# A Review of Decontamination and Cleaning Technologies Associated with Watercraft to Address Invasive Species

A Supplement to the Uniform Minimum Protocols and Standards for Inspection and Decontamination Programs for Dreissenid Mussels in the Western United States.

This document has been prepared by Conservation Collaborations, LLC and Pacific States Marine Fisheries Commission to further the efforts of the U.S. Fish and Wildlife Services' 100th Meridian Initiative and fulfill priorities within the Updated Recommendations for the Quagga and Zebra Mussel Action Plan for Western U.S. Waters (QZAP 2.0; 2020), specifically QZAP Action item B.9: Refine existing watercraft and equipment inspection and decontamination protocols and standards, as needed.

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# PREFACE

This document provides supplementary information to the *Uniform Minimum Protocols and Standards for Inspection and Decontamination Programs for Dreissenid Mussels in the Western United States* (UMPS IV; Elwell and Phillips 2021). The refinement of decontamination protocols continues to take place and UMPS IV focused on the preferred methods of physical removal and hot water to decontaminate watercraft and equipment. Further, UMPS helps to guide the general procedures for successful inspection and decontamination programs.

The tools addressed in this document do not currently have standard protocols associated with their use. Until standard protocols exist, this document is intended to provide general information on the intended use of these specific tools.

# GLOSSARY

**Clean –** A watercraft, trailer or equipment that does not show visible aquatic invasive species (AIS) or attached vegetation, dirt, debris, surface deposits, or non-verifiable water. This includes mussel shells or residue on the watercraft, trailer, outdrive or equipment that could mask the presence of attached mussels or other AIS.

The use of the term clean in association with watercraft indicates **Clean Drain Dry.**

- **Clean:** Remove attached vegetation, animals, mud, debris or surface deposits.
- **Drain:** Remove visible water in any compartment including but not limited to live well, bait well, bilge, storage lockers, floor, cooler, ballast tanks and bags, engine or motor, and engine compartment.
- **Dry:** No standing water. No detectable water on exterior or interior surfaces.

**Decontamination –** A treatment with the intent to kill, destroy, and remove AIS to the extent technically and measurably possible.

- **Full decontamination –** Applied to watercraft and trailer with suspected mussels, attached mussels, and other suspected AIS. Flush engine with hot water as defined in Watercraft Inspection and Decontamination (WID) Manual. Flush internal compartments, anchor, and equipment that may have come in contact with water. Hot water rinse of the hull and high-pressure spray to remove attached mussels or other AIS on the exterior. Physical removal of adult mussels or suspect mussels/AIS.
- **Standing water decontamination –** Hot water flush or rinse/spray as defined in WID Manual of engines, ballast tanks or bags, and interior compartments with standing water, equipment and/or exterior.
- **Plant decontamination (and other suspected AIS) -** Apply hot water as defined in WID Manual to kill plants that can’t be physically removed by hand during inspection.

# INTRODUCTION

Aquatic invasive species (AIS) represent a threat to the ecological function of lakes, rivers and reservoirs. Further, once established, AIS can have significant and costly impacts on our economy. To address the spread or introduction of AIS, management efforts have prioritized pathways to reduce this risk. Motorized and non-motorized watercraft have been a primary focus addressed in recent management efforts as they are recognized as a vector in the spread of AIS (Johnson et al. 2001, Mari et al. 2011).

Over two-thirds of states have either legal provisions that restrict launching or transporting AIS or a fully operational watercraft inspection decontamination program (Showalter Otts 2018). Further, 21 states now have a watercraft drain plug removal requirement (National Sea Grant Law Center 2024). Model legislation and model regulations that specifically address inspection and decontamination programs have been instrumental in standardizing these programs (Showalter Otts and Nanjappa 2014, Showalter Otts and Nanjappa 2016). Scientific research has improved methods among agencies who implement programs on watercraft inspection and decontamination across the nation. Additionally, increased communication and coordination among managing agencies has improved the success of these programs.

Standardizing the techniques utilized in watercraft inspection and decontamination has been a goal among managers and several products support this effort including the Watercraft Inspection and Decontamination Manual (Brown 2021), Advanced Watercraft Decontamination Manual, revised (2023) and Watercraft Inspection and Decontamination Trainer's Manual (Brown 2021).

To prevent the spread or introduction of AIS via motorized and non-motorized watercraft and other water-based equipment, effective techniques with consistent implementation are needed. Key research has been conducted on decontamination methods to provide confidence in the current methods applied. In general, the use of 140°F water for direct contact and 120°F water for flushing interior compartments coupled with appropriate exposure times are recommended for effective watercraft decontamination (Comeau et al. 2011, 2015 and see UMPS IV 2021). This technique combined with thorough visual and tactile inspection, physical removal of dreissenid mussels (*Dreissena polymorpha* and *Dreissena bugensis*) and dry time greatly reduces the risk that mussels or other invasive species will be spread.

The use of hot water with dry time has also been shown to be highly effective in killing other invasive species such as plants and invertebrates (Bayer et al. 2011, Jerde et al. 2012, Anderson et al. 2015). Further, standard procedures to conduct inspection and decontamination provide much needed consistency and reliability to operations across the West. The Western Regional Panel on Aquatic Nuisance Species Decontamination Think Tank Committee has developed and approved multiple decontamination procedures with expertise feedback in the process.

Recently, new tools have been developed to assist AIS managers to reach prevention and containment goals. Three of the tools that are readily available and are being installed and utilized across the United States, include on-demand hot water systems, the Clean Wake dip tank and the CD3 waterless cleaning unit.

Pressure washers are the main hot water decontamination system in use across the nation. There are a wide range of pressure washers available for AIS watercraft decontamination, which includes stationary, trailered, and skid units from a variety of manufacturers, as described in UMPS IV. The development and use of on-demand hot water systems for decontamination was a result of collaboration between western AIS programs and the marine industry during a multi-year collaborative process that also led to the publication of T-32: Design and Construction in Consideration of Aquatic Invasive Species (American Boat and Yacht Council 2018). At that time, pressure washers shared one common flaw in that the temperature fluctuated making it difficult to maintain consistent temperature and exposure times needed to achieve optimal decontamination of watercraft for AIS. On demand hot water systems are able to maintain the water temperature within 2 degrees which increases the efficacy of decontamination.

The development of the dip tank is rooted in the management of dreissenid infested reservoirs of the West and complex watercraft with ballast. At dreissenid infested waterbodies, such as Lake Powell, a combination of factors led managers to explore new methods to provide decontamination. These factors included a continuous significant number of watercraft with complex decontamination needs; watercraft operators experiencing extended wait times for decontamination processing; agency staff that were reaching physical and mental limits providing watercraft decontamination; and new watercraft designs released annually that posed continuous decontamination adaptation tools or methods.

Additional variables also influenced the need for alternatives, for example, a full decontamination of a complex watercraft can require significant amounts of water which pose operational needs that can be difficult to maintain, and design features of some complex watercraft, specifically those with multiple raw water devices, ballast systems, inboard or inboard/outboard engines, can be challenging and time-consuming to decontaminate. The majority of decontaminations are focused on flushing compartments that can't be drained to eliminate the risk of moving AIS in water on complex watercraft. New methods that could expedite wait times and provide standardized decontamination regardless of boat design were, and continue to be needed.

The promotion of AIS prevention behaviors can take many forms such as signs, handouts and cleaning tools for boaters. Several surveys have been conducted to understand barriers among boaters to practicing Clean Drain Dry behaviors (Donnelly 2018, Campbell et al. 2020, Kyle et al. 2022). Some of the primary reasons often given by boaters of why they may not practice Clean Drain Dry is a lack of cleaning stations, crowding at boat ramps, and a belief that others are not taking actions (Campbell et al. 2020, Kyle et al. 2022). Many managing entities recognize the lack of cleaning stations as a barrier that may be addressed by providing cleaning stations or tools at waterbody access points and boat ramps where inspection and decontamination is not required or provided by the managing agency.

Finally, there are multiple active projects underway that explore technology applications to enhance watercraft management. For example, the use of radio-frequency identification (RFID) to automate watercraft entry and exit points, and cellular anonymized data to inform watercraft use risk. There is also a continued need for scientific exploration in the use of hot water for a variety of situations and equipment, and new tools to address AIS challenges.

The goal of this document is to provide the best available information on new tools being used for decontamination and cleaning, an overview of their intended use, and suggested next steps for managers. This document does not contain any approved standard procedure for the tools presented in their use or operation.

# TOOLS FOR DECONTAMINATION

Research to determine the duration and temperature lethality for zebra and quagga mussels has influenced the current temperature parameters and standards used in decontamination of watercraft and associated equipment. The use of 140ºF water at the point of contact to kill mussels on the exterior (hull, engine and trailer) and 120ºF on the interior compartments to kill veligers and juvenile mussels are the current operational standards. The water temperature, duration and type of water application are further described in UMPS IV (see Elwell and Phillips 2021, pg. 25) for performing decontamination on watercraft. It is possible to achieve mortality for dreissenid mussels with water temperatures below 120ºF when coupled with specific time duration of exposure (see Comeau et al. 2011). The UMPS IV protocols utilizing hot water are unchanged. The use of chemicals remains unsuitable for general decontamination based on available scientific information.

For the past decade, AIS managers have utilized various equipment to deliver and conduct hot water decontamination on all types of watercraft. The equipment that is currently utilized to perform decontamination can generate specified water temperatures and may be portable or housed stationary pressure washer units (Figure 1). In general, the traditional methods to decontaminate watercraft require trained staff to direct hot water to the surfaces and compartments of the watercraft with hand tools. These traditional decontamination methods can be used with motorized and non-motorized watercraft, and for all components of a watercraft.

***Figure 1.*** *Operational variations of decontamination units.* ***Top left:*** *Mobile trailered unit.* ***Bottom left:*** *Recycled water circulating decontamination system.* ***Above right:*** *Mobile unit coupled with movable water collection tarp (photo: Quagga D, LLC).*

## GENERAL DESCRIPTION OF ON-DEMAND HOT WATER SYSTEMS

The recent development of on-demand hot water systems (also known as a tankless water heater) for decontamination have improved temperature-consistent water delivery (Figure 2). The on-demand hot water system is simply a water heater that heats the supplied water without using a storage tank. Heated water exiting the on-demand system can deliver low pressure water for flushing decontamination. With the proper attachments, the on-demand hot water system can perform all decontamination protocols described in the WID Manual. These systems are relatively easy to operate, maintain, and repair, and less expensive to install and utilize, as compared to pressure washers with water storage tanks. The on-demand hot water system requires an onsite power and water source, and to be installed inside a structure (i.e. building or trailer). The on-demand hot water systems are being utilized by many jurisdictions across the West.

***Figure 2.*** *Mobile inspection station with a built in on-demand decontamination unit at Loma, Colorado Port of Entry.* ***Top:*** *Inspection trailer.* ***Above:*** *On-demand hot water unit mounted inside inspection trailer.*

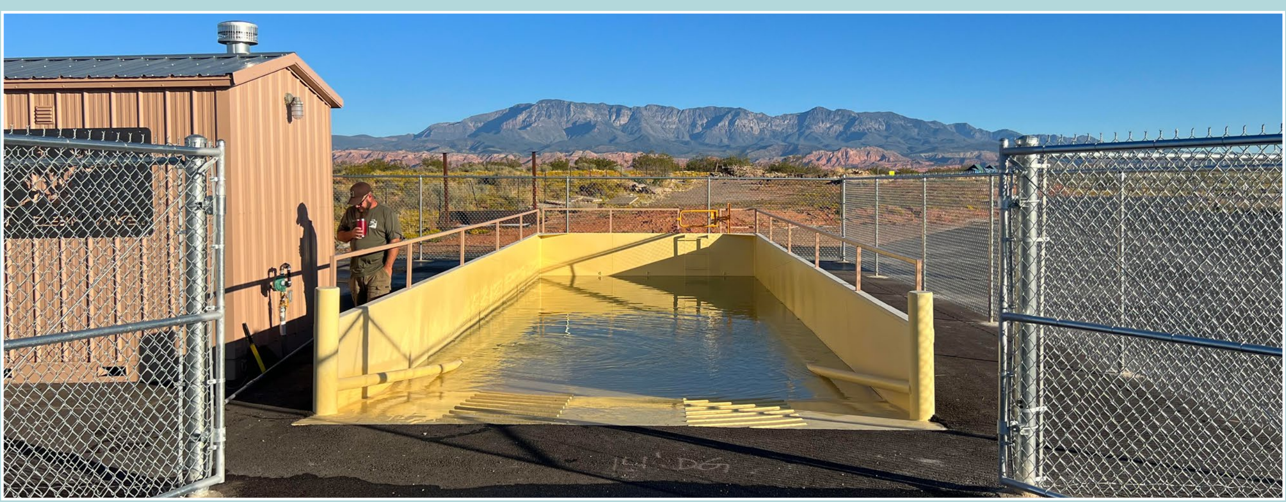
## GENERAL DESCRIPTION OF DIP TANK UNIT

In 2021, a new specialized watercraft decontamination unit was piloted, the dip tank (Figure 3), that targets specific areas of motorized watercraft for decontamination. The dip tank is a unit that is intended for submerging specific types of watercraft in hot water to decontaminate interior compartments and engines. The dip tank only provides decontamination to interior compartments of watercraft that are equipped with pumps, (which may include ballast tank, live well) and the engine. The large tank is a self-contained unit that holds frequently filtered hot water.

The dip tank method to decontaminate interior compartments and engines requires two operators (one in the towing vehicle and one in the watercraft) to submerge the trailered watercraft into the dip tank, and to engage the motor/engine and activate any pumps associated with interior compartments. Trained staff oversee safe use of the dip tank and consistent operations. The areas of the watercraft that are decontaminated with a dip tank most closely align with the procedures for traditional standing water decontamination (Western Regional Panel on ANS 2020a, 2020b, 2020c and 2023).

To determine if a dip tank is suited to incorporate with an AIS program, multiple factors may be considered. Factors may include, the amount of boating traffic, length of boating season, and if the primary watercraft that require decontamination are complex, often with ballast tanks, inboard or inboard/outboard engines, and would require a minimum of 45 minutes to decontaminate using "traditional tools". Additional site or jurisdiction factors not included here may also need to be considered for incorporating a dip tank.

*Two dip tanks in Utah. **Left:** Watercraft entering the dip tank on a traction ramp at Utah Lake. **Below:** Tank with hot water ready for watercraft decontamination at Sand Hollow. Photo credit: Clean Wake, LLC.*



Best application of dip tank decontamination use is:

- waterbodies where dreissenid mussels are present in a containment capacity,
- waterbodies without dreissenid mussels in a prevention capacity,
- off-water locations that see significant boat traffic (e.g. port of entry),
- jurisdictions that have the authority to inspect and decontaminate watercraft.

Currently there are six operational units across Utah (Figure 4). All models are different and customized. Each of the existing dip tanks varies in size, water capacity and other variables. However, all dip tanks hold approximately 8,000 gallons with a graded entry. The water in the tank/pool is heated to 110°F degrees with a 1M BTU liquid propane or natural gas boiler (depending on the location). There are three types of filters on each unit; 1) one filter removes large debris, and 2) two 25 and 100-micron filter bags are used to remove veligers, and other AIS. Finally, the system applies an ultra-violet sanitizer to minimize algae in the water.

## SPOTLIGHT ON THE UTAH LAKE DIP TANK

The Utah Lake dip tank became operational at the Utah Lake State Park in Utah in June 2023. At this watercraft inspection station, Utah Division of Wildlife has decontaminated a record number of 33 watercraft in one day. Wakeboard boats with ballast are prioritized and encouraged to use the dip tank. However, the dip tank is also used to decontaminate fishing boats, recreation boats, personal watercraft (PWC) and other watercraft types.

| Decontamination Capacity | | |
|---|---|---|
| **Year** | **Method** | **Watercraft Decontaminated** |
| 2022 | Traditional Methods | 599 |
| 2023 | Dip Tank Decontamination | 1,036 |


**Locations**

1 **Waheap Dip Tank**
2 **Utah Lake Dip Tank**
3 **Sand Hollow Dip Tank**
4 **Willard Bay Dip Tank**
5 **BullFrog Dip Tank**
6 **Flaming Gorge Dip Tank**

***Figure 4.*** *The location of existing dip tanks in the United States as of December 2024. Dip tanks are in Utah and operated by Utah Division of Wildlife Resources.*

## GENERAL DIP TANK OPERATION

The operation of a dip tank requires trained staff to conduct the decontamination and regular maintenance. For safety reasons, two people, a watercraft operator and vehicle driver, are required to use the dip tank.

- The dip tank must be at a temperature of 105 -110°F before watercraft decontamination can proceed.
- Trained staff will prepare the watercraft operator for entry and exit of the watercraft to the dip tank including draining the watercraft and placing the bilge plug.
- The vehicle driver backs a trailered watercraft into the dip tank. There are guide bars in the tank, similar to a car wash, to guide the trailer down into the tank to prevent damage and keep tires in line.
- The trailer sits in the dip tank's hot water for the entire process, being decontaminated and preventing AIS from being transported on the trailer.
- Trained staff will direct the watercraft operator in the boat to lower the engine and run at idle to move hot water through it.
- The watercraft operator will run all water pumps and intakes to circulate hot water through the ballast tanks, wells, and other raw water internal systems of the boat for the required time.
- Trained staff will also direct the watercraft operator in the boat to discharge water out of interior compartments and ballast.
- Once complete, the watercraft operator will turn off the engine and exit the dip tank. The watercraft operator will be directed to an area to pull the bilge plug to drain watercraft and complete the WID process.

Typical dip tank decontamination (the time that watercraft compartments are being flushed inside the dip tank) is 4 minutes. The entire process from start to finish averages 20 minutes per watercraft including education, data collection, backing the watercraft into the dip tank, actual decontamination time, pulling the watercraft out of the dip tank, and draining and applying a seal/receipt. These time estimates do not include wait time in line.

Safety measures are important to maintain throughout the general operation and maintenance of the dip tank use and are primarily focused on ensuring the safety of watercraft operators and other people associated with the watercraft while decontamination is occurring. People not involved in operating the watercraft remain in the vehicle during decontamination. Staff remain behind a safety barrier outside the dip tank and do not touch the watercraft during the process.

Any compartment, such as live well, bilge or ballast tank, in the watercraft must have a pump that can be turned on during dip tank decontamination. If there is no pump, then water will not be flushed into the compartment during a dip tank decontamination. The dip tank decontamination specifically targets interior compartments and the engine. However, dip tanks do have additional separate hoses that allow trained staff to manually fill compartments without a pump with hot water. This allows compartments without pumps, or other boat components, to be decontaminated while the dip tank can decontaminate the rest of the boat.

If a boat has adult zebra or quagga mussels attached or other AIS present, it is not recommended to be initially decontaminated in the dip tank. Instead, mussel impacted boats should be fully decontaminated with a pressure washer or on-demand system and hand tools. These boats may be flushed in the dip tank after the full decontamination is complete as an added layer of protection. The dip tank is not intended for full decontamination, plant decontamination, or bait treatment. The dip tank is also not used for hand-launched or non-trailered watercraft (such as kayaks, canoes, and paddleboards). Auxiliary tanks adjacent to the system are often used to decontaminate equipment such as life jackets, paddles, water toys, or other boating and fishing related equipment.

## NEXT DESTINATION RESPONSE TO DIP TANK DECONTAMINATIONS

Many waterbody managers across the West conduct monitoring to understand the presence or absence of AIS, including monitoring for dreissenid mussels. Historically monitoring methods have utilized plankton tow nets, settling plates and visual surveys to detect mussels. More recently, the use of environmental DNA (eDNA) for early detection surveys has been incorporated into monitoring programs. However, because eDNA detections can indicate the presence of DNA but not a physical organism, managers will conduct repeat surveys using traditional methods if eDNA indicates dreissenid DNA to guide further action. There have been previous examples of eDNA detections at waterbodies that have shown to be linked to contaminated sampling equipment or other sources.

At this time, it is not clear if watercraft that have been decontaminated with the dip tank are able to uptake and transport dead veligers to waterbodies where subsequent monitoring may detect dreissenid DNA. Understanding the DNA persistence within watercraft that have been decontaminated with a dip tank, and other decontamination methods, would help waterbody managers understand the sensitivity of eDNA monitoring.

Watercraft that has been inspected and decontaminated often will be sealed and an associated receipt provided to the watercraft operator. This communication allows the jurisdiction to receive the watercraft information about the relative risk of that watercraft. Ideally, any watercraft exiting a waterbody positive for dreissenid mussels will be decontaminated prior to launch on another waterbody. Decontaminated and sealed watercraft that arrive at a new waterbody or encounter a new inspection station may be:

- inspected and decontaminated again prior to launch based on agency protocol,
- inspected and permitted to launch based on agency protocol.

Watercraft that have been decontaminated with the dip tank may be similarly assessed by other managing jurisdictions in various ways. Watercraft that have been decontaminated with the dip tank also may be subject to another decontamination based on the receiving jurisdiction.

### DIP TANK DECONTAMINATION CAPABILITIES

**PROS**

- Best for complex watercraft with interior compartments that have pumps, such as ballast tanks, and inboard or inboard/ outboard engines
- Flushes interior watercraft compartments with pumps
- Kills veligers with 105° -110°F water
- Provides a standing water decontamination of engines and compartments with pumps

**CONS**

- Not the best use of WID resources for non-trailered watercraft, simple watercraft, non-motorized watercraft, or equipment
- Does not provide high pressure application of hot water
- Does not remove adult or juvenile mussels or other AIS attached to watercraft; not intended to remove attached adult mussels

# TOOLS FOR CLEANING

For over 15 years, AIS management agencies have been promoting self-cleaning by watercraft operators to prevent the spread of invasive species. **Clean Drain Dry** is the most common prompt for encouraging cleaning by watercraft operators. In recent years, waterbody managers have begun to include self-cleaning tool stations at water access points to encourage and foster cleaning practices for watercraft operators. These cleaning tool stations, e.g., CD3 units, are self-service contained waterless systems that house cleaning brushes, vacuums and other tools to assist people in cleaning watercraft. Because these units do not utilize hot water to kill any possible AIS, they are best described as a cleaning tool.

Situations where CD3 units works best:

- at remote access points for non-motorized watercraft,
- within jurisdictions without authority to require inspection and decontamination of watercraft,
- directly at water access points where watercraft operators are prompted to Clean Drain Dry.

## GENERAL DESCRIPTION OF UNITS

There are five different types of CD3 units that are used in a variety of applications depending on budget, site accessibility and waterbody specific recreational habits. CD3 units are located at various locations across North America (Figure 5). Three CD3 unit types have a wet/dry vacuum, air compressor, multiple hand tools, and lighting. The two remaining units house hand tools only (Figure 6). The units are self-contained and typically require a permanent stable surface for installation.

## GENERAL OPERATION

For the general Clean Drain Dry use with a CD3 unit, watercraft operators must take their own initiative to use the unit, as most units are unattended by AIS agency staff. A watercraft operator may encounter the CD3 unit at launch or access to a waterbody and choose which of the available tools to use on the unit. The vacuum can be used to remove excess water or debris on the watercraft. The air compressor (blower) can drive debris out of the watercraft and dry nooks and crannies. Hand tools such as a brush and grabber can

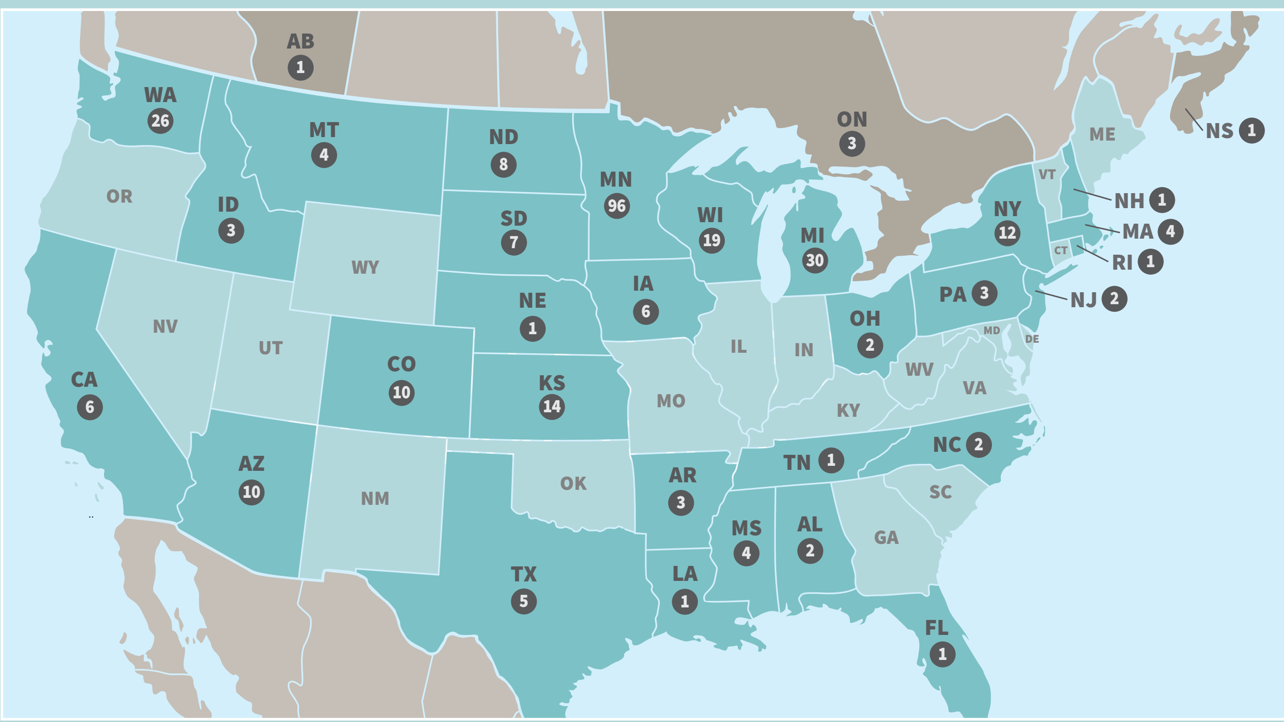



***Figure 5.*** *Location of CD3 Units across North America (June 2024)*

also be used to remove debris and scrub surfaces to remove dirt, plants and animals.

## NEXT DESTINATION RESPONSE TO CD3 CLEANING

Watercraft that have been self-cleaned with a CD3 unit will be assessed by an inspecting jurisdiction as per protocol to assess risk and other information provided by the watercraft operator. Use of a CD3 unit is only meant to allow watercraft operators an opportunity to Clean Drain Dry the watercraft themselves. All watercraft will be subject to inspection and decontamination requirements regardless of Clean Drain Dry actions taken by the watercraft operator.

### CD3 UNIT CAPABILITIES

**PROS**

- Best for user operated Clean Drain Dry of non-motorized, hand-launched, or simple watercraft and trailers
- Provides an opportunity for watercraft operators and anglers to clean watercraft, trailer and equipment in absence of an agency WID station

**CONS**

- Not for decontamination of watercraft
- Does not kill and may not remove invasive species


*__Figure 6.__ Various CD3 units in use at waterbody access locations in North America (photo credit Tahoe Regional Planning Agency).*

# CONSISTENT PRACTICES FOR MANAGERS

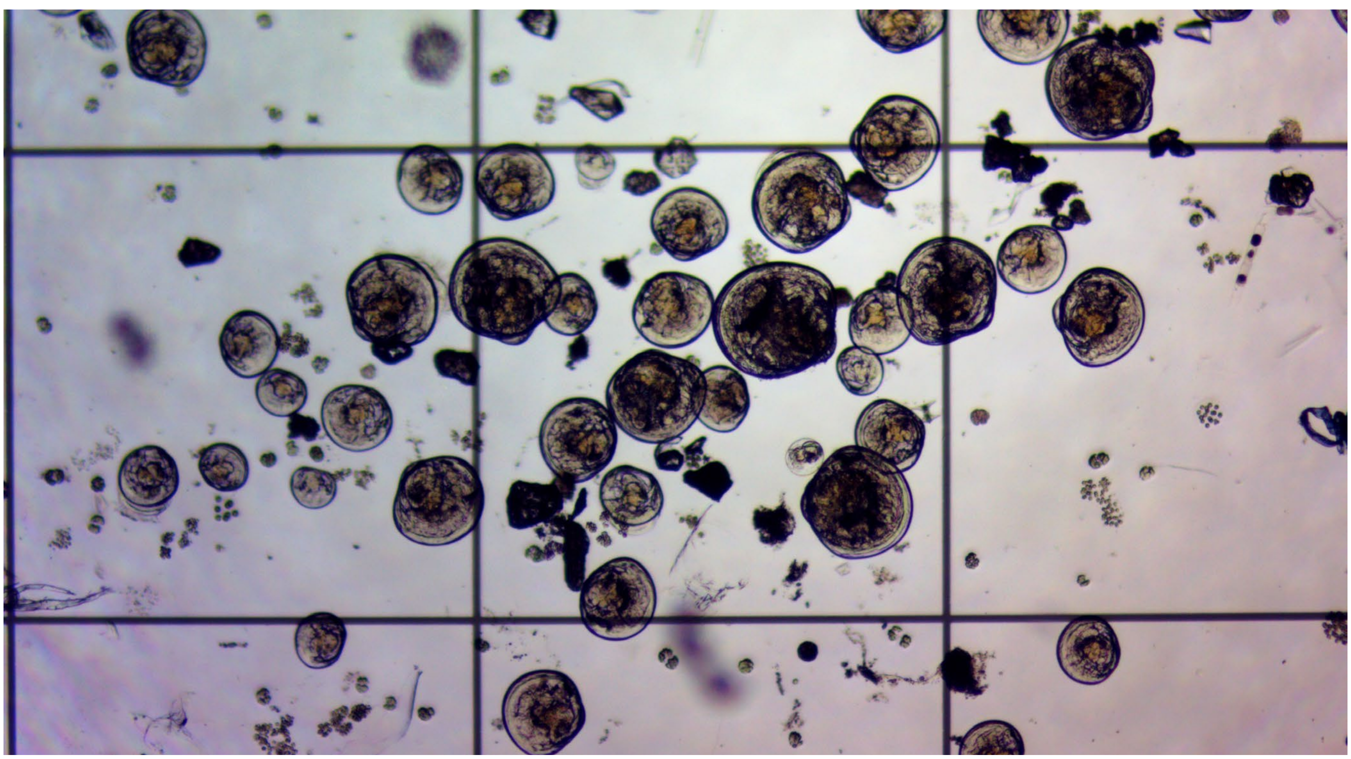
## CLEANING AND DECONTAMINATION

In order to better serve watercraft owners and operators, the use of consistent language and consistent recommendations should be promoted. Therefore, it is recommended that state, federal, Tribal and other entities that provide outreach on watercraft cleaning should adopt the following:

- Watercraft and associated equipment users should practice Clean Drain Dry. Decontamination with the use of hot water should be conducted by trained authorized professionals to ensure that protocols are adhered to, and safety hazards can be minimized.
- It may be possible that watercraft that have been decontaminated with a Clean Wake dip tank still has dreissenid or other AIS, or their DNA associated with the watercraft. In this situation, it may be possible for a decontaminated watercraft to transport DNA to another waterbody.

  DNA may be detected by monitoring of subsequent waterbodies and trigger managers to conduct additional monitoring to understand the nature of the DNA detection. DNA of organisms can be present from the live organism, dead organism, and other sources. When environmental DNA is detected, it serves as a management prompt for follow-up.

  Despite the goal of decontamination being to kill and remove dreissenids and other AIS from watercraft, it is still possible that viable DNA could be transferred to a new waterbody. A better understanding of potential lingering DNA associated with watercraft after decontamination or cleaning with any method and the possible implications DNA may pose must be considered by waterbody managers.
- The promotion of Clean Drain Dry practices for all types of watercraft is a positive prevention strategy. Regardless of the accessibility of tools for cleaning at watercraft access points, taking the steps of Clean Drain Dry is available to all watercraft user types, including non-motorized, motorized or other on-water recreationists.



*Dreissenid veligers visualized under microscopy. Multiple sizes represent different life stages. 1 square length = 1 mm.*
*Photo credit: Kelly Stockton-Fiti.*

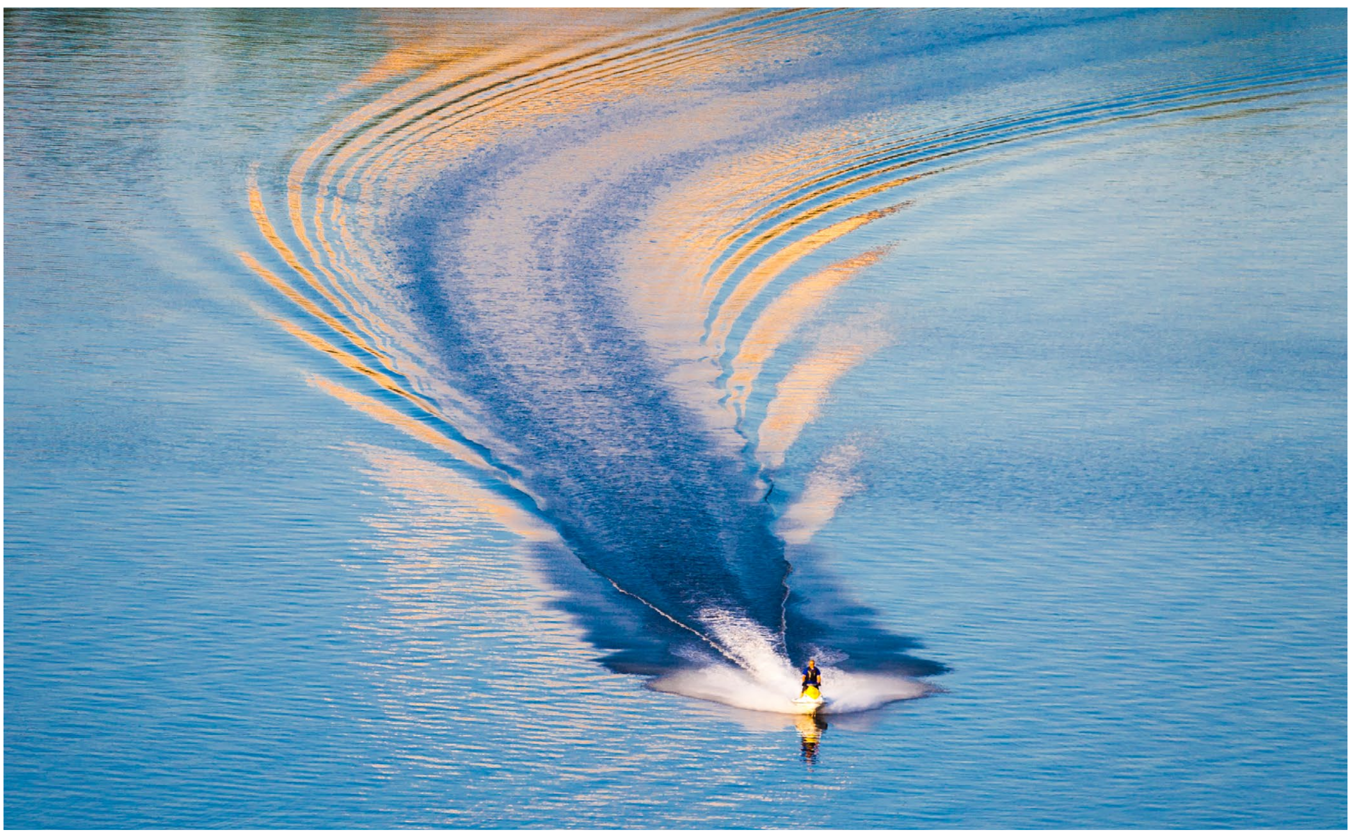
# NEW LITERATURE

Several iterations of the UMPS document have provided the scientific publications that have informed the current watercraft inspection and decontamination protocols. New research on AIS biology and management practices is important for the consideration of current protocols. Since the 2021 UMPS publication there have been multiple publications that provide information on AIS mortality, various methods to kill AIS, and inspection and decontamination effectiveness. These publications do not change the current standards from UMPS VI (2021) but are provided here to inform.

| Date | Authors | Title | Summary | Area of Study |
|---|---|---|---|---|
| 2018 | Coughlan, N.E. et al. | Parched plants: survival and viability of invasive aquatic macrophytes following exposure to various desiccation regimes. | Desiccation alone is likely insufficient to prevent the spread of plant fragments of aquatic invasive plants. Small plant desiccated fragments may be viable post treatment. | Aquatic invasive plant mortality to temperature and relative humidity. |
| 2020 | Coughlan, N.E. et al. | Better off dead: assessment of aquatic disinfectants and thermal shock treatments to prevent the spread of invasive freshwater bivalves. | Steam exposure resulted in 100% mortality of zebra and quagga at 30 seconds. Zebra and quagga mussels varied in mortality rates when exposed to disinfectants. | Quagga and zebra mussel mortality to disinfectants, and steam, hot air and dry ice. |
| 2020 | Campbell, T. et al. | Effectiveness of a CD3 System at removing macrophytes and small-bodied invertebrates from watercraft. | Hand removal and use of CD3 units by trained inspectors were not significantly different. Both were effective at removing AIS. | Cleaning method comparison. |
| 2021 | Fisher, S.M. et al. | Managing aquatic invasions: Optimal locations and operating times for watercraft inspection stations. | An analysis to optimize the placement and operating times of WID stations considered budget, propagule source and uncertainty. | Inspection station location prioritization. |
| 2021 | Mohit, S. et al. | Recreational watercraft decontamination: can current recommendations reduce aquatic invasive species spread? | Literature review to assess the effectiveness of decontamination measures for watercraft against AIS. | Decontamination effectiveness. |
| 2022 | Kinsley, A.C. et al. | AIS explorer: Prioritization for watercraft inspection – A decision-support tool for aquatic invasive species management. | A decision support tool guides the number of watercraft inspections needed to minimize spread between and among infested waterbodies. | Inspection station location prioritization at a county level. |
| 2023 | Mohit, S. et al. | Watercraft decontamination practices to reduce the viability of aquatic invasive species implicated in overland transport. | Experimental analysis of hot water, pressurized water and dry time for multiple AIS were compared for mortality. Hot water coupled with dry time was more effective than individual methods across all species tested. Methods were examined for feasibility for recreational boaters to complete. | Decontamination practices of hot water, pressurized water and air-drying impacts on seven species. |
| 2024 | Bleitz, M. et al. | A comparison of boat cleaning systems: invasive species removal, boater outreach and engagement, and cost. | Literature review of water-based and water-less cleaning systems are compiled to inform managers in incorporating different types of systems into programs. | Self-cleaning station review. |
| 2024 | Angell, N.R. et al. | Quantifying the effectiveness of three aquatic invasive species prevention methods. | Estimated the effectiveness of prevention actions of boaters, watercraft inspectors and hot water decontaminators. The highest intervention effectiveness was hot water decontaminators. | Prevention strategy comparison. |

# CONCLUSION

Managers working to balance the protection of natural resources, promote opportunities to recreate responsibly and manage resources for future use have considerable challenges to meet. Innovation helps to improve strategies that address decontamination and cleaning needs for watercraft. Consequently, as new tools are developed it will remain important for AIS managers to understand the suitability of those tools to adequately provide the best possible prevention methods. As dreissenids continue to advance to new waterbodies and new watersheds, the duplication of effort and efficiency of inspection and decontamination is needed.



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American Boat and Yacht Council. 2018. T-32 Design and Construction in Consideration of Aquatic Invasive Species. Annapolis, MD. 14 pp.

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# APPENDIX A - MANUFACTURER INFORMATION

On-Demand Hot Water Systems are available with all major home builder outlets and plumbing supply businesses.

**Clean Wake, LLC**
www.cleanwake.net
Highland, Utah
gatwood@cleanwake.net
385-287-7107

**CD3 Systems**
www.cd3systems.com
Minneapolis, Minnesota
stopais@cd3systems.com
612-568-8310

It is encouraged to contact the manufacturers and the current users of these systems for more information.