Engineered Wetlands for Treating Petroleum Hydrocarbon-Contaminated Water

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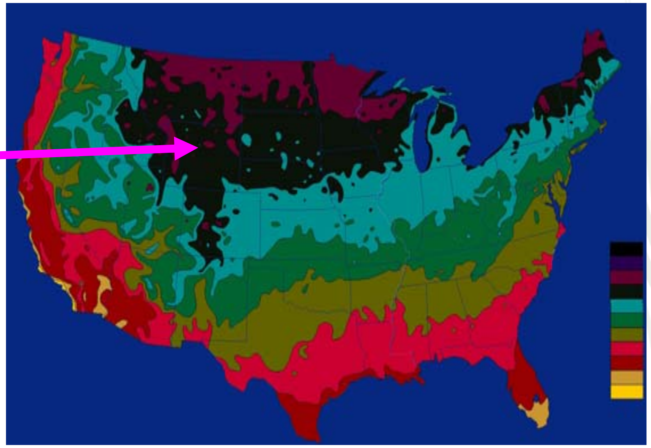
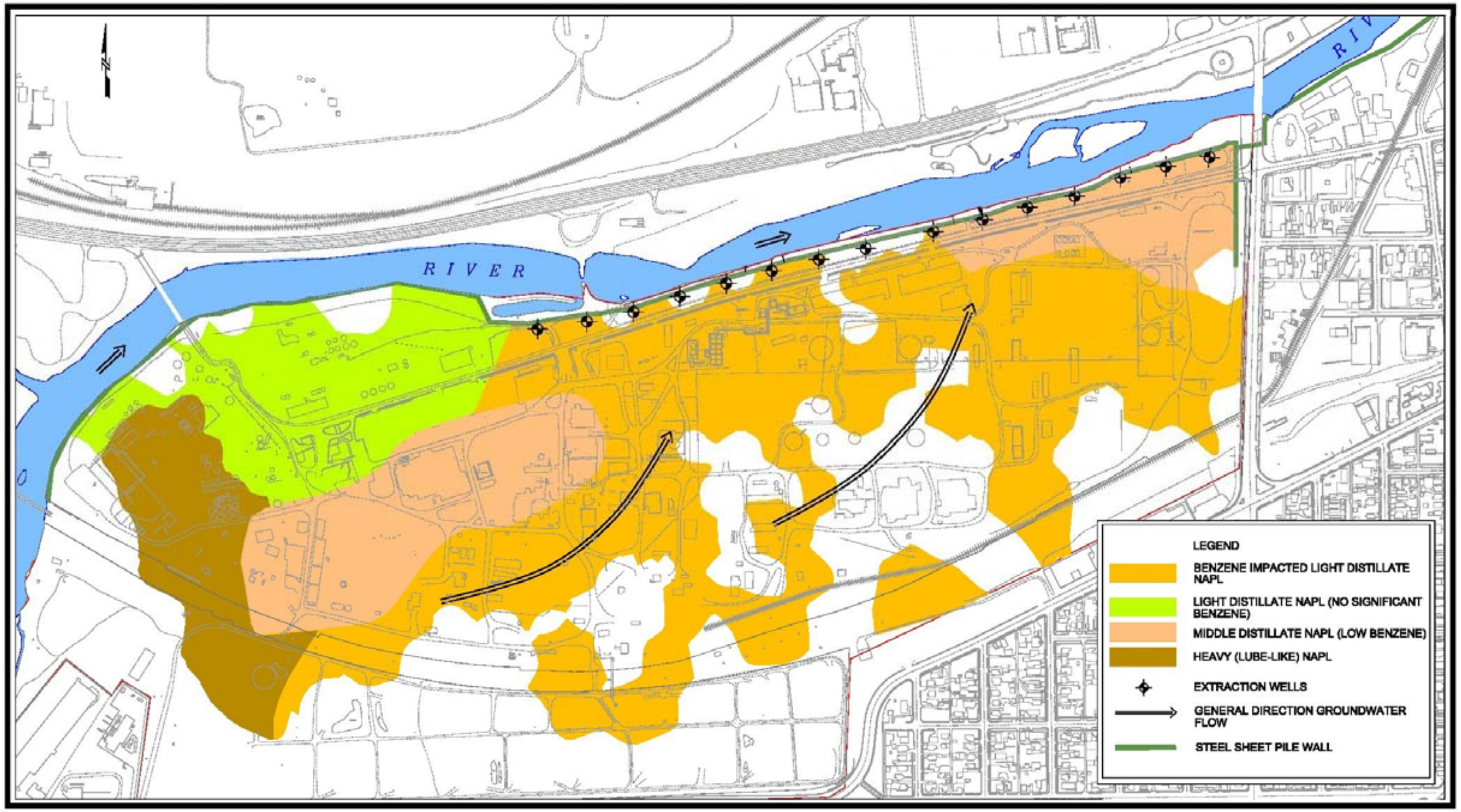
Casper Refinery Site

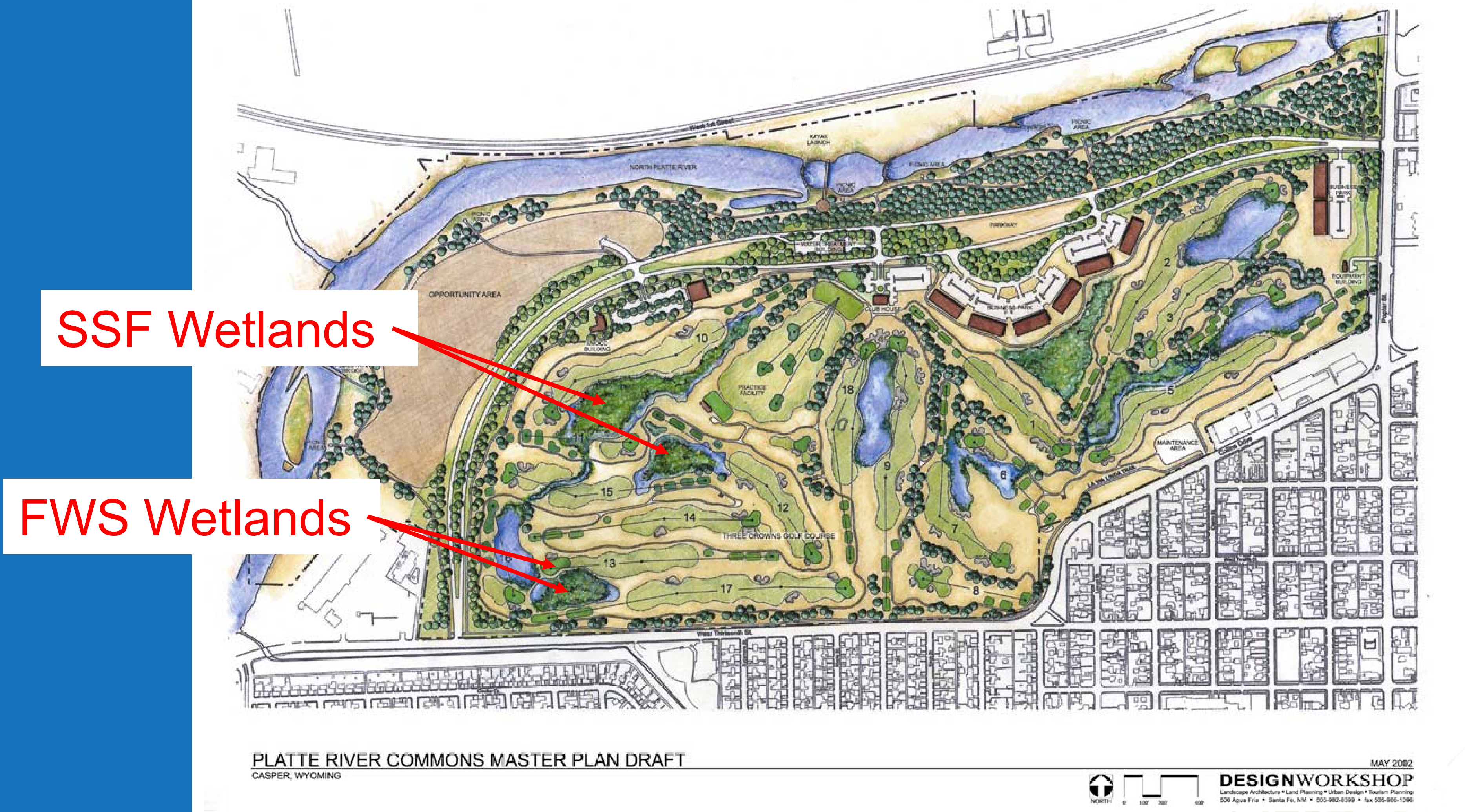
- Operated 1912 to 1991
- 37,000 m^3 of LNAPL recovered to date
- Extensive smear zone due to changing water table elevation
- 50 to 100 years to remediate site
- High mountain west: -35°C



LNAPL Distribution



Reuse Plan

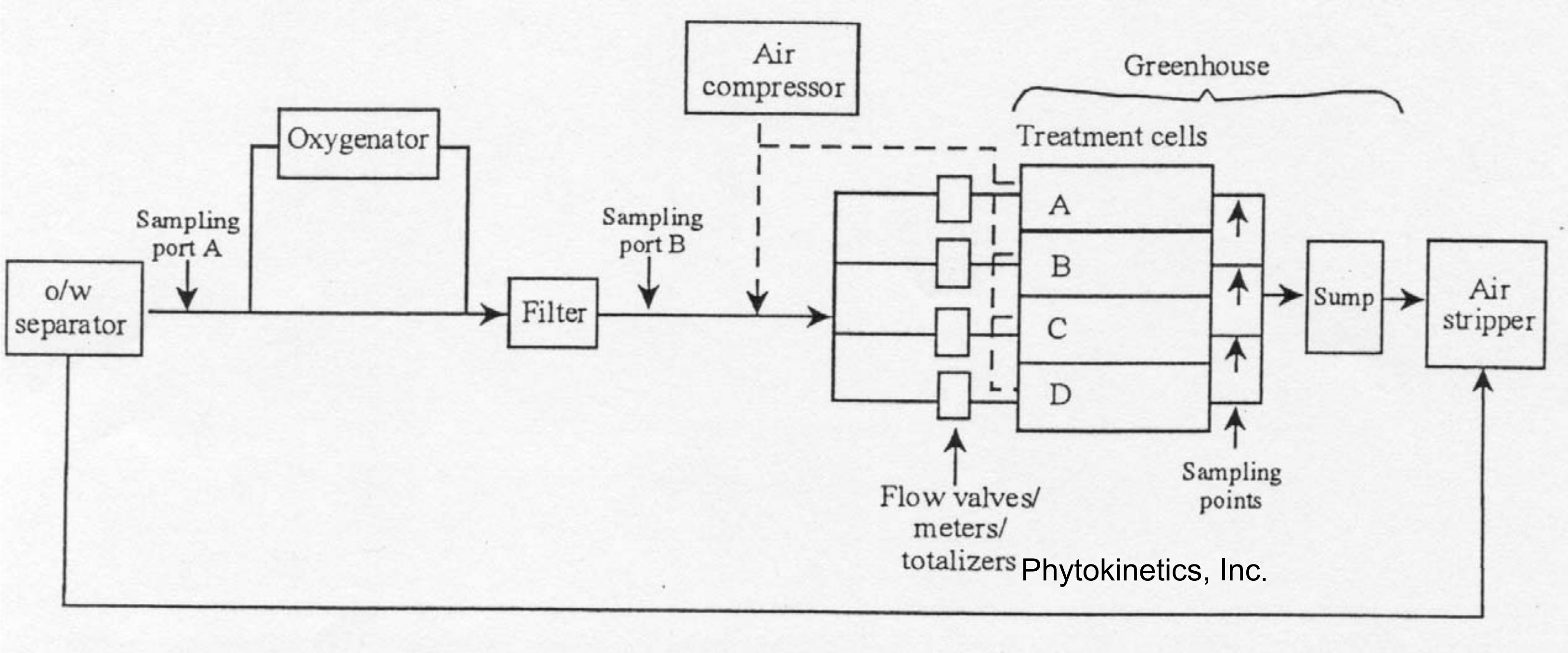

SSF Wetlands
FWS Wetlands
NORTH PLATTE RIVER
OPPORTUNITY AREA
THREE CROWNS GOLF COURSE
PLATTE RIVER COMMONS MASTER PLAN DRAFT
CASPER, WYOMING
MAY 2002
DESIGNWORKSHOP

Treatment Needs

- Influent benzene ~ 1.5 mg/L
- Effluent benzene < 0.5 mg/L due to RCRA requirements
- Final benzene < 0.05 mg/L to meet permit limit
- Final iron < 2 mg/L
- Operate at -35°C
- Pilot system operated to demonstrate concept, develop removal rates

Pilot Wetland System

- 4 cells
- Vertical upward flow
- With and without aeration
- With and without wetland sod

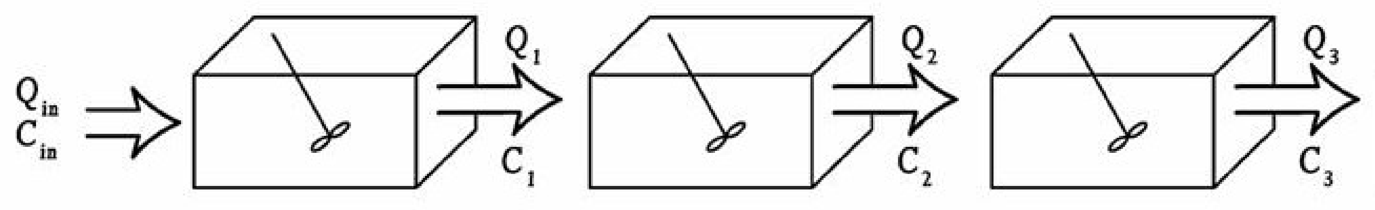


Phytokinetics, Inc.

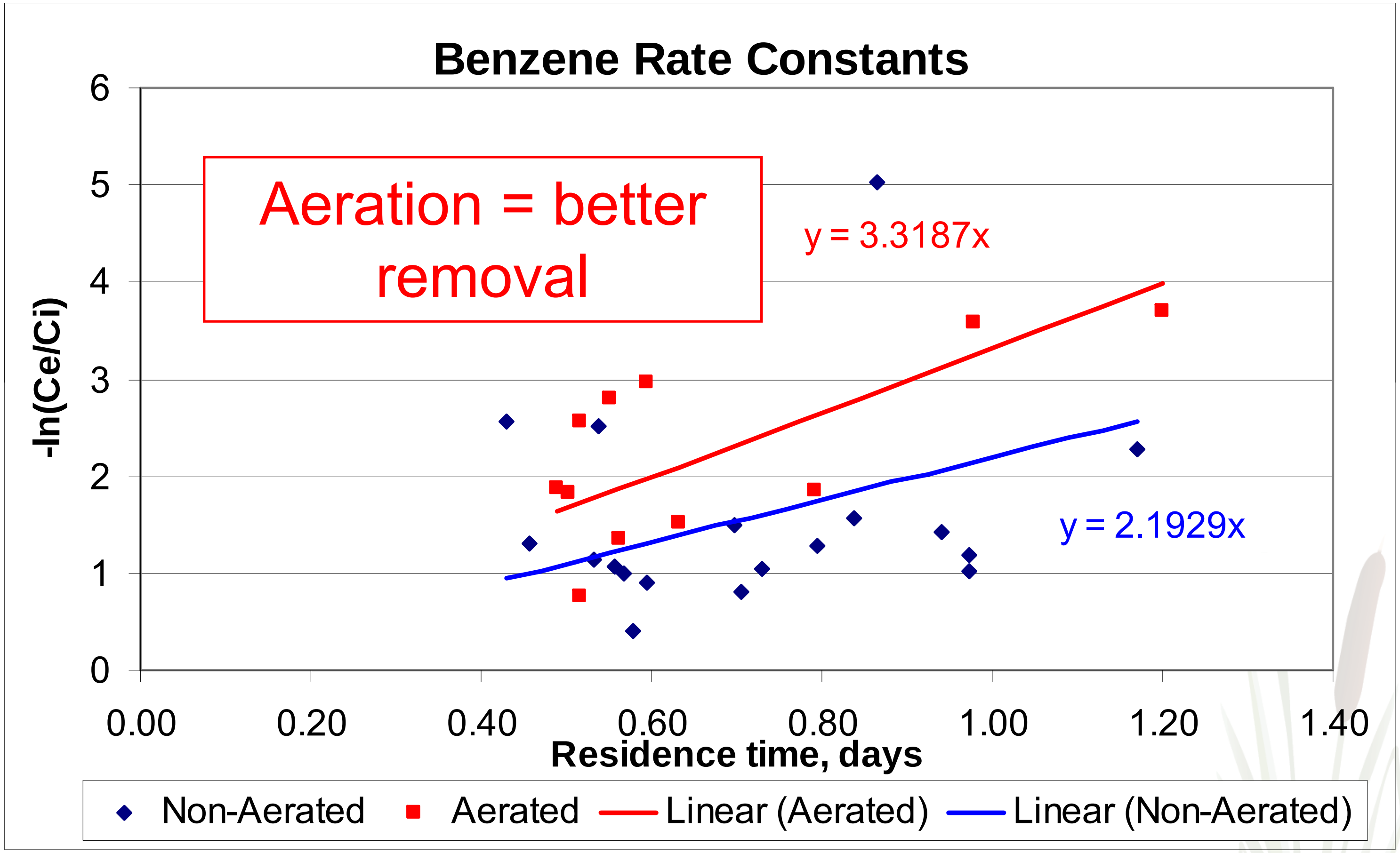
Pilot Unit Results

k_A, m/yr, based on 3 TIS

	Aeration		No Aeration	
Compound	Wetland Mulch	No Mulch	Wetland Mulch	No Mulch
Benzene	518	456	317	256
BTEX	356	311	257	244
TPH	1,058	965	725	579
MTBE	64	60	35	22

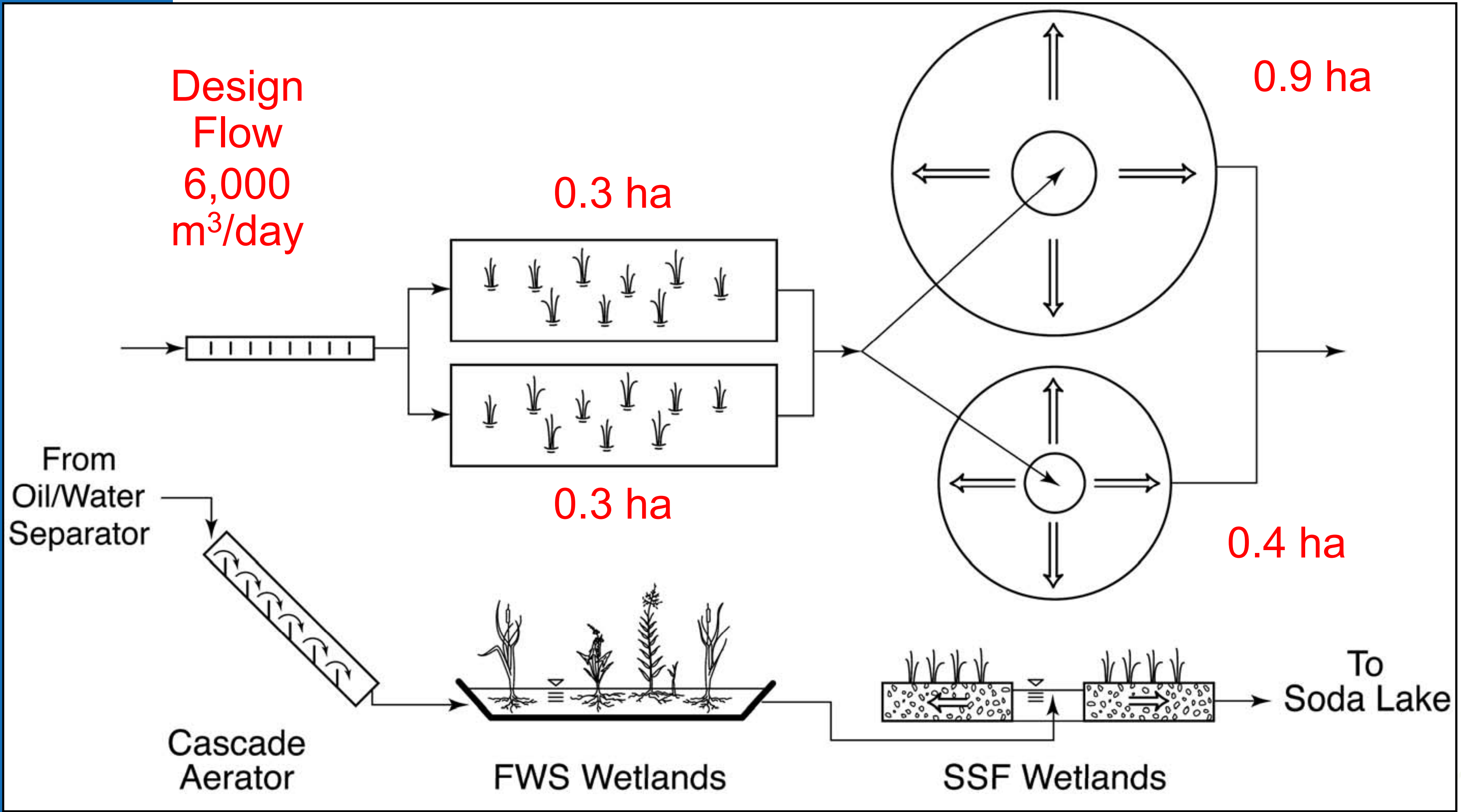


Pilot Results: Aerated vs. Non-aerated



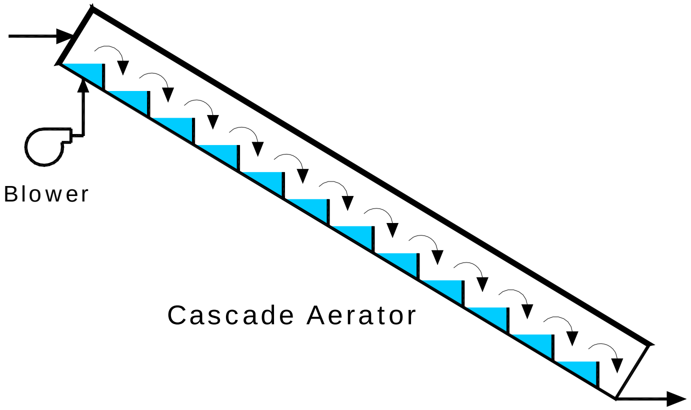
Area: 4 ha → 1.3 ha

Full Scale System



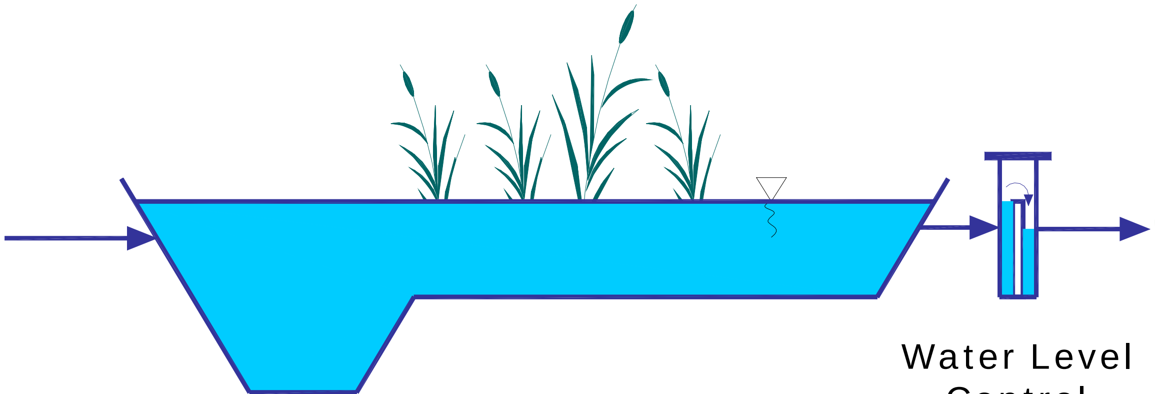
Cascade Aerator

- Oxidize Fe^{2+} to Fe^{3+}
- Benzene air stripping (1.5→0.5 mg/l at 3,000 m^3/day)
- Option to add second cascade for total capacity of 6,000 m^3/day

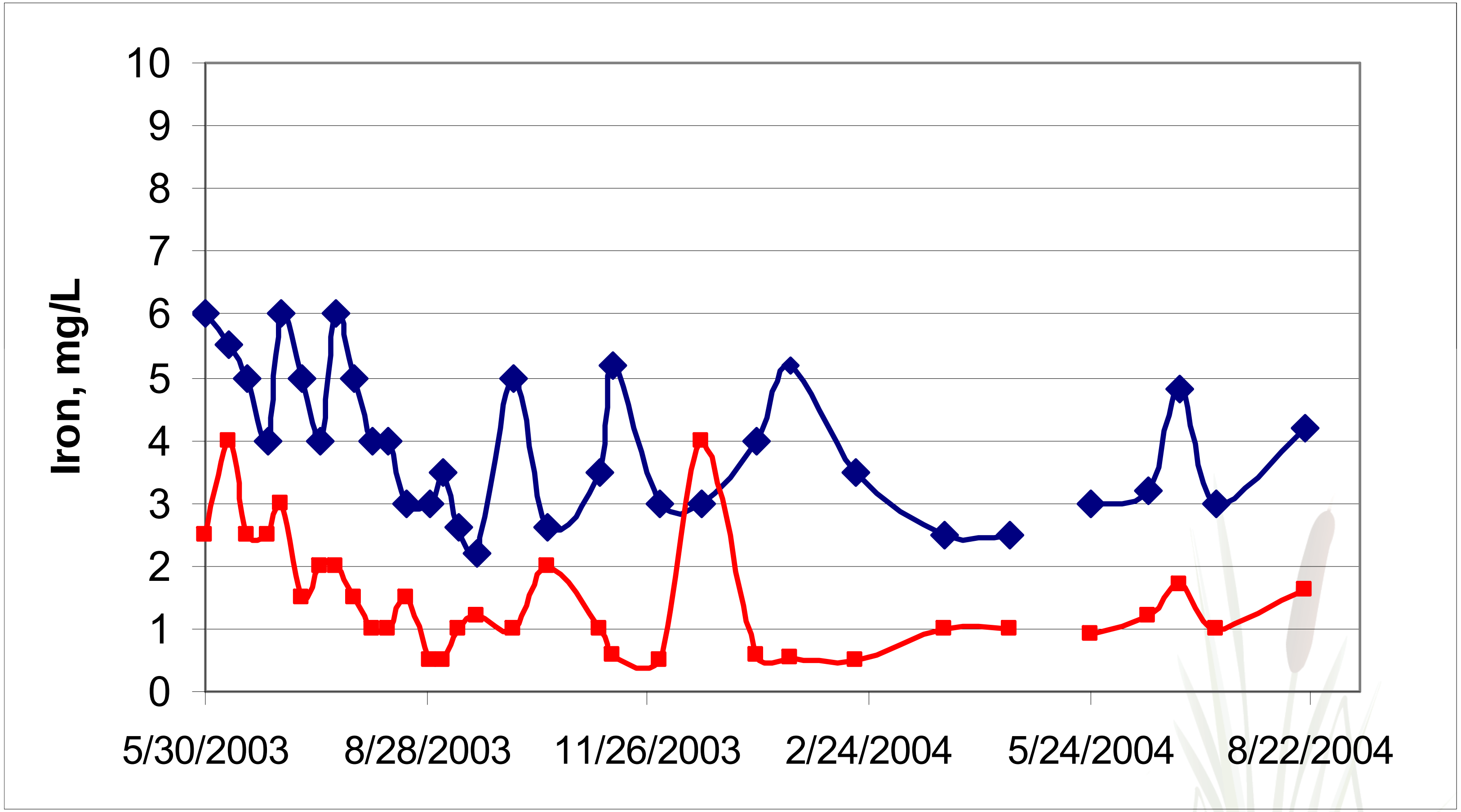


Surface Flow Wetland

- Iron removal by sedimentation
- Deep zones for sludge removal

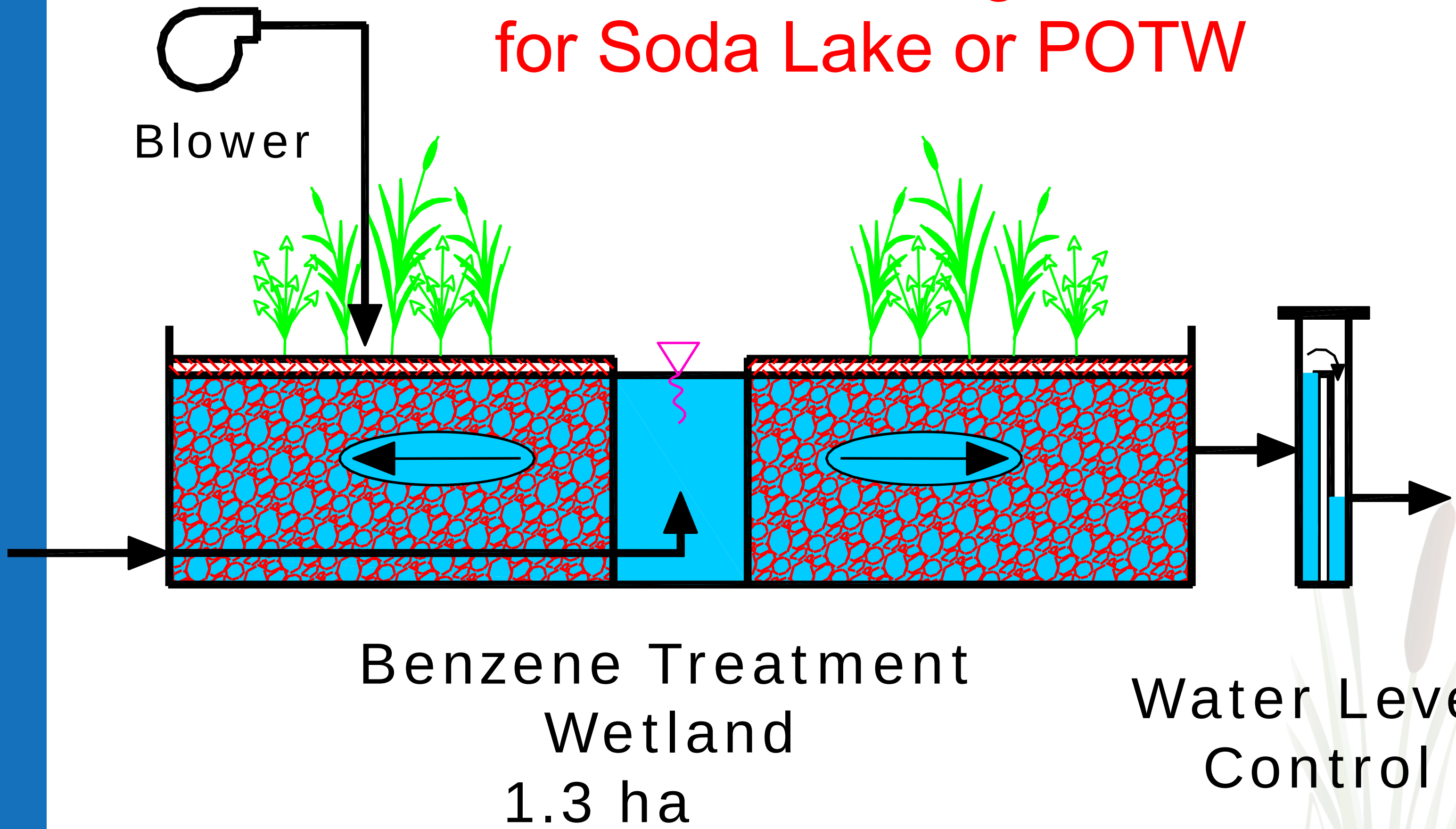


Surface Flow Wetland Iron Removal



Subsurface Flow Wetlands

- Achieve 0.05 mg/L benzene limit for Soda Lake or POTW



- Hydraulically pass 8.3 m^3/min

SSF Wetland Air Distribution

SSF Wetland Construction

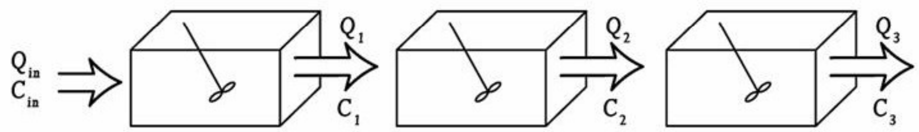
SSF Wetland Construction

Treatment Wetland Performance

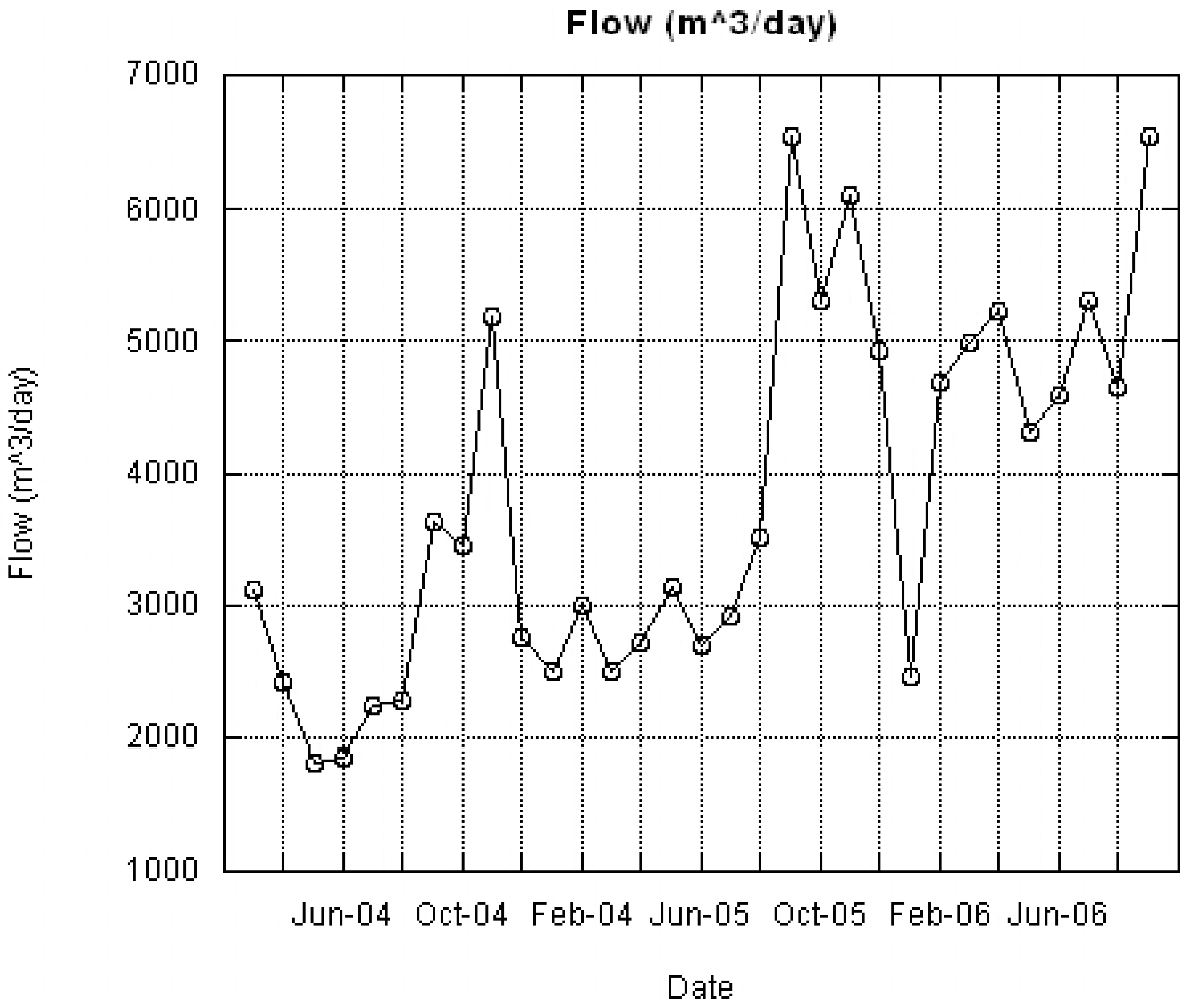
Compound	Wetland Influent	Wetland Effluent
Benzene, mg/L	0.17	Non-detect (0.01)
BTEX, mg/L	0.47	Non-detect (0.01)
GRO, mg/L	2.02	Non-detect (0.05)

Compound	k_A, m/yr
Benzene	~ 240
BTEX	~ 350
GRO	~ 325

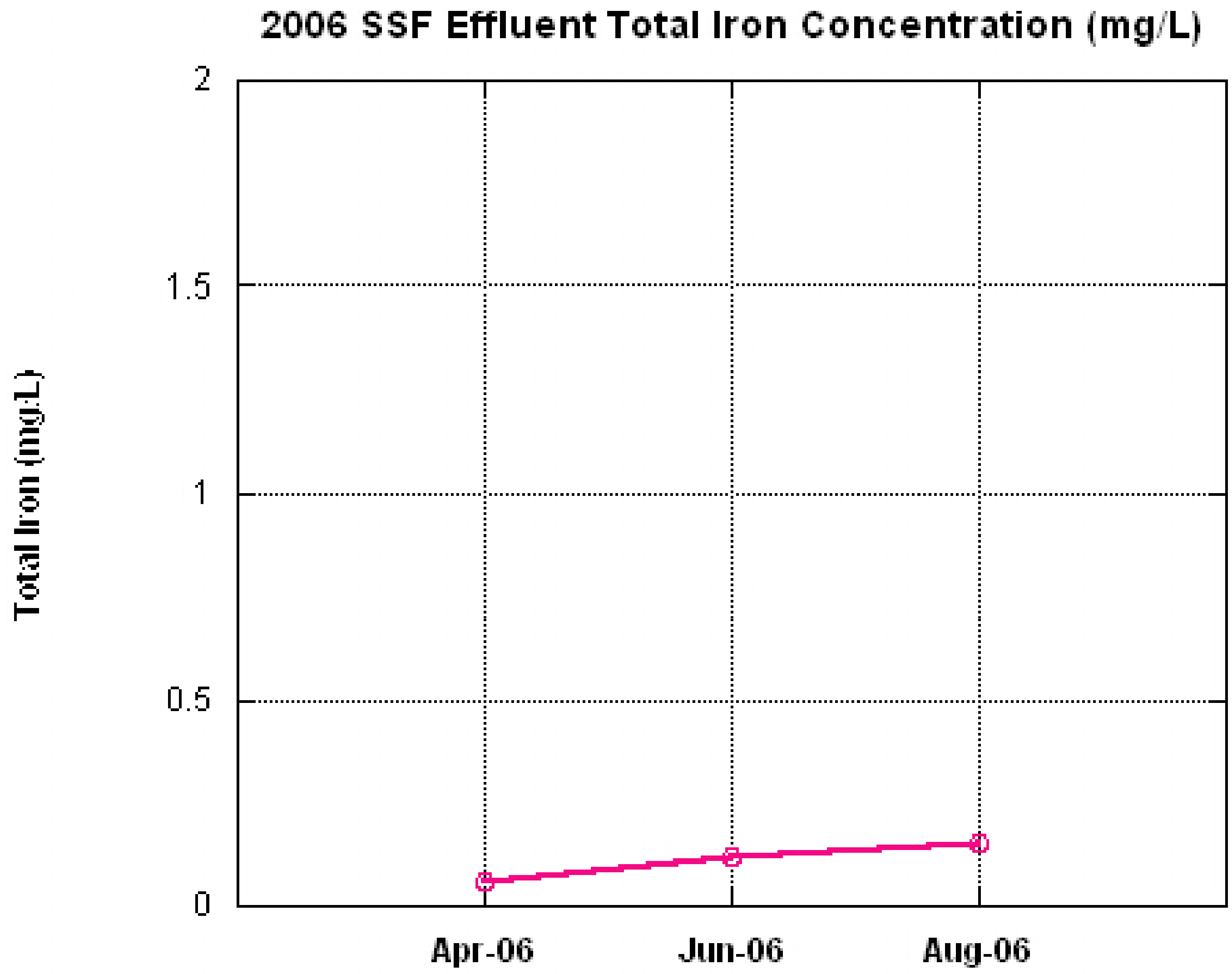
k_A based on 3 TIS



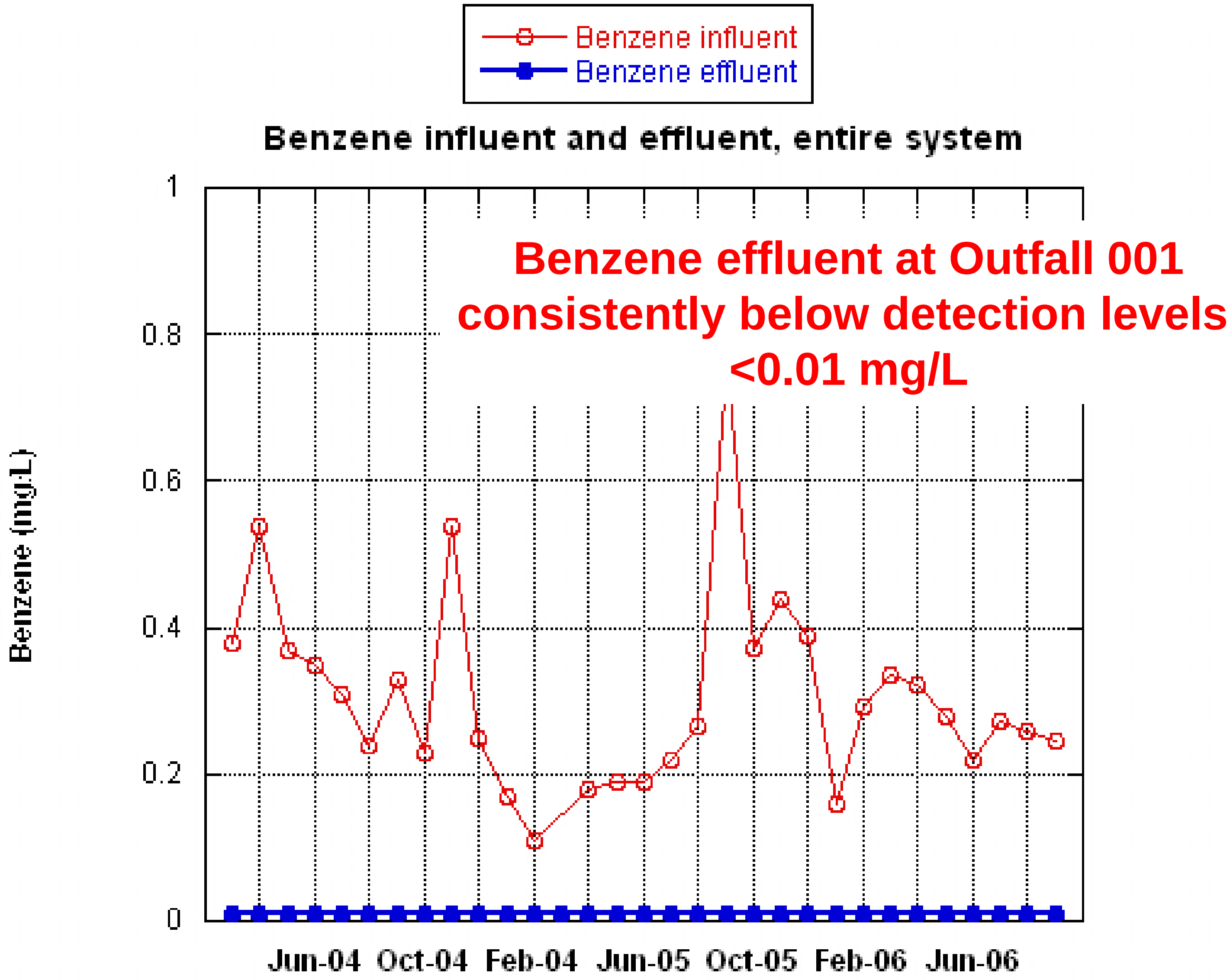
Approaching Design Flow



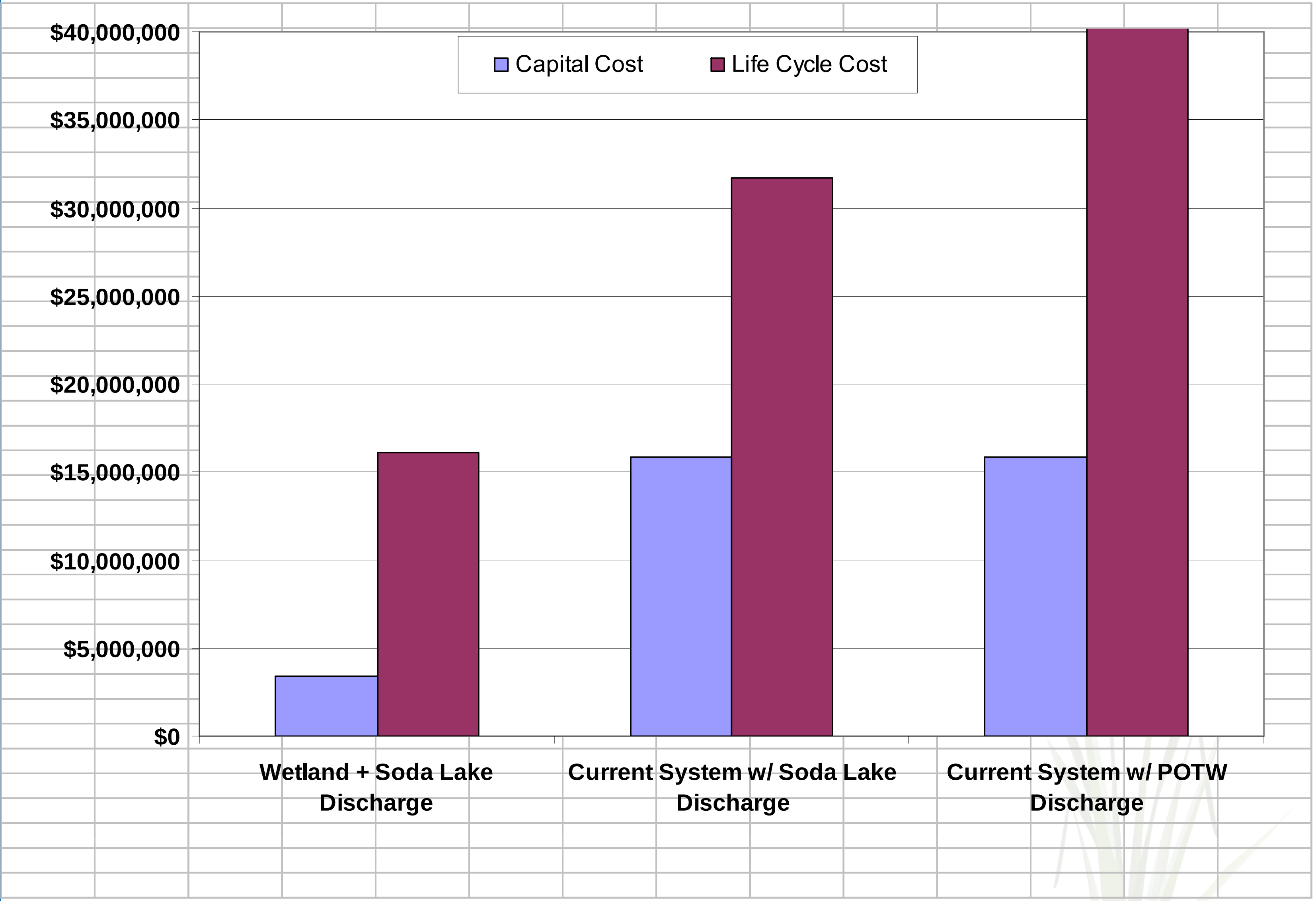
Effluent Iron Concentrations



Benzene Data: 2004 - 2006



Cost Savings to BP: Significant



Evapotranspiration and Engineered Wetland Design in Arid Climates

- Evapotranspiration (ET) is an important design parameter in arid climates
- The energy balance method can be used to calculate water losses due to ET

Energy Inputs – Energy Outputs = Change in Energy Storage (Δ)

$$[R_N + U_{in} + G] - [\lambda\rho ET \pm E_{loss} + U_{out}] = \Delta \quad (MJ/m^2 \cdot d)$$

The Penman Equation

- The Penman Equation is used to calculate ET

$$\lambda ET = \Phi(R_N – G) + (1- \Phi)\ \lambda K_e[P_w^{sat}(T) - P_w^{sat}(T_{dp})]$$

λ is the volumetric latent heat of water vaporization
Φ is the "Penman Estimator"
R_N is net solar radiation
G is conductive heat transfer to ground
K_e is the water vapor mass transfer coefficient (m/day·kPa)
P_w^{sat} is saturation water vapor pressure
T is temperature (dp = dew point)

Abu Dhabi design: ET effects

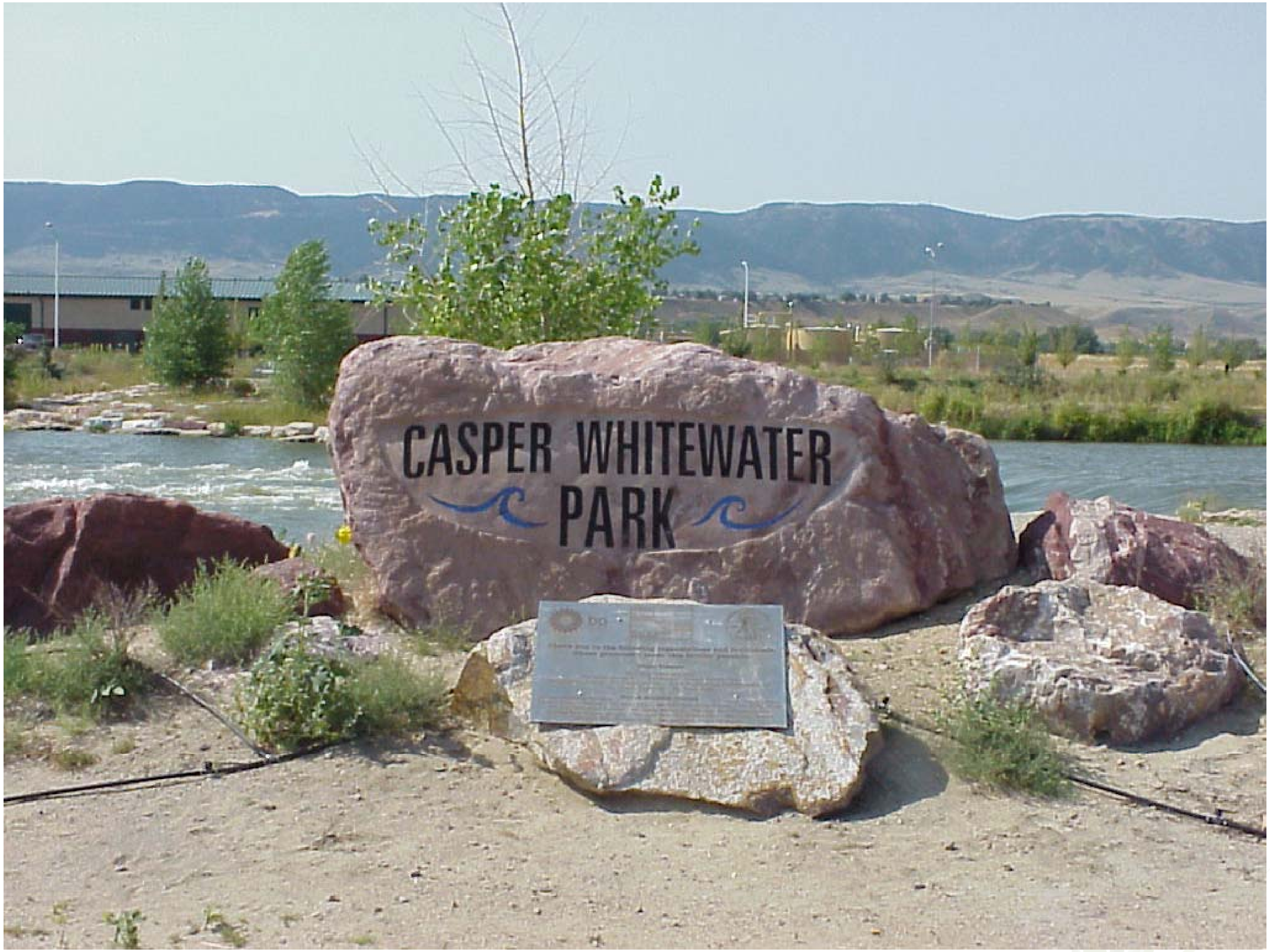
	ET (m/day)	Volume of water lost to ET (m^3/day)	% of water lost from wetland
Summer	0.0162	19.44	39
Winter	0.0021	2.56	5

Summer: **high temperature, low RH**
Winter: **higher RH**

Conclusions

- Aeration + wetland sod improved BTEX removal
- Cascade aerator + FWS wetlands effective in iron removal
- Full-scale system has produced non-detect effluent concentrations since May 2003
- BTEX k_A pilot: 356 m/yr (3 TIS)
- BTEX k_A full scale: 350 m/yr (3 TIS)

NAWE


CASPER WHITEWATER
PARK

Questions?