

Selected Case Studies

Applications of Sulfate Reducing Bioreactors in the Passive Treatment of Acid Mine/Rock Drainage

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Passive Treatment System Design Components

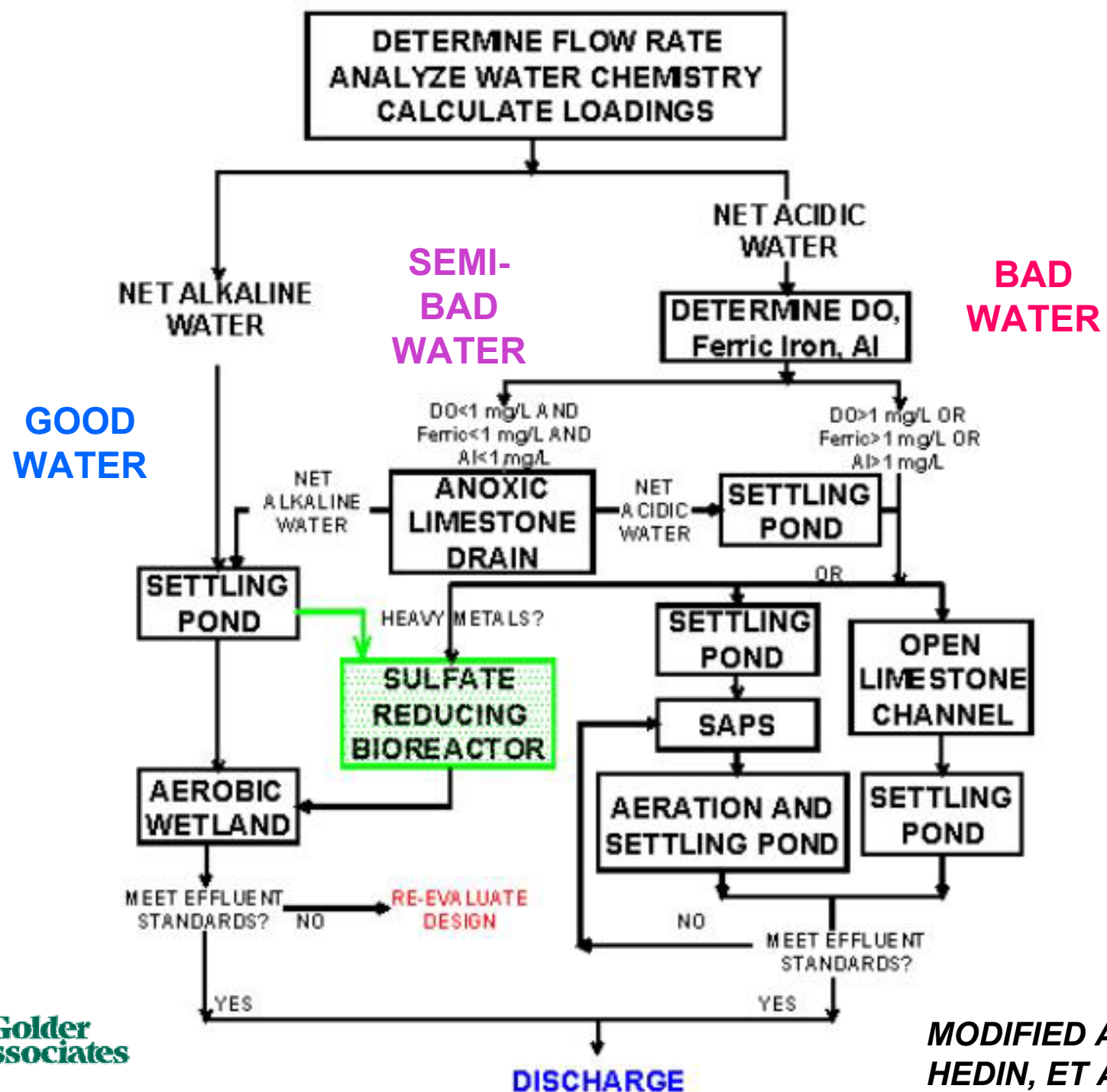
Biological Components

- **Anaerobic SRBR's**
- **Aerobic Cells or Rock Filters**
- Successive Alkalinity Producing Systems (SAPS)

Limestone Components

- Limestone Sand
- **Anoxic Limestone Drains (ALD's)**
- Alkaline Ponds
- Open Limestone Channels

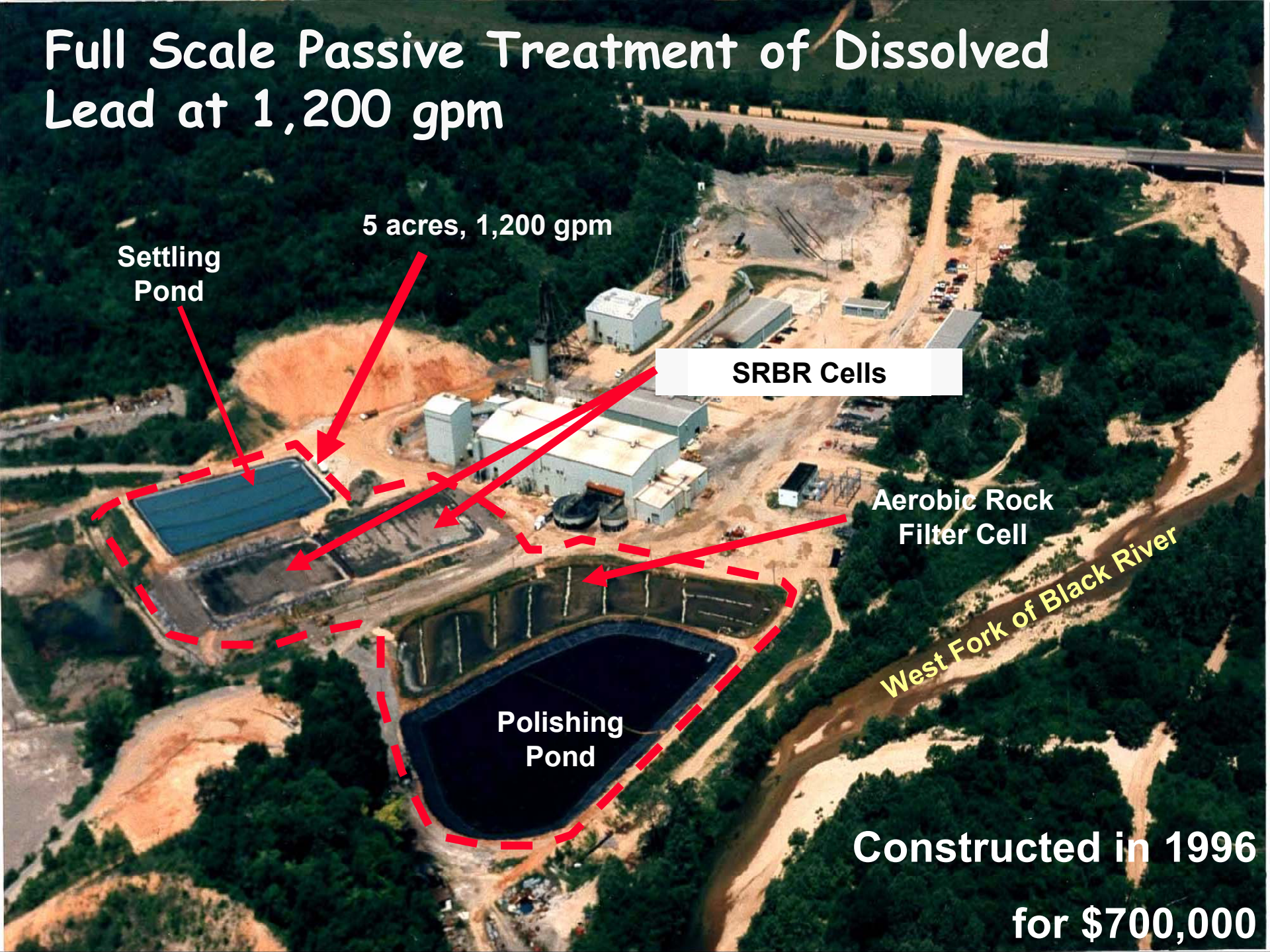
Settling Ponds & Flow Equalization Ponds,
Fluid Conveyances (Pipes & Channels)



Large Scale, Demonstration, and Pilot Scale Systems

- West Fork, Missouri, USA (Large)
- Judy 14, Pennsylvania USA (Demo)
- Fran Mine, Pennsylvania USA (Pilot)
- Golinsky Mine, California USA (Pilot)
- Wheal Jane Mine, Cornwall, UK (Pilot)
- Haile Mine, South Carolina (Pilot → Full)
- Other Ongoing Bench & Pilot Testing

Full Scale Passive Treatment of Dissolved Lead at 1,200 gpm



5 acres, 1,200 gpm

Settling Pond

SRBR Cells

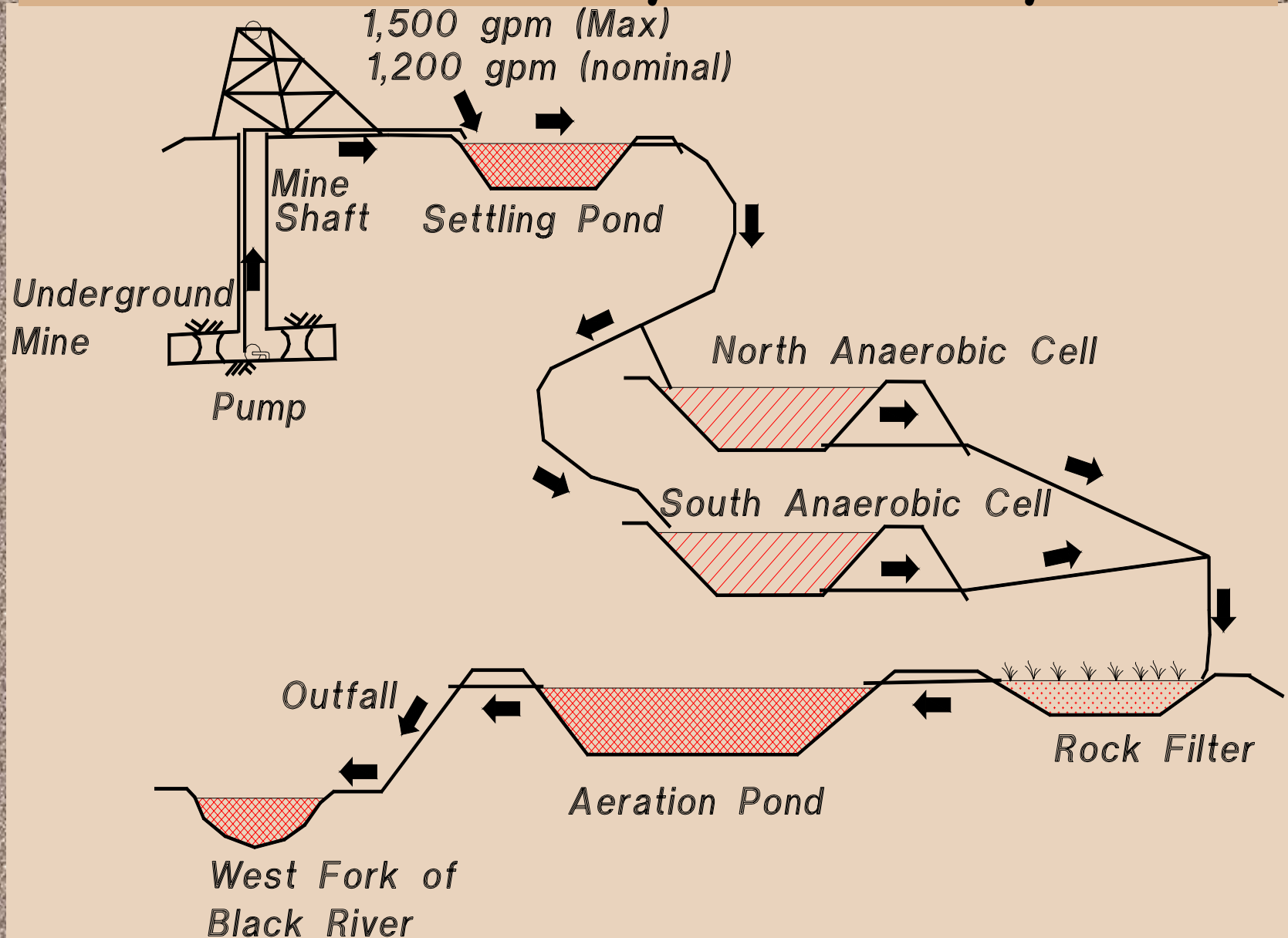
Aerobic Rock Filter Cell

Polishing Pond

West Fork of Black River

Constructed in 1996
for \$700,000

West Fork System Layout



West Fork Bioreactor

Key Components / Dimensions

- Settling Pond (0.75 acres)
- 2 Anaerobic (SRBR) Cells (0.5 ac each), 6 ft deep, 40 mil HDPE liner - substrate:
 - 67% sawdust, 19% limestone (low Mn),
 - 12% manure, 2% hay
- Aerobic Rock Filter - 1.4 acres
- HDPE-lined Aeration Pond - 2 acres
- Total cost with engineering: \$700,000

West Fork System Results

Influent Water

pH - 7.8 s.u.

Pb - 0.6 mg/L as
aqueous lead
carbonate complex

Zn - 0.08 mg/L

Sulfate ~180 mg/L

SRBR Effluent Water

pH - 7.8 s.u. (no change)

Pb - 0.027 to 0.05 mg/L
(meets NPDES
standard)

Zn - <0.05 mg/L

Sulfate - <140 mg/L

1,200 gpm (2.7 cfs), 24 hours/day, 7 days/week
Constructed in 1996

Demo Scale SRBR

Judy 14 Pennsylvania Coal Mine



**Constructed with Pennsylvania Growing Greener
Funds by the Blacklick Creek Watershed Association**

Judy 14 Project Background

- Seepage from Abandoned *Judy 14* underground coal mine (mined in 1950's)
- SAPS systems were not working
- Elevated aluminum caused plugging problems
- Experience from a pilot system @ 2.5 gpm on a similar water was good

Judy 14 Bioreactor

Key Components / Dimensions

- Valved diversion pipe
- One SRBR Cell 2.5 ft deep, 14,000 sf bottom area, 1 ft compacted clay liner, substrate:
 - 50% wood chips, 30% limestone;
 - 10% manure, 10% hay
- Aerobic Rock Filter - designed, but built undersized
- Total cost with engineering: \$158,000

Judy 14 SRBR Demo Results

Influent Water

pH - 3.0

Fe - 45 mg/L

Al - 33 mg/L

Mn - 2.6 mg/L

Zn - 0.86 mg/L

Cu - 0.10 mg/L

Ni - 0.32 mg/L

SRBR Effluent Water

pH - 6.6

Fe - 0.5 mg/L

Al - 0.07 mg/L

Mn - 2.3 mg/L

Zn - 0.06 mg/L

Cu - BDL @.0009

Ni - 0.002 mg/L

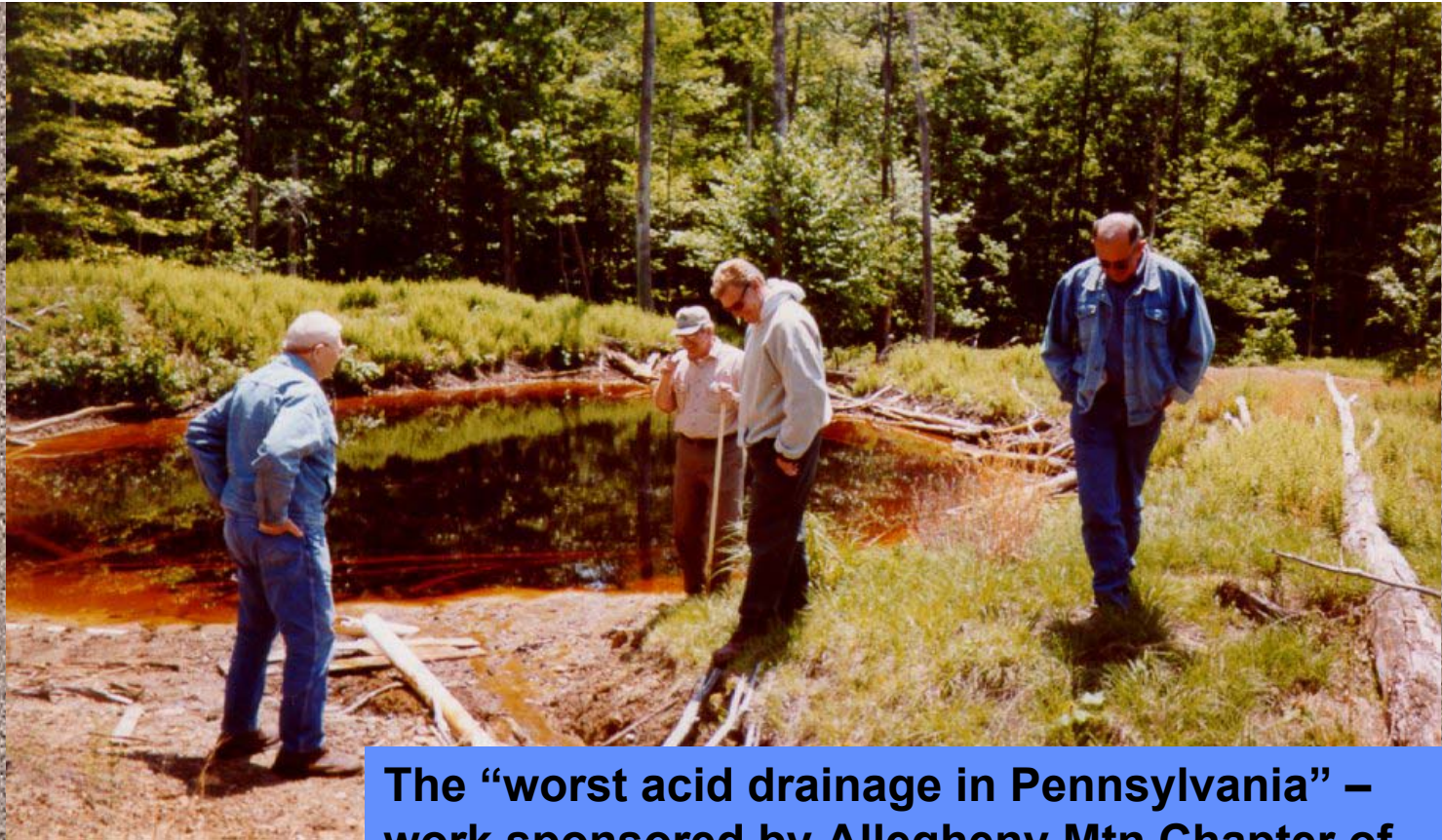
Flow: 10 gpm

Constructed in late 2002



See Also: [www.kcstream.org/Blacklick/Blacklick 2004.htm](http://www.kcstream.org/Blacklick/Blacklick%2004.htm) – sample id's 433 (influent) and 442 (SRBR effluent)

Pilot Scale Anaerobic SRBR Fran Mine Site Pennsylvania Surface Coal Mine



**The “worst acid drainage in Pennsylvania” –
work sponsored by Allegheny Mtn Chapter of
Trout Unlimited**

Local Residents



Fran Mine Project Background

- Abandoned surface coal mine seepage
- Mined in 1970's, pit was backfilled
- Injection of fly ash grout helped control MIW but it was not enough
- Total flow of 42 gpm @ full scale impacts 5 miles of trout fishery
- Bench scale SRBR tests successful - **no plugging problems from aluminum precip**
- Pilot system design and construction funded by private donations & govt grants

Fran Mine Bioreactor

Key Components / Dimensions

- Valved diversion pipe (problematic)
- One SRBR Cell 3 ft deep (buried), 4,350 sf bottom area; 40 mil PVC liner, substrate:
 - 50% wood chips, 30% limestone;
 - 10% manure, 10% hay
- Aerobic Rock Filter - designed, but not built; mini version added later.
- Total construction cost: \$42,400; engineering cost \$20,000

Pilot Scale Anaerobic SRBR Fran Mine Site



Soil Cover



Fran Mine Pilot SRBR Results

Influent Water

pH - 2.4

Fe - 298 mg/L

Al - 257 mg/L

Mn - 25 mg/L

Cu - 0.56 mg/L

Zn - 2.0 mg/L

Acidity - 2,734 mg/L

Sulfate - 3,215

Effluent Water

pH - 6.4

Fe - 64 ($\text{Fe}^{+2}=46$)

Al - <0.02 mg/L

Mn - 26.4 mg/L

Cu - BDL @0.0009 mg/L

Zn - 0.127 mg/L

Alkalinity - 1,038 mg/L

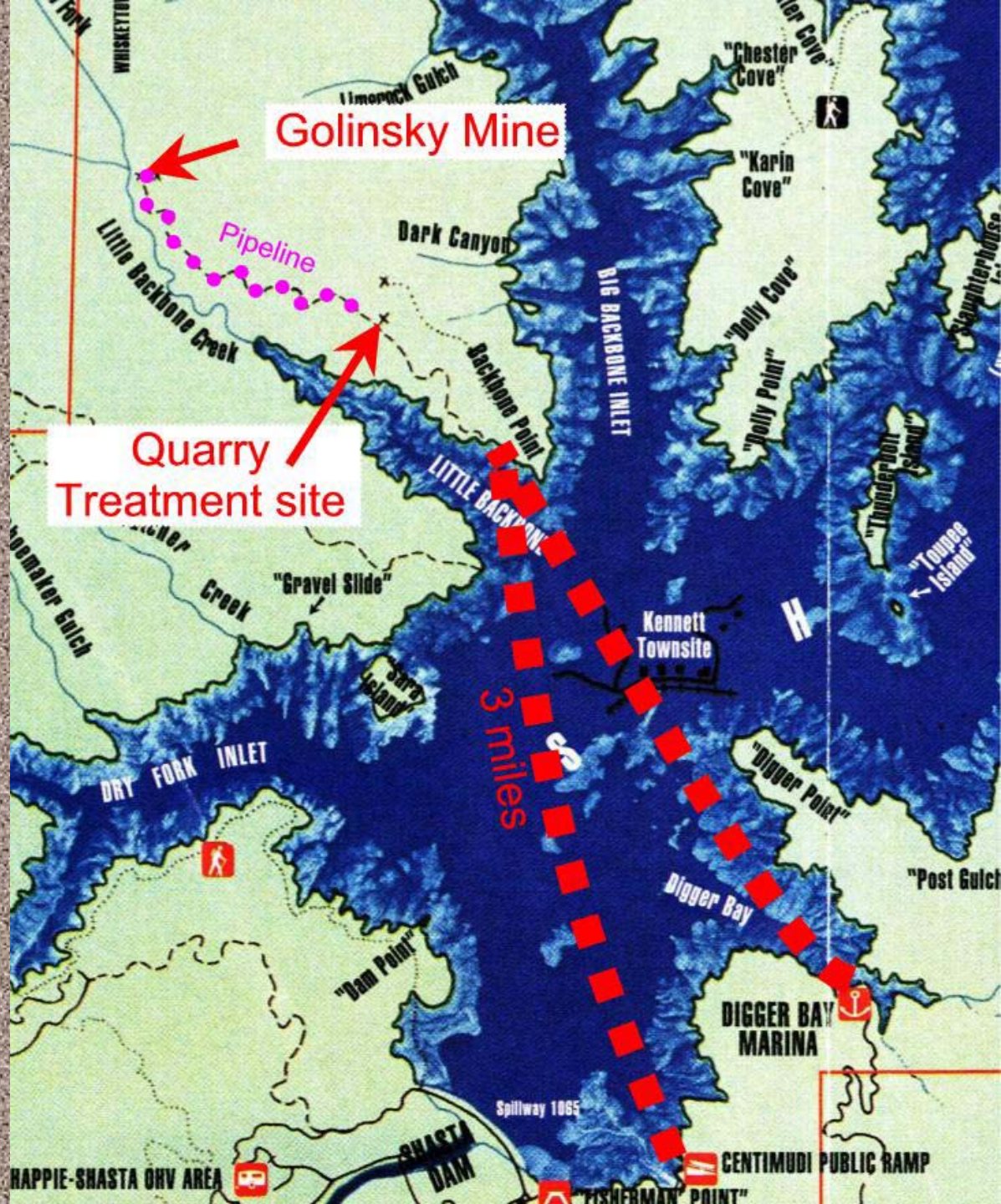
Sulfate - 752 mg/L

Flow: 1 to 2 gpm

Constructed in late 2002

Golinsky Mine, California

Site Location





Mine Adit Locations

Little Backbone Ck

Old Mill Site

Golinsky
Mine

Lower Adit (ARD Source)



Project Phases

- Bench Test (*Jan '04 to May '04*)
- Pilot Scale Test (*July '04 to June '06*)
- Full Scale Pipeline (*Fall, '04*)
- Full Scale Design and Construction
SRBR (in Future)

Bench Test Mobilization



Bench Test Layout



Bench Test Results Summary

Influent Water

pH - 3.0

Fe - 100 mg/L

Al - 40 mg/L

Mn - 1.2 mg/L

Zn - 55 mg/L

Cu - 22.6 mg/L

Ni - 0.07 mg/L

Effluent Water

pH - 6.0

Fe - 0.7 mg/L

Al - 0.15 mg/L

Mn - 1.4 mg/L

Zn - 0.2 mg/L

Cu - 0.0008 mg/L

Ni - 0.01 mg/L

Flow: 8.5 liters (2.25 gallons) per day

PILOT CONSTRUCTION

- Sulfate Reducing Bioreactor
- 8,000 Ft Long Pipeline
- Most components are pre-fabricated



Pre-fab Pilot SRBR Construction

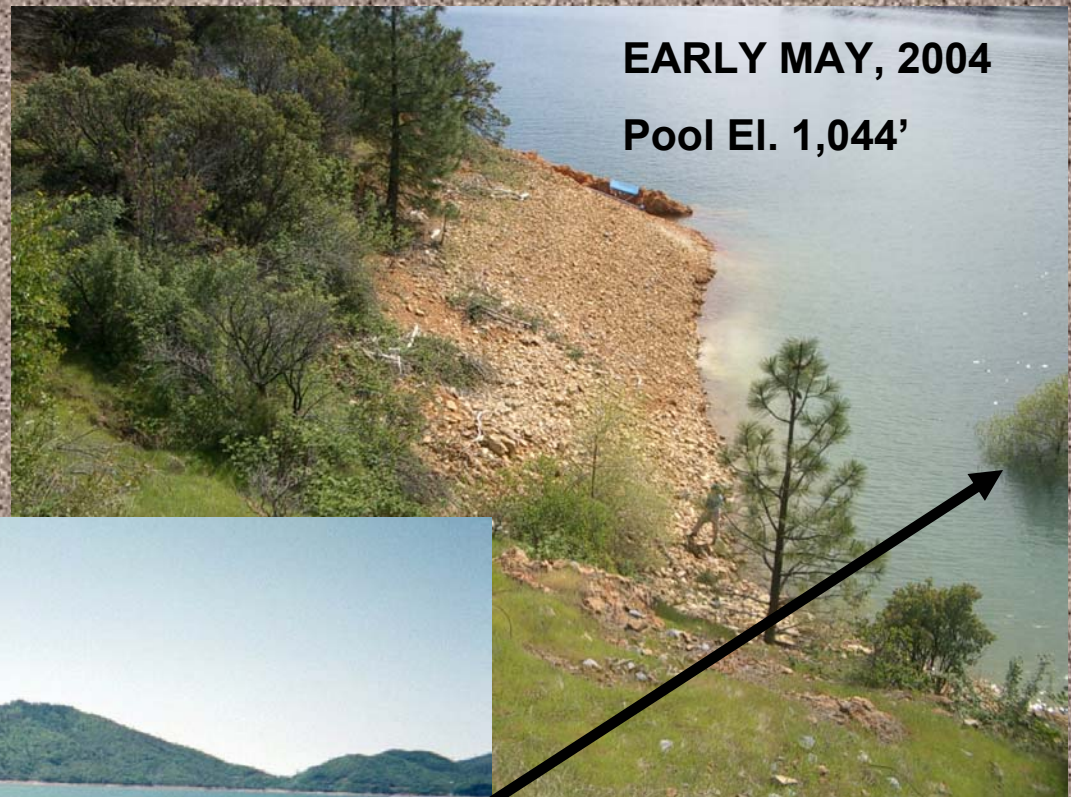


Treated Water Collection Piping

Equipment Mobilization



Dropping Lake Levels



Substrate Mobilization



Off-loading Substrate



Off-loading Substrate



Off-loading Substrate







SRBR Construction



SRBR Incubating



Full Scale Pipeline Phase Pipe Delivery



Pipe Assembly & Welding



Golinsky Mine Pilot Bioreactor Key Components / Dimensions

- Valved diversion (off 6" pipeline)
- One SRBR Cell 2.5 ft deep, 1,024 sf bottom area, 18 mil HDPE Permalon™ liner, substrate:
40% co-gen fuel, 29% limestone, 1% ash, 10% rice hulls, 10% manure, 10% hay
- Aerobic Rock Filter - not designed, but natural channel functioning as one.
- Total cost with engineering: ~\$350K

Pilot Test Results

Final 2004 Sampling Event (Nov. 11th)

Influent Water

pH - 3.0

Fe - 104 mg/L

Al - 24.5 mg/L

Mn - 1.3 mg/L

Zn - 54.9 mg/L

Cu - 9.0 mg/L

Ni - 0.031 mg/L

Cd - 0.71 mg/L

SO₄ - 797 mg/L

Effluent Water

pH - 7.2

Fe - 0.8 mg/L

Al - 0.06 mg/L

Mn - 2.5 mg/L

Zn - 0.1 mg/L

Cu - <0.003 mg/L

Ni - 0.007 mg/L

Cd - 0.006 mg/L

SO₄ - 488 mg/L

Eff+1 Water

pH - 7.2

Fe - 0.1 mg/L

Al - 0.03 mg/L

Mn - 0.03 mg/L

Zn - 0.03 mg/L

Cu - 0.01 mg/L

Ni - 0.025 mg/L

Cd - 0.006 mg/L

SO₄ - 467 mg/L



Flow: 1.0 gpm (DESIGN)

Pilot Test Results

Early 2005 Sampling Event (Feb. 17th)

Influent Water

pH - 2.6

Fe - 162 mg/L

Al - 44.2 mg/L

Mn - 0.85 mg/L

Zn - 47.2 mg/L

Cu - 33.3 mg/L

Ni - 0.044 mg/L

Cd - 0.47 mg/L

SO₄ - 1104 mg/L

Effluent Water

pH - 6.6

Fe - 22 mg/L

Al - 0.035 mg/L

Mn - 4.3 mg/L

Zn - 5.0 mg/L

Cu - <0.005 mg/L

Ni - 0.008mg/L

Cd - 0.005 mg/L

SO₄ - 1089 mg/L

Eff+1 Water

pH - 7.5

Fe - 7.9 mg/L

Al - <0.03 mg/L

Mn - 4.1 mg/L

Zn - 2.5 mg/L

Cu - <0.005 mg/L

Ni - 0.007 mg/L

Cd - 0.004 mg/L

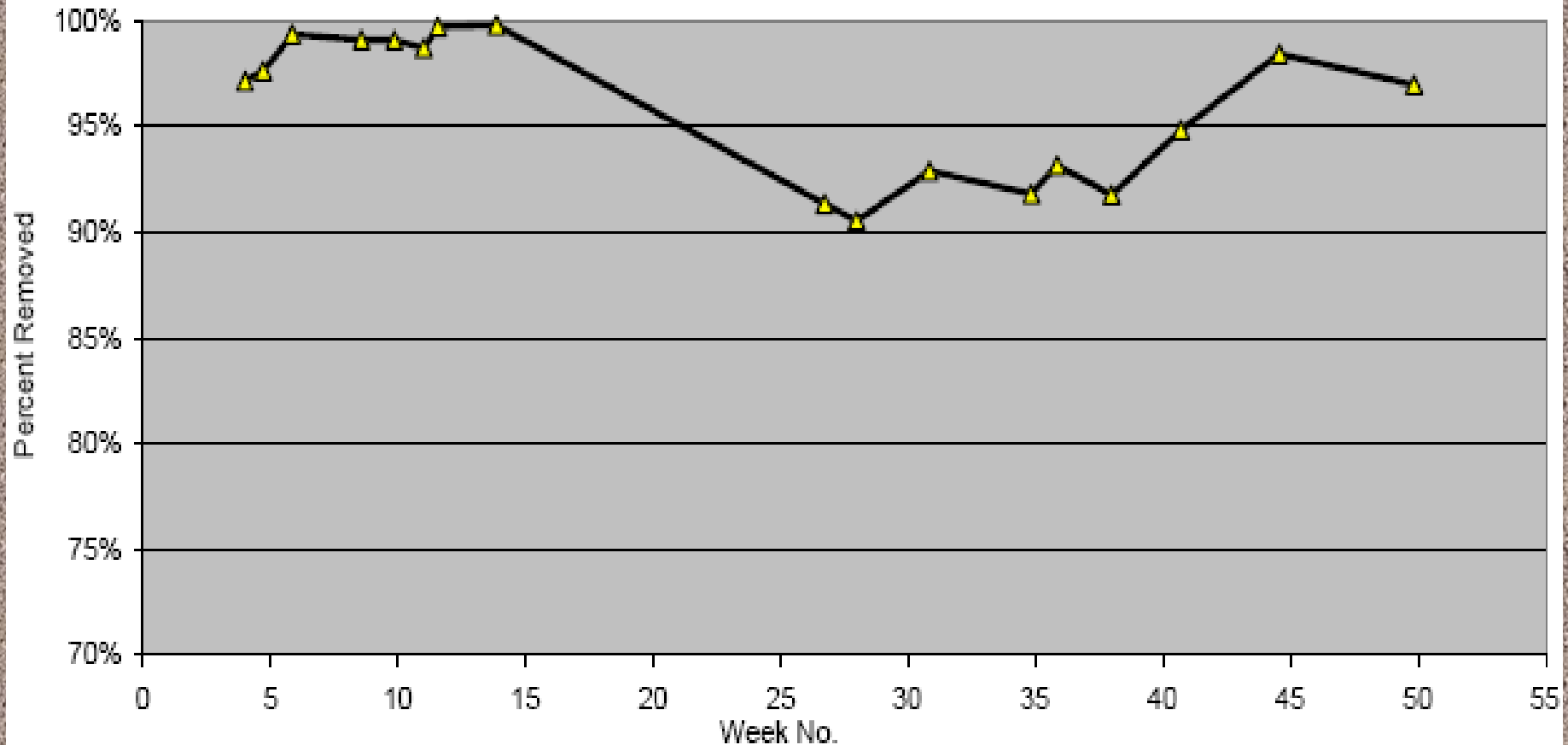
SO₄ - 1104mg/L



Flow: 2.0 gpm - **OVERLOADED 3X**

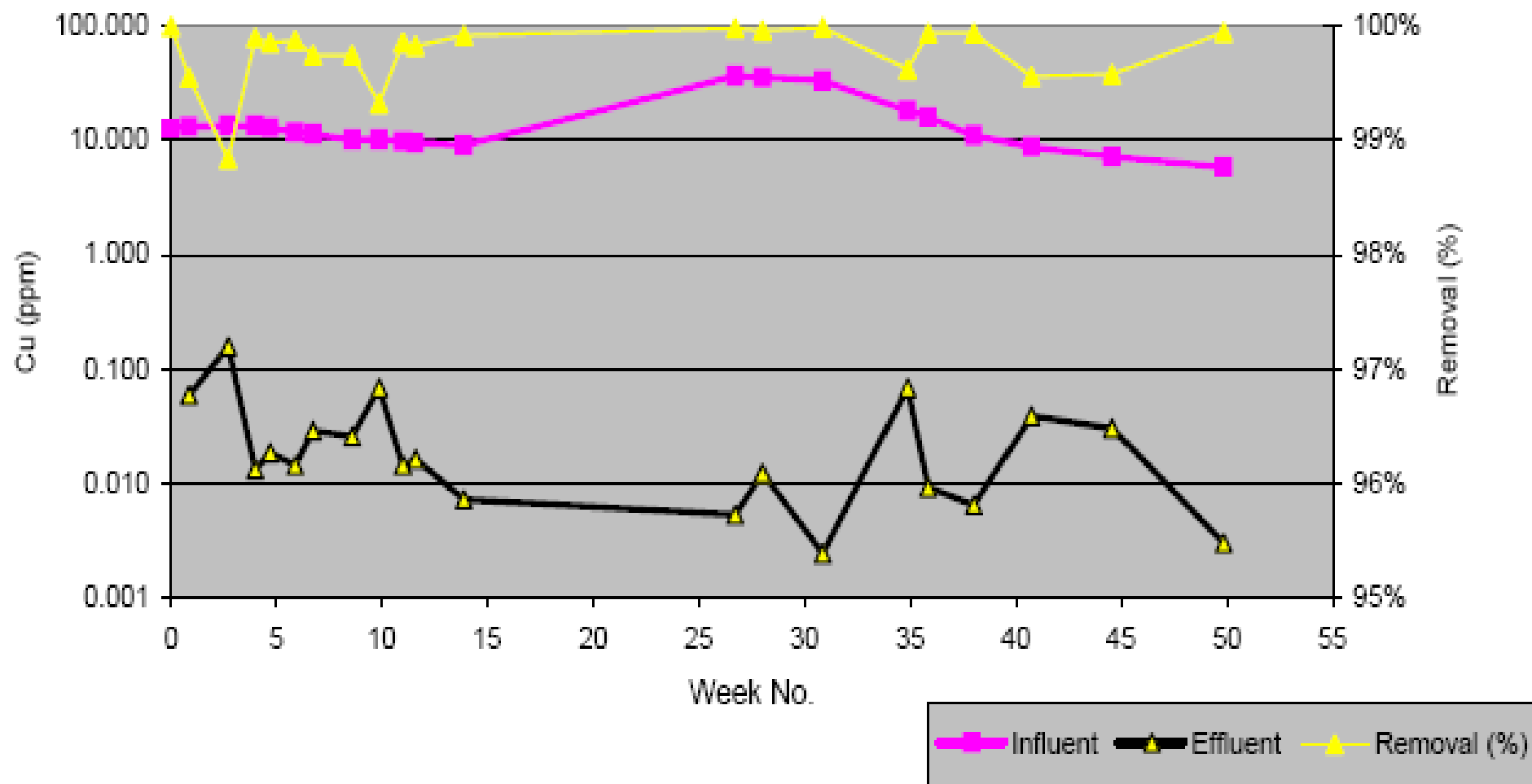
Pilot System Overload Recovery

Golinsky Pilot Combined Heavy Metals Removal
(Iron, Copper, Zinc, Aluminum, Cobalt and Cadmium)



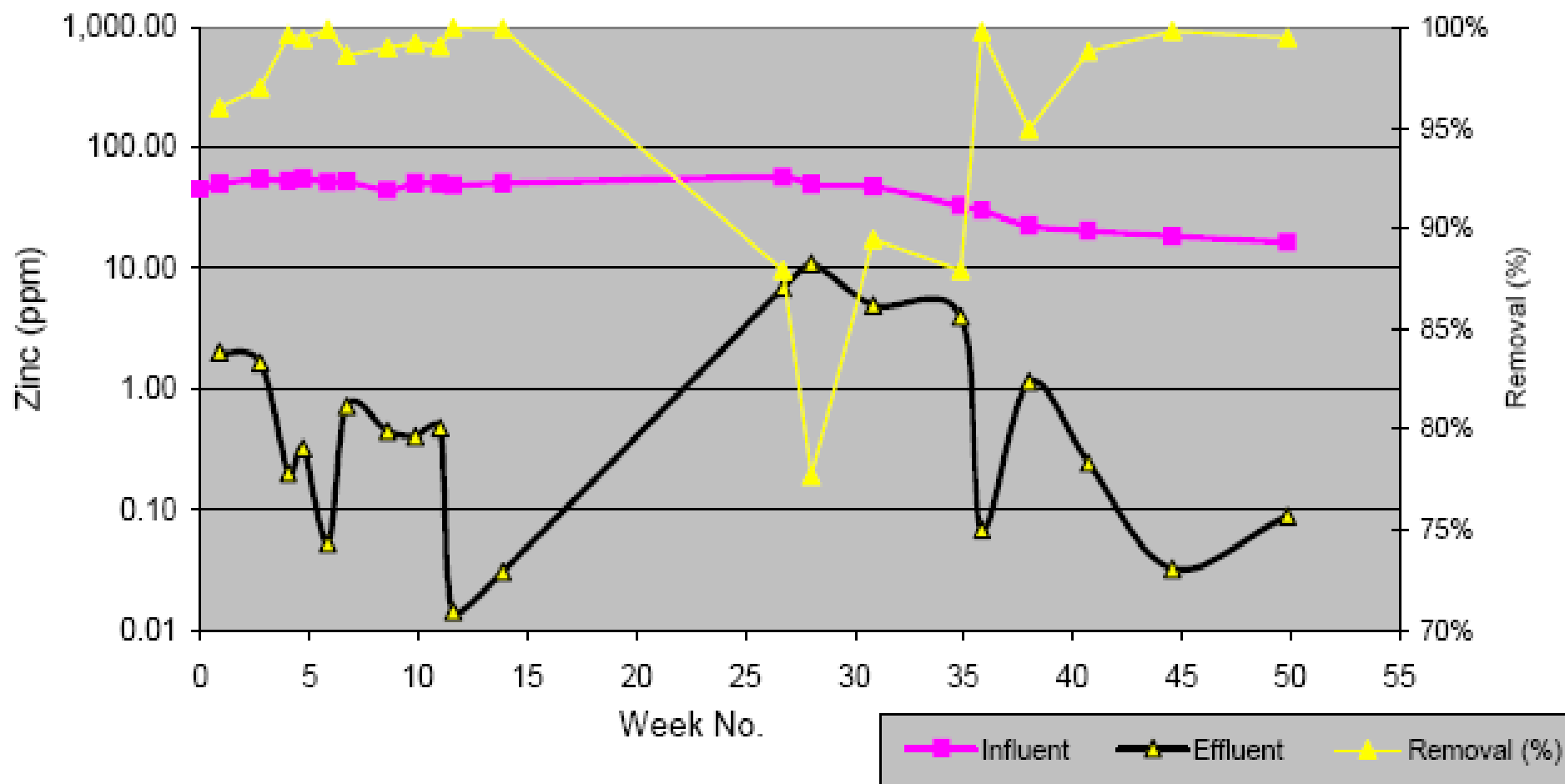
Pilot System Overload Recovery

Golinsky Pilot Copper Removal



Pilot System Overload Recovery

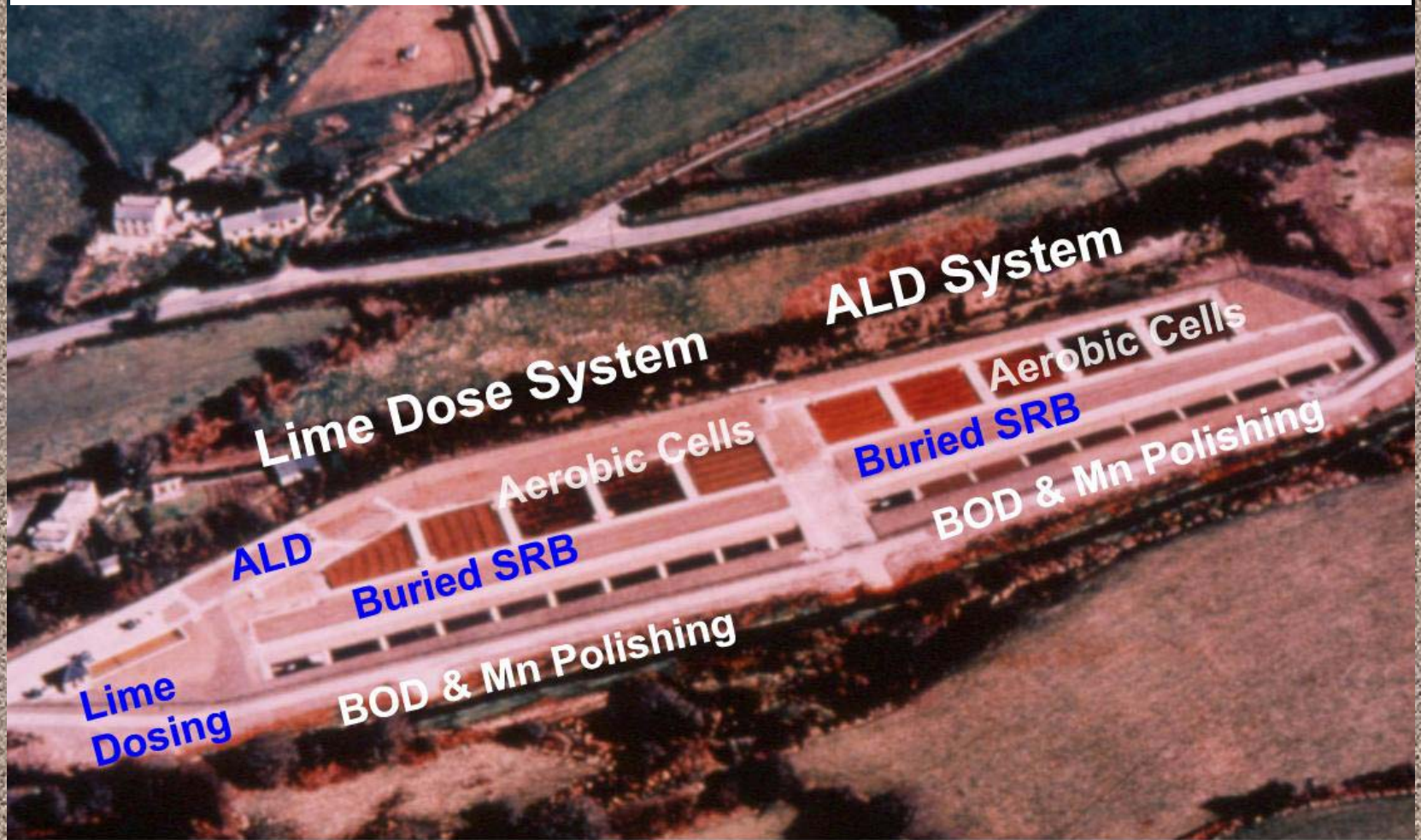
Golinsky Pilot Zinc Removal





Golinsky Pilot SRBR

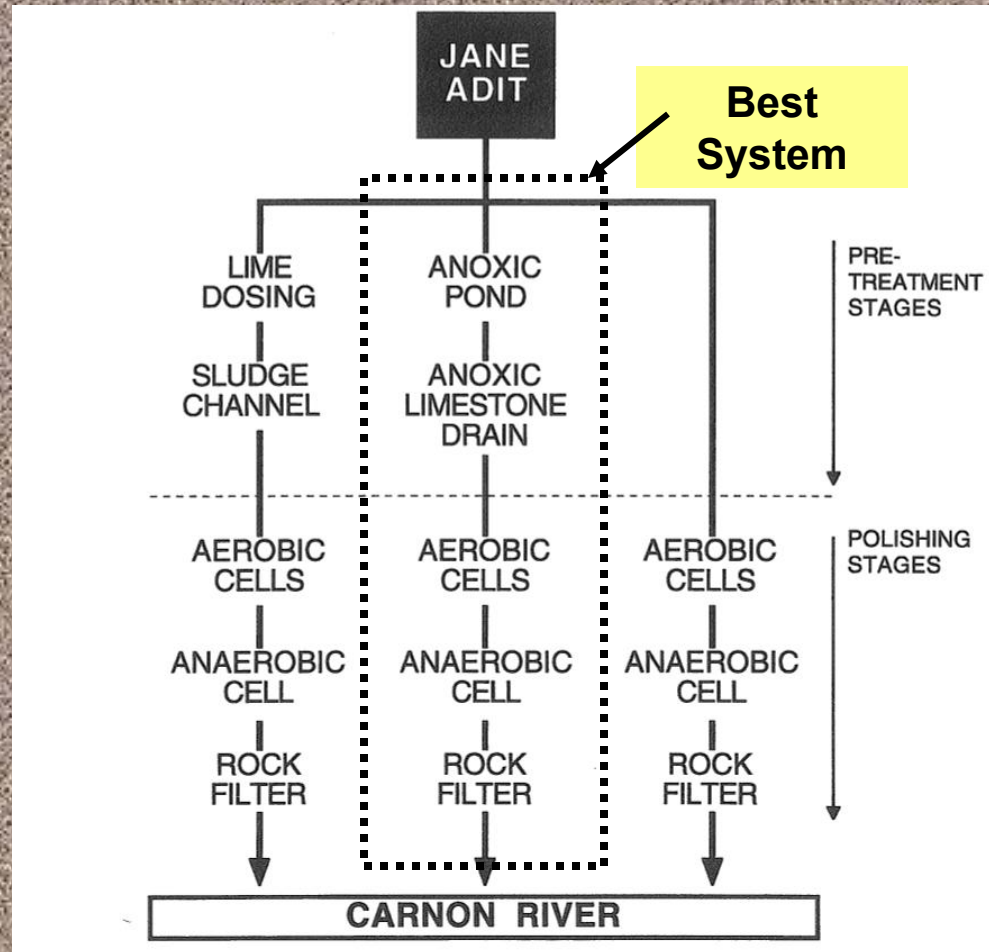
Pilot Scale Aerobic & SRB Wheal Jane Mine, Cornwall UK



Wheal Jane Project Background

- Abandoned underground tin mine closed in 1991; pumping stopped and the mine flooded
- Blowout event polluted nearby estuary in 1992
- Three parallel pilot passive systems built in 1995 to evaluate method to replace lime dosing
- Total flow of 4,755 gpm @ full scale
- Pilot test conclusion: not enough room to construct passive systems - lime dosing is preferred alternative.

Wheal Jane Pilot Tests Three Systems in Parallel



Wheal Jane Pilot (ALD System)

Influent

pH - 3.9
Fe - 110
As - 9
Al - 27
Mn - 8
Cu - 1.2
Zn - 80

ALD Effluent

pH - 5.9
Fe - 100
As - 1
Al - 10
Mn - 8?
Cu - n/a
Zn - 65

Aerobic Effluent

pH - 4
Fe - 10
As - 0.01
Al - 10
Mn - 8?
Cu - n/a
Zn - 65

SRBR Effluent

pH - 6
Fe - 5
As - 0.1
Al - 3
Mn - 24
Cu - 0.1
Zn - 10

R. Filter Effluent

pH - 7
Fe - n/a
As - n/a
Al - n/a
Mn - n/a
Cu - n/a
Zn - n/a

Flow: 2 to 4 gpm

Constructed in 1995

Cost = over 1£ million (all 3 pilot systems)

Haile Mine, SC

Full Scale (6 gpm)

- Three Sources - commingled
- Commissioned in June, 2005
- Based on bench & pilot tests

Haile Mine Site Layout

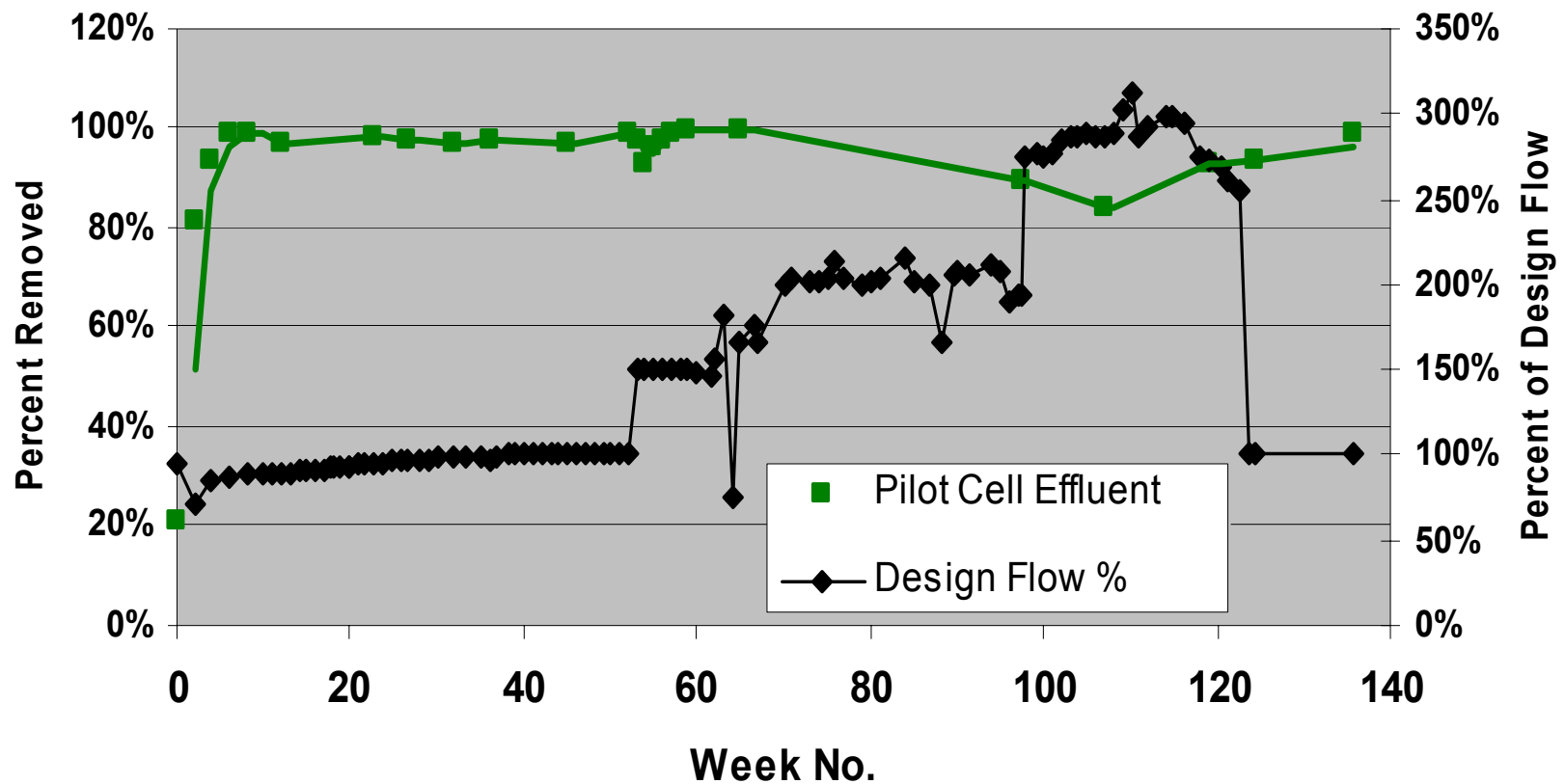




Haile Mine Pilot SRBR
Built in "Barren" Pond

HAILE PILOT RESULTS

Combined Heavy Metals Removal & Design Flow
Iron, Copper, Zinc, Aluminum, and Cadmium



One of Two Full Scale SRBR Cells Under Construction



Ongoing Studies

- Elizabeth Copper Mine, VT (bench)
 - South Open Cut (minor zinc, low pH)
 - Tailings Dam Seepage (mostly Fe w/other metals)
- Peerless Jenny King Mine, MT (Full)
- Luttrelle Repository, MT (Demo)

SOUTH OPEN CUT

Elizabeth
Mine, VT



South Open Cut Bench Test Results 8/2/05

Analyte	Influent	SRBR-1	SRBR-2	SRBR-3	SRBR-4
pH	3.75	7.16	7.04	6.72	6.76
ORP	-168	-314	-328	-325	-301
Flow liters/day		84	75	82	79
Al	5.4	0.14	0.11	0.13	0.13
Ca	68	153	157	274	183
Cd	0.0048	0.0036	0.0032	0.0037	0.0035
Co	0.071	0.004	0.004	0.005	B.D.L.
Fe	10.5	0.13	0.12	0.11	0.18
Ni	0.068	B.D.L.	B.D.L.	B.D.L.	B.D.L.
S	109	150	422	574	221
Sulfate Calc'd	328	451	1,265	1,722	662
Zn	0.93	0.39	0.41	0.47	0.43



Flow: 80 liters (20 gallons) per day



Tailings Dam



Bench SRBRs

Elizabeth Mine, VT



Tailings Dam

Bench SRBRs Under Construction

Tailings Dam Bench Test Results (Preliminary) 8/2/05

Analyte (mg/L)	TD-1 Inf	SRBR-5	SRBR-6	SRBR-7	SRBR-8
pH	6.22	6.52	6.43	5.77	6.05
ORP (mv)	-27.2	-107	-124	-156	-104
Flow Liters/day		4	4	4	4
Al	0.19	0.19	0.08	0.15	0.02
Ca	332	373	372	488	376
Cd	0.03	0.008	0.007	0.008	0.014
Co	0.13	0.01	0.01	0.02	0.03
Cr	0.004	0.005	B.D.L.	B.D.L.	B.D.L.
Fe	702	60	6.7	80	332
Ni	0.07	0.01	0.01	0.02	0.01
S	726	216	157	237	451
Sulfate Calc'd	2,178	647	471	712	1,352
Zn	0.94	0.40	0.32	0.10	0.09

Luttrell Site, 10 Mile Creek, MT Demo Cell Construction





More Demo Cell Construction

Completed Luttrell Demo Bioreactor May, 2003



Luttrell Demo Results July 8, 2005

Analyte	LUTRL-INFL PIPE	LUTRL-EFFLUENT-
<i>pH</i>	<i>4.40</i>	<i>6.09</i>
<i>ORP mv</i>	<i>265</i>	<i>-266</i>
Al (mg/L)	32	0.25
Ca	486	446
Cd	1.24	0.0064
Co	0.77	BDL
Cu	12.7	0.009
Fe	2.4	2.2
Mn	171	56
Ni	0.47	0.013
S	900	296
Sulfate Calc'd	2,699	887
Zn	210	0.35



Flow: ~1 gpm -1,440 gallons per day

Peerless Jenny-King, Montana



**UPPER
WETLAND
ZONE**

Peerless Jenny-King, Montana



**LOWER
MODIFIED
SRBR ZONE**



PJK Results July 18, 2005

Analyte	Infl.	Leaving UWZ	Infl SRBR's	Mid- SRBRs	End SRBRs	UWZ- Well	SRBR1- Well	SRBR2 -Well	SRBR3 -Well
pH	6.75	7.07	7.17	7.15	7.21	7.15	7.25	6.92	6.93
ORP mv	-	250	237	178	200	-30	-66	-121	-42
Ca	34	36	35	36	32	38	42	35	BDL
Cd	0.011	0.011	0.0045	0.0030	0.0061	0.0020	0.0014	BDL	BDL
Fe	0.33	0.4	0.0	0.1	0.1	3.7	0.8	0.3	BDL
Mn	4.6	4.7	1.9	1.5	0.3	15.6	2.7	1.5	BDL
S	31	31	30	31	26	20	3	19	BDL
Sulfate Calc'd	94	92	91	93	78	61	10	57	0.2
Zn	1.35	1.35	0.62	0.31	0.87	0.09	0.01	0.02	BDL



Flow: ~1 gpm -1,440 gallons per day

P.T. Advancements 1985 to 2005

- Established design protocol
 - Lab, bench, pilot studies
 - Physical and geochemical design parameters
- Wide range of operating conditions
 - pH 2.5 to 8.5
 - Metals (Fe, Cu, Pb, Zn, Cd, Cr, Mn, Hg, Mo, Al, Se, As, U, Co)
 - Non-metals (CN, SO₄, NO₃, NH₃, BOD₅, P)
 - Temperatures (0 to 30 deg C)
 - Flows up to 1,200 gpm

Data Needed to Get Started

- Flow rates -Avg., Min., & Max.
- Chemistry of solution (s): pH, metals, sulfate, acidity/alkalinity

With this info, we can develop an order of magnitude size of system in minutes.

- Acreage available for construction
- Discharge limits

Summary

- Passive components can be assembled in many variations which are driven by the AMD geochemistry (see design flow chart)
- Full scale systems are most successful when based on bench and pilot studies
- Passive treatment might not be feasible due to land availability (Wheal Jane)
- Some full scale systems have been operating for nearly a decade (West Fork)
- SRBRs are BIOLOGICAL systems overloading has consequences