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Geothermal Surface-Water Use in Lake Michigan: A Case Study of Discovery World, Milwaukee, Wisconsin

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Abstract

Open-loop, lake-source geothermal systems offer a sustainable alternative to conventional mechanical cooling by leveraging the relatively stable thermal properties of large natural waterbodies. However, the performance of such systems is highly sensitive to intake location, depth, and surrounding infrastructure—variables for which industry design standards such as the ASHRAE Handbook provide limited prescriptive guidance. This study investigates these variables through the case of Discovery World, a 120,000-square-foot museum in Milwaukee, Wisconsin, that operates a geothermal cooling-only system drawing approximately two million gallons per day directly from Lake Michigan. The facility reported summertime intake temperatures exceeding the 75°F heat exchanger design maximum, raising concerns about system efficiency and elevated utility costs. To characterize near-shore lake temperature conditions, two HOBO MX2201 temperature logger lines were deployed in Lake Michigan adjacent to Discovery World from September 28 through October 5, 2025. Results showed lake temperatures at both monitoring locations remained between 66 and 71°F, well below the 75°F design limit, with a difference of less than 0.5°F between the current intake and a candidate relocation site 400 ft offshore. Flow testing revealed a 1,143 GPM improvement following heat exchanger cleaning, confirming that quagga mussel colonization and sediment fouling—not intake location—are the primary performance drivers. Recommendations focus on increased cleaning frequency, chemical water treatment, upstream filtration improvements, and enhanced BAS instrumentation.

Keywords

Geothermal, lake-source cooling, open-loop system, quagga mussels, building performance

1. Introduction

Open-loop, lake-source geothermal systems draw water directly from natural waterbodies, circulate it through heat exchangers, and return it to the source. Such systems can substantially reduce reliance on mechanical chillers and boilers, offering both energy savings and sustainability benefits (Gaudard et al. 2019). However, system performance is highly sensitive to intake location, water temperature, depth, and surrounding infrastructure. Industry design standards, including the ASHRAE Handbook—HVAC Applications (ASHRAE 2019), provide limited prescriptive guidance for siting lake intakes and discharges, leaving engineers with few validated reference points for near-shore conditions in large freshwater lakes.

Discovery World, a 120,000-square-foot museum located on Milwaukee's lakefront, operates a geothermal cooling-only system drawing and returning approximately two million gallons of water per day directly from Lake Michigan (Jennings 2005). The original design called for intake pipes extending roughly 400 ft offshore, buried three feet below the lake bottom with an intake screen five feet above the lakebed to access colder, more stable water. However, the as-built system places the intake only five feet from the building footprint, far shallower and closer to shore than originally intended. The facility has reported summer intake temperatures reaching as high as 79°F, above the 75°F design maximum for the building's heat exchangers, reducing system efficiency and increasing utility costs (Schoettel 2025).

This case illustrates the broader challenge of balancing upfront construction savings with long-term system performance. Limited research has quantified the relationship between depth, temperature, and water quality in large freshwater waterbodies, making it difficult to reliably identify stable source water for geothermal system design. Without such data, facilities like Discovery World are constrained in their ability to make informed, cost-effective decisions regarding system improvements.

1.1 Objectives

This study seeks to answer: Where is the best location for Discovery World to access water for optimal cooling performance, and which improvement strategy provides the greatest life-cycle value? Specifically, the objectives are: (1) to characterize near-shore lake temperature conditions at and near the current Discovery World intake using field instrumentation; (2) to compare temperature conditions at the current intake versus a candidate relocation site approximately 400 ft offshore; (3) to assess the performance impact of biological and sediment fouling through before-and-after flow measurement; and (4) to develop evidence-based maintenance, controls, and monitoring recommendations.

2. Literature Review

Research on the thermal use of lakes and rivers for building systems has grown considerably over the past decade. Gaudard et al. (2018) and Gaudard et al. (2019) provide comprehensive analyses of the thermal potential of lakes and rivers for heating and cooling applications across European waterbodies, demonstrating that surface water systems can meaningfully reduce energy consumption and cooling tower dependence. Rybach (2022) reviews shallow geothermal systems including open-loop surface-water configurations, noting that intake temperature stability is critical and that vertical thermal profiling of source waterbodies is essential to reliable design.

Thermal stratification in large dimictic lakes like Lake Michigan is well-documented. Cole and Weihe (2016) describe the seasonal dynamics of lake mixing and stratification, including the formation of the epilimnion, thermocline, and hypolimnion during summer months. Anderson et al. (2021) analyzed approximately 30 years of mooring data from Lake Michigan and identified statistically significant warming trends in the surface and upper water column, with the strongest warming occurring near the surface and at approximately 100 ft depth. Trumpickas et al. (2015) examined nearshore thermal structure in the Great Lakes, finding that shallow coastal waters warm earlier in spring and exhibit stronger temperature gradients relative to offshore water in summer, directly relevant to near-shore intake siting.

Climate and water level variability add further complexity to lake-source system design. Sellinger et al. (2007) analyzed long-term water level declines in the Lake Michigan-Huron system, attributing variability to climate patterns, evaporation, and regional water management. The U.S. EPA (2021) documented warming trends across North American lakes, noting that Lake Michigan warmed by approximately 0.86°F between 1985 and 2009. NOAA CoastWatch (1973–2026) ice concentration data document significant interannual variability in Lake Michigan ice coverage, with implications for seasonal thermal recharge of deep water.

Invasive species management is a critical operational challenge for open-loop lake-water systems. O'Neill (1996) provides foundational documentation of zebra mussel biology, impacts, and control strategies, noting their preference for surfaces within seven to thirty feet of the water surface and temperatures between 62.6°F and 77°F. The Invasive Species Corporation (2025) documents the expansion of quagga mussels, which can colonize deeper and colder water than zebra mussels, making them a more persistent management challenge. Kelso and Milburn (1979) examined entrainment and impingement of fish at power plant intakes in the Great Lakes, establishing the regulatory basis for intake velocity and screening requirements that also apply to open-loop geothermal systems under the Clean Water Act (1972).

Environmental and regulatory constraints on lake-water withdrawal and discharge are governed at the state level. The Wisconsin DNR (n.d.) administers thermal water quality standards under WPDES permits, limiting discharge temperatures and chemical treatment to protect aquatic ecosystems. Geisthardt et al. (2021) document engineering interventions along the Milwaukee Harbor breakwater, which is relevant to this study given its proximity to the Discovery World intake and its potential influence on nearshore water movement. Maxwell (1919) provides historical documentation of Lake Michigan shoreline erosion rates, contextualizing the long-term infrastructure challenges facing lakefront facilities. Brandt (2010) offers accessible geological background on Lake Michigan's formation and physical characteristics relevant to understanding its thermal behavior.

Collectively, the literature establishes that near-shore thermal conditions in large lakes are highly variable, that intake location and depth meaningfully influence source water temperature stability, and that biological fouling from invasive mussels is a pervasive operational challenge for open-loop systems. However, field measurements quantifying the temperature differential between near-shore intake sites in urban harbor environments—and linking that differential to actual system performance—remain sparse. This study contributes original field data to address that gap.

3. Methods

Two complementary data collection strategies were employed: physical on-shore temperature logging and aggregation of historical off-shore data sources. On-shore data were collected using two HOBO MX2201 temperature logger lines deployed in Lake Michigan adjacent to Discovery World (500 N Harbor Dr, Milwaukee, WI 53202) from September 28 through October 5, 2025.

3.1 Monitoring Locations

Dock – Line 1 was positioned approximately 85 ft from the building near the existing raw-water intake, representing current intake conditions. Pier – Line 2 was deployed approximately 400 ft offshore at the Pier Wisconsin Cruise Dock, corresponding to a candidate relocation site closer to the original design intent. Prior to deployment on September 11, 2025, Jeff MacDonald (Professor at MSOE) conducted a site visit to collect sounding depth measurements confirming feasible deployment points and appropriate line lengths.

3.2 Logger Line Construction and Deployment

Each monitoring line consisted of three HOBO MX2201 temperature loggers affixed to approximately 20 ft of nylon rope and anchored with a five-pound weight at the bottom to maintain vertical orientation. Loggers were secured at nominal distances of 5 ft, 10 ft, and 15 ft above the weight, providing three discrete depth measurement points. Instruments recorded water temperature at one-hour intervals. Data were downloaded at retrieval using the HOBOconnect application and exported as Excel workbooks for analysis.

3.3 Historical and Supplemental Data Sources

Historical offshore temperature data were obtained from a U.S. EPA monitoring buoy located approximately 1,300 ft offshore of the Discovery World intake, with records from 2010 through 2024 (U.S. EPA n.d.). Building intake temperatures were obtained from Johnson Controls' Metasys BAS at Discovery World, using two sensors (model TE-631AP-1) positioned in the supply piping within one foot of each flat plate heat exchanger. Air temperature and meteorological data were collected from a NOAA meteorological station approximately 5,000 ft from the intake via the Seagull online platform (Seagull 2025). WE Energies engineers provided lake intake temperature trend data from the Oak Creek Power Plant for the same monitoring period (Congyer et al. 2026). A site visit to the Milwaukee Art Museum on November 11, 2025 provided comparative operational context from a similar lake-source system (Somers 2025).

3.4 Flow Performance Assessment

Flow readings were conducted in conjunction with heat exchanger cleaning on March 5–6, 2026. An ultrasonic flow meter was used by JM Brennan to measure lakeside flow before (February 9, 2026) and after (March 6, 2026) cleaning, providing a quantifiable measure of fouling-related flow restriction.

4. Data Collection

Air and water temperature data were collected across five monitoring sources from September 28, 2025 through October 5, 2025, with the exception of the EPA Buoy dataset, which spans April 26 through October 3, 2024. Table 1 summarizes each data source by location, distance from Discovery World, measurement depth, date range, and recorded temperature extremes.

Table 1. Summary of temperature monitoring data sources

Data Source	Location	Distance from DW	Depth	Date Range	Max °F	Min °F
Dock – Line 1 (HOBO)	Near current intake	85 ft	5', 10', 15' above lakebed	09/28/25–10/05/25	70.45	66.98
Pier – Line 2 (HOBO)	Candidate relocation	400 ft	5', 10', 15' above lakebed	09/28/25–10/05/25	69.98	66.43
Metasys BAS	Inside mechanical room	0 ft	13' below surface	09/28/25–10/05/25	70.12	66.29
EPA Buoy	Near design intent	1,300 ft	16–18' below surface	04/26/24–10/03/24	73.76	42.26
WE Energies Oak Creek	17 miles south	17 mi	32' below surface	09/28/25–10/05/25	67.49	59.17

Note: DW = Discovery World. Dock (Line 1) and Pier (Line 2) depths are measured above the lakebed. EPA Buoy and Metasys depths are measured below the lake surface.

Flow data were collected in conjunction with scheduled heat exchanger cleaning. Table 2 summarizes lakeside flow readings before and after cleaning both heat exchangers.

Table 2. Lakeside flow readings before and after cleaning heat exchangers

	One Pump @ 60 Hz	Two Pumps @ 60 Hz
Lakeside Flow Before Cleaning (02/09/26)	950 GPM	1,150 GPM
Lakeside Flow After Cleaning (03/06/26)	1,750 GPM	2,293 GPM

5. Results and Discussion

5.1 Numerical Results

On-shore water temperatures across all three monitoring sources remained notably stable relative to air temperature, which fluctuated by more than 20°F over the monitoring interval, peaking above 85°F on October 4–5, 2025. Water temperatures at all on-shore locations stayed within approximately a 4°F band throughout the week, well below the 75°F heat exchanger design limit.

Dock – Line 1 recorded a maximum of 70.45°F and a minimum of 66.98°F. Pier – Line 2 recorded a maximum of 69.98°F and a minimum of 66.43°F, a difference of less than 0.5°F across the monitoring period. The Metasys BAS lake supply temperature tracked closely with both logger lines, recording a maximum of 70.12°F and a minimum of 66.29°F, corroborating the field measurements and confirming that Dock – Line 1 is representative of actual intake conditions.

The most quantitatively significant finding came from flow testing. As shown in Table 2, cleaning both heat exchangers produced a 1,143 GPM improvement in lakeside flow when both pumps operate at 60 Hz (from 1,150 GPM to 2,293 GPM). This substantial flow deficit prior to cleaning directly demonstrates that mussel colonization and sediment fouling were restricting system performance.

5.2 Graphical Results

Air and water temperature data collected across all five monitoring sources from September 28 through October 5, 2025 are presented as a time-series graph (Figure 1). The graph illustrates the thermal stability of lake water relative to highly variable air temperature, and shows close agreement between Dock – Line 1, Pier – Line 2, and the Metasys

BAS intake temperature. The WE Energies data, collected 17 miles south at 32 ft depth, recorded consistently cooler temperatures (59.17°F to 67.49°F), reflecting the advantage of greater depth and offshore distance.

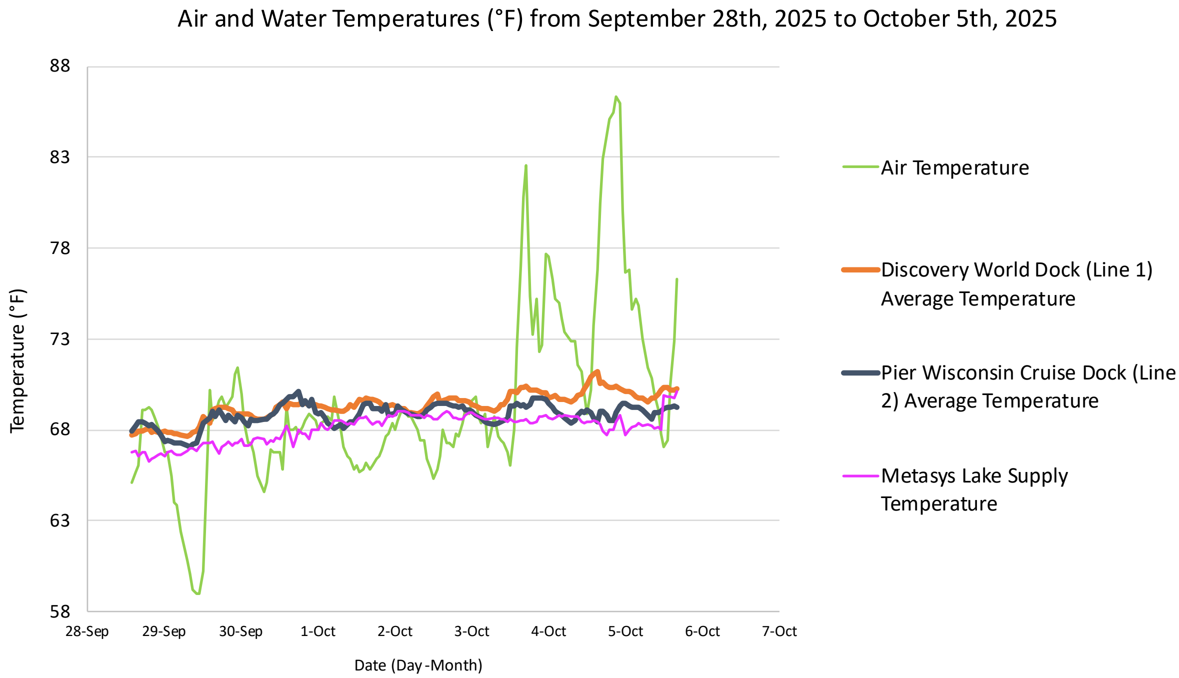

Figure 1. Air and water temperatures (°F) from September 28th, 2025 to October 5th, 2025

Photographs taken during the March 2026 heat exchanger cleaning (Figures 2 and 3) document quagga mussel colonization on heat exchanger plates and sediment accumulation in the lakeside piping. The dirty plate (Figure 2) shows heavy fouling material; the cleaned plate (Figure 3) exhibits residual discoloration, suggesting hydrogen sulfide formation or persistent biological fouling that warrants water chemistry investigation.

Figure 2. Photograph of heat exchanger flat plate before cleaning, with sediment fouling.

Figure 3. Photograph of heat exchanger flat plate after cleaning, which exhibits residual discoloration.

5.3 Proposed Improvements

Based on the temperature and flow findings, the following improvements are proposed, organized by category:

Maintenance: Increase heat exchanger cleaning frequency to a minimum of six times per year, concentrating cleanings during summer when mussel colonization peaks. Conduct water treatment testing to characterize system chemistry and evaluate chlorination within WPDES permit limits. Evaluate self-cleaning screen filters or a dedicated pre-filter on the lake water intake to reduce fouling load reaching the heat exchangers.

Controls and Instrumentation: Install flow meters on the building loop supply and return lines and integrate the existing lakeside discharge meter into the BAS. Add intake screen differential pressure monitoring with automated alerts. Install variable frequency drives (VFDs) on pump motors with control valves to enable variable flow in response to actual building load, reducing energy consumption during off-peak periods.

Monitoring and Future Research: Conduct summer temperature monitoring (June through August) at both Dock – Line 1 and Pier – Line 2 to characterize peak season conditions and confirm whether intake temperatures ever exceed the 75°F design threshold. Commission a hydraulic balancing report for the building loop to verify pump and pipe sizing relative to current loads.

Table 3 presents a preliminary cost-benefit comparison of the two most capital-intensive proposed improvements: automatic backwash filtration and increased manual cleaning frequency. All costs are estimates; actual installed cost for the filtration system will depend on equipment selection, site conditions, and contractor pricing.

Table 3. Preliminary cost-benefit comparison of proposed improvement strategies

Category	**Automatic Backwash Filtration System**	**Increased Manual Cleaning (6x/year)**	**Current Practice (up to 4x/year)**
Capital / Upfront Cost	$200,000–$250,000 (equipment, installation, engineering)	None	None
Annual Operating Cost	Minimal (routine maintenance; unknown, site-specific)	$15,000/year ($2,500/HX × 2 HX × 3 cleanings)	Up to $10,000/year ($2,500/HX × 2 HX × up to 2 cleanings)
Annual Cleaning Cost Savings vs. Current Practice	Eliminates manual cleaning costs after installation (up to $10,000/year)	Higher cost than current practice; investment in system performance and reliability	Baseline
Cooling Capacity Impact During Service	Continuous operation; no planned downtime required	One HX offline per day; full 2-day process reduces capacity, especially in summer	Same as 6x/year; 2-day process per cleaning event
Simple Payback Period	20–25 years based on avoided cleaning costs alone; shorter if energy savings are quantified	N/A (no capital investment)	N/A (no capital investment)
Recommendation	Consider as long-term capital improvement if energy savings can be quantified to improve payback	Recommended near-term; maximizes system performance with no capital outlay	Insufficient to maintain system performance per this study's findings

Note: Cleaning cost estimates based on $2,500 per heat exchanger per cleaning event (includes labor, materials, and plate replacement as needed). Backwash filtration capital cost range of $200,000–$250,000 includes equipment, installation, plumbing, and engineering/consulting fees; equipment-only cost is approximately $125,000. Payback *period is calculated on avoided cleaning costs only; actual payback may be shorter if energy and operational savings are formally quantified.*

5.4 Validation

The accuracy of Metasys BAS temperature readings was validated during a February 9, 2026 site visit. An infrared temperature sensor applied to the steel supply piping was compared against concurrent Metasys data, with less than a 2°F difference confirmed between sensor readings. The sensor model (TE-631AP-1) was documented. This validation confirms that BAS-reported intake temperatures are a reliable proxy for actual lake water intake conditions at the heat exchanger inlet.

The close agreement between Dock – Line 1 average temperatures and Metasys intake temperatures throughout the monitoring week provides cross-validation confirming that Line 1 is spatially representative of current intake conditions. The WE Energies data provide an additional external reference point, with temperatures at 32 ft depth and 17 miles south consistently lower than on-shore readings, consistent with established lake thermal stratification and offshore depth relationships (Cole and Weihe 2016; Anderson et al. 2021).

6. Conclusion

This study investigated the root cause of elevated utility costs and reduced system efficiency at Discovery World's lake-source geothermal cooling system in Milwaukee, Wisconsin. Field temperature measurements at two near-shore monitoring locations showed lake water temperatures remained well within the 75°F heat exchanger design limit throughout the monitoring period, with a difference of less than 0.5°F between the current intake and a candidate relocation site 400 ft offshore. The temperature data do not support intake relocation as a cost-effective performance improvement.

The most actionable finding is the 1,143 GPM flow improvement observed following heat exchanger cleaning, directly demonstrating that quagga mussel colonization and sediment fouling are the primary performance drivers. Addressing fouling proactively—through increased cleaning frequency, chemical water treatment, and upstream filtration improvements—represents the most direct and cost-effective path to the energy and operational savings originally sought.

This study demonstrates the value of systematic field measurement in diagnosing building mechanical system performance. The initial hypothesis that intake temperature was driving elevated utility costs was reasonable given available anecdotal data, but field measurement and flow testing allowed that hypothesis to be tested and set aside in favor of a more supportable explanation. Future work should prioritize summer temperature monitoring, water quality characterization, and a comprehensive building loop hydraulic balancing study.

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Biography

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