&G/FS	300 x 12-24	U, Se, Mn, V
Moffett NAS	1996	F&G/Pilot	30 x 25	CVOC
Lowry AFB	1995	F&G/Pilot	20 x 17	CVOC
Seneca Depot	1997	CRB/FS	600 x 10	CVOC
Dover AFB	1997	F&G/Pilot	50 x 25	CVOC

* CRB = Continuous Reactive Barrier, F&G = funnel & gate, FS = full scale; capture zone est based on flow modeling

Elements of the study

- Hydraulic evaluation of field PRBs
  - Water levels, flowmeters, slug tests, tracer studies
- Geochemical evaluation of field PRBs
  - Spatial and temporal trends in groundwater chemistry, and coring and mineralogical analysis of PRBs
- Microbiological evaluations
- Geochemical modeling using measured groundwater parameters

Hydraulic Performance Evaluation

Water level measurements are the best indicator of bulk flow

- A dense network of monitoring wells with uniform screened intervals gives the best results

Tracer tests are the best indicators under a variety of conditions; however, tracer tests are more expensive to conduct successfully

Plume concentrations can vary spatially, change seasonally or progressively over time, thus affecting residence time requirements

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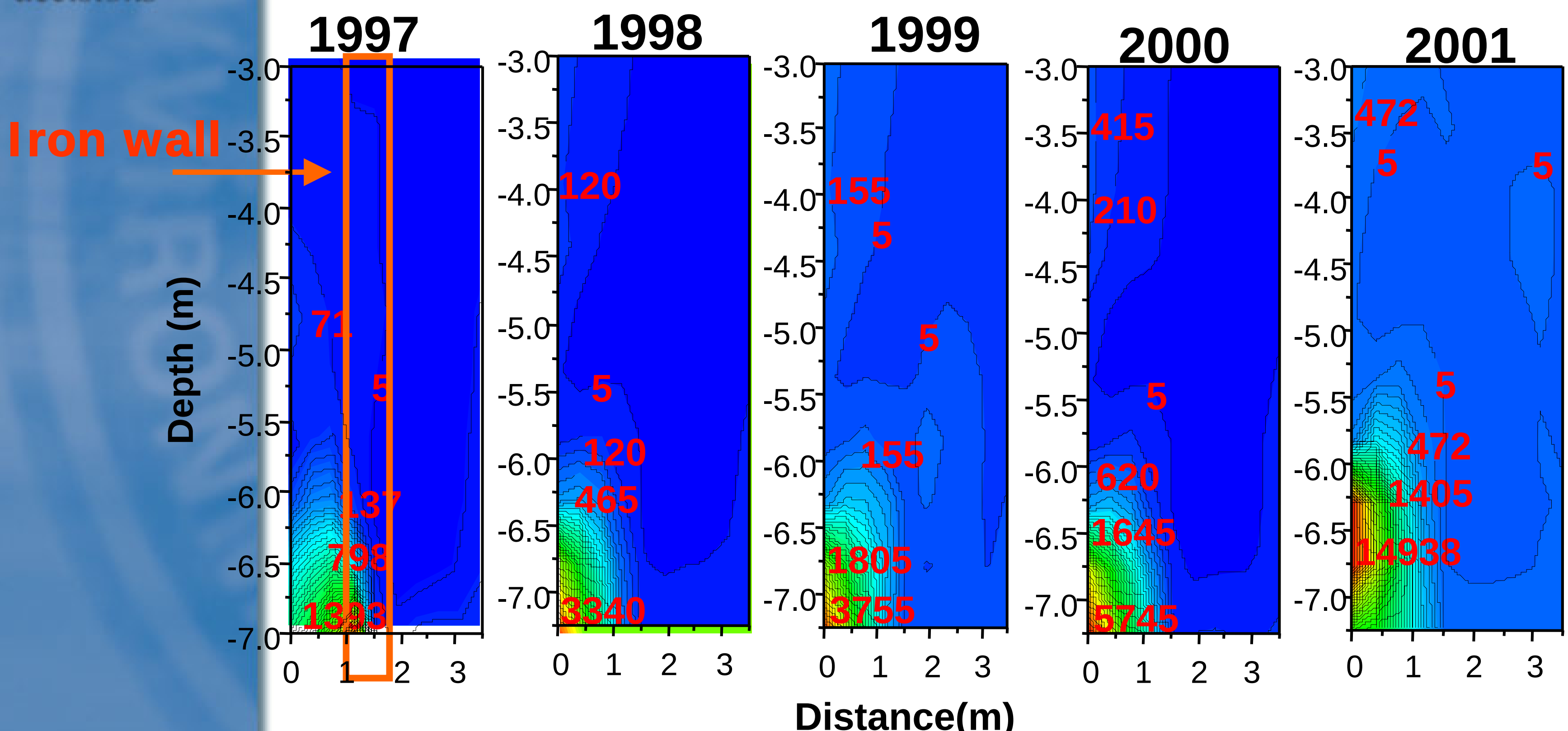
Elizabeth City

TCE Distribution



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Hydraulic Performance Evaluation

It is important to model a <u>range of hydraulic scenarios</u> at a site, and <u>not just use average</u> hydraulic property values in the design

- At most sites, it is not possible to estimate K within half- or or one-order of magnitude; even at Dover AFB and E City, sandy relatively homogeneous aquifers, slug tests results in local wells varied by around half order of magnitude
- Net result is a gw velocity that may vary over half- or one-order of magnitude, no matter how much characterization we do
- Seasonal variability in flow can affect gw flow direction estimates

Hydraulic Performance Evaluation

Many PRBs are located inside the plume boundaries. It has therefore been difficult to see a noticeable clean front develop on the downgradient side of the PRB, for one or more of the following possible reasons:

- At many sites, the number of pore volumes of groundwater flowing through the PRB since installation is still relatively low
- At some sites, contaminants trapped in finer sediments could still be diffusing out into the bulk flow (e.g., Moffett Field)
- At some sites, there may be flow bypass around or under pilot-scale PRBs (plume capture issue)
- At E City a clean front has been observed and at NAS Moffett, signs that a clean front may be imminent

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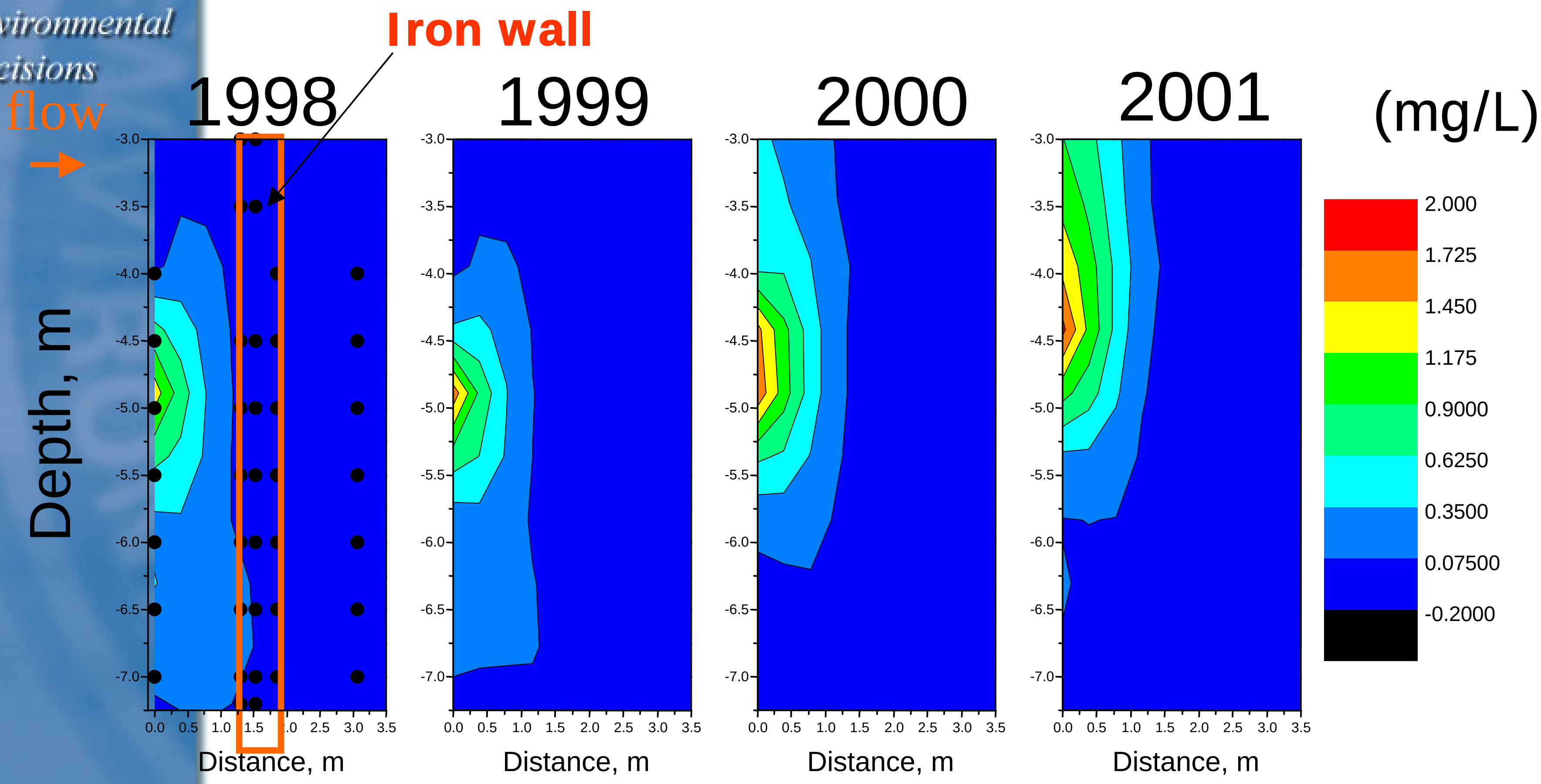
Elizabeth City – Cr distribution



Hydraulic Performance Evaluation

Modeling multiple flow scenarios and using appropriate safety factors are ways of addressing variability and incorporating uncertainty in the design of a PRB

There may be a choice between safety factors (higher initial capital investment) and future risk (back end cost to make changes to the PRB to improve performance)

Geochemical Performance Evaluation

❖Tools

- SEM-EDS
- Reflected-light microscopy
- Transmission Electron microscopy (TEM)
- XPS (x-ray photoelectron spectroscopy)
- XRD (x-ray diffraction)
- Inorganic carbon analysis/Sulfur analysis
- Microbial assays

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Geochemical Performance Evaluation

Consistent degradation of contaminants over 7 y (one exception) downgradient of iron

Spatial heterogeneity of mineral and biomass accumulation

- Generally most of buildup within 1st 10 cm

Buildup correlated to GW chemistry (TDS) and flow rate (mass flux)

Porosity loss rate from 1 to 4% per yr of original available volume

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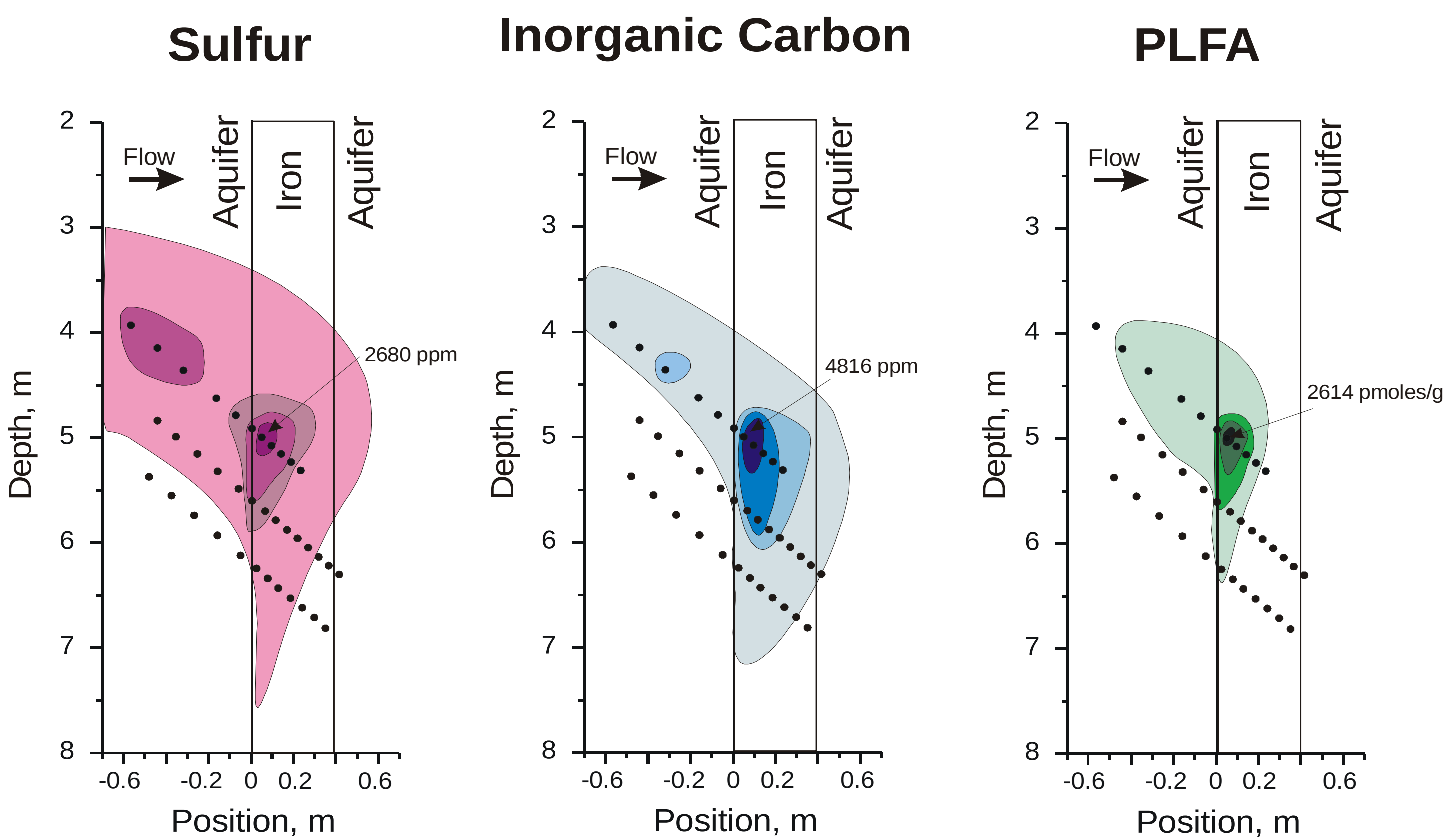
Mineral/Biomass Accumulation – E. City



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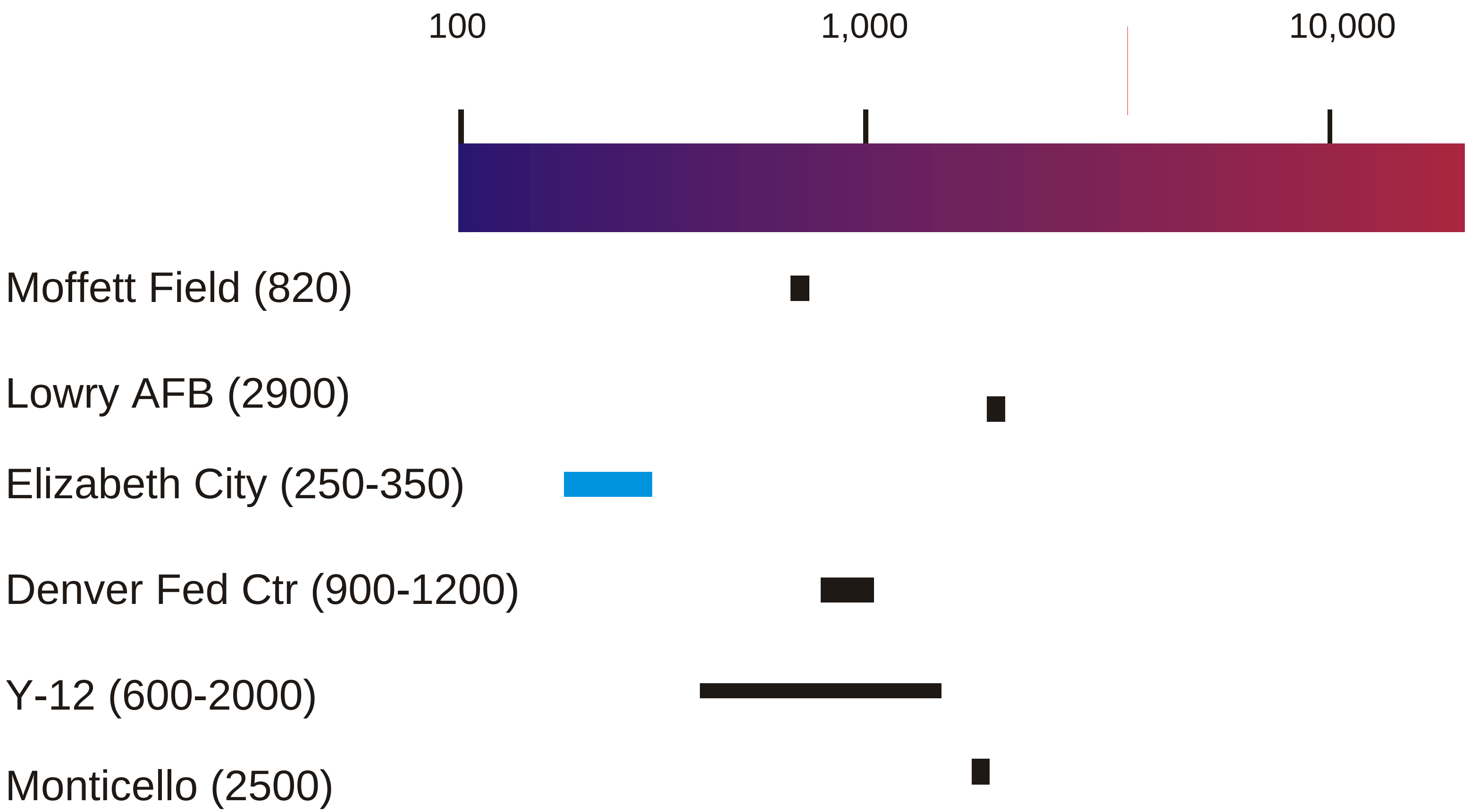
0

Total Dissolved Solids (mg/L)



Pore loss estimations

- Flow rate (flux in)
- Sulfate concentration/removal efficiency
- Bicarbonate concentration/removal efficiency
- Initial PRB porosity
- Iron corrosion (pore volume gain)
- Mineral molar volumes

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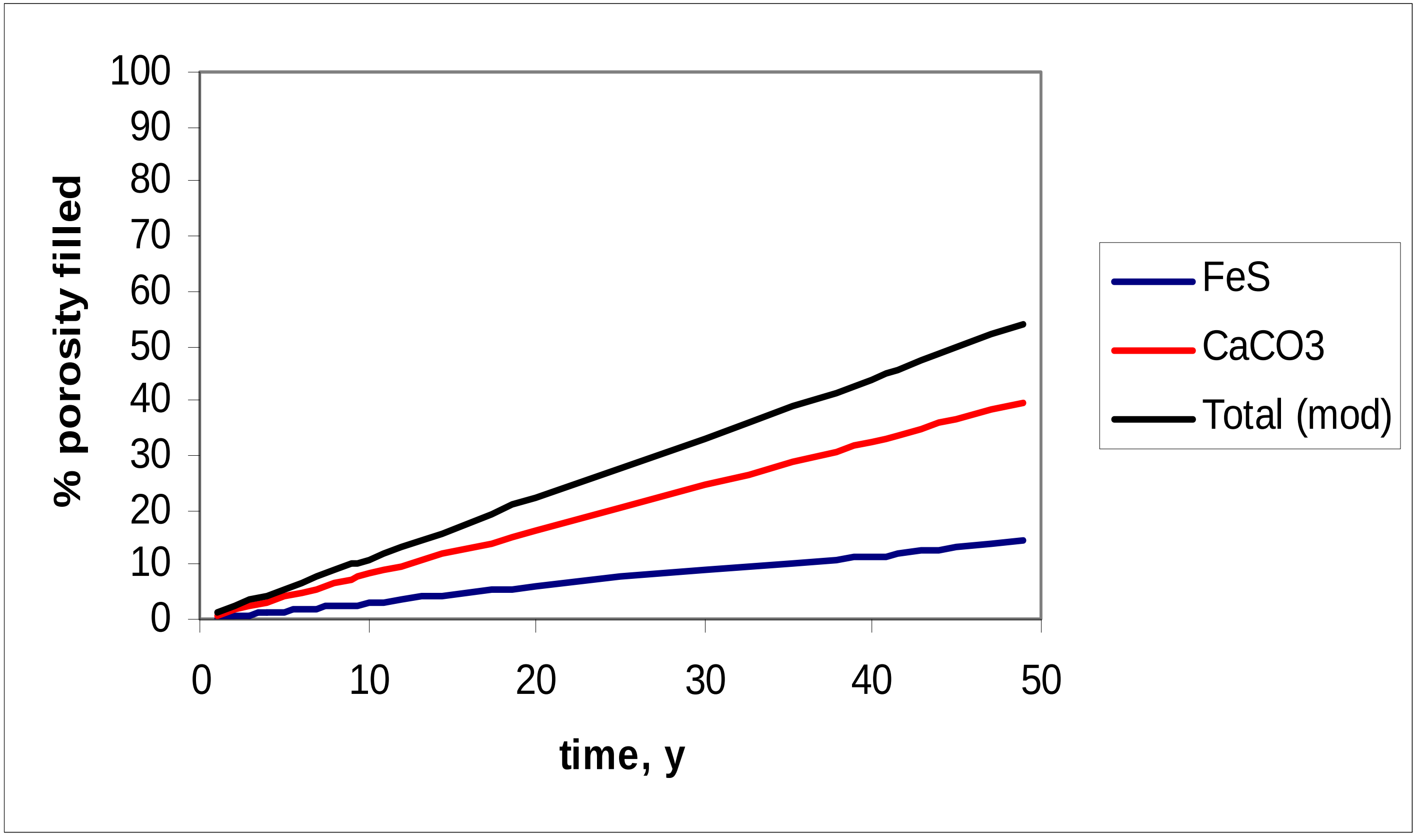
Porosity loss – Elizabeth City

Assume all ppt in front 10 cm, initial porosity = 50%



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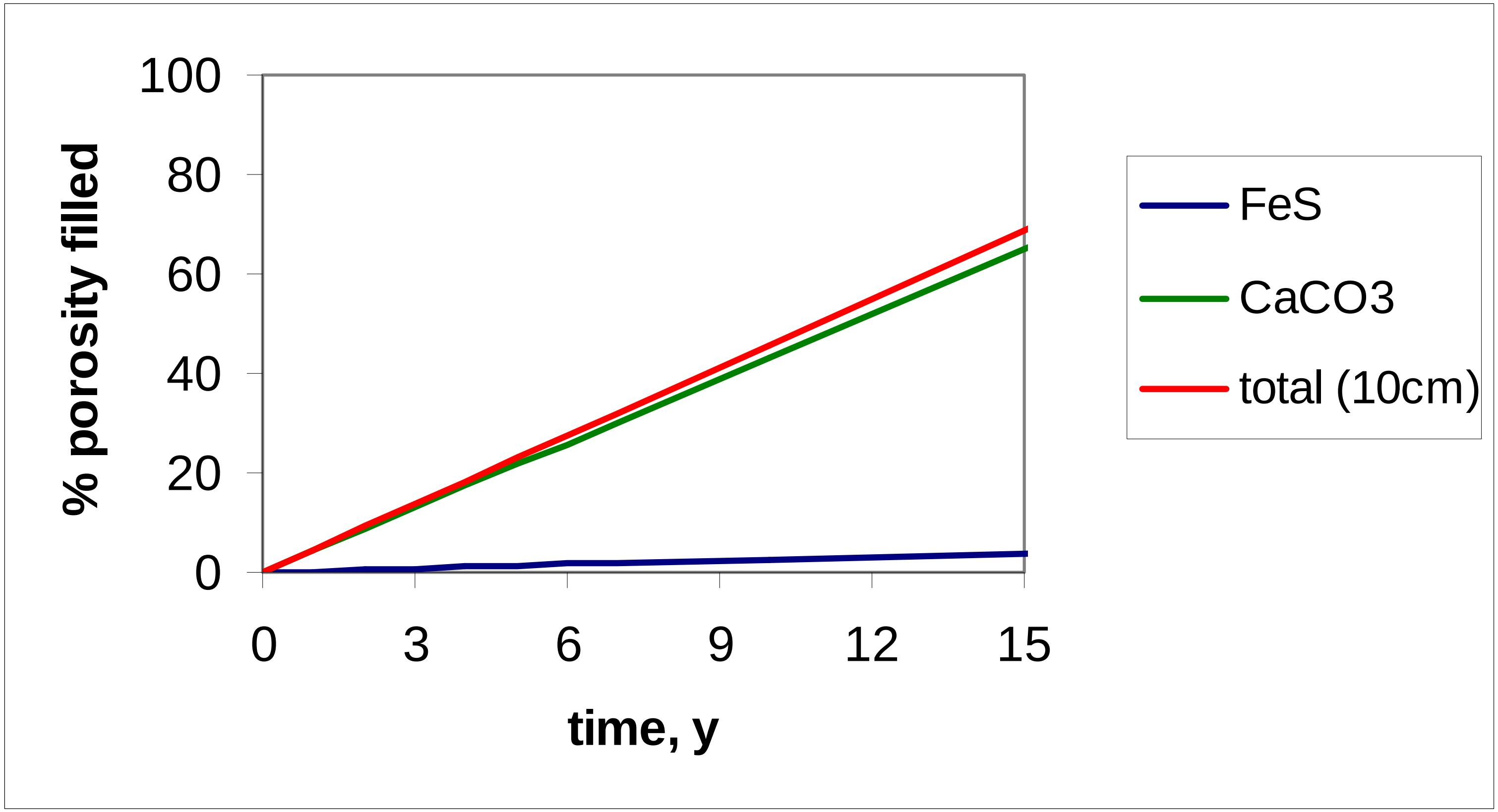
Porosity loss - DFC

Assume all ppt in front 10 cm, initial porosity = 50%



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Porosity Loss in PRBs

- ✓ Carbonate minerals in PRBs are dominantly: aragonite/calcite, iron hydroxy carbonate, and carbonate green rust.
  These minerals account for most of the pore space loss in PRB systems.
- ✓ Mackinawite is the dominant sulfur mineral in PRBs; it accounts for little pore space loss due to its high density.
- ✓ If oxidation is excessive, iron metal transformation can lead to significant loss of pore space.
  Influent waters to PRBs must be low in DO or other oxidants.

Geochemical Performance Evaluation

Vertically resolved hydro/geochem data needed during site characterization

High SO4, high CO3, high NO3 may impact performance, longevity

In fine textured formations, extra care should be taken during installation to insure restoration of hydraulic contact between iron and aquifer sediemnts

Microbiological Evaluation

Microbial biomass increase upgradient, downgradient, and beneath iron

Low biomass numbers within iron itself

Microbial communities dominated by anaerobic, sulfate-reducing and metal reducing bacteria

Highest accumulation of biomass at DFC

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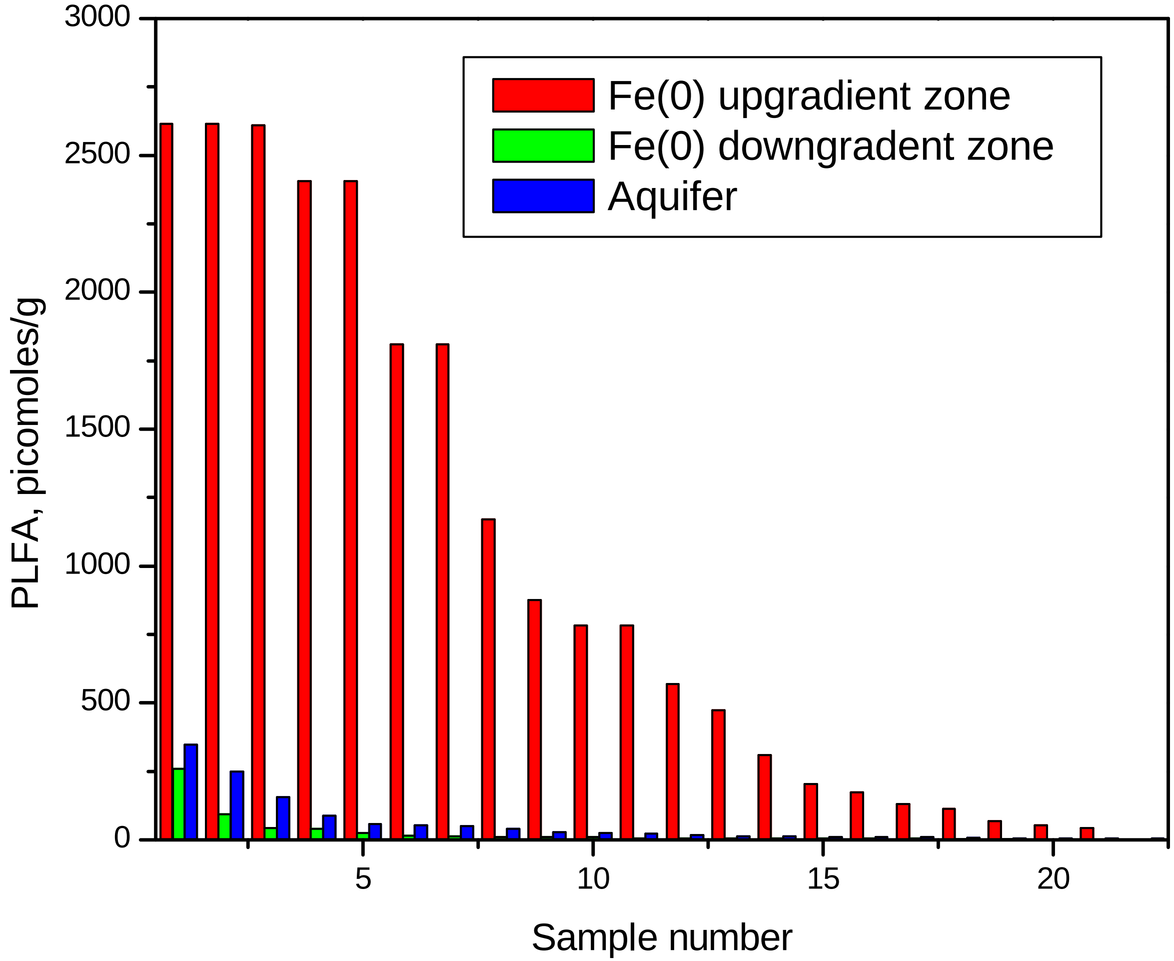
Enrichment of microbial biomass near the upgradient interface



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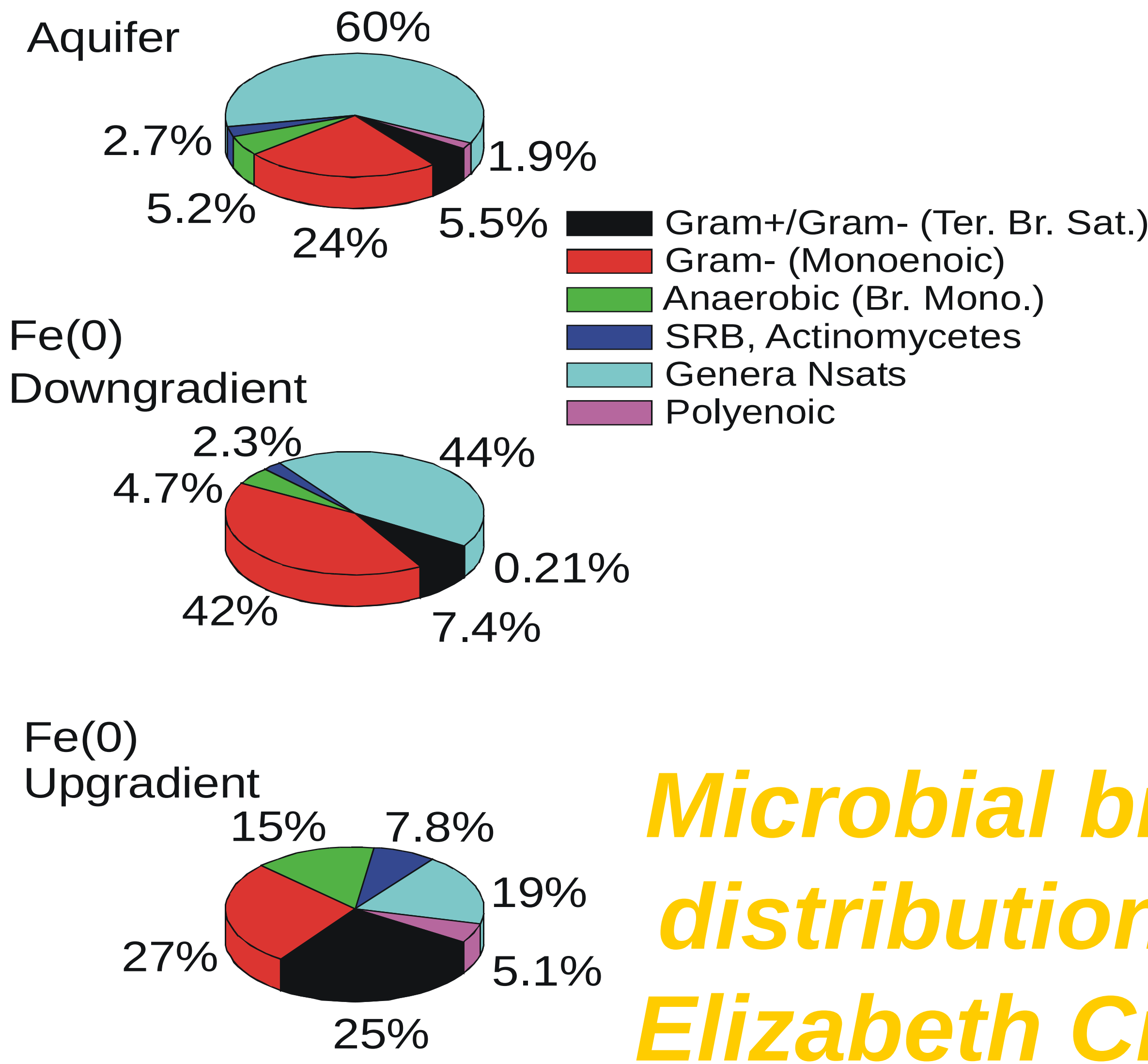
Microbial biomass distribution at the Elizabeth City PRB



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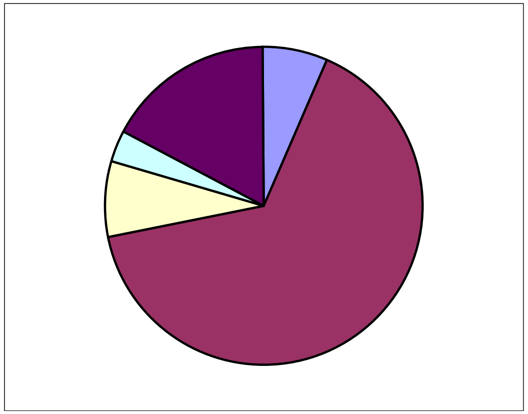
Microbial Biomass PLFA Distribution

DFC Cell 1



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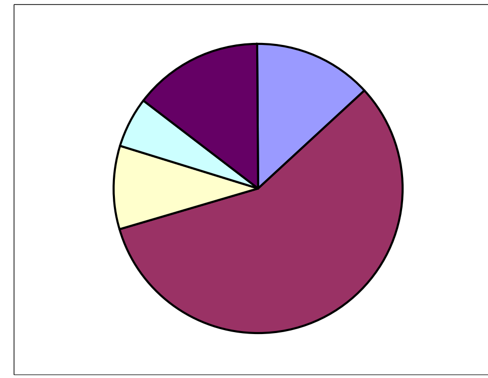
DFC Cell 2



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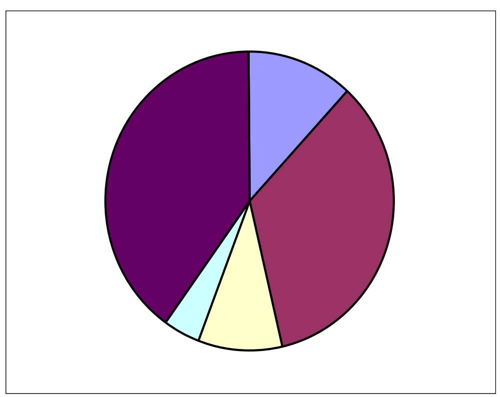
E. City



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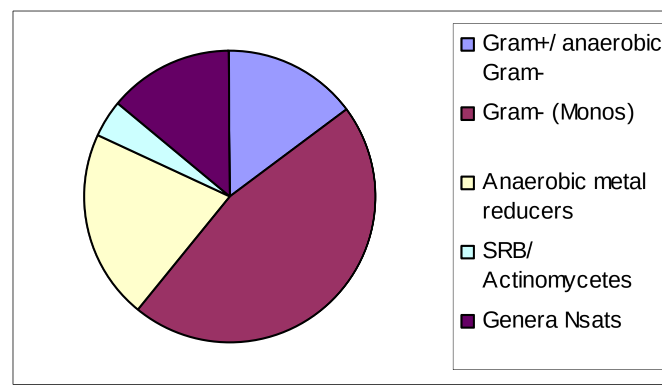
Moffett



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Cemented nodule from the DFC, Cell 2

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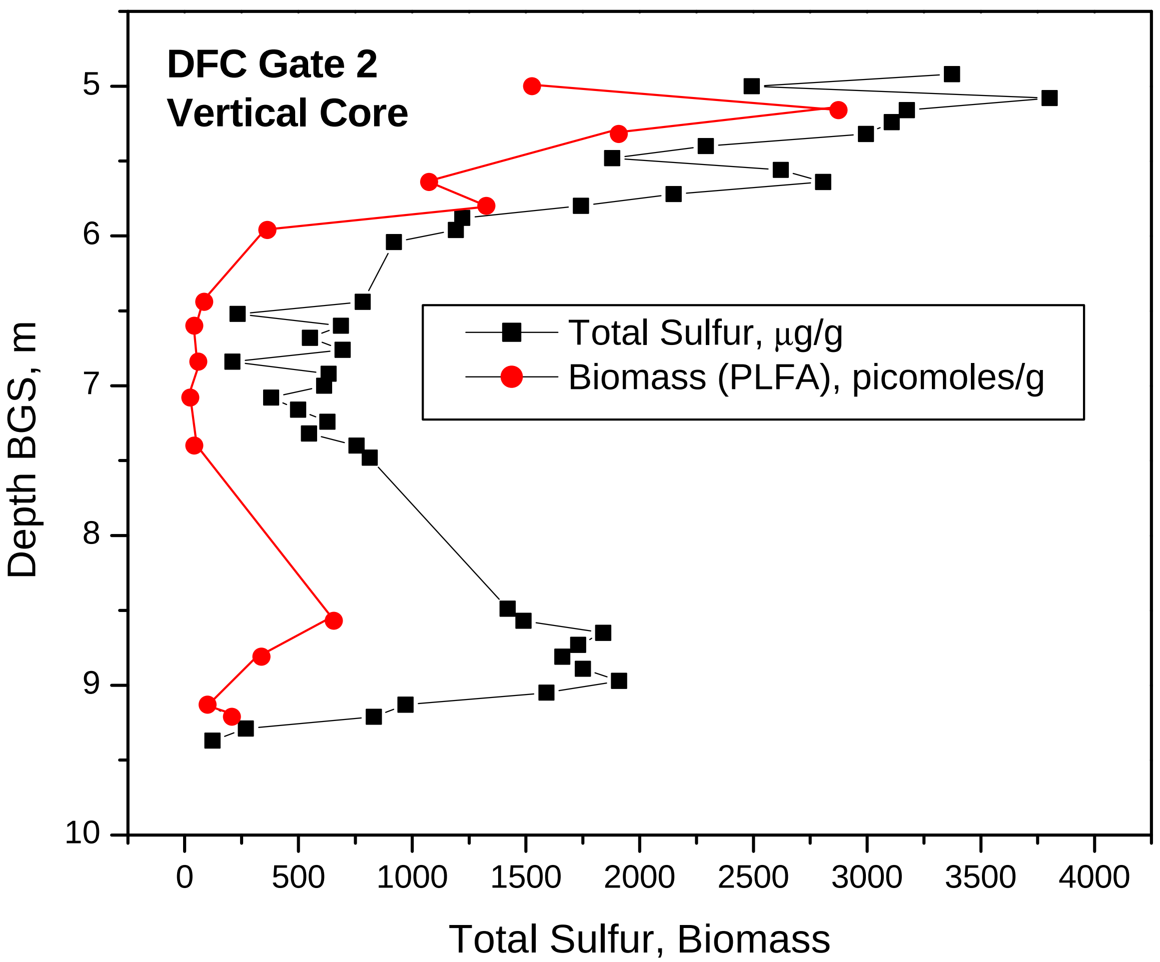
Microbial biomass and sulfur accumulation at DFC gate 2



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Geochemical Modeling Evaluation

Precipitation generally follows that predicted by geochemical modeling

Some variation in precipitates observed from site to site

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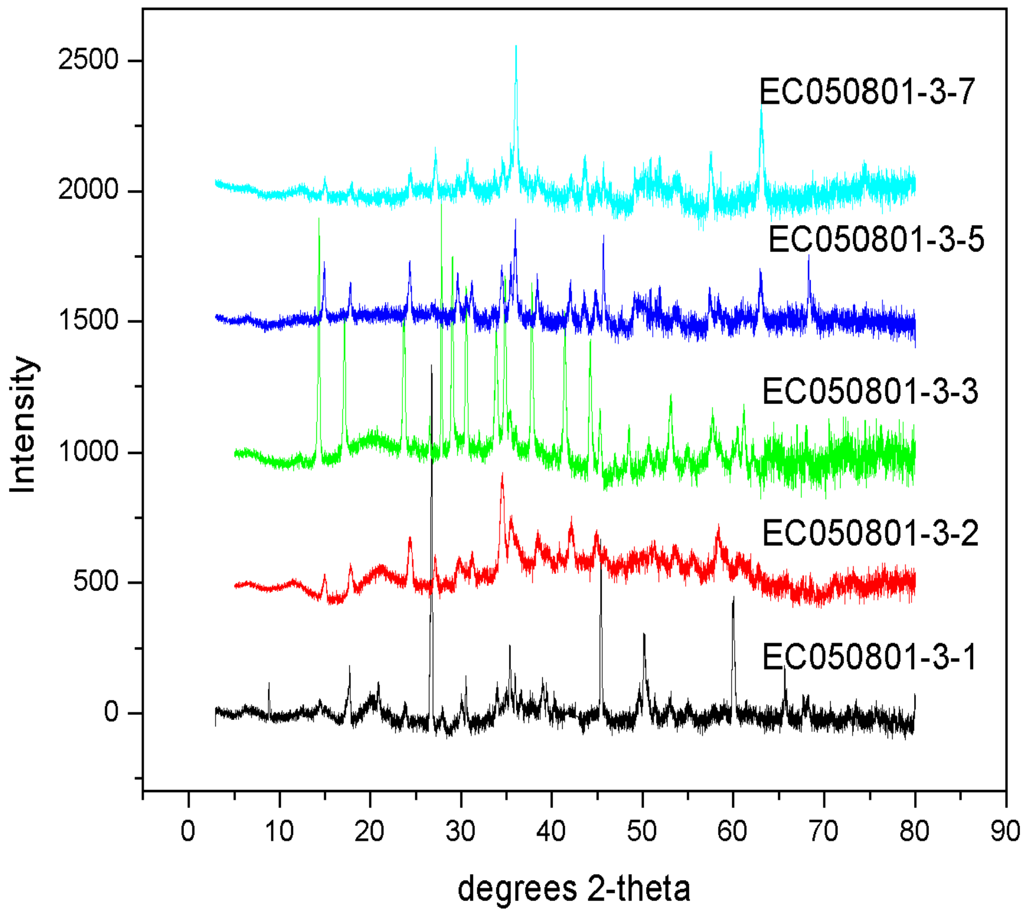
X-Ray Diffraction, E. City



FeS weak

Aragonite weak

Magnetite strong

Siderite absent

Fe-OH-CO3 strong

GRCO3 present

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Summary

Adequate site characterization imperative to maximize potential for successful PRB application

- Especially true for hydrologic characterization

Low-flow or passive sampling approaches are best

- Frequency can be decreased over time

Geochemical parameters as early warning indicators of decline in performance not documented

- pH may correlate with ‘disturbed’ flow field

Where fine textured formations exist, extra care must be taken to insure good hydraulic connection between aquifer sediments and PRB

Lifetime estimates generally exceed 10 yr with some to 30 yr