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Aquatic Nuisance Species Research Program

Incidence of Zebra Mussel on U.S. Army Corps of Engineers Structures

K. James Hay, Irene E. MacAllister, Rebekah C. Wilson,
and Abigail M. Brake

January 2020



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Incidence of Zebra Mussel on U.S. Army Corps of Engineers Structures

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Abstract

Zebra mussels (*Dreissena polymorpha*) are invasive/nuisance species first introduced into the Great Lakes region in the late 1980s. Since their introduction efforts have been underway to prevent and/or control their spread. Zebra mussel infestations can occur on submerged critical structure. For the U.S. Army Corps of Engineers (USACE) it is essential that hydraulic infrastructure are effectively and efficiently maintained to ensure proper water control and navigation. A study was conducted to determine the extent of the zebra mussel invasion on USACE districts and the impact zebra mussels have on USACE infrastructure. Consistent with available U.S. Geological Survey (USGS) data, it was found that zebra mussels are present within 24 of the 36 continental United States USACE district boundaries, although San Francisco and Galveston Districts have only isolated populations in non-USACE waters. Albuquerque and Omaha Districts appear to be the two districts most at risk for invasion. While infestations are common, 62% of the districts with USACE infested waters reported no or minimal impacts on the infrastructure or operation/maintenance costs. Those districts with impacts did not normally have cost figures readily available. It was also found that 12 districts have or have had zebra mussel monitoring programs in place.

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Preface

This study was conducted for the Aquatic Nuisance Species Research Program (ANSRP) via Funding Account Code 96 x 3123; AMSCO Code 008284. The ANSRP is sponsored by Headquarters, U.S. Army Corps of Engineers (HQUSACE) and is assigned to the U.S. Army Engineer Research and Development Center (ERDC) under the purview of the Environmental Laboratory (EL). Dr. Linda Nelson was the ANSRP Program Manager; Dr. Alfred Cofrancesco was Technical Director, Environmental Engineering and Sciences.

The work was performed by the Environmental Processes Branch, of the Installation Division; and the Materials Branch, of the Facilities Division, U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL). At the time of publication, Dr. George Calfas was Chief of the Environmental Processes Branch and Vicki VanBlaricum was Chief of the Materials Branch; Michelle Hanson was Chief of the Installation Division and Dr. Christa M. Woodley was Acting Chief of the Facilities Division. The Deputy Director of ERDC-CERL was Dr. Kiran-kumar V. Topudurti and the Director was Dr. Lance D. Hansen.

COL Teresa A. Schlosser was Commander of ERDC, and Dr. David W. Pittman was the Director.

1 Introduction

1.1 Background

Zebra mussels, *Dreissena polymorpha*, and quagga mussels, *Dreissena rostriformis bugensis*, are invasive/nuisance species first introduced into the Great Lakes region in the late 1980s (Benson 2014). Since their introduction into North American waters, efforts by various agencies (Invasive Mussel Collaborative 2018) such as the U.S. Geological Survey, U.S. Department of Energy, U.S. Department of Interior - Bureau of Reclamation, U.S. Fish and Wildlife Service, and the U.S. Army Corps of Engineers (USACE), have been underway to prevent and/or control the spread of dreissenid mussels (Mayer 2008).

Dreissenid mussels are bivalve mollusks that can attach to most firm substrates. Zebra mussels can filter approximately one liter per day which reduces the phytoplankton resulting in increased water clarity and changes in the ecological structure, promoting algae growth and threaten native fish and mussels (Invasive Mussel Collaborative 2018). Dreissenid mussels can spread via three mechanisms: (1) their larvae (veligers) can drift within bodies of waters, (2) the veligers can be transported by various means such as bilge water and waterfowl, and (3) the mussels can attach to surfaces that are moved from one body of water to another such as via boat hulls, sea planes and buoys (MassWildlife 2019). Furthermore, female zebra mussels are prolific and can produce up to 1 million eggs per year. All of the aforementioned have contributed to the spread of dreissenid mussels throughout reservoirs and waterways.

The USACE Navigation mission operates and maintains about 25,000 miles of waterways and channels, 191 lock locations on 41 waterways, and 926 coastal, Great Lakes and inland harbors (USACE 2018). It is essential that hydraulic structures (HSs) are effectively and efficiently maintained to ensure proper water control and navigation, as USACE inland waterways handle over \$70 billion worth of consumer goods annually and 48% of the \$2 trillion in U.S. marine transportation industry commerce passes through USACE maintained harbors (USACE 2017).

The USACE Dam Safety Program operates and maintains approximately 700 dams that provide benefits such as flood risk management, hydro-power, water supply, navigation, and recreation. There are more than 400 USACE recreational lakes and river projects (USACE 2019a).

Infestations of zebra and quagga mussels can occur on submerged critical structures such as water intake pipes, water filtration and electric generating plants (Figures 1 and 2). It has been estimated that the United States incurs \$1 billion per year in damages and control costs associated with management and mitigation due to zebra mussels (Pimentel et. al. 2005). Studies show that mussel adhesion may also accelerate corrosion on uncoated structures, leading to additional concerns on long-term impacts of bio-adhering species (Tennessee Aquatic Nuisance Species Task Force 2008; U.S. Army Corps of Engineers 1992, 1994, 1998) as shown in Figure 3.

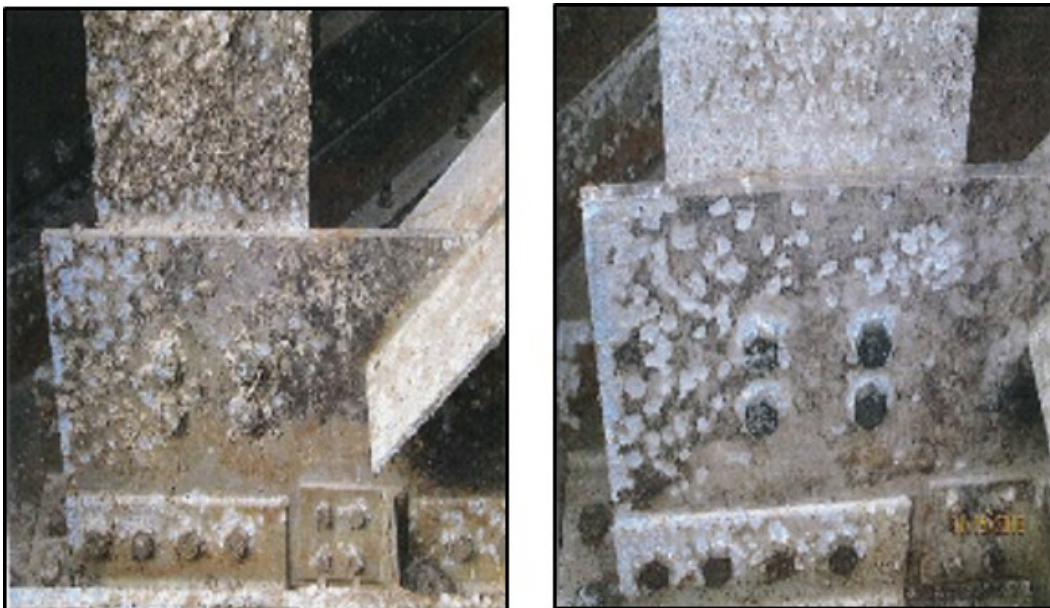
Figure 1. Zebra Mussels on sector gates at T.J. O'Brian Lock & Dam, Rock Island District 2015.



Figure 2. Zebra Mussels on emergency bulkheads at Emsworth Lock & Dam, Pittsburgh District 2016.



Figure 3. Severe pitting corrosion of bulkheads at Pittsburgh District before (left) and after (right) removal of Zebra mussel encrustation.



1.2 Objectives

The object of this work was to investigate and determine (1) the current status of the zebra mussel invasion on USACE districts, and (2) the economic and structural impacts zebra mussels have on USACE infrastructure.

1.3 Approach

The study was conducted using currently available resources including scientific (and gray) literature, web-based information (including electronic databases) as well as by gathering information through informally administered personal questionnaires.

1.4 Scope

This study discusses the extent and impact of zebra mussels on U.S. Army Corps infrastructure throughout the continental United States (CONUS). This includes seven divisions and 36 districts.

2 Methods

2.1 Literature review

A review of scientific as well as gray literature was conducted to help determine the extent of mussel infestations affecting USACE infrastructure across all the districts in the continental United States.

2.2 Questionnaire

The information sought through the questionnaires includes the presence and location of zebra mussels in each district, the history of infestation, the types of infrastructure affected, the types of infrastructure surfaces infested, the costs associated with zebra mussel mitigation and prevention, and the types of preventative measures taken against zebra mussels. This information was then compiled and analyzed to provide an overview of the extent and impact of zebra mussels on USACE infrastructure.

The questionnaire was developed with input from the project development team (PDT), informal questioning of stakeholders including the U.S. Bureau of Reclamation. The latest questionnaire instrument used is included in Appendix A.

A list of appropriate district contacts was developed using a list of personnel on the USACE Invasive Species Leadership Team (ISLT) and the attendee list from the 2018 USACE Lock Maintenance Workshop. Emails were sent out to those contacts and follow up sessions were conducted via phone and/or email depending on the responses. Many of the contacts were helpful and took it upon themselves to aid in collecting information. The lead point of contact (POC) of the ISLT, Damian Walter of the Walla Walla District, sent the questionnaire to all the members of the ISLT. Many of the contacts sent images and reports providing information related to zebra mussel in their districts and/or divisions. The responses to the questionnaire are assembled in Appendix A. Some of the information in the questionnaire responses were provided by the district representative directly and some were inserted by researchers conducting phone interviews or from compiled email responses.

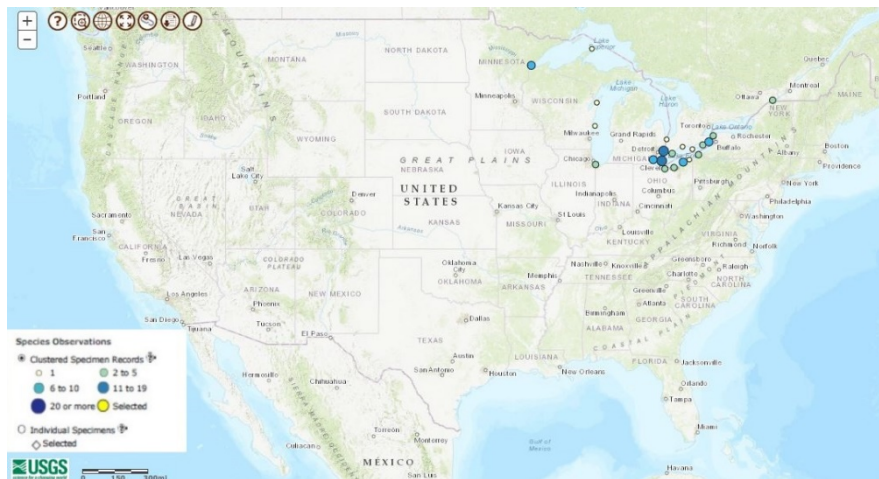
3 Results

3.1 Literature review

The following current references (2007 or later) relate to the occurrence and impact of zebra mussels on USACE districts and infrastructure:

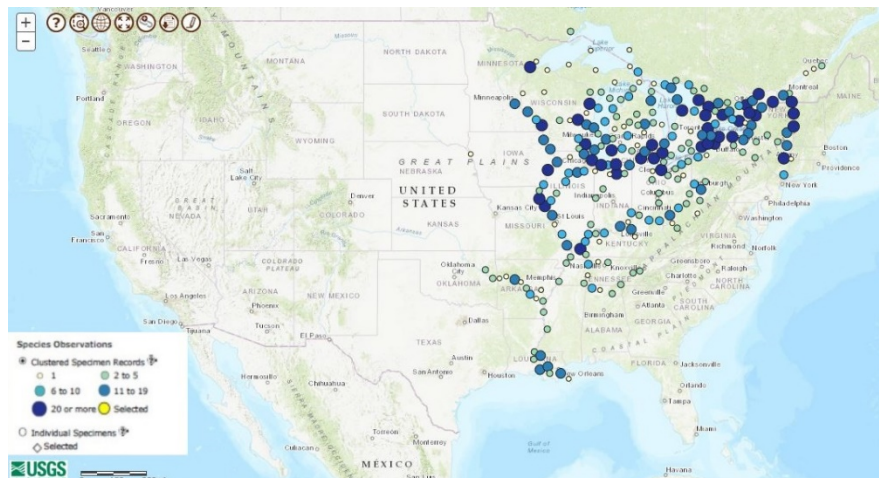
USGS - The U.S. Geological Survey (USGS) maintains a database of non-indigenous aquatic species which include data regarding the zebra mussel infestation in the continental United States (USGS 2019). These data are based on reports of confirmed zebra mussel observations. Each observation is referenced for further details. Figures 4 to 7 show the extent and spread of the zebra mussel infestation over the last 33 years.

Figure 4. Point distribution map of *Dreissena polymorpha* throughout CONUS through 1989.



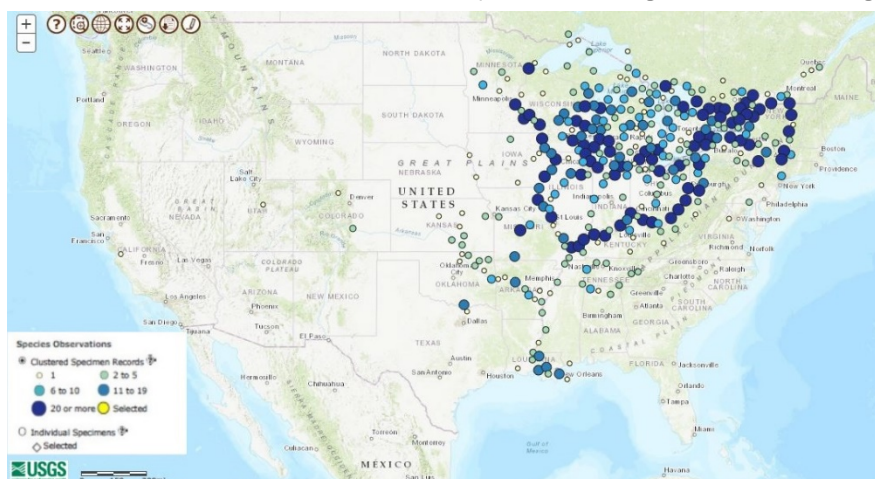
Source: USGS (2019)

Figure 5. Point distribution map of *Dreissena polymorpha* throughout CONUS through 1999.



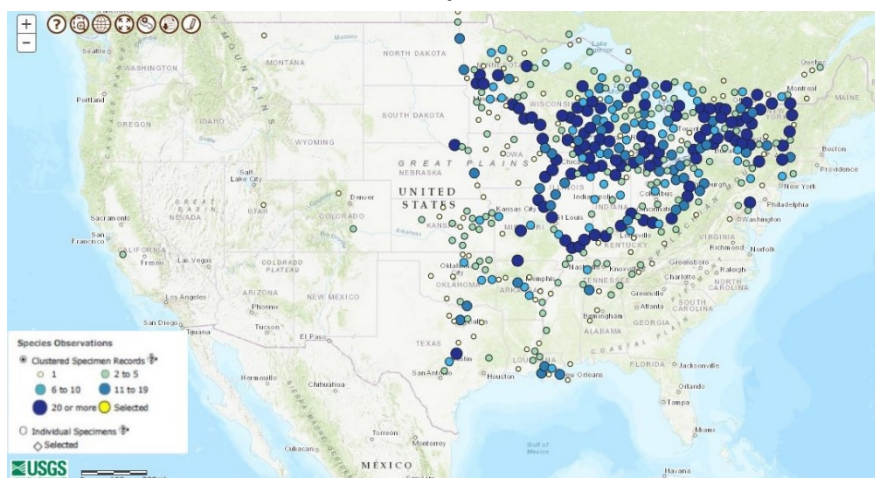
Source: USGS (2019)

Figure 6. Point distribution map of *Dreissena polymorpha* throughout CONUS through 2009.



Source: USGS (2019)

Figure 7. Point distribution map of *Dreissena polymorpha* throughout CONUS through February 2019.



Source: USGS (2019)

Bureau of Reclamation — The Bureau of Reclamation published a report providing an assessment of the impact of invasive mussels on the Fort Randall Dam and Powerplant, which is in the Omaha District and impounds Lake Francis Case on the Missouri River in South Dakota (U.S. Dept. of the Interior 2017). The report's purpose was to provide USACE with an assessment of the vulnerability of the facility to invasive mussel impacts should that infestation occur.

E2 Consulting Engineers, Inc., URS Group, Inc. — A report submitted to the St. Paul District in 2007 titled “Risk Assessment and Decision Analysis Support for Invasive Mussel Management for the St. Croix Basin

and Adjacent Upper Mississippi River” provides extensive background on the biology, ecology, risk and consequences of establishment, and habitat suitability for invasive mussels.*

USACE, Fort Worth District — The Fort Worth District published a report titled *Zebra Mussel Resource Document – Trinity River Basin, Texas* (USACE 2013) with the purpose of providing the knowledge for the monitoring, treatment, and anticipated cost of zebra mussels. The document is specific to the Fort Worth District regarding the presence and potential impacts of zebra mussels but also presents background material, such as biology and history, that is applicable anywhere.

Colorado Parks & Wildlife — A newsletter published by the Colorado Parks & Wildlife (CPW) Invasive Species Program lists actual past and estimated cost figures for the impact of zebra and quagga mussels in the United States and Canada (CPW 2016). References for all cost figures are provided. The cost figures are organized into three categories: Industrial Facilities, Water Treatment, and Power Generation. There are no references specific to USACE, but a conclusion that can be drawn from the newsletter is that invasive mussels have caused significant Operations and Maintenance (O&M) costs to multiple facilities. For example, it is estimated that industry spent \$3.1 billion over 10 years, and the total cost for the Eastern U.S. is \$100 to \$500 million per year.

Tulsa District – USACE — Tulsa District released a response plan for the infestation of zebra mussels at Denison Dam.[†] This report discusses the history and current (2010) state of the infestation as well as potential impacts of the zebra mussels on the Denison Dam infrastructure. Recommendation are also presented for monitoring and preventing extensive damage.

ISLT — In an unpublished document (2018, Appendix C) drafted by ISLT, intended as a letter to Headquarters, U.S. Army Corps of Engineers (HQUSACE) in response to a National Invasive Species Council (NISC) request regarding the impacts of invasive species on USACE, there is discussion that USACE estimates an \$80 million per year total impact from all

* Bartell, S. M., Y. Wu, S. K. Nair, J. Orr, and J. Ragland. 2007. *Risk Assessment and Decision Analysis Support for Invasive Mussel Management for the St. Croix Basin and Adjacent Upper Mississippi River*. Final Report for the U.S. Corps of Engineers. E2 Consulting Engineers, Inc. and URS Group, Inc., USACE contract number W912ES-05-D-0002 Task Order 07.

† Laney, E. E. 2010. *Tulsa District Response Plan for the Infestation of Zebra Mussels (*Dreissena polymorpha*) at Denison Dam, Lake Texoma, Oklahoma and Texas*. USACE Tulsa District, Planning & Environmental Division, Environmental Compliance and Analysis Branch.

invasive species. This estimate is not broken down by species. It is a concern that the impact to the Corps' infrastructure will be lost time, capacity, and/or capability. A specific example is given regarding the zebra mussel infestation at Gavins Point Dam where reduced hydropower generation and increased downtime were realized. It mentions that the Corps has not done a complete assessment but has rather dealt with each case depending on immediate impact or need. The document then provides examples of efforts the Corps has made toward zebra mussel prevention and treatment but then concludes by writing "in general given constraints on budgets our agency has to react versus prevent."

Bureau of Reclamation — The Bureau of Reclamation published another report providing an assessment of the impact due to invasive mussels on the Hoover, Davis, and Parker Dams (U.S. Department of the Interior 2016). This report specifically addresses quagga mussels but gives recent cost figures for the impacts of mussels on dam facilities.

Norfolk District — An aquatic life assessment for the James River Streambank Stabilization Project* contains an appendix that provides a freshwater mussel survey report. That report claims that there are no zebra mussels in the James River basin (a large part of Norfolk District). It does, however, mention that there has been a reporting of zebra mussels in Prince William County, VA (within the Potomac River Basin), which is in nearby Baltimore District.

Missouri Department of Conservation — An online article regarding zebra mussel control discusses the invasion into Missouri in 1991 (MDC 2018). The article specifically mentions that mussels were first reported in the Mississippi River and then later found in the lower Meramec River (both areas are in the St. Louis District).

Lake Champlain Committee — A web article on the Lake Champlain Committee website discusses invasive species (Lake Champlain Committee 2018). It specifically mentions that zebra mussels entered Lake Champlain around 1993. Lake Champlain is in the New York District.

TPWD News — A news release by Texas Parks & Wildlife Department (TPWD) presents the information that Lake Georgetown (a USACE lake in Fort

* Norfolk District. 2015. *James River Streambank Stabilization Project – Biological Assessment, Essential Fish Habitat Assessment, and Effects to Anadromous Fish*. Norfolk, VA: U.S. Army Corps of Engineers (USACE) Norfolk District.

Worth District) and Lake Livingston (a Trinity River Authority lake in Galveston District) in Texas are infested with zebra mussels (TPWD News 2017).

Gaarder — A news article published in the Omaha World Herald tells of the recent observation of zebra mussels at Cunningham Lake, NE (in Omaha District). It also mentions that they have been present in Lake Zorinsky since 2010 (Gaarder 2018a). The Cunningham and Zorinsky Dams were built by USACE and the lakes are leased to the City of Omaha. A more recent article reports that USACE will drain Cunningham Lake to eradicate two invasive species, zebra mussels and common carp (Gaarder 2018b).

Ducey — A news article on the Omaha World Herald's website www.omaha.com describes the inevitable spread of zebra mussels throughout Nebraska (Ducey 2018). It mentions that the Missouri River is already infested and a number of lakes are also infested or suspect. This includes waters in both the Omaha and Kansas City Districts.

San Justo Reservoir — A news article on the Benito Link Website (benitolink.com) discusses the infestation of zebra mussels on the San Juan Reservoir in San Benito County, CA in 2008 (Biles 2015). The lake is within the boundaries of the San Francisco District, but is operated by the San Benito County Water District (i.e., not a USACE lake). The lake has been under quarantine ever since. Another news article on the same website describes the results of a county board meeting where county and federal officials claimed that it may be years before the reservoir is reopened (Chadwell 2016). Later in 2016, the Bureau of Reclamation published a proof-of-concept report on the eradication of zebra mussels in San Juan Reservoir using potash (O'Meara and Hosler 2016). A final report describing the development of a mussel eradication plan using potash was published in 2018 (USDOI 2018). The plan includes four steps: drawing down the reservoir, applying potash to achieve 100 ppm potassium, holding the treatment for 30 days, and monitoring/evaluating the treatment.

Benson — The first chapter in the book, "Quagga and Zebra Mussels: Biology, Impacts, and Control, 2nd Edition" provides an extremely detailed account of the history of the dreissenid mussel invasion into North America. The author references the year that dreissenids were first sighted in major rivers and discusses their introduction to lakes and infrastructure up until 2010 (Benson 2014).

North Dakota Game and Fish Department – A news release by the North Dakota State Government indicates that zebra mussels were discovered in Lake Astabula (NDGF 2019). Lake Astabula is a St. Paul District managed lake on the Sheyenne River north of Bald Hill Dam.

South Dakota Game, Fish, and Parks – A news release by the State of South Dakota indicates that zebra mussels were discovered in Lake Sharpe (South Dakota GFP 2019). Lake Sharpe is a USACE Omaha District managed lake on the Missouri River just west of the Big Bend Dam.

3.2 Questionnaire results

3.2.1 Questionnaire responses

Of the 36 CONUS USACE districts, 28 provided fairly complete responses and seven provided partially complete responses. One district (St. Louis) did not respond. Considering the time needed to answer the questionnaire and to do so voluntarily by a limited number of district representatives, it is reasonable to expect that some information will be missing or possibly inaccurate.

3.2.2 Mussel occurrence on Corps Infrastructure

Table 1 lists summarized and edited responses extracted from the questionnaire and literature that describe the extent at which zebra mussels (ZM) are or were present in USACE districts and on USACE infrastructure. The table includes all CONUS districts, including those where answers to the questionnaire were not received or were incomplete. Blank entries in the table indicate a lack of response or the lack of literature, or are not applicable for that particular question. Answers with a footnote indicate that some or all of the answer was obtained from literature.

Table 1. Summarized district responses regarding presence of zebra mussels.

District	Office Symbol	Are ZM Present Within District Boundaries?	Extent of Presence on Infrastructure	History
Buffalo	LRB	Yes	At Black Rock Lock (only infrastructure in district) at manageable levels.	
Chicago	LRC	Yes	Most locations, significant population at Brandon Lock & Dam.	
Detroit	LRE	Yes	At many projects throughout Lakes Huron, Michigan & Erie. More prevalent further south. Numerous commercial/recreational harbors on each lake note presence during routine O&M activities. This typically includes navigation channels and coastal navigation structures (breakwaters, piers, revetments).	

District	Office Symbol	Are ZM Present Within District Boundaries?	Extent of Presence on Infrastructure	History
Huntington	LRH	Yes	Widespread. They are present at all nine Navigation projects on the Ohio and Kanawha Rivers as well. No significant populations have been noted at other lakes, but they are likely present in low densities	Historically have been discovered in high densities at Alum Creek (1999), Dewey (2004) and Fishtrap (2009) Lakes. Peaked around 2007
Louisville	LRL	Yes	At the Louisville District locks and dams and Ohio River at Ohio Falls Station	
Nashville	LRN	Yes	Widespread but population much less now.	Population peaked ~2001-2002, as high as 23000/sq. m in some areas
Pittsburgh	LRP	Yes	Widespread. At all navigation dams	Peaked ~2007, population crashed ~2010-11, now stabilized
Memphis	MVM	Yes	Lower Mississippi River and Lower Ohio River	
New Orleans	MVN	Yes	Minimal infestation because most infrastructure near saltwater.	
Rock Island	MVR	Yes	Widespread	Much less abundant now and population is stabilized
St. Louis	MVS	Yes (1)	Mississippi River and connected waters (1)	Invasion started in 1991 (Mississippi River) (1)
St. Paul	MVP	Yes	Gull Lake, Cross Lake Dam, Pine River Dam. Zebra mussels present in the Mississippi River primarily downstream of Lake Pepin in Pool 4. Zebra mussels present at Locks and Dams 4 – 10. Recently observed at Lake Ashtabula in North Dakota (Sheyenne River, 2)	In the Upper Mississippi River (UMR), populations are fluctuating annually with die off and recruitment events at all structures.
Vicksburg	MVH	Yes	No recent activity except at #3 Lock and Dam on Red River	
Baltimore	NAB	Yes	Cowanesque Lake and Curwensville Lake, low density and abundance.	Population on decline over last few years
New England	NAE	Yes	Minimal infestation	
New York	NAN	Yes (2)	Non-typical USACE infrastructure	Invaded Lake Champlain in 1993 (3)
Norfolk	NAO	No (3)	Non-typical USACE infrastructure	Observed in Potomac River Basin in nearby Baltimore District(4)
Philadelphia	NAP	Yes	Blue Marsh Lake	
Kansas City	NWK	Yes	Widespread. Just recently found on the downstream side of Harry S. Truman Dam	Relatively recent infestations
Omaha	NWO	Yes	Yes, at Gavins Point Dam. Not yet at Fort Randall Dam in 2018, but expecting them soon there in raw water piping. Literature shows present in Missouri River and lakes near Omaha, NE, and Lewis and Clark Lake on NE/SD border (5,6). More recently discovered in Lake Sharpe, which is past Fort Randall Dam (7).	
Portland	NWP	No	Not present	

District	Office Symbol	Are ZM Present Within District Boundaries?	Extent of Presence on Infrastructure	History
Seattle	NWS	No	Not present	
Walla Walla	NWW	No	Not present	
Charleston	SAC	No	Not present	
Jacksonville	SAJ	No	Not present	
Mobile	SAM	No	Not present	
Savannah	SAS	No	Not present	
Wilmington	SAW	No	Not present	
Albuquerque	SPA	No	Not present	In 2010, there was an isolated sighting on a boat on the Arkansas River.
Los Angeles	SPL	No	Not in any USACE-managed California lakes. No zebra/quagga mussel at any district projects. SPL does not hold permanent pools at any of the projects except for Alamo Dam in Arizona and they do not have any zebra/quagga mussel issues.	
Sacramento	SPK	No	Not present.	
San Francisco	SPN	Yes (6,7,8)	Isolated/quarantined presences in San Justo Reservoir and Ridgemark, both in San Benito County and not operated by USACE (8,9,10)	
Fort Worth	SWF	Yes	Present in five lakes but none in the lakes with hydroelectric structures. In Lake Georgetown (11)	Observed high population shortly after introduction, then collapse, then rebound to a steady manageable level.
Galveston	SWG	Yes	Not present in Galveston District's Area of Responsibility (AOR). Lake Livingston is furthest south with ZM and it is not a Corps lake (but within district boundaries) (11)	
Little Rock	SWL	Yes	Bullshoals Lake, White River tail waters (low density), McClellan-Kerr Arkansas River Navigation System	First incident in 2007 at Bullshoals Lake, peaked in 2013 and lessened since.
Tulsa	SWT	Yes	Multipurpose lakes with hydropower: Ft. Gibson, Keystone Lake, Eufaula, R.S. Kerr, Webbers Falls, Denison Dam, Other lakes: Kaw, Oologah, Skiatook, Chouteau, Newt Graham, W.D. Mayo, Texoma, Council Grove, El Dorado Reservoir, John Redmond Reservoir, Marion	Incidents during 2010-2012 impacted O&M.
(1) MDC (2018). (5) Gaarder (2018a,b). (9) Chadwell (2016). (2) NDGF (2019). (6) Ducey (2018). (10) CDFW (2018). (3) Lake Champlain Committee (2018). (7) South Dakota GFP (2019). (11) TPWD News (2017). (4) Norfolk District (2015). (8) Biles (2015).				

3.2.3 Impacts of Mussels on Corps Infrastructure

Table 2 lists summarized and edited responses from the districts regarding questions related to the impact zebra mussels have or have had on their infrastructure. This table only includes the districts that provided answers to these questions.

Table 2. Summarized district response regarding impacts of zebra mussels.

District	Office Symbol	Surfaces	O&M Impact	Mitigation	Prevention
Buffalo	LRB		No interference with operations and don't typically add O&M costs, minor nuisance		
Chicago	LRC	Found on steel and concrete, but not the rubber seals. Also possibly around the Metropolitan Water Reclamation District (MWRD) controlled structures near lock (sluice gates). A lot on flooring mooring bits and bottom of gates. Probably in valve tunnels.	No increased maintenance specifically due to mussel attachment, yet.	Any attachment near submerged moving parts seem to be crushed or swept off during operation.	
Detroit	LRE	Typically observed adhered to armor stone, steel sheet pile and timber cribbing on navigation structures (piers, breakwaters, revetments)	Do not interfere with our routine O&M as there is minimal O&M associated with these structures	None	No
Huntington	LRH	Adhered to gates, sills, cables, tunnels, boats, docks, etc.	Infestations at Dewey Lake resulted in extra cleaning and maintenance of gate structures. There was no down time for our flood control structures.	Regular exercising of outlet gates	No
Louisville	LRL	Lock and dam surfaces, gaging stations and raw water wells	Not a significant impact on stations operations so far (except for interfering with water quality sensors).	Scraping or brushing off, chlorine tablets	
Nashville	LRN		No known current or potential impacts to hydropower projects	Chlorination strategies as a control technology were abandoned sometime after 2002 due to lack of zebra mussel fouling problems.	Hydropower plants at Barkley and Cheatham Dams have discontinued regular monitoring although the infrastructure is in place to conduct future monitoring, if deemed necessary
Pittsburgh	LRP	Lock walls, floating mooring bits, intakes, aluminum bulkheads	No reports of impact to steel structures, significant corrosion to aluminum maintenance bulkheads (decreased lifetime)	Coatings on aluminum bulkheads to minimize corrosion	
Memphis	MVM	Concrete, attached to Articulated Concrete Mat (ACM)			Monitoring
New Orleans	MVN		Not lately		
Rock Island	MVR	Concrete	There is no known direct impact but it could be a tax		Adult zebra mussel populations are

District	Office Symbol	Surfaces	O&M Impact	Mitigation	Prevention
			on the system such as eroding the concrete faster needing replacement or repair more quickly		monitored along with long-term native mussel populations in all pools 11 -16 of the UMR. Veliger monitoring is ongoing at Cordova, IL in Pool 14.
St. Paul	MVP	Gate's skin plate and concrete piers	Just had a recent incident at Gull Lake, MN - opened a gate on a dam and couldn't close it due to ZM.	Empty zebra mussel shells impacted barge passage with locks and dams in the late 1990s. Dredged from lock chambers and deposited in approved landfills.	Adult zebra mussel populations are monitored along with long-term native mussel populations in all pools of the UMR. Veliger monitoring also occurred until 2012 in the UMR and major tributaries and continues in the St. Croix River watershed.
Vicksburg	MVH	Concrete walls	No recent activity except #3 lock and dam on Red River		
Baltimore	NAB	Along the shoreline and on concrete trash racks, underside of beach and navigational buoys, concrete walls inside of wet wells	None	None	Projects display informational signs to deter boaters from transporting zebra mussels and other invasive species into and out of lakes. Monitoring done during routine inspections.
New England	NAE	Concrete, steel, aluminum, submerged structures and equipment, navigation gate safety railings, top gate access hatches, two navigation gate lifting arms, gate sill and gate pedestals on the bottom of the channel.	Yes, it is a recurring maintenance item about three times per year. Also, they minimally effect corrosion and the functionality of water level sensors.	Removed by scraping. Also tried pressure washing, but it was not very effective.	
Philadelphia	NAP				Blue Marsh Lake has a monitoring program
Omaha	NWO		Zebra Mussels within the Gavins Point Project have resulted in upwards of a 50% increase in the time needed to complete routine maintenance tasks that involve the plants cooling water systems. Omaha can only qualify but not quantify the impacts	Current plan is to use an ultrasonic device to kill the mussels as/if they enter our raw water piping.	

District	Office Symbol	Surfaces	O&M Impact	Mitigation	Prevention
Albuquerque	SPA				Yes (funding is an issue). Early detection program with water sampling and analysis. Monitor 6 projects by sampling plankton between June and September. Also some boat inspections are done by NM and CO State Parks.
Sacramento	SPK				Monthly substrate monitoring, posted bulletins, partnership with the California Department of Fish and Wildlife (CDFW)
Fort Worth	SWF	Gates, concrete surfaces.		They have scraped off in past but put coatings on 4 to 5 years ago and are now considering new coatings to redo.	Early detection program with the state, academia and USGS. Careful water management practices
Little Rock	SWL	Found on all surfaces below water surface down to around 35 feet on the lake side of Bull Shoals Dam. Most concerning are the ones adhering to intake openings and pipes which could in time cause water inflow restrictions and even blockage.	None	None, other than scraping them off of areas above the normal water line left behind after a high water event.	No
Tulsa	SWT		O&M impacts to each hydropower facility varies and dependent on stage of invasion, type of strainers, and design of powerhouse. The design of three powerhouses (Eufaula, R.S. Kerr, and Denison) includes a deluge system for the facility's transformer fire suppression, which can be impacted by zebra mussels. In 2012, Ft. Gibson reported an increase in O&M by 10 work hours due to impacts on A/C system. At Eufaula in 2010, it took 10 work hours (\$905.00) to clean clogged cooling water intake strainers and 48 work hours (\$4,344.00) to clean the main unit head gates. In 2011, it took 10.5 work	Chlorine tablets/injectors have not been used	

District	Office Symbol	Surfaces	O&M Impact	Mitigation	Prevention
			hours (\$950.00) to clean cooling water intake strainers and 4 work hours (\$362.00) to clean transformer fire suppression equipment. In 2012, 7 work hours (\$724.00) were spent cleaning cooling water intake strainers and 8 work hours were spent on cleaning transformer fire suppression equipment. During fire suppression tests (2012), impacted function of the system by clogging the pump and the process was stopped, pump filter/strainer cleaned, and process restarted. This interruption occurred several times and had there been an actual need for the fire suppression, there may have been complications.		

4 Discussion

4.1 Mussel occurrence on Corps infrastructure

The results of the questionnaire and literature search indicated that zebra mussels are present in 24 CONUS USACE districts. This includes all the districts in the Great Lakes and Ohio River and Mississippi Divisions, all in the North Atlantic Division except Norfolk (Norfolk District 2015), all in the Southwestern Division, the Kansas City and Omaha districts in the Northwestern Division, and the San Francisco District in the South Pacific Division. These results are mostly consistent with the reported sightings in the USGS database (USGS 2019) as shown in Figures 9 and 8, except for some isolated sightings out in the western portion of CONUS (Colorado, Utah, and Montana) and Alabama. These discrepancies are mostly due to isolated one time incidents in which zebra mussels are no longer present or the status of mussel persistence is unknown. The occurrences in Colorado and Utah (all 2008) are each based on a single report and have either a “failed” or “extirpated” status. Montana’s occurrence is due to a single observation in 2016 with a current “unknown” status. In Alabama (Mobile District), zebra mussels have been reported nearby in the Tennessee River according to the USGS database, but literature evidence of their presence within the district boundaries is elusive. The USGS database has two recent (2017) individual observations within the district boundaries near Bankhead Lake, but both currently with “unknown” status. This could be an indication that Mobile District may be at risk for invasion. Albuquerque and Omaha (already experiencing a presence, Ducey 2018) also seem to be at risk based on the questionnaire responses.

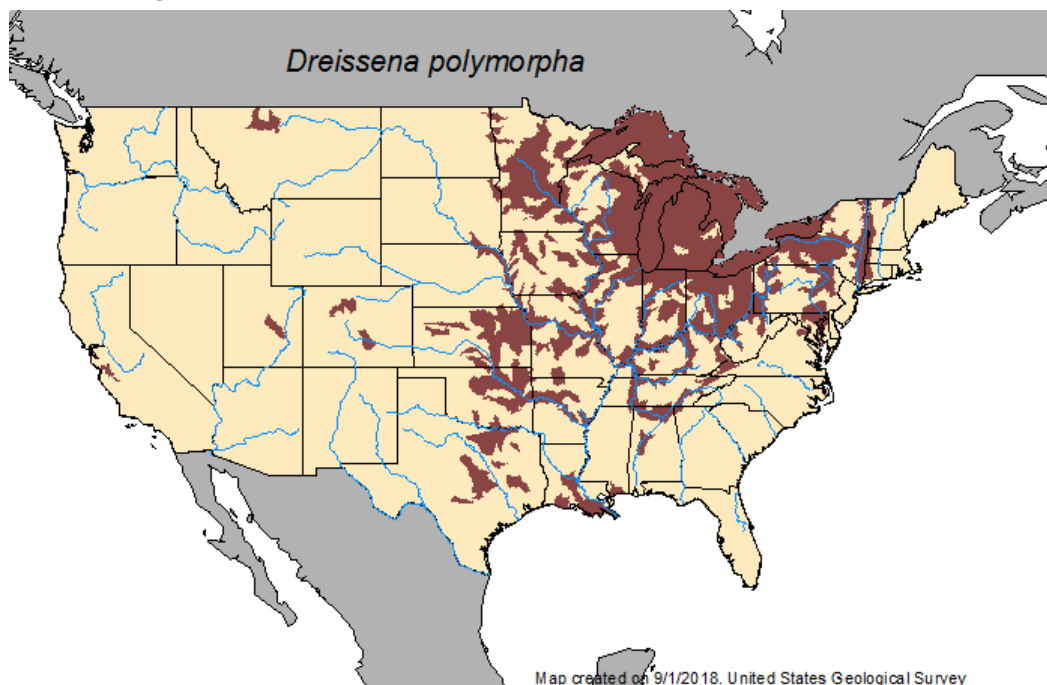
The results of mussel presence indicated in Table 1 and Figure 8 are based on the district boundaries and not on whether mussels are present in USACE-managed waters. San Francisco District, for example, has two patches shown in Figure 9 that are due to two isolated observations in 2008 and 2012 and currently listed with “established” status by USGS. The 2008 observation is at San Justo Reservoir (not a USACE lake), which has been under quarantine since 2008 and an eradication plan has been pursued (O’Meara and Hosler 2016).

Figure 8. USACE districts with a zebra mussel presence within district boundaries, shading represents a presence.



Source: <https://www.usace.army.mil/Locations/>.

Figure 9. USGS database representation of zebra mussel observations.



The 2012 sighting is at a nearby golf course, the Ridgemark gold course pump (CDFW 2018). Neither site is currently a threat to San Francisco District. Galveston District is another example. The only observed and currently active mussel presence is in Lake Livingston (TPWD News 2017), which is within the district boundaries but not a USACE-managed lake.

The general history of the zebra mussel infestation is that it first occurred in the Great Lakes (most likely Lake Erie) and spread across the country via waterways and boats. The infestation started during the late 1980s in the Great Lakes and Ohio River Division, and spread to the North Atlantic Division and the Mississippi Valley Division in the early 1990s, and then infested the Southwestern Division by the 2000s (Benson 2014). In many districts, that have been infested for multiple years, the zebra mussel population stabilized after experiencing a boom followed by a die off. This pattern was supported by responses from seven districts (Huntington, Nashville, Pittsburgh, Rock Island, Baltimore, Fort Worth, and Little Rock). The districts that are experiencing noticeable infestations are near the outer edges of the infestation pattern, where new populations are in the beginning stages of establishment, shown by Figures 8 and 9. These include Kansas City, St. Paul, New England, Vicksburg and perhaps, Fort Worth and Tulsa. Omaha is also just inside the expanding boundaries of mussels and is currently experiencing an invasion. Those districts just outside the establishment boundaries (Albuquerque, Mobile) may be at risk of invasion. It is also interesting to observe that the zebra mussels have almost completely avoided the South Atlantic Division, perhaps due to environmental factors. The lack of establishment in the South Atlantic Divisions may indicate that if Mobile District is eventually invaded, the infestation may not be as severe as the infestations that occurred in northern and western Districts.

Most of the districts that report zebra mussels in USACE-managed waters also report that they are present on USACE infrastructure. One notable exception to this is Fort Worth, where they are present in five lakes but not in the lakes with hydroelectric structures.

4.2 Extent of mussel impacts at Corps Infrastructure

According to the questionnaire responses, zebra mussels were found to adhere to most underwater surface, including concrete, metal, wood, and aluminum. This is consistent with the widely known behavior of zebra mussels (Snyder et al. 1992, Marsden and Lansky 2000). The only notable exception was with the Chicago District reporting that the zebra mussels

did not attach to rubber which can be found on seals for some movable components, such as gates. This is in contrast to Snyder et al. (1992), who specifically mention rubber and vinyl as suitable substrates, and to Miller and Payne (1992), who specifically discuss rubber gate seals as being vulnerable to zebra mussel attachment.

Miller and Payne (1992) also present the different types of public infrastructure that are potentially vulnerable to zebra mussels (Table 3).

Table 3. Facilities/structures likely to be affected by zebra mussels (Miller and Payne 1992).

Facility	Structure
Navigation (Gated) Locks	Reservoirs and Outlet Works
Chamber walls	Spillways (crest, gates, and energy dissipaters)
Water intakes	Conduits (intakes, screens, emergency and regulating valves, and energy dissipaters)
Filling and emptying valves	Emergency closures and dewatering valves
Culvert walls	Water quality release works (valves and monitoring equipment)
Lower and upper approaches (including navigation buoys)	Associated recreation areas (docks, boat ramps, floating structures, beaches, and swimming areas)
Upper gates	
Lower gates	Pumping Plants
Emergency closure	Approach (trash racks, approach walls, and chamber)
Navigation aids	Pump (propellers, propeller shafts, and suction bell)
Dewatering equipment (including bulkhead slots)	Delivery line
Monitoring equipment	Dewatering equipment
Mooring bits	Monitoring equipment
Ladders	
Piping (including raw water facilities such as those used for fire protection)	Drainage Structures
Grating and screening	Gaging Stations (staff gates, float gates, and bubble gages)
	Flood walls and gates
Navigation Dams	Flap gates
Control gates (opening and closing, as well as seals and crests)	Debris control structures
Navigation pass (wickets and sills)	Grade control structures
Dewatering and emergency closure	Flow control and water level control structures (stop logs and rubber dams)
Maintenance equipment	
Monitoring equipment	Hydropower
	Turbines
	Water distribution systems

Structures mentioned in the questionnaire results include many of the entries in Table 3, but more specifically they are: gates (all parts except rubber seals), valve tunnels, timber cribbing on navigational structures (piers, breakwaters, revetments), cables, boats, docks, lock and dam surfaces, gaging stations, raw water wells, floating mooring bits, intake openings and pipes, concrete trash racks, underside of beach, navigational buoys, water sensors, transformer fire suppression equipment, and cooling water intake strainer. The questionnaire yielded consistently similar structures (to which zebra mussels have adhered) as described in the list provided by Miller and Payne [1992], with the only inconsistencies being either vaguely included in the structures of Table 3 (e.g., cribbing, cables) or not considered infrastructure, more specifically “boat.” However, recreational boat hulls were specifically mentioned as impacted by zebra mussels by Cole et al. (2010) in their report regarding impacts of aquatic nuisance species at USACE projects. In summary, it appears that zebra mussels do not exclude any surfaces or structures to which they can attach, although can do so with varying degrees of preference (Marsden and Lansky 2000) and with the possible exception of rubber seals.

Of the 22 districts that have zebra mussels in USACE-managed waters excluding St. Louis (nonresponse), 13 (62%) reported no or minimal impacts to infrastructure O&M. Many of these installations have had mussel long standing mussel infestations and several discussed the history of these infestations. The general sense was that the mussel invasion was strong at first, then died off and has stabilized at manageable levels. Some of these installations have experienced an impact on O&M in the past but are no longer impacted beyond a perceived minor nuisance. This is particularly true for the Great Lakes and Ohio Division, where the initial invasion began.

The remaining eight districts with zebra mussel occurrences in USACE-managed waters had notable impacts: Huntington, Pittsburgh, St. Paul, Vicksburg, New England, Omaha, Fort Worth, and Tulsa. Four of these districts are notable because of isolated recent incidents: at Huntington a buildup on Dewey Lock required extra cleaning and maintenance on the gate structures; at St. Paul, a gate could not be closed due to the buildup of zebra mussels; at Vicksburg there has been the infestation at #3 Lock and Dam on Red River; and at Omaha it has been reported that maintenance time has increased by about 50% at Gavins Point Dam. New England District has a recurring maintenance three times per year due to mussels and experience corrosion and water level sensor damage. Fort Worth District

has had to scrape mussels off their infrastructure in the past and have applied coatings. They are currently needing to recoat some surfaces. Tulsa District experienced numerous O&M issues back in 2010-2012 that were detailed in Table 2, which resulted in about \$7K in extra costs. Pittsburgh District has experienced significant corrosion issues with their temporary aluminum maintenance bulkheads (see Figures 2 and 3). Figures 10 and 11 show zebra mussels concentrated around stainless steel bolts on a Montgomery Locks and Dam aluminum bulkhead. Figures 12 and 13 show the corrosion remaining after the bulkhead was power-washed.

Figure 10. Zebra mussels on Montgomery aluminum bulkhead (image 1).



Figure 11. Zebra mussels on Montgomery aluminum bulkhead (image 2).



Figure 12. Montgomery aluminum bulkhead after power washing.



Figure 13. Montgomery aluminum bulkhead after power washing (closeup).



Other than the cost figures provided by Tulsa District, costs are not well known or documented. The ISLT also does not have good cost accounting of the impacts caused by ZM (Appendix C). It is noticeable that the costs and maintenance activities that are reported do not seem exorbitant, and do little to support the estimated costs in CPW (2016). Cole et al. (2010) found that while there have been some exorbitant cost estimates attributed to zebra mussels, their survey did not reveal any management costs directly due to zebra mussels at USACE infrastructure. Cole et al. also point out that none of the locks covered by their survey were impacted even though zebra mussels were present.

According to the questionnaire responses currently employed mitigation techniques used by USACE include scraping, chlorination, and exercising movable parts to crush and sweep off. Omaha District mentioned that they plan to use an ultrasonic device if zebra mussels invade their raw water piping (at Fort Randall Dam). The U.S. Department of Interior (USDOI 2016, 2017) actually suggest using an ultraviolet treatment for the cooling water system at Fort Randall Dam (not ultrasonic), like the system they installed at Parker Dam (Quinn 2018). USACE planned to drain Cunningham Lake near Omaha, NE (Gaardner 2018b)

In relation to mussel prevention, some districts report having monitoring programs to alert of possible invasions or proliferation. These districts are Memphis, Rock Island, St. Paul, Baltimore, Philadelphia, Albuquerque, Sacramento, and Fort Worth. Rock Island and St. Paul districts periodically monitor zebra mussel populations at significant native mussel beds by dive surveys in close proximity to Mississippi River locks and dams providing long-term spatial and temporal trends in zebra mussel population levels near infrastructure.* Nashville has monitored in the past and has kept the monitoring equipment in place so that it could start up again if necessary. Not noted in the survey results, Seattle, Portland and Walla Walla districts all conduct some monitoring in conjunction with the 100th Meridian Group, states and USGS.† Fort Worth District has used coatings with some positive results and is now reconsidering newer coatings for reapplication. This indicates that monitoring programs are being successfully used by the districts and that there is some interest in new coating technology.

There seems to be a sense of dread in a couple of districts that are in or on the verge of an invasion (Albuquerque, Omaha) probably because the initial impact of an invasion in a new area can be the largest. These districts have hydropower facilities and there is concern that the zebra mussels will cause costly O&M impacts.

* Kelner, D. E., email communication with author regarding report review, 6 June 2019

† Walter, D. J., email communication with author regarding report review, 9 May 2019.

5 Conclusion

The following conclusions were made after a review of current literature and the administered questionnaire to the 36 CONUS USACE districts.

1. ZM are present within 24 district boundaries in varying population densities. Observed densities strongly depend on the phase and longevity of the invasion. Two of those districts have isolated infestations that are not in USACE waters.
2. Survey and literature results for the presence of ZM are consistent with the USGS reporting database with the exception of a few observations in western CONUS and in the Mobile District.
3. The ZM invasion is slowly spreading west with Albuquerque and Omaha districts at risk for future infestations. Both districts have expressed concern about possible infestations. Mobile District may also experience a future infestation, although ZM have thus far avoided infiltrating the South Atlantic Division. It is likely any future invasion will not be as severe as those documented in neighboring northern and western districts likely due to less favorable environmental conditions.
4. The districts with occurrences of ZM present have observed ZM adhering to their infrastructure and attached to all different types of USACE structures as predicted by Miller and Payne (1992).
5. ZM were found to adhere to all types of surfaces, with the possible exception of rubber.
6. Sixty-two percent of the districts with reported ZM presence in USACE waters claim little to no impacts on their infrastructure or O&M costs. Actual cost figures are not well known even with the installations experiencing impacts. The results do not support the exorbitant cost figures estimated by the literature.
7. Eight districts reported notable ZM impacts to their infrastructure. Those districts are near the outside borders of the invasion map and have had more recent infestations.
8. The common pattern of invasion that has been observed is one of a peak concentration, a die back and then the stabilization of the ZM population at manageable levels.
9. Twelve districts reported either having current ZM monitoring programs or had monitoring programs in place in the past. These monitoring programs are used to detect ZM presence and/or concentrations.
10. Fort Worth district has previously employed mussel resistant coatings and is currently interested in newer coatings.

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Acronyms and Abbreviations

Term	Definition
ACM	Articulated Concrete Mat
AOR	Area of Responsibility
CDFW	California Department of Fish and Wildlife
CONUS	Continental United States
CPW	Colorado Parks and Wildlife
HS	Hydraulic Structure
HQUSACE	Headquarters, U.S. Army Corps of Engineers
ISLT	Invasive Species Leadership Team
MWRD	Metropolitan Water Reclamation District
NISC	National Invasive Species Council
O&M	Operations and Maintenance
PDT	Project Development Team
POC	Point of Contact
TPWD	Texas Parks and Wildlife Department
UMR	Upper Mississippi River
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey
WWW	World Wide Web
ZM	Zebra Mussels

Appendix A: Questionnaire Responses

A.1 Great Lakes and Ohio River Division.

Table A-1. Questionnaire Responses: Buffalo LRB District.

Questions	Answers
Are there zebra mussels in your district? If so, at which locations within the district are they present?	The Buffalo District has zebra and quagga mussels on our lock (Black Rock Lock) at the District Office
If not, has the district ever had zebra mussels (in the past but died off -may hint at cyclical patterns)?	
How bad is the infestation? Estimate density and abundance in the district.	Black Rock Lock is the only infrastructure we operate and maintain besides harbor O&M. At the lock, they are at manageable levels. The mussels are very widespread in the Great Lakes though
On what surfaces do they adhere? Are they on the infrastructure, if so where?	
Are zebra mussels interfering with O&M? If so, at what cost?	They don't interfere with operations and don't typically add O&M costs, they are a minor nuisance
What methods are used for mussel mitigation (facility retrofit, scraping, chemicals, jet washing, desiccation)?	
What is an estimate of down time due to zebra mussel mitigation?	
Does your district take any preventative measures to deter zebra mussels?	
Please provide projects impacted by zebra mussels and a point of contact	
Additional comments:	The lock will be dewatered this winter for maintenance

Table A-2. Questionnaire Responses: Chicago LRC District.

Questions	Answers
Are there zebra mussels in your district? If so, at which locations within the district are they present?	Yes. Most locations.
If not, has the district ever had zebra mussels (in the past but died off -may hint at cyclical patterns)?	N/A
How bad is the infestation? Estimate density and abundance in the district.	Brandon Road Lock & Dam has a significant population noticeable when dewatering.
On what surfaces do they adhere? Are they on the infrastructure, if so where?	They are found on the steel and concrete but not the rubber seals. Also possibly around the MWRD controlled structures near the lock (sluice gates). A lot are the on flooring mooring bits and along bottom of the gates. Probably in the valve tunnels.
Are zebra mussels interfering with O&M? If so, at what cost?	There is no increased maintenance specifically due to mussel attachment, yet.
What methods are used for mussel mitigation (facility retrofit, scraping, chemicals, jet washing, desiccation)?	Any attachment near submerged moving parts seem to be crushed or swept off during operation.
What is an estimate of down time due to zebra mussel mitigation?	
Does your district take any preventative measures to deter zebra mussels?	No
Please provide projects impacted by zebra mussels and a point of contact	
Questionnaire: Detroit LRE District	Answers
Are there zebra mussels in your district? If so, at which locations within the district are they present?	Zebra mussels are found at many of our projects throughout Lake Huron, Lake Michigan & Lake Erie. More prevalent as you move further south on the lakes. We have numerous commercial/recreational harbors located on each lake, so we are not listing them all, but typically will note the presence of the mussels during routine O&M activities. These projects typically include navigation channels and coastal navigation structures (breakwaters, piers, revetments).

Questions	Answers
If not, has the district ever had zebra mussels (in the past but died off -may hint at cyclical patterns)?	As we have never tracked any kind of definitive information, it is difficult to say whether the prevalence has declined or increased.
How bad is the infestation? Estimate density and abundance in the district.	We do not have any good estimates of density or abundance and do not track any kind of data/observations.
On what surfaces do they adhere? Are they on the infrastructure, if so where?	They are typically observed adhered to armor stone, steel sheet pile and timber cribbing on our navigation structures (piers, breakwaters, revetments)
Are zebra mussels interfering with O&M? If so, at what cost?	They do not interfere with our routine O&M as there is minimal O&M associated with these structures (due in part to lack of funding, but also the nature of the structures - minimal routine physical maintenance, and when required you are talking replenishing/replacing stone, repairing/replacing SSP due to damage, encapsulating timber cribbing if accomplishing a major repair to those type of structures). Presence of the mussels can interfere with visual inspections - say by underwater ROV or divers. Our projects do not include the type of infrastructure that can be more seriously impacted, such as water intakes, water level gages, etc. The possible exception being the Soo Locks Complex, but the colder waters of Lake Superior seem to deter the presence of the mussels.
What methods are used for mussel mitigation (facility retrofit, scraping, chemicals, jet washing, desiccation)?	We do not pursue any work related specifically to removal of mussels. As noted above, the presence of the mussels has little to no impact on major maintenance when required.
What is an estimate of down time due to zebra mussel mitigation?	None
Does your district take any preventative measures to deter zebra mussels?	No
Please provide projects impacted by zebra mussels and a point of contact	

Table A-3. Questionnaire Responses: Huntington LRH District

Questions	Answers
Are there zebra mussels in your district? If so, at which locations within the district are they present?	Yes. Historically have been discovered in high densities at Alum Creek (1999), Dewey (2004) and Fishtrap (2009) Lakes. They are present at all nine Navigation projects on the Ohio and Kanawha Rivers as well. No significant populations have been noted at other lakes, but they are likely present in low densities.
If not, has the district ever had zebra mussels (in the past but died off -may hint at cyclical patterns)?	N/A
How bad is the infestation? Estimate density and abundance in the district.	See attached MFR. Densities seemed to have peaked around 2007 at Dewey Lake. Mussel densities were too high to estimate. Dewey densities have significantly decreased since 2007. No estimates on abundance have been made for the District.
On what surfaces do they adhere? Are they on the infrastructure, if so where?	They have adhered to gates, sills, cables, tunnels, boats, docks, etc.
Are zebra mussels interfering with O&M? If so, at what cost?	Infestations at Dewey Lake resulted in extra cleaning and maintenance of gate structures. Zebra mussels significantly clarified the lake creating a deeper epilimnion and a large increase in submerged macrophytes. This interfered with our Recreation mission (fishing, boating, etc.).
What methods are used for mussel mitigation (facility retrofit, scraping, chemicals, jet washing, desiccation)?	Regular exercising of outlet gates.
What is an estimate of down time due to zebra mussel mitigation?	There was no down time for our flood control structures.
Does your district take any preventative measures to deter zebra mussels?	No
Please provide projects impacted by zebra mussels and a point of contact	District – Andrew Johnson, Andrew.n.johnson@usace.army.mil <mailto:Andrew.n.johnson@usace.army.mil> Dewey – David Freeland, David.e.freeland@usace.army.mil <mailto:David.e.freeland@usace.army.mil> Fishtrap – Rodney Holbrook, Mark.r.holbrook@usace.army.mil <mailto:Mark.r.holbrook@usace.army.mil>

Table A-4. Questionnaire Responses: Louisville LRL District.

Questions	Answers
Are there zebra mussels in your district? If so, at which locations within the district are they present?	Yes at the Louisville District locks and dams and also Ohio River at Ohio Falls Station.
If not, has the district ever had zebra mussels (in the past but died off -may hint at cyclical patterns)?	N/A
How bad is the infestation? Estimate density and abundance in the district.	
On what surfaces do they adhere? Are they on the infrastructure, if so where?	Lock and dam surfaces, gaging stations and raw water wells.
Are zebra mussels interfering with O&M? If so, at what cost?	They inhibit the ability to inspect structures at times, but can be brushed off easily enough when we inspect or work on things. We (Markland L&D, Ohio River) have seen zebra mussels, but I would not say that it has had a significant impact on the stations operations up to this point (except for interfering with their water quality sensors).
What methods are used for mussel mitigation (facility retrofit, scraping, chemicals, jet washing, desiccation)?	Scraping or brushing off, chlorine tablets.
What is an estimate of down time due to zebra mussel mitigation?	
Does your district take any preventative measures to deter zebra mussels?	
Please provide projects impacted by zebra mussels and a point of contact	Cannelton and Smithland L&D (Ohio River): Zebra mussels are a primary pest.

Table A-5. Questionnaire Responses: Nashville LRN District.

Questions	Answers
Are there zebra mussels in your district? If so, at which locations within the district are they present?	In the Cumberland River, zebra mussels have been observed in low numbers downstream from Old Hickory Dam (CRM 216.2). A single zebra mussel was documented in 1999 at CRM 306.3, near the upper end of Old Hickory Reservoir. Further upstream, the only confirmed occurrence was at the Conley Bottom Marina on Lake Cumberland.
If not, has the district ever had zebra mussels (in the past but died off -may hint at cyclical patterns)?	Based on available records, zebra mussels have been documented in the Tennessee River since circa 1990. By late 2001, there were potentially significant increases in the population density of zebra mussels in several upper Tennessee River locations. There were large populations below Chickamauga Dam, within Watts Bar Reservoir, and below Watts Bar Dam. Densities in these areas ranged from 600 to over 23,000 per square meter. Compared to the upper reaches of the Tennessee River, the middle and lower reaches of the Tennessee River had very low zebra mussel densities. Maximum site density in Kentucky Lake, for example, was 0.05 mussels per square meter. A survey conducted in conjunction with the 2002 Wheeler Lock chamber dewatering revealed an estimated 200 zebra mussels per square meter in the upper end of the lock and 10 per square meter in the lower end of the lock. These populations apparently did/do not impact Corps missions
How bad is the infestation? Estimate density and abundance in the district.	When Barkley Lock (KY) was dewatered in 2001, a survey revealed mussel densities of less than 1 per square meter.
On what surfaces do they adhere? Are they on the infrastructure, if so where?	
Are zebra mussels interfering with O&M? If so, at what cost?	Nashville District has no known current or potential future impacts to our hydropower projects due to aquatic invasive species, i.e. zebra mussels.
What methods are used for mussel mitigation (facility retrofit, scraping, chemicals, jet washing, desiccation)?	Chlorination strategies as a control technology were abandoned sometime after 2002 due to the lack of zebra mussel fouling problems at Nashville District facilities.
What is an estimate of down time due to zebra mussel mitigation?	
Does your district take any preventative measures to deter zebra mussels?	Hydropower plants at Barkley and Cheatham Dams have discontinued regular zebra mussel veliger monitoring although the infrastructure is in place to conduct future monitoring, if deemed necessary. This is due to the fact that past veliger monitoring had never revealed numbers that reached a level that would indicate a significant increase nor a potential fouling problem.
Please provide projects impacted by zebra mussels and a point of contact	

Table A-6. Questionnaire Responses: Pittsburgh LRP District.

Questions	Answers
Are there zebra mussels in your district? If so, at which locations within the district are they present?	Yes. Allegheny, Ohio and Monongahela River Locks, Kinzua & Allegheny Reservoir, Berlin Lake, Mosquito Creek Lake. We've documented zebra mussel infestations at Berlin, Kirwan, and Mosquito Creek Lakes, and also at every navigation dam.
If not, has the district ever had zebra mussels (in the past but died off -may hint at cyclical patterns)?	According to our Water Quality Biologist, around 2010/2011 the zebra mussel population crashed throughout the District. Prior to 2008, we had problems with zebra mussels at the navigation dams and Mosquito Creek Lake in particular. For example, a 2007 photo of a Mosquito trash rack is attached; the Warren water supply intake was also completely clogged. However, around 2010 or 2011, it appeared that the zebra population crashed throughout the District. While populations have recovered, I don't think that they are as dense as they were
How bad is the infestation? Estimate density and abundance in the district.	Much less than in years prior to 2010.
On what surfaces do they adhere? Are they on the infrastructure, if so where?	See attached photo. Also, lock walls, floating mooring bitts, intakes.
Are zebra mussels interfering with O&M? If so, at what cost?	I have not had any reports of it, but did not get much feedback.
What methods are used for mussel mitigation (facility retrofit, scraping, chemicals, jet washing, desiccation)?	Unsure.
What is an estimate of down time due to zebra mussel mitigation?	
Does your district take any preventative measures to deter zebra mussels?	
Please provide projects impacted by zebra mussels and a point of contact	Contact Rose Reilly at 412-395-7357 or Tom Maier at 412-395-7219 for additional information. They are the best source of information on this topic.

A.2 Mississippi Valley Division*

Table A-7. Questionnaire Responses: Memphis MVM District.

Questions	Answers
Are there zebra mussels in your district? If so, at which locations within the district are they present?	Yes, Lower Mississippi River and Lower Ohio River.
If not, has the district ever had zebra mussels (in the past but died off -may hint at cyclical patterns)?	
How bad is the infestation? Estimate density and abundance in the district.	
On what surfaces do they adhere? Are they on the infrastructure, if so where?	Most of our experience with zebra mussels is illustrated in the attached image with mussels attached to ACM
Are zebra mussels interfering with O&M? If so, at what cost?	Not known
What methods are used for mussel mitigation (facility retrofit, scraping, chemicals, jet washing, desiccation)?	
What is an estimate of down time due to zebra mussel mitigation?	
Does your district take any preventative measures to deter zebra mussels?	Monitoring.
Please provide projects impacted by zebra mussels and a point of contact	

* Note: There were no responses from St. Louis MVS and minimal responses from Memphis and Vicksburg.

Table A-8. Questionnaire Responses: New Orleans MVN District.

Questions	Answers
Are there zebra mussels in your district? If so, at which locations within the district are they present?	Yes we do have zebra mussels, but they do not cause too much of a problem
If not, has the district ever had zebra mussels (in the past but died off -may hint at cyclical patterns)?	
How bad is the infestation? Estimate density and abundance in the district.	
On what surfaces do they adhere? Are they on the infrastructure, if so where?	
Are zebra mussels interfering with O&M? If so, at what cost?	Not much attention on mussels lately. Many of our structures are in coastal areas where the saltwater reduces excessive infestation. In those areas, I've seen oyster attachment to be much greater than zebra mussel attachment.
What methods are used for mussel mitigation (facility retrofit, scraping, chemicals, jet washing, desiccation)?	
What is an estimate of down time due to zebra mussel mitigation?	
Does your district take any preventative measures to deter zebra mussels?	
Please provide projects impacted by zebra mussels and a point of contact	Russell Beauvais - Old River Control - Miss and Atch Rivers, Vic Landry - GIWW - New Orleans to Calcasieu Lock, Tim Connell - Atchafalaya Basin, Tracy Falk - SW Louisiana saltwater control structures, Ray Newman - Bonnet Carre Spillway, New Orleans flood control structures and outlets

Table A-9. Questionnaire Responses: Rock Island MVR District

Questions	Answers
Are there zebra mussels in your district? If so, at which locations within the district are they present?	Yes. Pretty much everywhere in the district but not as abundant as they used to be in the 1990s. Most in the Illinois waterway (the original “epicenter” of the problem) but now not much anymore and they are hard to find. They don’t know exactly why that is the case but they suspect things like water temperature (mentioned Lake Pepin temperature). Same with the Mississippi River - much less abundant and population is stabilized.
If not, has the district ever had zebra mussels (in the past but died off -may hint at cyclical patterns)?	
How bad is the infestation? Estimate density and abundance in the district.	Should contact Dan Kelner (MVP) for population numbers.
On what surfaces do they adhere? Are they on the infrastructure, if so where?	concrete
Are zebra mussels interfering with O&M? If so, at what cost?	they have tried to quantify the impact of zebra mussels many times for cost and operation/maintenance and it’s really hard to do and is all over the board, and it’s as if there is no direct impact but it could be a tax on the system such as eroding the concrete faster than it should so that it would need to be replaced or repaired more quickly. Should contact Courtney Chambers for cost figures, if they exist.
What methods are used for mussel mitigation (facility retrofit, scraping, chemicals, jet washing, desiccation)?	
What is an estimate of down time due to zebra mussel mitigation?	
Does your district take any preventative measures to deter zebra mussels?	Monitoring in Cordova, IL.
Please provide projects impacted by zebra mussels and a point of contact	

Table A-10. Questionnaire Responses: St. Paul MVP District.

Questions	Answers
Are there zebra mussels in your district? If so, at which locations within the district are they present?	Yes. Gull Lake, Cross Lake Dam, Pine River Dam. Zebra mussels present in the Mississippi River primarily downstream of Lake Pepin in Pool 4. Zebra mussels present at Locks and Dams 4 – 10.
If not, has the district ever had zebra mussels (in the past but died off -may hint at cyclical patterns)?	
How bad is the infestation? Estimate density and abundance in the district.	Zebra mussel densities within the Mississippi River below Lake Pepin have exceed 10,000/m ² in the early 2000s in many areas. Populations have somewhat leveled off at lower levels below <1,000/m ² but population densities are highly variable and are cyclic with annual summer die-offs followed by large recruitment of new individuals in fall and spring.
On what surfaces do they adhere? Are they on the infrastructure, if so where?	Gate's skin plate and concrete piers.
Are zebra mussels interfering with O&M? If so, at what cost?	Just had a recent incident at Gull Lake, MN where they opened a gate on a dam and couldn't close it due to Zebra Mussels.
What methods are used for mussel mitigation (facility retrofit, scraping, chemicals, jet washing, desiccation)?	Empty zebra mussel shells dredged from lock chambers and disposed of.
What is an estimate of down time due to zebra mussel mitigation?	
Does your district take any preventative measures to deter zebra mussels?	
Please provide projects impacted by zebra mussels and a point of contact	

Table A-11. Questionnaire Responses: Vicksburg MVH District.

Questions	Answers
Are there zebra mussels in your district? If so, at which locations within the district are they present?	Yes – photos sent.
If not, has the district ever had zebra mussels (in the past but died off -may hint at cyclical patterns)?	
How bad is the infestation? Estimate density and abundance in the district.	
On what surfaces do they adhere? Are they on the infrastructure, if so where?	Concrete walls.
Are zebra mussels interfering with O&M? If so, at what cost?	I'm (KC Ellis) involved in maintenance on nine locks and dams, no recent activity except #3 lock and dam on Red River.
What methods are used for mussel mitigation (facility retrofit, scraping, chemicals, jet washing, desiccation)?	
What is an estimate of down time due to zebra mussel mitigation?	
Does your district take any preventative measures to deter zebra mussels?	
Please provide projects impacted by zebra mussels and a point of contact	

A.3 North Atlantic Division*

Table A-12. Questionnaire Responses: Baltimore NAB District.

Questions	Answers
Are there zebra mussels in your district? If so, at which locations within the district are they present?	Zebra mussels have been identified at Cowanesque Lake in Tioga County, Pennsylvania, and Curwensville Lake in Clearfield County, Pennsylvania.
If not, has the district ever had zebra mussels (in the past but died off -may hint at cyclical patterns)?	N/A
How bad is the infestation? Estimate density and abundance in the district.	The density and abundance of zebra mussels at both lakes would be characterized as low and sparse. The populations at both Curwensville Lake and Cowanesque Lake have been on the decline over the last few years.
On what surfaces do they adhere? Are they on the infrastructure, if so where?	@ Curwensville Lake - zebra mussels were previously seen along the shoreline and on concrete trash racks. This year, no zebra mussels have been observed. @ Cowanesque Lake - zebra mussels have been observed adhering to the underside of beach and navigational buoys when the buoys were removed in the Fall. Very few mussels were found last Fall when the buoys were removed. Zebra Mussels have also been observed adhering to the concrete walls inside of wet wells. However, during the most recent wet well inspection, coverage has declined to < 5% on the concrete walls inside the wet wells.
Are zebra mussels interfering with O&M? If so, at what cost?	No
What methods are used for mussel mitigation (facility retrofit, scraping, chemicals, jet washing, desiccation)?	Monitoring is performed during routine inspections at both lakes, but no mitigation efforts are required or being performed at this time.
What is an estimate of down time due to zebra mussel mitigation?	No down time has occurred.
Does your district take any preventative measures to deter zebra mussels?	Both projects display informational signs to deter boaters from transporting zebra mussels and other invasives into and out of the lakes.
Please provide projects impacted by zebra mussels and a point of contact	- Cowanesque Lake - Steve Sporer, head ranger (570) 835-5281; - Curwensville Lake - Tim Smay, head dam operator (814) 236-2000; - Baltimore District Office - Phil Cwiek Natural Resources Management Specialist (410) 962-6010.

* Note that no responses were received from New York NAN and Norfolk NAO Districts and minimal response from Philadelphia.

Table A-13. Questionnaire Responses: New England NAE District.

Questions	Answers
Are there zebra mussels in your district? If so, at which locations within the district are they present?	Yes.
If not, has the district ever had zebra mussels (in the past but died off -may hint at cyclical patterns)?	N/A
How bad is the infestation? Estimate density and abundance in the district.	Minimal infestation.
On what surfaces do they adhere? Are they on the infrastructure, if so where?	Concrete, steel, aluminum. Seem to attach to everything submerged, like structures and equipment. Navigation gate safety railings, top gate access hatches, and on the two navigation gate lifting arms. They also attached to the gate sill and gate pedestals on the bottom of the channel.
Are zebra mussels interfering with O&M? If so, at what cost?	Yes, it is a recurring maintenance item about three times per year. They do also minimally effect corrosion and the functionality of water level sensors.
What methods are used for mussel mitigation (facility retrofit, scraping, chemicals, jet washing, desiccation)?	Removed by scraping. Also tried pressure washing, but it was not very effective.
What is an estimate of down time due to zebra mussel mitigation?	
Does your district take any preventative measures to deter zebra mussels?	
Please provide projects impacted by zebra mussels and a point of contact	The City of Stamford does perform mussel removal in their treatment plant discharge channel once a year (takes ~6 hours).

Table A-14. Questionnaire Responses: New York NAN District.

Questions	Answers
Are there zebra mussels in your district? If so, at which locations within the district are they present?	Don't have USACE facilities with a FRM, Recreation, or Env Stewardship mission or component. Typically in these districts we are looking at harbors or nav channels that don't fit the FRM function.
If not, has the district ever had zebra mussels (in the past but died off -may hint at cyclical patterns)?	
How bad is the infestation? Estimate density and abundance in the district.	
On what surfaces do they adhere? Are they on the infrastructure, if so where?	
Are zebra mussels interfering with O&M? If so, at what cost?	
What methods are used for mussel mitigation (facility retrofit, scraping, chemicals, jet washing, desiccation)?	
What is an estimate of down time due to zebra mussel mitigation?	
Does your district take any preventative measures to deter zebra mussels?	
Please provide projects impacted by zebra mussels and a point of contact	

Table A-15. Questionnaire Responses: Norfolk NAO District.

Questions	Answers
Are there zebra mussels in your district? If so, at which locations within the district are they present?	Don't have USACE facilities with a FRM, Recreation, or Env Stewardship mission or component. Typically in these districts we are looking at harbors or nav channels that don't fit the FRM function.
If not, has the district ever had zebra mussels (in the past but died off -may hint at cyclical patterns)?	
How bad is the infestation? Estimate density and abundance in the district.	
On what surfaces do they adhere? Are they on the infrastructure, if so where?	
Are zebra mussels interfering with O&M? If so, at what cost?	
What methods are used for mussel mitigation (facility retrofit, scraping, chemicals, jet washing, desiccation)?	
What is an estimate of down time due to zebra mussel mitigation?	
Does your district take any preventative measures to deter zebra mussels?	
Please provide projects impacted by zebra mussels and a point of contact	

Table A-16. Questionnaire Responses: Philadelphia NAP District.

Questions	Answers
Are there zebra mussels in your district? If so, at which locations within the district are they present?	Yes, Blue Marsh Lake.
If not, has the district ever had zebra mussels (in the past but died off -may hint at cyclical patterns)?	
How bad is the infestation? Estimate density and abundance in the district.	
On what surfaces do they adhere? Are they on the infrastructure, if so where?	
Are zebra mussels interfering with O&M? If so, at what cost?	
What methods are used for mussel mitigation (facility retrofit, scraping, chemicals, jet washing, desiccation)?	
What is an estimate of down time due to zebra mussel mitigation?	
Does your district take any preventative measures to deter zebra mussels?	Blue Marsh Lake has a monitoring program.
Please provide projects impacted by zebra mussels and a point of contact	I would start with Scott Sunderland. Scott.D.Sunderland@usace.army.mil. He is the OPM at Blue Marsh Lake and could put you in touch with the District POC since a lot of their field projects only have Dam tenders.

A.4 Northwestern Division*

Table A-17. Questionnaire Responses: Kansas City NWK District.

Questions	Answers
Are there zebra mussels in your district? If so, at which locations within the district are they present?	Yes. Zebra mussel populations are currently found at both our Smithville Lake Project and Truman Lake Project in Missouri, Clinton Lake Project, Kanopolis Lake Project, Melvern Lake Project, Milford Lake Project, Pomona Lake Project, Perry Lake Project, Wilson Lake Project in Kansas, Rathbun Lake Project in Iowa, and the Missouri River
If not, has the district ever had zebra mussels (in the past but died off -may hint at cyclical patterns)?	
How bad is the infestation? Estimate density and abundance in the district.	Each of these waterbodies are currently classified as infested. Zebra mussel concentrations are being observed on water intakes, the dams and appurtenant structures.
On what surfaces do they adhere? Are they on the infrastructure, if so where?	
Are zebra mussels interfering with O&M? If so, at what cost?	As these populations are fairly new we have not had serious problems during operation, maintenance, inspection and rehabilitation efforts but we remain very concerned about zebra mussels increasing costs and impeding operation and maintenance of these facilities based on experience in other parts of the country.
What methods are used for mussel mitigation (facility retrofit, scraping, chemicals, jet washing, desiccation)?	
What is an estimate of down time due to zebra mussel mitigation?	
Does your district take any preventative measures to deter zebra mussels?	
Please provide projects impacted by zebra mussels and a point of contact	

* Note that no responses were received from Seattle NWS, however Spencer Heinz (NWP) indicated that there are no zebra mussel incidents in entire NWD except maybe the USGS dot in Montana and the Missouri River (NWK). The NWK response included much more than the Missouri River.

Table A-18. Questionnaire Responses: Omaha NWO District.

Questions	Answers
Are there zebra mussels in your district? If so, at which locations within the district are they present?	Our Dam (Fort Randall) does not have mussels or clams YET, but the Dam below us (Gavins Point Dam) does. So, yes. We will likely have them soon in any raw water piping that comes off of our penstocks....heat exchangers, chillers, etc. (at Fort Randall Dam)
If not, has the district ever had zebra mussels (in the past but died off - may hint at cyclical patterns)?	No.
How bad is the infestation? Estimate density and abundance in the district.	
On what surfaces do they adhere? Are they on the infrastructure, if so where?	Have seen information that ceramics and porcelain may deter them from adhering.
Are zebra mussels interfering with O&M? If so, at what cost?	Zebra Mussels within the Gavins Point Project have resulted in upwards of a 50% increase in the time needed to complete routine maintenance tasks that involve the plants cooling water systems. Asian Clams continue to create issues within several power facilities (Gavins Point). The impact is less severe than ZM at this time. Asian Clam issues dissipate as ZM outcompetes them. These are approximations based on talks with the field offices. We are currently unable to support those numbers with anything concrete. Omaha can only qualify but not quantify the impacts
What methods are used for mussel mitigation (facility retrofit, scraping, chemicals, jet washing, desiccation)?	Current plan is to use an ultrasonic device to kill the mussels as they enter our raw water piping.
What is an estimate of down time due to zebra mussel mitigation?	
Does your district take any preventative measures to deter zebra mussels?	
Please provide projects impacted by zebra mussels and a point of contact	

Table A-19. Questionnaire Responses: Portland NWP District.

Questions	Answers
Are there zebra mussels in your district? If so, at which locations within the district are they present?	No current zebra mussels in entire NWD known with possible exception of the one dot on the USGS map in Montana
If not, has the district ever had zebra mussels (in the past but died off -may hint at cyclical patterns)?	
How bad is the infestation? Estimate density and abundance in the district.	
On what surfaces do they adhere? Are they on the infrastructure, if so where?	
Are zebra mussels interfering with O&M? If so, at what cost?	
What methods are used for mussel mitigation (facility retrofit, scraping, chemicals, jet washing, desiccation)?	
What is an estimate of down time due to zebra mussel mitigation?	
Does your district take any preventative measures to deter zebra mussels?	
Please provide projects impacted by zebra mussels and a point of contact	
Additional comments	They are at Missouri River hydroelectric (NWK, buildup needing prevented).
Questionnaire: Walla Walla NWW District	Answers
Are there zebra mussels in your district? If so, at which locations within the district are they present?	Not yet.
If not, has the district ever had zebra mussels (in the past but died off -may hint at cyclical patterns)?	
How bad is the infestation? Estimate density and abundance in the district.	
On what surfaces do they adhere? Are they on the infrastructure, if so where?	
Are zebra mussels interfering with O&M? If so, at what cost?	
What methods are used for mussel mitigation (facility retrofit, scraping, chemicals, jet washing, desiccation)?	
What is an estimate of down time due to zebra mussel mitigation?	
Does your district take any preventative measures to deter zebra mussels?	
Please provide projects impacted by zebra mussels and a point of contact	

A.5 South Atlantic Division

Table A-20. Questionnaire Responses: Charleston SAC, Savannah SAS, and Wilmington SAW Districts.

Questions	Answers
Are there zebra mussels in your district? If so, at which locations within the district are they present?	No
If not, has the district ever had zebra mussels (in the past but died off -may hint at cyclical patterns)?	
How bad is the infestation? Estimate density and abundance in the district.	
On what surfaces do they adhere? Are they on the infrastructure, if so where?	
Are zebra mussels interfering with O&M? If so, at what cost?	
What methods are used for mussel mitigation (facility retrofit, scraping, chemicals, jet washing, desiccation)?	
What is an estimate of down time due to zebra mussel mitigation?	
Does your district take any preventative measures to deter zebra mussels?	
Please provide projects impacted by zebra mussels and a point of contact	
Questionnaire: Jacksonville SAJ District	Answers
Are there zebra mussels in your district? If so, at which locations within the district are they present?	No knowledge of zebra mussels ever being an issue on our projects.
If not, has the district ever had zebra mussels (in the past but died off -may hint at cyclical patterns)?	
How bad is the infestation? Estimate density and abundance in the district.	
On what surfaces do they adhere? Are they on the infrastructure, if so where?	
Are zebra mussels interfering with O&M? If so, at what cost?	
What methods are used for mussel mitigation (facility retrofit, scraping, chemicals, jet washing, desiccation)?	
What is an estimate of down time due to zebra mussel mitigation?	
Does your district take any preventative measures to deter zebra mussels?	
Please provide projects impacted by zebra mussels and a point of contact	

Table A-21. Questionnaire Responses: Mobile SAM District.

Questions	Answers
Are there zebra mussels in your district? If so, at which locations within the district are they present?	No
If not, has the district ever had zebra mussels (in the past but died off -may hint at cyclical patterns)?	
How bad is the infestation? Estimate density and abundance in the district.	
On what surfaces do they adhere? Are they on the infrastructure, if so where?	
Are zebra mussels interfering with O&M? If so, at what cost?	
What methods are used for mussel mitigation (facility retrofit, scraping, chemicals, jet washing, desiccation)?	
What is an estimate of down time due to zebra mussel mitigation?	
Does your district take any preventative measures to deter zebra mussels?	We do not have any preventative measures.
Please provide projects impacted by zebra mussels and a point of contact	

A.6 South Pacific Division *

Table A-22. Questionnaire Responses: Albuquerque SPA Division.

Questions	Answers
Are there zebra mussels in your district? If so, at which locations within the district are they present?	Not to date.
If not, has the district ever had zebra mussels (in the past but died off -may hint at cyclical patterns)?	There was one USGS zebra mussel hit on the Arkansas River back around 2010 near Pueblo. It was found on a boat and they (state parks and wildlife) now have a vigorous program to check boats. That was the only hit and there hasn't been one since.
How bad is the infestation? Estimate density and abundance in the district.	
On what surfaces do they adhere? Are they on the infrastructure, if so where?	
Are zebra mussels interfering with O&M? If so, at what cost?	
What methods are used for mussel mitigation (facility retrofit, scraping, chemicals, jet washing, desiccation)?	
What is an estimate of down time due to zebra mussel mitigation?	
Does your district take any preventative measures to deter zebra mussels?	Yes, and constantly funding these monitoring activities is an issue. Have an early detection program with water sampling and analysis for veligers. Monitor 6 projects - John Martin Dam (CO), Trinidad Dam (CO), Santa Rosa Dam, Abiquiu Dam (NM), and Cochiti Dm (NM) by sampling plankton between June and September. Also some boat inspections are done by NM and CO State Parks.
Please provide projects impacted by zebra mussels and a point of contact	

* Note that there were Limited responses from Los Angeles SPK and San Francisco SPN Districts.

Table A-23. Questionnaire Responses: Los Angeles SPL District.

Questions	Answers
Are there zebra mussels in your district? If so, at which locations within the district are they present?	No. None in any USACE lakes in California. We do not have any zebra/quagga mussel at any of our district projects. We do not hold permanent pools at any of our projects except for Alamo Dam in Arizona and I confirmed with the Park Manager there that they do not have any zebra/quagga mussel issues.
If not, has the district ever had zebra mussels (in the past but died off -may hint at cyclical patterns)?	
How bad is the infestation? Estimate density and abundance in the district.	
On what surfaces do they adhere? Are they on the infrastructure, if so where?	
Are zebra mussels interfering with O&M? If so, at what cost?	
What methods are used for mussel mitigation (facility retrofit, scraping, chemicals, jet washing, desiccation)?	
What is an estimate of down time due to zebra mussel mitigation?	
Does your district take any preventative measures to deter zebra mussels?	
Please provide projects impacted by zebra mussels and a point of contact	

Table A-24. Questionnaire Responses: Sacramento SPK District.

Questions	Answers
Are there zebra mussels in your district? If so, at which locations within the district are they present?	No. None in any USACE lakes in California
If not, has the district ever had zebra mussels (in the past but died off -may hint at cyclical patterns)?	No
How bad is the infestation? Estimate density and abundance in the district.	NA
On what surfaces do they adhere? Are they on the infrastructure, if so where?	NA
Are zebra mussels interfering with O&M? If so, at what cost?	No
What methods are used for mussel mitigation (facility retrofit, scraping, chemicals, jet washing, desiccation)?	NA
What is an estimate of down time due to zebra mussel mitigation?	NA
Does your district take any preventative measures to deter zebra mussels?	Yes – monthly substrate monitoring, posted bulletins, partnership with CDFW
Please provide projects impacted by zebra mussels and a point of contact	NA

Table A-25. Questionnaire Responses: San Francisco SPN District.

Question	Answers
Are there zebra mussels in your district? If so, at which locations within the district are they present?	
If not, has the district ever had zebra mussels (in the past but died off -may hint at cyclical patterns)?	
How bad is the infestation? Estimate density and abundance in the district.	
On what surfaces do they adhere? Are they on the infrastructure, if so where?	
Are zebra mussels interfering with O&M? If so, at what cost?	
What methods are used for mussel mitigation (facility retrofit, scraping, chemicals, jet washing, desiccation)?	
What is an estimate of down time due to zebra mussel mitigation?	
Does your district take any preventative measures to deter zebra mussels?	
Please provide projects impacted by zebra mussels and a point of contact	

A.7 Southwestern District*

Table A-26. Questionnaire Responses: Fort Worth SWF District.

Questions	Answers
Are there zebra mussels in your district? If so, at which locations within the district are they present?	Yes, in five lakes but none in the lakes with hydroelectric structures.
If not, has the district ever had zebra mussels (in the past but died off -may hint at cyclical patterns)?	The environment in Texas is hot and the water levels fluctuate a lot which makes it tough for the zebras to flourish. There are good years and bad. In general it was observed after introduction the zebras flourish then the population collapses once they eat themselves out of food and then will slowly rebound and level off at a manageable level. One year the flooding was so bad they adhered to picnic tables and buildings in flood zones and then when the water receded they were hung out to dry - decimating one generation of mussels.
How bad is the infestation? Estimate density and abundance in the district.	
On what surfaces do they adhere? Are they on the infrastructure, if so where?	Gates, concrete surfaces.
Are zebra mussels interfering with O&M? If so, at what cost?	
What methods are used for mussel mitigation (facility retrofit, scraping, chemicals, jet washing, desiccation)?	They have scraped off in past but put coatings on 4 to 5 years ago and are now researching new coatings to redo. Original product was a Sherman Williams product. Coatings don't work very well on some concrete surfaces such as wet wells because they can't really get them dry and zebra mussels are crafty that they will adhere to any crack or place where the coating is flawed

* Note that Tulsa SWT District provided a 2012 document on impacts of Zebra Mussels to hydropower plants and gave another contact; also note that the Pacific Ocean Division reported no zebra nor quagga mussels.

Questions	Answers
What is an estimate of down time due to zebra mussel mitigation?	
Does your district take any preventative measures to deter zebra mussels?	Early detection program with the state, academia and USGS. Worry about infestation in Sam Rayburn Reservoir because of water chemistry. They have a lot of water transfer between lakes so if one lake is infested there is a good chance another will be too. They work with the state to minimize chances through careful water management practices
Please provide projects impacted by zebra mussels and a point of contact	Study conducted by Bureau of Rec from 2014: https://www.swf.usace.army.mil/Portals/47/docs/Environmental/Water/Zebra_Mussel_Resource_Document_FINAL.pdf

Table A-27. Questionnaire Responses: Galveston SWG District.

Questions	Answers
Are there zebra mussels in your district? If so, at which locations within the district are they present?	I have not heard of zebra mussels being discovered in the Galveston District's AOR. Probably Lake Livingston is the furthest south and it is not a Corps lake.
If not, has the district ever had zebra mussels (in the past but died off - may hint at cyclical patterns)?	
How bad is the infestation? Estimate density and abundance in the district.	
On what surfaces do they adhere? Are they on the infrastructure, if so where?	
Are zebra mussels interfering with O&M? If so, at what cost?	Galveston has not had any infrastructure impacts from zebra or quagga mussels as of yet that I am aware of
What methods are used for mussel mitigation (facility retrofit, scraping, chemicals, jet washing, desiccation)?	
What is an estimate of down time due to zebra mussel mitigation?	
Does your district take any preventative measures to deter zebra mussels?	
Please provide projects impacted by zebra mussels and a point of contact	

Table A-28. Questionnaire Responses: Little Rock SWL District.

Questions	Answers
Are there zebra mussels in your district? If so, at which locations within the district are they present?	Yes there are mussels on Bullshoals Lake and as of 31 Aug 2018, the White River tail waters and in the MKARNS navigation system on the Arkansas River.
If not, has the district ever had zebra mussels (in the past but died off -may hint at cyclical patterns)?	N/A
How bad is the infestation? Estimate density and abundance in the district.	<p>Bull Shoals – They were first discovered in BSL in the upper parts in 2007. Each year after they spread to all other areas of the lake with highest concentrations in 2013. Although still present, they have since appeared to have lessened in density and abundance over the last 5 years.</p> <p>White River BS Tail Waters – Verified present in 2017 – At present they are found in very low density with the number of zebra mussels appearing to be highest directly below the dam, but have already been found up to 8 miles below the dam.</p>
On what surfaces do they adhere? Are they on the infrastructure, if so where?	They are found on all surfaces below the water surface down to around 35 feet on the lake side of Bull Shoals Dam. Most concerning are the ones adhering to intake openings and pipes which could in time cause water inflow restrictions and even blockage.
Are zebra mussels interfering with O&M? If so, at what cost?	At present they have not, however, at some point in the future, these may require manual removal or chemical treatment which could be quite costly.
What methods are used for mussel mitigation (facility retrofit, scraping, chemicals, jet washing, desiccation)?	None at present, other than scraping them off of areas above the normal water line left behind after a high water event.
What is an estimate of down time due to zebra mussel mitigation?	None at present.
Does your district take any preventative measures to deter zebra mussels?	None at BSL.
Please provide projects impacted by zebra mussels and a point of contact	<p>-Cherrie-Lee Phillip, Little Rock District Conservation Biologist</p> <p>-Bull Shoals Lake and White River Bull Shoals Tail Waters: Bruce Caldwell, Natural Resources Chief, Mountain Home Project Office</p> <p>-Jeremy Risley, District 2 Fisheries Supervisor, Arkansas Game and Fish Commission</p> <p>-Christy Graham, Trout Management Program Supervisor, Arkansas Game and Fish Commission</p> <p>-Jimmy Barnett (He can answer questions on densities) Aquatic Nuisance Species Coordinator, Arkansas Game & Fish (AGFC)</p>

Table A-29. Questionnaire Responses: Tulsa SWT District.

Questions	Answers (taken from 2012 document)
Are there zebra mussels in your district? If so, at which locations within the district are they present?	Yes, list of six multipurpose projects that include hydropower that have zebra mussels: Ft. Gibson, Keystone Lake, Eufaula, RS Kerr, Webbers Falls, Denison Dam. Other lakes w/ZM include: Kaw, Ooloagah, Skiatook, Chouteau, Newt Graham, WD Mayo, Texoma, Council Grove, El Dorado Reservoir, John Redmond Reservoir, Marion.
If not, has the district ever had zebra mussels (in the past but died off - may hint at cyclical patterns)?	
How bad is the infestation? Estimate density and abundance in the district.	
On what surfaces do they adhere? Are they on the infrastructure, if so where?	
Are zebra mussels interfering with O&M? If so, at what cost?	Operation and maintenance impacts to each hydropower facility in the Tulsa District varies and is dependent on the stage of zebra mussel invasion, the type of strainers that are used, and the design of the powerhouse. The design of three powerhouses (Eufaula, R.S. Kerr, and Denison) includes a deluge system for the facility's transformer fire suppression, which can be impacted by zebra mussels. In 2012, Ft. Gibson reported an increase in O&M by 10 work hours to deal with the impacts of zebra mussels on the A/C system. At Eufaula in 2010, it took 10 work hours (\$905.00) to clean clogged cooling water intake strainers and 48 work hours (\$4,344.00) to clean the main unit head gates. In 2011, it took 10.5 work hours (\$950.00) to clean the cooling water intake strainers and 4 work hours (\$362.00) to clean the transformer fire suppression equipment. In 2012, 7 work hours (\$724.00) were spent cleaning the cooling water intake strainers and 8 work hours were spent on cleaning the transformer fire suppression equipment. During the fire suppression tests (2012), zebra mussels impacted the function of the system by clogging the pump and the process had to be stopped, the pump filter/strainer cleaned, and the process restarted. This interruption occurred several times and had there been an actual need for the fire suppression, there may have been complications attributed to zebra mussels fouling the effectiveness of the fire suppression process and unknown extra costs associated as a result.

Questions	Answers (taken from 2012 document)
What methods are used for mussel mitigation (facility retrofit, scraping, chemicals, jet washing, desiccation)?	Chlorine tablets/injectors have not been used in any of the hydropower plants for zebra mussel control.
What is an estimate of down time due to zebra mussel mitigation?	
Does your district take any preventative measures to deter zebra mussels?	
Please provide projects impacted by zebra mussels and a point of contact	2012 document, "Zebra Mussel Impacts to SWT Hydropower Facilities", was provided by Tonya Dunn, Biologist, Tulsa District office.

Appendix B: Questionnaire Images

This appendix included zebra mussel images gathered during the questionnaire process from various Districts.

Figure B-1. ZM on concrete in lock chamber of #3 Lock & Dam on Red River, April 2017, Vicksburg District.



Figure B-2. ZM on concrete wall in lock chamber of #3 Lock & Dam on Red River, April 2017, Vicksburg District.



Figure B-3. ZM attached to ACM (articulated concrete mat), September 2012, Memphis District.



Figure B-4. Inspection gallery - Lake side of the dam after flood waters receded in 2015, Little Rock District.



Figure B-5. Lead Hill Park boat ramp 2015, Little Rock District.



Appendix C: Invasive Species Leadership Team Document

The following content was drawn from an unpublished Invasive Species Leadership Team (ISLT) document, drafted in 2018 and titled *HQ USACE NISC Response*.

- 1 The U.S. Army Corps of Engineers manages significant infrastructure related to power, water, and transportation. The USACE manages water based transportation for both commercial and recreational purposes across the country. The Corps manages inland navigation and the lock and dam systems that facilitate this system. The Corps also manages navigation and federal channels in conjunction with coastal ports to facilitate international shipping and transportation. The Corps navigation program crosses between water and transportation in respect to the inquiry. In addition the Corps is the largest federal producer of hydropower. The Corps is also charged with our flood risk management program, which has significant resources related to directing, managing, and storing water to prevent flooding. For the Corps to manage navigation, hydropower, and flood risk management the agency needs manpower and facilities; the agency has an extensive building system both directly and indirectly related to its missions.
- 2 In general the Corps infrastructure is impacted in both direct and indirect manners from invasive species. An example of a direct impact would be the water hyacinths clogging a flood control structure due to rapid growth followed by rising waters and structure failure or flooding based on the inability to move water through the structure. While water hyacinth is a challenge to the Southern U.S. primarily, other floating and emergent invasive plants cause similar impacts and challenges throughout the country. An example of an indirect impact is Napier grass out competing the established turf on a levee system; as more and more Napier establishes vehicles have difficult traversing the levee; more rutting occurs from vehicles and the growth pattern of Napier grass allows for channeling and rutting to occur during heavy rainfall. Eventually the system needs physical repairs in addition to the re-establishment of acceptable turf.
 - 2.1 The Corps' infrastructure is impacted in a variety of manners, but in general the concern is long-term buildup of invasive species and impacts moving to lost time, capacity, capability, or a combination of all three. All of these losses equate to expenditure impacts to control the species and remediate the impacts. A specific example related to lost time impacts

in navigation was provided on the current challenges with water hyacinth infestations on the White River. Another example is reduce capacity for hydropower generation and increased down time because of zebra mussel infestations at Gavins Point Dam.

2.2 Broadly the Corps estimates the costs related to these impacts to be around \$80 million annually. The Invasive Species Leadership Team (ISLT) reports these impacts annually to NISC for the cross cut budget. The agency also recognizes that our estimating process is dated and plans to review and update one business practice annually to ensure we are providing accurate numbers.

2.3 In general the Corps has not completed any type of wholesale assessment; normally, work is done on a case by case basis and in response to an immediate impact or need. With the continued limitations on Operations and Maintenance (O&M) preventative measures as suggested have not been the norm. In relation to zebra and quagga mussel infestations some efforts for preventative measures and changes in business practices have been instituted; our agency in conjunction with Bureau of Reclamation and Depart of Energy continue to research for treatment technologies and coatings to improve our capability to manage mussels and prevent establishment. Additionally, we have modified intake structures for water supply and hydropower at some locations based on understanding of when, where, and how these invasive mussels attach. The Fort Worth District has worked to minimize the possibility of spread through the water supply program. Other examples exist of similar efforts, but in general given constraints on budgets our agency has to react versus prevent.

2.4 See 2.3.

3 In reference to secondary impacts please see example from 2.1; the Corps has invasive species challenges that have primary and secondary or direct and indirect impacts. In the Southeast U.S. increase risk of wild fire and hotter fires are secondary impact from Cogongrass infestations that eliminate biodiversity from understory of pines or open grasslands. *Arundo donax* is causing similar challenges in California, and the Southwest U.S.

3.1 Invasive species such feral hogs and iguanas both are seen to have detrimental impacts to the environment, but both cause significant impacts to infrastructure through rooting and burrowing. Feral hog rooting on levees causes direct impacts to the structural integrity of the levees, negative impacts to

the turf designed to protect the levee surface, and often spreads invasive seeds into the turf through manure.

- 4 The Corps conducts the vast majority of invasive species management activities as part of the Operations and Maintenance program; the management of invasive species as part of project operations is basic authority. The Corps does have some specific programs such as Removal of Aquatic Growth (RAG), and the Aquatic Plant Control Program; these authority are specific authorities within the Rivers and Harbors Act to address invasive plant issues related to navigation and flood risk management.
 - 4.1 Within the Corps the Invasive Species Leadership Team (ISLT) provides support to field and recommendations to leadership on the management of invasive species. The ISLT follows a Program Management Plan that uses both executive order and federal law along with internal regulations and guidance to set priorities for the agency. Within the PgMP an annual work plan is developed to guide activities. In addition the ISLT sets research priorities for Aquatic Plant Control Research Program and the Aquatic Nuisance Species Research Program.
- 5 In general, the Corps has projects at every aspect of the scale. The agency has areas or projects that are conducted baseline surveys and annual monitoring for new species to projects that are completing reactionary to immediate problems. The ISLT promotes EDRR and is looking for ways to incentivize EDRR efforts; outside of this most activities are driven at a local level leaving the Corps with the entire spectrum. Invasive species activities are prioritized in the budget process along with all other project needs; a separate funding stream is not available, so invasive species projects are competing with other activities for funding and ranked out in the budget process annually.
- 6 Overall, the gap for supporting or improving invasive species management activities related to infrastructure or otherwise is dollars. The Corps has significant backlogged maintenance activities of all types and funding is limited.
- 7 If the Corps or other agencies have a consistent and adequate funding streams all the other challenges can be addressed over time through prioritization of capital. An aspect of invasive species management that is difficult to address especially in the Corps budget is consistency. If a project or district can annually maintain a level of funding to support invasive species activities success is more likely than getting large pots of money inconsistently.
- 8 A mission of the ISLT is to continue to refine the Corps invasive species expenditure data and report to NISC as part of the cross cut budget ex-

ercise. The ISLT will begin a review of formula for each business practice to ensure we still reporting accurate numbers. In addition within the pie chart we assume that the Navigation, Hydropower, and Water Supply numbers are direct or indirect impacts to infrastructure. Currently, the ISLT reports the following: <https://corpslakes.erd.c.dren.mil/employees/invasive/pdfs/USACE%20FY13-16%20Invasive%20Species%20Cost%20Estimates.pdf>

8.1 The Corps does not have a mechanism at this time to report detailed budget numbers; the ISLT developed formulas based on reviewing budgets and budget packages, work load execution, and interviewing project managers related to each business line.

8.2 The Corps does not break out these costs or impact in any manner.

9 Damien Walter, Jon Lane, and Jeremy Crossland

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