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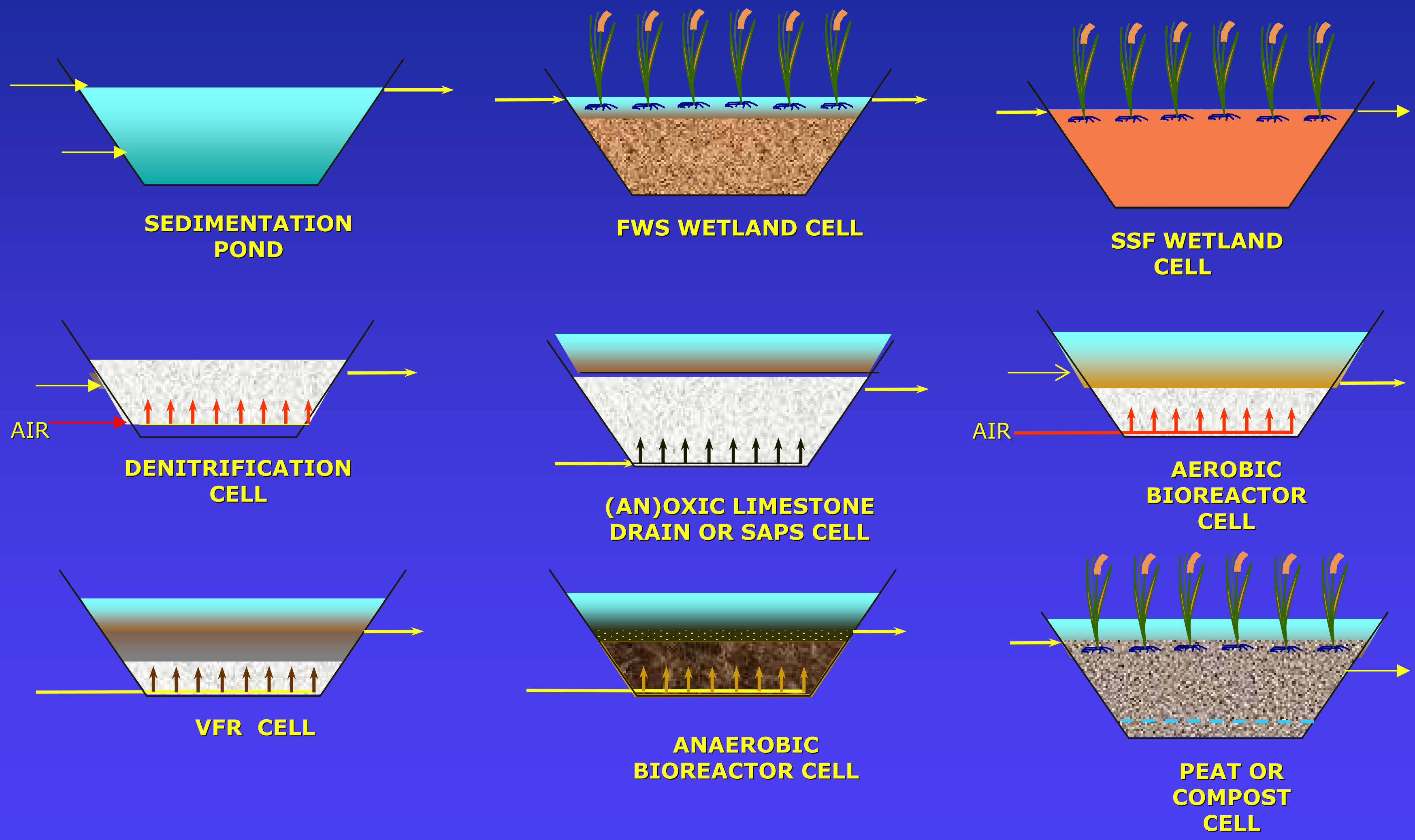
ADVANCES IN THE USE OF CONSTRUCTED WETLANDS TO TREAT MINE DRAINAGE


THERE ARE VARIOUS KINDS OF CONSTRUCTED WETLANDS
Pond & FWS CW Cells at Alfred, Ontario
• POND WETLANDS
• FREE WATER SURFACE WETLANDS
• SUB-SURFACE FLOW WETLANDS
– Horizontal SSF
– Vertical SSF
• CONSTRUCTED & ENGINEERED TREATMENT WETLANDS
– Passive & Semi-Passive

METHODS TO CREATE AN ENGINEERED SSF WETLAND

- Provide Aeration Under The Substrate
- Use Engineered Substrates That Have Chemical Affinities To Some Pollutants
  - E.g., Steel slag for PO_4, green sand for Zn
- Add Things To The Process
  - E.g., Heat, dilution, alkalinity
- Use Phytoremediating Plants
- Manipulate Process Conditions
  - E.g., recycle, tidal flow, separate competing reactions
- Express Other Processes As EW Cells
  - E.g., ABRs, limestone drains, SAPS

ENGINEERED WETLAND CELL OPTIONS



TODAY'S PRESENTATION

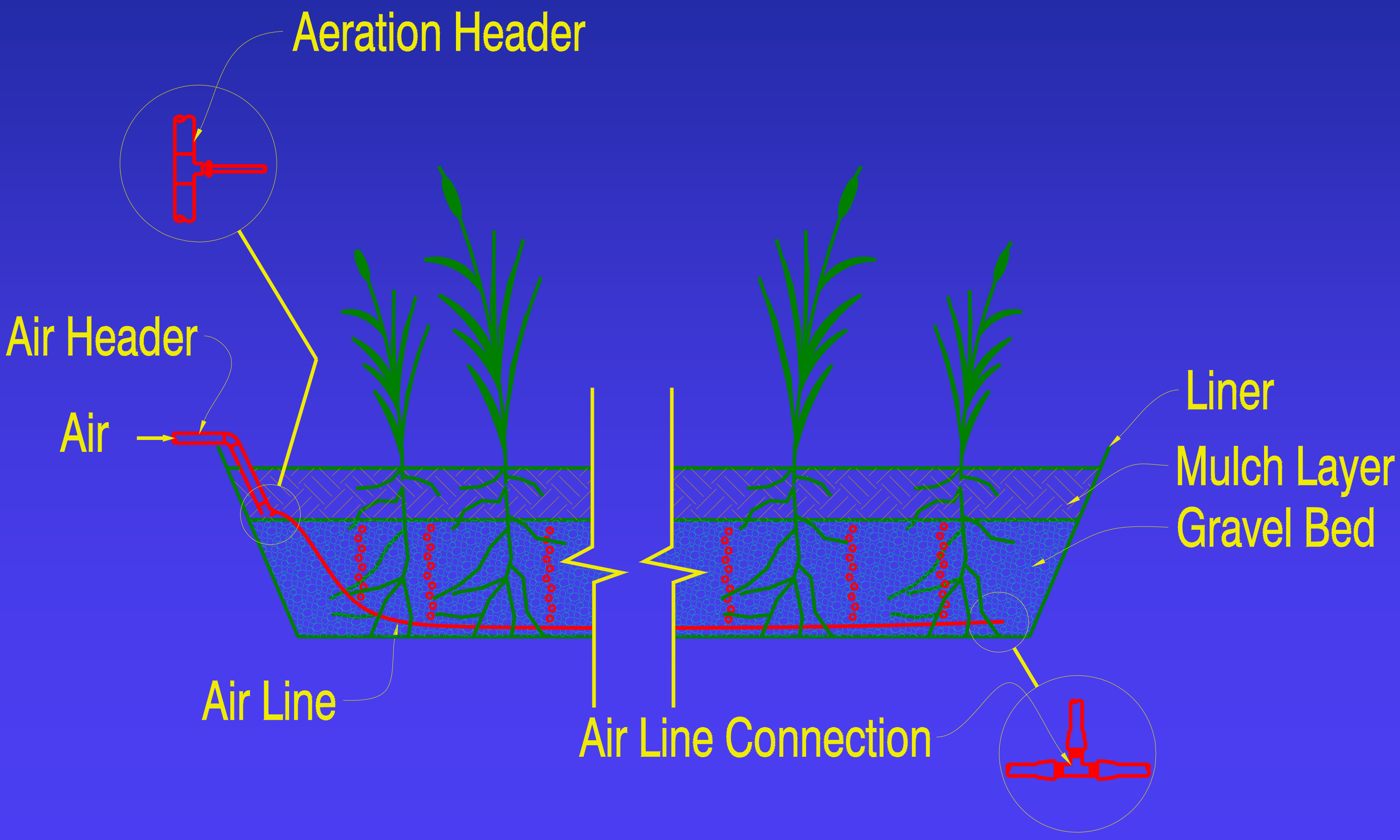
- New VSSF EW Technologies That Have Particular Applicability For The Mining Industry
  - Pilot-Scale Treatability Testing
- Aerated Sub-Surface Flow Engineered Wetlands
- Anaerobic Bioreactors (ABRs)
- pH Control Plus ABRs
- Some Example Projects

AERATED VSSF EWs

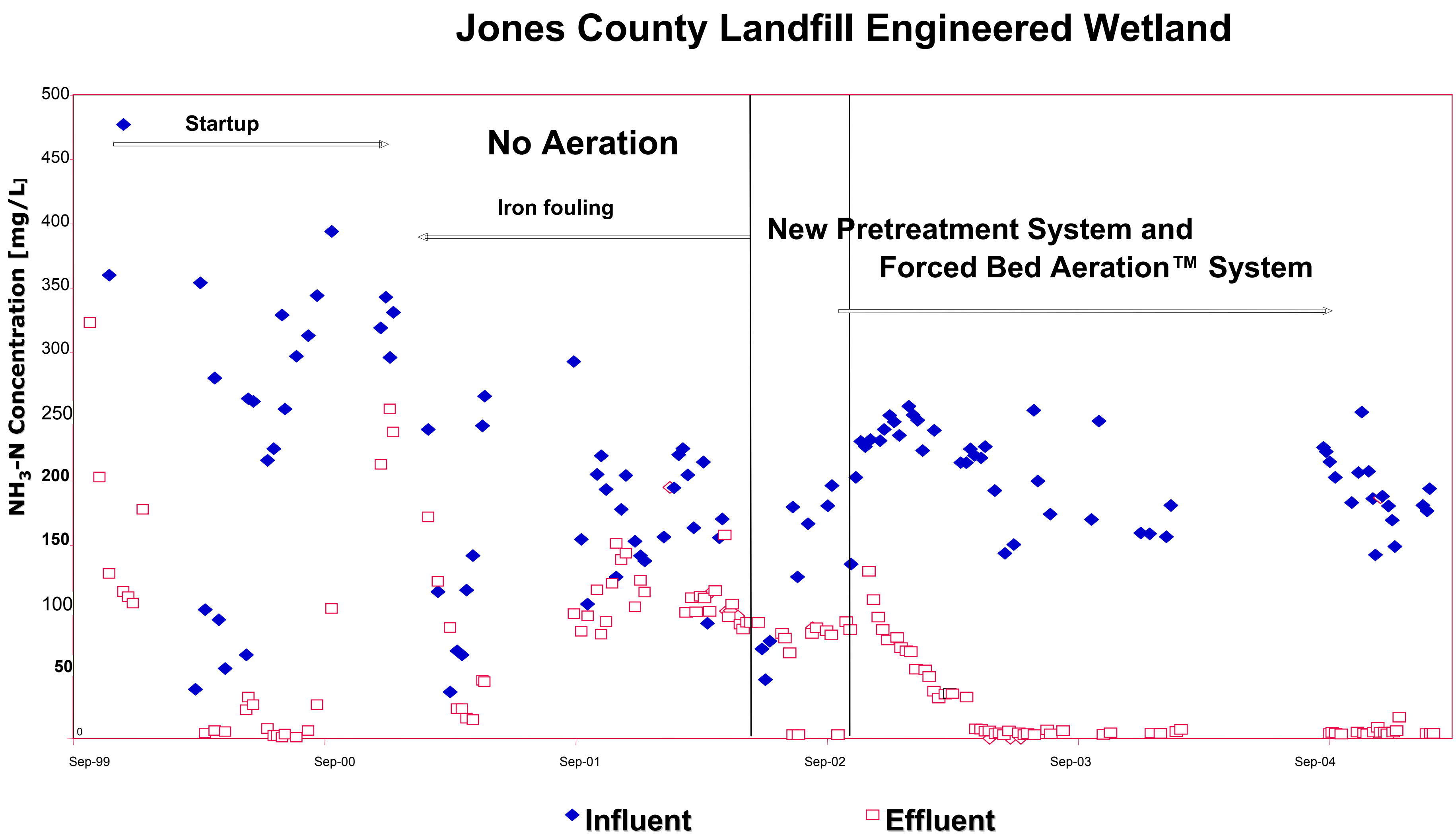
CELL AERATION IN ENGINEERED WETLANDS

- Air Can Be Added To Some Of The Cells Of Engineered Wetlands
  - Not fully passive but air is/can be made available for many applications
  - Aerators, diffusers
- Supplement Natural Aeration By Plants & Surface Re-Aeration
- Aerate Under Gravel Beds In SSF Wetland Cells

FORCED BED AERATION™



THE IMPACT OF SUBSTRATE AERATION ON AMMONIA CONCENTRATIONS FOR AN EW



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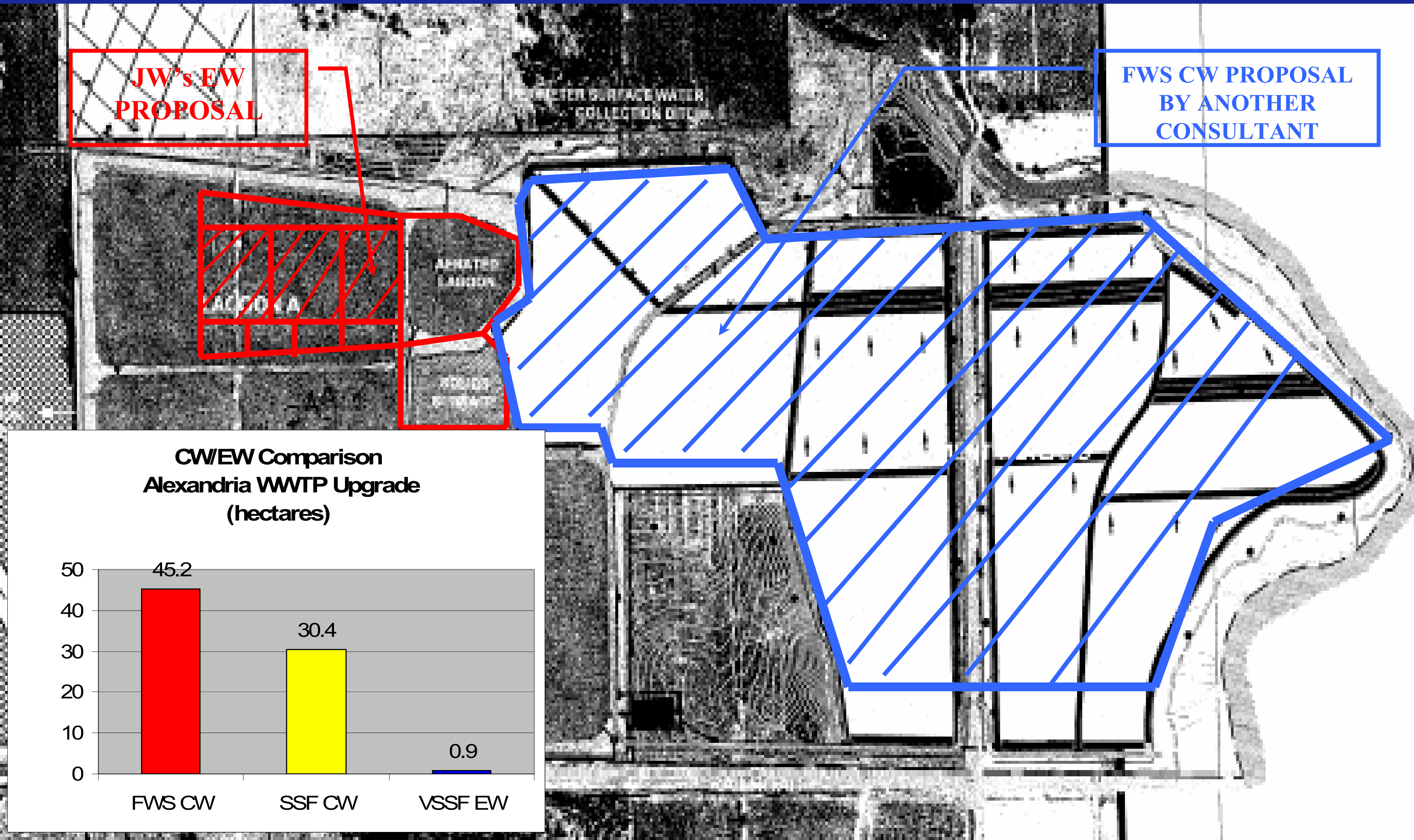
THE IMPACT OF USING AN AERATED VSSF EW SYSTEM
(ALEXANDRIA WWTP UPGRADE)



THE ADVANTAGES OF AERATED VSSF EWs

- Vastly Superior Performance
  - Summer & winter
- Very Much Smaller "Footprints"
- Ability To Treat Wastewater At Much Higher Flow Rates
- Semi-Passive Treatment
  - Possible eventual evolution to passive treatment

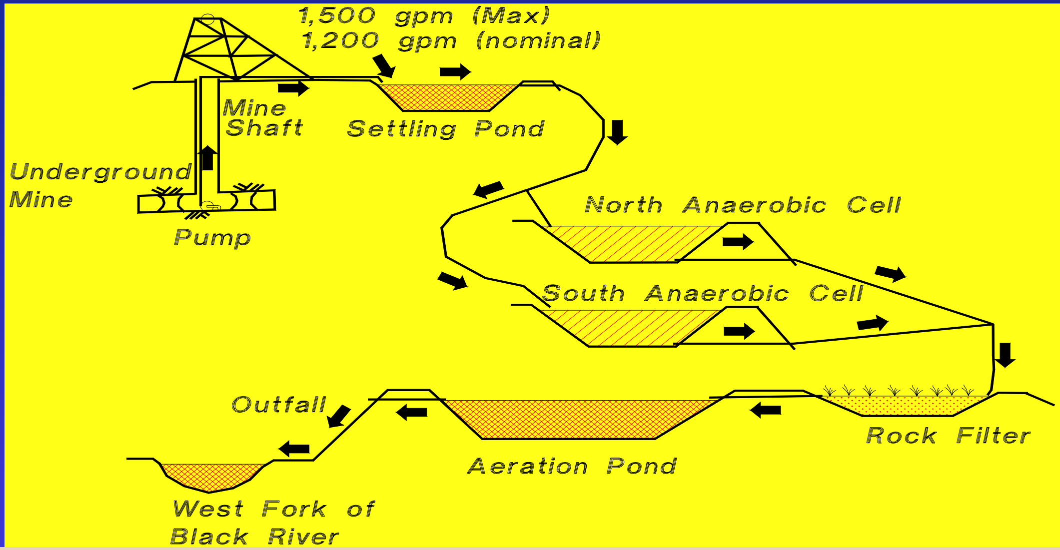
ANAEROBIC BIOREACTORS

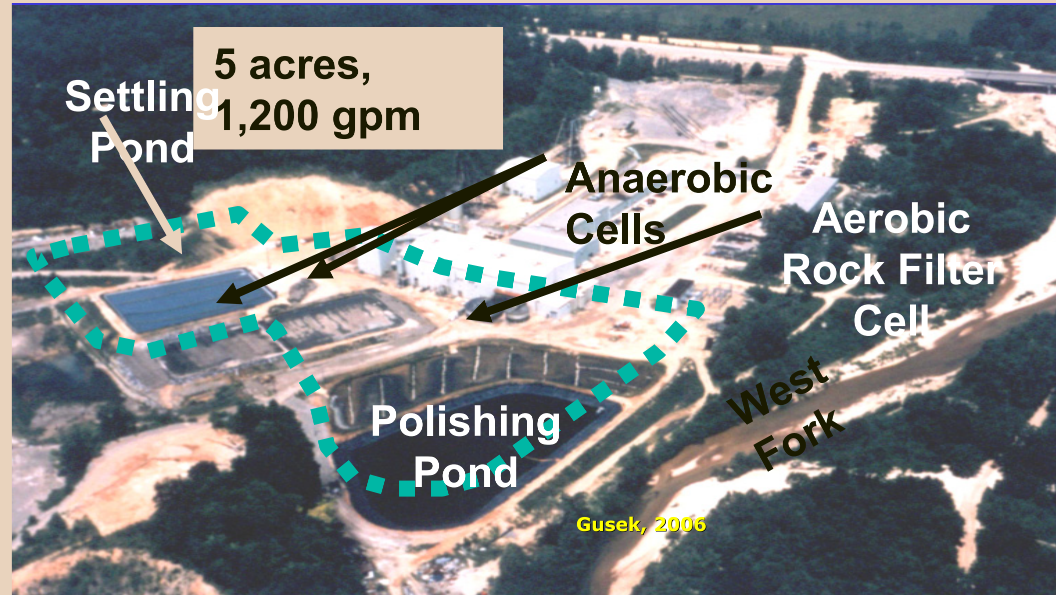
ANAEROBIC BIOREACTORS (ABRs)

- Developing New Biotechnology
  - Sometimes called sulphate-reducing bacteria bioreactors (SRBRs)
- Remove Dissolved Contaminants From ARD & NMD
  - E.g., Zn, Cu, As, Ni, Cd
- Precipitate Metals In Organic Substrate
- Biological Reactions
  - SRB & Other microbial communities
- Other Processes Involved
  - Adsorption & absorption
  - Hydroxides precipitation
  - Suspended solids filtration

SOME US MINES WITH SEMI-PASSIVE ABRs

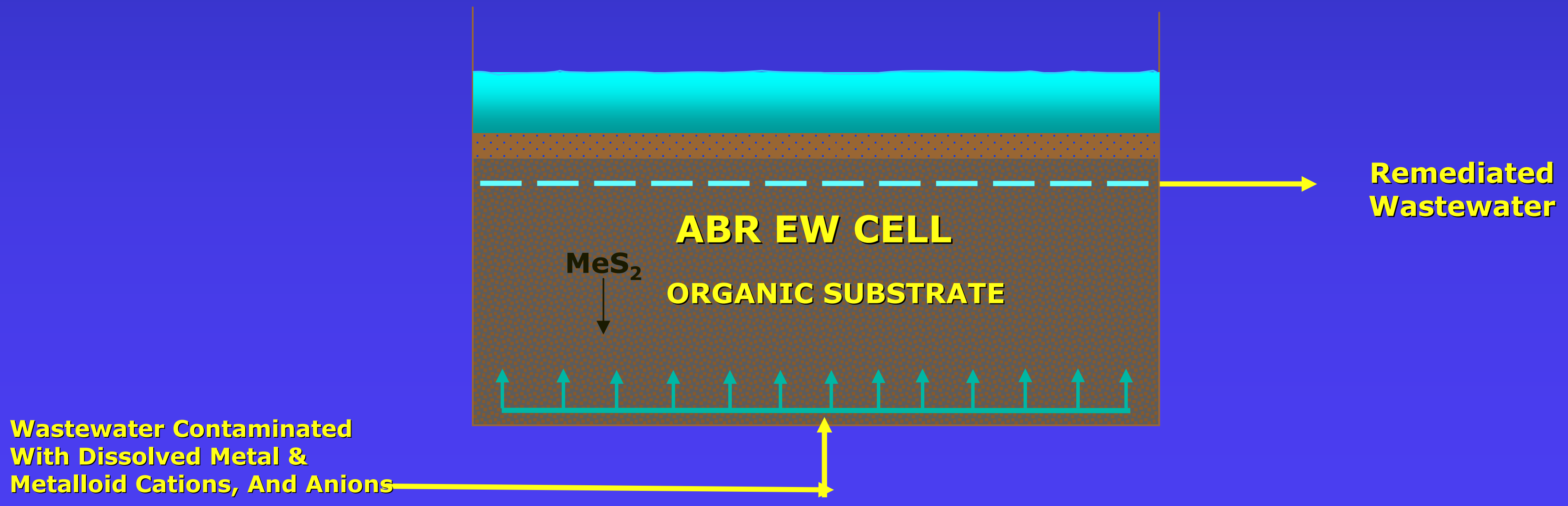
- Lilly Orphan Boy
- Surething
- West Fork
- Judy 14
- Fran Mine
- Golinsky Mine
- Fabius Coal Mine
- Wheal Jane Mine
- Haile Mine
- Golden Giant
- Elizabeth Copper Mine
- Peerless Jenny King Mine
- Lutrell Repository
- Teck Cominco Smelter
- Burleigh Tunnel
- MSF Waste Rock
- Forest Queen





ANAEROBIC BIOREACTORS CAN BE EXPRESSED AS VSSF EW CELLS

- Upflow or Downflow VSSF Design
- Organic Substrates
- Removal Of Some Cationic Dissolved Metals (e.g., Zn) By Sulphide Precipitation
- Removal Of Some Anionic Dissolved Metals (e.g., As) By Biosorption/Sulphide Precipitation



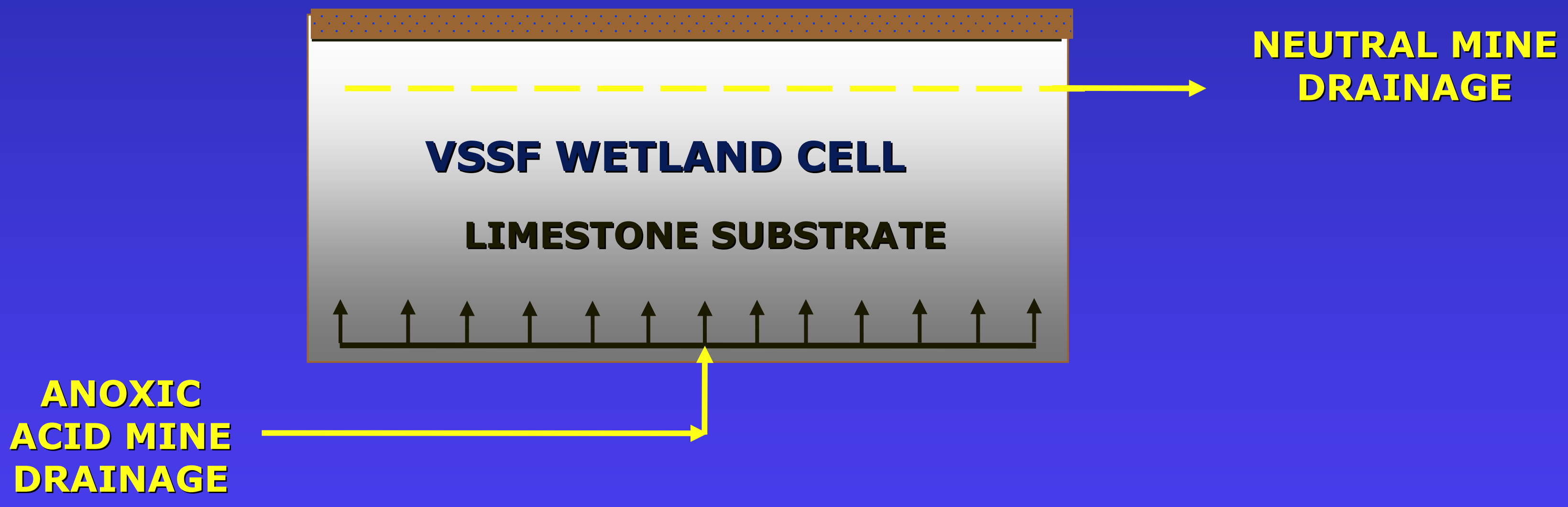
Anoxic operation

INCORPORATING pH CONTROL INTO EWs

LIMESTONE DRAINS CAN BE USED AS ENGINEERED WETLAND CELLS

- Upflow Or Downflow VSSF EW Cell Designs, Un-Planted
- Inorganic Substrates
- Anoxic, Oxic Or SAPS Types
- Open, Buried Or Layer Of Standing Water Above Surface
- Removal Of Some Metals (e.g., Fe) By Physical & Chemical Processes

ANOXIC DRAIN AS AN ENGINEERED WETLAND CELL

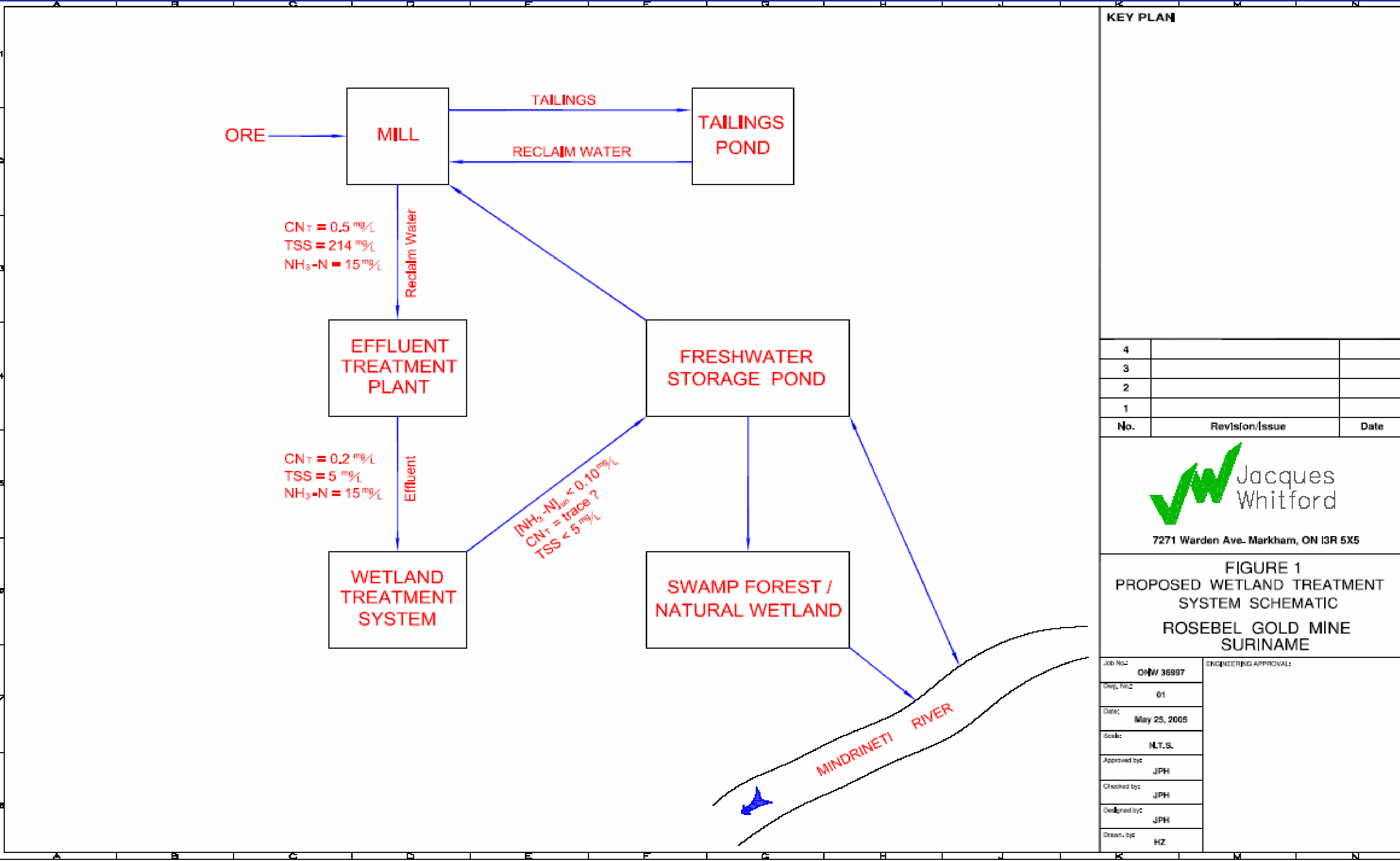


CASE STUDIES

ROSEBEL GOLD MINE
AERATED VSSF EW SYSTEM

ROSEBEL GOLD MINE IN SURINAME, SOUTH AMERICA

EXCESS RECLAIM WATER MUST BE TREATED BEFORE DISPOSAL
ROSEBEL SURINAME



OBJECTIVES OF THE RGM TREATABILITY TEST AT ALFRED COLLEGE

- Demonstrate Reclaim Water Can Be Treated In An EW System
- Demonstrate That VSSF EW Morphology Gave Results As Good As HSSF EWs
- Determine EW Kinetics & Scale Up Parameters
  - Simulated & Actual Reclaim Water
  - NH_3 & CN were main CoCs
- Define Operating Philosophy & Design For Later On-Site Pilot Unit

RGM RECLAIM WATER CHEMISTRY

	Range Actual RW	Synthetic RW	Tote Actual RW
pH	7 - 9	7.5	8
NH_3-N	5 -15	17	5.7
TSS	4 - 100	25	13
CN	0.05 – 0.5	0.3	0.15

*

TREATABILITY TEST RESULTS – AMMONIA NITROGEN REMOVAL

Run	Feed	Air	NH_3-N Removal Influent mg/L	Effluent mg/L	Removal %
A	S	On	17.31	0.31	98.2
B	S	Off	12.96	3.90	69.9
C	A	On	5.71	0.05	99.1
D	S	On	14.65	0.08	99.4

S= Synthetic RW A = Actual RW, T = 25 °C, aerated VSSF EW cell

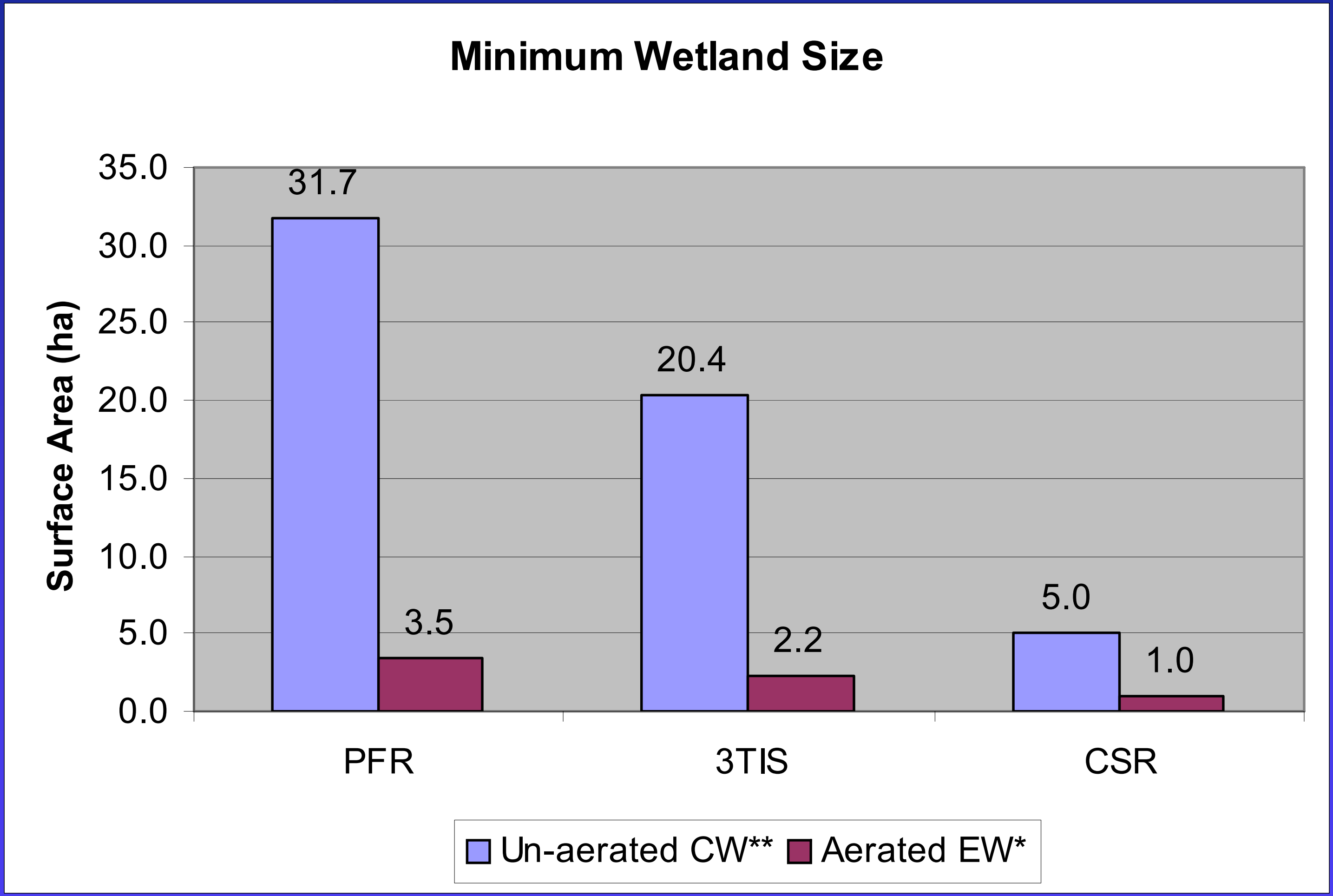
TREATABILITY TEST RESULTS
AMMONIA NITROGEN REMOVAL RATE CONSTANTS (day^{-1})

Run	Feed	Air	PFR	CSR	3TIS
A	S	On	1.5	20.9	3.2
B	S	Off	0.5	0.9	0.5
C	A	On	1.5	35.2	3.6
D	S	On	1.6	56.6	4.4
Average: A, C, D			1.5	37.6	3.7

S= Synthetic RW A = Actual RW, T = 25 °C, aerated VSSF EW cell

CW/EW IMPACT ON WETLAND SIZE

(NH_3-N: 15 → 1.5 mg/L, 16,000 m^3/d, 25 ºC)



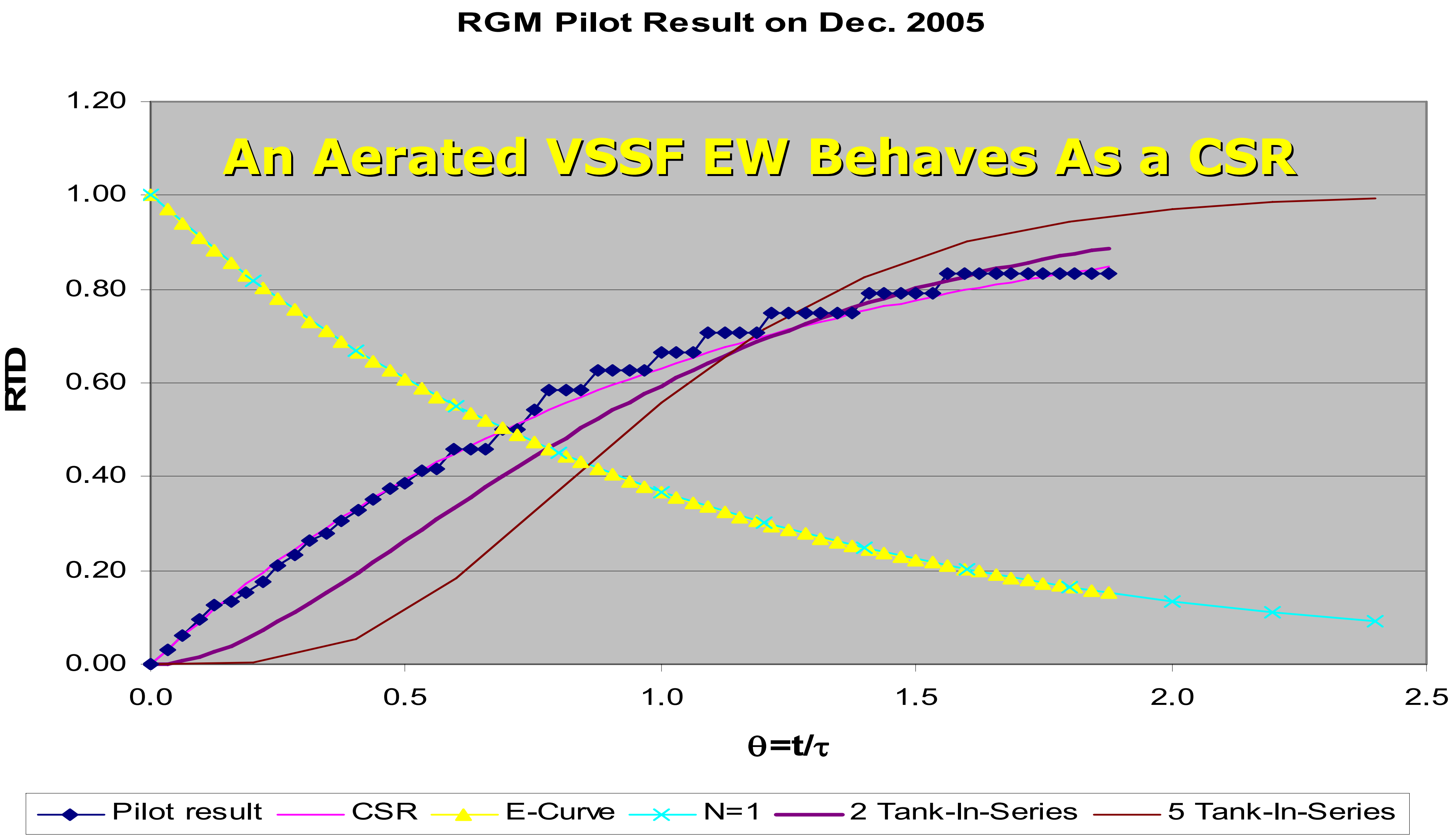
* Substrate 1.5 m thick, θ = 1.02

** Substrate 0.7 m thick, θ = 1.04 (Kadlec & Knight, 1996)

OBJECTIVES OF THE ON-SITE TREATABILITY TEST AT ROSEBEL

- Compare Off-Site Indoor Testing with On-Site Outdoor Testing With Actual Feedstock
- Simulate the High Performance Aerated Lagoon Which Will Precede EEW Cells
- Evaluate Growth & Root Penetration With Local WL Plant: *Typha domingensis*
- Carry Out A Tracer Test For An EW Cell
- Test The Potential Of A Nearby Swamp Forest Natural Wetland To Polish EW System Effluent

ROSEBEL SURINAME
ON-SITE PILOT TESTING TRACER TEST



ROSEBEL SURINAME
ON-SITE PILOT TESTING
CYANIDE REMOVALS DURING ON-SITE TREATABILITY TEST

	Aerated Lagoon Cell	Aerated VSSF EW Cell	AL And Both EW Cells	Overall System
May 18 - Jul. 12	54%	50%	85%	88%
Aug. 2 – Nov. 15	53%	33%	80%	84%
Nov. 29 - Dec. 13	61%	6%	75%	83%
Dec. 27 - Jan. 17		40%	48% (EW Cells only)	71%

ROSEBEL SURINAME FULL-SCALE AERATED LAGOON

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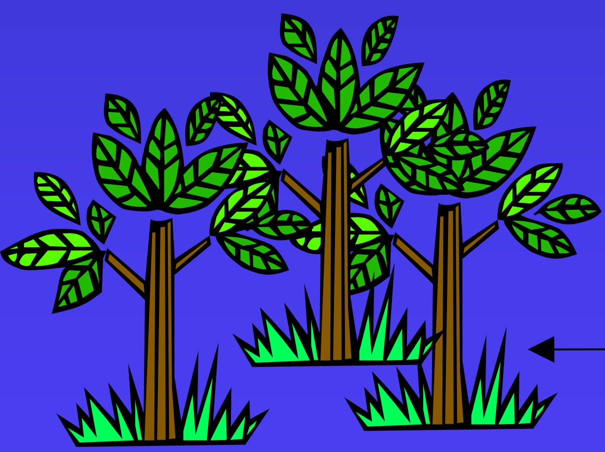
ANAERObIC BIOREACTORS AS PART OF AN EW SYSTEM

NATURE WORKS TRAIL EW DEMO

- Teck Cominco Lead Zinc Smelter in Trail, BC
- Old Landfill Leaching Zinc & Cadmium
- Old Arsenic Dump Pit Leaching Arsenic
- Leachates Treated in Smelter WWTP
  - Slip streams available for treatment
- Demonstration Scale Engineered Wetland System Commenced in 1997
  - Initially only periodic operations
  - System has evolved steadily
  - Now 5 years of results; summer & winter

NATURE WORKS DEMO EW SYSTEM TRAIL, BC

Anaerobic Bioreactor 1 → Anaerobic Bioreactor 2 → HSSF 1 → HSSF 2 → HSSF 3 → POND WETLAND →

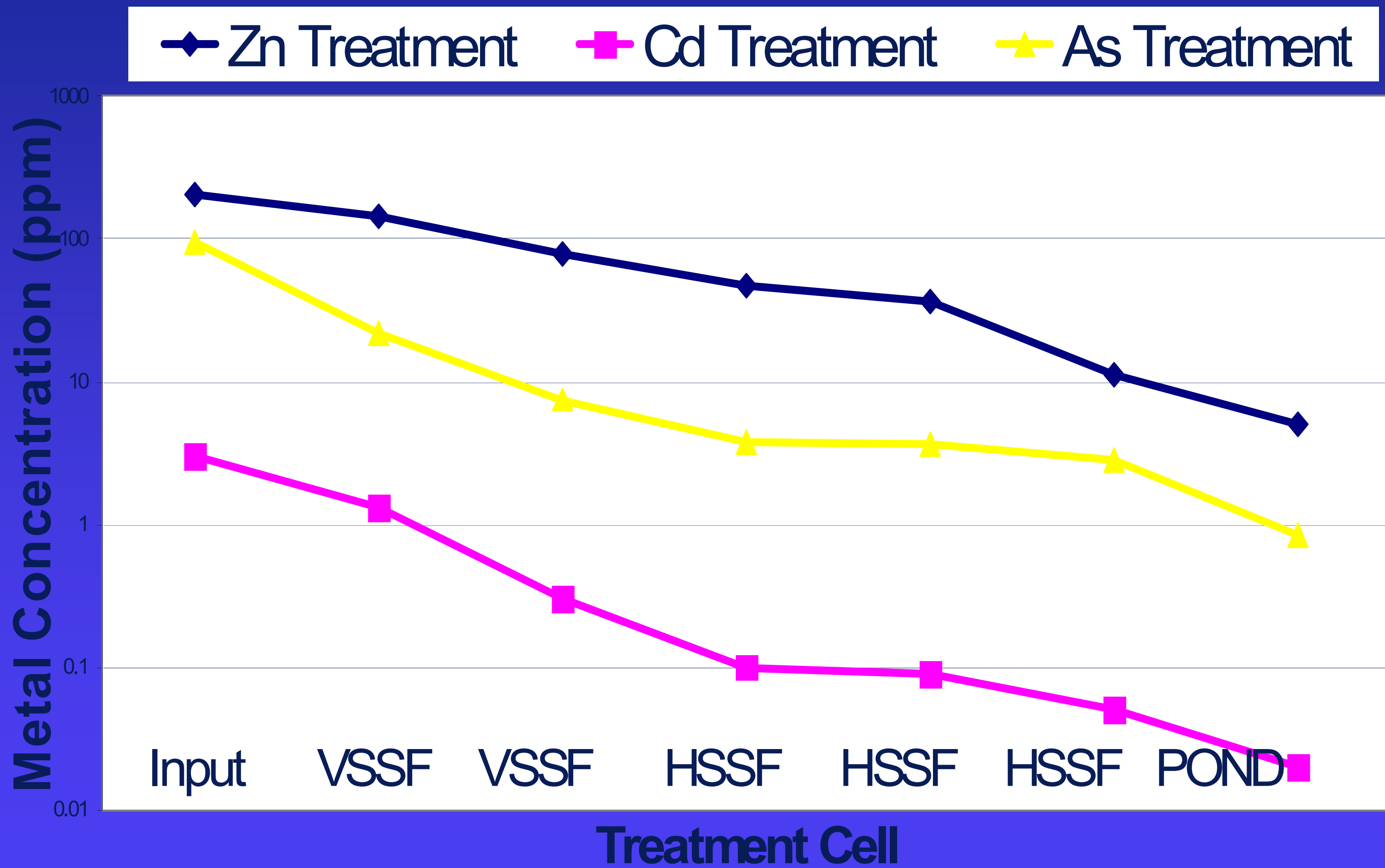


NATURE WORKS TRAIL EW DEMO
CONSTRUCTION DETAILS

- Initial phase constructed in 1997 as three gravel bed HSSF EW cells
- Bench scale testing showed need for pre-treatment to reduce metals
- 1st ABR added in 1998
- 2nd ABR added in 2000
- System winterized in 2000
- Operated from 289 – 353 d/yr from 2001 -2005 at ~ $7 m^3/d$

AVERAGE DISSOLVED METAL REMOVAL OVER FIVE-YEARS

EW DEMO UNIT, TRAIL, BC



METALS REMOVAL IN DEMONSTRATION ENGINEERED WETLAND SYSTEM 2001 - 2005

	Influent Concentration (mg/L)	Effluent Concentration (mg/L)	Removal (%)
Arsenic	95	0.8	99.2
Cadmium	3.0	0.02	99.3
Zinc	205	3.6	97.5

Nature Works Demonstration System at Teck-Cominco, Trail, BC

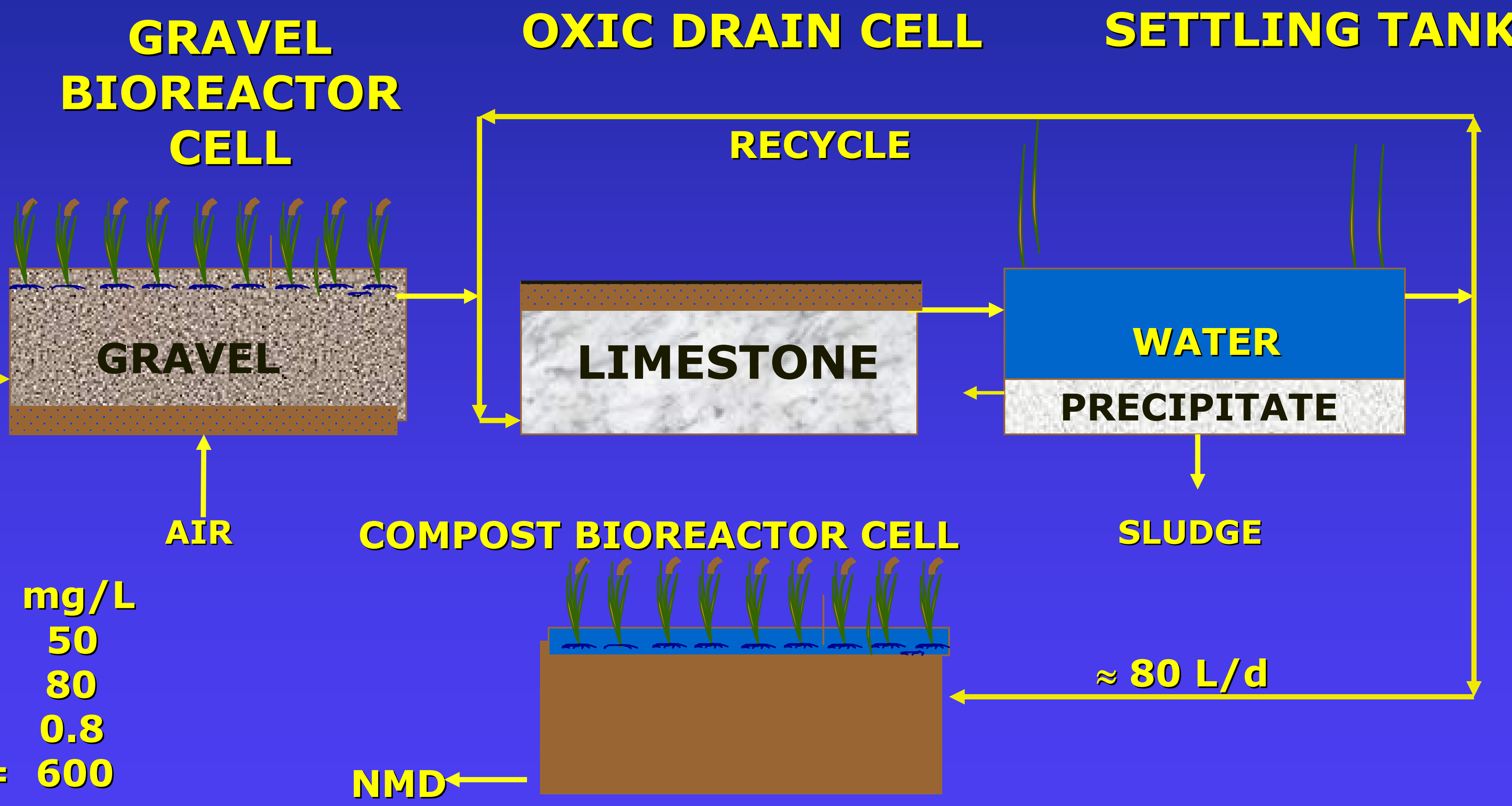
pH CONTROL & ABRs AS EW SYSTEMS

SOLID ENERGY HAS LARGE OPEN CAST COAL MINE AT STOCKTON,NZ

- **40 Large Waste Rock Piles**
  - Stripped mudstone overburden
  - Acid-generating
- **High Rainfall Area**
  - Several m/y
- **High Al ARD**
  - pH 3, Acidity 200 – 800 mg $CaCO_3$/L
  - 15 <Fe > 50 mg/L
  - 50 < Al > 100 mg/L, Al:Fe $\approx$ 2:1
  - 200 – 800 mg/L sulphates
  - High suspended solids, other dissolved metals
- **Treatability Test**

EW TREATABILITY TEST AT CANMET

DESIGN OF ENGINEERED WETLAND PILOT UNIT FOR STOCKTON



ARD
pH 3

	mg/L
Fe^{2+}	50
Al^{3+}	80
Ni^{2+}	0.8
$SO_4^{=}$	600

TOTAL EW PILOT UNIT METALS REMOVALS

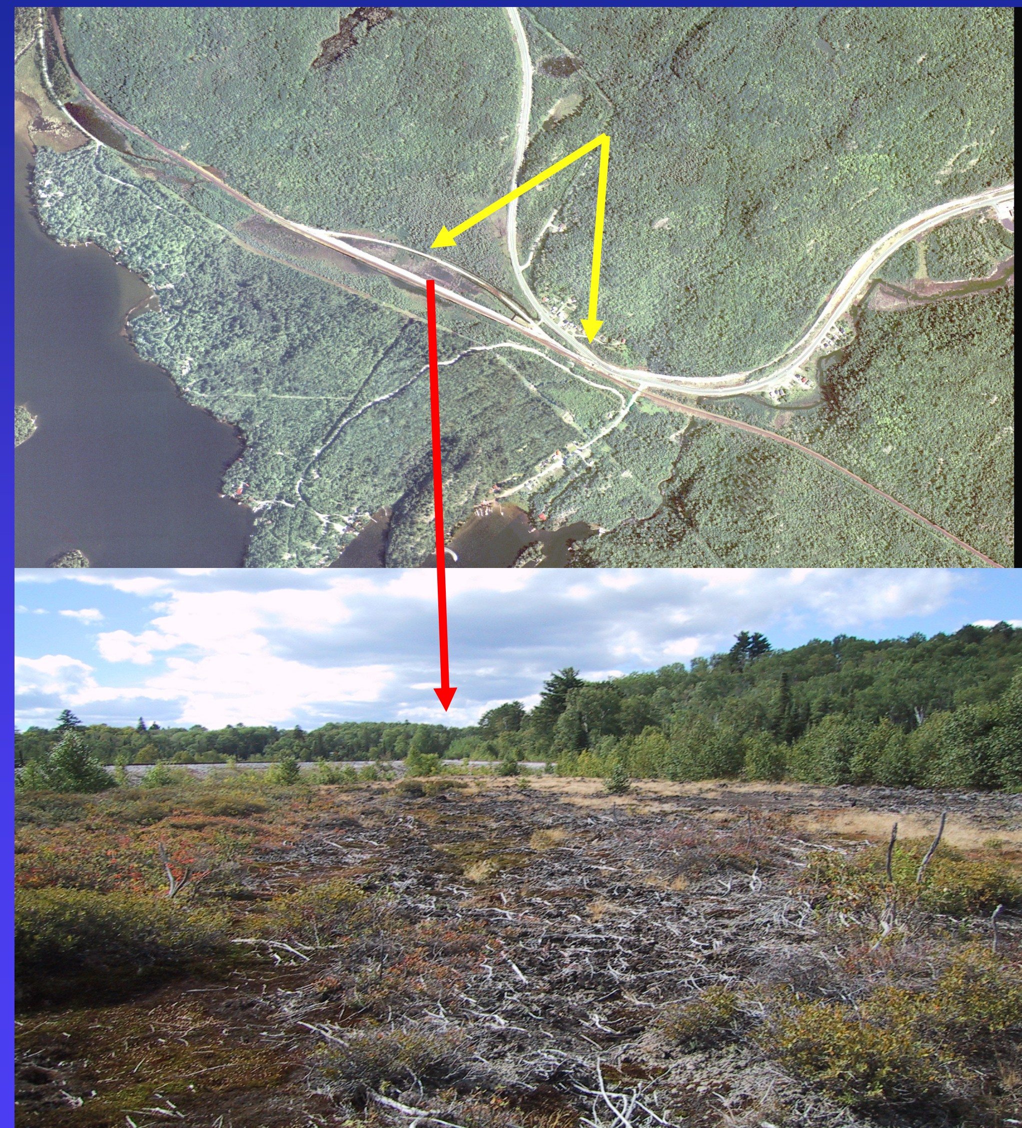
Metal	Percent Removed
Fe^{T}	99.7
Al^{3+}	99.9
Ni^{2+}	96.7

CONCLUSIONS

- Fe- & Al-Containing ARD Of Can Be Treated in An EW To High Removal Levels
- An EW Configuration Of An Aerobic Bioreactor, A Limestone Drain & An ABR Is Feasible
- Ferrous Iron Can Be Oxidized Almost Completely In An Aerobic Bioreactor
- OLDs Can Be Operated Under Near Turbulent Flow Conditions
  - Mitigates clogging & armouring
- The Downstream ABR Was Effective In Removing Remaining Dissolved & Suspended Metals

ARD-CONTAMINATED RAIL MARSHALLING YARD

- Marshalling Yard & Rail Spur
  - Historic NiS slurry transport in open cars
  - Contamination of GW & surface water with ARD
- Multi-Phase Project
  - Sampling, Hydraulic Studies
  - Potential For uncontaminated water diversion
  - Treatment of ARD with ABR-based EW
  - Pilot studies at CANMET



CANMET TREATABILITY TEST
TRAIN 1 OLD + Settling Pond

	Concentration (mg/l)		% Removal
	Inlet	Outlet	
Aluminum	2.1	1.5	25
Cobalt	0.6	0.5	11
Copper	2.6	2.2	15
Iron	135.0	83.5	52
Nickel	12.7	11.9	6
Zinc	0.8	0.7	17

Influent pH = 7.5

CANMET TREATABILITY TEST
TRAIN 1 ABR # 1

	Concentration (mg/l) Inlet	Outlet	% Removal
Aluminum	1.5	0.4	71.4
Cobalt	0.5	<0.01	98.5
Copper	2.0	<0.01	99.7
Iron	83.5	6.8	91.9
Nickel	12.0	0.02	99.8
Zinc	0.7	0.09	87.0

Influent pH = 7.5

CANMET TREATABILITY TEST
TRAIN 2 ABR # 1

	Concentration (mg/l) Inlet	Outlet	% Removal
Aluminum	2.1	0.2	91.7
Cobalt	0.6	<0.01	99.0
Copper	2.6	<0.01	99.9
Iron	135.0	2.5	98.1
Nickel	12.7	<0.01	99.9
Zinc	0.8	0.04	95.3

Influent pH = 3.0

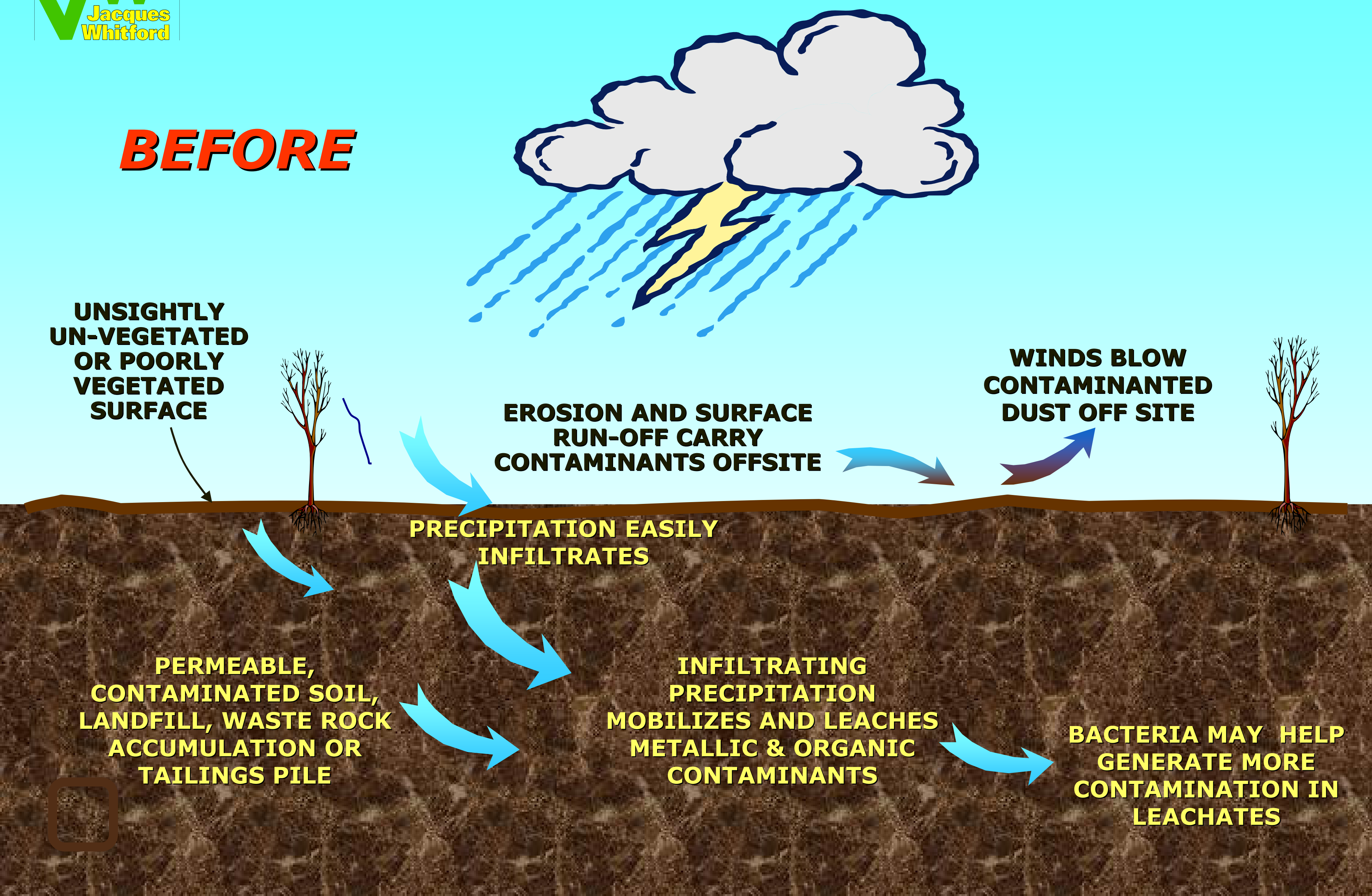
TREATABILITY TEST - CONCLUSIONS

- ABRs Provided Good Treatment of Both ARD and Pre-Treated NMD
  - Handled low pH influent in Train #2
  - Pre-treatment not needed in this case
  - Rate constants determined
- Dosed OLD Performance Mixed
  - Protected from $Al(OH)_3$ clogging
  - Did not prevent ochre armoring
- Pulp & Paper Biosolids Were Good ABR Substrates
  - Have to watch out for TSS & Metals leaching

QUESTIONS?

INTEGRATED TREATMENT SYSTEMS

PHYTOSTABILIZATION COVERS



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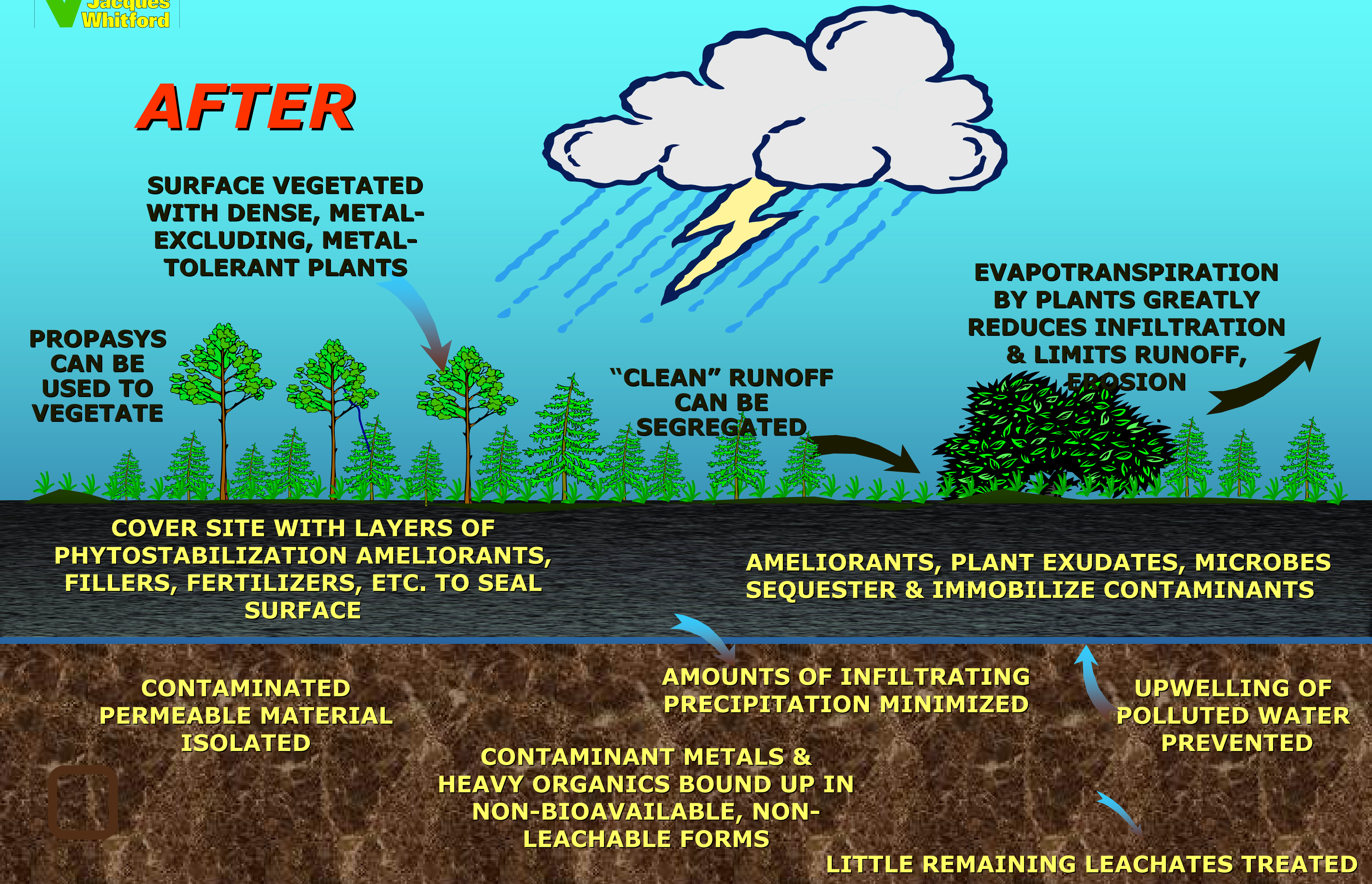

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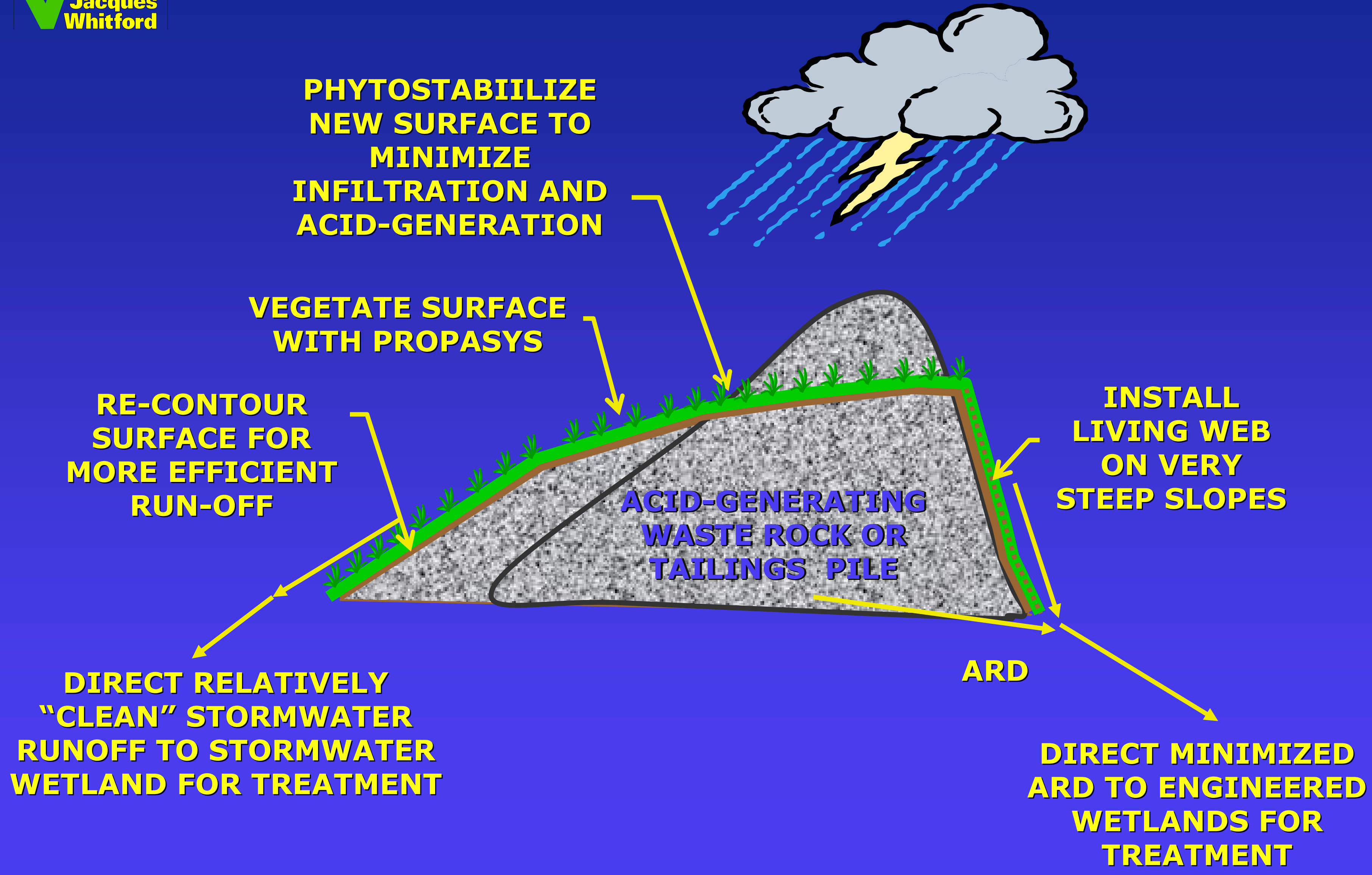
ADVANCED BIOENGINEERING SYSTEM FOR MINING WASTES



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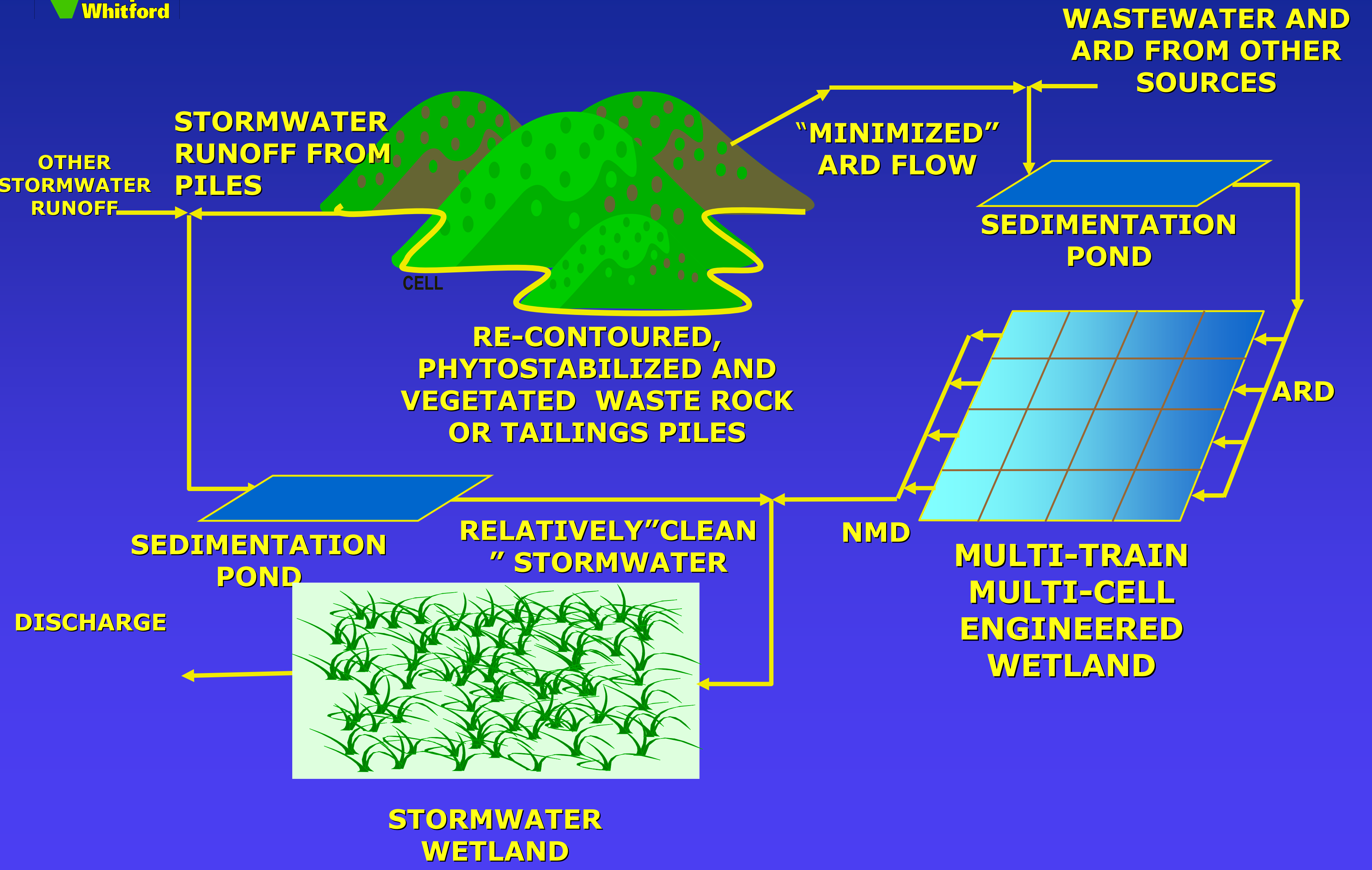

ADVANCED WETLANDS-BASED SOLUTIONS FOR THE MINING SECTOR

- **Treatment of Dissolved Metal Cations & Anions**
  - **Nickel, zinc, copper**
  - **Arsenic, molybdenum**
  - **ABR-Based Engineered Wetland Systems**
- **Removal of Biologically Oxidizable Pollutants From Mine Drainage**
  - **Ammonia, CN**
  - **Aerated VSSF EWs**
- **ARD Treatment**
  - **Aerobic Bioreactor/OLD/Pond/ABR EWs**
  - **ABR-Based Engineered Wetland Systems**
- **Integrated Treatment Systems**
  - **Phytostabilization + SW WLs + EWs**

SOME PROJECTS HAVE MASCOTS