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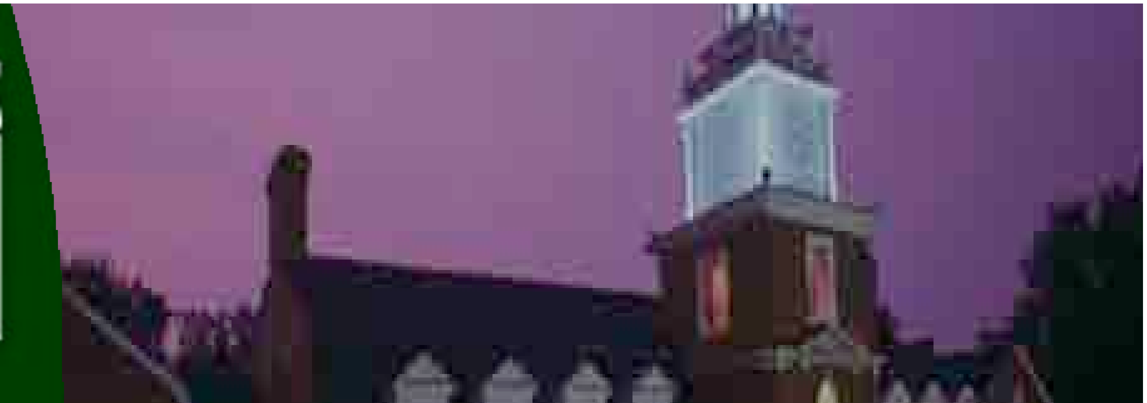

Development of an Innovative Treatment System for the Truetown Discharge

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OHIO UNIVERSITY

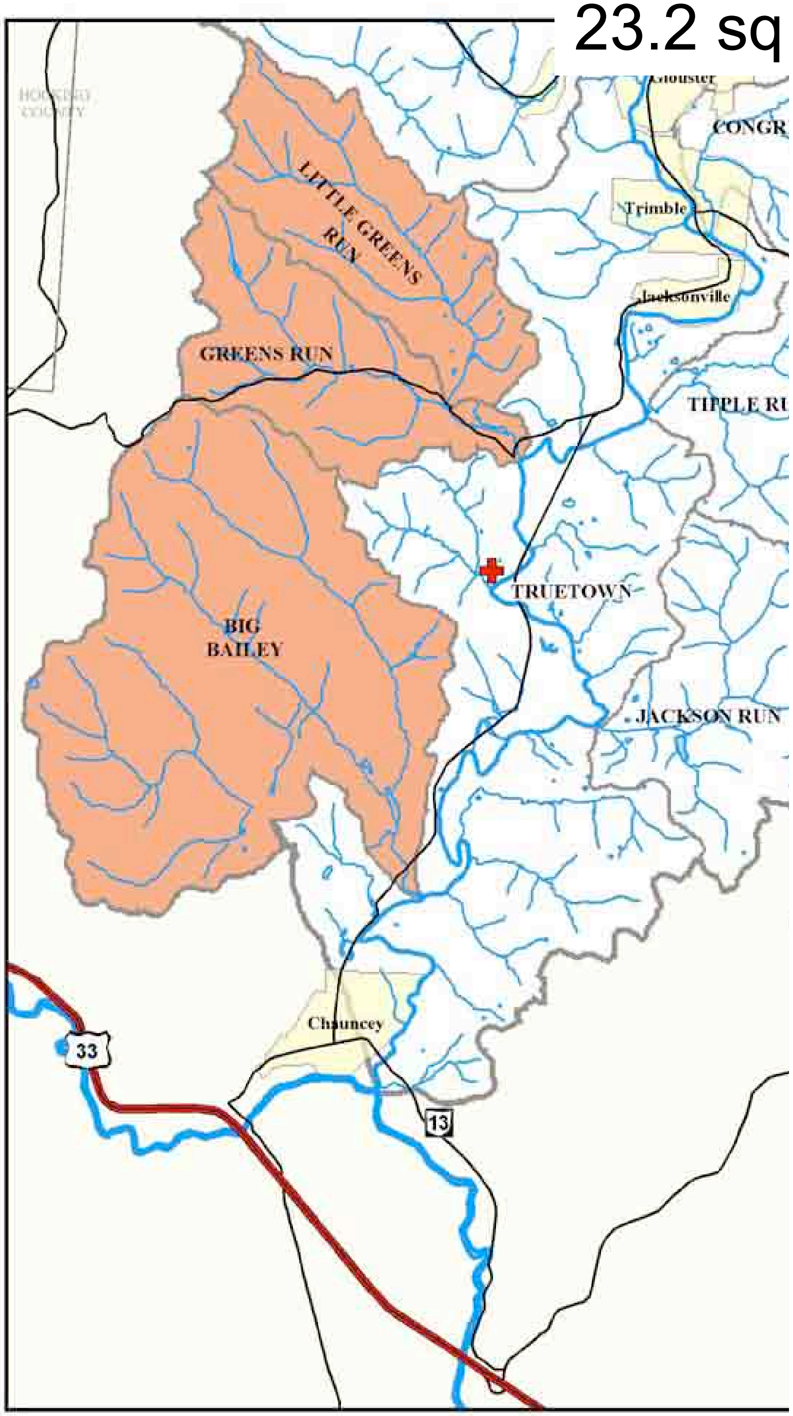
Service Learning

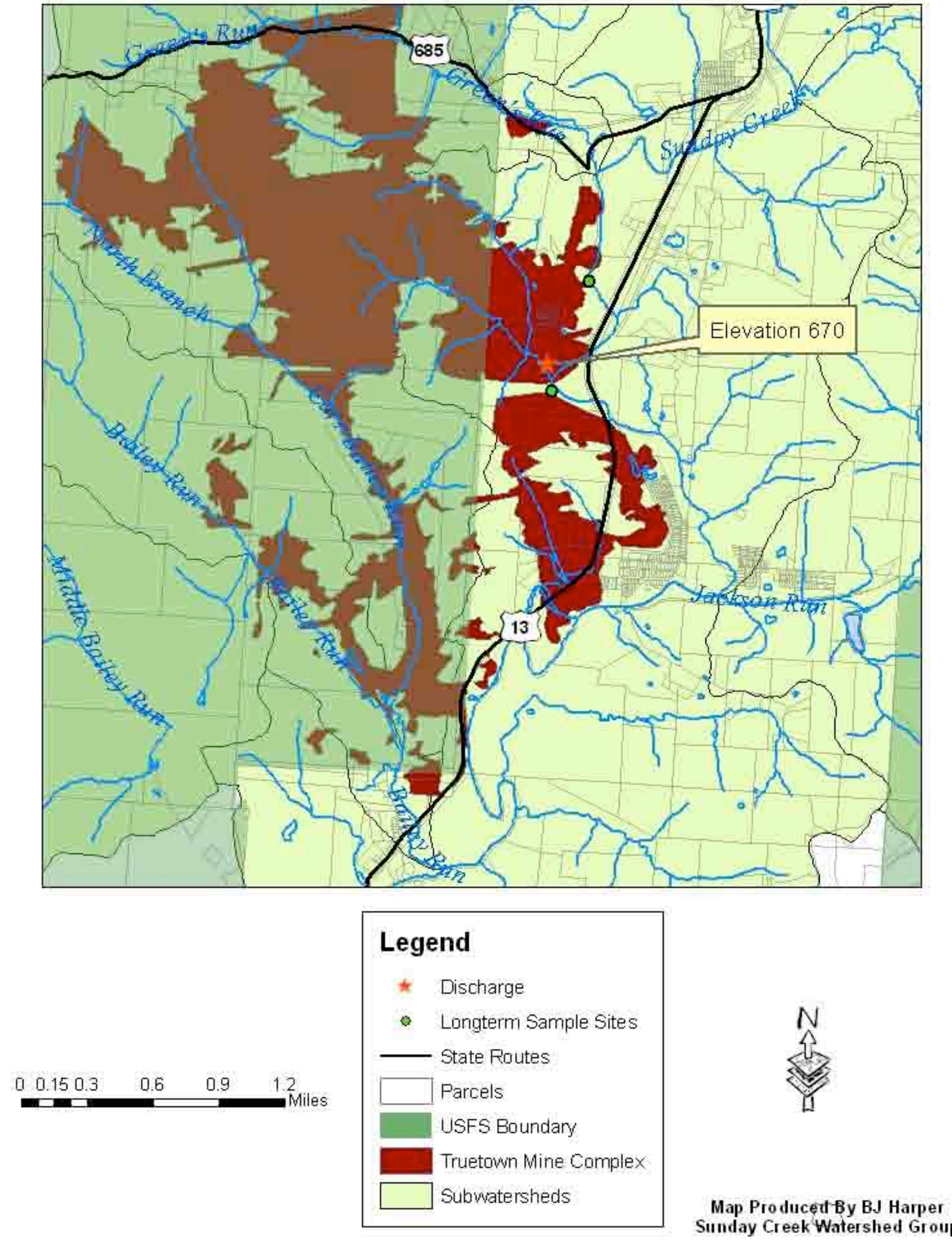
- Sunday Creek watershed group evaluating remediation alternatives for Truetown mine discharge
- very hot source with land constraints that requires an innovative approach
- one option being considered is **production of drinking water and resale of iron sludge produced**
- excellent project for courses in the environmental engineering department
  - CE 491A: Env Eng Senior Design
  - CE 555: Advanced Water Treatment
- this presentation is the proposed treatment plant based on their work
- at this point just a preliminary design

Truetown Mine History

- Located at pump station for abandoned coal mine AS-193
- Pump station was sealed in 1963, upon abandonment
- Ruptured in 1983 due to high hydrologic head and erosion of the iron and concrete seal
- Channel was dredged to carry water to tributary and then into Sunday Creek

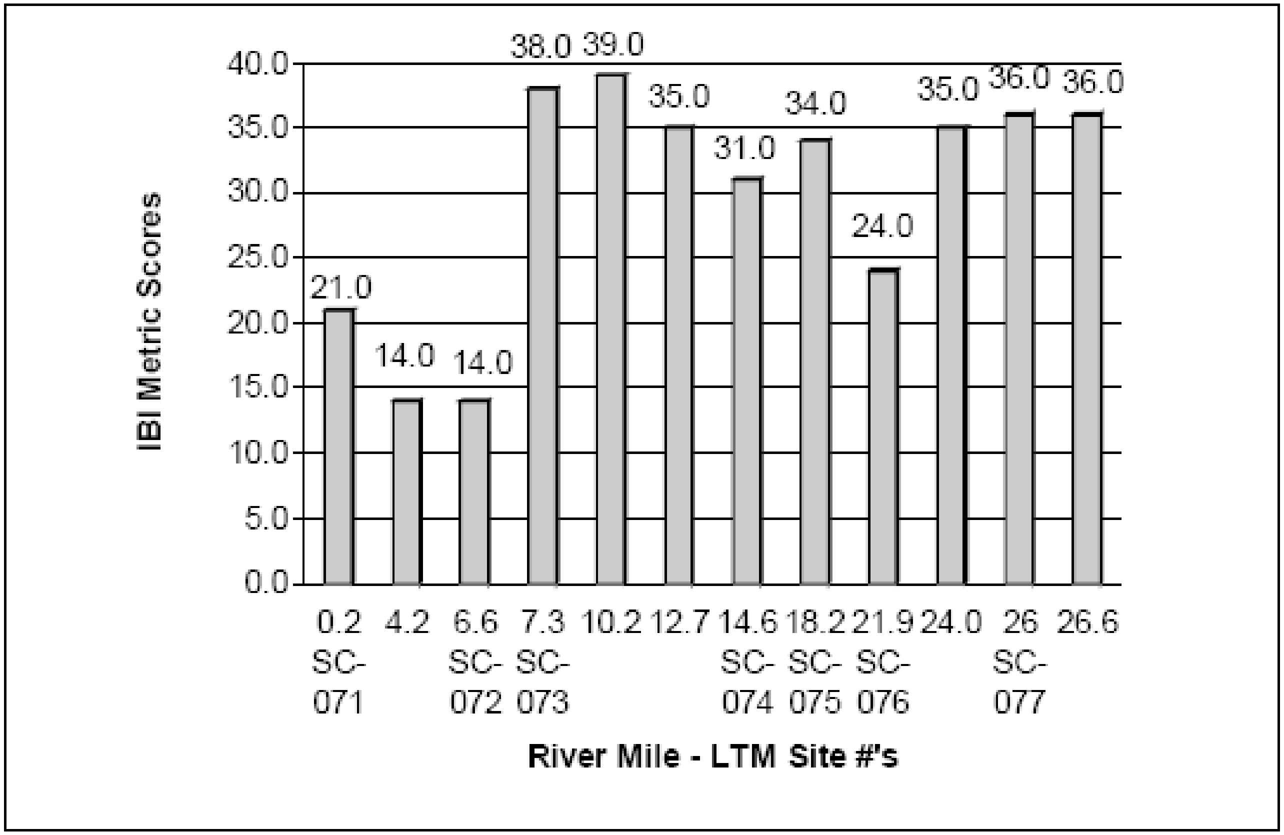
23.2 sq mi of hydrologically connected mines





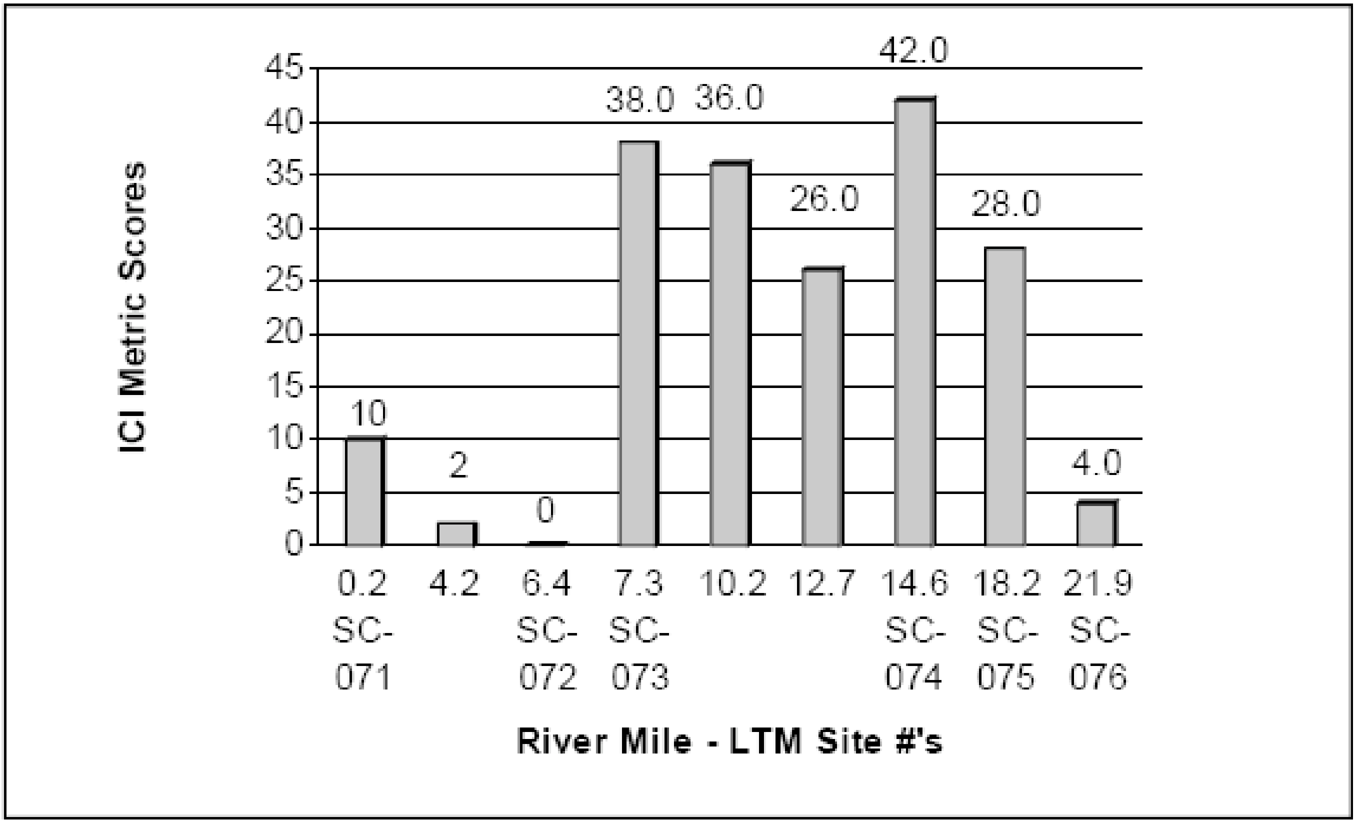
Biological Impacts

Figure 13: IBI scores at Sunday Creek mainstem and LTM sites



Biological Impacts

Figure 14: ICI scores at Sunday Creek mainstem and LTM sites



Primary Discharge Pollutants

- Discharge: 1.9 cfs or 1.2 million gallons per day
- Average Concentrations - 380 mg/L iron, 730 mg $CaCO_3$/L acidity
- Iron loadings - 1,875 kg/day
- Metal loadings - 1,943 kg/day

- not enough space for a passive treatment system
- a doser would fill Sunday Creek with sludge

Water Supply Benefits

- many intensive, engineered treatment technologies available that are reliable and tested
- sale of drinking water and iron sludge can offset operational costs
- may make new funding sources available for construction costs

Drinking Water Treatment Requirements

	Feb 2007 (mg/L)	EPA Secondary Standards (mg/L)
aluminum	4.4	0.2
iron	382	0.3
manganese	7.3	0.05
pH	4.7	> 6.5
sulfate	2080	250
hardness	895	50-150*
total dissolved solids	3220	500

*no standard for hardness but this is the recommended range

Other Drinking Water Constituents of Concern

	Feb 2007 (ug/L)	MCLs (ug/L)
Antimony	< 3	6
Arsenic	< 40	10
Barium	< 100	2,000
Beryllium	< 12	4
Cadmium	< 10	5
Chromium	< 10	100
Copper	< 10	1,300
Lead	< 4	15
Mercury	not analyzed	2
Selenium	< 90	50
Thallium	< 2	2

Treatment Technologies

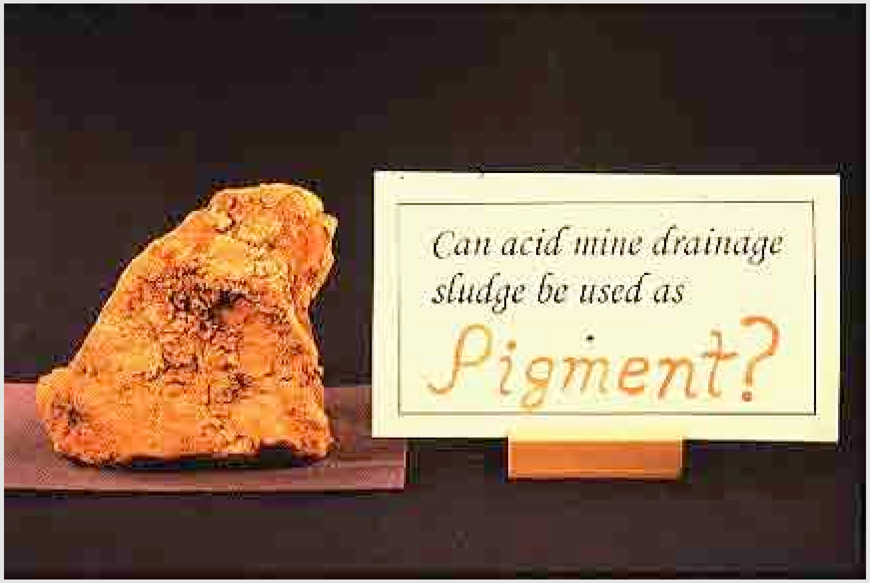
- Alkali dosing, oxidation, and settling (ODAS)
  - removes metals and acidity
  - sulfate, hardness, and TDS still fail standards
- Lime softening
  - removes hardness, metals, and acidity
  - need large complex treatment plant
  - high sludge production
  - sulfate and TDS still fail standards
- Ion exchange
  - removes sulfate and TDS
  - can remove hardness with second set of exchangers
  - regeneration brine disposal
- Reverse osmosis (also called nanofiltration)
  - removes all
  - requires metal removal for pretreatment
  - reject brine disposal

Treatment Train Possibilities

- Lime softening + Ion exchange
- ODAS + Ion exchange + Ion exchange
- ODAS + Reverse osmosis

Paint Pigment

- Fine powders used as colorant in paints
- Qualities
  - High tinting strength
  - Stable at ambient temperatures
  - Permanence and stability



Pigment Production from AMD

- currently most profitable AMD byproduct
- Hedin Environmental EnvironOxide™ Pigment
  - only AMD sludge brought to market
  - harvested from old passive sites and alkaline discharges
- active treatment produces poor pigment quality sludge
  - need to raise pH with alkali to accelerate iron oxidation with air
  - unreacted and precipitated alkali reduces purity of iron sludge

Strong Oxidants

- strong oxidants can oxidize iron at low pH
- results after 10 minutes

75% 100% 150%
$KMnO_4$

75% 100% 150%
NaOCl

75% 100% 150%
H_2O_2

Strong Oxidants after 20 hr

75% 100% 150%

$KMnO_4$

75% 100% 150%

NaOCl

75% 100% 150%

H_2O_2

Residual Iron Concentrations

Initial water: pH = 4.66, ferrous iron = 380. mg/L

Oxidant	pH after 10 minutes	Total iron after 20 hrs (mg/L)
75% $KMnO_4$	4.23	207
100% $KMnO_4$	3.10	185
150% $KMnO_4$	2.96	146
75% NaOCl	2.84	79.1
100% NaOCl	2.88	48.2
150% NaOCl	6.51	0.098
75% H_2O_2	2.68	112
100% H_2O_2	2.76	112
150% H_2O_2	2.80	114

150% NaOCl sample was clear. All others were slightly orange.

Design for Iron Recovery

- Oxidizing all ferrous iron not feasible
  - Over 2 tanker trucks of bleach per day
  - Free chlorine residual too high in resulting water (810 mg/L)
- With 3% of total treatment flow for pigment production:
  - 1x 3500 gallon tanker 12.5% NaOCl per week
  - 12.5% NaOCl bleach solution
  - Dose of 7 mL 12.5% NaOCl/ L of water
  - 810 mg/L free chlorine reduced to 0.07 mg/L when combined with remaining flow

Iron Sludge Reclamation

- Iron Oxide Pigment in 2001 market price of $2.14 per kilogram with a demand of 70,000 metric tons[1]
- Bleach cost $0.36 per gallon[2]
- One tanker truck of bleach per week

= 36,000 gal water treated per day

= 98.3 kg pigment produced per day

= $110 per day potential profit [3]

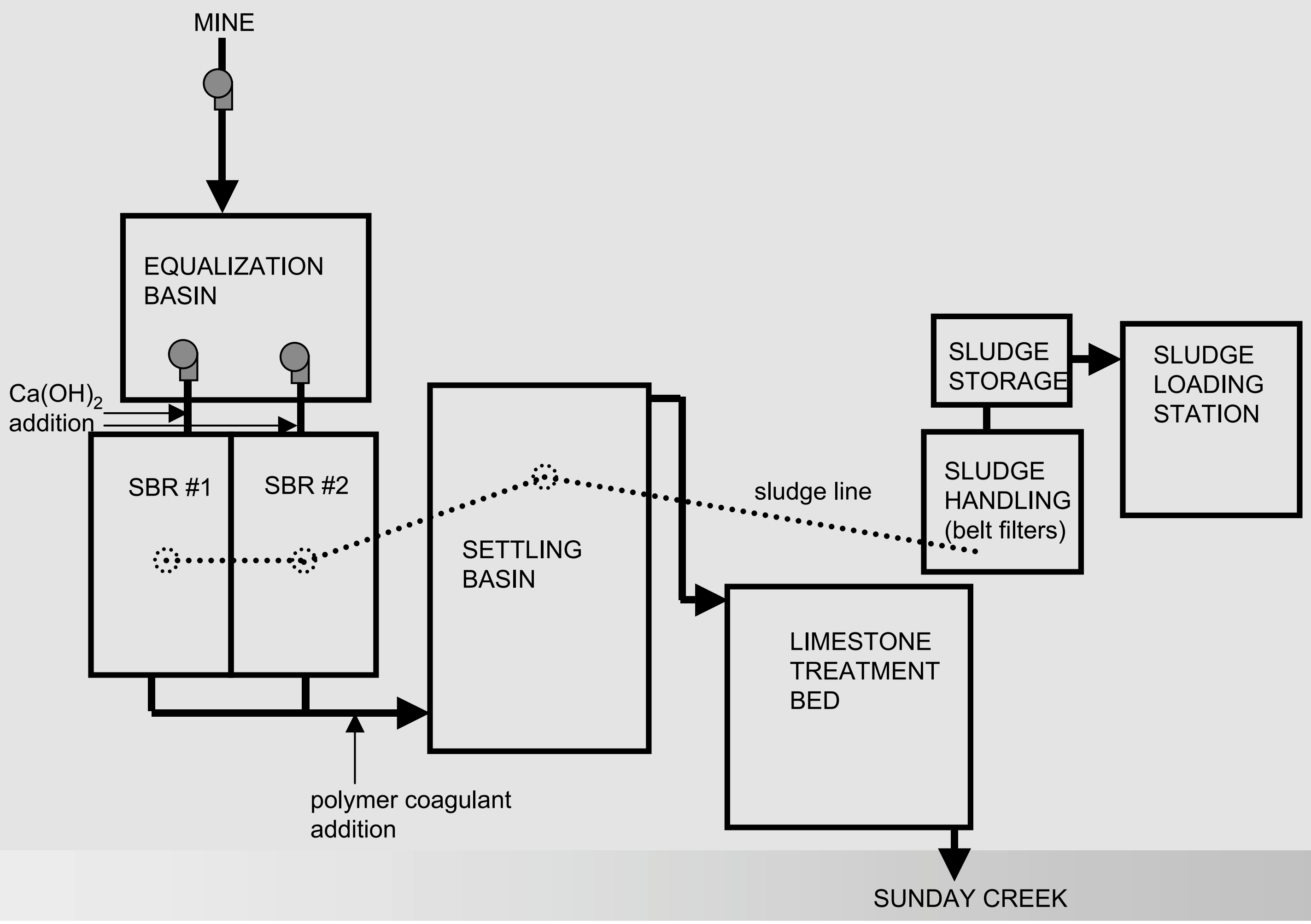
1. http://minerals.usgs.gov/minerals/pubs/commodity/iron_oxide/750401.pdf
2. Ulrich chemical costs
3. Assumes $3.00 2007 cost of iron oxide pigment and $5/day energy operating costs

Potential Problem

- sludge from rapid oxidation darkens upon drying
- further experiments required to enhance FeOOH production from rapid oxidation
- preliminary analysis shows Fe dominates but significant fractions of Ca, S, and Na

Water Treatment Design

Basic Treatment Plant Design



Equalization Basin

- Holds about 6 hours of flow from the mine
- Water from basin is fed to either pigment production or sequence batch reactors

Sequence Batch Reactors

- Two reactors, each 202,000 gallons
- 3 cycles per reactor per day
- Filling (1.68 hr), air delivery (1.13 hr), sedimentation (4.19 hr), draining (1.0 hr)

Sequence Batch Reactors

SBR #1		**SBR #2**	
Time (hr)	SBR Function	Time (hr)	SBR Function
0	Filling	0	Sedimentation
1.68	Air Delivery	4.19	Draining
2.81	Sedimentation	5.19	Filling
7	Draining	6.87	Air Delivery
8	Filling	8	Sedimentation
9.68	Air Delivery	12.19	Draining
10.81	Sedimentation	13.19	Filling
15	Draining	14.87	Air Delivery
16	Filling	16	Sedimentation
17.68	Air Delivery	20.19	Draining
18.81	Sedimentation	21.19	Filling
23	Draining	22.87	Air Delivery
24	Filling	24	Sedimentation

Sedimentation Basin

- SBR Effluent is dosed with polymer in a rapid mix tank
- Held in a sedimentation basin for 6 hours w/ sludge collection
- Water from basin fed to either limestone bed or filters

Limestone Treatment Bed

- About 0.6 MGD enters the treatment bed
- Dimensions of 85’ x 85’ x 15’ deep (retention time of about 1 day)
- Effluent discharges to Sunday Creek

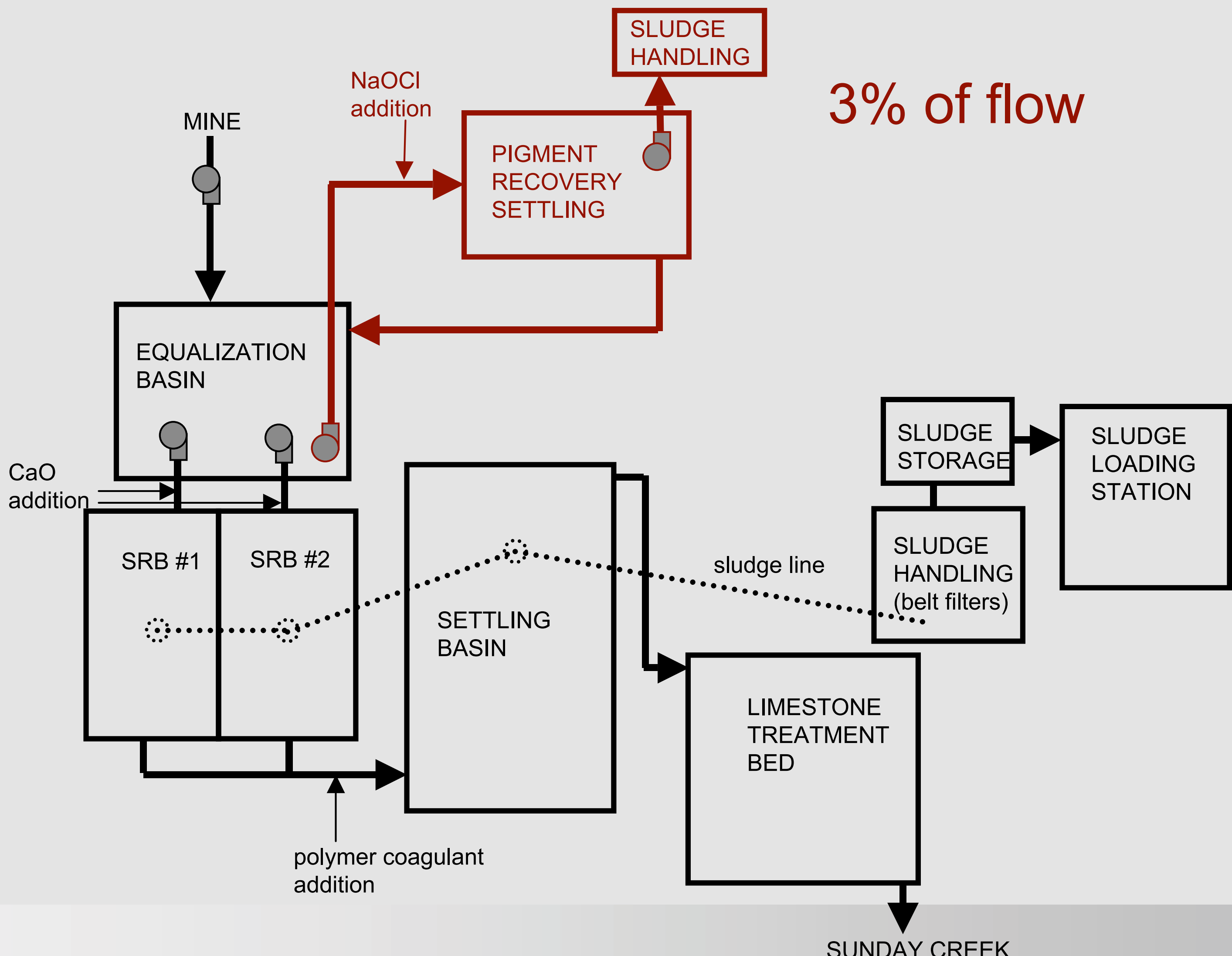
Sludge Handling Facility

- Producing about 3,200 kg sludge per day
- Wet volume of 41,700 gal (2% solids)
- Use 4 belt filter presses

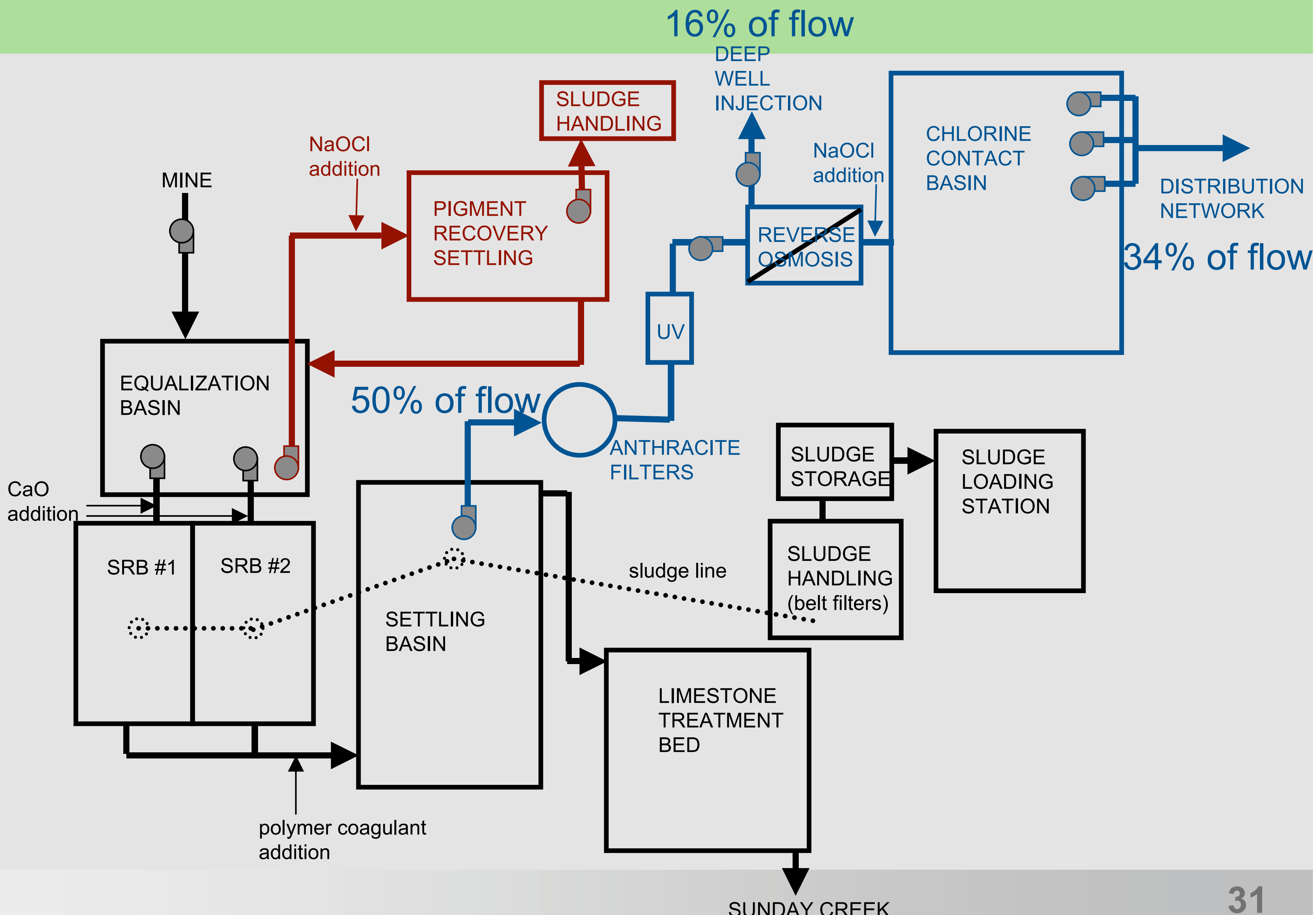
Sludge Handling Facility

- Filter Press increases solids to 18%
- Reduces sludge volume to 4,230 gal
- Hauled to landfill daily with 16 yd^3 truck

Treatment Plant with Pigment Recovery



Treatment Plant with Pigment Recovery and Water Supply



Drinking Water Design Flow

- Service Area: Truetown & Millfield
  - Population of about 2,120
  - Assume 180 gpdc → 0.38 MGD
  - Design for 0.40 MGD product
  - 0.6 MGD treated
    - 0.4 MGD product
    - 0.2 MGD brine disposal

Anthracite Filters and UV

- ~ 0.6 MGD fed to filters from sedimentation basin
- Filter effluent passes through UV disinfection system
  - Inactivates bacteria that can cause biofouling of RO membranes

Reverse Osmosis

- 10:4 array with 6 membranes long
- ESPA3 membranes
  - 98.5% rejection
  - 400 ft^2
- 2 booster pumps
- 2 cartridge filter housing
- 65% recovery

Reverse Osmosis

RO program licensed to:					
Calculation created by:					
Project name:	Truetown AMD		Permeate flow:	280.00	gpm
HP Pump flow:	430.8	gpm	Raw water flow:	430.8	gpm
Recommended pump press.:	138.4	psi	Booster pump pressure:	7.0	psi
Feed pressure:	109.4	psi	Permeate recovery:	65.0	%
Feedwater Temperature:	12.8	C(55F)			
Feed water pH:	8.0		Element age:	0.0	years
Chem dose, ppm (50%):	3.2	NaOH	Flux decline % per year:	7.0	
Acidified feed CO2:	0.22		Salt passage increase, %/yr:	10.0	
Average flux rate:	12.0	gfd	Feed type:	Surface Water	

- pH adjust with NaOH
- Antiscalant necessary for Ca and Mg
- Booster pump 280 gpm and 140 psi

Reverse Osmosis

Stage	Perm. Flow	Flow/Vessel Feed	Flow/Vessel Conc	Flux	Beta	Conc.&Throt. Pressures		Element Type	Elem. No.	Array
	gpm	gpm	gpm	gfd		psi	psi			
1-1	231.4	43.1	19.9	13.9	1.14	89.7	0.0	ESPA3	60	10x6
1-2	48.6	49.8	37.7	7.3	1.03	62.5	0.0	ESPA3	24	4x6

	Raw water		Feed water		Permeate		Concentrate	
Ion	mg/l	CaCO3	mg/l	CaCO3	mg/l	CaCO3	mg/l	CaCO3
Ca	231.0	576.1	231.0	576.1	4.399	11.0	651.8	1625.5
Mg	77.8	320.2	77.8	320.2	1.482	6.1	219.5	903.4
Na	571.8	1243.0	572.7	1245.0	51.027	110.9	1541.6	3351.2
K	13.5	17.3	13.5	17.3	1.470	1.9	35.8	46.0
NH4	0.0	0.0	0.0	0.0	0.000	0.0	0.0	0.0
Ba	0.000	0.0	0.000	0.0	0.000	0.0	0.000	0.0
Sr	0.000	0.0	0.000	0.0	0.000	0.0	0.000	0.0
CO3	0.1	0.2	0.1	0.2	0.000	0.0	0.3	0.5
HCO3	11.8	9.7	14.0	11.5	8.398	6.9	24.4	20.0
SO4	2036.0	2120.8	2036.0	2120.8	114.215	119.0	5605.0	5838.6
Cl	18.2	25.7	18.2	25.7	2.850	4.0	46.7	65.9
F	0.0	0.0	0.0	0.0	0.000	0.0	0.0	0.0
NO3	0.0	0.0	0.0	0.0	0.000	0.0	0.0	0.0
B	0.00		0.00		0.000		0.00	
SiO2	8.0		8.0		1.63		19.8	
TDS	2968.2		2971.3		185.5		8145.1	
pH	7.0		8.0		7.9		8.2	

Reverse Osmosis

	Raw water	Feed water	Concentrate
CaSO4 / Ksp * 100:	53%	53%	193%
SrSO4 / Ksp * 100:	0%	0%	0%
BaSO4 / Ksp * 100:	0%	0%	0%
SiO2 saturation:	7%	7%	17%
Langelier Saturation Index	-1.46	-0.39	0.49
Stiff & Davis Saturation Index	-1.64	-0.57	0.05
Ionic strength	0.07	0.07	0.20
Osmotic pressure	15.7 psi	15.8 psi	42.9 psi

- $CaSO_4$ saturation 193% below 200% control limit
- LSI 0.49 below 0.5 control limit
- Gypsum precipitation a concern
    - Pilot study best to determine whether an issue

Deep Well Injection

- RO brine disposal alternative
- Extreme costs
  - $1.9 million of construction
  - $11,000 in annual operation costs

Treatment plant construction costs

Item Description	Total Cost
Equalization Basin	$178,850
Pigment Recovery Facility	$172,920
Sequence Batch Reactors	$660,950
Sedimentation Basin	$354,530
Anthracite Filters	$75,880
Reverse Osmosis	$317,640
Deep Well Injection	$1,871,000
Clearwell	$331,850
Sludge Handling Facility	$326,605
Site Work / excavation	$90,000
Electrical	$75,000
Fence	$44,000
Misc Site Piping / Mechanical	$60,000
Misc Site concrete work	$55,000
Construction Contingencies	$240,000
Administration / Legal	$50,000
Engineering	$500,000
TOTAL	**$5,404,225**

Annual Energy Costs

Description	Unit Quantity	Required Horsepower	# Hours of operation per day per unit	Daily Cost	Annual Cost
Inlet Pumps	3	6	13	$15.71	$5,734.43
SBR Pumps	4	5.9	5.04	$7.99	$2,914.85
SBR Air Blowers	2	12	3.39	$5.46	$1,993.82
SBR Sludge Rakes	4	1	15.57	$4.18	$1,526.24
SBR Sludge Pumps	2	9	12	$14.50	$5,293.32
Sluice Gate Operation	2	10	2	$2.69	$980.24
Pigment Recovery Pumps	1	4.1	8	$2.20	$803.80
Pigment Sludge Rakes	2	1	18	$2.42	$882.22
Pigment Sludge Pumps	2	2.2	18	$5.32	$1,940.88
Sedimentation Sludge Rakes	2	1	24	$3.22	$1,176.29
Sedimentation Sludge Pumps	2	8	18	$19.34	$7,057.76
Belt Filter Press	4	12	24	$77.35	$28,231.03
Filter Dosing Pumps	1	5	12	$4.03	$1,470.37
Filter Backwash Pumps	1	12	2	$1.61	$588.15
UV Operation	1	5.5	24	$8.86	$3,234.81
RO chemical pumps	4	0.3	24	$1.93	$705.78
RO booster pumps	1	60	24	$96.68	$35,288.78
Deep well Injection Pumps	1	110	4	$29.54	$10,782.68
Distribution Pumps	2	11	16	$23.63	$8,626.15
System Electrical Monitoring	1	2	24	$3.22	$1,176.29
Lighting	1	3	8	$1.61	$588.15
TOTAL					**$120,996.03**

Annual chemical costs

Description	Chemical Unit	Unit Cost	Unit Quantity per day	Daily Cost	Annual Cost
Calcium Hydroxide	Gal	$0.44	3600	$1,584.00	$578,160.00
12.5% Sodium Hypochlorite (pigment)	Gal	$0.36	700	$252.00	$91,980.00
RO Antiscalant	Gal	$2.00	15	$30.00	$10,950.00
Caustic Soda for RO pH adjustment	kg	$0.20	14.5	$2.90	$1,058.50
12.5% Sodium Hypochlorite (Cl)	Gal	$0.36	4.4	$1.58	$578.16
Polymer	kg	$2.12	29.3	$62.12	$22,672.34
[redacted]					
TOTAL					$705,399.00

Miscellaneous costs

Description	Estimated Annual Cost
Pump Maintenance	$7,500.00
Blower Maintenance	$750.00
Sludge Facility Maintenance	$1,500.00
Sludge Hauling / Disposal	$35,000.00
Plant Operator (part time)	$20,000.00
Tank Maintenance	$1,000.00
RO Maintenance	$6,000.00
Chemical Injection Equip	$1,200.00
Miscellaneous Expenses	$2,000.00
TOTAL	**$74,950.00**

Annual costs

- $901,345 per year for operation / maintenance
- Making $131,820 per year in pigment sales
- Results in $769,525 per year
  - 0.527¢ per gallon of drinking water (0.4 MGD)

Total Costs

- Annual Operation Cost Offsets
  - Water billing rates (0.527¢ per gallon)
  - Pigment Sales ($132,000 per year)
- $5.4 million in construction with deep well
  - ($3.5 million without deep well)
- potential problems
  - can pigment grade sludge be produced
  - can RO bring AMD to drinking water standards
  - unknowns for complex plant

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