GALLOGLY COLLEGE OF ENGINEERING
SCHOOL OF CIVIL ENGINEERING AND ENVIRONMENTAL SCIENCE
The UNIVERSITY of OKLAHOMA

Pilot-Scale Wetland Design

Treatment Wetlands for Polishing Reclaimed Municipal Wastewater for Indirect Potable Reuse

PUDDLE BEAR WETLAND SOLUTIONS 2022

OKTO

NAIRNIA ENGINEERING

Environmental Science and Engineering Capstone Class of 2023

CEES 4913/4923

Project Overview

- Design pilot-scale wetland for indirect potable reuse of NWRF effluent
- Augment water supply into Lake Thunderbird
- Removal/reduction of contaminants of emerging concern (CECs)

NWRF Aerial View

City of Columbia, MO Treatment Wetlands

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Fall Semester Project Timeline

Resume Building

Team Organization

Project Site Visit

Team Assignments

Project Schedules

Preliminary Project Documents

- Sampling and Analysis Plan
- Health and Safety Plan
- Project Work Plan
- Quality Assurance Project Plan
- Literature Review

Spring Semester Project Timeline

Revised Project Documents

Field Episode 1: Testing and Sampling

- On site water testing
- Water sample collection
- Soil sample collection

Laboratory Testing

- Water Samples
- Soil Samples

Topical Report Literature Review

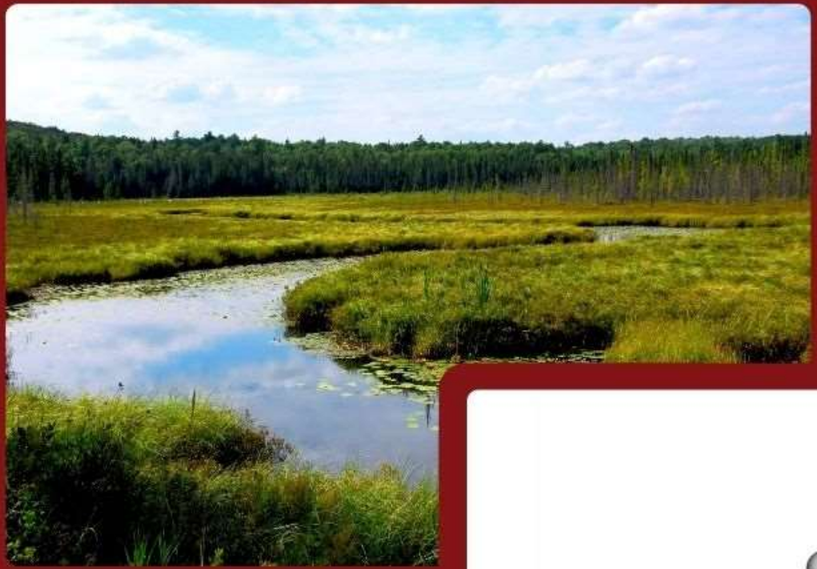
Field Episode 2: Dynamic Cone Penetrometer Testing

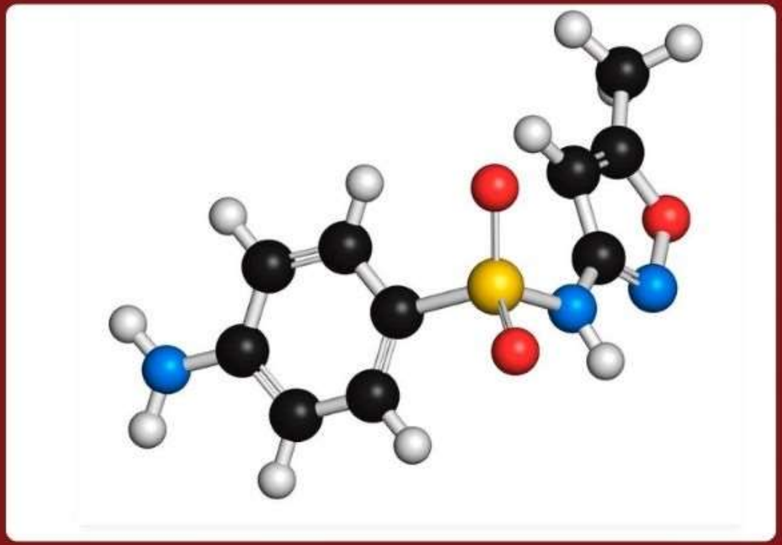
Spring Semester Project Timeline

- Draft Technical Report
- Draft Oral Presentation
- Discussion of Service Learning Objectives
- Final Presentation & Reports

Why a Wetland Treatment System?

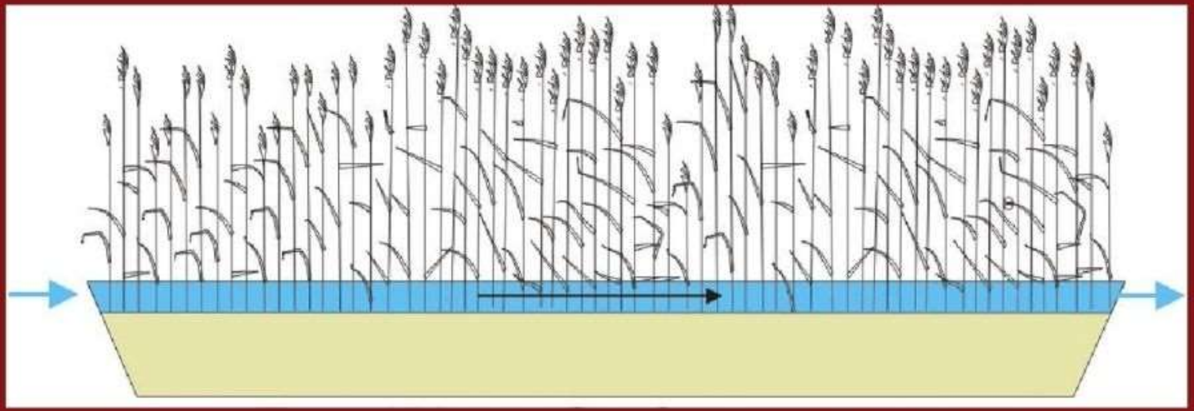
- CEC removal mechanisms
  - Phytoremediation
  - Biodegradation
  - Sorption
  - Photodegradation
  - Microbial degradation
- Reduction of excess nutrients
- Environmental buffer for Lake Thunderbird



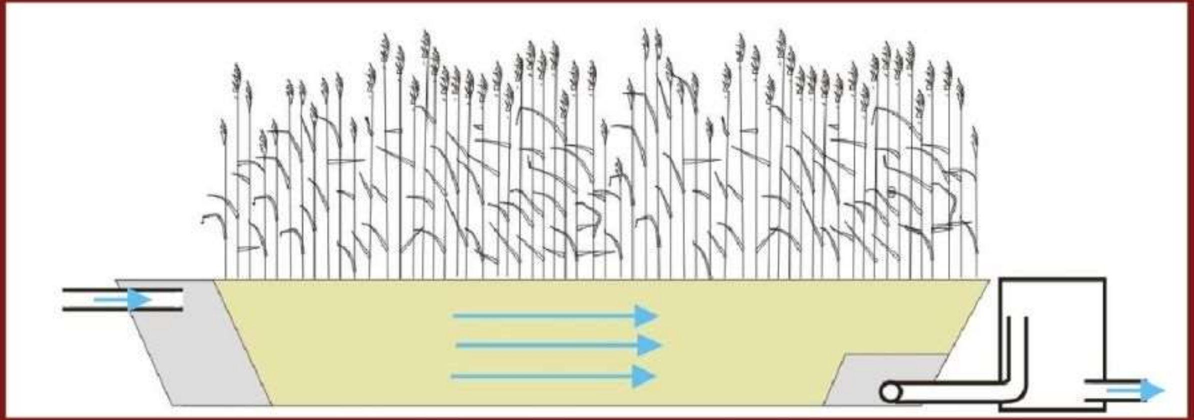


Sulfamethoxazole

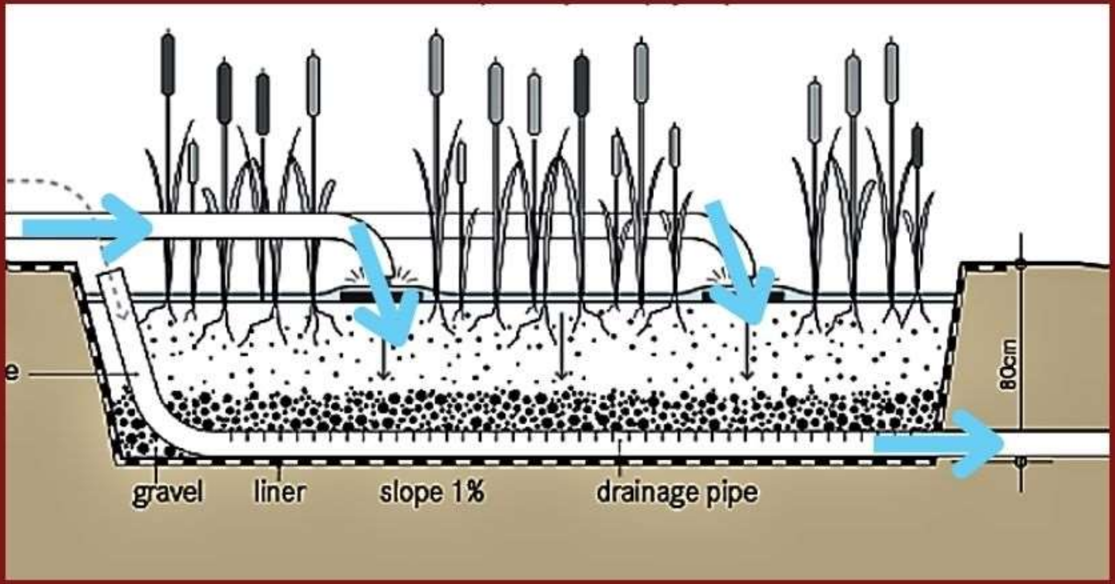
Wetland Types



Free water surface wetland (FWSW)



Horizontal subsurface flow wetland (HSSFW)

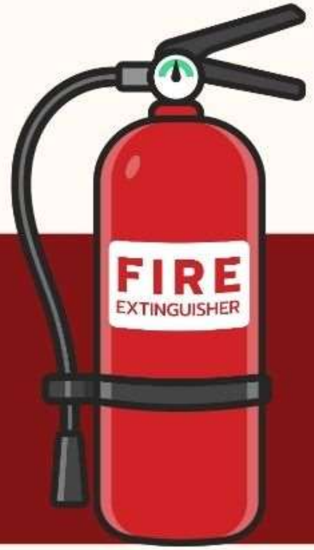


Vertical flow wetland (VFW)

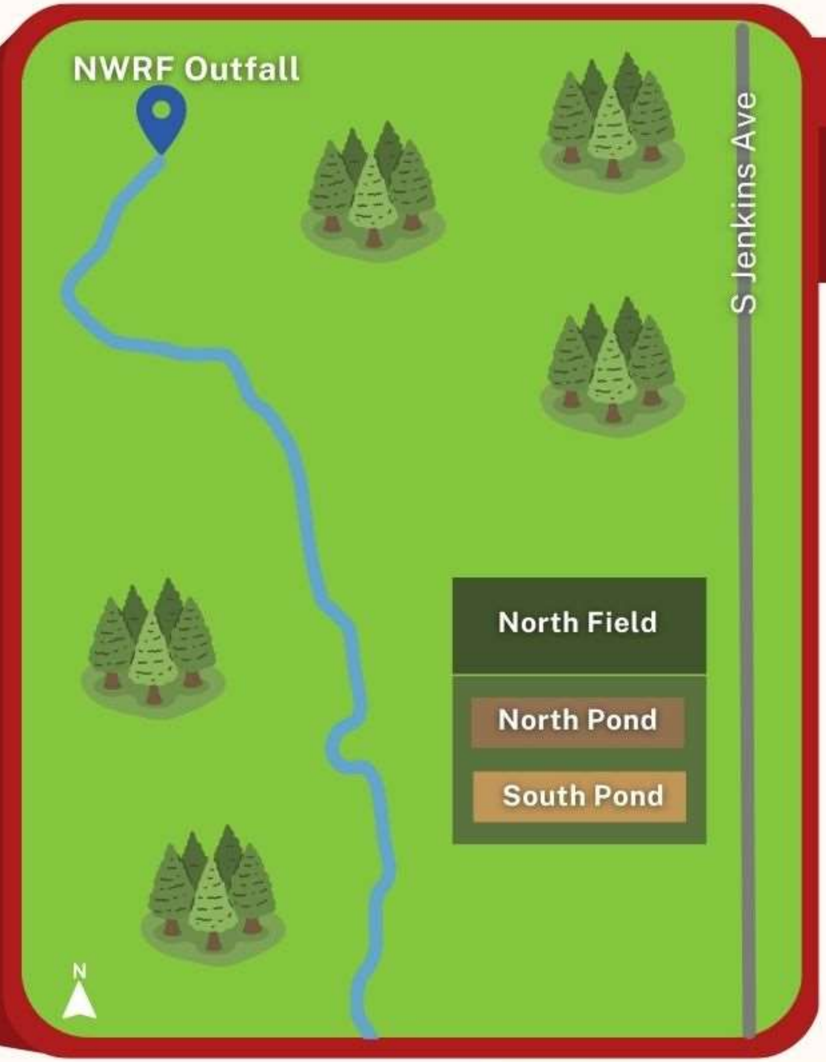
Contaminants of Emerging Concern

- **Hazardous to environment, animals, and humans**
- **CEC Types**
  - **Pharmaceuticals and personal care products (PPCPs)**
  - **Endocrine-disrupting chemicals (EDCs)**
  - **Preservatives**
  - **Sweeteners**
  - **Fire retardants**
  - **Stimulants**
  - **Pesticides**



Project Location



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Field Visits

Water Sampling

Dynamic Penetrometer

Soil Sampling

Water Sampling and Testing

- 5 Locations
- 26 Samples
- YSI Multiparameter Datasonde
  - pH
  - Dissolved Oxygen
  - Specific Conductivity
  - Oxidation-Reduction Potential
- Hach 2100Q Turbidimeter
- Hach Digital Titrator
  - Total Alkalinity

Soil Sampling and Testing

- 54 locations
- 172 samples
- Dynamic cone penetrometer tests

Soil Sampling Locations

Soil Sample Collection

DCP Testing

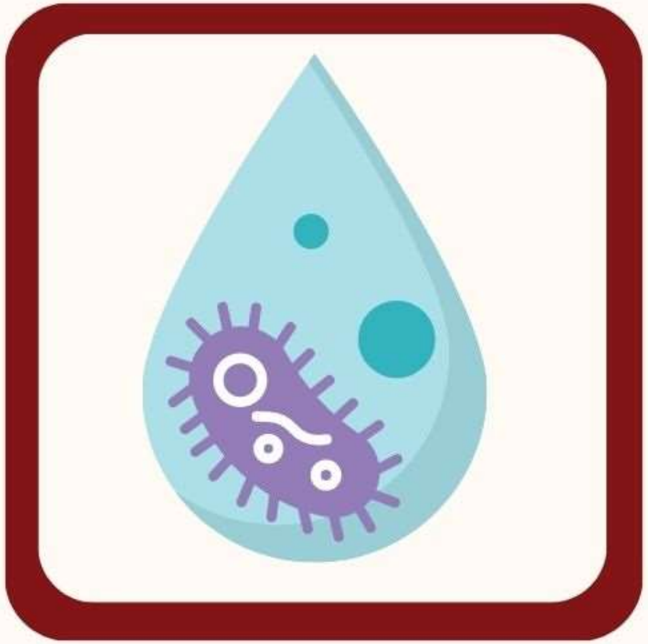
Laboratory Analyses

- Water analyses
  - Biochemical oxygen demand
  - Total suspended solids
  - Metals
  - Anions
  - Fecal indicator bacteria
- Soil analyses
  - Particle size distribution
  - Moisture content
  - Organic matter content
  - Cations
  - Hydraulic conductivity

Particle Size Distribution

Secondary Data

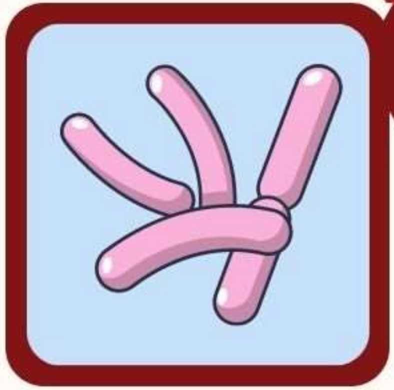
- LIDAR Data
- Thornton (2017) studied CECs present in NWRF effluent
  - Up to 98 different CECs analyzed
- NWRF effluent water quality parameter data at outfall from 2017 - 2022



Water Analyses







Turbidity	Nitrate & Nitrite	Phosphorus	BOD_5	Fecal Bacteria
3.97 ± 0.56 NTU	16.0 mg N/L	2.19 mg P/L	1.37 ± 0.11 mg/L	Present

Soil Constituent Averages

Analytes	North Field	Berms	North Pond	South Pond
Organic Matter Content (%)	1.86 ± 0.01	2.18 ± 0.01	0.48 ± 0.02	0.86 ± 0.01
Moisture Content (%)	15.12 ± 0.05	13.52 ± 0.02	6.51 ± 0.02	8.23 ± 0.03
Soil Classification	Silty Sand	Silty Sand	Poorly Graded Sand	Poorly Graded Sand
Nitrogen (mg/kg)	3.00 ± 1.37	-	0.75 ± 0.29	1.20 ± 0.57
Phosphorus (mg/kg)	19.38 ± 7.74	-	7.13 ± 1.25	6.50 ± 1.06

Puddle Bear Wetland Solutions

Team Members

Kylie Martin

Soil and Water Data Analysis & CAD/GIS Modeling

Sam Taylor – Leader

General Wetland Design & Water Treatment

Anthony Gallegos Garcia

Water Treatment & Hydraulic Design

Elina Avila

Wetland Vegetation & Water Treatment

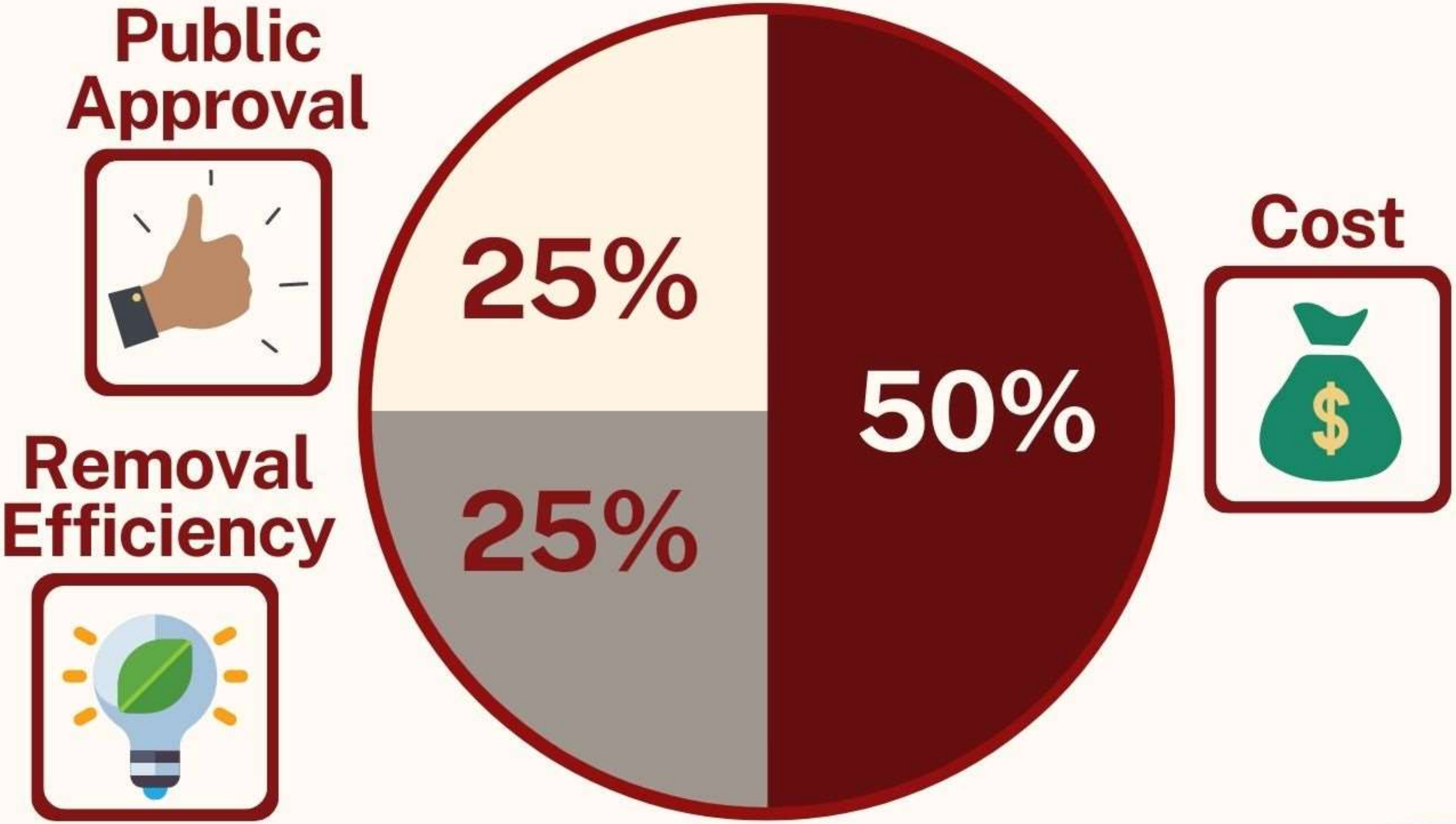
Matthew Varriale

Public Acceptance & Soil and Data Analysis

Yaseen Alwzzan

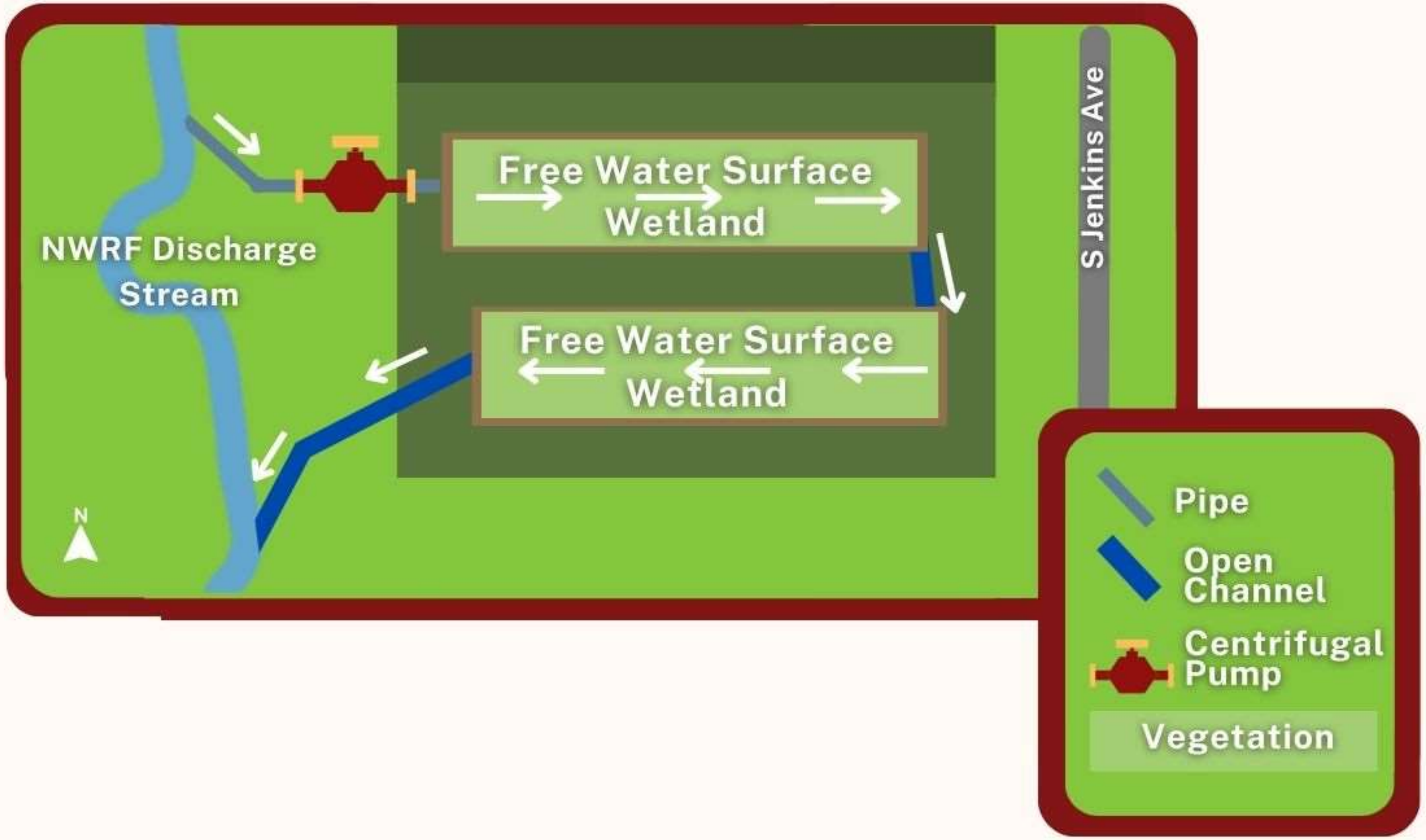
Finances & Soil and Water Data Analysis

Technology Evaluation Criteria



Design Alternative

Free Water Surface to Free Water Surface



Construction
$300,000

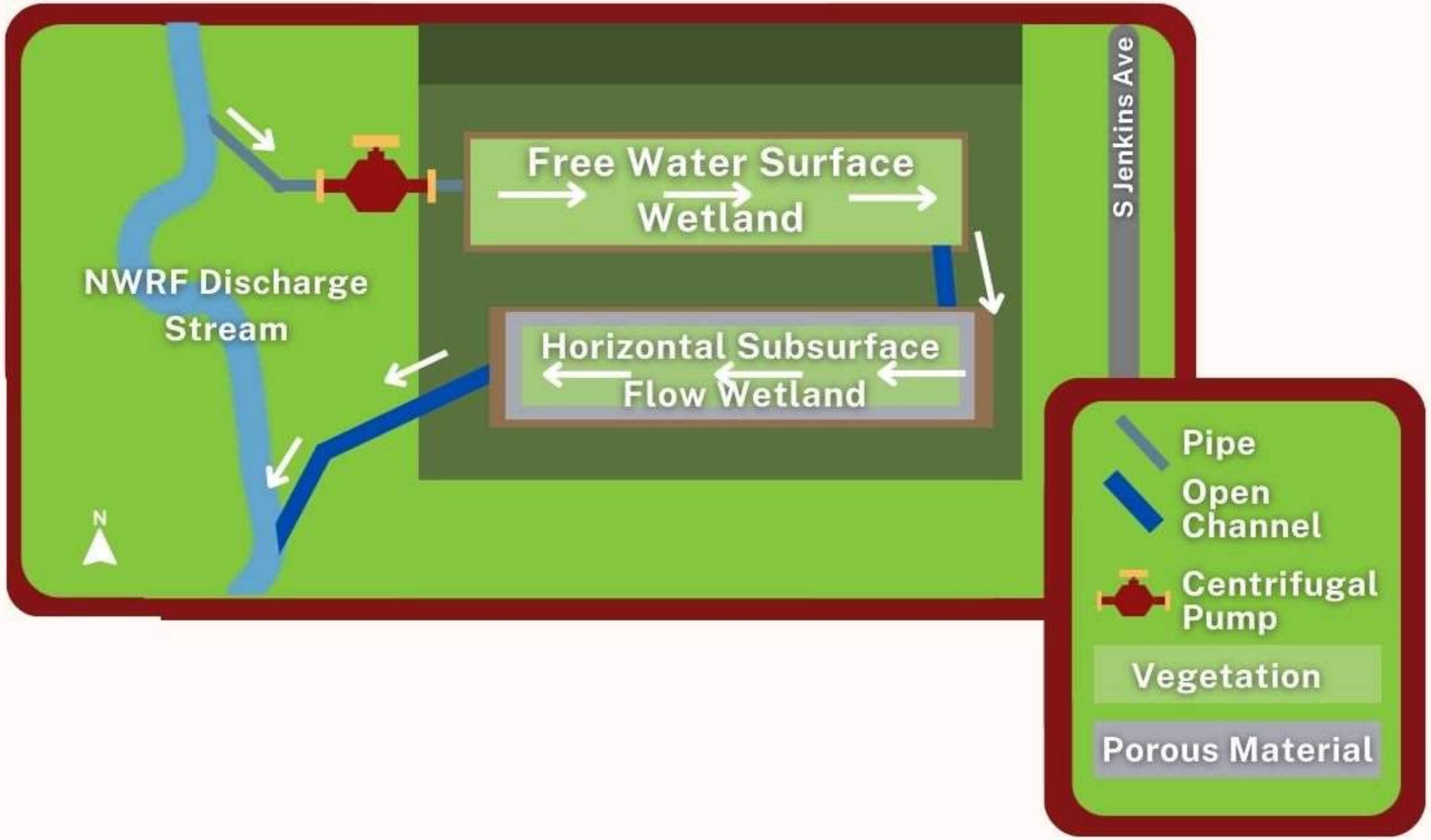
Operation & Maintenance (20 years)
$47,000

Grand Total
$347,000

2nd

Design Alternative

Free Water Surface to Horizontal Subsurface Flow



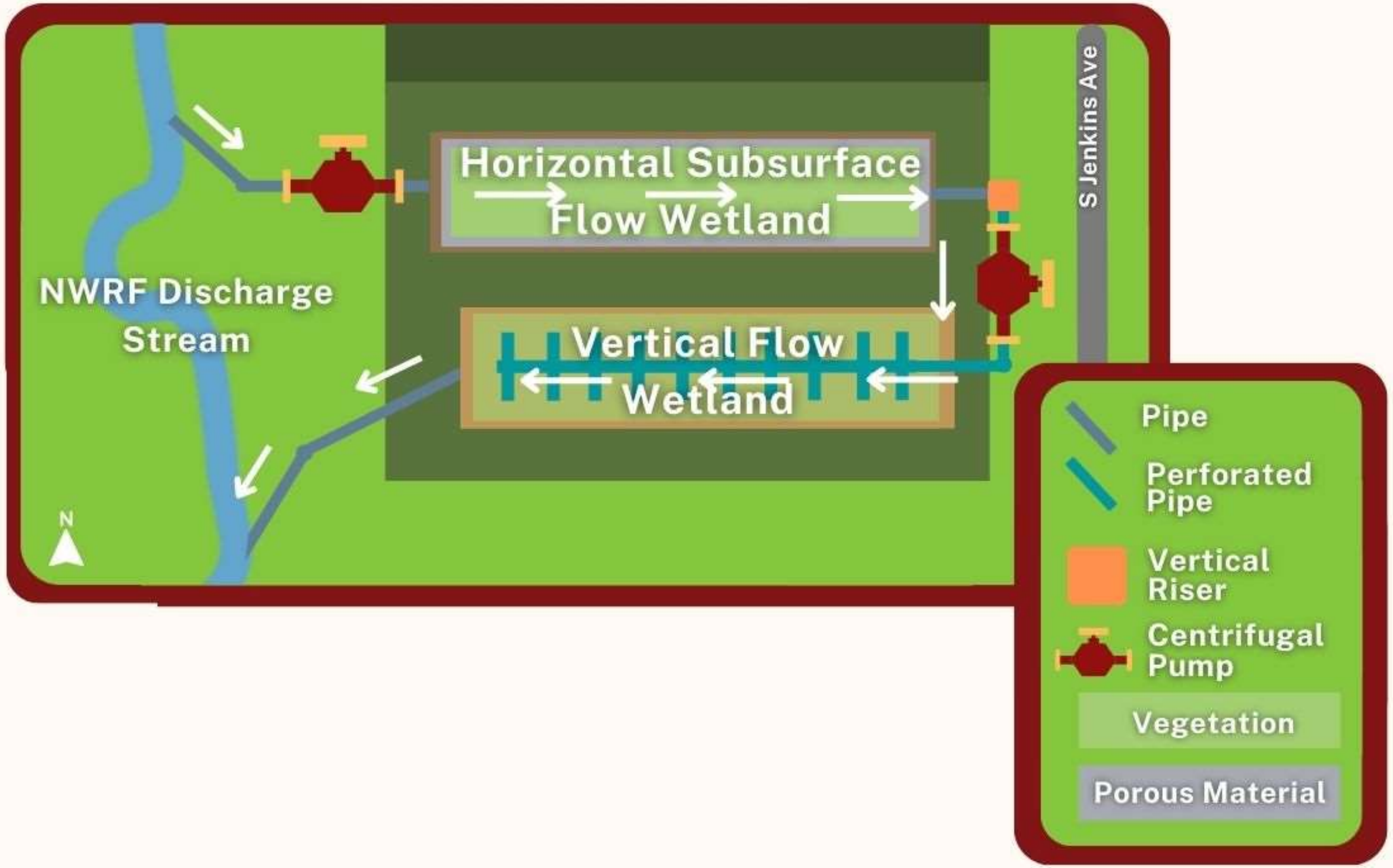
Construction
$492,000

Operation & Maintenance (20 years)
$132,000

Grand Total
$624,000

3rd Design Alternative

Horizontal Subsurface to Vertical Flow



Construction

$568,000

Operation & Maintenance (20 years)

$165,000

Grand Total

$733,000

Proposed Design

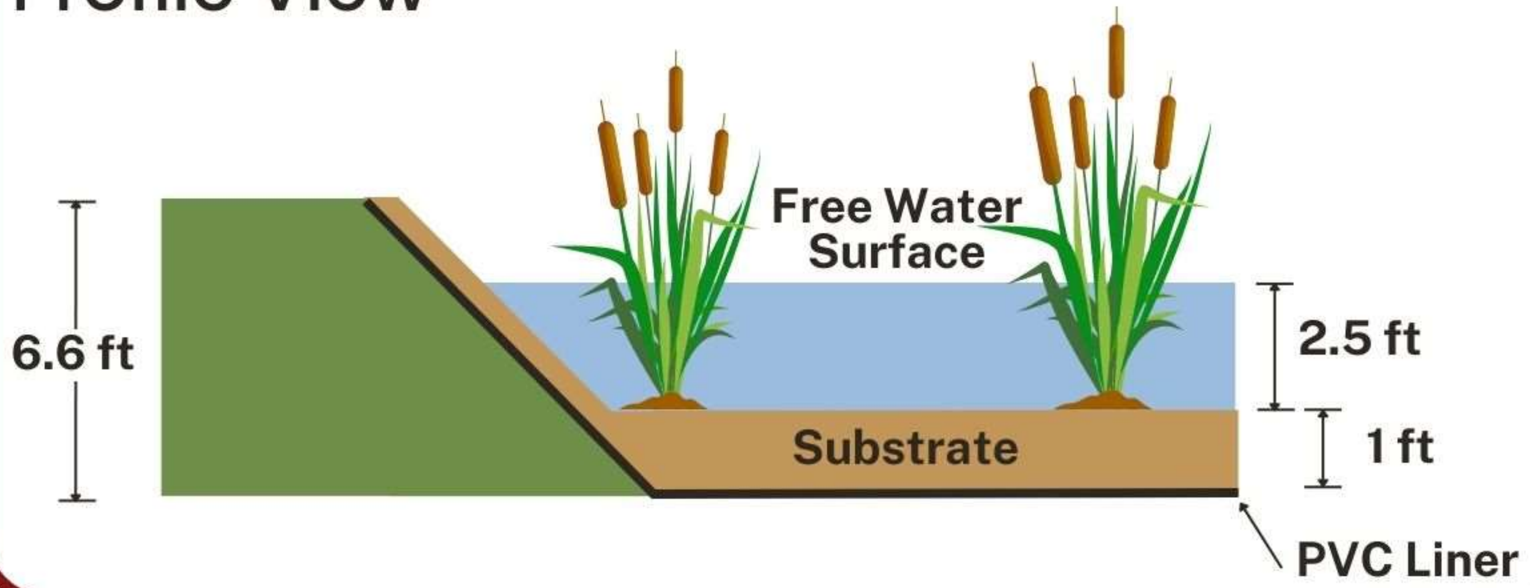
1st Alternative

Public Approval
- Ecosystem services
- Educational opportunities

Removal Efficiency
- 40% Phosphorus
- CEC removal

Cost
- Lowest cost
- $347,000 Net Present Worth

Profile View



Water Quality Improvement

	Turbidity (TAC)	BOD_5 (TAC)	Fecal Bacteria (TAC)	Phosphorus
Criterion	3 NTU	5 mg/L	20 CFU/ 100mL	max removal
Design Removal Efficiency	Meets Criterion	Meets Criterion	Meets Criterion	40%

Texas Administrative Code (TAC) - Surface Water Augmentation for Reclaimed Water

CEC Removal Efficiencies





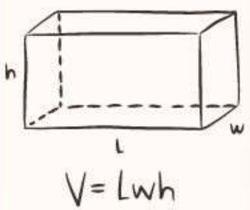

	4-nonylphenol	Amoxicillin	Theobromine	Sucralose	TCPP
CEC Type	EDC	PPCP	Stimulant	Artificial Sweetener	Flame Retardant
Removal	Varied Estimates Based on Literature				

Design Hydraulics

Flowrate

52 gal/min

Operating Volume



1.8 MGal

Hydraulic Retention Time

17 Days

Hydraulic Loading Rate

1.6 in/day

Wetland Area

1.59 Acres

Vegetation Characteristics

- Aquatic
- Native
- Perennial
- Aesthetics
- Functional
- Non-Invasive

Lanceleaf Frogfruit
Phyla lanceolata

Common Duckweed
Spirodela polyrrhiza

Soft Rush
Juncus effusus

American Bulrush
Schoenoplectus americanus

Courtesy of the New York Natural Heritage Program

Geotechnical Considerations

Substrate

- Natural substrate
- Biochar

PVC Liner

- Prevents water infiltration
- Stability

Berm Rebuilding

- Water retention
- South pond, east berm

- Healthy vegetation
- High sorption

Final Design

OKTO Engineering

OKTO Engineering

Annie Gilliam
Hydrologic Modeling

Jakob Cullifer – Leader
General Wetland Design

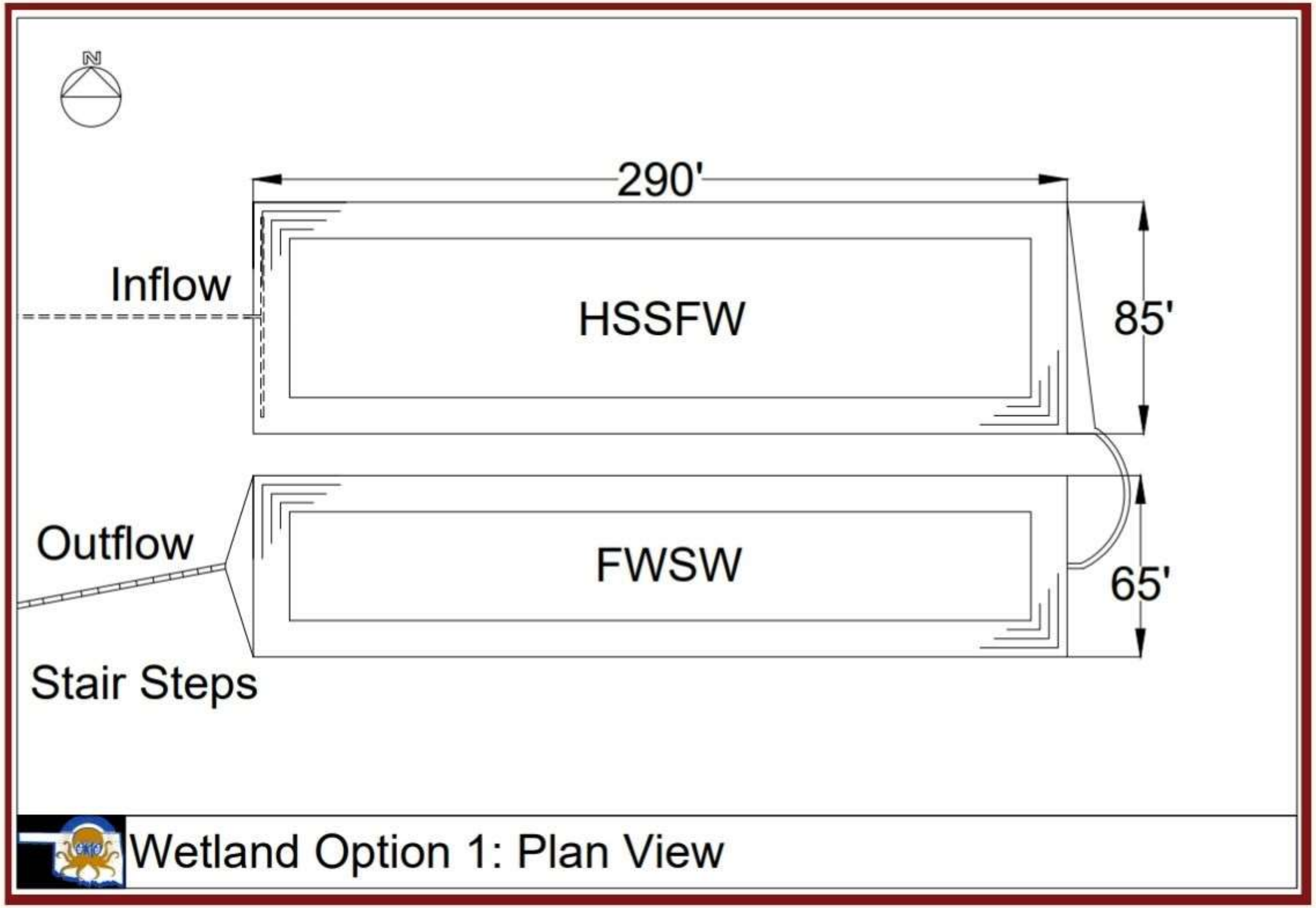
Holly Jones
Water Treatment

Abdallah Al Balushi
Cost Analyst

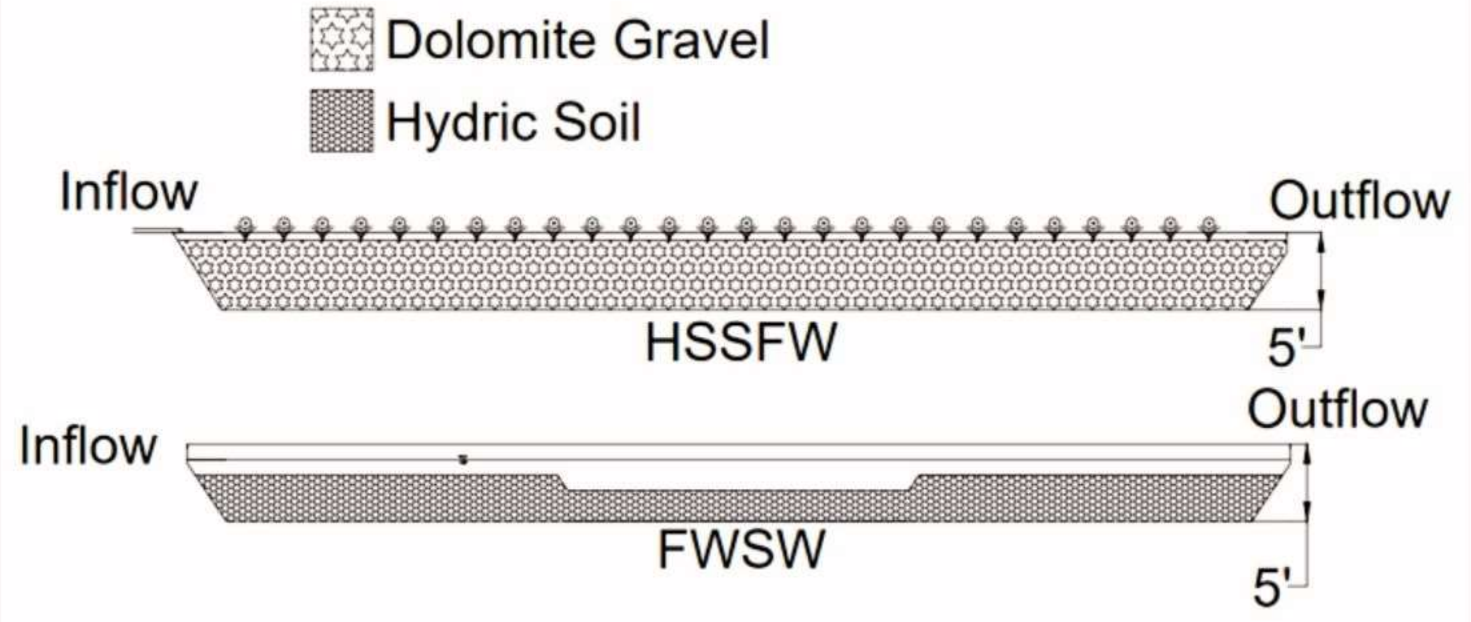
Nathaniel Wright
Vegetation Specialist &
Water Data Analyst

Elizabeth Watts
Soil & Water Data Analyst

Wetland Alternative #1

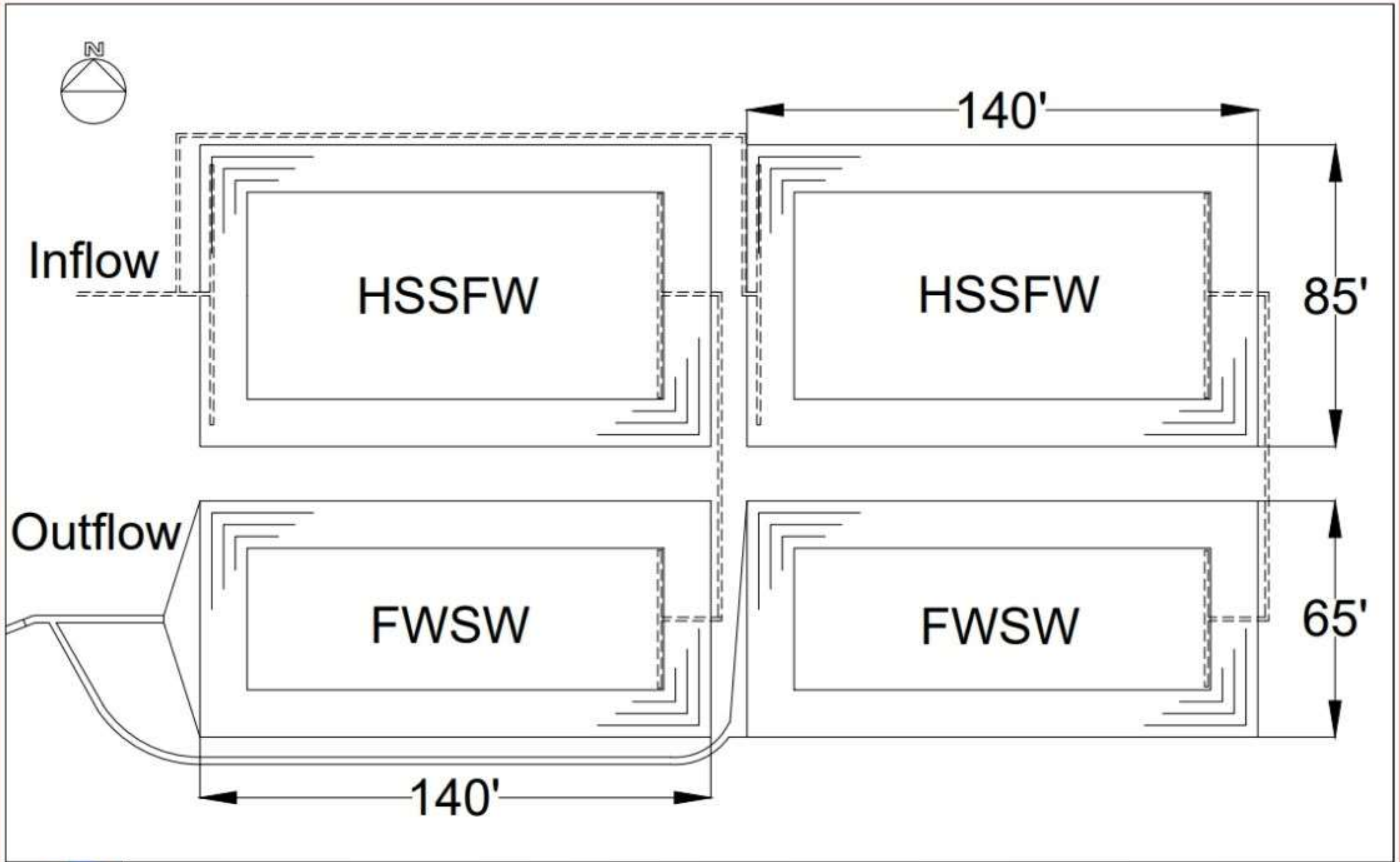


Wetland Alternative #1



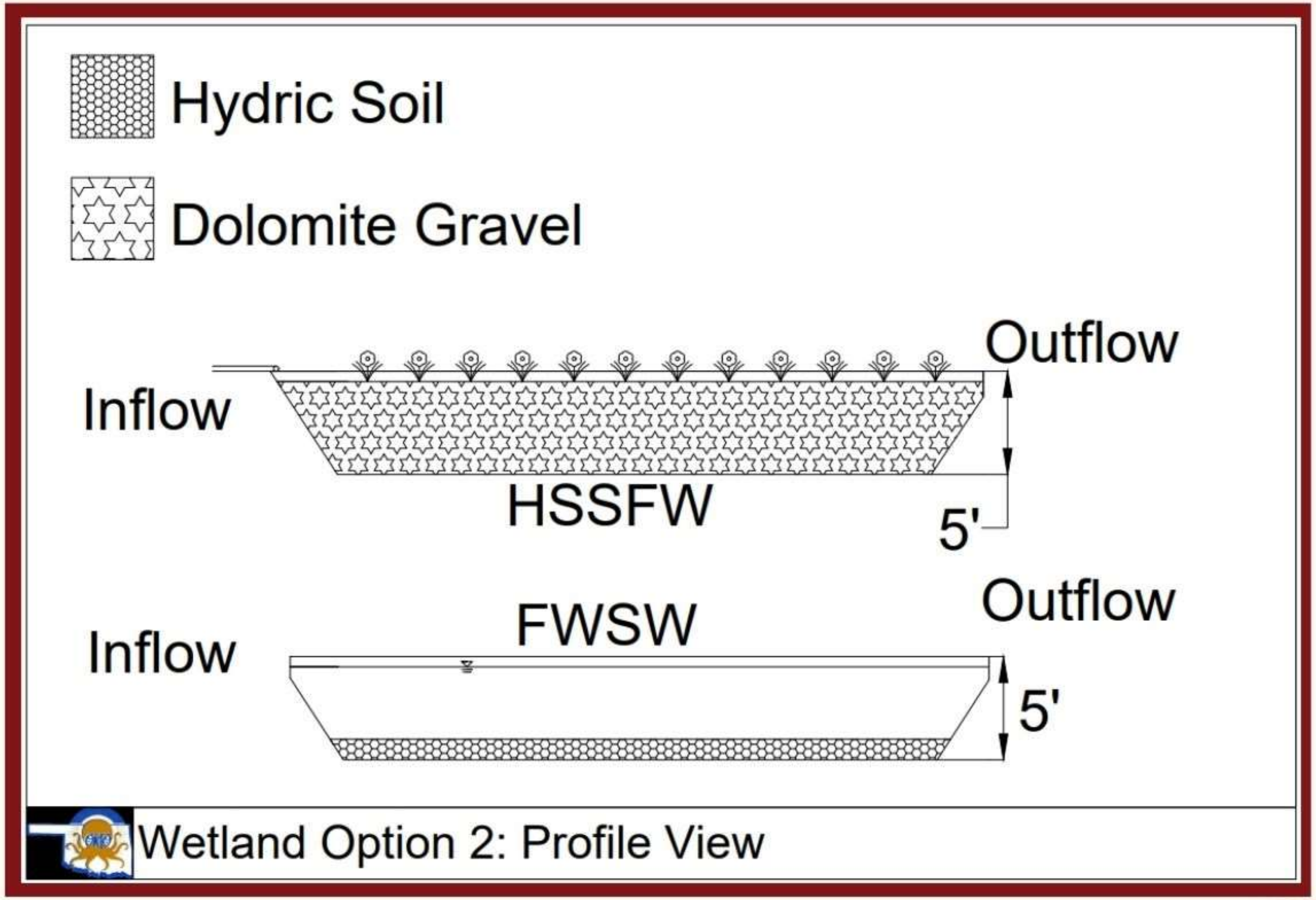
Wetland Option 1: Profile View

Wetland Alternative #2

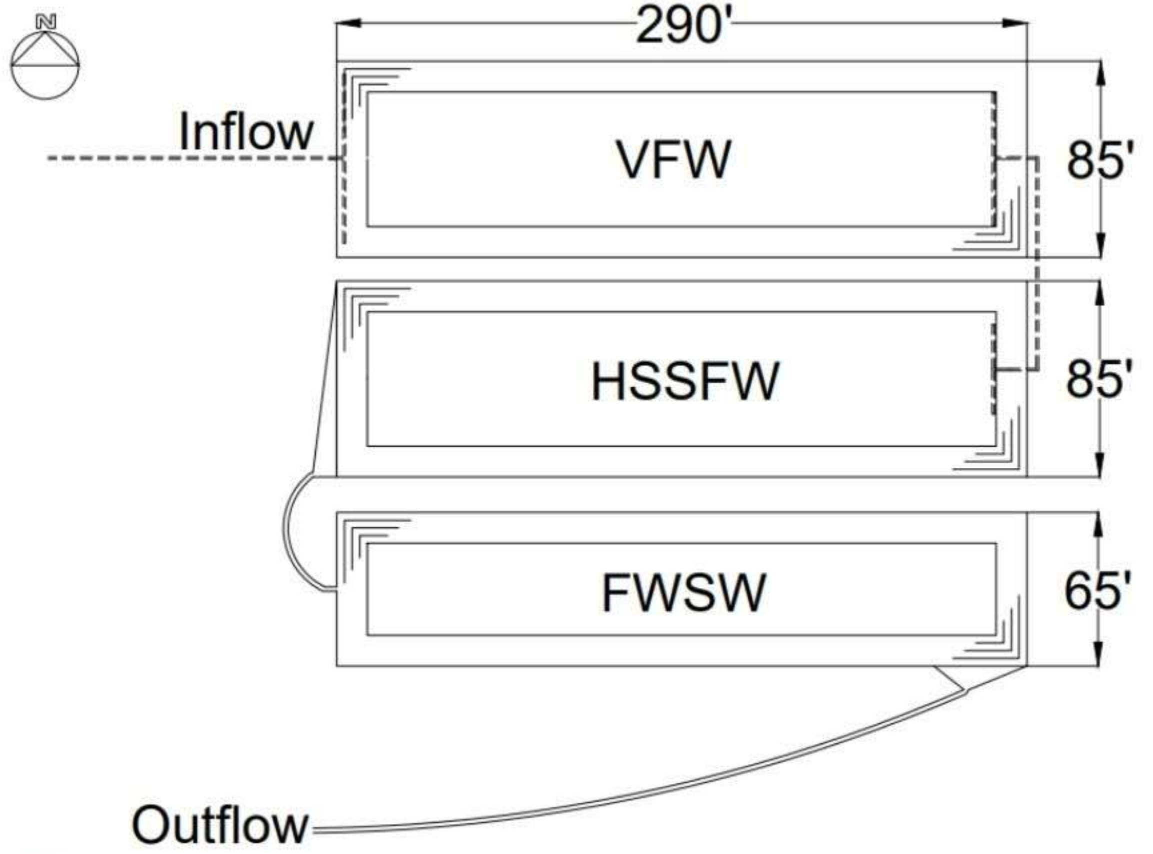


Wetland Option 2: Plan View

Wetland Alternative #2

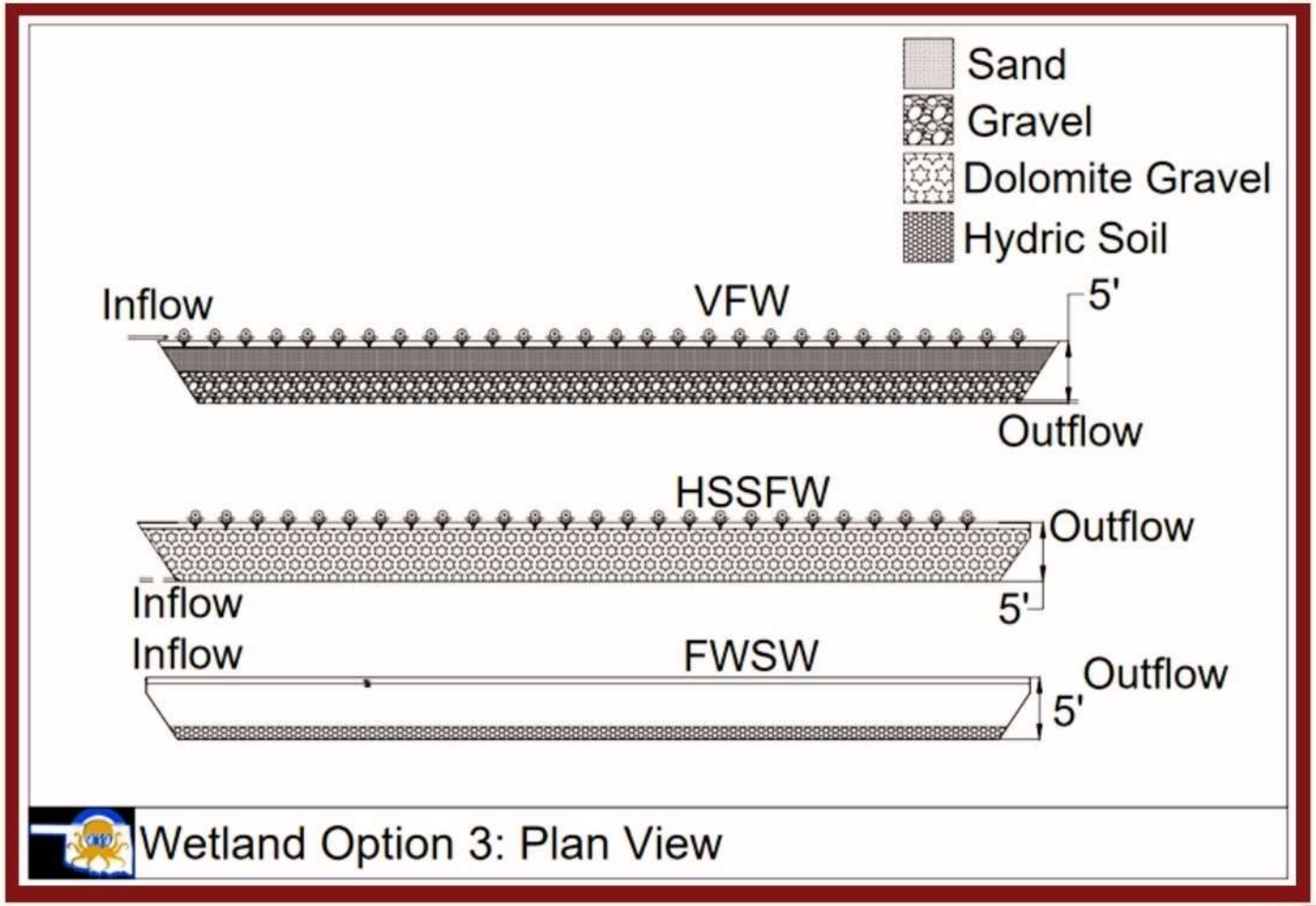


Wetland Alternative #3

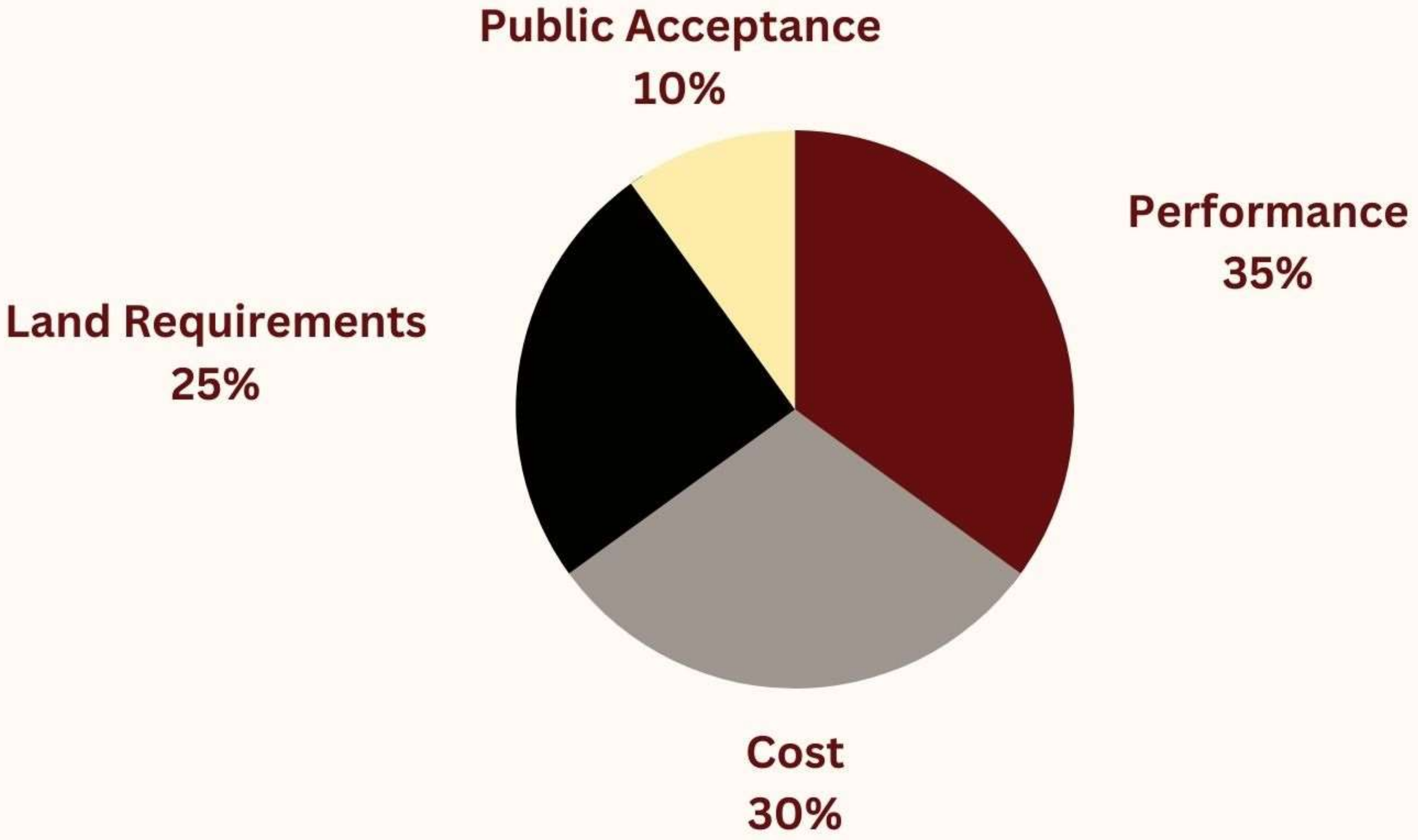


Wetland Option 3: Plan View

Wetland Alternative #3

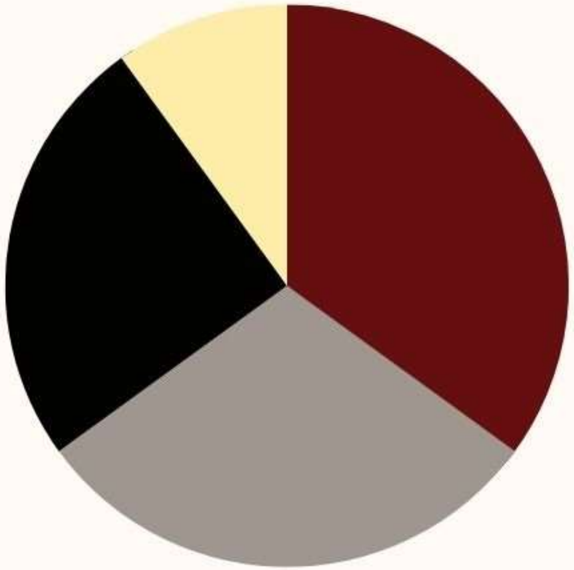


Evaluation System for Design Options



Evaluation System for Design Options

- Public Acceptance
    - Aesthetics
    - Activities



- Performance
    - Nitrate + Nitrite: 10 mg/L
    - Dissolved Reactive Phosphorus: 1 mg/L
    - CECs: Literature removal efficiencies

- Land Requirements
    - Space constraints

- Cost
    - Construction
    - O&M
    - Planned Replacements (5 years)

Preferred Wetland Alternative

Option 1

- HSSFW for Nitrogen
- FWSW for Phosphorus
- Removes target CECs
  - Sulfamethoxazole, Triclosan, Trimethoprim, Estrone, Diclofenac
- Utilizes native vegetation
  - Bulrush, Cattails, Water Lilies

Wetland Vegetation

HSSFW

- *Typha latifolia* (Cattail)
- *Schoenoplectus americanus* (Bulrush)
- *Panicum hemitomon* (Maidencane)

FWSW

- *Typha latifolia* (Cattail)
- *Schoenoplectus americanus* (Bulrush)
- *Nymphaea odorata* (Water Lily)

Physical Dimensions

North Pond (HSSFW)

- Surface Area: 23,300 ft^2
- Operating Volume: 28,000 ft^3
- Operating Depth: 4.5 ft
- Freeboard: 0.5 ft

Physical Dimensions

South Pond (FWSW)

- Water Surface Area: 17,100 ft^2
- Operating Volume: 39,000 ft^3
- Operating Depths: 1 ft - 2 ft
- Freeboard: 1 ft

Hydraulics

- HLR = 5.5 in/day
- HRT = 8 days
- Wetland flow rate = 40 GPM
- Flow rate varies ± 2% due to ET and precipitation

Contaminant Removal Efficiency

Nitrate+Nitrite	73% removal
Dissolved Reactive Phosphorus	55% removal
Target CECs	Removal varies

Cost Estimate

Construction: $380,000

Design Fee: $76,000

Start-Up Cost: $19,000

O&M: $25,000 (20 years)

Planned Replacements: $110,000

Total Cost: $ 610,000

Nairnia Engineering

Nairnia Engineering Members

Katrina Mason
Team Leader, Hydraulic and Hydrologic Design

Lauren Franze
Sample Data and Cost Analytics

Ariel Gillen
QA/QC, Geotechnical Design

Enrique Lambert
Vegetation, Public Acceptance

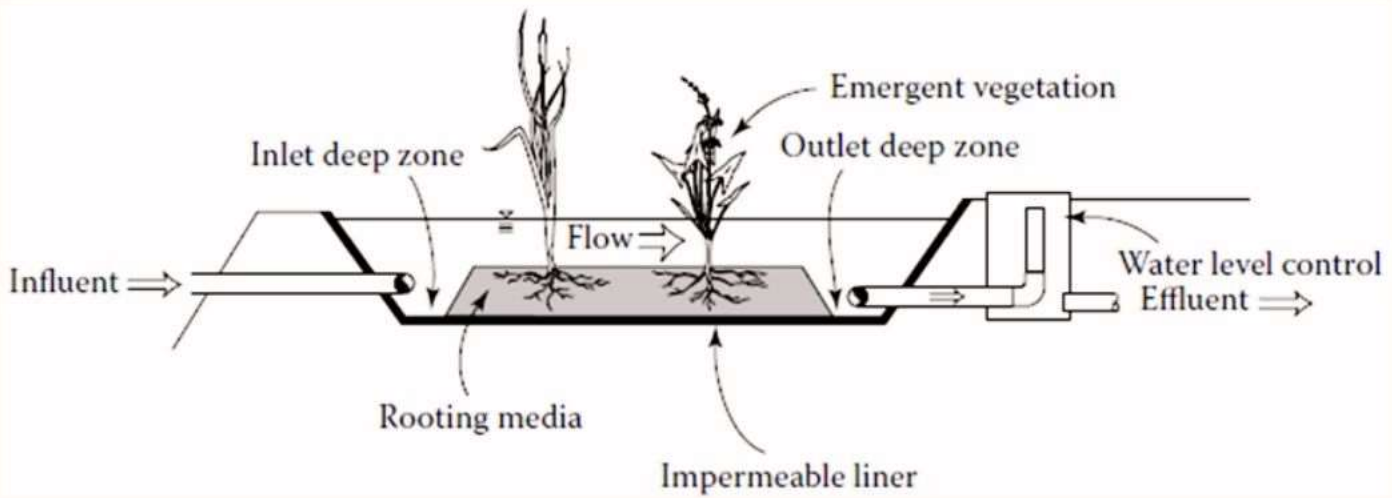
Daniel Guevara
Hydraulic and Hydrologic Design

Design Alternative #1

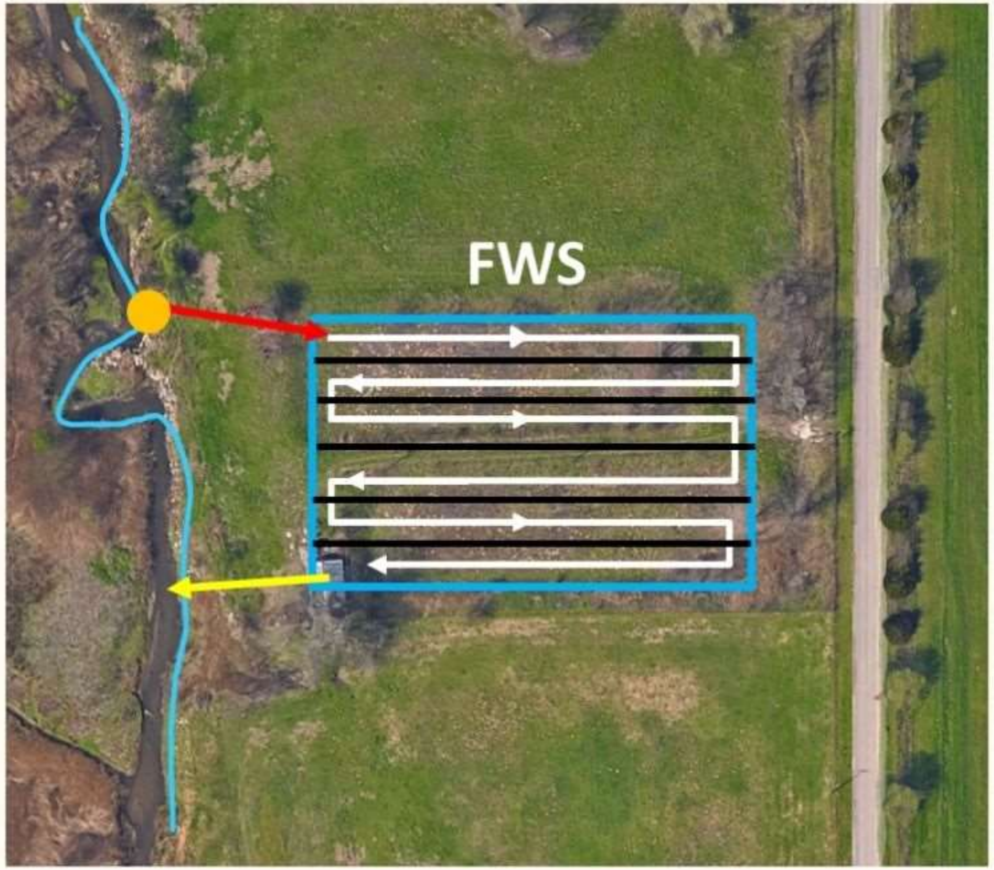
Construction: $170,000

O&M: $130,000 (30 years)

Net Present Worth: $300,000



(Kadlec and Wallace, 2009)

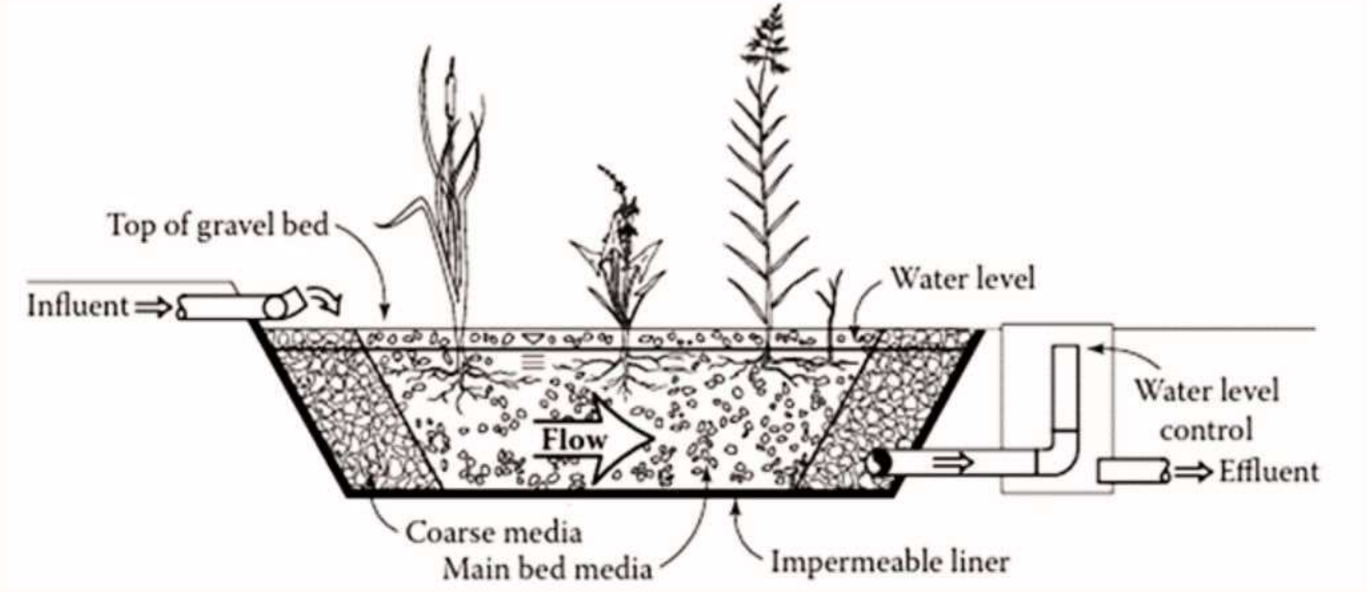


Design Alternative #2

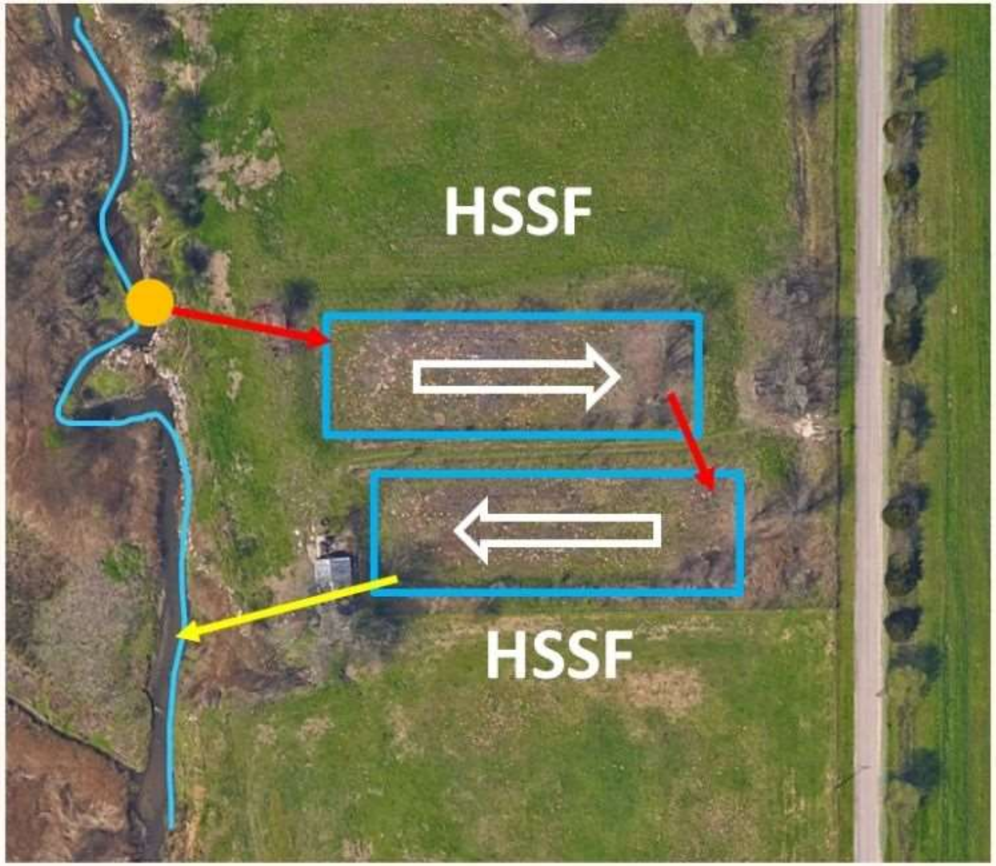
Construction: $710,000

O&M: $111,000 (30 years)

Net Present Worth: $821,000



(Kadlec and Wallace, 2009)

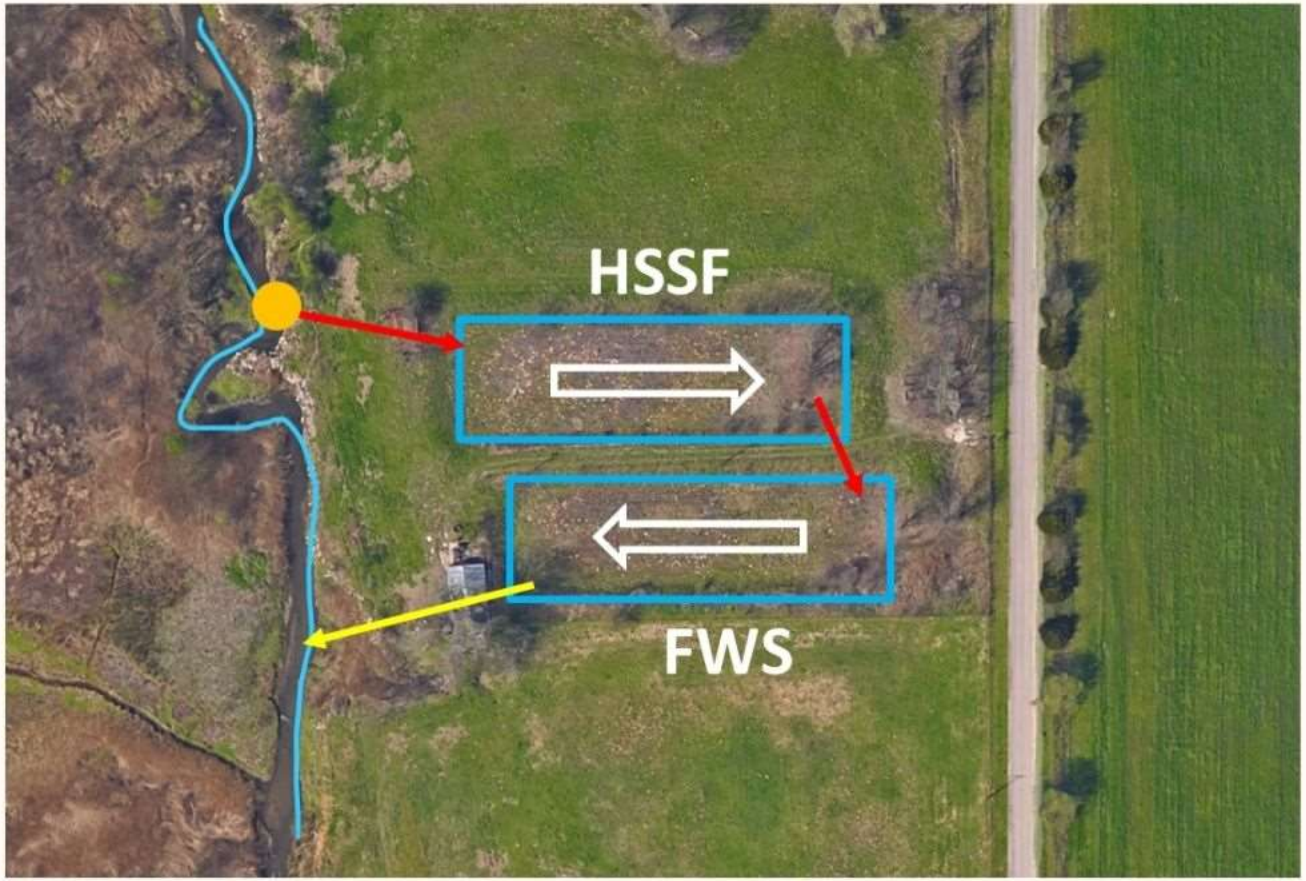


Design Alternative #3

Construction: $580,000

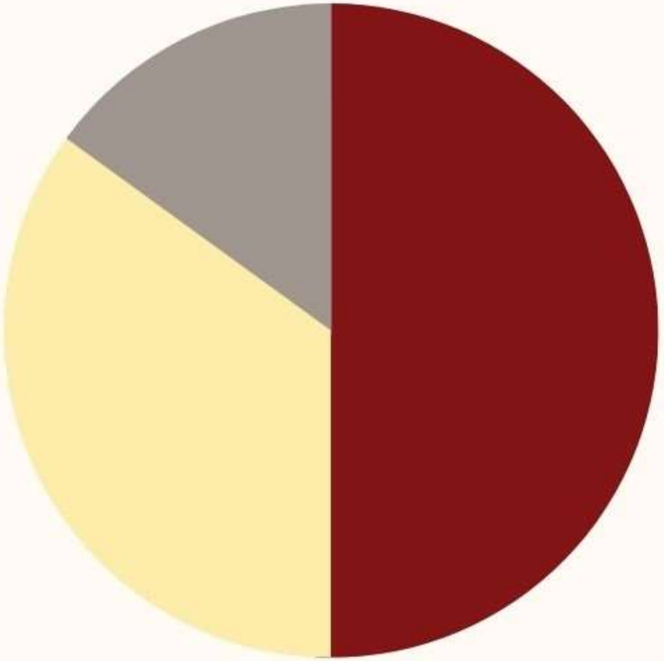
O&M: $100,000 (30 years)

Net Present Worth: $680,000



Evaluation System for Design Alternatives

Public Acceptance
15%



Efficiency
35%

Cost
50%

Cost

- Construction and O&M

Efficiency

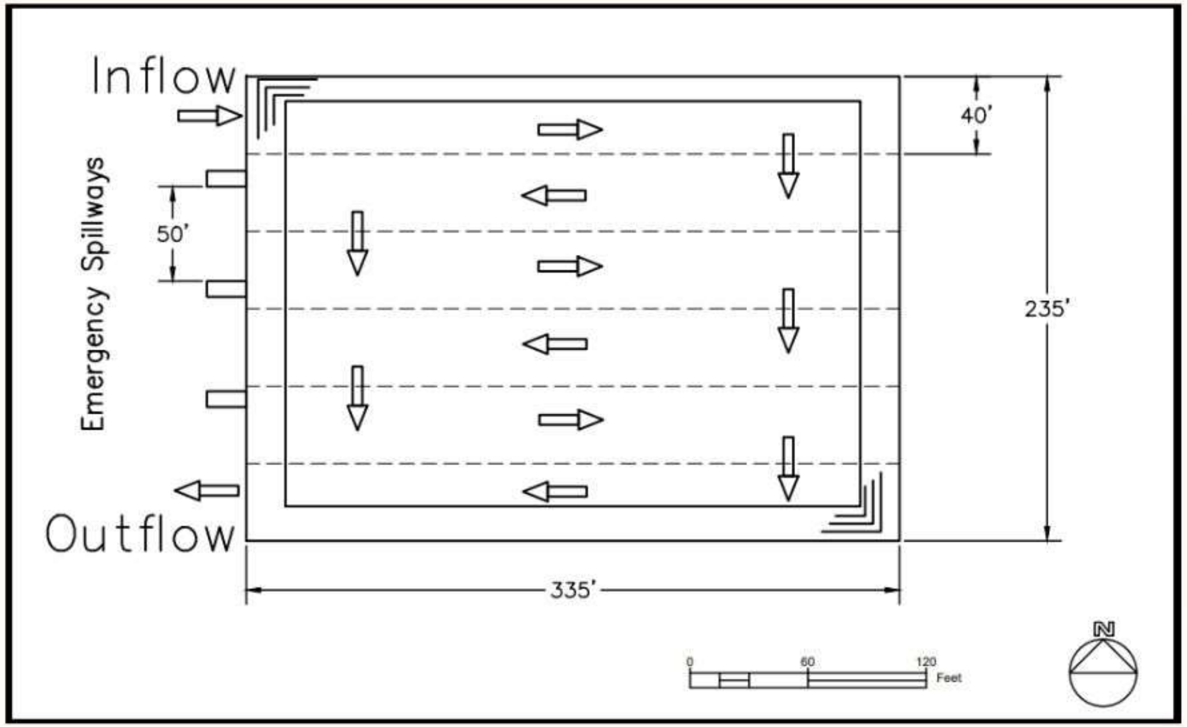
- Nitrate + Nitrite: 10 mg/L
- Dissolved Reactive Phosphorus : 0.09 mg/L
- CECs: Biodegradation rates

Public Acceptance

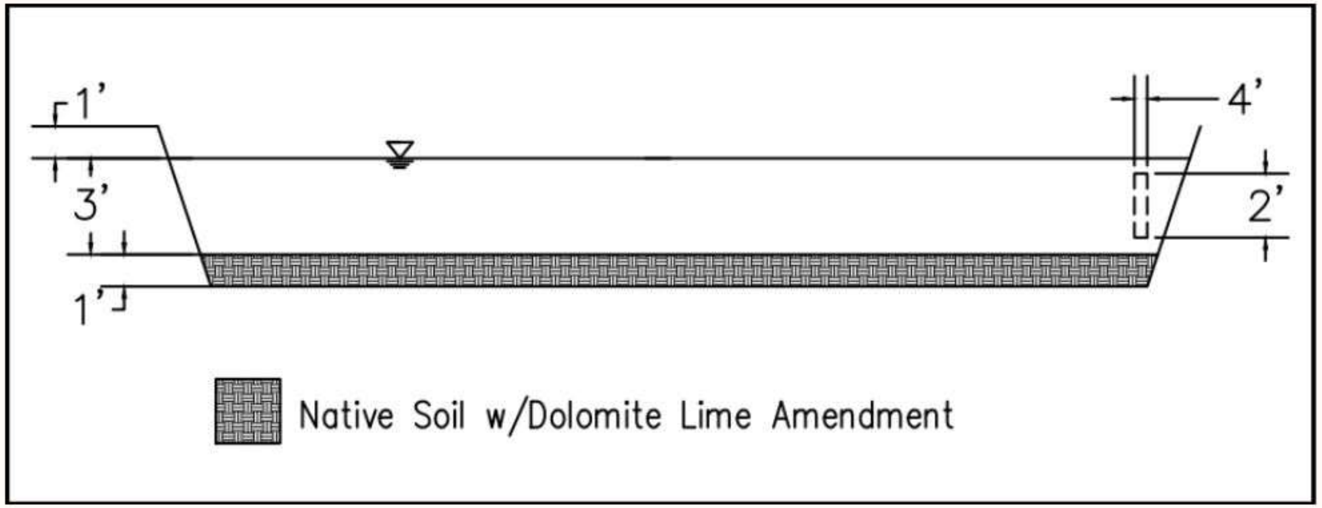
- Anticipated public perception and feedback

Selection of Preferred Alternative

Schematics of Preferred Alternative



Plan View



Profile View

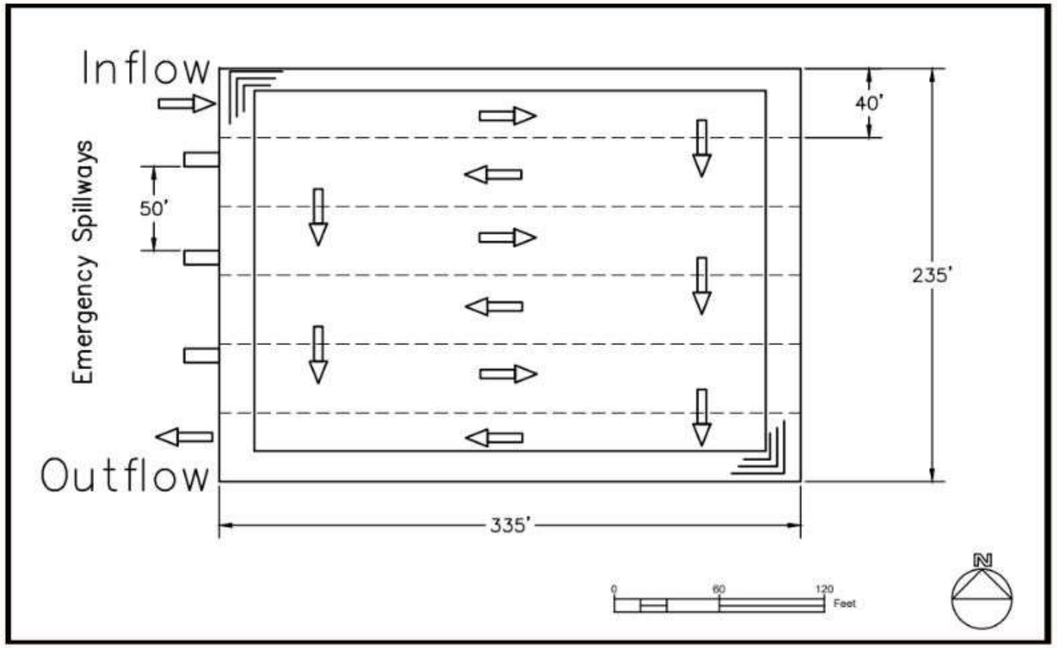
Footprint: 1.8 acres
Volume: 5 acre-ft

Flow: 82 gpm
HRT: 49-69 days

HLR: 0.67 in/d (49 days)
0.47 in/d (69 days)

Hydraulics

- **Automated pump**
- **Emergency spillways**
- **3" PVC pipe for inflow and outflow**
  - **Concrete channel for effluent**



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Geotechnical Design

- Removal of central berm
- Multiple emergency spillways and effluent channel
- High-density polyethylene (HDPE) liner
- 1' layer of soil with dolomite substrate

Vegetation

TP/TN Removal

- ***Ceratophyllum dermersum*** **(Coontail)**
- ***Vallisneria americana*** **(Eelgrass)**
- ***Canna indica*** **(Indian shot)**

CEC Removal

- ***Scirpus validus*** **(River club-rush)**
- ***Panicum virgatum*** **(Switchgrass)**

Mosquito Control

- ***Syngonium podophyllum*** **(Arrowhead)**
- ***Alisma subcordatum*** **(American water plantain)**

Eelgrass

River club-rush

Arrowhead

Contaminant Removal Efficiency

Nitrate + Nitrite

0.62 - 1.17 mg/L
93-96% removal

Dissolved Reactive Phosphorus

0.40 - 0.60 mg/L
73-82% removal

Acesulfame, Caffeine, Acetaminophen, Sucralose, Sulfamethoxazole

Removal varies

Cost Estimate

- **Capital Costs**
  - **≈ $170,000**
- **Operation and Maintenance Costs**
  - **≈ $130,000 (30 years)**
- **Net Present Worth**
  - **≈ $300,000**

Ending Remarks

Recommendations

- Compile database of measured CECs in NWRF effluent
- Develop design criteria for CEC removal based on mesocosm studies
- Assess viability of underlying groundwater as environmental buffer

Limitations

- Land area available is small
- CEC concentrations in effluent are highly variable
- Design criteria for CEC removal in wetlands do not exist
- Site could be flooded from Canadian River

Conclusions

- **Nature-based solutions can be used for indirect potable reuse**
- **Viable technology applied in other states**
- **Wetlands have effective nutrient removal**
- **CEC removal not well characterized**
- **Land intensive, but economical**

Acknowledgements

- City of Norman
  - Steven Hardeman, NWRF Utilities Superintendent and Plant Manager
  - Chris Mattingly, PE, Norman Utilities Director
  - Michele Loudenback, Division of Environmental Resilience and Sustainability
- Center for Restoration of Ecosystems and Watersheds
  - James Queen, Graduate Teaching Assistant
  - Justine McCann, Graduate Research Assistant
  - M'Kenzie Dorman , Graduate Research Assistant
  - Steinar Dahle, Graduate Research Assistant
- Dr. Russell Dutnell, PE, Riverman Engineering LLC
- Dr. Gerald Miller, PE, University of Oklahoma CEES Professor

Acknowledgements

- Environmental Engineering and Science Advisory Board
  - Shellie Chard, Water Quality Division - Department of Environmental Quality
  - Jason Masoner, US Geological Survey
  - Nathan Kuhnert, US Bureau of Reclamation
  - Steve Hardeman, Utilities Superintendent and Plant Manager
  - Chris Mattingly, PE, Norman Utilities Director
  - Michele Loudenback, Division of Environmental Resilience and Sustainability
  - Kyle Arthur, Central Oklahoma Master Conservancy District
  - Amanda Nairn, Central Oklahoma Master Conservancy District

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Thank you

We are now open for questions

PUDDLE BEAR WETLAND SOLUTIONS

NAIRNIA ENGINEERING

Environmental Science and Engineering Capstone Class of 2023

CEES 4913/4923