Summary of Research Related to the Potential Physical and Biological Impacts of Dredging to Channelize the Grand River

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Introduction

The Grand River Waterway proposal is not a typical harbor dredging project, but rather a river channelization project that would remove roughly 50 acres of shallow habitat through dredging portions of the Grand River in Kent and Ottawa counties. The project seeks to create a 7-foot deep channel through a 22.5-mile stretch of the Grand River between Grand Rapids and Bass River State Recreation Area near Eastmanville.

The Grand River Waterway economic impact study stated that river channelization via dredging will "help return the river to its natural state" and that "increased recreational opportunities and improved water quality may generate up to 49,000 net new visitor days annually … and an annual net new economic impact of up to $5.7 million." Research suggests that dredging will not improve water quality. A more likely scenario is reduced water quality, increased erosion of private and public land, increased deposition of sand and silt in certain areas, and harm to fish and wildlife populations. This paper deals specifically with physical and biological impacts, but it is important to note that these have economic implications, as well.

The physical and biological impacts of the Grand River Waterway project would likely extend far beyond the 50

acres that would be removed initially. Dredging to channelize a river causes radical changes to the way a river functions, affecting the shape of the channel and patterns of erosion and sediment deposition. Channelization typically harms water quality and destroys or reduces the quality of fish and wildlife habitat. It can be difficult to predict the severity of these impacts and specific locations that will be affected. However, the general pattern of negative consequences for the river environment are very well documented and supported by scientific research from around the world.

Summary of Key Points

- The Grand River Waterway plan is fundamentally different than harbor dredging projects in river mouth areas. It is a **river channelization** plan that would deepen portions of the Grand River to form a continuous 22.5-mile channel.

- River channelization will **not return the Grand River to its natural state**. This reach of the Grand River was shallow prior to dredging attempts that began in 1886. Michigan's Wildlife Action Plan notes channelization as one of the most serious threats to big river habitats including the Grand River.

- The Grand River Waterway plan is not the first attempt to channelize the Grand River between Grand Rapids and Eastmanville and improve conditions for navigation. The first attempt was a failure, and **reasons for that failure have not been fully addressed** by the Grand River Waterway plan.

Summary of Physical Impacts

- Available scientific literature suggests that **dredging will not improve water quality** in the Grand River. In fact, dredging to channelize a river typically leads to increased turbidity and dirtier water.

- Channelization often leads to **increased erosion of the stream bed** even after dredging is completed. The Grand River Waterway plan does not quantify the additional erosion and downstream sedimentation that would likely occur for many years after dredging.

- Channelization and increased boat traffic often lead to **increased erosion of the riverbanks**. The Grand River Waterway plan does not quantify the additional bankside erosion and loss of land, vegetation, and cultural resources that could occur.

- Channelization lowers the bottom of the river and therefore lowers the surface of the river, as well. This makes all non-dredged (off-channel) areas of the river shallower. The Grand River Waterway plan does not address the **loss of off-channel, wetland, and island areas** that could result from lowering the surface of the river.

- Plans for river channelization often fail to consider how **dredging can create more erosion upstream** of the dredged area and in tributary streams that flow into the dredged area. The Grand River Waterway feasibility study did not consider the potential impact of this upstream erosion (known as head-cutting) in areas including the Grand River in downtown Grand Rapids and in the lower end of tributaries such as Plaster Creek, Sand Creek, Buck Creek, and Deer Creek.

Summary of Biological Impacts

- Channelization has profound negative impacts on bottomv dwelling creatures that form the base of the food chain in rivers. The Grand River Waterway plan would almost certainly do **great harm to benthic macroinvertebrates** including larval insects that provide fish food.

- Dozens of rare species are associated with the Grand River corridor in Ottawa County, including 18 freshwater mussels. **Channelization is recognized as a major threat to freshwater mussels** and has been implicated in the extinction of several North American species.

- Channelization destroys shallow riffles and gravel bars that many fish species require for successful spawning. The Grand River Waterway plan specifically includes **dredging of a gravel bar area that provides high, quality spawning habitat** for state-threatened river redhorse. The same gravel bar area is a known destination for walleye, steelhead, and smallmouth bass anglers and provides habitat for northern pike, muskellunge, and possibly lake sturgeon.

- Channelization harms valuable gamefish and sensitive threatened and endangered fish species, leading to low-quality fish communities and **reduced fishing opportunities**.

- Even after maintenance dredging stops, a **river may not fully recover for several decades**. Even if the river does return to a new equilibrium state it will be different from the river as it was before channelization.

Key Points

The Grand River Waterway plan is fundamentally different than harbor dredging projects in river mouth areas. It is a **river channelization** plan that would deepen portions of the Grand River to form a continuous 22.5-mile channel.

- River channelization involves “straightening, widening, and/or deepening of stream channels, as well as bank stabilization and clearing or snagging operations” according to Mattingly et al. (1993). The Grand River Waterway proposal specifically involves both deepening of the stream channel and the removal of snags and other obstructions.

River channelization **will not return the Grand River to its natural state**. This reach of the Grand River was shallow prior to dredging attempts that began in 1886. Michigan’s Wildlife Action Plan notes channelization as one of the most serious threats to big river habitats including the Grand River.

- The Grand River was not naturally deep enough for deep draft vessels to navigate. That is why dredging of a 4.5-foot deep channel was attempted in 1886 (USACE 1978).

- The predictably negative impacts of dredging for river channelization were summarized in Michigan DNR's Grand River Assessment (Hanshue and Harrington 2017). "As a result of channelization, the stream becomes incised and is cut off from its adjacent floodplain. Therefore, the channel is forced to convey discharges that exceed original bankfull conditions. The kinetic energy that would normally be dissipated in the vegetated floodplain is directed to the stream bank, resulting in higher sheer stress and bank instability. As the banks begin to fail, sediment loads increase, resulting in increased bar deposition, further acceleration of bank erosion, increased sediment supply, channel widening and aggradation. The stream channel will continue to evolve toward a balance between the slope and valley and will ultimately form a new floodplain at a lower elevation. As these adjustments occur, subsequent responses to tributary morphology can be expected."

- Michigan's Wildlife Action Plan (DeRosier et al. 2015) lists channelization as one of the most serious threats to big rivers including the Grand River, stating that "channelization often results in decreased habitat diversity and increased channel instability."

- Like all rivers, the Grand River is a complex and dynamic system that involves four types of connections (lateral, longitudinal, vertical, and temporal) and changes to any of these dimensions can have ripple effects throughout the system (Ward 1989). Dredging to channelize a river increases its depth (a vertical change) and therefore has the potential for impacts up and down the river (longitudinally), to the side of the river in floodplains (laterally) and through time (temporally).

The Grand River Waterway plan is not the first attempt to channelize the Grand River between Grand Rapids and Eastmanville and improve conditions for navigation. The first attempt was a failure, and **reasons for that failure have not been fully addressed** by the Grand River Waterway plan.

- A 60-foot wide channel 4.5 feet deep was dredged in 1886. This channel extended for 11.25 miles downstream of Grand Rapids and was never completed. Highly variable water flows and shoaling that resulted from excessive erosion and deposition of sediment made it impossible to maintain the 4.5-foot depth. In 1887, a report concluded that a deep-water connection between Lake Michigan and Grand Rapids was impossible within the channel of the Grand River (Hanshue and Harrington 2017).

- The U.S. Army Corps of Engineers (USACE) is no longer responsible for dredging the Grand River between Grand Rapids and Bass River State Recreation Area. This reach (section) of river was officially abandoned as a commercial channel when Congress adopted the River and Harbor Act of 1930. The feasibility of re-opening this reach of the Grand River to federal dredging was investigated by USACE in 1978. Five alternative plans were addressed, including a "No Action" plan and a "Channel Dredging Plan" very similar to the 7-foot channel proposed by Grand River Waterway (USACE 1978). Ultimately, no action was taken to re-open this reach of river to dredging.

- The Army Corps' study concluded that the Channel Dredging Plan would both: 1) require removal of pilings and wingwalls that were originally placed in the river to aid navigation in 1930, and 2) likely require addition of new wingwalls to maintain the depth of the new channel (USACE 1978).

- The 2017 Grand River Waterway feasibility study (Edgewater Resources, LLC 2017) does not address the potential need for construction of new wingwalls identified in the 1977 study or the demonstrated inability of channelization and wingwall construction to maintain a 4.5-foot depth in 1886.

Physical Impacts

Available scientific literature suggests that **dredging will not improve water quality** in the Grand River. In fact, dredging to channelize a river typically leads to increased turbidity and dirtier water.

- A study of economic benefits of the Grand River Waterway used dredging of toxic contaminated sediment from the Toledo harbor as evidence that dredging can improve water quality (Benton and Bowers 2018), but the dredging in Toledo occurred from the mouth of the Ottawa River at Lake Erie upstream for 5.5 miles. This Ottawa River Cleanup was funded by the EPA and designed to remove PCBs and PAHs from the lower river (USEPA 2009). Channelization of 22.5 miles of the Grand River for navigational purposes is not at all comparable to the carefully designed removal of contaminant sediments from Toledo's harbor.

- While carefully designed dredging projects at river mouth areas can be an effective way to remove contaminants from the environment, dredging projects designed only to facilitate navigation are more likely to have the opposite effect. A review of research on the subject (Seelye and Mac 1984) concluded "The annual movement of over 10 million cubic meters of sediment by dredging activities in the Great Lakes is potentially harmful to the biota of the Great Lakes, not only due to the physical disruption of the habitat associated with dredging and dredged material disposal … but also the relocation and resuspension of sediments often contaminated with toxic organic and inorganic chemicals."

- Channelization of the River Main in Northern Ireland led to greatly increased peak sediment loads (Wilcock and Essery 1991). Although toxic sediments were not an issue, the median amount of sediment in the water increased sevenfold after channelization destabilized the river bed and river banks, leading to increased erosion. The authors noted that "dirty water is not therefore an infrequent event during channelization."

- Mainstem habitats in channelized sections of the Missouri River in Nebraska had turbidity values 4.5 times higher than un-channelized sections. Side-channel habitats with lower current velocity had turbidity values 2.5 times higher in channelized versus un-channelized sections (Morris et al. 1968).

Channelization often leads to **increased erosion of the stream bed** even after dredging is completed. The Grand River Waterway plan does not quantify the additional erosion and downstream sedimentation that would likely occur for many years after dredging.

- In a summary of the effects of channelization, Brooker (1985) wrote, "in a natural system, channel width and depth are also adjusted to flow regime … any destruction of this equilibrium may lead to the erosion of bed and bank material."

- The increased net erosion and downstream sedimentation that results from destroying this equilibrium state through deepening of the river is very different from the one-time impact of dredging itself. The disturbed river bottom can continue to erode for years as the river attempts to return to a state of dynamic equilibrium (Lane 1955; Langbein and Leopold 1964).

- An incised river can develop either from the direct result of dredging or from ongoing erosion post-channelization. The incised river channel has been cut so deeply that floodplains are abandoned, adjacent wetlands are drained, and formerly wetted banks are left exposed for much of the year (Rosgen 1997).

- In extreme examples, rampant erosion following de-stabilization of the stream bottom can be devastating to the entire river channel, bridges, and other riparian infrastructure. The Homochitto River in Mississippi was degraded to such an extent that the level of the river bottom eroded to drop 15 feet in elevation while the width of the river increased from an average of 96 feet to 328 feet, while deposition of sediment along the shore after floods left a sand-filled flood channel over 3,000 feet wide (Hartfield 1993).

- In a case study of channelization impacts on the Blackwater River and its tributaries in Johnson County, Missouri, Emerson (1971) found that “most bridges in Johnson County have been replaced or lengthened and have had vertical extensions added to the lower supports. In most cases the ends of the present bridges are threatened by bank erosion.” Emerson also noted increased flooding following channelization and the deposition of eroded sediment on riparian land after floods, which amounted to “about 2 m {over 6.5 feet} of deposition in 50-60 years.”

- The Grand River Waterway project area is particularly vulnerable to the effects of increased erosion after dredging. Substrate in this reach is primarily composed of sand and silt, which are very unstable and prone to erosion (Allan 1995; MDEQ 2011). Furthermore, many of the obstructions that would be removed under the Grand River Waterway plan are training walls (USACE 1909), some of which are still functioning to hold massive quantities of sand and sediment between the training wall and the bank.

- The feasibility study (Edgewater Resources, LLC 2017) did not fully account for the long-term erosion that would likely occur following dredging removal of training walls (which are referred as wingwalls in the feasibility study).

Channelization and increased boat traffic often lead to **increased erosion of the riverbanks**. The Grand River Waterway plan does not quantify the additional bankside erosion and loss of land, vegetation, and cultural resources that could occur.

- Dredging lowers the level of the river bottom, which also lowers the surface of the river. Continuing erosion can lead to development of an incised river, which forms new banks and leaves the old riverbank dry during periods of base flow. Periodical exposure of the riverbank, along with increases in current velocity, can result in extensive streambank erosion in channelized rivers (Brooker 1985; Rosgen 1997).

- A study of boat wakes in the Waikato River, New Zealand (McConchie and Toleman 2003), found that wakes from small boats (less than 18 feet long) generated wakes in excess of 100 times more powerful than natural background waves. Wakes from small boats generated far more suspended sediment than natural waves (up to 740 mg/l as opposed to 31 mg/l or less) due to increased streambank erosion.

- In the Grand River Waterway, boats could potentially be much larger than 18 feet, and larger boats generate far more erosive power (Parchure et al. 2001).

- Narrow channels are more subject to erosion than wide channels because the power of a boat's wake begins to decay as the wake moves away from the sailing line of the boat. If a channel does not allow for a wake to travel 4-6 times the length of the boat before hitting the shore, the riverbank will be subject to maximal erosion (McConchie and Toleman 2003).

- Based on the criteria above, the design vessel for the Grand River Waterway feasibility study (26 feet long with 8.5-foot beam; Edgewater Recourses, LLC 2017) would require a river 216.5 to 320.5 feet wide if it were travelling in the dead center of the river. Many areas of the Grand River in the project area are narrower than this (particularly areas where the channel is adjacent to an island).

- The dredged section of the Grand River below Bass River State Recreation area already experiences damaging and costly problems associated with erosion caused by boat wakes. Riverside Park in Ottawa County is one example where boat wakes are implicated in bank failure, substantial loss of park land, and the loss of many mature trees.

Channelization lowers the bottom of the river and therefore lowers the surface of the river, as well. This makes all non-dredged (off-channel) areas of the river shallower. The Grand River Waterway plan does not address the **loss of off-channel, wetland, and island areas** that could result from lowering the surface of the river.

- Portions of the Grand River are wide, shallow, sandy, and split into channels that form islands in the river. These areas may be susceptible to dewatering of the natural river channel and side-channels during periods of low flow if channelization lowers the river bottom too much.

- It is possible that portions of the current river channel, riverine wetlands, and side channels adjacent to islands would be seasonally dewatered if the Grand River is channelized. Over a relatively short period of time, some of these seasonally dry areas would be colonized by vegetation and converted to terrestrial habitat. Vegetation further reduces current velocity during high water and promotes accelerated accretion of silty sediment. On the Missouri River, side-channel "chute" habitats were almost completely eliminated from channelized sections due to the accumulation of silt (Morris et al. 1968).

- Loss of side-channels has the additional effect of connecting islands permanently to the mainland, with the possibility of connecting an island that is the property of a landowner on one side of the river to the property across the river.

- An incised river channel develops when erosion of the streambed is so severe that the river abandons its natural floodplain (Rosgen 1997; Blann et al. 2009). If an incised river develops after dredging of the Grand River, some connected bayous could become disconnected from the river, with potential impacts to fish and wildlife.

- In North America, up to 90% of riverine floodplain habitat is functionally extinct due to channelization, levee building, and other forms of cultivation (Tockner and Stanford 2002).

- Several rivers in western Tennessee experienced so much erosion after channelization of upstream areas that channel blockages formed where sand and silt settled out in downstream areas (Shankman and Smith 2004). These blockages prevent navigation in downstream areas and lead to stagnation of river water.

Plans for river channelization often fail to consider how **dredging can create more erosion upstream** of the dredged area and in tributary streams that flow into the dredged area. The Grand River Waterway feasibility study did not consider the potential impact of this upstream erosion (known as head-cutting) in areas including the Grand River in downtown Grand Rapids and in the lower end of tributaries such as Plaster Creek, Sand Creek, Buck Creek, and Deer Creek.

- Dredging lowers the bottom of the river. This can create an incised river channel and lead to head-cutting. According to Watters (2000), “headcuts are regions of disturbance moving upstream in zipper-like fashion, as the result of the upper boundary of the modification collapsing. Headcuts may move miles upstream.”

- According to Hartfield (1993), “a stream that is actively, or that has been recently, headcut may be identified by combinations of the following characteristics: extensive bank erosion; wide, degraded channels; meander cutoffs; uniform, shallow flows; chute formation; numerous whole trees within the channel; quicksand, or otherwise loose, unstable sediments; perched tributaries at low water.”

- Channelization of the Tombigbee River to form the Tenn-Tom Waterway in Mississippi and Alabama created headcuts in streams that flowed into the waterway. One of these streams was Magby Creek where a drop-control structure was necessary to prevent upstream erosion and stream degradation (USACE 1985).

- Dredging the lower four miles of Luxapalila Creek required the construction of grade control structures (small dams) to prevent head-cutting that would have eroded the stream farther upstream (Hartfield 1993).

- In tributaries of the Blackwater River, Missouri, Emerson (1971) noted that “the widening and deepening of the streams have caused serious erosional problems along their banks and headward erosion of gullies that lead into the tributaries.”

Biological Impacts

Channelization has profound negative impacts on bottom-dwelling creatures that form the base of the food chain in rivers. The Grand River Waterway plan would almost certainly do **great harm to benthic macroinvertebrates** including larval insects that provide fish food.

- A study of channelized and un-channelized sections of the Missouri River in Nebraska (Morris et al. 1968) concluded that "channelization of the river has reduced both the size and variety of aquatic habitat by destroying key productive areas." Channelization reduced the area of productive benthic habitat by 67%. The biomass of benthic macroinvertebrates drifting in the current was found to be 8.5 times higher in un-channelized versus channelized areas of the Missouri River.

- Macroinvertebrate communities in Ottawa County waters of the Grand River were characterized as "poor" based on sampling of river sediments in 2009. The study concluded that this reach of the Grand River still has not fully recovered from historic dredging (MDEQ 2011).

- Channelization reduced benthic macroinvertebrates by 90% in the River Moy, Ireland (McCarthy 1981).

- The removal of snags and other obstructions from the Grand River would include pilings and wingwalls that were initially placed in the river to improve navigation in addition to submerged logs and other natural large woody debris (Edgewater Resources, LLC 2017). Large woody debris is extremely important for sandy rivers like the Grand. Benthic macroinvertebrates that provide food for fish often have difficulty living on sand. Because of this, large woody debris can support 20 to 50 times more biomass (weight of fish food) than sandy habitat of similar area (Benke et al. 1984).

- By lowering the surface of the river, channelization would also affect the hyporheic zone (Ward 1998). This sub-surface zone of interaction between surface and groundwater provides habitat for a variety of insects and microbes that are important for nutrient cycling (Boulton et al. 1998).

Dozens of rare species are associated with the Grand River corridor in Ottawa County, including 18 freshwater mussels. **Channelization is recognized as a major threat to freshwater mussels** and has been implicated in the extinction of several North American species.

- The Michigan Natural Features Inventory (MNFI) database lists 50 designated species associated with the Grand River corridor in Ottawa County. This list includes species listed as threatened or endangered by the state of Michigan, along with species of special concern at risk of becoming threatened or endangered. It also includes extirpated species (e.g., weed shiner) that are no longer found in the area. Due to the difficulty of sampling rare species and the limited number of studies conducted, there are almost certainly rare species in this area that have yet to be officially recorded (e.g., state threatened lake sturgeon pass through this section of river when moving from Lake Michigan to Grand Rapids but have not yet been documented from Ottawa County waters of the Grand River).

- The MNFI database lists 18 freshwater mussels (Family: Unionidae) in Ottawa County waters of the Grand River, including three state endangered species and five state threatened species. Two aquatic snails of special concern are also found in this section of river.

- Dredging, channelization, and excessive erosion and deposition of sediment that result are recognized as major threats to native mussels. Mussels are directly destroyed and/or removed from the river by dredging, and mussels that remain in the river are subject to being smothered by silt deposition (Watters 2000).

- Federally endangered mussels have not been recorded in the 22.5v mile section of the Grand River slated for dredging. However, portions of this section in both Kent and Ottawa counties are classified as “Group 3” waters that are expected to support populations of federally endangered mussels (i.e., Snuffbox) according to Michigan freshwater mussel survey protocols (Hanshue et al. 2018).

- A survey of mussels at potential dredge sites in Kent County found live individuals of four listed species, including the state threatened Purple Wartyback and Black Sandshellu fragments of federally endangered Snuffbox shells were also found (Badgett 2019).

- Dams and channelization are leading causes of extinction for freshwater mollusks in North American and have contributed to the extinction of at least 12 mussel species and 45 snail species (FMCS 2016).

Channelization destroys shallow riffles and gravel bars that many fish species require for successful spawning. The Grand River Waterway plan specifically includes **dredging of a gravel bar area that provides high-quality spawning habitat** for state-threatened river redhorse. The same gravel bar area is a known destination for walleye, steelhead, and smallmouth bass anglers and provides habitat for northern pike, muskellunge, and possibly lake sturgeon.

- The River Main was one of the best Atlantic salmon fishing rivers in Northern Ireland. Channelization destroyed gravel habitat where salmon and brown trout built their nests (which are called redds), leading to declines in redd counts after the river was channelized (Wilcock and Essery 1991).

- The 1978 U.S. Army Corps of Engineers study acknowledged that dredging the Grand River would cause environmental harm including destruction of fish spawning habitat (USACE 1978).

- Channelization removes shallow riffle habitats and reduces the depth in pool habitat. This creates a more uniform river environment. A study of 40 streams in east central Indiana found that the loss of riffle and pool habitat was the main reason for the loss of several fish species from channelized streams (Lau et al. 2006).

- Research conducted during 2018 revealed a large congregation of spawning river redhorse at a gravel bar slated for dredging under the Grand River Waterway plan (Preville 2019). The same gravel bar is a known destination for walleye, steelhead, and smallmouth bass anglers and provides habitat for northern pike, muskellunge, and possibly lake sturgeon.

Channelization harms valuable gamefish and sensitive threatened and endangered fish species, leading to low-quality fish communities and **reduced fishing opportunities**.

- A summary of research on channelized rivers concluded that channelization typically results in substantial detrimental effects on fish populations (Brooker 1985).
- A review of over 430 studies on the effects of dredging found that suspended sediment, noise, contaminant release, and direct destruction of fish by hydraulic entrainment can have detrimental impacts on fish; behavioral effects were also noted including coho salmon avoidance of muddy water (Wenger et al. 2016).
- In the Luxapalila River, Mississippi and Alabama, the average weight of largemouth bass was eight times higher in un-channelized segments of the river versus channelized segments. The lengths of largemouth bass in the channelized segment were highly skewed toward smaller size-classes with very few catchable bass present (Arner et al. 1976).
- Fish communities in channelized sections of the Luxapalila River were dominated by migratory fish species that were just passing through the poor-quality habitat. Un-channelized sections of the Luxapalila River supported a wider variety of sport fish (Arner et al. 1976).
- Electrofishing in 20 channelized and 20 natural streams in Indiana found that natural streams had higher quality fish communities with higher IBI (Index of Biotic Integrity) scores. Natural streams held, on average, 4.2 environmentally sensitive fish species and channelized streams held an average of only 2.2. Species lost from channelized streams included valuable gamefish like smallmouth bass along with environmentally sensitive species like black redhorse and rainbow darter (Lau et al. 2006).
- Un-channelized sections of the Chariton River, Missouri, were home to 21 species of fish. Channelized sections held 13 species of fish, with biomass (the weight of all fish) reduced by 80% in channelized sections (Congdon 1971).
- In the River Boyne, Ireland, the ratio of salmonines (salmon and trout) to other less-valuable species was 14:1 before channelization. Erosion of and deposition of silty sediments degraded salmon and trout habitat, dropping this ratio to 5:1 following channelization (McCarthy 1981).

Even after maintenance dredging stops, a river **may not fully recover for several decades**. Even if the river does return to a new equilibrium state it will be different from the river as it was before channelization.

- In summarizing literature on river channelization, Brooker (1985) stated that “the rate of recovery for fish populations from the effects of channelization has been shown to be extremely slow, some streams showing no significant recovery after 30–40 years.

- Salmon and trout take the longest time to recover following disturbance, while species in the family Cyprinidae (including invasive common carp and native minnows) tend to recover in the shortest amount of time. Fishes in the sucker and perch families recover at intermediate rates (Detenbeck et al. 1992).

- A review of case histories from 49 rivers and streams around North America characterized channelization as a "press disturbance." This is in contrast to "pulse disturbances" that included chemical spills, major flooding, and other one-time disturbances. Fish recovered from pulse disturbances within one year 70% of the time. However, fish communities took 5 to 52 years or more to recover from the long-term impacts of channelization and other press disturbances (Detenbeck et al. 1992).

Literature Cited:

Allan, J.D. 1995. Stream ecology structure and function of running waters. Chapman & Hall, London, UK.

Arner, D.H., Robinette, H.R., Frasier, J.E., and M. H. Gray. 1976. Effects of channelization of the Luxapalila River on fish, aquatic invertebrates, water quality, and furbearers. U.S. Fish and Wildlife Service, FWS/OBS-76-08, Fort Collins, Colorado.

Badgett, N.M. 2019. 2018 Unionid surveys at 5 proposed dredge sites, Grand River, Kent County, Michigan. EcoAnalysts, Inc. O'Fallon, Missouri.

Benke, A.C., T.C. Van Arsdall Jr, D.M Gillespie, and F.K. Parrish. 1984. Invertebrate productivity in a subtropical blackwater river: The importance of habitat and life history. Ecological monographs, 54(1): 25-63.

Benton, C., and S. Bowers. 2018. The economic benefits of the Grand River Waterway. Anderson Economic Group, LLC, East Lansing, Michigan.

Blann, K. L., J. L. Anderson, G. R. Sands, and B. Vondracek. 2009. Effects of agricultural drainage on aquatic ecosystems: a review. Environmental Science and Technology 39: 909-1001.

Brooker, M.P. 1985. The ecological effects of channelization. The Geographical Journal 151(1): 63-69.

Boulton, A.J., Findlay, S., Marmonier, P., Stanley, E.H. and Valett, H.M. 1998. The functional significance of the hyporheic zone in streams and rivers. Annual Review of Ecology and Systematics 29(1): 59-81.

Congdon, J.C. 1971. Fish populations of channelized and unchannelized sections of the Chariton River, Missouri. Pages 52-83 *in* Stream channelization: A symposium. E. Schneberger and J.L. Funk (editors) American Fisheries Society, Special Publication 2, Bethesda, Maryland.

Derosier, A.L., S.K. Hanshue, K.E. Wehrly, J.K. Farkas, and M.J. Nichols. 2015. Michigan's Wildlife Action Plan. Michigan Department of Natural Resources, Lansing, Michigan. http://www.michigan.gov/dnrwildlifeactionplan

Detenbeck, N.E., P.W. DeVore, G.J. Niemi, and A. Lima. 1992. Recovery of temperate-stream fish communities from disturbance: A review of case studies and synthesis of theory. Environmental Management 16(1): 33-53.

Edgewater Resources, LLC. 2017. Grand River Waterway dredging feasibility study. Edgewater Resources, LLC, Saint Joseph, Michigan.

Emerson, J. 1971. Channelization: A case study. Science 173(3994): 325-326.

Freshwater Mollusk Conservation Society (FMCS) 2016. A national strategy for the conservation of native freshwater mollusks. Freshwater Mollusk Biology and Conservation 19:1-21.

Hanshue, S. K., and A. H. Harrington. 2017. Grand River assessment. Michigan Department of Natural Resources, Fisheries Report 20, Lansing, Michigan.

Hanshue, S. K., J. Rathburn, P. Badra, J. Bettaso, B. Hosler, J. Pruden, and J. Grabarkiewicz. 2018. Michigan freshwater mussel survey protocols and relocation procedures. U.S. Fish & Wildlife Service, East Lansing, Michigan. https://www.fws.gov/midwest/eastlansing/te/pdf/MI_Freshwater_Mussel_Survey_Protocol_Nov_2018.pdf

Hartfield, P. 1993. Headcuts and their effects on freshwater mussels. Pages 131-141. *in* K.S. Cummings, A.C. Buchanan, and L.M. Koch (editors). Conservation and Management of Freshwater Mussels. Proceedings of a UMRCC symposium. Upper Mississippi River Conservation Committee, Rock Island, Illinois.

Lane, E. 1955. Design of stable channels. Transactions of the American Society of Civil Engineers 120: 1234-1260.

Langbein, W.B., and L.B. Leopold. 1964. Quasi-equilibrium states in channel morphology. American Journal of Science 262(6): 782-794.

Lau, J, T.E. Lauer, and M.L. Weinman. 2006. Impacts of channelization on stream habitats and associated fish assemblages in east central Indiana. The American Midland Naturalist 156(2): 319-330.

Mattingly, R.L., E.E. Herricks, and D.M. Johnston. 1993. Channelization and levee construction in Illinois: review and implications for management. Environmental Management 17(6): 781-795.

McCarthy, D. 1981. The effects of arterial drainage on the invertebrate fauna and fish stocks of Irish rivers. Proceedings of the Second British Freshwater Fisheries Conference 1981: 208-13. University of Liverpool, Liverpool, England.

McConchie, J.A., and I. E.J. Toleman. 2003. Boat wakes as a cause of riverbank erosion: A case study from the Waikato River, New Zealand. Journal of Hydrology 42(2): 163-179.

MDEQ (Michigan Department of Environmental Quality). 2011. A biological survey of the lower Grand River watershed Kent, Ottawa, Muskegon, Montcalm, Ionia, and Newaygo counties, Michigan, August-September 2009. MDEQ Report 11/036, Lansing, Michigan.

Morris, L.A., R.N. Langemeier, T.R. Russel, and A. Witt, Jr. 1968. Effects of main stem impoundment and channelization upon the limnology of the Missouri River, Nebraska. Transactions of the American Fisheries Society 97(4): 380-388.

Parchure, T.M., W.H. McAnally, Jr., and A.M. Teeter. 2001. Desktop method for estimating vessel-induced sediment suspension. Journal of Hydraulic Engineering 127(7): 577-587.

Preville, N.M. 2019 (*in revision*). Habitat use and tributary occupancy of the threatened river redhorse (*Moxostoma carinatum*). Master's thesis. Grand Valley State University, Allendale, Michigan.

Rosgen, D.L. 1997. A geomorphological approach to restoration of incised rivers. Proceedings of the Conference on Management of Landscapes Disturbed by Channel Incisions. University of Mississippi, Oxford, Mississippi.

Seelye, J.G. and M.J. Mac. 1984. Bioaccumulation of toxic substances associated with dredging and dredged material disposal. U.S. Environmental Protection Agency, Report 905/3-84-005, Chicago, Illinois.

Shankman, D., and L.J. Smith. 2004. Stream channelization and swamp formation in the U.S. coastal plain. Physical Geography 25(1): 22-38.

Tockner, K., and J.A. Stanford. 2002. Riverine flood plains: present state and future trends. Environmental Conservation 29(3): 308-330.

USACE (U.S. Army Corps of Engineers). 1909, Grand River, Michigan, from Grand Rapids to Mouth of Bass River Showing the Location of Training Walls (in Seven Sheets). U. S. Army Corps of Engineers, Detroit, Michigan.

USACE (U.S. Army Corps of Engineers). 1978. Preliminary feasibility report on shallow-draft navigation, Grand River Michigan. U.S. Army Corps of Engineers, Detroit, Michigan.

USACE (U.S. Army Corps of Engineers). 1985. Tombigbee River and tributaries Mississippi and Alabama, U.S. Army Corps of Engineers, Mobile, Alabama.

USEPA (U.S. Environmental Protection Agency). 2009. Great Lakes Legacy Act Ottawa River Cleanup Underway. U.S. Environmental Protection Agency. News Release. Dec 23, 2009.

Watters, G.T. 2000. Freshwater mussels and water quality: A review of the effects of hydrologic and instream habitat alterations. Pages 261-274 *in* Proceedings of the First Freshwater Mollusk Conservation Society Symposium. Ohio Biological Survey, Columbus, Ohio.

Ward, J.V. 1989. The four-dimensional nature of lotic ecosystems. Journal of the North American Benthological Society 8(1):2-8.

Ward, J.V. 1998. Riverine landscapes: Biodiversity patterns, disturbance regimes, and aquatic conservation. Biological Conservation 83(3):269-278.

Wenger, A.S., E. Harvey, S. Wilson, C. Rawson, S. J. Newman, D. Clarke, B. J. Saunders, N. Browne, M. J. Travers, J. L. Mcilwain, P. L. A. Erftemeijer, J. A. Hobbs, D. Mclean, M. Depczynski, and R. D. Evans. 2017. A critical analysis of the direct effects of dredging on fish. Fish and Fisheries 18:967-985.

Wilcock, D.N., and C.I. Essery. 1991. Environmental impacts of channelization on the River Main, County Antrim, Northern Ireland. Journal of Environmental Management 32: 127-143.

Summary of Research Related to the Potential Physical and Biological Impacts of Dredging to Channelize the Grand River

Appendix I – 2019 Mussel Sampling in Ottawa County Waters of the Grand River

Appendix II – Response to Critique by Grand River Waterway's Consultants

Appendix III – List of Groups That Oppose and Support Grand River Waterway

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Executive Summary

These appendices provide an update to the May 9, 2019, MSU Extension working paper based on subsequent sampling conducted on the Grand River in Ottawa County and a critique of the working paper by GZA consultants working on behalf of the Grand River Waterway organization. Sampling conducted in August and September 2019 revealed shallow gravel habitat, large woody debris, and training walls in the path of proposed dredging in Ottawa County. A diverse mussel community was also discovered outside of the proposed channel in Ottawa County waters of the project area. Studies conducted to date cannot rule out the possibility of impacts to this site and other off-channel habitats that could result from changes in current velocity, sedimentation, and erosion post-dredging. Although the magnitude of negative impacts is uncertain at this time, published scientific literature from around the world supports the general conclusion that dredging to channelize a river harms benthic macro-invertebrates, freshwater mussels, and fish. This is supported by the Michigan Department of Natural Resources' Wildlife Action Plan and Grand River Assessment, which both list channelization as a serious threat to large river ecosystems.

Appendix I - 2019 Mussel Sampling in Ottawa County Waters of the Grand River

On September 7, 2019, retired Michigan Department of Environmental Quality scientist Joe Rathbun and Dr. Renee Mulcrone with Eastern Michigan University led a mussel sampling effort in Ottawa County waters of the Grand River between Grand River Park and the county line downstream of 28th Street. Collaborators included Grand Valley State University, Ottawa County Department of Parks and Recreation, the Grand Rapids Public Museum, Encompass Socio-ecological Consulting, Michigan Sea Grant, Michigan State University Extension, and independent volunteer SCUBA divers.

Sampling efforts included a qualitative survey of mussel species present at three sites, with a minimum of 4.5 person-hours of search time at each site in accordance with the Michigan mussel survey protocol (Hanshue et al. 2019). Qualitative analysis of substrate and obstructions was also conducted at these sites on September 7 and at two additional sites on August 21.

- Site 1 consisted of a shallow sand bar with some areas of embedded gravel. A single Fat Mucket (*Lampsilis siliquoidea*) was the only living mussel found on September 7, 2019.

- Site 2 contained a variety of depths and substrate types including sand, gravel, and cobble according to 2017 data. Although conditions prevented additional sampling in 2019, this area was used regularly by a tagged River Redhorse (*Moxostoma carinatum*) during 2017 and a juvenile Deertoe (*Truncilla truncata*) was recorded in 2017 (Preville 2019). The River Redhorse is a state threatened molluscivore and Deertoe are a mussel species of Special Concern in Michigan.

- Site 3 was an area where gravel, cobble, and boulder substrate were found in wadeable shallows. Qualitative sampling on September 7, 2019, revealed live mussels of three species. These included the Plain Pocketbook (*Lampsilis cardium*) and two Special Concern species: Deertoe and Pink Heelsplitter (*Potamilus alatus*).

- Site 4 was an extensive gravel-bottomed run with swift current. Although the water was shallow enough to stand, water velocity was too high for effective sampling on September 7, 2019.

- Site 5 included a deep, sandy run that was sampled by SCUBA divers and an adjacent shallow area of gravel, sand, and aquatic vegetation. Living mussels of seven different species were recorded, qualifying this as a site with a “diverse mussel community” under the guidelines of the Michigan mussel protocol (Hanshue et al. 2019). Living species included Deertoe and Pink Heelsplitter, which are species of Special Concern. Dead shells were abundant on the shallow gravel riffle, and dead shells included the state endangered Threehorn Wartyback (*Obliquaria reflexa*).

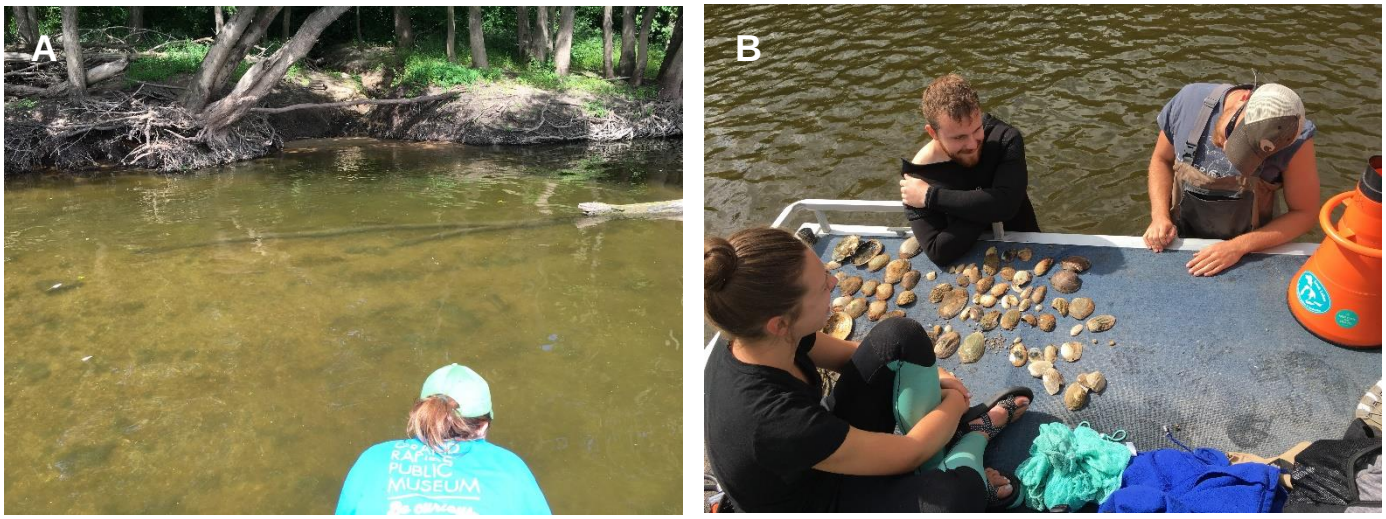

Figure 1. The Grand River in Ottawa County contains areas of hard substrate and diverse mussel communities within the Grand River Waterway project area. Gravel, cobble, and boulder habitat was found at Site 3 (Panel A) and living specimens of seven mussel species were found at Site 5 in addition to numerous dead shells (Panel B).

Appendix II - Response to Critique by Grand River Waterway's Consultants

On July 24, 2019, Rose & Westra, a division of GZA consultants working on behalf of the Grand River Waterway released their Grand River Waterway Evaluation (Mackey et al. 2019). This evaluation included a review of fish and mussel data from earlier surveys in addition to a critique of the preceding MSU Extension literature review. This appendix is a response to their critique, which was organized into three themes based on potential impacts to benthic macroinvertebrates, freshwater mussels, and fish.

Potential Impacts to Benthic Macroinvertebrates

From GZA consultants:

"The source cited in the working paper examined the heavily channelized and impounded Missouri River, which is orders of magnitude longer than the Grand River and the proposed project area… the Missouri River is not comparable to the proposed Grand River project and cannot accurately be used to analyze the impact that may arise…"

Response:

The working paper was a review of published literature that included 41 citations. The intent of this literature review was to describe the general classes of impacts that might be expected as a result of dredging, channelization, and increased large-vessel traffic on the Grand River. A literature review does not include new data or any attempt to estimate the magnitude of effects on a specific river. In short, the working paper provides a review of research from around the world suggesting dredging is generally bad for invertebrates and fish, but it does not determine exactly how bad impacts would be in the Grand River.

The Missouri River is, indeed, longer than the Grand River and the extent of disturbance on the Missouri River (through channelization and damming) is more extreme than what is proposed for the Grand River. Citations in the working paper involve work done in hundreds of water bodies and a variety of levels of disturbance. The general conclusion from the Missouri River study (Morris et al. 1968) is consistent with research on other systems that show a reduction in productive benthic habitat after channelization.

Some of the river systems included in papers cited by the working paper, like the Missouri, are larger than the Grand River, and others are smaller. For example, the Chariton River (Congdon 1971) and many of the Indiana streams studied by Lau et al. (2006) experienced significant loss of sensitive fish species despite being shorter than the Grand River.

Some of the disturbances cited by the working paper are less extreme than would be expected on the Grand River, as well. For example, the study that found boat wakes to be over 100 times as powerful as natural river waves utilized 18-foot boats (McConchie and Toleman 1983). The Grand River Waterway seeks to allow navigation of boats 26 to 49 feet long, which would create waves with even more erosive force than noted in the study cited by the working paper.

From GZA consultants:

"GZA agrees that woody debris and other underwater structures, such as wingwalls, provide important habitat for benthic macroinvertebrates. However, the proposed current dredge plans do not include the removal of any such structure."

Response:

The feasibility study produced for Grand River Waterway includes charts of the proposed dredging area that show many "unidentified objects" marked as "U" in the shaded area of proposed dredging along with some logs (see example on Sheet 15, Appendix A, Badgett 2019). Many of these unidentified objects are, in fact, remnants of underwater structures including wingwalls (aka training walls) and associated woody debris (see Figure 2). The report states "many objects were identified as potential hazards and categorized as a submerged log, object, or structure that may require removal" (p. 14, Edgewater Resources 2017).

The statement from GZA is therefore inaccurate on two counts: 1) it assumes that objects that were unidentified in the Grand River Waterway feasibility study were not training walls or woody debris, and 2) it does not acknowledge the logs that were noted as obstructions within the navigation channel designed by Edgewater Resources (2017). When GZA consultants contend that proposed dredge plans do not include the removal of training walls, they are referencing a study that did not properly identify known obstructions that appear on maps dating back over a hundred years (USACE 1909).

In a letter to Michigan Department of Natural Resources (DNR), professors from Grand Valley State University and Louisiana State University documented an area near Grand River Park where training wall structures were overlooked by the Edgewater Resources (2017) study (Wampler and Konsoer 2019). Using historic charts and multibeam echo sounding (MBES), Wampler and Konsoer mapped the river bottom from one bank of the river to the other and note that "the 2017 bathymetry survey performed by Edgewater Resources provided a limited view of the shape and morphology of the river. Significant areas near the edges of the river were not surveyed. The focus was on areas that would be dredged rather than providing a complete dataset for the bathymetry of the entire river."

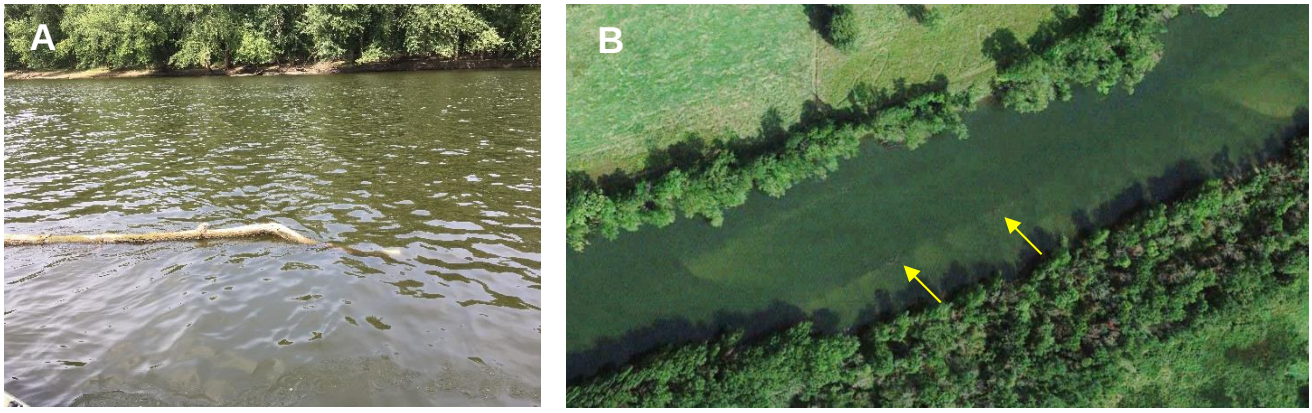

Figure 2. Remnants of training walls often halt the downstream progress of large woody debris. Panel A shows a log stuck on the top of a training wall on August 21, 2019. The Grand River Waterway feasibility study did not record the obstruction at this location as a training wall or woody debris. Panel B depicts a satellite image of at least two trees stuck along the straight line of a training wall in September 2017 (yellow arrows). The Grand River Waterway feasibility study noted two obstructions within the path of the proposed channel at this location in 2017; one was classified as a log and one was classified as "unknown."

Potential Impacts to Freshwater Mussels

From GZA consultants:

"The two mussel surveys conducted in support of the proposed project identified the area downstream of the 28th Street bridge, which comprises greater than two thirds of the project area, as low quality mussel habitat. Further, these studies found no living federally listed species within the proposed project area … It should be noted that the area of suitable mussel habitat is unknown to GZA at this time, as it has not been surveyed. GZA also agrees that channelization projects of any size may cause harm, both direct and indirect, to freshwater mussels including the listed species within the project area. However, given the relatively small and confined area of high quality mussel habitat, and the large portion of the project area that is devoid of mussel life, avoidance or mitigation methods could be implemented to further minimize impacts to freshwater mussels."

Response:

The area referenced in GZA's critique is almost entirely within Ottawa County waters. The 2018 study referenced by GZA (Ecological Specialists 2018) included proposed dredging areas under a 5-foot channel depth scenario. However, the Grand River Waterway proposed a 7-foot channel scenario in preparing the dredging charts that appear in the feasibility study (Edgewater Resources 2017) and the second mussel study referenced by GZA (Badgett 2019).

Data provided in Appendix I of this document demonstrate that portions of the proposed project area in Ottawa County are not devoid of freshwater mussel life, and at least one site contains a diverse mussel community. One of the studies referenced by GZA (Badgett 2019) did not include any sampling in Ottawa County waters, and the other (Ecological Specialists 2018) did not sample in a high quality gravel-bottomed run that would be dredged under a 7-foot channel scenario (Site 4 in Appendix I).

Dredging shallow areas of the river does have the potential to impact areas of the river outside the dredge channel, although, as GZA notes "in-depth hydromorphological modeling using empirical data collected within the proposed project area is necessary in order to accurately assess any changes that might arise from dredging activity." Such modeling has not been conducted, but this does not mean that no impacts outside the dredge area will occur.

The diverse mussel community noted in Appendix I (Site 4) was located within the project area but outside of the dredging area. Mussels at this site could be harmed if dredging alters depth, velocity, or sedimentation but, as GZA notes, "research to date has not attempted to adequately model the actual impact of dredging on off-channel areas." This suggests that additional research should be pursued, as opposed to relying on the incomplete information provided in past studies coordinated by Grand River Waterway.

Potential Impacts to Fish

From GZA consultants:

"Removal of high-quality fish habitat could also likely harm fish populations. The working letter references gravel bars as important spawning and foraging habitat … The only proposed dredge locations with high percent compositions of gravelly substrates have been identified upstream of the 28th Street bridge."

Response:

Gravel substrate areas are also found in Ottawa County waters of the project area downstream from the 28th Street bridge, although previous studies coordinated by Grand River Waterway did not identify them. As noted above, Ecological Specialists (2018) considered a 5-foot channel scenario and did not sample at least one gravel-bottomed area that would be dredged under the 7-foot scenario (Site 4, Appendix I). Additional high quality gravel substrate is found in off-channel areas that could also be indirectly affected (Sites 3 and 5, Appendix I). Shallow sandy areas within the path of proposed dredging may serve as important nursery and feeding habitat for state threatened Lake Sturgeon. Although research has not yet documented sturgeon habitat use in the Grand River, some preliminary sampling has already been conducted and more comprehensive efforts are expected to begin in 2020.

Summary

From GZA consultants:

"Based on a review of the MSU working letter and readily available literature, GZA cannot accurately estimate the extent of impacts to biological life as a result of the proposed project. However, GZA questions whether a subset of claims within the MSU working letter are applicable to the proposed project due to the use of literature documenting effects of dredge projects orders of magnitude larger than the proposed project."

Response:

Published literature from a wide variety of rivers, both larger and smaller than the Grand River, demonstrates that dredging has negative consequences for benthic invertebrates, freshwater mussels, and fish. Michigan DNR plans related specifically to the Grand River (Hanshue and Harrington 2017) and similar rivers in Michigan (Derosier et al. 2015) list dredging and channelization as major threats to river life.

Put simply, the Grand River Waterway project is very likely to be bad for fish, mussels, and other aquatic life but it is not possible to say exactly how bad without additional research.

From GZA consultants:

"GZA recommends the use of avoidance, minimization, and mitigation as methods to minimize the potential impacts caused by the proposed project."

Response:

Minimizing or mitigating damage is only necessary when damage occurs. The Grand River Waterway project could attempt to avoid dredging high-quality habitats in preference for low-quality habitats, but this would still ignore the potential for off-channel impacts.

Many Michigan water bodies are dredged to facilitate navigation, and coastal communities are largely in favor of numerous harbor dredging projects that contribute to thriving economies around the state. These dredging projects also have negative ecological consequences, but local support for harbor dredging demonstrates that residents are willing to accept the negatives considering the benefit to their communities.

The overwhelming opposition to the Grand River Waterway demonstrates the purported benefits of the project do not outweigh the potential damage in the minds of many. To date, 48 organizations have taken a formal stance in opposition to the project, including one county, three cities, one village, and five townships with Grand River frontage; a single resolution has been passed in support of Grand River Waterway (Appendix III).

Appendix III - List of Groups That Oppose and Support Grand River Waterway

The following groups formally oppose the Grand River Waterway project:

County Government

Ottawa County Board of Commissioners
Ottawa County Parks and Recreation Commission
Ottawa County Planning and Policy Committee
Ottawa County Planning Commission

Municipal Government

City of Ferrysburg
City of Grand Haven
City of Grandville
City of Holland
Crockery Township
Georgetown Township
Grand Haven Township
Robinson Township
Polkton Township
Park Township
Spring Lake Township
Village of Spring Lake

Businesses and Related Organizations

Aamazon Natural Resources Consulting, LLC
Grand Haven Chamber of Commerce
Grand Haven Area Convention and Visitors Bureau
Grand Lady Riverboat / Steamboat Park Campground
GR Paddling, LLC

Tribal Government

Little Traverse Bay Bands of Odawa Indians
Pokagon Band of Potawatomi Indians

Fishing and Conservation Clubs

Grand Haven Steelheaders
Grand Rapids Steelheaders
Izaak Walton League of America – Dwight Lydell Chapter
Lunker Hunter Spoonplugging Club of Grand Rapids
Michigan Muskie Alliance
Michigan Steelhead & Salmon Fisherman's Association
Michigan United Conservation Clubs
Schrems West Michigan Trout Unlimited
West Michigan Walleye Club

Other Organizations

American Rivers
Clean Water Action
Climate Reality Project – West Michigan Chapter
Friends of the Lower Grand River
Grand Rapids Audubon Club
Grand Rapids Public Museum
Grand River Watershed Arts and Music Council
Grand Valley State University Student Senate
Lakeshore Water Protectors
Michigan Environmental Council
Michigan League of Conservation Voters
Muskegon River Watershed Assembly
Owashtanong Islands Audubon Society
Progressive Women's Alliance of West Michigan PAC
Quiet Water Society
West Michigan Environmental Action Council

The following groups formally support the Grand River Waterway project:

Georgetown Township Finance Committee

Literature Cited:

Badgett, N.M. 2019. 2018 Unionid surveys at 5 proposed dredge sites, Grand River, Kent County, Michigan. EcoAnalysts, Inc. O'Fallon, Missouri.

Congdon, J.C. 1971. Fish populations of channelized and unchannelized sections of the Chariton River, Missouri. Pages 52-83 *in* Stream channelization: A symposium. E. Schneberger and J.L. Funk (editors) American Fisheries Society, Special Publication 2, Bethesda, Maryland.

Derosier, A.L., S.K. Hanshue, K.E. Wehrly, J.K. Farkas, and M.J. Nichols. 2015. Michigan's Wildlife Action Plan. Michigan Department of Natural Resources, Lansing, Michigan. http://www.michigan.gov/dnrwildlifeactionplan

Ecological Specialists. 2018. Unionid Surveys at Proposed Dredge Sites, Grand River, Kent and Ottawa Counties, Michigan. O'Fallon, Missouri.

Edgewater Resources, LLC. 2017. Grand River Waterway dredging feasibility study. Edgewater Resources, LLC, Saint Joseph, Michigan.

Hanshue, S. K., and A. H. Harrington. 2017. Grand River assessment. Michigan Department of Natural Resources, Fisheries Report 20, Lansing, Michigan.

Hanshue, S. K., J. Rathburn, P. Badra, J. Bettaso, B. Hosler, J. Pruden, and J. Grabarkiewicz. 2019. Michigan freshwater mussel survey protocols and relocation procedures. U.S. Fish & Wildlife Service, East Lansing, Michigan. https://www.fws.gov/midwest/eastlansing/te/pdf/MI_Freshwater_Mussel_Survey_Protocol.pdf

Lau, J, T.E. Lauer, and M.L. Weinman. 2006. Impacts of channelization on stream habitats and associated fish assemblages in east central Indiana. The American Midland Naturalist 156(2): 319-330.

Mackey, M., J. Novak, and M. Westra. 2019. Grand River Waterway Evaluation. GZA GeoEnvironmental, Inc. https://static1.squarespace.com/static/5093be30e4b0979eac7c3594/t/5d3f9798c8c7860001b6e587/1564448667838/Grand+River+Waterway+Summary+Memo+07242019.pdf

McConchie, J.A., and I. E.J. Toleman. 2003. Boat wakes as a cause of riverbank erosion: A case study from the Waikato River, New Zealand. Journal of Hydrology 42(2): 163-179.

Morris, L.A., R.N. Langemeier, T.R. Russel, and A. Witt, Jr. 1968. Effects of main stem impoundment and channelization upon the limnology of the Missouri River, Nebraska. Transactions of the American Fisheries Society 97(4): 380-388.

Preville, N.M. 2019. Habitat use and tributary occupancy of the threatened river redhorse (*Moxostoma carinatum*). Master's thesis. Grand Valley State University, Allendale, Michigan. https://scholarworks.gvsu.edu/theses/942/

Wampler, P.J. and K. Konsoer. 2019. Critique of Grand River Waterway sediment sampling protocol https://friendsofthelowergrandriver.org/wp-content/uploads/2019/08/Critique-of-Grand-River-Waterway-Sediment-Sampling-Protocol-2.pdf