EXECUTIVE SUMMARY

From Invasion to Recovery

A Diagnostic Framework for Restoring Eurasian Watermilfoil-Dominated Lakes

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Introduction

Precision Ecohydrology Diagnosing Systems. Identifying Leverage. Restoring Resilience.

Precision Ecohydrology develops systems diagnostics for coupled Earth systems. Our assessments integrate multiple independent lines of evidence to evaluate competing explanations, distinguish observation from interpretation, resolve the causal architecture underlying observed system behaviour, separate externally forced processes from locally reversible drivers, and identify the highest-leverage opportunities to restore resilience.

We work across coupled hydrological, atmospheric, ecological, geological, industrial, economic, and societal systems, recognizing that environmental challenges emerge from interactions among these processes rather than from any one component in isolation. By identifying the mechanisms that generate system behaviour, our work provides a scientifically rigorous foundation for restoration, adaptation, and long-term decision-making.

Ecological Context

Ecological dominance rarely emerges from a single cause. It develops when multiple stabilizing processes weaken simultaneously, allowing one species to exploit conditions that previously constrained its expansion. Invasive species therefore represent more than biological introductions. They are indicators of altered ecosystem function.

Eurasian watermilfoil (*Myriophyllum spicatum*) exemplifies this process. Across North America it has become one of the most successful submerged aquatic invaders, forming persistent surface canopies that displace native vegetation, alter habitat structure, and interfere with recreation and water management. Management has consequently focused on suppressing the plant through mechanical, chemical, and biological means. These interventions can reduce biomass, often very effectively, but they do not necessarily restore the ecological processes that determine whether the species regains dominance.

The persistence of Eurasian watermilfoil is therefore best understood as the expression of an ecological state rather than the behaviour of an individual species. Nutrient enrichment, sediment nutrient recycling, repeated disturbance, vegetative fragmentation, reduced competitive pressure from native macrophytes, and weakened herbivore feedbacks together create a system that consistently favours recolonization. As long as these processes remain intact, repeated intervention becomes necessary because the conditions selecting for dominance remain unchanged.

This report approaches management from the perspective of ecological diagnosis. Rather than treating Eurasian watermilfoil as the primary object of intervention, it identifies the causal architecture that allows the species to dominate. Each invasion is resolved into a sequence of interacting mechanisms: the initiating conditions that permit establishment, the processes that reinforce persistence, the pathways that accelerate spread, the feedbacks that stabilize dominance, and the ecological controls that have been diminished or lost. Understanding these mechanisms allows interventions to be directed toward restoring ecosystem function rather than repeatedly suppressing its symptoms.

The methodology developed here follows a systems framework built around five questions.

What initiated the ecological transition?

Which processes now maintain it?

Which mechanisms amplify its expansion?

Which feedback stabilizes the new state?

Which ecological counterforces have been lost?

By resolving these components independently, restoration can be directed toward the smallest set of interventions capable of shifting the system back toward a resilient ecological equilibrium.

Although developed using Eurasian watermilfoil in New Jersey as the focal system, the framework is intentionally broader. The objective is not simply to improve management of a single invasive species, but to provide a reproducible methodology for diagnosing ecological dominance, identifying system leverage points, and designing restoration strategies that address underlying causes rather than recurring symptoms.

Methodology

This report applies a systems-based diagnostic framework to identify the ecological conditions governing Eurasian watermilfoil dominance and to determine the highest-leverage opportunities for restoration.

The analysis integrates multiple independent lines of evidence, including:

- **Watershed characterization** (land use, hydrology, and nutrient sources)
- **Limnological assessment** (water chemistry, trophic status, and lake condition)
- **Remote sensing** (historical imagery and ecological change detection)
- **Plant physiology and invasion ecology** (growth, competition, and dispersal mechanisms)
- **Restoration ecology** (evidence for ecological recovery and long-term resilience)

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Diagnosis

Application of the diagnostic framework to nine New Jersey lakes demonstrated that Eurasian watermilfoil dominance is governed by measurable ecological conditions rather than a single statewide cause. Each lake was interpreted from its own ecological signals—including water chemistry, water clarity, chlorophyll, internal phosphorus loading, and watershed land use—to identify the mechanisms maintaining invasion and the restoration pathways most likely to produce durable ecological recovery.

What the design claims	What we check	The decision it drives
The lake sits at the eutrophication hinge	Total phosphorus, chlorophyll, Secchi clarity	Above or below the clear-water threshold, near 0.03 mg/L phosphorus or the local target?
Internal loading is the memory	Bottom-water phosphorus and the number of anoxic days	Must the sediment be neutralised before any clarity gain can hold?
Milfoil holds a canopy lock	Percent cover, biovolume, canopy height	Can natives be seated without first opening the canopy?
The native guild can remap	Native richness; presence of *Chara*, *Vallisneria*, pondweeds	Which native guild fits this lake (Section 8)?
Fragment pressure sustains the invasion	Boat-ramp and marina density, flow paths	Where does containment begin?
Herbivory is weak	Weevils per stem, sunfish abundance	Protect and build the weevil, or treat it as a minor lever?
The watershed keeps feeding the trigger	Developed and agricultural land in the watershed	Which subwatershed gets the first nutrient intervention?

The analysis showed that no single management strategy is appropriate across all systems. Instead, each lake occupies a different position along a common causal pathway linking nutrient enrichment, sediment nutrient memory, fragmentation, canopy formation, and diminished ecological resistance. This diagnostic framework provides a consistent method for distinguishing symptoms from the processes that sustain them and for matching restoration actions to the governing ecological conditions.

Three broad restoration classes emerged from the analysis:

- Nutrient-enriched valley lakes are maintained by elevated external nutrient inputs reinforced by internal phosphorus recycling from anoxic sediments. These systems require nutrient reduction, sediment management, and long-term restoration of ecological function before durable suppression of Eurasian watermilfoil can be achieved.
- Moderately enriched lakes retain favourable ecological conditions for recovery. Reducing nutrient inputs, re-establishing dense native macrophyte communities, and restoring biological regulation are expected to produce the greatest ecological response and the most durable long-term outcomes.
- Clear, oligotrophic lakes exhibit fundamentally different ecological behaviour. Nutrient limitation is no longer the principal management lever, and invasion depends primarily on propagule pressure, disturbance, and habitat availability. Prevention and rapid response therefore provide substantially greater ecological benefit than post-establishment restoration.

The diagnosis also established a clear implementation sequence. Greenwood Lake and Swartswood Lake emerged as the highest-priority opportunities for near-term restoration, offering the strongest combination of ecological readiness and expected return on intervention. Lake Hopatcong, Lake Musconetcong, Cranberry Lake, and Deal Lake require longer-term, nutrient-first restoration programs owing to persistent watershed inputs and legacy sediment phosphorus. Round Valley Reservoir represents a prevention-focused system where protecting existing ecological resilience offers greater value than large-scale treatment following establishment.

To strengthen confidence in the restoration design, every load-bearing scientific claim underpinning the framework was independently evaluated against the published evidence before inclusion in the final protocol. The resulting restoration sequence therefore reflects both ecological diagnosis and evidence verification, providing a condition-weighted pathway from field validation through pilot restoration and broader implementation.

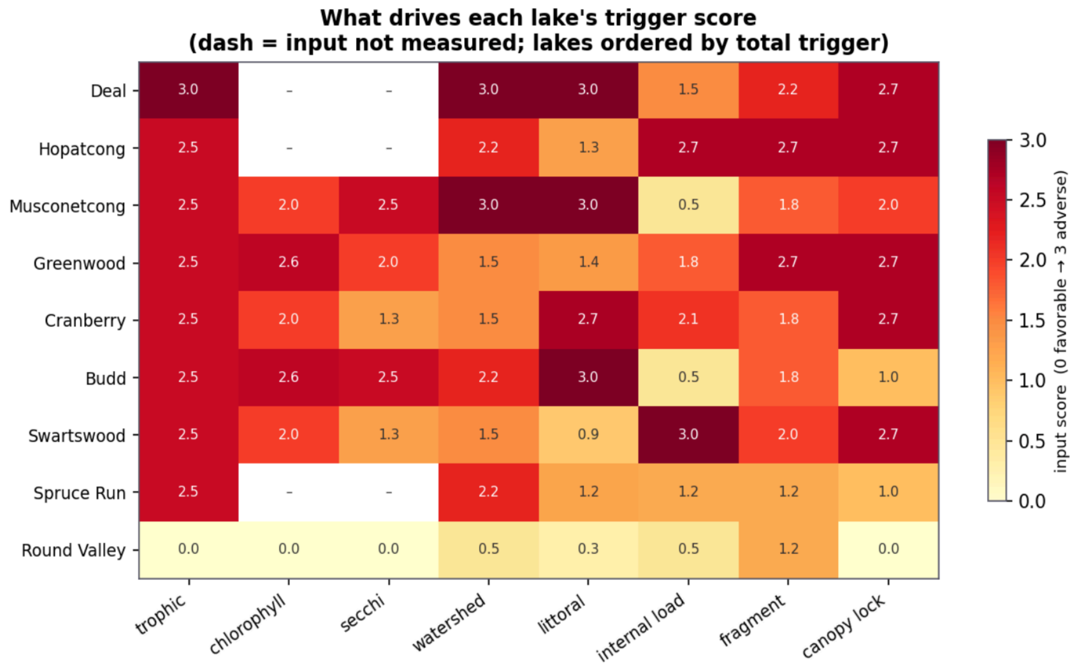
Across all nine lakes, a consistent conclusion emerged: long-term restoration depends on restoring the ecological processes that regulate nutrient cycling, disturbance, native plant competition, and biological feed-backs. Diagnosis therefore shifts management from recurring symptom suppression toward interventions that modify the mechanisms governing ecosystem behaviour, providing a pathway toward progressively self-sustaining ecological resilience.

Implementation Strategy

The restoration program is guided by a condition-weighted implementation framework that translates ecological diagnosis into a prioritized sequence of field actions. Rather than applying a uniform management strategy across all lakes, implementation is directed by each lake's **Trigger Score**, which quantifies the ecological conditions favouring Eurasian watermilfoil establishment and persistence. Combined with the system's Memory Index and supporting field observations, the Trigger Score identifies where ecological conditions strongly reinforce invasion and where restoration must first address the underlying environmental drivers.

Lake	Trigger score	Reading	What drives it
Deal	2.6	Locked monoculture	Hypereutrophic; heavily developed watershed; a full, shallow shelf to colonise
Hopatcong	2.4	High	Internal phosphorus load under summer anoxia; developed, boat-heavy shoreline
Musconetcong	2.2	High	Very shallow and fully colonisable; inherits Hopatcong's nutrient load
Greenwood	2.1	High	High algal turbidity and a stratified internal load feeding the niche
Cranberry	2.1	High	A broad littoral shelf and a septic-driven phosphorus load
Budd	2.0	High	High algal turbidity over a full littoral shelf
Swartswood	2.0	High	The heaviest internal load of the group: anoxic all summer
Spruce Run	1.6	Moderate	Moderate mixed pressure; milfoil presence not yet confirmed
Round Valley	0.3	Low (prevention case)	Deep, clear and oligotrophic, with almost no plantable shelf

Implementation progresses through a phased sequence of validation, pilot restoration, and broader rollout. Initial field investigations confirm the principal ecological mechanisms identified during diagnosis, including nutrient dynamics, native vegetation, herbivore activity, and sediment processes. Restoration interventions are then selected and weighted according to the ecological processes maintaining each system, ensuring that management effort is directed toward the highest-leverage control points rather than applied uniformly across all lakes.



Performance is evaluated through predefined ecological indicators and decision gates that measure changes in ecosystem function, native community recovery, and the progressive reduction in intervention intensity as ecological resilience is restored. The implementation sequence provides a repeatable framework that can be adapted to additional lakes while remaining responsive to local ecological conditions.

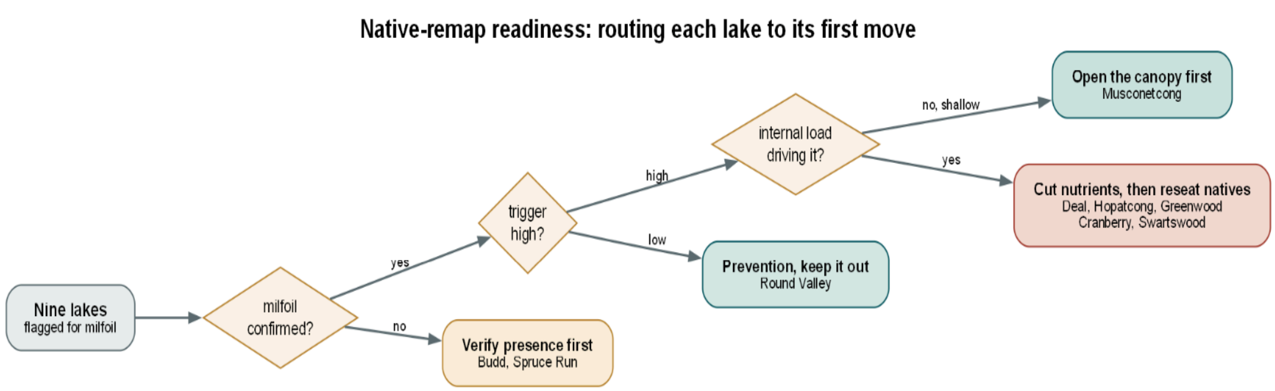


Figure 4. Native-remap readiness. Each lake is routed by three questions to its first move: confirm presence, prevent, open the canopy, or cut nutrients before reseating natives.

Conclusion

Eurasian watermilfoil is not simply an invasive plant; it is an indicator of ecological imbalance. Lasting restoration depends on identifying and restoring the processes that regulate ecosystem function rather than repeatedly suppressing the visible symptoms of degradation.

The full report establishes a complete diagnostic and restoration framework for nine priority New Jersey lakes, supported by independently verified evidence and a condition-weighted implementation strategy. Together, these elements provide a practical pathway from ecological diagnosis to measurable restoration outcomes.

The framework is intended to support agencies, lake associations, conservation organizations, and funding partners seeking durable, science-based solutions to aquatic ecosystem restoration. We welcome opportunities to collaborate in field validation, pilot implementation, monitoring, and broader program delivery, adapting the framework to local conditions while maintaining the diagnostic principles established in this report.

Invasive plants do not create ecological imbalance—they reveal it.