SELENIUM TREATMENT
ARCH-EASTERN, BIRCH MINE

WEST VIRGINIA MINE DRAINAGE TASK FORCE SYMPOSIUM

March 26, 2013

Conestoga-Rovers & Associates
Arch Coal, Inc.

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Conestoga-Rovers & Associates (CRA)

- Al Meek

Arch Coal, Inc.

- Keith Odell

Bratton Farm

- Ben Faulkner

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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**

Knight Ink Permit S-2019-88

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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.

Modeling Summary by Discharge

				10 yr 24 hr storm		
Discharge I.D.	Average runoff (gpm)	Average seep flow (gpm)	Average :otal flow (gpm)	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

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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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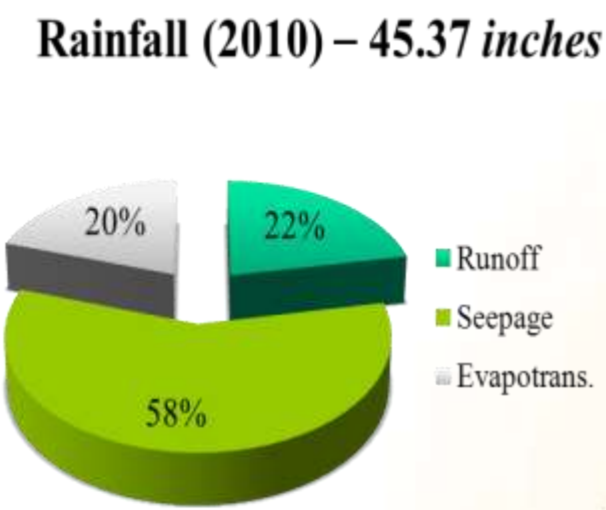
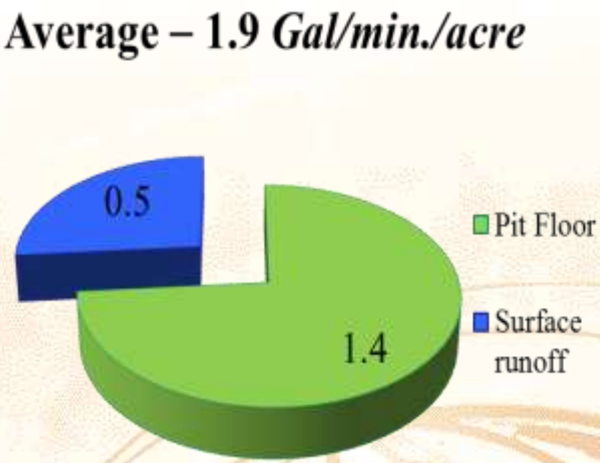
Modeling Summary of Contributing Precipitation





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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

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

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

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

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 $0.38/1000 Gallons 10 yr. period, 8% NPV

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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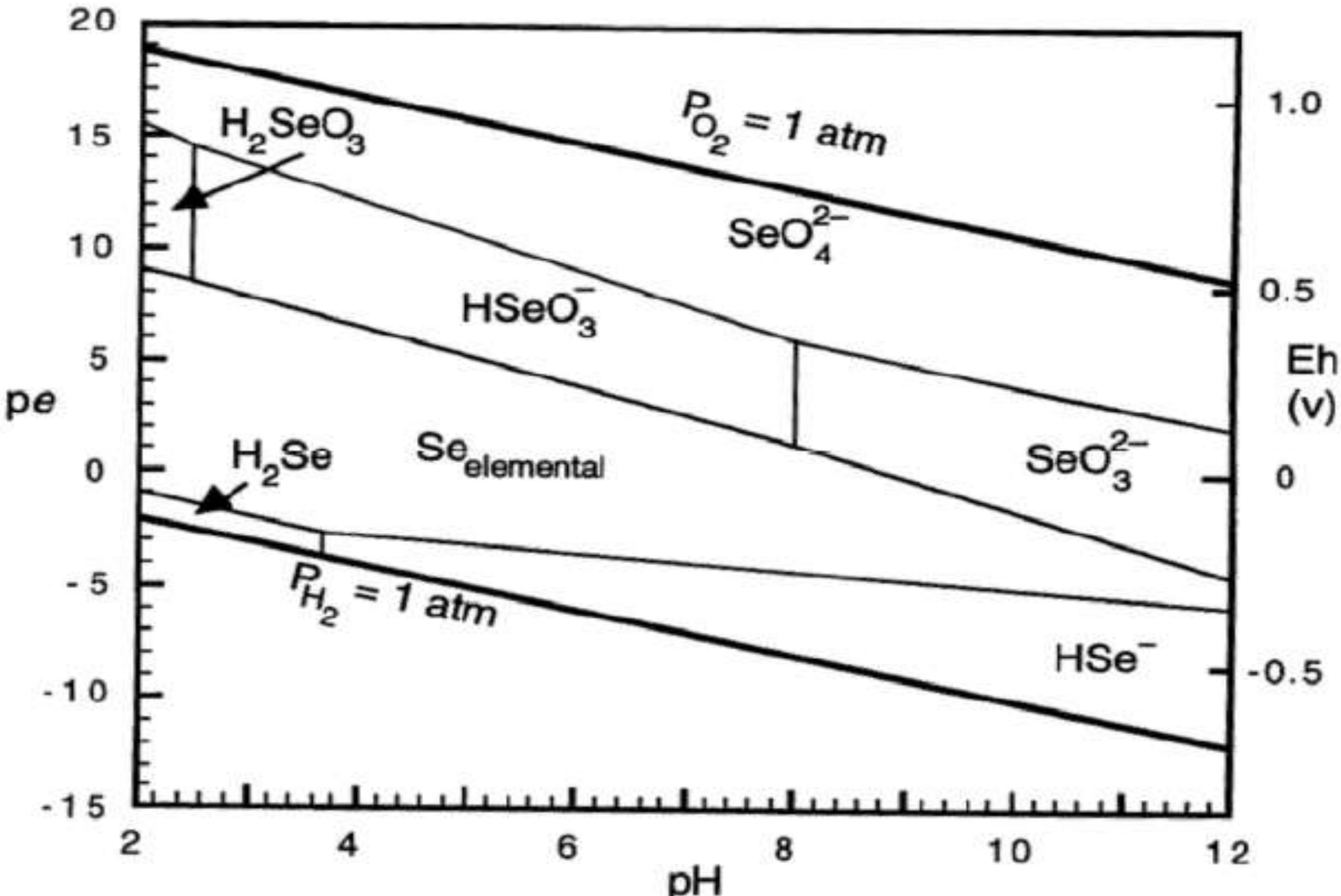
Chemistry of Selenium Treatment



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

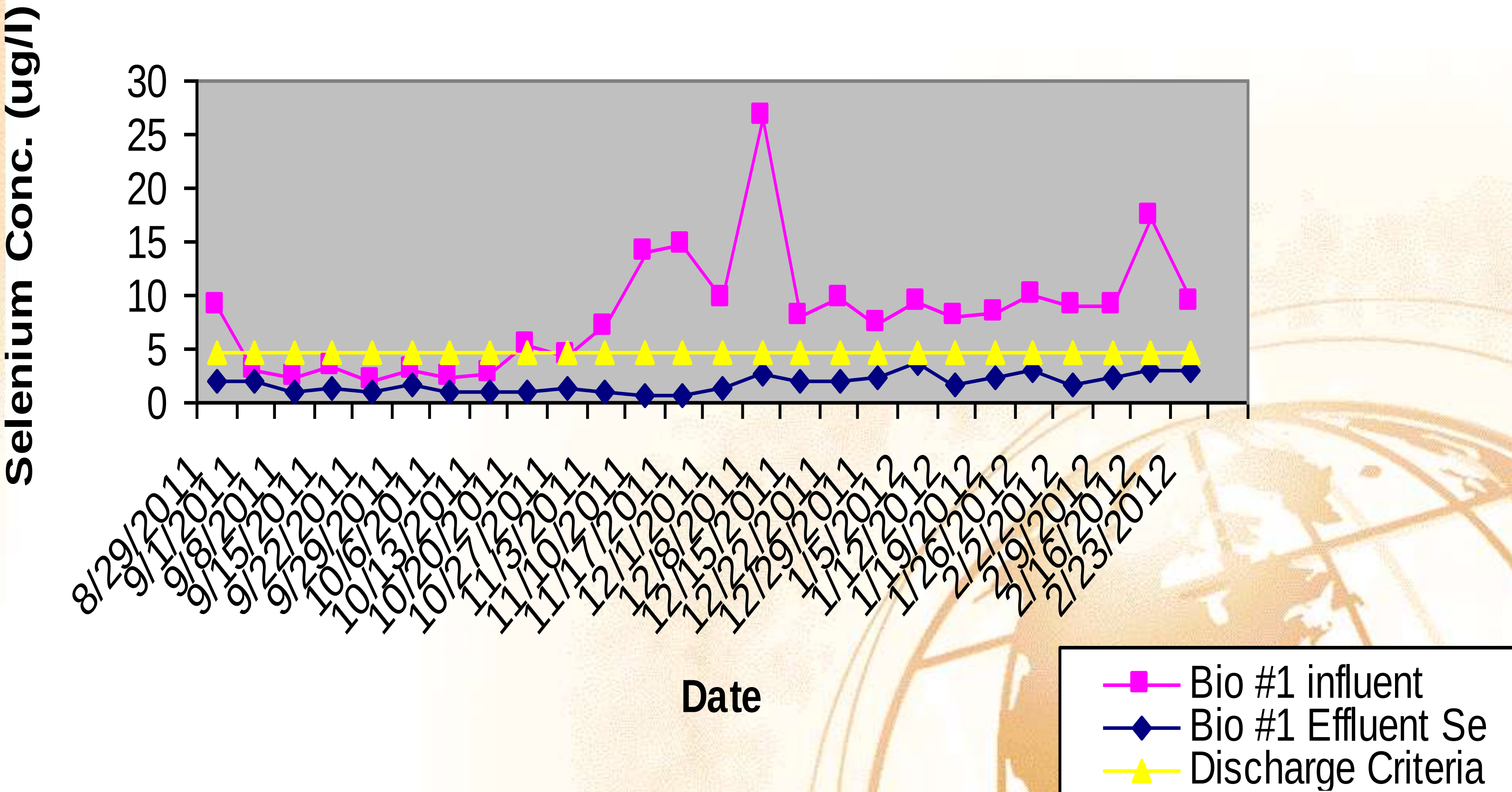
- $4CH_3C0^- + 3SeO_2 > Se^{\circ} + 8CO_2 + 4H_20 + 4H^+$

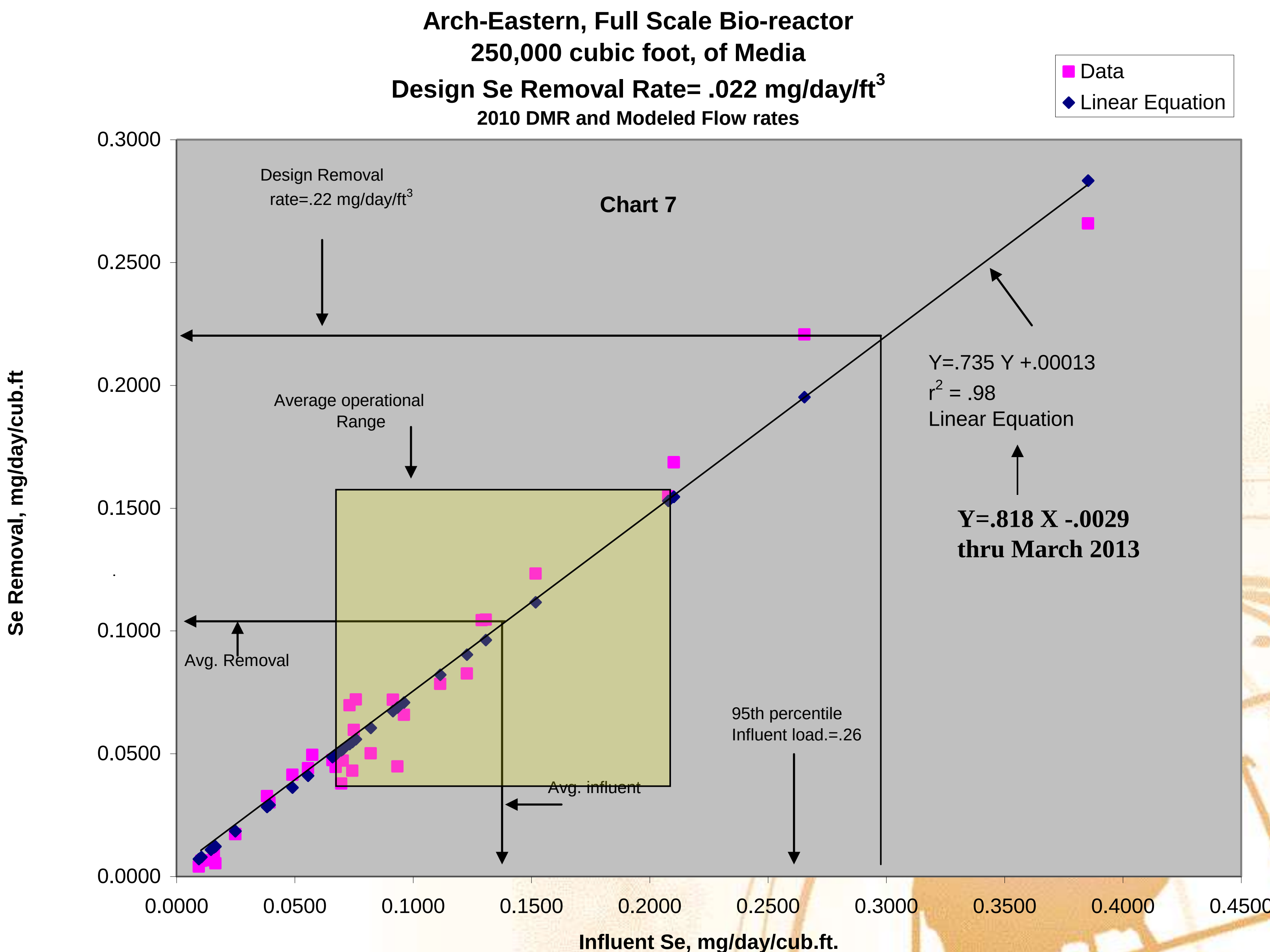
- Selenium (Selenate/Selenite) is reduced to its elemental state, where it precipitates out of solution and remains in the bio-reactor substrate.

- 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).

Demonstration Bio-reactor Results

Arch-Eastern, Bioreactor # 1





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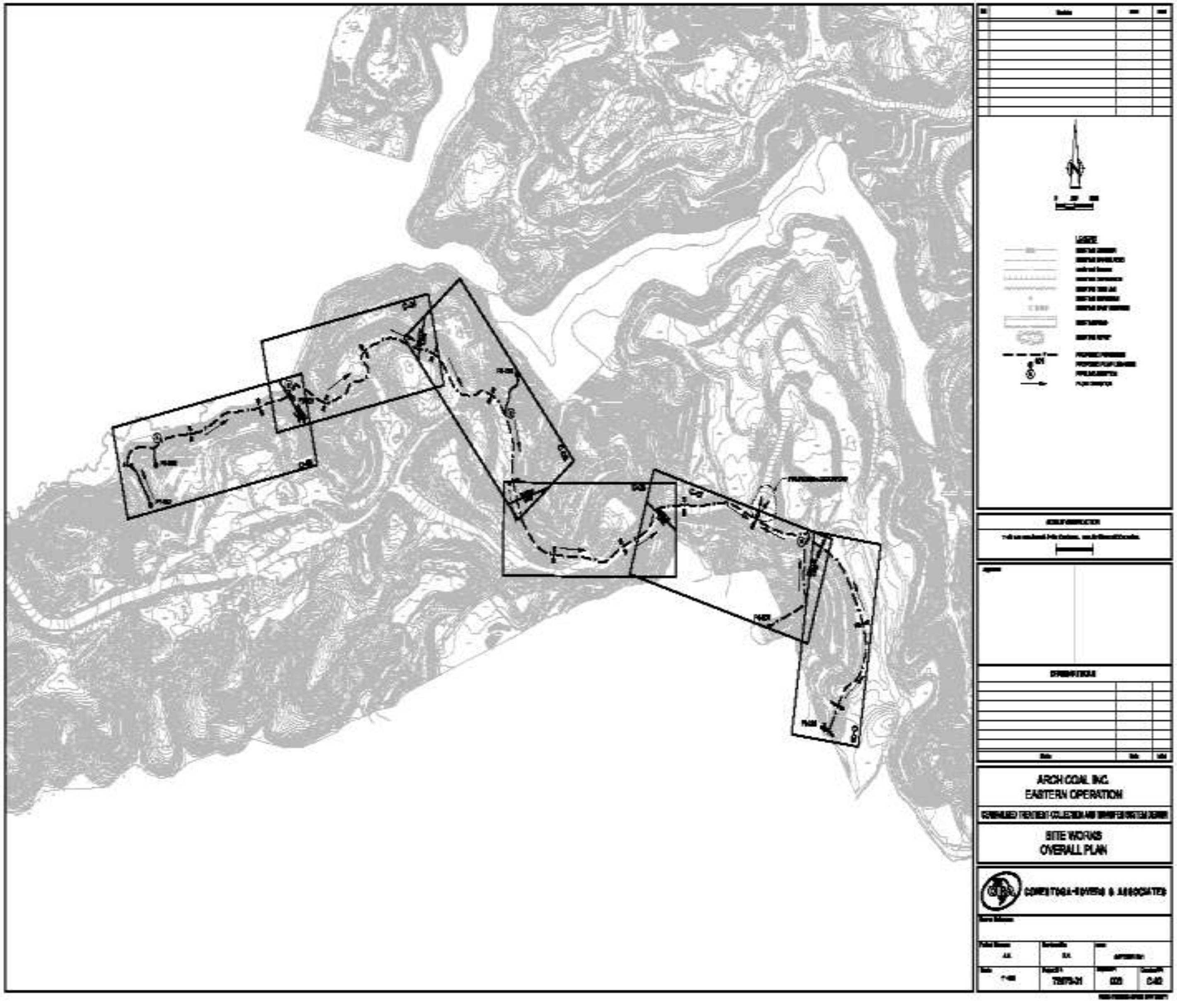
Full Scale Implementation

- Full Scale Design Criteria (Established earlier in the project).
  - Flow 800 gpm
  - 95^{th} 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***

SYSTEM DESIGN



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EASTERN OPERATION
SITE WORKS
OVERALL PLAN
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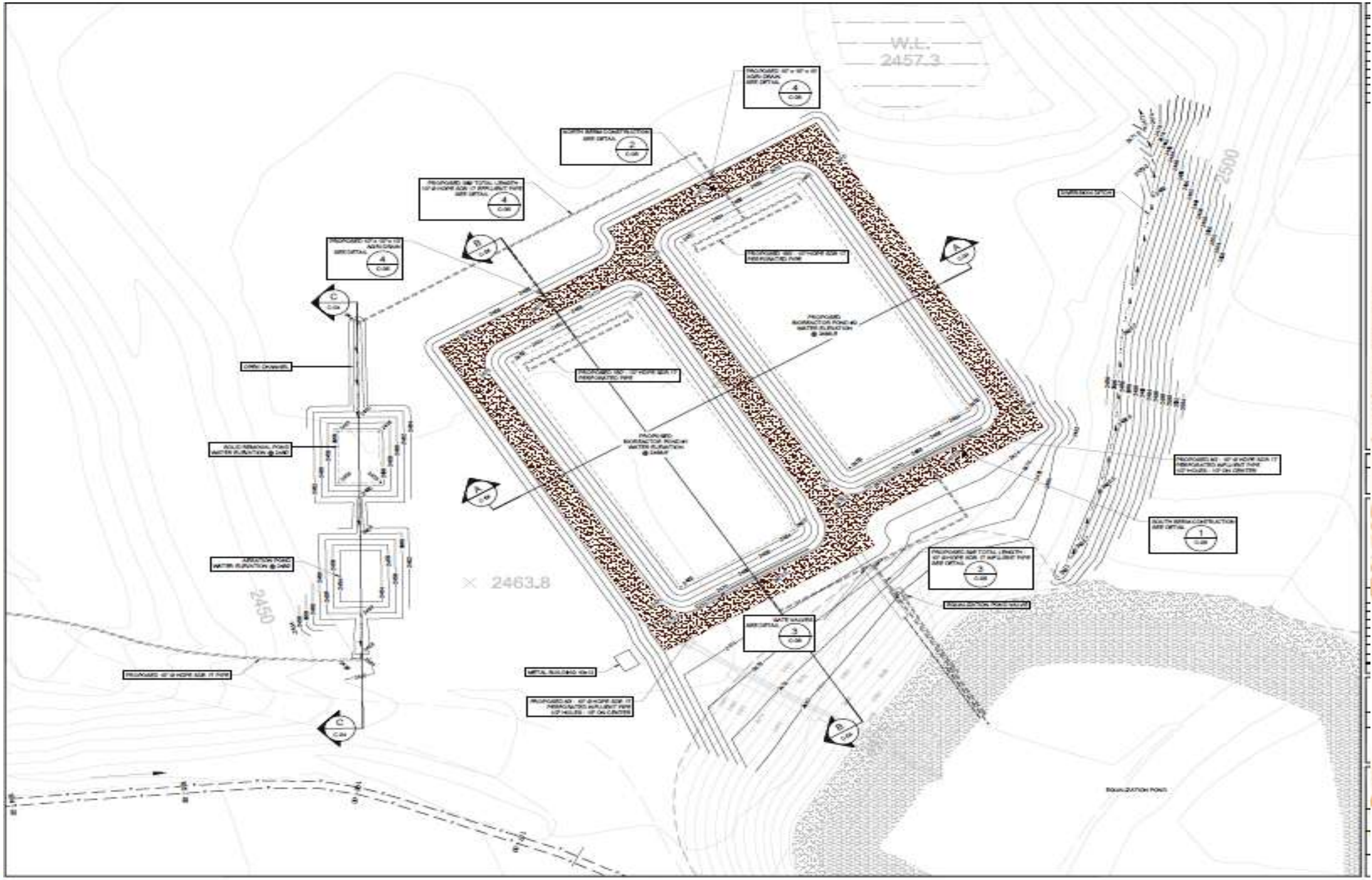
Full scale Bio-reactor Design, Plan View



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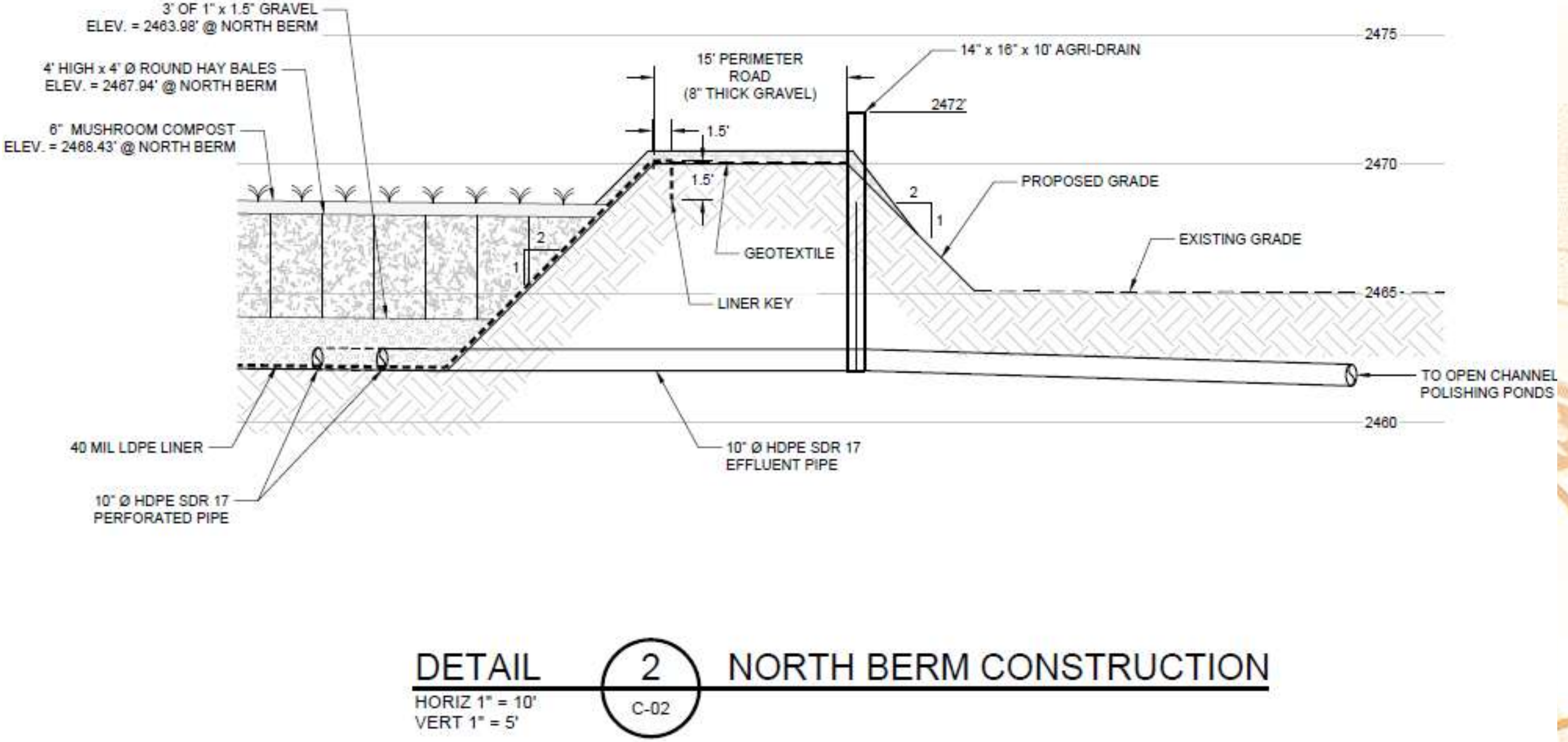
Full scale Bio-reactor Design, Outlet section



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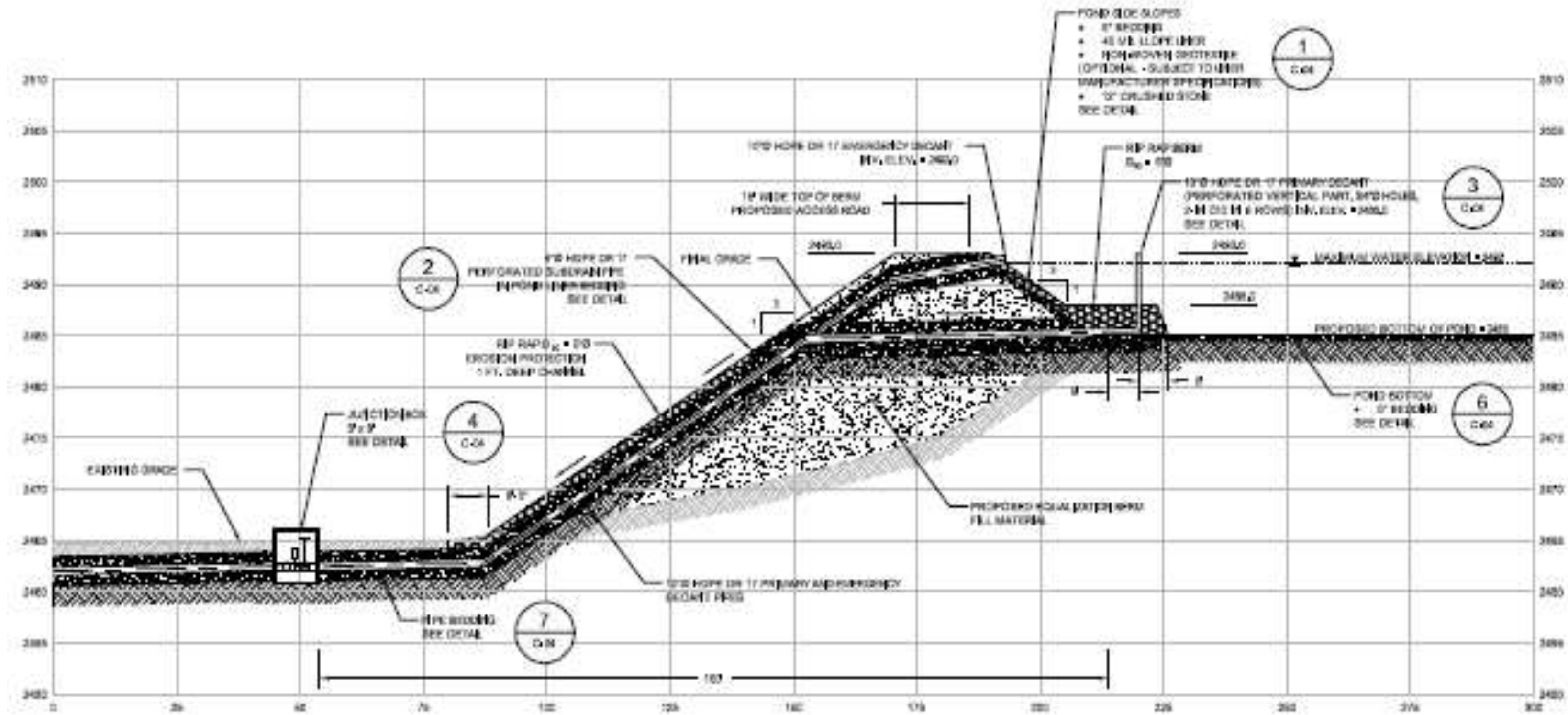
Full scale Bio-reactor Design, Eq. Feed Pond



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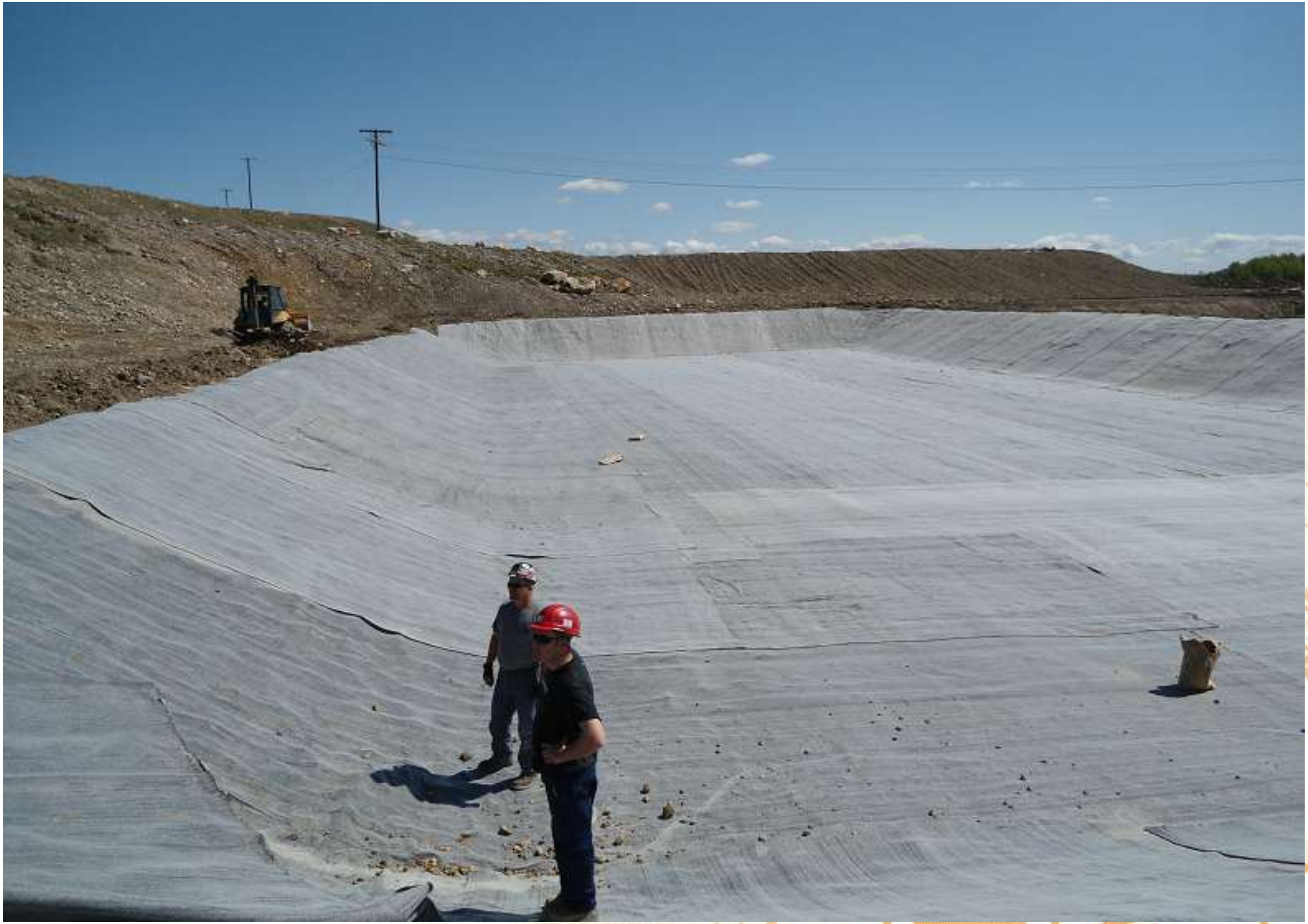


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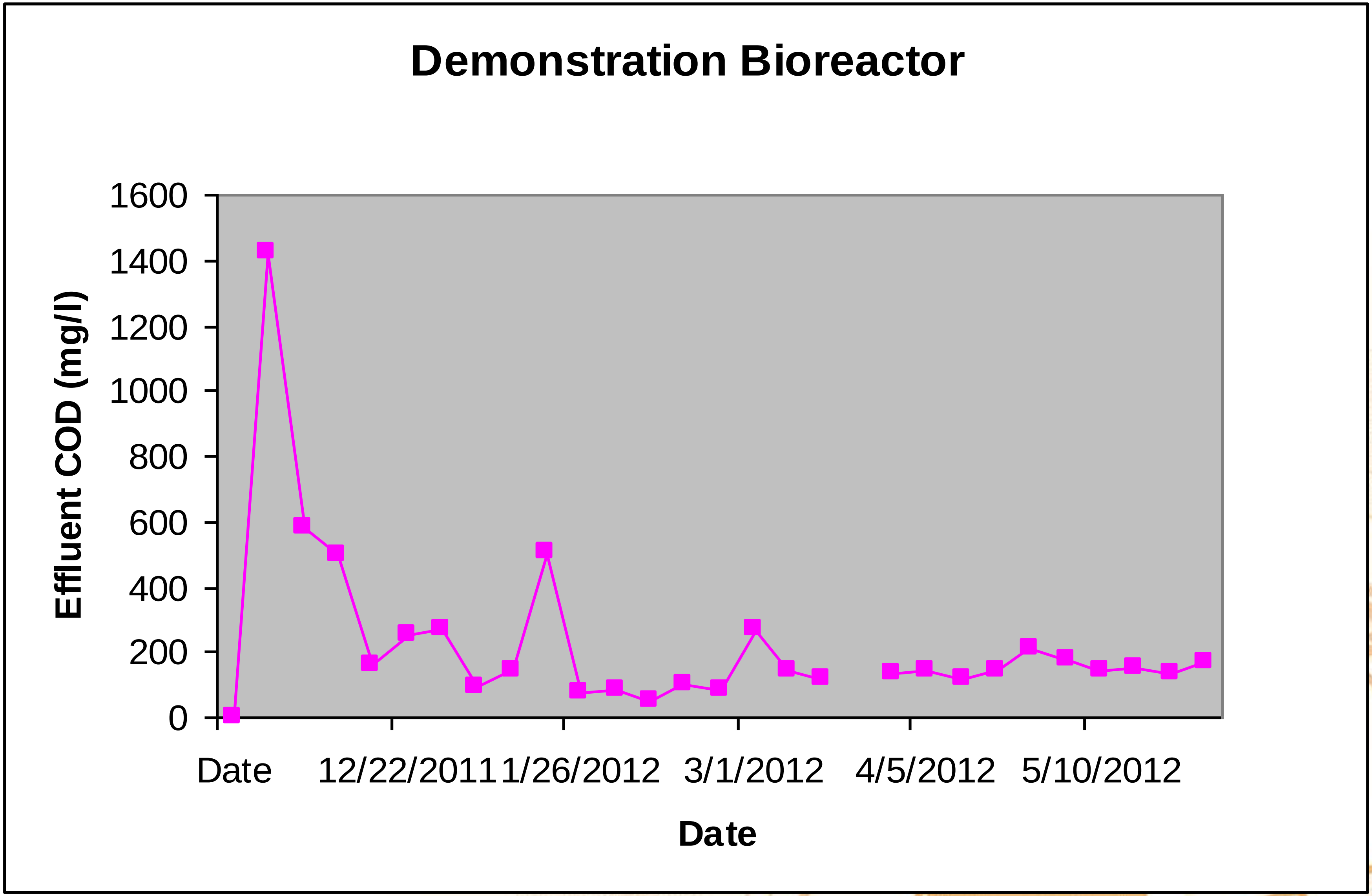
System Cost

Construction Self Performed by Arch

- Estimated Cost
  - Collection and Transfer System- $1.8 Million
  - Bioreactor Treatment System $0.6 Million
    - » Total $2.4 Million
- Actual Cost
  - Collection and Transfer System- $1.6 Million
  - Bioreactor Treatment System $0.5 Million
    - » Total $2.1 Million

SYSTEM START UP

SYSTEM EQUILIBRIUM



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Equilibrium Period, Full Scale System

Date	Flow	COD mg/l PP 1 in	COD mg/l PP2 out	COD Rm lb/hr
6/1/2012	350	6610	4620	349
6/21/2102	459	292	39	58
6/28/2012	417	166	118	10
7/12/2012	1000	143	122	11
8/7/2012	938	136	42	44
8/14/2012	1000	125	41	42

System Performance

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Modeled vs. Measured Flows

Hydrologic Modeling to Develop
Design Basis

Pump Hrs X Measured pump rate = Measured Flow

Date	001Pump Hr meter hrs	Day/period	Pump Rate gpm	Avg. Flow for period (gpm)	Pump Op. % of time	Rainfall inches	Rainfall per day (in)
6/25/2012	51		470				
6/29/2012	68.3	4	470	85	18.02%	0.98	0.25
7/19/2012	147	20	470	77	16.40%	1.98	0.10
8/1/2012	340.1	13	470	291	61.89%	6.24	0.48
8/8/2012	439.6	7	470	278	59.23%	0.82	0.12
8/14/2012	537	6	470	318	67.64%	1	0.17
8/21/2014	605.4	7	470	191	40.71%	0.86	0.12
8/27/2012	614.7	6	470	30	6.46%	0.4	0.07
9/4/2012	675.4	8	470	149	31.61%	0.8	0.10
9/20/2012	825.6	16	470	184	39.11%	2.67	0.17
10/8/2012	950.2	19	470	128	27.32%	1.95	0.10
11/30/2102	1531.5	53	470	215	45.70%	1.83	0.03
1/2/2013	2051.9	33	470	309	65.71%	4.71	0.14

TOTAL FLOW	55,937,520
Minutes/per.	264,960
Gpm	211
Avg Pump OP	39.98%

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Modeled Flow vs. Measured Flow

Pump ID.	001	005	007	021	031	036	Total (gpm)
Avg. Flow- 6 month period (**Modeled gpm**)	164	108	128	91	100	43	635
Avg. Flow - 6 month period (***Measured gpm***)	211	121	181	82	73	37	705
Flows Range Observed (gpm)	30-318	5-329	36-441	14-223	30-154	1-115	
Pump Utilization	40%	21%	41%	19%	16%	11%	
							Ratio
Measured/Modeled Flow Ratio	1.29	1.11	1.41	0.90	0.73	0.87	1.11
	Modeled Precip. In.	Measured Precip. In.					Ratio
Measured/Modeled Precipitation Ratio	22.9	24.24					1.06

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Selenium Treatment

SYSTEM PERFORMANCE

Summary to Date

- No non-compliant discharges for Selenium since installation (9 months)
- Median Se Removal Rate = 81%
- Average Se Removal Rate = 72%
- Raw water Selenium concentrations ranged from 8.2 to 2.0 ug/l. Less than Design Concentrations
- Lowest Removal Rates observed during high flow that result in lower HRT and Higher ORP

SYSTEM OPERATION

PUMP SYSTEM MONITOR PANEL

Structure	Depth to Bottom of Weir (in)	Depth to top of water (FT)	Depth to top of water (in)	Flow CFS	Flow GPM	Total GPM	Internal H^1.5	Head (FT)	C = See Reference above	L = Width Rect. Weir (FT)	ORP	Temp °C	Temp °F	EQ Basn pool el below Riser top (in)
AD-1	64.2	4.95	59.4	1.14	509.56		0.25	0.40	4.47	1.083	-184	6.9	44.42	
AD-2	64.2	4.92	59.04	1.26	564.55	1074.1	0.28	0.43	4.47	1.083	-172	7.4	45.32	
PP2 weir	8		3.4375	2.38		1068.3	0.23	0.38	3.33	3.125				-28
AD-1	64.2	4.96	59.52	1.09	488.32		0.24	0.39	4.45	1.083	-184	6.9	44.42	
AD-2	64.2	4.93	59.16	1.21	542.48	1030.8	0.27	0.42	4.45	1.083	-172	7.4	45.32	
PP2 weir	8		3.5625	2.28		1025.4	0.22	0.37	3.33	3.125				-29
AD-1	64.2	4.96	59.52	1.06	477.70		0.24	0.39	4.35	1.083	-183	6.7	44.06	
AD-2	64.2	4.93	59.16	1.18	530.68	1008.4	0.27	0.42	4.35	1.083	-175	6.5	43.7	
PP2 weir	8		3.625	2.24		1004.1	0.22	0.36	3.33	3.125				-29
AD-1	64.2	5.08	60.96	0.67	298.74		0.14	0.27	4.61	1.083	-182	3	37.4	
AD-2	64.2	5.11	61.32	0.56	251.82	550.6	0.12	0.24	4.61	1.083	-182	4	39.2	
PP2 weir	8		5.0625	1.24		556.8	0.12	0.24	3.33	3.125				-42
AD-1	59.2	4.65	55.8	0.74	330.24		0.15	0.28	4.75	1.083	-177	4.5	40.1	
AD-2	59.2	4.7	56.4	0.56	249.21	579.4	0.11	0.23	4.75	1.083	-186	4.2	39.56	
PP2 weir	8		4.9375	1.32		592.3	0.13	0.26	3.33	3.125				-42
AD-1	59.2	4.7	56.4	0.72	324.16		0.11	0.23	6.18	1.083	-194	2.6	36.68	
AD-2	59.2	4.76	57.12	0.47	209.95	534.1	0.07	0.17	6.18	1.083	-192	2	35.6	
PP2 weir	8		5	1.28		574.4	0.13	0.25	3.33	3.125				-43
AD-1	59.2	4.63	55.56	0.84	377.19		0.17	0.30	4.92	1.083	-181	4.7	40.46	
AD-2	59.2	4.68	56.16	0.65	290.70	667.9	0.13	0.25	4.92	1.083	-179	4.5	40.1	
PP2 weir	8		4.625	1.52		684.1	0.15	0.28	3.33	3.125				-40
AD-1	59.2	4.72	56.64	0.33	147.12		0.10	0.21	3.20	1.083	-178	6.2	43.16	
AD-2	59.2	4.75	57	0.26	117.88	265.0	0.08	0.18	3.20	1.083	-189	5.8	42.44	
PP2 weir	8		6.25	0.57		257.7	0.06	0.15	3.33	3.125				-46
AD-1	47.2	3.68	44.16	0.41	183.33		0.13	0.25	3.10	1.083	-201	8.6	47.48	
AD-2	47.2	3.72	44.64	0.32	142.77	326.1	0.10	0.21	3.10	1.083	-225	7.7	45.86	
PP2 weir	8		6	0.70		314.4	0.07	0.17	3.33	3.125				-42
AD-1	52.2	4.12	49.44	0.49	221.94		0.11	0.23	4.32	1.083	-196	6.2	43.16	
AD-2	52.2	4.15	49.8	0.40	181.01	402.9	0.09	0.20	4.32	1.083	-221	8.1	46.58	
PP2 weir	8		5.625	0.90		406.0	0.09	0.20	3.33	3.125				-46

OPERATIONAL LESSONS LEARNED

- ORP is the best indicator of operational performance
  - Flow rate and Temp. affect ORP
  - ORP and Hyd. Retention time affect selenium removal rates
- System Start-up (Eq. period) can be a challenge
  - Ambient Temp affect COD level
  - Flow Rate affect COD level
- Consolidation of discharges (collection & transfer) has had un-anticipated benefits.
  - Less monitoring labor
  - Has allowed for more economical treatment reagents for manganese control that will save significant $’s in treatment costs.

Longevity of System?

- Good Question!!
- Hay is the Carbon source, and Carbon is used up in the treatment process.
- Demonstration Bioreactor lost 25% of hay volume in 1 yr of operation.
- Some hay loss do to compaction and settling
- Cattail production can supplement hay loss
- Bioreactors of this type, will require supplemental hay addition on a periodic basis