



Kendra Waltermire

**Lessons Learned from
Mature Phyto Plots Drive
Optimizations for New Design**

Jacobs

**Challenging today.
Reinventing tomorrow.**

1999

Wood Preservative Waste Remediation with Tree Plot

Laramie, Wyoming



2004

Cottonwood Trees to Address Toluene, Ethylbenzene, Xylenes, and Phenol

Pensacola, Florida



Hydraulic Control and Vegetative Landfill Cap

Tualatin, Oregon

1990

Hexavalent Chromium Reduction with Grasses

Hinkley, California

2001

Seep Control on Industrial Landfill Cap

South Charleston, West Virginia

2019

Soil and Groundwater Contamination

Mature Plots



Shallow Plume Interception



Landfill Cap and Leachate Treatment

Mature Plot Problems

- Slow removal uptake rate or degradation rate
- Decrease or no uptake during winter months
- Phytotoxicity and other stressors
- Contaminant degradation stalling at daughter compounds
- Decreased remediation due to inadequate rooting depth
- Long-term irrigation requirements
- Loss of land use long-term for client



Houston, we've had a problem here. – Jim Lovell

Questions for Mature Plot Success

- ✓ Are the root systems interacting with site COCs?
- ✓ Is the plot reducing site COCs?
- ✓ Are specific areas meeting the threshold/criteria?
- ✓ Is hydraulic control established as planned?
- ✓ Is biomass increasing, or stabilized?
- ✓ Are plants in good health/vitality?
- ✓ What is the timeline to final clean closure?



Long-term Monitoring

Water Consumption and Balance

- Pressure transducers
- Frequency domain reflectometry

Microbial Community Samplers

- Bio-Trap® Samplers
- Phospholipid fatty acid (PFLA) samples
- Next-generation sequencing

Rooting Depth

Contaminant concentration reduction

- Bioaccumulation in plant tissue
 - Tree core sampling
 - Plant tissue analysis
- Nutrient Evaluation
 - Salinity increasing with ET
 - Macro- and micro-nutrients
- Plant biomass measurement
- Vegetative Cover Density
- Capillary Fringe Area



Operation and Maintenance; Low Cost, Not No Cost



Proactive maintenance

Retrofitting is important

Plant expert to inspect at least once per year

- Plants monitored for animal, fungus, and insect damage

Pruning, such as removal of suckers

Repairs to the irrigation system and lines

- Adjustments to irrigation schedule and drip lines

Fertilization or application of compost/manure

Additional plantings

Seeding of forbes, legumes, and grass



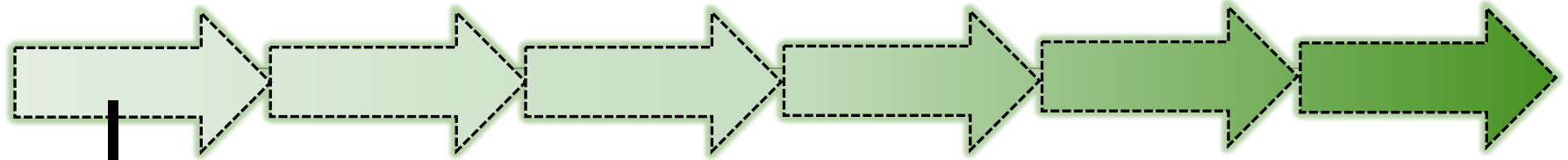
Before pruning



A well-shaped plant
after pruning

New Phytotechnology Solutions

Jacobs



Endophytes



What are Endophytes?

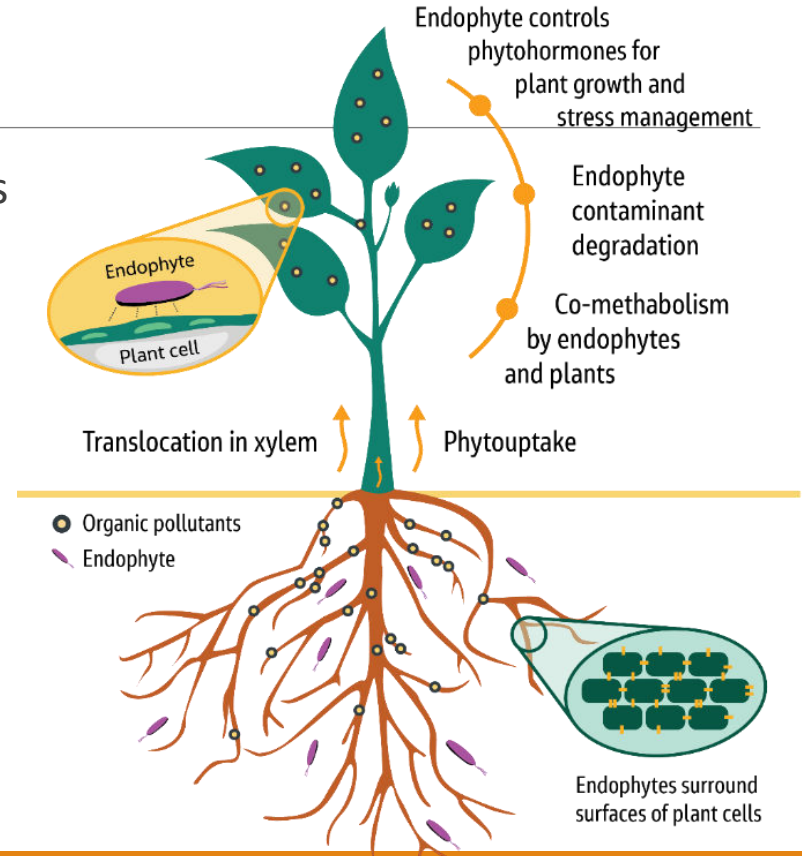
Internal symbiotic organisms living inside trees

Select endophytes have adapted to environmental challenges

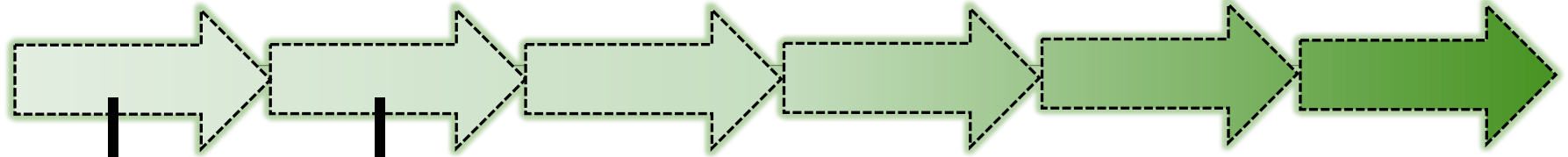
- Isolated, characterized in the lab

Inoculated trees can tolerate higher levels of stress which enhances:

- tolerance to the contaminants,
- survival,
- growth,
- vitality,
- enhanced contaminant degradation rates



Phytoremediation Has Progressed



Endophytes

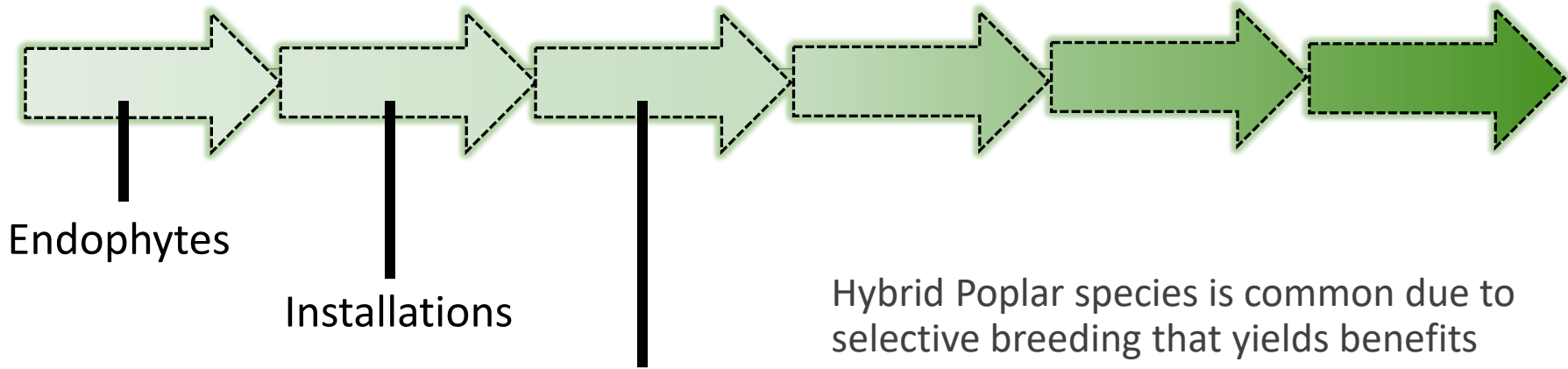
Installations

Tree poles

Deep borings



Phytoremediation Has Progressed

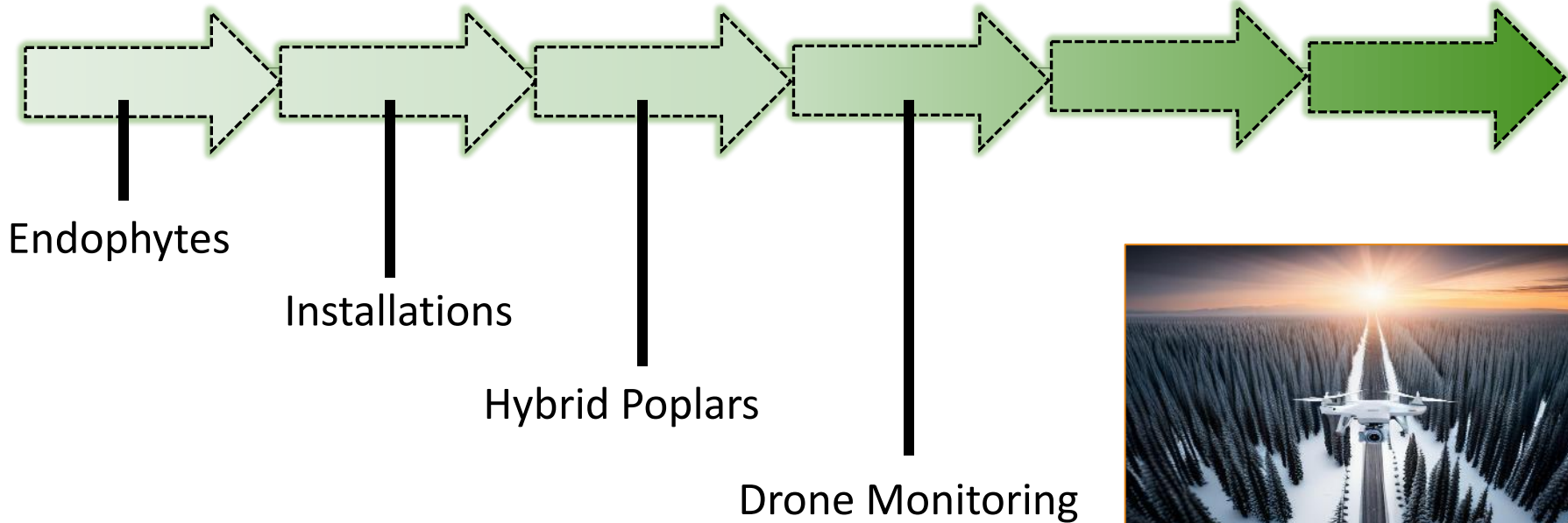


Hybrid Poplar species is common due to selective breeding that yields benefits

- Rapid growth (six to ten times faster than similar species)
- High water yield (up to 3,000 gal/yr/tree)
- Enhanced tolerance to chemicals
- Disease-resistant species
- “Nurse” trees for native species in mixed plantings
- Deep rooting and tolerant of bore hole planting

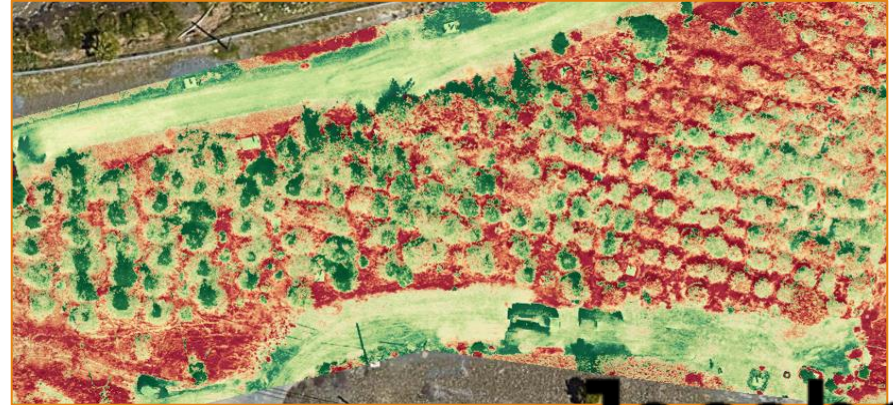


Phytoremediation Has Progressed



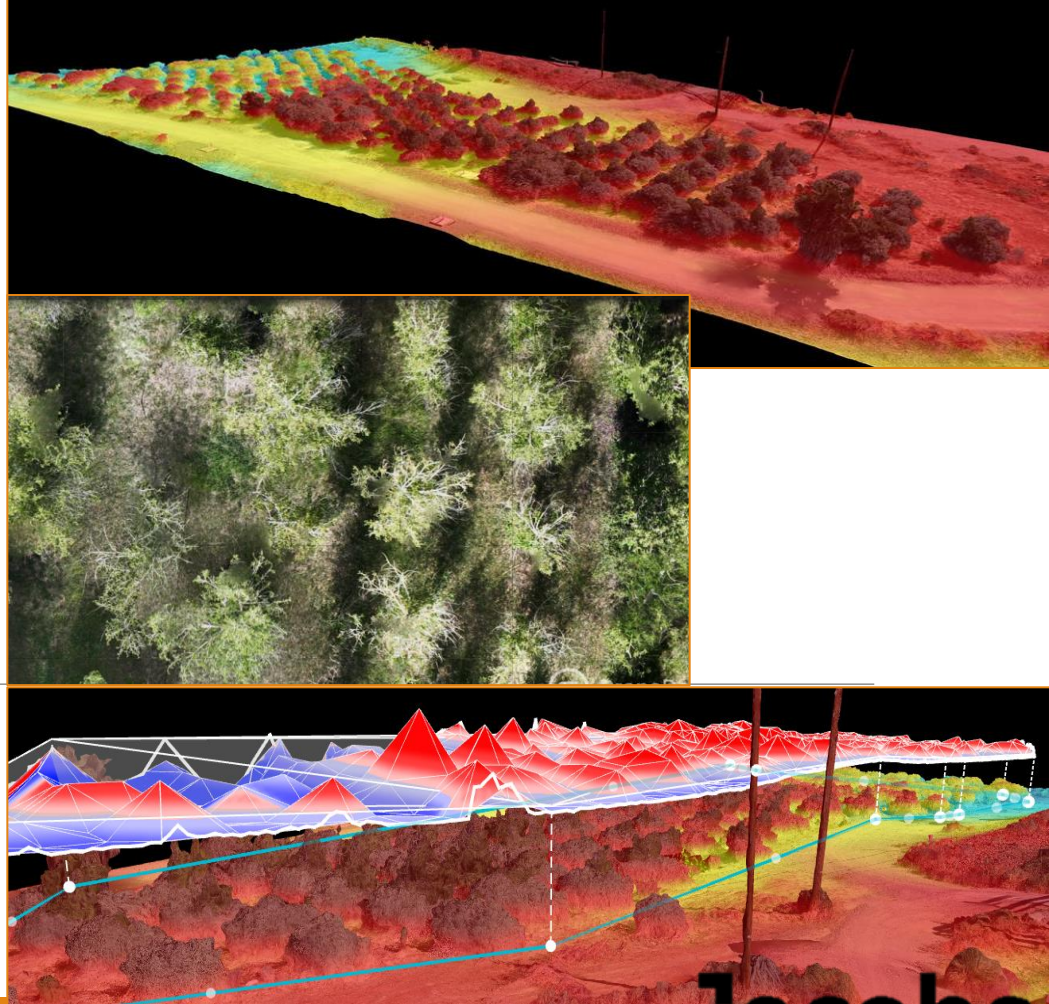
Example Site Using Drone Monitoring

- Chemical manufacturing plant with phyto-capped mercury waste landfill next to a river
- Plants root through cover soil directly into high-salinity landfill waste to remediate and create an inward hydraulic gradient
- 10-year-old site is mature with 80% canopy cover, 10 m trees, 2 m tall salt bush, plus 8 other species
- Annual biomass measurements are used to update the water balance model
- Large areas of dense vegetation – cannot walk through for monitoring
- Stressed plants in dense areas are only visible from drone images



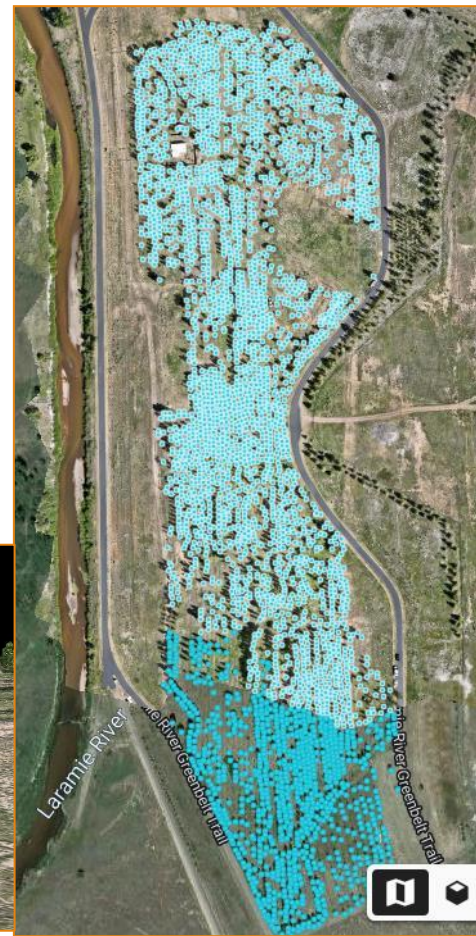
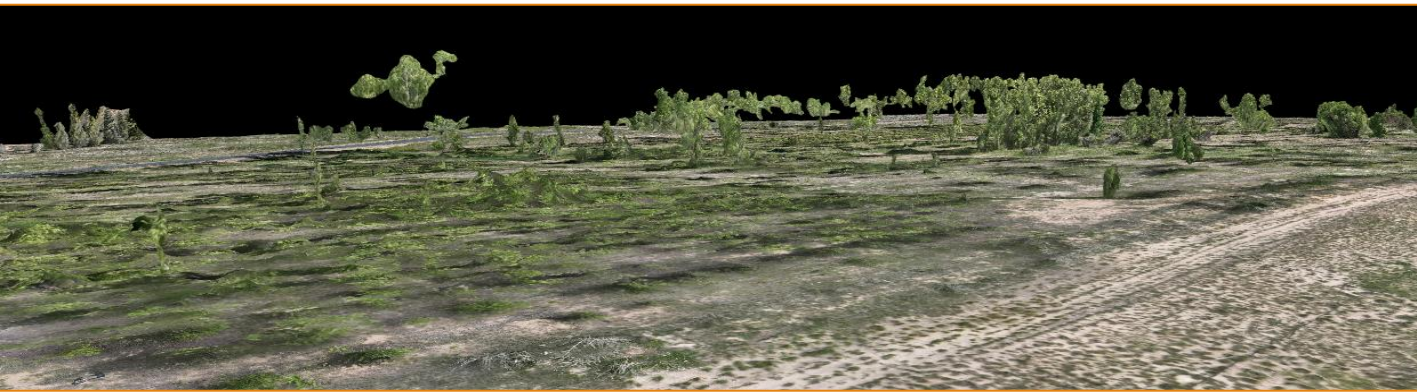
Typical Deliverables from Drone Image Capture

1. Photos/video/panoramas
 - Single photos/videos
 - Stitched and 360° panoramas
2. High-resolution orthorectified imagery
(accurate measurements)
3. 3D Model and resulting derivatives
 - Digital elevation and terrain models
 - 3D object model; Point Clouds
4. Vegetation health index (with special infrared sensors)

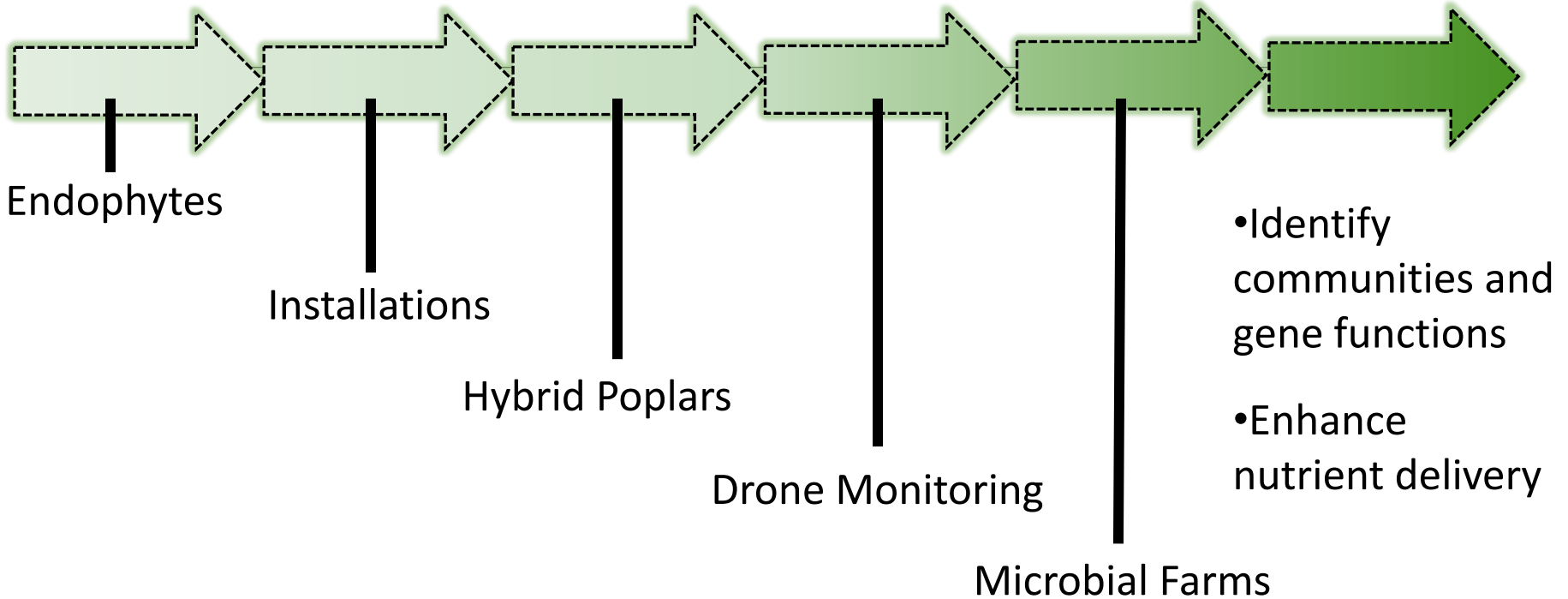


Focused Management

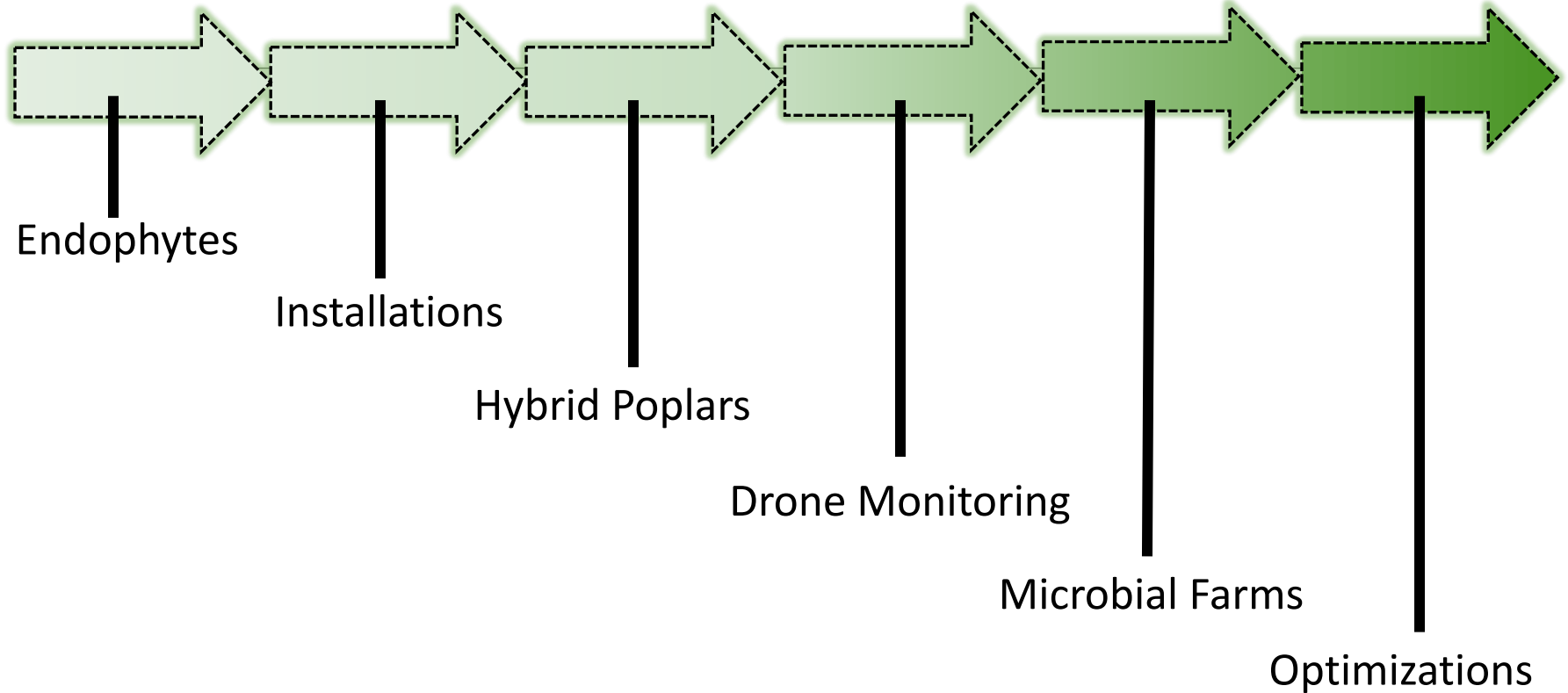
- 3D models can track accurate biomass and vigor changes over time
- Currently developing algorithms and working with new software that provides higher accuracy for shadows and movement



Phytoremediation Has Progressed



Phytoremediation Has Progressed



Resilience to Climate Change



Resilient to moderate sea level rises

In the San Francisco Bay area, a life cycle assessment (LCA) determined primary and secondary impacts from moderate sea level increase on a shoreline site

The moderate increase in sea level rise decreased groundwater hydraulic gradient; therefore, reduced plume migration and increased natural biodegradation.

Source: Phytoremediation: Climate change resilience and sustainability assessment at a coastal brownfield redevelopment, Environment International, Volume 130.



Design for resilience

Select species that can be effective in both today's conditions and the future 20 + years

- Drought-tolerant
- Marsh or riparian species

Allow adaptability due to climate change in the design

Design for additional species additions on a cycle such as every decade to stay ahead of the changes

Carbon Offsets



Benefits of Trees

- Carbon Dioxide Removal (CDR)
- Increased health
- Increase water infiltration rates
- Reduced temperatures



Net Zero Offsets

- Typical offset is 10 tons of carbon per acre of trees per year
- Need to ensure proper selection of trees, including proper O&M funded and scheduled for at least 25 years
- Many companies have carbon offset goals and are a part of the United Nations “Business Ambition for 1.5 degree C” initiative and the UN-supported global campaign, “Race to Zero”

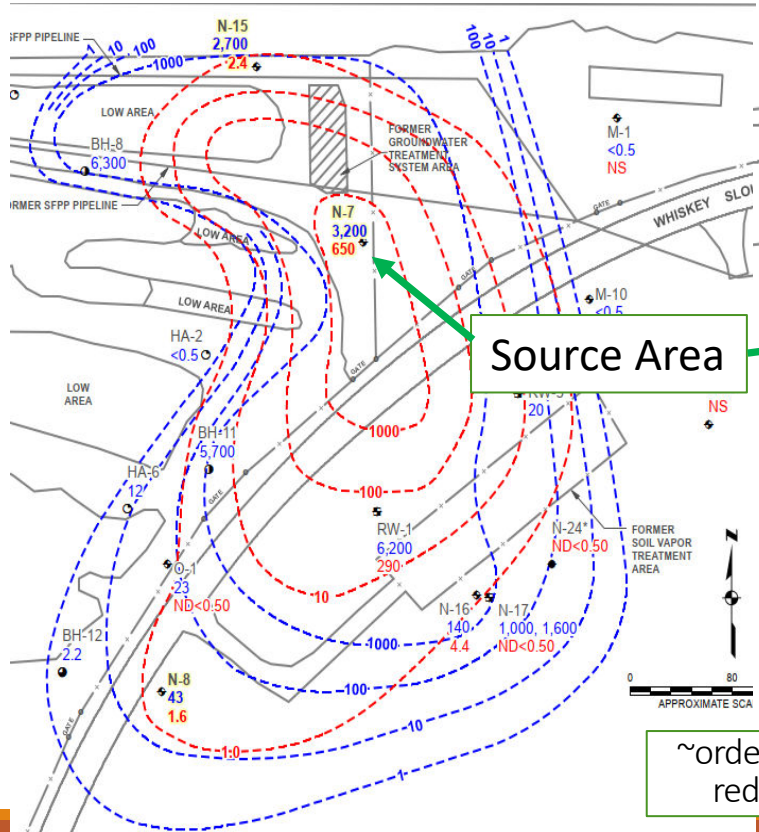
Green Design Options



- Solar-powered pump for drip irrigation potentially from an existing monitoring well
- Capture rainwater for irrigation water from nearby buildings or air conditioning condensation
- Dense ground cover to reduce weed growth
- Native species to enhance biodiversity and aesthetics

Holt, CA – Benzene ($\mu\text{g/L}$)

2001 and 2021



Explanation:

- ◆ Shallow Groundwater Monitor Well
- Deeper Groundwater Monitor Well
- ⊕ Groundwater Extraction Well
- Fence
- Hand Auger Borings - Shallow
- Direct Push Borings - Shallow
- Direct Push Borings - Deep

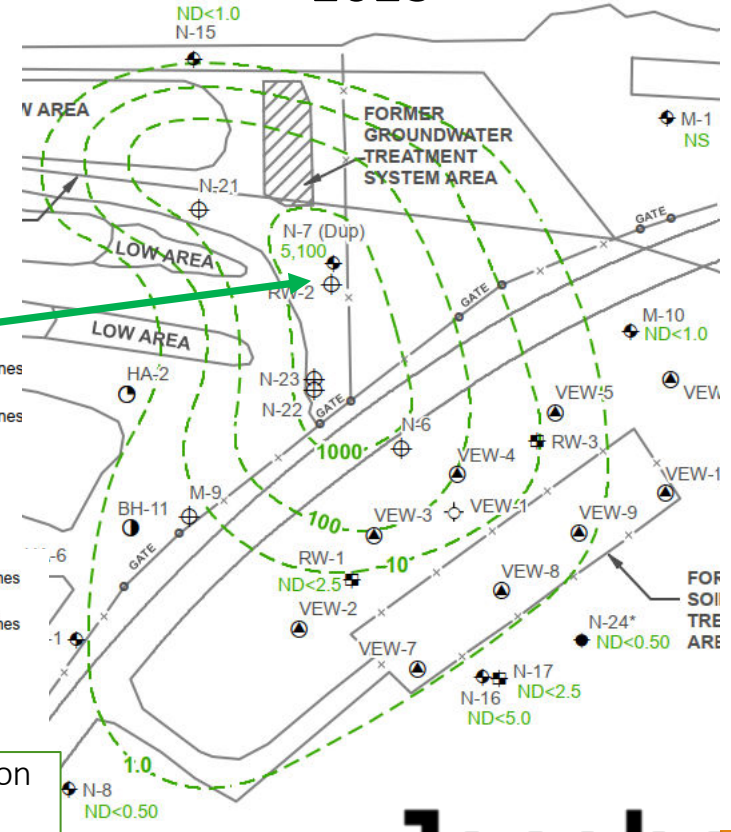
2001 Source Area Investigations

- Hand Auger Borings - Shallow
- Direct Push Borings - Shallow
- Direct Push Borings - Deep

- - - Dissolved TPHg Isoconcentration Contour Lines Based on Spring 2021 Analytical Data
- - - Dissolved TPHg Isoconcentration Contour Lines Based on Fall 2001 Analytical Data
- 1.1 Dissolved TPHg Concentration Milligrams per Liter (mg/l)
- 20 Historical Dissolved TPHg Concentration Milligrams per Liter (mg/l)
- - - Dissolved Benzene Isoconcentration Contour Lines Based on Spring 2021 Analytical Data
- - - Dissolved Benzene Isoconcentration Contour Lines Based on Fall 2001 Analytical Data
- 3.1 Dissolved Benzene Concentration Micrograms per Liter (ug/l)
- 20 Historical Dissolved Benzene Concentration Micrograms per Liter (ug/l)

~order of magnitude concentration reduction and receding plume

2023



Tree Poles and Endophytes






One Year Later (2022)

Two Years Later (2023)

Updated Photos



Questions?
Thank you!

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Jacobs booth #26

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