T2PM Workshop Report

Treatment Technologies for Phosphorus Mitigation

Everglades Research and Education Center | Belle Glade, Florida
April 21–22, 2026

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Executive Summary

Excess phosphorus (P) is one of the most pervasive water quality challenges in the United States. This challenge is particularly acute — and consequential — in South Florida, where agricultural and urban runoff flows through the watershed and a network of canals toward Lake Okeechobee, the Caloosahatchee and St. Lucie estuaries, the Stormwater Treatment Areas (STAs), and ultimately the Everglades Protection Area. Even at very low concentrations, excess P disrupts native plant communities, fuels harmful algal blooms, degrades habitat, and undermines the ecological and economic vitality of one of the world's most significant wetland systems.

South Florida has invested substantially in addressing this challenge. Five large-scale STAs, encompassing approximately 62,000 acres, have collectively removed over 4,700 metric tons of phosphorus since 1994 — a landmark achievement. Best Management Practices (BMPs) in the Everglades Agricultural Area (EAA) have exceeded their mandated 25% P load reduction target for decades. Yet despite these incredible achievements, some challenges persist in meeting the U.S. EPA's Water Quality-Based Effluent Limit (WQBEL) of 19 parts per billion (ppb) total P (TP) in outflow.

This gap between what existing infrastructure achieves and what regulation requires was the driver for bringing different stakeholders together to discuss current P capturing technologies, their use in South Florida contexts, and the benefits and challenges of each. Held on April 21–22, 2026 at the University of Florida's Everglades Research and Education Center (EREC) in Belle Glade, Florida, the Treatment Technology for Phosphorus Mitigation (T2PM) Workshop engaged approximately 50 participants from regulatory agencies, water management authorities, academia, technology industry, and environmental organizations. The event was organized under the T2PM initiative, a National Science Foundation Responsible Design, Development, and Deployment of Technologies (ReDDDoT) Phase 1 Planning Grant (Award No. 2427542) led by researchers associated with the NSF-funded Science and Technologies for Phosphorus Sustainability (STEPS) Center (Grant No. CBET-2019435) and the Sustainable Phosphorus Alliance.

Over two days, participants heard from six presenters covering a range of complementary P mitigation research and technologies, from engineered sorbents and ion-exchange systems to treatment wetlands and infrastructure-based approaches; toured the Taylor Creek Stormwater Treatment Area in Okeechobee County, took an airboat ride on marshlands surrounding Lake Okeechobee, and engaged in three structured roundtable discussion sessions. A pre-workshop registration survey and an earlier multi-sector P management survey (Survey 1) provided additional grounding in stakeholder priorities.

Key themes emerging from the workshop include: (1) a strong consensus that no single technology will meet South Florida's P removal challenge at scale; a portfolio approach integrating complementary technologies at appropriate deployment points is needed; (2) scalability and cost remain the dominant barriers to translating promising lab and pilot results into real-world deployment; (3) regulatory pathways and permitting complexity continue to deter early adoption of innovative technologies; (4) P recovery for beneficial reuse — as fertilizer or struvite — is viewed as an economic enabler that can offset treatment costs; and (5) field demonstration and pilot data at meaningful scale are urgently needed to support stakeholder confidence and regulatory approval.

The T2PM Workshop was designed as a catalyst, not an endpoint. Its outputs will inform a short list of viable technologies for co-development, a community of practice among participants, and future funding proposals. The lessons learned here are directly transferable to nutrient-impacted systems across the United States, including the Great Lakes basin, the Chesapeake Bay watershed, and the Mississippi Delta.

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1. Background and Context

1.1 The Phosphorus Problem in South Florida

Phosphorus (P) is an essential nutrient, but in excess it becomes a pollutant. The Everglades ecosystem evolved under extraordinarily low-phosphorus conditions — native communities such as sawgrass marshes and periphyton mats are exquisitely sensitive to even modest increases in P concentration. Historical P concentrations in the natural Everglades were typically below 10 parts per billion (ppb). Agricultural drainage and urban runoff entering the system carry P concentrations many times that background level.

The South Florida watershed drains a roughly 16,000-square-mile area extending from the Kissimmee River basin in the north, through Lake Okeechobee, the Everglades Agricultural Area, and the Water Conservation Areas, to Florida Bay in the south (Figure 1). Agricultural activities including row crops, as well as cattle ranching and vegetable production across the Lake Okeechobee watershed — are the dominant sources of elevated P loads. Urban stormwater, leaky septic tanks, and atmospheric deposition also contribute. This nutrient-enriched runoff drives shifts in plant communities, loss of periphyton, expansion of cattail monocultures, and low-oxygen conditions that threaten aquatic biodiversity — all of which ultimately compromise water supply for more than seven million South Floridians.

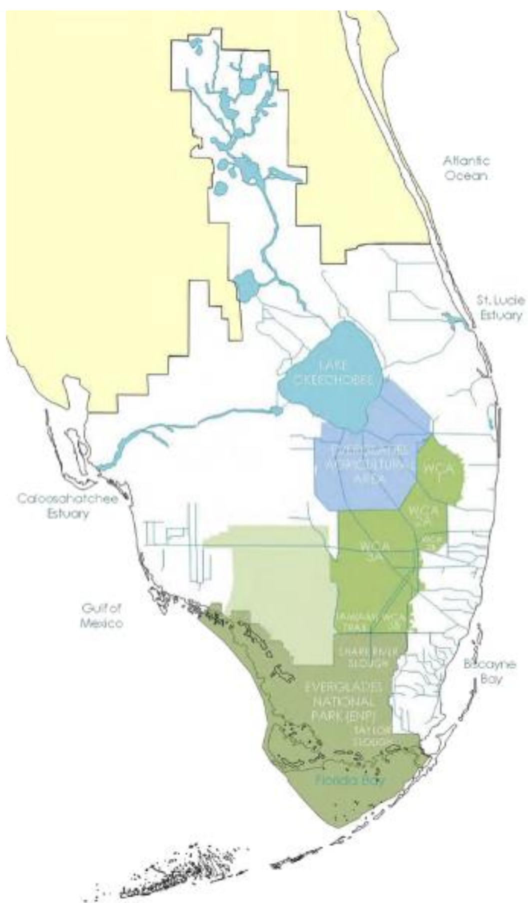

Figure 1: South Florida watershed management map and Everglades. *Image Credit:* www.everycrsreport.com/reports/IF10111.html.

The recent designation of P as a critical mineral in the United States and the 2026 Executive Order 14387 which officially recognized elemental P as a critical material both add a further dimension: effective P capture from water systems can, in some contexts, recover a finite and strategically important resource. This designation has elevated interest in technologies that not only remove P but recover it for beneficial reuse as fertilizer, potentially improving the economic viability of treatment technologies.

1.2 Existing Treatment Infrastructure and Its Limits

South Florida's response to the P challenge has been substantial. The Everglades Forever Act of 1994 mandated construction of the Stormwater Treatment Areas, and by 2026 five STAs covering approximately 62,000 acres were operational — the largest system of treatment wetlands in the world. Together, these systems have treated more than 32 trillion liters of water and removed over 4,700 metric tons of TP, averaging a 77% TP load reduction.

Alongside the STAs, Best Management Practices (BMPs) in the EAA have reduced P loads from agricultural fields by well above the required 25% since the BMP program was established in the 1990s. These programs represent a major investment and a genuine environmental success.

Yet, meeting the EPA's Water Quality-Based Effluent Limitation (WQBEL) limit across all treatment areas under variable hydrology, hurricane disturbances, and with legacy P in sediments, continues to pose a challenge. There is widespread recognition that existing infrastructure alone will not close this gap, and that complementary technologies operating at appropriate points in the treatment train are needed.

1.3 The T2PM Initiative

The Treatment Technologies for Phosphorus Mitigation (T2PM) initiative is a Phase 1 Planning Grant funded by the National Science Foundation under its Responsible Design, Development and Deployment of Technologies (ReDDDoT) program (Award No. 2427542). The project is led by Principal Investigator Jango Bhadha at the University of Florida. The T2PM Workshop was the capstone engagement event, convening a cross-sector group of approximately 50 participants to evaluate the technologies identified through prior research and stakeholder surveys, establish shared priorities, and build a collaborative foundation for future proposals.

2. Challenges to Phosphorus Mitigation

2.1 Scalability

Perhaps the most consistently cited challenge across the pre-workshop registration survey, the earlier Survey 1 on P management, and workshop presentations is scale. South Florida's hydrologic systems operate at massive volume: the STAs process on the order of 1,000 million gallons per day (MGD). Technologies that perform well in laboratory or small pilot settings frequently struggle to achieve equivalent performance when confronted with the hydraulic throughput, variable inflow concentrations, and infrastructure requirements of full-scale deployment. Sourcing the appropriate material(s) to upscale from lab and pilot scale is also a challenge.

Even with 84 pilot projects in various stages of development in Florida, most remain at small scale. Florida's Department of Environmental Protection (FDEP) Innovative Technology Grant Program, which can fully fund projects without requiring matching contributions from agricultural producers, has catalyzed interest — but bridging from a few hundred acres to the tens of thousands of acres represented by the Lake Okeechobee watershed or the STA system remains a defining challenge.

2.2 Cost and Economics

Cost was identified as a top concern by both technology users (n=16) and developers (n=9) in the pre-workshop Survey 1 (Figure 2). Users prioritized scalability (21%), cost-effectiveness (20%), and performance uncertainty (14%) as their leading adoption challenges. Developers identified scalability for widespread use (27%), cost of materials or production (23%), and end-user adoption (23%) as their primary deployment barriers.

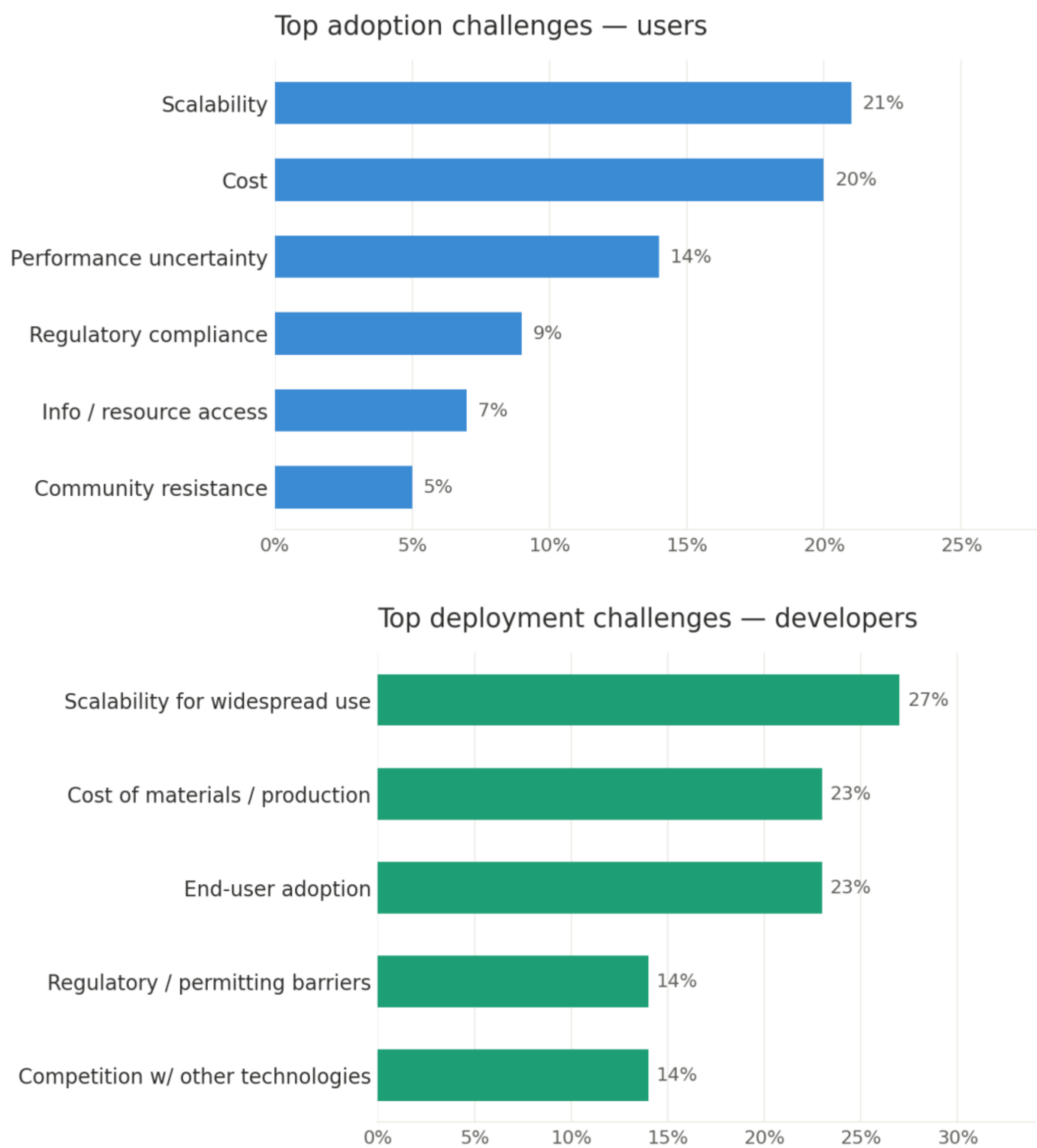

Figure 2: User adoption (top, n = 16) and developer deployment (bottom, n = 9) challenges for P mitigation technologies as identified by survey participants.

The lifecycle economics of P treatment are complex. For adsorption-based technologies, the cost per pound of P removed varies substantially by material: commercial aluminum-based sorbents and lanthanum-modified bentonite range from $20 to $300 per pound of P removed at single-use. Regenerable systems have the potential to dramatically reduce per-cycle costs as cycles increase — one research system described during the workshop reported costs decreasing from $23/lb (single cycle) to $0.42/lb at 50 cycles — but achieving regeneration at field scale adds its own engineering and operational complexity.

Treatment wetlands, by contrast, offer very low operating costs once constructed, but carry substantial land acquisition costs and long construction timelines. Hybrid approaches — combining chemical treatment (such as alum or iron-based precipitation) with constructed wetlands — can improve performance at the cost of ongoing chemical inputs and associated regulatory considerations.

2.3 Regulatory and Permitting Complexity

Regulatory complexity was a recurrent theme. Florida's water quality regulatory environment involves multiple agencies — FDEP, the Army Corps of Engineers, the South Florida Water Management District, and the U.S. Fish and Wildlife Service, among others, each with jurisdiction over different aspects of technology deployment. Permitting timelines can extend years, and the requirements for demonstrating "no adverse environmental impact" for novel materials (such as lanthanum-modified sorbents or hydrogel systems) in sensitive receiving waters are stringent and often undefined in advance.

Several registration survey respondents specifically cited the need for streamlined pathways from proof-of-concept to field deployment, as well as clearer guidance from FDEP and the EPA on what types of third-party validation and monitoring data are required for regulatory approval. The December 2025 effective date of new Florida nutrient rules adds urgency: technology providers are navigating a shifting compliance landscape with limited precedent for novel approaches.

2.4 Legacy Phosphorus

Legacy phosphorus accumulated in soils, sediments, and drainage canals represents a particularly intractable element of the problem. Even if external inputs were eliminated today, internal loading from legacy P stores would continue to impair water quality for years to decades. Managing legacy P requires a different toolkit than preventing new inputs: strategies such as soil capping, soil inversion, targeted dredging, biological uptake, and in-situ P immobilization are all being explored, but each carries its own cost, logistical, and ecological tradeoffs.

The STA system itself is affected by legacy P in accumulated sediments. Several STAs show elevated internal loading that compromises outflow quality regardless of inflow conditions. Research into management strategies for legacy P in STAs — including soil inversion as piloted in the STA-1W expansion — is ongoing but has not yet been demonstrated at full scale.

2.5 Stakeholder Alignment and Risk Aversion

Moving technologies from the laboratory or small pilot into real-world deployment requires alignment across a complex stakeholder landscape. Agricultural producers, water managers, regulatory agencies, technology developers, environmental advocates, and funding bodies each bring distinct priorities, risk tolerances, and decision-making timelines. Risk aversion is particularly notable in the regulatory context where agencies require robust evidence of performance and ecological safety before approving novel approaches in sensitive receiving waters.

Workshop discussions and registration survey responses consistently highlighted the importance of early, transparent stakeholder engagement, not as a box to check, but as a genuine input into technology selection and deployment design. Participants also noted that data transparency and shared monitoring frameworks are essential for building the cross-sector confidence needed to move technologies forward.

2.6 Environmental and Hydrologic Variability

South Florida's subtropical climate creates treatment system conditions that challenge many technologies: seasonal variability in inflow concentration and volume, episodic hurricane impacts, extreme wet/dry cycles, and the presence of elevated dissolved organic matter, co-ions (sulfate, carbonate), and biological growth can all affect technology performance. Laboratory bench-scale results, often obtained under controlled conditions with synthetic water, do not always translate directly to field performance (pH variability and competing ions).

Workshop participants stressed the value of field demonstrations under South Florida conditions specifically, not just for regulatory purposes, but to generate credible performance data that stakeholders can evaluate in context.

3. Phosphorus Mitigation Technologies: Current State

The T2PM Workshop showcased a range of P mitigation technologies (Table 1) spanning different mechanistic approaches, deployment contexts, and readiness levels. The following sections describe the major technology categories represented, drawing on presentations, the pre-workshop surveys, and the broader project literature review.

3.1 Constructed and Treatment Wetlands

Treatment wetlands remain the foundation of South Florida's P mitigation strategy and represent the most mature and well-characterized technology in the portfolio. The Everglades STAs — five large, constructed wetlands totaling ~62,000 acres function through a combination of plant uptake, biological immobilization, and physical settling to reduce TP from typical inflow concentrations of 70–200 ppb to outflow concentrations of 10–30 ppb.

Treatment wetlands were presented as a technology class, emphasizing their well-established long-term performance, low operating costs, ecological co-benefits (habitat creation, carbon sequestration), and adaptability to a range of configurations. Key design considerations include inflow water characteristics, hydraulic loading rate, land availability, soil and topographic conditions, and the distinction between load reduction and concentration reduction objectives.

Innovations in wetland design address some of the limitations of conventional systems. Hybrid approaches combining chemical pre-treatment (alum or iron-based coagulation) with constructed wetlands can improve performance at high-volume, low-concentration systems. Soil management strategies — including soil capping, inversion, and in some cases removal — address legacy P in accumulated sediments. Small, passive, on-farm treatment wetland systems represent an emerging research priority for addressing edge-of-field P loads in agricultural landscapes, where land availability is often constrained and the tradeoff between nutrient retention and drainage/flood control is particularly acute.

The main constraints for wetlands are land area requirements and the high capital cost of construction and hydraulic infrastructure. In the STA context, land acquisition costs in South Florida are substantial, and available parcels adjacent to existing treatment areas are increasingly limited. Distributed, smaller-scale treatment wetlands — sited within agricultural operations rather than centralized — may partially offset land constraints while providing landscape-scale P load reductions.

Table 1: Technology Comparison Summary

Technology	Maturity	P Removal Efficiency	Deployment Context	Recovery Potential	Key Considerations
Treatment Wetlands (STAs, constructed wetlands)	Commercial / Deployed	72–89% load reduction	Large-scale watershed, edge-of-field	No	High land area required; low operating cost; ecological co-benefits; hybrid designs available
La-Modified Sorbents (algal biomass precursor)	Pilot / Field Demo	>99% (bench scale)	Stormwater ponds, distributed systems	Conditional	Scale-up underway; cost dependent on batch consistency; La management needed
Functional Hydrogels (PEI/PMVEMA)	Lab / Early Pilot	Up to 65 mg P/g	Flow-through systems, variable pH environments	Yes (on-demand release)	Multi-cycle regeneration at very low cost (50+ cycles); pending scale-up
Iron-Based Sorbents (Bayoxide)	Commercial (arsenic); Phosphate pilot	High; context-dependent	Drinking water, industrial; STA polishing candidate	Yes (with AquaCare regeneration)	30+ yr track record; regeneration demo expected 2027–2028
HAIX Resins (ion exchange)	Lab / Pilot	13,000+ bed volumes before breakthrough	High-concentration waste streams, STA polishing	Yes (struvite)	3–5x higher uptake vs. commercial resins; scalable modular design
Donnan Dialysis (tube-in-tube)	Lab	80–85% recovery (target)	Wastewater polishing, nutrient-rich streams	Yes (phosphate + ammonium)	Low energy; seawater as receiver; membrane material optimization ongoing
Infrastructure-Based Media (OWOS / Flo-Water)	Commercial (stormwater BMPs)	50-90%+ TP reduction (context-dependent)	Urban stormwater inlets, catch basins, tile drainage	Possible	Distributed deployment; compatible with MS4 / TMDL programs; easy retrofit
Agricultural BMPs (soil testing, controlled application)	Fully Deployed	>25% P load reduction (EAA mandate met)	Farm-level source control	No	Foundational; mature program; cannot alone close the regulatory gap

3.2 Adsorption-Based Technologies

Adsorption — the binding of dissolved phosphate ions to solid sorbent materials — is the most actively researched category of novel P treatment technology. The fundamental appeal is high specificity: properly engineered sorbents can capture dissolved inorganic phosphate (the most bioavailable P fraction) from high-volume, low-concentration water streams, exactly the conditions that challenge wetlands and other passive approaches.

3.2.1 Lanthanum-Modified Sorbent Materials

Lanthanum-modified sorbent materials using algal biomass (specifically Sargassum seaweed) as a precursor were also presented. Lanthanum is highly selective for orthophosphate through multiple binding mechanisms: electrostatic attraction, ligand exchange, and inner-sphere complexation resulting in a very stable, insoluble precipitate ($LaPO_4$).

Laboratory studies demonstrated near-complete phosphate removal (>99%) within 20 minutes at a loading of 0.2 g/L in the presence of natural organic matter. The research group has advanced to a scale-up and field demonstration phase (Project INV45), deploying the material in a stormwater pond at FAU's Boca Raton campus with third-party performance verification underway. Challenges include the cost of batch synthesis from seaweed precursors, consistency across batches, and managing the lanthanum-loaded spent material after use.

3.2.2 Functional Hydrogels

A novel hydrogel system composed of polyethyleneimine (PEI) and polymethyl vinyl ether-co-maleic anhydride (PMVEMA) was presented that captures inorganic phosphate across a broad pH range and releases it under mild desorption conditions. Key performance characteristics include a maximum P capture capacity of 65 mg P/g sorbent at pH 4.5, and release efficiency exceeding 96% under mild alkaline conditions (< 0.001 M NaOH). The material demonstrates high selectivity for orthophosphate relative to competing ions such as nitrate and sulfate.

Compared to conventional sorbents (see technology comparison table, Section 3.5), the hydrogel system is designed for multi-cycle regeneration, dramatically reducing per-cycle cost as reuse increases. Current work focuses on transitioning from laboratory demonstration to pilot scale and exploring industry partnerships for deployment.

3.2.3 Iron-Based Commercial Sorbents

A crystalline iron oxyhydroxide media was presented with more than 30 years of deployment history primarily for arsenic and phosphate removal in drinking water and industrial applications. The material selectively removes phosphate through specific adsorption to iron hydroxide surfaces. The developer has partnered with other organizations to develop a regeneration process applicable to phosphate-rich environmental water streams, with full-scale demonstration results expected in 2027–2028. The regeneration process recovers phosphate as a concentrated waste stream that can potentially be used for struvite or other product recovery.

3.3 Ion Exchange and Membrane Technologies

Two complementary ion exchange technologies for phosphate recovery were presented:

Hybrid Anion-Exchange (HAIX) Resins consist of polymeric beads loaded with iron (oxy)hydroxide nanoparticles. The nanoparticles significantly improve both selectivity and capacity for phosphate relative to conventional ion exchange resins. Laboratory data showed 3–5 times greater phosphate uptake compared to commercial alternatives, with capacity for up to 13,000 bed volumes before breakthrough under tested conditions. Regeneration using simple base solutions changes the surface charge of the nanoparticles, releasing bound phosphate, which can then be recovered as struvite-based fertilizer.

Tube-in-Tube Donnan Dialysis systems use electrochemical potential gradients across ion-exchange membranes to selectively remove and recover phosphate and ammonium from waste streams without significant energy or chemical inputs. Seawater or reverse osmosis concentrates serve as sustainable receiver solutions for driving phosphate transfer across the membrane. Recovery efficiency approaching 80–85% has been demonstrated, with potential for modular, scalable implementation in distributed systems.

3.4 Infrastructure-Based and Distributed Approaches

Finally, an approach that converts existing stormwater infrastructure — inlet systems, catch basins, canals, drainage outfalls, and tile drainage — into distributed treatment assets by integrating engineered exchange and carbon media into inlet protection devices was presented. The system treats phosphorus, hydrocarbons, and other contaminants as water moves through drainage infrastructure rather than requiring centralized treatment.

The OurWaters & OurSoils (OWOS) presentation focused on distributed watershed treatment architecture and the strategic deployment of complementary technologies throughout the treatment train. The framework integrates engineered media, biological processes, infrastructure-based treatment systems, and Nature-based Solutions (NbS) within existing stormwater, drainage, canal, and water management infrastructure. Designed to complement BMPs, treatment wetlands, and phosphorus recovery technologies, the approach seeks to reduce nutrient and pollutant loading closer to the source while enhancing downstream water quality outcomes. Independent laboratory and field evaluations have demonstrated meaningful reductions in phosphorus, nitrogen, sediments, hydrocarbons, and other contaminants, including phosphate reductions exceeding 90% and nitrate reductions exceeding 80% under specific treatment configurations. The framework has also been evaluated in watershed-scale restoration planning efforts, including nutrient-impaired lake systems, emphasizing scalable deployment, adaptive management, and integration with existing water quality restoration programs.

The platform includes exchange media targeting nutrients and organic carbon, encapsulated biochar media for passive phosphorus interception, and stacked media configurations for high-load applications. Under high-flow stormwater conditions, where below-grade systems are designed to preserve hydraulic capacity and allow overflow during peak events, validation data report 50–60% TP reduction. Other configurations have demonstrated higher removal rates, as noted above. The approach is particularly suited to urban and suburban stormwater contexts where conventional wetland or sorbent technologies are not feasible, and where rapid, distributed deployment can achieve incremental but geographically broad improvements.

4. Deployment Contexts and Technology-Location Fit

A core insight from the workshop is that phosphorus mitigation is not a single-point problem. Rather, it requires interventions at multiple points in the treatment train, from source control on agricultural lands to polishing of near-compliant STA outflows (Table 2). The workshop roundtable discussions emphasized the importance of matching technology attributes to deployment context, and the Survey 1 data on developer-stated deployment targets confirmed a diverse range of envisioned applications.

Table 2: Strategic Deployment Pathway

Deployment Point	Highest-Need Application	Best-Fit Technology Types	Priority Actions
Agricultural Landscape (source control)	EAA farms, Lake Okeechobee watershed drainage	BMPs, small treatment wetlands, tile drainage inserts, biochar media	Expand BMP adoption; pilot edge-of-field wetland and media systems
Canal / Conveyance	South Florida canal network, Taylor Creek tributary to L. Okeechobee	Infrastructure-based media (OWOS), floating treatment, sorbent structures	Field demonstration in canal settings; develop hydraulic compatibility standards
STA Polishing	STAs exceeding 19 ppb WQBEL	Regenerable sorbents (La, HAIX, iron-based), hybrid wetland-chemical systems	Prioritize STA-scale pilot; establish regulatory evaluation framework
Stormwater Ponds	Urban/suburban retention ponds discharging to sensitive waters	La-modified sorbents, iron-based filter media, inlet protection systems	Expand FAU-type demonstrations; develop O&M protocols
High-Concentration Streams	Agricultural drainage, animal waste, wastewater polishing	HAIX resins, Donnan dialysis, struvite recovery	Identify recovery-revenue model; partner with wastewater utilities

4.1 Watershed and Agricultural Source Control

BMPs remain the foundation of source control in the EAA and Lake Okeechobee watershed. Soil testing, controlled fertilizer application, water control measures, and particulate matter control have exceeded the statutory 25% load reduction target since program adoption in the 1990s. However, BMPs alone are unlikely to close the regulatory gap.

Agricultural edge-of-field interventions represent a complementary layer. Small, passive treatment wetlands integrated into farm drainage systems, tile drainage inserts using biochar or exchange media, and controlled-release or slow-release fertilizer strategies can all reduce P losses before water enters the broader canal network. Participants cited the need for simple, contractor-deployable systems that can be maintained within existing agricultural operations without significant disruption to drainage and flood management.

4.2 Canal and Conveyance System Treatment

The South Florida canal network — approximately 2,100 miles of levees and canals managed by the South Florida Water Management District — represents both a treatment opportunity and a logistical challenge. In-canal treatment using sorbent-loaded structures, floating treatment platforms, or biochar-enriched inlet systems could reduce P loads before water enters STA treatment. Infrastructure-based approaches such as the OWOS Flo-Water platform are directly designed for this application context. However, the high flow velocities, large volumes, and variable chemistry of South Florida canals require robust, hydraulically compatible deployment configurations.

4.3 Stormwater Treatment Areas (STA) Polishing

Several existing STAs produce outflows that are close to — but still exceed — the 19 ppb WQBEL. For these systems, the marginal P removal needed is modest in terms of concentration, but the hydraulic scale is enormous. Technologies suitable for STA polishing must demonstrate: (a) effective removal at low inflow concentrations (10–30 ppb), (b) hydraulic compatibility with high-flow, shallow-water systems, and (c) cost-effectiveness at very large volumes.

Adsorption-based approaches, particularly if regenerable and recoverable, are the most frequently discussed candidates for STA polishing. Hybrid constructed wetland designs incorporating chemical treatment are another option. Participants noted that this application context is particularly demanding and that field demonstration at STA scale is essential before any technology can be considered for operational deployment.

4.4 Stormwater Ponds and Retention Basins

Stormwater retention ponds in urban and suburban areas represent an underutilized treatment opportunity. They receive P-laden runoff from developed landscapes and discharge to receiving waters or the canal network. Technologies such as lanthanum-modified sorbents, iron-based media in filter systems, and infrastructure-based inlet treatments have demonstrated applicability in this context and can be deployed at modest scale without the land and infrastructure requirements of constructed wetlands.

The Florida Atlantic University (FAU) field demonstration of La-modified sorbent materials in a stormwater pond at the Boca Raton campus represents exactly this type of application — a tractable, well-instrumented deployment that can generate credible field performance data at meaningful scale within a reasonable timeframe.

4.5 Wastewater Polishing and High-Concentration Streams

While the primary focus of the T2PM workshop was on environmental water (runoff, stormwater, STA outflows), several technologies presented are also applicable to higher-concentration waste streams such as agricultural drainage, animal waste effluent, or municipal wastewater polishing. HAIX resins and Donnan dialysis systems are particularly suited to these higher-concentration streams, where recovery of phosphate as struvite fertilizer becomes economically feasible. Recovered struvite — a slow-release fertilizer — can partly offset treatment costs and represents a step toward circular phosphorus management.

5. Stakeholder Priorities and Perspectives

This section integrates perspectives from three sources: (1) Survey 1, a multi-sector phosphorus management survey (~30 respondents) administered earlier in the project, (2) a pre-workshop registration survey completed by ~52 participants, and (3) the T2PM Workshop roundtable discussions and gallery walk outputs, documented through verbatim transcription of handwritten table notes. Together these inputs provide a layered, cross-sector picture of where participants agree, where tensions exist, and what they collectively identified as the highest-priority actions.

5.1 Pre-Workshop Registration Survey: Key Themes

The registration survey asked participants about their primary area of expertise, the greatest challenges they see in implementing P control measures, and the topics they felt would be most valuable for breakout discussions. Respondents represented a broad spectrum including water management researchers, treatment wetland specialists, sorbent and materials scientists, agricultural water managers, regulatory professionals, biochar practitioners, technology developers, and environmental engineers. The following themes emerged with notable consistency:

5.1.1 Scale and Economics as Dominant Barriers

Scalability was the single most frequently cited challenge across participant backgrounds. Respondents from academia noted the persistent gap between lab-scale performance and field reality. Industry respondents identified the cost of producing and deploying materials at environmental water treatment volumes as a core constraint. Regulatory and water management participants emphasized the scale mismatch between currently available pilot projects and the treatment capacity required for systems like the STAs or Lake Okeechobee. One respondent with STA research experience was direct: "Scalability" was their complete answer, framing it as the defining unresolved issue. Another noted the specific challenge of "low phosphorus concentration targets" and asked for realistic expectations on the timeframe for detecting downstream improvement after upstream P removal.

5.1.2 Regulatory Pathways

Multiple respondents — particularly those closer to the technology-to-practice transition — expressed frustration with the lack of clear, streamlined permitting pathways for novel technologies. One respondent asked specifically for breakout discussion on "navigating the process of proof of concept to commercialization from a regulatory standpoint, including which state/federal entities (FDEP, EPA, etc.) are most involved." Another identified the December 2025 effective date of new Florida nutrient rules as a driver of urgency, asking for focus on "scalable/adaptable solutions for compliance" under those rules.

5.1.3 Legacy Phosphorus and Nonpoint Sources

Watershed-scale respondents highlighted legacy P in soils and sediments as a major challenge, citing its spatial variability, the difficulty of quantifying it at watershed scale, and its persistence long after external inputs are controlled. The nonpoint source character of agricultural and stormwater P loading, which is driven by variable rainfall and difficult to predict or intercept, was also frequently raised, with one respondent describing it as "especially challenging in Florida" due to the intensity and variability of precipitation events.

5.1.4 Cross-Sector Collaboration and Implementation Science

Both technology users and developers expressed strong interest in better understanding each other's needs. One academic respondent articulated this clearly, asking for focus on "the implementation science needed to translate research into practice: what do academics need from industry, what does industry need from academics?" Another asked for discussion on "developing collaborations between stakeholders to pilot different approaches and pathways to adoption." The phrase "agency collaboration" as a standalone answer from one respondent points to the same concern from the water management side.

5.1.5 Metrics, Monitoring, and the Cost of Inaction

Several respondents raised the need for better, more standardized success metrics. One asked for focus on "determining metrics for success and how to scale up emerging phosphorus technologies in an economically and ecologically friendly way." Another specifically asked for discussion of "a breakpoint on urgency versus costs — when does the higher cost for rapid removal outweigh a less expensive but slower path forward?" This tension — between cost-effectiveness and the ecological and regulatory cost of delay — ran through multiple responses and surfaced repeatedly in the roundtable discussions as well.

5.2 Survey 1: P Management Perceptions

Survey 1 (n = 30), administered to a broader stakeholder group prior to the workshop, provides additional quantitative grounding. Key findings:

- Among user respondents, the top adoption challenges were scalability (21%), cost (20%), and performance uncertainty (14%). Regulatory compliance (9%) and access to information (7%) followed.
- Users prioritized environmental benefits (29%), cost effectiveness (21%), and proven effectiveness (21%) as the most important technology characteristics. Ease of use (14%) and regulatory compliance (7%) followed.
- Among developer respondents, the leading deployment challenges were scalability for widespread use (27%), cost of materials/production (23%), and end-user adoption (23%). Regulatory/permitting barriers (14%) were also prominent.
- Developers ranked cost effectiveness as the attribute users care about most (20%), while users ranked environmental benefits first (29%).
- The top support resources desired by developers were access to pilot sites or testing facilities, partnerships with researchers or institutions, and funding or investment opportunities.
- On measuring success, the plurality of respondents (7 of 20) used dollars invested per amount of P captured as their primary metric. Visible environmental improvement (6) and regulatory compliance (2) followed. Life cycle analysis (LCA) was noted as an additional criterion by one respondent.

5.3 Workshop Roundtable Discussions: Gallery Walk Outputs

The Day 2 roundtable sessions generated handwritten outputs from five tables across three rounds, subsequently transcribed by workshop team members. Upvotes (colored dot stickers) placed by participants during the gallery walk indicate items that resonated among participants. The following synthesis draws on those transcriptions directly.

Round 1: Technology Landscape and Fit-for-Purpose Applications

Participants categorized P mitigation technologies by readiness and deployment context. Technologies broadly viewed as ready now included constructed and treatment wetlands (including floating islands), biochar, alum, Phoslock (lanthanum-modified bentonite), and agricultural BMPs. Adsorption media that can be applied at the edge of field or directly in water bodies were also noted as ready, contingent on removal and disposal logistics.

Emerging technologies attracting interest included enhanced biochar integrated into floating wetland systems, hydrogels, nano-enhanced adsorption media, and electromodulation approaches for in-situ sediment P inactivation. Real-time monitoring platforms — as a complement to grab sampling — were highlighted as an emerging need rather than a treatment technology per se.

The highest-need deployment contexts, as ranked by upvotes across tables, were: legacy P hotspots, including dairy lagoon seepage to canals, old phosphate mines, and saturated wetlands flipping from

P sinks to sources; high-inflow STAs and water bodies where HABs are occurring; agricultural runoff at scale; and municipal stormwater contexts. One table drew an explicit trade-off comparison across technology categories, rating STAs favorably on scale and environmental trade-offs, chemical treatments highly scalable but site-dependent, and microbial/nature-based solutions as high in public perception but still uncertain in long-term ecological impact.

A recurring theme with strong upvote support was the need to decrease the gap between university research and implementation.

Round 2: Implementation Pathways, Constraints, and Enablers

Across all five tables, the barrier landscape was remarkably consistent. Regulatory complexity was ranked first by one table, noting variation by state and risk aversion around environmental and public perception concerns. Cost and funding availability were universally cited, with particular attention to lifecycle cost versus upfront capital (one table explicitly framed it as Capex + operating costs). Stakeholder consensus — across public, farmers, regulators, landowners, and technology providers — was ranked as a top-three constraint by multiple tables and received notable upvote support.

The most-upvoted single item in Round 2 was the need for co-funded grants between academia and industry for demonstration and piloting. The challenge of pilot-to-full-scale deployment was the highest-upvoted individual barrier in the round. Interdisciplinary teamwork fostered earlier in the development process also received attention. Taken together, these point to a consensus that the gap between research and deployment is less of a technical problem than a structural one, requiring deliberate cross-sector mechanisms.

On the enabling side, tables identified: DEP's Innovative Technology Grant Program and similar funding mechanisms; a third-party or government verification system for vetting novel solutions; leveraging the existing South Florida canal system for distributed treatment; and the economic potential of P recovery from captured material. One table noted that "cyclical approaches — P recovery to later offset overall project costs" could be a self-sustaining funding model. Another raised "monetizing ecosystem services," and the "cost of NOT doing a project" as reframing tools to shift institutional risk calculus, which received upvotes.

Hydrologic variability in South Florida, defined as extreme wet/dry cycles, hurricanes, and "flashy" flow regimes, was consistently identified as a practical implementation barrier distinct from cost or regulation. One table captured the operational challenge succinctly: "sometimes a lot of water, sometimes dry," noting that each site presents unique combinations of these variables even when the underlying challenge is similar. This reinforces the need for adaptable, modular technologies rather than one-size-fits-all solutions.

Round 3: Evaluation Metrics and Decision Framework

Round 3 outputs developed criteria for measuring success and supporting decision-making. On measuring success, participants emphasized the importance of long-term, permanent P reductions verified by high-resolution temporal and spatial monitoring. Ecosystem response indicators — chlorophyll-a trends, HAB frequency, and changes in native species composition — received strong upvote support, as holistic success metrics, complementing the more common regulatory metric of outflow TP concentration.

Importantly, participants also identified societal and economic benefits as valid success dimensions, upvoting property values, recreational use frequency, and improved societal well-being. Ecosystem services valuation was the highest-upvoted item in Round 3. One participant noted the value of “realistic goals driven by generational memory,” pointing to the long timescales over which P accumulation has occurred and over which recovery should be expected.

For decision-making support, participants identified: comparative techno-economic analysis (TEA) as a missing tool; better P sensors and flow monitoring infrastructure; cost and penalty of *inaction* as a reframing device for decision-makers; and more workshops, outreach, and new partnerships. Stakeholder trust-building — through initial demonstration successes, transparent data sharing, and public education to counter disinformation — received multiple upvotes and was framed as a prerequisite for regulatory and public acceptance of novel approaches.

One table closed with a note that has implications beyond the workshop: “P is a finite resource — think in terms of circularity.” This framing of phosphorus not as a pollutant to be disposed of but as a resource to be recovered and reused, points toward a fundamentally different economic model for P mitigation, one in which treatment systems generate value rather than simply incurring cost.

6. Field Visits and Observations

6.1 Taylor Creek Stormwater Treatment Area (TCSTA)

On the afternoon of Day 1, participants traveled by bus to the Taylor Creek Stormwater Treatment Area (TCSTA), operated by the South Florida Water Management District (SFWMD). The TCSTA treats agricultural and urban runoff from the Taylor Creek watershed before it enters Lake Okeechobee — one of the critical P input pathways to the Okeechobee system. Jill King from the SFWMD provided the group a historic overview of the TCSTA and current nutrient removal performance metrics.

The site visit allowed participants to observe first-hand the operational scale, hydrological complexity, and vegetation management challenges of a working constructed treatment wetland. The visit reinforced the context for many of the workshop’s technology discussions: the volumes involved, the variable inflow quality, and the land management requirements that characterize real-world STA operations are difficult to fully appreciate without direct observation.

6.2 Airboat Excursion

Following the TCSTA visit, participants took an airboat facilitated by Eaglebay Adventures through wetland areas adjacent to the treatment site. This excursion provided an ecological perspective on the receiving waters and the importance of phosphorus management for the health of native communities. For participants primarily familiar with laboratory or regulatory contexts, the direct observation of wetland habitats and their sensitivity to nutrient enrichment was an important grounding experience.

6.3 Soil Subsidence Post and Phosphorus BMP Program Tour (Day 2)

On the afternoon of Day 2, participants toured the historic soil subsidence post at the University of Florida’s Everglades Research and Education Center (EREC) in Belle Glade, along with a demonstration of the EAA’s Phosphorus BMP program. The subsidence post — installed in 1924 — visually documents the dramatic loss of organic Histosol soils in the drained EAA over the past century, providing a vivid illustration of the long-term consequences of soil loss in the region. The BMP program demonstration reinforced the scale and sophistication of existing source control efforts and provided context for understanding why complementary treatment technologies are needed downstream.

7. Synthesis: Key Findings and Knowledge Gaps

7.1 Areas of Strong Agreement

Several findings emerged with broad consensus across participant sectors, confirmed by both survey data and the upvote patterns from the gallery walk:

- *No single technology will solve South Florida's P challenge.* Participants across all roundtable table discussions independently converged on a portfolio that framed combining source control, treatment wetlands, adsorption-based polishing, and distributed infrastructure approaches. The highest-upvoted items in Round 1 often reflected this complementarity rather than competition between technology categories.
- *Pilot-to-scale is the critical bottleneck.* The challenge of translating pilot results to full-scale deployment received the highest upvote count of any single barrier in Round 2. This resonated across sectors: from academics frustrated by the gap between publication and practice, to regulators requiring demonstration data before approval, to operators uncertain about performance at STA hydraulic scales.
- *Field-scale demonstration data under South Florida conditions are essential.* Even technologies with strong lab performance face adoption barriers without credible field data. The gallery walk specifically highlighted the value of South Florida's existing infrastructure — STAs, canal systems, stormwater ponds — as demonstration sites that generate contextually relevant performance evidence.
- *Regulatory pathways need clarity and streamlining.* Regulatory complexity was ranked as the top barrier by one table and a top three barrier by most others. Participants specifically called for a third-party or government verification system for vetting novel solutions and for "right-sizing" permitting requirements to be timely, predictable, and reasonable.
- *P recovery changes the economic calculus*. The gallery walk outputs reinforced pre-workshop survey data: recovery of P as struvite or other usable products can offset treatment costs and reframe P mitigation as a resource recovery enterprise. One table explicitly noted cyclical P recovery as a self-sustaining funding model. The designation of P as a U.S. critical mineral provides additional policy motivation.
- *The cost of inaction must be made explicit.* Multiple tables called for reframing the decision calculus to include the ecological and societal cost of not acting — not just the cost of deploying a given technology. Ecosystem services valuation and the cost/penalty of no action were among the highest-upvoted decision-support tools identified.

7.2 Key Knowledge Gaps

The following gaps were identified as priorities for future research and investment:

- *Field performance data at STA-relevant scale*. Laboratory and small-pilot data exist for multiple sorbent technologies, but none have been demonstrated at the hydraulic scale of the STAs. Bridging this gap is the most critical near-term research need.
- *Long-term material performance and fate*. Questions about sorbent lifespan, regeneration efficiency over many cycles, and the environmental fate of spent materials (particularly

lanthanum-containing sorbents) in South Florida's receiving waters remain partially unresolved.

- *Legacy phosphorus management strategies*. Effective, scalable approaches for addressing internal P loading from accumulated STA sediments and in-field soil stores are not yet established at operational scale.
- *Performance under South Florida hydrologic variability.* Most technologies have been tested under controlled conditions. Their performance under the seasonal extremes, hurricane impacts, and variable chemistry of South Florida's water systems needs systematic evaluation.
- *Ecological risk and permitting standards for novel materials*. Standardized protocols for evaluating the ecological safety of novel sorbent materials (lanthanum, hydrogel polymers, iron-based media) in sensitive wetland receiving waters are needed for regulatory clarity.
- *Economic models for full treatment train costs*. Comparative lifecycle cost analyses integrating capital, operational, media replacement or regeneration, and P recovery revenue across technology combinations and deployment contexts are lacking.

8. Next Steps and Call to Action

The T2PM Workshop was designed as a planning exercise — a structured investment in shared understanding and collaborative direction-setting that will inform follow-on proposals for field co-development. The following next steps are anticipated:

8.1 Field Demonstration and Co-Development Proposal

Develop a short list of technologies that will form the basis for future proposals for field co-development and demonstration, which would likely involve deploying selected technologies at meaningful scale within the South Florida system. Potential partnerships include the SFWMD, cooperative landowners, and the DEP Innovative Technology Grant Program, with rigorous performance monitoring and stakeholder feedback integrated expected throughout. Funding from local, state and federal agencies will be explored.

8.2 Community of Practice

A community of practice connecting T2PM Workshop participants is planned as an ongoing outcome of the event. This will provide a mechanism for continued cross-sector exchange, data sharing, and coordination on P mitigation research and deployment across the diverse organizations represented. Participants interested in staying connected should contact Dr. Jango Bhadha (jango@ufl.edu).

8.3 Broader Applicability and Knowledge Transfer

The T2PM initiative was designed from the outset to generate lessons applicable beyond South Florida. The portfolio approach, the stakeholder engagement methodology, and the technology evaluation framework developed through this process are directly transferable to other nutrient-impacted systems across the United States, including the Chesapeake Bay watershed, Lake Erie, the Mississippi Delta, and drinking water systems impacted by agricultural runoff. The organizing team will support dissemination of T2PM findings through conference presentations, publications, and engagement with the broader phosphorus sustainability community.

8.4 Call to Action for Workshop Participants: How You Can Contribute

Researchers and Funding Agencies: Prioritize field-scale validation studies and collaborative data sharing. Engage with regulatory counterparts early in the technology development process to understand evaluation requirements. Consider P recovery as a design criterion.

Technology Developers: Seek pilot site partnerships through DEP's Innovative Technology Grant Program and SFWMD cooperative programs. Invest in standardized performance reporting that enables direct comparison across technology types and scales. Engage stakeholders early to understand operational constraints.

Regulatory and Water Management Professionals: Develop and publish clear, technology-specific evaluation frameworks for novel P treatment technologies in sensitive receiving waters. Engage with researchers and developers during field demonstration phases to ensure monitoring data meets regulatory needs. Champion funding mechanisms that reduce financial risk for early technology adopters.

All Participants: Stay connected through the T2PM community of practice. Share data, findings, and lessons learned. Help build the cross-sector trust that is ultimately the most important enabler of technology deployment at scale.

9. Workshop Participants and Organizing Team

9.1 Organizing Team

The T2PM Workshop was organized under NSF ReDDDoT Award No. 2427542:

- Jango Bhadha (PI), University of Florida
- Elise Morrison (Co-PI), University of Florida
- Jacob Jones (Co-PI), North Carolina State University
- Khara Grieger (Co-PI), North Carolina State University
- Matthew Scholz (Co-PI), Sustainable Phosphorus Alliance
- Alison Deviney (Collaborator), North Carolina State University
- Yicheng Yang and Berson Valcin (Collaborators), University of Florida

9.2 Keynote and Invited Speakers

- Edward C. Smith — Director, Office of Water Policy and Ecosystems Restoration, Florida Department of Environmental Protection (Keynote)
- Jan Genzer — Professor, NC State University (Functional hydrogels for phosphate removal)
- Masoud Jahandar Lashaki — Florida Atlantic University (Lanthanum-modified sorbent materials)
- Lee Blaney — Professor, University of Maryland Baltimore County (Ion-exchange technologies)
- Joey Tippett — Lanxess (Iron-based adsorber media)
- Corydon Coppola — OurWaters & OurSoils (Infrastructure-based treatment systems)
- Mike Jerauld — D.B. Environmental (Treatment wetlands)
- Jill King — South Florida Water Management District (Taylor Creek STA site host)

9.3 Participant Sectors Represented

Workshop participants (~50 total) represented the following sectors: regulatory agencies (including FDEP and SFWMD), academic research institutions, environmental engineering and consulting firms, technology developers and industry partners, environmental nonprofits, and agricultural producers and extension specialists.

Appendix: Workshop Agenda

Day 1 — Tuesday, April 21, 2026

Time	Activity
8:30 am	Registration & Welcome Coffee
9:00 am	Introduction — Jango Bhadha (University of Florida)
9:30 am	Keynote Address — Edward C. Smith, Director, Office of Water Policy and Ecosystems Restoration, Florida DEP
10:00 am	Break
10:15 am	Webinar Presentations (Academic): Jan Genzer · Masoud Lashaki · Lee Blaney
11:15 am	Break
11:30 am	Webinar Presentations (Industry): Joey Tippett · Corydon Coppola · Mike Jerauld
12:30 pm	Lunch on Bus / Ride to Taylor Creek Stormwater Treatment Area (TCSTA)
2:00 pm	Tour and Presentation at TCSTA — Jill King, SFWMD
3:00 pm	Ride to Airboat Facility
3:30 pm	Airboat Ride
4:30 pm	Return to EREC | Debrief / Networking

Day 2 — Wednesday, April 22, 2026 (Earth Day)

Time	Activity
8:30 am	Registration & Morning Coffee
9:00 am	Roundtable Discussion 1: Technology Landscape & Fit-for-Purpose Applications
10:30 am	Break
10:45 am	Roundtable Discussion 2: Implementation Pathways, Constraints & Enablers
12:15 pm	Lunch
1:15 pm	Tour: Soil Subsidence Post | Phosphorus BMP Program
2:30 pm	Roundtable Discussion 3: Evaluation Metrics and Gallery Walk
4:00 pm	Conclusion & Closing Remarks

This report was prepared by the T2PM Workshop organizing team.
For questions or additional information, contact Jango Bhadha at jango@ufl.edu.
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