# SELENIUM TREATMENT
# ARCH-EASTERN, BIRCH MINE

WEST VIRGINIA MINE DRAINAGE TASK FORCE SYMPOSIUM

March 27, 2012

Conestoga-Rovers & Associates
Arch Coal, Inc.

## Conestoga-Rovers & Associates (CRA)

- Al Meek

## Arch Coal, Inc.

- Keith Odell

## Bratton Farm

- Ben Faulkner

# Arch-Eastern, Birch Mine

- In March of 2011 a Consent Decree was entered by WVDEP requiring corrective action to comply with Selenium standard (i.e., 4.7 µg/l (average) and 8.2 µg/l (maximum )) at 10 discharge points on the Knight Ink surface mine.
- A corrective action plan developed by Arch and CRA to establish the following:
  - **Establish design criteria for treatment of waters associated with discharge points identified in the Consent Decree**
  - **Determine applicability of new and existing selenium treatment technologies**
  - **Complete alternatives analysis of selenium treatment system options.**
  - **Select Treatment Alternative**
  - **Design and construct system**
  - **Initial compliance by August 2012**

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# Arch-Eastern, Birch Mine Overview


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# Knight Ink Permit S-2019-88


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# Establishing Design Criteria

- Design Flow Rates
  - Hydrologic Modeling of Surface Runoff, Infiltration, Evapotranspiration and Shallow Ground Water (pit floor discharge)
    - — Developed Base Model (calibrated with weir data)
    - — Applied Base Model to 2010 rainfall
    - — Inserted 10yr, 24 hr. rain event in 2010 model year
- Design Selenium Concentration
  - Historical review of NPDES outfall monitoring
  - Surface water runoff analysis
  - Surface runoff and seep flow components of outfall concentrations

# Hydrologic Modeling-Conceptual Model

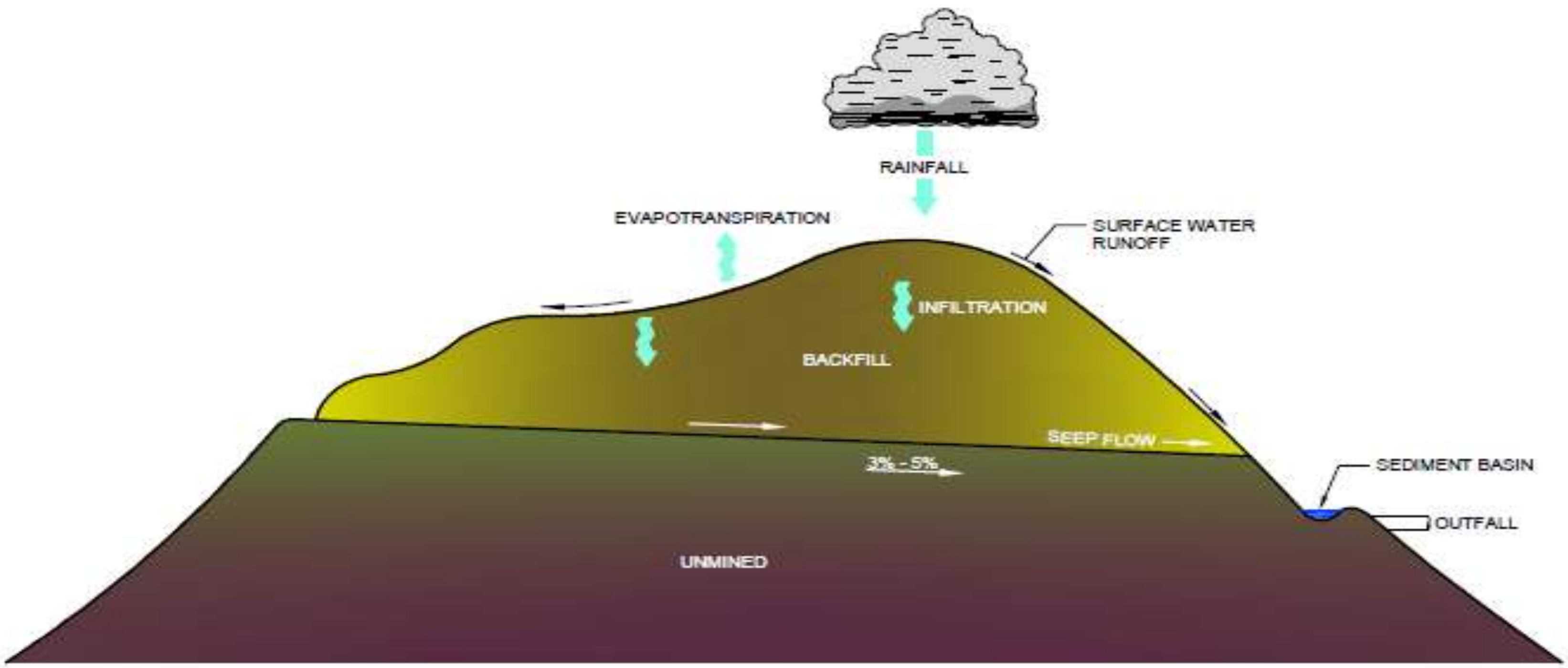


figure 3

SITE CONCEPTUAL MODEL - BENCH DRAINAGE
ICG EASTERN
***Cowen, West Virginia***

72673-00(002)GN-WA003 JUN 26/2011

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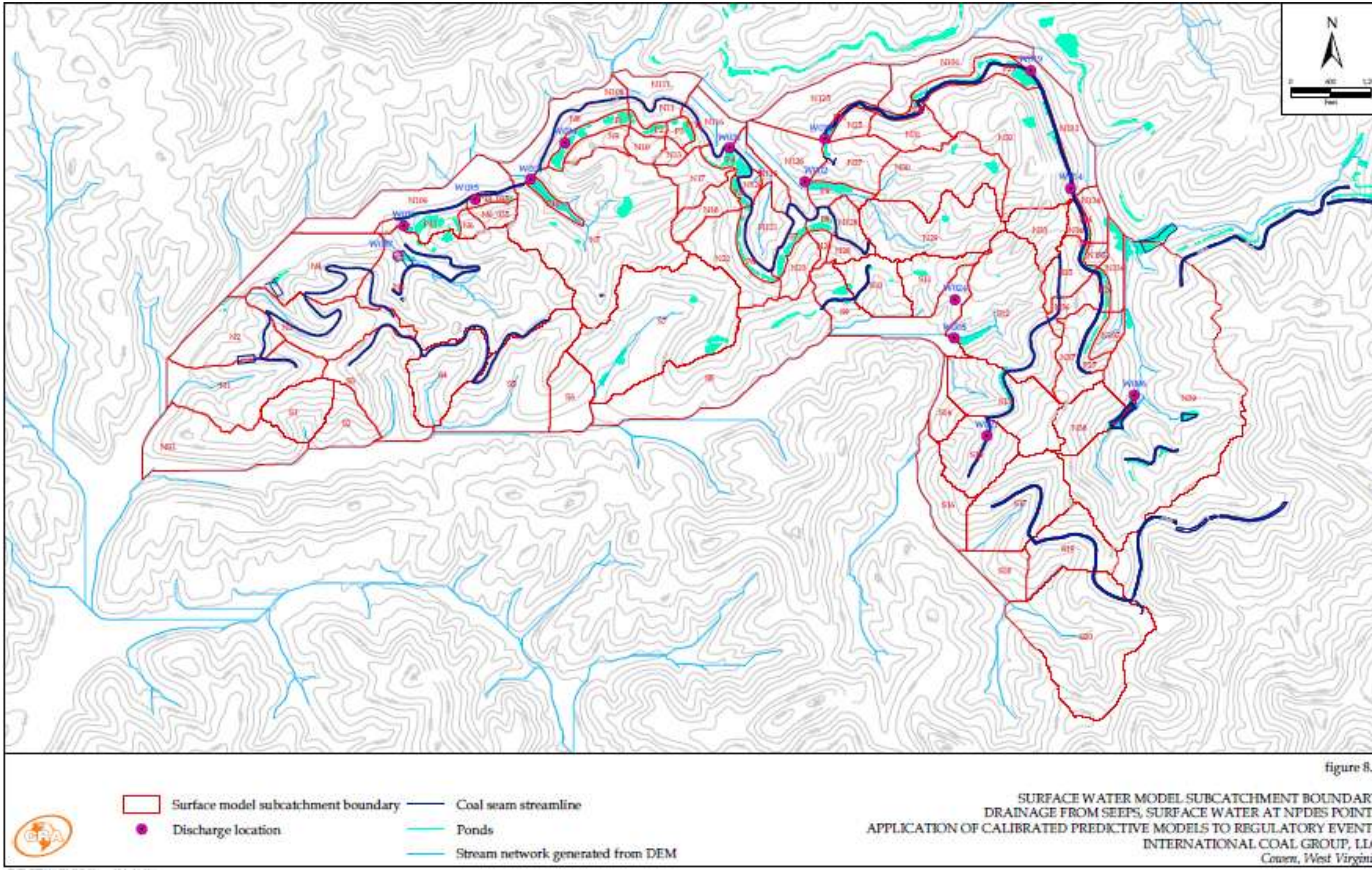
# Hydrologic Modeling

- Consisted of Three Separate Models
  - Surface Runoff
  - Infiltration/Evapotranspiration
  - Pit Floor (Seepage flow)
- Utilized the EPA developed Storm Water Management Model (PCSWMM)
- Conducted on-site flow monitoring to calibrate model.
- Utilized 2010 rainfall data and inserted a 10 yr, 24 hour event.

# Hydrologic Modeling-Surface Runoff

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# Hydrologic Modeling-Pit Floor Drainage Area

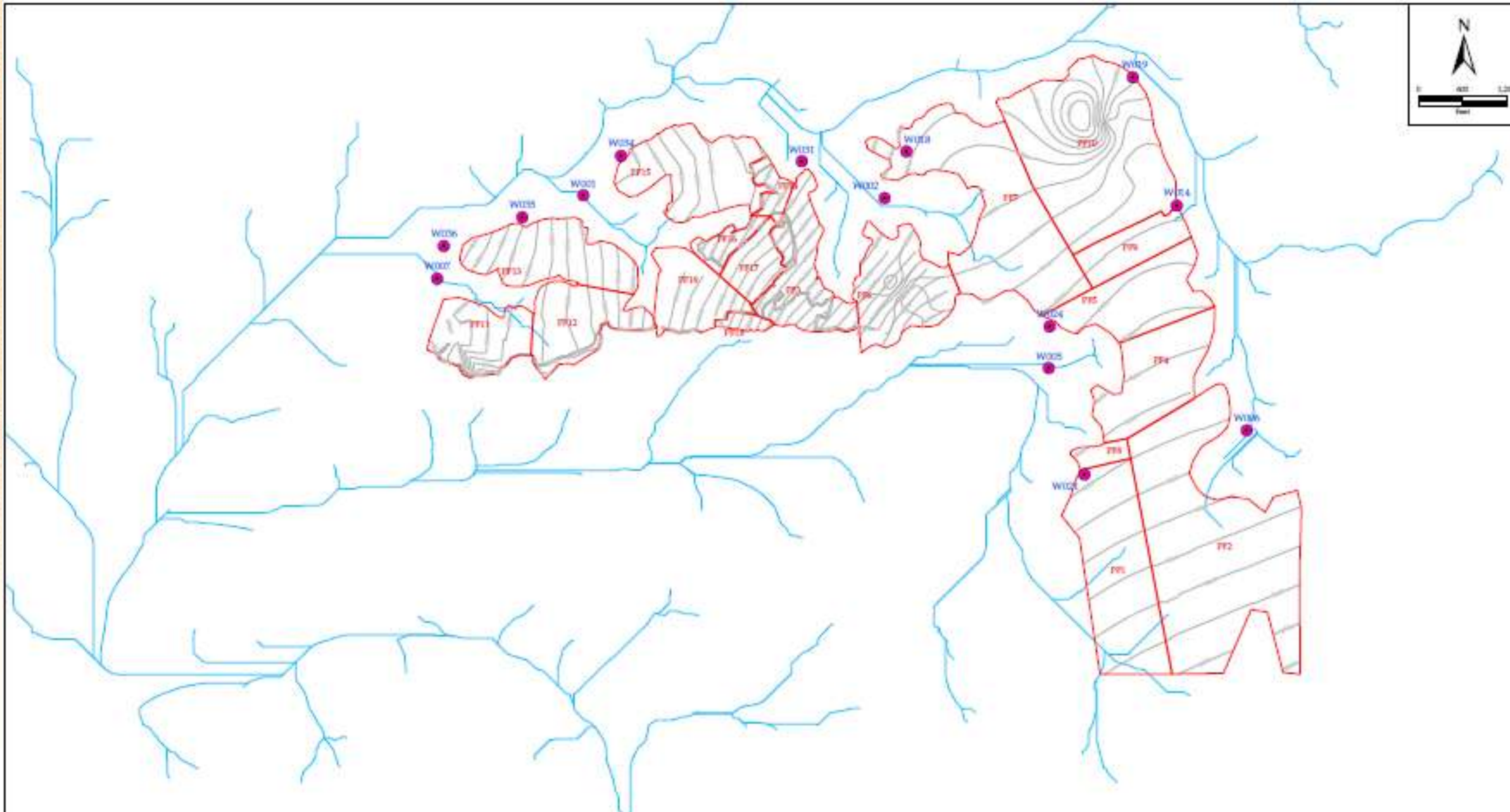

figure 8.7

Subcatchment boundary
Discharge location
Stream network generated from DEM

PIT FLOOR MODEL SUBCATCHMENT BOUNDARY
DRAINAGE FROM SEEPS, SURFACE WATER AT NPDES POINTS
APPLICATION OF CALIBRATED PREDICTIVE MODELS TO REGULATORY EVENTS
INTERNATIONAL COAL GROUP, LLC
*Cowen, West Virginia*

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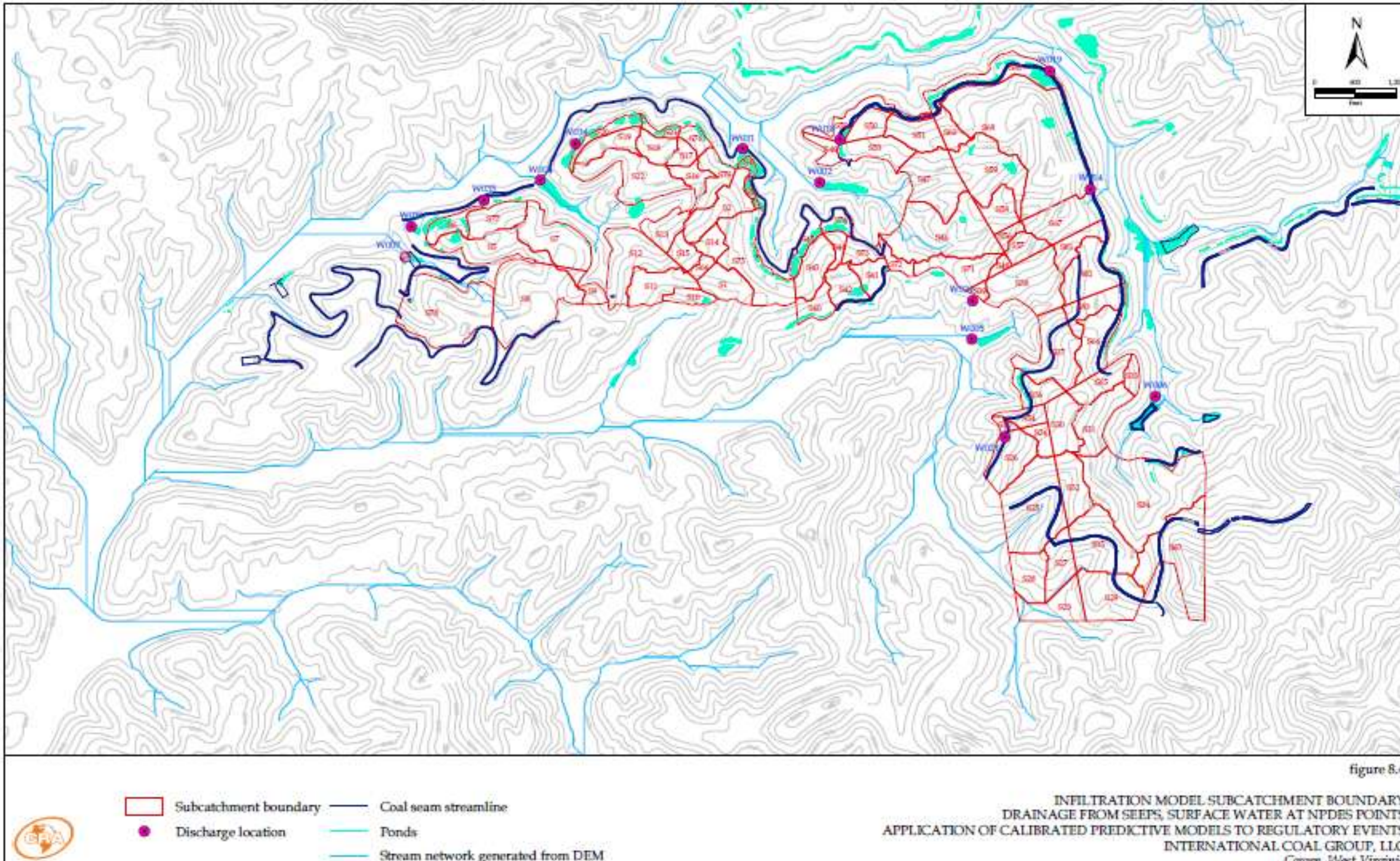
# Hydrologic Modeling-Infiltration

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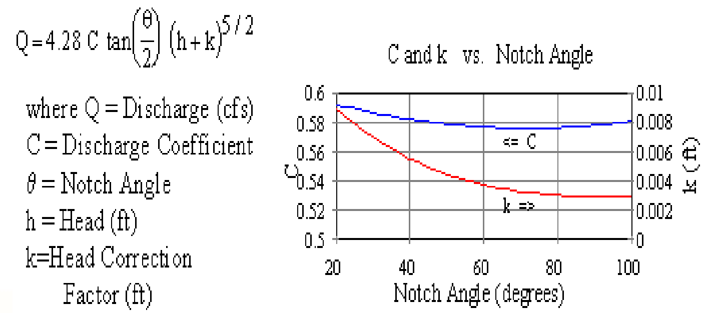
# Hydrologic Modeling- Model Calibration

# Hydrologic Modeling- Model Calibration

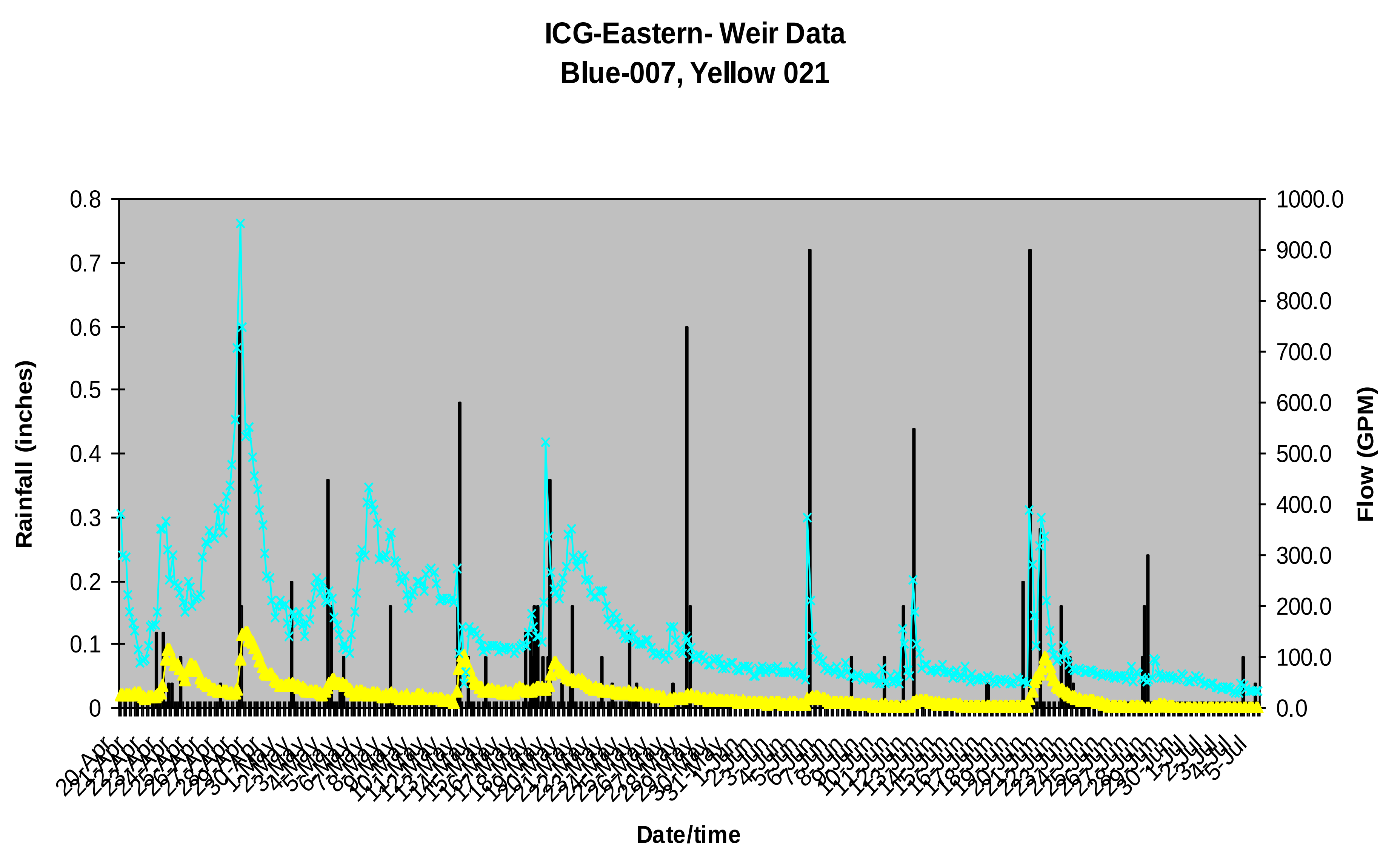



Input Parameters

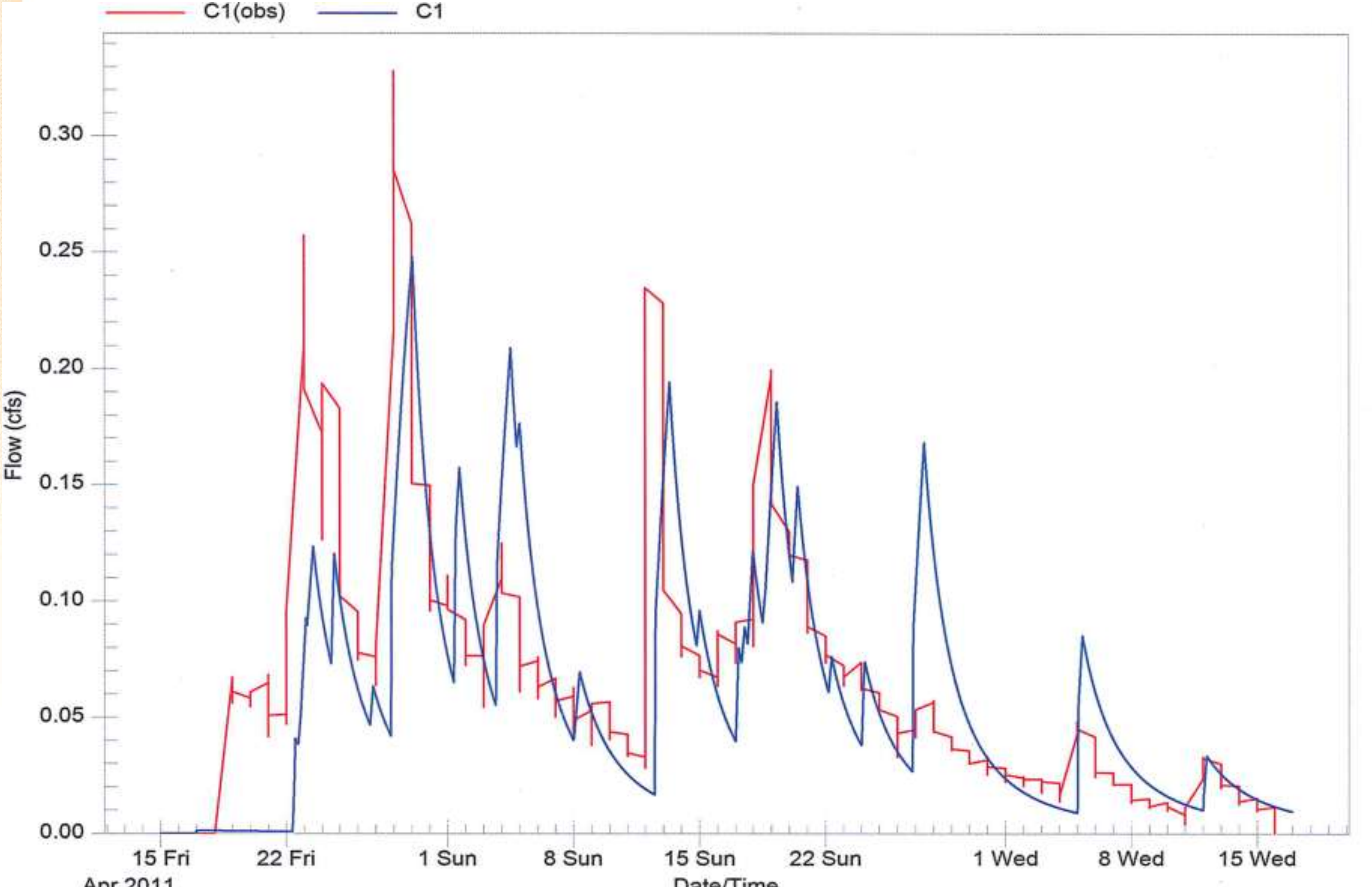
| | | | | |
|---|---|---|---|---|
| 90 deg. V-I | V-Notch | | Rectangular Weir | |
| Formula | Q=4.28 C Tan (v-angle deg./2) (H + K | | Q=C(L-0.2H)H3/2 | |
| | Q= Flow in CFS | | Q= Flow in CFS | |
| | K= Head correc | 0.002903 | C= Reference MSHA Design Manua Manual | 3.33 |
| | H= head (ft)above bottom of V-Notch | | H= head (ft) | |
| | Tan (90/2) = | 1 | L= width rect.weir(FT) | 4 |
| | C= Discharge C | 0.5779 | | |
| | Head adjustme | 0.49791 | | |

| Weir Id-- Date | Discharge 006 Time | H (head ft) | V-notch Flow CFS | Rect Notch Flow CFS | Total Flow CFS | Total Flow GPM |
|---|---|---|---|---|---|---|
| 2/13/2012 | 2:51:26 PM | 0.242 | 0.073 | 0.000 | 0.073 | 32.9 |
| 2/13/2012 | 3:21:26 PM | 0.237 | 0.070 | 0.000 | 0.070 | 31.4 |
| 2/13/2012 | 3:51:26 PM | 0.246 | 0.076 | 0.000 | 0.076 | 34.3 |
| 2/14/2012 | 4:21:26 PM | 0.247 | 0.077 | 0.000 | 0.077 | 34.8 |
| 2/14/2012 | 4:51:26 PM | 0.245 | 0.076 | 0.000 | 0.076 | 34.1 |
| 2/14/2012 | 5:21:26 PM | 0.251 | 0.080 | 0.000 | 0.080 | 36.1 |
| 2/15/2012 | 5:51:26 PM | 0.250 | 0.079 | 0.000 | 0.079 | 35.6 |
| 2/15/2012 | 6:21:26 PM | 0.255 | 0.084 | 0.000 | 0.084 | 37.5 |
| 2/15/2012 | 6:51:26 PM | 0.256 | 0.084 | 0.000 | 0.084 | 37.9 |
| 2/16/2012 | 7:21:26 PM | 0.252 | 0.082 | 0.000 | 0.082 | 36.6 |
| 2/16/2012 | 7:51:26 PM | 0.253 | 0.082 | 0.000 | 0.082 | 36.8 |
| 2/16/2012 | 8:21:26 PM | 0.254 | 0.083 | 0.000 | 0.083 | 37.0 |

# Hydrologic Model- Model Calibration



# Model Calibration

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# Model Output- surface/seep flow (2010 rainfall) by discharge

| Date/Time | Precipitation | W002 | W002 | W002 | | | |
|---|---|---|---|---|---|---|---|
| | | Runoff | Seep Flow | Total Flow | | T. Acre Ft | % runoff |
| M/d/yyyy | (in) | gpm | gpm | gpm | | per day | of T. Flow |
| 5/8/2010 | 0.28 | 0.0 | 43.9 | 43.9 | | 0.19 | 0.00% |
| 5/9/2010 | 0 | 20.4 | 84.2 | 104.5 | | 0.46 | 19.47% |
| 5/10/2010 | 0 | 0.0 | 57.2 | 57.2 | | 0.25 | 0.00% |
| 5/11/2010 | 0 | 0.0 | 39.8 | 39.8 | | 0.18 | 0.00% |
| 5/12/2010 | 0.22 | 0.0 | 29.0 | 29.0 | | 0.13 | 0.00% |
| 5/13/2010 | 1.66 | 14.2 | 53.7 | 67.9 | | 0.30 | 20.91% |
| 5/14/2010 | 0 | 2460.7 | 150.0 | 2610.8 | | 11.54 | 94.25% |
| 5/15/2010 | 0.47 | 0.0 | 145.4 | 145.4 | | 0.64 | 0.00% |
| 5/16/2010 | 0 | 60.9 | 217.2 | 278.2 | | 1.23 | 21.90% |

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# Modeling Summary by Discharge

| Discharge I.D. | Average runoff (gpm) | Average seep flow (gpm) | Average total flow (gpm) | 10 yr 24 hr storm Peak runoff gpm | Peak seep flow gpm | Total Peak gpm |
|---|---|---|---|---|---|---|
| 001 | 77.5 | 86.8 | 164.3 | 5462.0 | 1041.5 | 6503.5 |
| 002 | 88.1 | 72.7 | 160.8 | 6810.7 | 167.6 | 6978.3 |
| 005 | 41.6 | 67.1 | 108.8 | 3602.7 | 225.5 | 3828.2 |
| 006 | 13.4 | 192.4 | 205.8 | 1032.9 | 429.3 | 1462.2 |
| 007 | 31.1 | 97.4 | 128.5 | 3582.1 | 472.9 | 4055.0 |
| 014 | 14.0 | 26.6 | 40.6 | 1057.3 | 102.4 | 1159.7 |
| 021 | 22.7 | 68.4 | 91.0 | 1525.4 | 168.9 | 1694.3 |
| 031 | 22.6 | 77.7 | 100.3 | 1281.1 | 894.7 | 2175.8 |
| 034** | | | | | | |
| 036 | 19.3 | 23.6 | 42.9 | 719.6 | 239.5 | 959.2 |
| Totals | 330.3 | 712.7 | 1,043.0 | 25,073.9 | 3,742.4 | 28,816.3 |

** Discharges into 001, flow included in 001

# Modeling Summary of Contributing Precipitation

| Rainfall (2010) Total inches | Runoff Inches (%) | Seepage Inches (%) | Evapotrans. Inches (%) |
|---|---|---|---|
| 45.87 | 10.10 (22%) | 26.47(58%) | 9.30 (20%) |

| | Surface Runoff | Pit Floor | Total |
|---|---|---|---|
| Average Gal/min./acre | 0.5 | 1.4 | 1.9 |

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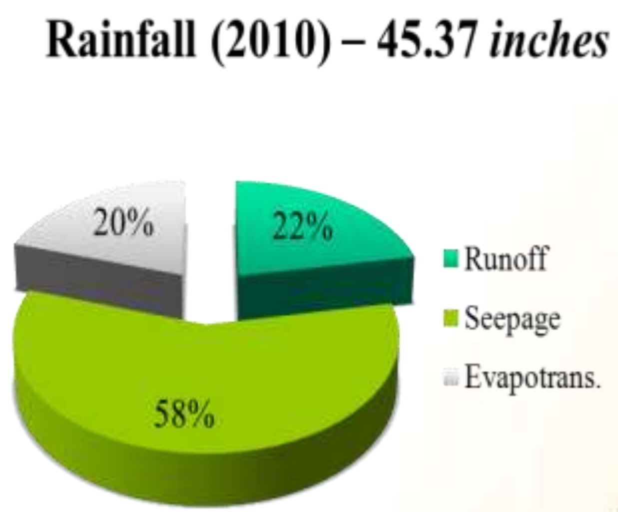
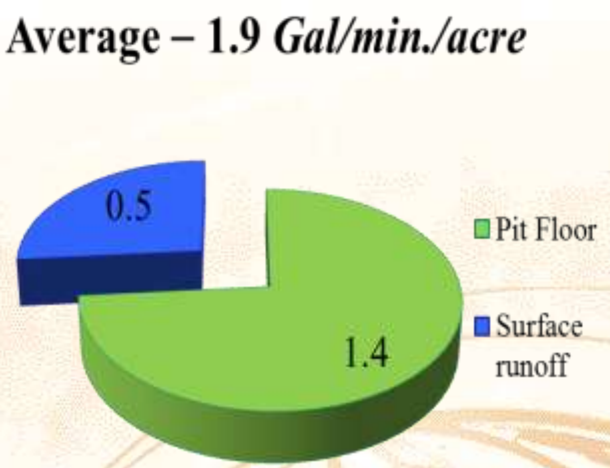
# Modeling Summary of Contributing Precipitation



# Determining Design Se Concentrations

## *From 2010 DMR Data*

| Discharge I.D. | Average Se Conc. µg/l | 95th Percentile Se Conc. µg/l | Maximum. Se Conc. µg/l |
|---|---|---|---|
| 001 | 4.59 | 11.13 | 17.50 |
| 002 | 8.38 | 20.03 | 34.90 |
| 005 | 6.97 | 10.40 | 11.60 |
| 006 ← | 2.10 | 5.95 | 15.10 |
| 007 | 6.21 | 13.34 | 20.50 |
| 014 ← | 2.47 | 6.80 | 9.00 |
| 021 | 9.66 | 16.34 | 32.90 |
| 031 | 6.72 | 15.94 | 21.00 |
| 034 | 3.82 | 9.50 | 10.60 |
| 036 | 13.25 | 20.45 | 21.20 |

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# Treatment Design Basis

Basis-- 2010 rainfall Modeled (W. 10yr-24hr) and DMR Selenium Conc.

| Discharge ID. | Average Flow gpm | Average Surface Runoff gpm | Average Seepage Flow gpm | Selenium (2010) Design Conc. µg/l** |
|---|---|---|---|---|
| 001 | 164.29 | 77.5 | 86.8 | 11.1 |
| 002 | 160.82 | 88.1 | 72.7 | 20 |
| 005 | 108.79 | 41.6 | 67.1 | 10.4 |
| 007 | 128.48 | 31.1 | 97.4 | 13.3 |
| 021 | 91.03 | 22.7 | 68.4 | 16.3 |
| 031 | 100.31 | 22.6 | 77.7 | 15.9 |
| 036 | 42.88 | 19.3 | 23.6 | 20.5 |
| Totals | 796.59 | 302.88 | 493.71 | |
| Weight Average | | | | 14.88 |

** 95 th Perentile Se concentrations

# Arch-Eastern, Birch Mine

- In March of 2011 a Consent Decree was entered by WVDEP requiring corrective action to comply with Selenium standard at 10 discharge points on the Knight Ink surface mine.
- A corrective action plan developed by Arch and CRA to establish the following:
  - ✓
  - Determine applicability of new and existing selenium treatment technologies
  - Complete alternatives analysis of selenium treatment system options.
  - Select Treatment Alternative
  - Design and construct system
  - Initial compliance by August 2012

# Alternative Treatment Analysis
# New and Existing Technologies

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# Treatment Design Considerations, Centralized vs. Independent

- Property access, permitting time requirements and jurisdictional wetlands immediately downstream of discharges, dictated that a **centralized treatment approach** be employed.
- Centralized Collection and Transfer System
  - Water level in ponds will be kept low via level controlled pump.
  - Pumps will deliver water to a centralized location for treatment
- Benefits of Centralized Collection and Treatment
  - Flow equalization is achieved in existing ponds
  - Treatment system can be constructed in most favorable location
  - Combining of flow allows for a lower Se. design concentration i.e., 95$^{th}$ percentile vs. max concentration

# Centralized Collection and Transfer System

# Centralized Collection and Transfer System (20,000 ft. Pipeline Transfer System)


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# Centralized Collection and Transfer System

- Key System Details
  - 2200 GPM pumping capacity via seven pumps
  - Surface Runoff Selenium concentrations found to be low, during precipitation events
  - Pump capacity nearly three times avg. flow, equivalent to 9.7 acre-ft./day
  - Level Controlled Automatic pump operation
  - 60 acre feet of storm water storage and flow equalization volume
  - System Owning and Operating cost is estimated at $0.48/1000 Gallons 10 yr. period, 8% NPV

# Selenium Treatment Alternatives Evaluation

- Completed Bench Scale Testing of the Following Technologies
  - Electro-Coagulation
  - Adsorbent Media
  - Iron Co-Precipitation

- Completed Pilot or Demonstration Scale Testing of the Following Technologies
  - Phyto -Remediation
  - Bio-Augmentation -*in-situ* pond treatment
  - Zero-Valent Iron Treatment
  - Ion-Exchange
  - Biological Reactor (Anaerobic Wetland) Treatment
    - With and Without Bio-Augmentation

# Selenium Treatment Alternatives Evaluation

- Bench Scale Results
  - Electro-Coagulation- *Bench scale tests had favorable results, equipment issues prevented further investigation of the technology*
  - Adsorbent Media- *Removal rates were insufficient to warrant further evaluation*
  - Iron Co-Precipitation- *Iron addition requirements were very high, did not move to pilot testing of the technology*

- Pilot Scale Results
  - Phyto -Remediation – Some removal during active growing season, not effective for higher Se loading
  - Bio-Augmentation (in pond) –Effective during low load, summer months, Not effective during winter months
  - Zero-Valent Iron Treatment- Effective Selenium Removal, High Iron generation
  - Ion-Exchange-Effective Selenium Removal, Large Brine disposal requirement
  - Biological Reactor (Anaerobic Wetland) Treatment-Effective Selenium removal, No Apparent Issues.

# Results of Focused Feasibility of Selected Technologies

| Treatment Technology | Estimated O&O Cost $/1000 Gal. 10yr | Pro's | Con's |
|---|---|---|---|
| Semi-Passive Biological Reactor | $0.38 | Low Maintenance, No Residual Material Handling Issues, Self Sustaining, Low Cost Operation Have installed simular systems that have shown long term success | Large footprint required, initial startup equilibrium period, Reaction to higher Se concentration is time consuming |
| Ion Exchange | $3.90 | Small Footprint required, Reaction period for higher Se Concentrations short. | Labor intensive, Residual Brine handling issue, Active mechanical maintenance issues. High Cost Operation, Treatment materials require storage, spill control |
| Zero Valent Iron | $3.00-$5.00 | Small Footprint required, Reaction period for higher Se Concentrations short. | Labor intensive, Residual Iron handling issue, Active mechanical maintenance issues. High Cost Operation, Treatment materials require storage, spill control Iron sludge handling and cost |

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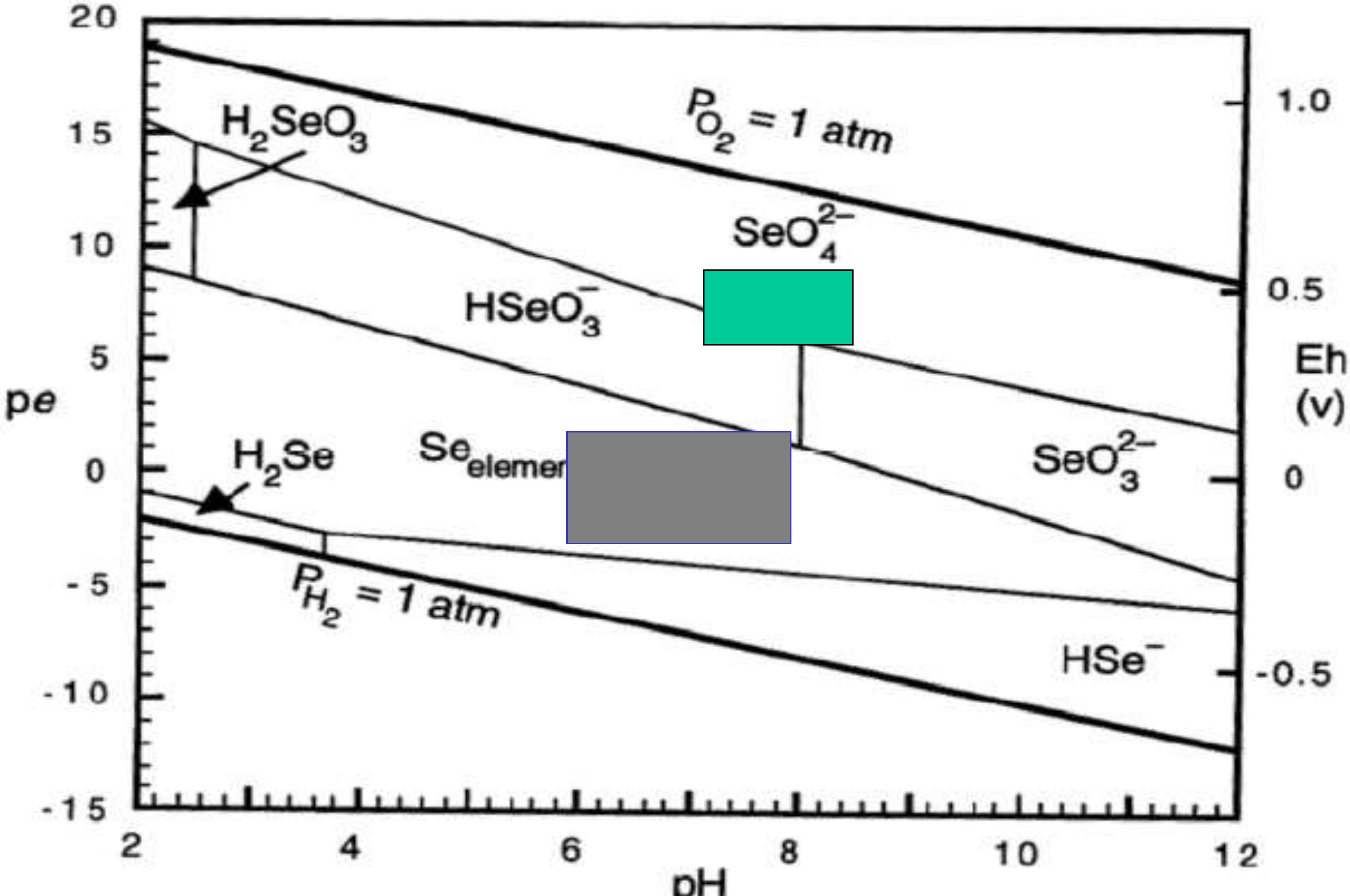
# Determination of Treatment

- In November, 2011 ARCH-Eastern Indicated to WVDEP that Centralized Collection & Transfer and Biological Reactor Treatment Would be Implemented in Accordance with the Site Consent Decree

  - Final sizing of the biological treatment system would occur after winter operation of the demonstration project.
  - Construction of the collection and transfer system would occur beginning in December 2011 (and it has)

# Chemistry of Selenium Treatment



# Chemistry of Selenium Treatment

- Most Treatment Strategies (except Ion exchange & Reverse Osmosis) Reduce Selenate (+6) to Selenite (+4) Elemental (0) or Selenide (-2) form.
- Reducing Condition can be created either chemically or biologically.
- Chemically by a reducing agent (e.g., -ZVI), biologically through decomposing organic matter and/or microbial respiration processes

# Chemistry of Selenium Treatment in Bio-Reactor

- 4CH3C0- + 3SeO2 → Se°+ 8CO2 +4H20 + 4H+

- Selenium (Selenate/Selenite) is reduced to its elemental state, where it precipitates out of solution and remains in the bio-reactor substrate.

- Key Factors to Removal
  - Form of Selenium, Arch-Eastern waters are > 95% Selenate
  - Eh (oxidation/Reduction) potential of the system
    - Affected by Temperature, Biological Activity, Flow Rate
  - Hydraulic Retention Time (detention time in the system)
    - Affected by Theoretical HRT (volume of the Bio-Reactor)
    - Affected by Actual HRT (Flow patterns within the system).

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# Chemistry of Selenium Treatment in Bio-Reactor

- Key Components of  Bio-reactor Design
  - Gravel Sub-Drain- Acts as a Biological Media and Principle Flow Path.
  - Hay Substrate- Acts as a Biological Media and Carbon Source for microbial activity. Reduces Eh of the System through decomposition
  - Mushroom Compost- Serves as a source of Nutrients to Microbes. Serves as growth media for cattails.
  - Cattails- Provides cover. Dying cattails replaces decomposing hay.
  - Microbes- Consumes available Oxygen, creates reducing conditions. (Some forms consume Oxygen associated with Selenate and Selenite ions)

# Bio-reactor Demonstration Project

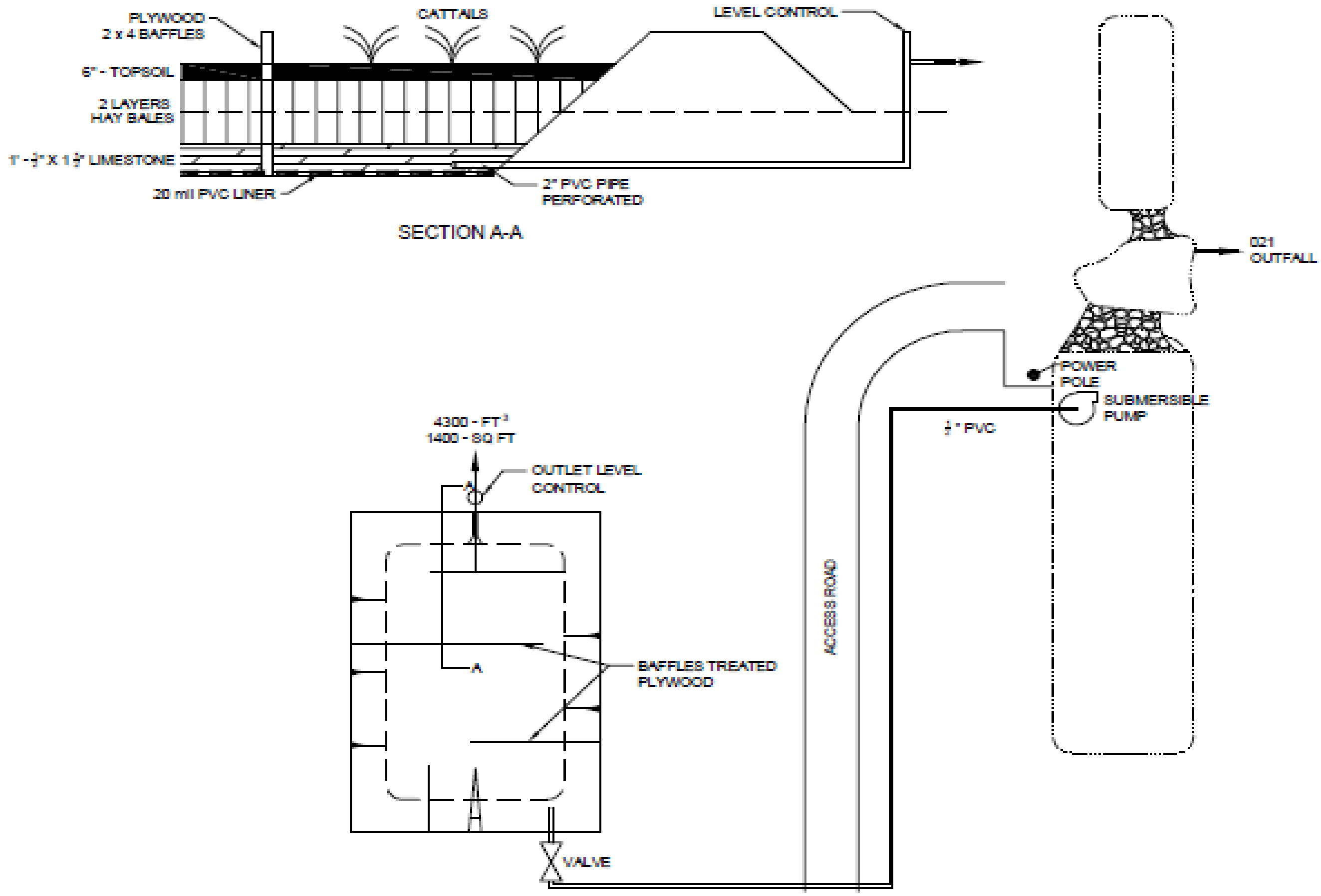


figure 1

SUB-SURFACE FLOW PASSIVE
BIO-REACTOR PILOT
ICG EASTERN
***Cowen, West Virginia***

72673-00(PRES001)GN-WA001 JUL 14/2011

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# Demonstration Bioreactor, Construction

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DEERE
240D
LC


Cattails

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SERIES 800C METER
RESET TO ZERO
FILL-RITE
TOTAL GALLONS
NICKEL PLATED
Tuthill
OVC
OHIO VALVE COMPANY

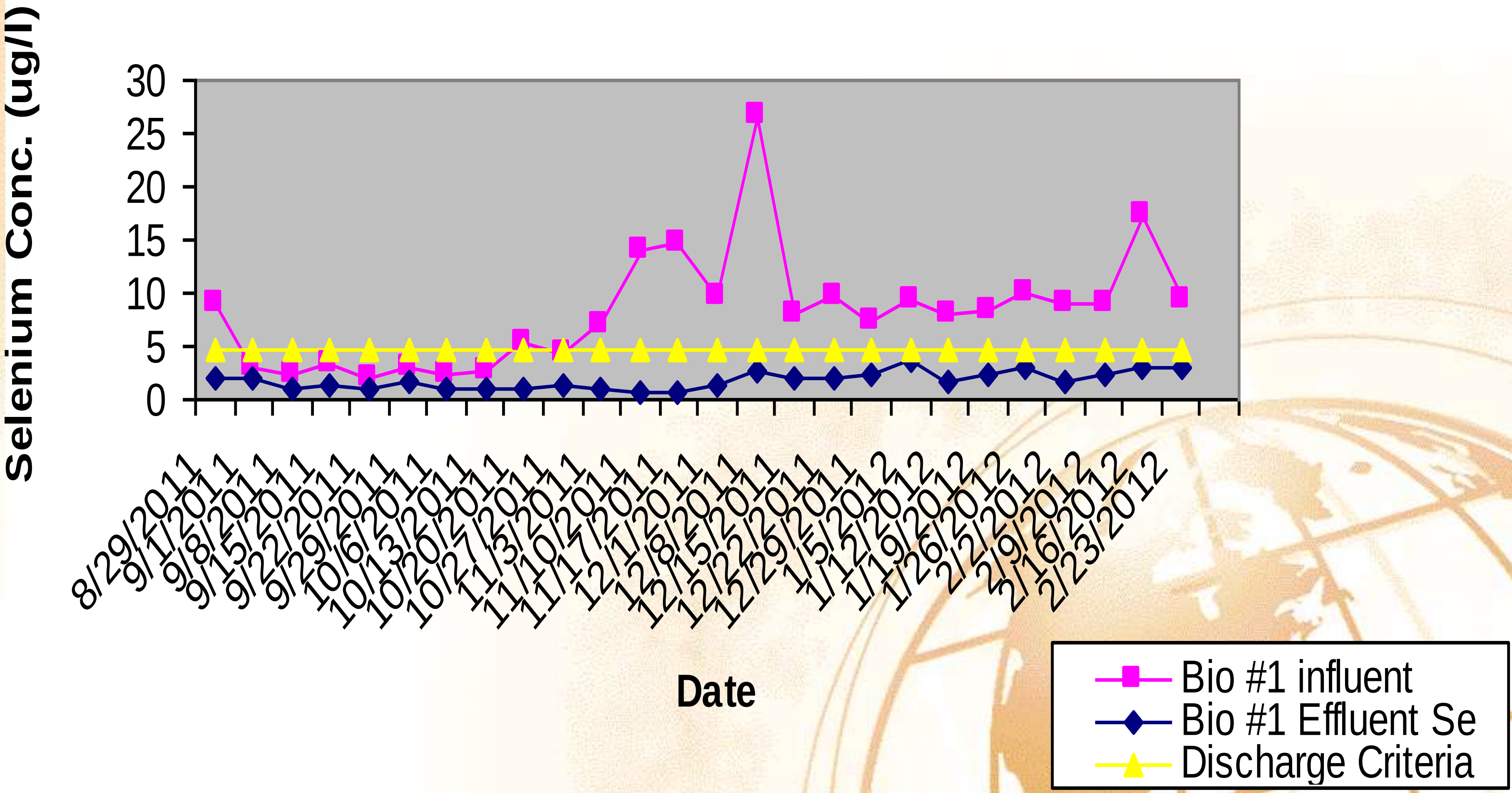

240D

# Bioreactor Demonstration Project-Key Features

- Lined System
- Fixed Bed-Plug Flow Biological Reactor
- Horizontal and Downward Flow
- Volume and Theoretical Hydraulic Retention Time (HRT) measured upon initial filling of the system
- Pumped, Measured inflow to the system
- Ability to increase Se concentrations to the influent
- Weekly analysis of daily composite samples
- Daily field reading of flow, pH, eH, Temp. and DO
- Continual operation from Mid-August thru February

# Demonstration Bio-reactor Results

# Arch-Eastern, Bioreactor # 1

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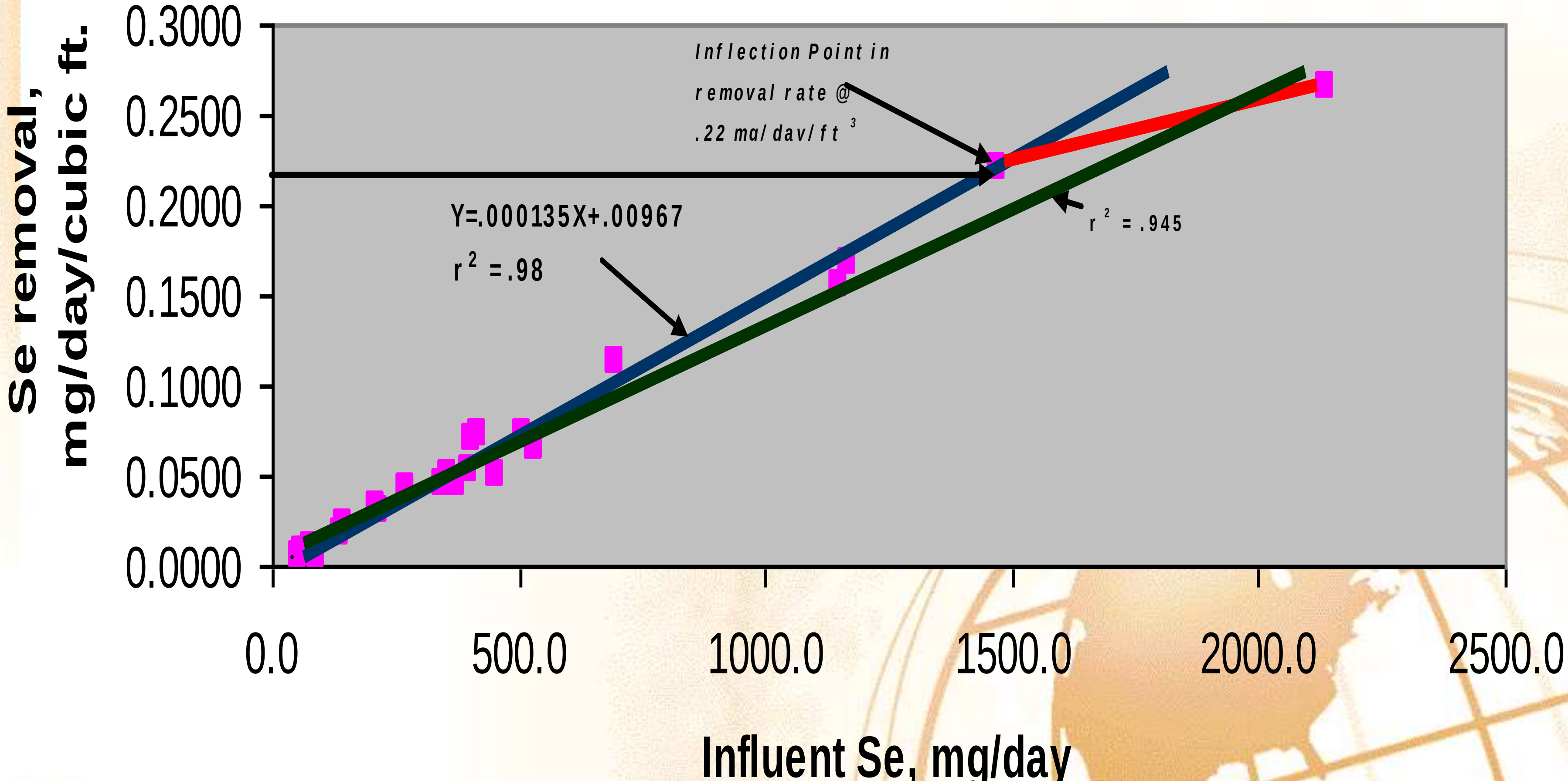
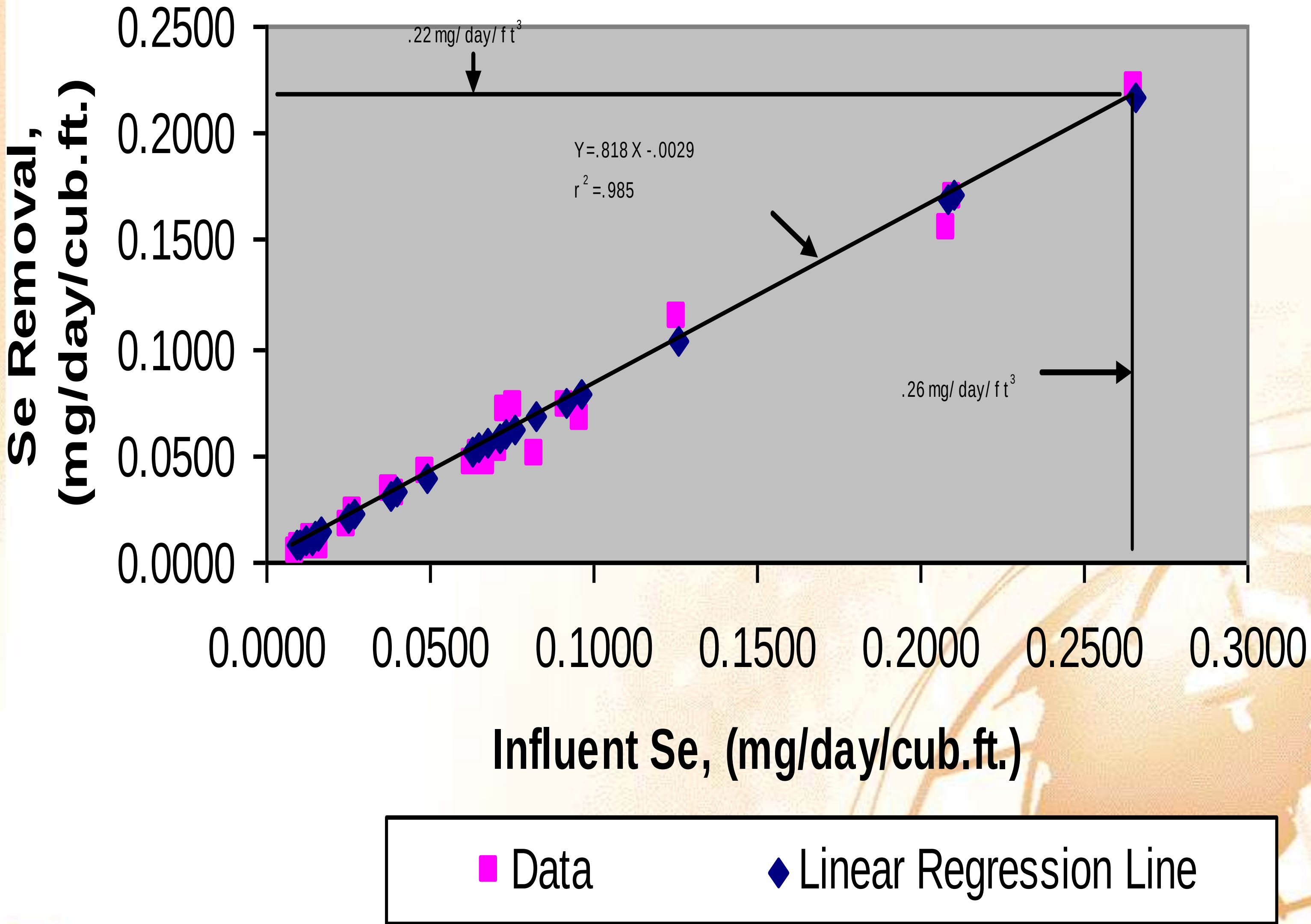
# Arch-Eastern, Bioreactor #1 Demonstration Project



# Arch-Eastern, Bioreactor #1

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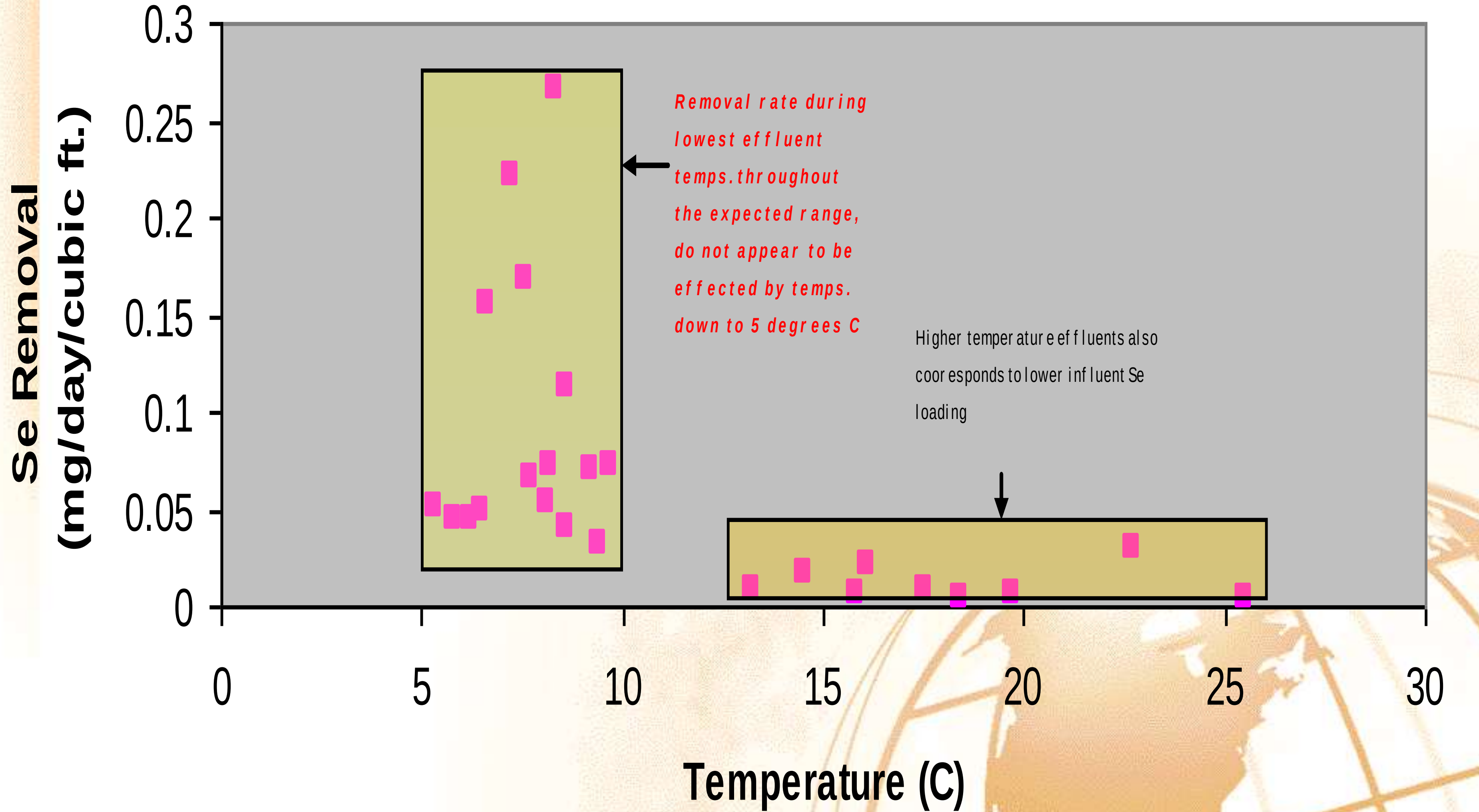
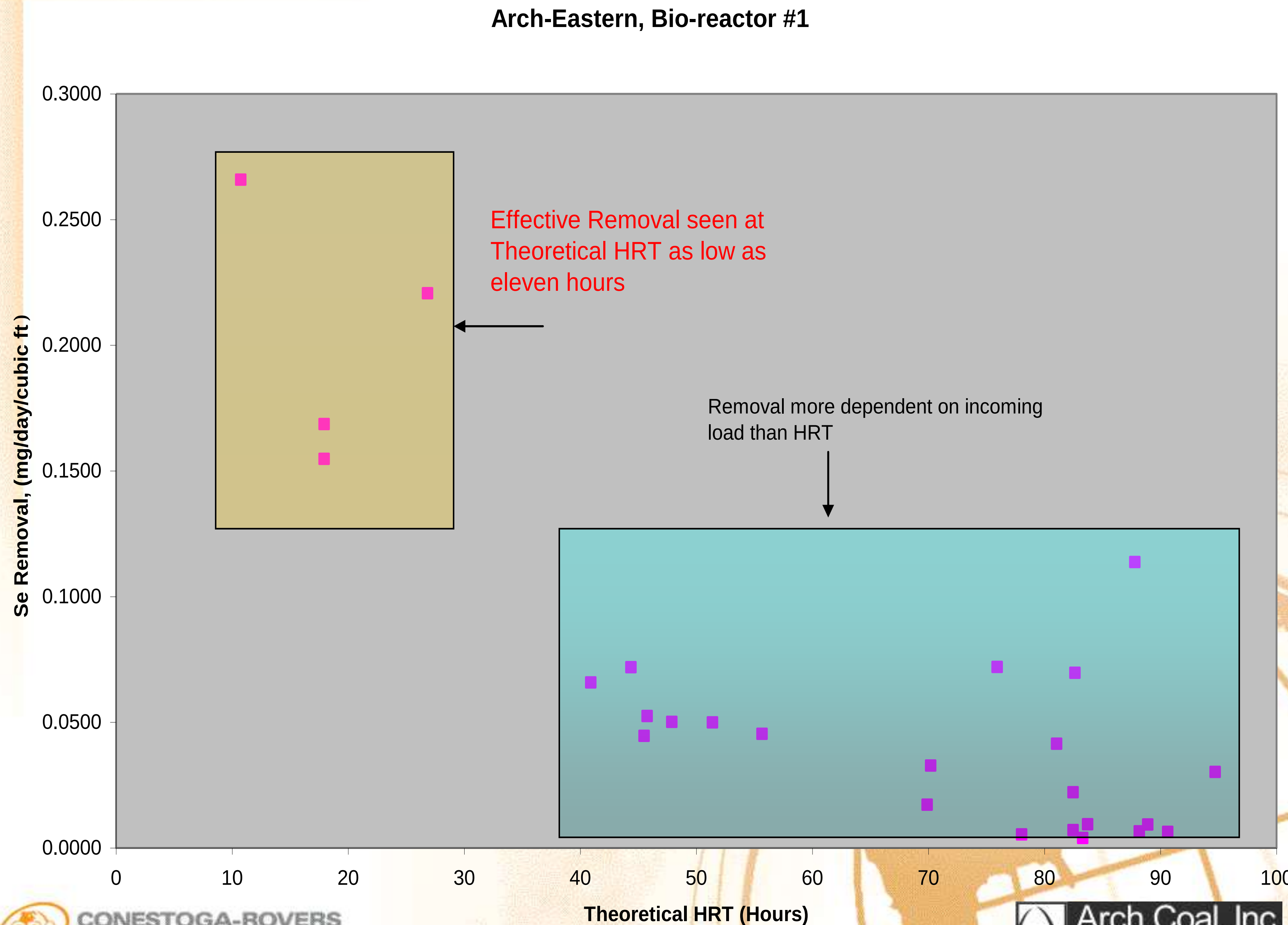
# Arch-Eastern, Bioreactor #1



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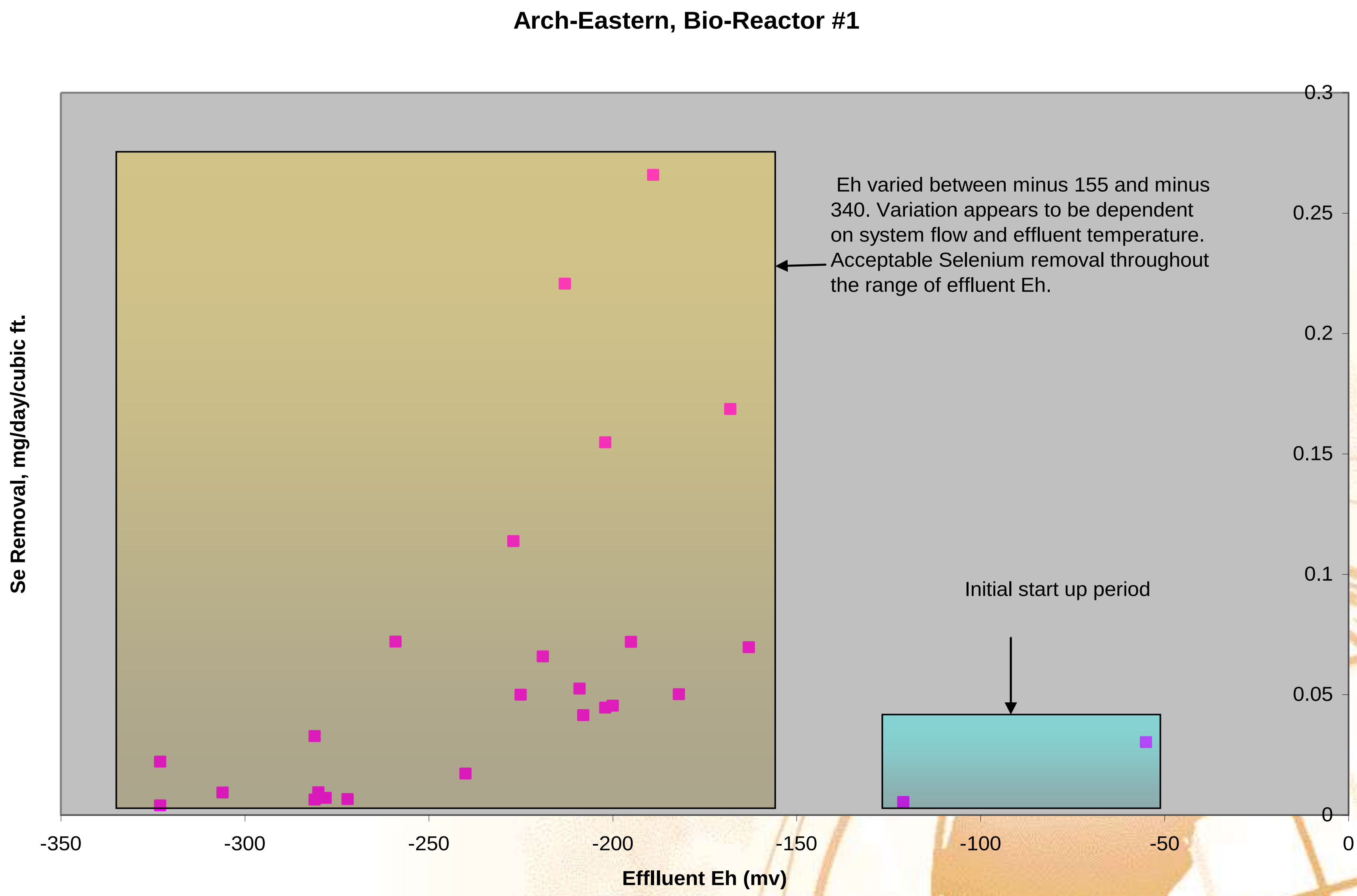


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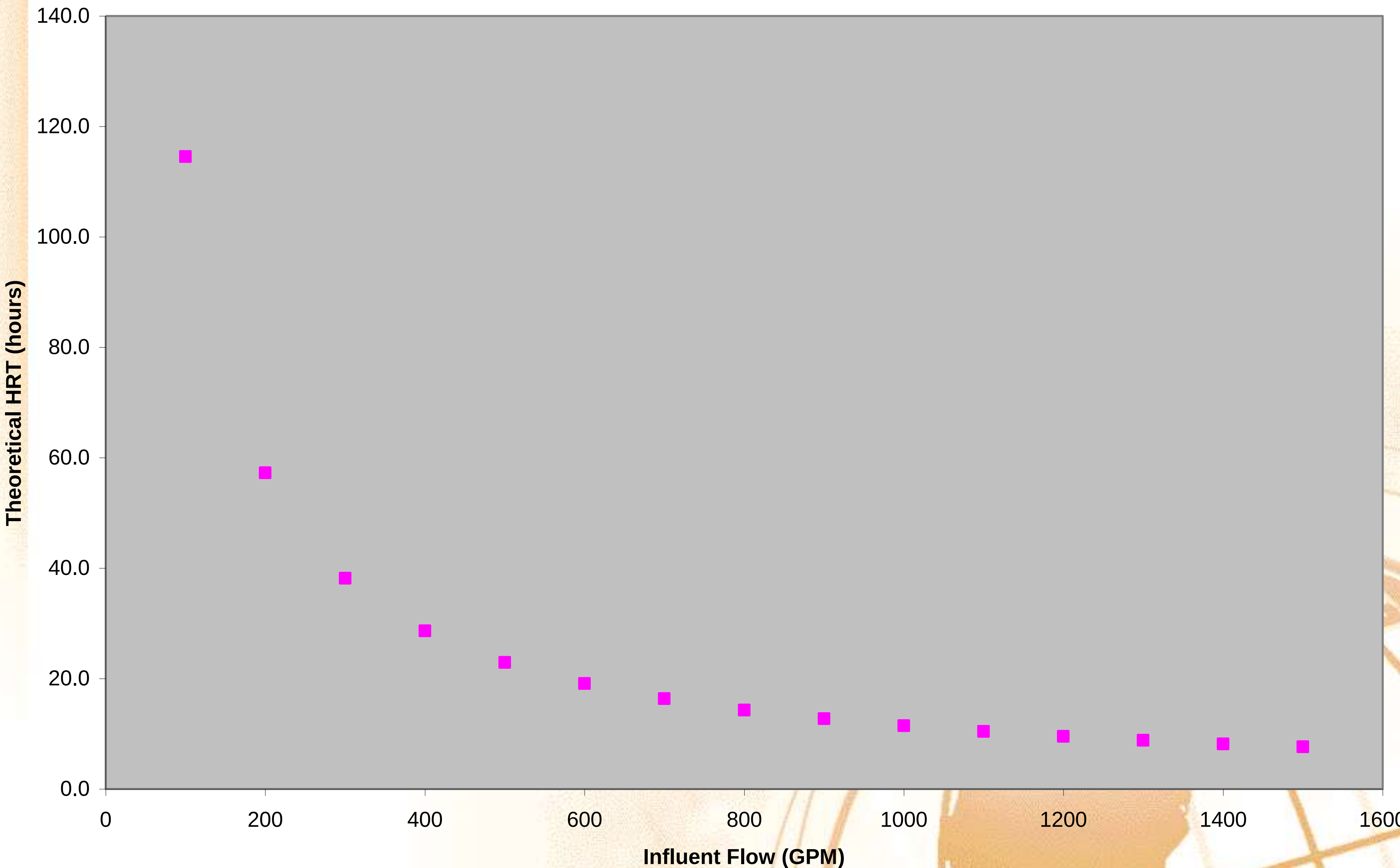
# Full Scale Implementation

- Full Scale Design Criteria (Established earlier in the project).
  - Flow 800 gpm
  - 95th Percentile Se concentration- 14.88
  - Effluent Concentration -2.35 µg/l (1/2 discharge criteria)
  - Yields a required Se removal of - 54635 mg Se/day
- Selenium removal rates of bio-reactor treatment established during demonstration testing
  - 0.22 mg/day/$ft^3$
- Full Scale Bio-Reactor Size
  - 54635 mg/day / .22 mg/day/$ft^3$ = ***248,340 $ft^3$***

# Arch-Eastern, Full Scale Bio-Reactor

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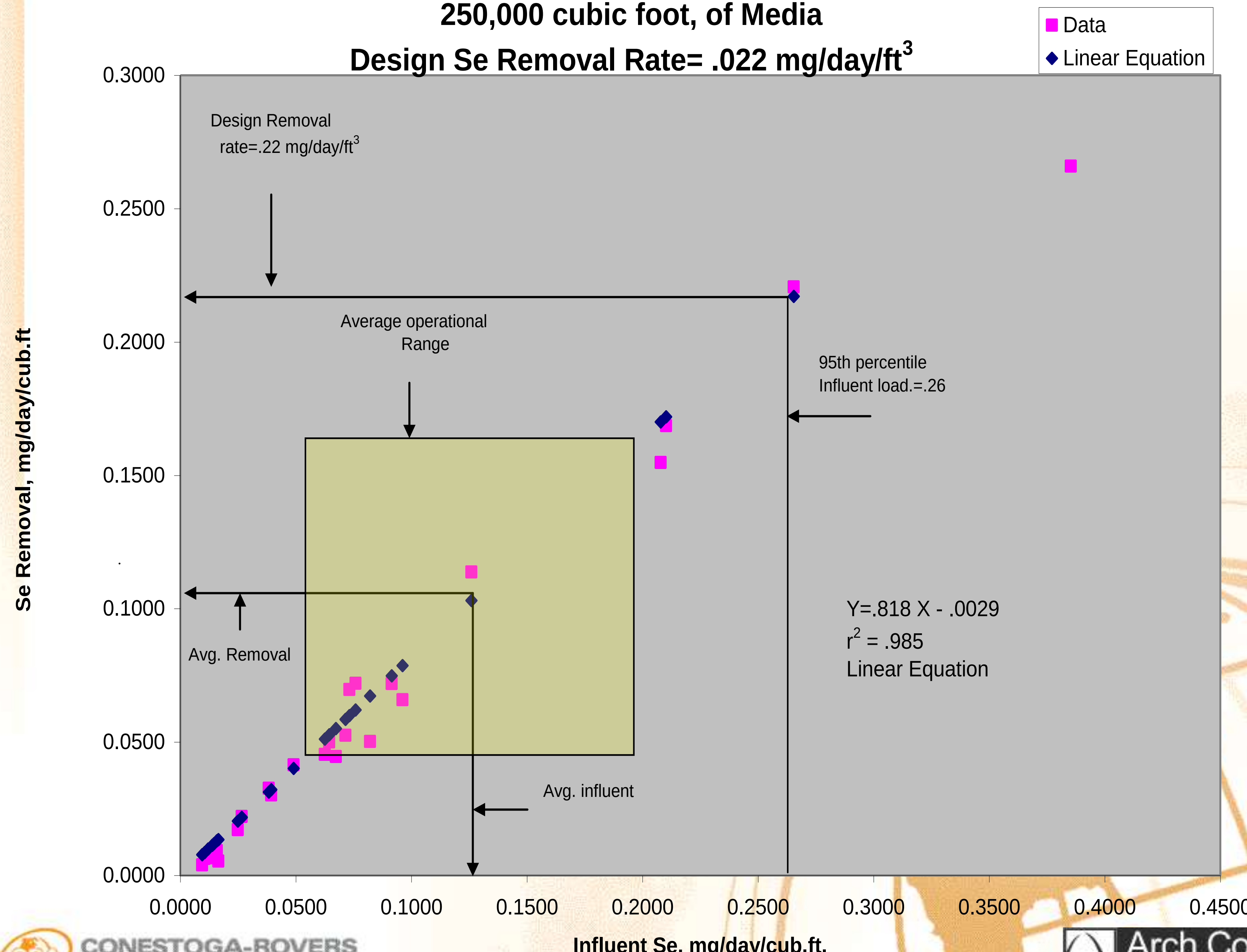
# Arch-Eastern, Full Scale Bio-reactor
## 250,000 cubic foot, of Media
## Design Se Removal Rate= .022 mg/day/$ft^3$

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# Quality Predictive Tool

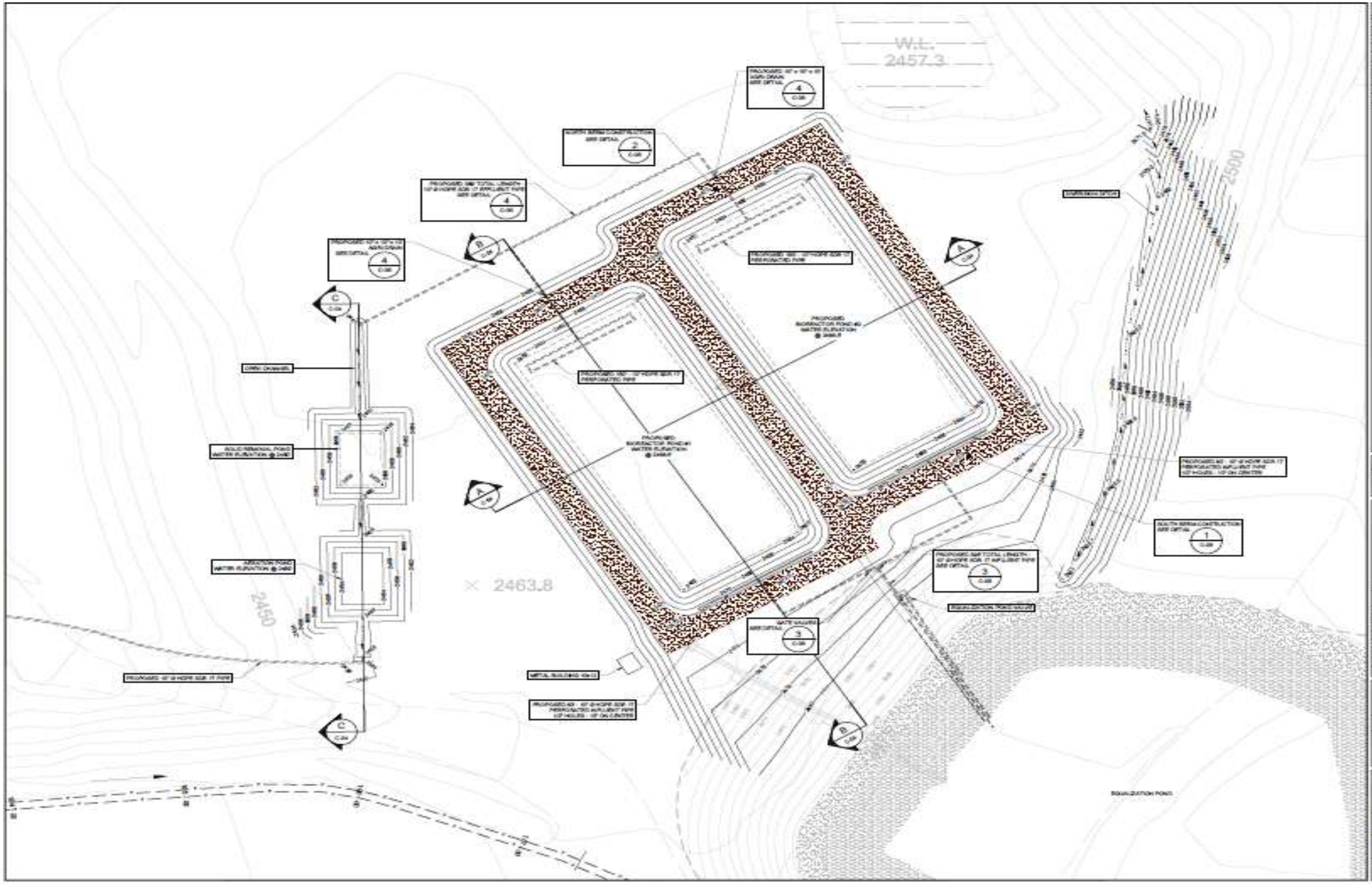
❖ The linear equation developed during the demonstration projects allows us to model expected effluent concentrations at various incoming loads

- Incoming Concentration 14.88 µg/l (95$^{th}$ percentile) at 800 gpm = effluent concentration of 2.35 µg/l
- Incoming Concentration 7.24 µg/l (average conc.) at 800 gpm = effluent concentration of 1.5 µg/l
- Incoming Concentration 19.7 µg/l at 800 gpm=

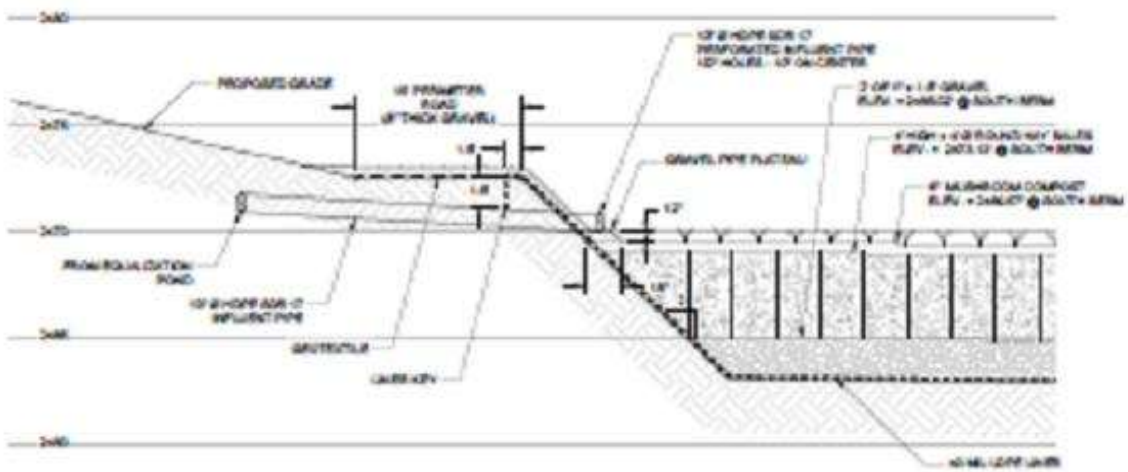
  effluent concentration of 3.7 µg/l
- Incoming Concentration 7.24 µg/l (average conc.) at 1150* gpm = effluent concentration of 1.45 µg/l

  * HRT at 10 hr.

# Full scale Bio-reactor Design, Plan View

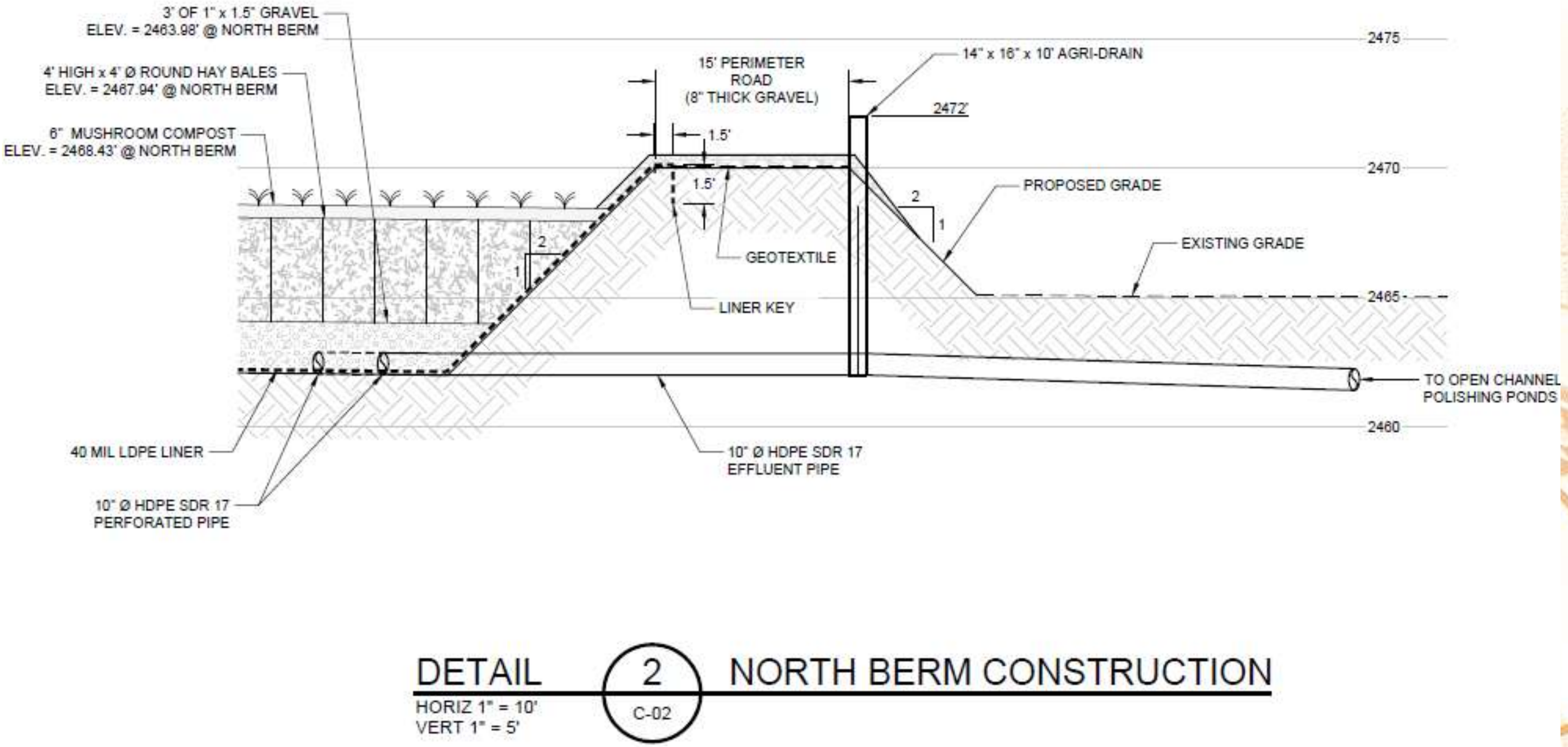


# Full scale Bio-reactor Design, Inlet section



DETAIL 1 SOUTH BERM CONSTRUCTION

# Full scale Bio-reactor Design, Outlet section

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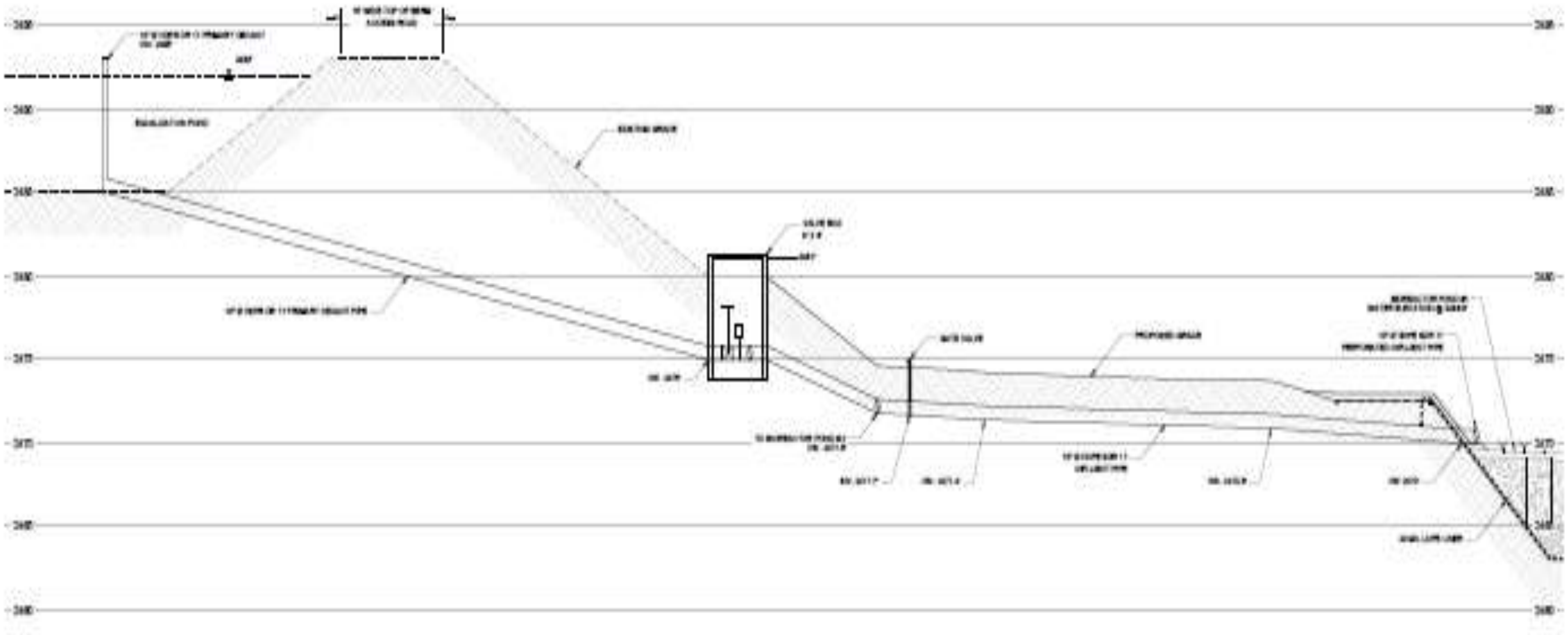
# Full scale Bio-reactor Design



DETAIL 3 INFLUENT PIPE AND VALVE BOXES

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# Conclusions, Completed Objectives

- **Establish design criteria for treatment of waters associated with discharge points identified in the Consent Decree- *800 GPM, 14.88 μg/l***
- **Determine applicability of new and existing selenium treatment technologies – *Bench and/or Pilot testing of 8 technologies***
- **Complete alternatives analysis of selenium treatment system options. -*Three Technologies Analyzed***
- **Select Treatment Alternative- *Collection and Transfer to Central Bio-reactor Treatment***
- **Design and construct system- *Design Completed, Construction underway***
- **Initial compliance by August 2012**

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