The Evolving Role of Constructed Wetlands in Remedial Wastewater Treatment – A 25 Year Perspective

Presented to:
The Society of Wetland Scientists
Mid-Atlantic Chapter 2014 Conference
State College, Pennsylvania

April 5th, 2014

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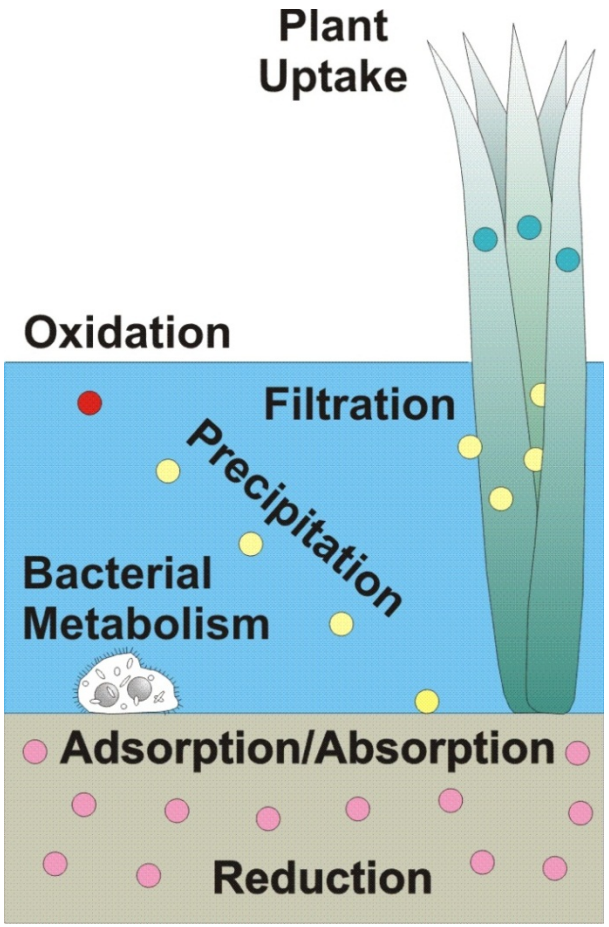
Origins of Constructed Wetland Treatment

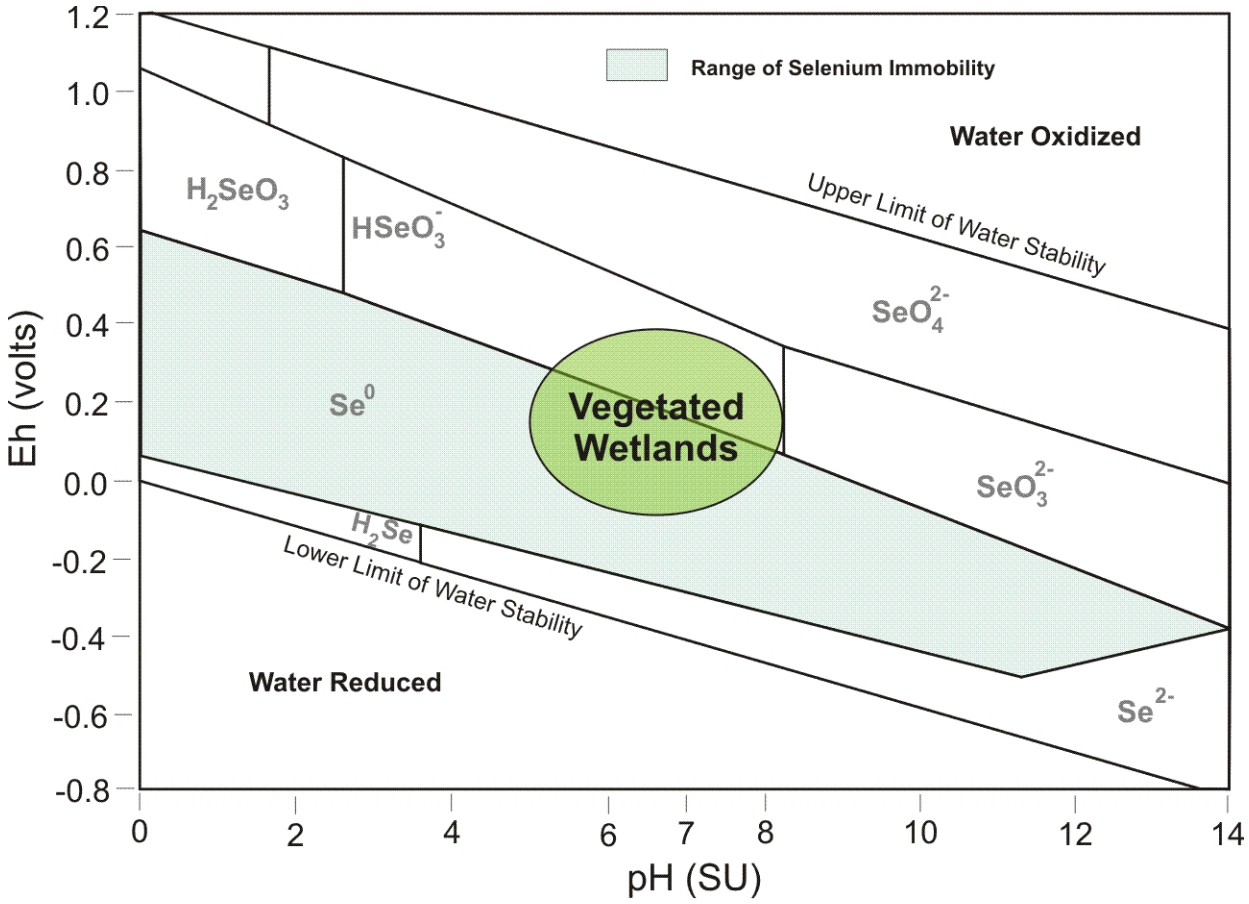
- General category of “passive” water treatment
- Uses natural contaminant removal processes with little or no external power or reagent feeds
- Developed in 1980s for abandoned mine drainage (AMD) and coal combustion residual (CCR) leachate
- Based on observations that water quality improved passing through natural wetlands
- Early designs focused on replicating natural vegetated systems

Constructed Wetland Treatment Concept

- Vegetated wetlands provide a variety of functions for contaminant removal
- Many different Eh-pH environments may be present
- Natural swamps originally trapped contaminants in coal
- Constructed wetland treatment seeks to replicate ore formation processes



Limitations Encountered



- Vegetated wetlands are not always effective for parameters with narrow Eh-pH removal ranges (Se, Mn,…)

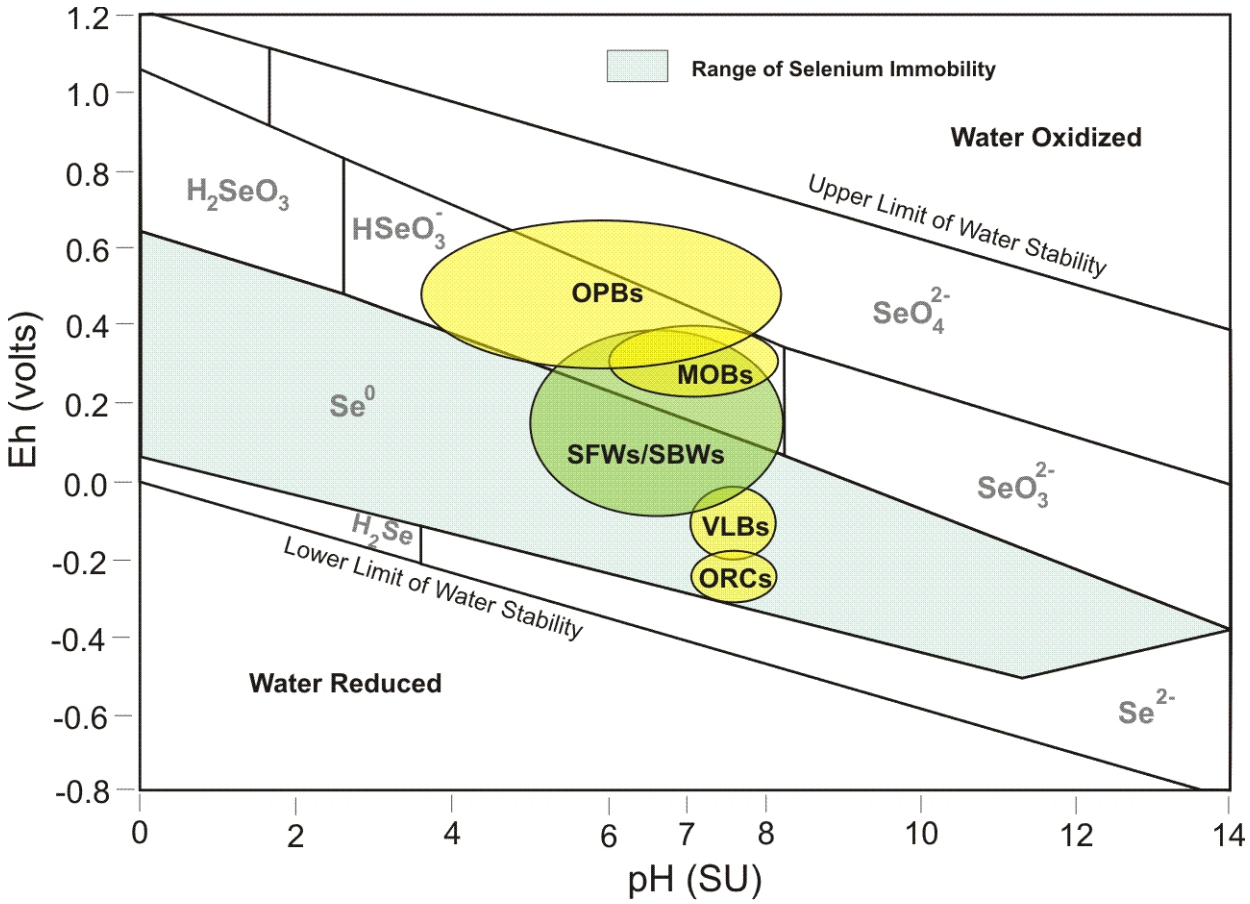
Phased Element Removal Technology (PERT)

- Greater control needed for Eh-pH conditions
- Research in 1990s isolated wetland treatment functions in targeted Eh-pH components
- PERT design approach sequences components in preferred natural order of ore deposition
- Allows more efficient sizing of components by predicting the discharge quality from each in sequence

Basic PERT Design Components

- Vertical Flow Limestone Beds (VLBs)
  - Downflow beds of limestone to remove acidity
- Oxidation/Precipitation Basins (OPBs)
  - Settling basins with influent aeration
- Surface Flow Wetlands (SFWs)
  - Aerobic vegetated wetlands for metals removal
- Organic Reduction Cells (ORCs)
  - Downflow organic beds with strongly reducing conditions
- Subsurface Flow Wetlands (SBWs)
  - Vegetated wetlands with porous substrates for solids removal
- Manganese-Oxidizing Beds (MOBs)
  - Aerobic gravel beds colonizing Mn-oxidizing bacterial

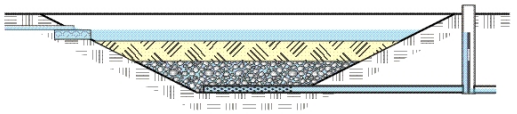
General Eh-pH Ranges for PERT Components



PERT Treatment Approach

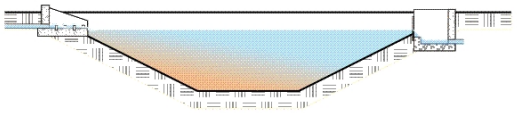
Passive Treatment Components

VLBs



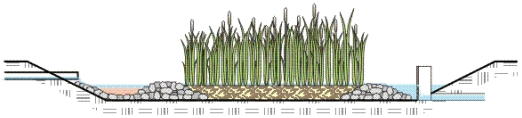
Vertical Flow Limestone Beds
(VLBs)
Primary neutralization
of acidity, increase of pH

OPBs



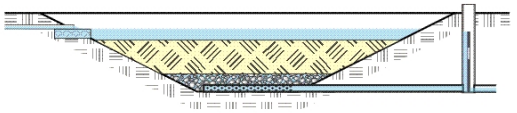
Oxidation/Precipitation Basins
(OPBs)
Primary removal for major
sludge-formers

SFWs



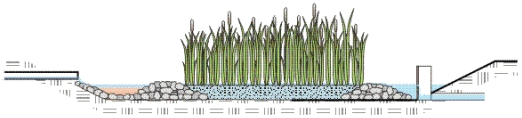
Surface Flow Wetlands
(SFWs)
Removal of remaining sludge-formers
and oxidizable elements

ORCs



Organic Reduction Cells
(ORCs)
Removal of trace elements
in reducing conditions

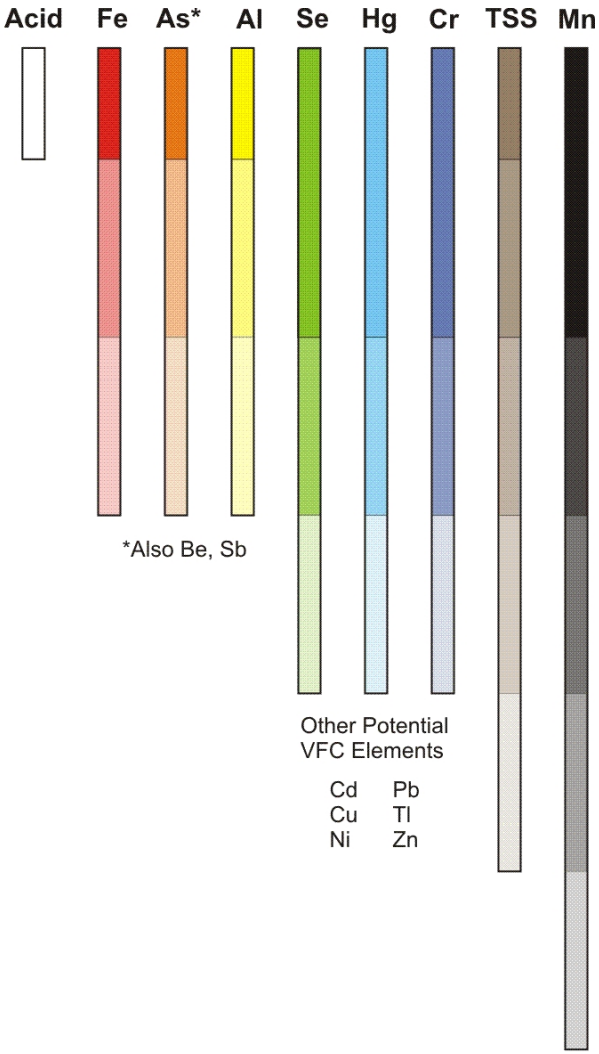
SBWs



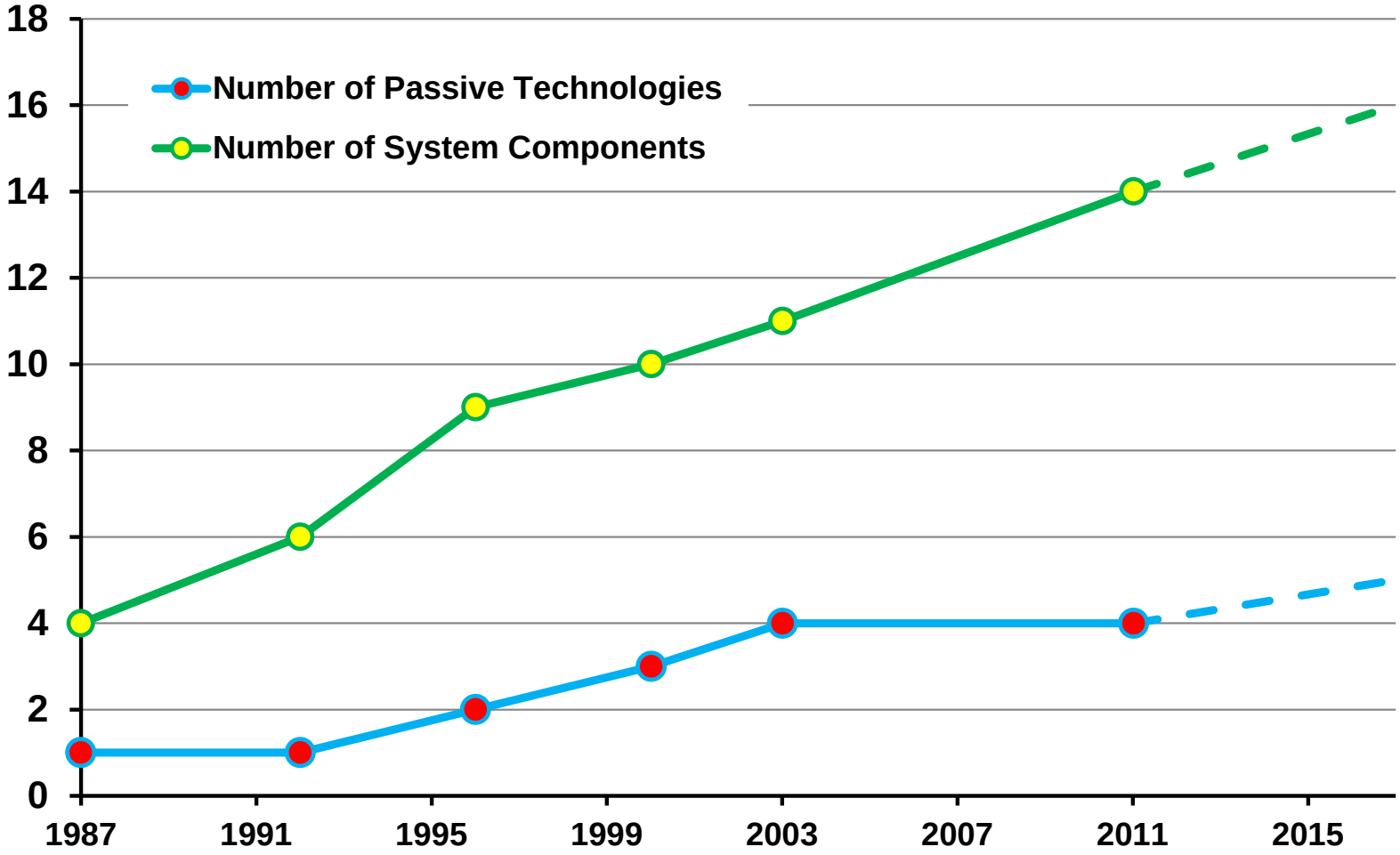
Subsurface Flow Wetlands
(SBWs)
Removal of remaining solids and
organic compounds from VFCs

MOBs

Manganese-Oxidizing Beds
(MOBs)
Removal of manganese and
related trace metals

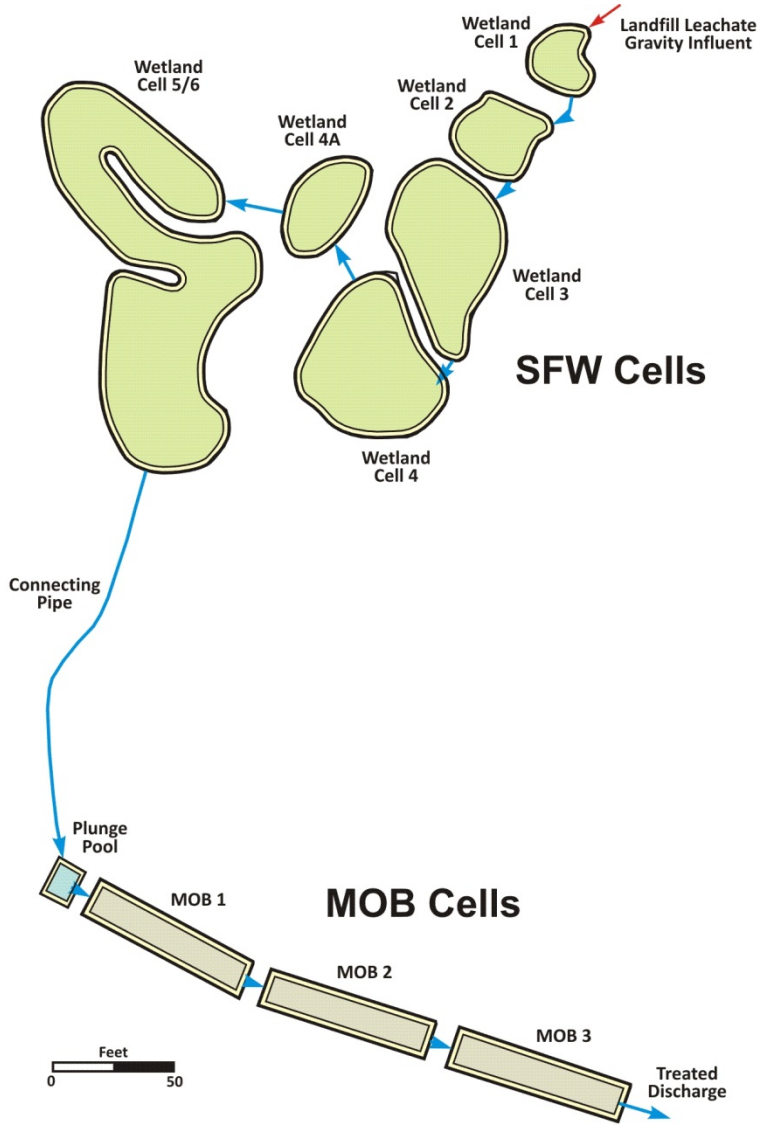


Constructed Wetland System Evolution
1987 – 2011



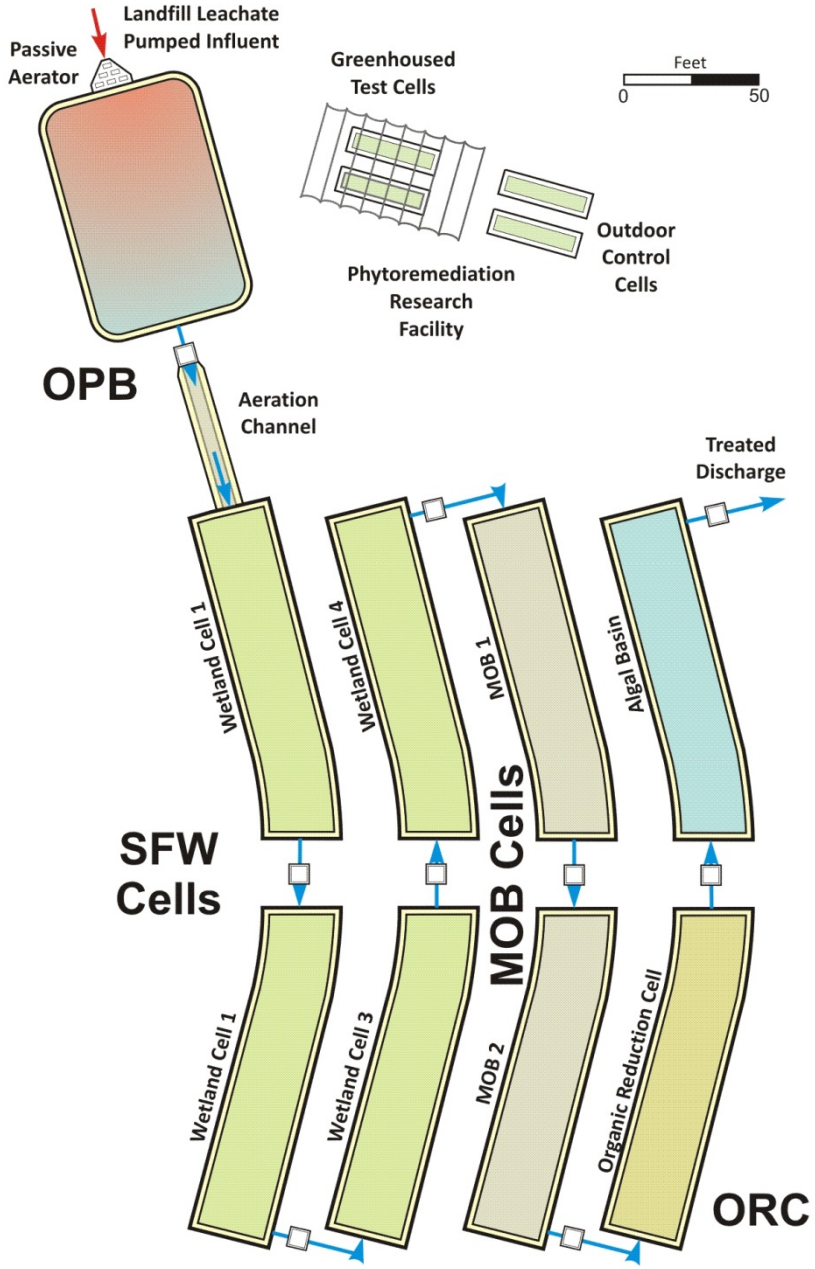
Albright System
1987

- CCR leachate and AMD
- Treating for pH, Fe, Mn
- “Free-form” wetland cell designs in 1987
- New SFW cells added in 1992 to improve Mn removal
- MOBs added in 1996 for final compliance



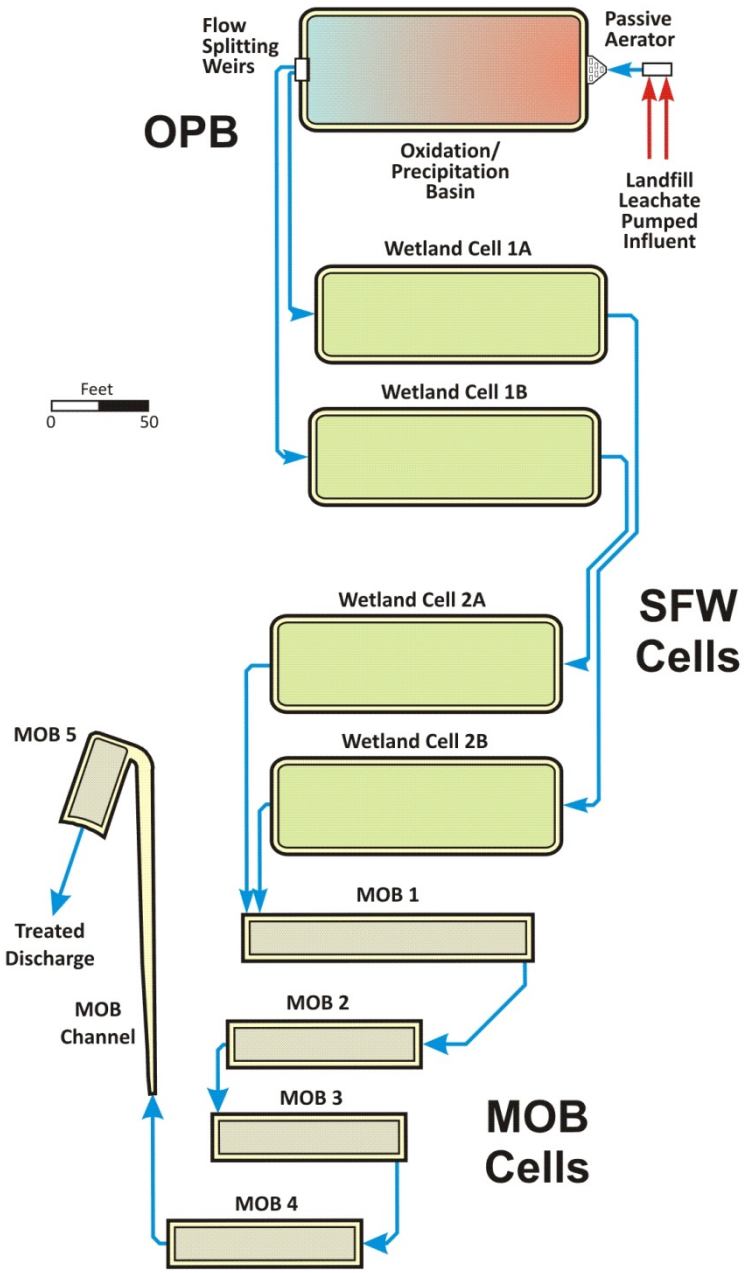
Springdale System 1995

- CCR leachate and AMD
- Treating for pH, Al, As, B, Fe, Mn, Se, TSS
- Research and compliance project with EPRI
- Tested multiple technologies together
- Multiple award winner – formed basis of PERT



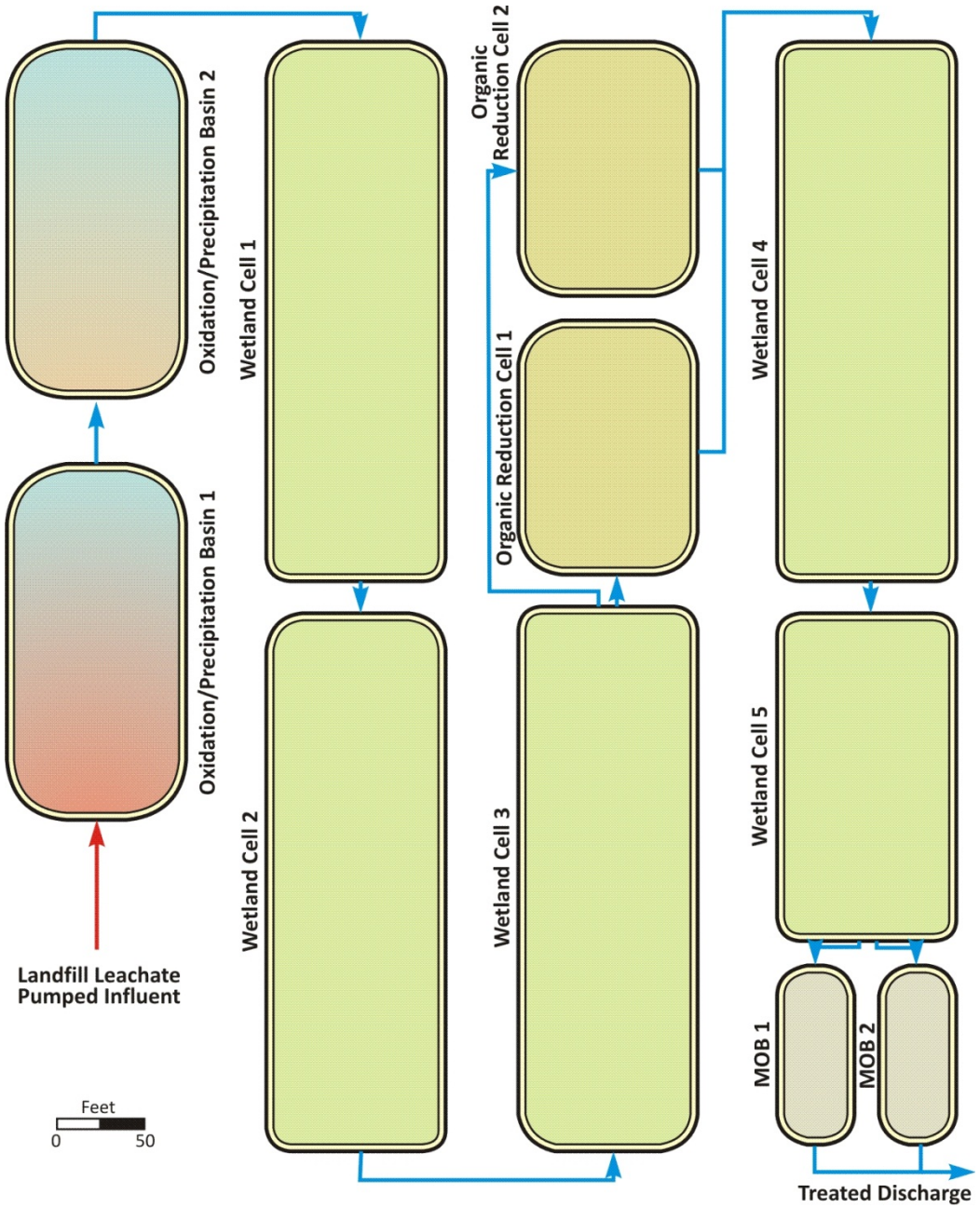
Hatfield System
2000

- CCR leachate and AMD
- Treating for pH, Al, As, Fe, Mn, Tl, TSS
- First full PERT application
- SFW cells used for polishing rather than primary Fe treatment
- Refined MOB sizing criteria, regular cell outlines



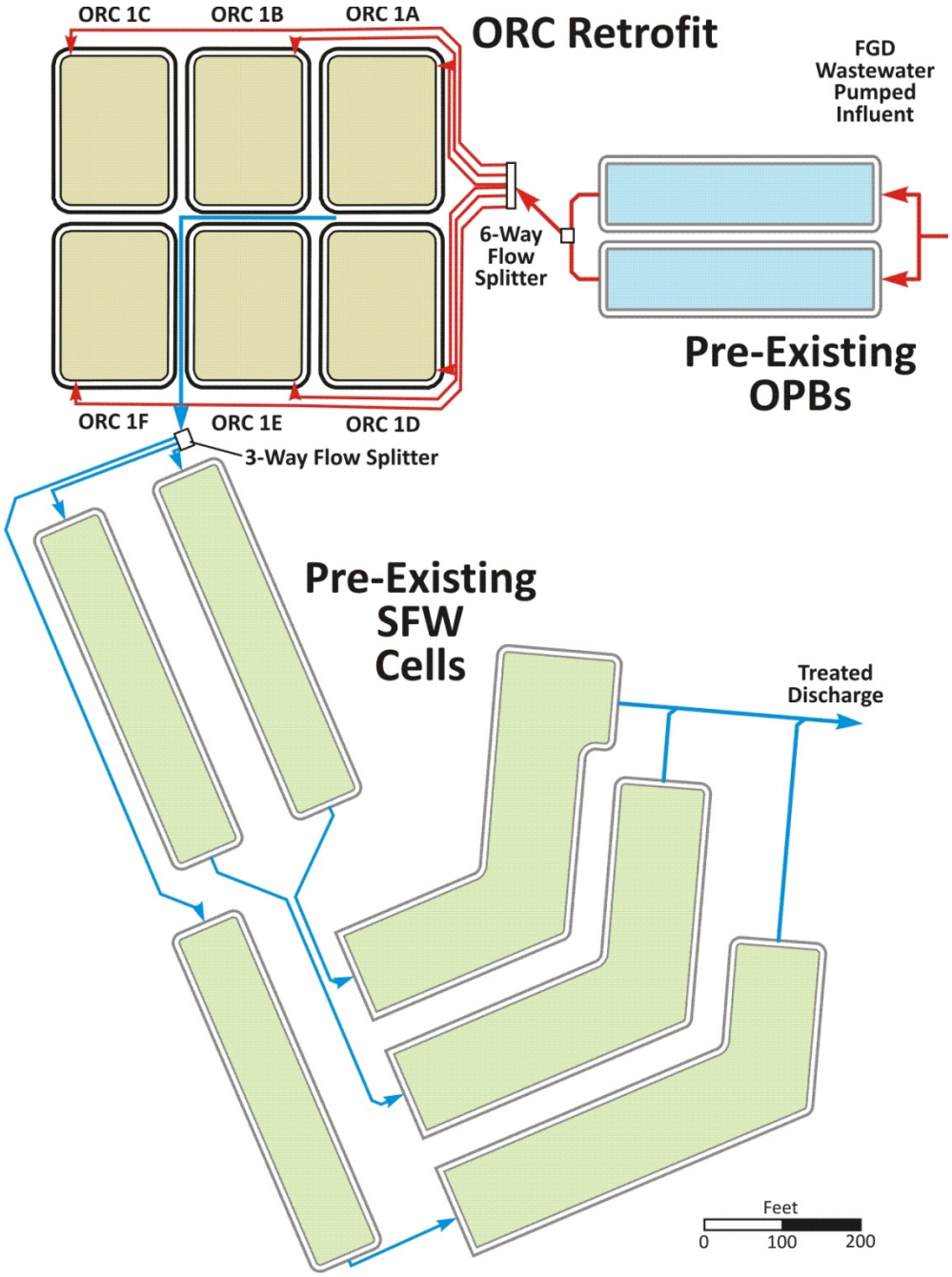
Harrison System 2003

- CCR leachate and AMD
- Treating for pH, Al, As, Cr^{6+}, Fe, Mn, Se, TSS
- First use of ORCs for Cr^{6+} and Se
- Secondary SFWs used for solids control

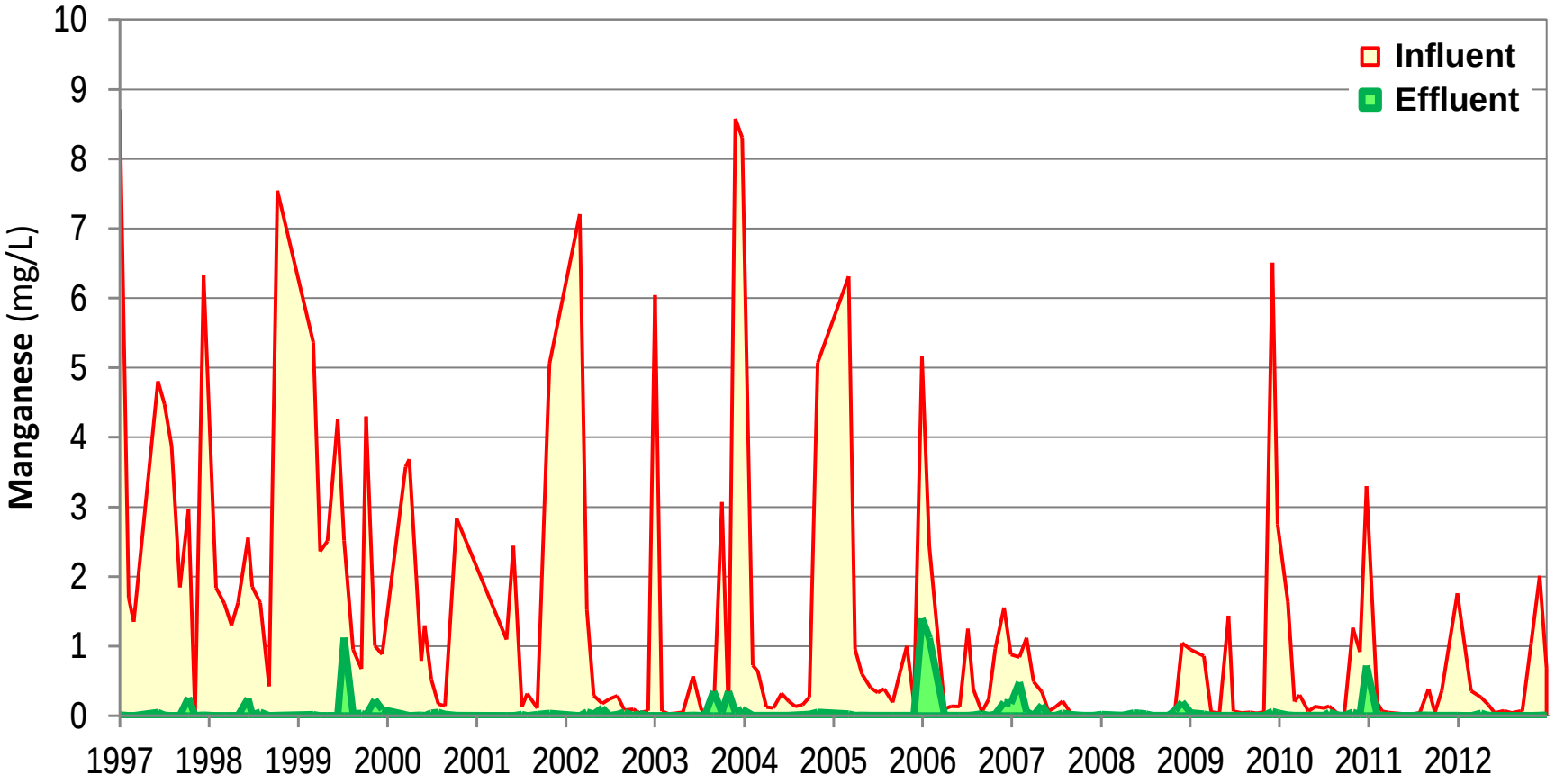


Marshall System
2011

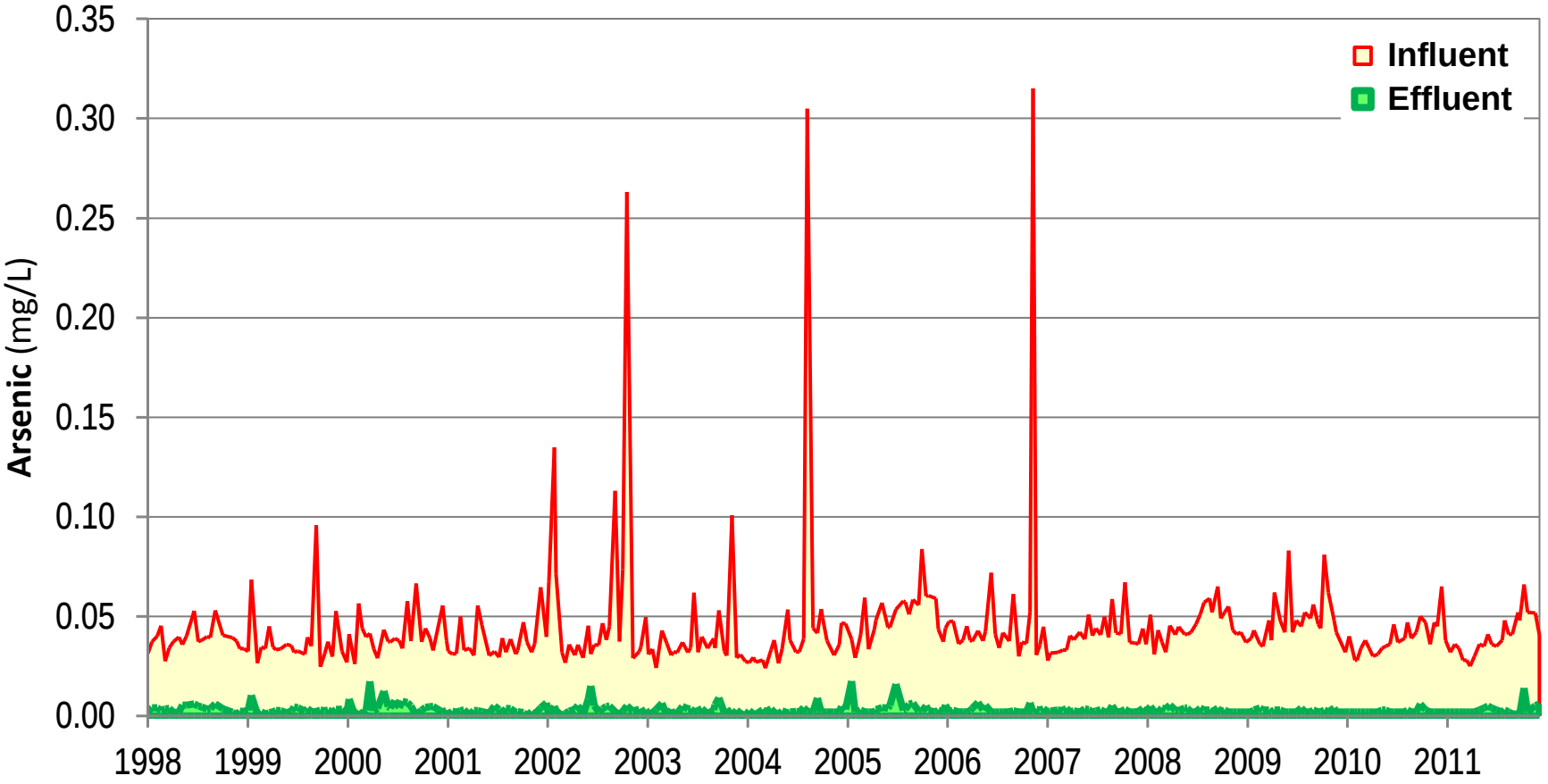
- Flue gas desulfuriza-tion (FGD) wastewater
- Treating primarily for As, Fe, Hg, Se
- Pre-existing SFWs had poor Se removal
- 3 SFWs replaced with 6 ORCs
- Greatly enhanced Se & Hg removal



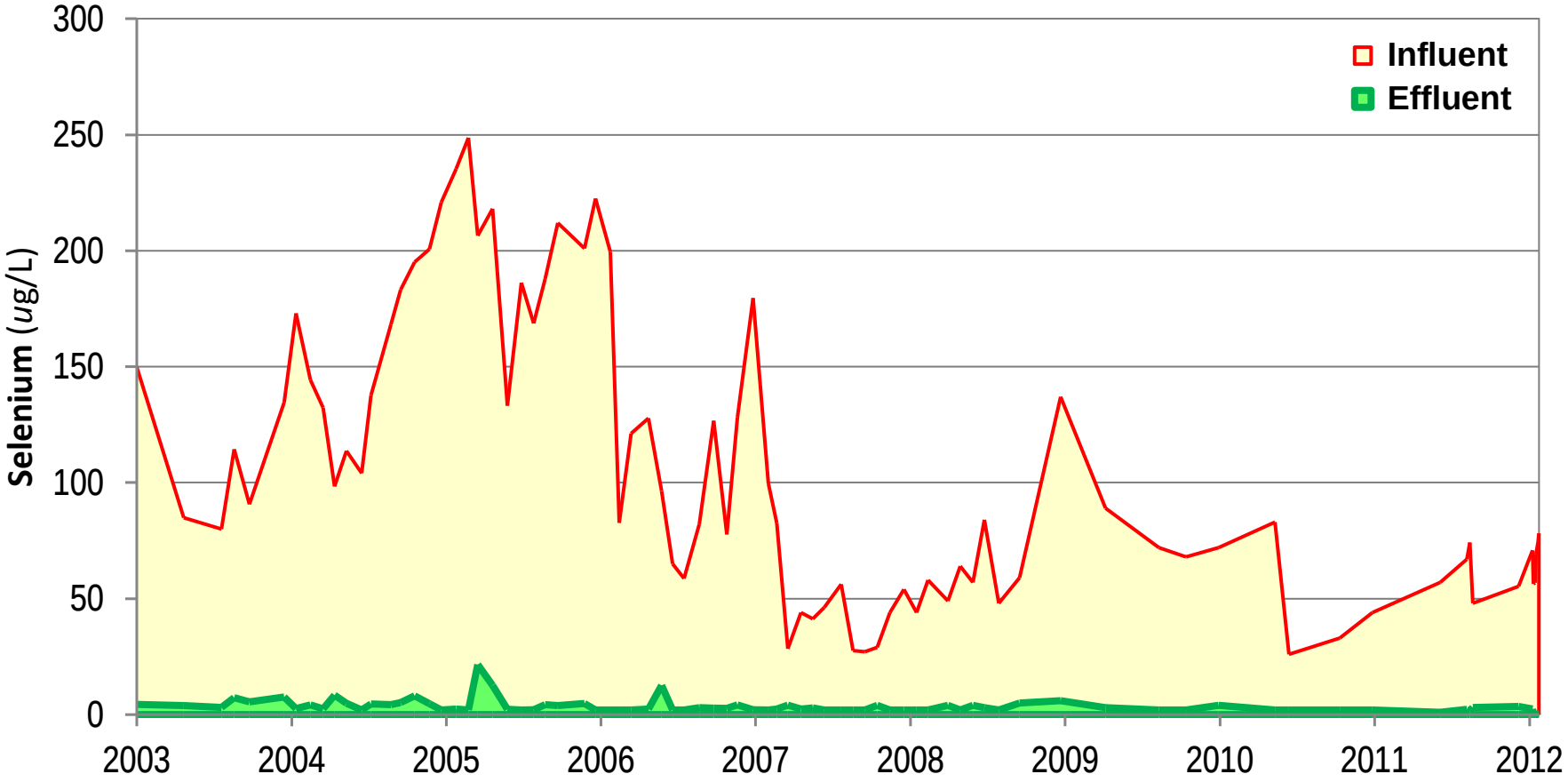
Long-Term Performance
Manganese – Albright



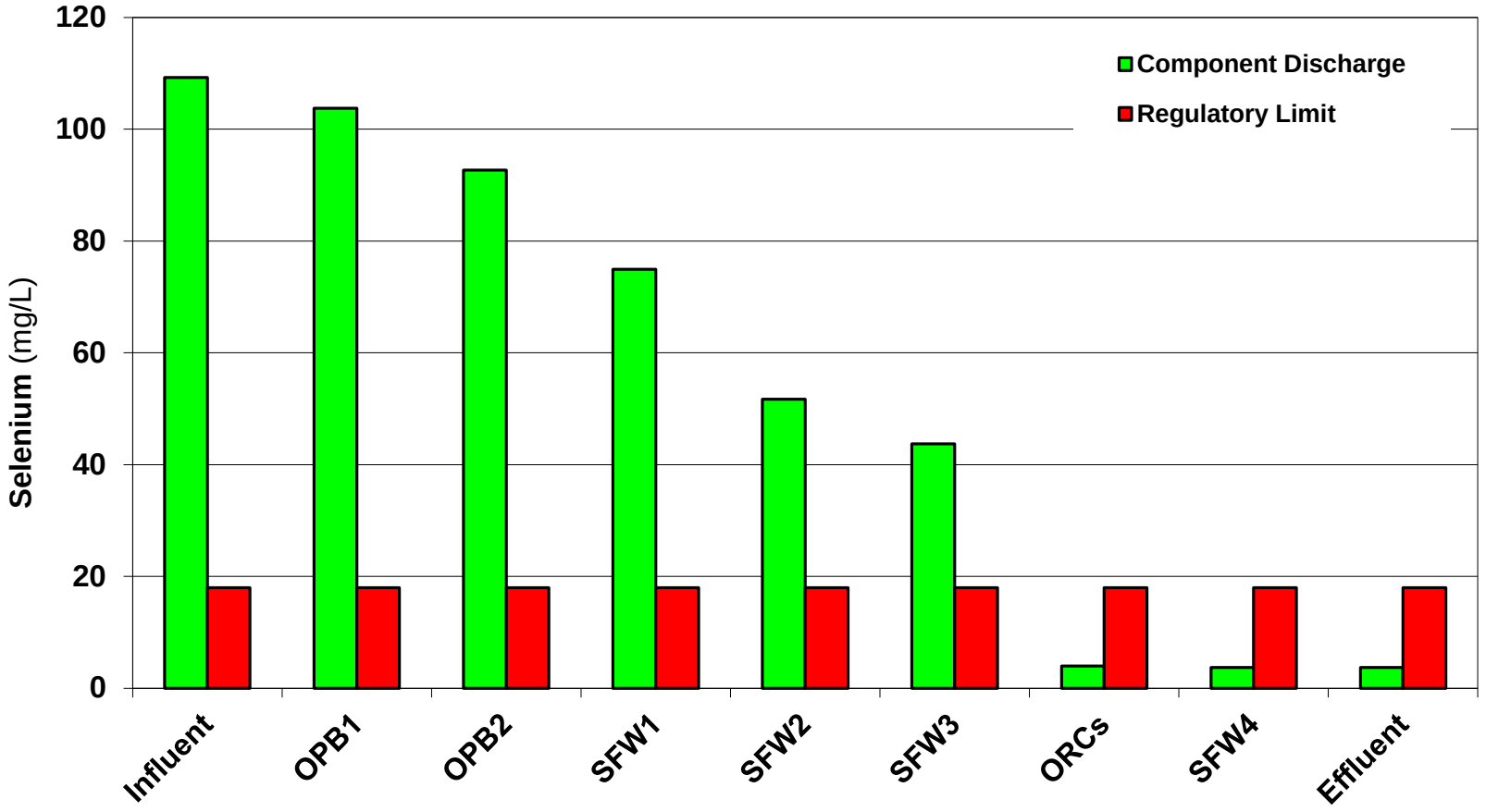
Long-Term Performance
Arsenic – Springdale



Long-Term Performance
Selenium – Harrison



System Component Performance
Selenium – Harrison



Future Considerations

- Vegetated wetlands will remain a key component of passive treatment systems
- Proposed EPA utility wastewater guidelines recognize biological treatment as a compliance option
- Biological systems are a low-cost, sustainable solution for wastewater remediation on remote and unstaffed sites
- Exclusion of wildlife may become a consideration for future designs

Wetland of the Future?

Questions & Discussion

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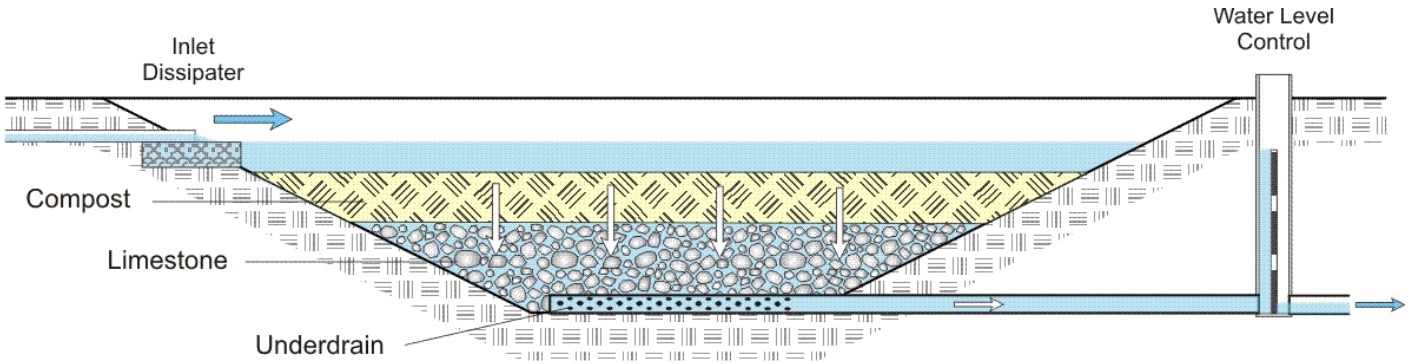
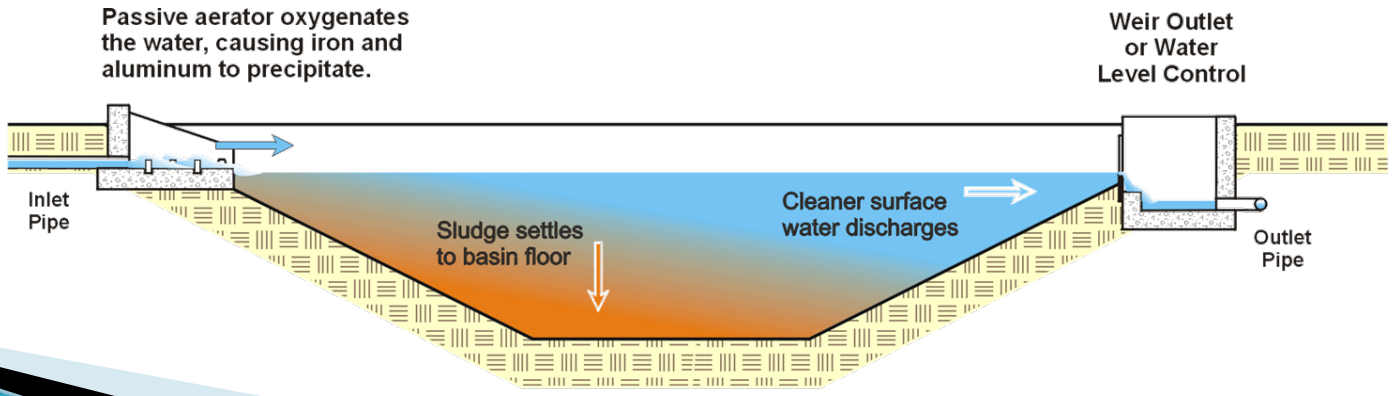
Vertical Flow Limestone Beds (VLBs)

- Used for acidity removal
- Basal limestone bed with top cover of organic compost
- Generate alkalinity from limestone and sulfate reduction
- Also remove Fe and Al, but this can cause clogging



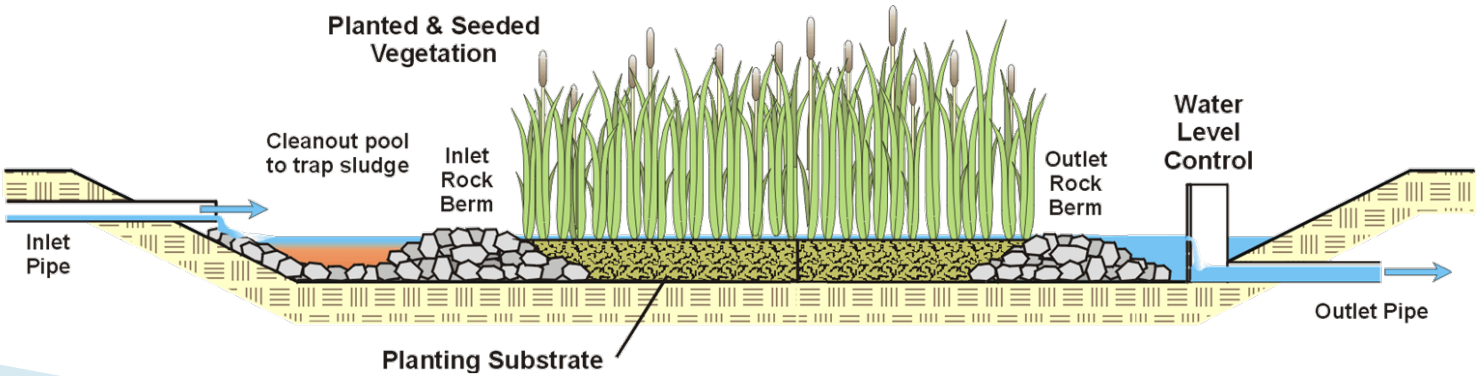
Oxidation/Precipitation Basins (OPBs)

- Used for aerobic precipitation of metals and sludge storage
- Deep open water basins, usually with 24+ hours detention
- Aeration provided at inlet
- Work well for Fe and Al, also remove As with Fe co-precipitation



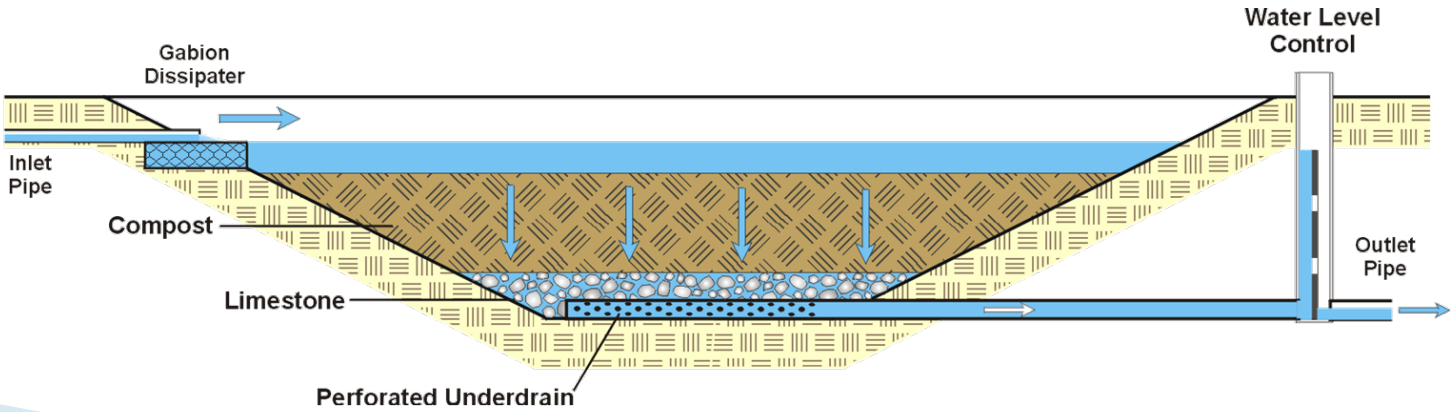
Surface & Subsurface Flow Wetlands (SFWs, SBWs)

- Effective for polishing many parameters
- Contain aerobic and anaerobic components
- Blended organic substrate and shallow water for SFWs
- Porous substrate for SBWs
- Work best for residual Fe, Al, and solids (TSS) removal



Organic Reduction Cells (ORCs)

- Similar to VFWs, but with a thick top organic bed
- Create strongly reducing conditions
- Effective for Se, Hg, Cr^{6+}, and others mobile in oxidizing conditions
- Should be followed by SFWs or SBWs for solids polishing



Manganese-Oxidizing Beds (MOBs)

- Shallow basins filled with 1 – 2 feet of gravel
- Create growth surface for manganese-oxidizing bacteria
- Mn deposited as pyrolusite (MnO_2)
- Require low influent Fe – placed at end of system