THE USE OF ADVANCED ECOTECHNOLOGY FOR REMEDIATING METAL- AND METALLOID-CONTAMINATED WATERS

James Higgins, Ph.D., P.Eng.
Al Mattes, B.Sc., Ph.D.
THE USE OF ADVANCED ECOTECHNOLOGY FOR REMEDIATING METAL AND METALLOID-CONTAMINATED WATERS

THIS PRESENTATION

• Semi-Passive Bioreactor Treatment Systems
  – Active, Passive & Semi-Passive Treatment
• Aerated Engineered Wetlands
  – BREW & SAGR Bioreactors
• Anaerobic Bioreactors
  – BNBRs, SAPS Bioreactors, BCRs, Specialty EWs (e.g., EBRs)
• Engineered Wetland Systems
• The EW Test project
SEMI-PASSIVE TREATMENT SYSTEMS
WASTEWATER TREATMENT SYSTEMS

• **Active Treatment Systems**
  – pH modification systems (e.g., HDS systems)
  – Biological treatment systems (e.g., activated sludge)

• **Passive Treatment Systems**
  – Constructed Wetlands (FWS & SSF)
  – Most kinds of phytoremediation
  – Most Permeable Reactive Barriers (PRBs)

• **Semi-Passive Treatment Systems**
  – Some chemical treatment systems (e.g., ALDs)
  – Biological treatment systems
  – Rhizofiltration & some phytoextraction
  – Engineered Wetlands (EWs)/Engineered Bioreactors (EBs)
SUB-SURFACE FLOW (SSF) CONSTRUCTED WETLANDS PROVIDE PASSIVE TREATMENT

ITRC 2003
ENGINEERED WETLANDS

• Evolved from SSF CWs
  – Now very different from them
• Semi-Passive, In-Ground Cells
• Design, Operating Methods, Flows, Other Process Conditions, Substrates and/or Morphologies Are Manipulated & Controlled
• Aerobic and Anaerobic Versions
KINDS OF AEROBIC ENGINEERED WETLANDS

- Aerobic Wetlands
- Fill & Drain EWs
  - Also called Pulse Flow wetlands
  - Engineered Stormwater Wetland Systems (ESWs)
- Aerated Engineered Wetlands
  - Bioreactor Engineered Wetlands (BREW Bioreactors)
  - Submerged Aerated Growth Reactors (SAGR Bioreactors)
  - Proven Ecotechnologies

An Aerated EW
**BREW BIOREACTORS**

_A KIND OF AERATED ENGINEERED WETLAND_

Aeration Grid before Gravel Installation

Air is supplied by a small blower beside the wetland

Distributor Half Pipes over Influent Piping just before Adding Final Gravel & Plants
**BREW BIOREACTORS CAN BE USED TO TREAT AIRCRAFT DE-ICING RUNOFF**

Three BREW Bioreactor Cells under Construction at BNIA

An Operating BREW Bioreactor at BNIA
### SOME BREW BIOREACTORS IN OPERATION

<table>
<thead>
<tr>
<th>Location 1</th>
<th>Location 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buffalo Niagara International Airport, NY</td>
<td>McArthur Airport, Islip NY</td>
</tr>
<tr>
<td>Edmonton International Airport, Leduc, AB</td>
<td>London Heathrow Airport, UK</td>
</tr>
<tr>
<td>Former Amoco Refinery, Caspar, WY</td>
<td>Laval Pole Yard, Laval, QC</td>
</tr>
<tr>
<td>Williams Pipeline Terminal, Watertown, SD</td>
<td>Jackson Meadows Marine, St. Croix, MN</td>
</tr>
<tr>
<td>ARCO Refinery, Wellsville, NY</td>
<td>Lake Allie, Renville Co, MN</td>
</tr>
<tr>
<td>The Dunes, Abu Dubai, UAE</td>
<td>Fleming College, Lindsay, ON</td>
</tr>
<tr>
<td>Yargon River Authority,Tel Aviv, Israel</td>
<td>Lutsen Sea Villas, Lutsen, MN</td>
</tr>
<tr>
<td>Fields of St. Croix, Lake Elmo, MN</td>
<td>Anoka County Landfill, Ramsey, MN</td>
</tr>
</tbody>
</table>
SUBMERGED AERATED GROWTH REACTORS
(SAGR Bioreactors)

- Kind of Aerated EW Similar to a BREW Bioreactor
  - SAGR Bioreactors are dedicated nitrification bioreactors
- Parts of Aerated Lagoon/SAGR Bioreactor Systems
  - Used to upgrade municipal facultative lagoon systems in cold regions for medium-sized communities
OPERATING SAGR TEST CELLS DURING MANITOBA WINTER
STEINBACH TEST UNIT
### SOME SAGR BIOREACTORS IN OPERATION

<table>
<thead>
<tr>
<th>Steinbach, MB*</th>
<th>Walker, IA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lloydminster, AB*</td>
<td>Sylvan Lake, SD</td>
</tr>
<tr>
<td>Perth, ON*</td>
<td>Shellbrook, SK</td>
</tr>
<tr>
<td>Blumenort, MB*</td>
<td>Kingsley, IA</td>
</tr>
<tr>
<td>Doaktown, NB</td>
<td>Balcarres, SK</td>
</tr>
<tr>
<td>Dawson Creek, BC</td>
<td>Colesburg, IA</td>
</tr>
<tr>
<td>Mentone, IN</td>
<td>Kennard, IN</td>
</tr>
<tr>
<td>Glencoe, ON</td>
<td>Grand Rapids FN</td>
</tr>
<tr>
<td>Mountain View, WY</td>
<td>New London, IA</td>
</tr>
<tr>
<td>Lamar, MO</td>
<td>Guthrie School, ON</td>
</tr>
<tr>
<td>Mentone, IN</td>
<td>Long Plain FN, MB</td>
</tr>
</tbody>
</table>

* Demonstration system
STEINBACH SAGR BIOREACTOR TEST RESULTS

• Three-Year, 2-Cell Demonstration Scale Testing at Lagoon-Based Municipal WWTP (2007 – 2010)
• Average Effluent NH$_3$-N $\sim$ 0.01 mg/L
• cBOD & TSS consistently $<$ 2mg/L
  – Full-scale $<$ 10/10 mg/L
• Fecal Coliforms $<$ 200 CFU/100 mL
  – Disinfection not needed
• No Bed Fouling at End of Test
AERATED BIOREACTOR DESIGN

• BREW & SAGR Bioreactors Are Designed Based on a Proven Reaction Kinetics-Based Models
  – Models determined by tracer tests
  – First order kinetics apply

• Reaction Rates Determined by Treatability Tests
  – Use actual or synthetic wastewaters spiked to worse case conditions
  – Proven for full-scale design
  – The technologies are proprietary & patented
ANAEROBIC BIOREACTORS (ABRs)
KINDS OF ANAEROBIC EWs

- Anaerobic Wetlands
- Anaerobic Bioreactors (ABRs)
  - Denitrification Bioreactors (DNBRs)
  - Successive Alkalinity-Producing Systems (SAPS Bioreactors)
  - Biochemical Reactors (BCRs)
  - Specialty Engineered Wetlands
  - Only BCRs well defined

A Demo Scale BCR Under Construction at Trail, BC
MAIN ANAEROBIC BIOREACTOR REMOVAL MECHANISMS

- Oxygen Removal
  - Aerobic Respiration
- Active Media Degradation
  - CDB, APB, methanogens ++
  - Produce feeds for ‘characterizing’ ‘bacteria’ (e.g., IRB, SRB)
- Removals by Reduction
  - NO$_3^-$ => N$_2$ (DNBR)
  - Fe$^{3+}$ => Fe$^{2+}$ (SAPS Bioreactor)
  - SO$_4^{2-}$ => S$^-$ (BCR)
  - SeO$_4^{4+}$ => Se$^0$ (Specialty EW)
LIMITATIONS OF ABRs ALONE

• Elution of Active Media Breakdown Products Must Be Managed
  – BOD, TSS, Org-N, Org-P

• Inability to Treat Oxidizable Contaminants in Wastewater
  – NH$_3$, BOD

• Incomplete Contaminant Removals
  – Some need both anaerobic & aerobic conditions for high removals

• Optimal Performance as “Cells” of EW Systems
ENGINEERED WETLAND SYSTEMS

• ‘Trains’ of Basins (Cells) in Series
  – One or more trains in an EW System
• Engineered Wetland Cells for 2° Treatment
• ‘Upstream’ Pre-Treatment
  – Rock filters, screens
• ‘Upstream’ 1°Treatment
  – Ponds, lagoons, cascades, limestone drains
• ‘Downstream’ 3°Treatment
  – Ponds, CWs, phosphorus removal cells, limestone drains, carbon filters
• Final Disinfection (sometimes)
  – Chlorine, UV
DENITRIFICATION BIOREACTORS (DNBRs)
DENITRIFICATION BIOREACTORS

- Semi-Passive DNBRs Are Used for Nitrate Removal
  - Also called *Woodchip Bioreactors, Denitrifying Bioreactors & Denitrification Biofilters*
  - More commonly used for agricultural runoff treatment but also find use with other wastewaters
  - Woodchips are most common active medium

- Denitrifying Bacteria (DNB)
  - \( \text{NO}_3^- \rightarrow \text{NO}_2^- \rightarrow \text{N}_2\text{O} \rightarrow \text{N}_2 \uparrow \)
  - These microbes use active medium (organic part of substrate) for metabolism
  - Facultative denitrifying bacteria can also use oxygen

Gruyer et al., 2012
DENITRIFICATION BIOREACTORS

• Denitrification is a more energetically favoured form of microbial respiration
  – Sulphate reduction yields less energy & thus tends to occur only when NO$_3^-$ is not available
  – Accordingly SO$_4^{2-}$ removal needs to occur sequentially after the removal of NO$_3^-$
  – If a wastewater contains both nitrate and sulphate and it desired to remove both, a DNBR may need to precede a sulphate-reducing BCR in an EW system

• Requires low DO conditions to work
• Full-scale EW versions not yet built
  – But should work

(Metcalf & Eddy, 2003)
SAPS BIOREACTORS
SAPS BIOREACTORS

- SAPS Bioreactors Are Downflow VSSF ABRs Used to Manage ARD without Ochre Precipitation
  - Evolved from combining compost wetlands and Limestone Drains
- Purpose Is to Generate Alkalinity while Avoiding Ferric Iron Hydrolysis
- Surface Water Layer and Organic-Containing Substrate Protect Limestone Below from Armouring
- Poor Performances So Far for Stand-Alone Versions

A SAPS Bioreactor Under Construction (Gusek, ICARD 2006)
BASIC DESIRED SAPS BIOREACTOR CHEMISTRY

• Ferric Iron in Influent Reduced
  \[ \text{Fe}^{3+} + e^- \rightarrow \text{Fe}^{2+} \]

• All Influent & Converted Ferrous Iron Hydrolyzed
  \[ \text{Fe}^{2+} + 2 \text{H}_2\text{O} \rightarrow \text{Fe(OH)}_2 + 2 \text{H}^+ \]

• Neutralization
  – pH raised to 5 - 7
BECAUSE IF ONE CAN KEEP THE IRON AS FERROUS, THE pH CAN BE RAISED WITHOUT SLUDGE PRECIPITATION

\[
Fe(OH)_3 = MnO_2 > Al(OH)_3 >> Fe(OH)_2 > Mn(OH)_2
\]

Insoluble \longleftrightarrow Soluble

• There Are Also Challenges if Influent Contains Any Appreciable Amounts of Aluminum (>1 mg/L)

\[
3 \text{CaCO}_3 + 2 \text{Al}^{3+} + 6 \text{H}_2\text{O} \rightarrow 3 \text{Ca}^{2+} 2 \text{Al(OH)}_3\downarrow + 3 \text{H}_2\text{CO}_3
\]

• Aluminum Hydroxide Sludge May Plug Interstices between particles
WHAT ONE WISHES TO AVOID IN A SAPS BIOREACTOR

- Ferrous Iron Oxidation
  \[4 \text{Fe}^{2+} + \text{O}_2 + 4 \text{H}^+ \rightarrow 4 \text{Fe}^{3+} + 2 \text{H}_2\text{O}\]

- Ferric Iron Hydrolysis
  \[\text{Fe}^{3+} + 3 \text{H}_2\text{O} \rightarrow \text{Fe(OH)}_3\downarrow + 3 \text{H}^+\]
IRON-REDUCING BACTERIA

A) *Shewanella Oneidensis* MR-1 Produce Confluent Biofilms and Filamentous Nanowires When Exposed to Electron-Acceptor Limited Conditions.

B) Very Few Nanowires Are Visible by Scanning Electron Microscopy When *Shewanella* MR-1 Biofilms Are Exposed to an Excess of Electron Acceptors (20% Dissolved O$_2$)

Photo from supporting figures of Gorby et al., 2006: [http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1544091/](http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1544091/)
SOME MINES WITH STAND-ALONE SAPS BIOREACTOR-BASED TREATMENT SYSTEMS

- Augusta Lake (IN, US)
- Bowden Close (UK)
- Brandy Camp (PA, US)
- Buckeye (OH, US)
- Filson (PA, US)
- Hanchan (Korea)
- Hohe Warte (Germany)
- Howe Bridge (PA, US)
- Oven Run (PA, US)
- Jennings (PA, US)
- Palena (Wales, UK)
- REM (PA, US)
- Schepp Rd (PA, US)
- Simmons Run (UK)
- Wheal Jane (UK)
- Whitworth (Wales, UK)
- #40 Gowen (OK, US)

- None are in Canada
- All but Hohe Warte Are at Coal Mines
- None face really extreme weather conditions
- Designs use empirical correlations developed for coal mine ARDs
BIOCHEMICAL REACTORS (BCRs)
BIOCHEMICAL REACTORS (BCRs)

- Remove Dissolved Metals & Metalloids
  - Sulphate reduction by SRB
- Add Alkalinity & Raise pH
- Reduce Sulphates to Produce Sulphides
- Active Media May Be:
  - A liquid added with feedwater (e.g., EtOH, glycols)
  - A solid part of the substrate (e.g., biosolids)
- More Developed Ecotechnology
BCR CHEMISTRY

• Sulphate Reacts with Active Media Degradation Products
  – Produces hydrogen sulfide and bicarbonate
    $$\text{SO}_4^{2-} + 2 \text{CH}_2\text{O} \Rightarrow \text{H}_2\text{S} + 2 \text{HCO}_3^-$$
  – Hydrogen sulfide reacts with metals
    $$\text{H}_2\text{S} + \text{Me}^{2+} \Rightarrow \text{MeS}_(s) + 2\text{H}^+$$
  – Produce metal sulfide and hydrogen

• Limestone Is Sometimes Necessary
  – Increase the alkalinity
    $$2 \text{H}^+ + 2 \text{HCO}_3^- \Rightarrow 2 \text{H}_2\text{CO}_3$$
  – Consume hydrogen
  – Thus raise the pH
    $$2 \text{H}^+ + \text{CaCO}_3(s) \Rightarrow \text{Ca}^{+2} + 2 \text{HCO}_3^-$$

• If There Is Not Enough Me$^{2+}$
  – H$_2$S will be lost as a gas
SULPHATE-REDUCING BACTERIA (SRB)

• Heterogeneous Group of Anaerobes
  – Species that vary morphologically, biochemically, nutritionally, & phytogenetically (Widdel, 1998)
  – Various shapes (rods, cocci, spirals)
  – Gram Positive & Gram Negative (spore formers & non spore formers)

• Grow Best at 6 < pH > 9
  – But some can grow in more acid environments
  – Limited pH-Eh ranges for optimum performance

Gould & Kapoor, 2003
MAIN BCR REMOVAL MECHANISMS FOR DISSOLVED METALS & METALLOIDS

• Sulphide Precipitation of Divalent Cations
  – E.g., Cd$^{2+}$, Cu$^{2+}$, Fe$^{2+}$, Ni$^{2+}$, Pb$^{2+}$, Zn$^{2+}$

• Sulphide Precipitation of Oxyanions
  – E.g., As$^{3+}$

• Hydroxide Precipitation
  – E.g., Al$^{3+}$, Fe$^{3+}$

• Carbonate Precipitation
  – E.g., Fe$^{2+}$, Mn$^{2+}$, Zn$^{2+}$
REQUIREMENTS FOR BACTERIAL SULPHATE REDUCTION

• Absence of Dissolved Oxygen
  - i.e., anaerobic conditions
• Source of Sulphate
• Source of Organic Carbon
• Presence of Sulphate-Reducing Bacteria
  - pH > 5, preferably ~ 7
• Method to Physically Retain Precipitates
SITUATIONS WHERE BCRs MAY BE USEFUL

- High Concentrations of Saleable Metals in MIW
- Low Cost Carbon Sources Available Conveniently
- Concerns about Lime Sludge Toxicity and Volume
- Strict Discharge Levels for Dissolved Metals and Sulphates

Brown et al., 2002
BURIED BCR MORPHOLOGY

Geosynthetic Liner

Topsoil

Influent

Sampling Port

Light Weight Fill

Inoculum

Discharge

Organic Matter & Limestone Mix

Downflow

Gravel Drainage Layer

Subgrade

Drainage system

Geotextile

Geosynthetic liner

ITRC, 2013
UPFLOW & DOWNFLOW WATER-COVERED BCRS

Upflow Biochemical Reactor

Drainage System

Overflow Spillway

Feed Distribution Zone (perforated pipe and gravel)
WHAT CAN BE TREATED IN AN BCR?

Periodic Table of Treatable Elements

Elements in **Blue** can be treated in a BCR

Gusek 2009
## SOME BCRs IN OPERATION

<table>
<thead>
<tr>
<th>Big Five Tunnel, CO</th>
<th>Lutrell Repository, MT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brewer Gold Mine, CO</td>
<td>Lilly Orphan Boy, MT</td>
</tr>
<tr>
<td>Burleigh Tunnel, CO</td>
<td>Naciamento*, NV</td>
</tr>
<tr>
<td>Calliope, MT</td>
<td>Park City, UT</td>
</tr>
<tr>
<td>Champagne Creek, ID</td>
<td>Peerless Jenny King Mine, MT</td>
</tr>
<tr>
<td>Dixon Run No. 3 Mine, PA</td>
<td>Silver Box, MT</td>
</tr>
<tr>
<td>Elizabeth Copper Mine, VT</td>
<td>Smolnik Mine, Slovakia</td>
</tr>
<tr>
<td>Fabius Coal Mine, WV</td>
<td>Surething, MT</td>
</tr>
<tr>
<td>Forest Queen, CO</td>
<td>Naciamento*, NV</td>
</tr>
<tr>
<td>Fran Mine, PA</td>
<td>Teck Lead Zinc Refinery, BC</td>
</tr>
<tr>
<td>Golinsky Mine, CA</td>
<td>Tudsequeh*, BC</td>
</tr>
<tr>
<td>Haile Mine, SC</td>
<td>West Fork, MO</td>
</tr>
<tr>
<td>July 14, PA</td>
<td>Wheal Jane Mine, UK</td>
</tr>
<tr>
<td>Laval Pole Yard, QC</td>
<td>Wood Cadillac, QC</td>
</tr>
<tr>
<td>Leviathan*, NV</td>
<td>Yankee Girl, Ymir Silver, BC</td>
</tr>
</tbody>
</table>
SPECIALTY ENGINEERED WETLANDS
SPECIALTY ENGINEERED WETLANDS

• Used to Remove Targetted Metal(loid)s
  – E.g., As, Cr, Mo, Sb, Se
• Same Kinds of Substrates & Other Layers as Ordinary BCRs
• There are Active Treatment Kinds as Well
  – E.g., Anaerobic sludge blanket reactors, fixed film bioreactors
• Removals in Some Semi-Passive Specialty EWs May Be Mediated by SRB
• Removals in Other Semi-Passive Specialty EWs May Be Mediated by Specific Microbes
  – Selenium-reducing bacteria
MOLYBDENUM REMOVAL IN SPECIALTY EWs

- Molybdenum is Removed by SRB Via Sulphate Reduction
  \[ \text{MoO}_2^{4-} + 2 \text{HS}^- + 6 \text{H}^+ + 2 \text{e}^- \rightarrow \text{MoS}_2\downarrow + 4 \text{H}_2\text{O} \]
- Mo will form complexes with Ca, Mg, K and Na
- Some Average Bench-Scale Test Results on a Mo-Containing Seepage from a Tailings Pond

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Inlet</th>
<th>Outlet</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>8.0</td>
<td>9.2</td>
</tr>
<tr>
<td>ORP (mv)</td>
<td>+2</td>
<td>-260</td>
</tr>
<tr>
<td>SO\textsubscript{4} (mg/L)</td>
<td>1403</td>
<td>1010</td>
</tr>
<tr>
<td>Mo (mg/L)</td>
<td>1.1</td>
<td>0.0008</td>
</tr>
<tr>
<td>Sb (mg/L)</td>
<td>1.1</td>
<td>0.3</td>
</tr>
</tbody>
</table>
ELECTROBIOCHEMICAL REACTORS (EBRs)

- Developed at University of Utah
  - Proprietary & patented ecotechnology
- Electrons at Low Voltage Supplied to Bioreactor(s)
  - 0.5 – 3 volt battery
  - \( \frac{1}{2} \) retention time, lower OPEX than ordinary BCRs
- Low Added Voltage:
  - Lowers & Controls ORP
  - Augments microbial transformations
  - Allows smaller, more robust systems
ENGINEERED WETLAND SYSTEMS
EW SYSTEMS ARE VERY DIFFERENT

• Superior Performance
  – Summer & winter
• Very Much Smaller “Footprints”
• Treat Wastewaters at Much Higher Flow and Loading Rates
• Semi-Passive Treatment
  – Process control during operation
• Economic to Build
  – Relatively low CAPEX & OPEX
• Relatively Low Energy Requirements
WHAT CAN BE TREATED IN AN EW SYSTEM?

- **Dissolved Metal(l oid) Cations & Anions**
  - As, Cd, Co, Cr, Cu, Pb, Mo, Ni, Sb, Se, Zn
  - Other biologically reducible contaminants, e.g., nitrates, sulphates

- **Biologically Oxidizable Contaminants**
  - Ammonia, Organics, PAHs, phenols, oil & grease

- **Chemically Precipitable/Sorbable Contaminants**
  - P, CN

- **Lower Effluent Contaminant Levels Down to Background Levels or Lower**
## Average CW/EW Performance (% Removals)

<table>
<thead>
<tr>
<th></th>
<th>CW System</th>
<th>EW System</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOD</td>
<td>50 – 90%</td>
<td>70 – 99%+</td>
</tr>
<tr>
<td>TSS</td>
<td>60 – 90%</td>
<td>70 – 95%+</td>
</tr>
<tr>
<td>TKN</td>
<td>40 – 60%</td>
<td>90 – 99%</td>
</tr>
<tr>
<td>TP</td>
<td>30 – 50%</td>
<td>95 – 99%+</td>
</tr>
<tr>
<td>Soluble Organics</td>
<td>80 – 95%+</td>
<td>95 – 99%+</td>
</tr>
<tr>
<td>Dissolved Metals</td>
<td>40 – 90%</td>
<td>90 – 99%+</td>
</tr>
<tr>
<td>Pathogens</td>
<td>2 – 4 log</td>
<td>3 – 9 log</td>
</tr>
</tbody>
</table>
HOW TO DESIGN AN EW SYSTEM?

• Pilot-Scale Testing at Test Unit
  – Same substrate as eventual full-scale
  – Indoor testing to control ‘environmental’ factors
  – Imported or artificial feedstock
  – Spiked to worse case conditions

• Determine kinetics
  – Rate constants for removals of chemicals of concern
  – Tests at varying flow rates, CoC concentrations, temperatures

• Carry Out Tracer Test
  – Determine what model best simulates flow in bioreactor
  – E.g.: \( \frac{C_o}{C_i} = (1 + \varepsilon . h . k_{CSR} . A/N . Q)^{-N1} \cdot \exp(-\varepsilon . h . k_{PFR} . A/Q)^{-N2} \)
ACTIVE vs PASSIVE TREATMENT SYSTEMS

Least Energy and O&M Needs

Passive Semi-Passive Active

CWs EWs Mechanical WWTPs

Most Cost Least

Most
PILOT-SCALE EW TEST UNITS

Schematic of Test Unit with BREW Bioreactor and BCR Cells

Typical Pilot Set Up
THE EW TEST PROJECT

• Purpose to Bring the Design of ABRs to the Same Level As That of Aerated EWs
• Carried Out at CAWT Facilities at Fleming College
  – Stantec design & supervision
• Two-Phase Project
  – Phase 1 indoor pilot-scale testing (underway)
  – Phase 2 outdoor demonstration-scale testing (when Phase 1 complete)
• Phase 1 Scope
  – SAPS Bioreactor and BCR Cells in Walk-In Environmental Chamber
  – Testing over range of temperatures & conditions
  – Kinetics & genomics measurements
THE PHASE 1 TEST UNIT
EW TEST PROJECT, PHASE 1
20°C TRACER TEST - SAPS BIOREACTOR CELL, BEST FIT MODEL

Tank- in-Series with Delay
TIS.PFR Model

Cout/Cin vs. Relative time (hr)
EW TEST PROJECT, PHASE 1
20°C TRACER TEST - BCR CELL, BEST FIT MODEL

Tank-in-Series with Delay
3TIS.PFR Model
QUESTIONS?