AAE TECH SERVICES INC.

TECHNICAL REPORT

ZEBRA MUSSEL DISPERSAL IN CLEAR LAKE

RIDING MOUNTAIN NATIONAL PARK

PREPARED FOR:
FAIRNESS FOR CLEAR LAKE GROUP

JUNE 2025

July 7th, 2025

Fairness for Clear Lake
Wasagaming, MB

Attn: Karly McRae

Re: Technical Report – Desktop Analysis of Zebra Mussel Dispersal in Clear Lake.

AAE Tech Services Inc. is pleased to submit this report to Fairness for Clear Lake, which provides an assessment of the physical, biological, and human-mediated factors influencing zebra mussel dispersal, with an emphasis on understanding the extent to which recreational boating would be expected to potential effect the in-lake spread of veligers following initial establishment. By integrating scientific literature, hydrodynamic principles, and relevant case studies, the report aims to support evidence-based decision-making regarding long-term lake management and recreational access.

Since 2006, AAE has supported environmental monitoring, aquatic health assessments, and stewardship planning across Manitoba. Our team brings extensive experience in assessing freshwater ecosystems and conducting technical studies to support lake and watershed management.

We appreciate the opportunity to support this project. Should you have any questions, please do not hesitate to contact the undersigned.

Best regards,

Mark Lowdon, M.Sc., E.P.
Owner and Lead Biologist
AAE Tech Services Inc.

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1. INTRODUCTION

AAE Tech Services Inc. (AAE) is pleased to present this desktop assessment of Zebra Mussel (*Dreissena polymorpha*) dispersal in Clear Lake, prepared on behalf of the Fairness for Clear Lake group. This work was initiated in response to the confirmed presence of zebra mussel veligers and adults in Clear Lake, located within Riding Mountain National Park, and the subsequent containment actions taken by Parks Canada, including the restriction of watercraft use on the lake (Parks Canada, 2022; Government of Manitoba, 2023).

Zebra mussels are an invasive freshwater species capable of profoundly altering aquatic ecosystems, degrading water quality, and damaging infrastructure, as well as posing economic risks to local communities by affecting recreational activities, tourism, property values, and water-based industries. In response to their detection, Parks Canada prioritized ecological protection by enacting various prohibitions on watercraft usage on Clear Lake. This began with a "one boat, one lake" policy in 2023, followed by a full ban on all watercraft in 2024, and a revised restriction in 2025 that permitted non-motorized boats under inspection while continuing to prohibit motorized vessels.

2. SCOPE OF WORK

This document provides a foundational review of the key mechanisms driving zebra mussel dispersal in Clear Lake, with a focus on the relative influence of natural hydrodynamic processes versus human-mediated activities, particularly recreational boating. Understanding these mechanisms is essential for assessing the likely trajectory of mussel spread and informing both short- and long-term monitoring and mitigation strategies.

This document has been prepared as a comprehensive study comprising three investigative components:

- **Phase 1** provides a review of zebra mussel biology and life history, focusing on the veliger stage and how these organisms are transported in freshwater environments.
- **Phase 2** focuses on the hydrodynamic conditions within Clear Lake - specifically wind-driven currents, thermal stratification, and lake turnover - to characterize how water moves through the system under natural conditions.
- **Phase 3** characterizes how zebra mussel veligers are likely transported throughout Clear Lake by integrating biological and hydrodynamic insights. It also evaluates the potential for recreational boating to influence or accelerate their spread, with comparisons to documented case studies from other infested lakes.

The goal of this study is to support science-based management decisions by clarifying the extent to which zebra mussel spread is driven by natural versus human-mediated mechanisms. With eradication no longer a feasible option, containment efforts must be grounded in realistic assessments of dispersal dynamics.

3. STUDY AREA

Clear Lake, located within Riding Mountain National Park in Manitoba, is a glacial freshwater lake with a surface area of approximately 30 km^2. It is of significant ecological, recreational, and economic importance, serving as a focal point for both park visitors and surrounding communities. The lake supports a wide range of recreational activities, including boating, swimming, angling, and shoreline leisure. Its developed shorelines, numerous access points, and recreational infrastructure, such as marinas, boat launches, and public beaches, make Clear Lake a central feature for tourism and local economic activity. To promote sustainable use and reduce the risk of aquatic invasive species introduction, watercraft cleaning stations have been installed at key access points.

Figure 1. Clear Lake marina and public beach at Wasagaming, MB. Zebra mussels were originally identified at Boat Cove to the west of this area and have since been identified on several docks east of the beach. (*Photo by: Clear Lake Marina*).

4. BACKGROUND

In November 2023, live adult zebra mussels were confirmed at Boat Cove, the same location where environmental DNA (eDNA) had been detected a year earlier (Parks Canada, 2023). In response, Parks Canada implemented a series of boating restrictions, including a complete ban on all watercraft during the 2024 open-water season as part of an aggressive containment strategy. However, by fall 2024, adult mussels were detected on docks and infrastructure several kilometres from the original site, indicating that dispersal had occurred despite the ban.

Due to Clear Lake's ecological sensitivity and the regulatory constraints of managing invasive species within a national park, eradication options were limited. Although chemical treatment was initially considered, it was abandoned after containment efforts failed and mussels were confirmed beyond the treatment zone. As a result, Parks Canada shifted its focus from eradication to slowing further spread through public education, shoreline monitoring, and restrictions on human-mediated vectors, such as

boats that may transport veligers or adult mussels to new areas of the lake. This document brings together biological and physical sciences to evaluate how zebra mussels may spread through Clear Lake via natural processes. The findings aim to inform ongoing discussions between Parks Canada and stakeholders regarding the effectiveness of current containment measures and the future of boating access on the lake.

A timeline of key events related to the detection and management of zebra mussels in Clear Lake is provided below in Table 1.

Figure 2. Containment curtain deployed on Clear Lake in August 2024.***(Photo by Parks Canada/Winnipeg Sun, August 2, 2024).***

Table 1. Timeline of key events related to the introduction, detection, and management response to zebra mussels in Clear Lake, Riding Mountain National Park

Date	Event
August 2022	Parks Canada detected zebra mussel environmental DNA (eDNA) near Boat Cove during routine monitoring in Clear Lake.
November 2023	Live adult zebra mussels (clump of 48 individuals) were discovered at Boat Cove.
May 2024	Parks Canada implemented a complete prohibition on all watercraft, including both motorized and non-motorized vessels. This response focused on containment and education, with no chemical or mechanical treatment initiated due to ecological sensitivity and national park regulations.
August 2024	A containment curtain was deployed in the area around Boat Cove - the initial detection zone - to contain and limit further spread of veligers from a localized source, especially during their critical reproductive window.
September 2024	The turbidity curtain was damaged by weather and dislodged shortly after installation; the curtain was removed for safety and effectiveness concerns. Follow-up monitoring detected juvenile zebra mussels attached to docks and infrastructure on the eastern end of Clear Lake, several kilometers away from Boat Cove.
Spring 2025	Parks Canada officially declared a ban on motorized watercrafts for the 2025 season on May 16, 2025. This ban specifically excluded motorized boats, permitting only non-motorized vessels with proper inspection and registration. The ban came after initial talks suggested boats would be permitted under a “one boat – one lake” policy.

5. ZEBRA MUSSELS IN CLEAR LAKE

5.1. Zebra Mussel Life History

Zebra mussels are small, invasive freshwater bivalves with a two-stage life cycle: a planktonic larval stage and a sessile adult stage. Reproduction typically begins in spring and continues through the summer when water temperatures exceed 12 °C, with peak spawning often occurring between 18 °C and 24 °C (Nichols, 1996). Fertilization is external, with males and females releasing gametes into the water column. A single female can produce tens of thousands to over a million eggs annually, depending on environmental conditions (Ackerman et al., 1994; Marsden, 1992). After fertilization, larvae (veligers) hatch within a few days and remain suspended in the upper mixed layer (epilimnion) for approximately 1 to 4 weeks. During this time, they are planktonic and undergo several developmental stages, including the D-shaped and pediveliger phases. Once developed, pediveligers settle onto hard substrates such as rocks, aquatic vegetation, docks, or boat hulls where they attach using byssal threads and transition into juvenile mussels.

Zebra mussels typically reach reproductive maturity within their first year and may live for 2 to 5 years. Adults are sessile and highly efficient filter feeders, removing large volumes of phytoplankton and suspended particulates from the water column. This feeding behaviour alters nutrient cycling, increases water clarity, and often facilitates the growth of aquatic macrophytes. Dense mussel colonies can outcompete native species, smother benthic habitats, and cause extensive damage to water infrastructure. The success of zebra mussels as invaders is due in part to their high fecundity, rapid development, and tolerance for a wide range of environmental conditions. However, their ability to spread throughout freshwater systems also depends on external transport mechanisms during the veliger stage. These dispersal processes, particularly those driven by wind, current, and mixing events, are discussed in detail in the following sections.

Figure 3. Zebra mussels colonize in clusters over hard surfaces, which can include rocks and boulders, or ropes, docks, or other structures in shallow water.
(Photo by: AAE, 2024 of mussels in the Brokenhead River).

5.2. Water Mixing Dynamics

The physical movement of water within Clear Lake is governed by a combination of wind-driven circulation, surface currents, thermal stratification, seasonal mixing, and wave activity. Understanding these hydrodynamic processes is critical for evaluating how suspended materials, such as nutrients, sediments, or biological particles, may be redistributed within the lake environment.

Wind-driven mixing plays a dominant role in generating surface currents (Drake & Bossenbroek, 2004). Sustained winds across the lake surface exert shear stress that results in longshore and cross-lake currents. These currents can move substantial volumes of water and influence circulation patterns, particularly in the upper layers of the lake. In Clear Lake, prevailing winds generally originate from the northwest, resulting in consistent eastward and southward surface flow during open-water months (USGS, 1994).

Surface currents contribute to localized mixing dynamics, especially in shallow or nearshore areas. The interaction between wind direction, lake morphology, and shoreline features can promote either retention of water in embayment or outward flushing from sheltered zones. These conditions vary depending on fetch (maximum length of open water present), amount of exposure, and underwater terrain.

Thermal stratification occurs seasonally, typically beginning in late spring and persisting through summer. During this time, the water column separates into three distinct layers: a warm surface epilimnion, a cooler intermediate metalimnion, and a cold bottom hypolimnion. Stratification restricts vertical water movement, limiting exchange between surface and bottom waters except during turnover events (Mackie & Claudi, 2010).

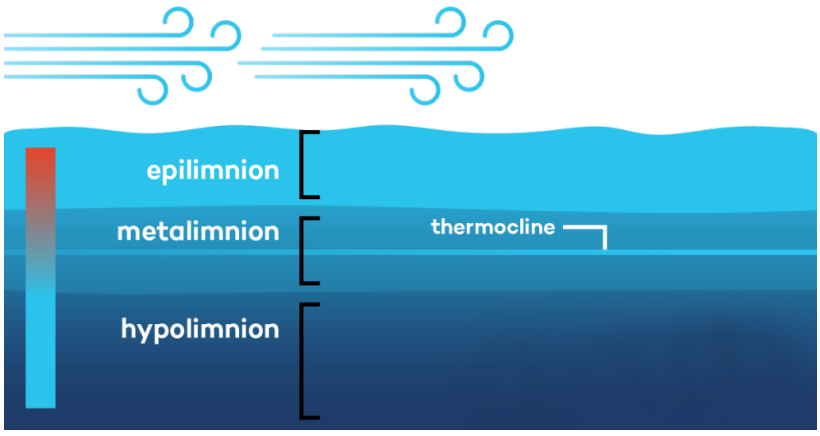

Figure 4. Diagram describing freshwater lake thermal stratification. Deep water systems like Clear Lake typically remain thermally stratified for most of the year, and full-column mixing is limited or absent. (*image by IISD Experimental Lakes, 2018).*

Seasonal turnover does not occur within Clear Lake as it remains thermally stratified for most of the year due to its depth. In lakes deeper than approximately 30 feet, thermal layering is more stable, and full-column mixing is limited or absent. As a result, vertical redistribution of suspended materials is restricted, and circulation is largely confined to the upper layers of the water column, except during rare or extreme weather events that may temporarily disrupt stratification.

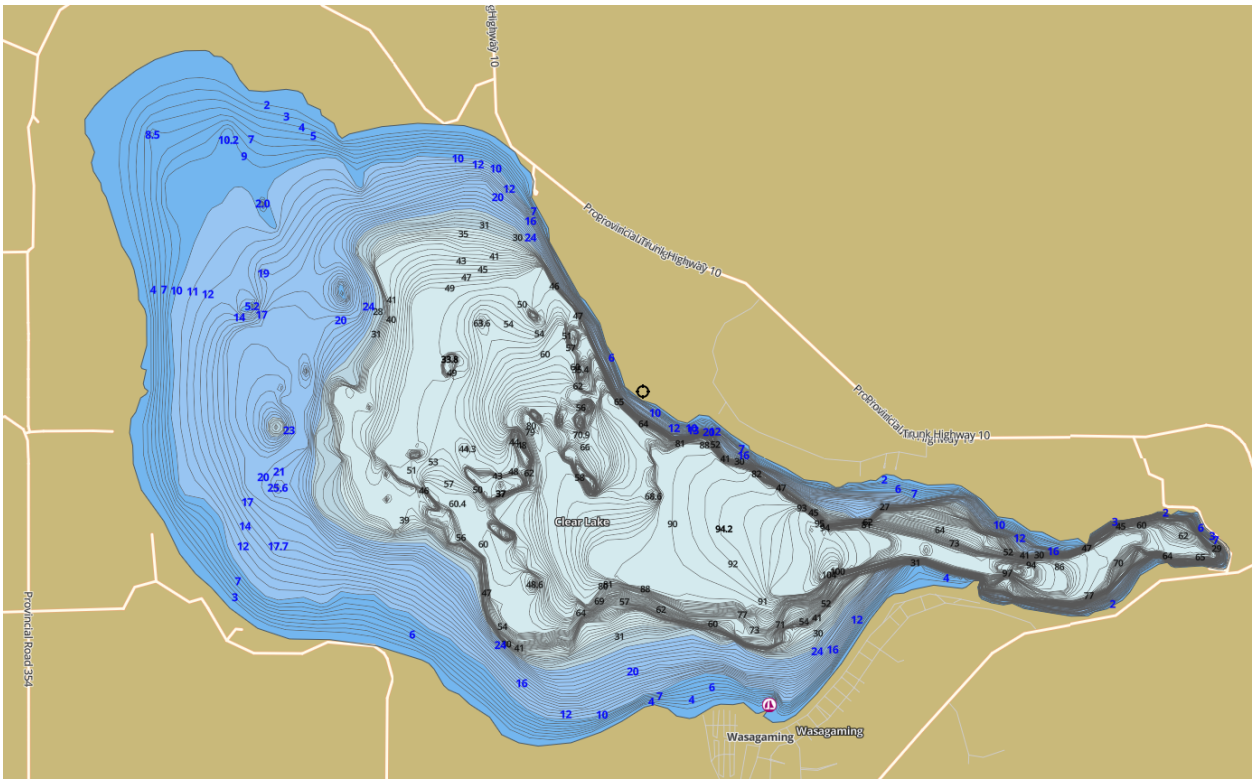

Figure 5. Bathymetric profile of Clear Lake. Depths slope relatively uniformly to 40-70 feet, with maximum depths of 90+ feet (27+ meter) in the central and eastern portions of the lake.

Wave activity, particularly during storm events or prolonged windy conditions, generates turbulence in nearshore zones. This can affect sediment resuspension and local water movement, especially in shallow areas exposed to dominant wind directions, such as shorelines and the shallower regions around the Wasagaming marina and boat cove.

The hydrodynamic processes described here provide essential context for understanding how water moves within Clear Lake under natural conditions. While no biological assumptions are made here, this physical foundation informs the next phase of the study, which evaluates how these processes may influence the dispersal of zebra mussel veligers following their introduction.

5.3. Natural Dispersal of Zebra Mussels

Understanding the natural dispersal mechanisms of zebra mussels is critical for evaluating the feasibility of containment strategies within Clear Lake. Once introduced, zebra mussel veligers can spread through freshwater systems without human assistance, driven by the lake's physical characteristics and seasonal hydrodynamic conditions. This section outlines the dominant physical forces responsible for within-lake transport, summarizes relevant findings from comparable systems, and discusses the implications for long-term management and monitoring.

As mentioned, veligers in Clear Lake are primarily transported by natural physical processes. Research from other medium to large lakes has demonstrated that veligers can disperse several kilometres within just a few days to weeks through wind-driven circulation and other hydrodynamic forces, without any human involvement (Horvath & Lamberti, 1999; Horvath & Crane, 2010). The role of these mechanisms is well documented in comparable lake systems. For example, modelling by Sadro et al. (2012) showed that wind-induced circulation alone was sufficient to transport passive planktonic particles across sub-basins in Lake Tahoe. Similarly, studies in the Great Lakes and other inland reservoirs have identified wind-driven flow and shoreline boundary currents as the dominant vectors of early-stage veliger dispersal (Mackie & Schloesser, 1996; McCartney & Mallez, 2018; Peyer et al., 2009). These findings reinforce the conclusion that natural hydrodynamics can account for the rapid, basin-scale spread of zebra mussels in the absence of human-mediated transport.

Once zebra mussels have established in multiple areas of a lake, eradication becomes virtually impossible. To date, only one confirmed case of full eradication exists: Lake Waco, Texas, where early detection, rapid response, benthic barriers, and intensive manual removal successfully eliminated the population (Texas Parks & Wildlife, 2021). Other efforts, such as in Christmas Lake, Minnesota, temporarily reduced populations but ultimately failed to prevent recolonization outside treated zones (U.S. Geological Survey, 2018). These examples highlight the extreme difficulty of eradication once mussels are no longer confined to a small, isolated area.

To date, there are no documented examples of zebra mussels remaining confined to a single section of a lake once established. Natural circulation processes consistently result in system-wide infestation, rendering partial containment efforts, such as turbidity curtains or limited chemical treatments, largely ineffective over the long term.

5.4. Influence of Recreational Boating on Dispersal

Recreational boating is a well-known vector for the inter-lake spread of invasive species such as zebra mussels; however, its role in intralake dispersal after establishment is relatively limited (Johnson et al., 2001; Bossenbroek et al., 2001). In Clear Lake, boat activity may cause localized mixing or resuspension of veligers in shallow bays or sheltered shoreline areas, but large-scale dispersal is primarily driven by natural hydrodynamic forces. Field and modelling studies show that zebra-mussel veligers can traverse an entire lake the size of Clear Lake within a single 2–4-week larval phase, even when no boats are present (Horváth & Lamberti 1999; Bossenbroek et al. 2001).

Studies from similar lakes support this view. In Lake Simcoe (Ontario), mussel dispersal patterns closely followed natural water circulation rather than boat activity (Vanderploeg et al., 2010). Research in Seneca Lake (New York) and Lake Tahoe also showed that physical mixing and wind-driven currents explained larval movement better than boating (Hoyer et al., 2015; Minchin et al., 2002). Reviews by Bossenbroek et al. (2001) and Johnson et al. (2001) conclude that while boating is critical for moving mussels between water bodies, its influence within a lake is secondary to natural hydrodynamics.

Therefore, full bans on recreational boating within Clear Lake are unlikely to significantly slow zebra mussel spread and may cause unnecessary economic and social impacts. Instead, management should prioritize preventing new introductions between lakes through strong inspection programs, public education, and watercraft cleaning stations, while supporting safe boating practices within the lake.

6. DISCUSSION

While recreational boating may cause some localized mixing, the large-scale dispersal of zebra mussel veligers is primarily driven by natural forces. With initial containment efforts having failed and mussels now documented beyond the boat cove area, full-lake dispersal is likely inevitable, due to natural circulation patterns, regardless of human activity. This challenges the effectiveness of ongoing watercraft bans, which may reduce the risk of spreading mussels to other waterbodies but offer little benefit in preventing spread within the lake. Meanwhile, boating restrictions impose significant economic costs on local businesses, tourism, and recreation.

Since natural dispersal will continue regardless of boating activity, management must balance ecological protection with economic sustainability. Understanding the physical and biological drivers of veliger transport is essential for accurately modelling spread and evaluating management trade-offs. In Clear Lake, where zebra mussels are confirmed at multiple sites, natural circulation will continue to drive spread. Therefore, localized boating bans are unlikely to stop dispersal and may create social and economic burdens without ecological gain. Efforts should instead focus downstream to prevent spread to

connected waterbodies by identifying high-risk areas and implementing targeted mitigation. Management should prioritize predictive modelling, lake-wide monitoring, and strategies that reduce the risk of downstream dispersal.

7. RECOMMENDED STRATEGIES AND FUTURE STUDIES

To better inform science-based management decisions for Clear Lake, future studies should prioritize understanding how natural hydrodynamic processes influence the ongoing spread of zebra mussels. Although this evaluation is informed by comparative literature and case studies, the implementation of a site-specific hydrodynamic model could enhance predictive capabilities significantly. This model should incorporate lake bathymetry, prevailing wind patterns, surface temperatures, and seasonal stratification, with particular focus on wind-driven surface currents that transport veligers passively throughout the water column. A 3D hydrodynamic model calibrated to Clear Lake's physical conditions would allow simulation of current velocities, dispersal trajectories, and mussel transport under varying climatic scenarios (e.g., wind events, turnover, shoreline flow). These simulations could identify areas most susceptible to early colonization and inform monitoring priorities.

In parallel, the following practical strategies are recommended to support both ecological protection and continued community use:

- **Implement a "One Boat, One Lake" Policy:** This approach ensures that boats used on Clear Lake remain exclusively within it, reducing risk of interlake transport of invasive species.
- **Mandatory Decontamination and Inspection Protocols:** All boats and equipment leaving Clear Lake should undergo thorough inspection and cleaning to prevent or reduce the risk of spread to outside waterbodies.
- **Public Education and Outreach:** Continue to raise awareness among lake users about zebra mussel biology, spread mechanisms, and responsible boating practices. Education is critical to community cooperation and long-term success.
- **Ongoing Monitoring of Veliger Densities and Settlement:** In situ sampling across multiple depths and locations should be used to validate model predictions and detect early establishment hotspots.
- **Assessment of Habitat Suitability:** Evaluate shoreline substrate types, water chemistry, and microhabitats that may promote local zebra mussel colonization.

By combining predictive lake modeling with practical on-the-ground management, public outreach, and biological monitoring, Parks Canada and local stakeholders can move toward an evidence-based, adaptive strategy that supports both environmental stewardship and economic resilience.

8. CLOSURE

This report presents the results of a three-phase desktop assessment of zebra mussel dispersal within Clear Lake, Riding Mountain National Park. The project was initiated by local stakeholders in response to confirmed detections of veligers and adult mussels between 2023 and 2024, and aimed to evaluate the biological, physical, and anthropogenic factors influencing the spread of zebra mussels. While Parks Canada's management decisions remain rooted in ecological priorities, stakeholders in the Clear Lake region have expressed concern regarding the long-term effects of continued watercraft restrictions on local lake access and use.

This assessment does not evaluate or recommend policy but provides a foundational understanding of the biological and physical processes influencing zebra mussel spread, providing stakeholders with the necessary information to evaluate and comment on Parks Canada's management decisions to date, particularly with respect to 2025 boating restrictions. Although Parks Canada's containment strategy is currently based solely on ecological protection, the inclusion of these findings may help inform broader stakeholder discussions.

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